MASTER

1980 Conference on Industrial Energy Conservation Technology

April 13-16, 1980
Houston, Texas

Proceedings

Vol. I



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INDUSTRIAL ENERGY CONSERVATION TECHNOLOGY

PROCEEDINGS OF THE 1980
CONFERENCE AND EXHIBITION

Hyatt-Regency Hotel
Houston, Texas
April 13-16, 1980

Sponsored by the
Energy Utilization Department
of
Texas Industrial Commission

A project of the Texas Energy Conservation Plan funded by The U.S. Department of Energy through the Governor's Office of Energy Resources.

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INTRODUCTION

1980 was the second year of the Industrial Energy Conservation Technology Conference and Exhibition, and it was a year of progress on many fronts. Attendance grew from 800 to over 1300, with participants coming from as far away as Japan, Israel, and France. The international quality of the conference was further underscored by the very substantial contribution of papers and attendees from both public and private sectors in Canada. While the conference drew intense interest from the Southwestern U.S., over 40% of the participants came from outside the region.

The conference grew in content as well as participation. From 123 papers presented in 1979, the technical program expanded to more than 150 papers, necessitating extension of the conference to three full days to accommodate the required number of sessions. Presentations concentrated on state-of-the-art hardware for industrial energy conservation. Many advanced technologies which were reported as "under development" in 1979 were reported as "in place and operating" in 1980, and many new projects and programs were reported in the developmental stages.

The organization and structure of the conference received high praise from most participants, and credit for this effort must be given to the members of the Steering Committee, session chairpersons, and the staff of the Texas Industrial Commission who made the whole thing work. The quality of the technical presentations and exhibits, too, received high marks, due to the conscientious preparation by the authors and exhibitors.

Finally, special recognition is due to Jennifer Evans and Sarah Williams, without whose expert editorial assistance these Proceedings could not have been completed.

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Abstracts must be received by the Technical Program Director no later than October 15, 1980. Final papers will be due on or before March 1, 1981. The program will be limited to 150 papers.

Submit abstracts to: Technical Program Director
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INDUSTRIAL WASTES AS A FUEL

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With the advent of scarce supplies and rising costs for traditional industrial fuels such as natural gas and fuel oil, a large amount of technical data has been collected and published to encourage their efficient use. This same data is readily available for coal since it was at one time a major industrial fuel and is still used extensively for electric power generation. However, combustion data for other fuels such as wood and solid materials typically generated as industrial wastes can only be found in widely scattered and more obscure sources. Therefore, this information is not always easily accessible to operating personnel at plants where these type fuels are being utilized. The resulting lack of proper information many times leads to poor fuel utilization because of less than optimum combustion efficiencies. Operational and maintenance problems may also be caused by a misunderstanding of combustion characteristics.

It is becoming more important that all fuels be utilized efficiently even in the case where they are waste by-products with related disposal costs. For example, a furniture company might now be burning its waste wood scraps at low combustion efficiencies (high excess air levels) in its boiler, as a method of "free" disposal. However, as wood returns to the scene as an industrial fuel, this waste wood may become saleable by-product. Improved combustion efficiency would reduce the amount of waste wood fired in the boiler and allow more to be sold for fuel to other users. In another case, a particle board manufacturer might be firing a boiler on waste wood dust for two days a week with the balance of his boiler fuel needs being made up with natural gas. Improved combustion efficiency while firing the dust would result in increased firing time on dust with an equivalent reduction in firing time on natural gas.

Efficient utilization of all fuels whether they are purchased or a waste by-product is important to reducing operating costs and thereby improving profit margins. In light of the potential economic returns, this paper will present physical and chemical data for determining the combustion characteristics and efficiencies for a wide variety of industrial wastes. Wood and other cellulosic materials such as bagasse will be discussed first, followed by other solid materials representative of industrial waste. Case studies illustrating the economic advantages of conversion to firing of industrial wastes and efficient operation of these type facilities will be presented.

Wood and Other Cellulosic Materials

Cellulose based fuels are expected to become more and more important to the industrial community. These include industrial waste by-products such as wood scraps, sawdust, bagasse, paper and cotton rags or scraps. In addition, the future energy supply in the United States may reach a point where tree growth will be managed for the primary purpose of supplying industrial fuel. Because of this, the following presents the chemical and physical data necessary to determine combustion characteristics for cellulosic fuels and to assure efficient operation of equipment being fired with these type fuels.

Types of Material

Green wood consists primarily of carbohydrates, water and ash. On a dry basis, it consists of approximately 55 percent fiber or cellulose, 27 percent lignin, 17 percent "extractives" and 1 percent ash. Cellulose, $(C_6H_{10}O_5)_y$, is a carbohydrate which derives its name from the fact that it forms the cellular, fibrous framework in wood that encloses other carbohydrates, such as starches and sugars having the same chemical formula as cellulose but different physical properties. As plants grow, some of the cellulose tissue hardens and is converted into lignin, a complex substance related to carbohydrates, but containing less oxygen. Extractives are sub-

stances within the wood fiber which can be dissolved out with water, ether, benzene or other inert solvents. Wood extractives typically include sugars, tannin, vegetable acids, essential oils, resins and pigments.

The primary chemical elements found in wood are carbon, C; hydrogen, H_2; and oxygen, O_2; accompanied by small amounts of ash. Some woods also contain negligible quantities of sulfur, S; and nitrogen, N_2. Table 1 presents typical ultimate analyses (on a dry basis) for some woods found in the United States. The major chemical difference between wood and other fuels is its high oxygen content which influences both its heating value and the air requried for combustion.

Bagasse is a waste fuel that is a by-product of the production of sugar from cane. Sugar cane is an agricultural product which grows in stalks from 10 to 12 feet high. In normal processing operations, the stalks are cut into smaller pieces, 2 to 3 feet long, before being sent to the shredding, or cutting operation, which is called "disintegration" or "defibration". This serves to open up the hard rind for subsequent extraction of the sugar bearing juice.

Sugar cane is very similar to wood in that it consists of cellulose fiber which makes up the tissue which encloses sugars such as sucrose ($C_{12}H_{22}O_{11}$) and glucose ($C_6H_{12}O_6$). Water and small quantities of mineral ash are also present. Typically, sugar cane is made up of from 10 to 17 percent cellulose fiber and from 83 to 90 percent sugar on a moisture and ash free basis.

The extraction of sugar from cane involves crushing the disintegrated cane between rollers followed by spraying or soaking with water accompanied by additional squeezing. The fibrous material that is left after almost all of the sugar has been extracted is bagasse and typically might consist of about 40 percent fiber, 2.5 percent sugar, 55 percent moisture and 2.5 percent ash. The relatively high ash content in many samples of bagasse is due to trash and dirt picked up in harvesting the cane.

Table 1 includes typical ultimate analyses (on a dry basis) of bagasse from different countries. The carbon content is slightly lower and the oxygen content a little higher than in wood, possibly due to the extraction process which it has undergone.

Other cellulose based materials which might be used, particularly as primary fuel supplements, include cotton rags or scraps, regenerated cellulose such as rayon or cellophane and various kinds of paper. Of lesser importance are other materials of vegetable origin such as plant trimmings, leaves and food wastes (e.g., citrus rinds and seeds or coffee grounds) which might occur as industrial waste by-products but are typically found in municipal refuse. The chemical compositions of these materials are very similar to that wood. Table 2 presents typical ultimate analyses (on a dry basis) of various refuse components which are commonly found as waste which might eventually become fuel sources.

Moisture

Moisture is the most variable item in the composition of cellulosic fuels. Its value ranges from almost none in some paper material to 6 percent in kiln-dried woods to over 60 percent in green wood or bagasse and up to 80 percent in green bark. It is of importance in combustion calculations because it difectly influences the heating value of the fuel being burned by increasing the proportion of inert matter present and because it requires some of the heat released during combustion to evaporate it and superheat it to the combustion chamber exit temperature. The latent heat required by the water is non-recoverable since the flue gases must exit at some temperature above their dewpoint.

An accurate determination of moisture content for cellulosic materials can be obtained by heating a weighed sample at 212 °F until no further weight loss is observed. The difference between the original weight and that of the dried sample divided by the original weight is the moisture fraction "as received" which is the value that is used in combustion calculations. In the lumber industry it is customary to speak of moisture in wood on an "oven-dry" basis, whereby the loss of weight in the sample tested is divided by the oven-dried weight rather than the original sample weight. The percent moisture "oven-dry" must then be converted to the "as received" basis before using it in combustion calculations.

For woods such as southern yellow pine which contain oils which are easily volatilized, determination of moisture content by the oven drying method is not accurate because the oils will be evaporated along with the moisture. In these cases it is necessary to use the more elaborate distillation method, wherein the water and oil are measured separately.

Other methods which are less reliable, but quicker, for judging the moisture in cellulosic materials consist of measuring their electrical resistance or using an instrument known as a wood hygrometer.

Heating Value

The high heating value of any cellulosic fuel may be determined by a bomb calorimeter. From the close similarity of the ultimate analyses of different types of cellulose based substances, it might be reasonable to assume that on a dry basis their heating values would be similar. Comparison of the values listed in Tables 1 and 2 indicate that this is not the case. In the case of wood, the heating value depends on the physical structure and form of the wood tissue, and still more on the presence of resins, gums, tannins, essential oils and pigments. Resin alone, for instancee, may increase the heating value of the same wood as much as 15 percent. Table No. 1 shows that the heating value of dry softwoods is a little higher, on the average, than that of hardwoods, due perhaps to the fact that most softwoods are conifers containing more resin and oils. This also accounts for the fact that various kinds of paper, which are essentially wood cellulose with all of the other wood constituents removed, have lower heating values than the woods from which they are made. Other cellulose based substances which are low in resin and oils show this same trend (e.g., cotton, dry grass, pecan shells, etc.).

As mentioned, the chief factor affecting the heating value of cellulosic substances is their moisture content. In the case of wood refuse or bagasse, the amount of trash, dirt, leaves or grass picked up during harvesting may also influence heating values.

In sugar mill practice, bagasse analyses are frequently reported in terms of its fiber, sucrose, glucose, moisture and ash content. If these are given, the high heating value (HHV) of bagasse in BTU per pound may be computed from:

$$HHV = 8550F + 7119S + 6750G - 972M \quad (1)$$

Where: F = fiber, lb per lb of bagasse
S = sucrose, lb per lb of bagasse
G = glucose, lb per lb of bagasse
M = moisture, lb per lb of bagasse

If the high heating value is known for any cellulosic fuel, its low heating value (LHV) in BTU per pound at constant pressure may be calculated using equation (2).

$$LHV = HHV - 9720\ H_2 - 1110\ H_2O \quad (2)$$

H_2 and H_2O in equation (1) are the weight fractions of hydrogen and moisture, respectively, taken from the ultimate analysis ("as fired"). Typical heating values are presented in Table 1 for various woods, and bagasse from different countries and Table 2 for other refuse components. The heating values of materials with moisture contents other than those noted in these tables may be calculated by assuming that heating value is proportional to combustible content (i.e., proportional to amount of inert material present of which moisture is a constituent).

Excess Air Level and Combusiton Efficiency

The excess air level and combustion efficiency for firing with a cellulosic fuel may be determined easily from measurable parameters and known combustion relationships such as those presented in Figures 1, 2, 3, and 4.

Figure 1 presents volumetric percent CO_2 in the dry combustion products as a function of percent excess air for various values of the ratio $[C/H_2 - 0.10\ O_2]$. Therefore, if the concentration of CO_2 in the flue gases is measured, for example with Orsat or Fyrite analyzer, and the ultimate analysis of the material being fired is known or can be accurately estimated, the excess air level may be determined very easily from this figure.

Figures 2, 3, and 4 present combustion efficiencies for equipment fired on cellulosic fuels with moisture contents of 6%, 24%, and 50%, respectively. These combustion efficiencies are plotted as a function of volumetric percent CO_2 in the dry combustion products for various stack exit temperatures. These curves are based on combustion of a typical cellulosic fuel but should be reasonably accurate for any cellulosic fuel at a fixed moisture content. This results from the fact that the other major constituents of the flue gases are oxygen, nitrogen carbon dioxide which have approximately equal heat capacities in the range of temperatures under consideration. Once the flue gas temperature and CO_2 concentration and fuel moisture content are known, combustion efficiency may be determined directly or by linear interpolation using Figures 2, 3 and 4.

Industrial Wastes

This section will take a look at solid industrial wastes which might serve as either primary or secondary fuel sources. These wastes might be gene-

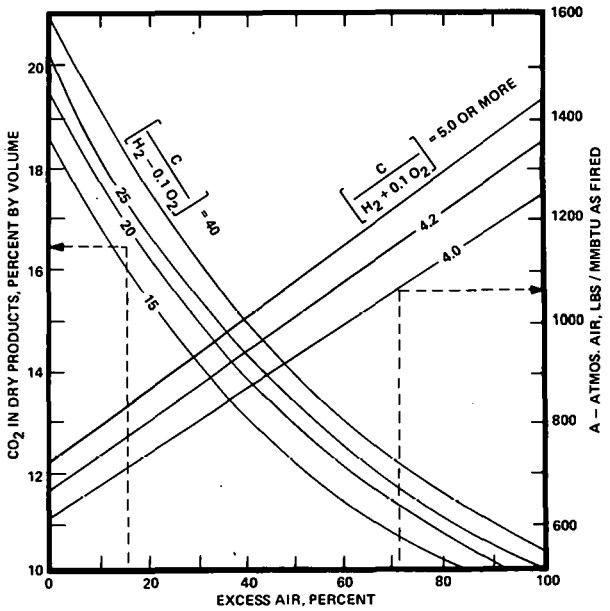


FIGURE 1. FLUE GAS CO_2 CONCENTRATION AND COMBUSTION AIR FLOW RATE AS A FUNCTION OF EXCESS AIR LEVEL FOR FIRING CELLULOSIC MATERIALS

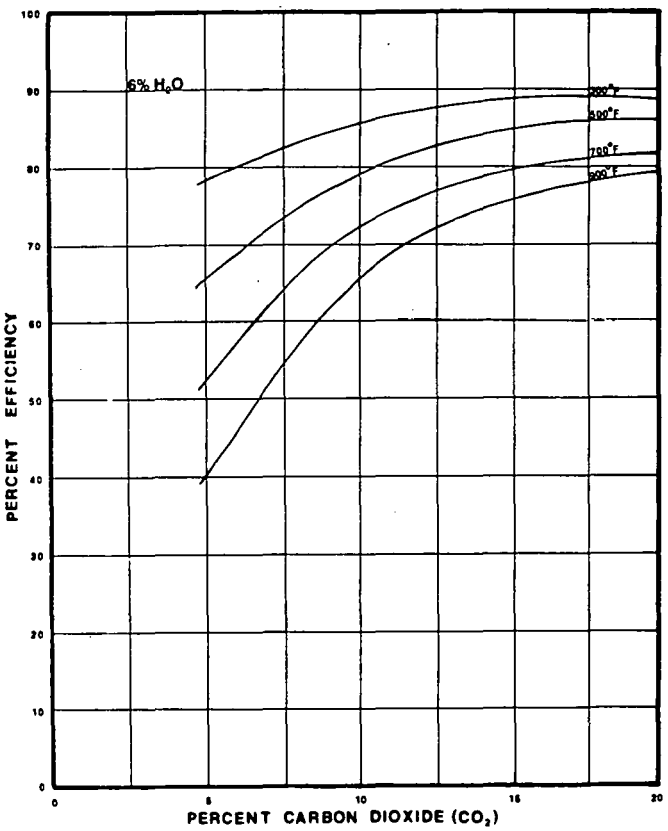


FIGURE 2. COMBUSTION EFFICIENCY AS A FUNCTION OF EXCESS AIR LEVEL FOR FIRING CELLULOSIC MATERIALS WITH 6% MOISTURE CONTENT

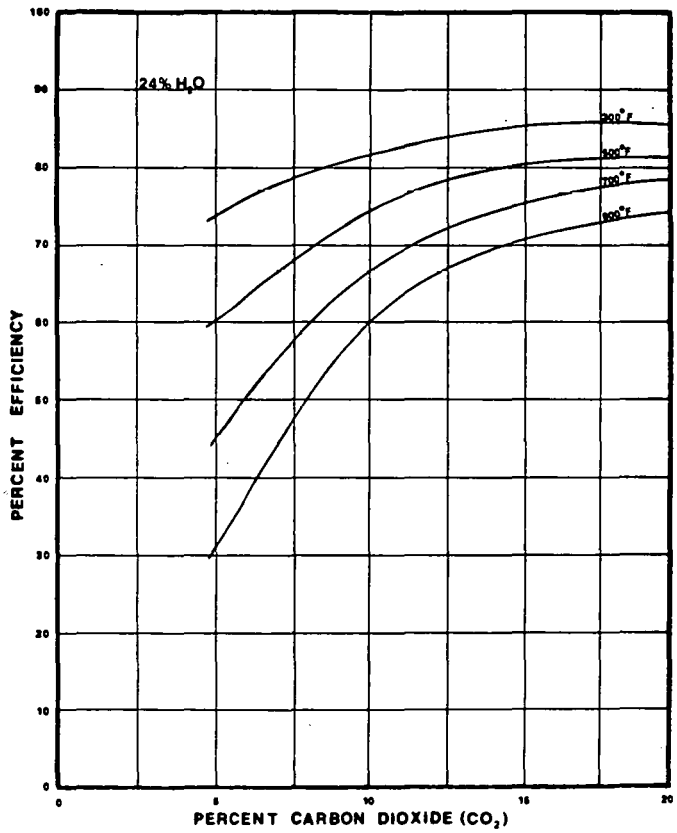


FIGURE 3. COMBUSTION EFFICIENCY AS A FUNCTION OF EXCESS AIR LEVEL FOR FIRING CELLULOSIC MATERIALS WITH 24% MOISTURE CONTENT

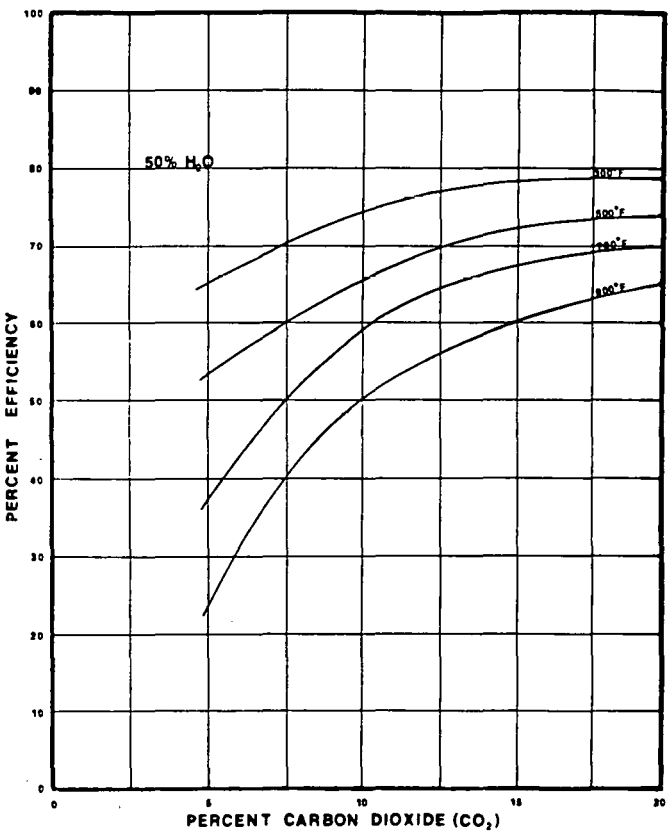


FIGURE 4. COMBUSTION EFFICIENCY AS A FUNCTION OF EXCESS AIR LEVEL FOR FIRING CELLULOSIC MATERIALS WITH 50% MOISTURE CONTENT

rated in substantial quantities as industrial waste by-products but are more typically found as constituents of industrial refuse. It is also conceivable that, in certain situations, industries may in the future, utilize either municipal refuse or "refuse derived fuel (RDF)" as an energy source. For this reason, the general characteristics of these types of materials will also be presented. The burning of any solid material is, in many ways, very similar to the burning of coal or wood.

Types of Materials

Solid combustible waste materials fall generally into three different classes: animal, vegetable or man-made. The primary chemical constituents of each are carbon, C; hydrogen, H_2, and oxygen, O_2, the same as for coal or wood. However, the relative proporations of these elements may vary considerably. For example, rubber and petroleum based plastics contain mostly carbon and hydogen with little or no oxygen, whereas some materials of animal origin such as cooked meat scraps or leather contain all three of these elements in proportions approaching those of cellulosic materials.

Heating Value

The moisture content of industrial and municipal wastes has the largest detrimental effect on heating value. The high ash content for some of these materials may also have some influence. The high carbon content in materials such as rubber, polyethylene and plastic film leads to higher heating values. As with other solid fuels, the high heating value of industrial and municipal waste substances may be determined by burning a sample in a bomb calorimeter.

Excess Air Level and Combustion Efficiency

The excess air level and combustion efficiency for firing with the solid materials described in this section may be determined in a manner similar to that described for wood in the previous Section. Figure 5 presents volumetric percent CO_2 in the dry combustion products as a function of percent excess air for various values of the ratio $[C/(H_2-0.10_2)]$ and is suitable for use with materials which have carbon, hydrogen, and oxygen as primary constituents. Figure 6 presents the same relationship between flue gas CO_2 concentration and percent excess air for various values of the ratio C/H_2 and is intended for use with materials which have only carbon and hydrogen as primary constituents and contain little or no oxygen. Figure 5 is used for firing of materials such as meat, rubber and carpet wastes while Figure 6 is used for firing of materials such as petroleum based plastics. Therefore, if the concentration of CO_2 in the flue gases is measured, for example with Orsat or Fyrite analyzer, and the ultimate analysis of the material being fired is known or can be estimated, the excess air level may be determined from Figure 5 or 6, whichever is appropriate. When firing a mixture of waste materials or a mixture of waste material(s) and primary fuel, the ultimate analysis should be measured or estimated from ultimate analyses using the weight percentage of each component of the mixture.

Figures 7, 8, and 9 present combustion efficiencies for equipment fired with waste materials whose primary constituents are carbon, hydrogen, and oxygen for fuel moisture contents of 6%, 24%, and 50%, respectively. The combustion efficiencies are plotted as a function of volumetric percent CO_2 in the dry combustion products for various stack exit temperatures. These curves are based on combustion of a typical waste material containing carbon, hydrogen and oxygen as primary constituents, but should be reasonably accurate for any waste material of this type at fixed moisture content. As discussed in the previous section for the combustion of cellulosic fuels, this results from the fact that the other major constituents of the flue gases are oxygen, nitrogen and carbon dioxide which have approximately equal heat capacities in the range of temperatures under consideration. Once the flue gas temperature and CO_2 concentration and fuel moisture content are known, combustion efficiency may be determined directly or by linear interpolation using Figures 7, 8, and 9.

Figure 10 presents the same relationship between flue gas temperature and CO_2 concentration and combustion efficiency as the previous three curves but is intended for use with fuels whose primary constituents are carbon and hydrogen and contain little or no oxygen. The curves in Figure 10 are based on combustion of a typical fuel oil but should be reasonably accurate for use with such materials as petroleum based plastics because their chemical compositions are similar. Small variations in the proportions of carbon to hydrogen in the material being fired should have little effect on combustion efficiencies obtained from Figure 10 for the same

reason cited in the previous paragraph, i.e., the heat capacities of the major constituents of the flue gases are approximately equal in the range of temperatures under consideration. Once the flue gas temperature and CO_2 concentration are known, combustion efficiency may be determined directly from Figure 10. The curves in Figure 10 are based on zero percent fuel moisture content since solid waste materials with chemical compositions resembling petroleum products are generally dry.

STORAGE AND HANDLING

Solid fuel handling systems can be made up of a wide variety of components. The exact combination of specific equipment items will depend on the quantity, form, and condition of the fuel, as well as the plant configuration. Figure 11 shows a generalized flow diagram for solid fuel handling and storage systems.

Unloading

In most cases the industrial waste that is fired at an industrial site is actually produced where it is consumed. However, there may be situations where waste material may be hauled from the site where it is produced to the location where it will be consumed. In the cases where the waste material is hauled to the place where it is consumed the material will have to be unloaded. Waste material usually arrives at industrial plants by truck, rail, or in some locations by barge. The first step in the material handling process, then, is unloading the incoming fuel.

It is important to accomplish this quickly to both minimize labor costs and avoid demurrage charges A common rule of thumb recommends providing the capacity to unload a three-day fuel supply in an eight hour shift.

A determination of exactly what type of unloading equipment would be required is primarily dependent on the type of transport vehicle used for delivery. For example, if the waste material is delivered by truck, and the plant arrangement is favorable, it may not be necessary to provide any specialized unloading equipment. It would prove entirely adequate to simply have the truck dump to a small outdoor storage pile or into a basement bin.

A rail delivery system, on the other hand, would require equipment capable of bringing the hopper cars to a specific unloading spot. This could range from a simple capstan to a sophisticated automatic positioner, depending on the number of cars that must be unloaded. The unloading system should be designed to be compatible with the specific type of hopper car that is used to deliver waste; the three basic designs are: (a) conventional, manually lock-door, saw-tooth hopper, (b) bottom-dump, and (c) top-dump.

A shaker or vibrator is normally required to assist in unloading the saw-tooth hopper design. This is particularly true when the waste material is wet or frozen. These units are also available in a wide range of models, from light to heavy duty.

In cold weather, waste material in hopper cars may arrive frozen, and a thawing system could prove to be necessary. Most of these systems use either gas-fired or electric radiant heaters installed in a thawing shed through which the hopper cars pass. The heaters are turned on for each car individually as it moves into position.

The receiving hoppers under the track must be designed properly. A key requirement is that the sides must slope at least 50 to 60 degrees from the horizontal. Stainless steel linings are recommended to minimize maintenance and generally improve hopper performance. Another point to consider is waterproofing or flood protection for hoppers near water.

Many waste material carrying ships and barges don't have the capability to off load without external assistance. Depending on the size of the operation, dockside equipment such as clamshell bucket elevators, towers or bridges may be required for this function.

Feeders

Once the waste material has been unloaded at the plant site, regardless of its mode of delivery, the next step is to transport it from its temporary storage pile or undertrack hopper to a more permanent storage or use area. This is accomplished with the aid of a class of devices known as feeders. A feeder delivers waste material at a controlled rate from a storage areas to a point where a conveyor can conveniently handle it for further transport.

Apron feeders transport waste material by means of chain mounted overlapping steel pans that carry, rather than drag or scrape, the material. Normally, the maximum angle of operation for an apron feeder is 25 degrees, unless the pans are fitted with cleats to prevent backflow. These feeders operate at low speeds of 25-30 feet per minute (fpm) or less.

Bar-flight feeders are particularly suited to situations where pit depth must be held to a minimum.

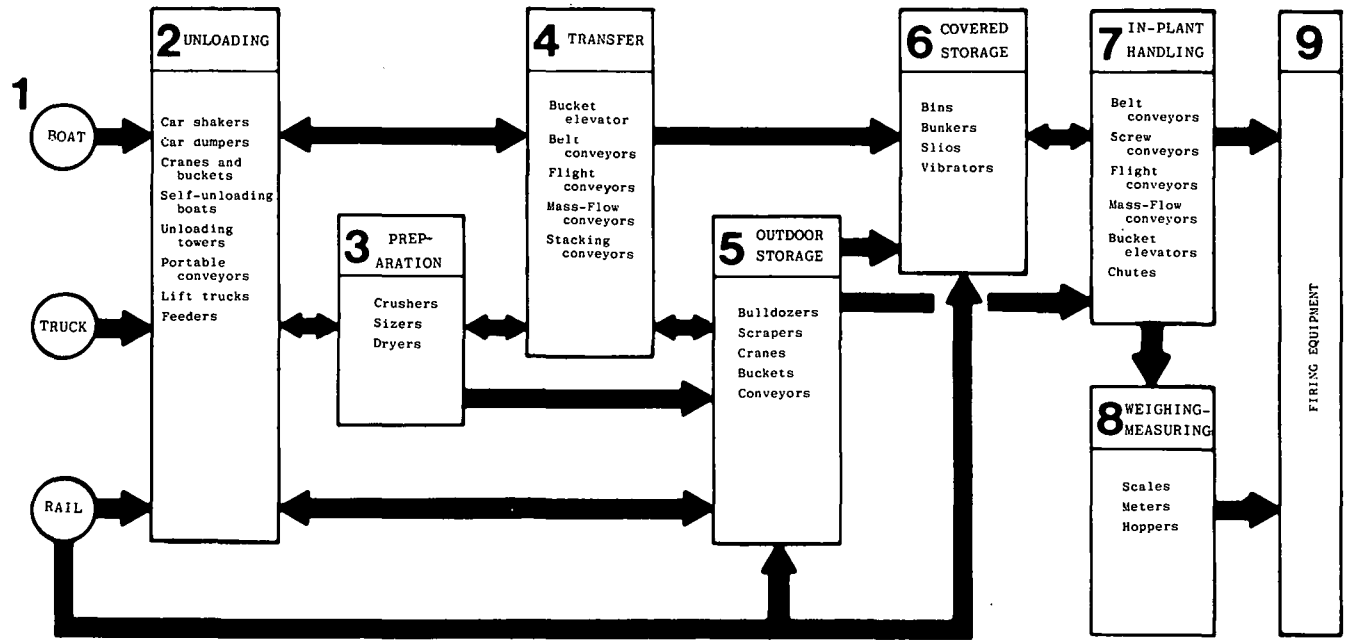


FIGURE 11.
SOLID FUEL HANDLING FLOW CHART

They have bars (or flights) suspended by two sets of chains such that when the bars are pulled over the flat bottom of a trough, they drag the waste material along between them.

Both reciprocating feeders and vibrating feeders agitate incoming waste material, and so help prevent hopper clogging with lump material. The former type is designed with a horizontal feeder pan that is driven back and forth by connecting rods. As the pan is pushed forward, waste material drops from the overhead hopper to the pan's back end; as the pan returns, waste material drops off the front end to a receiving conveyor for further transportation.

A vibrating feeder has no parts subject to friction wear, which means little maintenance is required. Modern designs operate through a sinusoidal excitation force which is instigated by a rotary vibrator drive. The force is amplified through a spring system that holds the feeder pan; the pan is thus vibrated in a fore-and-aft motion that is imperceptible, due to the small vibration amplitude imparted. The waste material, however, flows smoothly along the apparently immobile pan. Its feed rate may be changed by varying the intensity of vibration.

Screw conveyors are useful as feeders in applications where less than two hopper cars per week are received, or all deliveries are made by truck; in other words, in smaller operations. They can be used where waste material comes in small sizes and is free from tramp iron, and other foreign objects. Screw conveyors are relatively inexpensive and of simple construction. Their capacity becomes restricted when they are inclined.

The pneumatic conveyor is one type of equipment that finds more widespread use in wood and similar materials. These are relatively simple devices that are most effective on dry wood waste particles of small size. The principal drawbacks to pneumatics are the requirement for cyclones to perform air/particle separation at the delivery points (since particulates can cause air quality violations), and the relatively high horsepower requirements for fans. In addition, pneumatic conveyors shouldn't be used on unsized material; they require uniformly sized particles to ensure even flow characteristics. If the wood material contains large amounts of sand, wear points must be specially treated; if sand content is extremely high, pneumatic conveyors should not be used.

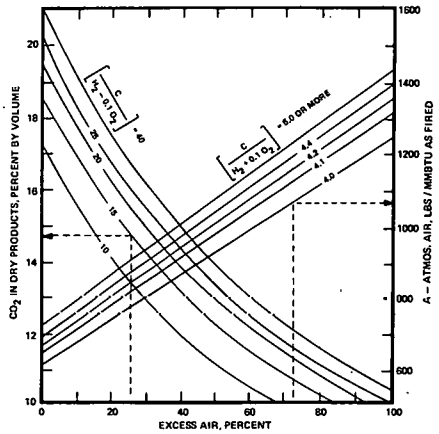


FIGURE 5. FLUE GAS CO_2 CONCENTRATION AND COMBUSTION AIR FLOW RATE AS A FUNCTION OF EXCESS AIR LEVEL FOR INDUSTRIAL WASTES (OXYGEN A PRIMARY CONSTITUENT)

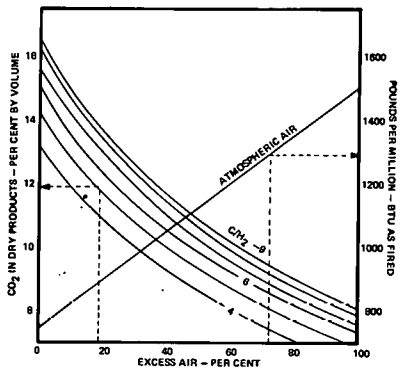


FIGURE 6. FLUE GAS CO_2 CONCENTRATION AND COMBUSTION AIR FLOW RATE AS A FUNCTION OF EXCESS AIR LEVEL AIR FOR INDUSTRIAL WASTES (OXYGEN NOT A PRIMARY CONSTITUENT)

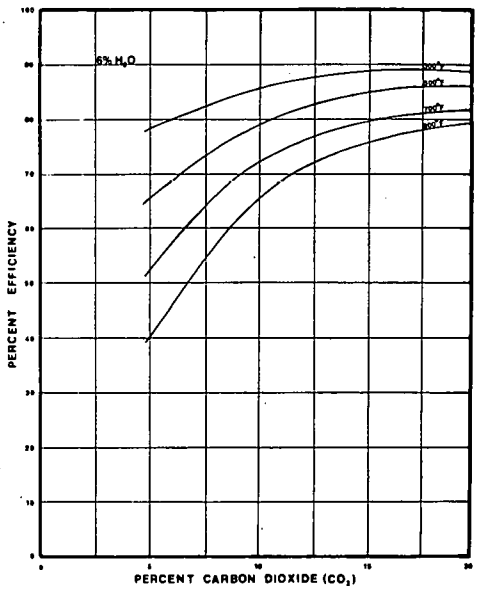


FIGURE 7. COMBUSTION EFFICIENCY AS A FUNCTION OF FLUE GAS CO_2 CONCENTRATION FOR FIRING INDUSTRIAL WASTES (OXYGEN A PRIMARY CONSTITUENT) WITH 6% MOISTURE CONTENT

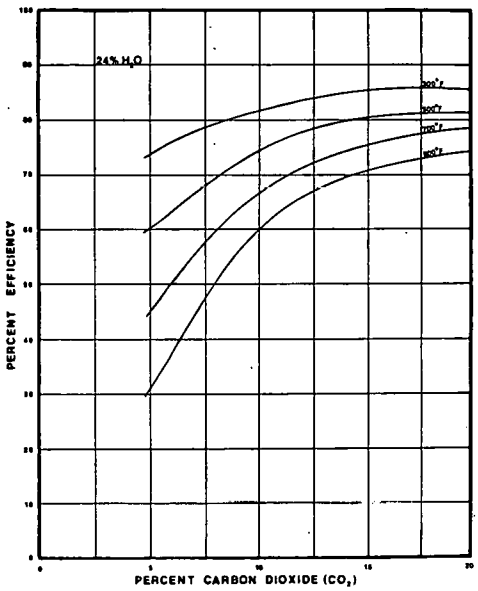


FIGURE 8. COMBUSTION EFFICIENCY AS A FUNCTION OF FLUE GAS CO_2 CONCENTRATION FOR FIRING INDUSTRIAL WASTES (OXYGEN A PRIMARY CONSTITUENT) WITH 24% MOISTURE CONTENT

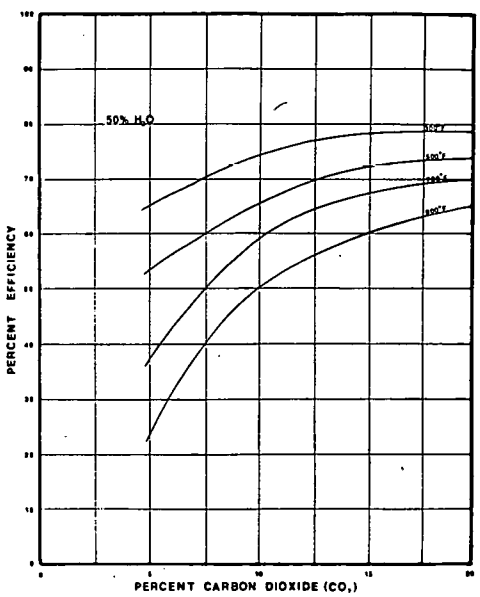


FIGURE 9. COMBUSTION EFFICIENCY AS A FUNCTION OF FLUE GAS CO_2 CONCENTRATION FOR FIRING INDUSTRIAL WASTES (OXYGEN A PRIMARY CONSTITUENT) WITH 50% MOISTURE CONTENT

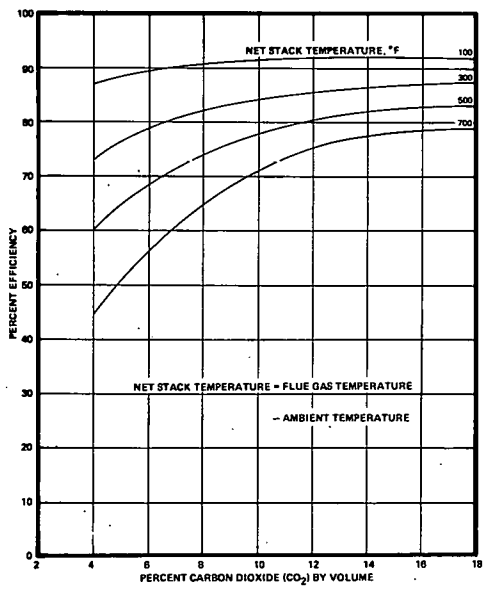


FIGURE 10. COMBUSTION EFFICIENCY AS A FUNCTION OF FLUE GAS CO_2 CONCENTRATION FOR FIRING INDUSTRIAL WASTES (OXYGEN NOT A PRIMARY CONSTITUENT)

In addition to the material handling equipment that will be required, it may be necessary to reduce the particle size of the waste material or otherwise group it in uniform size particles. The size reduction may be accomplished by means of hogging, shredding, or grinding.

Sizing of industrial waste is a very important step in the handling process. Conveying, as well as the other handling operations, proceeds much more smoothly with uniformly sized material. The sizing operations required for a given plant depend on the condition of the waste material. Screening can be a useful first step to segregate the particles requiring reduction in size.

In many cases, size reduction is accomplished by means of a hog. These units are available in many sizes and styles, with hammermill and knife-type hogs being most commonly used. Tramp metal and rock separators are required to protect this equipment from potentially severe damage to the cutting/grinding surfaces.

Depending on the individual application, it may prove desirable to dry the waste fuel prior to use. The section of this paper dealing with combustion efficiency addresses moisture content and corresponding heating values. Again, there are many varieties of drying equipment available, with rotary driers and dry kilns being widely employed.

Weighing Industrial Wastes

There are two points at which waste material should be weighed. The first is at time of delivery, to ensure that the quantity received is the same as the quantity paid for. Secondly, the amount of industrial waste burned should be carefully weighed to allow an accurate monitoring of plant performance.

The weight of industrial waste delivery can be determined either at the unloading point or in the handling system. The various types of scales available are the truck, rail, combination truck/rail, and conveyor belt units. Typical weight indicators for these scales include dials (with or without an automatic printout), registering beams, and digital indicators. The weight of a load is transmitted to the weight indicator from the scale either mechanically (levers) or electrically (load cells). A hybrid system is also used, which, like the pure electrical load cell system, allows remote sensing. Load cell scales are generally more expensive than mechanical-lever scales in the low to middle capacity ranges. They can sometimes compensate, though, with a shallower, less-costly pit and a lower installed cost. With fewer moving parts, the load cell scale may have lower maintenance costs as well.

The conveyor belt scales continuously weigh moving waste material by multiplying the speed of the belt by the varying load. The total flow can be computed by a totalizer or integrator and displayed at any time. Both mechanical and electrical models are available.

Both scales and feeders are used to weigh waste material between the storage bunker and boiler. Feeders are available to handle up to 100 tons per hour (tph), whereas scales have capacities in the 10 to 30 tph range.

The scale's principle of operation entails filling a weighing hopper to a preset weight level, whereupon the hopper automatically dispenses the waste material to the boiler feed system. Various feeder types can be used for weighing; i.e., table, pocket, drag, apron, belt, gravimeteric, a pneumatic feeder. The first is controlled by a level indicator, but delivers widely varying quantities even at constant speed. The next five types are considered volumetric, although the belt feeder is the most accurate of that group. None of the volumetric feeders take into account changes in the industrial waste density. The gravimetric feeder is the most expensive and accurate of all types listed above. It maintains a constant weight of waste material per foot of belt; the rate of material flow by weight is therefore directly proportional to motor and belt speed. Most of the feeders are operated by the combustion control system, and the more accurate their measurements of fuel flow, the better their control of the fuel/air ratio. This translates to higher boiler efficiency as well as lower dust loading on air pollution control equipment.

Outdoor Waste Material Storage

There are two basic categories of waste material storage; "live" (or active) storage, which directly supplies firing equipment; and "dead" (or reserve) storage, that serves as a buffer for delays in shipments or other unforeseen difficulties in replenishment. Live storage is generally under cover, with reserve storage outdoors. Occasionally one type of storage can accomplish both jobs.

Where the outdoor storage is strictly for re-

serve, an incoming shipment is usally split so that part goes to live under-cover storage, and the remainder added to the reserve. The number and frequency of outdoor-to-indoor transfers depends on factors such as the size of the pile in relation to plant use, and the particular waste materials storing qualities.

Storing Industrial Wastes Under Cover

A covered structure such as a silo, bin or bunker is nearly always used to store the active waste material stockpile. The type of structure depends on the required storage capacity. A simple bin might prove sufficient in a small plant, whereas larger capacities require using in-plant bunkers, tanks and silos. Very large capacities require specially constructed storage containers outside the plant.

Enclosed storage has the following advantages over outdoor storage piles: (1) most enclosed storage structures will fill and discharge without the need to use mobile equipment, (2) the waste material will be kept dry and in good condition, and (3) enclosed storage is significantly more aesthetically pleasing.

Silos are commonly constructed of concrete and hollow tile. They are cylindrical, and come with either single or dual storage compartments. Bunkers are usally suspended from beams high above the floor; the two basic designs are cylindrical and parabolic. The parabolic bunkers often have problems discharging material because of dead space between the outlet gates. Cylindrical bunkers with conical hoppers can also experience discharge problems if the cone's slope is not sufficient. Plug or funnel flow could occur, which means that only the central portion of the waste material is drawn down, and the bunker would not completely empty.

The desired flow condition is called mass flow, where all the waste material in the storage container is in motion whenever any is withdrawn. This eliminates dead or stagnant areas and reduces the liklihood of spontaneous combustion. Other flow problems, such as ratholing (which is a form of funnel flow) and arching (or bridging) occur when bunkers, chutes and hoppers are not designed properly. Chutes should change direction gradually, be inclined steeply, and flare in the direction of flow. Also, the angle of convergence should be kept to a minimum when two streams of industrial wastes flow together.

Enclosed storage can also experience segregation problems. Additionally, in bunkers feeding stoker-fired boilers, segregation can cause uneven size distribution across the stoker and result in less efficient combustion. This can be prevented by either using a nonsegregating chute to route the waste material from the bunker to the stoker feeder, or load the storage bin in layers.

There are several types of monitors that find use on storage bunkers. A top level indicator allows automatic filling of the bunker. The two most common types are the paddle and gamma ray monitors. Another variety of gamma ray monitor is used in chute downspouts for detection of ratholing and arching. They can be linked with a vibrating unit to automatically break up the flow obstruction.

Moving Waste Material Into the Plant

This phase of waste material handling can be either quite simple or complex, depending on the size of the operation. Because both reserve and live storage inventories have to be continuously juggled, systems are required to convey waste material to both areas, as well as from live storage to bunkers in the plant. In small, simple operations, a lift truck with a scoop might be sufficient to handle these functions, whereas larger facilities would require more extensive, specialized equipment.

Waste material must normally be moved horizontally and vertically in transfer operations. Many pieces of conveying equipment are capable of performing both functions, but some designs are quite specialized.

Bucket elevators are very popular for vertical lifts. The two common types are the continuous bucket and centrifugal discharge models. The former uses a closely spaced (overlapping) bucket arrangement and operates at a relatively low speed, yet has a larger capacity and can handle a wider range of material sizes than the centrifugal discharge design, which is usually restricted to medium-size chunks. A third type is the perfect, or spaced bucket positive discharge, elevator. This is a variation of the centrifugal discharge unit with buckets mounted on two strands of chain and snubbed back under the head sprocket to invert them for positive discharge. These units are specifically designed for materials that are sticky or tend to pack.

Flight conveyors use a pair of endless chains with regularly spaced scrapers that pull or drag the material along a trough. They are most effective on horizontal or slightly inclined runs, and require little headroom.

Continuous-flow conveyors (also known as bulk-flow or Redler type conveyors) are essentially enclosed ducts containing closely spaced flights, and can be used on horizontal, vertical, or inclined runs These are versatile units with flexible connecting joints which permit easy movement around corners. The casings are dust-tight.

Belt conveyors, which were mentioned earlier as feeders, enjoy wide application for horizontal and slightly inclined conveying. Most of these units are fitted with magnetic equipment for separating tramp iron.

Ash Handling

Ash is the incombustible mineral matter left behind when some waste materials burn completely. Ash removal is practiced from two sources: the bottom of the furnace; and from collecting devices at the stack, such as cyclone separators, electrostatic precipitators, and bag filters. These two general categories of residue are known as bottom ash and fly ash, respectively. In stoker-fired furnaces, there is more bottom ash than fly ash.

The goal is to remove the collected ash for ultimate disposal in the most economical means possible. There are several approaches available, with plant size generally being the determining factor as to which is selected. Smaller plants normally use a system comprised of: (a) conveyor pipeline for moving ash from collecting hoppers at the stack and furnace, (b) airtight receivers for separating air and ash, (c) automatic discharge gate for channeling ash to a storage bin, (d) air washer to collect fine ash and dust particles before discharging air to the atmosphere, and (e) a steam, water or mechanical air exhauster. The mechanical exhauster is the most efficient, but the steam and water units are easier to maintain. The steam exhauster is especially attractive if the plant has a waste steam supply. Water exhausters, with discharge normally dumped to a sewer, are being used less due to increasingly stringent pollution regulation and dwindling water supplies.

Medium-sized plants normally use a pneumatic system. A vacuum-type arrangement is suitable for handling up to several hundred tons of ash daily, but higher tonnages require a positive pressure conveyor system. Large plants generate such large amounts of ash that a wet system is employed, with ash carried from collecting hoppers to disposal points with a sluice conveyor.

At least brief mention should be made about densified biomass (DBF). Wood and other types of waste agricultural products can be reduced to uniformly shaped pellets, briquettes, or other forms, which have a density in the vicinity of twice that of the original biomass (on the same moisture basis). Due to the uniform particle sizes and low moisture contents (typically 10%), DBF definitely provides storage and handling benefits.

CASE STUDIES

Cogeneration from Wood Residue at a Lumber Company

Introduction

This case study presents a review of the conversion of one industrial plant's energy base from natural gas and purchased electricity to wood residue. This plant in the lumber and wood industry is currently using its wood residue to cogenerate process steam and electricity. During normal operation the plant is self sufficient in these two areas and obtains all its fuel from byproduct wastes.

This company manufactures hardwood and softwood dressed lumber for a regional market made up primarily of building materials wholesalers and retailers. Approximate total yearly production is 53,000,000 board feet and total employment is on the order of 75 people.

Their processing takes saw timber and debarks, saws, planes, and kiln drys it to produce dressed lumber. Wood and bark residues on the order of 335,000 pounds per day are produced as waste products

Typical full capacity electrical load for the plant is 1800 KW during daylight operation, and normal off-shift load is 600 KW; typical energy required for kiln operation is 1.9×10^7 BTU/hr. maximum (cold) load and 1.1×10^7 BTU/hr. running load per kiln. Saw and planing mills operate 10 hours per day, five days per week; kilns operate 24 hours per day, seven days per week.

Statement of Objectives

This organization set out to develop and complete a program which would achieve the following objectives:

1. To productively dispose of their wood wastes with a minimum of handling.

2. To reduce plant energy costs.
3. To reduce dependence on external, uncontrollable supplies of energy and develop lower cost, available fuel sources.
4. To continue to operate within local and federal emission guidelines.

To satisfy these objectives, this company developed a plan to purchase a boiler fired by wood residue to provide steam to their dry kilns and to purchase a turbine generator unit which would generate, from the same steam, all of their electricity. Implementation of this plan began in 1976, with the start of installation of a 75,000 pound per hour boiler and was concluded March, 1979 with successful commercial operation of their 7500 KW turbine generator.

Economic Analysis

Based on a cost of three million dollars for the total system design, procurement, and installation, the following Economic Analysis applied to this conversion:

Actual cost		$3,000,000
Less: Tax credits		
Investment tax credit (10%)	300,000	
Energy tax credit	300,000	600,000
Adjusted first cost		$2,400,000
Estimated yearly fuel savings	576,000	
Less: Estimated yearly operating costs	150,000	
Net savings		426,000
Payback period (2,400,000÷426,000)		5.6 years
Time adjusted rate of return (assume life of Investment is 30 years)		17%

Conclusions

On balance, this long term asset acquisition has a relatively rapid payback, while satisfying all of the stated objectives. When rising prices for conventional fuels are considered, the rate of return and payback will improve still further. This plant is currently investigating possibilities for purchase of excess generating capacity by the public utility in its service area.

Wood-Cardboard Fired Heating System

Introduction

A manufacturing and warehousing operation in Southwest Georgia presently generates two truckloads of wood and cardboard waste per day from normal operations. Coinciding with the waste removal problem was the issue of heating a 300,000 sq. ft. warehouse facility on their grounds. They approached Georgia Tech for an analysis of a system which would utilize their wood-cardboard waste to heat their warehouse. The analysis was to address the following objectives.

1. To productively dispose of their wood-cardboard wastes with a minimum of cost and handling.
2. To provide for heating of new warehouse facility at a minimum energy cost.
3. Analysis of heating value of potential fuel source.
4. To reduce dependence on external, uncontrollable supplies of energy and develop a heating system utilizing available alternate fuel sources.
5. To operate within local and federal emission guidelines.

Analysis Results

A heating system which includes a furnace (capable of handling up to 80,000 lbs of waste fuel daily), air to air heat exchanger, appropriate ductwork, air pollution devices, fans and controls would cost approximately $200,000 to $250,000. A comparable steam generating system would cost approximately $800,000. Estimated values of heat provided by the system is 2.2×10^7 BTU/hr based on a 12 hour heating day. Using a standard gas fired unit heater system, it would take 31.4 MCF/hr of natural gas to achieve this out-put. Thus, for a given heating season savings of up to 3×10^{10} BTU or $60,000 could be realized.

Economic Analysis

Based on a cost of $240,000 for the total system procurement and installation, the following economic analysis applies to this program.

Actual cost		$240,000
Less: Tax credits		
Investment tax credit (10%)	24,000	48,000
Adjusted first cost		$192,000
Estimated yearly fuel savings	60,000	
Payback Period (192,000÷60,000)		3.2 yrs
Time adjusted rate of return (assume life of investment is 30 years)		31%

Conclusions

This long term asset acquisition has a relatively rapid payback, generous rate of return and satisfies all of the stated objectives. When rising prices for conventional fuels are considered, the rate of return and payback will improve even further.

Installation of a Multiple Fuel Boiler at a Carpet Company

Introduction

This case study presents the technical and economic factors weighed by one carpet company in coming to the decision to purchase a boiler capable of firing solid fuels as well as oil in lieu of one which could fire only fuel oil.

The company was involved in a major expansion of its operating facilities. A new plant site had been purchased which had no existing boiler equipment. The process to be installed at the new site would require 250 HP to 300 HP of boiler capacity to supply steam at 125 PSIG saturated. It was expected that the process would be operated for three shifts each day, six days a week and 50 weeks per year.

If a conventional scotch marine package boiler were purchased it would have to be fired on fuel oil alone since no natural gas was available in the area surrounding the new plant. No. 6 fuel oil was ruled out for the size boiler needed due to the additional equipment requirements and operating and maintenance considerations. Therefore, No. 2 fuel oil would have to be the primary fuel.

Coal and waste wood were both available in the area at competitive prices. In addition, it was felt that carpet waste, which is produced in large quantities by other operations within the company, might be used to supply part of the fuel input to the boiler. It was estimated that, on the average, 50% of the required energy input could be supplied by this waste from the company owned operations alone

Not only would the carpet waste be "free" at its source, but it would also have no associated transportation cost. Empty trucks would be arriving at the new plant site to haul finished product to the company owned carpet tufting operation which is the primary producer of the carpet waste. These trucks could be utilized to get the waste from its source to its point of use which would mean that the carpet waste would represent a completely "free" energy source for the boiler.

The only negative consideration for the company's management was that, if a solid fuel were to fired, EPA emissions requirements would have to be met. It was felt that a boiler could be purchased which could be fired on coal, wood or mixtures of carpet waste with coat or wood in blends of up to 50 percent waste (based on heating value) while still falling within EPA particulate guidelines.

Based on this assessment, the company's management made the decision to purchase a combustion system capable of firing fuel oil, coal, wood or solid industrial wastes.

Combustion System

The complete combustion system consists of a three-pass, firetube package boiler capable of firing fuel oil or solid fuels such as coal or wood, either separately or simultaneously, and all necessary fuel preparation, storage and handling equipment. Combustion of the fuel oil is achieved by an air-atomizing oil burner, capable of burning any commercial grade of fuel oil. Combustion of the solid fuels is accomplished with a hydraulically operated, single retort, underfeed stoker with dead plate or side dumping grates.

The conveying system, which is designed to handle coal but is suitable for other solid fuels, consists of one inclined conveyor with discharge spout, down spout, hopper cover, level controls and combustion disconnect starter. The fuel will be stored under cover in a 30' X 30' x 30' concrete and block building open on one end to allow transport of the fuel by front-end loader from storage to the conveying system. The carpet waste will be shredded to a uniform size before being mixed with the coal or wood waste.

Company management selected the system described above primarily on the strength of the following considerations:

1. The boiler was guaranteed to meet EPA particulate emissions requirements without a baghouse or scrubber.
2. The solid fuel grate and dual burner both remain installed at all times providing ready-to-fire flexibility.

Economic Analyses

The calculations for combinations of waste fuel are similar. The results for all four cases are presented in tabular form in Table 3.

TABLE I - TYPICAL ANALYSES OF CELLULASIC COMPONENTS

	Percent by Weight						Heating Value, BTU per lb		Atmos. Air at Zero Excess Air	CO_2 at Zero Excess
SOFTWOODS+	Carbon C	Hydrogen H_2	Sulfur S	Oxygen O_2	Nitrogen N_2	Ash	High	Low	lb/10^6 BTU	Air, %
Cedar, white	48.80	6.37	...	44.46	...	0.37	8400*	7780	709	20.2
Cypress	54.98	6.54	...	38.08	...	0.40	9870*	9234	711	19.5
Fir, Douglas	52.3	6.3	...	40.5	0.1	0.8	9050	8438	720	19.9
Hemlock, Western	50.4	5.8	0.1	41.4	0.1	2.2	8620	8056	706	20.4
Pine, Pitch	59.00	7.19	...	32.68	...	1.13	11320*	10620	702	18.7
White	52.55	6.08	...	41.25	...	0.12	8900*	8308	723	20.2
Yellow	52.60	7.02	...	40.07	...	0.31	9610*	8927	710	19.3
Redwood	53.5	5.9	...	40.3	0.1	0.2	9040	8498	722	20.2
HARDWOODS+										
Ash, White	49.73	6.93		43.04	...	0.30	8920*	8246	709	19.6
Beech	51.64	6.26	...	41.45	...	0.65	8760*	8151	729	20.0
Birch, White	49.77	6.49	...	43.45	...	0.29	8650*	8019	712	20.0
Elm	50.35	6.57	...	42.34	...	0.74	8810*	8171	715	19.8
Hickory	49.67	6.49	...	43.11	...	0.73	8670*	8039	711	20.0
Maple	50.64	6.02	...	41.74	0.25	1.35	8580	7995	719	20.2
Oak, Black	48.78	6.09	...	44.98	...	0.15	8180*	7587	714	20.5
Red	49.49	6.62	...	43.74	...	0.15	8690*	8037	709	19.9
White	50.44	6.59	...	42.73	...	0.24	8810*	8169	715	19.8
Poplar	51.64	6.26	...	41.45	...	0.65	8920*	8311	716	20.0
BASASSE										
Hawaii	46.20	6.40	...	45.90	...	1.50	8160	7538	687	20.3
Java	46.03	6.56	...	45.55	0.18	1.68	8681	8043	651	20.1
Mexico	47.30	6.08	...	45.30	...	1.32	8740	8149	646	19.4
Peru	49.00	5.89	...	43.36	...	1.75	8380	7807	700	20.5
Puerto Rico	44.21	6.31	...	47.72	0.41	1.35	8386	7773	627	20.6

* Calculated from reported high heating value of kiln-dried wood assumed to contain 8 percent moisture.

TABLE 2 - ANALYSES OF TYPICAL REFUSE COMPONENTS

	Percent by Weight						High Heating Value BTU/lb	Moisture
	Carbon C	Hydrogen H_2	Oxygen O_2	Nitrogen N_2	Sulfur S	Inerts		
Meat Scraps, Cooked	59.59	9.47	24.65	1.02	0.19	3.11	7.623	...
Fried Fats	73.14	11.54	14.82	0.43	0.07	0	16.466	...
Leather	42.01	5.32	22.83	5.98	1.00	21.16	7.243	...
Rubber Composition, Heel Sole Catch	53.22	7.09	7.76	0.50	1.34	29.74	10.899	...
Plastics, average	78.0	9.0	13.0				15.910	...
high	90.0	10.0					19.303	...
low	55.8	7.0	37.2				9.580	...
Polyethylene	85.6	14.4					19,950	...
Vinyl	47.1	5.9	18.6		(Chlorine = 28.4%)		8,830	...
Vinyl Chlorida - Vinyl Acetate Copolymer								
Plastic Film Mixed Contaminated with Food Waste	67.21	9.72	15.82	0.46	0.07	6.72	13,846	...
Carpet Waste								
Medium Nap, Olefin Primary, Jute Secondary, EVA Laminate	41.10	2.70	13.85	0.88	0.02	41.45	7,703	...
Medium Nap,Jute Primary Cushion secondary(2" wide) Latex Laminate	41.55	2.41	6.36	0.82	0.19	48.67	5,791	...
Short Nap,Olefin Primary Cushion, Secondary (1.75" wide) Latex Laminate	37.64	2.35	3.57	0.75	0.35	55.34	7,721	...
Short Nap, Olefin Primary Cushion Secondard(.75" wide) Latex Laminate	29.47	2.04	7.72	0.55	0.08	60.14	6,816	...
*Inerts-Ash, Glass, Metal, Stone, Ceramincs								
Newspapers	49.14	6.10	43.03	0.05	0.16	1.43 1.52	7,974 8,480	5.97

TABLE 3 ECONOMIC ANALYSES OF THE INSTALLATION OF A MULTIPLE FUEL BOILER

Case	Fuel	Annual Fuel Cost Savings, $	Net Annual Cost Savings, $	Payback Period, Years	Time Adjusted Rate of Return, %
1	Coal	90000	42400	3.19	31.2
2	Wood Waste	101700	48300	3.80	35.5
3	Mixture 50/50 Coal and Carpet Waste	111100	53000	2.55	39.1
4	Mixture 50/50 Wood Waste & Carpet Waste	117000	56000	2.41	41.4

Conclusion

The use of correct combustion information can improve the efficiency of industrial waste fired systems This improved efficiency will result in more energy being extracted from the waste material which will result in reduced dependance on fossil fuels. While the burning of industrial wastes may cause increased storage, material handling and maintenance problems these problems will be more than offset by reduced fossil fuel consumption. The impact of these problems can be minimized by properly designing the system.

Acknowledgement

Development work for this paper was done under Georgia Tech's Industrial Energy Extension Service. The Industrial Energy Extension Service is a four-year voluntary program that has as its goal a 10 to 20 percent reduction in the projected 1980 energy needs of Georgia's Industries. The Georgia Office of Energy Resources is sponsoring the program, under a grant from the Department of Energy, as a major part of an overall State Energy Conservation plan.

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THE CONVERSION OF WASTE TO ENERGY

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ABSTRACT

Almost every industrial operation produces some combustible waste, but conversion of this to useful energy is often more difficult than with other energy recovery projects and requires careful attention to design, operating and maintaining the facilities. Each application requires a careful approach tailored to the installation, but some general design and economic principles do exist. Several waste to energy projects will be discussed to illustrate these principles.

Energy recovery from the combustion of by-product and waste materials is perhaps the most challenging of energy conservation techniques from an engineering and operational viewpoint. For this reason, there are many opportunities in a variety of industries which have not been exploited, but there is increasing incentive to do so. The recent rapid increase of fuel cost is being compounded by the escalation of landfill disposal costs and the ever-tightening regulations on air and water emissions. Implementation of the Resources Conservation and Recovery Act of 1976 will immediately affect the cost and availability of landfills.

Since there is no "grandfather" clause, many small landfill operations will terminate, and those remaining will incur significant additional operating costs to comply with regulations. For sanitary landfills, the disposal cost is likely to range from $5 to $10 per ton for ideal conditions, to $10 to $50 per ton if soil and site conditions are less favorable.[1] Many industrial wastes will arbitrarily be considered hazardous because they are ignitable, corrosive, reactive, or toxic and would be covered by regulations which are even more costly to comply with.

Almost every industrial operation produces some combustible waste, but effective utilization as energy requires a unique approach tailored to each installation. This can best be illustrated by discussing some of the general principles which apply to combustible waste energy recovery and then providing examples.

Effective design of waste-to-energy equipment requires a knowledge of the chemical composition and physical properties of the waste. Elements such as sulfur and chlorine can create corrosive products of combustion which require attention to materials of construction and temperature profile within the boiler and furnace as well as scrubbers. Sodium, vanadium, lithium, and postassium can result in the

rapid deterioration of most refractory materials. Metallic ash can create fouling and emission problems. Even seemingly harmless elements and compounds such as nitrogen and water can cause problems. The high conversion of fuel nitrogen compounds to nitrogen oxides may require control techniques such as two stage combustion. Water, because of its high latent and specific heat can limit energy recovery as illustrated by Figure 1.

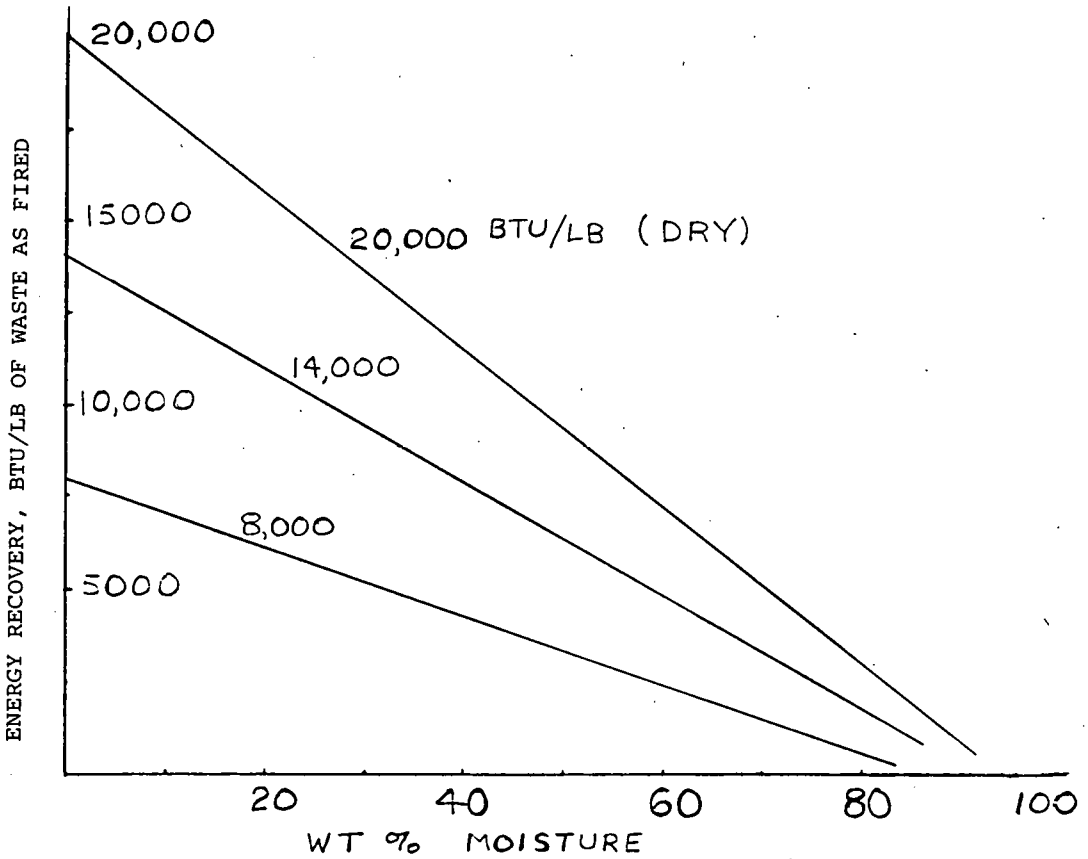


FIGURE 1 - ENERGY RECOVERY AS A FUNCTION OF MOISTURE AND DRY LOWER HEATING VALUE FOR 400°F EXHAUST

Physical properties are also important. An important parameter for gases is the Wobbe index, defined as the lower heating value in Btu/SCF divided by the square root of the specific gravity, as shown in the following:

$$\text{Wobbe Index} = \frac{\text{LHV}}{\sqrt{\text{SG}}}$$

Since a burner, flow meter, and control valve may be considered to be orifices, gas flow is inversely proportional to the square root of the specific gravity. Thus, the Wobbe Index can be used to compare the firing characteristics of combustible gases when designing burners.

To design the liquid fuel burner and valve train, the viscosity and the viscosity/temperature relationship must be known as well as any tendency for the fluid to cause plugging or fouling. Solid waste

characteristics such as particle size, bulk density, and angle of repose are relevant to the design of material handling equipment to store, prepare, and burn waste. Because of the mechanical problems involved, it is best to simplify such systems as much as possible.

No matter what the form of the waste, it is important to calculate the adiabatic flame temperature or combustion temperature of the system. This requires trial and error calculation involving the heating value of the fuel and the specific heat of the products of combustion and can best be done with a computer program or using the Kennan & Kaye Gas Tables. The flame temperature is required to select refractory materials and must be high enough to maintain stable combustion.

The design of waste to energy conversion equipment requires careful coordination with other plant facilities. Because of the inherent variability of the quality and quantity of wastes, a significant sample of hard data should be used to determine the design basis. Although there is often a tendency to overestimate the mass of available waste, over-design can be just as uneconomical as under-design. Because waste to energy equipment is usually very capital intensive, unutilized capacity is costly.

The system must match the energy requirements of the facility. For example, many manufacturing plants utilize energy primarily for space heating for which there is no demand in the summer. Absorption air conditioning could provide the means to recover energy year-round. If energy for heating is not required, electric power generation may be feasible, especially in light of new FERC regulations which encourage power generation from renewable resources and cogeneration.

However, chemical composition of the waste may place limitations on the design of heat transfer equipment such as limiting steam temperature and pressure which would limit power generation efficiency. If possible, 24-hour per day operation is preferred because of:

(1) improved equipment utilization
(2) reduced thermal cycling
(3) reduced start-up fuel consumption
(4) improved safety, because start-up is the most hazardous part of combustion equipment operation.

The costs of designing, operating, and maintaining the facilities should be realistically considered during the economic analysis of the project because most waste to energy systems require significantly greater attention. Neglect of these special requirements can be very costly in the long run.

Having discussed some general principles, several specific applications will be used to illustrate these principles.

An excellent example of energy recovery from a waste gas stream is in operation at the Petro-Tex Chemicals' petrochemical plant in Houston. A gas stream composed of 90% inerts (nitrogen and carbon dioxide)

and 10% combustibles (hydrogen and hydrocarbons) is incinerated at 1400°F. Because of the quantity of inerts, supplemental natural gas firing with a grid burner is required to maintain the required flame temperature. The natural gas supplies about 85% of the energy.[2] Seven hundred fifty psig steam is recovered in a fin tube boiler and economizer. The stack temperature is 340°F; even lower stack temperatures could be obtained if a low pressure boiler were included. The grid burner and heat recovery boiler equipment represent well proven technology applied to energy recovery from gas turbine exhaust. Considerable effort was required to provide a uniform gas and air flow distribution to maintain a uniform temperature profile to assure complete combustion.

Special combustion equipment is not always required to handle combustible waste. Petro-Tex is currently developing a project to blend polymer waste which is more viscous than heavy fuel oil with lighter by-product oils that are currently burned in conventional boilers.

A boiler at Tenneco Chemicals in Pasadena illustrates another technique involved in firing by-product liquids and gases. A conventional 200,000 lb/hr package boiler is fitted with a refractory lined furnace approximately 25 feet long and 8 feet in diameter. The monolithic refractory lining can withstand flame temperatures of over 3,000°F. The furnace provides the turbulence and high temperature residence time to complete burning of oil containing up to 10% combustible solids, a mixture of alcohols and water, a waste gas stream at low pressure and low heating value, and a plant fuel gas of widely varying composition and Wobbe Index. About 25% of the combustion air flow passes through an air jacket surrounding the shell to recover 1 million Btu/hr of heat and enters the furnace through tuyeres downstream of the burner to promote spinning flow and turbulence. The burner consists of a single throat with guns for fuel gas and liquid fuels surrounded by an annular opening for the waste gas.

An electronic analog control system maintains stable operation despite variation in energy input from the fuels. Feedback from the steam flow controls air and fuel with cross limits to ensure that a safe air to fuel relationship is maintained during changes. The air flow is trimmed by the oxygen analyzer and the refractory temperature is monitored by six platinum rhodium thermocouples. A Wobbe index analyzer compensates fuel gas flow measurement for changes in composition. A three element feedwater control system maintains water level.

Modular, controlled air solid waste incinerators/heat recovery systems are now marketed by several companies including Consumat (dominant in the large units), Comtro, Environmental Control Products, Basic, and Kelley (dominant in small units). All are functionally similar. Untreated waste is loaded into a ram feeder from the tipping floor by a skid steer front end loader.

The ram, capable of 50,000 pounds of thrust, pushes the waste into the primary chamber into which air is introduced in a substoichiometric quantity. A lazy, sooty flame results allowing most of the ash to remain in the chamber to be pushed through to an ash removal system by a series of rams. The gas goes to a secondary chamber where air is added to complete combustion of the gases and particulates carried up from the primary chamber before entering a boiler or heat exchanger at about 1800°F. Newport News Shipbuilding is developing a project to generate high pressure steam from 75 tons per day of wood and paper waste. The cost will be about $4.2 million and the cost savings, about $1 million/year. At the other end of the spectrum, Tenneco Automotive is proposing a two ton per day system to burn dry wood, paper, and lint costing $78,000 and saving $33,000/year.

Fluidized beds are used for a variety of combustion applications including wood and agricultural wastes, waste treatment sludge, and chemical incineration. A fluidized bed can be used to recover noncombustible chemicals from a waste stream. When gas is passed through a homogeneous bed of solids within a certain velocity range, the solid behaves like a liquid. The combination of the turbulence in the bed and contact with the hot bed media completes the combustion of difficult to burn materials. An inherent advantage of the fluidized bed is the ability to burn solids or liquids with a minimum of pretreatment. Disadvantages are:

(1) Particulate carry-over
(2) Melting of the bed media and subsequent slagging of cyclones and boilers.
(3) Large fan power requirements.

The gasification of solid wastes may be advantageous especially when converting equipment designed to burn oil or gas. Fixed bed gasifiers have been found to be a problem for a size greater than 10 to 20 million Btu/hour because of bridging, channeling, and ash removal. A fluidized bed avoids these difficulties and has the advantage compared to combustion, of reducing air horsepower requirements, eliminating slagging by operation at lower temperatures, and reducing the quantity of gas to be cleaned. Some by-product char and liquids as well as low Btu gas is produced for firing in boilers or other combustion equipment.

Although these examples by no means completely cover the diverse field of combustible waste energy recovery, it is illustrative of the variety of techniques available for cutting energy and disposal costs. The uniqueness of these applications mandates that the best available technical resources be committed, including staff, consultants, and proprietary equipment and technology. It is also extremely important to have a management commitment to sound maintenance and operational practices. If these stipulations are followed, the conversion of waste products to energy is very profitable.

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ENERGY RECOVERY FROM SOLID WASTE FOR SMALL CITIES: HAS THE TIME REALLY COME?

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ABSTRACT

The City of Longview, Texas is evaluating modular, two stage incineration with waste heat recovery to produce steam for sale to industrial consumers. An envisioned 150 tpd waste disposal facility would serve the area population of approximately 100,000. Estimates for operating cost and steam conversion efficiency were based on historical data obtained from a similar facility located in Salem, Virginia. The total projected break-even cost in 1982 for production of 150 psig saturated steam for a completely consumptive use was $7.95 per 1000 lb. The projected break-even cost in 1982 for 600 psi steam superheated to 700 deg. F for a consumptive use was $8.72 per 1000 lb. excluding the cost of water deionization facilities. These costs compare favorably with projected costs of steam production using natural gas as a boiler fuel but are not competitive when compared to use of locally available lignite. The results indicate that the time has come for smaller cities with a potential for industrial steam sales to consider energy recovery from solid waste using modular, two stage incineration with waste heat recovery.

I. INTRODUCTION

The City of Longview, Texas is currently evaluating resource recovery as a means of reducing the quantity of municipal solid waste to be disposed by landfill. The City is located in a part of Eastern Texas that is experiencing an extremely rapid rate of industrial growth. The growth is attributable to an abundance of natural resources including oil, natural gas, lignite, iron ore, and water and its location in the sun belt. The City owns and operates a landfill that has an estimated lifetime of two to three years. Landfill will likely continue after closure of the existing landfill, either through construction of a new city owned landfill or contracting with a private firm that proposes to construct a landfill in the area. Resource recovery methods have attracted a great deal of interest in recent years from a number of Federal governmental agencies. The Department of Energy recently proposed regulations outlining a loan guarantee program for urban waste demonstration facilities (1). The Environmental Protection Agency (EPA) has launched a series of seminars on resources recovery technology (2). Of the resource recovery technologies discussed by governmental agencies and others, energy recovery in the form of steam for sale to industrial consumers appears to be the most favorable for the City of Longview. The envisioned technology entails combustion of municipal solid waste in a modular, two stage incineration system with waste heat recovery. The purpose of this paper is to describe the City's evaluation of this technology. A considerable amount of research has been done on the technology by the United States Army Corps of Engineers (3). Modular incineration facilities are currently in operation at a number of military installations and at least seven municipal facilities (4). Although EPA sponsored studies have been performed on some of the existing facilities, the results are not known to be available to date. Because of the lack of published operating data, the City initiated its own limited evaluation of an existing facility. The municipal facility in Salem, Virginia was selected for evaluation.

II. SALEM, VIRGINIA ENERGY RECOVERY FACILITY

A. Introduction

The City of Salem, Virginia made the decision in July 1976 to perform a detailed feasibility analysis of modular incineration with waste heat recovery. The modular incineration facility was offered as an alternative to use of a regional landfill located approximately 30 miles from the City. Construction of a solid waste transfer station would be required to use the regional facility. Area was not available for construction of a City-owned landfill within its corporate boundaries. Municipal general obligation bonds were approved by the voters of Salem in March 1977 and construction contracts were awarded for the facility in September 1977 (5). The voters of the City approved a bond issue for the project in March 1977 and contracts were awarded for construction of the facilities during September 1977. Initial startup occurred a year later in October 1978 and the plant was brought up to full capacity by December of the same year.

B. Description of Facility

The characteristics of the system are summarized in Table 1. Steam that is produced by the facility is sold under a 20-year contract to Mohawk Rubber Com-

pany which is located at a site immediately adjacent to the facility

TABLE 1

CHARACTERISTICS OF SALEM ENERGY RECOVERY FACILITY

Capacity: 100 tons/day of municipal solid waste

Steam Production Capacity: 20,000 lb./hr.

Period of Operation: 24 hours/day, 5 days/week, 52 weeks/yr.

Site Area: 2.2 acres

Capital Cost: $1.9 million (excluding land)

Steam requirements for Mohawk are in excess of the steam production capacity of the energy recovery facility so that virtually 100 percent of the steam that is produced will be sold. The facility employs two dual incineration systems manufactured by Consumat Systems Inc. Each system is capable of independent operation and includes two automatic loaders, two primary combustion chambers, one secondary combustion chamber, and waste heat boiler. A single wet ash conveyor and quench tank serves both of the dual incineration systems. The incinerator building which houses the incineration units was sized to provide covered storage for a considerable amount of solid waste. Solid wastes are sorted only to remove items which will interfere with incineration such as mattresses, pallets, etc. Other preliminary processing is not employed. Weighing scale facilities are provided on the site for monitoring solid waste disposal by the facility. The City employs 11 people at the facility including two operators for each eight hour shift.

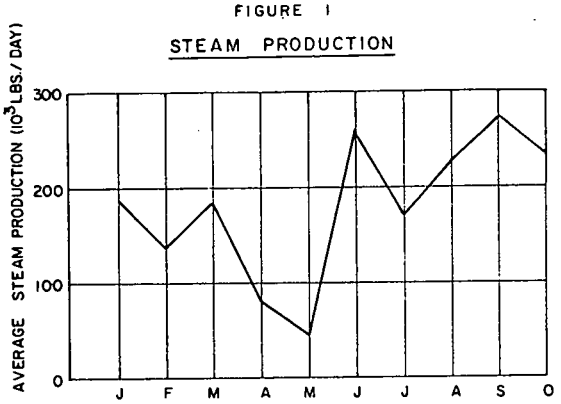
C. Historical Data

The City of Salem has done a thorough job of monitoring operating parameters and costs for their facility. These data are discussed in detail in the following paragraphs.

1. Operating Data - Average daily steam production is shown for each month of 1979 in Figure 1. As shown in the figure, steam production suffered a significant decline in April and May. This decline was caused by mechanical difficulties with the waste loading hoppers and the waste heat boilers. Production has steadily increased since that time and is currently approaching design capacity.

FIGURE 1

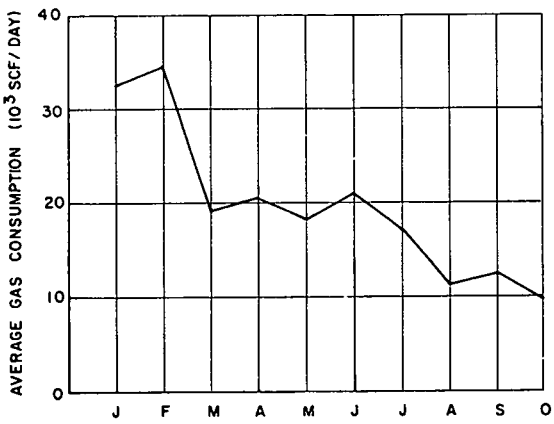
STEAM PRODUCTION



Average daily gas consumption for each month is shown in Figure 2. During the first part of the year, gas was being consumed in the secondary combustion chambers to decrease particulate emissions to acceptable values. Later in the year, air feed rates to the combustion chambers were optimized resulting in a substantial decline in gas consumption. Current gas consumption is mainly attributable to startup of the facility on a weekly basis.

FIGURE 2

GAS CONSUMPTION



As shown in Figure 3, waste disposal in the facility increased steadily during 1979 to the point that the unit was operating at 77 to 88 percent of design capacity at the end of the year. Future operation is expected to achieve consistent disposal in excess of 90 percent of design capacity.

One of the most important aspects of an evaluation of economic feasibility is the efficiency of waste heat recovery equipment in recovering energy released by combustion of solid wastes. Historical steam conversion is shown in Figure 4. Steam conversion during

1979 peaked at 3800 lb. steam per ton waste, then leveled out in excess of 3000 lb. per ton during the the last part of the year. A conversion rate in excess of 3000 lb./ton is expected for the future.

FIGURE 3

WASTE DISPOSAL

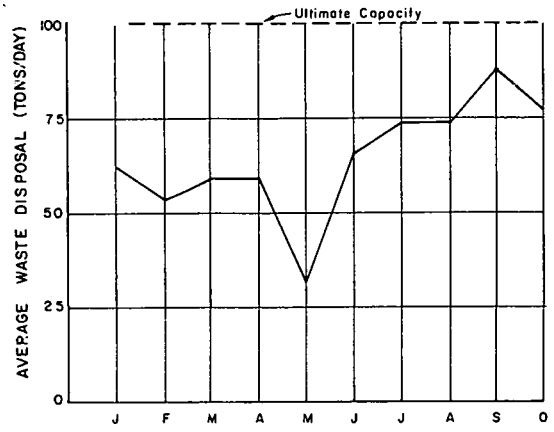
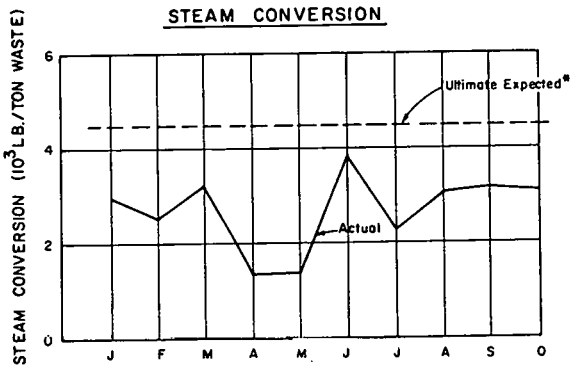


FIGURE 4

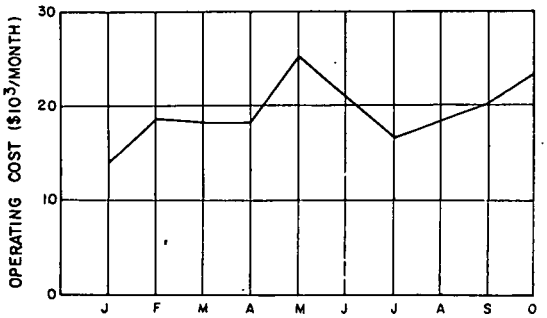
STEAM CONVERSION



* Ultimate expected steam conversion was calculated using solid waste heat value of 4500 BTU/Lb. and waste heat boiler efficiency of 0.6.

FIGURE 5

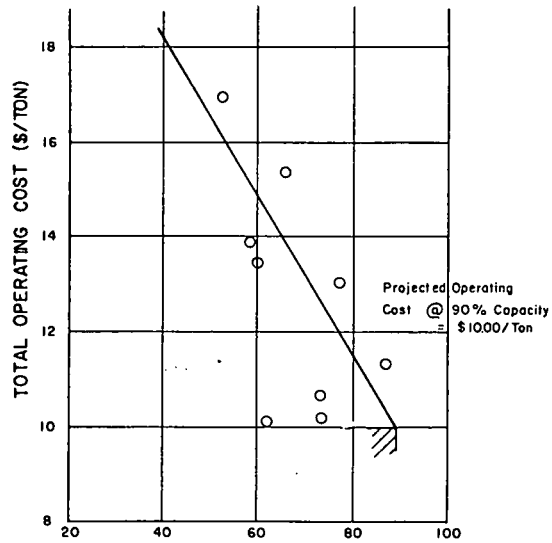
OPERATING COSTS



2. Cost Data - Operating cost are monitored routinely on a monthly basis as shown in an example statement of revenue and expenditures in Table 2. Total operating costs for each month are shown in Figure 5. Except for the peak during the mechanical difficulties in May, a gradual but steady increase in operating cost was experienced throughout 1979. Unit operating cost per ton for disposal of solid waste decreased in proportion with increases in the average monthly disposal rate as shown by the correlation in Figure 6. The unit cost value for May was not used in the correlation because of the abnormal conditions during the month. The projected unit operating cost for 90 percent of design capacity is $10.00 per ton.

FIGURE 6

PROJECTION OF OPERATING COST



III. PROPOSED LONGVIEW ENERGY RECOVERY FACILITY

A. Potential Industrial Steam Consumers

Two industries in the City of Longview have a demand for steam which far exceed the expected capacity of the proposed incineration facility. Of these two facilities, one has declined interest in the project and confirmation of interest from the other industry is pending at this time. The second industry has a demand for steam in two pressure catagories. The primary steam pressure used in the facility is 600 psi. superheated to 700°F. The secondary level used by the facility is 150 psi. saturated steam. Either category of steam pressure could consume in excess of the production capacity of the energy recovery facility. Sources of boiler fuel for this industry include

TABLE 2

STATEMENT OF REVENUE AND EXPENDITURES

FOR THE MONTH OF SEPTEMBER 1979

	BUDGET	ACTUAL	
OPERATING REVENUE:			
SALE OF STEAM	$17,593.33	$14,394.66	
DISPOSAL OF GARBAGE	1,416.67	2,575.77	
OTHER INCOME	-0-	-0-	
TOTAL OPERATING REVENUES	$19,010.00		$16,970.43
OPERATING EXPENDITURES:			
SALARIES OF PERSONNEL	$10,029.08	$11,286.60	
MAINTENANCE OF EQUIPMENT	333.33	1,323.57	
MAINTENANCE OF FACILITY	2,166.67	2,937.12	
ASH REMOVAL & DISPOSAL	416.67	352.00	
SUPPLYIES	416.67	171.36	
TELEPHONE	50.00	50.00	
FUEL	1,208.33	763.40	
UNIFORMS	-0-	(38.65)	
UTILITIES	1,433.33	3,352.40	
MISCELLANEOUS	41.67	-0-	
TOTAL OPERATING EXPENSES	$16,095.75		$20,197.80
LOSS ON OPERATING BEFORE DEBT SERVICE			(3,227.37)
LESS DEBT SERVICE			(11,870.42)
NET LOSS FOR SEPTEMBER 1979			$(15,097.79)

natural gas and surface-mined lignite which is locally available.

B. Description of Proposed Facility

General criteria for preliminary design of the proposed facility are shown in Table 3. A design developed around this set of criteria should exemplify an adequate amount of redundancy to provide dependable service for both disposal of solid waste and production of steam. A more detailed discussion of the components of the facility is included in the following paragraphs.

1. Incineration and Heat Recovery Equipment - Modular equipment would be shop manufactured and field assembled at the site of the facility. In a typical installation the incineration equipment supplier would supply all manifolding, controls, stacks, support platforms, and an ash conveyor with a quench tank to serve all three incinerators. Boiler feed water equipment would include a deaerator, chemical feed pumps, a blowdown receiver and boiler feedwater pumps. A metering system would also be provided to monitor steam production.

2. Incineration Building - A storage area for solid waste and all of the incineration and heat recovery equipment would be housed in a pre-engineered metal building with an approximate floor area of 28,800 square feet.

TABLE 3

GENERAL PRELIMINARY DESIGN CRITERIA

1. Unit should be capable of operating @ 2/3 capacity under failure of any single module.
2. Facility should have maximum capacity of 150 TPD with capability for expansion by adding a similar unit to 300 TPD. Building, plant layout, etc., should be geared toward expansion.
3. Unit should have following modules:
   a. 3 primary combustion chambers married to 3 secondary combustion chambers with a capacity of 50 TPD each.
   b. 2 waste heat boilers manifolded to receive heat from any of the secondary chambers with a capacity of 100 TPD equivalent each.

3. Weighing Scale Building - a weighing scale would be provided to monitor waste disposal at the plant. A building with an area of approximately 800 square feet would also be provided to house office facilities, restrooms, and weighing scale readout equipment.

4. Access Roadways and Parking - It would be necessary to reconstruct approximately 1,800 L.F. of existing oiled dirt road and construct new roadway over a distance of some 2,000 L.F. to provide access for solid waste handling vehicles to the facility. A considerable amount of paving will also be required within the boundary limits of the energy recovery facility for access to the waste storage area and visitor and employee parking.

5. Utilities from City - It would also be necessary to provide water and sewer service from City-owned systems to the site. Approximately 4,400 L.F. of sewage line, a sewage lift station and approximately 4,400 L.F. of water line would be required.

6. Piping to Industry - An estimated 2,200 L.F. of steam line would be required to connect the energy recovery facility and the industry. Production of steam at the higher pressure of 600 psi would require piping of deionized water from the industry to the facility.

7. Accessories - Other equipment required for the facility would include three skid steer loading tractors, four residual ash containers and propane fuel storage equipment for the tractors.

C. Cost Estimate

A cost estimate for energy recovery facilities to produce 150 psi steam is shown in Table 4. As shown in the table, the total estimated project cost for 1980 is $3,987,100. That same cost projected to 1982, allowing for inflation, is $5,001,104. Production of steam at 600 psi superheated to 700 deg. F would add approximately $800,000 to the capital cost of the facility. The increased cost is mainly attributable to the higher cost of the waste heat boiler and the additional piping required for deionized water to the facility.

IV. FEASIBILITY ANALYSIS

A. Financing

The currently envisioned method of financing is through municipal revenue bonds. Repayment of these bonds would be through collection of tipping fees and sale of steam to the industrial consumer. Based on current market conditions, we would anticipate that bonds would be available to the City of Longview at an interest rate of 8 percent annual. These bonds would extend over a 20-year payment period. Other methods of financing including federally subsidized loans, federal grants or industrial ownership may be considered in the future.

B. Period of Operation

Most facilities of this type are operated on a continuous 24 hour a day, five day per week basis. It is usually not practical to extend the operation to seven days per week. Solid wastes are collected on an eight hour per day, five day per week schedule and it is necessary to perform routine maintenance on the waste heat boilers and other equipment routinely on a weekly basis. Future consideration will be given to overcoming these problems so that seven day per week operation may be realized. Continuous, seven day per week operation would dramatically enhance the economic feasibility of this technology. However, the feasibility evaluation for this study is based on the most common 5 day per week period of operation.

C. Steam Conversion Efficiency

As discussed in Section II, the Salem facility achieved a steam conversion efficiency of approximately 3,000 pounds per ton of solid waste. This value was used as a basis for the feasibility evaluation. This value is significantly lower than a value which would be calculated using a solid waste heat content of 4,500 BTU per pound of solid waste and a waste heat boiler efficiency of 60 percent as is often suggested by incineration equipment manufacturers.

D. Steam Sale

It is currently envisioned that steam would be sold from the Longview facility on a basis that is very similar to the method used for the Salem Plant. Under this system, steam is sold at 1.6 times the cost on a BTU basis of the boiler fuel used by the industrial facility.

E. Landfill Alternate Disposal

In assessing the feasibility of this project, the amount of revenue saved by reduction of the waste to be disposed by landfill must be considered. A recent

TABLE 4

COST ESTIMATE FOR FACILITY

PRODUCING 150 PSI STEAM

			ESTIMATED COST ($1980)
1.	Incineration and Heat Recovery Equipment:		2,514,800
	Incinerator, Boiler & Internal Piping, Electrical, Manifolds & Stacks	2,380,000	
	Deaerator, Chemical Feed, Blowdown Receiver & Feedwater Pumps	80,000	
	Electrical Service	20,000	
	Instrument Air System	15,000	
	Steam Piping w/ Insulation	9,800	
	Water Piping	2,000	
	Steam Metering System	8,000	
2.	Incineration Building:		485,600
	Foundation & Other Concrete	139,400	
	Building Shell & Insulation - 28,800 s.f.	172,000	
	Plumbing	14,400	
	Electrical & Mechanical	47,500	
	Heating	50,400	
	Duct Work & Vents	10,100	
	Fire Protection System	51,800	
3.	Weighing Scale Building:		75,000
	Weighing Scale	35,000	
	Building - 800 s.f.	40,000	
4.	Access Roadways, Parking & Sitework:		224,200
	Repalce Existing Oiled Dirt Road - 1,800 l.f.	81,000	
	New Roadway - 2,000 l.f.	93,000	
	Driveways	13,600	
	Parking	8,400	
	Clearing, Grubbing, Grading - 2 acres	4,000	
	Fencing	24,200	
5.	Utilities from City:		159,300
	Sewer - 4,400 l.f. 8", Manholes & Lift Station	116,400	
	Water - 4,400 l.f. 6" & Fire Hydrants	42,900	
6.	Piping to Industry:		80,000
	Steam - 2000 l.f. 8" Insulation & Expansion Loops	80,000	
7.	Accessories		21,000
	Skid Steer Tractors - 3 ea.	15,000	
	Residual Ash Containers - 4 ea.	4,000	
	Propane Storage for Tractors	2,000	
	Total Construction Cost		3,559,900
	Engineering, Legal & Permits		427,200
	Total 1980 Project Cost		3,987,100
	Total Projected 1982 Project Cost (12% Annual Inflation)		5,001,400

study of the City-owned landfill in Longview showed a unit cost including operation and amortization of the facilities of $1.65 per ton of solid waste (6). The projected 1982 cost, allowing for inflation, would be $2.04 per ton. This value compares favorably with a value that is being discussed for the proposed privately owned facility to be located in the Longview area as discussed previously in Section I.

F. Breakeven Steam Cost

The conditions discussed above were used as a basis for evaluation of the feasibility of the energy recovery facility. Justification of the facility would consist of a cost for production of steam which in consideration of the reduced landfill disposal cost would offset the total capital and operating cost of the facility. This criteria for justification would insure that customers of the City would not be burdened with increased solid waste disposal fees incurred as a result of the operation of the energy recovery facility.

Feasibility data expressed in projected 1982 costs for the facility are summarized in Table 5. As shown in the table, the breakeven steam cost for the 150 psi steam generation facility is $7.95 per thousand pounds. The breakeven natural gas boiler fuel cost is $4.14 per mcf for the facility. Breakeven costs for a facility to produce 600 psi steam are $8.72 per thousand pounds of steam and $4.54 per mcf of gas.

TABLE 5

FEASIBILITY DATA SUMMARY

FOR FACILITY PRODUCING 150 PSI STEAM

1982

Ammortized Capital Cost = $510,000/yr.
Disposal Cost for Debt Service = $14.50/ton*
Operating Cost = $402,000/yr.*
Disposal Cost for Operation = $11.40/ton*
Total Disposal Cost (Capital & Operating)= $25.90/ton*
Break-even Steam Cost = $7.95/1000 lb.
Break-even Natural Gas Boiler Fuel Price = $4.14/MCF

IV. CONCLUSIONS

The feasibility of an energy recovery facility for the City of Longview will be established in the near future on receipt of confirmation of interest from the remaining candidate for industrial consumption of the steam. The industry will provide projections of fuel costs for 1982. If these costs are in excess of the break-even cost and the industry agrees with the other conditions established to determine feasibility, the project will be justified.

In view of Federal regulations for decontrol of natural gas prices, the break-even costs discussed in the previous section could be significantly less than the cost of natural gas boiler fuel in 1982. However, the cost of substitute boiler fuels such as locally available lignite may be less than the break-even cost.

The results of this paper show that modular, two stage incineration with waste heat recovery to produce steam for industrial consumption is a viable technology and should be considered for other small cities that have industrial consumers for steam production.

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6. Johnston, Waymon L., S. Frank Crumb and H. Lynn Millegon, "A Study on Alternate Methods of Residential Solid Waste Collection by Cost Effectiveness" prepared for the City of Marshall and the City of Longview by the Center for Urban Programs - Texas A & M University, July 1978.

* Based on projected operation at 90 percent of design capacity (135 tpd)

COGENERATION/COGENERATION - SOLID WASTE

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ABSTRACT

This paper reviews the rationale for cogeneration and basic turbine types available. Special considerations for cogeneration in conjunction with solid-waste firing are outlined.

Optimum throttle conditions for cogeneration are significantly different than normal practice for condensing units. The basic approach to cycle optimization is outlined with some typical examples offered.

WHY COGENERATION?

The basic reason for cogeneration is that the electrical power from cogeneration can be produced at about twice the thermal efficiency of central station power, even at a relatively small scale. There is no condensing loss from generation of power whenever the turbine exhaust steam is used for process requirements. Accordingly, the additional fuel input for power generation is the actual thermal value of the electricity produced (kW x 3413) plus:

- incremental boiler losses
- generator losses
- mechanical losses (bearing and gear)

Thermal efficiencies for such power production can be 75% or higher.

COGENERATION - SOLID WASTE FIRING

Basically, all of the considerations which favor cogeneration from fossil fuel apply equally to cogeneration when firing solid waste. There are some additional considerations which are specific to solid waste, however, which should be considered.

Normally, a fossil fuel fired boiler/power plant operates to meet the load requirements. Fuel input and purchase are tailored to the needs of the load.

Solid waste projects have a dual mission: energy plus solid waste disposal. Extensive stockpiling of solid waste for fuel is not practical. Consequently, the plant utilizing solid waste as a fuel must not only meet the load needs but must also consume the fuel, needed or not. In many cases, this will result in summer steam production in excess of summer load.

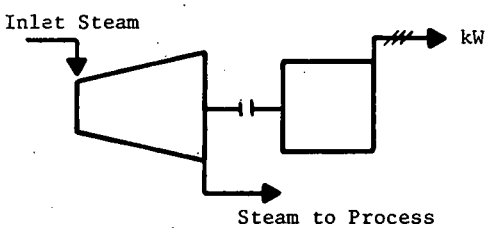
When firing a fossil fuel, the condensing section of a cogeneration turbine may not be economical; but with solid waste firing, it may be a very attractive option. This is particularly true where utility rates reflect summer peaks.

There are also some technical factors relating to solid waste cogeneration which will become evident in subsequent parts of this paper.

TURBINE TYPES

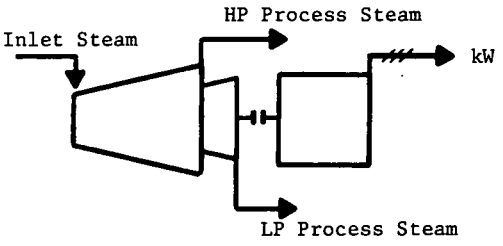
The simplest cogeneration turbine is the straight non-condensing or back pressure turbine which can be illustrated as follows:

BACK PRESSURE TURBINE



Automatic extraction turbines provide controlled outlet pressure steam at some pressure intermediate between the inlet pressure and the exhaust pressure. Some examples follow:

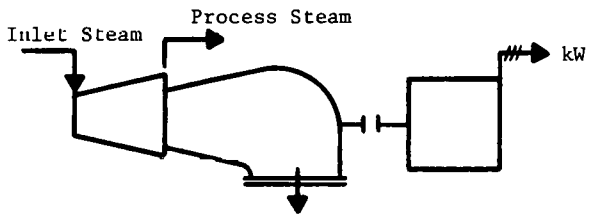
AUTOMATIC EXTRACTION BACK PRESSURE TURBINE



This configuration can be applied where the using facility employs more than one process pressure.

An interesting application of this type provides a main high pressure section for the principal flow of steam to process with a small section to reduce steam to a pressure appropriate for feedwater heating. This section effectively replaces auxiliary drive turbines thermally and generally better functionally and economically.

AUTOMATIC EXTRACTION CONDENSING TURBINE



In this configuration, a condensing section is provided to obtain additional electrical generation from steam not needed for process. The exhaust steam in this case is subject to condensing losses and does not share the inherent cogeneration advantages. In some cases, particularly where steam is produced from solid waste, a condensing section can be economically attractive.

The foregoing is only a partial classification of configurations available. Multiple automatic extractions prior to a back pressure or condensing section are possible. Admission of steam produced at lower pressures (induction) can be incorporated. Uncontrolled (variable pressure) extraction can be added to any of these turbine types.

SELECTION OF THROTTLE CONDITIONS

It has been normal practice for condensing turbine applications to select throttle conditions which would result in moisture in the exhaust of about 10 - 12% at absolute pressure of 1-2" Hga. Conventionally, the relationship of throttle pressure/temperature would be:

Pressure psi	Temperature ° F
400	750
600	825
800	900
1250	924
1400	1000

These conditions will seldom permit optimization of turbine applications intended primarily for cogeneration.

As a generalization, the high-load factor backpressure or extraction process condition will be the starting point for selection. From this, the state line can be projected backward to determine optimum throttle conditions.

The following simplified Mollier diagram illustrates this approach (Figure 1).

Explanation

The simplified Mollier diagram indicates three common process pressure lines: 300, 200 and 150 psi. The heavy "vertical" lines illustrate typical turbine state lines extended upward from saturation at these pressures. The triangular area between the process pressure line, the state line from saturation, and the selected steam temperature is the envelope within which the back pressure section of a cogeneration turbine can be selected.

Since this is normally the most thermally effective part of a cogeneration turbine, the selection of throttle conditions for the back pressure section to the major process pressure should receive the primary emphasis.

The available energy for generation is the vertical distance (enthalpy difference) between the throttle condition and the state line end point at the process pressure. If we shift the state line to the right within the triangular envelope, the available energy for generation is reduced and the amount of desuperheating of the process steam is increased.

Examination of the pressure lines to the upper left of the chart indicates that optimum selection results in relatively high throttle pressures for the given superheat temperature. The dashed state line to the right of the diagram indicates a typical condensing turbine state line for throttle conditions of 400 psi 750° F. With such a selection, the amount of generation which can be done in the back pressure section is substantially reduced. This will be further decreased for a given process flow by a substantial desuperheating requirement.

The selection of an optimum state line results in high throttle pressures which appear unconventional to those more accustomed to condensing generation. However, such a selection will normally prove most cost effective.

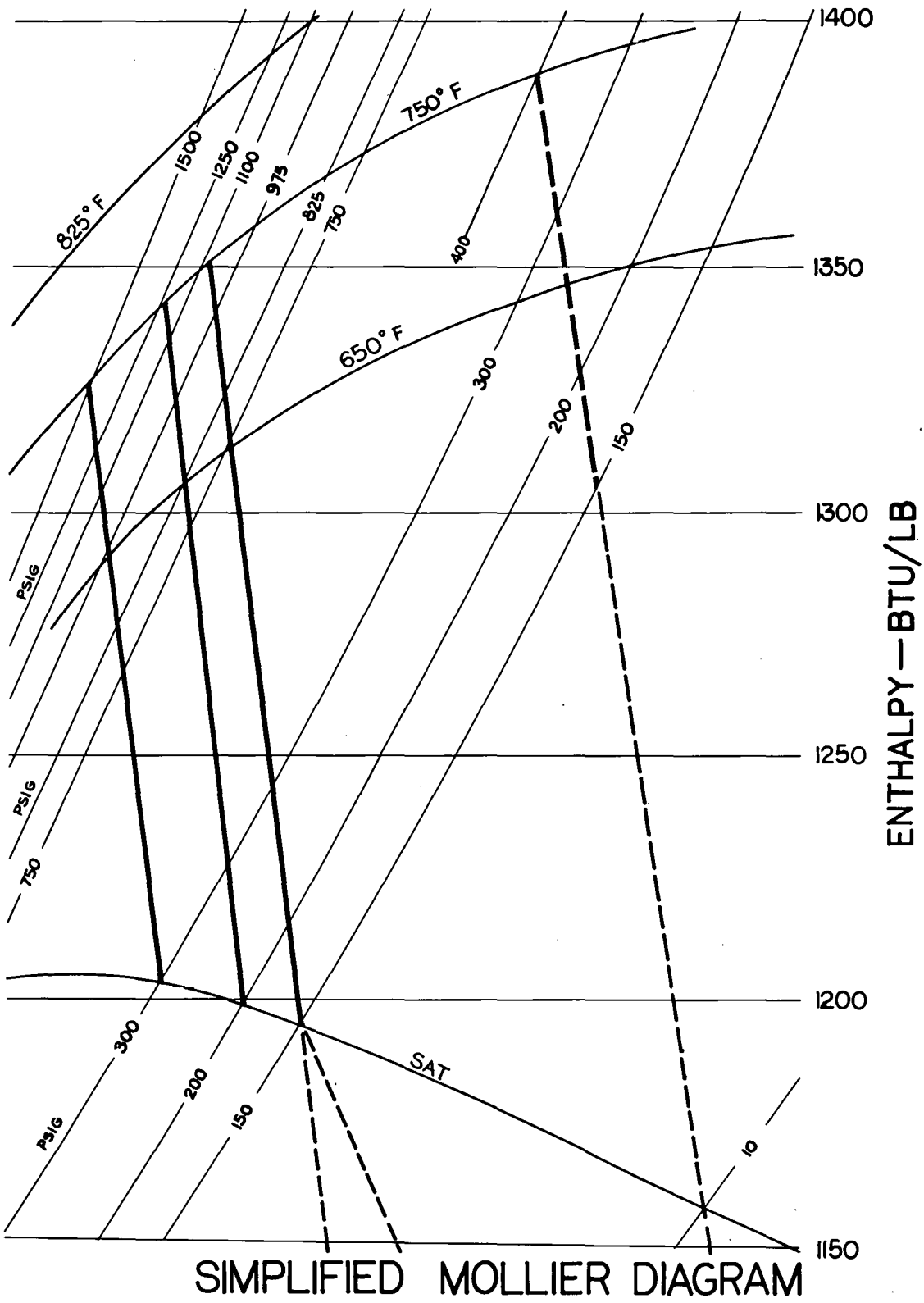

1400
1350
1300
1250
1200
1150
ENTHALPY—BTU/LB
825° F
750° F
650° F
1500
1250
1100
975
825
750
400
300
200
150
PSIG
750
300
200
150
10
SAT
SIMPLIFIED MOLLIER DIAGRAM

Figure 1

A tabulation of typical throttle conditions appropriate to common process load pressures follows:

650° F Superheat Temperature

process steam psi (saturated)	150	200	300
throttle pressure psi	750	825	975
kW per 100,000 pph	3300	2900	2400

750° F Superheat Temperature

process steam psi (saturated)	150	200	300
throttle pressure psi	1100	1250	1500
kW per 100,000 pph	4400	4000	3100

The foregoing is based on certain assumptions of turbine internal and generator efficiency which are consistent between cases. Specific equipment characteristics should be considered in actual selection of throttle conditions.

It is noticeable that these selections result in higher throttle pressures than would be the "normal" selections for the corresponding superheat temperature with a straight condensing turbine. If the turbine is of the extraction plus condensing configuration, these selections will result in higher levels of moisture in the exhaust stages to the condenser than is customary with conventional practice for condensing turbines. Turbine suppliers should be alerted to this in the process of selecting a cycle and particularly when purchasing a turbine.

Technology has advanced in this area and provides measures to accommodate the higher moisture levels. Blading design and materials have been substantially improved. Moisture extraction can also be provided in final stages to reduce final stages erosion.

Another alternative is to select a less efficient group of turbine stages for the condensing section to provide a condensing state-line end point which is above the manufacturer's acceptable level. Considering the difference in load factor and relative cost, condensing section efficiency is normally a much less important consideration than an appropriate cycle and efficiency for the high pressure section.

OTHER CONSIDERATIONS ASSOCIATED WITH SOLID WASTE FIRING

If steam is to be produced from solid waste in mass burning boilers, then certain inherent characteristics of this approach must be recognized.

1) Volumetric feeding of a hetrogenous fuel results in steam flow/pressure fluctuations. Means must be taken to smooth these out (accumulator?) or else to live with them. Some European projects employ a fast acting turbine by-pass valve to dump surges to lower stages or to the condenser.

2) Alternation of oxidizing-reducing atmospheres can result in excessive water wall tube metal wastage. Superheater corrosion at high SH temperatures has been excessive in some instances from various phenomena. High rates of deposits on tubes require frequent sootblowing and may contribute to corrosion/erosion. These factors have resulted in lower availability than industrial expectations for mass burning units.

Fortunately, cogeneration normally does not require superheater temperatures above 750° F, which are generally deemed acceptable with a carefully designed superheater, even with mass burning.

The limited experience with semi-suspension firing of coarse shredded solid waste and the much greater experience with this method of firing similar cellulose based fuels indicates that all of these problem areas are greatly reduced.

SPECIAL CONSIDERATIONS

The experienced forced outage rate for such turbine generators is less than 0.05% with 87% of even this experience believed to be attributed to relatively easily controlled causes. With this very high level of reliability, it is worth exploring commercial aspects considered beyond the scope of this paper relating to stand-by/demand charges versus load curtailment.

Our experience indicates more outages associated with relatively small interconnected turbine generators resulting from the interconnection than from the turbine generators. Much attention should be given to proper relaying and load shedding to gain maximum advantage from interconnected cogeneration.

A reducing/desuperheating by-pass is probably not warranted in most cases by turbine forced-outage considerations; however, it is a relatively minor cost. If installed, it can possibly be utilized advantageously in some circumstances to economically exploit limited fuel storage in a strategy to conserve solid waste fuel at night in order to maximize higher value daytime electrical production.

This involves - for solid waste fired projects - a careful analysis of optimizing the two dual missions - energy supply plus waste disposal.

COST FACTORS

The capital cost per kW is not significantly affected by selection of initial steam conditions[1]. However, for a given steam flow, the turbine capacity may be significantly affected by initial conditions.

As an example, consider alternative conditions - conditions with state lines to produce 200,000 lbs. per hour of 150 psi steam.

pressure	1100	750	900	600	150
temperature	750	650	750	750	5
h_1	1352	1314	1366	1370	1194
h_2	1194	1194	1280	1320	-
Δh	158	120	86	50	-
kW	8800	6600	4800	2800	0
Turbine $/kW	155	170	215	340	
M$	1360	1120	1030	950	0
Δ kW		2200	2800	2000	
ΔM$		140	90	80	
$/$\Delta$kW		64	50	40	
Boiler Heat Input					
10^6 Btuh	286	277	269	263	246
Relative Heat Input	1.16	1.13	1.09	1.07	1.0

Expanding the above to incorporate capital effects on other plant elements, it is likely that electrical generation, 8800 kW for each 200,000 pph of process steam, can be achieved for a differential capital cost of less than $2 million. The economic payout, of course, depends on the comparative fuel costs; however, with equivalent raw fuel cost, the cogeneration savings for maximizing back pressure cogeneration potential should be approximately 50% of the fuel component alone of purchased power. A payout of one year or less is not abnormal. With solid waste fired projects, it may be even greater.

References

[1] An excellent reference for cogeneration applications is Steam Turbines by John T. Meador, available from NTIS, U.S. Dept. of Commerce, 5825 Port Royal Road, Springfield, VA 22161 - printed copy $6.50.

IMPROVING INDUSTRIAL REFRIGERATION SYSTEM EFFICIENCY; ACTUAL APPLICATIONS

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ABSTRACT

This paper discusses actual design and modifications for increased system efficiency and includes reduced chilled liquid flow during part load operation, reduced condensing and increased evaporator temperatures for reduced system head, thermosiphon cycle cooling during winter operation, compressor intercooling, direct refrigeration vs brine cooling, insulation of cold piping to reduce heat gain, multiple screw compressors for improved part load operation, evaporative condensers for reduced system head and pumping energy, and using high efficiency motors.

INTRODUCTION

There are many methods of reducing energy in refrigeration systems most of which relate directly to compressor and pumping power requirements. Many of these methods can be implemented for a modest cost and some only require changes in system operating procedures.

Compressor power depends on the system head which can be reduced by lowering the condensing temperature or increasing the chilled liquid temperature. This can be accomplished with cold cooling water when available, increased chilled liquid supply temperature when allowed, and by maintaining clean condenser and evaporator heat transfer surfaces. System power can be partially reduced by throttling liquid flow at part load when design flow is not required and even at full load when higher chilled liquid return temperatures are allowed.

CENTRAL WATER CHILLING

A large complex of office and research laboratory buildings is served by a central chilled water distribution system with over 6000 feet of underground headers. Over 9000 tons of installed refrigeration capacity is located in two central machinery buildings. This paper will only discuss one of these buildings which houses two 2000 ton, R-12 centrifugal refrigeration machines each designed to chill 4000 gpm of water from 54°F to 42°F. A 6000 gpm counterflow cooling tower is mounted above each refrigeration unit on the roof.

Because of increased system demand from a new research laboratory, a third 2000 ton chiller is being installed. This new chiller is similar to the existing units but is more energy efficient. Figure No. 1 is a tabulation of refrigeration system data and Figure No. 2 is a system flow diagram. High efficiency (High Flux) evaporator tubes were used which reduced compressor power to 1712 HP whereas existing units require 2080 HP for 2000 tons. This saved more than 17% HP at full load.

Reduced Water Flow

Vertical turbine pumps circulate cooling water and chilled water through each refrigeration unit. During part load operation the chilled water is throttled which saves some pumping energy and also reduces compressor input energy by increasing the chilled water return temperature which reduces the compressor head. Since chilled water temperature differential (ΔT_e) and flow (gpm) are related by the expression Gpm/Ton = $24/\Delta T_e$ an increase in ΔT_e will reduce the required flow for a given capacity. This system uses a 12°F

ΔT_e which saves 800 gpm and about 30 HP at full load. Compressor input energy is also reduced by 1.1% HP/°F or about 20 HP. The installed turbine pumps have a very flat HP curve so that very little pumping energy is saved by throttling at part load.

Condenser cooling water is usually not throttled because compressor input energy would be increased and would cancel part or all of the pumping energy saved. Condenser cooling water flow (Gpm) and temperature differential (ΔT_c) are related by the expression: Gpm/Ton = $30/\Delta T_c$. If ΔT_c is increased from 10°F to 15°F the pumping flow decreases by 33%. For this system a 100 HP turbine pump circulates 6000 gpm with a ΔT_c = 10°F. Even with ΔT_c = 15°F which reduces the flow to 4000 gpm only 10 HP is saved because of the flat pump HP curve. However, the increased ΔT_c would increase compressor energy input by 3% or 34 HP at 66% compressor capacity which more than cancels the pump savings.

Reduced Head

Compressor head can be reduced by allowing the cooling water temperature to drop with outdoor temperature. Instead of cycling cooling tower fans to save fan energy, it is better to operate the fans to reduce cooling water temperature.

In these 2000 ton systems the design cooling water temperature of 85°F is allowed to drop to a minimum of 65°F which reduces the compressor head and saves 22% HP at full load. Figure No. 3 is a part load curve with three entering condensing water temperature.

Compressor head can also be reduced by increasing the chilled water supply temperature. However, laboratories require close control of temperature and humidity which limits the maximum allowable chilled water supply temperature. In this system the maximum supply temperature usually varies between 50°F and 55°F depending on outdoor weather conditions. For example, if the supply temperature were increased from 42°F to 50°F the compressor power would be reduced by about 9%.

System operation has been attempted with cooling water temperatures below 65°F and chilled water supply temperatures above 50°F but was not successful. These conditions caused the compressor to operate below its minimum stable capacity and required the hot gas by-pass valve to open cancelling any energy saving from reducing the compressor head.

Thermosiphon Cycle

During cold weather it is necessary to operate water chilling equipment because of internal building heat gains and to maintain critical laboratory temperature and humidity conditions. For the past 6 years a thermosiphon system has been used with the 2000 ton chillers to supply chilled water during cold weather.

Whenever the outside wet bulb temperature drops to 45°F or lower, the compressors are shut down and cold cooling tower water is used to chill water. Figure No. 4 is a schematic of this system. Cold cooling water flows through the condenser and condenses R-12 vapor. Cold liquid refrigerant then flows to the evaporator by gravity where it is boiled by warm (50° to 55°F) chilled water and returns to the condenser as vapor where the cycle is repeated. As refrigerant boils heat is removed from the chilled water which increases the refrigerant temperature and pressure. This produces a small pressure differential between evaporator and condenser causing the refrigerant to flow.

This system has operated for more than 3000 hours each winter between October and April and has saved over $45,000 per year. Average winter cooling loads are about 650 tons with peak loads exceeding 2000 tons most of which can be supplied by this system. Modifications for adding thermosiphon to the existing 2000 ton units cost $65,000 and consisted of installing one 7½ HP refrigerant circulating pump, installing spray nozzles in the evaporator, and enlarging the hot gas by-pass line.

The new 2000 ton chiller will include a "free cooling" system which is basically

the same as thermosiphon but without a pump and evaporator nozzles. High flux evaporator tubes and larger vapor lines will be used to increase heat transfer and minimize pressure drop. Figure No. 5 compares the performance of free cooling vs thermosiphon designs. The predicted free cooling capacity is double that of thermosiphon.

Intercooling

An intercooler (economizer) is installed on each unit which improves system efficiency by 8%. Figure No. 4 shows how this intercooler is connected to the system.

Condensed liquid refrigerant is throttled to an intermediate pressure in the intercooler (approximately 70°F saturated vapor during summer operation) where flashed vapor returns to the compressor and liquid flows on to the evaporator. This flashed vapor enters the compressor between 1st and 2nd stages and cools hot compressed vapor.

For low temperature evaporators such as -22°F, an intercooler can save 16% HP.

DIRECT PROCESS COOLING

A process refrigeration system installed over 15 years ago is shown schematically in Figure No. 6. Three separate cooling circuits were used to cool a process chemical and consisted of 1) an ammonia refrigeration cycle, 2) a 30% ethylene glycol brine circuit, and 3) an R-11 thermosiphon loop.

The ammonia compression refrigeration cycle cooled the brine which was circulated through an R-11 condenser. Cold R-11 liquid (41°F) was fed to jacketed vessels by gravity where process heat boiled the R-11 liquid. The resulting vapor returned to the condenser and the cycle was repeated.

A recent process expansion increased the refrigeration demand to 640 tons which required additional refrigeration equipment. Instead of simply expanding the existing system a study was made to determine if an alternate cooling method could be used to increase system efficiency. The results showed that a direct R-114 refrigeration system (Figure No. 7) would considerably reduce the total system HP/Ton and therefore a new system was installed.

In this new system R-114 refrigerant is compressed by two 3-stage centrifugal compressors and condensed by cooling tower water in shell and tube condensers. Warm R-114 liquid flows through two subcoolers where a small portion of the liquid is throttled to cool the main flow of high pressure liquid. Vapor from the subcoolers returns to the compressors where it cools hot compressed vapor and bypasses at least one stage of compression. This improves the refrigeration cycle efficiency by 14%.

Subcooled high pressure liquid flows 200 feet through a pipe header to an accumulator where it is throttled to 24°F. This cold liquid flows by gravity to a surge tank (disengaging pot) and on to jacketed process vessels where the liquid is vaporized. R-114 vapor then flows to the accumulator and on through 200 feet of vapor header to compressor suction where the cycle is repeated.

This new system eliminated two shell and tube heat exchangers (R-11 condenser and ammonia evaporator), large brine circulating pumps, increased compressor suction temperature from 10°F to 16°F, and improved process heat transfer by reducing the jacket cooling fluid temperature from 41°F (R-11) to 24°F (R-114).

Figure No. 8 compares energy balances for both old and new systems. If the old system had simply been expanded, a total of 2220 HP would have been required for 640 tons or 3.45 HP/Ton. By using the more efficient R-114 system only 1018 HP is required or 1.59 HP/Ton. Annual electrical energy savings is $166,000 based on a 70% average load.

CENTRAL AMMONIA PROCESS REFRIGERATION

An existing central ammonia refrigeration system is used for chemical process cooling and because of safety, operational, and energy concerns is undergoing modifications. Only the energy improvements will be discussed here.

Figure No. 9 is a schematic flow diagram of the modified system which is basically the same as the existing except for

1) insulating cold vapor headers, 2) replacing old reciprocating compressors with multiple screw compressors, 3) replacing old shell and tube condensers and cooling towers with evaporative condensers and 4) operating condensers at reduced temperatures. These modifications will save an estimated $100,000 in annual electrical costs.

Parallel screw compressors with an installed capacity of 2508 tons will provide cooling for normal process loads of 1200 tons (peak loads of 1500 tons) and building air conditioning demands up to 600 tons. Warm condensed ammonia liquid is pumped through plant distribution headers to 26 process evaporators (shell and tube, plate, jacket, and coil types). Liquid is throttled to 24°F in most of the evaporators and cold vapor returns through plant vapor headers to a central suction trap where entrained liquid is removed. Liquid free vapor is compressed and condensed and the cycle is repeated. Some evaporators operate at -28°F and must use booster compressors to produce the lower pressure and to return ammonia vapor at plant vapor header pressure. The 600 ton air conditioning evaporators operate at 34°F and return vapor through separate headers to compressors designated for higher suction temperatures. Both process and air conditioning compressors are cross connected for system flexibility and reliability.

Specific energy saving features are discussed below.

Insulated Vapor Headers

Over 3000 feet of 24°F ammonia vapor piping (8 inch average diameter) will be insulated to reduce heat input during warm weather. This heat load can be as much as 80 tons during a hot summer day or 30 tons as an annual average.

Insulation also reduces compressor suction superheat which increases compressor efficiency and lowers its discharge temperature. For this system (96°F designed condensing temperature) a 10°F reduction in suction superheat saves 3% HP and lowers the discharge temperature about 15°F.

The cost of insulating all vapor headers is $35,000 and will save an estimated 50 HP of compressor power. This amounts to over $12,000 in annual electrical cost savings.

Multiple Screw Compressors

Because of increased maintenance costs and difficulty in obtaining spare parts, three existing 200 ton reciprocating compressors (30 years old) will be replaced. Since the two existing 624 ton screw compressors have performed well for over 3 years, two additional units, 300 tons each, will be installed.

Average compressor load is about 70% of design and many hours of operation are at lower loads down to 20% capacity. Thus, it would be more efficient and would provide better system flexibility to install two small units than another large 624 ton unit.

Figure No. 10 is a typical screw compressor part load curve. If, for example, one 600 ton unit were installed and operated at 150 tons (25% capacity) there would be a 15% power penalty. However, if two 300 ton compressors were installed, one could be shut down while the other unit operated at 50% capacity with no power penalty. This would save about 20 HP for an annual electrical savings of $1800 based on 2000 hours of operation at 150 tons.

Two additional screw compressors (280 ton and 380 ton units) are being installed to supply 600 tons of building air conditioning load. These compressors are connected to a separate higher temperature (34°F) suction trap and vapor header instead of using the 24°F header with an evaporator back pressure valve. This 10°F increase in compressor suction temperature saves 93 HP or over 15% of design power input.

All four new compressors will be driven with high efficiency motors having 1% better efficiency than standard motors. This will save a total of $4000 annually in electrical costs and will cost about $1500 extra for all four units.

Evaporative Condensers

Three 800 ton evaporative condensers will be installed on the mechanical equipment building roof replacing and combining the functions of two existing cooling towers and eleven shell and tube condensers. These condensers will provide about $8^{\circ}F$ lower condensing temperatures saving 10% compressor power. The combined fan and pump power is 18% lower than that of the cooling tower water system. Evaporative condensers have been operating successfully in a similar ammonia refrigeration system for over 10 years.

Reduced Condensing Temperature

The condensers will be operated at full capacity until a minimum allowable condensing temperature of $68^{\circ}F$ is reached. Then fans and pumps will be cycled and cells will be drained and shut down. By allowing the condensing temperature to drop from $96^{\circ}F$ (design) to $68^{\circ}F$ (minimum) the compressor head is reduced saving over 36% HP.

In order to provide sufficient liquid distribution pressure for process evaporator supply at minimum condensing temperatures, a 10 HP booster pump is used. This liquid ammonia pump is easily justified from the energy savings at low condensing temperatures. A subcooler is used in the booster pump suction line to prevent pump cavitation and to improve refrigeration cycle efficiency. For each $10^{\circ}F$ of subcooling, cycle efficiency increases by about 2%. Approximately $20^{\circ}F$ of subcooling is planned for the modified system.

Summary

Three different refrigeration systems were discussed which have been or will be modified for improved operating efficiency. Some of the energy saving methods discussed such as reduced condensing temperatures, increased chilled liquid temperatures, reduced liquid flows, and insulating cold surfaces can easily be applied to existing systems. Other methods require modification of existing equipment or installation of new energy efficient equipment.

Bibliography

1. White, T. L., "Application of Energy Conservation Methods to Industrial Refrigeration Systems", ASME Paper No. 78-IPC-Pwr-5.
2. Shea, D. P., Shelton, J. E., and White, T. L., "Industrial Application of a Direct Refrigeration System for Energy Conservation", ASME Paper No. 80-Pet-1.

	OLD CHILLER DESIGN	NEW CHILLER DESIGN
Chilled Water Capacity (Tons)	2000	2000
Refrigerant	R-12	R-12
Compressor HP	2080	1712
Evaporator:		
Chilled Water Temperature-In/Out (°F)	54/42	54/42
Refrigerant Temperature (°F)	32.9	39
Copper Tubes	Finned	High Flux
Fouling Factor (Tubeside)	.0005	.0005
Condenser:		
Cooling Water Temperature-In/Out (°F)	85/94.8	85/94.5
Refrigerant Temperature (°F)	101.6	103.3
Copper Tubes	Finned	Finned
Fouling Factor (Tubeside)	.001	.001

FIGURE NO. 1 — WATER CHILLER DATA

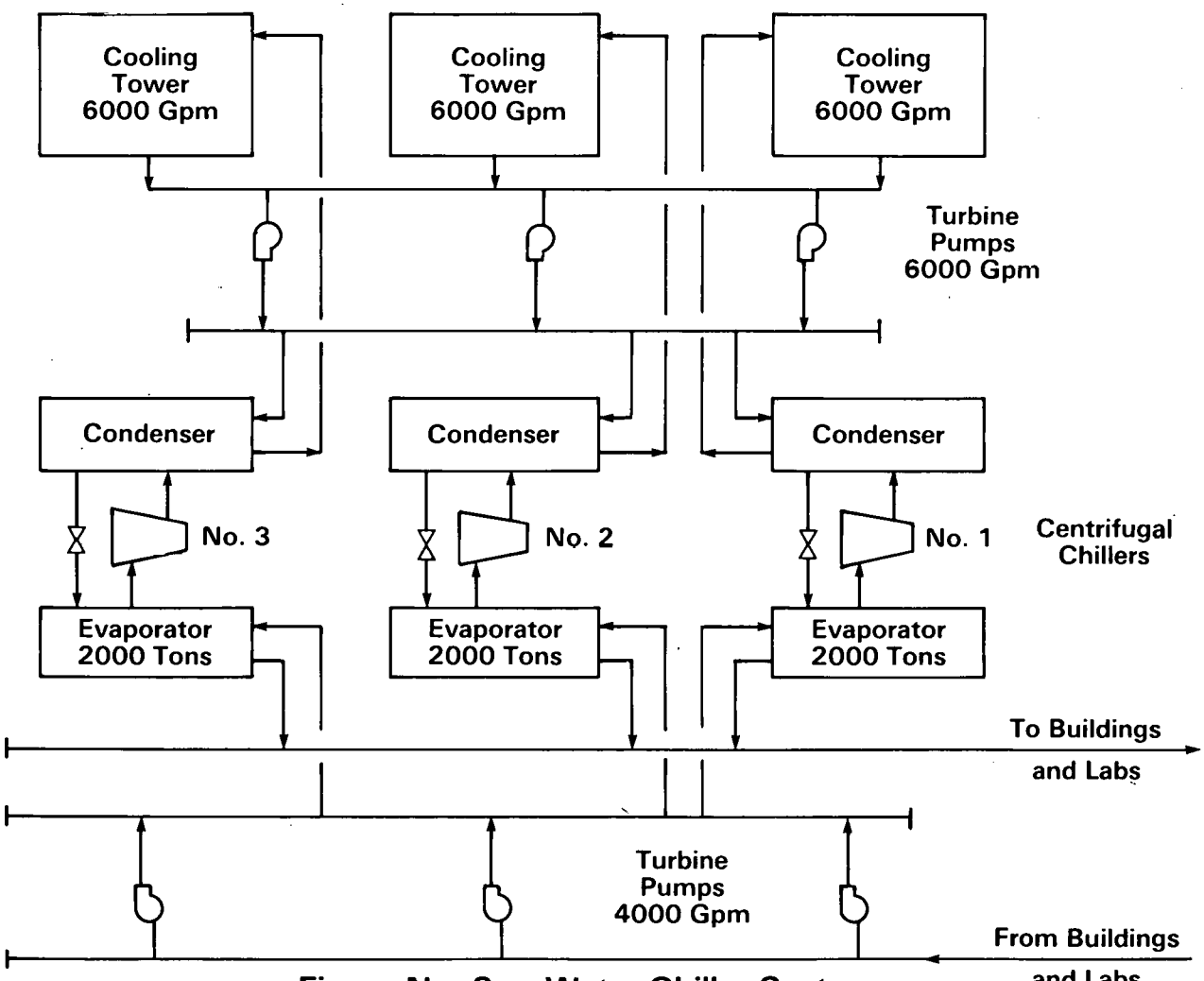


Figure No. 2 — Water Chiller System

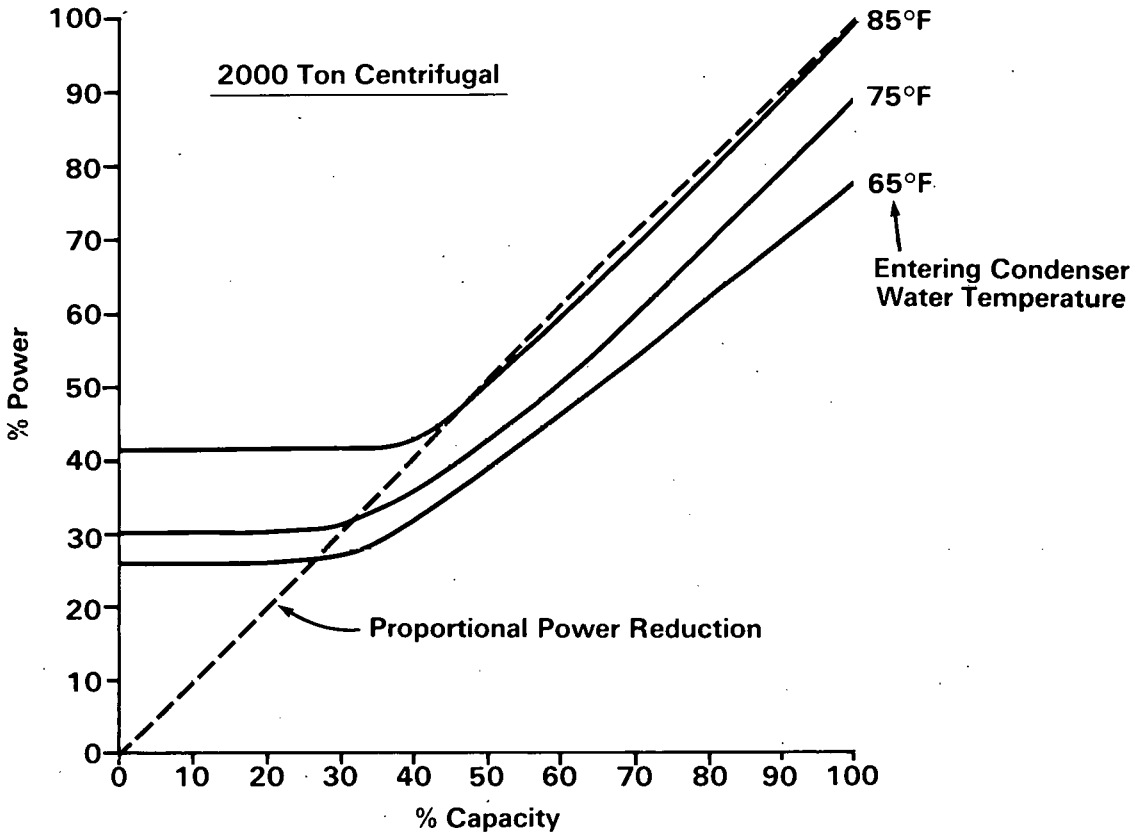


Figure No. 3 — Centrifugal Part Load

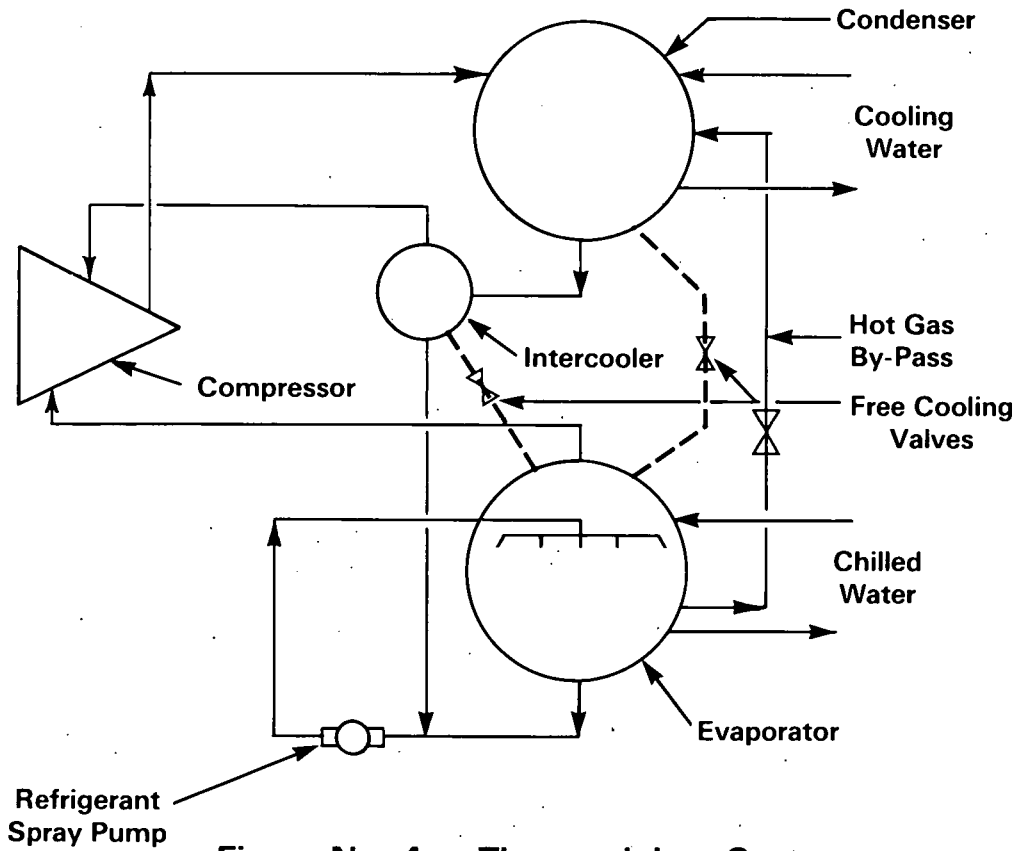


Figure No. 4 — Thermosiphon System

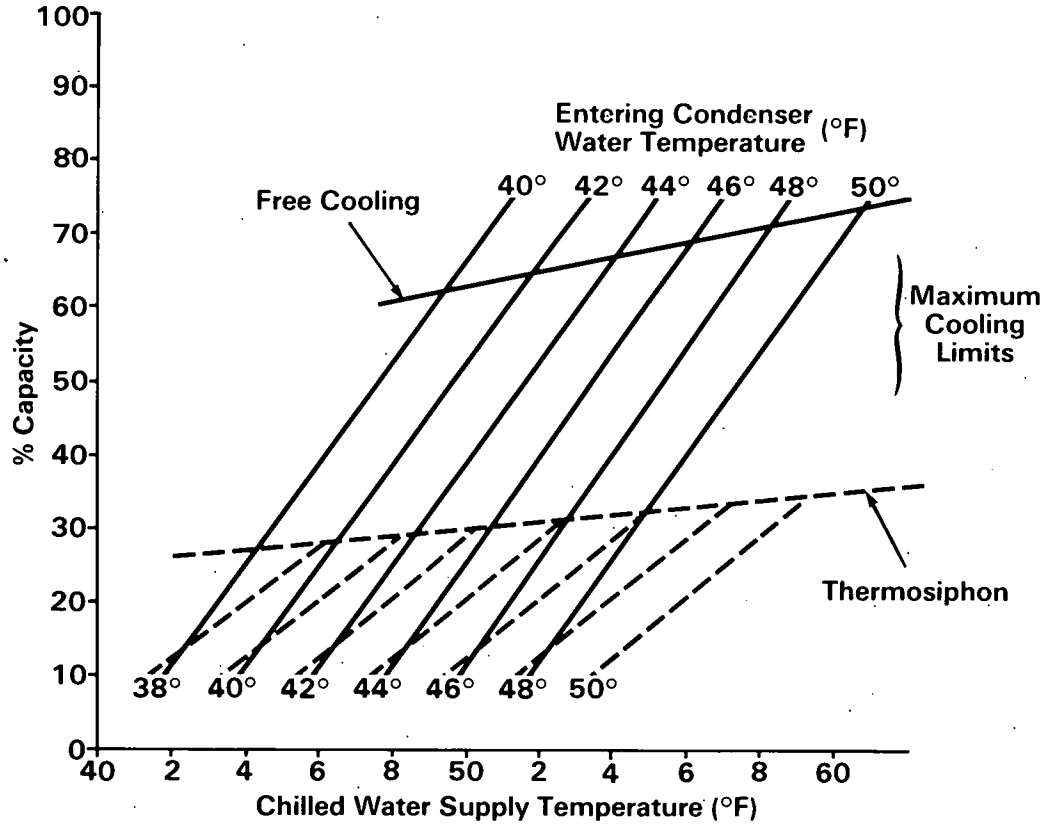


Figure No. 5 — Thermosiphon Performance

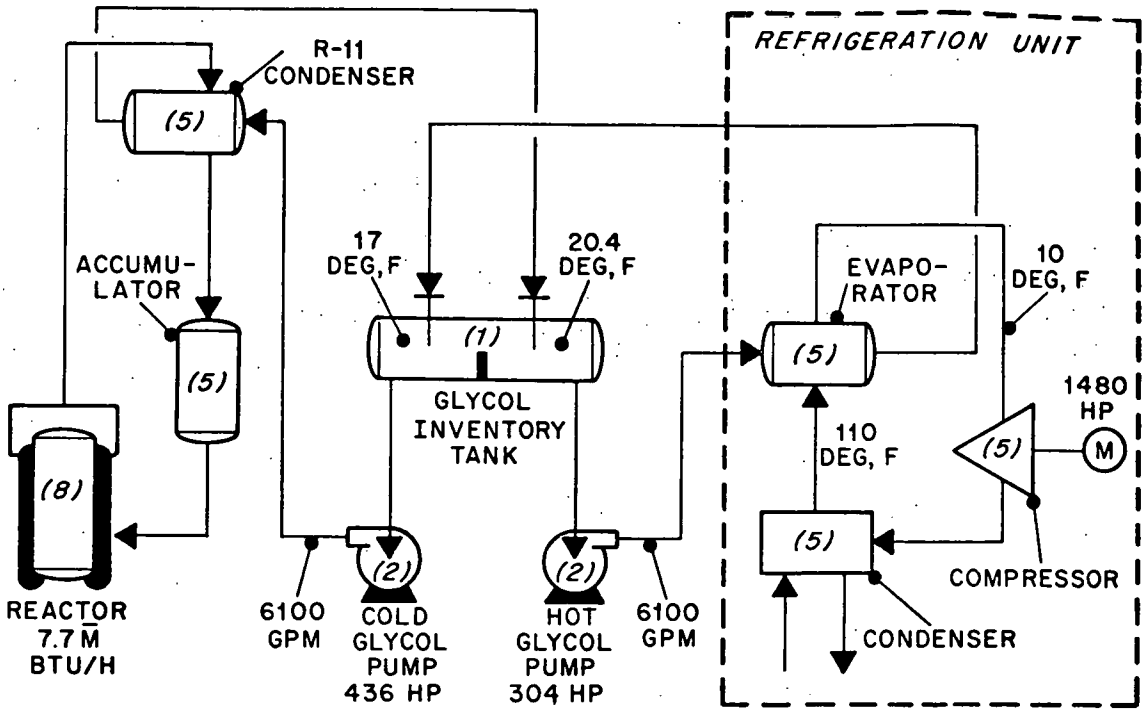


FIGURE NO. 6 — BRINE SYSTEM

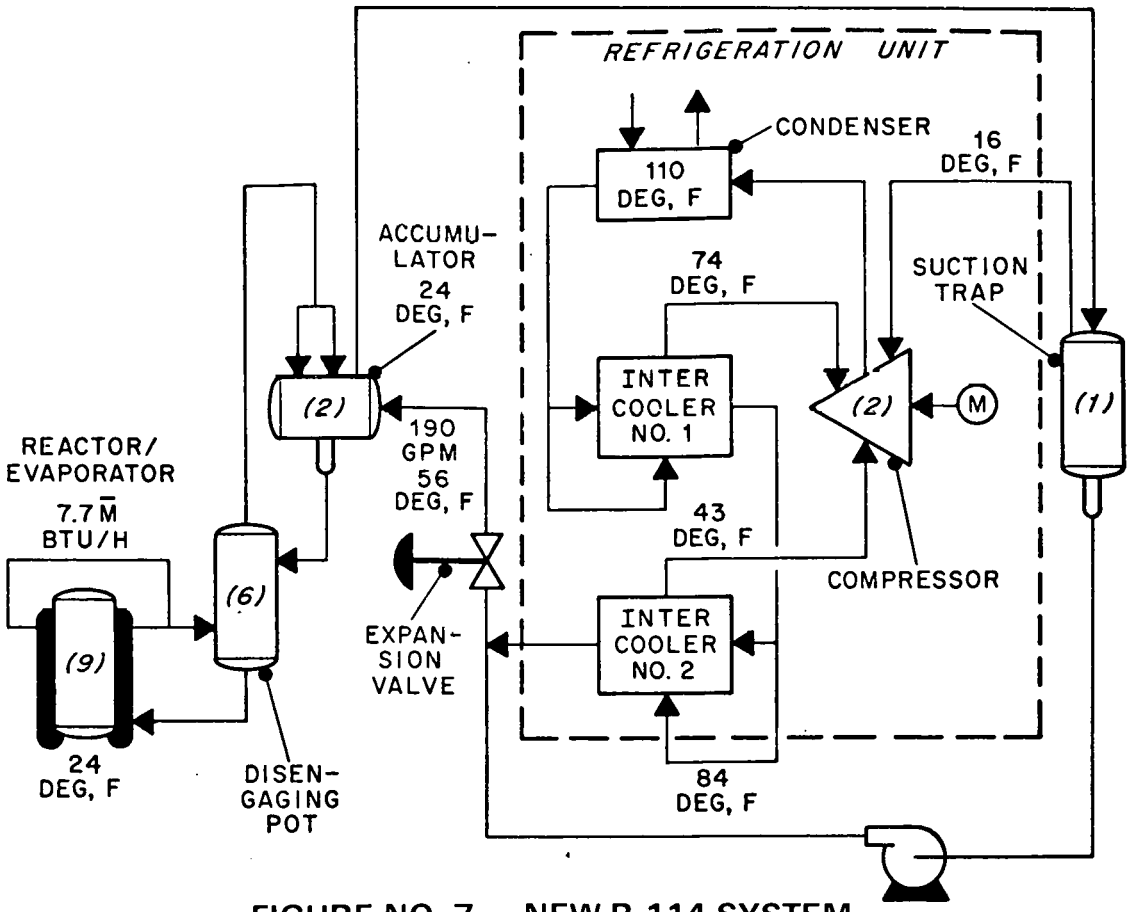


FIGURE NO. 7 — NEW R-114 SYSTEM

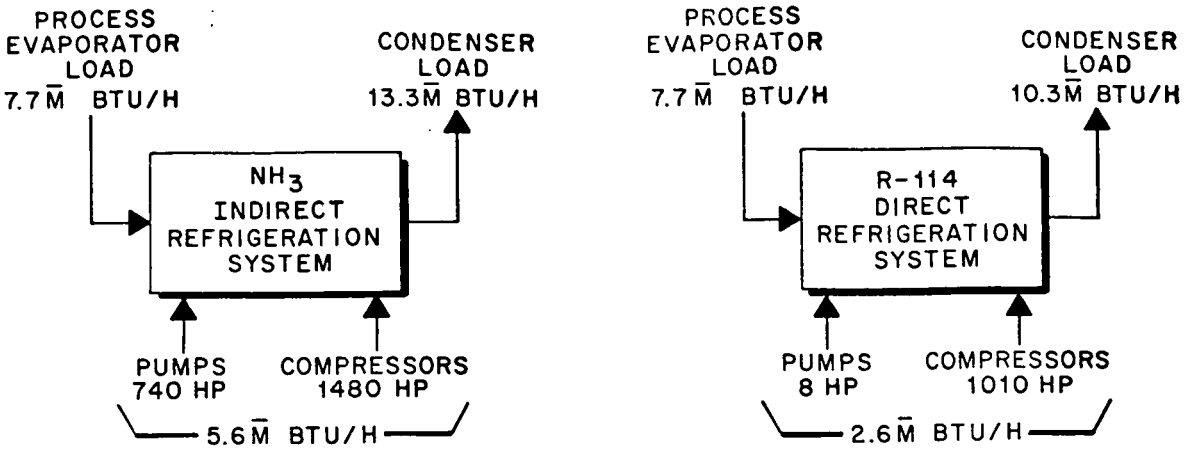


FIGURE NO. 8 — ENERGY BALANCES

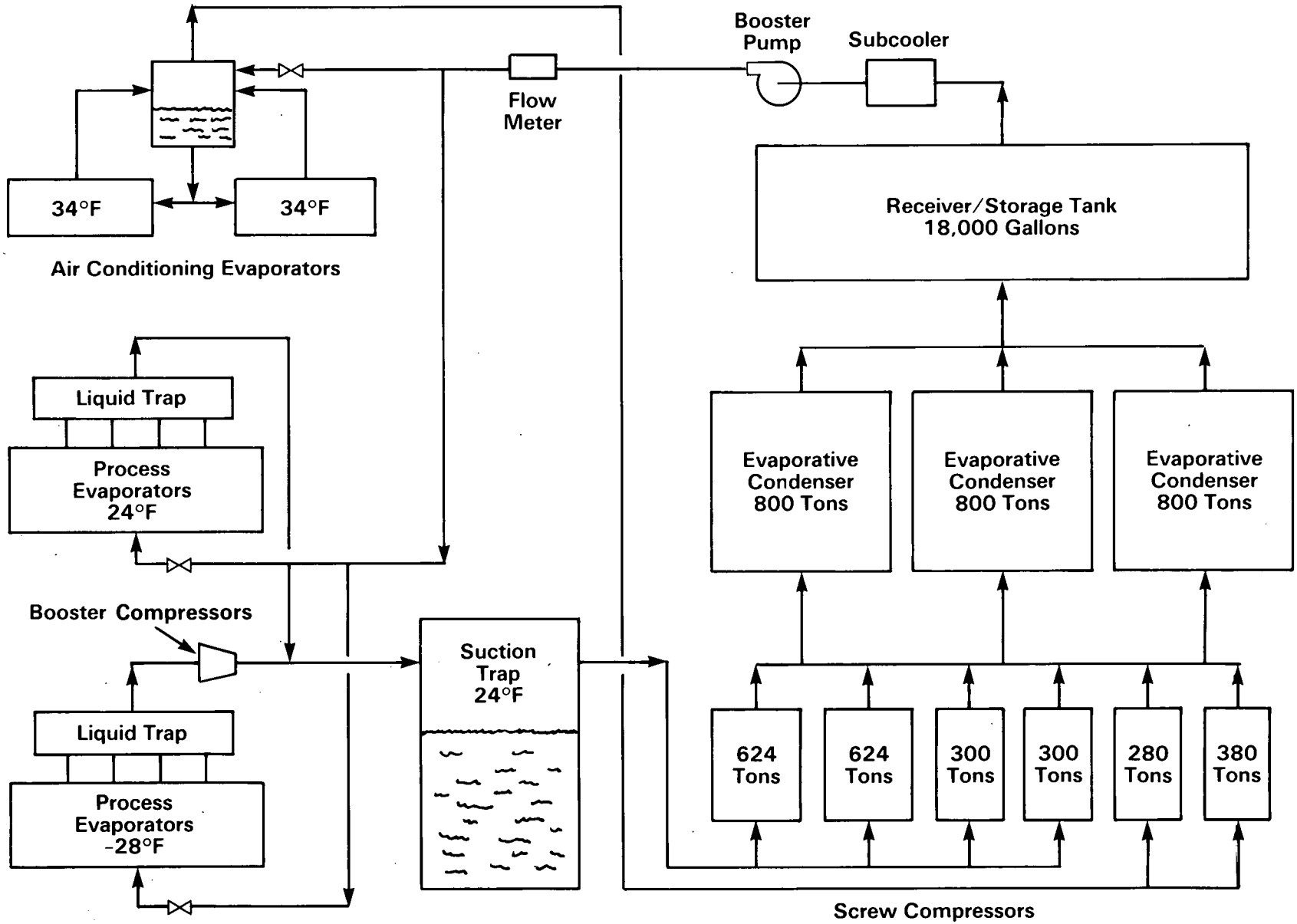


Figure No. 9 — Ammonia System

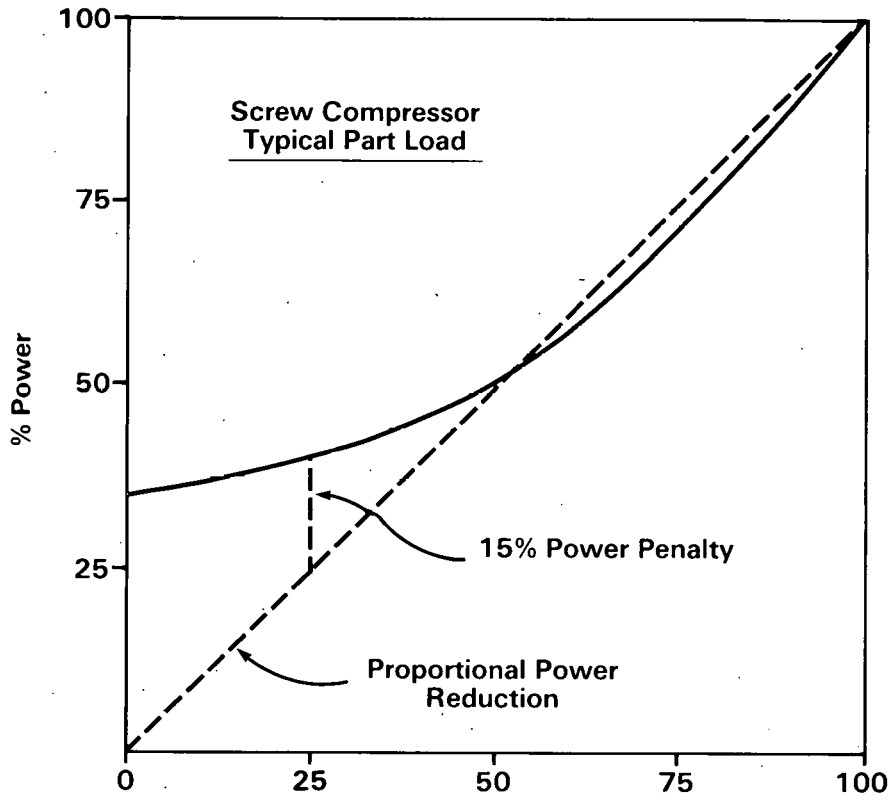


Figure No. 10 — Screw Part Load

COMPUTER CONTROL OF REFRIGERATION SYSTEMS IN A FOOD-MANUFACTURING PLANT

Thomas E. Halaska

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ABSTRACT

Computer control of the cold rooms and freezers and of the environmental cooling (Manufacturing Plant and Office air conditioning) has given Stuckeys in excess of 20% dollar savings in electricity.

This paper deals with the specifics of the control system used and the results obtained.

STUCKEY'S PLANT

Stuckey's has been in the Pecan and Pecan Candy business for 40 years. You have no doubt seen the road-side stores. The candy sold in those stores is all manufactured in Eastman, GA, and shipped by truck to the stores.

We produce approximately 6,000,000 pounds of candy per year with 250 employees.

Eastman is the National Headquarters for Stuckey's. Total people load of the entire facility is 425.

There are 20,000 square feet of freezers maintained at 18 deg. F., 4,000 square feet of cold rooms maintained at 35 deg., and 85,000 square feet in the plant and shipping department maintained at 72 deg. In addition, the 15,000 square feet of office space is airconditioned.

The above loads amount to 300 tons of cooling, all under computer control.

PURPOSE & SCOPE OF PROJECT

The cost of energy has been rising rapidly, reaching $5.1661 per MBTU for the 1977 calendar year. Energy and taxes had become our most rapidly-rising costs. In 1977 we used 28,773 MBTU's at a cost of $149,000. Of this, electricity accounted for $119,700. (3,875,000 kilowatt hours @ 3.85¢ ea.).

Electricity costs were the place to start looking for significant savings. Each load of three horsepower or greater was examined and defined in terms of its share of the electrical demand, whether it was temperature sensitive (i.e. needed to run more or less depending on temperature, such as an air conditioner would), and what its time schedule was.

Computer Control

In early 1978 we were seriously looking at literature on control devices, talking to others in the food industry, and quickly getting nowhere. The controllers available were either just too costly, or were merely sophisticated time clocks without real intelligence (or both).

Then in April, 1978, we were introduced to the concept of energy control by computer. A seminar was arranged in Macon, Georgia, by Energy Accounting Systems, Inc. An Andover Controls Corp. 'Sunkeeper' was demonstrated. This was a special-purpose, specifically designed unit for energy control. This is the controller we eventually bought.

The Computer -- There are 32 digital and 32 analog inputs to the computer, and 32 digital outputs. It is the analog capability that makes this unit worthwhile.

The inputs are hardwired to the digital and analog sensors, including the power company's meter. The outputs are hardwired to the relays controlling the various loads. We added a MODEM, and the computer can communicate anywhere. Access to the computer is password protected.

The Software -- A digital input is connected to the power company's meter, giving a pulse each time so many watt-hours are used. By counting these over a defined time interval, the kilowatt demand level is monitored. We use 5 levels of priority. If the demand is running too high, the lowest level is shed. If the demand continues too high, the second level is shed, etc.

Additionally, there are digital inputs from three humidity sensors in the candy plant. Since

high humidity is detrimental to candy, if it exceeds 60 pct. a digital signal is sent to the computer and the plant air conditioner in that area is turned on (demand control permitting). Every load is permitted to have priority or emergency over-ride commands. For instance, if the plant is calling for humidity control and if the temperature is above a certain point, then that air conditioner can not be shed for demand control.

There is an analog probe in every controlled area. Ours are all temperature, but there are also devices available to sense pressure, speed, etc. The temperature control is much more accurate than that provided by conventional thermostats. In addition, there is a temperature probe outside. By knowing the outside temperature, the controlled temperature in some areas can be changed to minimize the 'delta-T' (i.e. the temperature difference between the controlled area and the outside temperature). This feature has saved many Kilowatt hours.

1978 Was Transition Year -- The computer was ordered September 5, 1978, and installation was complete October 1. The peak had already been set for the year that summer, so nothing could lower the billing demand until summer of 1979. Georgia Power Company has a 95%-of-peak-demand minimum billing for eleven months following the peak. The rest of 1978 was used monitoring the loads and writing software for control.

Serious control began in January, 1979.

RESULTS

The following results compare our experience in 1979 against calendar 1977. 1977 was the last complete year without any controls. 1978 was a transition year with much experimentation. Then 1979 is the first full year under computer control.

During this comparison, the 1977 figures were updated to reflect an additional load of 82 kilowatts (equipment added during 1978 and 1979). The dollar rates were not changed. They remain at actual 1977 levels.

During those two years, our cost of energy has risen 34.8% to $6.94 per MBTU. But, total energy consumption declined 15.2% to 24,402 MBTU.

1. Total savings were $43,500 from the following areas: two months of peak demand reduced 137 KW, $2109; reduced billed demand of 101 KW, $8865; reduced energy consumption of 4508 MBTU, $31,267; and 3% state sales tax on the above, $1,267.

Instead of $169,000 energy cost in 1979, we would have paid out $213,000 without controls.

We produced 5,750,000 pounds of candy in 1979. That's an average cost of energy of $.0294 per pound. Without controls, each pound would have to absorb $.0370. That would have been 25.8% higher.

2 Being good Americans, we saved our country the fuel necessary to produce 4,508 MBTU's, and we saved the Georgia Power Company from having to provide 101 KW's of generating capacity for Stuckey's.

3. The Department of Energy is talking about an energy efficiency measurement called an EUI (Energy Utilization Index). Energy Accounting Systems of Macon calculated ours as having improved 15.1% to an EUI of 381,900.

4. Maintenance of the controlled equipment has improved. Normally two or three compressors of the 22 being controlled would be replaced during a typical year. From October, 1978, to the present, NOT ONE was replaced.

Maintenance of the computer itself has been minimal. One triac failed, and the board it was mounted on was replaced under warranty.

5. Improved temperature stability in all areas. The computer reacts instantly to temperature needs. For instance, the freezers are maintained with ±1 degree. The DOE requires a setting of 78 degrees in the offices. We can maintain a steady 78. The program logic is key to this accuracy while still saving energy.

6. Proof of the computer's accuracy: In addition to measuring demand for control purposes, we have it measure the peak for the month. When the electric bill comes, the actual demand shown on it is always with 1% of the computer's reported demand.

7. The computer provides evidence of compliance with the Federal temperature regulations. The computer maintains a history file which is printed out at necessary intervals. There, black-on-white, is proof of the actual temperature in each area. Figure 1 is an example.

8. Compliance with any changes in regulations or desired temperatures is as easy as typing a new temperature in on the computer terminal. This is another reason for password protection. You don't want unauthorized people playing games with temperatures.

9. The operating logic (the program) is easily modified to accomodate most demand measurement and billing methods presently in use or contemplated by utilities around the country.

```
FH
      P01 P05 A07 A08 A09 A10 A11 A13 A20 A21 A22 A23 C02

00:00  070 071 068 039 073 074 074 079 018 018 039 068 114
01:00  070 071 068 035 072 077 074 078 018 018 050 068 113
02:00  070 072 068 038 072 077 075 075 018 018 050 069 107
03:00  070 071 068 042 075 075 074 077 018 018 046 069 112
04:00  070 071 068 033 075 077 075 079 020 018 052 069 107
05:00  070 071 068 038 072 074 075 078 018 018 054 068 103
06:00  070 070 068 038 074 076 075 072 019 018 044 067 107
07:00  070 072 068 040 077 078 076 079 018 018 039 066 107
08:00  070 071 068 036 073 077 075 074 017 018 040 067 106
09:00  070 072 068 040 075 079 075 075 019 018 043 064 120
10:00  071 071 068 039 073 078 075 078 018 018 049 066 119
11:00  070 071 067 036 075 078 075 079 019 018 041 068 118
12:00  070 071 067 041 073 077 074 075 018 018 052 070 127
13:00  070 071 069 036 072 079 075 078 019 020 044 072 126
14:00  070 072 068 044 072 080 075 077 019 019 039 072 127
15:00  069 069 068 036 074 080 075 075 018 018 051 072 132
16:00  071 071 068 036 072 080 075 080 019 019 053 072 126
17:00  070 072 070 044 074 076 075 080 018 018 052 072 128
18:00  069 072 068 036 072 075 075 080 018 018 037 070 126
19:00  070 071 068 042 072 076 075 077 018 018 050 067 117
20:00  071 071 068 039 072 075 075 080 018 018 052 065 110
21:00  070 071 067 044 075 075 075 077 018 018 049 063 114
22:00  071 072 067 042 073 075 074 075 018 018 046 063 108
23:00  068 070 067 037 074 074 073 079 019 018 039 063 105
00:00  071 071 067 035 075 073 073 073 018 018 039 061 107
01:00  071 072 067 042 072 076 074 078 018 018 038 061 102
02:00  069 071 067 036 070 073 073 079 019 018 040 063 101
03:00  070 071 066 043 072 077 072 077 018 018 042 061 105
04:00  072 072 066 045 070 076 076 074 018 018 050 063 104
05:00  070 071 066 044 074 077 073 076 018 019 052 062 105
06:00  070 072 066 043 076 077 073 073 018 018 044 063 136
07:00  071 071 068 037 075 072 074 075 018 018 043 063 201
R
PT
E179 1980 MAR 10 MON 07 14 16
R
```

Figure 1. History printout of temperatures in 12 controlled areas and of the total demand from midnight, March 9, 1980, through 7 AM, March 10.

Statistics

In figures 2 through 5 are the graphs of the results. While the dollar amount of the electric bills has risen, the kilowatt-hour energy consumption has decreased, as has the kilowatt demand.

The 3-year monthly graph and the F-ratio show the three years, 1977 - 1979. What happened during the 1978 transition year may be of interest.

The T-test for matched pairs (Figures 6 - 9) matched January, 1977, (x-value) with January, 1979, (y-value); then February, 1977, with February, 1979, etc., for twelve pairs. Note the decrease in the mean values of the kilowatt hours and of the kilowatt demand. Also, note the lower standard deviation for all values, proof of the closer control.

Program Example

```
SM C01
  C2                  MY  3 A1>75
                            OI3

  03                  ML  4 FB5              ML  2 OB5

  04 FD1              ML  5 TM>4

  05                  ML 10 A1<75            ML 10 OB5
                            FI3

  10 OD1              ML  2 TM>4

  EM                  ML  4 A1>77            ML 10 A1<70
                            OB6
```

This program segment controls one of the Plant air conditioners.

Defining the terms:

- FD1 - allows load #1 to run
- OD1 - turns off load #1
- A1 - "analog #1" (the temperature)
- OI3 - "on input #3" (humidity too high)
- FB5 - "off bit #5" (demand bit #5 off, i.e. OK to run)
- OB5 - "on bit #5" (demand bit #5 on, i.e. not OK to run)
- TM - "time in minutes"
- FI3 - "off input #3" (humidity OK)
- OB6 - "on bit #6" (time of day between 6 AM - 12 PM)

Beginning on line 02: go to line 3 when either A1 exceeds 75 or if OI3 (too high humidity). Line 03: go to line 4 if bit #5 is off, else go to line 2 if bit #5 is on. Line 4: Allow load #1 to run. Go to line 5 when time in minutes exceeds 4. Line 05: Go to line 10 when A1 is below 75 and FI3 (humidity OK), else go to line 10 if OB5 (demand control bit #5 comes on, i.e. not OK to run). Line 10: OD1 (turn off load #1). Go to line 1 when time in minutes exceeds 4. Line EM: (priority or emergency instructions): Go immediately to line 4 (turn on load) if both A1 exceeds 77 and time is between 6 AM and 12 PM. Or, go immediately to line 10 (turn off load) if A1 is below 70.

```
008
01                  XL 10 OUR>5
                          WKD<SUN

02 OB6              XL  3 OUR>6

03 OB7              XL  4 TM>29

04 OB8              XL  5 OUR>16          XL 20 WKD=SAT
                                                OUR>11

05 FB8              XL  6 OUR>21

06 FB6,7            XL  1 OUR=0

10                  XL 20 MTH=JAN         XL 11
                          DOM=1

11                  XL 20 MTH=APR         XL 12
                          DOM=4

12                  XL 20 MTH=MAY         XL 13
                          DOM=26

13                  XL 20 MTH=JUL         XL 14
                          DOM=4

14                  XL 20 MTH=SEP         XL 15
                          DOM=1

15                  XL 20 MTH=NOV         XL 16
                          DOM=27

16                  XL 20 MTH=NOV         XL 17
                          DOM=28

17                  XL 20 MTH=DEC         XL 18
                          DOM=25

18                  XL 20 MTH=DEC         XL  2
                          DOM=26

20 FB6-8            XL  1 OUR=0
```

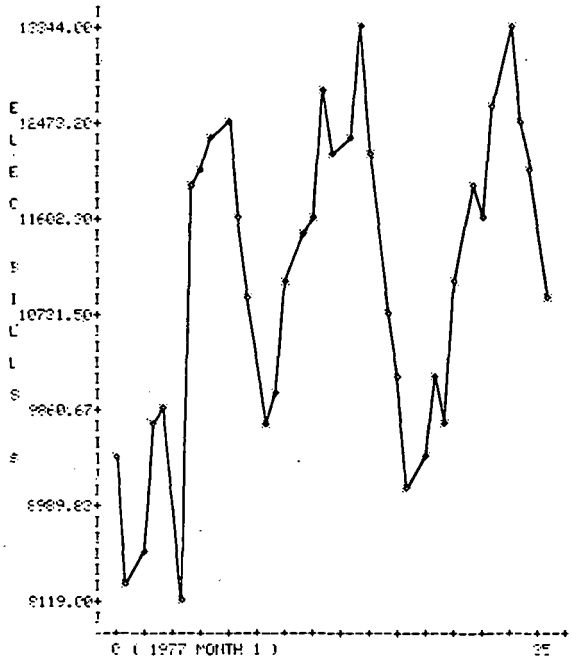
This program segment tells each load control segment the time of day, day of week, and if it's a holiday. Office air conditioners, for instance, do not run from 12 noon on Saturday to 7 AM on Monday, or on a Holiday, or weekdays after 5 PM.

TIME SERIES ANALYSIS I

TEST FOR TREND (Z) = 1.46385

VARIANCE ACCOUNTED FOR BY TREND = 16.61 %

TREND LINE EQUATION:
Y' = 9996.59 + 54.8886 X
ORIGIN: 1977 - MONTH 1
TIME UNIT: 1 MONTH



ANALYSIS OF VARIANCE

SUMMARY TABLE

SOURCE	SS	DF	MS
TOTAL	7.05267E+07	1	
BETWEEN	6.74573E+06	2	3.37286E+06
WITHIN	6.3781E+07	33	1.93276E+06

F-RATIO = 1.7451
DEGREES OF FREEDOM = 2 & 33
PROBABILITY OF CHANCE = 0.189

GROUP	N	MEAN	S.D.
1977 ELEC BILL	12	10363.6	1617.06
1978 ELEC BILL	12	11382.9	1172.63
1979 ELEC BILL	12	11124.9	1345.27

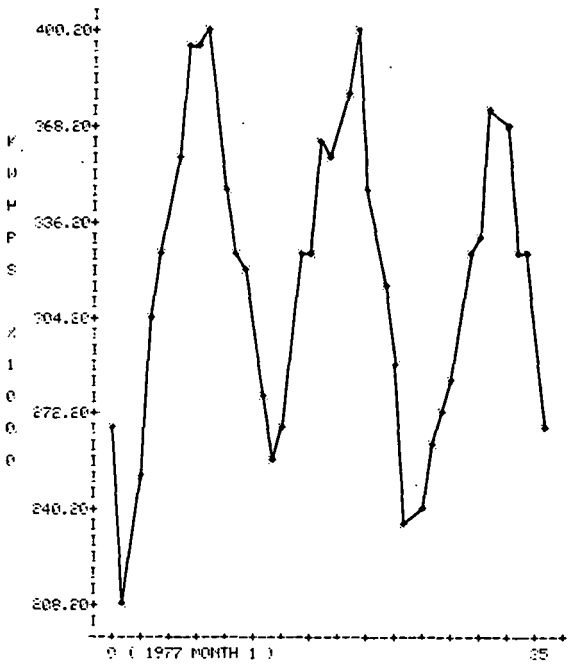
Figure 2. Monthly electric bills ($).

TIME SERIES ANALYSIS I

TEST FOR TREND (Z) = .87831

VARIANCE ACCOUNTED FOR BY TREND = -0.00 %

TREND LINE EQUATION:
Y' = 314.509 - 7.68339E-03 X
ORIGIN: 1977 - MONTH 1
TIME UNIT: 1 MONTH



ANALYSIS OF VARIANCE

SUMMARY TABLE

SOURCE	SS	DF	MS
TOTAL	9.39687E+10	1	
BETWEEN	4.90832E+09	2	2.45416E+09
WITHIN	8.90603E+10	33	2.6988E+09

F-RATIO = .909352
DEGREES OF FREEDOM = 2 & 33
PROBABILITY OF CHANCE = 0.585

GROUP	N	MEAN	S.D.
1977 KWHRS	12	322917	59981.3
1978 KWHRS	12	322242	46743.6
1979 KWHRS	12	297867	48100.6

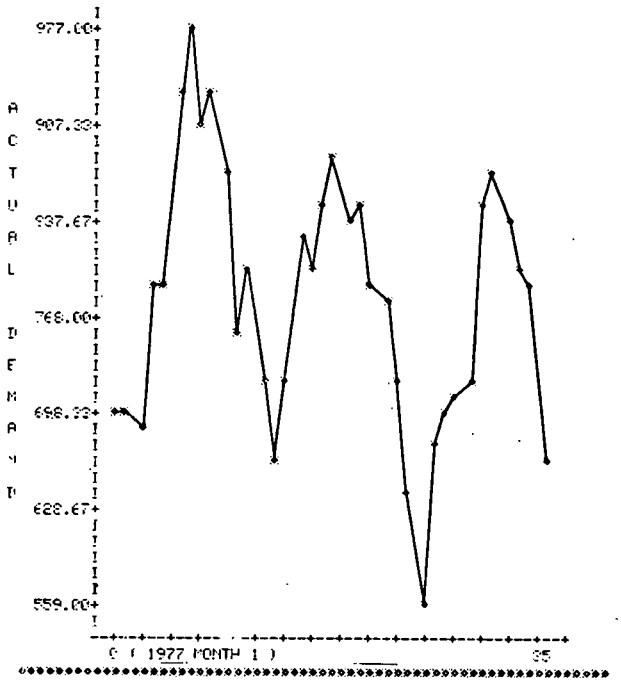
Figure 3. Monthly Kilowatt Hours used.

T I M E S E R I E S A N A L Y S I S I

TEST FOR TREND (Z) =-.29277

VARIANCE ACCOUNTED FOR BY TREND = 4.48 %

TREND LINE EQUATION: Y' = 808.986 - 1.88468 X
ORIGIN: 1977 - MONTH 1
TIME UNIT: 1 MONTH



A N A L Y S I S O F V A R I A N C E

SUMMARY TABLE

SOURCE	SS	DF	MS
TOTAL	509362	1	
BETWEEN	45947.5	2	22973.8
WITHIN	463415	33	7982.87

F-RATIO = 2.8781
DEGREES OF FREEDOM = 2 & 33
PROBABILITY OF CHANCE = 0.069

GROUP		MEAN	S.D.
1977 ACTUAL DE	12	816.583	102.894
1978 ACTUAL DE	12	781.583	66.9878
1979 ACTUAL DE	12	729.667	94.1931

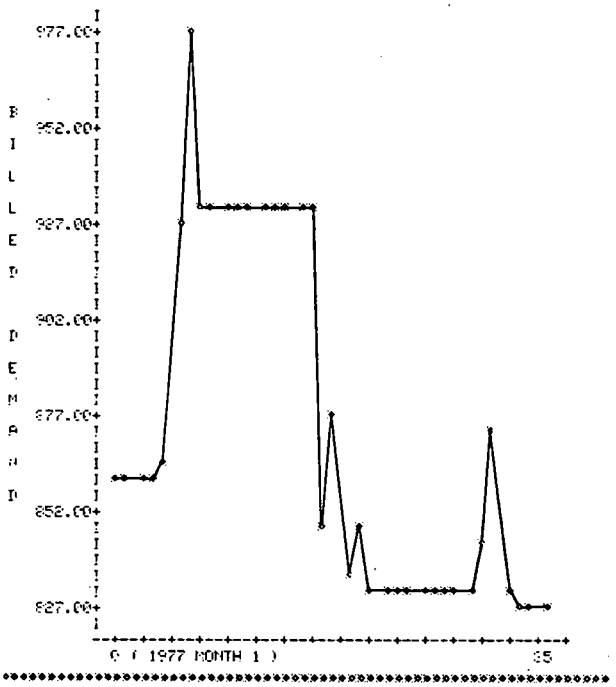
Figure 4. Actual Demand Per Month.

T I M E S E R I E S A N A L Y S I S I

TEST FOR TREND (Z) = .29277

VARIANCE ACCOUNTED FOR BY TREND = 37.86 %

TREND LINE EQUATION: Y' = 919.354 - 2.67104 X
ORIGIN: 1977 - MONTH 1
TIME UNIT: 1 MONTH



A N A L Y S I S O F V A R I A N C E

SUMMARY TABLE

SOURCE	SS	DF	MS
TOTAL	73378.5	1	
BETWEEN	29575	2	14787.5
WITHIN	43803.5	33	1327.38

F-RATIO = 11.1404
DEGREES OF FREEDOM = 2 & 33
PROBABILITY OF CHANCE = 0.000

GROUP	N	MEAN	S.D.
1977 BILL DMD	12	903.25	41.4283
1978 BILL DMD	12	877.667	46.0227
1979 BILL DMD	12	833.917	12.1552

Figure 5. Billed Demand Per Month.

T - T E S T R E S U L T S

VARIABLE X: 1977 ELEC BILL VARIABLE Y: 1979 ELEC BILL

MEAN OF X	= 10363.6	MEAN OF Y	= 11124.9
S.D. OF X	= 1548.17	S.D. OF Y	= 1288
S.E. MEAN	= 466.792	S.E. MEAN	= 388.345

NUMBER OF PAIRS (N) = 12

CORRELATION OF X WITH Y (R) = 0.731

DIFFERENCE (MEAN X - MEAN Y) = -761.334

DEGREES OF FREEDOM (DF) = 11

T-RATIO FOR THE DIFFERENCE = -2.36443

PROBABILITY (2 TAILED TEST) = 0.036

Figure 6. Comparison of Monthly Electric Bills, 1977 and 1979.

T - T E S T R E S U L T S

VARIABLE X: 1977 KWHRS VARIABLE Y: 1979 KWHRS

MEAN OF X	= 322917	MEAN OF Y	= 297867
S.D. OF X	= 57427.9	S.D. OF Y	= 46052.9
S.E. MEAN	= 17315.2	S.E. MEAN	= 13885.5

NUMBER OF PAIRS (N) = 12

CORRELATION OF X WITH Y (R) = 0.896

DIFFERENCE (MEAN X - MEAN Y) = 25050

DEGREES OF FREEDOM (DF) = 11

T-RATIO FOR THE DIFFERENCE = 3.18723

PROBABILITY (2 TAILED TEST) = 0.009

Figure 7. Comparison of Monthly Kilowatt Hours Used, 1977 and 1979.

T - T E S T R E S U L T S

VARIABLE X: 1977 KW DEMAND VARIABLE Y: 1979 KW DEMAND

MEAN OF X	= 816.583	MEAN OF Y	= 729.667
S.D. OF X	= 98.5159	S.D. OF Y	= 90.1831
S.E. MEAN	= 29.7037	S.E. MEAN	= 27.1912

NUMBER OF PAIRS (N) = 12

CORRELATION OF X WITH Y (R) = 0.788

DIFFERENCE (MEAN X - MEAN Y) = 86.9166

DEGREES OF FREEDOM (DF) = 11

T-RATIO FOR THE DIFFERENCE = 4.65409

PROBABILITY (2 TAILED TEST) = 0.001

Figure 8. Comparison of Actual Demand Per Month, 1977 and 1979.

T - T E S T R E S U L T S

VARIABLE X: 1977 BILL DEM VARIABLE Y: 1979 BILL DEM

MEAN OF X	= 903.25	MEAN OF Y	= 833.917
S.D. OF X	= 39.6669	S.D. OF Y	= 11.6378
S.E. MEAN	= 11.96	S.E. MEAN	= 3.50892

NUMBER OF PAIRS (N) = 12

CORRELATION OF X WITH Y (R) = 0.826

DIFFERENCE (MEAN X - MEAN Y) = 69.3333

DEGREES OF FREEDOM (DF) = 11

T-RATIO FOR THE DIFFERENCE = 5.95522

PROBABILITY (2 TAILED TEST) = 0.000

Figure 9. Comparison of Billed Demand Per Month, 1977 and 1979.

SUMMARY

Thermostats control only temperature. Time clocks and dehumidistats can provide load control. These operate independently of each other, even though they may all control one unit, such as an airconditioner.

Most plants will have many separate airconditioners, each with its own thermostat, and possibly a dehumidistat and time clock; and each running or not running completely independently of each other.

The computer ties all these elements together, plus demand measurement and outside temperature measurement, into one, unified system.

The imagination of the programmer is the only limit on utilizing the input information for control.

COOLING TOWERS, ENERGY-CONSERVATION MACHINES

~~1980 CONFERENCE ON INDUSTRIAL ENERGY CONSERVATION TECHNOLOGY~~

Robert Burger
Burger Associates
Dallas, Texas

ABSTRACT

Cooling towers, in all too many industrial plants, are often the neglected units of the process chain which are hidden bonanzas for energy conservation and dollar savings. By lowering the entire systems temperature by the use of colder water returning from the cooling tower, greater chemical product volume can be condensed and less energy is required to run compressors. This paper will discuss two case histories and the rapid cost-effective savings thereby accruing through retrofit.

GASOLINE REFINERY COOLING TOWER

Designers and Engineers of petrochemical plants, chemical processing facilities, and refrigeration systems expend considerable time and expertise on the specialized equipment, "plumbing", flow diagrams, and rightly so due to the importance of these components. However, in many cases, they take the cooling tower and its production of cold water for granted.

Cooling towers are often the neglected units of the process chain which are hidden bonanzas for energy conservation and dollar savings when properly engineered and maintained. In many cases, the limiting factor of production is the quality and quantity of cold water coming off the cooling tower.

The major role of the cooling tower is to remove waste heat in the chemical reaction. In a condensation process, it is obvious that the colder the water, the more product can be produced at a lower unit cost. The degree of elevation of the process temperature above ambient conditions is the sum of the tower's approach of the cold water to the wet bulb temperature, the cooling range (which equals the temperature rise in the heat exchanger) and the terminal difference in the exchanger. A reduction in operating temperature, always desirable for economic reasons, may be obtained by increasing the capability of the cooling tower's performance (1).

The importance of colder water for the compression of gases is evident in that all compressors have one thing in common; a major portion (80 %) of the energy is converted to heat. This rejected heat must be continuously removed at the same rate it is generated or the compressor will overheat and shut down. Reducing the operating temperature of the compressor will proportionately reduce the energy input requirements (2). In other words the colder the water returns to the equipment, the less energy is required to produce the same degree of work at lower cost.

To optimize the cooling system, basic fundamentals of thermal transfer, modern retrofit techniques, and materials must be understood. Interrelationships of fill packing, drift eliminators, water distribution, and static operating pressures can be calculated with the most efficient materials and configuration utilized. A professional field inspection by a qualified engineer can determine the upgrading potential, mechanical and structural conditions of the cooling tower.

The first case history at a Texas Eastern Refinery clearly indicates the importance in value of the utilization of colder water returning from a well engineered and rebuilt cooling tower functioning at optimum levels of performance.

Design Conditions of the 2 cell counterflow tower were originally to cool 6,500 GPM of water from entering the tower at 108°F leaving at 90°F during an ambient wet bulb temperature of 78°F. The manufacturer's data and associated fan curves indicated that the two 18 foot diameter airfoil aluminum fans utilizing 40 HP drivers were to produce 300,000 actual cubic feet per minute (ACFM)

of air per fan. This was designed to provide a Delta T of 18°F with a 12°F approach to the wet bulb.

During the field inspection of this unit, the cooling tower engineers interviewed Operating Personnel who indicated that at the most, the tower was producing 70 to 75 % capability at full heat load.

Pullman-Kellogg was awarded a contract to double the capacity of the Alkylation Unit and determined quite early in the engineering phase of the program, that the cooling tower was indeed a weak link in the process. To yield the projected quantity of increased product, 10,500 GPM of water, approximately 60 % greater capability of the existing 6,500 GPM rate must be circulated through the system, which initially indicated erection of a new tower. However, plot plan constraint problems and budgetary requirements dictated that if the existing tower could be rebuilt to accommodate the newer capacity, considerable savings in time, plot area, and dollars would accrue over the alternative installation of new O.E.M. equipment. Another consideration is that this retrofit work qualifies for tax deductible maintenance while a new tower would have to be paid for by the more expensive after tax capitalization dollars.

The field survey resulted in an affirmative report, that with proper engineered retrofit, the 6,500 GPM tower had indeed the capability of cooling 10,500 GPM to design requirements.

The existing configuration of this 25 year old tower, while designed with the optimum state of the art at that time, consisted of wood splash bar fill packing on 8" vertical centers spaced 8" horizontally apart. The water distribution system was fabricated from Redwood in closed troughs, gravity feed falling on splash cup distribution devices, Fig. 1.

The drift eliminators consisted of heavy 2 pass Redwood eliminator blades, Fig. 2. All three of the above elements were not functioning efficiently i.e., many of the nozzles were clogged which provided poor water distribution as evidenced in the photograph of Fig. 1.

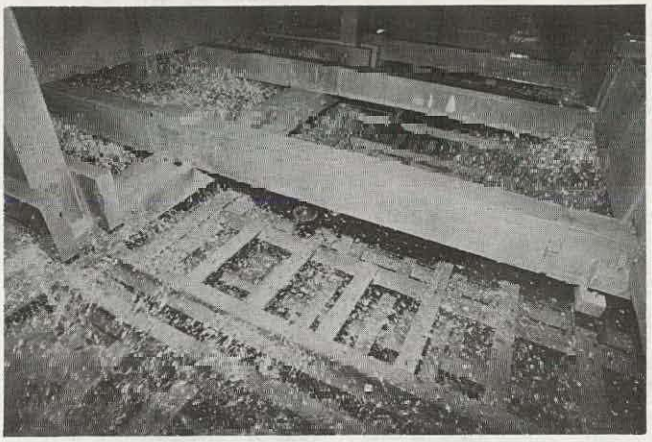


Fig. 1. Uneven old fashioned water distribution troughs and splash nozzles with some malfunctioning and clogged, together with inefficient wood slat splash bars.

The filling slats, being thin section Redwood, were beyond their useful life and were warped and considerably out of position in many areas for good heat transfer utilization. The drift eliminators were permitting solid droplets of water to be discharged from the tower and were creating additional static pressure due to the heavy 2 pass required by the discharging air. Thermal engineering calculations (3) and



Fig. 2. Heavy two pass wood eliminator blades causing high static pressure and permitting droplets to escape.

manufacturer's heat transfer characteristic curves (4) indicate that by installing 48" of cellular fill, Fig. 3, replacing the spray system with noncorroding PVC and nonclogging large orifice (1 ½" diameter) nozzles producing a square spray pattern, Fig. 4, together with a low static pressure highly efficient drift eliminators, there will be a capability improvement in operation of cooling the 10,500 GPM of water to the required Design Conditions of entering at 108°F leaving at 90°F at a 78°F wet bulb.



Fig. 3. Installations of high thermal transfer cellular fill surfaces provide over a 50 % increase in capability with the projection of an additional 50 % increase by installing more material. PVC branch arm for water in process of being fitted.

It is also evident that if the additional gallonage was not added to the tower, the rebuilt facility could now cool the 6,500 GPM from 108 to 85 at 78°F wet bulb indicating a new capability of providing a 24° Delta T with a 7° approach to the wet bulb.

Further, there is a discussion at Management Level that a new requirement of cooling 15,500 GPM is being considered for future expansion. Engineering calculations

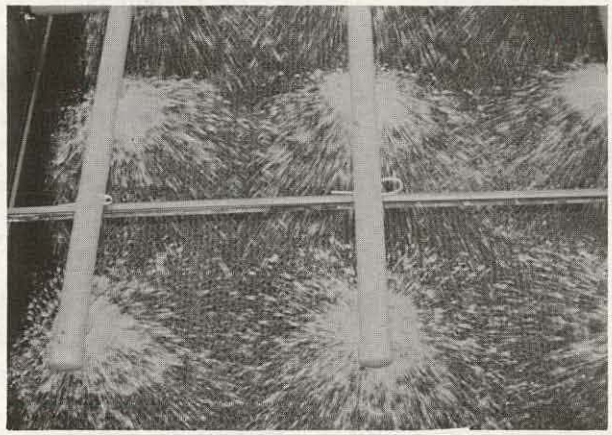


Fig. 4. Uniform water distribution is obtained by nonclogging, noncorroding large orifice (1 ½" diameter) nozzles on PVC piping.

indicate the tower will have the capability of cooling this increased volume. While requiring considerably more money, it would be cost-effective when the additional water could be used to produce approximately 1,000 additional barrels a day of lead free high octane gasoline. The savings in plot area and new construction would more then offset the labor and materials involved in excavating the underground piping to change them from 12" to 14" diameter together with installing new 60 HP motors and 20 foot diameter fan blades required to generate sufficient cooling air. This clearly illustrates the viability of modern retrofit techniques which can upgrade this original Design from cooling 6,500 GPM to a new level of 15,500 GPM.

The basic retrofit thrust is to provide modern upgrading techniques since maximum performance is obtained in a given volume of filling when the water distribution is uniform and air velocity is constant throughout.

Changes in the water distribution system have a significant effect on the characteristic (KaV over L) in producing colder water (5).

Mr. Duane Nash, Fig. 5, Project Engineer stated that "the colder the system runs, the more efficiently we can turn out the product". Utilizing the original capacity of

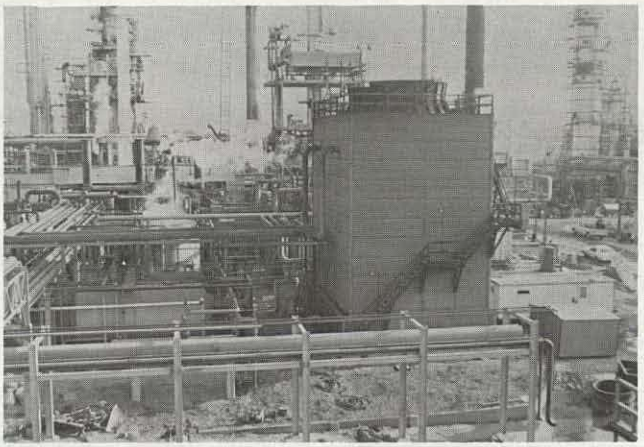


Fig. 5. Alkylation cooling tower with internals rebuilt now cools 10,500 GPM to Design Conditions compare to original 6,500 GPM capacity. A 60 % increase utilizing existing mechanical equipment and shell.

6,500 GPM of cooling water circulation, the output of the alkylation plant producing high octane gasoline was 3,000 barrels per day. Increasing the circulating cooling water to 10,500 GPM, will produce the new design delivery of 4,700 barrels with a future capability of 6,000 barrels per day when the ancillary equipment is added. Production is doubled but because of colder water delivery from the cooling tower, total circulating waterflow requirements need not be multiplied by a factor of two.

The energy savings and dollar profits obtained through the engineered retrofit of the 6,500 GPM cooling tower to now cool 10,500 GPM at colder water return, while endemic to this particular installation is quite typical of many older cooling towers found in Industry. Since originally designed 25 years ago, cooling tower technology today has advanced where, in the hands of experienced thermal, mechanical and structural engineers, these large efficient energy savings can be accomplished. The percentage of improvement will differ from location to location but the net result is a savings for the Owners and a reduction of energy consumption, whether it be steam or electricity to power the system or provide chemical process cooling water. As further confidence in the capability of the tower, it behooves the Operators and Owners to invest in a certified Cooling Tower Institute Performance and Acceptance test (6). The tower is tested by qualified impartial engineers and observers to determine the parameters of operation along the guidelines developed by the Cooling Tower Institute which is the professional International Organization of cooling tower manufacturers, users, consultants and suppliers. For a modest fee, a comprehensive report will be provided to the Owner and this investment is a worthwhile protection for the investment in either new equipment purchases or the rebuilding and retrofit of existing installations.

As Professional Engineers in todays climate of escalating high energy costs, there is an increasing awareness and responsibility to the Client to investigate any and all methods and systems and no stone should remain unturned in the search to reduce energy consumption for his operation.

REFRIGERATION SYSTEM, 1,400 TONS

In refrigeration systems, the importance of colder water for the compression of gases is evident in that all compressors have one thing in common: A major portion (80 %) of the energy is converted to heat. This rejected heat must be continuously removed at the same rate it is generated or the compressor will overheat and shut down. Reducing the operating temperature of the compressor will proportionately reduce the energy input requirements (2). In other words the colder the water returns to the equipment, the less energy is required to produce the same degree of refrigeration at lower cost.

The pressure-enthalpy diagram (sometimes called a Mollier Diagram) serves as a valuable tool for understanding and analysing refrigeration performance. Engineers, having worked with this diagram, understand that it simplifies the job of calculating the requirements for the cycle. Knowing only the evaporating and condensing temperatures, we can diagram the entire cycle. From the diagram the values for each of the refrigerant properties can be read directly. The changes

in these values can then be followed through each process. The heat rejected in the condensor is equal to the energy absorbed in the evaporator, plus the energy applied by the compressor. The quantity of energy supplied just balances the quantity rejected. Energy is not used up or created, but is merely pumped from one place to another. Approximately 3.25 % kilowatt savings are provided for each one degree colder water delivered to the machinery (7).

The Design Conditions of this counterflow tower were originally to cool 4,200 GPM of water from entering the tower at 95°F discharging at 85°F during an ambient wet bulb temperature of 78°F. The manufacturer's data and associated fan curves indicate that the two 18 foot 0" diameter air foil aluminum fans driven by 60 HP electric motors will produce 425,000 actual cubic feet per minute (ACFM) of air per fan. This was designed to provide a 10°F cooling range - Delta T - with a 7°F approach to the wet bulb.

Mr. Philip V. Manning, Property Manager for the Owners, Fig. 6, has stated that upon analysis of the operating costs and results, the Owners (a large Inter-National Insurance Company) anticipate a rapid payback by the decrease in steam consumption, lower operating head pressures and slower turbine speeds which will more then pay for the investment by the end of 1979. Mr. Manning also reiterated his strong believe that while the compressors and condensors are the heart of the refrigeration system, the cooling tower is equally as important and its maintenance is essential to the profitable operation of a building.

Solid proof that the retrofit and upgrading of this cooling tower is cost-effective can be seen in Fig. 7. These Con-Ed steam bills, one dated May 12th to June 13th 1978 indicating a 2,904 M pounds consumption as against 1,438 M pounds used from May 11th to June 12th 1979 shows a decrease of 1,470,000 pounds of steam purchased to power the system. Multiplied by the $.00785552 pound cost, this one month produced an $11,547.14 savings. The important criteria of cooling tower performance is the wet bulb temperature since an exceedingly low wet bul will require a proportionate less power input. The climatological reports (8) observed every three hours by the U.S. Weather Bureau, shows that comparative days selected for "before and after" performance data that the wet bulb temperatures averaged within 0.4 of a degree.

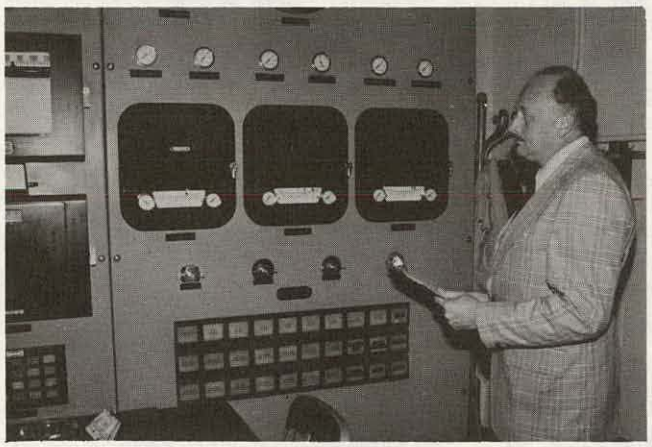


Fig. 6. Mr. Philip V. Manning, Property Manager, states "on the basis of saving $11,547.14 from May 11th to June 12th 1979 we anticipate cost recovery of the $58,131.00 by the end of this operating season".

Prior to the retrofit, the information furnished by the Operating Engineering Department indicated a probable deficiency of between 4 to 6°F in return water to the air conditioning / refrigeration equipment with head pressures excessively high before the rebuilding project was started. The resultant energy costs during a nine months 1978 air conditioning season amounted to steam-bills of $183,674.00 to power the system.

The existing configuration of this 22 year old tower, while designed with the optimum state of the art at that time, consisted of a 10' high pack of wood splash bar wet decking fill 8" on center horizontally and 6" vertically. The slats measured 1 3/4 wide by 5/16" thick. The water distribution system, was fabricated from 10" diameter

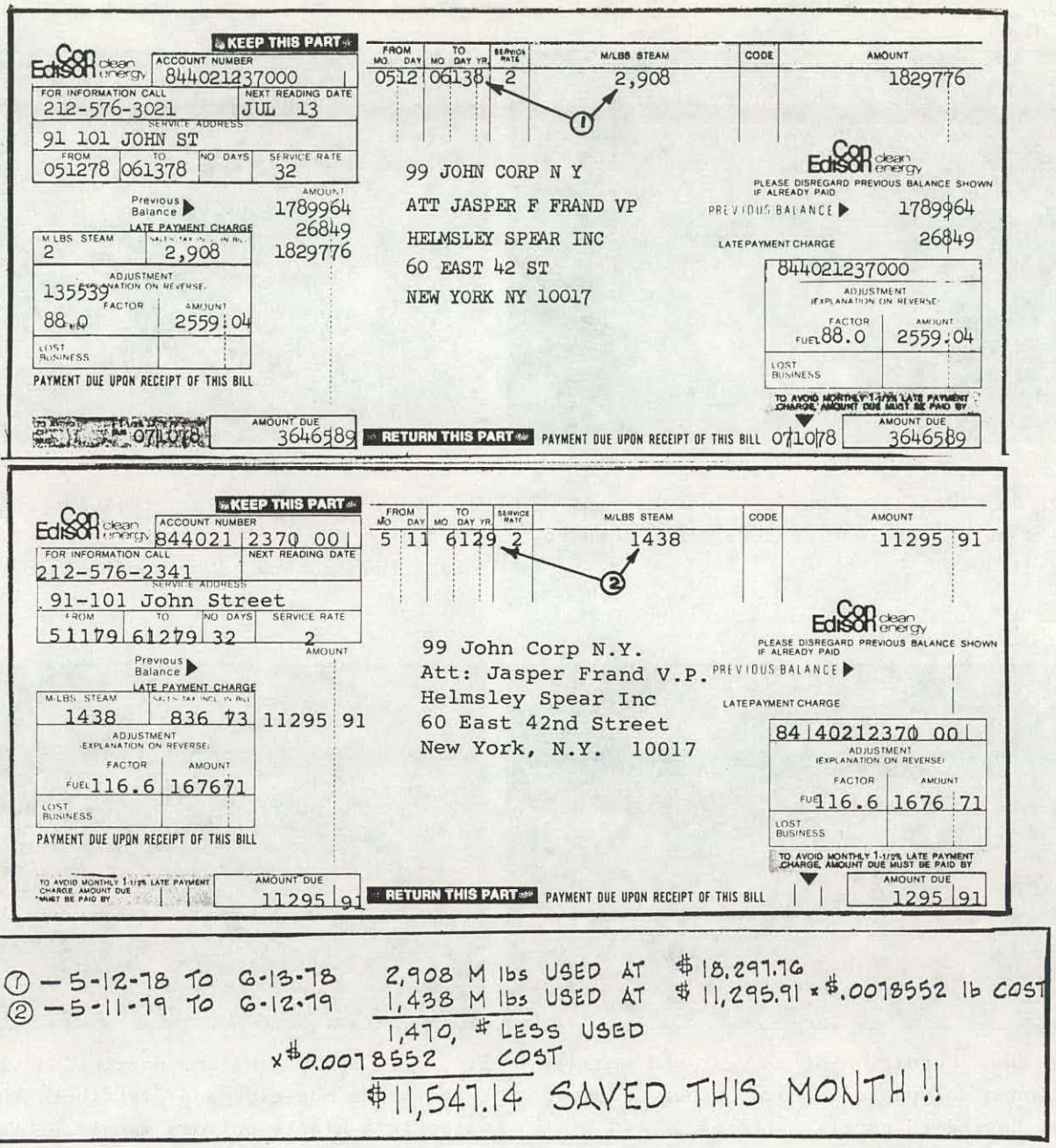


Fig. 7. The actual bills indicating an $11,547.14 savings the first month the rebuilt upgraded cooling tower was placed on stream.

galvanized steel headers with 1" diameter threaded pipe branch arms having a total of 360 bronze nozzles with ¼" diameter spray orifices. The drift eliminators, consisted of a 3 pass zigzag heavy wood slat conventional type blades.

Thermal engineering (3) and manufacturer's heat transfer characteristic curves (4) calculate that by installing 36" of cellular fill, Fig. 8, replacing the spray system with non-corroding PVC and non-clogging large orifice (1 ½" diameter) nozzles producing a square spray pattern, Fig. 9, together with low static pressure, highly efficient drift eliminators, there should be an approximate 28 % improvement in operation. This upgrading percentage would be reflected in 5 to 6°F colder water than previous operation and



Fig. 8a. Deficient wood fill splash bar trays on 8" vertical centers being removed for disposal.

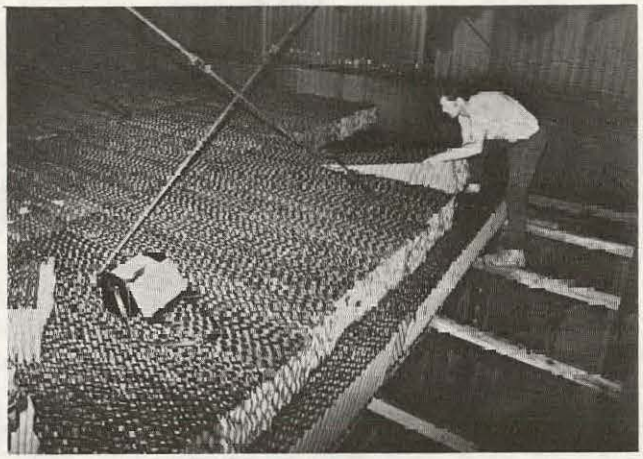


Fig. 8b. High efficiency cellular fill installed to produce a 4 to 5°F colder water return than generated by wood splash fill.

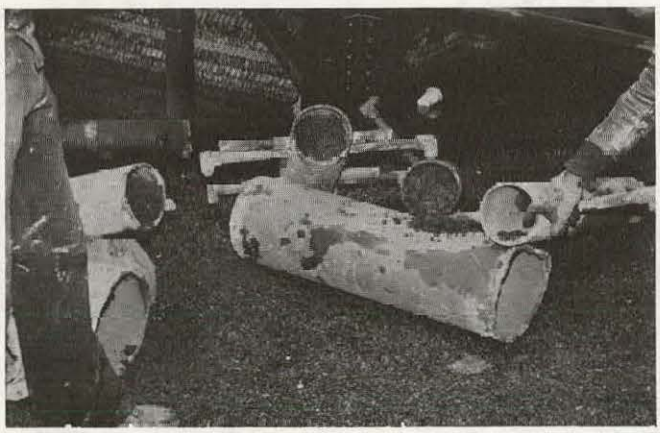


Fig. 9a. Condition of 22 year old accumulation of cloggage in spray pipes and small arms having ¼" nozzle orifices.

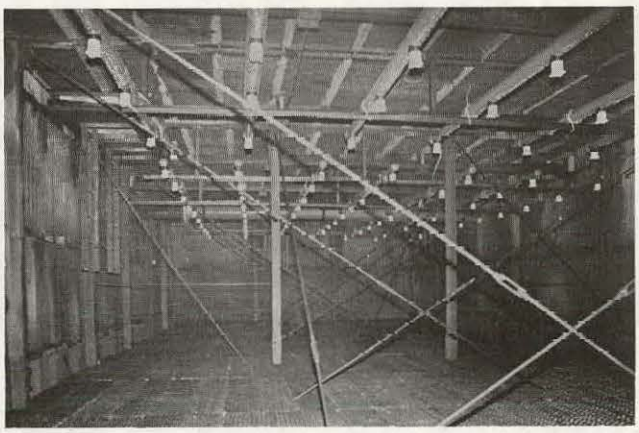


Fig. 9b. Spray arms and nozzles on 42" centers are non-clog and distribute the water in a highly uniform manner.

28 % reduction of power consumption.

Analysis of the total system temperatures proved illuminating and provides an important insight of the necessity for having a well performing cooling tower in the refrigeration system. While operating under the old fashioned fill, eliminator, and piping system, the temperatures of the refrigeration cooling water circuit averaged 100 to 105°F on the tower and returning at 90 to 95°F. This provided the necessary 10°F range of operations for the refrigeration machinery, Fig. 10.

After upgrading, the 10°F range was still provided but the water on the tower was now 95 to 100°F and coming off at 85 to 90°F. The efficiency of the rebuilt and upgraded tower lowered the entire temperature gradient by 10°F and this 10°F lower operating level is what produced the $11,547.14 savings per month. The retrofit cost of $58,131.00 will be paid back to the Owners within 5 to 6 months, then providing additional operating profit as the cost of utilities rise.

DATE	TEMPERATURE °F					
	AMBIENT	CONDENSER		WET BULB	APPROACH TO WET BULB	RANGE (ΔT)
		OUT	IN			
7·1·77	85	103	95	66	29	8
7·6·77	84	96	87	72	15	9
7·8·77	80	103	93	75	18	10
7·15·77	90	100	90	78	12	10
7·18·77	84	98	90	71	19	8
AVERAGE	84	100	91	71.8	18.6	9

THERMAL DATA BEFORE UPGRADING

DATE	TEMPERATURE °F					
	AMBIENT	CONDENSER		WET BULB	APPROACH TO WET BULB	RANGE (ΔT)
		OUT	IN			
8·1·79	80	86	76	70	6	10
8·4·79	83	92	82	76	6	10
8·8·79	88	90	80	67	13	10
8·10·79	88	94	84	75	9	10
8·21·79	81	89	79	68	11	10
AVERAGE	84	90.2	80.2	71.2	9	10

THERMAL DATA AFTER UPGRADING & RETRO-FIT

Fig. 10. Comparative data indicates that at same average wet bulb and ambient temperatures, the approach was reduced by 9°F while maintaining 10° cooling range. Note that the entire system temperature has been lowered by 10°F.

As further proof of the capability of a tower, it behooves the Operators and Owners to invest in an certified Cooling Tower Institute Performance and Acceptance test (6). The tower is tested by qualified impartial engineers and observers to determine the parameters of operation along the guidelines developed by the Cooling Tower Institute which is the professional International organization of cooling tower manufacturers, users, consultants, and suppliers. For a modest fee, a comprehensive report will be provided to the Owner. This investment is a worthwhile protection for the investment in either new equipment purchases or the rebuilding and retrofit of existing installations.

Since energy costs will continue to climb in the foreseeable future, engineers with cooling tower responsibility will do well to look at the utilization of colder water as a means of conservation and increased profit.

These two case histories clearly illustrate this point. An upgrading program is in the planning stage for a large Southwestern Public Utility and the bottom line for the 750 megawatt installation is that one degree (1°) colder water is worth $500,000.00 to the Utility.

An important step toward an energy management analysis of a Building, Plant, or Process should include a thorough engineering

inspection and judgement of the cooling tower by a specialist in this field. An evaluation, performed at nominal cost, is submitted in a formal report with recommendations, budget costs, and evaluation of the thermal, structural, and mechanical condition of the equipment. This feasibility study will assist in determining the extend of efficiency improvement that is available to the Client together with costs and projected savings.

While all cooling tower/refrigeration system might not provide such a dramatic cost effective payback as this case history, the return of a customers investment in upgrading his cooling tower can be a surprising factor of operation and should not be neglected.

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WASTE-HEAT RECOVERY FROM REFRIGERATION IN A MEAT-PROCESSING FACILITY

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ABSTRACT

A case study is reviewed on a heat recovery system installed in a meat processing facility to preheat water for the plant hot water supply. The system utilizes waste superheat from the facility's 1,350-ton ammonia refrigeration system.

The heat recovery system consists of a shell and tube heat exchanger (16"Ø x 14'0") installed in the compressor hot gas discharge line. Water is recirculated from a 23,000-gallon tempered water storage tank to the heat exchanger by a circulating pump at the rate of 100 gallons per minute. All make-up water to the plant hot water system is supplied from this tempered water storage tank, which is maintained at a constant filled level.

Tests to determine the actual rate of heat recovery were conducted from October 3, 1979 to October 12, 1979, disclosing an average usage of 147,000 gallons of hot water daily. These tests illustrated a varied heat recovery of from 0.5 to 1.0 million BTU per hour. The deviations were the result of both changing refrigeration demands and compressor operating modes.

An average of 16 million BTU per day was realized, resulting in reduced boiler fuel costs of $30,000 annually, based on the present $.80 per gallon #2 fuel oil price. At the total installed cost of $79,000, including test instrumentation, the project was found to be economically viable.

The study has demonstrated the technical and economic feasibility of refrigeration waste heat recovery as a positive energy conservation strategy which has broad applications in industry and commerce.

INTRODUCTION - Heat recovery from refrigeration is not new technology. Prior installations exist using various accepted methods of extracting waste heat from the compressor discharge side of a refrigeration system for use in various applications requiring low grade waste heat. The project in this report involved standard indirect heat recovery technology for recovery of the higher quality superheat at an existing meat processing plant (SIC 2013) by preheating hot water for the plant. This paper is intended to describe the actual installation and to report on measured performance under real plant conditions as a contribution to the literature on the documented performance of this type of energy conservation project.

The meat packing plant involved in this project was opened in 1978, and was originally designed to incorporate refrigeration waste heat recovery. However, capital availability required the new plant to be stripped of any nonessential capital and this resulted in construction without the refrigeration heat recovery project. After initial operation however, it became clear that refrigeration waste heat recovery for use in preheating plant hot water still appeared technically feasible and may even be economically feasible as a stand-alone retrofit project. Initial estimation suggested the project could produce annual energy savings on the order of one-third the total installation cost, and upon this basis the heat recovery project was undertaken.

The superheat range of heat recovery was arbitrarily selected in order to obtain higher waste heat temperatures. Full condensing heat recovery would have recovered more total heat but there were doubts whether such a lower temperature heat recovery could cost justify the much larger heat recovery installation for full condensing.

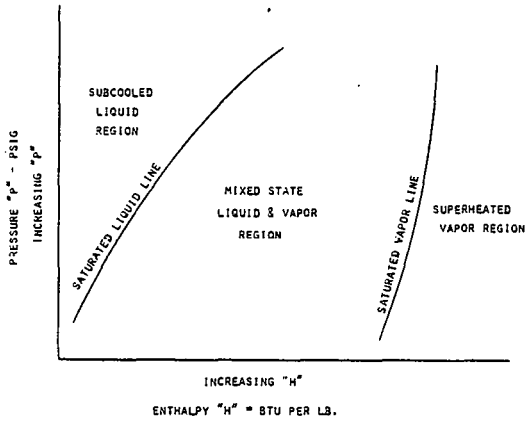
The installation also included monitoring instrumentation for the purpose of evaluating real performance especially as a function of changes in compressor output. This resulted in a slightly more costly installation than necessary for heat recovery.

In concept, the project was intended to produce a reasonable volume of stored preheated water and was not designed to always maximize extraction of all superheat theoretically possible. Thus many practical decisions of the design were arbitrary in order to minimize the design and engineering costs of the project.

One of the specific reasons for monitory performance of this installation was for confirmation of its cost effectiveness and its application to other similar company facilities.

BACKGROUND REVIEW OF REFRIGERATION - This section provides a brief review of refrigeration theory to explain the nature of the waste heat source. In order to discuss the recoverable waste heat which is available from an industrial refrigeration system, it is first helpful to define and examine a mechanical refrigeration system. A mechanical refrigeration system transfers heat away from a substance to be cooled to another substance by circulating a refrigerant. There are four major components in a refrigeration system: 1) an evaporator, 2) a compressor, 3) a condenser, and 4) an expansion or metering device. Circulated within the system, the refrigerant is a fluid which has the capability of changing from a liquid to a vapor, being compressed and being condensed, all at moderate pressures.

In order to understand the refrigeration cycle it is necessary to examine what occurs relative to pressure and heat content within the refrigerant as it changes state. A simplified pressure/enthalapy (Mollier) diagram is shown in Figure 1.



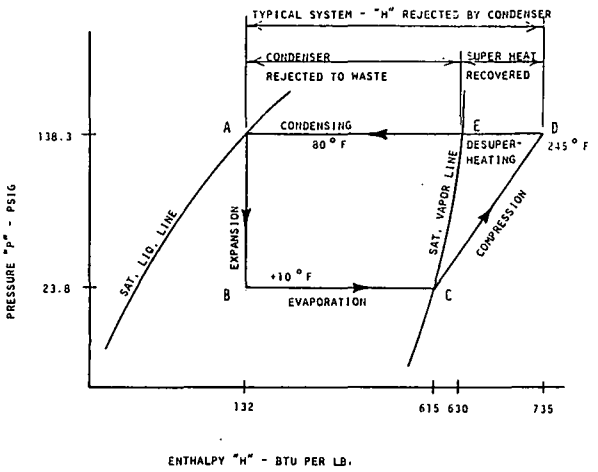
SIMPLIFIED PRESSURE - ENTHALPY DIAGRAM
FIG. 1

The diagram shows three distinct regions which are separated by the saturated liquid and saturated vapor lines. At all points on and to the left of the saturated liquid line, the refrigerant is in the liquid state. Removal of heat from the refrigerant existing as a saturated liquid changes it to a subcooled liquid. At all points on and to the right of the saturated vapor line, the refrigerant exists as a gas. Addition of heat to the refrigerant existing as a saturated vapor changes it to a superheated gas. Between the lines of saturation the refrigerant exists in the mixed state of both liquid and vapor.

Within either the subcooled or superheated regions of the diagram the addition of heat at constant pressure will raise the temperature of the refrigerant. Conversely, a rejection of heat from the refrigerant will lower its temperature if the pressure is held constant. Since this addition or rejection of heat is observed with a thermometer, it is referred to as sensible heat.

Within the mixed state region the addition or rejection of heat at a constant pressure does not change the temperature of the refrigerant. Instead, the addition of heat increases the percentage of vapor present. The rejection of heat increases the percentage of liquid which is present. This heat is referred to as the latent heat of vaporization.

A line superimposed on the Mollier diagram, shown in Figure 2, traces the states through which the refrigerant passes during a refrigeration cycle. Pertinent examples of typical pressures and enthalapy



TYPICAL AMMONIA REFRIGERATION CYCLE
FIG. 2

values have also been added to the diagram. These values would correspond with R-717, ammonia refrigerant, which is the most widely used industrial refrigerant. Although the refrigeration cycle is a continuous loop, the discussion will begin as the refrigerant is fed to the expansion device.

At point "A", Figure 2, liquid refrigerant (ammonia) at 80°F and 138.3 PSIG, containing 132 BTU per pound, is fed to an expansion device. As the ammonia is expanded through the device, its condition is changed from a saturated liquid to a mixture of liquid and vapor at point "B" on the diagram. Since no heat has been added, the ammonia still contains 132 BTU per pound. However, pressure and temperature have dropped to 10°F and 23.8 PSIG.

Thus the low temperature refrigerant enters the evaporator at a temperature which is lower than the substance to be cooled. The temperature difference (TD) allows a flow of heat from the substance to be cooled to the ammonia refrigerant.

Since the ammonia is in the mixed state, the heat added to it is latent heat of vaporization which vaporizes the available liquid rather than raising the temperature of the refrigerant. Therefore, at point "C" in the cycle the ammonia is still at 10°F and 23.8 PSIG. However, due to heat gained from the substance, which is cooled, the ammonia, which is now a saturated vapor, contains 614.9 BTU per pound.

Although superheat can be added to the refrigerant as it passes through the evaporator in some types of systems, it is minimized to prevent excessive heat build-up in the compressors.

During compression the pressure increase on the vapor in the compressor raises the temperature of the gas. The mechanical energy of the motor-driven compressor is also converted to heat in the vapor. This heat of compression, as well as any heat which was picked up by the refrigerant in the piping from the evaporator to the compressor, superheats the hot ammonia gas.

In the typical refrigeration system as shown in Figure 2, the superheated hot ammonia gas, which left the compressor at 245°F and 138.2 PSIG, containing 735 BTU per pound, would enter the condenser (Figure 2, point "D"). In the condenser heat is rejected from the ammonia to the cooling media as shown in Figure 2 between points "D" and "A". At point "A", the refrigerant is again an 80°F liquid containing 132 BTU per pound of ammonia.

In the condenser both sensible and latent heat have been rejected from the ammonia, thus the condenser device, in practice, is both a desuperheater and a condenser. Condensing during the rejection of the latent heat of vaporization was accomplished in the cycle between points "E" on the saturated vapor line (0% liquid) and point "A" the saturated liquid line (100% liquid). Before condensing of the vapor can take place, the sensible superheat as shown between points "D" and "E" must be rejected from the superheated vapor.

This superheat, available prior to condensing, is the source of recoverable waste heat to be addressed by this case study. This high quality (high temperature), available heat varies from levels of 500 to 3,000 BTU per ton-hour of refrigeration depending on the compressor operating mode.

Refrigeration systems used in the meat industry are often compound systems that have several stages of compression. For example, a low stage would be for freezers held at or below 10°F and compressors on the low stage discharge to the suction of a second stage of compressors called the high stage. The high stage system also provides cooling for rooms held at say 20°F to 50°F in addition to further compression of the low stage refrigerant vapors.

DESCRIPTION OF INSTALLATION - Although the plant system described by this paper is a compound system, only the high stage compressors directly contribute to the recoverable superheat. Therefore, this

paper will not concern itself with the low stage system.

The high stage system at the project plant consisted of a combination of two rotary screw compressors and six reciprocating compressors. The reciprocating compressors in this system track the changing refrigeration load of the plant while the rotary screw compressors are base loaded at 100% capacity. In the event that enough load is not being carried to keep a screw compressor completely loaded at peak efficiency, it is dropped off the line and reciprocating compressors are started to pick up the load.

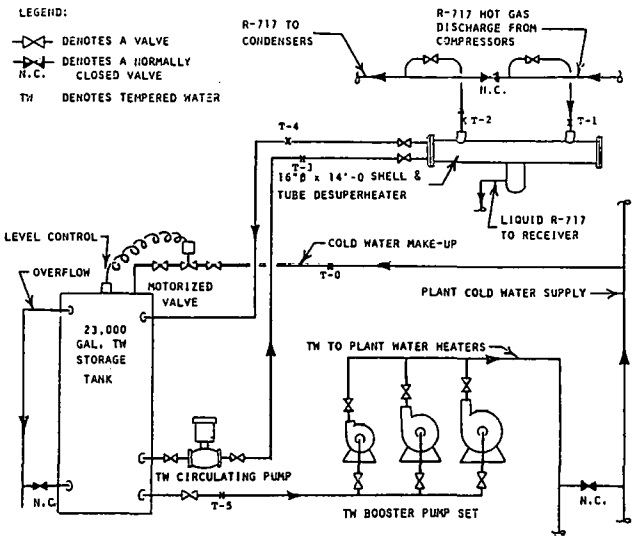
The screw compressors are equipped with high pressure liquid refrigerant injection for oil cooling. This oil cooling system reduces the heat content of the discharge gas from these machines to about 652 BTU per pound at 110°F. This feature of the screw compressors acts to reduce the superheat available and is one disadvantage of applying heat recovery to this type of screw compressor. The hot gas discharge from the reciprocating compressors carries about 735 BTU per pound at a temperature of 245°F.

The heat recovery system selected used a 16"Ø x 14' shell and tube heat exchanger with stainless steel tubes in a mild steel shell installed in the common compressor discharge line as shown in Figure 3. It was fully insulated since its installation site was outdoors. Valves provide isolation of the heat exchanger for inspection of the ammonia side of the heat exchanger. Superheated discharge gases pass through the shell side of the exchanger while water is circulated through the 3/4" diameter tubes.

The water circulated through the heat exchanger was pumped from a tempered water storage tank (tank) at a design rate of 100 gallons per minute (GPM) and returned to the tank. As the water passes through the heat exchanger, heat is transferred from the superheated ammonia gas to the water.

The storage tank had a design 23,000-gallon capacity and was of fiberglas construction. Two inches of polyurethane insulation provided protection against severe heat losses through the tank walls to the outside ambient air temperatures.

The storage tank furnished preheated (tempered) water to the plant water heaters through a three-stage pump set. Pump design capacities were 80, 120 and 200 GPM. This pump set maintained proper hot



RECOVERY OF WASTE SUPERHEAT FROM THE REFRIGERATION SYSTEM
FIG. 3

water system pressures by running combinations of pumps as called for by the automatic pressure control system, which was an integral part of the system.

As water is pumped from the tempered water storage tank to the hot water heaters, a constant level in the tank is maintained. Cold make-up water at 57°F replaces water pumped to the water heaters. The make-up water is supplied from the plant softening system as is all other plant water. Softening is necessary because of the extreme hardness of the plant water supply.

In addition to the major hardware mentioned, the heat exchanger was equipped with a freeze protection device which turned on the system circulating pump if water temperatures in outside piping approached freezing. Also, meters, thermometers, and pressure gauges were installed for the purpose of evaluating the performance of the waste heat recovery system.

The refrigeration waste heat recovery system at the meat processing facility was formally evaluated October 3 through October 12, 1979. Data was gathered in the form of temperatures, pressures and flow rates. A single representative 24-hour period is presented in this case study.

Throughout the test period, continuous temperature recordings were made at six locations within the heat recovery system. Points monitored are shown in Table I, and are also shown on the system schematic in Figure 3.

Point Number on Recorder	Description	Temperature Range
T-0	Plant cold water	57°F
T-1	Ammonia hot gas, into heat exchanger	125 - 149°F
T-2	Ammonia hot gas leaving heat exchanger	77 - 95°F
T-3	Tempered water into heat exchanger	69 - 87°F
T-4	Water leaving heat exchanger	82 - 102°F
T-5	Tempered water to plant water heaters	69 - 87°F

TABLE I

Thermocouple temperature sensors were inserted into oil-filled temperature wells installed in the system piping. Temperature wells in the ammonia hot gas piping were installed within 12 inches of the heat exchanger to minimize weather effects due to uninsulated piping being exposed to outside conditions.

Each thermocouple was connected to a Leeds and Northrup multipoint temperature recorder. Accuracy of recorded temperatures are plus or minus 1°F.

Temperatures recorded at Point T-1, ammonia hot gas into the heat exchanger, differ from the discharge temperatures associated with the screw (110°F) and reciprocating machine (245°F). All compressors discharged into a common line and thus gas temperatures recorded reflect the resulting mixed gas temperature. That temperature depends on the ratio of reciprocating machine capacity running versus total running capacity.

The refrigeration system in this plant was equipped with standard pressure monitoring devices. The devices sense and record operating pressure such as compressor suction and discharge pressure. In the test these pressures were monitored to provide information on the operating conditions of the compressors and to determine the heat content of the discharge gas.

Performance charts for each compressor revealed actual capacities at 160 tons of refrigeration for each reciprocating compressor and 425 tons for the screw compressor. This information was used hourly in calculating heat available in discharged gas, as summarized in Table II.

Heat content in the gas was found by using the observed averaged hourly pressure and temperature of the gas and locating that point on the Mollier chart as set forth in the background section of this paper.

One Hour Intervals	Running Capacity (T.R.)	Hot Gas Temperators (T-1) - (T-2)	Superheat Transferred (MMBTU)
7:00 am	692	128 - 83	.50
8:00	692	128 - 84	.50
9:00	712	131 - 85	.55
10:00	712	130 - 85	.50
11:00	692	127 - 85	.50
12:00 pm	732	134 - 83	.60
1:00	752	134 - 84	.60
2:00	592	128 - 85	.50
3:00	747	134 - 84	.65
4:00	732	132 - 86	.60
5:00	732	132 - 86	.60
6:00	772	137 - 88	.65
7:00	792	142 - 91	.65
8:00	772	136 - 91	.60
9:00	812	142 - 93	.65
10:00	852	147 - 91	.70
11:00	852	147 - 88	.60
12:00 am	826	143 - 82	.80
1:00	852	144 - 79	.95
2:00	806	142 - 78	.90
3:00	842	142 - 77	.80
4:00	852	145 - 77	1.00
5:00	716	131 - 78	.70
6:00	832	142 - 78	.90
TOTAL	---	--- --	16.0

TABLE II

SUPERHEATED AMMONIA TEMPERATURES AND HEAT TRANSFERRED

Superheat from the ammonia, in BTUs per hour, was tracked for purposes of evaluation and summarized in a one-day test in Table II. In order to determine the amount of recovered heat added to heat water, water flows and water temperatures had to be known.

The pump used to circulate water from the storage tank through the heat exchanger was specified at 100 gallons per minute (GPM). By test it was found that the pump actually moved water at a rate of 115 GPM.

Water supplied from the storage tank to the plant water heaters was metered through a turbine type meter. The meter had a continuous flow recorder as well as a totalizer.

The meter was calibrated to assure accuracy since it was this quantity of water which was to be the basis of the final performance of the heat recovery system.

Accuracy of the meter is plus or minus 1.5% of the meter scale.

The raw data shown in Table III was taken from recordings made for the 24-hour period commencing at 7 a.m., October 4, 1979. Each temperature shown was the average temperature during the one-hour interval. The volume of water supplied to the plant water heaters was taken from the totalizer on the water flow meter during corresponding intervals.

One Hour Intervals	Water to Heaters (gal/hr)	Temperature Points T-0	T-1	T-2	T-3	T-4	T-5
				(°F)			
7:00 am	2,400	57	128	83	77	89	77
8:00	2,700	57	128	84	78	90	78
9:00	3.300	57	131	85	79	90	79
10:00	5,100	57	130	85	79	91	79
11:00	5,700	57	127	85	78	90	78
12:00 pm	3,300	57	134	83	77	90	77
1:00	3,300	57	134	84	78	91	78
2:00	5,400	57	128	85	79	90	79
3:00	3,900	57	134	84	79	90	79
4:00	2,400	57	132	86	79	91	79
5:00	2,400	57	132	86	81	92	81
6:00	2,100	57	137	88	82	94	82
7:00	2,100	57	142	91	84	97	84
8:00	2,100	57	136	91	86	97	86
9:00	2,100	57	142	93	87	100	87
10:00	15,000	57	147	91	84	100	84
11:00	13,000	57	147	88	78	96	78
12:00 am	13,000	57	143	82	75	89	75
1:00	17,000	57	144	79	71	89	71
2:00	14,000	57	142	78	69	87	69
3:00	11,000	57	142	77	69	86	69
4:00	9,300	57	145	77	69	86	69
5:00	3,900	57	131	78	70	84	70
6:00	3,300	57	142	78	71	85	71

TABLE III

TEMPERATURE AND HOT WATER FLOW DATA

Table IV summarizes the observed average hourly temperature increases in both water through the heat exchanger and the water from storage to the plant hot water system. Also shown are the computed averaged hourly rates of heat added for each water flow, based on the simple multiplication of temperature difference times the flow of water in pounds per hour. The total heat recovered for the day is shown for each water flow. Referral to Table III, however, reveals the storage tank temperature at the end of the day test was 6°F lower. This is a calculated 1.2 MMBTU withdrawal which when substracted from the heat sent to the plant reveals a corrected one-day net heat transfer to the plant hot water heaters of 21.6 MMBTU.

One Hour Intervals	(T-4 - T-3) Δ T-1	Heat Recovered (MMBTU/hr)	(T-5 - T-0) Δ T-2	Heat Supplied To Heaters (MMBTU)
7:00 am	12	.7	20	4
8:00	12	.7	21	.5
9:00	11	.6	22	.6
10:00	12	.7	22	.9
11:00	12	.7	21	1.0
12:00 pm	13	.7	20	.5
1:00	13	.7	21	.6
2:00	11	.6	22	1.0
3:00	11	.6	22	.7
4:00	12	.7	22	.4
5:00	11	.6	24	.5
6:00	12	.7	25	.4
7:00	13	.7	27	.5
8:00	11	.6	29	.5
9:00	13	.7	30	.5
10:00	16	.9	27	3.4
11:00	18	1.0	21	2.3
12:00 am	14	.8	18	1.9
1:00	18	1.0	14	2.0
2:00	18	1.0	12	1.4
3:00	17	1.0	12	1.1
4:00	17	1.0	12	.9
5:00	14	.8	13	.4
6:00	14	.8	14	.4
TOTAL	--	18.3	--	22.8

TABLE IV

WATER TEMPERATURE INCREASES AND HEAT TRANSFERRED

The summary of the one-day heat transfers is as follows:

HEAT TRANSFER	MMBTU/DAY
From ammonia in heat exchanger	16.0
To water in heat exchanger	18.3
From storage to plant	21.6

This summary appears inverted where logically the heat from ammonia would be the largest and heat to the plant the smallest. However, with temperature accuracies of ±1°F for each measurement and water temperature differences as low as 11°F, it is easy to realize the computed heat values could be in error by as much as ±20 percent. This could alone explain the variance shown in the recovered heat values.

The flows of refrigeration waste heat summarized in Table II reveals a varying but still relatively uniform waste heat flow available as superheat. Notably, the temperatures of the ammonia gas discharge, however, did vary from a high of 149° F. to a low of 126°F.

By contrast, the demand for hourly hot water needs as shown in Table III reveals a large range of flows from a high of 283 GPM to 35 GPM of water for hot water service, thus making full use of the stored heat. For example the last column of Table III for the period of 10 p.m. to 3 a.m., the stored water temperature decreases rapidly due to high flow for plant clean-up. Conversely, note the reduced hot water demand from 4 p.m. to 9 p.m. resulted in the ability of the storage tank to slowly increase in temperature. Without storage, the heat recovery system could not provide the heat as needed for plant hot water use.

Based on the above data it was concluded that on a conservative basis heat recovery system extracted at least 16 MMBTU of reusable waste heat.

ECONOMICS OF INSTALLATION - The heat recovery system by preheating hot water normally heated by steam, provided a corresponding reduction in steam use thus directly saving on the #2 fuel oil used by the boilers. At the cost of oil then at 80¢/gallon, the 16 MMBTU of heat recovered can be converted to fuel savings as follows:

$$16 \frac{\text{MMBTU}}{\text{day}} \times \frac{1}{.78} \text{ eff. (fuel to useful heat)} \times \frac{\text{gal oil}}{.14 \text{ MMBTU}} \times \frac{\$.8}{\text{gal. oil}} = \$117/\text{day}$$

$117/day x 250 days/yr. = $29,250/yr. in fuel savings

No inclusion was made on maintenance and pump operation cost, but they were expected to be very minor when compared to the fuel savings.

The total installation cost was $78,800, thus a simple payback ratio revealed a payback of about 32 months based on October, 1979, prices for oil.

As a matter of supplemental interest, a best case calculation could reveal a much more attractive economic return by 1) using 18.3 MMBTU recovered by the water from the exchanger, 2) using an averaged projected oil cost of $1.30/gallon over the first two-year life of the project, and 3) applying the present ten percent energy savings investment tax credit for the energy project as allowed under the Energy Tax Act of 1978. The combined result of these three factors is to reduce the simple payback to less than 16 months.

In either case the computations revealed a very attractive payback on this project and demonstrated its economic feasibility.

BILLET HEATING WITH THE HOMOPOLAR GENERATOR

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ABSTRACT

Forging billets are presently brought from room temperature to forging temperature using one of three heating methods -- indirect heating in a furnace, either fuel-fired or electric; direct electric resistance heating; or induction heating. Homopolar generators, operating in the pulsed mode, offer a fourth possible billet heating method. Although basically a direct resistance heating method, the homopolar generator type of power supply has several advantages over a conventional transformer-type supply. First, homopolar generators can be designed to deliver energy at much higher power levels than transformers, resulting in very much shorter heating times than are required using conventional direct resistance heating systems. The shorter heating times minimize oxide scale formation on the billets. Second, pulsed homopolar generators, because they do not impose an increased load on the power mains during delivery of pulses, permit power averaging and minimize demand charges. When compared with slot furnaces, homopolar generator billet heating systems offer increased operating efficiency as well as the advantages of ease of maintenance and freedom from the necessity of maintaining temperature under no-load conditions in addition to the much reduced scale formation.

INTRODUCTION

The technology of pulsed homopolar generators, a product of government-funded research in the area of controlled thermonuclear fusion, may be of immediate benefit to the metal forging and rolling industries as a power source for billet heating.

The University of Texas Center for Electromechanics (UT-CEM) has been involved since 1972 in programs intended to address the need for large pulsed power supplies for use in experiments leading to controlled thermonuclear fusion power generating plants.[1] Since that time, UT-CEM has been involved both in design studies and in construction and testing of a number of pulsed power generators intended to meet a broad spectrum of performance requirements in terms of quantity of energy stored and energy delivery rates.[2,3,4,5] One of these machines, the 5 MJ homopolar generator, was designed and built in 1974 to further explore the electrical characteristics of this type of machine operated in a pulsed mode. The machine exceeded its design goals by a considerable margin, and it has become apparent that machines of this kind offer promise as pulsed power sources in a variety of industrial, military, and research applications.

The use of pulsed homopolar generators for welding large sections has been described previously.[6,7] The use of such generators for pulsed electrical resistance heating of billets for forging and rolling processes offers some very attractive advantages over conventional heating processes, including cost savings.

BILLET HEATING

The heating of steel billets for forging and rolling operations is typically accomplished in direct natural gas fired slot furnaces. Because of the circumstances surrounding their operation, such furnaces typically operate at 5 to 7% thermal efficiency.[8] The fact that such furnaces operate with direct combustion generally precludes the use of less expensive (and less clean) fuels because of problems associated with contamination of the steel. The incremental pricing provisions of the Natural Gas

Policy Act of 1978[9] and curtailments of industrial usage of natural gas may well serve to make alternate heating processes mandatory, regardless of efficiency considerations.

Another liability of the direct gas-fired heating of metals is the formation of oxide scale on the surface of the billets due to the presence of oxygen in the furnace. Although this loss is understandably difficult to quantify, it has been estimated at approximately 4% of the throughput of the furnace.[10,11] In addition to a loss of throughput in general, this oxide formation also represents a loss of valuable alloying elements, many of which must be imported into the United States.

A logical alternative to direct gas fired heating of metal billets is electrical heating; since it is likely that electricity will remain the basic industrial "medium-of-exchange" regardless of the mixture of primary energy sources that evolves to meet our future energy needs. Electrical heating of billets is conventionally accomplished by one of three methods: induction heating, indirect resistance heating, or direct resistance heating. For high production rates of single billet size, induction heating is attractive, for although the capital costs are high, the efficiency can be high also[12] (~70% electrical efficiency), and contact with the billet is avoided. The process is not particularly versatile, however, since each billet size requires a special coil size and a significant change in billet cross section can require a change in operating frequency.[13] Furthermore, when using induction for through heating, electromagnetic "skin depth" considerations limit the process to billets with fairly slender aspect ratios.

Indirect resistance heating is used in some small controlled atmosphere heat treating furnaces, but is typically so inefficient that it does not merit further consideration.

Direct electrical resistance heating of billets is potentially the most attractive method, since it requires the least equipment, involving merely introducing the metal billet into an electrical power circuit. It is especially effective on non-ferromagnetic materials with relatively poor thermal conductivities, such as stainless steel, which are difficult to heat by direct combustion and provide poor coupling to induction heaters. Unfortunately, up to the present time, practical considerations have limited the process to use with those billets having the proper size and aspect ratio (i.e., resistance) to interface with suitable power supplies, typically transformers with low voltage, low impedance secondary windings. Such transformers are not generally capable of producing steady state secondary currents of more than 100 kA, and this limits the heating rate possible for any given billet. Rectifiers on the transformer output greatly improve the heating efficiency of the process by depositing the heat uniformly through the cross section of the billet rather than concentrating it at the surface where radiative, conductive and convective losses are highest. Figure 1 shows steady state DC heating of a 5 1/4 in. square by 60 ft long mild steel billet, such as might be used in a shape rolling operation. Curve A shows constant voltage heating of the billet (the simplest, least costly approach) with the peak current limited to 200 kA, which does not reach 2400° F, while curve B shows the effect of maintaining the current constant at 200 kA by varying the transformer output voltage. Curve C shows the voltage variation necessary to accomplish curve B. In the case of curve A the heating efficiency is 34%, while in the case of curve B the efficiency is improved to 98.9%. In both cases the efficiencies of the transformers and rectifiers are <u>not</u> included in the efficiency figures given.

While direct electrical resistance heating is attractive over a certain range of applications because of its simplicity and minimal equipment requirements, the technique is applicable only to long, slender billets having relatively high electrical resistance. As the cross sectional area of the billet increases and/or the length of the billet decreases and its resistance becomes low relative to the winding impedance of the transformer, an increasing fraction of the electrical energy is deposited in the winding of the transformer itself, and the overall efficiency of the process suffers. Electrically, the problem is actually one of impedance matching between the source and the load, and the need for a source with lower impedance than the transformer becomes apparent. Furthermore, the heating times available with this mode may still result in some oxidation of the workpiece surface unless the process is carried out in an inert atmosphere. As the processing time per billet is re-

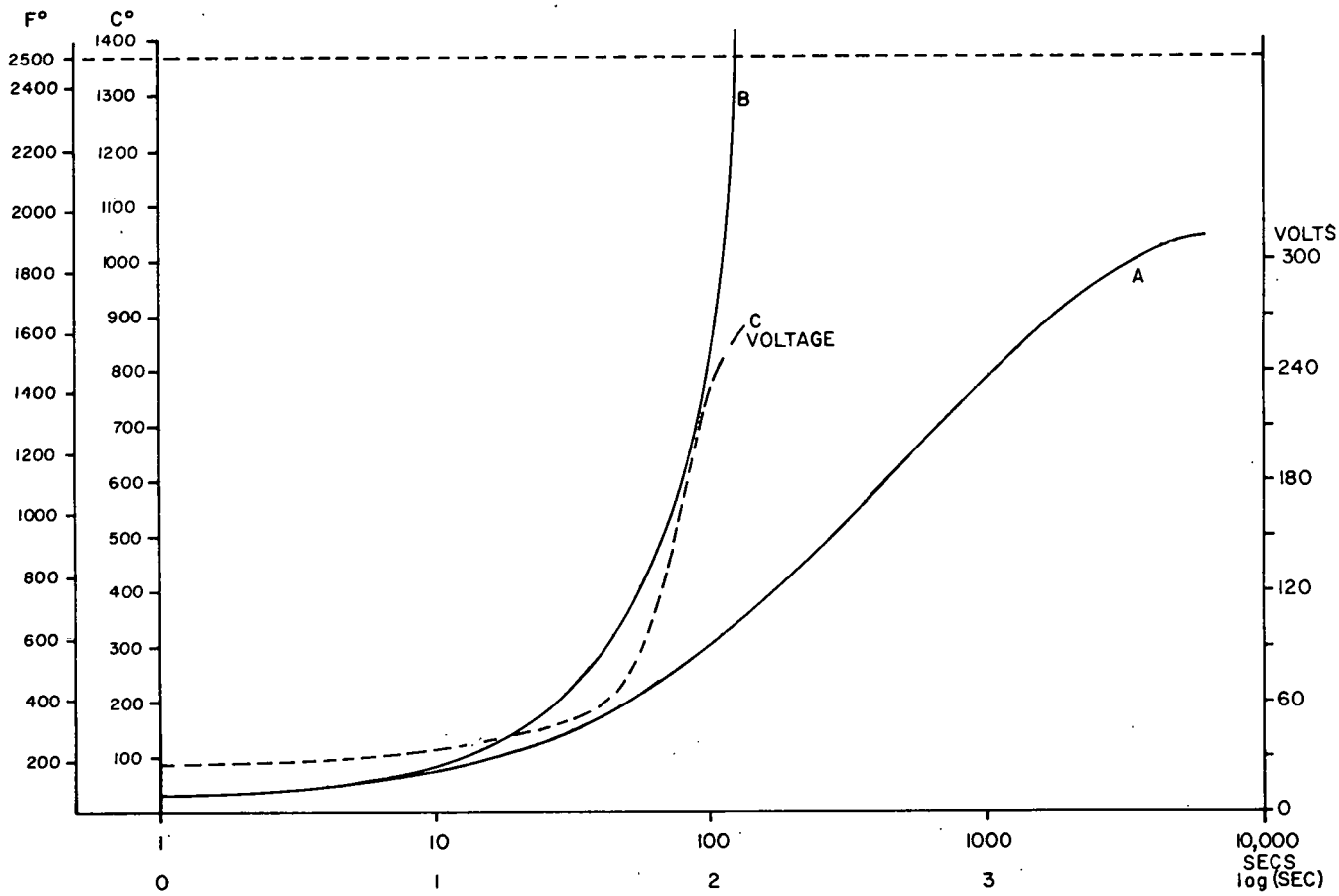


Figure 1. Direct Electrical Resistance Heating of 5 1/4 in. sq by 60 ft long steel billet

duced (as would be the case for smaller, lower impedance, billets) the time required to load and unload the heating fixture becomes significant with respect to the heating time, imposing undesirable and costly surges on the utility line.

The proposed new process of pulsed homopolar generator billet heating addresses all of these difficulties.

THE PULSED HOMOPOLAR GENERATOR

Inertial energy storage using homopolar electromechanical conversion is the least expensive and most compact among the practical methods of energy storage which would allow energy to be drawn from the utility grid in a continuous mode, including loading and unloading cycles as well as "dead" periods, to eliminate demand charges and peaking loads on the utilities, and then deliver that stored energy in a pulsed mode to heat the billet quickly. Although homopolar generators can be built in several configurations to suit the load they are intended to drive, [14,15] Figure 2 shows a typical drum type homopolar generator such as might be used for billet heating.

In homopolar machines, a voltage is generated across a conductor that moves through a unidirectional magnetic field. The essential difference from a conventional generator is that the current travels through the rotor itself which is the energy storage flywheel and makes only one transit across the magnetic field. There are no rotor windings and there is no commutator. The homopolar machines therefore inherently produce high current and low voltage and are not suited for transmitting energy over long distances. For some applications, however, including resistance welding and other forms of resistance

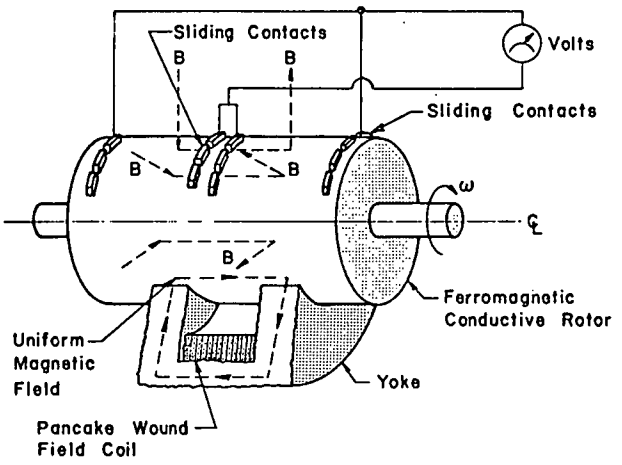


Figure 2. Drum Type Homopolar Generator

heating, the electrical characteristics of these machines are ideal.

Since in a homopolar machine the brushes must slide on the rotor at a large radius and must carry full power, frictional brush losses and heating are significant and contribute to brush wear. Two developments help overcome this basic machine limitation. The first is the use of the generator as a stored energy machine in a pulsed duty mode. Remotely controllable brush actuation mechanisms which lower the brushes when necessary during a discharge, but raise them during external motoring, minimize machine frictional losses and brush wear. Second, the development of very high metal-content composite brushes has further increased the wear life of brushes operating at high current densities for pulsed power machines of this kind.[16,17,18]

The simple solid rotor configuration offers at least two significant advantages over some of the complex geometries used in the past. First, with no slots, wedges or laminations, the rotor consists only of a right circular cylinder of steel, so the manufacturing cost is inherently low. Second, and just as important, when using the homopolar machine in a pulsed duty, stored energy mode in which the machine rotor serves also as the energy storage flywheel, the deceleration forces resulting during a discharge are body forces acting directly on all rotor mass elements in which the energy is inertially stored. Thus the decelerating torque is distributed and stresses are relatively low. This means that the energy can be safely transferred very quickly at very high power levels. This is not the case when using an external flywheel, because the entire decelerating torque must be transmitted through a connecting shaft, thus limiting the energy transfer rate due to allowable shaft stress levels.

The energy available in a single pulse from a homopolar generator is of course the inertial energy stored in the rotor.

$$E = \frac{\pi \delta R^4 t \omega^2}{4}$$

where E = Energy (J)
δ = Density of rotor material (kg/m^3)
R = Rotor radius (m)
t = Rotor length (m)
ω = Rotor angular velocity (rad/s) .

Homopolar generators of interest for billet heating use steel rotors (δ= 7833 kg/m^3), and the surface velocity is limited by brush life considerations to 200 m/s ($v = R\omega$ = 200 m/s) so that

$$E = 2.461 \times 10^8 R^2 t \quad .$$

Homopolar generators storing from a few kilojoules (10^3 joules) to several gigajoules (10^9 joules) have been designed. UT-CEM has a 5 MJ (5×10^6 joules) homopolar generator. The largest such generator ever built stores 500 MJ. Such generators can produce voltages from tens to hundreds of volts as required and are capable of producing currents from hundreds of thousands to millions of amperes. The internal resistance of such generators is lower than a power transformer, typically of the order of 10^{-5} ohms. The ranges of voltages and currents available from practical homopolar generators are compared with those for present day resistance welding transformers in Figure 3.

BILLET HEATING WITH THE HOMOPOLAR GENERATOR

Since both the electrical resistivities and heat capacities of metal alloys vary with temperature, voltage drops and energy requirements must be integrated as functions of temperature to predict the heating requirements of a particular billet accurately. UT-CEM has developed a computer code to make this calculation which also calculates thermal losses

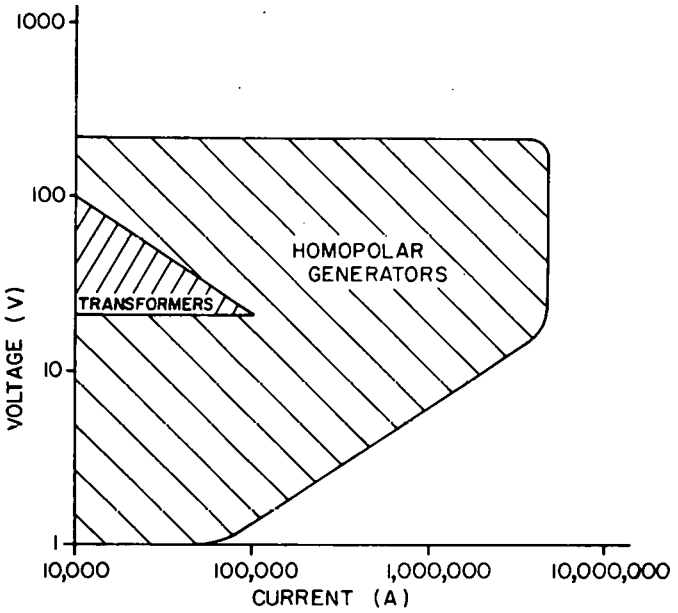


Figure 3. Comparison of Homopolar Generator and Transformer Operating Parameters

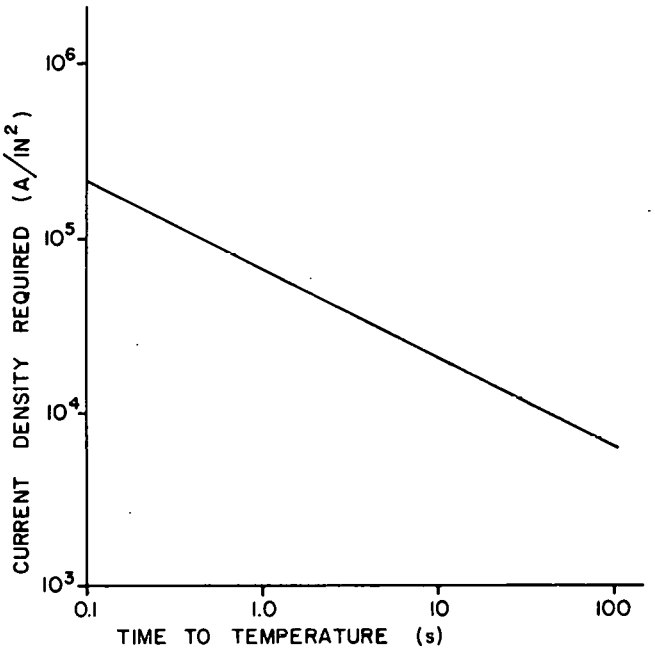


Figure 4. Current Density Required to Heat Ferrous Materials to 2400°F

due to radiation and convection. For estimating the heating requirements for a billet, however, the following values will prove useful. Most ferrous alloys require about 4×10^5 joules/lb to heat them from room temperature to 2400°F. For a typical heating efficiency of 80%, this means that each pound of steel to be heated requires 5×10^5 joules of energy to be stored in the homopolar generator. For an average resistivity of 75×10^{-6} Ω-cm, typical of most common ferrous alloys, the current density required to raise a billet to 2400°F in a time t is given by

$$\frac{I}{A} = \frac{6.103 \times 10^4}{\sqrt{t}}$$

where

I = current (A)

A = billet cross sectional area ($in.^2$)

t = time (s)

This relationship is plotted in Figure 4.

The final parameter we need to know is the voltage drop associated with the billet in question. Once the heating time has been determined, this can be easily found by inserting the necessary current density (I/A) from Figure 4 into the following equation.

$$V = 2.95 \times 10^{-5}\left(\frac{I}{A}\right)\ell$$

where

V = voltage required (V)

$\left(\frac{I}{A}\right)$ = current density required ($\frac{A}{in.^2}$)

ℓ = billet length (in.)

As an example of how to use this information, consider a 4 inch diameter, 24 inch long steel billet weighing 85 pounds to be brought up to 2400°F in 5 seconds. From Figure 4 this would require a current density of ~3×10^4 A/$in.^2$ or a total current of

$$I_{total} = (3\times10^4 \frac{A}{in.^2})\ \pi\ (2\ in.)^2 = 3.8\times10^5\ A$$

The voltage required to accomplish this would be

$$V = (2.95\times10^{-5}\Omega\text{-in.})(3\times10^4\frac{A}{in.^2})(24\ in.) = 21.24\ V$$

The total energy required to be stored in the homopolar generator would be

$$E_{HPG} = (85\ lb)(5.0\times10^5\ J/lb) = 42.5\ MJ$$

These figures are comfortably within the performance range of commercially available homopolar generators.

Since the generator rotor is simply a flywheel, it can be brought up to speed in a number of ways. Since the generator can also function as a motor, it can be self-motored from a DC power supply, but this is generally unattractive except in very special cases. Motoring schemes that are attractive include variable speed DC motors with SCR drives, AC induction motors with eddy-current couplings or hydrostatic drives, AC synchronous motors with variable frequency drives, and wound rotor induction motors with variable armature resistors. For field portable units, diesel or internal combustion engines can be used. The exact choice of motoring system depends upon the particular application.

To continue the previous example, assuming one billet to be heated every two minutes and a conservative 50% motoring efficiency for the generator:

$$\text{Motor Power} = \frac{(42.5 \times 10^6 \text{ J})}{(120\text{s} - 5\text{ s})(0.5 \text{ efficiency})}$$

$$= 739 \text{ kW input power}$$

Such calculations allow the potential of pulsed homopolar billet heating to be compared with conventional systems with which the reader may be familiar.

SUMMARY AND CONCLUSIONS

The pulsed homopolar generator is an attractive alternative to other methods of billet heating, since it has the extremely low internal impedance necessary to interface efficiently with metal billets having a wide range of aspect ratios. Furthermore, the rapid heating rates involved eliminate the loss of valuable alloying elements and difficulties during forging and rolling operations through the formation of oxide scale. Although the initial cost of pulsed homopolar billet heating is higher than that of the slot furnace it replaces, several studies have shown that the savings in fuel cost and oxide scale loss offer economic payout in from four to less than two years. The device is so compact and the heating time so rapid that the pulsed homopolar billet heating technique offers interesting new possibilities in incorporating the heating process into other metal handling and processing operations.

The Center for Electromechanics of the University of Texas at Austin would welcome the opportunity to investigate the applicability of this new process to your billet heating problems.

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The authors wish to thank Mr. Ted Aanstoos for generating the computer code to predict the heating times quoted in this paper. This work was funded by the Texas Atomic Energy Research Foundation.

IMPROVED EFFICIENCY IN LADLE PREHEATING: A CASE STUDY

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ABSTRACT

The Advanced Technology Ladle Preheater program is a joint industry and gas utility funded project. The Cadre Corporation of Atlanta, Georgia is the prime systems contractor, Southern California Gas Company and The Gas Research Institute are research sponsors, and Cameron Iron Works is the industrial participant for testing and demonstration. The project was initiated in May, 1979, with prototype testing of a full scale 60 ton ladle heater beginning January, 1980. This paper discusses the history of the Advanced Technology Ladle Preheater and presents a case study of the thermal efficiencies and economics of conventional ladle preheating practices versus improved ladle preheating practices.

INTRODUCTION

During the past two and one half years, The Cadre Corporation and Cameron Iron Works have investigated the practices of ladle preheating. Cameron Iron Works installed meters on its horizontal ladle preheater stands at its Cypress, Texas facility and has evaluated the fuel utilization and relationship to the amount of steel produced at this plant. The Cadre Corporation has conducted extensive national and international studies on ladle preheating practices in the United States, Canada and Western Europe. The studies, conducted by Cadre, indicate that improved methods of ladle preheating practices could result in an annual energy savings of 100 to 150 trillion BTU's per year. Further examination and testing of conventional ladle preheaters used at Cameron Iron Works reflected a thermal efficiency of 3% as compared to 59% for the Advanced Technology Ladle Heater.

Present practices of ladle heating have been compared to an attempt to "heat the world", and that is precisely what takes place when high volumes of natural gas or fuel oil are directed from an open burner into the mouth of the ladle. There is no heat recovery in these practices and considerable energy is consumed in preheating the ladle to receive molten metal or the curing of ladles that have been reworked.

Conventional ladle preheaters result in stratified heating of the refractory within the ladle and cause "cold spots" and then often result in spalding or cracking of the refractory when the molten metal is poured into the ladle. Testing of the Advanced Technology Ladle Preheater proved that the ladle can be very uniformly heated to high temperatures rapidly without damage to the refractory. The uniformity of heating is expected to dramatically reduce (possibly up to 50%) the refractory repair due to damage from molten metal being poured from the furnace into the ladle. As further test information becomes available, the potential of reducing the furnace melt temperature by at least 50°F is possible.

CONVENTIONAL LADLE HEATER CONFIGURATION

Each plant has its own unique method for preheating, curing, and holding ladles. Vertical, horizontal, and tipped positions have been observed. Burners range from an open gas pipe, inspirators, compressed air/gas mixers, to power burners installed in walls or roofs.

The open burners usually direct the flame to the

bottom of the ladle with direct flame impingement. The flames lick up the sides and the heat is allowed to escape to the atmosphere. The efficiency of this "gas guzzler" is generally 2%. In addition, the direct flame impingement creates hot spots with possible refractory damage and reduced refractory service life.

An improvement to the open burner is the power burner installed in a well or roof. This discussion will be limited to the horizontal unit, as employed by Cameron Iron Works. As shown in the next slide, a power burner is fired through a wall with the ladle positioned horizontally in front of the wall and as close as practical, normally 12" to 18". This system captures most of the radiation loss but large quantities of flue gas are allowed to escape to the atmosphere through the opening between the ladle and wall. These systems have efficiencies in the 2 to 4% range, which varies according to how close the ladle is placed to the wall, and the quality and maintenance of the combustion system. The system as shown in this slide will heat a 60 ton ladle from ambient to 1200°F in 12 hours with 11 million BTU's per hour input. This is a very expensive and time consuming process.

Under these conditions of the ladle preheat, the refractory brick experiences a severe thermal shock when the molten metal, at approximately 3000°F, is poured from the furnace into the ladle. The molten steel must transfer heat to the refractory brick until the temperature differential is reduced between the brick and the steel. Under these conditions, the ladle must be completely relined after approximately 20 furnace taps. An approximate cost for ladle relining is $20,000 for a 60 ton ladle. The bricks are made with an alumina base and are very expensive.

A comparison of this conventional system and the Advanced Technology Ladle Heater will be made a little later in the presentation.

HISTORY OF THE ADVANCED TECHNOLOGY LADLE HEATER PROGRAM

After significant research conducted by the Cadre Corporation and assisted by Cameron Iron Works, the formal program was initiated in May of 1979. The initial participants included the Cadre Corporation, Cameron Iron Works, and Southern California Gas Company, and Dr. Steve Davis, Consultant to Cadre. Major subcontractors, who participated in the program, were Hague International of South Portland, Maine, Thermodyne Products, Houston, Texas and J. T. Thorpe Products of Houston, Texas. The Gas Research Institute joined the project in January, 1980. A systems approach was used in the design and development, to ensure compatibility of design parameters and test objectives with the state-of-the-art hardware and equipment that was to be used.

Formal design reviews were held during May, July, September and November of 1979, with all team members and major subcontractors, to ensure that results of development work were communicated and effectively integrated into the program. The system completed fabrication and limited checkout on December 17, 1979, at which time it was moved to the Cameron Iron Works, Cypress, Texas plant for installation and checkout. Subsystem testing began immediately and full scale system testing and evaluation started on January 2, 1980. The system was completely adjusted to meet process requirements of the Cameron Iron Works, Cypress Melt Shop and put into production use for field demonstration on February 18, 1980. Presently, the system is being utilized for curing reworked ladles and preheating ladles for electric arc furnace tapping. The system will undergo field demonstration, testing and modifications, as required, through 1980.

COMPARISON OF SYSTEM PERFORMANCE - CAMERON CONVENTIONAL LADLE HEATER VERSUS THE CADRE ADVANCED TECHNOLOGY LADLE HEATER

Plant tests were conducted with a fully instrumented 60 ton ladle to determine system efficiencies, heat-up rates, temperature uniformities, and fuel consumptions for the conventional ladle heater and the Advanced Technology Heater.

The Cameron conventional heater has a burner operating at an input of 9.84 million BTU's per hour. This slide illustrates the uniformity in the ladle where the surface varies from less than 500°F to 1329°F in four hours. The next slide illustrates heat penetration into the refractory with thermocouples

buried at various depths in the refractory.

System efficiencies for the two burners were determined by comparing the quantity of fuel burned versus the pounds per hour of each component of flue gas, mainly N_2, CO_2, CO, O_2 and H_2O. The flue gas loss was then determined by summing the change in enthalpy for each constituent from the flue gas temperature to ambient. The latent heat of vaporization of water is included in the flue gas loss. The flue gas analysis was obtained using Oxygen, CO, and CO_2 analyzers. Radiation and convection losses of the heater lid were calculated and included in the overall efficiencies.

The next slide illustrates the efficiency of the Advanced Technology Heater as a function of time during a heat-up cycle. In a similar manner, the efficiency for the conventional ladle heater was calculated and is illustrated on the following slide. The average efficiency for the Advanced Technology Heater is 59%, and the average for the Cameron conventional heater is 3%; therefore, the system efficiency is improved by 56%.

The Advanced Technology Heater can cure a "green ladle" in 8.1 hours at terminal temperature of 2000°F. The gas consumption for the complete cycle is 9.72 MCF at a cost of $29.16.

The conventional heater takes the ladle to a maximum of 1200°F in 12 hours. The gas consumption for the complete cycle is 118 MCF at a cost of $354.00.

When using the Advanced Technology Heater, the cost savings per curing cycle is $324.84. In addition, the Advanced Technology Heater cured the ladle to 2000°F in 8.1 hours, where the conventional heater at full firing rate can only heat the ladle to 1200°F in 12 hours.

ECONOMIC BENEFITS OF IMPROVED EFFICIENCIES IN LADLE HEATING

The major benefits of the Advanced Technology Ladle Heater over the conventional heater are:

1. Energy conservation
2. Faster heat-up time and high temperature capability
3. Extended refractory life
4. Possible reduction in electric furnace tapping temperature due to higher ladle temperature

Test data was obtained on both systems for two types of heating cycles, heat-up and maintain, and curing "green ladles". Using Cameron's typical annual operation, the conventional system had an annual fuel consumption of 77,113 MCF for an annual present cost of $231,340.00. The Advanced Technology System with its improved efficiency is projected to use 14,162 MCF for an annual present cost of $42,487.00 or an annual savings of $188,853.00.

The Advanced Technology Heater can heat the surface of the ladle to 2300°F in 1½ hours with a temperature differential of 115°F any place on the refractory surface. The conventional heater can heat the surface of the ladle to 1500°F in 12 hours with a temperature differential of 1000°F. The faster heat-up times can improve production if a waiting period is required to properly heat a ladle. Depending on the operation, a reduced number of ladle heater stations may be possible with resultant savings.

Discussion with other steel makers have suggested it may be possible to reduce the furnace tapping temperature by as much as 50°F when high temperature, uniformly heated ladles are used. This can result in faster melting cycles, improved electrode life, improved refractory life, and overall lower melting costs.

High temperature, uniformly heated ladles could result in ladle refractory life being extended by as much as 100%. The average cost of reworking a 60 ton ladle is $20,000. It is possible to use a ladle 8 times per day with a single electric arc furnace, which would result in a yearly repair bill of $2,800,000. When using the Advanced Technology Ladle Heater, a refractory repair savings of $1,400,000 may be experienced. Testing will continue at Cameron through 1980 to verify the exact savings.

The following slides depict the economic benefit and payout for various size ladles and gas cost. The criteria used in development of this information is presented in the next slide.

The next slide is a theoretical economic eva-

luation using gas at $3.00 per thousand cubic feet. The ladle size in tons is plotted across the bottom. Payback is plotted on the right side and return on investment on the left. As previously mentioned in the criteria slide, a base cost of the heater is assumed and a variable cost is used for each different ladle size. The payout begins at 1.5 years for a 50 ton ladle and improves to 3/4 of a year for a 450 ton ladle. The minimum return on investment is 60% and the maximum is 115%.

The next slide is essentially the same except it is for a 110 ton ladle with gas cost varying between $3.00 and $4.25 per thousand cubic feet. For this size ladle, the payout is between 1 and 1.5 years.

Approximately 20 to 30 new electric furnaces are being built in the U.S.A. each year. Most of which require new ladle heaters which cost $50,000 to $60,000 each and have no energy saving features. A realistic evaluation would require you to subtract the cost of a new conventional ladle heater from the cost of the Advanced Technology Heater. In most cases, this will result in a payout of less than one year with a very high return on investment.

SUMMARY

With the phased deregulation of natural gas, the primary metals industries will be required to implement strict conservation measures in order to remain competitive. Waste heat recovery and utilization in ladle preheating is an excellent place to start.

THE USE OF ALUMINUM PROCESS REJECT HEAT AS THE SOURCE OF ENERGY FOR A DISTRICT HEATING SYSTEM

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ABSTRACT

Rocket Research Company (RRC) is investigating the use of industrial process reject heat as a source of energy for large scale district heating. The District heating System is a network of closed-loop hot water pipes that recover energy from the fume hood ducts at the Intalco aluminum reduction plant and transmits the energy to commercial, residential, and institutional users in Bellingham, Washington for space and hot water heating.

1.0 INTRODUCTION

Under a Department of Energy (DOE) Contract, Rocket Research Company (RRC), a division of ROCKCOR, is investigating the use of industrial process reject heat as a source of energy for large scale district heating. The city of Bellingham, Washington is the site specific user and the reject heat is recovered from the Intalco Aluminum Corporation plant located in Ferndale, Washington. The baseline District Heating System is a network of closed-loop hot water pipes that recover energy at approximately 220°F from the fume hood ducts at the Intalco aluminum reduction plant and transmits the energy to commercial, residential, and institutional users for space and hot water heating. Tradeoff studies show that the District Heating System concept is both technically feasible and economically competitive with existing heating systems using conventional fossil fuels or electrical energy.

Approximately 40 percent of the low quality heat generated at Intalco which is presently unuseable by the industrial plant can be effectively applied to space and hot water heating in the city of Bellingham by means of a hot water district heating system to serve as many as 20,000 residences and commercial buildings. By the year 2000, the cost of this energy is projected to be approximately one quarter that of conventional energy sources. If waste heat recovery was realized from all of the country's aluminum plants, a savings equivalent to six to eleven million barrels of oil could be realized annually. Waste heat recovery from all industrial plants suitable for district heat purposes could provide a net energy savings of 5 - 8 quads annually if applied nationwide.

The viability of the district heating concept is dependent on institutional issues, as well as economic and technical considerations. The current program to implement a system in Bellingham is addressing these areas in detail so that confidence can be established in the overall effectiveness of the planned program prior to a major commitment of funds.

This paper describes the technical concept for recovering waste heat from the Intalco Aluminum plant, and using this waste heat as the energy source for a district heating system. The program objectives, technical approach, and results of the study to date are discussed.

2.0 SYSTEM DESCRIPTION

A typical district heating system includes: a source of thermal energy, a network of underground pipes for transporting and distributing the heat transfer media, a load or user of the thermal energy, and a means of storing thermal energy until it is needed. The Bellingham district heating system includes each of these elements. The source of thermal energy is the process exhaust gases from an aluminum plant. A network of underground pipes transports the heat transfer media, water, to the service area and distributes it to the users - residential, commercial, and institutional buildings, where it is used for space and domestic water heating. Thermal energy in the form of hot water is stored in insulated metallic tanks when the demand is low and withdrawn from the tanks as required.

The district heating system flow schematic for Bellingham is presented in Figure 1. The interface between the aluminum plant and the district heating system is a group of counterflow air to water heat exchangers installed in the plant fume collection ducts. The waste heat source is the hot

gases in the primary air pollution control (fume collection) system ducts. The total mass flow rate of gas in the Intalco fume collection ducts is 7.0×10^6 lbs/hour at 250°F (representing an energy source equivalent to 3.02×10^8 Btu/hour above an ambient temperature of 70°F). A total of twenty heat exchangers will be installed in the fume collection ducts coming from the potline buildings at a location upstream of the baghouse (dry scrubber). Bypasses are installed in the heat exchangers to limit the maximum water temperature leaving the heat exchanger to a predetermined value, nominally 220°F.

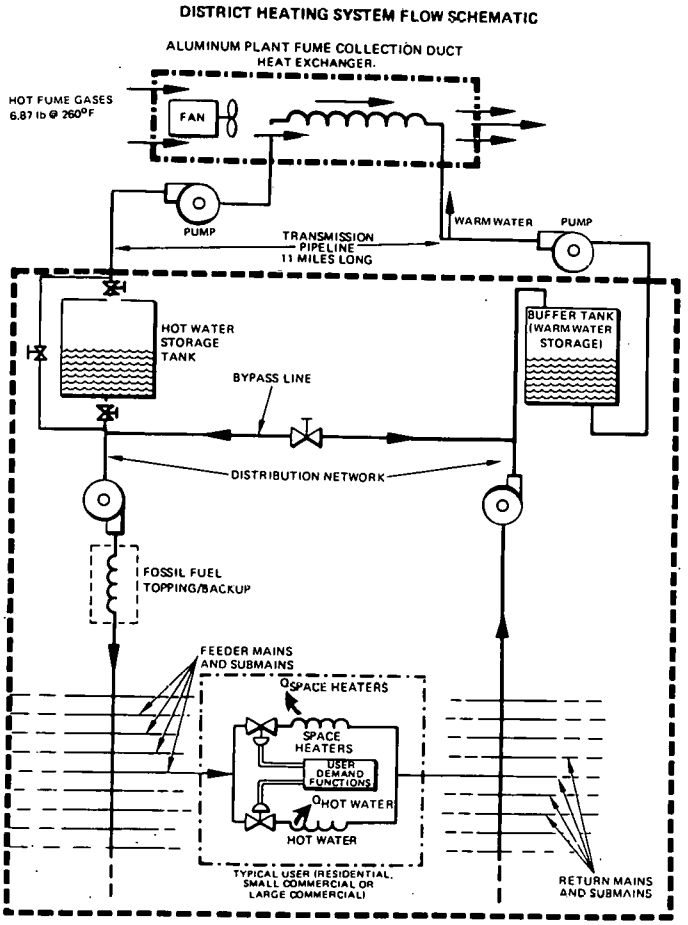


FIGURE 1

The transmission pipeline consists of two underground steel pipes, insulated with glass fiber and mounted in prefabricated concrete culverts. The circulating water flow rate through the transmission pipeline is constant and independent of demand during most of the year. During summer, when the user demand is low and the water in the storage tanks has reached peak storage temperature, the flow rate will be reduced as pumping capacity is reduced to conserve electrical energy. The underground water transmission line is routed eastward from the plant through the town of Ferndale to an interstate highway, a distance from the plant of about 6 miles. The transmission line then follows the interstate highway on a southeasterl direction 4 miles to a point on the highway next to the Bellingham airport and about 2 miles north of the city, where the hot water storage tanks are located. Supply water for the city and return water from the city are routed to separate storage tanks at this point.

Aluminum production is essentially a constant process; thus the available energy recoverable from the fume collection ducts is produced at a constant rate. The energy load requirements of the district heating system will vary by a ratio of up to four to one on both a daily and seasonal basis. The thermal energy storage (hot water) tank in the system acts as a buffer to store energy recovered from the plant during periods of low district heating demand, and to supply energy during periods when the demand on the district heating system is in excess of the amount of energy recovered from the aluminum plant. In the event of an extended period of cold weather, and, hence, high energy demand, the thermal energy storage may be depleted. User energy demands will be satisfied in that case by a fossil fuel boiler alternate heat source. This alternate heat source is sized to deliver the entire system demand, if necessary, and thus will also act as an emergency backup system in the unlikely event that energy from the aluminum plant was unavailable. Tradeoff studies indicate that 100% backup capability has minimal cost impact upon the overall system. This feature has been included to satisfy potential users that an industrial facility can close, and still preserve the district heat system integrity.

In addition to the fossil fuel boiler, there are nine other industrial facilities in the Bellingham area which are being evaluated to determine if their waste energy streams can be used to increase the thermal capability of the district heating system on either a supplemental, a backup, or a peak load basis. These nine facilities include a refuse burning facility, two oil refineries, a sludge burning facility, a pulp and paper mill, cement plant, plywood plant, and two seafood processors.

The energy demand in the distribution system is satisfied by a controlled water flow rate through constant temperature drop user heat exchangers. The distribution system main will run underground from tl thermal energy storage facility into the Bellingham service area along the Interstate highway and street right-of-ways. Underground feeder mains connected to

the distribution main will be buried in the street easement. The various users will be connected off the feeder mains. The return lines will be buried in the same trenches as the feeder and distribution lines. The distribution, feeder, and return lines will be covered with a 2-inch thick urethane foam insulating layer. The user connection lines may be either CPVC (chlorinated polyvinylchloride) pipe or steel pipe insulated with urethane foam insulation.

The specific interface requirements between the district heating system and the user will vary greatly depending upon the type of user served and the type of heating equipment that is currently installed in buildings that will be converted for district heating use. Installation of user heat exchangers (i.e.,duct coils) must meet local building and plumbing codes, as well as operating temperatures. The district heating system is designed for a nominal 75°F temperature drop across each user system except where existing hydronic systems are in place. This relatively high temperature drop will cause an increase in the cost for converting some consumer heating systems, but will lead to a net reduction in overall system construction costs because it will permit the use of smaller, less expensive distribution pipes. The interface between the district heating system and the user will be of the "direct connection" type. With this direct type connection, the hot water from the district heating system circulates through the users' heating system. With only a few exceptions, all areas of the Bellingham district heating system are capable of operating at the maximum pressures and temperatures of the system in their particular area. For those exceptions, where system pressures have to be increased significantly, buildings in the area will be served through a substation which will provide pressure control. A single substation is capable of controlling pressures to a grouping of residential and institutional type buildings.

Approximately 50% of the residential buildings in the city of Bellingham have forced air type heating systems. To convert this type of system, the existing furnace will be removed and a conversion kit installed. The conversion kit will consist of an enclosure which interfaces with the existing ducting and which includes a duct coil and a motor driven fan. The hot water from the district heating system circulates through the duct coil, and the motor-driven fan circulates the warmed air through the system as the furnace heated system had done previously. Conversion of a hydronic system is accomplished by bypassing the hot water boiler with the supply and return lines from the district heating system.

A preliminary selection has been made for the routing of the transmission lines, location of the hot water storage tanks, and the routing of distribution mains into the Bellingham service area. In addition, evaluations have been completed of the cost of installing the system in various service areas which consist of selected sections of the 22 neighborhoods which make up the city of Bellingham. The time phasing of the construction includes use of mobile boilers to provide heat for the initial group of customers connected to the district heating system. This approach will provide revenues to the district heating utility during the period of heavy capital outlay for construction of the main transmission lines and hot water storage tanks.

Current activities are being directed toward selecting the initial service area and defining its growth pattern and growth rate. The initial service area will be supplied with hot water from mobile boilers, and cost optimization studies will define the schedule for constructing the transmission line from Intalco and the installation of equipment at Intalco. Cost optimization studies will also define the size of the hot water storage tanks, and when this size has been determined, alternate sites for locating these tanks will be evaluated. A preliminary site selection for these tanks was at the Bellingham airport, but recent studies have shown the advantage of locating these tanks closer to the service area.

3.0 PROGRAM STATUS/RESULTS TO DATE

The current program effort is directed toward achieving the program objectives identified in Table 1. To achieve these objectives, the program has been organized into the five major tasks listed in Table 2. The specific approach to the program objectives is described below, along with the current status of each of the five program tasks.

Table 1. PROGRAM OBJECTIVES

- Accurately assess economic viability
- Verify institutional compatibility
- Achieve public acceptance
- Evaluate technological risk areas
- Evaluate alternate sources of thermal energy.

Table 2. PROGRAM PLAN

Task 1 - Marketing Analysis

Task 2 - Technology Review

Task 3 - Additional Thermal Source Evaluation

Task 4 - Institutional Considerations

Task 5 - System Cost Analysis

3.1 Marketing Analysis

In the process of determining the potential energy market, RRC conducted a comparative evaluation of each of the 22 neighborhoods which collectively make up the city of Bellingham. The first step in the process was to select those neighborhoods which indicated the most promise of being cost effective to connect to the district heating system. The neighborhoods selected were then subjected to a detailed energy assessment. In selecting the most promising areas of the city, the intent was to identify the areas with the higher thermal demand density, lower conversion costs, and closer proximity to the anticipated routing of main transmission lines. For this preliminary selection of district heating areas, RRC worked very closely with city and county operating and planning departments. From the City Planning Department, population and building density data was obtained for each neighborhood, as well as growth projections for a 20-year period. From the County Assessor's office, information was obtained concerning the types of heating systems installed in specific buildings. The County maintains data on computer tape which contains the results of a survey conducted for the County Assessor entitled, "Land Parcel Information Survey" (LPIS). This tape contains data concerning every taxable parcel of land in the city of Bellingham and provides descriptions of the buildings located on these parcels. Any parcel of land, or building, can be accessed by either a 7-digit code, or by the street address.

During the course of the building energy surveys energy information was input to an edited copy of the LPIS tape. This modified version of the LPIS tape was used as the repository for "Consumer Data List" (CDL) information. The CDL is a listing of energy characteristics for each building in the district heating service area. Included in this listing are items such as: type of building (residential, commercial, etc.), floor area, type of construction, energy consumption (by month and peak demand), type of fuel used, type of heating system, etc. As a result of an energy survey conducted previously by the city of Bellingham, detailed energy characteristics of all schools, hospitals, public housing and city, state and federal buildings are available. This information was transferred to the LPIS tape. The 70 largest buildings were selected as the subject of a mail survey to obtain detailed energy information. A building owners workshop was also conducted which provided additional information.

The basic market potential for thermal energy in the city of Bellingham has been determined and characterized. Twelve neighborhoods have been selected as the district heating service area within which the system will initiate service from mobile boilers. Within this service area, the system will grow to maturity as, first, the Intalco facility and then the alternate energy suppliers are integrated into the system. Within each neighborhood the buildings have been categorized as: small residential, large residential, commercial, industrial, or institutional. For each category of building in each neighborhood, information is now available on the number of buildings, a general description and location of each building, average and peak energy demands, type of heating systems, fuel used, and year of construction. Descriptions of the smaller buildings and their types of heating systems have been used to estimate conversion costs. The year of construction of the building and the type of furnace or boiler has been used to estimate the year when the building owner will have to replace the furnace or boiler at a considerable expense, or, alternately join the district heating utility. The conversion cost information is used to determine the cost effectiveness to the utility and its subscribers of having a specific building connected to the system. This information is presently being used in the estimates of the cost of energy that are being made for various distribution networks and service areas.

In addition to knowing the energy potential of the market, it is also necessary to know how much of this market potential will be realized and when it will be realized. For RRC to be in a position to determine the rate of subscription, the rate at which consumers will join the new district heating utility, it is necessary that the potential subscribers understand what a district heating system is and how both their community, and they as individuals will be affected by the system. The first activity in the market analysis task was the

preparation of a market analysis plan. One of the objectives of this plan was to "determine the rate of subscription," and another objective was to "achieve public support of the program from an informed community". To assist in the effort to realize these objectives, RRC issued a subcontract to Martin-Simonds Assocaites (MSA), a consulting firm with expertise in community involvement programs. As part of the Public Information program, a community advisory group (CAG) was formed. Included in this group of 24 members is a retired construction company executive who had accepted the request by RRC and members of the community to serve as chairman of the CAG. The CAG includes a cross-section of the community - local citizens' groups (League of Women Voters, Environmentalists, etc.) representatives from the local gas utility and from the local electrical utility, city and county planning department members, the press, and others.The community advisory group meets each month to review and discuss issues concerning the planned district heating program. This group participation provides a medium for the various groups to let their feelings and desires be known concerning some controversial issues such as public versus private ownership of the utility, routing of the water transmission lines, and others.

As a means of demonstrating the support of the city administration of Bellingham for the Phase III demonstration program, and to express the intent of the city to establish a district heating utility, a resolution to this effect was presented to the Bellingham City Council for consideration. This resolution was passed unanimously by all members of the City Council and by the Mayor.

A market analysis report, presently being prepared, will provide a detailed description of the market analysis effort. With the issuance of this report, the market analysis task will be more than 90% complete, and the "to-go" tasks will consist of the following:

1. Support of the community advisory group meetings held each month.
2. Preparation and conduct of a presentation to the administrators at Western Washington University in Bellingham to solicit their commitment to join the district heating utility.
3. An update of the information used to establish the basis for subscription rates used in the cost analysis. This effort may include the design and conduct of an information survey.
4. The market analysis report will be revised to incorporate new information, if necessary.

3.2 Technology Review

In the process of integrating the Intalco facility with the district heating system, the primary constraint is that the construction and operation of the district heating system not interfere with the normal operation of the Intalco facility and shall not introduce a safety hazard to Intalco personnel or equipment. For example, the air ducting fans in the bag houses are running at capacity, and the additional impedence that will result from installing heat exchangers in the fume collection ducts will require replacement of the existing fans with those of higher capacity. In addition, installation of the heat exchangers in the ducts and the planned insulation of sections of ducting could shift equilibrium of the pollution control process to the point that maximum emission levels were exceeded. A shift in operating conditions may also cause scaling to occur in the ducts. A significant operating cost of the Intalco facility is associated with the replacement of the filter elements in the bag houses on a maintenance type basis. A shift in operating temperature in the baghouse could increase the frequency with which filters have to be replaced. To evaluate the impact that the district heating system construction and operation will have on the Intalco facility, RRC has defined the following areas:

a. The design, construction, and operating characteristics of the heat exchangers, the maintenance method and frequency to be used for cleaning fouling-material buildup from the heat exchanger elements.
b. The method to be used to install heat exchangers with a temporary interruption of the pollution control system.
c. Excavating and tunneling methods to be used for installing and routing water distribution lines to prevent impact to required road traffic of trucks hauling molten metal and other cargo.
d. The methods and construction schedule for replacing the fans in each of the baghouses.

e. Modifications required to structures at Intalco to support the additional load of the heat exchangers.

f. Statistical characterization of the gas temperatures at a number of locations in each of the 20 fume collection ducts.

g. The influence that a shift in process temperature will have on the ability of the Intalco pollution control system to limit emission levels of fluorides and other products in the fume stream.

To assist in the effort to determine the impact to Intalco when the facility is integrated with the district heating system, RRC issued a subcontract to the Bechtel Corporation, the firm that designed and constructed the Intalco facility. When Bechtel's study effort was completed, and when RRC had finished the last of nine separate studies in support of the same effort, the results were documented in a preliminary report and provided to Intalco for their review and comment.

To facilitate this review, RRC made a presentation to Intalco's management and technical personnel to describe the procedure followed in conducting the study and to present the results obtained and the conclusions drawn. In response to the information presented, Intalco has identified areas of RRC's proposed plan which require change or further evaluation. These changes are presently being made, and the evaluations are being conducted. When completed, RRC will hold another coordination meeting with Intalco to present the results of the changes made and the additional evaluations conducted.

The second activity of the technology review task is concerned with the technological status of the equipment and materials that will be used in the construction and operation of the district heating system. The purpose of this effort is to identify areas of technological risk that constitute a potential impact to the cost and schedule of the planned program. When such a risk is identified, a plan is established to assess the magnitude of the problem and to recommend approaches for eliminating the problem or reducing it to an acceptable level. Items that fall in this category are the transmission and distribution piping and insulation, the user heat exchanger, and the energy meters and flow meters to be used in the system. Also included in this category is the heat exchanger that will be installed in the fume collection ducts at Intalco. During an earlier phase of this program, a probe had been installed in one of the fume collection ducts at Intalco for test purposes. The buildup of fouling material on the probe element caused enough concern on the part of RRC and Intalco that a heat exchanger evaluation was conducted, and this in turn led to a plan for conduct of additional probe tests under more controlled conditions. These tests are now in process, and the objective is to assess the magnitude of the fouling potential. In addition to the probe testing, studies were conducted to evaluate methods of locating the heat exchanger downstream of the baghouse, where the heat exchanger elements are not exposed to the fouling environment. These studies have included the evaluation of modifications required to the baghouse structure to install heat exchangers and an analysis of the impact on heat exchanger sizing and operating characteristics as a result of operating at lower temperature. These studies have shown that location of the heat exchangers downstream of the baghouse is not feasible because of heat losses in the baghouses that reduce gas temperatures below a practical level. In addition, the structural problems associated with modifying the baghouses to accommodate the heat exchanger load is significant.

Another activity included in the technology review task is to define the technological status of the equipment used to build and operate district heating systems in Europe and in the Scandinavian countries and to identify equivalent equipment on the American market. The objective is to provide the means for evaluating the risks and benefits of the more recent equipment developments against the benefits of mature equipment. Equipment specifications will be developed in the coming months.

The third activity of the technology review task concerns thermal energy storage methods. The baseline approach for this program is the use of above-ground, insulated tanks; however, previous studies have indicated the cost effectiveness of aquifer storage for increasing the capability of the district heating system and enlarging the service area. For this reason, aquifer storage has been included as an alternate method to be evaluated. A comparative evaluation of the technical and economic characteristics of the above-ground, insulated tank versus aquifer-type storage is being conducted. Exploration wells were recently drilled to locate a confined aquifer in the Bellingham

area by Fugro Northwest, under a separate contract from Battelle Pacific Northwest Labs. Rocket Research ›mpany plans to use aquifer data generated by this effort as an input to characterize the cost savings when aquifers are utilized.

A third method for thermal energy storage to be included in the comparative evaluation of storage methods, involves the use of abandoned coal mines under the city of Bellingham for storage of hot water. The local gas utility had at one time considered storage of natural gas in these mines. Activities to date in the evaluation of the three thermal storage methods has been limited to the collection of information.

3.3 Additional Thermal Source Evaluation

The feasibility of integrating additional industrial waste heat thermal energy sources into the district heating system on a direct, backup or supplemental use basis appears very attractive. As a result of energy audits of 150 northwest industries conducted by RRC under contract to the Pacific Northwest Regional Commission and the Bonneville Power Administration, information is available documenting an appreciable amount of energy available in the waste streams of facilities in the proximity of the planned district heating system. Those facilities which were considered to be potential sources are identified in Table 3. Additional surveys were conducted to determine the willingness of the plant owners to join the district heating system, to obtain data to determine the thermal energy supply capability, and to identify impediments to integration and operation of the additional facilities with the district heating system. This survey has been completed, and each facility has been evaluated to determine the merits of supplying the district heat system with thermal energy. A selection has been made of those facilities which showed the most promise, and the selected facilities will now be subjected to a detailed evaluation.

Table 3. ADDITIONAL THERMAL ENERGY SOURCES TO BE EVALUATED

- Solid waste burning facility, between Ferndale and airport
- Sludge burning operation of Bellingham in southern sector of city
- Mobil refinery at Ferndale
- Georgia Pacific Pulp and Paper Mill on the water in downtown Bellingham
- Columbia Cement Plant located in the industrial area within the Bellingham city limits
- Mt. Baker Plywood Plant in the Bellingham industrial area
- Seafood Processors: Bumble Bee Seafoods, Bellingham Foods, and San Juan Seafoods
- Arco Refinery at Cherry Point, approximately 3 miles northwest of Intalco

This detailed evaluation will include a description and cost estimate of the required facility changes, definition of the contracts/agreements required between the facility and the DHS utility, institutional considerations, and identification of potential risks. The results of this assessment will include recommendations for 1) integrating the selected facilities with the DHS, 2) modifying the facility to increase its capacity, and 3) maximizing long-term reliability.

The technical and economic characteristics of the recommended alternate energy sources will be individually integrated with the district heating system, and then in selected combinations to determine the impact that these additional sources will have on the district heating system. The impact on institutional considerations for the integrated system will also be considered.

3.4 Institutional Considerations

The identification and solution of the legal, political, and institutional constraints is a major requirement for implementation of the planned district heating system.

The following activities have been conducted as part of this effort.

- A community advisory group has been formed in Bellingham. One of the functions of this group is to review and discuss some of the more significant institutional issues such as public versus private ownership of the district heating system, financing, service area selection, hookup policy, and environmental impact.
- Meetings have been held to discuss financing options with underwriters, management consultants, and bond counsel.
- Meetings have been held with members of the Washington State Utilities and Transportation Commission concerning

regulations applicable to the district heating system.

- Implementation of the DHS has been discussed in detail with the local natural gas and electrical utilities (Cascade Natural Gas and Puget Power and Light Company). Representatives of these companies are also members of the community advisory group.
- DHS right-of-way acquisition has been discussed with planners and State Department of Transportation personnel. The City Public Works Department in Bellingham is involved in evaluating the impact of the DHS.
- The above activities are discussed in some detail in an Interim Institutional Considerations Report recently issued.

Identification of the general legal, political, and institutional constraints and benefits related to the process of developing the planned district heating system is also being pursued. This analysis will consider impact on the environment, impact on existing utilities, contracts between the district heating system (DHS) and the energy supplier, and between the DHS and energy consumers, DHS liability, permits and rights-of-way required. All public and private ownership/management entities that can own and manage the system to obtain/purchase, distribute and sell thermal energy in the form of hot water are being analyzed. The various structures will be examined with respect to enabling authority, financing, regulation, taxation, experience with energy management and distribution, general powers, and acceptance by the public. Actions, such as new legislation, which are required to enhance the relative position of each entity are being identified. The ownership/management entities will then be evaluated on a comparative basis to determine minimum cost to the potential users.

3.5 System Cost Analysis

To determine the economic viability of a district heating system under the various approaches available for financing the system, when owned and operated by the public and private entities, is a difficult task. Establishing an accurate cost estimate for installing and operating a district heating system and identifying the factors that influence cost is crucial to the decision for system implementation. To provide a point of reference for the cost analysis, a system planning effort has been conducted to refine preliminary estimates of the cost of heat at the consumer interface. Prior to conducting the final economic computations, the following design and performance requirements for the district heating system will be finalized:

a. The district heating scheme and operational description.
b. The information contained in the consumer data list.
c. Routing of the piping system by a team which includes representatives from Bellingham, Whatcom County, the Bellingham Port Authority, and the Bellingham Building Commission.
d. Fixing probable rates of hookups.
e. The type and size of the hot water storage subsystem and its planned location.
f. Heating loads and load variations including growth rate of heating loads for the time period under consideration.
g. The location and sizing of supplemental or backup type thermal energy sources.

The capital costs of the district heating network is a function of the major subsystems. Each major subsystem is being analyzed parametrically to determine cost influence factors, and these data will be used to optimize the total system cost rather than the costs of the individual subsystems. The following information is being generated for the transmission/distribution subsystem, the storage subsystem, the control and instrumentation subsystem, and the heat exchanger subsystem.

Transmission/Distribution Subsystem

The layout for the district heating network will be drawn based on geological data, meteorological data, town plans, consumer and heat source locations. This layout will include peaking and backup plant sites and the hot water storage subsystem, and will consider future expansion possibilities.

Peaking and backup plant types will be selected.

Suitable alternatives for network materials and structures will be selected. This will include above-ground, under-ground, and tunnel alternatives. All applicable transmission pipe materials and construction concepts will be evaluated.

Performance analysis will be updated to optimi pipeline diameter versus parasitic pump losses and to identify optimal flow velocities when comparing

the cost of piping versus the cost of pumping. Thermal performance analysis has been conducted to determine heat loss versus insulation thickness of the network. Optimal insulation materials and thicknesses will be selected.

- The sizing for the district heating network will be calculated for appropriate cases representing different numbers of consumers joining the system.
- Conditions which result in the minimum transmission costs for the district heating system, at a given heat load, will be established.
- The characterization of system effluents (if any) will be evaluated for institutional considerations.

Heat Exchanger (Installed in Fume Collection Duct) Subsystem

The sizing of the heat exchanger will be evaluated to provide the optimum economic balance of low pressure drop, high heat transfer surface capability, low fan power (within conservation target), and low operation and maintenance cost for heat exchangers and fans.

Storage Subsystem

Detailed performance requirements of the hot water storage subsystem have been defined from the network operation aspect. The capacity of the storage subsystem and its location will be optimized to achieve the most efficient economic operation.

Control and Instrumentation Subsystem

A preliminary scheme for the control and instrumentation subsystem has been prepared, and capital costs will be determined. Several sets of controls are required in the district heating system to maintain system reliability, and to prevent operational problems to the utility. Instrumentation is required for both status and diagnostic purposes.

The cost analysis will be based on the system design and performance requirements previously established. Specifications will be prepared for the selected system alternatives and cost proposals solicited from suitable suppliers and contractors. After evaluating these cost proposals, a final selection will be made of the type of equipment to be used. Based on the results of this optimization, the network capital costs will be established. The investment cost data for the equipment and for network construction costs and annual operating costs will be calculated at selected interest rates and escalation factors, based on European experience and U.S. cost and wage levels. Operating and maintenance costs for the district heating system will be determined by means of computer programs based on experience gained with similar district heating systems. The profitability of district heating from the suppliers' viewpoint will be studied. Various profitability criteria, such as return on investment will be obtained from computer results. The computer program used will also provide projections of annual cash flow and payback period. By means of the profitability sensitivity to different parameters, such as number of consumers joining the system, the rate structure and the cost of heat will be analyzed. The accuracy and reliability of the cost analysis will be defined in terms of error bands with corresponding probability factors for the more significant cost parameters so that the cost information can be presented in terms of confidence levels.

AN ANALYSIS OF THE USE OF FLUIDIZED-BED HEAT EXCHANGERS FOR HEAT RECOVERY

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ABSTRACT

The principles of fluidized-bed operation and the factors affecting the performance of a fluidized-bed waste heat boiler (FBWHB) are discussed in detail. Factors included in the discussion are bed temperature and pressure, heat transfer coefficient, gas properties, solids properties, and tube geometry. Qualitatively, no operating or technical difficulties are envisioned for employing fluidized-bed units in waste-heat boiler applications. Fluidized-bed units generally require a minimum of operating attention and maintenance and the installation of an adequate control system. A general FBWHB design methodology is presented along with a preliminary engineering design for a space heating application. A flowsheet, mass balance, and equipment sizes are presented for a FBWHB system that would produce hot water by recovering part of the heat energy contained in a hot gas.

INTRODUCTION

Higher fuel prices and scarcities of fuels have resulted in increased industrial emphasis on energy conservation. Methods for recovery of waste heat, which have been used since the industrial revolution, are now being reevaluated, and advanced concepts are being tested. Waste-heat recovery devices, as typically used in industry, preheat combustion air, fuel, or process material or produce hot water or steam for process use. Typical heat-exchange devices used for heat recovery are recuperators, regenerators, waste-heat boilers, heat pipes, heat wheels, and fluidized-bed heat exchangers.[1] Each of these heat recovery devices has applications for which its particular technical characteristics make it best suited. One of the lesser known of these devices, the fluidized-bed heat exchanger, may represent a significant opportunity for industrial energy conservation. However, questions concerning the advantages of incorporating this technology into industry, the role of government in promoting this technology, and the current market status of the technology need to be explored.

The objective of this paper is to characterize the current state of fluidized-bed, waste-heat recovery technology. Included are a discussion of the major technical concepts and their development or commercial status, a detailed analysis of the effects of the important design parameters on the performance of a fluidized-bed, waste-heat boiler (FBWHB), a general FBWHB design methodology, and a preliminary engineering design of a FBWHB system.

This paper deals with part of a larger study on FBWHB technology conducted by Argonne National Laboratory (ANL) for the Office of Industrial Programs of the Department of Energy (DOE). The objectives of the larger study are to determine critical factors affecting FBWHB performance, promising industrial applications, and areas of technical uncertainty in order to provide DOE with information useful in planning and policy formation for its research, development, and demonstration efforts. The other four parts of the ANL study of FBWHB technology are as follows:

- A market-oriented evaluation of the acceptability of FBWHB technology to industry;
- An environmental assessment of FBWHB technology;
- A comparison of FBWHBs and competing technologies for recovery of waste heat;
- An analysis of the investment decision process and economics associated with FBWHB technology.

FLUIDIZED-BED, WASTE-HEAT RECOVERY TECHNOLOGY

Fluidized-bed units have been used extensively in the petroleum, chemical process, metal extraction, and other industries. A schematic of a fluidized-bed unit is shown in Fig. 1. At the underside are an inlet line and a plenum chamber, from which the gas passes through a distributor plate into the fluidized-bed zone. The fluidized bed consists of small

particles (with diameters generally less than 2000 μm) that are suspended in the gas stream. A minimum gas velocity is required to suspend the particles; the maximum gas velocity that can be tolerated is that which would entrain the particulate solids and carry them out of the unit. Those particles with free-fall velocity greater than the gas velocity disengage in a region above the bed.

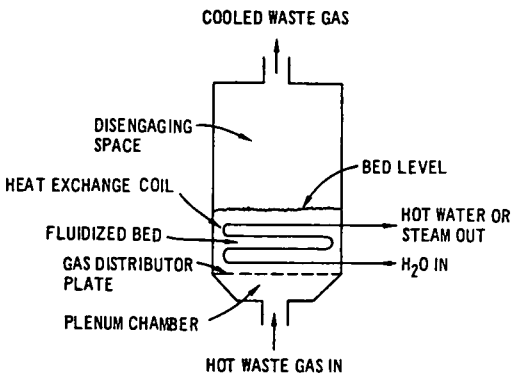


Fig. 1. Typical Fluidized-Bed Unit

The bed can be heated or cooled by circulating a heat-transfer medium through coils immersed in the fluidized particles. The rate of heat transfer can be many times higher than that of conventional shell-and-tube heat exchangers, allowing the size of a fluidized-bed reactor to be reduced proportionately. Because of the rapid movement of particles in the bed and the exchange of heat between particles and gas, the temperature of the bed remains fairly constant. Also, because of this rapid heat transfer by gas and particles, any differences in the temperature of the incoming gas and the bed temperature is lost at a small distance (within an inch or so) above the distributor plate.

Because the bed material has the characteristics of a liquid, solid particles can be readily added or withdrawn from the bed. This may be important for pollution control applications in which solid particles are added to react with noxious components in the waste-gas stream and then are removed to be discarded or regenerated for reuse.

Disadvantages must also be considered. If the material is a friable particulate, broken pieces can be elutriated from the bed. Also, in high-velocity gas streams (at velocities higher than are used in the fluid bed itself but which may exist in the exit gas piping and equipment) such as those used in transporting particles, any hard solid particles transported may cause erosion of metal components. In addition, the pressure drop required to force the gas through a bed of solid particles can be higher than that for other types of heat-transfer equipment used in similar applications. If particles are removed continuously, the residence times of the particles in the bed will be nonuniform because of the rapid mixing that occurs. This becomes important only when FBWHBs are used for pollution control.

In comparison with other types of waste heat recovery units (conventional waste-heat boilers, recuperators, and stock preheaters), FBWHBs can transfer more heat per unit volume. FBWHBs will be physically smaller than other heat-recovery units, which is important for retrofit operatings and also from the standpoint of construction costs. Also, the bed temperature is uniform, which is important if one wants to operate at a bed temperature near the acid dewpoint, and the bed contains compounds (SO_2, SO_3, H_2O) that could condense and corrode metal surfaces.

FBWHB Concepts

In current usage, the term "waste-heat boiler" suggests a unit in which part of the heat energy contained in a waste gas stream is transferred by a heat exchanger to a liquid, usually water, to produce hot water or steam. Conceptually, however, besides recovery from a gas, waste heat could also be recovered from either a liquid or a solid. Altogether, nine configurations are possible. The use of a FBWHB for accomplishing these nine configurations is diagrammed in Fig. 2 without further description. Information on four couplings in which fluidized beds were used was obtained from the literature, as follows:

- Commercial-size FBWHBs have been designed, constructed, and operated in the gas-to-vapor and gas-to-liquid configurations;[2-5]
- Parametric data have been obtained using laboratory scale equipment for the liquid-liquid configuration;[6-9]
- A conceptual design has been presented for the solid-to-vapor configuration;[10] and
- Some data have been obtained in laboratory-scale experiments for the solid-to-gas configuration.[11]

Commercial or Development Status of FBWHB Concepts

Of the nine possible configurations, probably the most important for FBWHB application will be the transfer of heat from a hot waste-gas stream to water to produce hot water, saturated steam, or superheated steam. Fluidized-bed units have already been constructed for this application; the largest unit currently in operation can produce 8000 lb/hr of 200-psig steam by extracting heat energy from the exhaust gas of a 12,000-hp diesel engine.[2] This unit was

developed by a British company, and similar units are available in the United States.

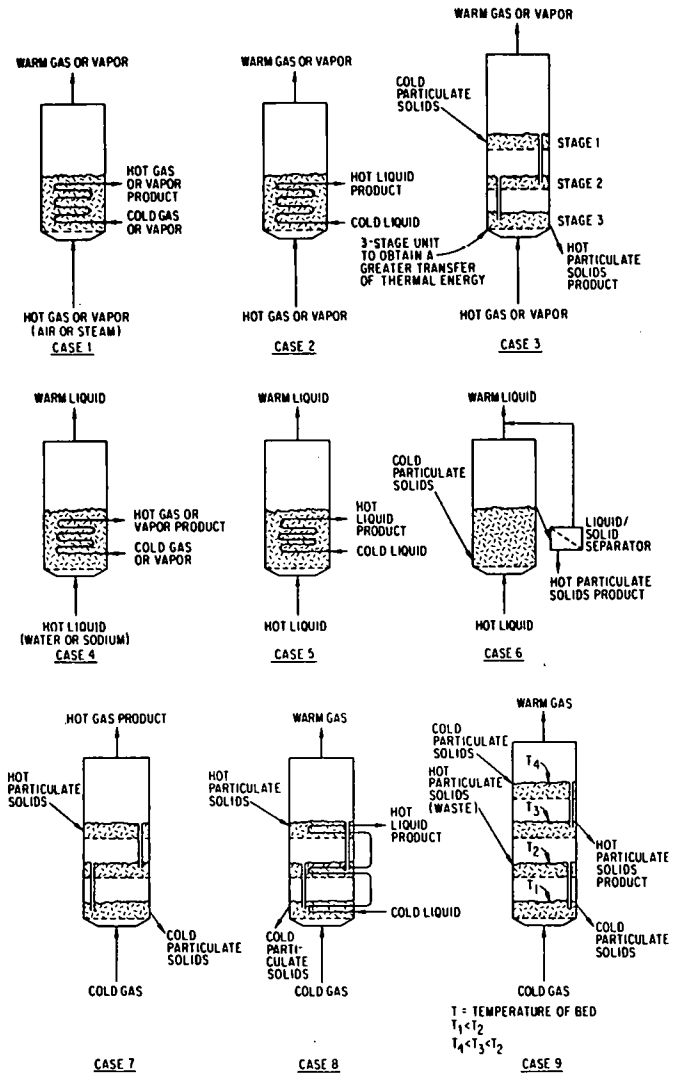


Fig. 2. Possible FBWHB Configurations

A schematic drawing of a smaller version of this unit, which is designed to heat water for space heating, is shown in Fig. 3.[3] The main features are the fluidized bed, one row of finned tubes immersed in the bed (through which flows the water to be heated), an expansion chamber above the bed, and an induced-draft fan that exhausts the gas from the expansion chamber to the stack. A damper controls the flow rate of hot gas into the fluidized bed. When it is expanded, the fluidized bed is approximately seven inches high, in contrast to bed heights of two feet or more used in this country. This feature, which the manufacturer calls the "shallow bed" concept, is an outgrowth of studies related to gas combustion in shallow beds for home space-heating applications.[4] The principle has been extended to burning coal for producing hot water, raising steam, and heating air.[2,5] An advantage claimed for this principle is that the heat transferred per unit surface area of immersed tubes is higher than in deeper beds.

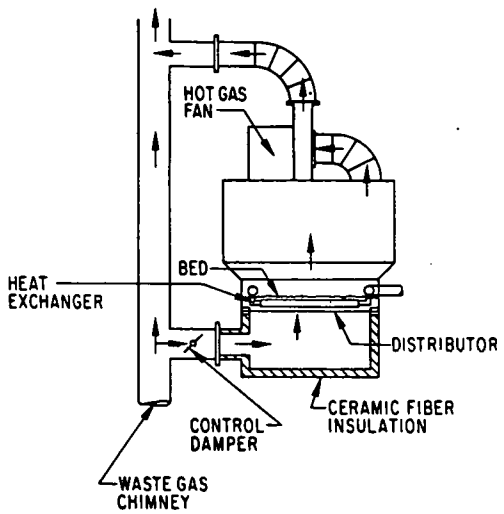


Fig. 3. Packaged Waste-Heat Recovery Unit (from Virr)[3]

In another FBWHB application, the transfer of heat energy from a chemically contaminated, hot geothermal liquid to clean water in a fluidized-bed unit has been studied on a pilot-plant scale.[6-9] The geothermal liquid is not a waste stream in this application; however, the process typifies a liquid-liquid recovery system and is discussed here as if the geothermal liquid were a waste stream (which it could be in another application).

Equipment for a liquid-fluidized unit is similar to that in a gas-fluidized unit: a distributor plate particulate solids that are fluidized, a disengaging zone, and a tube bundle (immersed in the bed) through which the heat energy is transferred (see Fig. 4).[6] The geothermal liquid flows on the outside of the tube bundle, and the moving particulate solids here prevent fouling of the tube surfaces by their gentle scrubbing action.

In still another application, preliminary studies have been made of the transfer of heat energy from hot solids to cooler air passing through tubing immersed in a fluidized bed.[10] The intended application was to recover the heat energy from a very hot, dust-laden, chemically contaminated gas stream exiting from a magnetohydrodynamic (MHD) generator.

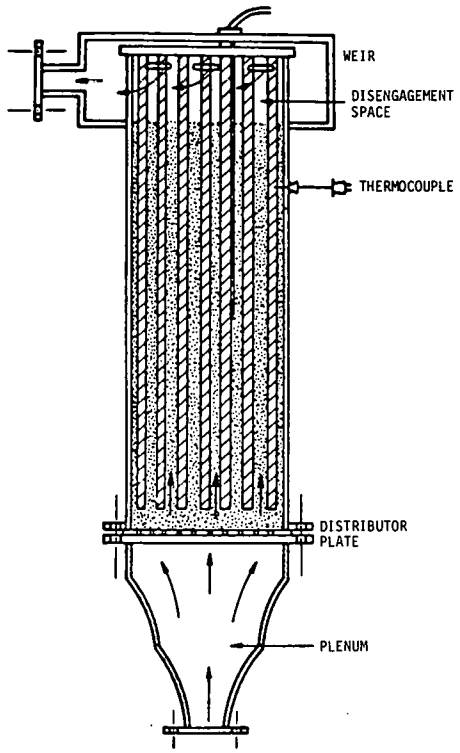


Fig. 4. Liquid-Liquid Fluidized-Bed Waste-Heat Boiler

The plan was to drop finely divided solid particulates (here, metal shot) into the ascending MHD gas stream, allowing the particles to absorb heat before falling into a fluidized bed, where the heat energy in the solid particulates would be transferred to air passing through the immersed heat-exchange tubes. The temperature of this heated air would be increased before it entered the MHD generator by combusting fuel in it. A schematic drawing illustrating the process is shown in Fig. 5.

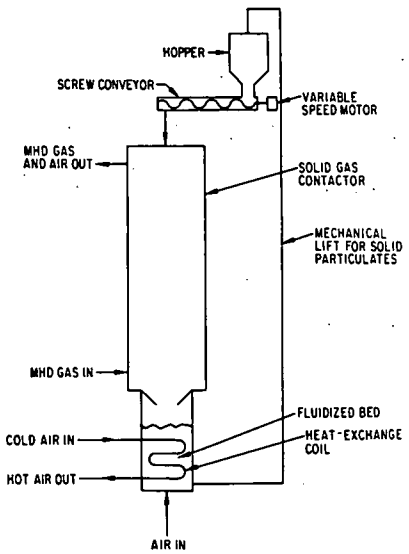


Fig. 5. Schematic for Removal of Heat from a Hot Gas Utilizing Finely Divided Solid Particulates

To demonstrate the process, studies were carried out in a unit about 1.5 m high and 0.15 m in diameter. The gas temperatures were low (100-150°C), and the particles of steel or copper shot that were dropped through the heated gas were about 350 μm in diameter. Tubes in the bed contained either water or air. From the results of these studies, the experimenters concluded that although heat transfer to particles falling through a hot gas could be predicted from theoretical considerations, applications such as MHD heat-recovery units would have to be studied individually to determine economic feasibility.

Heat exchange from a hot solid to a liquid can be accomplished using a fluidized-bed cooler such as that shown in Fig. 6, which is for cooling hot alumina particles. This design, which Kunii and Levenspiel presented [11], may be only conceptual, because no further information about it could be found in the literature. The hot alumina particles enter the fluidized bed at the left under a weir, move laterally, and exit at the right side of the unit. The bed is fluidized by air, which also leaves on the right side. The heat originally contained in the particulate is removed by circulating cooling water through the coils immersed in the bed. The heated air exiting from the bed could be used as combustion air or for some other purpose.

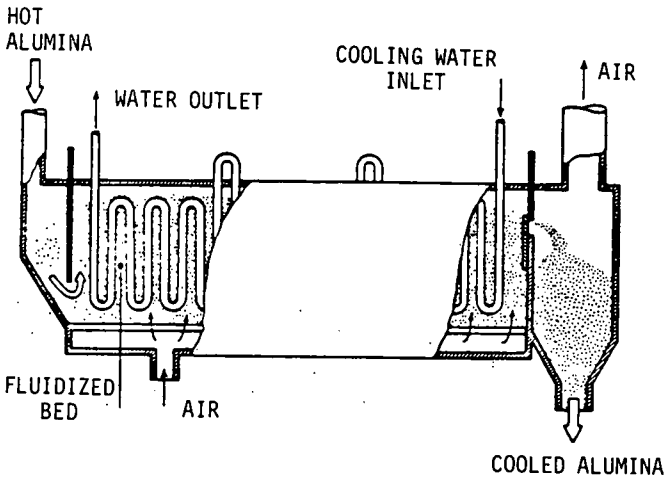


Fig. 6. Fluidized Cooler for Hot Alumina (from Kunii and Levenspiel)[11]

TECHNICAL CONSIDERATION IN THE DESIGN OF FBWHB SYSTEMS

The main components of a fluidized-bed, waste-heat boiler are (1) a gas distributor plate through which the gas is distributed over the cross-sectional area of the bed, (2) a bed of particulate solids, (3) a bundle of tubes that carry the heat-transfer fluid,

and (4) a disengaging space that allows particles carried out of the bed to disengage from the fluidizing gas and fall back into the bed. Also, a system for removing particulate solids from the gas leaving the FBWHB is necessary when the gas has to be cleaned to meet state or federal regulations.

The sizes and designs of the FBWHB components depend on the particular application, but the following general comments can be made:

- Although many gas distributor plate designs are available, "mushroom cap" diffusers evenly spaced on the plate are preferable because this arrangement prevents the bed particles from dropping through the holes when the bed is not fluidized. However, this design is costly and more typically a punched or drilled plate is used for the distributor. The open area of the holes in the plate would be about 2% of the plate area, and the pressure drop across the plate would be about one-third of the drop through the bed.
- Generally, the temperature of the bed will be the temperature of the product (e.g., hot water, saturated steam, or superheated steam) plus the differential temperature required for moving the heat energy to the product (i.e., the difference between bed and product temperatures). To limit corrosion of the metal in the immersed tubes, the bed temperature should be maintained above the dewpoint of any acidic gases present. Because of the desire to operate at a low bed temperature so that a greater portion of the available heat can be removed from a waste gas, the bed temperature in most applications will be in the 300-700°F range.
- System pressure is limited only by strength of construction materials.
- The height to which the solids are fluidized can vary from a minimum of about 7 inches (which is the height of the expanded bed in an available industrial unit having one row of cooling tubes) to any reasonable height. The taller the bed, the larger the fan capacity needed to overcome the additional pressure drop through the bed. This additional cost would be balanced by a saving resulting from the smaller cross-sectional area of the bed.
- The design of the cooling tube bundle is complicated by the many factors affecting heat transfer, such as the operating conditions (temperature, pressure, gas velocity), the properties of the particulate solids and the gas, and the number and positioning of the tubes. In the transfer of heat from the bed to the heat-transfer fluid inside the tubes, the heat energy must flow successively through a gas film outside the tube, a corrosion layer, the metallic tube wall, another corrosion layer, and finally through a gas film inside the tube. The heat-transfer rate is limited mainly by the resistance of the gas film on the outside of the tube. The effect on the heat transfer rate of increasing the value of a design or operating parameter is shown in Table 1.

Table 1. Response of the Heat Transfer Rate to an Increase in the Value of a Design or Operating Parameter

Parameter	Effect on Heat Transfer Rate
Gas velocity through bed	The rate increases, reaches a maximum, and then decreases
Temperature of bed	Increases
System pressure	Increases
Conductivity of gas	Increases
Specific heat of bed particles	Increases
Density of bed particle	Increases
Size of bed particles	Decreases
Heat exchanger variables	
Temperature of metal tube	Increases
Diameter of tube	Increases
Adding fins to tube	Increases rate unless the fluidization pattern is disturbed
Horizontal and vertical spacing of tubes in the heat-exchange bundle	Improves rate if the fluidization quality was originally poor because spacing of the tubes was too close

- No system would be required for removing particulate solids from the waste-gas stream before it is exhausted from the FBWHB to the stack unless the hot gas originally entering the bed required cleaning to conform to state or federal pollution standards. A disengaging space is provided above the bed to allow particles that are elutriated from the bed to drop back into the bed, although some may still be elutriated.

Materials of construction will be selected on the basis of the temperature and pressure of the system each application, as well as the corrosive contaminants in the waste gas. Corrosion data indicate that austenitic alloys are suitable for construction of the

heat-transfer tubes at metal temperatures of 700°C or less and that low-chromium steels can be used in tubes where the metal temperature is less than 400°C.

lative costs of transferring a unit of heat (using 51-mm tubing carrying fluid at 180 atm) indicate that mild steel is favored at fluid temperatures to 240°C, 2.25% chrome steel to 430°C, and Niomic PE16 to 550°C.

Qualitatively, no operating or technical difficulties are envisioned for employing fluidized-bed units in waste-heat boiler applications. Fluidized-bed units generally require a minimum of operating attention and maintenance.

Design Methodology

As indicated earlier, although empirical and semiempirical correlations have been developed for calculating heat-transfer rates in a fluidized bed, these are generally unsatisfactory for systems that are dissimilar in size and bundle configuration to those from which the data for the correlations were obtained. To design a FBWHB system, information obtained by Howe and Aulisio [12] while testing the heat-transfer capabilities of a tube bundle for the Rivesville fluidized-bed coal-combustion plant was used. Mass and energy balances for a typical FBWHB application were calculated and are presented in the following section. A detailed description of the calculation procedure is contained in Reference 13. Figure 7 shows the general approach used in the FBWHB design.

The design starts with a characterization of the application which consists of determining mass and energy flows. If it appears that an adequate match between waste heat availability and the need for recovered heat exists, the design continues. Initial specifications are selected for the bed material, exhaust gas velocity, and bed temperature. Based on these specifications, the value of the heat transfer coefficient can be determined experimentally or from published information. The heat transfer coefficient is used to calculate an overall heat transfer coefficient and heat balance. The heat balance implies a bed temperature which can be checked with the value previously selected. If the two values do not match, a new bed temperature is selected and a new heat balance is calculated. When the calculated bed temperature matches the selected bed temperature, the design can continue. The area of the bed is then calculated based on the total amount of heat transferred. The bed area determined must coincide with the value selected for gas velocity. The final step is the specification of the tube spacing and bed height.

Other appoaches to the specification of a FBWHB exist which may be more appropriate for specific application. The methodology presented here was selected primarily because of its general applicability and simplicity.

Mass Balance and Equipment Studies

The flowsheet and information on the mass balance, equipment sizes, and materials of construction for the entire FBWHB system are presented in Fig. 8 and Tables 2 and 3. The FBWHB, rated at 1,000,000 Btu/hr, has a cross-sectional area of 7.6 sq ft and is 8 ft tall. The fluid bed, which has an expanded height of 27 inches, consists of alumina particles having an average diameter of 800 μm. Immersed in

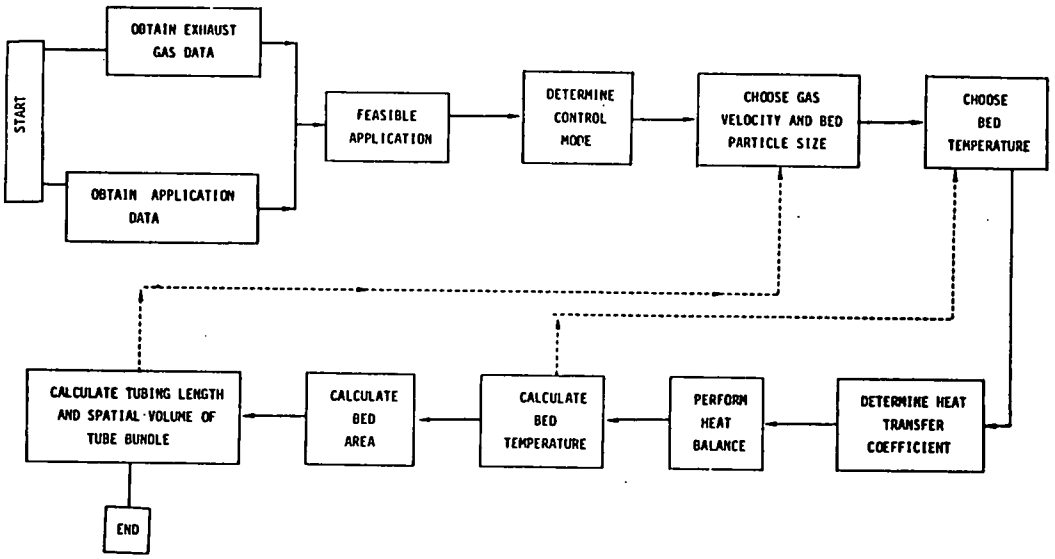


Fig. 7. FBWHB General Design Methodology

the bed are 18 horizontal, 2-in-dia tubes inside which water, at a rate of 40 gpm, is being heated to 195°F. Approximately 4500 cfm of waste gas passes through the bed at a velocity of 7 ft/s. The entering gas temperature is 1500°F; the bed temperature is about 860°F.

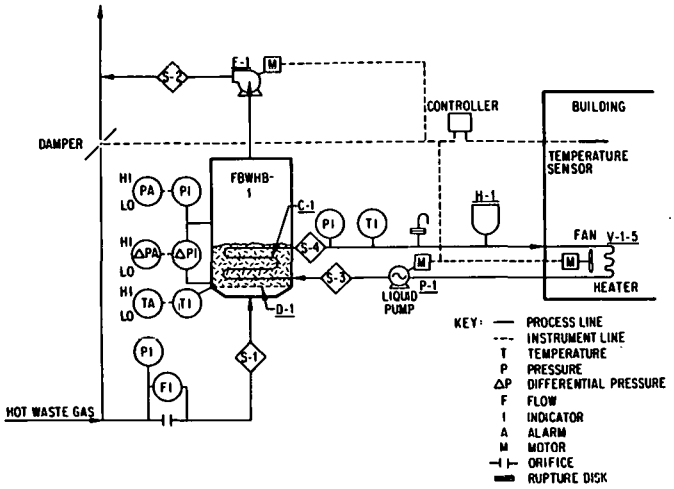


Fig. 8. FBWHB Flowsheet

Table 2. FBWHB Equipment Sizes and Materials of Construction

FBWHB-1

Fluidized-Bed, Waste-Heat Boiler
90 in. high
5.0 ft long x 1.5 ft wide
T_{Bed} = 860°F
ΔP = 25.9 in. H_2O
Atmospheric pressure
Gas Velocity 7 ft/s
Top section, bed and above:
Carbon steel AISI-SAE-1020
Bottom section:
Type 316 alloy lined with castable ceramic

C-1

Heat-Transfer Coils
82.2 ft
2-in. tubes, #12 B.W.G.
2% Cr-1/2% Mo alloy steel

D-1

Distributor Plate
ΔP = 9 in. H_2O
5 ft x 1.51 ft
0.1-in. dia holes
0.650-in. horizontal spacing
0.059 in. thick
Type 310 alloy
Supported by a grid, Type 310 alloy

F-1

Blower
Spencer turbine
Centrifugal blower
60-in. water gauge

H-1

Liquid Hold Tank
100 gal
Carbon steel

P-1

Centrifugal Pump
50 gpm

V-1-5

Building Heaters
Marcaro unit heaters
286,000 Btu/hr
1/2-hp air circulation motor

Table 3. FBWHB Mass Balance

Component	Stream	
LIQUID	S-3 Liquid Entering Tube Bundle	S-4 Liquid Leaving Tube Bundle
H_2O (18)[a] lb-mol/hr	1111.1	1111.1
Gal/min	40.0	40.0
Temp., °F	145	195
GAS	S-1 Hot Waste Gas Entering FBWHB	S-2 Cooled Waste Gas Leaving FBWHB
N_2 (28.02), lb/mol/hr	142.57	142.57
CO_2 (44.01), lb-mol/hr	17.18	17.18
O_2 (32.00), lb-mol/hr	3.43	3.43
CH_4 (16.04), lb-mol/hr	0	0
Total dry, lb-mol/hr	163.18	163.18
H_2O (18), lb-mol/hr	34.36	34.36
Total wet, lb-mol/hr	34.36	34.36
Total gas, lb/mol/hr	197.54	197.54
Total gas, lb/hr	4861	4861
Total gas, ft^3/min	4708	3171
Temperature, °F	1500	860
Pressure, atm	∿1	∿1

[a]Figure in parentheses is molecular weight.

CONCLUSION

As demonstrated in this report, sufficient knowledge exists to design, build, and operate a commercial-scale FBWHB for heat recovery purposes. Gas-fluidized units that produce hot water or steam are now operating. Areas of technical uncertainty still exist, however, if one wants to design an optimum unit. Because of these uncertainties, the usual method of design relies on empirical data derived from similar applications or from prototype units.

The major areas of technical uncertainty associated with FBWHB technology are:

- Determination of overall FBWHB heat-transfer coefficients;
- Determination of fluidization characteristics;
- Determination of bed-expansion characteristics;
- Determination of attrition rates of FBWHB solid particulate media;
- System control;
- System life; and
- System reliability.

The items as listed represent candidate areas for future DOE research and development activity in fluidized-bed, heat-exchange technology. Further studies, including laboratory or pilot-scale investigations, will enhance the chances of successful FBWHB demonstration and commercialization.

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DEVELOPMENT AND TESTING OF A FLATTENED U-TUBE HEAT EXCHANGER

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ABSTRACT

Due to the present high cost of energy and the fact that costs are expected to continue rising in the future, those engaged in thermal processing must adapt new philosophies to maximize production efficiency. In most instances, the cost of energy may no longer be regarded as an insignificant factor in the cost of operation. Therefore, efficient use of energy and energy recuperation systems must be carefully evaluated.

This paper discusses the development and testing of a U-Tube type flue gas energy recovery system for fuel fired industrial heat treating furnaces. The flattened U-Tube configuration was selected since its relative simple fabrication makes the unit quite cost effective.

Development will be described beginning with the formulation of a numerical type mathematical model of the proposed heat exchanger which was computerized and then used to perform a parameter study to optimize the unit design.

Analysis of data, generated by laboratory testing of the final computer selected design as a result of the computer study will be presented. Comparison of the experimental data to the computer model will also be demonstrated.

INTRODUCTION

An investigation was conducted to define the energy requirements of direct fired industrial heating processes in the temperature range of 1200°F to 2000°F. The purpose of this investigation was to determine the economics of preheating the combustion air with waste heat from the process flue gases with respect to the cost of commercially available heat exchangers. The result of these surveys indicated that existing commercial equipment is not cost effective, i.e., the payback period is not considered to be reasonable. Therefore, a research and development program was undertaken to generate a cost effective recuperator design which has a high effectiveness and is reliable and compact.

Heat transfer characteristics of various types of heat exchangers were studied to give some general guidance into the geometry which may be optimum for 1200°F to 2000°F operating temperatures. The resulting concept was to develop a compact, modular, metallic heat exchanger in which a higher overall heat transfer coefficient would be achieved by increasing flue gas side radiation and air side convection.

ANALYTICAL INVESTIGATION

A numerical computerized finite difference model was written for a counterflow heat exchanger. The assumptions upon which the model was based are: (1) Within any element, the temperature of the shell, tube, air and flue gases do not vary; (2) The heat exchanger is adiabatic; (3) The thermal inertia of the shell and tube is negligible and (4) The thermal conductivity of the tubes is very high. On the air side of the heat exchanger, convection is the only mode of heat transfer considered. On the flue gas side of the heat exchanger convection and radiation exchange between the outside of the air tube, the flue gases and the inner wall of the flue stack is considered.

COMPUTER MODEL PARAMETER STUDY

A parameter study was conducted using the computerized model of the counter flow heat exchanger. The purpose of this investigation was to determine which parameters are most influential on the overall heat transfer coefficient, so that design concepts for a compact and high effectiveness recuperator could be formulated. As a result of this study,

three major conclusions were reached. First, the effect of reradiation area on overall heat transfer coefficient was determined. As illustrated in Figure 1, a 40 percent increase in the overall heat transfer coefficient is attainable when the reradiation area is increased to 3 times the primary exchange area. Primary exchange area is defined as air tube outside surface area. By examination of Figure 1 it can also be seen that additional increases in the ratio of reradiation area to primary exchange area begin to yield a diminished payback in terms of the overall heat transfer coefficient. Secondly, the computer results indicated, as shown in Figure 2, that when air side velocity is increased by a factor of four, a 90 percent increase in the overall heat transfer coefficient is obtained. In performing the parameter study it was assumed that the increase in velocity is achieved by maintaining a constant air tube surface area and decreasing the cross sectional flow area. Finally, the significance of gas radiation on the flue gas side was determined, and the important conclusion was that heat transfer by gas radiation is greater than convection on the flue gas side of the heat exchanger at temperatures above 1400°F.

FORMULATION OF DESIGN CONCEPTS

Based upon the results of this investigation, design concepts were formulated for the flattened U-Tube Heat Exchanger. In order to maximize heat fluxes in the flue gas side of the heat exchanger, a flue stack of relatively large cross sectional area would be employed. This would result in large ratios of reradiation area to primary exchange area, and longer mean path lengths with respect to gas radiation. To increase the rate of heat transfer on the air side of the heat exchanger it would be desirable to reduce in cross sectional flow area while maintaining constant air tube outside surface area. This would be accomplished by flattening conventional round tubes resulting in a duct with a considerably reduced cross sectional area, leaving the outside surface area basically unchanged.

LABORATORY TESTING

An experimental facility, shown in Figure 3, was assembled in the laboratory to determine the performance of the flattened U-Tube configuration. To provide a reasonable simulation of the effective gas emissivity and surface emissivities present in an actual flue stack, an 18 inch diameter stainless steel tube was lined with 3 inches of refractory. To simulate the entering air and flue gases, a combustor was installed upstream of the flue stack (heat exchanger shell) with a perforated plate mounted at the entrance to induce a uniform flow profile. The test facility was instrumented with aspirated thermocouples to measure entering and exiting temperatures of the air and flue gases. At rated capacity, that is, 2500scfh air entering at 100°F and 2750 scfh of flue gases entering at 1800°F, the exiting temperatures were 800°F for the air and 1170°F for the flue gases. The air tubes were initially 4 inch diameter round tubes with a 1/8 inch wall thickness made of Incoloy and then flattened to a width of 1.25 inches. The pressure drop across this configuration was calculated to be 6 inches of water column (wc).

Initial test results indicated that the flattened U-Tube configuration did not perform as expected, that is, the measured combustion air temperature was 480°F versus the predicted 800°F (overall heat transfer coefficient) resulting in a U of 3.8 when U is defined as:

$$U = \frac{MCp\ (Ta_i - Ta_o)}{A\ lmtd}$$

and

$$lmtd = \frac{(Ta_o - Tf_i) - (Ta_i - Tf_o)}{\ln\left\{\frac{Ta_o - Tf_i}{Ta_o - Tf_o}\right\}}$$

Also the effectiveness at this condition is 22 percent where effectiveness ($\mathcal{E}$) is defined as:

$$\mathcal{E} = \frac{Ta_o - Ta_i}{Tf_i - Ta_i}(100)$$

This performance was a result of the fact that the system was designed for a pressure drop of 6 inches of (wc) to achieve an overall heat transfer coefficient of 7.0 and the measured pressure drop was 1.8 inches (wc). These results imply that a design employing a higher air side fluid velocity is required to achieve a greater overall heat transfer coefficient. This is easily achieved

with the present design configuration as demonstrated by a second test conducted at higher air flow rates. With an air flow rate of 4100 scfh the pressure drop increased to 3.6 inches (wc) and the overall heat transfer coefficient was calculated to be 6.5 from the test results.

To verify the effect of increased pressure drop at reduced flow rates, the U-Tube was reflattened to a reduced width of 7/16 of an inch. With this tube width the pressure drop and rated capacity was 10 inches water column resulting in an exiting air temperature of 850°F, and $\mathcal{E}$ of 44 percent and an overall heat transfer coefficient of 7.5 Btu/hr.ft^2°F.

A second series of laboratory tests was conducted to determine the operating characteristics of the flattened U-Tube heat exchanger while operating as a component of a combustion system which also included a burner and temperature and combustion controls. The heat exchanger design in this second series of tests is somewhat more refined than the design employed in the previous tests. The heat exchanger has been modularized into units of 5000 scfh air flow rates requiring two U-Tubes to be manifolded at the inlet and outlet into one common coupling. Since the facility used for these tests employed a 1.0 x 10^6 Btu/hr. burner, a flue stack was designed to accommodate two heat exchanger modules as shown in Figure 4.

Thermodynamically, the heat exchanger performed essentially as predicted. The unit delivered an exiting air temperature of 950°F while firing the burners stoichiometrically at a rate of 1.0 x 10^6 Btu/hr. with a furnace temperature of 1800°F. For this condition the overall heat transfer coefficient was 7.8 and the effectiveness was 50 percent. The air side pressure drop was measured at 14 inches (wc) comparing reasonably well with the predicted values of 10 inches (wc) at an air temperature of 1000°F.

FIELD TESTING

The flattened U-Tube heat exchanger design has been applied to five new batch type gantry furnaces at National Castings Division of Midland-Ross. These furnaces are used for normalizing and tempering large steel castings and the operating temperature for these processes is 1780°F and 1220°F respectively. Extensive measurements were taken while operating the furnaces under production conditions during both normalizing and tempering cycles.

Substantial fuel savings were realized as a result of applying the flattened U-Tube heat exchanger modules for both process cycles. In a typical normalizing cycle the average flue gas temperature entering the heat exchanger was 1775°F and the average air temperature out was 865°F resulting in an effectiveness of 46 percent and a calculated fuel savings relative to a similar system without recuperation of 32 percent. For a typical tempering cycle the average flue gas temperature entering the heat exchanger was 1265°F and the average air temperature was 552°F resulting in an effectiveness of 39 percent and a calculated fuel savings of 45 percent.

CONCLUSION

A compact modular metallic heat exchanger has been developed to recover waste heat from flue gases generated by various industrial thermal processes. This recovered heat is used to preheat the air used for combustion at the burners. Results obtained from testing this heat exchanger in the laboratory and at a field test site indicate that a considerable fuel savings may be expected as a result of applying the flattened U-Tube heat exchanger design.

NOMENCLATURE

Symbol	Quantity	Units
A	Heat exchanger air tube outside surface area.	ft^2
Cp	Constant pressure specific heat.	Btu/lbm°F
M	Mass	lbm
Ta_i	Air temperature entering heat exchanger.	°F
Ta_o	Air temperature leaving heat exchanger.	°F
Tf_i	Flue gas temperature entering heat exchanger.	°F
Tf_o	Flue gas temperature leaving heat exchanger.	°F
U	Overall heat transfer coefficient.	Btu/hr.ft^2°F
ϵ	Heat exchanger effectiveness.	

EFFECT OF RERADIATION AREA ON OVERALL HEAT TRANSFER COEFFICIENT

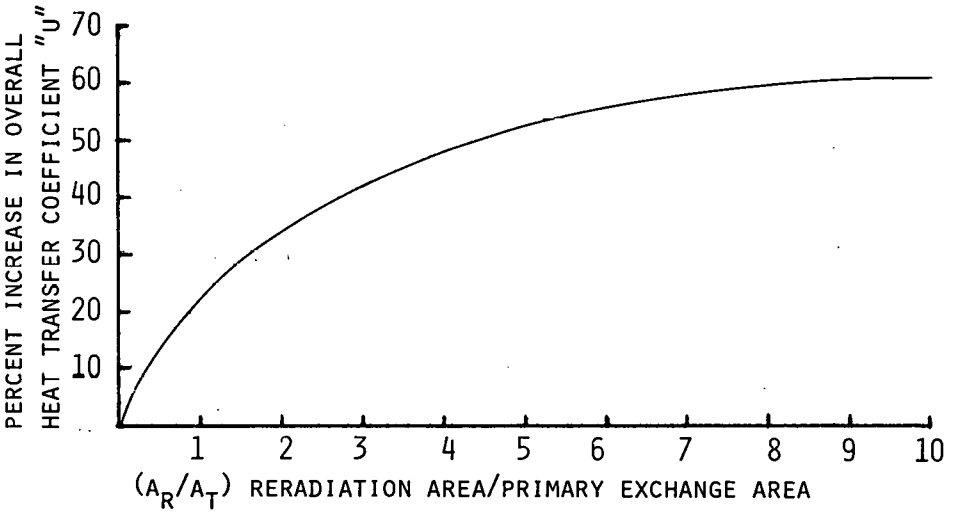


FIGURE 1

EFFECT OF AIR VELOCITY ON OVERALL HEAT TRANSFER COEFFICIENT

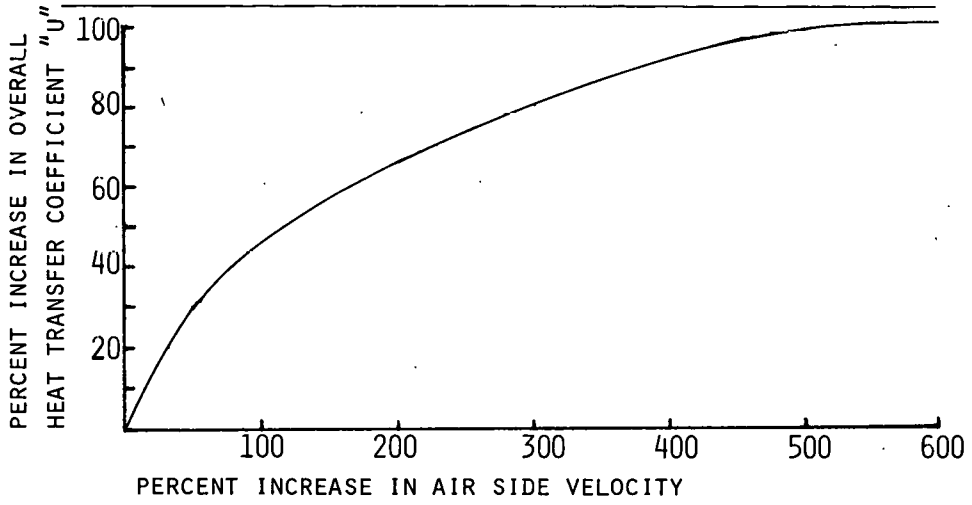


FIGURE 2

FLATTENED U-TUBE HEAT EXCHANGER
TEST FACILITY

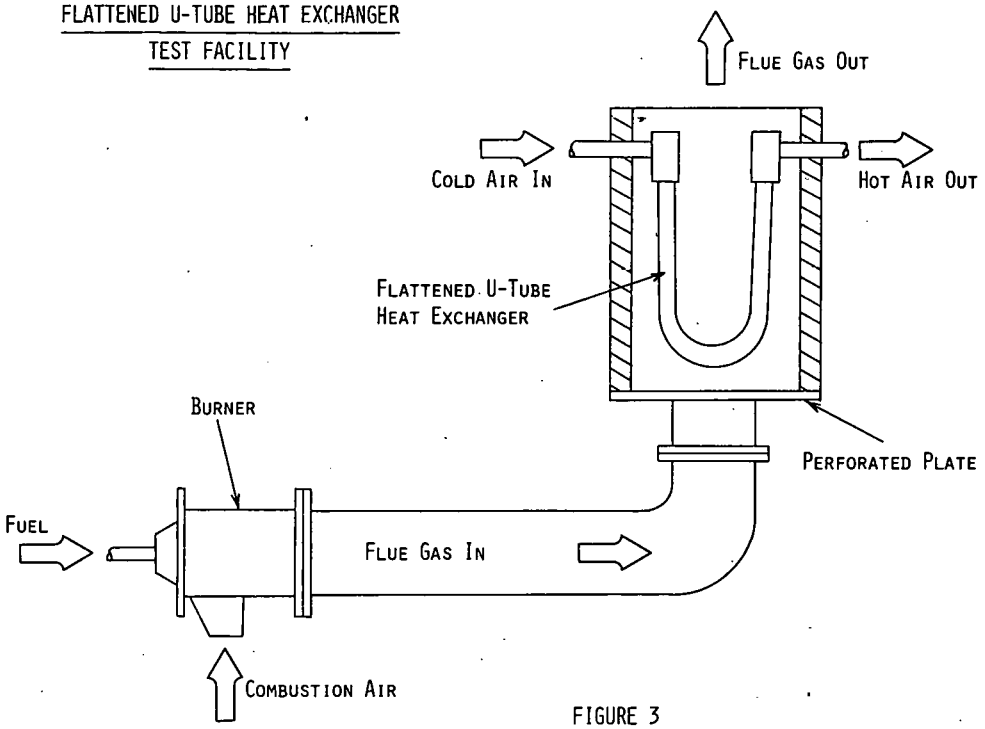


FIGURE 3

FLATTENED U-TUBE RECUPERATOR FLUE STACK ASSEMBLY

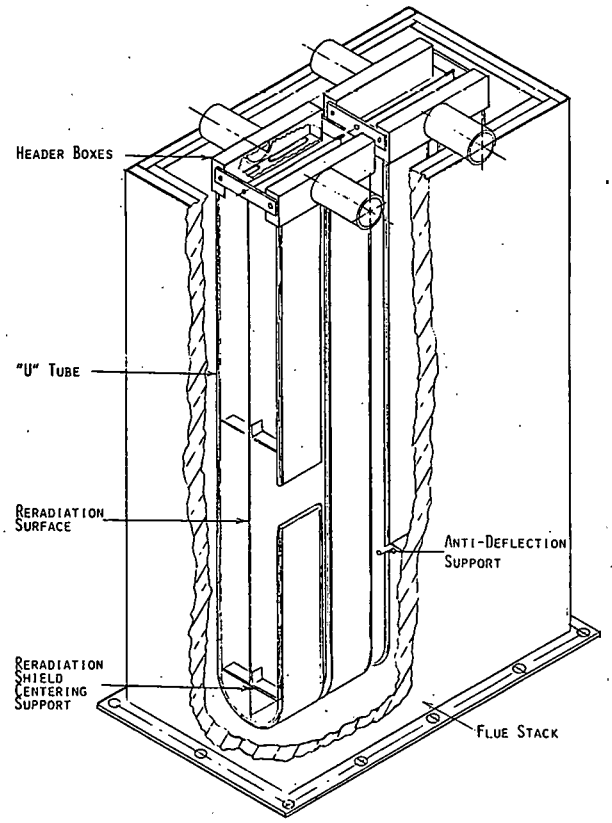


FIGURE 4

EVALUATION OF THE ENERGY-SAVING POTENTIAL FROM FLUE-GAS PRESSURIZATION

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ABSTRACT

The potential for recovering energy from low pressure furnace flue products is limited when standard heat recovery equipment is utilized. Efficient energy recovery can be accomplished by providing a flue gas side pressure drop across a heat exchanger placed in the path of the combustion gases. This paper summarizes practical methods of providing a driving force to accomplish this pressure drop and discusses optimization techniques for economical heat recovery.

THE CASE FOR PRESSURIZATION

Figure 1 details the impact of providing a pressure drop to recover energy with a convective heat exchanger. As an example, for 2000°F flue gas, the specific energy recoverable is 135 Btu/lbm if a 10 inch wc pressure drop is provided, while only 25 Btu/lbm can be recovered at .1 inch wc. The work of compression is 16 Btu/lbm, giving a net realizable energy recovery of 119 Btu/lbm, almost five times that which can be recovered at .1 inch wc. The fact that

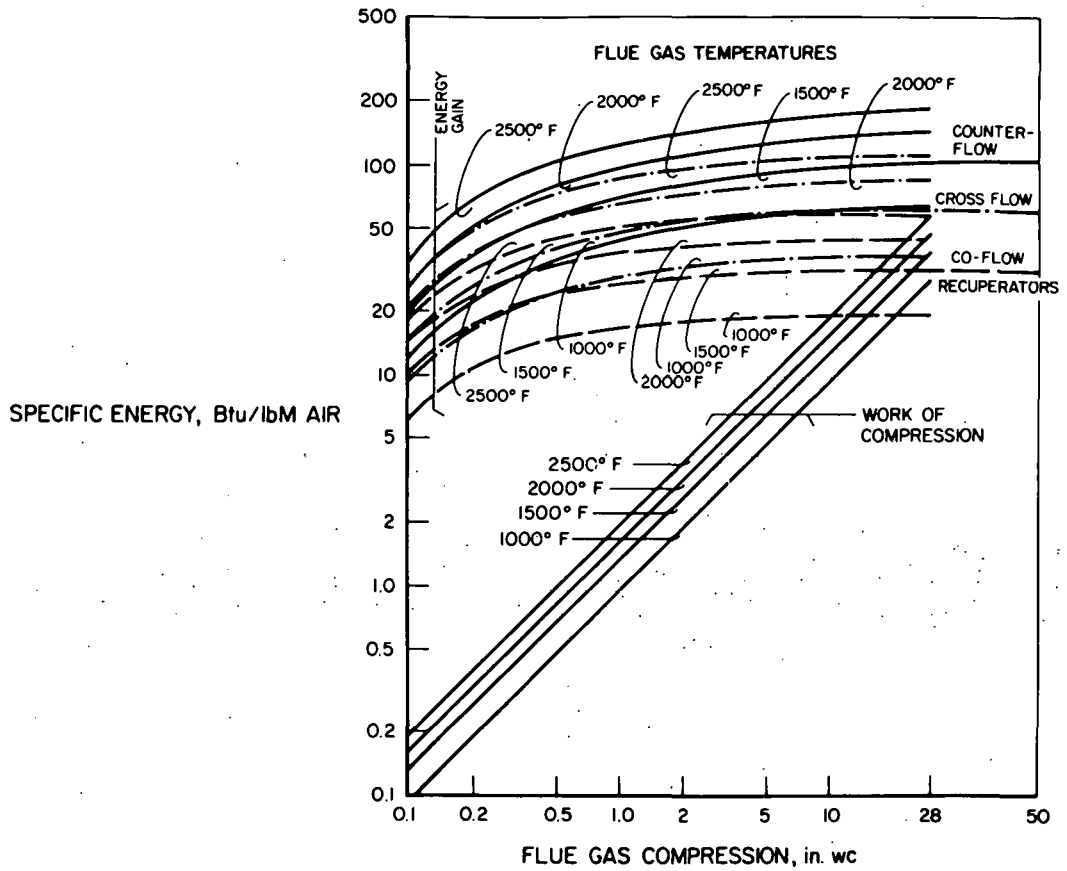


Figure 1. ENERGY GAINS AND LOSSES DUE TO PRESSURIZATION

the recoverable energy increases at a decreasing rate while the work of compression continues to rise with increasing pressure suggests that there is an optimum point of pressurization.

Figure 2 combines the work of compression with energy savings and shows that the optimum pressure is approximately 5 to 8 inches wc, at least for a counterflow heat exchanger. As will be shown later, the gas temperature under consideration for a convective heat exchanger is 1600°F for the convective portion of the recuperation equipment. It is significant that for a unidirectional flow heat exchanger, the compression can very quickly result in a loss or, at best, be useless if the pressure is as high as 11 inches wc. For a counterflow exchanger, however, the cost of pressurization is an almost insignificant part of the benefits realized.

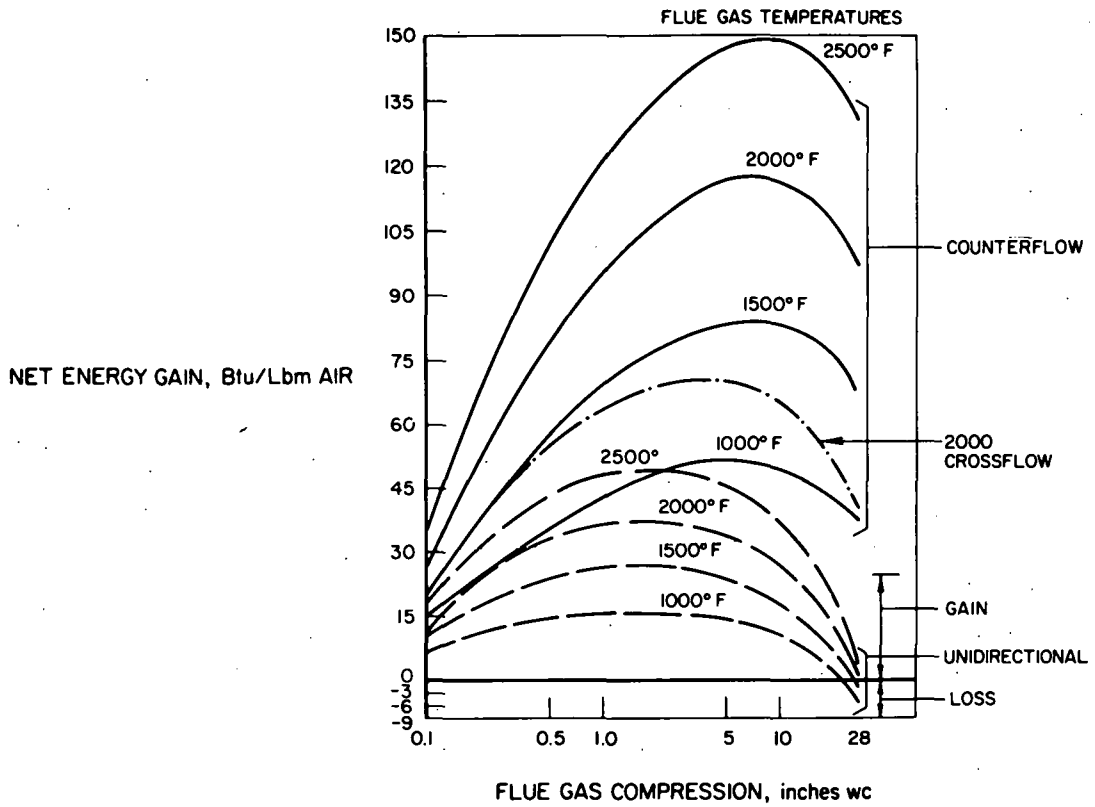


Figure 2. NET ENERGY GAIN SHOWING OPTIMUM PRESSURIZATION

Figure 3 shows the realizable savings in fuel with a given air preheat temperature. These savings are used to compute the investments that could be considered feasible for recuperation equipment purchase and installation. Heat recovery is not, however, limited to preheating combustion air.

Pressurization by Jet Pump

The flue gases may be pressurized by a jet pump (Figure 4), which shows promise of being practical. The principle is essentially the same as the air ejectors used to remove air from the condensate in power plants.

A jet pump uses a driving fluid at a higher pressure than the flue gas to entrain the gas. The driving fluid flows through a nozzle, where most of the pressure is turned into kinetic energy. The flue gas is entrained, the two are mixed in a mixing section, and pressure is then recovered in a diffuser.

To obtain the higher efficiencies available for a jet pump, however, it appears from investigations that are currently under way that the pump must be custom fabricated for a particular installation. Also, the fan that would be necessary to raise the driving fluid pressure would consume approximately the same amount of energy that would be consumed if a fan alone were to be used for the driving force. The mass of the driving fluid is approximately 10% of that of the flue gas.

Despite some apparent disadvantages, pressurization by jet pump shows promise of feasibility, both in a physically practical and economic sense. Investigation is under way to determine this.

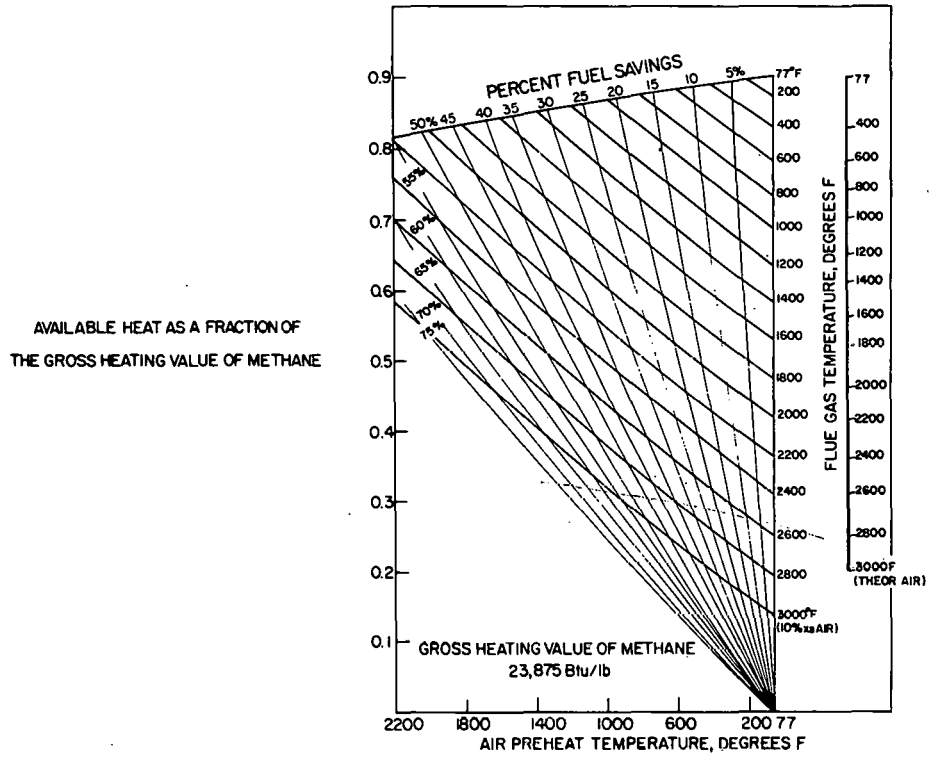


Figure 3. AVAILABLE HEAT AND FUEL SAVINGS DUE TO COMBUSTION AIR PREHEAT METHANE BURNED WITH 10% EXCESS AIR

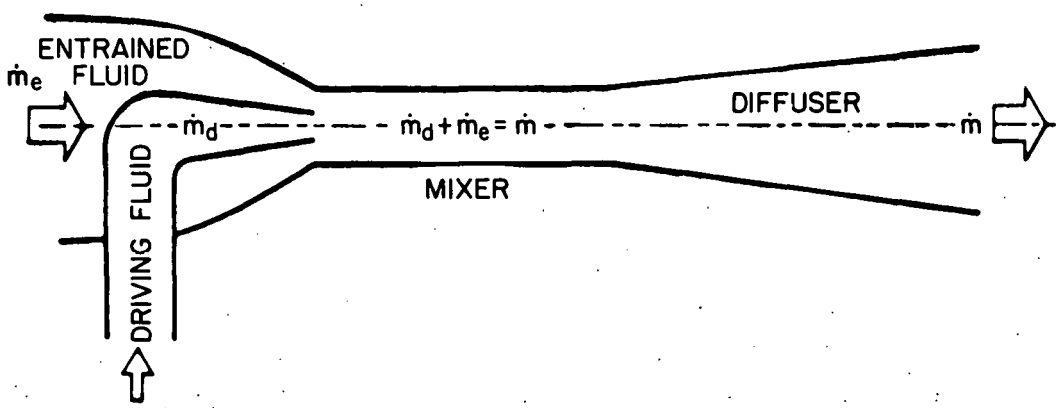


Figure 4. A CONVENTIONAL JET PUMP

Pulse Chamber Pressurization

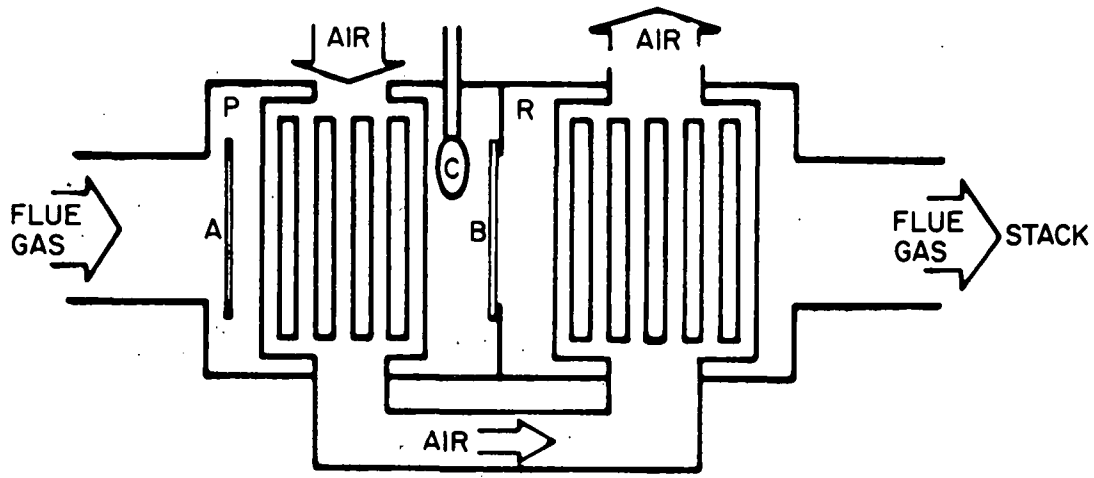
Pressurization can be accomplished by using a pulse pressurization chamber (Figure 5). Pressurization is accomplished by alternately isolating the inlet and outlet of the chamber and then adding heat energy while the chamber is isolated. Isolation would have to be accomplished with rotary valves.

This method of pressurization has been demonstrated to be physically possible; however, the main problem associated with building a pulse chamber of reasonable size is sealing, and the method does not appear to be economically feasible.

Precooling and Pressurization

Many of the furnace installations under consideration discharge flue gas at 2000°F. There are gross strength and corrosion problems associated with the conventional materials used in available metallic heat exchangers at this temperature. However, at 1600°F, the problems are considerably alleviated.

Past attempts have been made to precool hot flue gases with ceramic heat exchangers. However, the ceramic heat exchangers have been associated with significant leakage problems. Figure 6 shows



P PULSE CHAMBER
R RECUPERATOR
A INTAKE GATE
B RELEASE GATE
C PULSE BURNER

Figure 5. PULSE RECUPERATOR

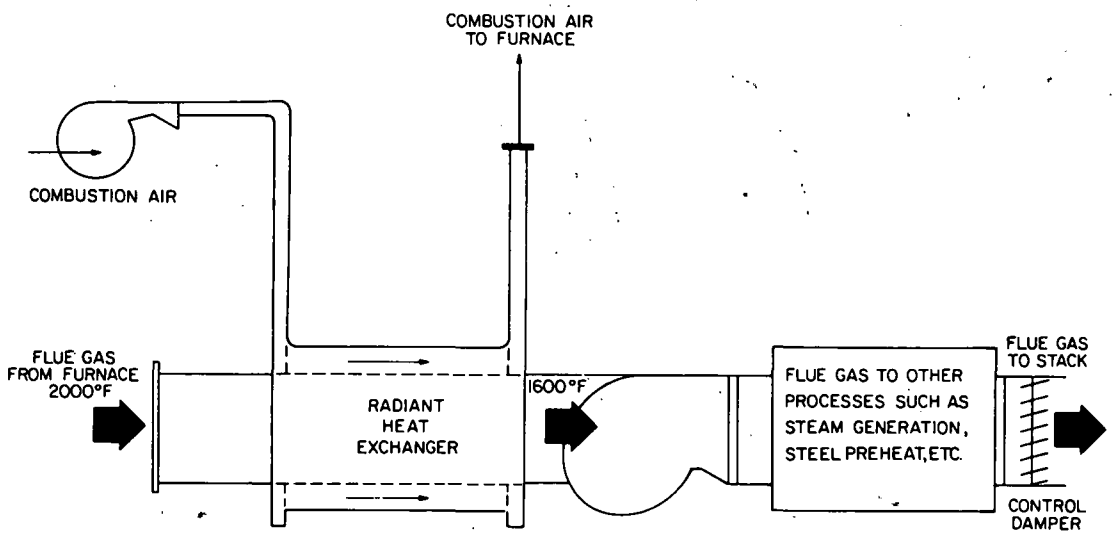


Figure 6. GENERAL ARRANGEMENT OF PRESSURIZED FLUE GAS SYSTEM

a method of precooling the flue gas to 1600°F by taking advantage of the high radiation potential of the gas. The energy of precooling is transferred to the combustion air and is therefore conserved, and the pressure drop through the radiant heat exchanger is an order of magnitude of 10^{-4} inches wc. The radiant exchanger for the furnace shown is 3 feet in diameter and 5 to 6-1/2 feet in length. It is relatively simple in design, and preliminary inquiries have shown that it can be fabricated at a reasonable cost.

ECONOMICS

An economic analysis was made using the return on investment method. A set of assumptions must be made for the analysis, which can be tailored to an individual firm's needs. The assumptions made for this case are as follows:

1. Gas (for savings) and electric (for costs) rates are escalated by 13.5%, the American Gas Association concurring. Gas price beginning 1980 is \$.37/1000 ft^3.

2. The project was applied to an installation that has a 10-year useful life remaining.
3. The addition is depreciated by accelerated (sum-of-years-digits) method with no salvage value.
4. The tax rate is 50%.
5. Net cash flows can be reinvested at the firm's cost of capital. Flows were discounted at 15%.
6. All cash flows are received in a lump sum at the end of the year.
7. The firm has sufficient taxable income to realize the effective tax saving potential of an investment tax credit of 10% of the investment.
8. Insurance costs are 1%, and other costs are 1% per year of the investment.
9. The fuel saving is approximately 37.5% of the fuel input without recuperation equipment and with a flue gas discharge temperature of 2000°F.

Table 1 gives an example of the method used to compute the cash flows and those for a ten year period. The cash flows shown are for the maximum feasible investment for a 250 MM Btu/hr furnace. Note that insurance and other (maintenance) costs are functions of the investment.

An iterative technique solves for the internal and actual rates of return for the cash flows generated. A second technique solves for the maximum feasible investment, i.e., that investment for which the internal and actual rates of return are exactly equal to the cost of capital.

Table 2 shows the results of an analysis for three furnaces; 3mm Btu/hr, 30 MM Btu/hr, and 250 MM Btu/hr fuel inputs. The internal and actual rates of return shown are for the estimated capital investments.

PILOT SCALE FACILITY

A pilot scale facility has been designed to demonstrate the optimization and economics of the program. A flow diagram with instrumentation is given in Figure 7. The pilot scale facility demonstration will utilize combustion air preheat only, and will not attempt cogeneration.

Figure 8 presents a heat and mass balance for the facility, which is designed for a 3 MM Btu/hr input. Figure 9 is a schematic of the convective heat exchanger to be used.

MAXIMUM FEASIBLE INVESTMENT OF $16,255,829

CASH FLOWS, 1980	COST DEDUCTED	ACCOUNT, $
GAS SAVING		2,748,915
LESS COSTS:		
OPERATING (Electricity)	127,645	
INSURANCE	162,558	
OTHER	162,558	
NET GAS SAVING		2,296,154
LESS TAXES		1,148,077
AFTER TAX SAVING		1,148,077
ADD TAX SAVING BY EXPENSING $2,955,605 OF DEPRECIATION		1,477,803
NET CASH FLOW		2,625,880

FOR 1980 ONLY, THE INVESTMENT TAX CREDIT OF $1,625,583 IS ADDED FOR A NET CASH FLOW OF $4,251,463. CASH FLOWS WERE COMPUTED IN THE SAME WAY FOR THE REMAINING YEARS.

Table 1. DETAILED ECONOMIC ANALYSIS FOR A 250 X 10^6 Btu/hr FURNACE

FURNACE SIZE 10^6 Btu/hr	MAXIMUM JUSTIFIABLE EXPENDITURE	ESTIMATED CAPITAL INVESTMENT	INTERNAL RATE OF RETURN	ACTUAL RATE OF RETURN
3	$ 195,070	$ 150,000	19.8%	17.1%
30	$ 1,950,700	$ 275,000	79.6%	33.2%
250	$16,255,829	$2,000,000	88.6%	36.9%

FLUE GAS TEMPERATURE - 2000°F
AIR PREHEAT TEMPERATURE - 1300°F
BEGINNING 1980 FUEL PRICE - $0.37/THERM

Table 2. SUMMARY OF ECONOMIC ANALYSES FOR FURNACES OF VARIOUS SIZES

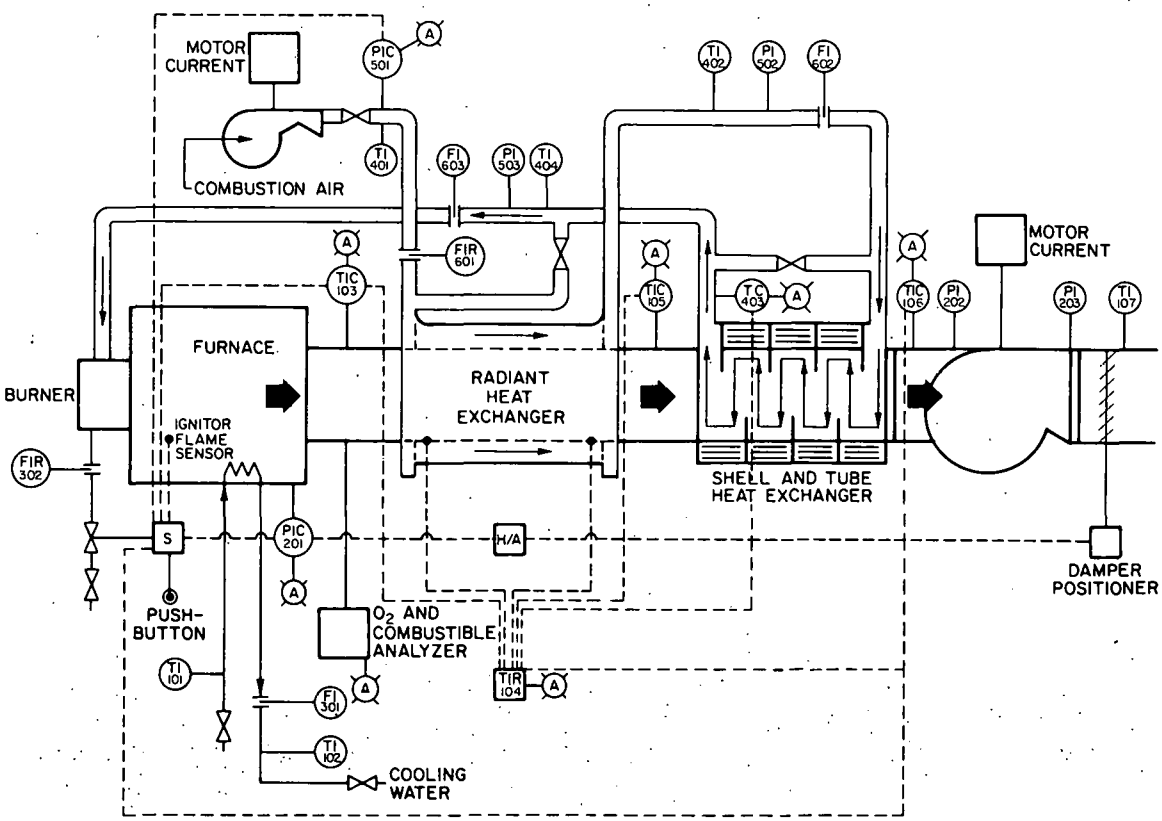


Figure 7. OVERALL SYSTEM INSTRUMENTATION

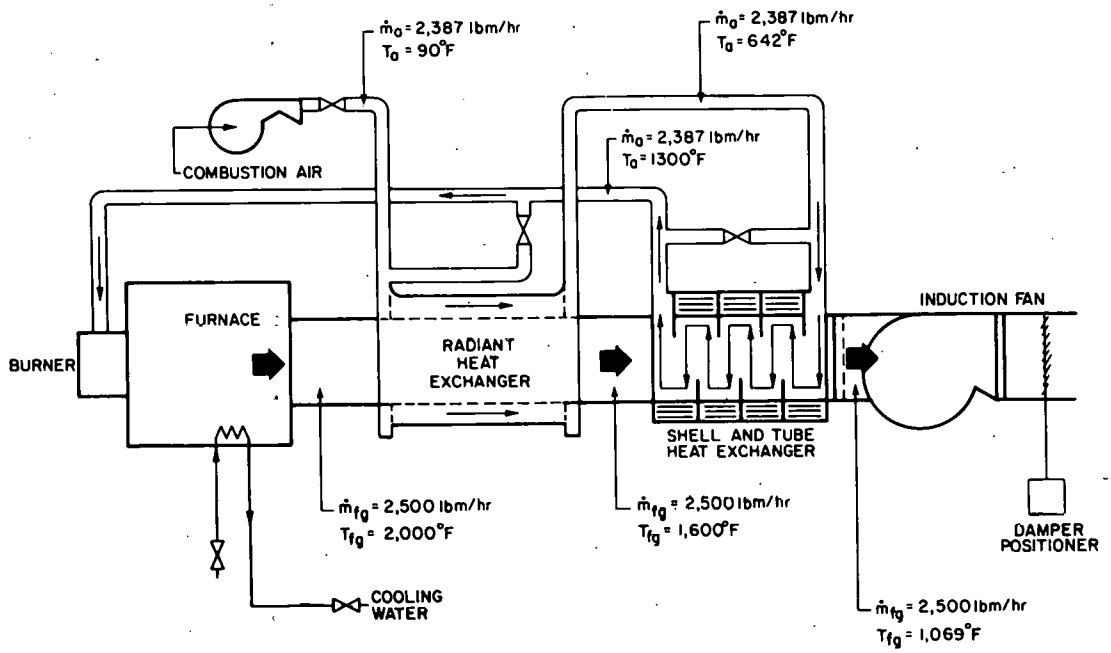


Figure 8. DESIGN CONDITIONS RESULTING FROM HEAT AND MASS BALANCE CALCULATION

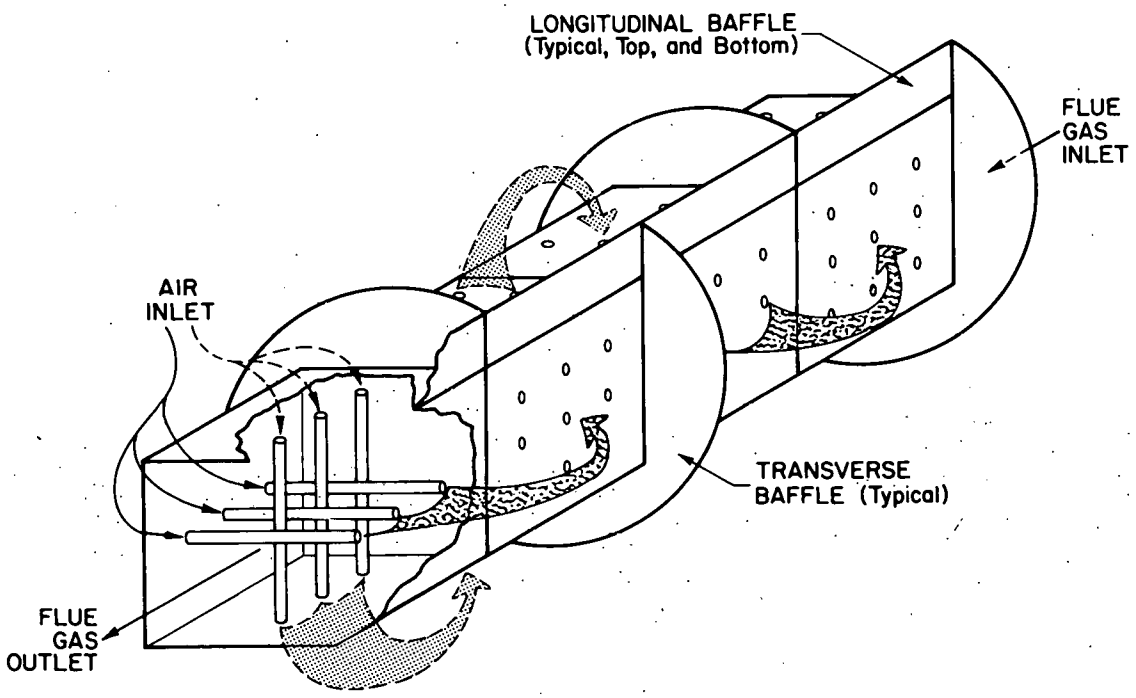


Figure 9. INTERNAL VIEW OF CONVECTIVE HEAT EXCHANGER

DESIGN, STRESS ANALYSIS AND OPERATING EXPERIENCE IN FEEDWATER HEATERS

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ABSTRACT

The performance of feedwater heaters has a direct bearing on the thermal efficiency of the plant. A typical feedwater heater may have three distinct regions of heat transfer, namely desuperheating, condensing and subcooling zones. The design challenges attendant on successful heat transfer in each zone are summarized in the paper.

Deficiencies in the current design codes and standards are also discussed.

The paper draws heavily from the proceedings of the Feedwater Heater Workshop* edited by Libs and Singh.

In addition to focussing attention on the state-of-the art technology deficiencies, the paper also offers some remedial measures for improved design.

The final segment of the paper gives a synopsis of the most commonly reported operating problems. A diagnosis of the troubles is also presented to aid a prospective designer or user in avoiding a repetition of past mistakes.

INTRODUCTION

Feedwater heaters are central to the regenerative heating of the working substance (water) in a power plant since they improve thermodynamic efficiency of the closed power cycle. This improvement is often significant if the number of heaters, heater size, steam bleed-off rate, etc. are properly selected [1]. Equally important, however, is the assurance that plant operational reliability is not adversely affected. This consideration has provided a great impetus in recent years to improve the heater design, material selection, operating procedures and preventive maintenance techniques. An effort in this direction was made by the Electric Power Research Institute in 1979 by sponsoring a feedwater heater workshop [2], with participation by vendors and users, with the express purpose of identifying the outstanding technical problems and developing recommendations to alleviate the problems. Significant conclusions derived from this workshop are summarized in the following material. Additional design concepts developed by the authors in this field since the publication of the proceedings [2] are also described.

The purpose of this paper is not to present a survey of state-of-the art of feedwater heater technology. Rather, the intention is to provide a critique of certain major design and operational problems and highlight possible alternatives available to the designer and engineer. In order to derive a meaningful set of conclusions, it is important to view the feedwater heaters as an element in the whole of the power plant, since a perspective focused on the heaters as an isolated component without intimate relationship to the remainder of the plant is too parochial to yield meaningful results.

The following sections present a systematic analysis of the structural and thermal-hydraulic design, stress analysis and operating experience of feedwater heaters.

STRUCTURAL DESIGN

Heater designs are based on the ASME design code [3] and standards for closed feedwater heaters [4]. The ASME codes provide the design rules for determining pressure boundary thicknesses. The feedwater heater standards furnish the additional requirements and guidelines to ensure a certain minimum quality of hardware. Both documents have evolved through decades of experience and input from a broad cross-section of the engineering

*Held in New Orleans, La., March 12-13, 1979

community. However, no such text can expect to answer all questions on the subject. Furthermore, advances in power plant design generally require additional considerations the analyses of which are more subtle, and hence more difficult to quantify. A typical example is the tubesheet thermal transient problem which we will dwell on in some detail.

High pressure feedwater heaters require thick tubesheets and channel barrels. The tubesheet is integrally welded to the shell and channel resulting in a "T" shape junction (Figure 1).

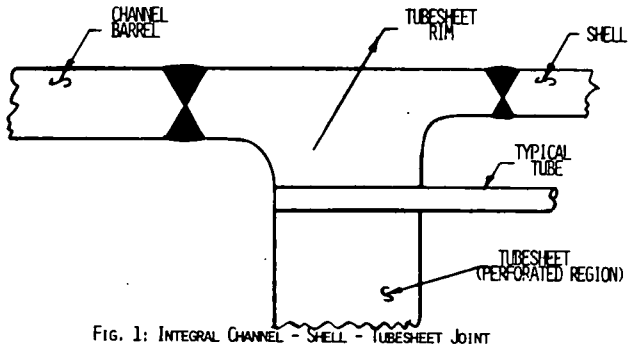


FIG. 1: INTEGRAL CHANNEL - SHELL - TUBESHEET JOINT

The shellside surface of the tubesheet is exposed to condensing steam. The tubeside surface and the perforated interior are exposed to the feedwater. Different segments of the tubesheet "see" different feedwater temperatures. This produces thermal stresses across pass partition lanes which may reach significant values. Thermal stresses are self-limiting; i.e. they are deformation bound. For this reason, they are altogether ignored in Section VIII of the Code. They are important, however, if the equipment is subjected to cyclic conditions. These conditions undoubtedly exist, although attention is seldom paid to their proper evaluation.

Fluctuations in feedwater inlet temperature can cause additional problems in the tubesheet. As shown by Gardener[5] the perforated region of the tubesheet is essentially at the temperature of the tubeside fluid, except for a thin skin on the shellside surface of the tubesheet through which a rapid transition of the metal temperature takes place. The unperforated rim of the tubesheet, on the other hand, has a complex temperature distribution which is more evenly responsive to the fluid temperatures on its two faces. If for some reason the fluid coming into the channel barrel undergoes sudden temperature change, the components of the "T" region react quite differently. The perforated interior of the tubesheet follows the channel fluid temperature with little time lag. The unperforated rim responds much more slowly. The temperature change in the channel barrel is even slower. The shell abutting the channel barrel experiences little effect. The interior of the tubesheet seems to adjust to the temperature change far more rapidly than its surrounding elements will allow, resulting in severe stresses. These stresses, often called thermal transient stresses, have a highly complex time-dependent amplitude. They are especially critical in those regions where metal ductility is low, such as heat-affected zones around welds. Many cracks observed in girth seams between channel barrel and tubesheet may have originated from a thermal transient event similar to the one described in the foregoing.

Thermal stresses call for less material and reduced rigidity. Mechanical loads, such as internal pressure, call for more material or increased rigidity. A suitable compromise between these two opposing requirements is necessary to ensure a reliable design. Fortunately, minor design modifications often help achieve a satisfactory solution. For example, in one instance, tapering the channel barrel locally was found to reduce the thermal stresses significantly without increasing the pressure-induced stresses materially. Figures 2, 3 & 4 show variations of the same concept which have proved effective in practical problems.

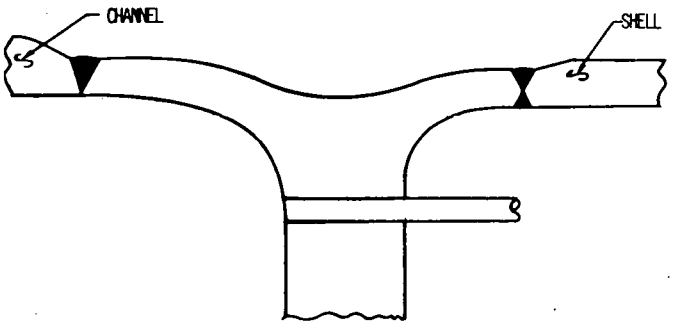


FIG. 2: FLAT TUBESHEET WITH CONTOURED SHELL & CHANNEL

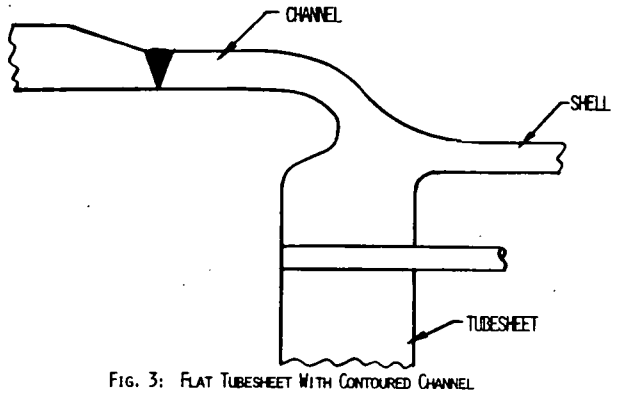


FIG. 3: FLAT TUBESHEET WITH CONTOURED CHANNEL

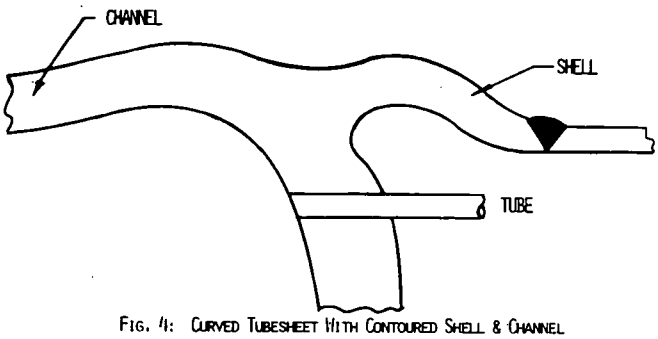


FIG. 4: CURVED TUBESHEET WITH CONTOURED SHELL & CHANNEL

Thermal stresses in the U-bend region are another cause for concern. Feedwater heaters with drain cooling and desuperheating sections may have large inter-leg temperature drops in the U-tubes. Since the U-tubes are built in at the tubesheets, the resultant differential thermal expansion must be absorbed by the U-bends. The small diameter U-bends are particularly susceptible to this problem. This problem can be accurately predicted using an appropriate thermoelastic model [6], and many defective designs may thus be identified at an early stage.

In addition to the thermal stresses, the mechanical loadings on the heaters due to reaction from attached piping are an area of concern. There is a tendency to view the feedwater heater nozzle ends as anchors for the connecting piping. The piping stress analysis is performed assuming the heater nozzle end undergoes no rotation or movement. Clearly, this is incorrect, for the nozzles are usually no sturdier than the adjoining pipe. The implications of this on the heater design are much greater, however. Instead of treating the heater shell barrel surface as the point of fixity (which is a more excusable idealization), locating the anchor at the nozzle end results in greatly increased moment on the shell surface. The shear forces developed at the nozzle end appear as shear forces plus overturning moments on the heater surface. These contrived increases in the applied loads act to demand added local reinforcements and bigger heater supports with many dollars spent without improving the hardware.

The welds enclosing the desuperheating and subcooling zone shrouds are another area of concern. These welds are not accessible during in-service inspection. Nevertheless they experience extremely high thermal stresses. A crack in the shroud weld does not violate the pressure boundary integrity, but it can seriously affect thermal performance and lead to localized tube erosion. We will discuss other factors relating to thermal performance in the next section.

THERMAL-HYDRAULIC PERFORMANCE

Feedwater heaters normally deliver the required heat duty. The most common problem in this area may be subdivided into two categories:

a. Flashing in the drain cooling zone.
b. Flow induced vibration in the condensing zone.

Flashing in the drain cooling zone may be due to a variety of causes, such as a leak in the shroud or through the interface baffle plate holes or pressure loss. The latter occurs when the drain subcooling surface is ineffective (due to flow bypass or fouling), and thus the water is not subcooled. Pressure drop due to flow in this zone causes the water to reach the saturation temperature and flash. Most of the time however, flashing occurs in the outlet piping.

This flashing is highly detrimental to heater integrity. Tube cavitation and erosion damage are commonly observed results.

Flow induced vibrations in the condensing zone may be due to standing waves (sonic vibrations) or tube vibrations caused by fluid-elastic type of energy transfer. The former case is mainly a nuisance to operators and does no physical harm to the equipment. The latter case is a serious problem. It may be developed from a variety of causes. The most common cause is inadequate desuperheating and localized condensing in the condensing zone. Thus slugs of water-steam mixture are formed which hammer away at the tube surface. The most expedient remedy is to increase the coolant flow (if possible) to accentuate the desuperheating and condensing processes.

STRESS ANALYSIS

As mentioned earlier, feedwater heaters are designed to Section VIII Division 1 of the Boiler and Pressure Vessel Code [3]. This code bases design on primary membrane and bending stresses only. Primary membrane stress is the average stress across the cross-section of a "shell like" member excluding the effect of discontinuities and stress concentrations. Primary bending stress is the linearly varying stress component across the thickness in "plate like" members excluding the effect of discontinuities and stress concentrations. The allowable stress in Section VIII is set equal to 25% of the ultimate strength of the material. In addition, conservative design rules are specified to account for non-primary stresses. In order to simplify the design effort, the code specifies conservative design rules. It would therefore appear that designing the equipment using a comprehensive stress analysis will economize on material and fabrication. This is generally, but not always, true. The reason lies in the uneven margin of safety built into Section VIII Division 1 for local membrane and secondary stresses. For example, nozzle-shell junction reinforcement rules in Section VIII yield maximum local membrane stress less than 1.5 times the nominal allowable stress (usual limit for such stresses) if the ratio of the two diameters does not exceed 0.3. For ratios of diameters over 0.5, the code prescribed reinforcement is usually not sufficient. A design based on detailed stress analysis will reveal such inadequacies. A stress analysis based design may turn out to be more expensive than a code design.

There are, however, several areas where stress analysis yields unqualified benefits. For example, the design of flat covers must be made in accordance with code rules as well as the Feedwater Heater Standards [4]. The formula in reference 4 is based on limiting the maximum deflection at the center of the flat cover. It leads to excessive thicknesses for large diameter covers (over 50"). Maximum cover deflection can be reduced by other inexpensive means, such as an outer beam bracing grid. A stress analysis based design can take advantage of such design strategies whereas a formula-based design can not.

Flange design is another area where stress analysis methods yield economical and yet more reliable designs.

Overall, heaters designed using a comprehensive stress analysis will be more reliable from the structural and mechanical point of view.

OPERATING EXPERIENCE

Operating experience in feedwater heaters from a broad cross section of the industry indicates the following major problem areas.

a. Tube wastage in the drain cooler region: Flashing, flow-induced vibration, and erosion at drain-cooler inlet are major heater problems. Use of a too thin ($\approx$ 1") end baffle results in seepage of steam into the drain cooling zone, causing severe localized erosion. Poor drain cooler inlet design is also found to cause generation of vortices at the inlet region which actuates tube erosion. The most serious wastage occurs when excessive pressure drop and insufficient cooling at the drain cooler inlet region causes the condensate to flash. The erosion rate from such flashing phenomena can be extremely rapid, resulting in tube failure within a matter of a few days of operation.

   Steam seepage can be eliminated by light rolling the tubes into the end baffle. However such a fix can cause additional thermal stresses. The designer should carefully evaluate these stresses prior to using the rolling concept. Another method is to make the end baffle substantially thicker and drill close-tolerance holes in these baffles.

   Flow straighteners at the drain cooler inlet have been found to reduce vortex formation at the inlet nozzle.

b. Erosion at the inlet header: Mechanical erosion of the ends and tubesheet ligaments due to incorrect header geometry has been identified as a frequent source of problems. It is well known that the erosion rate is a strong function of the incident velocity. Therefore erosion rate can be reduced by selecting low flow velocities. Unfortunately, such a design alternative is not too palatable to heater manufacturers

since it reduces heat transfer rate and thus increases the heater size. Locating the header inlet nozzle too close to the tubesheet is another contributing factor in header erosion. Again, economics dictates that the header length be kept at a minimum, especially in high pressure heaters.

Aspects of the inlet erosion problem are currently being studied at Joseph Oat Corporation through an Electric Power Research Institute funded project. The central goal in this project, which encompasses both theoretical modeling and model testing, is to devise inexpensive yet effective improvements to alleviate the erosion problem. The experiments are scheduled to begin in July 1980.

c. Flow induced vibration: Vibration problems ensue from excessive tube span and/or inadequate flow passages. The incidence of flow induced vibration has dropped considerably in recent years as the designer and manufacturers have learned to avoid them, though not fully understanding them. The International Energy Agency is currently investigating several aspects of the vibration phenomena. More precise design guidelines are expected to emerge from this study.

d. Operating vents: Users report varied success with heater vents. The usual complaint centers around the vented gases containing far too much steam, accumulation of non-condensibles in the condensing zone and consequent loss in heat transfer rate. Proper vent design requires a good understanding of condensation heat transfer and subsonic gas dynamics. It is difficult to specify firm guidelines in this area.

e. Tube plugs: Plugging of leaky tubes is found to cause tube failures in adjacent tubes if the plugs are not properly designed. The temperatures distribution around a plugged hole in the tubesheet is quite different from that in the unplugged region. Stresses caused by differential thermal expansion are enough to damage the neighboring tube-tubesheet points. Flexible plugs (as opposed to solid plugs) are found to give best results.

f. Structural failures: Cracks on tubesheet surfaces in the channel-tubesheet joint region, failure in the desuperheating shroud weld, and drain-cooling zone shroud welds are commonly reported problems. In order to improve reliability in this area it will be necessary to perform a more thorough stress analysis than is presently common to the industry. Such analyses are, however, expensive. Furthermore, a clear knowledge of all temperature cycles is necessary for a meaningful analysis. Often such information is not available, making a definite analysis extremely difficult at best.

In addition to the above, miscellaneous reported problems included improperly located instrument taps, lack of suitable inspection ports, and so on.

CONCLUSION

High plant availability and equipment reliability led to an examination of feedwater heaters. A synopsis of the state of the art in mechanical and thermo-hydraulic design has been presented. A brief review of commonly reported operating problems in heaters is also given. It is clear from this discussion that several significant problems in the feedwater heater technology remain to be solved. Most pressing problems relate to flashing activated erosion in the drain-cooler zone and mechanical erosion in the header inlets.

The power industry in the U.S. appears to have settled on the use of 304 stainless steel as the tubing material. In Europe, carbon steel is more prevalent. A solution to the corrosion-erosion problem may prompt a wider use of carbon steel in the U.S.

The structural problems are, comparatively speaking, more traceable. Methods, namely finite element analysis codes, exist to predict structural problems. Greater use of such methods will undoubtedly add to heater reliability.

The Electric Power Research Institute, Nuclear Power Division, is currently working on the development of a project to conduct an instrumented test program on operating plant feedwater heaters to determine transient and steady state pressures,

velocities, temperatures, etc. in the tube and shell regions. This performance monitoring is expected to lead to research and development projects which will provide the basis for improved heater design and specification guidelines.

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CANADA'S VOLUNTARY INDUSTRIAL ENERGY-CONSERVATION PROGRAM

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ABSTRACT

Industrial Energy Conservation in Canada is organized and promoted through a voluntary program that is administered by industry. Industry is divided into fifteen sectors, each of which is represented by a Voluntary Task Force. Information exchange, goal setting and progress reporting are carried on through these Task Forces which are staffed with industrial volunteers and representatives from the major trade associations. Inter-industry liaison is accomplished via a Coordinating Committee comprised of the individual Task Force Chairmen and representatives of the federal government. While the program has been in existence only since 1976, impressive gains have already been made and targets have been set for 1980 and 1985. The strength of the program lies in its candid cooperation between industry and government. There has, to date, been no need or advantage to implementing a government mandated program for industrial energy conservation in Canada.

BACKGROUND

Canada is a nation blessed with natural resources. This relative abundance of natural resources had, even through the time of the 1973 OPEC embargo, prompted a belief on the part of most Canadians that the country would continue to have access to an unlimited supply of cheap energy. Steady depletion of conventional domestic crude oil supplies, rapid energy price escalations, interruptions in foreign supply and awareness of international hardships have now prompted the realization that Canada's domestic energy resources must be husbanded.

Canada is now facing a period during the mid 1980's where foreign crude oil will be required to satisfy 30% of the nation's domestic demand. Beyond that period, Canada has the opportunity to regain self-sufficiency in all forms of energy.

Let's take stock of Canada's energy resources:

- The Athabasca tar sands contain over 800 billion barrels of bitumen - more than the combined reserves of the total Middle East. Of this, 35 billion barrels are extractable with current technology, and new, deeper extraction methods are the subject of intensive research and development.
- Recent new finds of natural gas in conventional producing regions have yielded a "gas bubble" that will satisfy domestic demand well into the 1990's - even with the announced additional exports to the U.S.A. Off-shore and Arctic gas discoveries indicate that additional gas supplies will likely be forthcoming to meet demands even further into the future.
- Canada possesses 1/4 of the world's uranium reserves and has developed a proven reactor technology for conversion of these resources into useful electric power.
- Canada's coal reserves are calculated to be enough to satisfy demand for some 900 years into the future.
- Abundant forest lands promise that, with proper management, renewable biomass energy could be made available to complement other energy sources.
- Canada's coasts have some of the world's most extreme tides. These could be harnessed for their renewable energy.
- Only half of the nation's hydro-electric power potential has been harnessed to date.

- Contrary to its popular image, Canada's climate is still temperate enough to promise a substantial generation of solar power in the longer term future.

Thus, while the immediate future will present problems in satisfying energy demands, the fear of "freezing in the dark" due to the unavailability of energy is a message which lacks credibility in the Canadian environment.

The messages which do ring true to Canadians are:

- Conserve energy now to buy the time required to mature the technologies that will bring supplemental energy forms (such as the tar sands) on-stream.
- Invest in energy conservation since the barrel saved is cheaper than the cost of the replacement barrel.
- Conserve energy since it is profitable to do so.

The Canadian government has recognized the need for an intensive energy conservation effort across all sectors of Canadian society. One problem that had to be addressed was: how should government proceed in its efforts to encourage energy conservation within Canada's industries.

In May 1975, the federal ministers of Energy, Mines and Resources, and of Industry, Trade and Commerce, called together a select group of Chief Executive Officers of Canada's most influential industrial companies. At that time, Government underlined the inescapable fact that since Canadian industry accounts for 40% of the nation's energy demand, Canada's industries would have to be diligent in their energy use - if the national energy conservation imperative was to be met.

A challenge was laid at industry's doorstep. Could industry voluntarily encourage and implement energy conservation? Could this sector of Canadian society properly manage its own energy affairs and by doing so, obviate the need for legislated programmes to assure energy restraint? Could Canadian industry assume a leadership role to demonstrate the impact of energy conservation to other sectors of Canadian society?

The challenge was not only accepted but was welcomed by the assembled industry leaders. This cooperative and consultative approach by government on a national imperative was refreshing. Thus, a unique industry/government relationship and programme for voluntary energy conservation had its beginning.

In March 1976, less than a year after the initial government appeal was made, industry leaders reassembled to define the plan of attack that had been formulated. The plan, with some over-simplification, was as follows:

1. Industry would commit to initiating a comprehensive programme of voluntary industrial energy conservation.
2. This programme would include, as far as practicable, all industries across Canada.
3. Voluntary conservation targets for improving the efficiency of energy use would be established by industry, and a regular schedule of reporting progress toward these goals would be maintained.
4. Efforts would be made to share non-proprietary energy conservation technologies between companies.
5. Primarily through its employee work force, industry would seek to promote energy conservation in the off-the-job environment of the larger social community.

As a first step, industry, at the March 1976 Ministerial conference, reported that ten Industry Sector Task Forces had been established to promote the objectives of the "Voluntary Programme for Industrial Energy Conservation". This move to subdivide Canadian industry into sectoral divisions was made in recognition that constraints, opportunities and operations varied widely between industries. A paper producer, for example, has unique problems that are not shared by the beverage manufacturer, and vice-versa.

Each of these Task Forces committed to achieving stated energy conservation goals by year-end 1980. While there was variation in the accounting methodologies of different Task Forces, most sectors utilized a "Btu/unit of production" reporting system. This system defines the energy required to produce a given product expressed as Btu's (British Thermal Units) per ton of steel, Btu's per gallon of soft drinks, or Btu per ton of newsprint, etc. These measures of energy intensity are monitored and compared with a base year standard (i.e. how many Btu's/unit of production

were required to manufacture the same item prior to embarking on an energy conservation programme). The ase year for most sectors was 1972.

The ten original Task Forces and their commitments to reduce the energy required per unit of production were as follows:

Task Forces	1980 Goal
Ferrous Metals	3%
Non-Ferrous Metals	6%
Industrial Minerals	10%
Textiles	11%
Pulp and Paper	12%
Machinery	15%
Food Products	15%
Transportation (Mfg.)	15%
Electrical & Electronics	15%
Chemicals	17%

It should be noted that because of the vast differences between industry operations, it is difficult to use these goals for comparative analysis. The Steel Industry's goal of 3% was every bit as challenging and significant as the Chemical's goal of 17%.

The weighted average of the commitments made in 1976 was to improve Canadian industry's energy efficiency by 12% by year-end 1980 compared to the 1972 base year rate of energy use. Or, in other words, to use an average of 12% less energy to manufacture each unit of production throughout Canada.

Since the 1976 conference, the list of Task Forces has been expanded. The Beverage Industry has joined in reporting with the Food Industry. The Wood Products Industry has formed a Task Force on energy use in Canada's forestry operations. The Petroleum Refining Industry has voluntarily committed to monitor and report its energy use. The Plastics Fabricating Industry has also joined the Task Force system. The Machinery group reorganized to split out Farm Machinery Manufacturing as a separate Task Force.

Many of Canada's medium and smaller firms do not have a common basis upon which they can organize a Sector Task Force. The Canadian Manufacturers' Association has offered to catalyze these smaller firms into a Task Force for "non-aligned" firms and seek ways to compile their data into a single weighted average progress report.

Thus, there are now fifteen Industrial Sector Task Forces and the list is still growing as the "gospel" is spread to all quarters of Canadian industry. It is now estimated that more than 80% of industry's energy use is represented by companies who have aligned themselves with the Voluntary Task Force system.

THE PROGRAM

The question that can reasonably be asked is "Why would industrial firms choose to voluntarily practise energy conservation and commit to reporting via the Sector Task Force programme?"

The motivation is basically two-fold:

1. Energy Conservation is Good Business! Cost avoidance by minimizing energy purchases is universally appealing whether the purchases are being made by a homeowner or a petrochemical producer. The incentive is profit retention.
2. The inefficiencies, costs and complications that traditionally accompany bureaucratic management of government legislated programmes are undesirable. It is in everyone's best interests, (government included), if a federally mandated programme can be avoided. A voluntary system is far more palatable.

Accepting that the voluntary industrial energy conservation programme provides benefits to the participating company, one might still question if such a programme is desirable from a national perspective.

A mandated, government audited programme would require supporting a substantial government bureaucracy at national expense. The Canadian voluntary reporting system is administered by industry, and less than 5 man years of federal effort are currently required to encourage and support the industry programme.

But even more important, the history of human nature has taught us that an imposed regime requires continued imposition. Once the pressure is relieved, the situation generally regresses. Our voluntary system is based on motivation and acceptance at the level of each individual company. Being built from the bottom up, rather than imposed from the top down, encourages credibility but, more importantly, assures

perpetuation. Canada is going to need to rely on energy conservation as a survival strategy through to the turn of the century. Thus, there is obvious advantage to the self-perpetuating voluntary system based on individual company profit motivations.

How exactly does the voluntary Task Force system work?

There are five key participants in the programme:

1. Individual Companies.
2. Trade Associations.
3. Industry Task Force.
4. The Task Force Coordinating Committee.
5. Government.

Companies

The basis of the entire programme rests with the dedication of the individual company. This dedication invariably starts with the recognition that saving energy makes good business sense. Avoiding needless energy waste cuts costs and improves profits. Redesigning processes or developing new processes to save energy improves a company's competitive position. Since energy conservation is being practised by other manufacturing firms both in Canada and abroad, companies are being faced with the need to be energy efficient as a requisite to survival in the market place.

Once the advantages and need to improve energy management are acknowledged, the individual companies must implement a plan of attack. This invariably starts with senior management commitment and the appointment of "Energy Managers" or "Conservation Coordinators" to get on with the task.

The first target for attack is the elimination of wasteful uses through "housekeeping" projects. Turning off lights during off-hours, adjusting thermostats, plugging steam leaks, and shutting down idle equipment are some examples of how wasteful abuses of energy can be corrected. The dedication of the work force is the key to success in these areas.

The second battle in the company's war for energy efficiency is in "retrofitting" existing processes. In these operations, money as well as dedicated people is necessary to improve efficiencies. Some examples of "retrofit" projects would be: double glazing windows, adding insulation to pipes and walls, installing control devices on boilers and electrical circuits, replacing equipment like motors and pumps with new, more energy efficient and properly sized units. Many of these energy investments pay for themselves in less than three years through reduced energy bills. Others, on a larger scale, can be far more costly and have longer paybacks. For example, installing cogeneration equipment or recovering low-level waste heat could require considerable time to generate offsetting savings in energy bills. Many factors enter into a company's decision on when and where to invest in energy savings. Not the least of these is the availability of capital. Like the homeowner who realizes that improved insulation will cut fuel bills, the company must have the money available to invest in conservation projects while still meeting other commitments in its "family budget".

The third, and most promising, area that companies attack is that of new processes and new technologies. These hold the promise of the greatest savings, but they are the most difficult and costly to implement. Long lead time for R & D and engineering design are required. Completely new plants are often necessary at costs in the millions of dollars. The companies and industries that are most aggressive in these activities are, however, wisely carving out a more secure competitive position as the costs of energy continue to escalate.

Companies with conservation programmes, be they at the housekeeping, retrofit or new process stage, all need some measurement system to tell them how well their effort is succeeding. The Btu/unit of production system of measuring energy efficiency fills that need very nicely. By periodically checking on how much energy has been purchased to manufacture a given volume of products, company Energy Managers can quickly see if their investments in energy projects are having the predicted effects.

With Btu/unit data in hand, a company can easily use these <u>same</u> data, in combination with other companies, to report the progress of an Industry Sector. There is no need for multiple reporting systems to satisfy government needs. The accumulation of individual company data to yield a national perspective provides the most accurate means of monitoring total progress. This system also has credibility since the data

reported to government are the same data that are used to manage the company's internal programme.

Trade Associations

Trade Associations play a key role in the reporting process. Trade Associations, like the Canadian Pulp and Paper Association, or the Canadian Chemical Producers Association, compile each company's data to yield a weighted average Sector total. This is generally done in confidence to protect a company's proprietary data, but it does produce a meaningful bench mark of Industry Sector average performance to which individual companies can compare. In all cases, the individual company is accountable for the credibility of its data submissions, and must accept that, should audits ever be initiated, they will be held accountable.

The Trade Associations also provide valuable secretarial, administrative and public relations assistance to the Sector effort.

The Canadian Manufacturers' Association is unique in its activities in support of the voluntary conservation effort. The CMA has undertaken to encourage energy conservation within the small and medium sized firms who do not have existing trade associations to represent them.

With government assistance, the CMA has prepared a special motivational programme for Chief Executive Officers to highlight the profitability of energy conservation. A second presentation is then given by the CMA to assist plant level managers in getting their new conservation programmes underway. The CEO and Energy Manager seminars will be conducted at the rate of about one a week over the next ten months throughout Canada.

Task Forces

The Task Forces are the committees that encourage and report the energy conservation activities and results for each Industry Sector. They are comprised of key Energy Managers from companies within each Sector and representatives from Trade Associations.

The Task Forces also play a major role in promoting information exchange between member companies on non-proprietary energy conservation techniques. Many of the Task Forces have held workshops and seminars; others publish newsletters and technology bulletins.

Through the Task Forces, peer pressure is used to encourage non-member companies to start programmes and participate in reporting.

The Task Forces also act as a focal point for dialogue with government on energy policy as well as energy conservation issues. They also assist in conducting surveys and studies relative to their industry. It is through the Task Force initiatives that problems common to an Industry Sector are identified and solutions are sought.

The Coordinating Committee

The Coordinating Committee of the Voluntary Industrial Task Force Programme provides a forum where the Chairmen of the 15 individual Task Forces can meet to exchange ideas and experiences and address problems of inter-industry concern. This group acts as a "Steering Committee" with government to resolve problems and chart the future course for the voluntary program across all Industry Sectors. It is in this forum that the diversity of needs of large, energy-intensive Sectors, such as Non-Ferrous Metals Industry, can be identified, on equal footing, with the less energy-intensive but more diverse Sectors, such as the Food and Beverage Industry. The Coordinating Committee also provides the vehicle for the more mature Task Forces to share their experience with recently formed Task Forces. The Coordinating Committee also compiles industry-wide reports to government and the public.

The Federal Government

The Federal Government provides assistance and support to the voluntary programme. While the government does not direct or administer the effort, a close cooperative liaison is maintained to assure that industry is kept aware of government's priorities and proposals. Government, in turn, is kept informed of industry's problems, opportunities and limitations. The relationship has, to date, been candid, cooperative and highly productive.

In addition to its observer status in the Task Force system, Government plays a role in providing incentive and development programmes to encourage industrial energy conservation.

The "Energy Bus" programme is one visible evidence of this effort. In this programme, federally funded, provincially operated vans are dispatched on request, to individual firms. The staff, equipped with two minicomputers on each "bus", conducts a preliminary energy audit of the facility, defining conservation opportunities and evaluating payback on suggested investments. Over 2,000 such visits have been made and close to 50 million dollars worth of potential energy savings have been identified. This was an average saving of about 14% per visit. The service is free and confidential.

Limited federal funds are also made available when individual Task Forces are unable to fund administrative needs. The government also enters, on request, into joint sponsorship of seminars and publications with the Task Forces.

The Voluntary programme, in simplified terms, focuses the attention and assistance of government, trade associations, other industries and other companies on helping individual companies in their efforts to save energy. The intent is to strengthen the company effort and, as a result, strengthen the national effort and performance. The programme depends on cooperation and candor while respecting the limits imposed by propriety. To date, friendly persuasion, peer pressure and self-esteem have successfully prompted action and maintained credibility. The need for "watch-dogging" has not been evidenced.

STATUS

The remaining question is: "Is it working?"

As previously mentioned, more and more Industry Sectors and individual companies are seeking participation. The premise that industry would accept and promote the voluntary approach has been fortified.

Through coordination of the Task Forces, a common accounting and reporting methodology for use by all sectors of industry has been developed. The Task Forces are at varying levels of sophistication in using this method. The newer Task Forces such as the Plastics Industry and Forest Products groups are still at the educational stage. Others such as the Transportation and the Electrical and Electronics Task Forces are coming to grips with the job of completely changing their previous reporting methodologies. Complete reporting by all Task Forces will not be achieved until July of this year. However, the bulk of industrial energy consumption is presently accounted for by the eight Task Forces who have provided standardized data submissions. These results, displaying achievements through year-end 1978, are as follows:

Task Force	Year-End 1980 Goal	Year-End 1978 Actual	"Savings" (Btu x 10^{12})
Chemicals	17%	17.3%	63.2
Petroleum Refining	18%	15.0%	50.6
Textiles	11%	14.9%	5.8
Machinery	15%	14.0%	0.3
Pulp and Paper	12%	11.9%	44.6
Food and Beverage	15%	9.7%	4.8
Industrial Minerals	10%	6.6%	4.5
Non-Ferrous Metals	6%	3.6%	4.3
Total of 8 Task Forces	12%	10.7%	174 x 10^{12}

As can be seen, the compiled total performance has almost achieved the target of 12% improved energy efficiency two years ahead of schedule. In the process, a demand for the energy equivalent of 30 million barrels of crude oil per year is being avoided. When expressed as crude oil equivalents, this equates to 13.4% of the Canadian demand for imported crude during 1978.

THE FUTURE

All Industry Sectors have voluntarily committed to setting new targets for energy efficiency gains through 1985.

All the Task Forces are now utilizing the standard Btu/unit of production methodology for reporting energy efficiency improvements. Most of the more energy intensive Task Forces such as the Chemicals and Ferrous Metals (steel) Task Forces continue to employ 1972 as their base year for comparison. The more recently organized Task Forces, and those who have completely revised their reporting, found that 1972 base year data were unavailable. Thus, sectors such as the Plastics Industry predicated 1985 goals against more recent

base year standards. Efforts are underway to attempt to mathematically extrapolate these later base years back to 1972.

The following tabulation has not corrected all Task Force goals to a uniform 1972 base year. Thus, the combined (industry-wide) goal is somewhat conservative.

Task Force	1980 Goal	1985 Goal
Chemical Industry	17%	31%
Electrical and Electronic Mfg.	15%	20%
Ferrous Metals (steel)	3%	7.1%
Food and Beverage Industries	15%	22.5%
Industrial Minerals	10%	16.3%
Farm and Industrial Equipment	(new)	N/A
Machinery	15%	22%
Non-Ferrous Metals	6%	15%
Petroleum Refining	18%	25%
Plastics Industry	(new)	13.1%
Pulp and Paper	12%	30%
Canadian Textiles	11%	25%
Transportation (Mfg)	15%	24.5%
Wood Products	(new)	N/A
Non-Aligned	N/A	N/A
Total Canadian Industry	12%	23%

These increased goals are an indication of industry's continuing effort to improve energy efficiencies. Now that "housekeeping" efficiencies have been largely achieved, future progress is closely tied to the rate at which industry can invest capital in energy conservation projects and in longer term R & D programs. Cooperative studies and surveys are now underway between industry and government to identify means by which capital investments can be accelerated. Longer term joint demonstration project funding is now also becoming available through coordinated federal/provincial government programs. It is hoped that these near and longer term efforts will yield even higher results by 1985 and beyond.

Is the system working? Indeed it is! To the satisfaction and pride of both government and industry, the expectations of 1976 are being exceeded both in the number of participants and in the volume of energy being saved.

PROBLEMS

Are there problems?

Like all human endeavours, the voluntary Task Force approach to energy conservation has its shortcomings. On balance, however, the benefits appear to outweigh the problems. It also appears that many of the problems encountered are also common to other industrial energy management approaches.

Time to Mobilize

One unique problem encountered in the voluntary industrial approach in Canada is the time required to mobilize and mature the national programme. Since the emphasis is placed on the motivation and implementation of individual company programmes, the build-up of a nation-wide effort is slower and more cumbersome. A great deal of time and individual hand-holding is needed to spread the "gospel" and to build a network of strong Task Forces. A mandated system would have undoubtedly hastened the pace - but at the expense of more significant objectives.

We have been fortunate in having a government that appreciates the longer term advantages that the system promises. Our government has offered patient support and assistance (even in the face of international criticism) while the programme was in its infancy. The programme is still growing, but the wisdom of the government's approach is starting to be confirmed by the results that are now being reported.

Consensus

A second problem is encountered in the administration of the programme. Since the voluntary Task Force programme is an industry effort administered by industrialists, it strives to achieve consensus on major problems rather than dictating decisions. Since the programme encompasses the full spectrum of industry, (i.e. from bakeries to pulp mills), consensus is often illusive. To the credit of the Task Force Chairmen, their candid dialogue and spirit of give-and-take at the Coordinating Committee has been successful in maintaining a cooperative environment. This, in turn, has allowed the democratic process to function. It should, however, also be noted that, while being cumbersome, the

participative management approach has intensified a sense of ownership and dedication to the programme at the company, Task Force, and Coordinating Committee levels.

Reporting Methodology

One particular problem that was encountered, (and hopefully resolved), was in obtaining consensus on a standard reporting methodology which would allow us to accumulate data from the multitude of individual reporting companies into a single national progress report. Utilizing the experiences in other countries, and from the more advanced Canadian companies, a system was eventually agreed upon. Training manuals have now been developed to teach company plant personnel how to use the standard method as a means to monitor their energy conservation efforts and to use these data for consolidated reporting to the government. We believe that once the chosen (Btu/unit of production) reporting system is fine tuned by experience, it will provide a standard method that will be equally useful to the small practitioner as well as to the complex, sophisticated energy-intensive firms.

Allocation

There is a final problem of major significance. The intensifying unrest in the Middle East, when coupled with Canada's continued near-term dependence on imported oil, suggests that we may well be faced with energy rationing before the turn of this century. Energy supply allocation legislation is already on the books and available for speedy implementation if and when necessary. This legislation, in its current form, does not recognize the discriminatory effects that would result from uniform allocation to both energy conservative and non-conserving manufacturers. A company that has diligently practised energy conservation has, in fact, reduced its degrees of freedom in times of rationing. On the other hand, the non-conserving firm would, in a uniformly applied allocation scheme, enjoy an advantageous position. Its reduced fuel allotments could be off-set by initiating conservation measures. Work is underway between the Task Forces and the various government agencies to rectify this shortcoming.

We hope to be able to factor energy conservation "credits" into the allocation formulae. If successful, we may also be able to provide an additional incentive for firms to participate in the voluntary program since allocation reductions would, hopefully, be lower and less disruptive to the conduct of their business.

SUMMARY

In summation, Canadian industry and government are proud of the system we have created, and proud of what has been accomplished to date. We now look forward to even greater achievements. We are dedicated to a continuance of the uniquely candid and cooperative relationship between industry and government. This spirit of mutual dedication has, perhaps more than any other factor, been the element that has allowed us to progress.

The self-serving motivation for cost avoidance in industry is supportive to the national objectives of reducing demand and dependence on foreign sources of crude oil. With proper education and incentives, the voluntary approach to industrial energy conservation can achieve the desired results. Legislated mandates are unnecessary.

Hopefully, other sectors of Canadian society will follow the industrial example in striving to cope with the energy problems of today so that we can all realize the energy promises of tomorrow. Industry is, in dramatic fashion, showing that Canadians can buy the time needed to develop the nation's future energy alternatives such as renewable energy and the tar sands.

OVERVIEW OF U.S. DEPARTMENT OF ENERGY PROGRAM IN INDUSTRIAL ENERGY CONSERVATION TECHNOLOGY DEVELOPMENT

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ABSTRACT

The primary responsibility for Federal industrial energy conservation is in the Office of Industrial Programs which reports to the Assistant Secretary for Conservation and Solar Energy. The objectives of the Federal program are to: achieve maximum implementation of existing and new energy conservation technologies; substitute, where possible, abundant fuels for scarce fuels; and minimize energy loss in waste streams. The basic strategy is cost-shared research, development, and demonstration leading to commercialization of energy-efficient technology. Considerations for project selection are: energy savings, acceleration of implementation, level of private effort, benefits to industry, cost-sharing, and degree of risk. Projected industry savings of the current program are 1.5 Quads by 1985 and 5.5 Quads by 2000.

Since energy has been forced upon our consciousness as not only a national, but world problem, the United States along with other countries has adopted strong measures to develop solutions. The formation of a cabinet level Department of Energy to bring into focus the varied and dispersed Federal activities related to energy is a major change in our government structure. The formation of an International Energy Agency is another.

The major program functions of the Department of Energy (DOE) are embodied in Conservation and Solar Energy, Fossil Energy, Nuclear Energy, Resource Applications, Environment, Defense Programs, and the Office of Energy Research (Figure 1). Among the other functions of the Department, perhaps the rules and regulations on energy production and use, developed by the Federal Energy Regulatory Commission and the Energy Regulatory Administration, impact most on our subject today. Industrial energy conservation efforts for the Department of Energy are assigned to the Office of Industrial Programs which reports to the Assistant Secretary for Conservation and Solar Energy (Figure 2). We will walk through the program in industrial conservation developed by this Office, but it is important to note that many other programs of the Department have an impact on industrial conservation, for instance, fluidized bed combustion, hybrid vehicles, driver training, synthetic fuels, thermal storage, to name a few.

The Federal objectives for energy conservation are to improve energy efficiency and to substitute abundant for scarce fuels (Figure 3). Translated to the industrial program, these objectives become: (1) achieve maximum implementation of existing and new energy conservation technologies in as short a time as possible; (2) substitute, where possible, abundant fuels for scarce fuels; and (3) minimize the energy loss embodied in waste streams of all types (scrap, waste materials, flue gases, and other energy-containing flows).

FIGURE 1

Department of Energy Organization

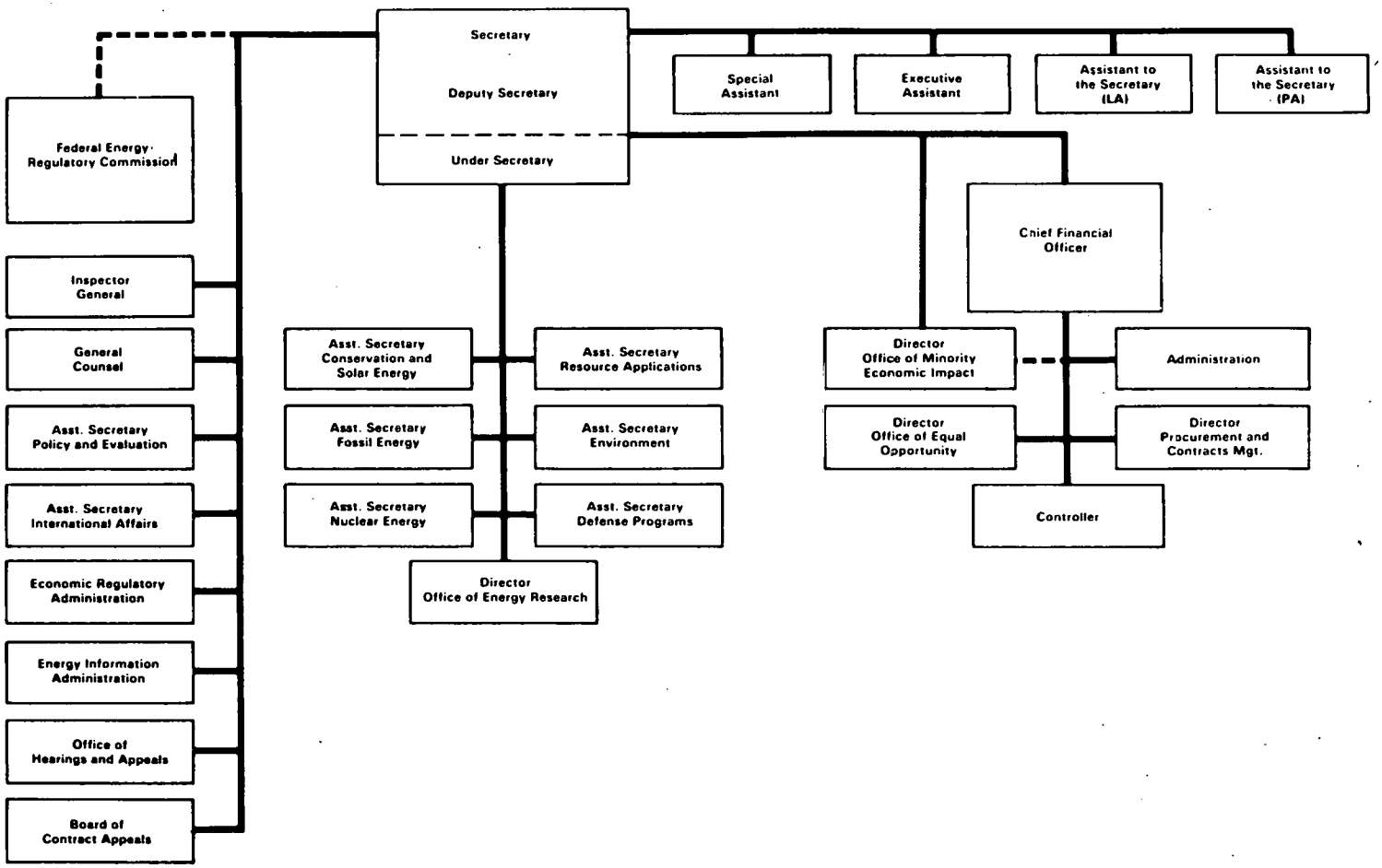
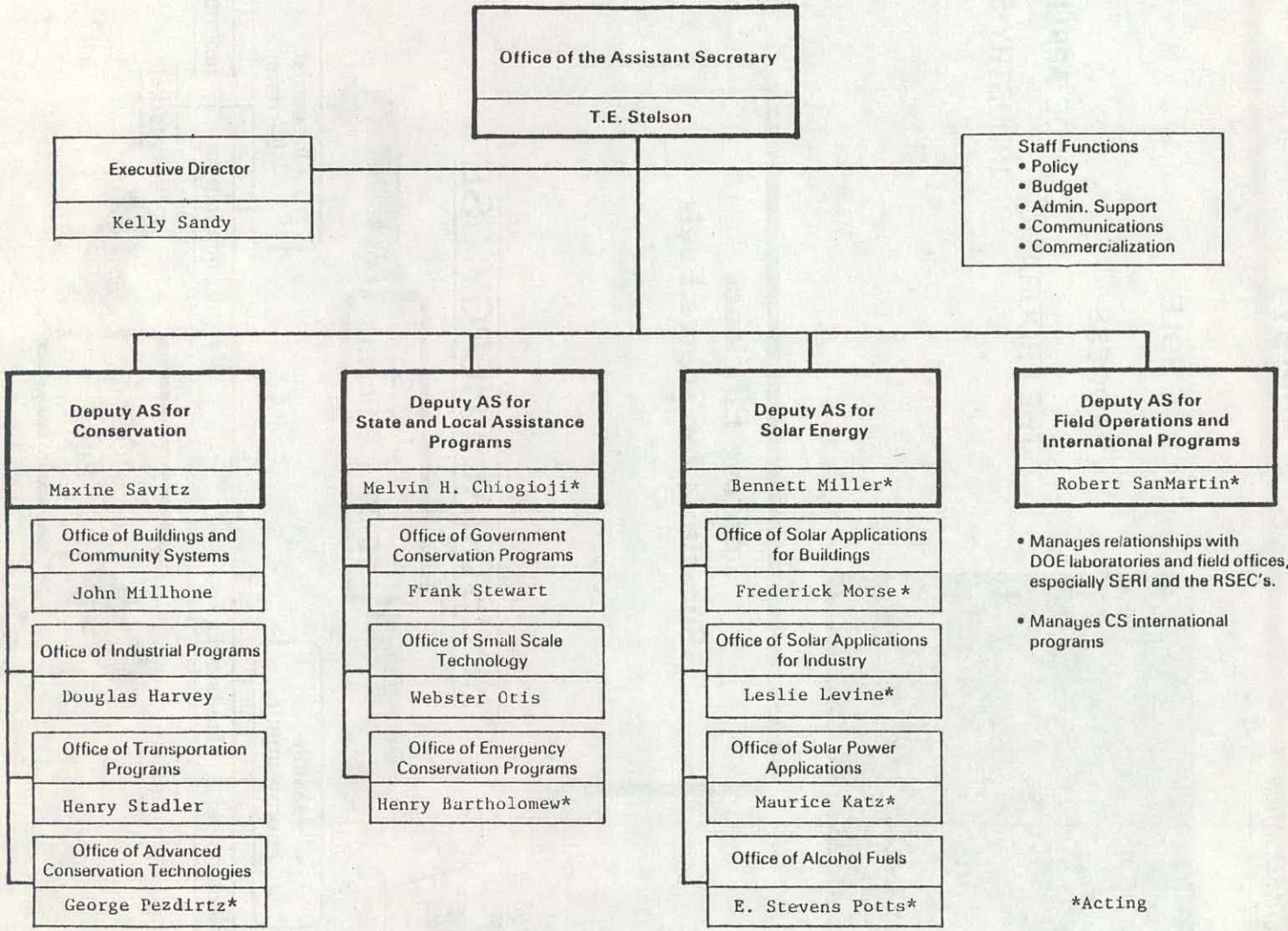


FIGURE 2

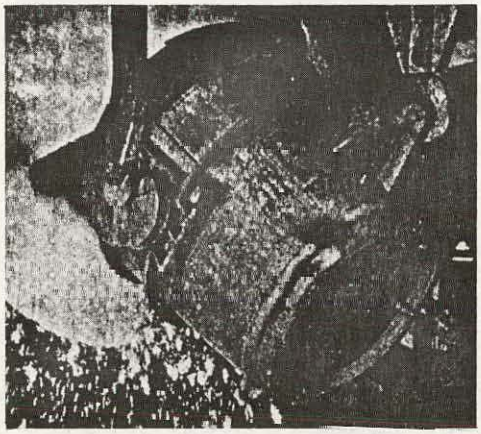
Conservation and Solar Energy

2/4/80



DOE INDUSTRIAL ENERGY CONSERVATION

Partnership To Save Energy



- DOE ROLE
- PROCESS
- THE PROGRAM
  - WIDE APPLICATION
  - INDUSTRY-SPECIFIC

Improve Efficiency
Substitute for Scarce Fuels

FIGURE 3

DOE IE

INDUSTRIAL ENERGY USE

37% of U.S.
10-30% Efficient

feasible improvements
- efficiencies
- losses
- feedstocks

industrial barriers
- economics
- market
- technology

DOE Role

- *"high risk" new technologies* → *R&D* → *industrial demonstration* → *commercial-ization*
- *existing technologies* →

FIGURE 4

DOE's approach to meeting these objectives has been to establish a partnership with industry to jointly develop the process and the program to achieve these objectives (Figure 4). Realizing that conservation is only achieved where the energy is used, DOE's industrial program has assumed the role of helping to define the potential for energy conservation and then assisting industry to realize this potential. The basic strategy is a cost-shared program of research, development, and demonstration of selected energy conservation technologies. These may be either existing, but underutilized technologies, or new developments with a degree of risk associated with their adoption by industry. They may be applicable across industry sectors, such as new developments in heat exchanger construction, or industry specific, such as hot inspection and scarfing of steel billets. In any case the projects are intended, if successful, to lead to adoption of the demonstrated technologies by industry and result in energy and cost savings.

Implementation of the strategy starts with an analysis of energy use to define target areas having major potential for energy conservation. In some cases, modest savings are possible in a large number of applications across industry sectors such as in combustion control or cogeneration (Figure 5). This type of target area is susceptible to what we term wide-application technology. In other cases the target areas are specific processes in specific industries. This thrust of the program is intended to address the conservation potential in individual energy intensive industries, such as steel, aluminum, Cement, and glass. We have identified nine industries which together account for about 60 percent of industrial energy consumption in this group.

Our next step in developing the industrial conservation program is to try to identify the barriers to conservation in each of the target areas. (Figure 6) These may be technical or institutional. Each industry differs in many ways and we need to understand the industry in order to achieve the implementation of the technology developed and the consequent energy savings. The basis for selection of project candidates are: high energy savings potential; non-redundance with efforts of private industry; potential for acceleration of implementation; the degree of fragmentation in an industry sector; and the degree and appropriateness of cost-sharing. This is one of the areas where the partnership concept provides a real pay-off. With the identification of the specific technology options, we can solicit proposals from industry and other sources to develop solutions. In many cases, unsolicited proposals are submitted that correspond to program objectives in target areas. Each project candidate is thoroughly screened for technical feasibility and for economic viability. This includes an extensive analysis of risk, costs and benefits. We conceive the industrial program role to be one of assuming enough of the risk, whether technical or economic, to permit the technology to be developed and demonstrated to the point where it is clearly shown to be feasible or not. In an effort of this sort, it is expected that some approaches will fail. We review projects frequently so that they may be terminated expeditiously if necessary, or conversely, perhaps accelerated to obtain the benefits more quickly. There are 8 projects with potential for providing significant energy savings that are currently being accelerated by various means.

In almost all cases, projects are cost-shared with industry partners. The desired result is commercialization of the technology. Some of the

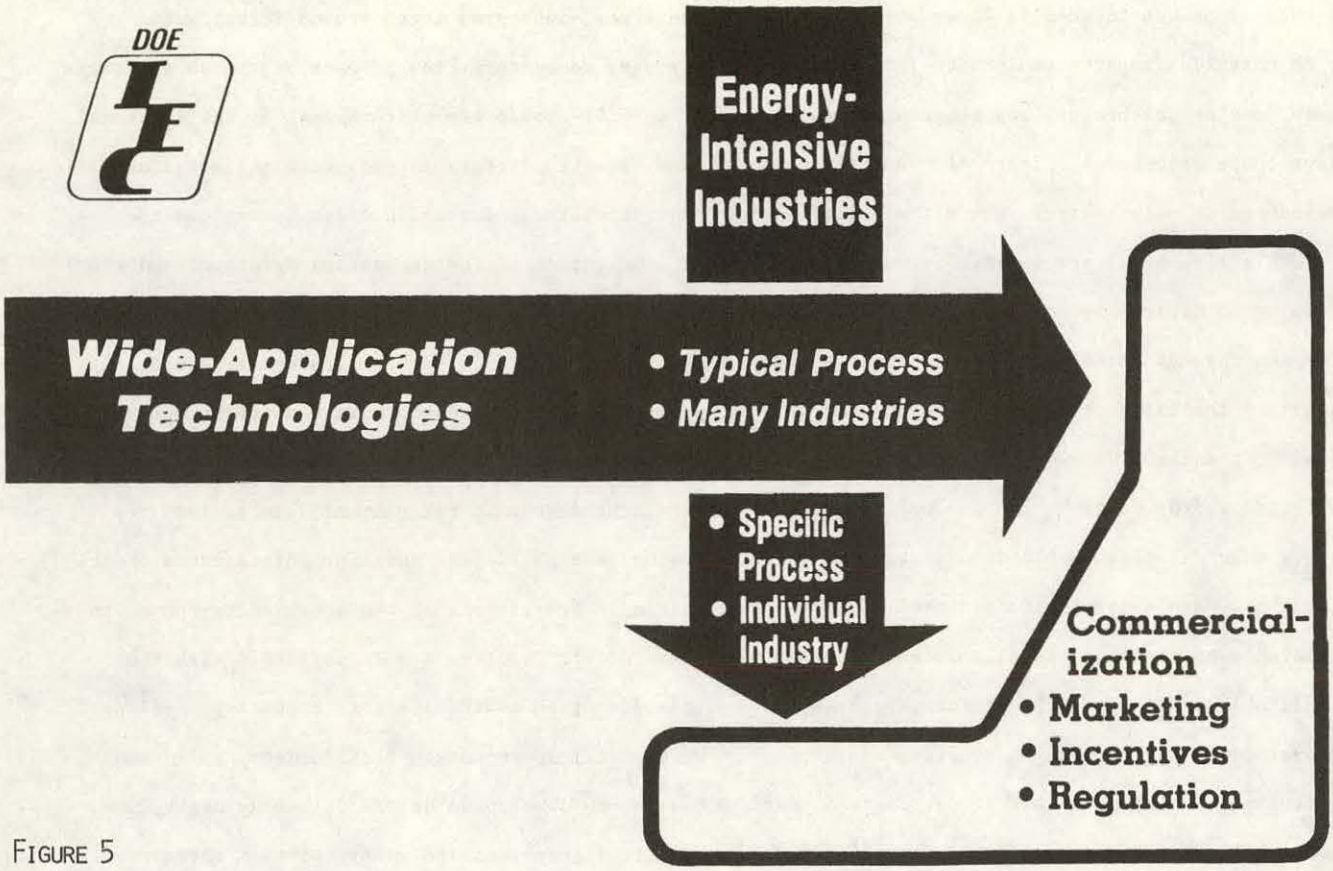


FIGURE 5

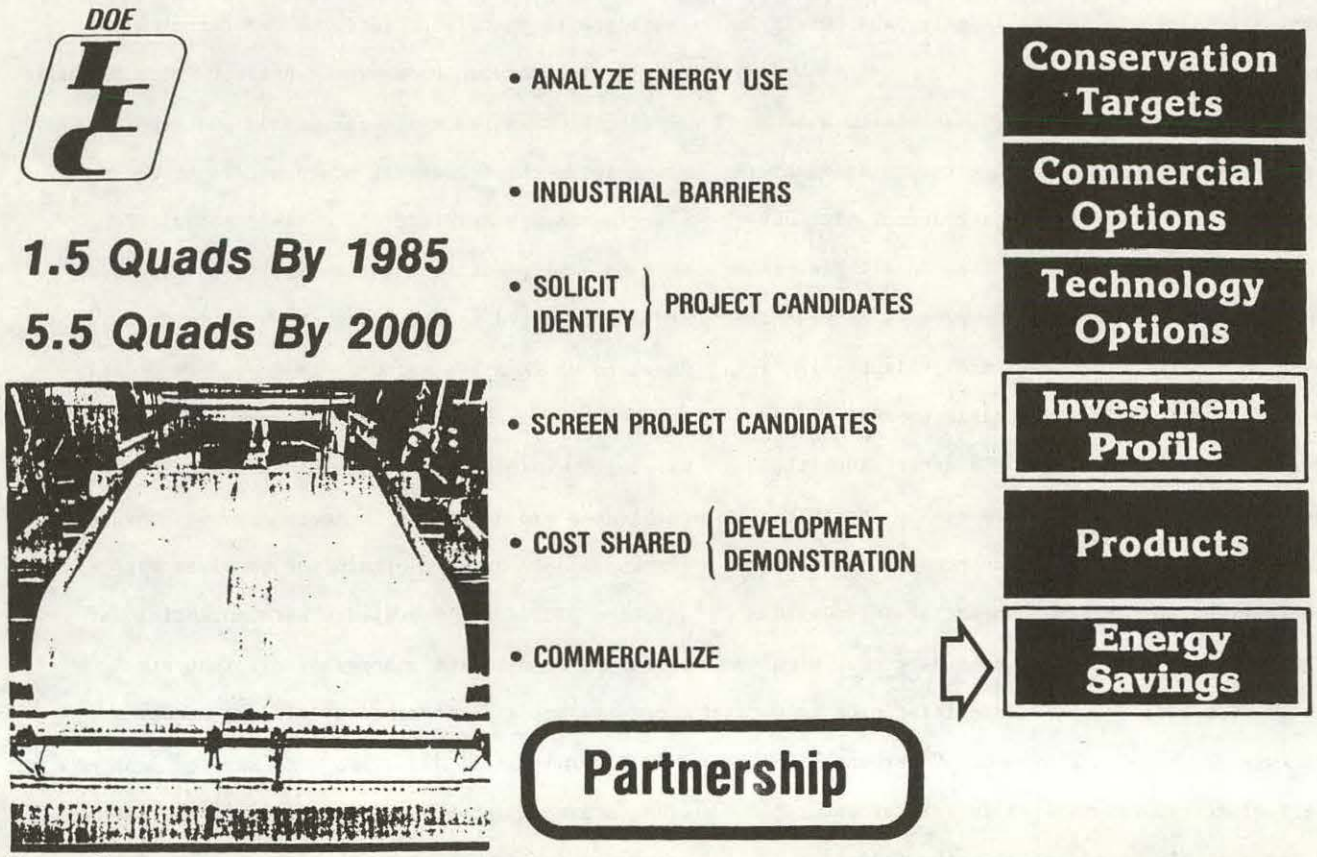


FIGURE 6

most successful efforts to date resulted when the participants in the project included, for instance, an equipment manufacturer, a potential industry customer who provided the demonstration site, and the industry as represented by its trade association. The participation of the industry, through its trade association, in the whole process from concept through development and demonstration made sure the technology met industry requirements and led to implementation by several companies even prior to completion of the project.

If the program sounds complicated, be assured it is not. When stripped to its fundamentals, the industrial energy conservation program is to find the best opportunities for reducing energy use and to develop solutions for these opportunities in partnership with industry.

Where do we stand now? The program as it stands today is about two years old; however, its roots go back at least to 1973 in several different Federal agencies. The goals of the program are a reduction in industrial energy use of 1.5 Quads by 1985 and 5.5 Quads by 2000. Some 90 technology projects are now underway at a budgeted cost of 30 million dollars in FY 80. In addition, the industrial program includes a significant technology deployment effort budgeted at 10 million dollars in FY 81. Although technology deployment is not part of this overview, its role in implementation of the technology developed cannot be overstressed. Technology in a report on the shelf is almost worse than none, so we are working hard at developing efficient technology transfer strategy for each case to effect commercialization as rapidly as possible.

A brief look at the two thrusts of the program, horizontal - wide-application technologies, and vertical - energy-intensive industries, will provide some insight into how the program functions.

Wide-application technology, by definition, addresses conservation opportunities spread across all industry sectors (Figure 7). Here we look at the commonalities of industrial feedstocks; fuel; combustion; products; waste streams such as waste heat, by-products, and materials wastes; and processing. For convenience, this area is divided into waste energy utilization, alternative materials, and cogeneration. Taking waste energy utilization as an example of this area, we have a group of projects designed to improve recuperation particularly at higher temperatures, an effort in heat pumping again aimed at higher temperatures; and a group of projects aimed at the very low temperature waste heat streams (Figure 8). There is another group of projects aimed at preventing waste by improving high temperature insulation. Finally, there is a group of projects in advanced combustion aimed at reducing the source of waste energy. Philosophically, waste energy utilization is the wrong end of the horse to work on. However, until we learn how to remodel the horse, we will have to apply the best horse sense we have wherever it is applicable.

The energy saving goal for this sector is 0.6 Quads by 1985 and 1.83 Quads annually by 2000. Note that this group of projects is expected to contribute about one-third of the 5.5 Quad goal for 2000, reflective of both the amount of waste energy and the many technologies that are available to reduce energy waste.

Ceramic recuperators provide an example of the technology development program in action. Some of the large energy waste streams are at temperatures too high for use of available recuperators.

DOE

Wide-Application Technologies

- Typical Process
- Many Industries

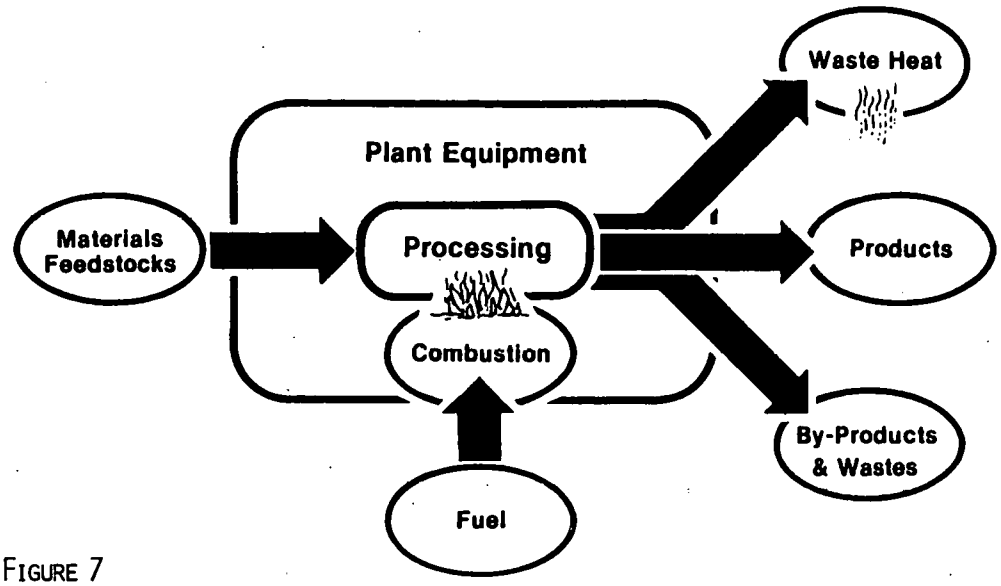


FIGURE 7

DOE

Wide-Application Technologies

Waste Energy Utilization

1985 0.60 quads

2000 1.83 quads

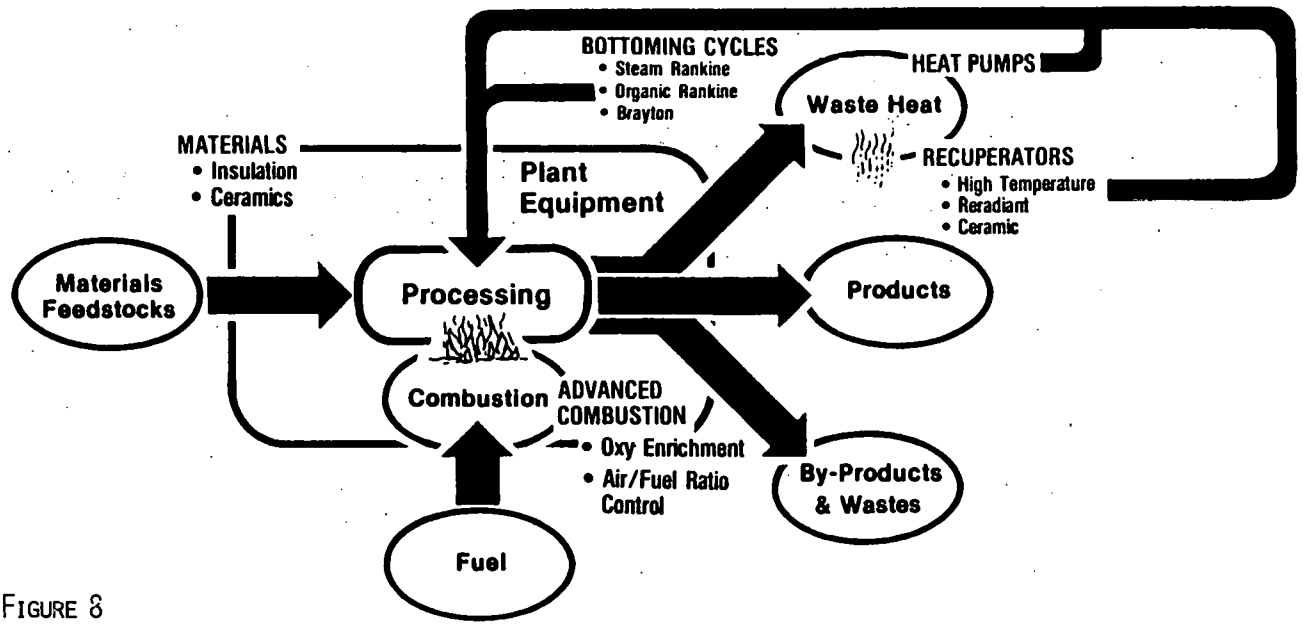


FIGURE 8

Development and demonstrations are underway on a built-up, cross-flow, thin-wall module of a nominal capacity of 850 cubic feet per minute. Five early demonstrations including corrosive gas flows up to 2600°F have shown the feasibility of the development and led to some initial commercial sales. Fuel savings from preheating combustion air are 30 percent. A second ceramic recuperation development is in preheating combustion air for glass furnaces. Here again, corrosion resistance at higher exhaust gas temperatures permits improvement in fuel use.

Another project that has wide applicability is air fuel ratio control. Accurate control of air-fuel ratios can permit operation of burners close to stochiometric. The objective of this project is to demonstrate the savings attainable by actively controlling the ratio for multi-burner combustors. A prototype unit operating in manual mode, has demonstrated fuel savings in excess of 2 percent on an oil-fired burner. Greater savings are anticipated by using automatic control. Following the oil-fired tests, demonstrations will be conducted on gas-fired and coal-fired boilers.

In the area of energy intensive industries, we are looking at the vertical thrust approach, industry specific technology (Figure 9). Altogether, projects developed for the nine industries in this area are expected to contribute 2.2 Quads to the 5.5 Quad goal for 2000. These projects are efforts to develop specific energy-saving changes in manufacturing processes and thus, in many cases, require significant capital investment to implement. Industry's participation, therefore, is particularly critical to success in these efforts, in selection of projects, in development and demonstration, and finally in commercialization. A few examples will illustrate the approach.

In the textile industry, the major use of energy is for drying, removing the water used as a carrier in several different processing operations. The dyeing operation is one of these operations. Dyes are applied from a water solution and the fabric is dried after color is applied. A technique called foam dyeing is being practiced in Europe and is being investigated in this country, but no companies had installed the process in production. In foam dyeing, the dyestuff is suspended in a water based foam significantly reducing the water that has to be removed prior to the next operation. DOE has entered into a cost-sharing agreement with a textile company to demonstrate the technology on a production line. Initial results are better than anticipated in that the process achieves the expected energy savings but apparently also provides an improved product.

The estimated energy savings if a reasonable penetration of the potential market is achieved is 52 trillion BTU's per year.

The steel industry, our largest energy consumer, at 3.8 Quads per year, is a natural target for energy conservation effort (Figure 11). Limited capital development from a mature industry, massive requirements for process changes, and mandatory investments in regulatory requirements are some of the factors cited as inhibiting energy conservation in the steel industry. Yet there are opportunities for significant energy-use reductions. One of these is at the point where the billets from the steel production step are cooled, inspected for surface blemishes which are manually removed in a process called scarfing, and then reheated for the next processing operation. Significant energy losses are incurred in cooling, then reheating the billets. The purpose of this effort is to develop a system to inspect and scarf, if necessary, the steel slab while

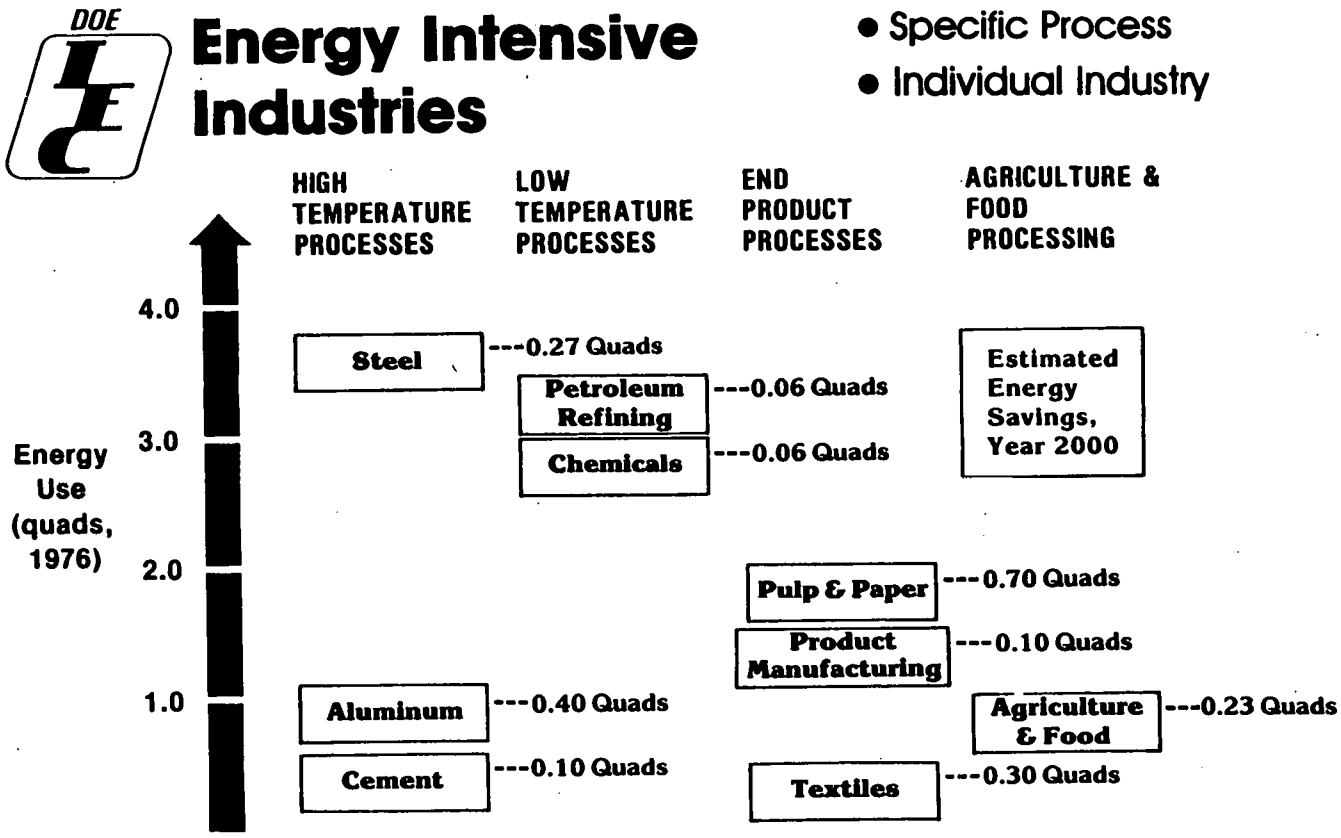


FIGURE 9

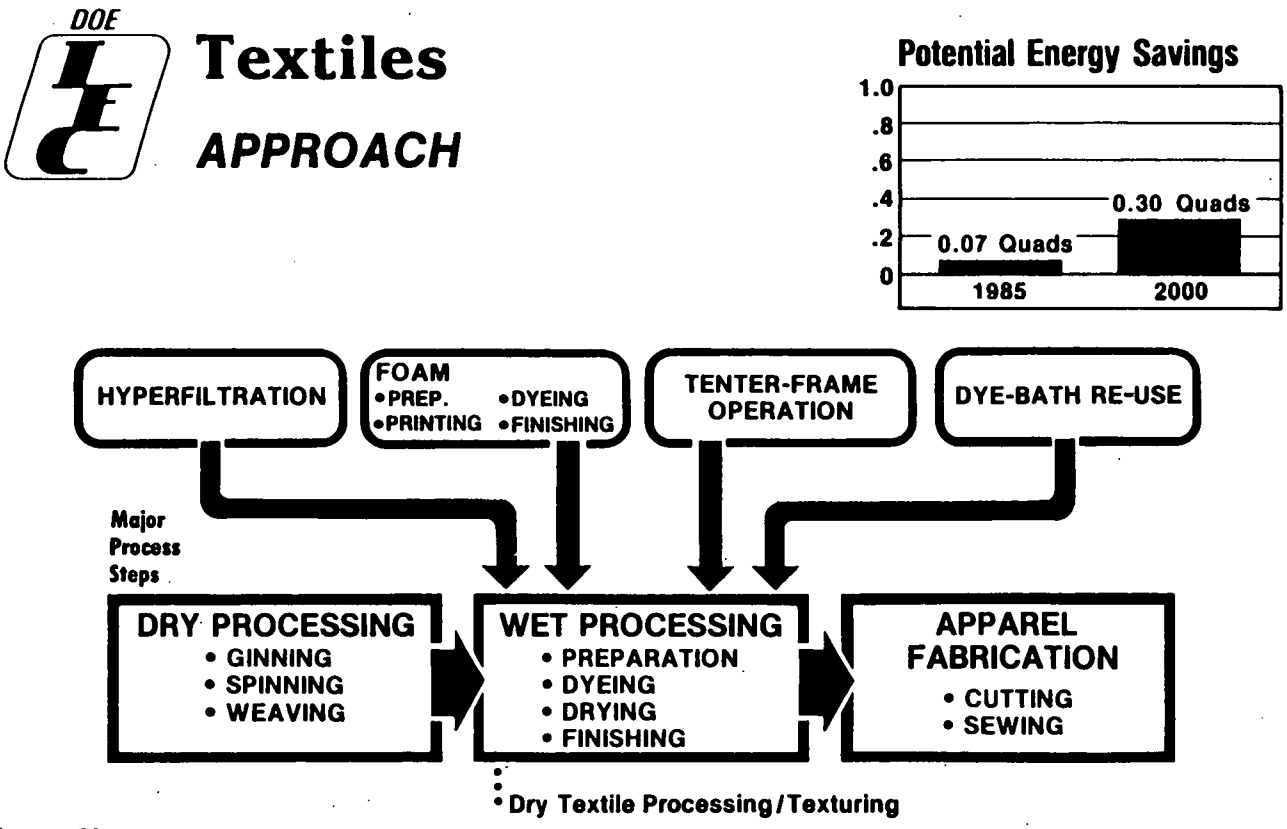


FIGURE 10

hot. This would allow direct rolling with possible incremental heating while maintaining a high quality surface. Energy savings could reach about 0.25 Quad/year.

A final example in the product manufacturing sector involves an opportunity to reduce the energy used to power hand tools (Figure 12). An analysis indicated that significant energy is used to power hand tools and that electric powered tools, especially high frequency 180 and 360 Hertz, are more energy efficient. Several demonstrations are underway on industry production lines to verify the study results. Estimated savings from the use of high-frequency electric over pneumatic powered hand tools, where feasible, are in excess of 76 trillion BTU per year.

The industrial energy conservation program is in a constant state of flux as we continue to improve the focus on the conservation target areas. For instance, you may have noted that the goals for the petroleum refining and chemical industries are only 0.06 Quads savings per year in 2000; yet these two industries are numbers two and three in energy consumption. We are not satisfied that we have an adequate program for these two industries that are so close to the heart of Texas. We won't be satisfied until we have explored all the options in depth with knowledgeable members of these industries. We are constantly completing projects and initiating new ones as opportunities are uncovered. As an example, we are considering a project to speed the development and demonstration of a novel, more efficient process to produce methyl tertiary butyl ether (MTBE), to date the only additive approved by the Environmental Protection Agency as an octane booster additive for gasoline. The developers claim the concept has potential for improving the energy efficiency of other chemical reactions also.

We need better measures of the effectiveness of the conservation program. No energy is saved until the technology developed is installed and used in industrial plants. Our 1985 and 2000 goals are based on a reasonable market penetration of demonstrated technology, so we are developing a means for measuring this market penetration and, hopefully, the actual energy saving achieved.

Those of you familiar with the industrial energy efficiency reporting program targets may wonder how these targets mesh with the R&D goals of saving 1.5 Quads annually by 1985 and 5.5 Quads by 2000. Upon reflection, I believe you will realize these are the technology developments that will boost our industrial energy efficiency improvement into that next range of 20 to 30 percent that we have said would probably require some capital investment. Some may help us move into the next range of 30 to 50 percent improvement. You might say the technology development effort is attempting to keep a stock of demonstrated more energy efficient technology available for industry to adopt as the applicable conservation opportunities are identified.

I will close with that truism, that a barrel of conservation is usually the lowest cost energy source (Figure 13). An analysis of 30 of our energy conservation projects showed the cost of energy obtained from conservation efforts was lower than almost any other energy source in 1978. At today's prices, I am sure there would be no contest.

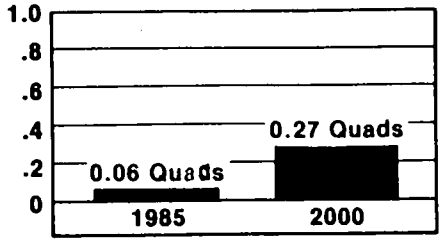
Let me reiterate, this program is a partnership of industry and government. Industry's participation is vital. We salute your past achievements and we solicit your continuing cooperation to solve our Nation's energy problems.

DOE

Steel

APPROACH

Potential Energy Savings



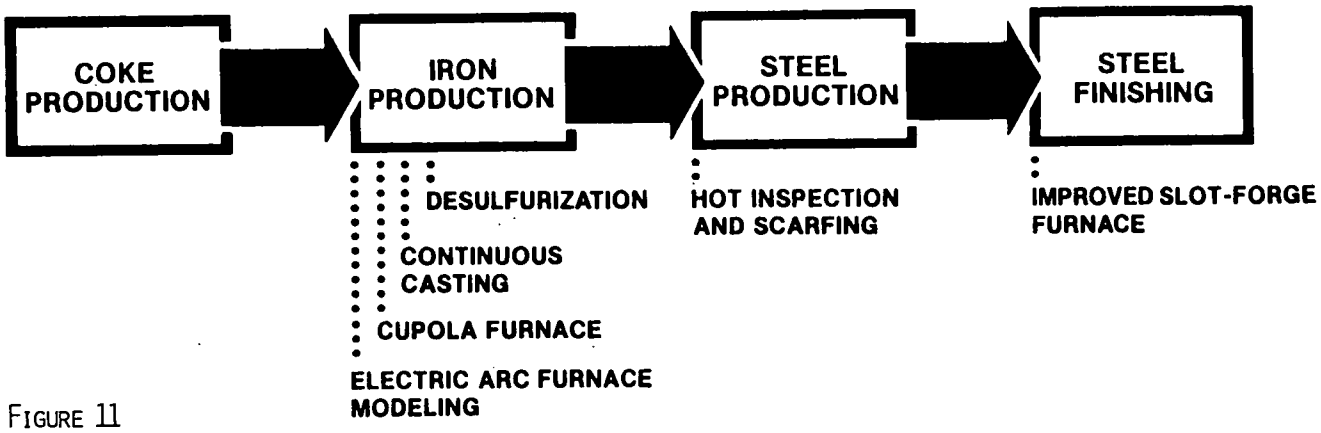


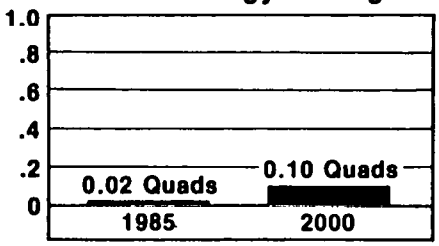
FIGURE 11

DOE

Product Manufacturing

APPROACH

Potential Energy Savings



Major Sector Categories

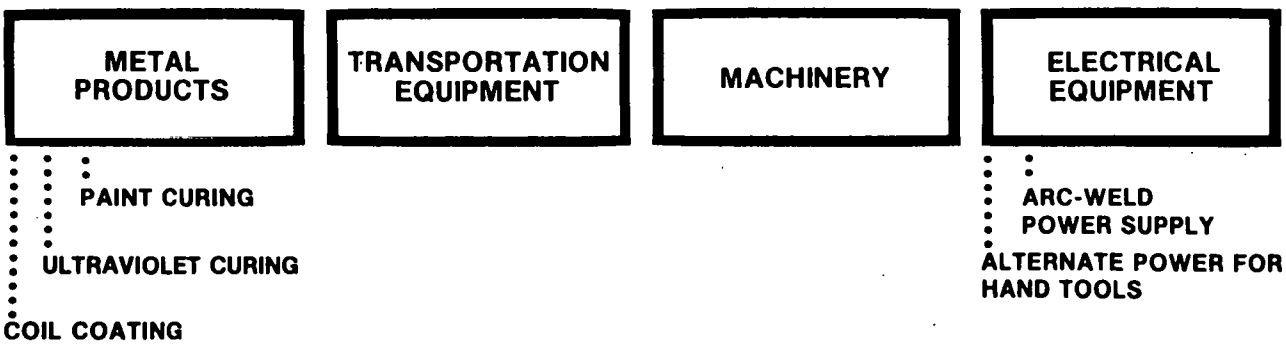


FIGURE 12

DOE

CONSERVATION Vs. COST OF FUEL

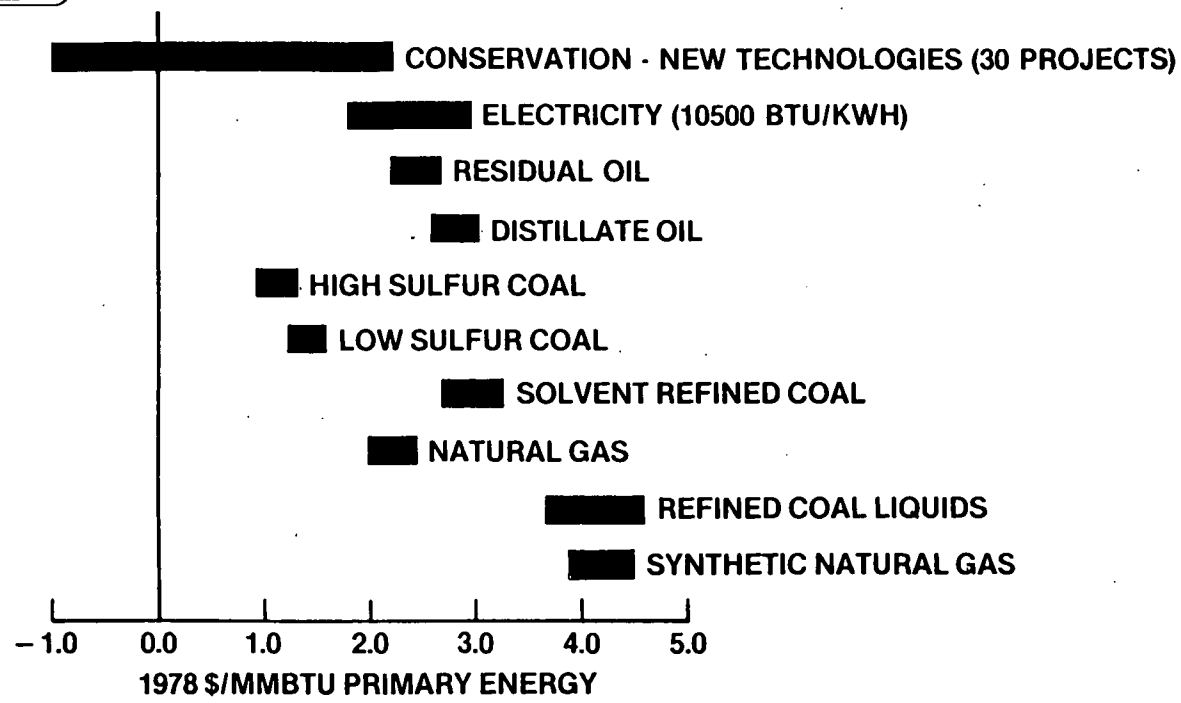


FIGURE 13

THE FRENCH NATIONAL ENERGY-CONSERVATION PROGRAM: THE CASE OF INDUSTRY

JACQUES ZYSS

HEAD OF THE INDUSTRY AND AGRICULTURE DIVISION

ENERGY CONSERVATION AGENCY

DEPARTMENT OF INDUSTRY-FRANCE

PARIS, FRANCE

France is certainly one of the industrialzed countries which has been the most severely affected by the energy crisis. It has thus been necessary since 1974 to plan and execute a bold, far-reaching government policy for energy reconversion. There are a number of reasons for this situation, which is chiefly due to the structure of our sources of energy supplies and to the status of our system of energy consumption on the eve of the crisis in 1973.

Figure 1 shows the evolution of over-all energy consumption and the breakdown of this consumption between the different forms of energy during the last two decades.

Three factors must be pointed out :

- During this period economic growth has been very rapid (Gross National Product was multiplied by 2.1, between 1960 and 1973) and has been followed up by a substantial increase in energy consumption (multiplied by 2 between 1960 and 1973).

- Hydrocarbons, and particularly petroleum products, have fueled most of this growth : their consumption increased by 430 % between 1960 and 1973, and their share in our energy sources rose from 31 to 67 %).

- As a result, we became increasingly dependent on foreign sources of energy. Since France has few and dwindling domestic resources, the rate of dependence on foreign imports rose from 38 % in 1960 to 67 % in 1973.

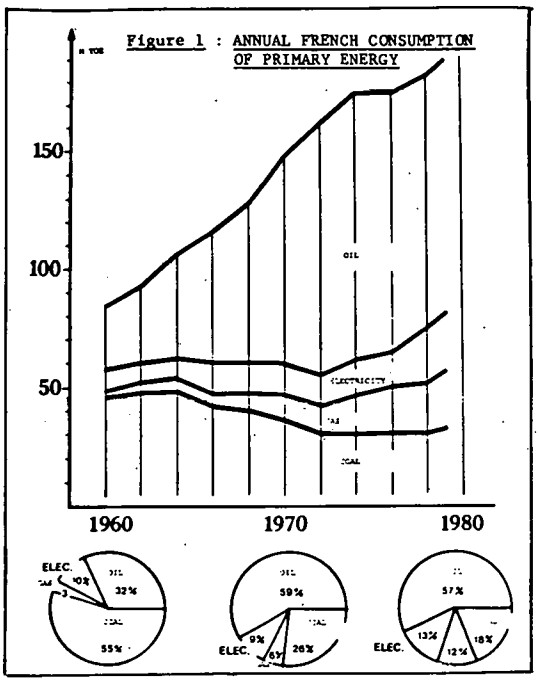
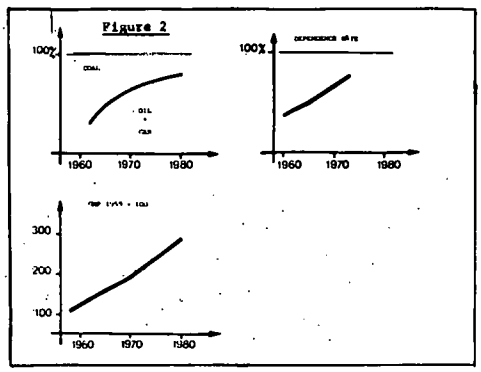
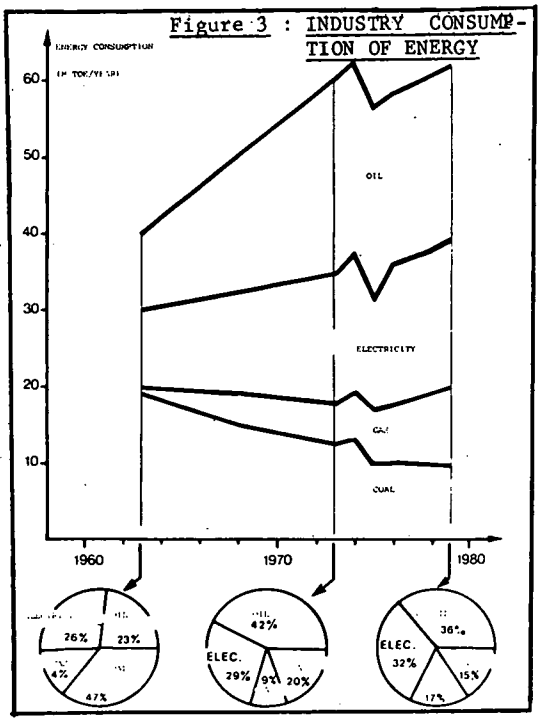


Figure 1 : ANNUAL FRENCH CONSUMPTION OF PRIMARY ENERGY



The same comments can be made with respect to a comparable analysis of the pre-1973 trends in industrial energy consumption, which is shown on figure 3.

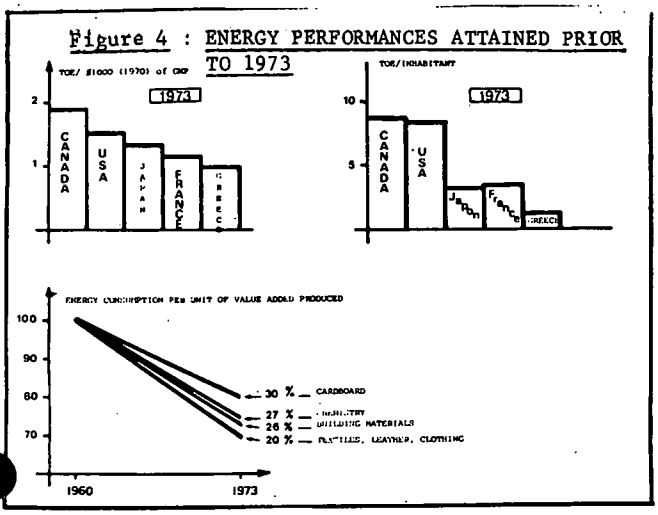
Figure 3 : INDUSTRY CONSUMPTION OF ENERGY



This evolution took place in an industrial environment that was characterized by an accelerated renovation of the means of production accompanied by a steady decline in the cost of energy, after allowance for inflation.

In the 1960's, french industry went through considerable structural changes and opened itself widely to world competition : most of our to-day's plant were therefore built in this period.

Figure 4 : ENERGY PERFORMANCES ATTAINED PRIOR TO 1973

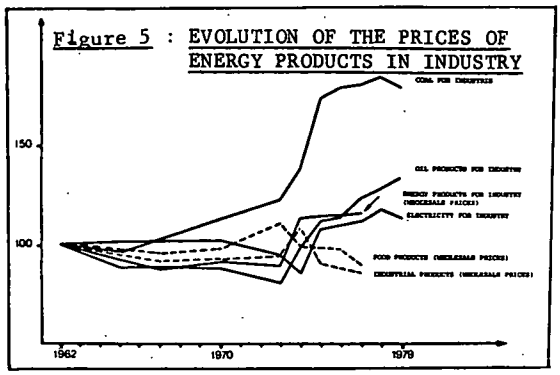


This accelerated transition, which in addition was a contributing factor in the accelerated imports of petroleum, partially accounts for the fact that international statistics place France among the foremost countries in rational use for energy, whether it is measured in terms of consumption per unit of Gross Domestic Product or per capita consumption.

Over the period 1960-1973, the rate of decrease of energy consumption per unit of industrial added value amounted to 2 % a year.

This trend, moreover, developed as figure 4 shows within the framework of a steady decline in the price of energy (except coal, which was in the process of being phased out after depletion, on current economic conditions, of our own reserves) measured in terms of inflation adjusted costs or even, in some cases, in terms of unadjusted costs.

Figure 5 : EVOLUTION OF THE PRICES OF ENERGY PRODUCTS IN INDUSTRY



In 1973, french économy and especially french industry were thus characterized by :

. a satisfactory adaptation to the structure of energy prices ;

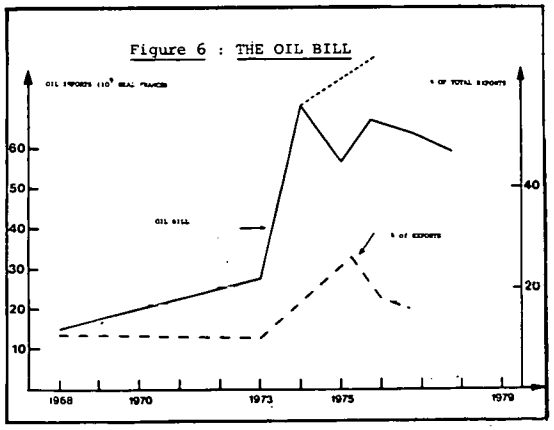
. an apparently favorable situation with respect to energy specific consumption in most sectors ;

. a clear predominance of oil-derived products.

That gives an idea of the degree to which the shock of 1973 had severe repercussions of the french economy, to the extent that all the former advantages then became disadvantages.

- Our energy imports became a heavy burden, because of dependence on petroleum. Figure 6 shows the evolution of the oil bill.

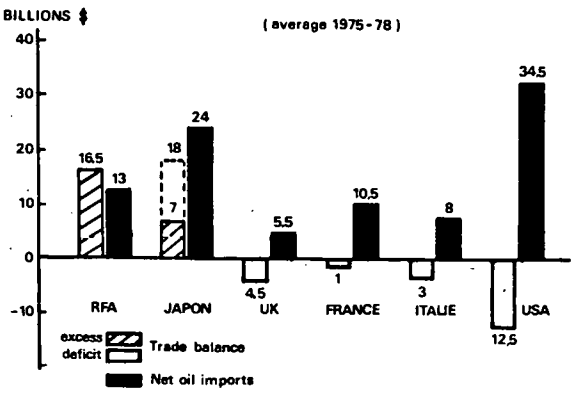
Figure 6 : THE OIL BILL



- Our high existing level of rational use of energy rendered further improvements in energy productivity more difficult than in other countries.

Furthermore, unlike Japan or Germany, our existing balance of payments left us only a very narrow margin to adapt to new trade conditions, as figure 7 shows.

Figure 7 : NET OIL IMPORTS AND TRADE BALANCE

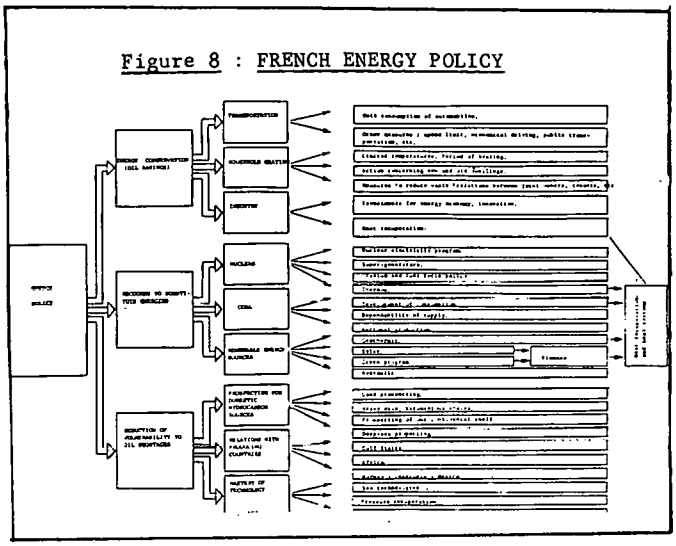


Therefore, France had, from year 1973 on, to redefine a brand new energy policy and shifted its emphasis into the three following directions :

- energy conservation ;
- reduction of our vulnerability with respect to oil ;
- Increased reliance on alternative sources of energy.

Figure 8 below shows the main lines of that new policy.

Figure 8 : FRENCH ENERGY POLICY



- First, energy conservation in all sectors of consumption, including industry.

- Second, reduction of our vulnerability with respect to oil, which is to be accomplished by means of three types of program :

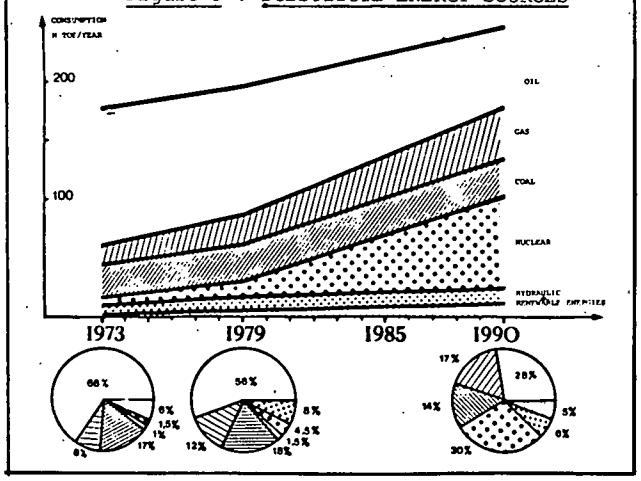
. a program for domestic hydrocarbons, including reinforcement of traditional domestic propecting, introduction of new activities to extract heavy oil, forced extraction, exploration of the continental shelf and deep sea exploration ;

. a set of related actions aimed at diversification of our sources ;

. programs designed to enable us to master the technology necessary to carry out these objectives.

- And finally, the third part of our new energy policy, the recourse to alternatives to the hydrocarbons as sources of energy will be based on an increased reliance upon nuclear energy, coal, and renewable energy sources, for which currently projected consumptions are shown on figure 9.

Figure 9 : SUBSTITUTE ENERGY SOURCES



. The French nuclear program, which already generates 4,5 % of our primary energy, is the largest in the world when measured in relative value not only whih respect to the investments made for nuclear power plants construction (in 1985, it will correspond to 60 % of our consumption of electricity and 20 % of our over-all consumption, and in 1990 these proportions will amount to 73 % and 30 %) but also with respect to research and development (supergenerator, uranium policy and fuel cycle, breeding reactors).

The development of this program is subject to two limiting factors :

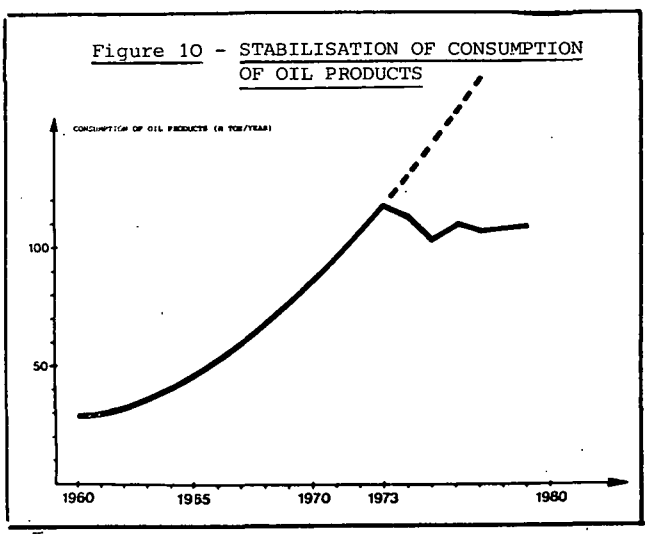
. The first of these is technical, and results from the physical limits to the speed in constructing nuclear power plants (the choice of sites, the environmental factors to be taken into consideration , our nuclear industry's capacity of production, the burden of financing the program).

. The second is economic, and results from the attention paid to integrating the use of electricity in a long-term program.

. Coal, natural gas and renewable energy sources (geothermal , solar or biomass) are to make their contribution by satisfying and increasing portion of our energy needs (in 1990, hydraulic power and other renewable energies will provide 10 % of our primary energy needs, while coal and natural gas will provide 30 %).

. Consequently, the consumption of oil products must, as figure 10 shows, be reduced to 80 Mtoe (million tons of oil equivalent) a year, whereas a continuation of the previous trend would have brought it to 210 in 1990, and we consumed 108.5 in 1979. The share of oil in our energy consumption will drop from 66 % in 1973 (and 56 % in 1979) to 30 % in 1990.

Figure 10 - STABILISATION OF CONSUMPTION OF OIL PRODUCTS

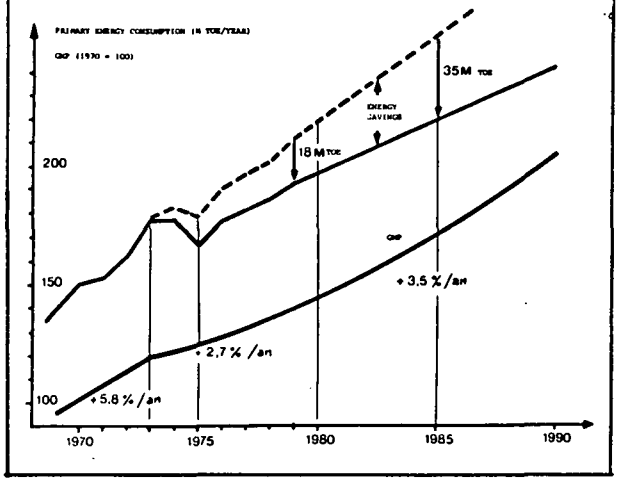


Within this over-all energy policy framework, what role is to be played by the energy conservation program.

An essential one, both from a quantitative and an economic point of view.

From a quantitative standpoint, the goal of energy economies is shown by figure 11, in which the upper curve represents a projection of the trend prior to 1973 and the lower curve shows the consumption actually forecast.

Figure 11 : GOAL FOR ENERGY CONSERVATION



These projections, based on the assumption that average yearly economic growth on the next decade will be 3,5 %, demonstrate how much is at stake.

In 1985 and 1990, the energy conservation goal represents respectively 80 % and 70 % of the projected nuclear electricity production, and 35 % and 65 % of the oil consumption.

This reduction corresponds to a decrease from 0,95 to 0,7 in the elacticity of the consumption of energy compared to economic activity.

In economic terms, this program allows for the best possible distribution of the financial ressources of the nation for the necessary energy shift, without endangering economic growth.

It is indeed necessary as in figure 12 to compare, the cost of the investment which makes it possible to economize a unit of energy with the cost of the investment which would be necessary to produce that same unit. Whenever the former costs less than the latter an investment which economizes energy reduces by the difference between these two figures the cost of our energy program, and this can represent huge financial savings.

Figure 12 : COST OF ENERGY PRODUCED AND COST OF ENERGY SAVED 1978 figure

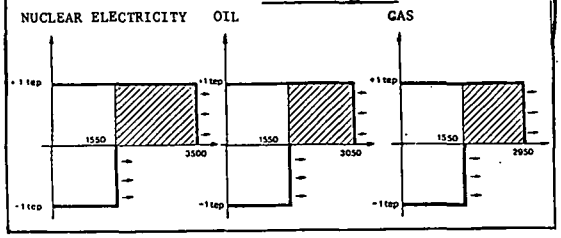


Figure 13 : ENERGIE-SAVING POTENTIAL IN INDUSTRY

4 Mtoe /a year : CONVENTIONAL OPERATIONS AIMING AT MORE RATIONAL USE OF ENERGY (HEAT INSULATION, PROCESS CONTROL, READAPTATION OF BURNERS, HEAT RECUPERATION, HEATING AND VENTILATION OF BUILDINGS)

2 Mtoe /a year : RECYCLING OF WASTES AS BY-PRODUCTS FOR ENERGY PRODUCTION

2 Mtoe /a year : LIQUID WASTE HEAT RECUPERATION

1 Mtoe /a year : OPTIMIZATION OF DRYING OPERATIONS

3 Mtoe /a year : COGENERATION

4 Mtoe /a year : ECONOMIES OF ELECTRICITY IN ITS CONVENTIONAL USES (POWER, LIGHTING)

5 Mtoe /a year : PENETRATION OF ELECTRICITY IN NEW SPECIFIC USES (HEAT PUMP, INDUCTION HEATING PHASE SEPARATION)

3 Mtoe /a year : NEW INDUSTRIAL PROCESS

22 Mtoe /a year, which represents 35 % of industry consumption in 1979 (62 Mtoe).

From a qualitative point of view, the energy economy program is consistent with our objectives insofar as the environment and the improvement of working conditions are concerned.

But sometimes, economics is not all. From a strategic standpoint, our energy conservation program is in any case indispensable for it does not seem possible to obtain more than currently projected from our programs of diversification and substitution and notably from nuclear energy and and other new energy sources. The gap between demand and offer must therefore offer some incentive for conservation. As a ceiling has been set for petroleum, therefore energy conservation is definitely a must.

It must in fact be looked upon as a real and profitable mine of potential energy.

That raises two questions :

. How big is this mine, and what is the potential rate of extraction ?

. What measures, if any, must be taken by government to make sure that such mine-digging proceeds under best possible conditions ?

But in the first place, what is the size of the mine ?

Figures concerning the industrial sector only will be given, but an examination of the other sectors would lead to similar conclusions.

An initial approach by techniques of energy conservation, as shown on figure 13, reveals that their potentialities are considerable.

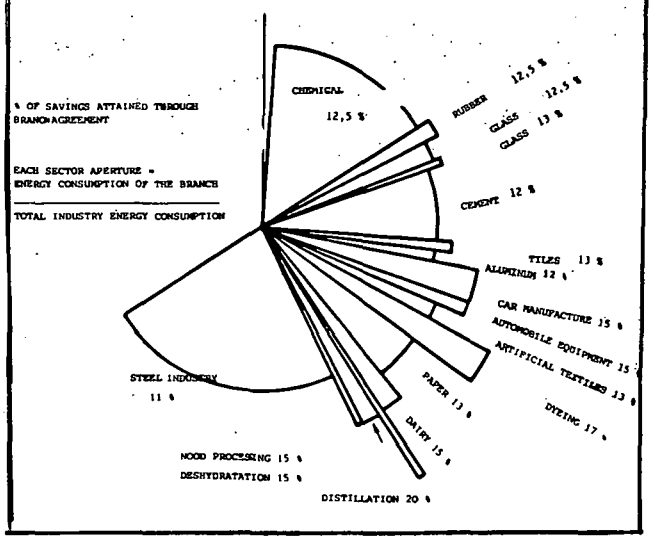
It is clear that in the long run (1990) the specific consumption of industry could be reduced by more than 30 % on the basis of now available technologies.

Taking into consideration the many R.D. projects currently under way, the potential sources of energy conservation will certainly be even greater, and it is not unreasonable to imagine that the specific consumption of industry could be reduced by more than 50 %.

A second approach to this question can be made by analyzing each industrial sector.

The French Department of Industry has concluded 37 energy conservation agreements with different branches of industry, who have pledged to reduce their energy consumption in 1980, by comparison with 1973, in the proportions shown for most of them in figure 14. All indications tend to show that these objectives will be attained and even surpassed by the end of this year.

Figure 14 : OBJECTIVES FOR SPECIFIC CONSUMPTIONS CUTS (1980)



The role assigned to energy conservation our energy program is therefore ambitious but realistic.

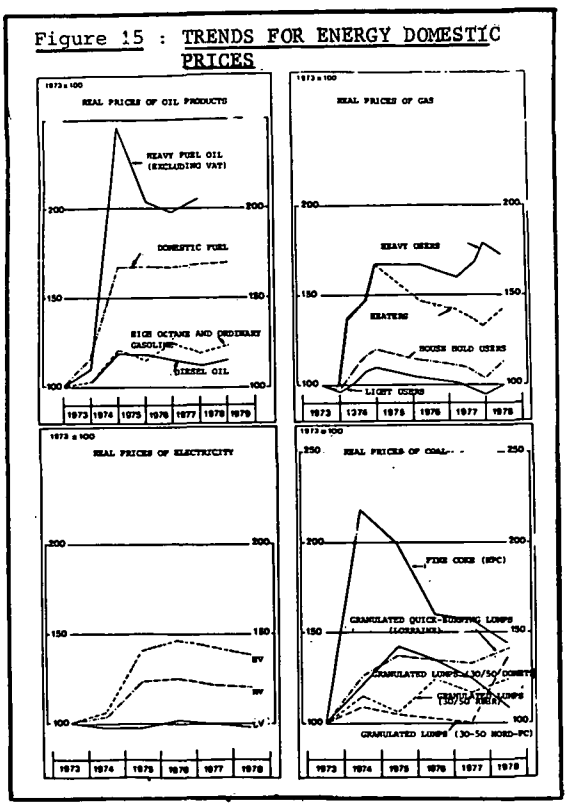
But how do we plan to reach this goal ?

To do so, we are relying both on spontaneous functionning of the market and on substantial interventions by the government.

It is, indeed, clear that the best incentive to conserve energy should be the increasing cost of that energy. Investments that conserve energy are inherently beneficial, unlike for example environmental investments. But it is essential that the pricing of energy should reflect real costs so that the increase in the cost of our supplies can be immediately passed along, to all the consummers.

Figure 15 shows to what extent that objective could to be attained in France. It is, in any case, of the utmost importance now to eliminate all tariff and commercial practices that have the effect of subsidizing consumption.

Figure 15 : TRENDS FOR ENERGY DOMESTIC PRICES



But the operation of the laws of the market is not allways in itself sufficient :

- The complexity of our economy does not always make it possible to attain instantly a price policy that is really the best possible one from the energy conservation policy point of view and distortions may subsist for a certain length of time.

- The persistence of effects of the situation prior to 1973 sometimes results in delaying the decisions of business executives, and furthermore the contradictory information that is circulated concerning the energy market causes some of them to refrain from anticipating the larger price increases that are ahead of us.

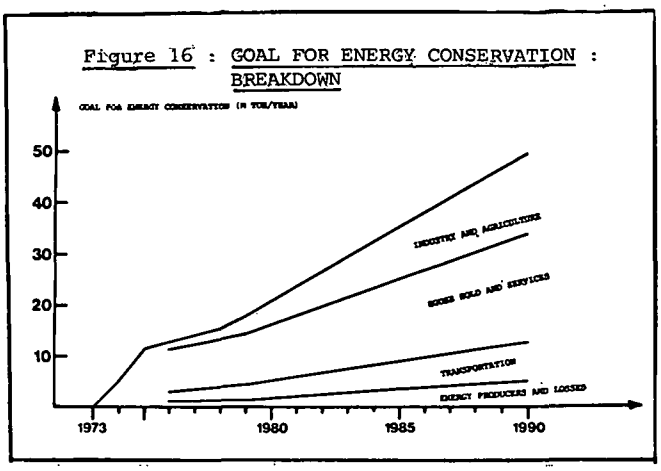
- The decision to invest in order to conserve energy is, as previously stated, in competition with the decision to invest in order to produce more energy : but the first type of decision is made by a large number of economic agents on a completely decentralized mode, while the second type of decision depends on powerful and highly centralized enterprises : the major energy producers of the nation.

- These producers are willing to wait a relatively long time to recover their investments (15 to 25 years), where executives out of the energy sector often will not make an investment to conserve energy that will not pay for itself in less than a few years.

That is why France has established a policy of very active involvement by government authorities to compel or incite consumers, especially those in industry, to save energy.

As figure 16 shows, our energy conservation program relies on every sector of consumption in the country, including industries.

Figure 16 : GOAL FOR ENERGY CONSERVATION : BREAKDOWN



To implement this policy was created in 1974 an Agency for Energy conservation, which is a public Agency , placed under the Ministry of Industry, responsible in France for energy policy.

The Agency has a twofold mission :

- It draws up and proposes to the Government the elements of the national policy of energy conservation.

- It carries out this policy, along four major lines :

. regulations relating to the use of energy ;

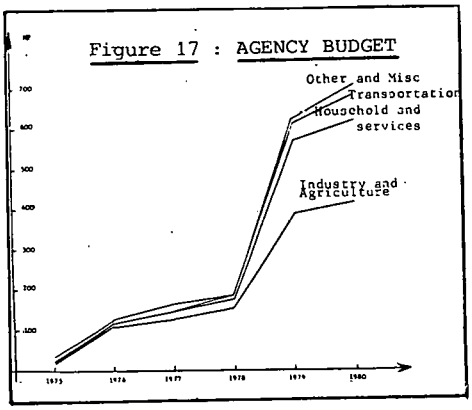
. increasing public awareness of the problem, providing technical information and training :

. encouraging the demand for energy conservation, notably by providing financial incentives towards investments ;

. stimulating the offer of energy conservation equipment and services, by setting up and demonstrating new techniques, and by interventions aiming at better and more efficient marketing and commercialization in this field.

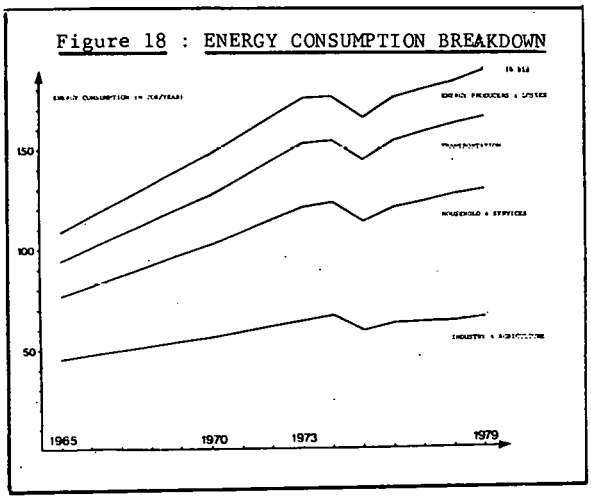
The Agency has been granted a constantly increasing budget which may soon amount to more than a billion francs a year.

Figure 17 : AGENCY BUDGET



I will now briefly sum up the measures that have been taken by the Agency whith respect to the industrial sector, which in 1979 accounted for one third of the country's consumption, as figure 18 shows.

Figure 18 : ENERGY CONSUMPTION BREAKDOWN



First of all, in the field of regulations, two types of measures were taken.

In the first place, major energy consumers were subjected to a regular visit (every 3 years), at their own expense, of an energy expert who determines the energy balance of the enterprise and issues recommendations as to the improvements that should be made in the operation and even the design of the installations. The expert's conclusions are submitted to the enterprise executive and the Agency.

In addition, a certain number of written regulations set obligatory minimum standards for certain types of commonly used equipment : heat generators, thermic isolation installations and ventilation of industrial buildings, in particular.

Other written regulations are under study, but it is clear that this type of measure is not, in itself, sufficient to permit to reach our objectives. The great variety of means of using energy in industry, and the necessity of not penalizing our enterprises by comparison with their foreign competitors would preclude reliance on a purely regulatory policy.

The problem is, indeed, within the framework of an open, liberal, competitive economy, to incite enterprises voluntarily to take actions that make it possible to conserve energy.

There are three types of action :

- First step : change habitual procedures and accept to make a few modest investments to improve the operation of installations. In general, this involves elimination of certain forms of waste which the increase in the price of energy have rendered flagrant : such course of action is usually called "improved house-keeping".

- Second step: undertake larger investments to alter by retrofit or even redesign the industrial installations. What is involved here is an over-all program of reoptimizing the productive apparatus for maximum energy efficiency.

- Finally, we must start immediately to prepare the future by launching research development and demonstration programs.

Each of these three types of action involves a corresponding type of intervention by Agency.

The first type is based on making industry personnel aware and instructed on the problem.

Figure 19 below shows how this policy is implemented.

Later, at the stage of demonstration, the Agency can grant a 50 % subsidy to the first full-scale user of a new installation. The Agency pays the full cost of a campaign of measurement and evaluation; the results of which are made public.

Finally, at the end of the cycle, we are now contemplating ways to encourage the creation of commercial networks in charge of handling the sales promotion, sales and installation of energy conservation equipment.

This last series of measures and the resulting industrial programs enable us to consider that the French capital goods industry has been able to find means to adapt itself in depth to the new energy conditions and that it is ready to supply not only the French market but also foreign markets with innovations in energy conservation equipment. The effort that we have made at the same time in French enterprises to stimulate a demand for such equipment guarantees a vast domestic market for it that will help to provide a large number of references and to reduce the cost of production.

This new aspect of French industry should be better known and, hopefully, appreciated in the U.S.A.

Now, after that general description of the principal means of intervention by the Agency in the industrial sector, it may be of interest to try to evaluate some of the results so far obtained.

Figure 22, which gives figures set up after correction for variations in climate and activity, shows that substantial results have already been obtained.

It is particularly interesting to note that with the same quantity of energy as in 1978, industry produced 13 % more value added in 1979.

Figure 22 : ENERGY CONSERVATION BREAKDOWN
— SAVINGS (MTOE/YEAR)
--- FINAL CONSUMTION BY SECTOR

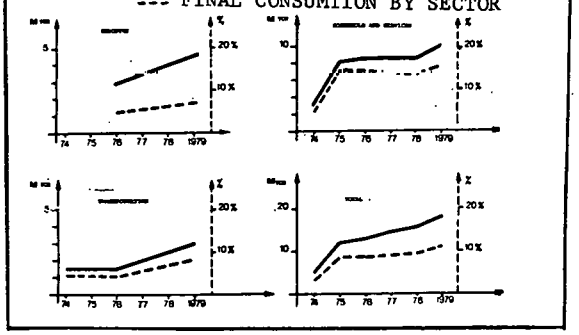
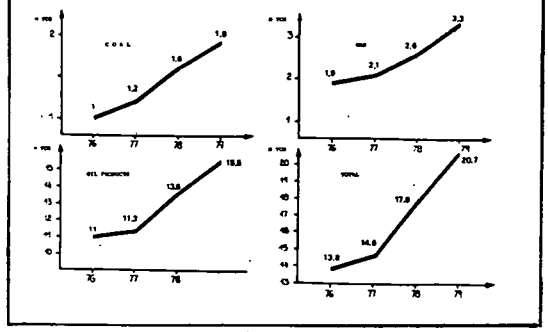


Figure 23 below shows how the energy conservation results break down according to the various energy sources involved.

Figure 23 : ENERGY ECONOMIES BY FORM OF ENERGY



In 1979 as figure 24 shows the rate of investments undertaken with the help of the Agency to conserve energy was quite encouraging, and amounts to three times as much as during the previous years.

Figure 24 : INDUSTRIALS INVESTMENTS RESULTING IN ENERGY ECONOMIES

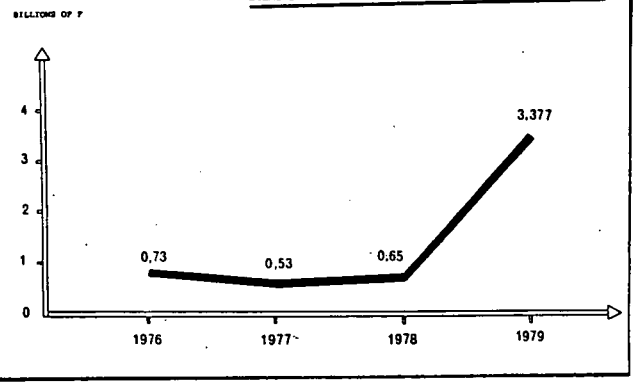
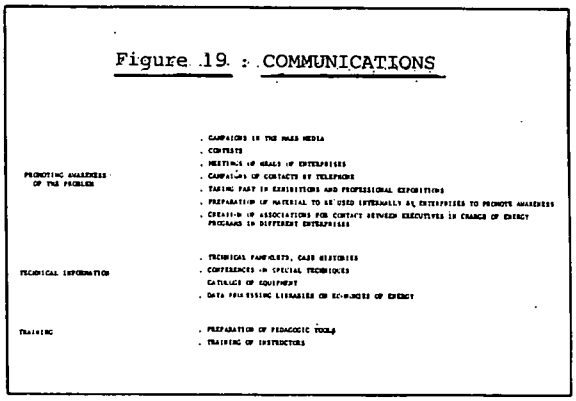
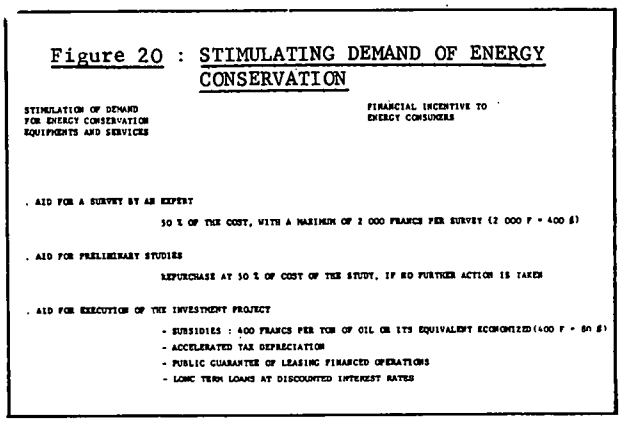


Figure 25 below shows the breakdown of there investments in term of number and cost, according to a ratio that is their cost per t.o.e. of energy yearly saved.



Once the ground has thus been prepared, our second type of intervention involves the use of financial aid to accelerate the market demand for energy conservation goods and service.

Figure 20 sums up the measures taken.



These procedures allow the Agency to assist an industrial enterprise at each step of its own program of energy conservation :

. If it is necessary to establish an energy balance for the enterprise and then seek the best possible distribution of energy flow, the Agency can subsidize the intervention of an expert if such an intervention is not already mandatory.
The intervention amounts to 50 % of the expert's cost, not to exceed 2 000 francs.

. If the possibility of making an investment exists but necessitates a preliminary study by a consultant, the Agency may aid the industrial executive by guaranteeing to repurchase this study at 50 % of its value, in the event that no further action can be taken after completion of the study.

. Finally, during the phase of execution of the investment project, the Agency distributes or provides access to various procedures of financial assistance :

- Subsidies, amounting to 400 francs per ton of oil or its equivalent economized, can be awarded to all operations whose cost for each ton economized is between 2 000 and 7 000 francs - which, at current prices of industrial energy in France, corresponds to an amortization of the investment within a period of between 2 and 7 years.

- Long-term and middle-term loans at favorable rates can be used to supplement these subsidies. They benefit from a 2 point discount by comparison with ordinary rates.

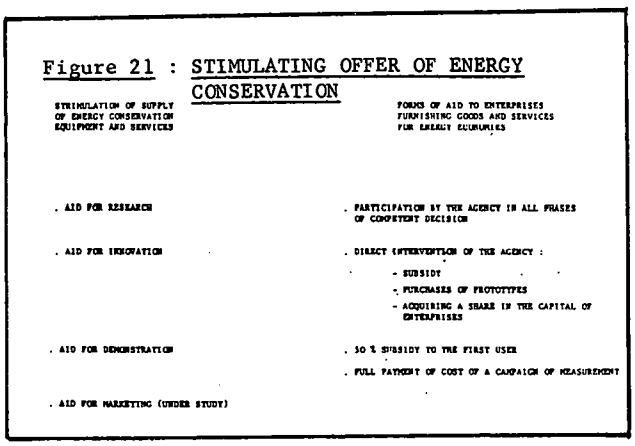
- The material used can be written off at an accelerated rate of depreciation for tax purposes.

- Finally, when the investment is financed by credit-lease, the industrial executive can ask for a guarantee by a public funds reserve set up by the Agency.

These financial aids are granted or examined by the Agency's regional representatives, and provide for supplementary facilities for small and middle-sized enterprises. The Agency is now considering a plan to improve their effect by having them handled by a certain number of economic agents who are directly concerned whith the success of the program of energy conservation : those who install or construct equipment.

The fourth and final aspect of the Agency's activities, which complements the preceding one, consists in also stimulating the offer of energy conservation.

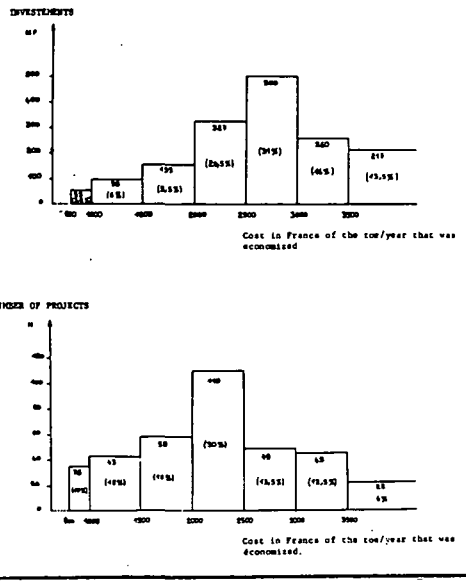
Figure 21 below shows the main lines of that program.



At the stage of basic research, the Agency takes part with various French or European organizations in the distribution of grants for research, and implicitly coordinates actions in the field of energy.

At a higher stage of development, the Agency may intervene directly through the distribution of subsidies, the purchage of prototypes, or acquiring a share in the capital of enterprises.

Figure 25 : BREAKDOWN ACCORDING TO DEGREE OF PROFITABILITY OF ENERGY-SAVING INVESTMENTS IN INDUSTRY (IN 1979)



But french industry still has a considerable way to go :

. it must divide by 2.7 its consumption of petroleum products, which necessitates notably the replacement of 2 out of 3 steam generators.

. at the same time, it will have to invest 60 billion francs to economize 6 M tons of petroleum or equivalent fuel on existing installations.

. finally, it will also have to contribute to the success of our objectives for the transfer of energy sources by a fivefold increase in coal consumption.

To conclude this rapid survey of our program for energy conservation, four points are to be emphasized.

The first is that there is nothing incompatible between the idea of energy conservation and a program of growth, economic and social progress. The mechanical correlation observed during the last few decades between growth and energy consumption is not at all inevitable. Not only is it the object of a policy of energy conservation to decouple these parameters, but above all it must be realized that if the growth of the years to come will have to be a moderate one, it is possible to find a potent motive force in that very quest for decoupling.

A policy of energy conservation can play a potent role in stimulating economic activity :

. It affords the most efficient allocation of the investments which the nation has granted in order to carry out its energy reconversion, by the most advantageous allocation of expenditures between energy production and conservation. This optimization cannot but play a positive role in restoring our major economic equilibrium.

. It permits a reduction in the cost of manufactoring for enterprises and thus improves their competitive position : this is a second growth factor.

. Finally, it affords the possibility of creating new activities and jobs to furnish goods and services to conserve energy, for which there certainly exists a world-wide market.

The second point will be the following remark: in a world that is troubled by imposing economic and monetary difficulties, caught between the reefs of inflation and recession, this type of boost to industry offers the special advantage, at least as a general rule, of leading to no further aggravation of existing tensions :

. No aggravation of the monetary tensions, because the boost is not an inflationary one.

. No aggravation of commercial tensions, since the market that is open is a substantial one and there are many places available within this market.

. Finally, and by definition, this type of action should permit a relaxation of tension on the petroleum markets.

What kind of program can contribute to continued growth and, at the same time, to a relaxation of all these tensions ?

I shall add, and this will be my third point, that french industry is resolutely committed to the search for energy conservation. But I should like to add that the initial results obtained have been permitted by an active involvment of the french equipment industry. In this connection, the success of the two conferences between France and the United States which were organized in 1978 in Paris and last February in Washington encourages us to feel that the cooperation started in this way could be rapidly expanded.

Finally, and this will be the last point, it is clear that these positive aspects of an energy conservation program cannot be durably and successfully obtained in a single country unless all other countries are engaged in similar efforts. Otherwise, the efforts of the countries engaged actively in this respect would be confiscated by the others whereas, in the long run, all would suffer.

That is the reason why such an exchange of information on government energy conservation programs can be useful when given at such a conference, which gathers representatives of the industrial community of a country which, on one hand, consumes 30 % of the world's petroleum production and, on the other hand, seems now determined to join the rest of the industrialized countries in their efforts toward energy conservation and ever better energy efficiency.

THE ROLE OF THE CANADIAN GOVERNMENT IN INDUSTRIAL ENERGY CONSERVATION

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Canada has undertaken to become self sufficient in energy by 1990. To buy the necessary time to develop domestic supplies, energy transport systems and to extend the time life of energy reserves, we have embarked on an energy conservation program which aims at a 2% growth rate in energy use by the year 1990. The primary objective of the Industry Energy Conservation Program is to achieve a high degree of energy efficiency in manufacturing and process industries. Reduced energy costs in industry achieved through intelligent investment and operating practice is central to the program strategy.

The industry program has been developed in consultation with Canadian industry and is completely voluntary on their part. The program has five main elements: 1. Industry Energy Conservation Task Forces 2. Information and awareness packages 3. Fiscal and Financial incentives 4. Industry Data Base Development and 5. Industry policy studies.

By selecting the voluntary approach to deal with energy conservation we have maintained the traditional cooperative relationship between government and industry in Canada and have been able to manage a successful energy conservation program with a minimum of government intervention and bureaucracy. Industry sets the energy conservation goals, identifies the opportunities to conserve energy, and finally reports on the improvements in energy efficiency.

Government for its part supports industry with a number of program elements designed to overcome the many barriers to energy efficiency which exist in Canada. These programs are deliberately biased to deal with the liquid fuel supply situation in eastern Canada and to encourage the use of wood waste as a fuel. As new barriers to the efficient use of energy are identified these programs are modified accordingly.

THE ROLE OF THE CANADIAN GOVERNMENT IN INDUSTRIAL ENERGY CONSERVATION

In discussing the role which the Canadian Government plays in the industry energy conservation program, I propose to introduce very briefly the reasons why government has a responsibility to be involved in the field of energy conservation in industry, I will touch on the reasons why we in Canada have selected the voluntary approach to industry energy conservation, I will mention the special fuel type and regional aspects to the conservation program, run through very quickly the barriers which exist to effective energy conservation in Canada and finally I will mention the various program elements which have been divised to deal with as many of these barriers as is possible.

THE NEED FOR ENERGY CONSERVATION

The reason why there must be energy conservation is of course obvious to all of us here. The economies of the industrialized nations of the world are vulnerable due to their dependance on imported oil and immediate action is required to improve the energy efficiency of industry to reduce industry's dependence on oil and to secure long term supplies of reasonably priced energy.

Canada, like other industrialized nations, is attempting to do something about the energy supply problem because our future, the future of our industrial base is in jeopardy.

Oil is the only form of energy which Canada must import at the present time and we are in the

enviable position of having the potential to become self-sufficient in oil in the not too iistant future. The immediate energy problem in Canada is not so much one of not having enough energy but rather one of being unable to transport economically the appropriate quantities of oil and gas from the supply region to the demand region. Our longer term problem is a diminishing supply of low cost forms of energy.

Having stated our problem in this brief fashion, let me go on to say that it is our belief that it is the responsibility of the federal government to ensure that all regions of Canada have available to them adequate supplies of energy which are equitably priced. This is fundamental to Canada's energy policy and applies to all sectors of the economy.

We are concerned that all industry survive the impact of the rapid price increases in energy and that they will be provided with a reasonable amount of time in which to implement energy conservation measures. The short term solution to the energy supply difficulties which exist in Canada has been to import oil to supply the liquid fuel demands of the eastern regions of the country and at the same time employ a subsidy program for imported oil to sheltered Canadians from the world oil price spiral. This short term solution is admittedly not acceptable in the longer run for obvious reasons, and we are developing on a priority basis new energy supplies and transportation systems which when combined with improvements in energy efficiency will allow Canada to supply the nations energy demands from Canadian sources at prices under world levels.

Each time one speaks about energy conservation, a considerable amount of the discussion time must first be spent on energy supply and this should not surprise us. After all, the need for energy conservation and how one proceeds in developing a government program is established by the supply situation of the country. If we examine the Canadian Energy Conservation Program we will find many of the elements are responses to the energy demand/supply problems of regions the country.

The results of a successful energy conservation program, that is the energy made available through improved energy efficiency, will become a major contributor to the energy supply strategy for most countries. By the year 1990, we anticipate that the Canadian program will have been instrumental in reducing the annual growth rate of energy use from a historical figure of 5% to something in the range of 2%. We have structured the energy conservation program to fit into both our short term and long term energy supply planning. For example, we have introduced a distinctive regional or fuel type bias to the conservation program as an assist to the energy supply strategy. The program is biased to promote greater energy conservation in the eastern regions of Canada with special emphasis on replacement of liquid fuels. While these program distortions sometimes seem to be counter-productive, they are nevertheless effective means to make use of the energy conservation program to help solve a short term supply problem.

ROLE DEFINITION

In actively supporting the voluntary energy conservation program for industry, the Canadian government hopes to promote a high degree of energy efficiency in the manufacturing and process industries. Reduced energy costs in industry achieved by decreasing the amount of purchased energy per unit of production is central to our strategy. We are firm in our belief that an industry which has intelligent operating and investment practices will also employ these skills in managing their energy conservation program. It seems only logical to us that energy conservation decisions should be left to industry. As you can appreciate industry's cooperation and efforts are fundamental to the continued success of the Canadian energy conservation program. By way of illustration, industry is forecasting a 23% improvement in energy efficiency between 1972 and

1985 and I believe this figure will increase to 50% by the year 2000.

By selecting the voluntary approach to deal with energy conservation in industry we have maintained the traditional cooperative relationship between government and industry in Canada and we have been able to manage a rather successful energy conservation program with a minimum of government intervention and bureaucracy. Industry sets the energy conservation goals, identifies the opportunities to conserve energy, and finally reports on the improvements in energy efficiency.

In developing the government strategy for this Industry Energy Conservation Program, a number of assumptions were made.

1.) Industry, given the correct energy price signals would reduce their energy costs per unit of output by using intelligent energy management.

2. Government involvement in the energy conservation efforts of industry should be kept to a minimum.

3. Government involvement in industry's energy conservation efforts would be limited to assisting in coordination of activities and facilitating the exchange of information between the various industry sectors.

4. Government financial and fiscal assistance would be structured to overcome some rather specific fuel type problems, regional problems and marginal industry problems.

As we heard earlier, the industry energy conservation program is based on the existence and work of the fifteen industry sector Task Forces and the Coordinating Committee of these Chairmen. I won't say much more about the Task Forces and the Coordinating Committee except to emphasize that these organizations form the nucleus which the government program supports.

THE GOVERNMENT PROGRAM

This program consists of four distinct elements. First there is the information and awareness packages which are designed primarily to alert people to the need to conserve energy and to the economic opportunities presented by energy conservation. Second we have fiscal and financial incentives which are designed to promote and accelerate certain types of energy conservation investments. Third we are developing an industry data base which will provide industry and government with energy use data against which to measure themselves and fourth we have initiated a number of industry policy studies which are designed to assist industry in identifying opportunities for energy conservation and to provide economic data for use in program modification. These four program elements are intended to permit government to direct resources in the most efficient manner towards assisting industry to improve energy efficiency.

In spite of our very best efforts and the carefully designed government program, a number of policy studies have indicated that there are many energy conservation opportunities which are being missed. These studies indicate that the rate and level of implementation of energy conservation measures in the industrial sector is governed by a complex set of physical, economic, attitudinal and institutional factors. I would like to talk about these factors or barriers.

THE BARRIERS

Different barriers can act individually or collectively to bias business decisions regarding energy conservation activities. Furthermore, the barriers vary from company to company, also with location, time, the nature of the industry, the nature of the market and the multitude of particular factors which reflect the internal nature of the company and the external influences which act upon it. Barriers can also be considered to originate at the corporate,

government or personal level.

Let's look at a few of these barriers.

The current energy pricing policy in Canada, which keeps oil and gasoline well below world prices, or even the replacement price, dilutes the impact of the energy conservation programs of government. The impact of an increase in the world price of crude oil which we would expect to decrease oil use is often reduced or delayed by institutional, national and information barriers so that the full impact may never be realised. The energy conservation program has no means to alter the energy price directly but as an Energy Department we are aware that energy prices kept so low that they do not even keep pace with the consumer price index is not conducive to energy conservation.

Energy rate reform is under active study in numerous jurisdictions; the rate structures employed by all Canadian electrical and gas utilities acts as a barrier to energy conservation; lower block prices are set for energy as more energy is used in a given time period. Take or pay contracts set charges for blocks of energy supply in a time period regardless of the energy use. There is not much economic motivation for industry to spend time and money reducing energy use if this is not reflected in lower energy bills. Our program is unable to directly bring about change in this area, but we are able to exert some influence to change.

A third barrier to energy conservation is introduced by the dominant position in Canada of capital and energy intensive industries. The slow response by industry to committing large capital investments to accomplish energy savings, can be attributed to the value of existing fixed assets being so large when compared to an energy cost increase. We can't expect a rebuild after each change in the oil price so we must wait for the equipment to become obsolete, to breakdown or to simply wear out at which time the cost of energy can hopefully influence the choice of more energy efficient plants. Our fiscal and financial incentive programs are designed to perhaps accelerate the decision to rebuild or modernize and to select energy efficient technology.

A very real barrier faced by many firms in the industrial sector is the inability to raise the necessary capital to undertake all of the conservation projects that meet their firms' investment criteria. This is a problem faced by most companies and we are studying various means to overcome this barrier without at the same time becoming industry's rich Uncle.

A barrier is identified in the fiscal treatment accorded energy related projects or research and development. The system is definitely tilted to favour expenditures on conventional energy supply over energy efficiency or renewable energy.We are gradually bringing about change in the corporate tax regulations which would at least put investments in energy conservation on an equal footing with energy supply investments.

A barrier can be found in the practice of firms in the industrial sector using different criteria for energy conservation investment than they do for production expansion investment. For example, Canadian experience indicates that a pre-tax rate of return of better than twenty-five percent is generally required for cost reduction investments while as low as ten percent will frequently be accepted for production expansion. The results of a study of 130 cases of energy conservation investment opportunities in a range of Canadian industries, as done by Energy, Mines and Resources, indicates that the very great number had to have less than a 3-year payback. Those with a longer than 3-year payback were generally not undertaken. We are undertaking additional policy studies which will attempt to define what government action would be required to bring about a satisfactory change.

A particularly worrisome barrier to effective energy conservation is the ability of large firms

to pass-on their high energy costs to their customers. With this ability, economically attractive conservation opportunities will frequently not be acted on until the supply of energy becomes a factor. We are not able to deal with this barrier at the present time, but we are inclined to believe that something will have to be done in time.

The lack of proven technological solutions to various energy conservation problems is a barrier which all involved recognize and which we in Canada deal with by means of research and development grants for industry energy conservation R&D and energy conservation demonstration projects.

Another major barrier particularly for the smaller firms is the lack of information on how to improve efficiency of the system and what the bottom line impact will be. We know from experience that plants frequently delay undertaking energy cost savings investment until they are stimulated from the outside. This soft barrier results in a waste of significant amounts of energy throughout the system, and as well a considerable loss of income to companies. Our information and awareness program has been structured to overcome this barrier. The energy bus program is an important segment of this program and of course the energy management seminars are equally important.

The widely divergent views on energy supply and prices which are discussed in the media almost daily contribute to confusion and uncertainty on energy matters. The media tends to give sensational treatment to new oil or gas discoveries without giving all of the important details such as the cost of developing those finds and what the cost to consumer will ultimately be. This acts as a barrier to energy conservation investment. We are all aware that industry looks for a climate of stability as a base for investment decisions. Yet the views expressed publicly by each of the players in the energy game appear to reflect an uncertain if not chaotic future. The future is not all that uncertain or chaotic and the prospect that it might be, is a clear hindrance to decision making on investment for energy conservation purposes. Here again we attempt to overcome this barrier with the information and awareness program.

When major, and some minor, conservation measures are introduced, such as heat recovery, as an example, there is often a genuine fear and hence another barrier that production will be disrupted. This is a serious barrier in some cases and we have developed a program of financial support for energy conservation demonstration projects which will spread the financial risk and thus accelerate the introduction of these projects or changes which could disrupt production.

When economic conditions are depressed, industrial capacity is frequently under-utilized, resulting in reduced energy efficiency and lower levels of cash flow. This is a barrier over which we have very little control. Recent economic trends are reflected in the poor utilization in some of our industrial sectors and thus inefficient use of energy. We see very little that our program can do to overcome this barrier.

Recognizing that all of these barriers inhibit in varying degrees the essential energy conservation efforts in industry, the Canadian Energy Conservation Program for Industry attempts to deal with as many of them as possible. As I have already stated, we cannot deal with all of the barriers or problems but all are under continuous scrutiny and efforts are being made to initiate changes whenever possible.

CONCLUSION

In summing up the role of the Canadian government in the Industrial Energy Conservation Program, I would characterize government as a concerned observer who will lend a hand when required. Government action, that is government's role, is taken with ful appreciation that industry's primary objective in

introducing an energy management program is not so much to reduce energy use but rather to reduce the energy cost component of their operations and possible to obtain some measure of supply security. Government expects that this would be accomplished by industry adopting only those measures or undertaking investments which are in accordance with sound industrial management and investment practice.

Industry on the other hand must remember that the Canadian government's objectives in attempting to influence Industry's energy investments are first to ensure that cost effective energy conservation investments which are superior to energy supply investments, when measured on the social scale, will be favoured by industry and second that investment in energy conservation and energy supply be accelerated.

INDUSTRY'S ROLE: ACTION OR REACTION

Richard L. Aspenson

3M Company, St. Paul, Minnesota

ABSTRACT

We in business have a responsibility to voice our concerns, share our technical knowledge and contribute to effective energy legislation. And we also must get involved in the rule making proceedings of the regulatory process. I admit that it is not an easy task. I will briefly describe the principle legislative and regulatory energy issues and show you what our company is doing to impact on them.

Mr. Ray Herzog, Chairman of the Board, 3M Company, recently said in a speech to the St. Paul Chamber of Commerce, "Business people in the 80's must take action to bring understanding to business by striving to participate, fully and constructively, in all aspects of our society -- government, schools, civic and cultural groups." We in business do have a responsibility to voice our concerns, share our technical knowledge and contribute to effective energy legislation. And we most certainly must get involved in the rule making proceedings of the regulatory process. I admit that it is not an easy task. The Congressional Record, as you know, records everything congressmen want the people to think they said. The Federal Register prints the rules and regulations developed by the 120 federal agencies. The 7000 regulations put out every year are suppose to say what the regulators think Congress said.

Energy is only one of the many issues that Congress, the Administration and the federal agencies are involved with. The energy situation has created a maze of energy legislation generated by Congress and the Administration the past several years. Do you realize that in this session of Congress there are 840 pieces of energy legislation before 120 committees and subcommittees. Of course, all of these will not pass; however, those that do go through will end up as additional regulations.

It is essential that we as the technical community and we as the business sector get involved in this process. Washington is receptive to our concerns -- they want our constructive criticism -- they need our technical knowledge -- they look forward to our advice and counsel. But, let us be constructive, not destructive, and let us be positive, not negative. And most important of all, let our thrust be action, not reaction. Let me explain. What I am saying is that we should be identifying those energy issues that are important to our country and especially the industrial community and promoting our positions at the embryo stage of the legislative process. We are being reactive if all we do is testify at a regulatory hearing. Please understand, I am not saying that we should not participate in the promulgation of the regulations. This is important, too. What I am saying is that if we were involved in the development of the legislation it would be an easier task to understand and comment on the regulations. In fact, if the agency interpreted the statute and the intent of Congress correctly, involvement in the regulatory proceedings would be greatly reduced.

Many of you present today are involved in energy issues at the congressional and regulatory levels. Some of you probably would like to be. My message today is that we all should be.

In the timeframe of today's presentation it is impossible to cover all of the important energy issues and the impact that each could have on our respective company's operations, growth and profits. What I will attempt to do is briefly describe the principle legislative and regulatory energy issues and show you what our company is doing to impact on them and how we are doing it. Each of our respective companies has a wealth of technical talents within our many disciplines that are, in many cases. an untapped resource in impacting energy legislation. Each of us is active in various professional engineering societies and product trade associations.

Many of the societies and trade groups play an active governmental role and have established high credibility with the Administration, Congress and the agencies. 3M's major involvement on energy issues has been through the trade and society route. We find this an excellent way to exchange views, cross-fertilize concepts, resolve differences of opinions and develop a position that in most cases has more substance than if it were the opinion of the individual company. Another distinct advantage of a group position is the greater acceptance and credibility by Congress, or the agency, with this approach.

With the balance of the time that I have, I would like to list the energy issues that we have been involved in and the trade group and (or) society that we have worked with for each.

In each issue we have had to ask ourselves -- should we get involved, why do we care, what is our position, how do we do it? I hope to address this line of thought process on the issues we cover today.

NATURAL GAS

1. Incremental Pricing
2. Deregulation
3. Priorities of End Use

PETROLEUM

1. Deregulation
2. Excess Profits Tax

CONSERVATION

1. Reporting
2. Equipment Performance Standards
3. Building Performance Standards
4. Emergency Plans
5. Incentives

COAL

1. Industrial Fuel Use Act
2. Synthetics
3. Environmental

PROFESSIONAL SOCIETIES

American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE)

American Society of Mechanical Engineers (ASME)

American Institute of Chemical Engineers (AIChE)

American Institute of Architects (AIA)

TRADE ASSOCIATIONS

National Association of Manufacturers (NAM)

Chemical Manufacturers Association (CMA)

Chamber of Commerce (C of C)

Council of Industrial Boiler Owners (CIBO)

Process Gas Consumers Group (PGCG)

Business people can provide leadership and problem solving abilities to government on energy matters. The solution to our energy dilemma will not be easy, cheap or fast. Mr. Herzog also said, "This can be a decade of progress and opportunity if all of us, in the private sector, demonstrate that activism, optimism, realism and doing, count." Thank you.

DEERE & COMPANY ENERGY-MANAGEMENT PROGRAM

P. Michael Boyd

Deere & Company
Moline, Illinois

ABSTRACT

An overview of the Deere & Company energy management program is discussed. A review is made of seven key elements which have contributed to the success of the program. Installed projects and established programs are identified and discussed. The results achieved by Deere & Company in energy conservation are quantified.

Major points presented are audits, energy accounting, monitoring program results and feedback reporting.

The corporate energy management program is detailed. This includes organization, personnel requirements, energy efficiency goals and maintenance of a corporate data base.

Deere & Company appreciates the opportunity to discuss energy management and conservation with you. Energy is a topic that will occupy our thoughts for many years to come and certainly will be in the forefront in the near future. It is a subject that has become increasingly complex. Fuel availability is a fluctuating phenomenon. Technology to enable energy conservation and to supply efficient alternate non-depleting sources is complex. Government intervention is becoming increasingly pervasive in energy management. National and certainly industrial responsibilities in wise energy management is a commitment. But it is difficult to determine how one finds a reasonable path to energy security.

Deere & Company faced the issue -- what can we contribute to energy conservation? As one reviews the initiation of an energy management program, one finds that he is faced with a problem that encompasses a large and varied range of disassociated data.

It soon became apparent that an energy breakdown and analysis of major manufacturing processes and environmental uses of energy was necessary.

Continued study indicated increased refinements were necessary and that energy consumption would have to be analyzed by fuel type.

With the accumulated data, a reference point is established. The reference point is based upon interpretation of fuel mix requirements, analysis of fuel use for process and for environmental and cognizance of fuel costs and availability.

Additional work is then required to organize an energy management program. Direction must be given to channel resources into productive areas of energy management and conservation.

In summary, energy data is required to establish

a mile marker to define the existing situation. Definition must be in sufficient detail to enable an effective first effort. So, the message is to start somewhere in an energy conservation program and the process will gel and goals will come into focus.

Deere & Company progressed painfully through this process of establishing an energy management and conservation program. I would like to share with you our experience in organizing an energy management program.

In searching back and examining the various aspects that first originated with, or evolved from, our energy program, it is possible to identify several key elements that we believe have contributed the most to the success of our program. These key elements are also identifiable in the most successful programs in other industries that we have examined. Therefore, we shall focus on them. These elements are, we believe:

Top Management Support

Energy Audit

Full-Time Energy Coordinators

Direct Responsibility and Control at Unit Level

Realistic and Objective Yardstick

Developing Energy Ethic

Feedback

I'd like to comment on these elements briefly so you understand what we mean by them and why they are important to the success of an energy conservation effort.

Each of you is aware of the importance of having the backing of your superiors in the accomplishment of any particular goal you might seek to achieve. In terms of energy conservation, we have been fortunate at John Deere to have had the active support of many key executives of our corporation. This support has further been reinforced at the top management level at our factories. Without this support our program could not have achieved the results that it has, because a fundamentally sound and ultimately successful program begins with this single most important element. This is certainly the cornerstone for a successful energy conservation effort.

A well-organized and ultimately successful program begins with a comprehensive energy audit. An energy audit is a planned effort aimed at identifying, categorizing, and quantifying all the various energy forms and energy uses that exist in a factory, or for that matter any business, commercial or public building or your home. We conducted such an audit at each one of our factories at the outset of our program. We ended up with an analysis of yearly energy consumption by fuel type for each factory and this then also permitted a composite profile for the whole corporation.

We were able to determine the magnitude of our energy use, the energy mix and conversion losses. This is important since areas possessing the greatest savings potential were identified. Each of Deere's units were individually surveyed to determine the corporate compilation.

Upon breaking this usage down into function we

determined that on a yearly basis, environmental needs comprised one-third of our usage and process two-thirds. Obviously the subdivisions must be tailored to a particular company's operations. However, such an audit does allow one to prioritize the energy conservation effort to maximize its effectiveness.

A full-time energy coordinator on location is essential to obtain maximum success in a conservation program. In a company with multiple plants we believe that a coordinator should be established at each location. We think that anything less falls short of full commitment and maximum potential will not be reached. The next key element is closely related.

"Direct Responsibility and Control of the Program Activities at the Local Level." Administratively these two concepts are interrelated and very important. In every case where energy coordination is a part-time job, other pressures will dominate. At each John Deere manufacturing unit there is at least one full-time energy coordinator who is a member of the plant engineering group. The coordinator reports to that unit's management and is responsible for administering the local effort. As a matter of fact, the downtown tractor factory at Waterloo, Iowa has a staff of five engineers dedicated full-time to energy conservation in addition to a supervisor. The Product Engineering Center and Engine Works also each have an energy coordinator. These local people are directly responsible for the success of their individual programs. At our corporate office in Moline an Energy Management Division coordinates the effort on a company-wide basis.

We feel that it is crucial to develop a realist and objective "yardstick" to measure progress. John Deere uses a rather complex program to do this. It takes into account tons of product, degree days and square feet. Nevertheless, the bottom line for us is BTU/ton and since the start of our program we have achieved a significant reduction in the energy required for a finished ton of product. These kinds of yardsticks are objective. Tons out the door is a known figure - the utility bills are known amounts. The results are easily audited.

From the analysis, then, of our energy audit data, a computer analysis program was developed as the tool or "yardstick" by which our energy conservation progress is measured.

Essentially, our program is a stepwise regression analysis which predicts expected energy usage had there been no energy management and conservation program.

The actual consumption is then compared to the predicted consumption to determine energy savings. This tool has turned out to be the backbone of our reporting system for evaluating each unit's energy saving techniques.

Two final key elements merit mention.

The people that comprise a company can enhance a conservation program if they are convinced it is for their good as well as the company's. We strive to develop an energy "ethic."

The energy management and conservation program at Deere has been instrumental in increasing our energy awareness level. Energy

efficiency is now a fundamental element of our management decision criteria. However, the average employee is also contacted through posters, articles, films and meetings. Although energy costs comprise only a small portion of our overall manufacturing costs, we are convinced that a strong "energy ethic" is not only vital but "good business" as well.

One of our factories has had an animated movie produced which features a polar bear hero. He represents the central theme of an energy conservation awareness program. The program continues through the use of posters and newsletters to keep the energy conservation theme and Lester in the minds of employees.

The last key element I will discuss is termed feedback.

The success of an energy program is dependent upon how effectively the progress and activities are communicated among the various unit and corporate organizations. Unit results and program accomplishments are published in a quarterly report to corporate and plant managers and engineering.

A regular and accurate method of reporting the progress being achieved by a conservation program is the final key ingredient of a well-organized and executed effort.

In summary, these are the seven key elements that we have found to be most essential for a successful program.

Each element, we feel, is independently important and therefore essential to the group of elements.

I will now present some of the actual operating and hardware changes that have been implemented as a result of our commitment to save energy. These projects basically include modifications to the systems providing environmental comfort and modification of manufacturing processes to conserve energy.

I categorize the Deere & Company energy conservation program into three phases. Phase I is the housekeeping phase. Phase 2 is the conservation phase, and Phase 3 is the conversion stage. These phases are not a set progression since there is overlap and interrelationships with projects occurring concurrently.

During the housekeeping phase, we implemented a program of lower maintained building temperatures and reduced but sufficient lighting levels. We also initiated a review of building insulation policies. Deere attempts to maintain a temperature of 65°F in occupied buildings and 50 footcandles in offices and manufacturing areas. The results are that workers dress accordingly both in the shop and in the office areas. We have rewired our lighting system to enable zone lighting and have in some cases removed up to 50% of fluorescent lamps and in the shop and warehouse areas have been able to eliminate alternate fixtures. Concurrently, each unit reviewed the use of insulation to reduce energy requirements. The use of insulation has contributed considerably to the reduction of energy requirements in our buildings.

Another program at one unit included a drastic reduction in window area. Extensive window areas in an existing building have been covered with insulated metal siding.

This housekeeping phase requires relatively small capital investment and enables quick and sizeable energy savings. This is the cream off the top of the energy consumption.

Phase 2 includes a series of projects which are more technically complex and more capital intensive. Basically, these are waste heat recovery systems and modification of building utility systems.

A popular program of relighting has been continuing which involves relighting with more energy efficient lighting.

Another continuing program is the modification of direct fired HV units from 100% outside air to units with return air capability.

An example of this was constructed at one of our factories. Existing HV units were dismantled and a return air duct and mixing box were added to the units. The burner plates were revised and the controls remodeled to enable automatic damper operation.

In the process area, use of waste heat recovery has developed into a sizeable program. On forge furnaces with sealed combustion chambers incoming combustion air is preheated with the waste heat exhaust that was previously exhausted.

Air filtration in areas such as welding where air quality can be a problem is another application of energy reduction. Filtration of the air to remove contaminants enables the recirculation of the filtered air.

Since one of the major energy intensive operations at a factory is heating make-up air, any reduction in the amount of make-up air to be heated is a large contribution to energy conservation.

Another application of the same principle is illustrated by source capture of the air contaminant. Weld fumes at individual weld stations are captured directly and filtered from the air.

This is a review of some applications of equipment and process revisions to achieve energy conservation.

Phase 3 is a category of energy reduction projects that are most difficult to implement. I separate these since they are projects which press the existing technology or which have unique economic problems.

John Deere is interested in solar energy. We have a solar installation that provides 75% of the domestic hot water for 1000 employees on two shifts. The system provides water flow averaging 75 Gal/Min with maximum demand of 2,700 Gal at 140°F for lavatories and showers. This was an experimental installation to give us "hands on" experience in this low temperature application. It did not have a good return on the investment. The economic factors do not favor a solar solution in the majority of cases. We recognize the economic roadblock will decrease as energy costs increase. We see increased use of solar in industry for hot water heating for low temperature applications such as: ovens, parts washers and domestic hot water. One must recognize, however, that these low temperature applications represent only a small part of the energy used in much of industry.

Deere & Company has four waste incineration facilities in operation or planned. Each project

has unique features that entered into economic and engineering analyses. For one application the requirement of a paint oven closely matched the energy available from the plant's solid waste. For this application, the hot flue gas passes through an air to air heat exchanger providing heated air for the paint oven.

Another application of waste incineration provided the incineration of 35 tons of solid waste and 2,400 gallons of waste liquid each production day. This is waste material that required expensive landfill and contract hauling for disposal. The energy produced from the waste incineration is low pressure steam which supplements an existing steam system relieving a potential steam energy deficit.

This is an overview of the Deere & Company energy conservation program. Much has been done to improve our energy situation, however, much more needs to be done. Energy conservation and management remains a major concern for Deere & Company. The results of our efforts have been measured and quantified. Let's review the results.

A comparison of actual energy consumption compared to predicted consumption without any energy conservation demonstrates the success of the program. In fiscal year 1979, 14.2 million BTU x 10^6 were consumed compared to 25.4 million BTU x 10^6 had there been no conservation program.

Our energy reductions for fiscal 1979 were 44% when compared to predicted values. Energy conservation translates directly to dollars and thus to the maintenance of a competitive position. These reductions have provided a buffer against rising energy costs.

Our energy costs per MM BTU have risen 303% over the last seven years. The average increase per year is 22%.

Over the same period BTU/Ton of production has decreased 39.47%. The Federal Department of Energy has set a target goal of 15% reduction of our industry to reach by 1980 when compared to a 1972 base.

Another statistic of interest, I think, is the fact that for the last five years, 1975 through 1979, we used less total energy company-wide than in 1972 despite some 56% increase in tonnage and 44% increase in manufacturing space over that period of time.

In 1972 we were 61% reliant upon natural gas in manufacturing operations. In 1979 that number has fallen to 39%. This reflects the beginning of a self-imposed trend within our company. We have established a long-range energy plan with one of its chief cornerstones being the elimination of natural gas for space heating and reductions in process usages where feasible. This plan will require large capital expenditures, and perhaps in some cases a reliance on unproven technologies. The experience and data gathered over the past several years through our conservation program has been an essential tool in allowing us to embark on a positive course of action.

Energy conservation is a challenging arena. The wise selection of energy mix and the efficient use of energy is a goal to which Deere & Company is committed. Our message is to encourage the adoption of vibrant energy management programs and to work together to achieve wise use of energy.

FACING THE ENERGY DILEMMA; ONE COMPANY'S APPROACH, ENERGY MANAGEMENT AT 3M AT THE PLANT LEVEL

Thomas F. Marson

3M Center, St. Paul, Mn.

ABSTRACT

Many Plant Engineers profess to need help organizing and establishing a comprehensive, continuing energy management program. This paper describes the methods utilized to establish the State and National award-winning programs at 3M. Also described is a systems monitoring concept designed to predict, monitor and control energy use in major buildings. The B.S.E.S. (Building Specific Energy System) measures building cooling-heat demand, compares against specific building standards and reports on a continuous basis.

I propose today to cover three areas:

I. How to set up a successful and continuing Energy Management Program.

II. Some specific energy savers not in general use, and methods to implement them.

III. Results to date in 3M Center programs.

THE SUCCESSFUL PROGRAM

There's never only one way to accomplish any project, including Energy Management - from now on, let's call it EM. I believe the most successful and continuing EM programs do have at least the following ingredients: (not necessarily in order of importance)

1. Someone in charge (full time, if at all possible).
2. Teams.
3. Metering.
4. Goals and regular reporting of results.
5. Involve all employees.
6. Develop test areas to prove results and debug.
7. Perform audits.

ENERGY MANAGER

In most facilities, the Plant Engineers-Maintenance Superintendents are in charge of the EM programs. By and large, they do a creditable job. However, it's been another duty added to the person who may already be one of the busiest persons in your plant. Even with his already back-breaking schedule, if he puts enough emphasis, he can get some pretty spectacular results in the short run.

Although, I'll bet if he was relieved of all his other duties, he could more than double his plant's savings. But, in the long run, emergency programs fade because there are always too many other more immediate problems. After all, we can always get to that savings project next week; right now, we've got to keep the plant running.

I'm convinced, if your plant has an annual energy bill of $500,000 or more, full-time Energy Manager can at a minimum pay back double his salary. A word of advice, when you select your full-time EM person, pick someone who:

1. Wants the job because he or she feels it is vital.
2. Is highly respected for past demonstrated abilities.
3. Is a self-starter and is not easily discouraged by minor failures.
4. Is a "nit-picker" and has extreme persistence.
5. Can work and relate well to all levels of personnel.
6. Accepts full responsibility for accomplishments of your plant.
7. Is a good organizer and goal setter.

I've emphasized the Energy Manager's position and the characteristics of the person filling it because it is probably the single most important ingredient in a successful and continuing EM program.

If you pick the right person, your Energy Manager will probably take responsibility for the remaining six points.

Set up teams involving line supervision representing all significant areas of the plant. Line supervision involvement is particularly important where specific programs involve such objectives as

insuring that unneeded lighting is turned off, machine power supplies deactivated during all stoppages (even short breaks), dock doors are kept closed, as well as eliminating waste of inert gas, plant air and water. Periodic surveys of conditions are necessary to audit results and keep interest, but line supervision's commitment, or lack of it, will make or break these housekeeping kinds of programs. Having supervisory personnel on the team is vital in strengthening that commitment.

METERING

Metering on main energy supplies - i.e. KWH, KW, water, steam, inert gas, propane, natural gas, etc. - are, of course, necessary in order to verify plant billing and chart overall results. However, unless you have submeters in sufficient quantity to evaluate high use areas, you're operating "blind" in your ability effect control. It's been our experience that when high users are identified and made to cover the cost of their use - the usage will decrease. In one of our plants, the only water supply is from our own wells and at times barely enough to keep production going. Sub-metering is substantial and used very effectively to charge the high users. In that plant, control is simply a matter of vigilence and followup. In short, "the bad guys" are easy to spot. However, in the same plant, there were not enough meters to measure inert gas. The new inert gas generator we thought we would have to buy would have cost 100 times the price of additional meters we purchased to help control overuse. With additional local metering, we spotted high-use areas, and were able to curtail excess use.

Before our committees went into action, plant inert gas generating capacity was marginally able to keep up with demand. As a matter of fact, capital dollars were forecast for larger machines. Now, six years later, there has been no need to expand supply capacity and no serious production curtailments due to shortages. Roughly $200,000 capital investment was saved, not to mention operating energy not used in the form of natural gas and electricity.

GOALS AND REPORTING

When you have your energy metered and submetered as necessary, setting goals and working toward improvement are the obvious next step. You've probably heard the old saying, "People do well what the boss checks." I believe that's true, especially for long term. Setting goals and reporting progress in EM is no less necessary than in any other part of your business. As for long term, I become more convinced every day that EM will be with us for the rest of our lifetime. Energy will be an ever-increasing cost of making products and EM may even be the key to our economic survival.

EMPLOYEE INVOLVEMENT

Take pains to improve employee awareness and involvement.

Employees can do much to help or hinder energy conservation programs. We believe most employees want to help. After all, maximizing profits by minimizing waste helps insure existing jobs and makes growth possible. Conserving energy not only does that - but, it just might help keep a plant open - period! 3M-ers have used a variety of measures to heighten awareness. To name a few:

- Put reflective, highly visible decals on laboratory fume hoods indicating how much it costs to operate a year ($800 today).
- Install decals on room light switches as a reminder to turn out lights when leaving rooms.
- Put decals on machines reminding operators how much it costs to operate each hour.
- Put decals on deactivated light fixtures - "Lamp removed for energy conservation."
- Publish articles in company publications.
- Seek suggestions for energy saving programs. Especially, set up suggestion programs for maintenance and utilities employees. They know how most systems operate and are in a unique position to suggest changes. Give them positive feedback - let them know the results of their suggestions. It's positive reinforcement - it works!

DEVELOP TEST AREAS

Many times, "taking off" on a new, very large program requires large expense costs or capital approvals. Developing test areas to prove value to your management is sometimes the only way to get approval for the larger programs. A few examples:

- All steam traps in one major building at one of our St. Paul area plants were tested. That building had 150 traps; 10% were found to be leaking. That data, extrapolated to the rest of the plant, indicated a potential steam savings of $140,000 annually. We then started a plant-wide testing and repair program.

- We wanted to justify a permanently installed computer-operated electrical demand control system. Shedable loads were identified and a manual system put in place. In the first year, $45,000 or 10% of the demand charges were saved. That exercise justified the capital costs; next year our mini-computer control system was approved.
- At 3M Center, a clock timer was installed on one domestic hot water circulating system to test employee reaction and evaluate savings. The results looked good and no complaints were received. Now, 23 are installed and saving electricity and steam.

CONDUCT ENERGY AUDITS

All too often, the saying, "Can't see the forest for the trees" is true. A thorough audit by a qualified group from outside the plant is a very good idea. It will guarantee a complete survey and "energy balance" review. I'm sure we can all see some improvements in our own areas, but most of us are just too biased about our own operations to be totally objective.

A well-done audit will not only be thorough, it will be objective and should provide a priority program to follow. Your Energy Manager will have a creditable plan of action.

SPECIFIC EM PROGRAMS

I'm sure each of you have completed EM activities and have on-going programs of general nature and some specifically suited only to your plant and processes. In one form or other, I'm sure you've been engaged in:

- Resetting water temps downward.
- Weather stripping and caulking.
- Reducing fresh air make-up.
- 2nd and 3rd pass at cooling water - heating water.
- Reduced some lighting.
- Change thermostat settings.
- Installed low wattage fluorescents.
- Turn out unnecessary lights at night.
- Reduced boiler excess air.
- Convert to more efficient lighting types.

The list could go on and on. I'd like to give you a sampling of a few specific actions we've taken at 3M Center in the last two years or so that I feel probably would be useful in your plant. I'll give you enough data about these actions that you can easily implement them when you go back home.

I, personally, feel most comfortable with EM actions that are permanent. We all know that many actions to save energy are flexible, in other words, have a way of reverting backwards, and so that the savings program you had instituted won't stay in place. The next three examples are semi-permanent actions in our 3M Center complex.

EXHAUST FANS PUT ON TIMERS IN A LABORATORY BUILDING

We felt that the only way we could rely that the fans would be turned off when not needed was to put them on timers. There are 19 relatively small area exhaust fans in the building, totalling slightly over 23,000 cfm. The clocks are set to reduce run time from 168 hours to 62 hours per week.

- The steam savings for heated air make up are $7,700 annually.
- The chilled water (cooling) savings for make up air are $3,156 annually.
- The electrical savings for the 19 fans:

	6.9 HP	$ 950	Annually
-	The costs: Clocks	$ 665	
	Labor	$ 912	
	Material	$ 950	
_	Total annual savings		$11,834
	Total estimated cost		$ 2,527
	1st year savings		$ 9,307

We expect to expand this program to all areas.

Survey your buildings - how many exhaust fans do you have that are candidates?

DOMESTIC HOT WATER CIRCULATING PUMPS

Many major buildings use domestic hot water circulating pumps to insure that hot tap water is available instantly at all points in the system. Generally, these pumps are 1/3 HP and operate continuously 7 days/week, 52 weeks per year. By installing time clocks and operating the pump 72 hours a week instead of the maximum of 168 for each system, we find:

- Electrical costs are reduced by $41.00/year.
- Steam costs are reduced by $249.00/year.

A typical circulating system in one of the laboratory buildings at 3M Center has over 2200 feet of copper pipe - 2-1/2", 2" and 3/4" - all insulated. Even though insulated, there is more heat loss when the entire piping run is held at system operating temperature than when the circulation is stopped. If we could assume no losses would occur when the circulation is stopped, 278 million BTU annually would be saved. However, there are obviously some

losses due to cool-down and reheating the system on start-up.

We feel conservatively, however, that a minimum of 30% of the 278 million BTU's are saved. Approximate verification of this estimate was made by measuring condensate from a test installation.

- ONE-TIME COST OF CLOCK & INSTALLATION = $150.00

Possibly the most important aspect is that each system so converted can be expected to save ≅ 100,000 lbs. of steam a year, at little or no inconvenience to anyone.

We've converted 23 systems to date. If you've got two or twenty in your plant, you should still do it. A payback in less than one year is good business in any case.

- ADDITIONAL BONUS - LESS PUMP MAINTENANCE

DELAMPING

Delamping is simply surveying each area and determining what light fixtures can be permanently deactivated. Permanent deactivation is clearly possible in many areas since the trend in the past two or three decades has been to higher lighting levels than recommended today. Standards are becoming increasingly more conservative now. An example of what can be done is our company headquarters building. That 16-story structure was surveyed floor-by-floor to determine those fixtures that could be eliminated by removing the ballast fuses. Approximately 2400 2-lamp fluorescents have been deactivated. The arithmetic comes out to $8.91 per year for each fixture taken out of service - for a savings of over $24,000 annually in ONE large building for this action alone.

$24,000 savings annually for a one-time labor cost of $9,600 is pretty good business any way you figure it.

RETROFIT STEAM PIPE INSULATION

In most plants, there are steam pressure reducing stations, flanges, valve bonnets, strainers, etc., that have never been insulated. As originally installed and in the era of cheap steam, they were left uncovered because most of those components were considered maintenance items.

THESE SURFACES SHOULD BE INSULATED NOW!

We've covered them using standard insulating techniques. Also, insulating contractors cooperated with us to develop custom-fit, reusable, heavy density fiberglass cover for special components such as PRV's.

We've calculated conservatively a 1.3 year payoff in steam savings and some small contributions from reduced air conditioning load. However, our experience to date indicates the contribution from reduced air conditioning loads is much greater than our initial estimates. We now feel the payback will come in about one year.

In order to make easier work of calculating costs and savings, we developed a simplified system of calculations. With this system, any person can be quickly trained to go into an equipment room, do the measurements as necessary to justify the the cost of increased insulation.

Remember, many equipment rooms today run so hot from these uncovered components they require constant exhaust fans operation. You're very likely to have this condition in your plant.

BUILDING SPECIFIC ENERGY STANDARDS (BSES)

Steam generation facilities produce regular fuel consumption and steam output reports.

At 3M Center, a Monthly Power and Refrigeration Report is produced and is monitored by the power plant management to constantly check on individual boiler and chiller operating efficiencies. This has had obvious results, as the overall efficiency always hovers near the ultimate possibility for this type of equipment.

The picture changes, however, after the steam and chilled water leave the power house. No system had previously existed to check on whether these utilities were being used effectively or not.

We knew that we had competent and conscientious air conditioning craftsmen operating the systems in each building, but also were aware they really had no standard by which to judge performance of the entire building system, except proper environmental temperatures, humidity, and satisfied occupants. Modern systems designed to simultaneously supply heating, cooling, dehumidification, and humidification give super control, but are also capable of great waste through equipment malfunction or improper adjustment.

We suspected each building has its own unique heating-cooling energy profile - major factors being age, type of construction, occupancy, design of HVAC system.

Our initial approach consisted of going back over four years of historic data and developing a winter heating curve. (Figure I)

The curve plots steam consumption versus outside air temperature. While we plotted history, our craft personnel gave us current daily steam totals for the previous 24 hours; that new data was added to the graphs.

It became clear that a definite steam usage curve could be plotted for each building.

Note the two curves shown on Figure II . The upper was derived from monthly average steam use and corresponding monthly average outside air temperatures during 1975, 1976 and 1977. You see some months with nearly the same average temperature, yet the entire monthly steam use is 30% greater. An obvious problem when seen graphically. However, in the day-to-day operation of the building and without a standard of performance, it was not noticed at that time. If the occupants were happy, so were the operators.

The lower curve is made up of later data - after initiation of the BSES program. Note the curve is about 30% lower and readings are grouped much more closely. What makes it even more interesting is that these new observations were made daily and still group closely. The curve is lower because of an HVAC retrofit program done in that building and the points are more closely grouped because our operators are enthusiastically involved trying to operate their building to the standard.

Some interesting observations can be made from looking at these graphs. In particular, notice the large differential in monthly average usage for a given average outside air temperature. Such things as leaky steam valves, inoperative fan timers, etc., can cause a large increase in consumption rates and yet go undetected unless the actual rate is checked daily against some kind of norm. This BSES system makes it possible to avoid the extended waste of energy due to equipment malfunction or operator misadjustment.

We've also plotted each building's chilled water consumption by daily monitoring.

A combination of outside dry bulb and wet bulb temperature can produce a usable curve. For more accurate daily reading, we are in the process of adding BTU meter adapter heads to the chilled water flow meters. These meters are read on a daily basis during the cooling season. The craftsman checks his observed use against the master curve.

IMPROVEMENTS IN THE SYSTEM

As with every system, there is always a way to make it more effective, and this system, which requires considerable man-hours to operate, is no exception. The next phase is to have a micro processor monitor and record all the building metered utilities plus outside air temperatures and dewpoint. The justification is the ability to have constant usage monitoring with high and low rate alarms instead of once-a-day readings and to reduce manpower to operate the system. It will be a relatively simple program to have the micro processor redefine the curves to lower ideal values as more educated operation of building air handling systems optimizes usage. The lowered and improved values will then be placed into the computer's memory to become the new standard.

What have been the results of our conservation efforts in 3M Company?

In 1979, 3M won the Minnesota Energy Savers Excellence Award for Large Industry and March, 1980, National recognition with the National Energy Resources Organization Award. The Minnesota award was for conservation activities, more efficient building design and energy efficiency retrofit programs. The National award cites energy management activities, van pooling and the "3P" (Pollution Prevention Pays) Program.

3M CENTER RESULTS

1973-1979 Steam use, a decrease of 37%/sq. ft.
Refrigeration, a decrease of 45%/sq. ft.
KWH, a decrease of 16%/sq. ft.
Domestic water, a decrease of 41% sq. ft.

In summary, I hope I have left you with some ideas to take back to your plant. Nothing we've described to you is really difficult or complex, but it is time consuming.

We all have to realize EM is a long-term proposition and staff accordingly. With the right staff - a combination of full-time EM people and committee members with other primary duties - we can make continuous improvements and guard against slipping backward on last year's improvements.

I feel we've only begun and will continue to improve and optimize every year!

Thank you for your kind attention.

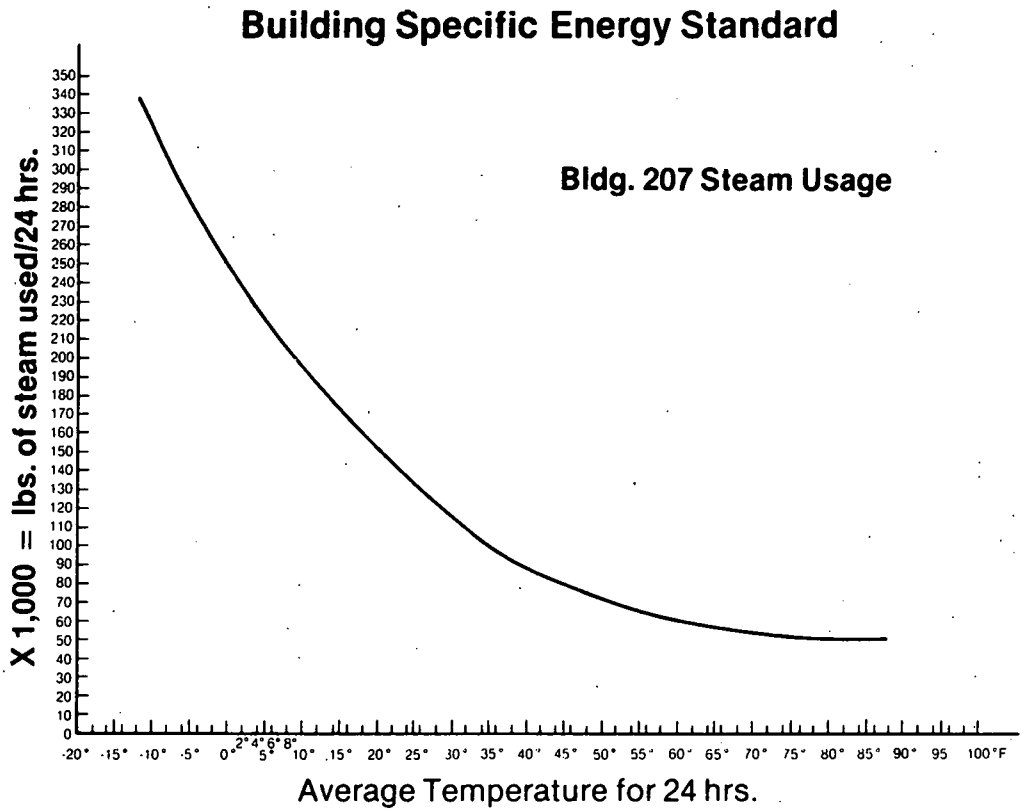


FIGURE I

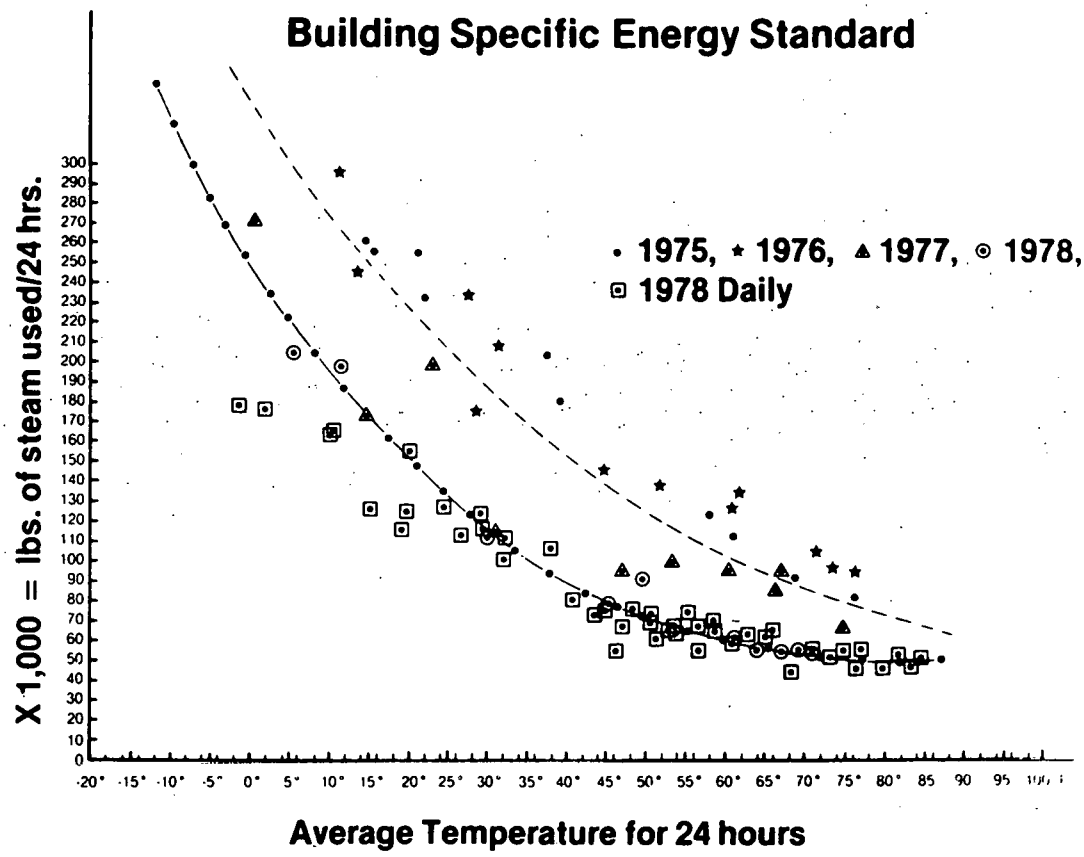


FIGURE II

TRENDS IN GULF COAST POWER SUPPLY, DEMAND, AND COSTS

Lloyd G. Posey, Jr.
The Pace Company
Houston, Texas

ABSTRACT

During the 1980s, both the cost and availability of industrial electric power will become critical to corporations contemplating expansions and new sites along the Gulf Coast. Fuel costs have grown rapidly, and the shift to coal and nuclear power has sharply driven up capital outlays for new generating stations. Power costs have risen accordingly and will continue to do so for the foreseeable future. Furthermore, the rates of cost increases will vary widely among the utilities on the Gulf Coast so that their competitive positions will change significantly over the next ten years. Reserve margins will remain adequate for some utilities. Others, though, face periods of several years in which reserve margins could fall enough to threaten brownouts and service interruptions. This paper examines the economic and environmental factors which will affect the growth of power demand. Future trends in industrial power costs are also examined. The primary focus is on the industrialized areas of the Gulf Coast, but the paper also considers many general issues.

The Pace Company has monitored and forecast electric power costs for many years in conjunction with site selection projects, energy analyses, and other types of studies. In the last few years, we have observed significant shifts in both the outlook for industrial power and the importance of power costs and availability in corporate planning. These changes have been noticeable in the industrial areas along the Gulf Coast because of the concentration of heavy industry as well as the increasing use by the electric utilities of fuels other than natural gas for power generation. The purpose of this paper is to analyze the trends which will influence the supply, demand, and cost of electric power to industrial customers in the Gulf Coast area through 1990. We will discuss general trends, but our primary focus will be on the territory served by the six major public utilities encompassing most of the Gulf Coast industrial regions. These utilities (shown in Figure 1) are the following:

- Houston Lighting & Power
- Central Power & Light
- Gulf States Utilities
- Louisiana Power & Light
- Mississippi Power
- Alabama Power.

We will address four major topics:

- **Power Forecasting Methodology**
  We will discuss the power forecasting model used by Pace in preparing electric power cost forecasts.
- **General Trends in Electric Energy**
  Based on our forecasting experience and our semi-annual study, "The Pace Energy and Petrochemical Outlook to 2000," we will highlight significant trends in the United States which will influence the future of electric power.
- **Trends Affecting Gulf Coast Power Supply and Demand**
  We will focus specifically on the Gulf Coast region and analyze the factors influencing industrial power in the service areas of the six utilities examined.
- **Outlook for Gulf Coast Power**
  Finally, we will present a synopsis of the outlook for cost and availability of industrial electric power on the Gulf Coast, including some of the highlights from our recent study, "Gulf Coast Power Forecasts, 1979-1990."

POWER FORECASTING METHODOLOGY

Power forecasts for an individual utility are prepared according to a procedure which combines Pace's energy forecasting models with analyses of the specific utility company's operations. Figure 2 illustrates the basic methodology used. Each step is discussed below along with key assumptions.

Demand Growth

The first step in preparing a forecast is to determi the demand for power in the service area. Forecasts a prepared for both peak and average demand. The former

establishes the schedule for generating capacity additions and determines future reserve margins, while the latter sets the total fuel requirements, influences load factors, and ultimately determines revenues and power costs. The Pace Energy Model provides updated regional forecasts for growth in electric power demand for the Household/Commercial and Industrial sectors of the economy. These regional forecasts are adjusted for recent historical trends shown by the specific utility company and for factors affecting the outlook in the company's service area. Our forecast growth rates are substantially lower for the 1980s consistent with the general slowdown in the economy and the higher power costs which we show as a result of our studies. However, the results also reflect penetration of electric power into existing fossil fuel markets resulting from factors discussed later in this report.

Generating Capacity

Forecasts for additions to generating capacity are then prepared. Almost all new capacity will be either coal or nuclear power plants. No unannounced nuclear plants are considered since the lead time for construction would make it impossible for new nuclear projects not already in an advanced stage of planning to be completed by 1990. We do predict that several as yet unannounced coal units will be needed by the late 1980s to supply increased demand and support reserve margins.

We analyze each major announced expansion to determine if the officially stated in-service date appears reasonable based on current construction status, financing, regulatory matters, and other pertinent issues.

Fuel Mix Forecast

The power demand forecasts and the generating capacity forecasts combine to produce the fuel mix forecasts. All nuclear and coal-fired facilities are considered as base load plants. Gas-fired plants are treated as base load units to the extent that they burn low-cost contract gas. Remaining base load and peak load requirements are supplied by fuel oil, gas, and, where available, hydroelectric generators.

Fuel Cost Forecast

Three sources of information provide data to forecast fuel costs for each utility:

- Fuel contracts between the utility and its suppliers
- The utility's estimates for specific fuels
- Estimates derived from the Pace Energy Model.

Fuel contract prices and quantities provide much of the near-term cost data and some of the longer-term figures. Utility company estimates based on their experience with specific suppliers and Pace Energy Model forecasts are used to estimate costs for future contracts and non-contract purchases.

Capital Costs

Capital requirements for new facilities are derived from both utility company estimates and Pace data for power plant costs considering location and other factors. In determining total costs for new generating plants, we include allowances for funds used during construction (AFUDC). Where regulations permit, construction work in progress (CWIP) is allowed as working capital for rate calculations, and we reduce the AFUDC credit accordingly; in cases where we have anticipated a delay in the start-up of a new plant, we escalate the construction costs to reflect both additional AFUDC and costs.

Regulatory and Rate Issues

The regulatory and rate issues of most importance in forecasting rates are:

- Return on investment allowed in formulating rates
- Granting industrial rate increases above cost-of-service level
- Delays in granting rate increases.

For each utility company, we examine past history and assess the regulatory climate to predict the likely effect of these issues.

Power Cost Forecasts

Our power cost forecasts for each year are derived by combining projections for the capital and operating costs for each type of power, our estimates of the overall fuel mix, and considerations regarding the willingness of state regulatory commissions to grant timely and adequate increases in rates.

Analysis of Power Availability

An electric utility company must satisfy three basic requirements in order to supply fully the power demands of its customers:

- It must obtain an adequate supply of fuel to operate its power generating facilities.
- It must expand its generating capacity as needed to match demand and provide an adequate reserve margin.
- It must be able to acquire power from other utilities when needed to supplement its own generating capacity.

Fuel Supplies. Analysis of fuel supplies focuses primarily on the distribution of fuels in the fuel mix and their prices rather than actual availability. We do not believe that any of the six Gulf Coast utilities will face shortages of coal, fuel oil, or nuclear fuel supplies through 1990.

Reserve Margins. To determine whether a utility will be expanding its generating capacity fast enough to meet demand, we calculate reserve margins based on the excess of nameplate capacity at time of peak demand. Firm purchase contracts and interchange agreements are included as capacity. Where appropriate, interruptible power is excluded from the peak load demand.

Purchased Power. For cases in which low reserve margins are possible, we evaluate the possibility of purchasing power from other utilities. In some cases, firm contracts already exist or are being negotiated. In others, purchases may be needed from other operating companies within a system, other members of a power pool, or other utilities.

GENERAL TRENDS IN ELECTRIC ENERGY

Before examining the Gulf Coast utilities, we first will address three general issues which concern the power industry in the United States in the coming decade. Implications for specific Gulf Coast utilities are noted.

Growth of Power Demand Relative to Other Energy Sources

Economic growth in the United States has diminished and is likely to continue to do so in the next decade. At the lower rate of economic growth projected, the gain in expenditures on service as a fraction of total GNP will cease. Private investment will remain generally stable, and personal consumption expenditures will be a larger fraction of future GNP. These economic factors will promote relatively higher growth in energy consumption. However, these factors will be more than offset by rapidly rising energy prices so that energy demand will actually grow at a lower rate than the GNP. Total electric power will accordingly experience slower growth. However, the percentage of electric energy in the total energy supply will increase (see Table I) as electric power penetrates existing fossil fuel markets in both the Industrial and Household/Commercial sectors. Siting, environmental, and economic constraints will contribute to this trend by favoring a smaller number of large-scale utility power plants over a large number of smaller-scale industrial energy sources. Industries facing environmental restrictions on air emissions, higher liquid fuel prices, and curtailments of natural gas supply will increasingly find it preferable to purchase more electric power ("clean coal") rather than convert directly to coal themselves. We already see evidence of this trend in site selection studies in areas requiring emission offsets. Utilities must therefore plan to supply a greater portion of industrial energy demand. However, countering this trend will be improvements in energy efficiency for new processes as technology evolves to offset higher feedstock and energy costs.

Regulatory Climate

State and federal regulatory policies will continue to cause the greatest changes in the utility power industry ir the 1980s. The Powerplant and Industrial Fuel Use Act of 1978 has caused Texas and Louisiana utilities to plan major coal and nuclear plant additions. These plants require much greater capital outlays and longer lead times so that the utilities have had to seek substantial rate increases to sustain earnings and generate capital. Political pressure, particularly in states with elected regulatory agencies, has in many cases led to denial of adequate rate relief and even resulted in delays and cancellations of some projects. These political pressures have abated in some states when the utilities approached crisis conditions, but lengthy hearings and legal appeals will continue to characterize rate cases. In addition, many regulatory agencies (especially those elected by popular vote) have shown a tendency to increase industrial rates above a cost-of-service level. This trend has affected recent rate cases in Louisiana but has not been evident in Texas, Mississippi, or Alabama.

The nuclear regulatory climate has been highly unfavorable since the incident at Three Mile Island. Uncertainty will underlie nuclear power for the foreseeable future. A utility ordering a nuclear power plant today can have no certainty about the ultimate cost or eventual completion date. Through 1990, nuclear generating capacity will be determined almost entirely by completion of plants under construction. Construction delays and rising costs for nuclear plants are affecting five of the six major Gulf Coast utilities and are seriously jeopardizing future power supplies for some.

Alternate Fuels and Utility Power

Many studies are either in progress or planned to assess the feasibility of generating electric power from new sources such as wind, solar energy, and biomass. Solar energy will receive the greatest attention, but major commercial applications will not be likely before 2000. Alternate sources will not significantly affect electric power supply, demand, or costs in the Gulf Coast area before the end of the century.

TRENDS AFFECTING GULF COAST POWER SUPPLY AND DEMAND

In the Gulf Coast area, several trends are emerging which will alter the traditional patterns of industrial growth. These changes in turn will affect the expansion requirements of the utilities and ultimately affect power costs and reserve margins.

Petrochemical Demand

Although GNP growth is expected to remain low

during the 1980s, rising energy costs will stimulate petrochemical demand as plastics become more competitive with more energy-intensive products (e.g., metals). Between now and 1990, total petrochemical consumption will rise by more than 50 percent and will more than double by the end of the century. This growth has important implications for the Gulf Coast area where many basic petrochemicals and derivatives are produced. For example, most of the ethylene produced in the United States (80 percent) is manufactured in the areas served by the four Texas and Louisiana utilities emphasized in this paper. While many of the traditional incentives for siting new facilities on the Gulf Coast are diminishing, Pace estimates that the total additional power demand for petrochemical expansion alone in this area could run as high as 3,000 megawatts.

Limits to Industrial Expansion

On the other hand, there are trends which will tend to minimize power consumption by limiting industrial growth in this region. These factors will be especially significant along the upper Texas coast and the Mississippi River in Louisiana. These are maturing industrial areas with only a small number of new deepwater sites available.

The 1977 Clean Air Act Amendments are imposing further restriction to growth by requiring emission offsets for non-methane hydrocarbons (NMHC) and sulfur dioxide (SO_2). For example, the Houston area is a non-attainment region for NMHC so that any new source must be offset by elimination of more than an equivalent amount of NMHC from existing sources in the region. When the 1977 Amendments were passed, the Houston area was judged to be an attainment region for SO_2, which meant that new SO_2 emission sources could be permitted up to a maximum level according to the PSD ("Prevention of Significant Deterioration") provisions of the Act. However, the attainment designation was made retroactive to 1975 SO_2 levels when the Clean Air Act was originally passed. Conversion of boilers to residual fuel oil in the Houston area between 1975 and 1977 resulted in the PSD increment for SO_2 being consumed before the 1977 Amendments defining PSD became law. Therefore, in the Houston area, emission offsets are required for both NMHC and SO_2. These offsets are regarded as scarce corporate resources by the industries already operating in the area. They will be used carefully to optimize industrial growth with the least expensive offsets used first. Of course, there have been major improvements in plant operation and design to reduce emissions. In 1974, polyethylene and polypropylene manufacture resulted in 50 to 70 pounds of emissions per ton of product versus 2 to 5 pounds per ton of product in 1978. Nonetheless, at some point, the remaining offsets could become too expensive to justify further expansions. For example, use of lower-sulfur fuel oil may be justifiable to obtain SO_2 offsets (if such fuel oil is available); however, extensive deployment of flue gas desulfurization costing four or five times as much per quantity of sulfur removed may prove uneconomical.

The effect of the Clean Air Act Amendments of 1977 is thus to disperse industry away from concentrated areas such as the Houston Ship Channel. Such dispersion is counter productive to optimizing the energy efficiency of industry being promoted by the Department of Energy. At some point, the DOE and the Environmental Protection Agency may clash over such issues, and some moderation in this dispersion of industry may occur. However, for now it appears that in the Gulf Coast area, new industry will tend to move away from the concentrated areas on the Houston Ship Channel and some parts of the NOBAR corridor (New Orleans-Baton Rouge) along the Mississippi River. Utilities serving less concentrated areas (e.g., Central Power & Light, Alabama Power) may well benefit from this dispersion. Movement toward inland locations for plants not absolutely requiring deepwater sites could also result in increased industrial growth in areas such as East Texas.

Cogeneration and Independent Power Supply

Cogeneration projects have been studied for several years in the Gulf Coast area, and some major projects involving one or more industrial companies have been considered. In general, however, economics have not been favorable for such ventures. Large capital outlays for projects not related to a company's primary business purpose have deterred some projects, while escalating operating expenses (e.g., coal costs) have affected others. We do not believe major cogeneration projects will be economically attractive for the foreseeable future. However, concern over the reliability of power supply from the major utilities may prompt some industries to undertake cogeneration projects to ensure continued operation. One major project of this nature is already underway, and we know of others under study at this time. (We will discuss the reserve margin problems of the six Gulf Coast utilities in the next section.)

Power demand for the aluminum industry and some large chemical concerns will be a major source of uncertainty in determining future industrial demand for the utilities. There are only a few such plants on the Gulf Coast, but they are power-intensive operations (on the order of 500 megawatts each). As natural gas contracts expire and gas prices rise, these plants, which traditionally have generated their own power, will seek to purchase power or enter into joint venture projects with the utilities. Such moves could significantly affect a utility company's expansion plans.

Relative Costs of Industrial Power

Utilities have historically billed customers based on the cost incurred to provide power to them. Industrial customers have a generally steady load factor, take power at higher voltage levels, and have minimal distribution requirements. Thus generation, transmission, and distribution costs are all much lower for supplying industrial customers, and they have accordingly had lower rates. When power is generated in a low capital cost gas-fired station with inexpensive fuel, the transmission and distribution savings are more pronounced. The industrial rate schedules are much lower than residential and commercial schedules in this case. However, as capital-intensive coal and nuclear generating stations are added, the industrial rate will not appear as relatively favorable. In addition, there is a "pro-consumer" trend toward flattening rate structures so that industrial consumers pay more than a cost-of-service share for power and in effect subsidize other utility customers. While we have seen no evidence of this trend developing in Texas, the Louisiana Public Service Commission has granted two rate increases in the form of a constant charge per KWH to all customers, thus increasing industrial rates somewhat above a cost-of-service level in that state. If such a trend continues in Louisiana, industrial power costs in Texas, Mississippi, and Alabama would be more competitive.

OUTLOOK FOR GULF COAST POWER

The trends outlined above will obviously affect all six Gulf Coast utilities, but there are key differences which will cause industrial power costs to rise at different rates and which will affect reserve margins differently for each of them. The four utilities operating in Texas and Louisiana are moving toward coal and nuclear operations at a different rate but are well behind the Mississippi and Alabama utilities in making these conversions. A brief synopsis follows for each of these six utilities:

Houston Lighting & Power

Houston Lighting & Power (HL&P) is the nation's sixth largest utility and sells over half its output to industrial customers. Major coal plants are already in service, and others are being added. The company's biggest problem has been the delays and cost increases associated with the South Texas Nuclear Project (which also involves Central Power & Light). Its other nuclear project, Allen's Creek, was originally slated for 1985 but now appears unlikely to be in operation by the end of this decade. Because of the delays in the nuclear program, HL&P has had to rely more heavily on coal plants as well as arranging purchase contracts from other utilities. Reserve margins will nonetheless be tight during the early 1980s, and if the South Texas Project is not in service by 1985, the reserve margin could fall well below 10 percent with resultant power shortages.

Central Power & Light

Central Power & Light (CP&L) is placing its first coal unit in service this year. It presently enjoys healthy reserve margins, and we forecast it will need no additional capacity until its share of the South Texas Nuclear Project is added to the system. Further delays in this project could result in tight reserve margins in 1985 or 1986, but coal and lignite additions thereafter should boost margins to satisfactory levels. This factor coupled with the growth limitations in the Houston area and NOBAR corridor will make CP&L attractive to new industrial customers.

Gulf States Utilities

In the mid-1970s, Gulf States Utilities (GSU) embarked upon an expansion program including two nuclear stations and several coal units. Financial problems have forced cancellation of one nuclear plant and delayed construction of the other. GSU has only one long-term fuel contract and is thus at a disadvantage with respect to fuel costs and supply compared to other utilities. We forecast that reserve margins will be lower for GSU than for other utilities in the first half of this decade and will be very tight even if there are no other delays in its construction program.

Louisiana Power & Light

Favorable low-cost gas contracts and strong reserve margins characterized Louisiana Power & Light (LP&L) in the 1970s, but this situation will change in the 1980s. Favorable gas contracts will extend through the decade, but the company will be forced to deal with problems of gas supply curtailments, delays in nuclear expansion, and possibly periods of tight reserve margins. LP&L is now facing a large curtailment from its major gas supplier, and some adjustment in future delivery schedules appears likely. Two major nuclear expansions are slated for the early 1980s. LP&L will use all of the output of the Waterford 3 plant and a substantial portion of that from Middle South Utilities' Grand Gulf unit. Waterford 3 has been delayed by financial problems, and of course both plants have encountered the same types of delays and cost increases as other nuclear plants. Once these units are in service, LP&L should have satisfactory reserve margins for the rest of the decade. However, further extensive delays in both plants could reduce reserve margins to nearly zero in a few years. Reserve margins could also be adversely affected by the present gas curtailment depending upon the ability of the company to substitute fuel oil for gas on a long-term basis.

Mississippi Power

Mississippi Power, a relatively small utility, formerly lied heavily on natural gas, but since the early 1970s has had significant coal-fired capacity. Coal is now the primary fuel with oil and gas providing lesser quantities of power. Mississippi Power is already operating essentially as the Texas and Louisiana utilities will in the mid-to-late 1980s. However, Mississippi Power has no current or planned interest in a nuclear power plant. Another key difference between Mississippi Power and the other five utilities is that it has excessive reserve margins which will likely continue through 1990. Consequently, no construction of new capacity is planned. The company is presently committed to acquisition of a small share of four coal-fired units under construction by Georgia Power, a Southern Company affiliate.

Alabama Power

Unlike the other five utilities in our study, Alabama Power relies predominantly on coal and hydroelectric sources for its power supply. Natural gas and fuel oil have been used only to operate small turbines for peak loading and cold starting. A nuclear plant was placed in service in late 1977, and a second unit is under construction. The remaining capacity additions in the 1980s will be coal and hydroelectric units.

The most serious problem Alabama Power has had to deal with has been obtaining rate relief through the Alabama Public Service Commission. The Commission's refusal to grant any rate relief in the late 1970s led to curtailments in the company's construction program and a drastic loss of earnings. A management audit required by the state cleared the company of accusations made by the state and was critical of the Commission. Alabama Power has finally received adequate rate relief and has been able to continue its construction program, and the future appears more promising for the company. We forecast comfortable but not excessive reserve margins throughout the 1980s.

Relative Power Costs

During the 1970s, the relative costs of industrial power from these six utilities were determined largely by the availability of low-cost natural gas. Louisiana Power & Light recently has had substantially lower power costs than the other five utilities. However, as gas contracts expire, higher-priced fuel oil will become important in generating power from existing plants. Furthermore, new plants generating power from coal and nuclear energy will become prominent. The competitive position of the utilities will accordingly shift to favor those with less costly (i.e., older) coal and nuclear units, although through 1990 low-cost gas will still be a significant factor. Thus, LP&L will remain competitive on a cost basis, although its advantage will diminish as its gas contracts expire and as it adds nuclear and coal plants. Albama Power, on the other hand, has had higher power costs because of its reliance on coal and nuclear energy. Its power costs will be comparatively stable through the 1980s so that it will become highly competitive on a cost basis. By the late 1980s, Alabama Power will very likely have the lowest industrial power rates on the Gulf Coast assuming that they can continue their construction program without undue delays due to inadequate rate relief. Mississippi Power will not have quite as favorable a position as Alabama Power due to its significant use of fuel oil, and it will probably remain at the higher end of the range of power costs. Houston Lighting & Power and Central Power & Light will experience cost increases at different times in the mid-1980s depending on new plant start-ups and gas contract expirations, but by the end of the decade their costs should be more competitive with LP&L. Gulf States Utilities will be in a less advantageous position because of its fuel contract situation and will have a more difficult time competing with the other utilities.

Combining our cost projections and reserve margin forecasts, we conclude that Alabama Power and Central Power & Light will be in the best position in the latter half of the decade to offer reliable power at competitive rates to industries unable or unwilling to locate in the more concentrated area served by HL&P and in the NOBAR corridor served by LP&L and GSU.

TABLE 1

UTILITY POWER SHARE OF INDUSTRIAL SECTOR ENERGY

	QUADRILLION BTU			
	THERMAL	UTILITY POWER	TOTAL	PERCENT UTILITY POWER
ACTUAL				
1950	12.83	2.56	15.39	16.6
1960	15.73	4.21	19.94	21.1
1970	20.56	6.82	27.38	24.9
1975	18.29	7.92	26.21	30.2
1978	19.50	9.50	29.00	32.8
FORECAST				
1980	18.89	9.90	28.79	34.3
1985	21.51	12.05	33.56	35.9
1990	23.63	14.38	38.01	37.8
2000	29.27	19.61	48.68	39.9

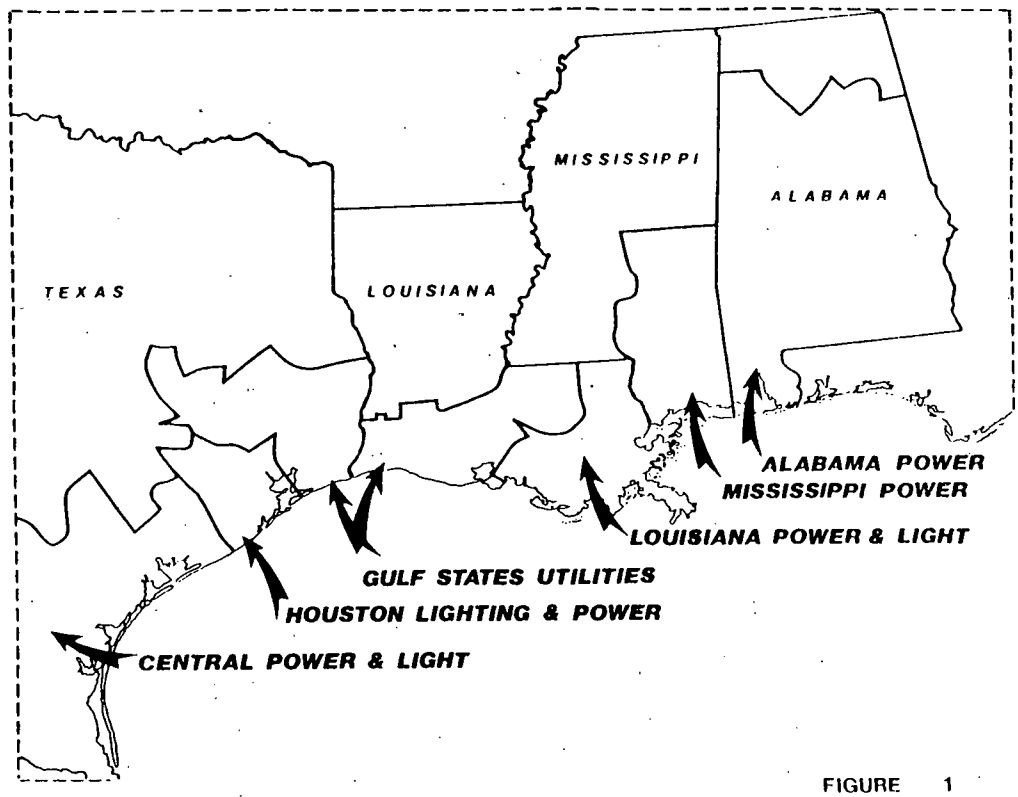


FIGURE 1

UTILITY SERVICE AREAS

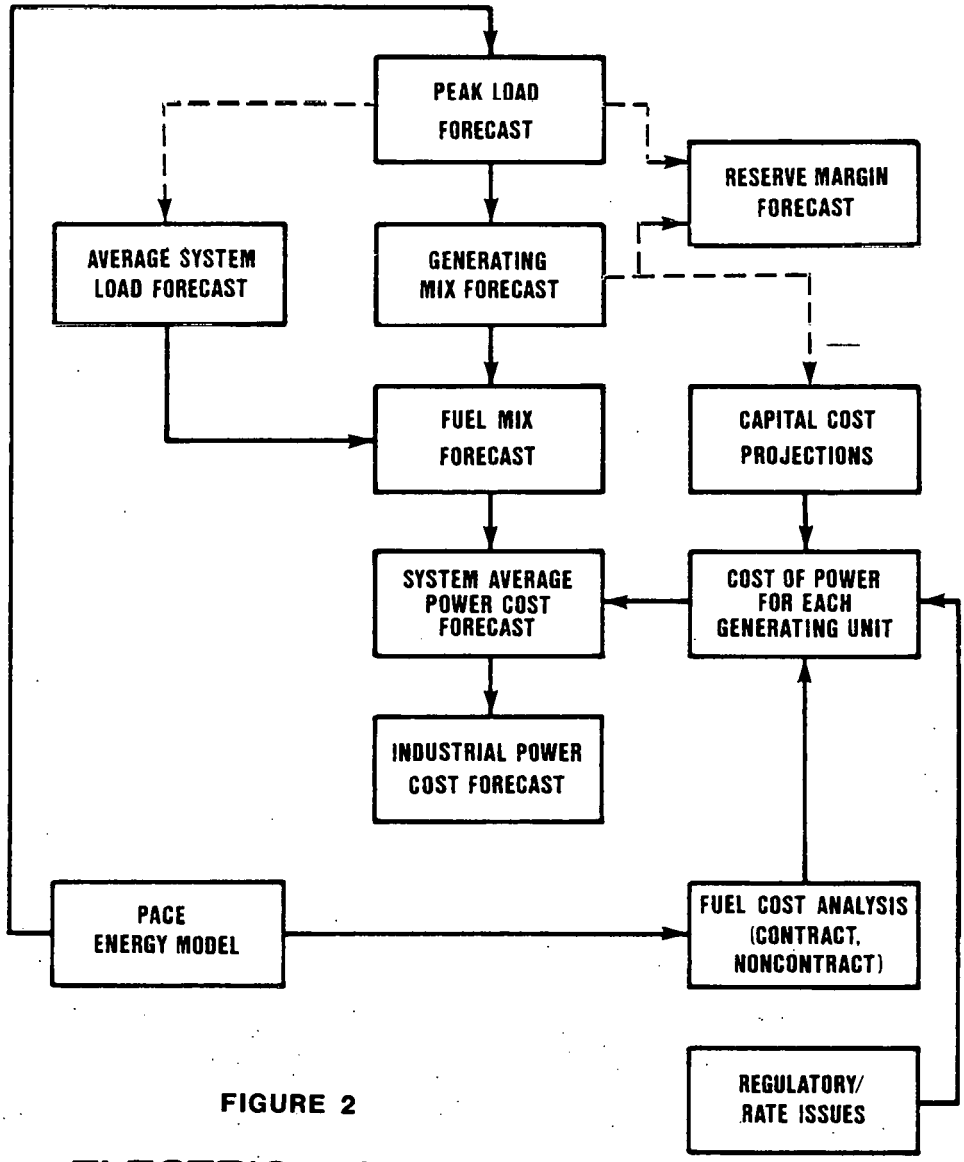


FIGURE 2

ELECTRIC POWER
COST FORECAST MODEL

EVALUATION OF INDUSTRIAL ENERGY OPTIONS FOR COGENERATION, WASTE-HEAT RECOVERY, AND ALTERNATIVE-FUEL UTILIZATION

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ABSTRACT

This paper describes the energy options available to Missouri industrial firms in the areas of cogeneration, waste heat recovery, and coal and alternative fuel utilization. The project, being performed by Synergic Resources Corporation for the Missouri Division of Energy, identifies and evaluates technological options and describes the current status of various energy resource conservation technologies applicable to industry and the economic, institutional and regulatory factors which could affect the implementation and use of these energy technologies. An industrial energy manual has been prepared, identifying technologies with significant potential for application in a specific company or plant. Six site-specific industrial case studies have been performed for industries considered suitable for cogeneration, waste heat recovery or alternative fuel use. These case studies, selected after a formal screening process, evaluate actual plant conditions and economics for Missouri industrial establishments. It is hoped that these case studies will show, by example, some of the elements that make energy resource conservation technologies economically and technically feasible in the real world.

BACKGROUND

The Missouri Division of Energy (formerly the Missouri Energy Program) is a division of the Missouri Department of Natural Resources, and has the responsibility for promoting energy conservation and alternate energy resource utilization, as well as for planning and policy analysis. Since early 1978, staff members of the Division/Program have been trying to get industrial firms in Missouri interested in several energy conserving technologies. While some plants in Missouri were cogenerating or recovering waste heat already, there was little interest in switching to coal or alternative energy resources because of high capital costs and uncertainties regarding regulation and future energy prices.

Previous efforts at workshops had resulted in varying degrees of success. At the same time, the staff recognized a need for a manual or some sort of document that could keep industrial energy managers abreast of state and national regulations affecting energy decisions, people to contact in state government, and the status of various technologies. In addition, the Fuel Technology Program had a need for identifying plants that were using alternate fuels and those that had potential to use alternate fuels.

An advisory group to the Energy Program, the Missouri Industrial Energy Consortium, requested similar action by the state. The result was the development of a project, funded jointly by state government and Federal funding from the Energy Policy and Conservation Act of 1975 (EPCA), to assist industry in Missouri in understanding technical options for industrial energy conservation. The scope of work for the project was defined by the staff of the Missouri Energy Program and reviewed by members of the Consortium. Synergic Resources Corporation was selected on a competitive basis as the contractor to perform this project.

PROJECT OBJECTIVES

The principal objectives of this project are to:

- Develop a manual for use by industrial energy managers as a reference for state and Federal energy (including environmental) responsibilities, and as a technical reference on certain industrial energy technologies. The manual is being developed so that it can be updated easily, and will in effect be a continuous reference document that would be expanded and revised as necessary.
- Develop a computer program that will provide industrial plant information on a selective basis, such as fuel type, fuel quantity used, SIC code, county location and amount of fuel used. Initially this program is to be driven with data from the National Emissions Data System (NEDS) tapes from the Missouri Division of Environmental Quality. Ultimately, data will be expanded as additional information is supplied by industry. The Missouri General Assembly is presently considering a bill that would protect the confidentiality of energy information provided to state government on a voluntary basis.
- Conduct site-specific feasibility studies of selected energy technologies at industrial plants in the state. The purpose of these case studies is not to demonstrate technical and economic feasibility, but to provide material for seminars to be held on the results of the feasibility studies in order to create interest by industry throughout the state. The emphasis in the seminars is to be on the criteria which make a particular technology feasible or unfeasible, and the major factors influencing the results. The use of plants actually located in the state will create more local interest and will point out regulatory problems specific to the state of Missouri.

INDUSTRIAL ENERGY CONSUMPTION PATTERNS IN MISSOURI

The energy consumption by fuel type in the industrial sector in Missouri in 1977 is summarized below:(1)

Fuel Type	Trillion Btu	%
• Natural Gas	90.7	38.2
• Coal	52.4	22.1
• Electricity	32.1	13.5
• Petroleum Products	62.3	26.2
• Total	237.5	100.0

The major energy-intensive industry groups are:(2)

- SIC 32 - Stone, Clay and Glass Products
- SIC 28 - Chemicals and Allied Products
- SIC 33 - Primary Metals
- SIC 20 - Food and Kindred Products
- SIC 34 - Fabricated Metals

These five industry groups consume over 75 percent of the energy consumed in the manufacturing industries.(3) These industries also consume over 80 percent of the natural gas in the manufacturing sector.

The declining availability and increasing prices of natural gas are already having significant impacts on Missouri industry. Natural gas curtailments have already occurred and were particularly severe during the 1976-77 winter. Missouri produces only a negligible amount of natural gas and crude oil. The state has about 5 billion tons of coal reserves(4) and produces over 5 million tons a year of coal, primarily for electric utility use.

The high dependence of Missouri industry on natural gas leads to concerns regarding efficient utilization and switching to more abundant or renewable energy resources. The technical options for conservation and fuel switching are numerous, and while most large industrial firms have the internal capabilities for identifying and assessing these options, small and medium-sized firms need assistance in sifting through the myriad of technical, economic and institutional aspects of industrial energy technologies.

THE INDUSTRIAL ENERGY MANUAL

An Industrial Energy Manual has been prepared(5) to provide a description of:

- Various energy resource conservation technologies applicable to industry, including cogeneration, waste heat recovery, coal-using technologies, wood, municipal, industrial, and agricultural wastes, solar energy and fuel cells.
- Institutional and regulatory factors which could affect the implementation and use of these energy technologies.
- Economic and incentive aspects of using these technologies.
- Roles of various state government agencies most relevant to industrial energy concerns.

It is intended that industrial users of this manual can use this manual to identify technologies with significant potential for application in a specific company or plant. However, it is not anticipated that any plant energy or utilities manager will use this manual to make specific decisions concerning implementation of any technologies for his plant.

Rather, the manual should, hopefully, provide enough information about the economic and energy advantages of using these technologies, to encourage site-specific studies of the applicability and feasibility of alternative energy-conserving technologies. These analyses would then result in implementation of energy resource conservation technologies where feasible.

TECHNOLOGIES COVERED

The technologies addressed in the manual include:

- Cogeneration
- Waste Heat Recovery
- Coal Utilization
  - Conventional Combustion
  - Fluidized Bed Combustion
  - Gasification
  - Liquefaction
- Wood Waste Utilization
- Municipal, Industrial and Agricultural Waste
- Solar Energy for Industrial Process Heat
- Fuel Cells

For each technology, a general description of the technology, economic data and institutional/regulatory factors are provided.

SCREENING AND SELECTION OF INDUSTRIES

Using the data available from the Missouri Department of Environmental Quality, NEDS tapes, an initial list of industrial firms was prepared. A computer program was then developed to screen these industries using one or more of the following criteria:

- SIC Codes (2-, 3- or 4-digit)
- County
- Fuel Type
- Hourly Fuel Use Rate
- Annual Fuel Use
- Process Type
- Stack Temperature

This program can be used to identify industrial firms having a number of common characteristics as required for different purposes by the Missouri Division of Energy.

A screening/selection procedure was then developed to select candidates for case studies. The procedure attempted to assure that:

- There is a high probability of selecting industrial plants which are likely to be good candidates for cogeneration, waste heat recovery and/or fuel switching.
- There is a high probability of rejecting industrial plants which are not likely to be good candidates.
- The process of screening and selection is carried out efficiently.

Starting with a complete listing of all industrial plants reporting in the NEDS data base, the first step was to screen by SIC using 20 three-digit SIC groups. The second screening was based on hourly operating rates. Plants using less than 2.5 million Btu/hour were considered too small for case studies. The remaining firms in the 20 SIC's were examined for stack temperature/flow rate, type of process and other available information. Based on this analysis, about 50 firms were selected.

A two-page questionnaire was sent to these plants to obtain specific data on plant energy consumption, operating characteristics, etc. About 30 responses were received. The information in these questionnaires was reviewed to select the most promising candidates for cogeneration, waste-heat recovery and alternative fuel use case studies.

THE CASE STUDIES

The six case studies being performed are summarized in Table 1.

Dayco Corporation may be able to reduce its steam generation and waste disposal costs by installing an incinerator with heat recovery to burn waste products and in-plant domestic trash. When operating at full capacity, this plant produces over 400,000 pounds of trash per day, about 80 percent of which is rubber product wastes. Incineration of these wastes could virtually eliminate a $40,000 annual waste disposal charge and generate up to 5,000 pounds of steam per hour.

The Quaker Oats Company plant in St. Joseph is producing oat, wheat, and corn products. This facility currently has very old boilers and has a very significant, constant electric load for milling and grinding equipment. This facility may be able to reduce its energy costs substantially by installing a cogeneration facility that can generate virtually all of Quaker's steam needs and reduce its electricity purchases by two-thirds. A combustion turbine with waste-heat boiler is envisioned for this cogeneration plant.

At the A. P. Green Refractories Company, existing kilns fueled by natural gas, and No. 2 fuel oil during gas interruptions, use exhaust gases for refractory

Table 1. Missouri Case Studies

Firm/Location	Type of Business	Type of Case Study	Proposed System
Dayco Corp./ Springfield, MO	Rubber Products	Alternative Fuel	Incineration of Waste Products for Heat Recovery
Quaker Oats/ St. Joseph, MO	Food Products	Cogeneration	Combustion Turbine w/ Heat Recovery Boiler
A. P. Green/ Mexico, MO	Refractories	Waste Heat Recovery	Preheat Kiln Combustion Gases from Kiln Exhaust
Bob Monnig Ind./ Glasgow, MO	Galvanized Metal Products	Waste Heat Recovery	Waste Heat Boiler on Kettle Furnace Exhaust
Missouri Steel Castings/ Joplin, MO	Steel Castings	Waste Heat Recovery	Recuperators on Heat Treat Furnace Exhaust
Syntex Agribusiness/ Verona, MO	Food Supplements (Human & Animal)	Alternative Fuel	Coal-Fired Fluid Bed Boiler

product preheating. This reduces kiln exhaust gases from about 2,400°F to about 800°F. With four of five kilns normally operating, total exhaust air flow of about 6,500 ACFM is available for recovery. Two obvious potential uses for this waste heat are combustion air preheating and office building space heating. Heat transfer over the distance from kiln exhaust to inlet (almost 500 feet) could be costly, while seasonal use of this heat for space heating is unlikely to be economical.

Bob Monnig Industries is a small custom galanizing firm using natural gas for a single kettle furnace and a small steam boiler. The case study will evaluate the feasibility of using 800°F exhaust gases from the kettle furnace to raise steam to displace gas consumption at the boiler. A heat recovery boiler could be easily connected to the kettle furnace flue duct. Other considerations for this facility include energy conservation activities like insulation of the furnace flue duct and an insulated cover for the kettle for off-hours use.

The case study of Missouri Steel Castings Company will concentrate on application of recuperators to the exhaust from two existing heat-treat furnaces. Depending on the product being treated, the furnaces operate at temperatures from 950°F to 1,700°F, 24 hours a day, 5 days per week. Recuperators would be used to preheat combustion air to these natural gas-fired furnaces, and will probably be applicable to an additional new furnace which is planned.

Syntex Agribusiness Company is interested in replacing gas/oil fired boiler capacity with a fluidized-bed combustor/boiler fueled by coal (inexpensive, high-sulfur Missouri coal, if possible). This new boiler could replace a number of old boilers and add steam capacity for planned additions. Missouri coal prices of about 80 cents per million Btu ($20 per ton) should provide a significant operating cost advantage over incrementally priced natural gas, currently about $2.60 per million Btu. Fluidized-bed combustion with limestone sorbent (another Missouri natural resource) should sufficiently control NO_x and SO_x emissions, while baghouse, wet scrubbers or electrostatic precipitators will control particulate emissions.

SEMINARS

The Missouri Division of Energy is planning a series of seminars to disseminate the information assembled in the manual, including the results of the six case studies. These workshops will be conducted during Summer 1980.

CONTINUING ACTIVITIES

The Missouri Division of Energy views the industrial energy program as a continuing activity rather than a "one-shot" effort. It is expected that the industrial manual will be updated as new information becomes available. Also, additional case studies and seminars may be conducted, depending on the response to the initial seminars to be conducted in Summer 1980.

REFERENCES

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COST-ENERGY DYNAMICS: AN ENGINEERING-ECONOMIC BASIS FOR INDUSTRIAL ENERGY-CONSERVATION POLICIES

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ABSTRACT

This paper develops a theory called cost-energy dynamics that can be used to shape policies for industrial energy conservation. It is built on two hypotheses commonly observed in process engineering; namely, cost varies as positive power function while energy varies as negative power function of the system size and/or complexity. These two hypotheses, which have roots in thermodynamics, give rise to a technological parameter (denoted c) that can be determined for each unit process. Cost-energy dynamics ranks energy conservation potentials of industrial processes by the technology parameter c, aggregates energy consumption by unit processes, considers energy embodied in the investment, considers the trade-offs between cost and energy, and distinguishes bases for decisionmaking in the public and private sectors. Five unit processes are used to represent the U.S. manufacturing industry. The aggregated technology parameter for industry is determined to be about 3.5. This value and the data on existing energy consumption allow the determination of energy conservation potentials, extra capital investment requirements, and the possible energy picture by the year 2000. Several public policy tools are evaluated for their effectiveness in stimulating energy conservation.

INTRODUCTION

The purpose of this paper is to provide a basis and a versatile approach for analyzing energy conservation policies. We combine the principles of process analysis and engineering cost analysis to formulate a methodology which we call cost-energy dynamics (CED). We look at industrial energy use as the aggregate of energy inputs at the energy-consuming devices, i.e., by unit industrial processes. In this way, six or seven unit processes represent 90 percent of all industrial energy consumption. The technology of each unit process can be represented by a single parameter (c). The aggregation of the characteristics of the unit processes (capital stock, energy consumption, technology parameter, conservation target, etc.) yield the characteristics of the U.S. manufacturing industry. Among our results are the following:[1]

1. The smaller the parameter c, the larger the potential for cost-effective energy saving.
2. The price elasticity of consumption is related to c by the relationship $\xi = -1/(c+1)$.
3. The U.S. industry has an aggregated technology parameter of about 3.5. This leads to a 14 percent difference in energy productivity when prices increase by a factor of 2 over the life cycle.
4. There is a tradeoff between public policies designed to stimulate investment (e.g., investment tax credit, cash subsidies, loan guarantees, fast depreciation) and those designed to discourage consumption (e.g., excise energy taxes). Regulations are necessary when the economic perceptions of the government, the manufacturers, and the consumers are not similar. New technologies are needed for unit processes with high values of c.
5. Another 20 percent of increased energy productivity can be achieved by the year 2000 with an investment of $800 to $1,000 billion in retrofitting older equipment and in building newer equipment. Since capital may not be available to allow this level of investment, the likelihood is that additional energy saving would be less than 20 percent per unit output, or that newer technologies are necessary.

CRITERIA AND APPROACHES

Several criteria and analytical approaches have been used to develop cost-energy dynamics. They are summarized below.

Public and Private Sectors

The ultimate goal of the private sector is to turn a profit while that of the government is to insure national, social, and economic security. Private-sector investment in conservation is scrutinized on the basis of its economic attractiveness.

Economic Attractiveness

A project is economically attractive when its rate of return is high or when the unit cost of its products is low. An energy conservation project is economically attractive when the extra investment is recovered in a few years by savings in energy.

Conservation Measures

"Better housekeeping" involves tightening operation to ıve energy without large, additional capital expenditures. "Retrofitting" involves changing hardwares with existing or new technologies, thus requiring capital. "New construction" has the benefit of new information on energy prices. Cost-energy dynamics implicitly recognizes that better housekeeping measures are taken before retrofitting and new construction, but otherwise treats them on the same basis of cost-effectiveness.

Life-Cycle Cost Analysis

Life-cycle cost analysis can be done either in the inflationary dollars mode or the constant dollars mode. In either case, income taxes, ad-valorem charges, and depreciation are accounted for. The discount rate is the effective after-tax cost of money.[2] For the public sector, benefit-cost analysis is based only on the ratio of the assumed public cost of energy supply to the public cost of subsidy for energy conservation.

Process Analysis

Process analysis is done as fundamentally as possible from physical principles. The objective is to obtain a fundamental relationship between the energy consumption and the design size (or complexity) aimed at a fixed output. Where first principles cannot be simply utilized, basic empirical data independent of systems are used.

Laws of Thermodynamics

Both laws of thermodynamics are considered implicitly through two surrogates,[3] namely, the relationship between cost and design complexity and the relationship between process energy and design complexity. They are also used to determine the minimum energy requirement of the process (thermodynamic limit). New modes of energy use, new arrangement of system hardwares to maximize utilization of energy, and new technologies are not analyzed *a priori* but can be captured when empirical facts are available.

Time

Time is treated both implicitly and explicitly. Implicitly, it is embodied in the exchangeability with energy (e.g., reaction rates, concept of "haste makes waste"). Explicitly, it is expressed in quantities such as life cycle (service years), cost of money, depreciation rates, etc. In a dynamic analysis, the price of energy can also be expressed as a function of time.

Capital Cost and Energy Cost

Capital cost includes investment cost (i.e., total investment at the time of first operation) and costs needed to service that investment (returns on capital, recovery of capital, taxes, etc.). Of fundamental importance in these capital servicing costs is the federal income tax which effectively gives a weighting factor of about 1.5-2 to investment in the private sector. Government planners often underestimate the difficulty of attracting private capital to conservation programs by ignoring this weighting factor.

Energy cost is the unit cost at the point of end use multiplied by the quantity of energy consumption. For existing stock, the life-cycle energy cost is traced through historical data for the particular fuel since the device was first put into service and through the expected data for the remainder of life. Often a "reasonable" value would suffice. Future energy prices are represented by a price at first operation (the "present") multiplied by a compounded escalation factor (the escalation rate).

Embodied Energy

Embodied energy in goods and services is determined by multiplying the investment with an input-output coefficient (Bullard's energy intensity).[4] The necessary adjustments for inflation and margins must be made. The embodied energy is assumed needed before, or for simplicity, at the time the equipment is put in place.

Embodied energy in fuels is also determined by multiplying the quantity of fuel with a coefficient appropriate for that particular fuel. This embodied energy is assumed needed before, or for simplicity, at the time of fuel consumption.

COST-ENERGY DYNAMICS

Formulation

In formulating CED, we let K designate costs in dollars, and E, energy in MMBtu (million Btu). Subscripts used are T for total, I for investment, E for process energy, and o for constant values independent of changes in capital or process energy. A "dot" superscript over a quantity designates the annual rate. Then, the total life-cycle cost and life-cycle energy requirement of the energy consuming systems are

$$K_T = K_o + K_I\,(\dot{E}) + K_E\,(\dot{E}) \qquad (1)$$

$$E_T = E_o + E_I\,(\dot{E}) + E_E\,(\dot{E}) \qquad (2)$$

The implicit assumption in the above equations is that capital and energy are substitutable while

other factors of the operation — namely, labor and materials — are additive. This is acceptable in most processes involving hardwares. When energy, capital, labor, and materials interact simultaneously, their interaction is more appropriately described by numerical methods (e.g., econometric).

It is important to determine the functions K_I, K_E, E_I, and E_E explicitly in terms of physical and economic quantities of the design. For lack of space, only the results are presented below; the interested reader is referred to Reference (1).

$$\dot{K}_I(E) = Z_I \dot{I}(E) \tag{3}$$

$$\dot{K}_E(E) = N Z_E p_o \dot{E} \tag{4}$$

$$\dot{E}_I(E) = \delta \dot{I}(E) \tag{5}$$

$$\dot{E}_E(E) = \varepsilon N \dot{E}, \tag{6}$$

where

$$Z_I = \bar{\phi}/CRF(x,N) \tag{7}$$

$$Z_E = \frac{1}{N} \sum_{i}^{N} \left(\frac{1+y}{1+x}\right)^i \tag{8}$$

$$\dot{I}(E) = b_1 + b_2 \left(\frac{E-a_1}{a_2}\right)^{-c} \tag{9}$$

In the above equations, Z_I is the present worth factor of the capital investment; $I(E)$ is the energy dependent capital investment (dollars); N is the life cycle (years), p_o is the unit cost of energy at the time of first operation ($/MMBtu); Z_E is the present worth factor of the life cycle energy costs, δ is the weighted energy intensity of the investment (MMBtu/$); ε is the energy intensity of fuel (MMBtu/MMBtu); ϕ is the levelized capital fixed charge throughout the life cycle; CRF(x,N) is the capital recovery factor for effective cost of money x over N years; y is the estimated escalation rate of fuel price over the life cycle; and b_1, b_2, a_1, and a_2 are constants.

Tables 1, 2, and 3 give typical values for Z_I, Z_E, CRF(x,N), δ and ε and some further clarifications of their meaning.

Equations (3) through (8) were formulated through a rigorous yet straightforward application of life-cycle cost analysis and embodied energy considerations. Equation (9), however, needs some conceptual explanations. For a known system and fixed economic output, the size or the complexity of the hardware is basically inversely proportional to the energy consumption ($E = a_1 + a_2\ size^{-\alpha}$), and the equipment cost is basically proportional to the size ($I = b_1 + b_2\ size^{\beta}$). The positive quantities α and β are called size exponents and are often available in handbooks.

TABLE 1 : TYPICAL VALUES OF Z_E

The fuel price factor is defined as $Z_E = \frac{1}{N} \sum_{i}^{N} \left(\frac{1+y}{1+x}\right)^i$

where

N = planning horizon
x = effective discount rate
y = annual fuel escalation rate

Planning Horizon N (years) and Effective Discount Rate x (yr^{-1})	Z_E for y (yr^{-1}) of Price Escalation			
	y = 0.06	y = 0.10	y = 0.15	y = 0.20
N = 5				
x = 0.06	0.972	1.119	1.285	1.473
x = 0.08	0.920	1.057	1.212	1.387
x = 0.10	0.872	1.000	1.145	1.308
x = 0.12	0.827	0.948	1.083	1.236
x = 0.14	0.787	0.900	1.027	1.169
N = 10				
x = 0.06	0.950	1.233	1.609	2.106
x = 0.08	0.859	1.108	1.436	1.868
x = 0.10	0.781	1.000	1.287	1.665
x = 0.12	0.713	0.907	1.160	1.490
x = 0.14	0.654	0.826	1.050	1.340
N = 20				
x = 0.06	0.907	1.509	2.621	4.695
x = 0.08	0.754	1.219	2.063	3.613
x = 0.10	0.636	1.000	1.433	2.819
x = 0.12	0.544	0.832	1.335	2.231
x = 0.14	0.471	0.702	1.097	1.790
N = 30				
x = 0.06	0.866	1.868	4.484	11.522
x = 0.08	0.666	1.346	3.056	7.530
x = 0.10	0.527	1.000	2.142	5.041
x = 0.12	0.428	0.766	1.546	3.462
x = 0.14	0.356	0.603	1.148	2.439

Equation (8) is obtained by correlating I and E on the basis of these two engineering facts which clearly have roots in thermodynamics. Of particular interest in this correlation are the following:

1. The quantity $c \equiv \beta/\alpha$ can basically be determined from handbooks or from simple principles. We call it "technology parameter."
2. The quantity b_1 is the first cost component which is fixed (independent of design size). Examples are the architect-engineer fees and installation costs (where applicable).
3. The quantity a_1 is the energy design point below which the process characterization is no longer valid. Sometimes this is synonymous with the thermodynamic limit of the process.[5]

Cost Optimization and Energy Optimization

When a reference design is available (with known $K_{I,Ref}$, $\dot{E}_{Ref}$, etc.), Equations (1) through (9) can be normalized such that we can work with ratios instead of absolute quantities (e.g., $\dot{E}/\dot{E}_{Ref}$ instead of $\dot{E}$). In this way, the equations can be treated mathematically without concern for units until the final stage of the analysis. Then Equations (1) and (2) are

TABLE 2 : TYPICAL VALUES* OF Z_I, $\bar{\phi}$, CRF (x,N)

Discount Rate x (yr^{-1}) and Planning Horizon N (years)	CRF (x,N)	$\bar{d}_{SYD}$	$\bar{\phi}$	Z_I
N = 5				
x = .06	.2374	.2078	.287	1.21
x = .08	.2505	.2104	.311	1.24
x = .10	.2638	.2127	.335	1.27
x = .12	.2774	.2150	.360	1.30
x = .14	.2913	.2174	.385	1.32
N = 10				
x = .06	.1359	.1088	.183	1.35
x = .08	.1490	.1114	.207	1.39
x = .10	.1627	.1141	.231	1.42
x = .12	.1770	.1166	.257	1.45
x = .14	.1917	.1191	.284	1.48
N = 20				
x = .06	.0872	.0590	.135	1.55
x = .08	.1019	.0617	.162	1.59
x = .10	.1175	.0642	.191	1.62
x = .12	.1339	.0666	.221	1.65
x = .14	.1510	.0687	.253	1.68
N = 30				
x = .06	.0726	.0422	.123	1.67
x = .08	.0888	.0448	.153	1.72
x = .10	.1061	.0469	.185	1.75
x = .12	.1241	.0488	.219	1.77
x = .14	.1428	.0504	.255	1.79

* The definitions of Z_I, $\bar{\phi}$, CRF (x,N and $\bar{d}_{SYD}$) are as follows:

$$CRF\ (x,N) = \frac{x}{1-(1+x)^{-N}}$$

is the capital recovery factor for the effective discount rate x over the planning horizon N.

$$\bar{\phi} = \frac{CRF\ (x,N)}{1-\tau} - \frac{\tau}{1-\tau}\,\bar{d} + \pi$$

is the annual levelized fixed charge rate for capital-related services, τ is the effective income tax rate, $\bar{d}$ is the levelized depreciation rate (schedule dependent), and π is the ad-valorem charge rate. We use the sum-of-the-years'digit schedule (SYD) for $\bar{d}$ and the value of 0.02 for π.

$$\bar{d}_{SYD} = \frac{2\,[N\ CRF\ (x,N)\ -1]}{N\,(N+1)\,x}$$

is the SYD depreciation charge levelized with discount rate x over period N, and

$$Z_I = \frac{1}{1-\tau} - \frac{\tau}{1-\tau}\,\frac{\bar{d}}{CRF\ (x,N)} + \frac{\pi}{CRF\ (x,N)}$$

is the present worth factor for all charges related to capital.

differentiated with respect to $\dot{E}/\dot{E}_{Ref}$ and the results set equal to zero, we obtain respectively the cost optimum and energy optimum design points for process energy, $\dot{E}_{Kopt}$ and $\dot{E}_{Eopt}$:

$$\dot{E}_{Kopt} = \dot{E}_{Ref}\,[cK_{I,Ref}/K_{E,Ref}]^{1/(c+1)} \qquad (10)$$

$$\dot{E}_{Eopt} = \dot{E}_{Ref}\,[cE_{I,Ref}/E_{E,Ref}]^{1/(c+1)} \qquad (11)$$

$$= \dot{E}_{Kopt}R^{-\xi}$$

where subscript "Ref" refers to the reference design with respect to which the optimization is made, $K_{I,Ref} \equiv Z_I I_{Ref}$, $K_{E,Ref} \equiv NZ_E p_o \dot{E}_{Ref}$, $E_{I,Ref} \equiv \delta K_{I,Ref}$, $E_{E,Ref} \equiv N\epsilon\dot{E}_{Ref}$, $R \equiv Z_E\delta p_o/Z_I\epsilon$, and $\xi = -1/(c+1)$.

Figure 1 shows the relationship between the cost optimum and energy optimum designs as well as the region of interest of first-cost conscious firms, life-cycle conscious firms, and the government. The cost optimum, $\dot{E}_{Kopt}$, is the design point at which the total life-cycle cost of the process is minimum. The energy optimum, $\dot{E}_{Eopt}$, is the design point at which the total demand on energy resources is minimum. Since R is always smaller than 1 and ξ negative for real systems, $\dot{E}_{Eopt}$ is always smaller than $\dot{E}_{Kopt}$. Naturally, when energy is cheap and when emphasis is strongly placed on the availability of capital, firms tend to underdesign (i.e., for points to the right of $\dot{E}_{Kopt}$). When the future is rather predictable and when energy cost is high, firms would try to design systems to operate as proximate to $\dot{E}_{Kopt}$ as possible. When the fuel is a scarce commodity, it might make sense from the government's recipient to design to the left of $\dot{E}_{Kopt}$. Only under extreme cases would a design for the energy optimum point $\dot{E}_{Eopt}$ be realistic. When energy prices increase drastically and beyond the original expectation, the firm would retrofit the hardware to decrease the energy consumption. Given time, the firm would retrofit its systems to stay competitive; the government could accelerate the retrofitting process by providing incentives such as tax credits. New devices are put in place to either accommodate growth or to replace older devices which are no longer economic to operate. At times of high

TABLE 3: SELECTED VALUES OF THE ENERGY INTENSITY OF GOODS AND SERVICES (δ)

1967 Input-Output Data

SIC	Industrial Sector Description	δ* (MMBtu/$(1967))
20.02	Sawmills	0.076
20.09	Wood products	0.083
24.01;02	Pulp mills, paper mills	0.221
27.01	Chemicals	0.303
28.01	Plastics	0.243
28.02	Synthetic rubber	0.329
30.00	Paint	0.136
35.01	Glass	0.112
36.01	Cement	0.518
36.02	Bricks	0.037
36.14	Gypsum	0.171
36.17	Asbestos	0.119
36.20	Mineral wool	0.168
37.01	Steel	0.282
37.02	Steel foundries	0.104
37.04	Primary metal	0.157
38.04	Primary aluminum	0.428
40.03	Heating equipment	0.079
40.04	Fabricated structural steel	0.137
42.05	Fabricated wire products	0.169
42.08	Pipes	0.082
43.01	Steam engines	0.079
43.02	Internal combustion engines	0.069
44.00	Farm machinery	0.079
45.01	Construction machinery	0.075
48.01	Food product machinery	0.057
48.02	Textile machinery	0.066
48.04	Paper industry machinery	0.068
49.01	Pumps, compressors	0.061
49.03	Blowers	0.069
49.06	Industrial furnaces	0.079
49.07	General industrial machinery	0.071
53.07	Carbon products	0.167
58.01	Storage battery	0.108
61.07	Transport equipment	0.109
65.01	Rail transportation	0.098
65.03	Truck transportation	0.058
69.01	Wholesale trade	0.040
69.02	Retail trade	0.038
70.01	Banking	0.023
78.04	Federal government enterprises	0.040

*These values were selectively extracted from Bullard et al.[4] The conversion of K_I to E_I usually requires a combination of a specific δ and those of the trade margin. For 1980 $, the values for δ are appreciatively less than half the values in this table.

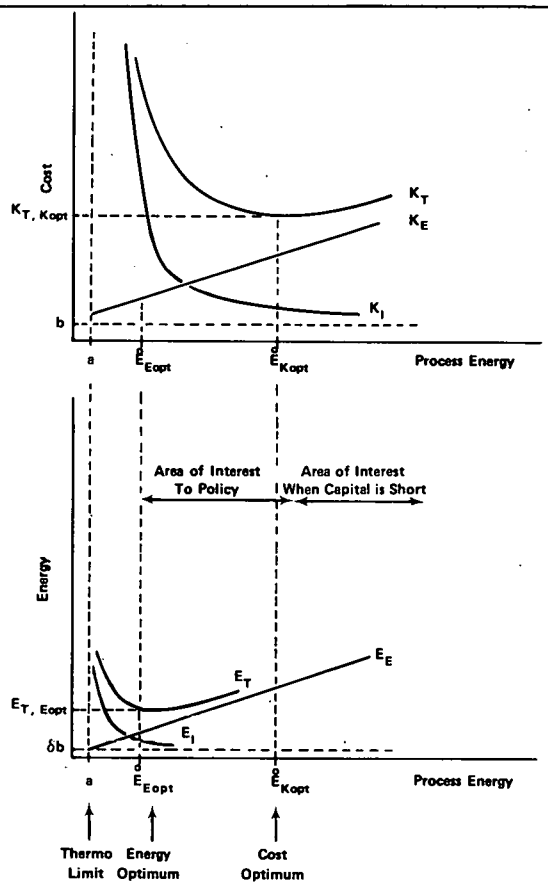


FIGURE 1: COST OPTIMUM AND ENERGY OPTIMUM DESIGN

Note that E_{Kopt} changes as energy price and planning horizon change, but E_{Eopt} is relatively unchanged for a specific technology. Area of interest to public policy is between E_{Kopt} and E_{Eopt}. To hasten retrofit, the area of interest also covers values of process energy larger than the current E_{Kopt}.

energy prices, firms would design new devices to benefit from all cost-saving conservation measures, including fuel switch and new technology. However, the cost optimum E_{Kopt} (which can be modified by Z_I and Z_E, hence by X, N, p_o, and y) can be perceived differently by the firm and by the government. In order to stimulate energy saving in the direction of public good, the government can devise regulations to force or can provide tax incentives to stimulate firms to slightly overdesign new systems.

Overdesign and Underdesign

Figure 2 shows that when the design is not at the cost optimum, the total cost of the operation increases. If we designate the system at cost optimum as the reference system, σ_I as the relative change in capital cost ($\sigma_I = \Delta K_I/K_{I,Ref}$), σ_E as the relative change in energy operating cost ($\sigma_E = \Delta K_E/K_{E,Ref}$), and σ_T as the relative change in total cost, then

$$\sigma_E = (E/E_{Ref}) - 1 \tag{12}$$

$$\sigma_I = (K_I/K_{I,Ref}) - 1 = (1+\sigma_E)^{-c} - 1 \tag{13}$$
$$\simeq -c\sigma_E + \frac{c(c+1)}{2}\sigma_E^2 - \frac{c(c+1)(c+2)}{6}\sigma_E^3 + \cdots$$

$$\sigma_T = \frac{\sigma_I + c\sigma_E}{H + c + 1} \tag{14}$$
$$\simeq \frac{1}{H + c + 1}\left[\frac{c(c+1)}{2}\sigma_E^2 - \frac{c(c+1)(c+2)}{6}\sigma_E^3 + \cdots\right]$$

$$H \equiv \frac{K_o}{K_{I,Ref}}$$

In the above equations, σ_E, σ_I, and σ_T are algebraic quantities, a negative sign meaning a saving, while a positive sign meaning an increase. Equations (13) and (14) are derived with the additional property, which will be elaborated further below, that at the cost optimum, c is the ratio of the (life cycle) energy cost to the (life cycle) capital cost.

When front-end capital is short, or when the device manufacturer is not also the user (e.g., manufacturer of automobiles, appliances, motors), underdesign to save on first-cost is usually the case. The public sector can help push the design towards cost optimum by tax incentives or by regulations. The tax incentives should be of the magnitude of $\sigma_I \simeq |c\sigma_E|$.

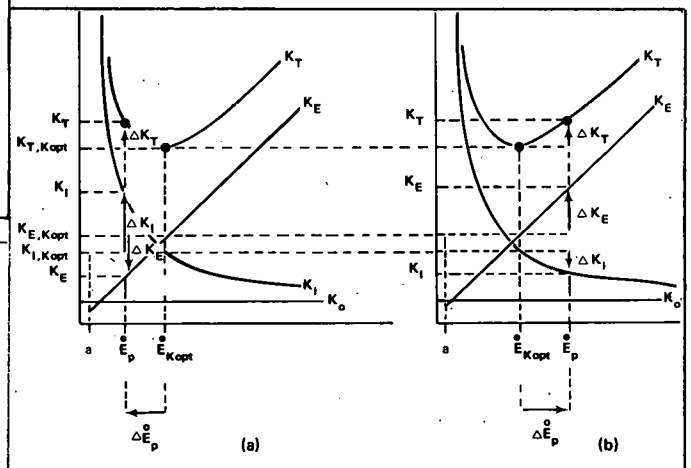


FIGURE 2: DEPARTURE FROM COST OPTIMUM

(2a) Overdesign to save energy: government subsidy is proportional to $c\sigma_E^2/2$.

(2b) Underdesign by industry to sell equipment to consumers at low first-cost: government subsidy is proportional to $c\sigma_E$.

If an overdesign is deemed necessary, the tax incentives should also be proportional to $\sigma_I \simeq |c\sigma_E|$ when the manufacturer is not also the user. Otherwise, they need only be proportional to $\sigma_T \simeq c\sigma_E^2/2$ because

the operator eventually can recover parts of the extra capital cost with savings in energy costs.

rofit for Both Energy and Cost Saving

Figure 3 illustrates the case in which a design is made in the era of low energy price ($p_1 = N_1 Z_{E,1} p_o$). When energy price increases beyond the designer's original expectation [curve $K_E(p_2)$ instead of $K_E(p_1)$], the operator would be well advised to spend some extra capital to retrofit the system such that the total cost would be at the new cost optimum (point C instead of point B). If ν is the ratio p_2/p_1, and the reference system is taken as the one before the retrofit, then

$$\sigma_E = \nu^{-1/(c+1)} - 1 \qquad (\nu > 1, \text{ energy saving}) \qquad (15)$$

$$\sigma_I = \nu^{c/(c+1)} - 1 \qquad (\text{extra investment}) \qquad (16)$$

$$\sigma_T = \frac{\sigma_I + \nu c \sigma_E}{H + 1 + \nu c} \qquad (\text{total cost saving}) \qquad (17)$$

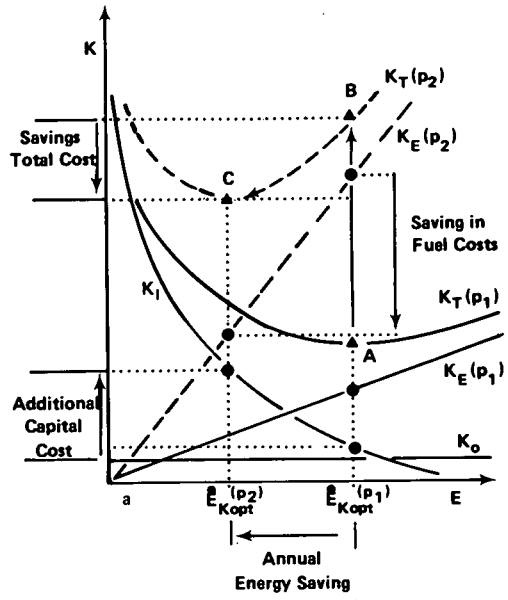


FIGURE 3: RETROFIT FOR BOTH ENERGY AND TOTAL COST SAVING

Point A: The system was optimized to operate at $\dot{E}_{Kopt}(p_1)$.

Point B: Subsequent to fuel price increase, total cost is no longer optimum.

Point C: Retrofit is needed to bring total cost to the new optimum.

Embodied Energy in the Extra Investment

The effect of the embodied energy in the extra investment is to reduce the saving in process energy. e interesting feature is that such embodied energy must be invested before or at the time of the conservation effort, and usually in a different manufacturing sector of the economy. What is then the energy saving to society? Would, for example, an energy saving from extra insulation be neutralized by the extra energy needed to manufacture the insulation? These questions can be routinely addressed by CED, but for lack of space, only the following conclusions are presented here. The interested reader is referred to Reference (1).

1. When there is an economic payback for the retrofit, then there is also an energy payback which is often much shorter.
2. An overdesign beyond cost optimum but not the energy optimum is still saving energy. The real constraint is the economics of the overdesign. When the overdesign is targeted at saving premium fuel such as oil or electricity, then it may be quite worthwhile.

Significance of the Technology Parameter c

The coefficient c, which we call the technology parameter, is the ratio of the cost and energy exponents; that is $c \equiv \beta/\alpha$. Since both β and α can be obtained either from handbooks or from simple principles, c is rather fundamental. We expect that for a specific unit process, say direct heating, c may change over a range due to system-specific characteristics, but it remains rather basic that c can be determined from first principles when these system-specific characteristics are known. A study of Equations (9) through (14) yields the following properties of c:

1. c is the ratio of the (life cycle) process energy cost over the (life cycle) capital cost at the cost optimum.
2. c is also the ratio of the (life cycle) resource requirements of process energy over the (life cycle) resource requirement of embodied energy.
3. c is the percentage increase of capital costs for every 1 percent change of energy saving.
4. The quantity $\xi = -1/(c+1)$ is the elasticity of energy demand because when price increases by a factor ν (over the life cycle), Equation (10) yields

$$\frac{\dot{E}_{Kopt}(p_2)}{\dot{E}_{Kopt}(p_1)} = \left(\frac{p_2}{p_1}\right)^{-1/(c+1)} = \nu^{\xi} \qquad (18)$$

When price difference is by a factor of 2 (e.g., Western European versus U.S. energy prices before 1973, or U.S. energy prices in 1978 compared to those in 1973), then Equation (18) yields a difference of 14 percent for the two optimum designs. This number is arrived at by using $c \approx 3.5$ as will be explained below.

APPLICATION TO U.S. MANUFACTURING INDUSTRY, 1980-2000

The above development of CED is now applied to the U.S. manufacturing industry. We are interested in finding the aggregated technology parameter of the industry, the potential for additional savings by the year 2000, the extra capital requirements, and the government measures necessary to stimulate such savings.

Five Unit Processes

Table 4 shows the projected 1980 energy consumption in the U.S. manufacturing industry broken down by six SIC categories and five unit processes. The six industrial sectors represent about 80 percent of all energy consumed by the entire industry. Similarly, the five selected unit processes represent about 70 percent of the energy consumed by all processes. The five unit processes are summarized below. The reader is referred to Reference (1) for further details.

Direct Heating — Furnaces, kilns, ovens, and industrial boilers account for about two-thirds or 6 quads of industrial process heat. More than 40 percent is used in metal and glass industries at temperatures above 1800°F. The petrochemical industry accounts for another 30 percent, mostly at temperatures above 400°F. The most attractive options for conversation in this area include reducing heat losses, recycling of heat into the process, and using waste heat to cogenerate steam, electricity, or space heat. We find the conservation parameter for direct heating to be in the range of 3-15, with the lower end applying to high-temperature operations.

Distillation — This is a major unit process used in the petrochemical and food industries. Energy consumption is on the order of 2 quads per year. The major options for conservation include increasing the number of trays, changing the column diameter, cascading columns, and improving flow characteristics. Values of c were found to be between 1 and 10. We chose a value of 2.8 based on a detailed study on tray and tray diameter optimization.

Evaporation — This is an industrial process used to concentrate a liquid product. Industrial evaporators consume about 1.5 quads of energy annually. Conservation options include increasing the number of effects or evaporation units, and improving the heat transfer characteristics of the condensate. The technology parameter c was found to be between 1.1 and 1.6. We chose 1.4 on the basis of a detailed study on adding effects.

Mechanical Drive — Mechanical drive represents the largest use of electricity in industry, consuming more than 400 billion kWh annually, or about 4 quads equivalent of primary resources. Industrial motors, particularly larger ones, have always been highly efficient, and many conservation opportunities arise only because motors are often operated below the peak capacity for which they are designed. On the basis of

TABLE 4 : PROJECTED 1980 ENERGY CONSUMPTION IN THE MANUFACTURING INDUSTRY BY UNIT PROCESSES*

SIC	Sector	Fuels for Direct Heat (quads)	Fuels for Evaporation (quads)	Fuels for Distillation (quads)	Electricity for Drive (10 kWh)	Other Unit Processes: Fuels (quads)	Other Unit Processes: Electricity (10 kWh)	Losses that can be Reduced by Thermal Insulation (quads)
20	Food	0.64	--	--	33.6	0.16	14.6	0.03
26	Paper	0.21	1.16	--	76.9	--	6.1	0.11
28	Chemicals	0.96	0.38	0.58	75.6	0.58	98.8	0.15
29	Petroleum	--	--	1.42	35.4	--	3.7	0.26
32	Stone, clay, glass	1.10	--	--	17.7	0.07	18.3	0.17
33	Primary metals	1.97	--	--	81.7	0.12	145.2	0.46
	Other sectors	1.22	--	--	132.9	0.27	108.6	0.10
	Total	6.12	1.55	2.00	453.8	1.20	395.3	1.28

(Total projected 1980 fuel use 10.87; electricity use 849.1 x 10^9 kWh.)

* Sources: Sara W. Boercker (1979). "Characterization of Industrial Process Energy Services," ORAU/IEA-79-9(R), Institute for Energy Analysis. Oak Ridge Associated Universities, Oak Ridge, Tennessee.

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* Notes: Values in this table are estimated by assuming a growth rate of 0.5 percent per year for fuel use and 3.4 percent per year for electricity use in the manufacturing industry between 1974 and 1980.

Values for losses that can be reduced by insulation are estimated by assuming half of the savings projected by Donnelly et al. for the "immediate term."

existing technology, we find electric motors between 5 hp and 100 hp to have a technology parameter between 30 and 40, with a weighted value of 15. The Exxon Alternative Current Synthesizer (ACS) is a new technology, which may be represented by a technology parameter of from 2 to 8. We assign a c value of 15 to represent past conservation performance and 8 to represent future prospects.

Insulation — We estimate that industrial heat loss amenable to reduction by insulation amounts to 1 to 2 quads annually. Assuming that half of the savings projected for 1980 by Donnelly et al.[6] has been achieved, the heat loss that could be further reduced by insulation is estimated to be 1.28 quads. The technology parameter for insulation falls between 1 and 2 depending on the curvature of the pipe surface. A value of 1.2 is selected for our example in this study.

Technology Parameter for the U.S. Industry

If I^+_{Ref}, E^+_{Ref}, and c^+ are respectively the referenced capital stock, energy use, and technology parameter of the U.S. manufacturing industry, then they can be obtained through the process of aggregation. The methodology is presented in Reference 1, and the results are shown in Table 5. The aggregated technology parameter c^+ is estimated to be 3.24 to first approximation and 3.5 to second approximation. With these values of c^+, the price elasticity of demand is between -0.22 and -0.24. A cutback in energy use of approximately 15 percent is thus predicted by Equation (18) when prices increase by a factor of 2 over the life cycle.

U.S. Industry in the Year 2000: An Estimate of An Optimum Energy Conservation Strategy

Table 6 summarizes the estimated costs of retrofits and new construction of the U.S. manufacturing industry by the year 2000. The assumptions are: industrial growth continues at 2.5 percent per year, 50 percent of existing capital stock would be retrofitted, and new construction would account for growth and retired stock. Price assumptions are: 1980 energy prices average at $3/MMBtu, price factor for retrofits is 2, life-cycle price increase factor is 2 according to industry's view and 3 according to the government's view.

We estimate that by 2000, the U.S. manufacturing energy use would increase from the current 20 quads/yr. to 33 quads/yr. if no conservation measures are implemented, 28 quads/yr. if the government would subsidize retrofit efforts, and 27 quads/yr. if subsidies are also available for overdesign. Industry would have to spend around $52 billion (1980 $) just

TABLE 5: ESTIMATE OF THE AGGREGATED CHARACTERISTICS OF THE U.S. MANUFACTURING INDUSTRY[a]

Unit Process	Reference[b] Energy Use $E_{Ref,i}$ (quads/yr)	Reference[c] Capital Stock $I_{Ref,i}$ ($ billion)	Technology[d] Parameter c_i	Relative[e] Energy Saving $\sigma_{E,i}$
Direct heating	6.12	50	3.0	0.10
Distillation	2.00	22	2.8	0.14
Evaporation	1.55	14	1.4	0.14
Mechanical drive	4.54[f]	8	15.0	0.05
Insulation	1.28[f]	11	1.2	0.20
Aggregated base	15.49	105	$c^+ = 3.24$	$\sigma^+_E = 0.103$

[a] This estimate is crude, used only to illustrate the methodology.

[b] Reference energy use for 1980 is from Table 4.

[c] Reference capital stock is not known with precision. It is estimated here in 1980 dollars, based on the relationship $I = K_E/cZ_I$. Furnaces are assumed to have N = 20 yrs., x = 0.10, y = 0.10, p_o = $2/MMBtu, hence I_1 = $50 billion; distillation: N = 20 yrs., x = 0.10, y = 0.10, p_o = $2.5/MMBtu, hence I_2 = $22 billion; evaporation: N = 20 yrs., x = 0.10, y = 0.10, p_o = $1.0/MMBtu, hence I_3 = $14 billion; mechanical drive: N = 15 yrs., x = 0.10, y = 0.10, p_o = $8/MMBtu(e), hence I_4 = $8 billion; insulation: N = 10 yrs., x = 0.10, y = 0.10, p_o = $1.5/MMBtu, hence I_5 = $11 billion.

[d] The technology parameters are from discussions on five unit processes; c^+ is calculated with Equation (19).

[e] The relative energy savings are assigned in view of the Energy Policy and Conservation Act target for 1980 (EPCA, P.L. 94-163);[7] σ^+_E is calculated with Equation (19).

[f] Although this value is used as a base for insulation calculation, it has already been counted elsewhere.

TABLE 6: U.S. INDUSTRY IN THE YEAR 2000: ESTIMATED COSTS OF RETROFITS AND NEW CONSTRUCTION WITH OPTIMUM ENERGY CONSERVATION

Assumptions	
Current manufacturing energy use	20 quads/yr
Healthy industrial growth	2.5%/yr
Relationship between energy and economy	1 to 1
Value of existing capital stock	$150 billion
Retrofit of existing stock by 2000	50%
Benefit after retrofit	15 years
New capital stock	50% of existing stock plus growth
Price factor for retrofits	2
Price factor for new construction (life cycle)*	
Industry's view	2
Government's view	3
Energy prices*	
Year 1980	$3/MMBtu (1980 $)
Year 2000	$11.5 - 20/MMBtu (1980 $)
Retrofit	
Capital stock to be retrofitted	$75 billion
Baseline energy use	10 quads/yr
Eventual retrofit by industry	14%, 1.4 quad/yr
Eventual extra capital cost	70%, $52 billion
Investment cost for conservation energy (I)	$2.5/MMBtu (1980 $)
Total capital cost for conservation energy ($K_I = Z_I I$)	$3.8/MMBtu (1980 $)
Government subsidy of investment cost, at 20%	$0.5/MMBtu (1980 $)
Government benefit/cost ratio (at $1 to 5/MMBtu public cost for energy supply)	4-20
Year 2000 energy use by retrofitted stock	8.6 quads/yr
New Construction	
Baseline energy need, year 2000	
To replace 50% of existing stock	10 quads/yr
To accommodate new growth	13 quads/yr
Subtotal	23 quads/yr
Optimized design, energy savings	
Industry's view	14%, 3.2 quads/yr
Government's view	21%, 4.9 quads/yr
Additional saving if government's view is adopted	8.5%, 1.7 quads/yr

* For the life-cycle price factor Z_E to be 2, the energy price increase must be around 17%/yr. in inflated terms or about 7%/yr. in real terms. When $Z_E = 3$, the increase is 10%/yr. in real terms (use Table 1 with x = 0.1, N^E = 20).

to retrofit 50 percent of existing stock. At a subsidy of 20 percent, either through investment tax credit or other means, the government's tab could be about $10 billion.

TABLE 6 (continued)

New Construction (continued)

Optimized design, capital stock	
Industry's view (v = 2)	$685 billion (1980 $)
Government's view (v = 3)	$940 billion (1980 $)
Benefit/cost of government-induced overdesign	
Extra energy saving	1.7 quads/yr for 20 years
Extra capital cost	$255 billion (1980 $)
Conservation energy cost of new construction	$7.5/MMBtu (1980 $)
Benefit/cost ratio (at $1-5/MMBtu public cost of energy supply)	0.1-0.7

Summary

Year 2000 manufacturing energy use	
Without conservation	33 quads/yr
With subsidized retrofit	28 quads/yr
With subsidized retrofit and overdesign of new construction	27 quads/yr
Year 2000 capital stock of energy-consuming devices	
Without conservation	$470 billion (1980 $)
With subsidized retrofit	$810 billion (1980 $)
With subsidized retrofit and overdesign	$1070 billion (1980 $)
Year 2000 energy bill**	
Without conservation	$380 billion/yr (1980 $)
With subsidized retrofit	$320 billion/yr (1980 $)
With subsidized retrofit and overdesign	$310 billion/yr (1980 $)

** The numbers here are based on $11.5/MMBtu (1980 $) for the year 2000. The magnitude of the energy bill, if anything, indicates that either the price increase assumptions are too high or drastic changes in the industrial energy use patterns will have to occur.

The overall investment requirements are very severe, however. An extra $660 billion is needed by 2000 for the retrofit and growth case, and $920 billion (1980 $) is needed when growth and overdesign also are desired. The magnitude of these figures convey several important messages:

1. The numbers as predicted here by CED need be refined, validated, and compared with those of other methods.
2. If indeed correct, industry would have severe problems raising such capital; hence the assumptions about growth and price increases would not be valid.
3. Drastic changes in fuel switch, manufacturing methods, product mix, and lifestyles are to be expected in the coming years.

EFFECTIVENESS OF PUBLIC POLICY TOOLS

A public policy is a course of action by the government designed to achieve a specific purpose. Energy conservation policies have the purpose of reducing energy consumption, specifically oil, without undue adverse effects on the economy and national security.[8-13]

Cost energy dynamics can be used to assess quickly the effectiveness of public tools commonly used to design and enforce policies. Equation (10), coupled with the definitions of Z_I and Z_E, can be used to determine a new cost optimum should c, Z_I, and Z_E change. A change towards a smaller c means that a new technology is available. Capital cost subsidies have the effect of reducing Z_I, hence reducing $\dot{E}_{Kopt}$. Such subsidies include outright cash subsidies, investment tax credit, accelerated depreciation, and low-interest loans. Energy cost disincentives have the effect of increasing Z_E, hence reducing $\dot{E}_{Kopt}$. Such measures include excise taxes on specific fuels and/or quota on fuel import. Regulations belong to a special category which is used when natural market forces alone are not sufficient to produce the desired results. These include mandatory fuel switch from oil to gas or coal, performance standards for automobiles and appliances, etc. Technology transfer is, like education, necessary to bring new knowledge to the users, particularly smaller industrial firms. For example, a government subsidized audit program for smaller industries is quite beneficial. Research and developments (R&D) have the net effect of decreasing c which is like saying that the end product can both be made cheaper and requires less energy. R&D can also change the product mix as well as the modes of energy utilization. We feel that R&D are not effective in the short term but extremely important in the long term. Table 7 displays the relative effectiveness of public policy measures for industrial energy conservation as analyzed by CED.

TABLE 7: RELATIVE EFFECTIVENESS OF PUBLIC POLICY MEASURES FOR INDUSTRIAL ENERGY CONSERVATION

Category	Effectiveness*	Cost-Energy Dynamics Evaluation and Remarks
A. Capital Cost Subsidy		
1. Cash subsidy	H	Fast results. Paperwork may slow down programs. 10% subsidy yields 10% energy savings; 20% subsidy yields 14% energy savings.
2. Increased investment tax credit (ITC)	H	Fast results. Encourages private incentives. Minimum paperwork; 20% ITC yields 4% energy savings; 30% ITC yields 7% energy savings.
3. Accelerated depreciation	M	Encourages private incentives. Minimum paperwork. Decrease of depreciation life from 20 to 10 years yields 2% energy savings, to 7 years yield 3% energy savings.
4. Low interest loan	M	Quite effective but limited in scope. Paperwork may slow program down. A guaranteed cost of money at 10%/yr instead of 12%/yr yields a savings of 4% in energy.
B. Energy Price Disincentive		
5. Excise tax	H	Fast results. Minimum paperwork. Encourages fuel switch. 20% exise tax yields a savings of 4%. A 30% exise tax yeilds 5%.
C. Regulations	H	Highly effective and results are predictable. Creates temporary hardship on specific sectors of economy. A must if gaps of motivations between manufacturers and consumers are to be bridged.
D. Technology Transfer	L-M	Needed for small industrial fir
E. Research and Development	L-M	Not effective in the short term but extremely important in the mid and long term. New technologies can cut both capital costs and fuel use drastically.

*H = high, M = medium, L = low

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10. The Industrial Equipment Efficiency Labeling Act, (H.R. S.1338), was introduced by Congressman Metzenbaum and others in 1979. This bill requires that standards for electric motors and pumps be set and enforced.
11. The Capital Cost Recovery Act, known as the "10/5/3 Legislation," was introduced by Representatives J. Jones and B. Conable, Jr., to the 76th Congress in 1979. If passed, structures will be depreciable in 10 years; equipment, 5 years; and vehicles, 3 years.
12. The Energy Productivity Act of 1979 (H.R. 5304) was introduced by Eckhardt and others to the 76th Congress in September 17, 1979, to provide incentives for industrial, commercial, and residential energy conservation.
13. The National Research Council (1979). "Alternative Energy Demand Futures to 2010," National Academy of Sciences, Washington, D.C.

ACKNOWLEDGMENTS

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PAYBACK ANALYSIS OF ENERGY PROPOSALS

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ABSTRACT

Payback analysis of investment proposals is one of the most widely used and often misapplied concepts in industry. Significant shortcomings are inherent to this method, its failure to consider the time value of money and inflationary factors being two. The problem of including the time value of money (to the firm) has been conquered by introducing the concept of discounted payback analysis. Recognizing the need of incorporating inflationary factors into economic analysis and the fact that the energy inflation rate often exceeds the inflation rate of the general economy, this paper develops a technique for including these parameters into payback analysis of energy investments. Included in the development of this method are examples of its correct and incorrect application with regard to energy (savings) related projects. Results are presented, indicating the analyst must be careful in the application of these parameters in calculating a proposal's payback, and in comparing energy related projects to non-energy related projects.

Simple payback analysis of investment proposals is likely the most applied method of investment analysis in industry today. Often, decision makers will ask, "What is the project's payback period?" before reviewing engineering design considerations. The popularity and acceptance of payback analysis are a direct result of the concept's simplicity. Unfortunately, the assumptions associated with this simplicity create the major drawbacks of this analysis method. Simple payback analysis ignores the time value of money, cash flows after the payback period, and the effects of inflation on future cash flows. The objective of this paper is to illustrate methods for accurately dealing with these shortcomings. Examples, using before tax cash flows, will be used extensively.

SIMPLE PAYBACK

Simple payback calculations involve determining the length of time necessary to recover the initial cost of an investment using a zero interest rate. In other words it is the length of time required for the cash inflows (savings) to equal the cash outflows (cost) of the project. Simple payback can be represented mathematically as follows:

Payback (yrs) = First Cost ($)/Annual Savings ($/yr)*

* Under the assumption that savings are constant throughout the life of the project. When this is not true, the savings are summed until the ratio exceeds unity.

Example 1:

A firm purchases a new machine tool for $10,000 with the expectation of a $1,800/yr savings that can be realized over the equipment it replaces. The new equipment will last 15 years. Salvage values of the new and the replaced unit are negligible.

Table 1. Computations for Example 1

End of Year	Investment	Estimated Savings	Unrecovered Balance
0	$-10000		$-10000
1		$1800	- 8200
2		1800	- 6400
3		1800	- 4600
4		1800	- 2800
5		1800	- 1000
6		1800	+ 800

Payback = 5.56 years = $ 10000 / $ 1800

DISCOUNTED PAYBACK

Rather than invest funds in the asset under consideration, the opportunity to use those funds elsewhere (in the business or in the bank) exists. The firm's track record over time will indicate some return on their total investment. Since the firm has

a history of earning that return (expressed as a rate), they desire to continue making current and future investments which earn at least as much to avoid dilution of the rate. This rate is known as the minimum attractive rate of return (MARR), and can be used as a criteria for selecting investment opportunities. It recognizes the earning power of money.

To recognize the time value of money, net positive expected (future) cash flows (savings) are discounted using MARR as the discount rate. This discounting illustrates the concepts of equivalance, since had the funds been invested at MARR elsewhere, future returns would reflect the compounding impact of the investment. When funds are discounted, they are reduced to the amount "today" (at the present) such that the expected cash flow (in the future) would result at an explicit point in time with an interest rate of MARR at work.

To illustrate, from Example 1, the $1800 saving expected one year from now when discounted to its equivalent dollars today, assuming a MARR equal 15%, is:

$$\frac{\$1800}{(1.15)^1} = \$1565$$

(Actually, it may be easier to see that $1565 today would be equivalent to $1800 one year from now by noting $\$1565\ (1.15)^1 = \$1800$.)

The discounting term can be expressed in general terms as:

$$\frac{1}{(1.0 + \text{MARR})^n}$$

where n is the number of years separating today from the expected cash flow being discounted.

To apply the time value of money to payback analysis, the discounted cash flows are aggregated until they first equal the investment cost. Since future cash flows will be reduced, the payback period will be extended, relative to simple payback.

Example 2:

Same facts as Example 1, with a MARR value equal to 15%.

It is interesting to note that the application of a MARR of 15% more than doubles the payback of this project. We have, however, taken into account the earning power of the $10000 we invested in the asset.

Table 2. Computations for Example 2

End of Year	Investment	Estimated Savings	Estimated Savings Dis. at 15%	Unrecovered Balance
0	$-10000			$-10000
1		$1800	$1565	- 8435
2		1800	1361	- 7074
3		1800	1184	- 5890
4		1800	1029	- 4861
5		1800	895	- 3966
6		1800	778	- 3188
7		1800	677	- 2511
8		1800	588	- 1923
9		1800	512	- 1411
10		1800	445	- 966
11		1800	387	- 579
12		1800	336	- 243
13		1800	293	+ 50
14		1800	254	+ 304
15		1800	221	+ 525

Payback = 12.83 years (occurs when unrecovered balance becomes non-negative)

PAYBACK - RECOGNIZING INFLATION - A WRONG APPROACH

Assume the analysis recognizes the annual savings of $1800 will take place in an inflationary period and reasons that those savings should be inflated. If the general economy is inflating at a rate of g% per year, the inflation saving would be:

$$\$1800\ (1 + g)^n$$

where n is the year when the $1800 future saving is expected to occur.

Example 3:

Same facts as Example 1, except the general inflation rate of the economy is g% and is to be taken into account.

Table 3. Computations for Example 3

End of Year	Investment	Estimated Savings	Inflated Savings (g = 12%)	Unrecovered Balance
0	$-10000			$-10000
1		$1800	$2016	- 7984
2		1800	2258	- 5726
3		1800	2529	- 3197
4		1800	2832	- 365
5		1800	3172	+ 2807

Payback = 4.12 years

The investment looks better than ever. However, the analyst has been inconsistant in computing values. He has rationalized the $1800 savings will in fact be larger than his estimate he made using todays dollars (for example, the price paid for fuel saved). However, this method has two shortcomings.

First it fails, as previously shown in Example 2, to discount future savings, recognizing the earning power of invested funds (the opportunity cost concept). Secondly, but not so clear, the method assumes all elements constituting the savings are escalating at the same rate, that of the general economy (g). These will be addressed in the following examples, respectively.

PAYBACK - RECOGNIZING INFLATION - CORRECT APPROACH

Here we have the opportunity to define purchasing power. Inflation is a rising general level of prices over time, such that more money is required to buy the same goods or services at a later date. In our example, we require the $1800 savings to have the same purchasing power, so we inflate each expected receipt by the relationship:

$$T_t = \$1800\ (1.0 + 0.12)^t,\ t\text{-}1,2\ldots15$$

where T_t = the "then-current" value at time t of the $1800 necessary to have the same purchasing power.

When dealing with "then-current dollars," the effect of both the earning power (opportunity cost) and the purchasing power lost (due to inflation) working in combination must be considered.

An investment, after t time periods would have to increase in value by $(1 + i)^t\ (1 + g)^t$ to maintain the equivalency concept. For example, $10000 now should be considered as equivalent to $\$10000\ (1 + i)^t$ t periods hence due to only its earning ability over time. Furthermore, since inflation is at work, the $\$10000\ (1 + i)^t$ must be increased by $(1 + g)^t$ to maintain no loss in purchasing power. Thus, when discounting then-current values to present worth values, care must be taken to use a discount rate which takes out the increase due to both the time value of money and inflation. This can be developed as follows:

$$\$_P\ (1 + i)^t\ (1 + g)^t = \$_{T_t}$$

where $\$_P$ represents the present worth of $\$_T$ (then-current) t periods hence. Then the discount factor to apply is:

$$\$_P = \$_{T_t} \left[\frac{1}{(1 + i)\ (1 + g)}\right]^t$$

$$\$_P = \$_{T_t} \left[(1 + i)\ (1 + g)\right]^{-t}$$

or $$\$_P = \$_{T_t}\ (1 + d)^{-t}$$

where $d = (i + g + ig)$ and we note d is taking on the role of a single discount rate. Returning to Example 3, the necessary discount rate is:

$$d = \left[0.15 + 0.12 + (0.15)(0.12)\right] = 0.288$$

Example 4:

Same facts as before, except both the effect of inflation and the time value of money are to be recognized.

Table 4. Computations for Example 4

End of Year	Investment	Expected Savings	Then-Current Savings (Inflated)	Discount Savings (d=0.288)	Unrecovered Balance
0	$-10000				$-10000
1		$1800	$2016	$1565	- 8435
2		1800	2258	1361	- 7074
3		1800	2529	1184	- 5890
4		1800	2832	1029	- 4861
5		1800	3172	895	- 3965
6		1800	3553	778	- 3188
7		1800	3979	677	- 2511
8		1800	4457	588	- 1923
9		1800	4992	512	- 1411
10		1800	5591	445	- 966
11		1800	6261	387	- 579
12		1800	7013	336	- 243
13		1800	7854	293	+ 50
14		1800	8797	254	+ 304
15		1800	9852	221	+ 525

Payback = 12.83 years

Notice this results in the same payback as Example 2 when inflation was ignored. This was to be expected since we inflated the $1800 values and then insured the discount rate contained an element to deflate them. Notice, we can write:

$$\$_P = T_t \left(\frac{1}{1+i}\right)^t \left(\frac{1}{1+g}\right)^t$$

which shows the discounting rate takes out both the earning power and then the inflationary aspect. This is why, when all elements constituting the net cash flow are expected to be impacted equally by the same inflation rate, inflation can be ignored. However, when some elements inflate at a rate faster (or different) than the general economy, a modification can be made to handle this condition, as will be demonstrated next.

PAYBACK - RECOGNIZING ENERGY INFLATION AT A RATE IN EXCESS OF THE GENERAL ECONOMY RATE

Assume the savings from the investment represent outlays for natural gas, and further, natural gas is expected to inflate at 20% per year, while the gener economy is only expected to inflate at 12%. The following example accounts for the energy inflation rate as well as the general inflation rate.

Table 5. Computations for Example 5

d f Year	Invest-ment	Estimated Fuel Savings	Then-Current Savings (Inflated)	Discount Savings (d=0.288)	Unrec-overed Balance
0	$-10000				$-10000
1		$1800	$2160	$1677	- 8323
2		1800	2592	1562	- 6761
3		1800	3110	1456	- 5305
4		1800	3732	1356	- 3949
5		1800	4479	1264	- 2685
6		1800	5375	1177	- 1508
7		1800	6450	1097	- 411
8		1800	7740	1022	+ 611

Payback = 7.4 years

Notice the payback is now much shorter. Each dollar not spent for natural gas will not be worth 20% more than other dollars at that time, since inflation has taken place. However, since the fuel savings were expected to result from not spending funds for fuel which is increasing in cost at a rate in excess of the general economy, not all of the purchasing power of the savings is taken back out when the "then-current" values are discounted. The difference in the discounted savings column between Table 4 and Table 5 represents a benefit to the investment and as such can be credited to it. This is why the payback period shortened from 12.8 to 7.4 years.

While we considered the entire $1800 in Example 5 to be the element (fuel) which was inflating at a rate different (faster) than the general economy, we need not be so restricted. Suppose $1000 of the savings were attributable to fuel and $800 to reduced maintenance and maintenance was considered to increase in its cost at a rate near the general economy. We have two equally effective choices. First, we can, year by year, inflate the $800 value at the general economy rate (g), inflate the $1000 value at the expected fuel rate (f), and add them together (since they occur at the same time). Then discount this total using the combined discount rate (d). The other way (more cumbersome) would be to ignore the effect of inflation on the maintenance and simply discount its cost savings at MARR. Then to inflate the fuel at rate (f) and discount those values back at (d). Either will provide the same result.

PAYBACK - RECOGNIZING INFLATION USING A MODIFIED INFLATION RATE

In Example 5, we recognized three different rates: (g) represented the expected inflation rate for the general economy, (f) represented the expected inflation rate for fuel, and (d) represented a discount rate which accounted for both the earning power due to inflation. It is possible to combine these rates. Let K = an equivalent elemental inflation rate on an incremental basis. We now set the effective present worth factor (the numerator inflated the savings and the denominator both deflated and discounted them to the present) equal to the effective incremental inflationary rate K, as follows:

$$\frac{(1 + f)^n}{(1 + i)^n (1 + g)^n} = \frac{(1 + K)^n}{(1 + g)^n}$$

which yields:

$$K = \frac{(1 + f)}{(1 + g)} - 1.0$$

To illustrate, Example 5 will be reworked using K as the inflationary factor. This is done as Example 6.

Example 6:

Using the modified inflation rate (K), rework Example 5.

$$K = \frac{1 + 0.20}{1 + 0.12} - 1.0 = 0.0714$$

Table 6. Computations for Example 6

End of Year	Invest-ment	Estimated Savings	Inflated Savings K=0.0714	Discount Savings at MARR=15%	Un-recovered Balance
0	$-10000				$-10000
1		$1800	$1929	$1677	- 8323
2		1800	2066	1562	- 6761
3		1800	2214	1456	- 5305
4		1800	2372	1356	- 3949
5		1800	2541	1264	- 2685
6		1800	2723	1177	- 1508
7		1800	2917	1097	- 411
8		1800	3125	1022	+ 611

Payback = 7.4 years

This example, as expected, yields the same result.

It is interesting to note the value of (K) above is very close to the difference between (f) and (g), and little error would be introduced by making this approximation.

CONCLUSION

This paper has addressed the payback analysis method of evaluating energy related projects. First simple payback was demonstrated and its shortcomings briefly discussed. To incorporate the time value of money concept, discounted payback was suggested and presented. To account for inflation properly, considerable care must be taken. The worst case occurs

where expected savings are inflated but not discounted. A correct way for handling inflation was demonstrated. Under the assumption all cash flows are expected to be impacted by the same inflationary environment, it was shown that inflation could indeed be ignored in the analysis. Two procedures were demonstrated for the more general case where some elements of the cash flows (such as energy) are inflating at rates in excess of the general economy's inflation rate.

THE GAS-UTILITY VIEW OF INDUSTRIAL ENERGY CONSERVATION

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ABSTRACT

The gas industry fostered more efficient energy utilization long before the idea of energy conservation became fashionable. It became apparent in the late '60's that misguided Federal Legislation was discouraging necessary search for new gas supplies and the gas industry mounted a determined engineering and development effort to stretch existing supplies until changes in the legislation could be implemented. These and similar programs are ongoing even now that the outlook for new gas supplies is constantly improving. This paper makes references to specific efforts by gas utilities in concert with industrial users.

Conservation means different things to different people. Long before it became popular to talk about energy conservation, the gas industry has been working to eliminate waste in the use of energy. At the same time, research has been underway to seek improvements in equipment and hardware that would effectively reduce the use of energy per pound of product. Real conservation must consider not only the impact on natural resources but on capital and human resources as well. Any measurement of efficiency should consider these elements.

The A.G.A. membership has a proud record of commitment to conservation as a vital component of this nation's energy policy. In assessing the specifics of this commitment - one must look to the local regulatory environment in which the utility functions. Where the environment is supportive, there is positive activity. As we move forward into the '80s, new directions for utilities will, for the most part, involve financial demands on the utility and - often new risks.

The ability of the utility to make its contribution to new developments in energy efficiency is directly related to the incentives provided. The gas industry's objective is to encourage the development of more efficiency energy utilization, then communicate the availability of these new methods to the various publics - and, finally, depending on the local environment - assist the public in the acquisition of these more efficiency utilization methods.

In many jurisdictions, gas companies are ncerned as to their ability to raise capital to support the traditional functions of a gas utility.

A key element in conservation is the maintenance of the American standard of living and a growing economy.

I can say, with the authority from my experience that with the proper regulatory climate and incentives, the gas utilities will provide the vigorous, innovative and efficient leadership needed to continue to enhance our standard of living and, at the same time, reduce energy consumption and our dependency on insecure or undesirable energy sources.

Let me describe some current and ongoing gas utility contributions to better energy use -
Last November 29, the Northern Illinois Gas Company held its sixth annual Energy Conservation Exposition. The conference, attended by over 700 of Northern's industrial and large commerical customers, had a general session of energy decisions and projections; gas supply and regulations; developments in utilization equipment and other subjects of broad interest. During the afternoon many concurrent technical sessions appealed to the specialist. Over 50 manufacturers exhibited the latest in efficient gas products and processes.

I only relate this as an example of the kinds of consumers meetings that gas utilities from the Pacific to Delaware Valley, from Minneapolis to Atlanta have been holding during this past decade. Many have been conservation oriented to make gas go further. Techniques in the efficient use of gas has been a central theme demonstrated by the manufacturer or utility utilization engineer.

Performing more as an agent for his customer than a utility representative - the well trained gas utilization engineer has a variety of skills to assist the consumer. On top of a formal engineering

education is laid gas industry training at schools, conferences and seminars conducted by the American Gas Association, the Institute of Gas Technology, the Industrial Heating Equipment Association or at manufacturer's training centers. Operating for many years is a three year course co-sponsored by A.G.A. and IGT leading toward a chartered Industrial Gas Consultant designation. The course includes three 2-week sessions at IGT over three years with monthly home study lessons. Subjects range from theory of combustion, process heating, burners and controls, metering, heat recovery and energy economics. While perhaps not a specialist in every heating process, the gas sales engineer can assist in design, installation, control, maintenance and service of in-plant gas distribution systems and utilization equipment. Plant surveys of ovens and furnaces for cost accounting and incremental pricing proration are among his skills. He is a source of information of national and local gas supply, rates and regulations.

These skills are sharpened annually, at an Industrial Gas Marketing Seminar. Besides technical sessions, this two and one-half day meeting includes a plenary session of general subjects to which industrial gas consumers of the area are also invited. The 1980 fall meeting will be in Dallas.

The uncertainty in the early 1970's of additional gas supply for the interstate market because of flawed national regulation, caused equipment manufacturers to redirect research and development of fuel fired processes to the applications of electric energy. To fill the void, three large gas distribution companies set up major programs to pursue research in the industrial area. The first priority was for new applications of gas, the second priority considered projects that would improve the efficient use of gas in applications that were threatened by other energies and the third priority was pure energy conservation. Over 30 projects are now in various stages of design, construction, field test or commercialization.

Two gas utilities co-sponsored at Thermo Electron, the development of a modular recuperator for radiant tube and direct fired heat treating furnaces. The recuperators were constructed at Holcroft, a division of Thermo Electron that makes continuous heat treating furnaces. After the successful field tests, Holcroft, five gas utilities and A.G.A. worked together in a commercialization program. The program included trade book advertising, direct mail to potential users and all gas utilities, a 20 foot exhibit for 10 trade shows, technical articles and conference presentations. The Holcroft recuperator and others of similar design are now standard equipment for radiant tube furnaces.

Customer - utility cooperation is exemplified by a tri-partner operation in central New Jersey. The National Energy Leasing Company, a subsidiary of National Utilities and Industries, Inc. parent company of Elizabethtown Gas Company, installed a gas turbine equipped with stand-by oil at the Regal Paper Company. The turbine, operated by the Jersey Central Power and Light Company produces electric power that is purchased by Jersey Central from the Leasing Company. A waste heat boiler plant, operated by Regal produces steam that is sold to Regal by the Leasing Company. The cost saving of both power and steam is about 15% and the installation serves as a peak shaver for the gas utility.

This year's A.G.A. Industrial Commerical Achievement Award was given to an industrial sales engineer of the Southern California Gas Company as a result of his work in stimulating, developing and completing a mobile Industrial Energy Conservation Center. Installed in a 32 foot van, is a roof mounted solar panel and system, 2 small high temperature furnaces, one with firebrick and one with fiber insulation, heat recovery units, a flue gas analyzer, a heat pipe demonstration unit, a computer programmed to study economic feasibility of a variety of heat conservation systems, plus charts and graphs pertaining to combustion technology. The van has equipment to produce its own power from compressed natural gas storage facilities. In one year the Conservation Center was visited by over 2,600 industrial consumers at 58 locations.

Since the enactment of the Natural Gas Policy Act, the supply of natural gas has improved steadily and most gas utilities are in a selling mode. However, they have not abandoned programs to assist their customers in the efficient utilization of gas. Conservation does not mean giving up a share of the consuming public market, not selling gas energy advantages where appropriate, not using natural gas energy. Conservation can mean better utilization of all forms of energy which can mean additional sales of gas energy and higher form value use of gas.

ENERGY CONSERVATION OPTIONS IN DISTILLATION PROCESSES

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This paper summarizes the results of a survey of energy conservation options applicable to distillation rocesses. Over twenty such options were identified, and eight of these were selected for detailed presentation. These options were chosen on the basis of good economics, applicability to retrofit situations, and/or the use of novel technology.

INTRODUCTION

Distillation is the most widely practiced technique for separating mixtures of chemical species. Its applications range from the separation of heavy petroleum fractions to the separation of liquefied air. Our society depends on distillation to provide the abundant energy and synthetic materials so essential to our modern life-style.

By its very nature, distillation is an energy intensive process. Components with different boiling points are separated by a series of fractional vaporization and condensation steps. The boiling of liquid components, with the associated high latent heat of vaporization, is an indispensable part of distillation. But while distillation will always require an energy input, the efficiency with which that energy is used can be greatly improved. This paper was written to assist process engineers in the technical and economic analyses of the energy conservation measures most suitable for their particular distillation applications.

The Potential for Energy Conservation

It is very difficult to account for all the energy used in distillation because of its broad and diverse applications. The bulk of distillation energy is, however, consumed in the petroleum, chemical, and natural gas processing industries. A recent study based on these industries has estimated the annual national distillation energy consumption to be about 2 quads, a quad being 10^{15} Btu. This represents three percent of the total U.S. energy consumption, or the equivalent of 315 million barrels of fuel oil per year. [1]

A ten percent reduction in distillation energy consumption would effect a significant savings. On a national basis this would be an annual savings of 200 trillion Btu, or the equivalent of 100,000 barrels of oil per day. If energy is valued at $2.50 per million Btu, the economic benefit would be $500,000,000 annually.

The technology to achieve these savings in distillation energy is available, and has been for many years. Proper distillation design is a compromise between the energy consumption and the capital cost of the equipment necessary to recover that energy. Energy conservation programs must compete with other programs for the available capital, and they must show an attractive return on investment to compete successfully.

Historically, energy prices have been so low that only rudimentary conservation efforts could be justified. In recent years that situation has changed rapidly, as can be seen in Figure 1. The price of energy has increased far faster than the cost of equipment. This implies that most existing distillation facilities, even those built as recently as two years ago, can justify energy conservation expenditures.

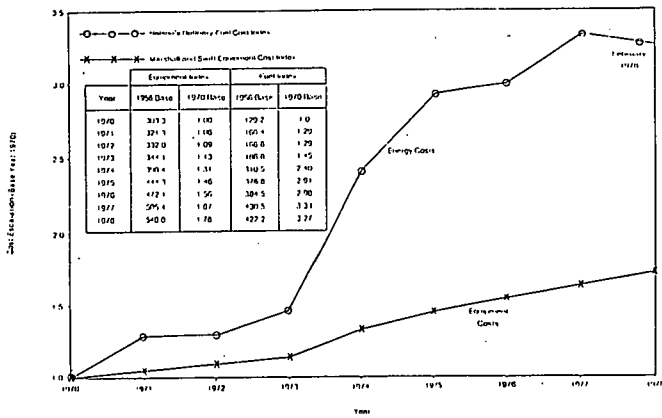


Figure 1. Escalation of fuel and equipment costs.

CATALOG OF ENERGY CONSERVATION OPTIONS

The first step in studying energy conservation for distillation systems was to catalog the available options. An attempt was made to key on those options which were specifically, or even uniquely, applicable to distillation, but a few more general options were included. The options identified included: advanced instrumentation and control systems, tray upgrading, waste heat recovery by heat exchange, mechanical power recovery, heat exchanger upgrading, increasing insulation, heat pumping, vapor recompression,

reboiler flashing, intermediate reboilers and condensers, split tower distillation, optimization of process variables, improvements in maintenance practices, sequencing in multicomponent distillation trains, use of a single column with sidestreams instead of a distillation train, two-stage condensation, extractive distillation, azeotropic distillation, liquid/liquid extraction, adsorption, and fractional crystallization.

These options were then screened to determine the desirability of a detailed study. Options were chosen for further study when they showed the potential to economically conserve energy, were commercially demonstrated, had retrofit potential, and/or represented a novel approach. Eight options were chosen for further study based on these criteria and then divided into categories based on the investment required.

One category of options required little or no investment, those being improvements to maintenance and operating practices. These items do not represent unique technology but are rather examples of good housekeeping and common sense. Although an important part of any conservation program, these options were not treated in this paper.

OPTIONS REQUIRING MODERATE INVESTMENT

The next category concerns those options which require only moderate investment, such as can be approved at the plant manager level in many cases. This category includes: increasing insulation, waste heat recovery, and upgrading the tower internals.

Increasing Insulation

The use of insulation to conserve process energy is a very commonplace practice. It was included here for two reasons. Many plants using traditional methods for calculating optimum insulation thickness quickly become "under-insulated" due to rapidly rising energy costs. The projected cost of energy at the half-life of the insulation should be used in the optimum thickness formulas to prevent this rapid obsolescence.

Secondly, while most plants do a reasonable job of insulating the process piping, many valves, flanges, and manways are left bare. The irregular shape of these fittings increases the cost of conventional insulation, and there is also a significant possibility of ruining the insulation due to leakage. Both of these problems can be overcome by using removable/reusable insulating covers which are available off-the-shelf in a range of standard sizes. The final cost is relatively low because they can be installed quickly by unskilled labor. The insulating blanket material is impervious to product leakage and weather.

The use of insulating covers for process fittings will be used here to illustrate the economics of adding insulation. Figures 2 and 3 show the energy saved and the payout time (for fuel valued at $2.50/MM Btu) for adding removable insulating covers to process valves and flanges respectively. Similar results can also be achieved on manways. As would be expected, the payout time decreases with increasing skin temperature and line size. Quite attractive payouts are indicated even at the lower range of the figure (300°F and 4 inch line size), so the economically attractive range of application should be even wider. [3]

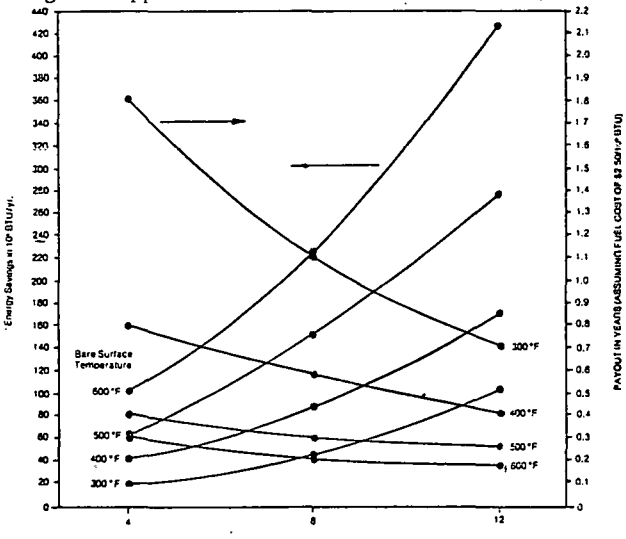


Figure 2. Economics for insulating valve bodies using removable/reusable covers.[3]

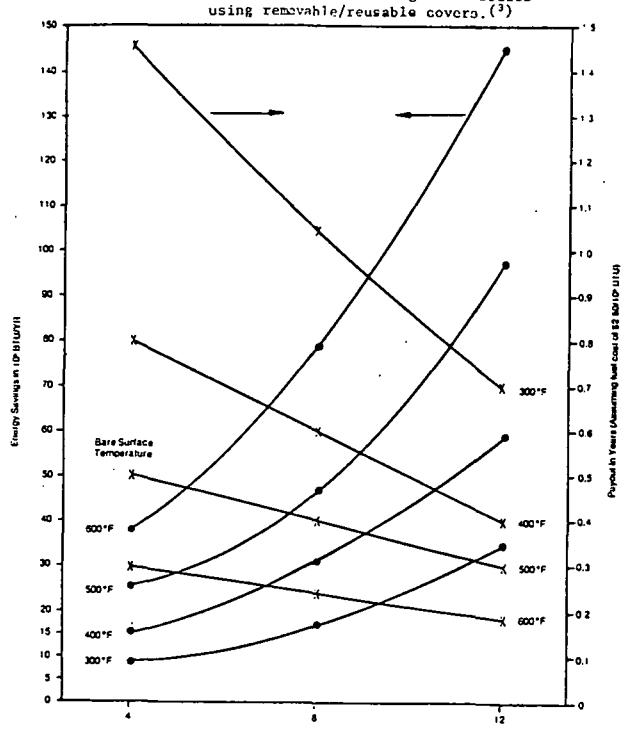


Figure 3. Economics for insulating flanges using removable/reusable covers.[3]

Waste Heat Recovery

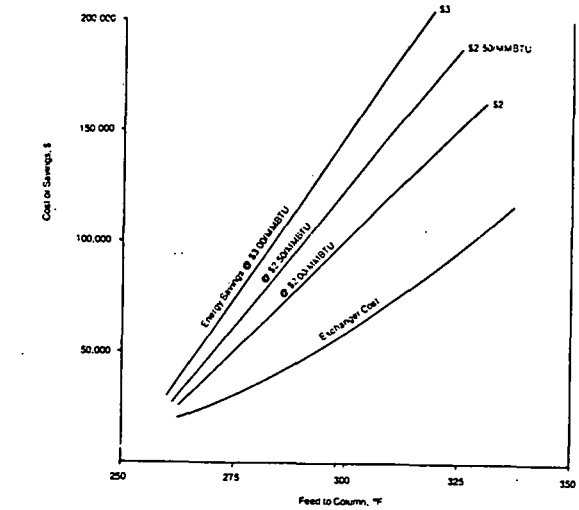
The purpose of this option is to study the means of more fully utilizing the heat in each stream leaving a distillation column. The recovery of this heat is more efficiently accomplished by heat exchange with other process streams. The other streams may be related to the same column, another nearby column, or an unrelated process which could economically use additional heat.

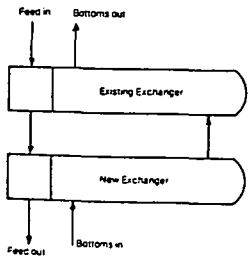
Two areas should be considered for improvement studies, existing exchangers with relatively large temperature approaches and process streams with no waste heat recovery. An existing exchanger may already be in use to recover process heat, but if the heat exchange area were greater, more waste heat would be recovered. There may also be streams not currently used for heat exchange whose temperatures are sufficiently high to heat another process stream, preheat combustion air to a fired heater, or even generate steam. The economics may not have been favorable for such an arrangement when the unit was designed, but the situation should now be reexamined. In studying this option, the cost of heat exchange area must be balanced against the savings realized from heat recovery.

An analysis of waste heat recovery for a naphtha debutanizer feed/bottoms exchanger is presented here. Figure 4 shows the existing exchanger with the new exchanger being added in series. The area of the original exchanger is approximately 1640 ft.^{2}, and the feed outlet temperature is 250°F.

Calculations were made for various feed outlet temperatures to determine the amount of additional area required. The savings were then determined from the increased heat recovery, which in turn reduced reboiler duty. A payout period can be calculated from the plot in Figure 4, by dividing the exchanger cost by the annual savings.

The upper limit of feed temperature increase is the bottoms product temperature. In Figure 5 the annualized cost of the recovery operation (cost of energy loss with any given size of new exchanger + installed cost for a new exchanger) is plotted against additional exchanger area. The minimum point on this curve is the optimum heat exchange area. Two different energy costs were used in calculating the optimum point, and it is clear that more area can now be justified with higher energy prices. There may be certain constraints on such a calculation, and in this specific case the feed column inlet condition was the limit on additional area. For this example, the payout is approximately 0.6 years.





Time for Savings to Equal Investment @ $2.50/mmBtu

Feed Temperature	Payout
270°F	0.67 yrs.
280	0.61
290	0.60
300	0.59
310	0.61
320	0.62
330	0.64

Figure 4. Economics for an additional feed/bottoms exchanger for a naphtha debutanizer.

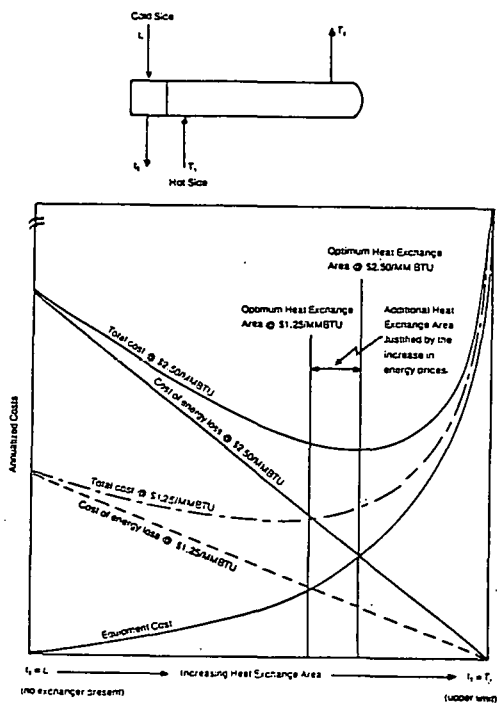


Figure 5. Graphical analysis of the optimum heat exchange area.

In this example a new exchanger was added in series to increase the heat transfer area. Another alternative is the use of extended surface tubes in existing exchanger shells. For boiling heat exchanger applications, a porous boiling surface can be applied to the tubes to increase heat transfer coefficients by a factor 10 to 30 times that for a bare tube. Spiral exchangers and plate-and-frame exchangers are also attractive when space is limited.

Tray Retrofit

Design of a new distillation column requires the determination of the optimum number of trays to make the desired separation. The more theoretical stages that are present, the less reflux is required to make any given separation. A balance must then be achieved between the cost of more trays and the energy savings possible from lowering the reflux. The bounding values are minimum trays at total reflux and minimum reflux with an infinite number of trays (see Figure 6).

The actual economic optimum is determined by the price of contacting equipment relative to that of energy. Figure 7 shows the results of such an economic study on a debutanizer in an ethylene plant.[4] Note that the optimum reflux ratio (here defined as actual reflux divided by minimum reflux) decreased from 1.4 in 1960 to 1.15 for the present. Continued operation at a reflux ratio of 1.4 is shown to incur approximately $60,000 net annual increased operating expense.

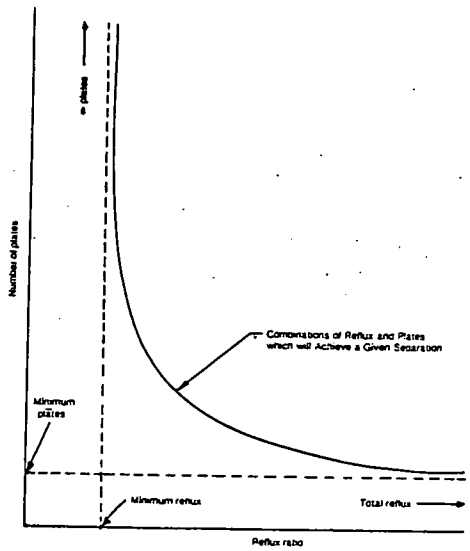


Figure 6. Schematic relationship between reflux ratio and number of plates and stages.

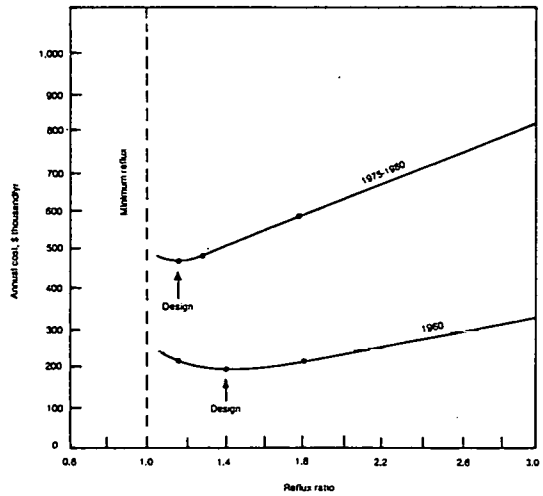


Figure 7. Comparison of annual cost vs. reflux ratio for a debutanizer in a large ethylene plant for 1960 and 1975-90 energy costs.[4]

The number of theoretical trays in a distillation column is the product of the number of actual trays and the tray efficiency. Therefore, an increase in theoretical stages can be achieved by: increasing the total number of actual trays by enlarging the column or reducing the tray spacing, or replacing the existing trays with a more efficient type.

Increasing the number of trays by enlarging the fractionating vessel can be probibitively expensive, but it is the most reliable way to be sure of increasing the total number of theoretical stages. Reducing the tray spacing to increase the number of trays in an existing vessel also has several drawbacks It could also be quite expensive due to the labor intensive modification of tray supports. Lowering the tray spacing could also cause a loss of efficiency due to entrainment and a resultant loss in capacity. The cost estimates presented here are based on completely retraying the column with a more efficient contacting device.

There are many types of contacting devices available. They can be divided into broad classes, such as trays (bubblecap, valve, and sieve) and packings (rings, saddles, and spirals). The efficiency and the pressure drop are the critical properties of the contacting device which determine the potential for energy conservation.

It is very difficult to generalize about tray efficiency (or height equivalent of a theoretical tray for packing) because of its dependence on the specific application. Consequently, no attempt will be made here to identify specific trays or packings which might result in improved efficiency. An analysis is presented to determine the energy savings

possible at various levels of increased tray efficiency. This information can be combined with rough cost data to make a preliminary economic analysis. If the result looks attractive, tray and packing vendors can be approached to determine the maximum feasible increase in efficiency and a more precise cost.

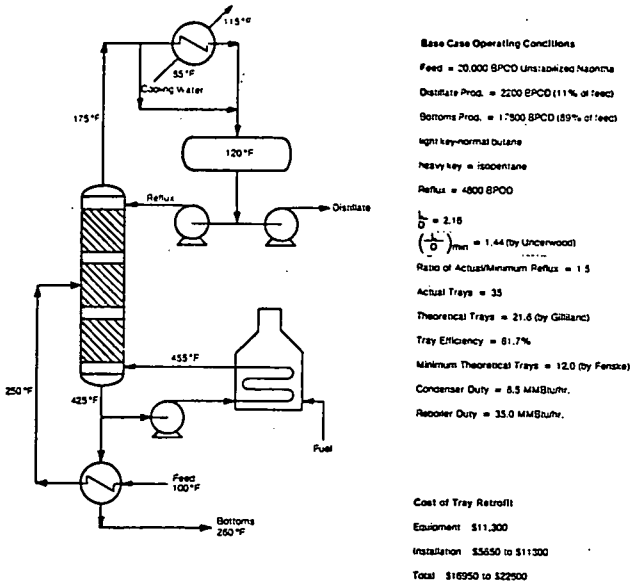
As an example of the economics of tray retrofit, an analysis was made for a naphtha debutanizer. This type of column is common in refineries, natural gas processing plants, and light olefin units. This is a relatively easy split characterized by low reflux ratios. The payouts for this kind of operation are not as attractive as those for a column splitting close boiling components with high reflux ratios. This case was chosen to illustrate the fact that reasonable payouts can be achieved for upgrading the trays of almost any reboiled distillation column.

Figure 8 shows the debutanizer and its basic operating conditions. Energy savings are calculated for an increase in theoretical trays of two, five, and ten percent. The cost of replacement for 35 actual trays has been estimated to be $11,300 for the equipment, and between $5650 and $11,300 for installation (depending on site specific factors). The payout time for this investment is plotted in Figure 9 for two different energy prices and two installation costs. This demonstrates that tray retrofit on the debutanizer becomes attractive if a three to four percent increase in theoretical trays can be achieved.

Energy savings can theoretically be achieved by increasing the number of theoretical trays in any reboiled distillation column. Columns in which all of the required heat enters with the feed cannot achieve this type of energy reduction (such as in crude distillation columns and catalytic cracker main fractionators).

The amount of savings for each case is dependent on how far the existing conditions are from the optimum balance of reflux to theoretical stages. The prime indicator of this is the ratio of actual to minimum reflux, where the following guidelines apply:

R/R min.	Potential for Cost Reduction
greater than 1.3	excellent chance for improvement
1.3 to 1.1	marginal, but deserves further study
less than 1.1	improvement doubtful



Retrofit Case

	1	2	3
Increase Theoretical Trays by	2%	5%	10%
L/D (by Gilliland)	2.12	2.04	1.94
Energy Savings (MMBtu/hr)	0.12	0.32	0.59
Annual Savings @ $2.50/MMBtu	$2376	6395	$11682
Payout for $16950	7.1	2.7	1.5
$22600	9.5	3.5	1.9

Figure 8. Example for analysis of the economics of tray retrofit.

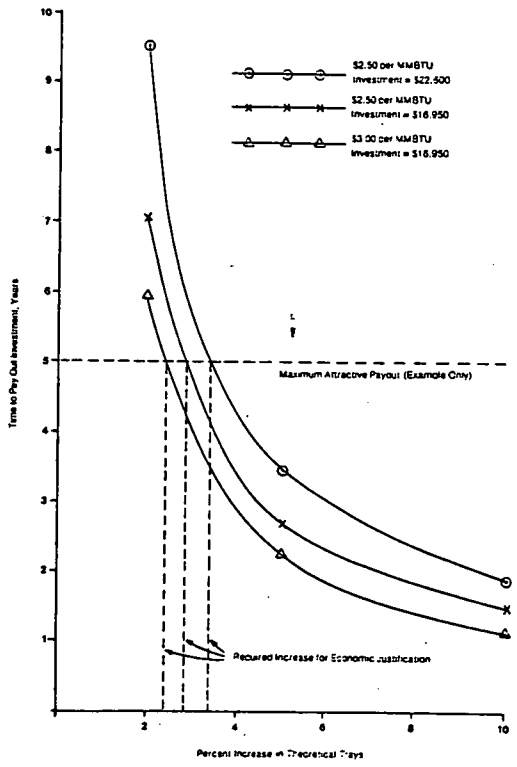


Figure 9. Economics for retraying a naphtha debutanizer.

These are very general guidelines, and there are many exceptions. A very energy intensive process (such as cryogenic separation of air) can justify reflux substantially lower than 1.1 times the minimum. On the other hand, if extensive heat recovery is coupled with low cost energy sources (such as low pressure steam), operation with reflux as high as 1.5 times the minimum can be economically attractive.

The option to upgrade the trays in a distillation column should always be seriously considered when making other large changes, especially if the vessel is to be modified. Trays must also be replaced periodically due to corrosion or accidental damage. Upgrading these trays (rather than replacement-in-kind) can offer an excellent payout in this situation, because only the differential cost between tray types must be justified.

OPTIONS REQUIRING MAJOR CAPITAL INVESTMENT

The most novel and innovative energy conservation options usually require major investment. The options chosen for study in this category include: advanced instrumentation and control systems, heat pumping, intermediate reboilers and condensers, two-stage condensation, and split tower (or multieffect) distillation.

Advanced Instrumentation and Control Systems

The control system for a distillation column has two basic functions: stabilizing the operation and optimizing the operation. When applied properly, the control system should insure the production of on-test products at minimum cost within the bounds of other equipment constraints.

Conventional distillation control systems have been designed only for stabilization, relying on operator intervention for any optimization. Advanced control systems are available using direct material balance control, feedforward control, on-stream product analyzers, and digital computers for optimization. Such systems can give more stable operation, control the column at the optimum operating point within equipment constraints, reduce the need for operator intervention, and reduce energy requirements and operating costs.

A conventional control system for a simple two component fractionator is shown in Figure 10. Product flows are level controlled. The reflux is set independently at a fixed rate, which is usually conservatively high. Product quality is controlled inferentially by varying the reboiler heat input to hold a constant temperature on some critical tray. This type of system is susceptible to variations in the heat balance which cause swings in product quality.

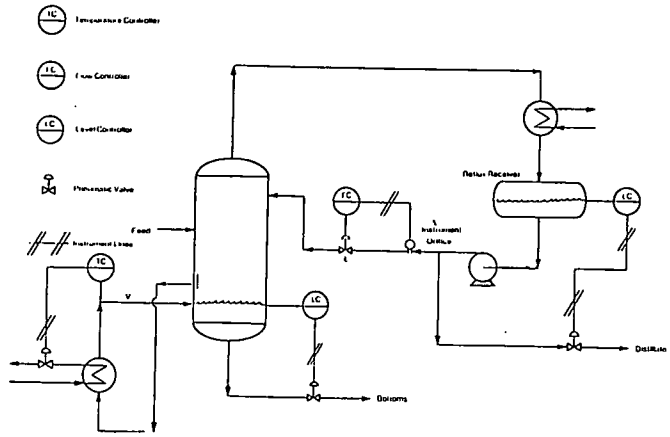


Figure 10. Distillation column with conventional control.

The effect of poor product quality control on energy requirements is shown graphically in Figure 11. Product quality variations may average out, a period of overfractionation balancing a period of underfractionation, resulting in a product with the desired specifications. There is an energy penalty associated with this fluctuating operation, however, since the energy requirement is not a linear function of the separation factor. Evergy can be saved by exercising tighter control on product quality (reducing overfractionation).

Direct material balance control systems, illustrated in Figures 11 and 12, can reduce swings in product quality, typically to within ± 0.5 percent of the specification. This improvement is achieved by using a control variable that is coupled more directly to product quality; that control variable is product flow rate. Consider the case of a simple two component separation. The amount of each component entering the tower is fixed by the feed rate and the relative component concentration. The purity of each product stream is then determined by the relative rate at which each product is withdrawn. With an onstream analyzer giving a continuous indication of product quality and resetting the product flows to meet specifications, very tight control can be achieved.[5]

Another feature incorporated in many advanced control systems is feedforward control. A conventional control system using feedback control must first sense a disturbance in one of the controlled parameters, and then take corrective action to return

the column to steady state. A feedforward system senses factors which could disturb the operation and compensates for them before the disturbance occurs. A classic example is the use of an analyzer to sense changes in the feed composition and adjust tower operations accordingly. Ideally, feedforward control could achieve perfectly stable operations, whereas feedback control can only minimize the magnitude of disturbances. A combination of feedforward and feedback control can achieve similar results with much simpler process models.

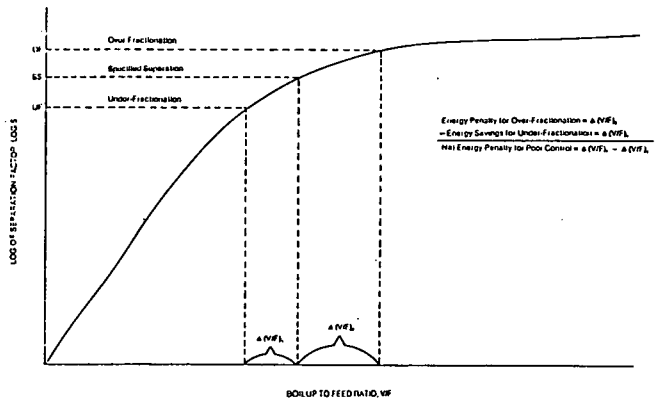


Figure 11. Effect of poor control on the energy requirements.

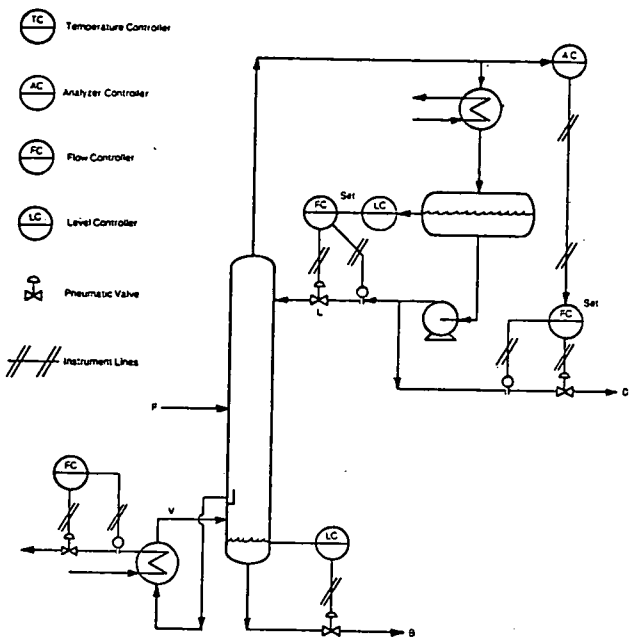


Figure 12. Direct material balance control using the distillate to control product quality.

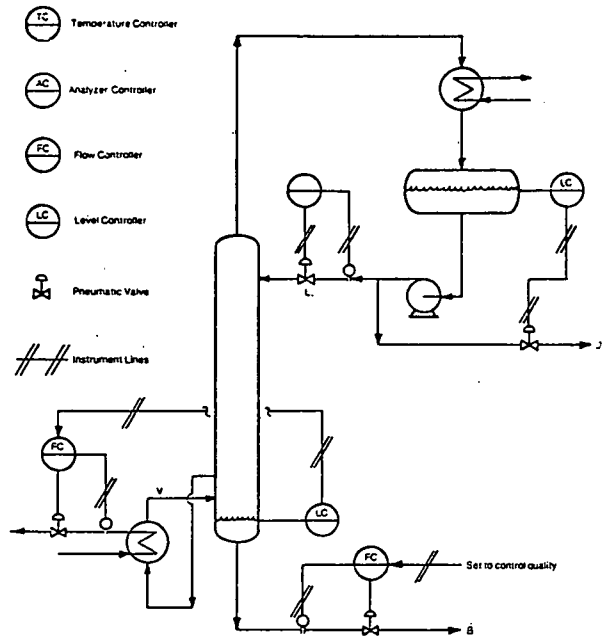


Figure 13. Direct material balance control using the bottom product to control composition.

Direct material balance control can be used with analog type controllers or with digital (computer) systems. Much of the savings due to reducing overfractionation can be achieved with relatively low priced analog equipment. The addition of a computer further expands control system capabilities to both stabilize and optimize the operation. A conventional control system attempts to maintain steady-state conditions, and within those bounds, it can be very effective when properly designed. A computer control system can go beyond steady state control by adjusting unit operations to an optimum within the bounds of the equipment design and safety constraints.

This type of control system was retrofitted to a series of light hydrocarbon fractionating columns in a gas processing plant. The direct material balance system was used to decrease overfractionation, and optimizing algorithms were used to increase heat transfer efficiency in hot oil reboiler system. This project was justified on the basis of a ten percent decrease in energy requirements, but it achieved a better than twenty percent decrease in actual operation. The actual savings were about 35 million Btu/hour for the 22,000 BPOD plant, or a savings of nearly $750,000 per year with fuel valued at $2.50 per million Btu.[6]

Similar savings due to a decrease in the amount of overfractionation can be achieved on any reboiled distillation column (but not on columns where all the heat enters with the feed). The exact amount of the

savings for any case depends on the efficiency of the conventional control system. Accumulated performance data showing product quality as compared to the specification should be examined. If the product quality does not stay within ±1 percent of the specification, then it is likely that an economic improvement can be achieved by an advanced control system. Ideally the product quality should be expressed in terms of the desired separation of the light key and heavy key, rather than some inferred quality like flash point, viscosity, color, etc. These characteristics may be too insensitive to the separation to detect small changes.

The atmospheric crude distillation column is the largest single consumer of energy in distillation. It offers significant opportunities for conservation because of its size and complexity. An advanced control system using a digital computer for optimization can cut crude distillation energy requirements by eight to ten percent and will usually pay itself out in less than one year. Similar results can be achieved with other large multi-product fractionators.

An advanced control system can reduce crude distillation energy requirements by the following methods: reduce the amount of overflash to a minimum, optimize circulating reflux flow rates, optimize crude flow rates through parallel exchanger trains and heater passes, and optimize the furnace combustion efficiency by maintaining proper excess air for varying fuels.

Proper crude unit design practice calls for a two to four percent overflash, which condenses to provide an internal reflux for the stripping trays below the feed point. With a conventional control system, it is very difficult to determine the degree of overflash for any given set of operating conditions, since overflash is an internal phenomenon. This difficulty often results in conservative operation with as much as eight to ten percent overflash. An advanced control system with a digital computer can monitor the degree of overflash by making a continuous series of heat and material balances. Overflash can then be minimized by controlling the withdrawal rate of the lowest sidestream product or by adjusting the heater outlet temperature. Overall energy requirements of most crude distillation units can be cut by several percent simply by keeping overflash in the design range.

An advanced control system can also improve performance in the upper sections of the column. Traditional operating philosophy calls for maximizing one product (which varies with seasonal demand) while keeping all products on-test. With a conventional control system, such operation often results in overloading one section of the column and thereby reducing tray efficiency, increasing the overlap betwee streams, and increasing steam and/or heat requirements in the sidestream stripper. A digital control system can overcome this by monitoring the internal vapor/liquid loadings, and maximizing the desired product within design loading constraints. It can manipulate the circulating reflux flows to both improve fractionation and optimize heat transfer. This type of control can reduce energy requirements by about another two percent.

A digital control system can also be used to improve heat transfer efficiency in fired heaters and exchanger trains where the crude is divided into a number of parallel passes. With a conventional control system, the operator usually tries to maintain equal pass outlet temperatures. This procedure can approach optimum operation, but such is seldom the case in actual practice. Computer algorithms can monitor the heat transfer to each pass and adjust the flow rates to optimize the total heat transfer, within safe operating limits. Such dynamic control could be accomplished with an analog system, but the safety factor and on-line time would be much lower. A digital system can boost heater (or heat exchanger) efficiency enough to reduce fuel consumption by 0.75 to 3 percent.

A computer can also be used to improve the combustion efficiency of the heater by controlling the amount of excess air. Analog control is adequate if a single fuel with a relatively stable heating value is used. However, gas shortages and industrial curtailments are encouraging the use of multiple fuels such as a combination of refinery gas, natural gas, and fuel oil. When such fuels are used, direct correlation of stack oxygen readings with the excess combustion air is no longer valid, as can be seen in Figure 14. Computer control of the excess air can improve the efficiency of natural draft heaters with damper air controls by 0.5 to 1.0 percent, and by up to four percent for systems with better air measurement and control.[5]

The techniques described in Figure 14 for the atmospheric tower of a crude distillation unit should be applicable to any large column performing a multicomponent separation with all heat energy entering with the feed. Many of these techniques (such as optimizing heat transfer in parallel passes and combustion control) are also applicable to other types

of distillation.

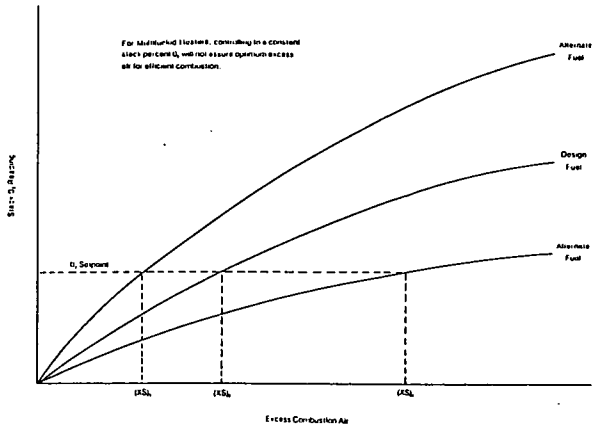


Figure 14. Relationship between stack O_2 and excess air for multifueled heaters.

Floating pressure control is another possible energy conserving control system. For most hydrocarbons, the relative volatility (or ease of separation) increases with decreasing pressure. Floating pressure control takes advantage of that property by maintaining the tower pressure at the lowest value at which the overhead vapors will condense. The pressure is, therefore, "floating" on the condenser capacity. Significant energy savings theoretically can result from taking advantage of increased cooling capacity at night, during the winter, and during rain, especially on columns equipped with air cooled condensers.

While this system has a significant potential for energy conservation, its acceptance has been limited. A difficulty in sensing column constraints is one problem. The exotic and unfamiliar equipment required (such as pressure compensated temperature sensors and differential vapor pressure sensors) is another. This technology is available, but significant development work is needed on each specific application to tailor the control system to the appropriate constraints.

Heat Pumping

In conventional distillation, heat is added to the column at the reboiler (usually by steam or a fired heater) and rejected at the overhead condenser (usually to cooling water or a refrigerant). The overall energy requirements of the column can be reduced significantly by using a heat pump for integration of these two functions.

A basic heat pump cycle using an external refrigerant is shown in Figure 15. Mechanical compression is used to raise the temperature level of the refrigerant above that of the reboiler. The heat liberated by the condensing refrigerant then reboils the bottoms liquid. The liquid refrigerant leaving the reboiler is then evaporated in the overhead vapor condenser, and the cycle continues. Thus the heat rejected from the overhead is used to reboil the bottoms with the aid of added mechanical work by the compressor.

There are two variations on the basic heat pump in which one of the column fluids acts as the refrigerant. Vapor recompression (not shown) uses the overheat stream as the working fluid, thereby eliminating the need for an overhead condenser. Reboiler flashing (shown in Figure 16) uses the bottoms streams as the working fluid, thus eliminating the reboiler.

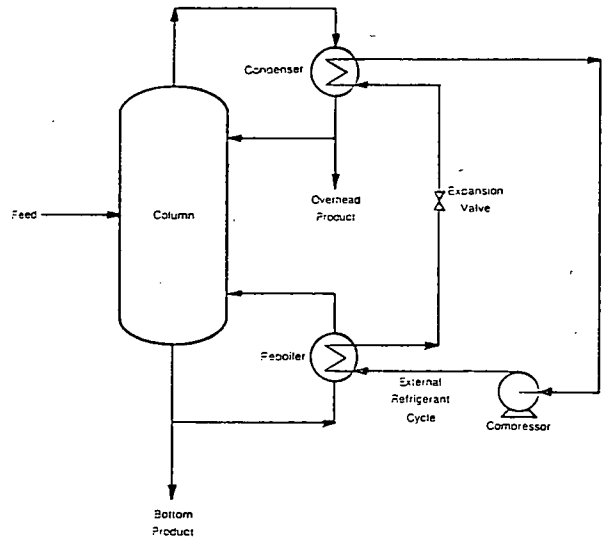


Figure 15. Heat pumping in distillation with an external refrigerant.

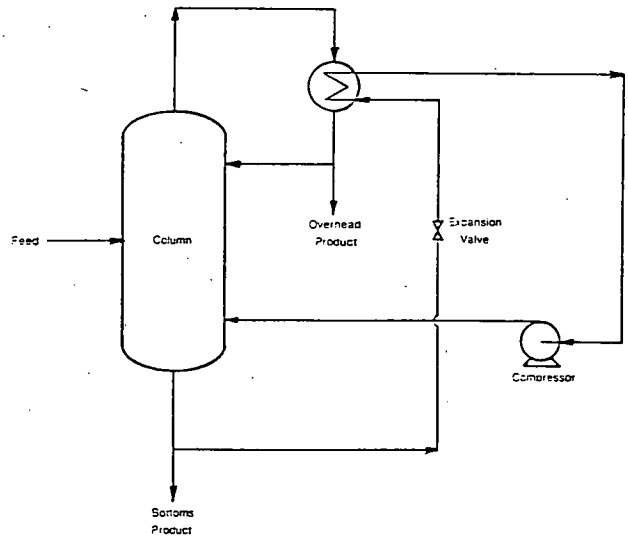


Figure 16. Reboiler flashing.

It is difficult to generalize about heat pump economics because they are very case specific. In many cases the heat pump cannot be applied for technical reasons, and in others it offers a poor to marginal

payout. But in those cases for which it is well suited, the heat pump can achieve significant savings and a rapid payout. In some new design cases, application of a heat pump can reduce the initial investment as well as the operating expenses.

A propane/propylene splitter was chosen to illustrate heat pump economics. Table 1 shows the operating and economic factors for a conventional splitter, a heat pump retrofit, and a heat pump incorporated in a new design.[7] Note that the column conditions were not varied in any of these cases, permitting the evaluation of the heat pump as an external energy conservation option. Application of the heat pump reduces energy consumption by 88 percent, but it shifted the energy source from low pressure steam to high pressure. The resulting payouts were 1.2 years for the new design and 2.1 years for the retrofit. The retrofit cast assumed no salvage values for the existing reboiler and condenser. As the salvage values of these exchangers approached market value, the retrofit payout would approach that of the new design.

TABLE 5-1. ECONOMICS FOR THE APPLICATION OF A HEAT PUMP TO A PROPANE/PROPYLENE SPLITTER

	Conventional Tower Design	Reboiler Flashing as a Retrofit	Reboiler Flashing on a New Column
Column pressure, psia	275	275	275
Overhead temperature, °F	115	115	115
Bottoms temperature, °F	135	135	135
Steam consumption, 10^6 Btu/hr	101*	12†	12†
Cooling water, 10^6 Btu/hr	101	6	6
Utility costs, 10^6 $/yr	3.06	1.10	1.10
Increased maintenance, 10^6 $/yr	--	0.28	0.28
Savings, 10^6 $/yr	--	1.68	1.68
Additional capital cost, 10^6 $/yr	--	3.44	2.04
Simple payout, years	--	2.1	1.2
After tax ROI, %	--	24.4	41.2

*Low pressure steam (valued @$2.50 per 10^3 lbs.)
†High pressure steam (valued @$3.50 per 10^3 lbs.)
All costs are in 1978 dollars.

Both heat pump applications assumed that no internal changes would be made to the conventional design. Heat pumping makes it possible to operate at a much lower pressure, which was constrained in the conventional case by condensation of the overhead stream with cooling water. Lowering the pressure increases the relative volatility, thus allowing a reduction in the reflux ratio and/or the number of trays. When coupled with other conservation options (such as high efficiency trays and enhanced surface exchangers), this can result in a capital expenditure well below the conventional design case and much lower operating costs.[7][8]

While heat pumping can produce significant energy savings, its range of applicability is limited. The following are general guidelines on its application:

- Compression work is determined primarily by the differential temperature (ΔT = reboiler temperature - condenser temperature). Heat pumping is best suited to column with a low ΔT, ideally 65°F or less.
- Heat pumping can be most easily justified in new unit design where column operating conditions can be modified to achieve an economic optimum.
- For retrofit situations, the following conditions apply:
  a) Columns currently using a refrigerated overhead condenser are prime candidates.
  b) Columns with an overhead temperature between 100°F and 250°F show a marginal payout because they can use relatively inexpensive utilities (cooling water and low pressure steam).
  c) Columns using high pressure steam in the reboiler with no heat recovery at the condenser are good candidates.
  d) Columns employing heat recovery at the overhead condenser show a marginal to poor payout.
- To use vapor recompression or reboiler flashing, the process stream must be a suitable refrigerant. Any fluid may be considered suitable if:

$$\frac{\Delta H_{vap}}{C_p T_2} \sim E_c$$

where ΔH_{vap} is the latent heat of vaporization in $\frac{Btu}{lb}$,

C_p is the heat capacity in $\frac{Btu}{lb.°F}$,

T_2 is the compressor discharge temperature in °R, and E_c is the compressor efficiency.[8]

If both the overhead stream and the bottom stream are suitable refrigerants, vapor recompression is the favored route for low pressure columns and reboiler flashing is favored at high pressure.

Intermediate Reboilers and Condensers (IR & C)

Conventional distillation is thermodynamically both expensive and inefficient because heat is added at its highest (and most valuable) level and removed at its lowest (most diffitult to recover) level. This situation can be eased by the use of intermediate reboilers and condensers (IR&C), such as

illustrated in Figure 17. IR&C can reduce energy costs by substitution of a less expensive form of ergy, increased opportunity for heat recovery, d improved internal operation of the column.

An intermediate reboiler can often use less expensive energy than a conventional reboiler, such as low pressure instead of high pressure steam. While this results in a reduction in operating cost, it does not achieve any direct savings of energy. However, since many plants have an excess of low pressure steam which must be vented if not used, its use in an intermediate reboiler could be considered an energy savings.

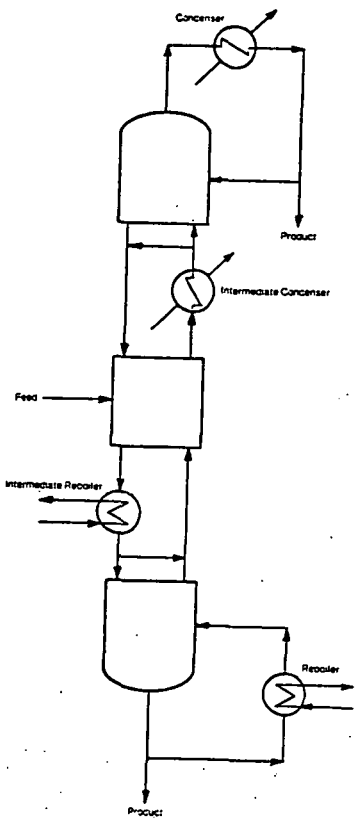


Figure 17. Distillation column with intermediate reboiler and condenser.

The same analysis can be applied to the condenser system. If the conventional column uses an expensive refrigerated condenser, significant savings could result from using an intermediate condenser with cooling water to reduce the refrigeration load.

A lower level of heat input and a higher level f heat removal also increase the opportunities for heat recovery by process heat exchange. Since the differential temperature between the intermediate reboiler and condenser is small compared to the overall column ΔT, the range of applicability of the heat pump principle is expanded greatly. This type of operation is illustrated in Figure 18.

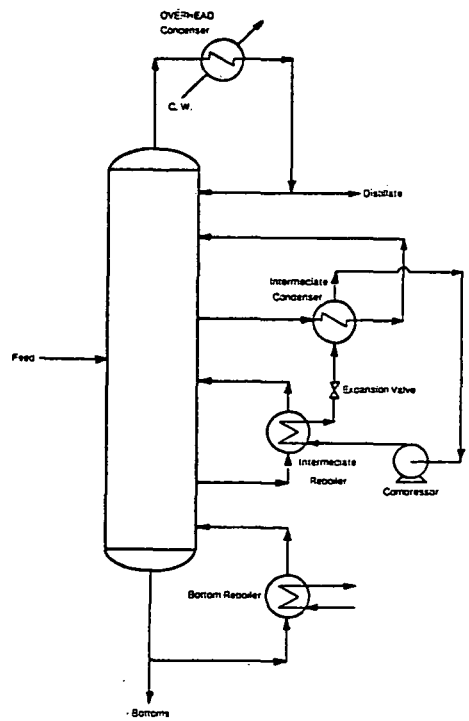


Figure 18. Heat pumping with intermediate reboiler and condenser.

Very little data could be found on the specific economics of IR&C. A very careful analysis should be made of each specific application, including a rigorous fractionation simulation. This option was included primarily because of its interaction with other attractive conservation options (such as heat pumping).

Two-Stage Condensation

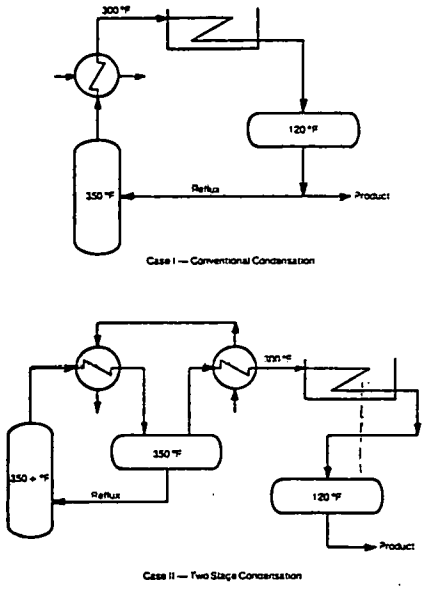
Much of the energy input into a distillation column is eventually removed at the overhead condenser. This heat energy is lost to the atmosphere if cooling water or air is used as the cooling medium. It is standard practice to recover as much of this energy as possible by process heat exchange, but a significant portion is lost because of the low temperature required in the distillate accumulator.

Two-stage condensation is a novel adaptation that will increase the energy available for process heat exchange. Energy is saved by condensing the vapors

in two stages, preventing sub-cooling of the reflux. The first stage condenses only enough liquid to reflux the tower. The second stage condenses and cools the distillate product.

A conventional overhead condensing system of an atmospheric crude column is shown in the upper part of Figure 19. All of the overhead vapors are cooled and condensed by process heat exchange down to some lower limit for economical heat recovery. The balance of the condensing/cooling is done by air coolers. This results in 40 MM Btu/hr process heat recovery and 60 MM Btu/hr loss to the atmosphere.

A two-stage condensation system for the same column is shown in the lower section of Figure 19. The reflux accumulator temperature is the same as that of the conventional tower top. The vapors leaving the first stage are then condensed in a conventional manner. All of the latent heat of the reflux is recovered, and a considerable portion of that for the distillate product. The result is 70 MM Btu/hr of process heat recovery and only 30 MM Btu/hr loss, which represents a 75 percent increase in recovered heat.[9]



	Case I	Case II
Heat Recovered, $10^6 \frac{Btu}{hr.}$	40	70
Heat Lost, $10^6 \frac{Btu}{hr.}$	60	30
Energy Savings, $10^6 \frac{Btu}{hr.}$	—	30
Savings, $/yr.	—	594 000
Incremental Investment, $	—	376,000
Simple Payout, years	—	0.6

Figure 19. Economics of two-stage condensation.[9]

The conditions at the first stage separator are identical to those at the conventional tower top. Thus, the first stage acts like an additional theoretical fractionating tray. This can have a beneficial effect on product quality and recovery and can also provide additional energy savings if applied to a reboiled tower. No credit should be assumed for any effects of better fractionation in the example crude tower.

The cost of this type of condenser system modification is relatively high, and it can therefore be most easily justified for large towers. The estimated cost for the example crude atmospheric tower is about $376,000. The energy savings would amount to about $600,000 per year (if energy is valued at $2.50 per MM Btu), resulting in a simple payout of 0.6 years.

This two-stage condensation system is applicable when the following guidelines are met: large spread between the bubble point and dew point of the overhead stream (this is typical of wide boiling point mixtures commonly encountered in petroleum refining), overhead temperature above the limit for economical process heat recovery, and most easily justified on large units where economy of scale comes into effect.

Split Tower Operation

The basic principle of split tower distillation is an increase in thermodynamic efficiency due to the repeated use of a given quantity of energy. The simplest of many possible applications is illustrated in Figure 20. Here a series of "n" towers are operated in parallel with approximately equal feed rates, but each at a different (decreasing) pressure. All of the required heat is applied to the first (highest pressure) column. Its overhead vapors are condensed by reboiling the next column, and so on. The energy required for the series is about $\frac{1}{n}$ times the single column requirement.

There are several constraints, both physical and economic, which limit the number of towers. The highest pressure tower must be below the critical point, its reboiler must not exceed the temperature of the hightst available heat source, and its temperature must not be high enough to cause thermal degredation of the product. The lowest pressure column is usually determined by the pressure at which cooling water can condense the overhead. Between these two extremes, there must be enough differential pressu (and temperature) from column to column to provide sufficient driving force for the condenser/reboiler. In this study, only two tower systems were examined.

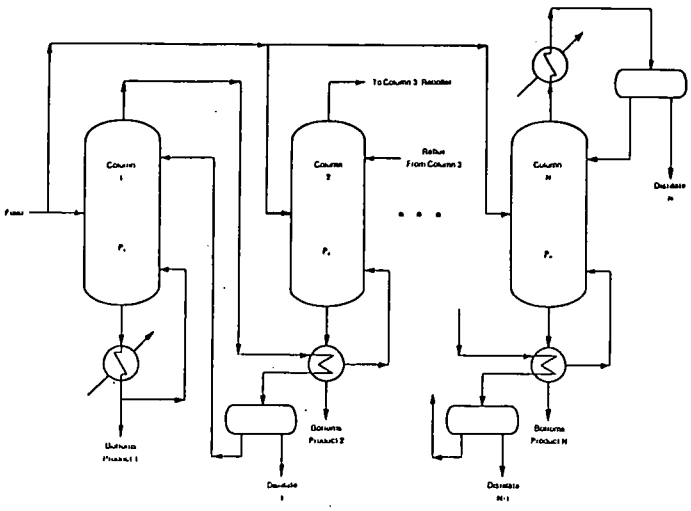


Figure 20. Multieffect distillation with individual feeds.

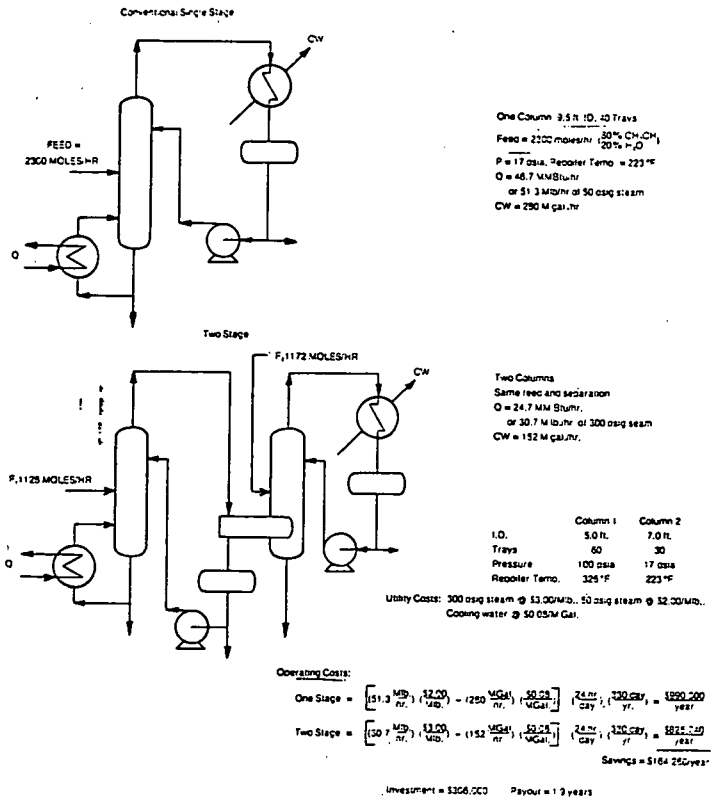


Figure 21. Economics of split tower operation for a methanol/water fractionator.[10]

This option was given a detailed examination by Tyreus and Luyben in 1975,[10] and showed marginal justification using the energy price data available then. The following example is one of their case studies scaled to current energy and equipment prices.

Figure 21 shows a conventional methanol/water fractionator for the production of 500 million pounds of methanol per year. The lower section of that figure shows the same separation performed by a two-stage distillation. Note that a 47 percent reduction in energy was achieved using the split tower approach, but at an incremental capital investment of $306,000 (scaled to 1978). Using current energy prices, one sees a savings of $164,000 per year and a 1.9 year simple payout.

The economics for a retrofit situation would be quite different. Note that the original single stage tower is significantly different from either of the two used in the split tower case. Unless substantial salvage credit is available for the existing tower, the capital investment that must be justified would be very high for a retrofit situation, and the resulting payout period would be long. Such an outlay could probably be justified if it was done concurrent with a planned unit expansion, so that the size of the low pressure tower would be close to that of the existing column.

The concept of split tower operation is theoretically applicable to any reboiled distillation column. It can be justified most easily for new units with high reboiler loads. The previously cited article by Tyreus and Luyben identified a break point of about 20,000 lbs/hr of reboiler steam usage (which corresponds to about 17 x 10^6 Btu/hr) above which split tower operation should be seriously considered. This level of reboiler load will typically be encountered when one or more of the following factors are present: high feed rate, high reflux ratio, and/or high latent heat of vaporation.

CONCLUSIONS

There are many options available to the engineer seeking to reduce the energy requirements of a distillation process. The technology for most of these options has been available for many years, but it has only recently become economically attractive.

This paper presents a greatly condensed version of the information available in two DOE publications: Energy Conservation: A Route to Improved Distillation Profitability (An Executive Briefing Report). Energy Conservation in Distillation (A Technology Applications Manual). Both are available through:

Department of Energy

Technical Information Center

P.O. Box 62

Oak Ridge, Tennessee 37830

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PRACTICAL APPLICATION OF DISTILLATION COLUMN ENERGY-CONTROL SYSTEMS

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ABSTRACT

Closed loop computer control of an ethylene column has been shown to save $350/day in improved ethylene recovery and $150/day in reduced energy consumption. These savings are achieved through material balance optimization and energy balance optimization.

The purpose of this paper is to describe how the material balance (hard target) and energy balance (soft target) control points are implemented. The paper covers the following topics: A Brief Review of Distillation, A Summary of Distillation Optimization, Quality Control (Hard Target), Safety (Soft Target), and Feed Forward - Interactive Control.

Both a general and a specific example are used. The specific example is an actual ethylene column.

DISTILLATION

Distillation is a process for separating two components:

1. Low boiling (light key)
2. High boiling (heavy key)

The boiling point difference may be small ($10^{o}F$ - $20^{o}F$) or large ($100^{o}F$ - $200^{o}F$). The boiling point difference plus other factors determine the size of a distillation column.

The purpose of this paper is not to determine the size of the column but to describe the steps to implement a successful computer control system on an existing column. To be more specific, an ethylene-ethane column will be discussed - ethylene is the light key and ethane is the heavy key.

Figure 1 shows a simple diagram for an ethylene column. As shown in Figure 1, the specification control for an ethylene column is the ethylene in the distillate or top product. The specification is typically 99.0% to 99.9% ethylene. The specification control is known as the hard target.

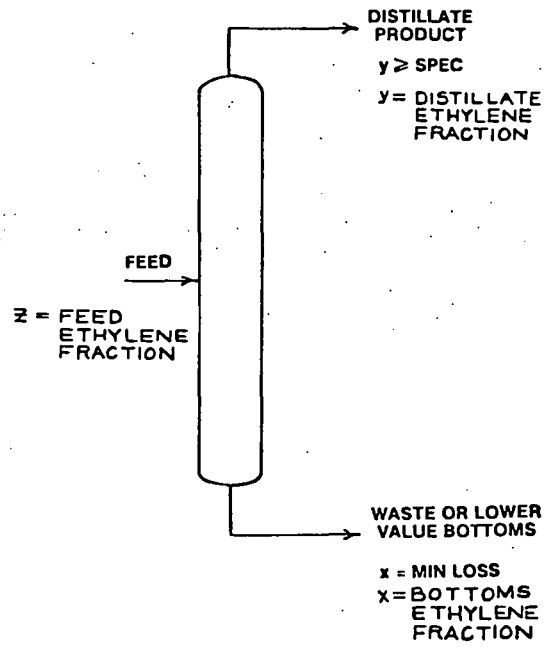


FIGURE 1 SINGLE PURITY SPECIFICATION

Once the hard target has been satisfied, the next goal is to maximize ethylene recovery by minimizing ethylene loss out the bottom. This is known as the soft target because it is only satisfied after the hard target has been satisfied.

Figure 2 shows a way to automate an ethylene column. In this case, the hard target distillate ethylene content is controlled by adjusting the bottom flow (material balance). The soft target ethylene content of the bottoms is controlled by adjusting the reflux flow (energy balance). Other instrument schemes have been recommended for ethylene columns. The purpose of this paper is to discuss how to implement the hard target and soft target controls rather than discuss the advantages and disadvantages of various instrument control schemes.

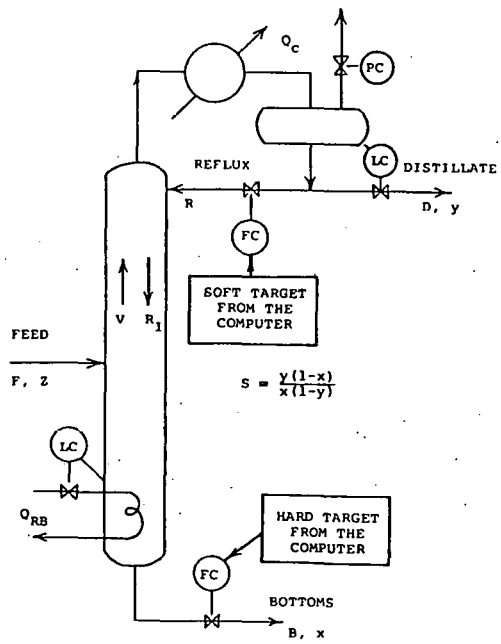


FIGURE 2 ETHYLENE COLUMN NOMENCLATURE

OPTIMIZATION CONTROL OF A DISTILLATION COLUMN

Several papers have been written on Distillation Column Optimization. Please refer to the attached Reference List. A simple definition of distillation column optimization is to find the most economica hard target and soft target for a column. The way these targets are determined is discussed in an ISA paper, "Objectives and Strategies for - - - Composition Control of Distillation Columns" by P. R. Latour, Reference (1).

Several figures have been taken from the above paper to refresh your memory on how the optimum hard and soft targets are determined. Figure 3 shows a mass balance around a distillation column. Simply stated, Figure 3 shows at zero top product (D/F = 0), the bottom product has the same flow and composition as the feed. And at zero bottom product flow (D/F = 1), the top product is the same as the feed. The in

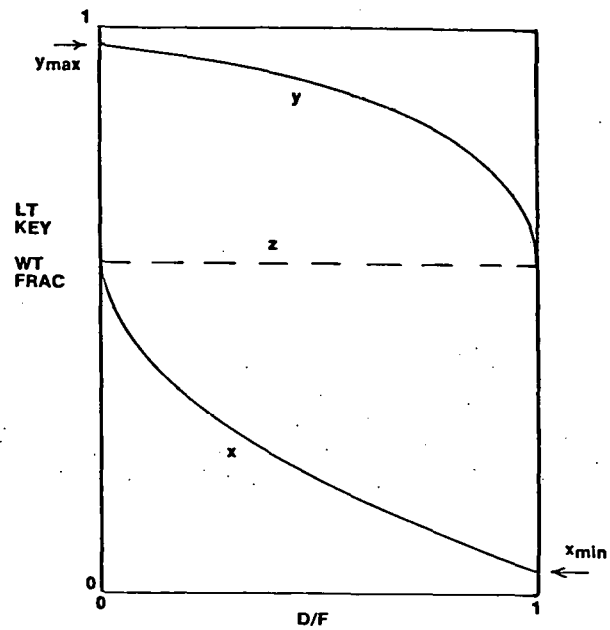


FIGURE 3 PROCESS STATICS—MASS BALANCE DIAGRAM

between points are the important points because this is where distillation columns operate. Figure 3 shows the curves for a generalized column - Figure 4 shows an

actual curve for an ethylene column. For this particular ethylene column at this particular time, pure ethylene (99.9%) was produced at a D/F of approximately 0.7.

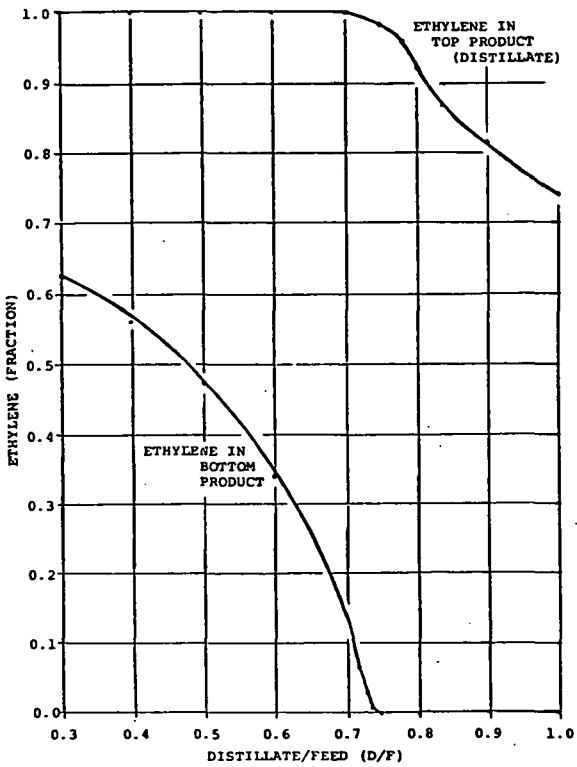


FIGURE 4 ETHYLENE COLUMN MATERIAL BALANCE

Chemical engineers have developed a Separation Factor (S) to express the degree of Component Separation:

$$S = \frac{y(1-x)}{x(1-y)} \qquad (1)$$

where

y = fraction of light key (ethylene) in the top

x = fraction of light key (ethylene) in the bottom

The separation factor increases as the top product becomes purer and purer in ethylene content or as the ethylene content of the bottom product gets less and less.

To improve the quality of both the top and bottom products at the same time, it takes additional energy. The energy affects on the column mass balance are shown in Figure 5. Increased 'S' is the same as increased energy.

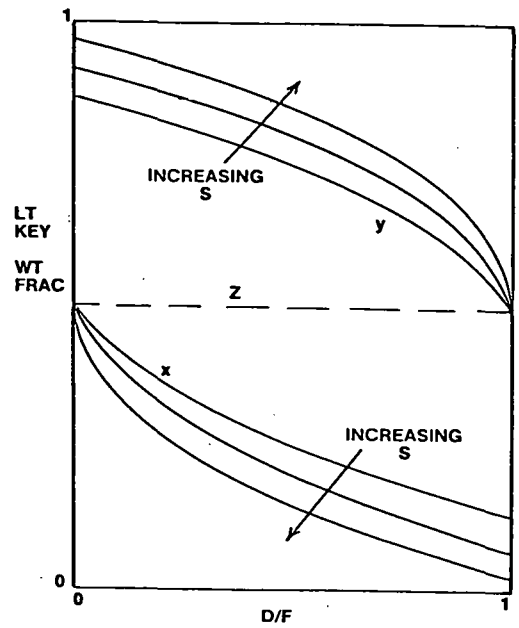


FIGURE 5 SEPARATION ENERGY AFFECTS MASS BALANCE STATICS

The optimum hard target and soft target can be calculated from the column material balance relationships, the relationship between the separation factor and energy, and the product values plus energy costs. Figure 6 shows the mass balance economics.

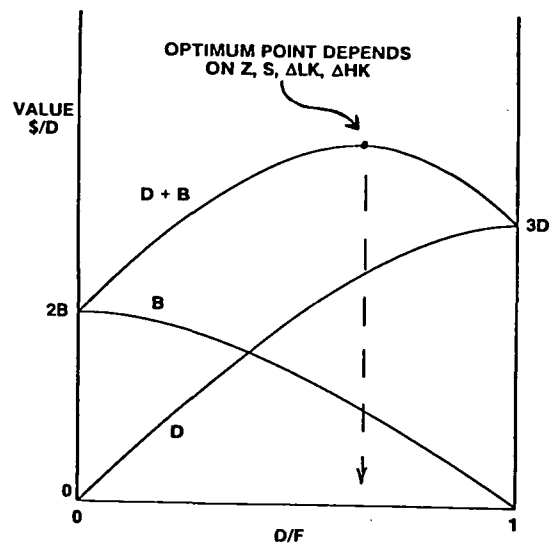


FIGURE 6 MASS BALANCE ECONOMICS

The economics are at total product value, not just at the individual top or bottom product values. Figure 7 shows the $/day recovery losses at two different feed compositions. The purpose of these curves is to show the optimum point to run a column is not always at the maximum allowable impurity. In other words, the ethylene column product should not contain the maximum amount of ethane (impurity) for all economic cases.

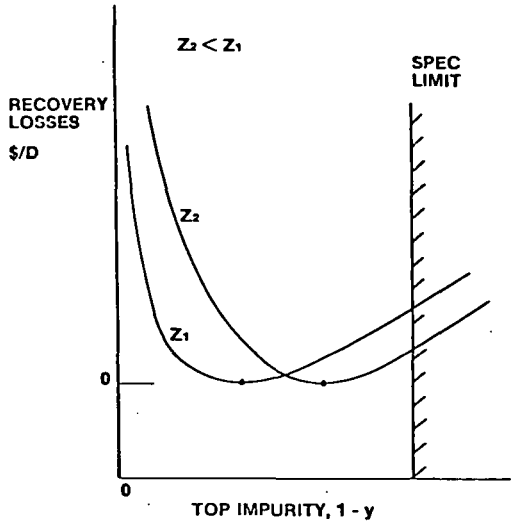
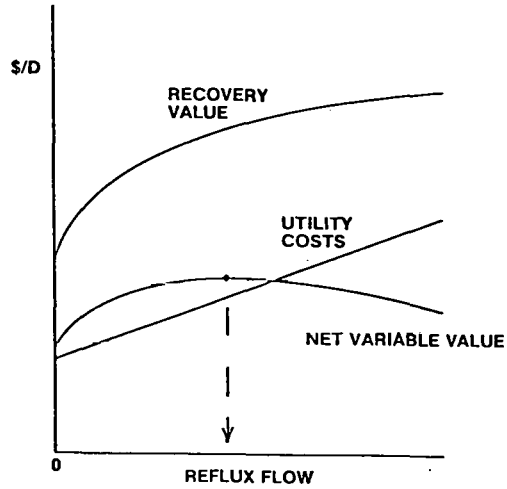


FIGURE 7 OPTIMUM PRIMARY COMPOSITION

Figure 8 shows the Energy Optimum. There is a trade-off between energy consumed and the amount of ethylene recovered (soft target). In the past when energy was inexpensive, distillation columns were generally run against a mechanical limit. This is not true today. Figure 8 represents an example of where energy costs dictate an intermediate reflux rate for maximum profit.

QUALITY CONTROL (HARD TARGET)

The number one priority for the ethylene column operator is to produce ethylene to meet or to be better than the required specification. With conventional control systems, the operator can make the most money



OPTIMUM REFLUX DEPENDS ON ENERGY COSTS, PRODUCT VALUES, FEED COMPOSITION, AND PRODUCT QUALITY SPECIFICATION OR OPTIMUM MASS BALANCE.

FIGURE 8 ENERGY BALANCE ECONOMICS

when the column is controlled at the specification or slightly below the specification. However, most operators control the column at significantly below the specification. For the example ethylene column described in this paper, the operator controlled the ethane in the ethylene product at 350 ppm when the specification called for 1400 ppm. An economic analysis showed that an increase in the actual ethane content from 350 ppm to 1400 ppm was worth about $350/day.

Why don't operators or operations management force the specification to be controlled at 1400 ppm? The answer is obvious - the penalty is too high. The operator can often control the column at the 1400 ppm specification for three days. The plant then goes through an upset which causes off-specification ethylene to be produced for several hours. The reprocess ing of the off-specification ethylene and

loss of customer relationships can often cost more than the $350/day saved during the three days operation.

The designer of an ethylene column computer control system must consider the above operating conditions in his computer control design. One way to understand these conditions is to study what the operators do to control the ethylene column hard target. Figure 9 shows a typical strip chart record of the ethane content superimposed on how the operator moved the bottom flow rate to maintain the ethane setpoint. In this particular example, a chromatograph is used to analyze the top product every twelve minutes.

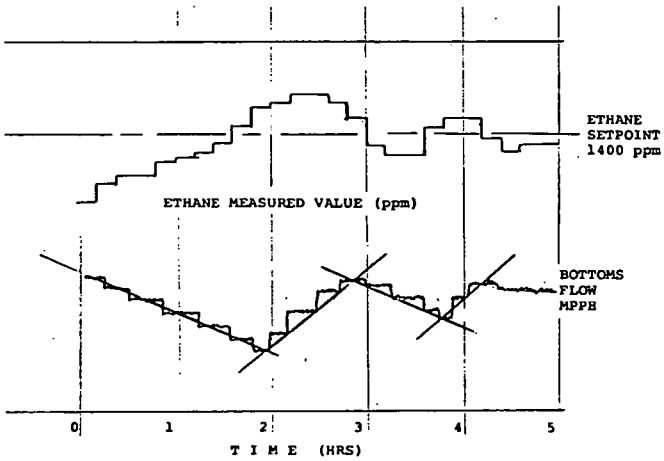


FIGURE 9 ETHYLENE COLUMN TOP PRODUCT
ETHANE CONTENT VS BOTTOM FLOW RATE "HARD TARGET"

The point to grasp from Figure 9 is the operators decrease the bottom flow rate slowly when the top product is in specification and they increase the bottom flow rate rapidly when the top product is out of specification. The process control design engineer can accomplish this same control strategy by using two process control gains - one for a positive error (setpoint-measured value) and one for a negative error. This is accomplished when the negative error gain is set equal to some constant times the positive error gain.

$$K_n = K_A * K_p \qquad (2)$$

where

K_n = gain at negative error

K_A = constant

K_p = gain at positive error

The goal is to have $K_A = 1$, but typically $K_A = 2$, when first implementing a hard target control loop.

The operators always have a maximum "move" limit per time basis. Example: The bottom flow rate should not be changed over "one root" (approximately 2 MPPH) over a fifteen minute period. The "move" limit may be different for a positive error than it is for a negative error.

SAFETY (SOFT TARGET)

The part of the ethylene column computer control program that prevents the computer from requesting an infeasible (unsafe) condition is the soft target (constraint) control system. The soft target control system checks the reboiler, condenser, and column conditions for safe operating conditions before the column reflux rate is changed.

Soft target control is accomplished through a constraint table as shown in Table I. The new reflux rates are calculated every few minutes. The optimizer calculation may be done on a slower time cycle. An example of how this works is shown in Table II. The five constraint values are calculated at time equals zero and at time one equals five minutes later.

The soft target is also subjected to

TABLE I

ETHYLENE COLUMN CONSTRAINT TABLE

"SOFT TARGET"

1 - New Reflux Flow Rate = f(Old Reflux Flow Rate, Top Pressure Drop)

2 - New Reflux Flow Rate = f(Old Reflux Flow Rate, Middle Pressure Drop)

3 - New Reflux Flow Rate = f(Old Reflux Flow Rate, Bottom Pressure Drop)

4 - New Reflux Flow Rate = f(Old Reflux Flow Rate, Reboiler Capacity)

5 - New Reflux Flow Rate = f(Old Reflux Flow Rate, Condenser Capacity)

6 - New Reflux Flow Rate = f(Old Reflux Flow Rate, Optimization Calculations)

. Each of the above calculations is made independently.

. Soft Target = Lowest New Reflux Rate

. f denotes the new reflux rate is calculated as a function of x and y

TABLE II

ETHYLENE COLUMN CONSTRAINT TABLE

"Example Soft Target Control"

	REFLUX RATE	
CONSTRAINT DESCRIPTION	TIME ZERO	TIME ONE
1 - Pressure Drop Across the Top	450	455
2 - Pressure Drop Across the Middle	500	420
3 - Pressure Drop Across the Bottom	460	455
4 - Reboiler Capacity	600	590
5 - Condenser Capacity	470	480
6 - Optimizer	430	430

. Time Zero the Optimizer Value would be set equal to the soft target.

. Time One indicates a partial tray pluggage has occurred in the middle of the column. The reflux rate calculated from the pressure drop across the middle of the column would be set equal to the soft target even though it would be more economical to operate at the optimized value.

move limits. For the case described in this paper, the move limit would be set about 40 MPPH.

Automatic measurement of the column capacity is a side benefit of soft target control. The column capacity is equal to:

$$C_p = (M_F/L_C) * 100 \quad (3)$$

where

C_p = column capacity %

M_V = measured flow (reflux) MPPH

L_C = lowest of the first five constraints MPPH

The energy savings accomplished by decreased reflux flow for the ethylene column described in this paper was estimated to be $150/day. The material balance savings of $350/day plus the energy savings of $150/day amounted to $500/day or $175,000/350 days (year). This ethylene column computer control system will be installed.

FEED FORWARD AND INTERACTIVE CONTROL

The primary goal of the ethylene column is to make specification ethylene product. The feedback hard target system described in the Quality Control Section of this paper is sufficient to accomplish this goal provided the feed composition and flow remain fairly constant and the reflux rate soft target does not change too rapidly.

A simple way to insure on specification ethylene is to increase the bottom product flow rate by 10% or more if the feed rate (feed forward) increases or reflux rate (interactive) decreases by 10%. This action would take place only if the feed rate increased +10% or the reflux rate decreased -10%. It is assumed the feed-back-hard-target system would control for positive feed changes or negative reflux changes of less than 10%. The 10% control parameter might be different for different columns.

In the simple form of feed forward and interactive control, the bottom product flow rate would not be changed for a decrease in feed rate or an increase in reflux rate since both these actions should produce purer ethylene than needed. The feed back control system would bring the ethylene specification back into control for these cases.

The simplified feed forward and interactive control system will produce on-specification ethylene. If the feed and reflux changes occur frequently (greater than ±10% - 12 times/day), a more sophisticated feed forward and interactive control system should be investigated. These more sophisticated systems save both material balance and energy costs because both increase and decrease changes are made more accurately. Thus, the hard target and soft target are controlled more closely.

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ENERGY-CONSERVATION POSSIBILITIES USING GAS-SEPARATING MEMBRANES

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ABSTRACT

The separation of gases using semipermeable membranes is a viable unit operation. A novel composite membrane combined with hollow fiber spinning technology enable Monsanto Co. to offer PRISM™ Separators to the industrial market. The separator module accepts a mixed gas stream and produces two enriched streams: one of which has concentrated the rapidly permeable gases and the second of which is enriched in the slowly permeable gases. Existing commercial installations have demonstrated energy and capital savings, ease of installation and operation and functional reliability.

The practical use of membranes to separate permanent gases is an economic reality. Over three years of commercial scale experience since 1977 has proven that effective membrane systems can:

A. Save capital
B. Save operating cost
C. Save energy

in gas stream separations.

Systems which do all three were offered to the market starting in November of 1979 by Monsanto under the name PRISM™ 1 Separators. This market entry was made only after full scale utility had been documented for over 30 months on several Monsanto process streams. In that period of time, the commercial demonstration units have shown consistently successful gas stream separations as predicted. Maintenance requirements and performance changes during this period have been minimal. Based on this experience, effective performance lifetimes of 5 years and more are anticipated for typical installations.

Before discussing existing energy saving uses of membrane separators in gas streams, we'd like to describe the PRISM™ Separator technology and the engineering design of the modular system.

Hopefully, with this brief background and some actual operating examples, you'll have enough preliminary information to anticipate new uses which will reduce energy consumption in your processes. Your first stage concepts can be readily translated to working units by consultation with Monsanto separation engineers experienced in most process industries. Finally, we'll offer a few thoughts on anticipated uses of membrane systems.

TECHNOLOGY

As many of you are aware, there are three issues which have had a major impact on the potential user's reluctance to try membranes for gas separations. The three issues, none of which is truly independent of the others, are:

Permeation rate
Longevity/Consistency
Environmental Resistance

Permeation Rate

Historically, making membrane systems with economically useful permeation rates has been the most difficult problem facing researchers in this field.
At constant temperature, there are only four variables affecting the permeation rate, Q_i, of a dense film for any component i. These are: the intrinsic permeability of the film polymer, P_i; the concentration gradient of component i across the film, Δc_i; the surface area of the film, A; and the film thickness, ℓ.
The variables are related in a straightforward manner where

$$Q_i = \frac{(P_i)(\Delta c_i)(A)}{\ell} \qquad (1)$$

The higher the intrinsic permeability, the differential driving force, or the area, the faster the flow. The thinner the film, the faster the flow. These are obvious conclusions.

Not so obvious, perhaps, are the practical limits imposed by these variables. The intrinsic permeability is the product of a gas component's solubility and its rate of diffusion in the film polymer. It is fixed when the polymer is chosen for the film. The concentration gradient for commercial uses is often limited by either process or economic constraints. The film area, of course, is limited primarily by economics and we'd like those to be as attractive as possible. The remaining variable, film thickness, ℓ, has been the major target of research and development effort for decades. Simply put, the problem is, first, to make a strong dense film which is only one or two molecules thick. Second, make sure there are no holes in the film which interfere with its ability to separate stream components. Finally, do all the above on a production line producing acres of film every day, all year long.

Asymmetric membranes with a thin, dense separating layer on a thick, porous "basement" structure have been around for some time (Figure 1). They are complex and tricky but manageable. One still does have the holes to contend with, however. They are the price paid to get the thinnest possible dense layer for a fast permeation rate. The holes destroy the separation capability of the dense layer, and this performance loss must be resolved (Figure 2).

Through the development of novel technology, Monsanto solved the problem of producing on a production line strong asymmetric membranes having the thinnest possible dense layer. This dense layer is without holes which interfere with its ability to separate stream components. Part of the secret is in the production of asymmetric hollow fibers. Although hollow fibers are complex and tempermental, competent scientists have developed processes for producing the hollow fibers with only a few holes in the dense layer.

Another part of the secret is to put a special coating over the dense layer. The special coating used in this novel approach is a very fast gas transport medium compared to the dense layer below it. Hence, the coating itself does no separating. What we believe it does is to keep the gases from flowing through the holes. As fast as the coating is compared to the dense layer, it is more than a million times slower than a hole. The result? Essentially all of the gas must now pass through the very thin, dense layer where the rules governing equation (1) can operate swiftly and effectively (Figure 3). This theory is described in much greater detail in papers by J. M. S. Henis and M. K. Tripodi to be published in Separation Science and the Journal of Membrane Science in 1980.

What has been achieved by this approach is the thinnest possible dense layer predictable from theory readily reproducible at production line speeds. This dense layer and coating are produced as a composite, asymmetric hollow fiber in a process operated on a commercial basis by the Monsanto Company of St. Louis, Missouri.

Longevity/Consistency

Once the technology for the composite fiber was understood, the ability to produce fast (that is, commercially economic) membranes with good separating capability has become a matter of high technology routine. One must exercise precise process control but results are predictable and reproducible. The options presented by the composite fiber allow a focus on polymer selection and production processes which insure reliability and reproducibility for mile after mile of fiber. The flexibility given to production by the composite technology allows process control of the entire fiber structure to insure an economically useful fiber lifetime.

In the applications for which we are designing systems presently, we typically expect fiber life of five years. Our oldest commercial installation has been on-stream for more than three years with no significant changes in operating parameters.

Environmental Resistance

Once again, the flexibility gained by a high permeation rate hollow fiber has broadened polymer choices significantly. The material options offered have allowed the selection of polymers which are highly resistant to low to moderate levels of a host of contaminants and coproducts often found in petrochemical and refinery streams such as:

- aliphatics
- olefins
- ammonia
- hydrogen sulfide
- sulfur dioxide
- carbon dioxide

Not the least of the contaminants tolerated is water. Saturation levels of water are not a problem for polymers in Monsanto's commercial system. This high water tolerance allows the use of inexpensive water scrubbing where some contaminants (e.g., NH_3) may exceed the polymer's resistance levels.

ENGINEERING DESIGN OF THE MEMBRANE SEPARATOR

System Operation

Simply put, the membrane separator is analogous to a shell and tube heat exchanger (figure 4). A mixture of fast (fast permeation through the polymer) and slow gases enters at one end of the shell. The mixture passes across the fiber "tubes" as it flows from one end of the shell to the other. Fast gases pass through the membrane more quickly than slow gases and are significantly enriched on the bore side of the fiber. This enriched fast gas stream passes out of the bore countercurrent to the shell flow and exits with partial pressures lower than the partial pressures of the fast gas in the feed stream.

On the shell side, slow gases have been concentrated and partial pressures have increased. The result is two enriched streams, one with higher partial pressures than the feed and the other with reduced partial pressures.

Relative Gas Flows

The commercial membrane system now available has been designed specifically to concentrate hydrogen as economically as possible. It is a fast gas in this membrane system. Helium is nearly as fast and water vapor is much faster. Water vapor is usually present at a very low partial pressure, however, and the driving force for permeation and concentration is also very low. Ammonia too is a fast gas.

Nitrogen, methane (alkanes), carbon monoxide, hydrocarbons in general are slow gases and tend to be rejected at the shell side exit.

Gases like oxygen, SO_2, CO_2 are intermediate in permeation rate. The entering gas mixture composition would determine on which side of the membrane such components would tend to be enriched.

COMMERCIAL APPLICATIONS

Hydrogen Recovery from Ammonia Purge Streams

A typical Kellogg ammonia plant process flow looks like figure 5. Note the purge stream which normally flows to a fuel header. The purge is necessary because the process feed streams carry small amounts of inert gases into the synthesis loop. The concentration of these inerts (e.g., CH_4, Argon) increases as more feed comes into the loop because very little inert gas is removed in the ammonia product stream. Ultimately the inerts reduce the partial pressure of the reactants on the catalyst bed lowering yield per pass. Hence the need to purge part of the recycle stream to control inerts. Unfortunately,

2/3 of the purge stream is hydrogen. That means a loss of reactant in the process feed that must be made up by converting more methane to hydrogen. The Monsanto ammonia plant in Luling, Louisiana, installed a PRISM™ separator system on the purge stream early in the autumn of 1979.

The process stream modification now looks like figure 6. Most of the inert purge is vented to the fuel gas header as before. A very large percentage of the hydrogen and some of the nitrogen reagent gas is now recycled, however. The net energy saving per ton of ammonia is close to 3/4 of a million BTU. Put another way, the production capacity of the ammonia plant at the same absolute energy consumption has been increased about 3%. More detail on this process can be found in a paper by MacLean, Prince and Chae titled "An Energy Saving Program in a 600 short ton per day ammonia plant" published in the March, 1980, issue of Chemical Engineering Progress.

Oxo Syn Gas

The oldest PRISM™ separator installation is functioning at Texas City, Texas, as a stream splitter. The problem Monsanto had in the process shown in figure 7 was a cold box bottleneck.

A downstream process had available capacity to convert additional feed to product. The required feed stream needed roughly equal parts of hydrogen and carbon monoxide. The cold box feed was about 3 parts hydrogen to 1 part carbon monoxide and the cold box was operating at capacity. The solution to the problem is seen in figure 8. The membrane stream splitter diverts some of the stream before it reaches the cold box delivering precisely the stream desired at no loss in line

pressure. The highly concentrated hydrogen permeate flows back to the hydrogen system at a reduced pressure. It is difficult to calculate the energy saving on this installation because it's hard to isolate the elements. A part of the energy saved, however, comes from eliminating the need to build a new cold box. Another part is also related to increased production efficiency. The entire complex is on-stream more reliably due to reduced stresses on the cold box. This approach also may be helpful in some complexes to reduce the stresses on hydrogen production plants operating beyond design capacity. If economics are a measure of energy saving, this is a highly successful energy conserving application. It has paid for itself many times over and continues to do so regularly.

Hydrogenation Purge Recovery

The Monsanto complex at Pensacola, Florida needed a high purity (99%) hydrogen reagent stream. The choices were to purchase the product, purchase a hydrogen generation process or upgrade part of an available stream. The latter option was chosen and both original and revised process streams are shown in figure 9. No muss, no fuss, no bother. The energy saving is small for this specific stream. The ease and speed of the retrofit and the economic advantages were the primary driving forces.

Refinery Applications

Collaborator tests in progress and proposals designed for potential customers are variations on the hydrogenation purge recovery. Typical existing processes might look like figure 10, a simplified diagram of the hydrogen flow around a hydrocracker.

Modifying this stream to reduce high purity hydrogen makeup flow could look like figure 11. One way to calculate the energy saving of such a retrofit installation requires knowing the total energy cost of the hydrogen from the hydrogen plant. From the gross energy saved in reduced hydrogen makeup, one subtracts the energy consumed in the recovery process and the energy lost to fuel in taking the hydrogen out of the waste gas stream. The value of the energy saved depends on local hydrocarbon costs, incremental production costs, and, most importantly, on the availability of adequate hydrogen plant capacity. As crude oil stocks become heavier and more contaminated with sulfur, this latter issue will have even greater impact. A paper by E. A. Maciula titled "Purify Hydrogen for Heavy Oil Processing" will explore this issue at the API Annual Refining meeting in May, 1980 in Houston.

What about the future

Increasing numbers of refinery applications seem certain as the average gravity of crude oil stocks increase and sulfur contaminant levels rise with greater depth of discovery. Both situations require more hydrogen, efficiently cascaded, to produce acceptable products.

Coal Conversion applications seem very likely, particularly in coal liquifaction which has a high hydrogen recycle. The flexibility and reliability of membrane separators should dramatically improve process on-stream time (and, in this case, time is energy) compared to alternative purification processes. Reduced stream pretreatment requirements suggest major capital and energy savings also.

One of the more exciting energy saving potentials is in the area of grass roots process redesign. The membrane permeator now available to the market will allow gas phase processes to be designed

with increasingly flexible reagent concentrations. Reactant ratios can be chosen primarily for conversion effectiveness. Membrane controlled recycle for the excess reagent gas is often simple and may offer economic advantages. A homely example might be NH_3 production extending the modifications previously shown in figure 6. Can H_2 levels far exceeding stoichiometry improve conversion per pass enough to exceed in energy saved the incremental energy cost of recompressing the recycled hydrogen? That is the figurative challenge we leave with you.

This new tool, a novel unit operation called membrane separation, is commercially available and economically viable. How can it save energy for you?

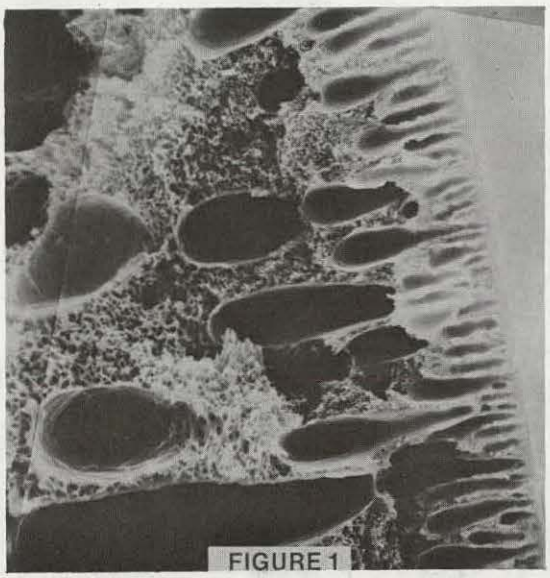


FIGURE 1

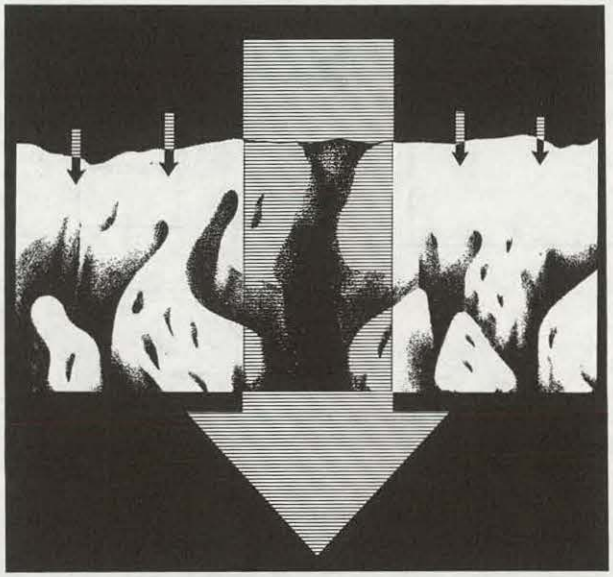


FIGURE 2

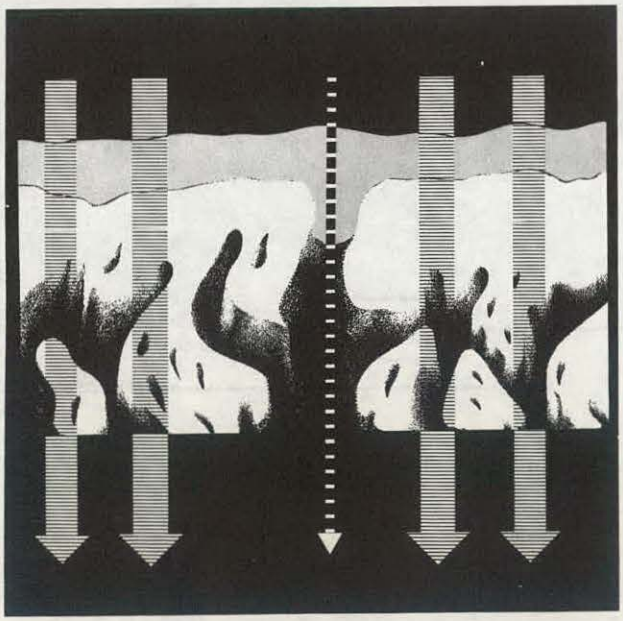


FIGURE 3

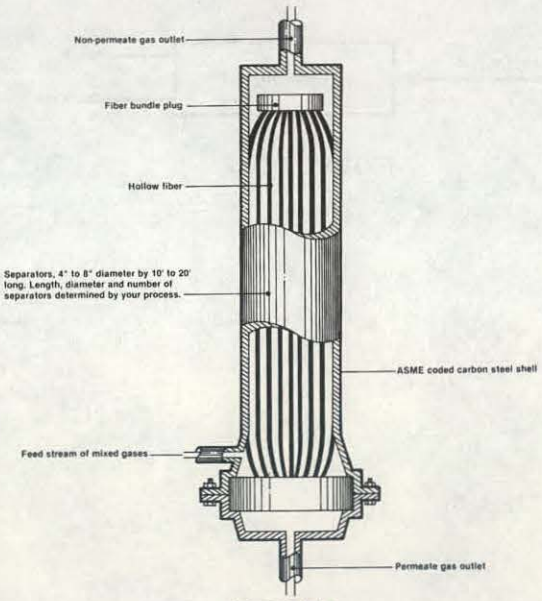


FIGURE 4

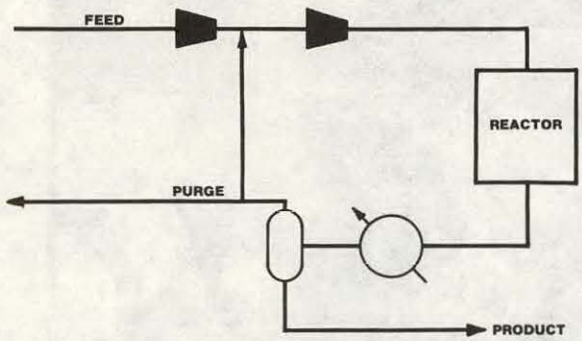


FIGURE 5

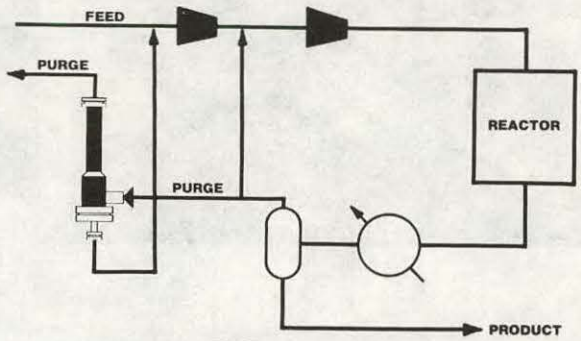


FIGURE 6



FIGURE 7

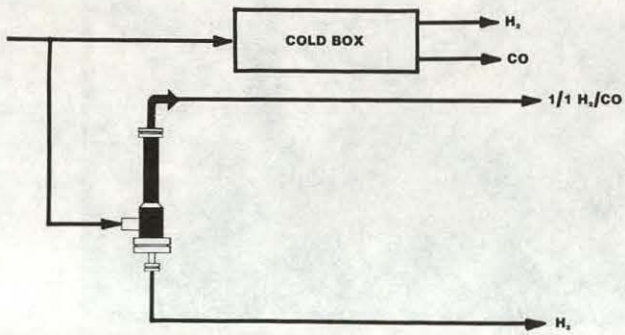


FIGURE 8

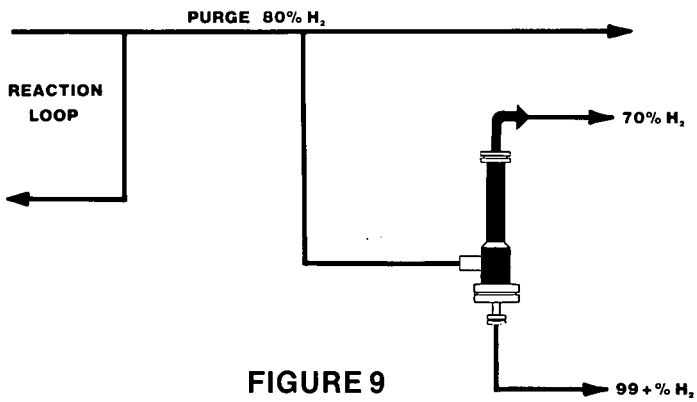


FIGURE 9

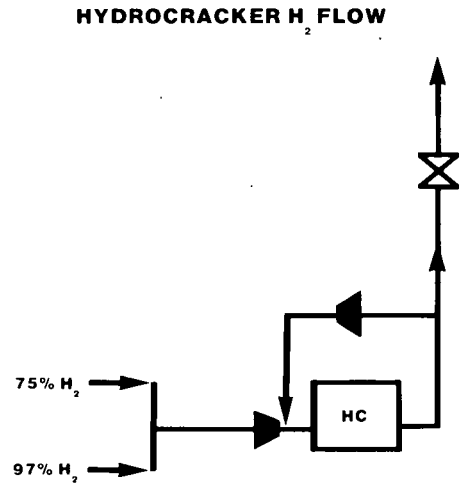


FIGURE 10

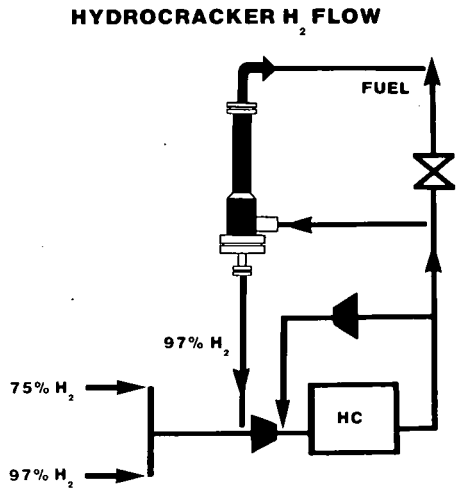


FIGURE 11

MAKING EDUCATION AND TRAINING IMPACT ON INDUSTRY

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INTRODUCTION

Making education and training impact on anyone these days seems to be an increasing difficult problem. Perhaps one of the reasons we see this growing problem and our relative failure in attempts to make education and training more effective is that institutions and individual motivations, which we have traditionally relied upon to create an educated or trained person, are in a tremendous state of flux.

In this paper I should like to explore factors or areas which impact on industrial training and education, and then present to you an innovative system which deals more effectively and more appropriately with each of these factors in order to create more effective programs. By more effective programs, I mean programs which are utilized by the individuals who are supposed to be "educated" or "trained" and which actually help them increase their productivity and performance levels on the job.

The prototype of this innovative system (to enhance productivity and training efforts in industry,) which we have recently developed at M.I.T. is focused on the topic of industrial energy conservation. Thus, the examples and illustration may make it all the more readily understandable to you.

In the context of this talk, education is simply defined as information or"know-how" that somebody wants or needs to work on a particular problem and does not currently possess. Thus, it may range from all of the skills and competencies associated with a higher degree if someone is contemplating a major shift in one's job responsiblities to simply finding out what is the appropriate equation or calculation to use to figure out the return on investment for a new piece of equipment.

We look at educational resources, therefore, as a whole constellation of information and know-how, rather than as the traditional structured and academic approach to the understanding of particular disciplines packaged and delivered in courses. We realize that this expanded definition of education is far more appropriate to the needs of industry. Industry does not necessarily need people to acquire higher degrees in subject matter areas. What industry tells us they are far more likely to need is people who have the ability to acquire what they need to know to do the jobs they are assigned.

There are five major factors which may affect an individual's attempting to find that kind of information or learn that kind of know-how. These factors may also be considered barriers if they stand in a person's way.

Table 1. Factors related to effectiveness of programs.

1. Motivation
2. Industrial Learning Styles
3. Cost
4. Organizational Climate
5. Accessibility

Obviously, the first and a very important factor associated with one's learning on the job and learning things related to the job is motivation. A series of recent studies and even some older ones [1a,b,c,d] indicate the motivation for additional education is most effective when it is job-driven. There are two types of job-driven motivation, and most often people are concerned with the first type, namely, that of obtaining a new degree which will help one obtain a promotion within a company or across companies. The second type of job-driven motivation comes from the need to acquire new knowledge related to tasks one must deal with in one's present position. This type of motivation is becoming increasingly recognized as an important reinforcer and as probably the most important driver for a particular individual to further his education and to update himself if his goal is to perform well on his current job, rather than to seek a new position.

The structure of most educational and training offerings to meet the needs of people with this second type of job-driven motivation is not very well suited to those needs. For example, an individual may require specific kinds of information or to learn specific kinds of new skills. The information may be available and offered through a series of short or long courses by professional societies or various universities. The timing of the offerings with the timing of an individual's needs may be quite askew. Recent studies by others[2] and some under my direction[3] indicate that people who attend these short courses and who take advantage of such offerings most often do so in a defensive fashion rather than in a productive fashion. By that I mean they take these courses to make sure that they still know all the things they are supposed to know in specific areas rather than to learn new things that they need to help them with current problems upon which they are working.

The second factor which we are becoming increasingly aware of as a component in the general educational process involves individual learning styles. It may very well be the case that all of the offerings in the world may be available to particular individuals; but if they are not made available in a manner which one is accustomed to using, they will not be utilized. If they are not utilized, they are obviously ineffective.

Recent studies of information transfer reinforce the old adage that people like to learn in the way they have learned to learn, but also indicate that people are quite willing to learn in new ways if that is the only way in which they can obtain needed information.[3] They are totally unwilling, by the same token, to take advantage of new modes of information transfer if these modes involve information that is tangential or even irrelevant to the job.

A third and obvious factor/barrier in obtaining new information and acquiring know-how involves its cost. And by cost I am talking about cost to the company as well as to the individuals--not only for the materials but for the time taken either away from one's personal free time to work on new things.

The current system of continuing education for engineers and technicians is relatively costly. Estimates are that the dollar cost for an individual and is or her company to participate in a three day professional society short course may easily exceed $1,000. This may be one of the factors accounting for the relatively small participation of the entire engineering and technical community in such continuing education efforts: approximately 3 percent of those eligible to participate and/or take advantage of these kinds of educational opportunities do so.[4a,b] Obviously, the other 97 percent are keeping themselves abreast in other ways or simply are not doing so.

A fourth consideration in one's openness to new ideas and willingness to learn things, especially if it involves an on-the-job situation, is the organizational climate of the industry in which one is working. It is not so easy for an individual work-on a team to be willing to display his ignorance of certain things, especially if those are things he is "supposed to know." Furthermore, if management does not encourage an openness about ignorance and provide opportunities to overcome certain lacks of knowledge and know-how, individual workers may find themselves operating in an increasingly defensive fashion, protecting their backs rather than moving to the front.

It isn't really possible for me to go into the organizational structure and its impact on an individual's performance in detail at this point. Suffice it to say that the organizational setting is a major component in the development or nondevelopment of the productivity of the individual worker.

Finally, the fifth factor and/or barrier to obtaining additional education, information, and know-how is that of accessibility. We have alluded to accessibility under the area of costs, indicating that situations requiring individuals to give up free time and to travel simply to take additional courses --our present system--is involving only about 3 percent of those who could take advantage of these opportunities. To involve the other 97 percent or even to double the 3 percent could mean great strides forward for American industry. By having a system which provided individuals with the necessary, knowledge, information, and competencies appropriate to their jobs in a form that was immediately accessible to them at a time when they needed it and where they were working, would be a great step forward. It is precisely this great step forward which the PROCEED system attempts to take.

PROCEED, which stands for "Program for Continuing Engineering Education," is a system which was designed to help overcome the barriers which the factors I have just outlined represent for individual engineers, scientists, and technicians in industry. The system which we have conceptualized and developed contains three essential components:

Table II. Components of the PROCEED System.

1. A personalized access system.
2. An associated data base.
3. Related educational materials which are competency based.

I shall describe the PROCEED system as it was developed for the topic of industrial energy conservation, and then show you how as a prototype it can work in a variety of areas and for a variety of topics to provide a much needed technology transfer service to industry in general.

THE PERSONALIZED ACCESS SYSTEM

The purpose of our personalized access system is to help the individual define and refine his problem so that the system can search its data base to find the most relevant and appropriate consultants, aides, educational information, etc. to solve his/her particular problem. To the user it is an interactive series of questions and choices presented to him by the computer to which he responds using four simple commands -"1", "2", "3", and "4." The user is shown what the commands stand for, so other than knowing how to log in on any kind of terminal, he need not know how to program or use computers.

Hidden to the user as an elaborate hierarchical tree-like structuring of the problem solving process which guides his or her search and helps locate the precise sets of information which are appropriate to the problem.

THE ASSOCIATED DATA BASE

consists of files of information,including listings of consultants (accessed by location and capability), educational materials, bibliographies, special purpose laws and standards, products and vendor data to name but a few. When the user has refined his problem he or the system will search the data base to come up with the type or types of information required to help work the solution.

THE EDUCATIONAL MODULES

which may be referred to by the search consist of a full set of self study, competency-based materials. Each is 100-150 pages long and can be ordered through the system. There are also case studies.

Table III. List of Modules and Authors and Companies.

1. Control Systems that Save Money
   F.G. Shinskey
   The Foxboro Company

2. Measuring and Improving the Efficiency of Boilers - D.F. Dyer, G. Maples, J.C. Maxwell, Jr.
   Dept. of Mechanical Engineering, Auburn University

3. Synthesis of Networks of Heat Exchangers
   G. Stephanopoulos
   Dept. of Chemical Engineering, University of Minnesota

4. Energy Conservation Opportunities in the Small Industrial Plant
   H. Eckerlin, A. Boyers
   North Carolina State University

5. Fuel Savings with Furnaces
   E.S. Monroe, Jr.
   Consultant

6. Space Conditioning
   L.D. Conta
   University of Rhode Island Energy Center

7. Heat-Waste Recovery
   W.F. Kenny
   Exxon Chemical Corporation

8. Energy Conservation and Process Selection in Adsorption, Gas Adsorption and Liquid-Liquid Extraction
G.E. Keller
Union Carbide Corporation

9. Efficient Lighting
R. Lee, M. Anderson
ANCO Engineering

10. Thermal Insulation
M.R. Harrison
John Mansville Corporation

11. Refrigeration
W.F. Ferguson
Borg-Warner Company

12. Energy Conservation in Distillation
T.W. Mix, J.S. Dweck
Merix Corporation

13. Energy Conservation in the Chemical Industry
S.A. Furbush
Allied Chemical Corporation

14. Thermodynamic Efficiency of Chemical Processes - J.D. Seader
Univ. of Utah, Dept. of Chemical Engineering

Table IV. List of Cases

1. Boiler Blowdown Heat Recovery in a Large Buildings Complex

2. Wet Grinding Phosphate Rock in the Phosphoric Acid Process

3. Heat Recovery in Polyethylene Plant

4. Steam Washing on an Evaporator

5. Ethylene Furnace Oxygen Monitor

6. Steam Balancing in a Refinery

7. Computer Control of a Natural Gas Liquids Fractionation Plant

8. Block Operation of an Ethanol Plant

9. Ethylene Capacity Expansion

10. Steam Generation From A Blowoff Gas Combustor

11. Improved Steam Stripping of Latex

12. Steam Balancing in a Chemical Plant

13. Steam Generation from Combustion of Waste Limits

14. Energy Conservation in a Sugar Refinery

In another session at this meeting we will present in detail a few specific programs which were constructed by the PROCEED system around an individual user's problem. Time now does not permit.

Given this outline of the system, it is appropriate to end by indicating how it responds to the factors originally mentioned and mentioning a few other topic areas for which such systems will be developed to comprise a truly valuable resource to industries in more areas than energy conservation alone.

So...

Motivation is clearly job-driven for the most part. People consult the system when they want help.

Individual learning styles are handled somewhat by allowing the user to access the system as far as he wants and use the the type of recommended resource he feels is appropriate.

Costs are estimated to be less than $50.00/access including the purchase of one or two relevant modules. Since each module is equivalent to a 12 hour course, the savings can be compared to the previously mentioned $1,000 plus figure.

Organizational climate becomes somewhat irrelevant. A new resource on the premises available through any terminal or telephone meshes totally with the natural work environment.

Accessibility is as close as the nearest terminal or phone.

Future topics under consideration and development are: waste treatment, toxic substances, CAD/CAM and several others. I would welcome your topic suggestions.

Thank you.

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1c. Kolb, David A. (1974) The Experimental Learning Theory of Career Development, Sloan School Working Papers 705, Massachusetts Institute of Technology, Cambridge, MA.

1d. Morris, Albert J. (1978) The Return on Investment in Continuing Education of Engineers, NSF Grant No. EPP75-21587, Genesys Systems, San Francisco.

2. Gerstenfeld, Arthur and Berger, Paul (1979) "Innovation, the Utilization of Information," paper presented at American Association for Advancement of Science Conference, Houston, TX.

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4b. Tribus, Myron, (private correspondence).

ENERGY-SYSTEMS TECHNOLOGY: A DEVELOPMENT IN EXPERIENTIAL LEARNING

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Mohawk College, Hamilton, Ontario

ABSTRACT

Energy Systems Technology is a three-year diploma program which started in September 1977 and will produce its first graduate technologists in June 1980.

The program of studies is multi-disciplinary and includes mechanical and electrical subjects with an energy orientation. Computers and communications are the secondary subject areas.

The experience gained in the development and operation of Energy Systems as a co-operative program is described together with experiential learning which is used for assessing the students' learning while on the job.

INTRODUCTION

The energy supply situation changed considerably during the seventies and has presented us with a tremendous challenge. The gap between supply and demand will become a reality in the eighties unless supplies are increased and demand is moderated. This problem is so large that few individuals will have the opportunity to make an impact: it must be hoped that collectively we can all do sufficient to make a smooth transition away from the fossil fuels on which we have become so dependent. The theme of this conference is conservation through energy management and this paper will describe a new program which has been developed at Mohawk College in Hamilton, Ontario designed to produce technologists who are equipped to assist in meeting this objective.

Before doing so, it is appropriate to describe Hamilton and the system of post secondary education in Ontario. Hamilton, the "steel city" is the centre of operations of the Steel Company of Canada and Dominion Foundries and Steel, the two largest producers of steel in Canada. Firestone, International Harvester and Proctor and Gamble are some of the international companies with plants in Hamilton. In addition, Hamilton is located within easy reach of Toronto, Oshawa, Brampton, Oakville, Kitchener, London, Brantford, Welland and St. Catharines, each of which contains major manufacturing industries.

There are other community colleges serving many of these areas outside Hamilton but Mohawk is the only college in Ontario, or in Canada, to offer this program.

Ontario is a province of some 400,000 square miles serving its population with 22 colleges and 14 universities. The universities offer 3 and 4 year baccalaureate degrees and graduate programs. The Ontario colleges were set up in 1967 to provide an alternative post-secondary education and have been very successful in developing career-oriented 2 and 3 year diploma programs and shorter certificate programs. These colleges, unlike many in other parts of Canada and in the United States, do not function as transfer institutions.

In co-operative education a number of paid work terms are incorporated with the semesters of academic study. Mohawk College is among the small number of Canadian colleges and universities which have adopted this model for some programs. Co-operative education is very popular among students and employers. Experiential learning can be based on co-operative education. In this case academic credit is given for learning which takes place during the work terms. Energy Systems Technology has been developed as an experiential program as part of a study at Mohawk College and the initial development has been supported by a Federal grant. This program has been attracting considerable interest for both its content and its methodology.

THE ENERGY TECHNOLOGIST

The role of the energy technologist was developed initially in the industrial context. The proposed technologist was perceived as a member of the plant engineering department or as part of the staff of the engineer responsible for energy management. Our model was a company which spends from one to five million dollars annually on fuel because we felt that companies spending much less than a million would be unlikely to be able to support an energy specialist on a full-time basis. On the other hand, companies in the ten million plus category would probably be so energy intensive that energy management would already be part of their way of life and so "Utilities" would likely be one of their production departments. If we are right in this assessment, then hiring patterns and training programs would already exist to meet their requirements for personnel. Our target then is those companies for which energy, until recently, was a fairly minor consideration but which are now faced with energy bills large enough to draw the attention of plant managers who are looking for ways to reduce costs and to meet voluntary, or mandatory, energy performance criteria.

Another target for our program is the institutional/commercial sector where directors of physical plant, construction engineering departments and building managers are trying desperately to curtail rising energy costs as their operating budgets shrink in real terms. It is interesting, and perhaps revealing, to note that initially the greatest support for our program in terms of co-operative placements came from this second group. We have also placed students with utilities and consulting engineers and anticipate that others will be placed with contractors and suppliers of energy management equipment.

With the industrial and institutional/commercial sectors as our principal target, and in the context of Mohawk College's strong tradition of providing a thorough grounding in basic engineering subjects within our engineering technology programs, we examined the specific competencies that this new technologist should have. Other disciplines, such as Mechanical or Electrical Engineering, have the advantages of being both long established and well defined. As a result the task of designing an educational program for the energy technologist was different since he has, at present (at least in Canada) no counterpart in the form of an "Energy Engineer". Firstly, then, there is no model to work from, and secondly there is a much smaller probability of the technologist being supervised by an engineer with the same type of background. (Up to this time the Energy Systems students have been directed on their work terms by Mechanical, Civil, Electrical, and Chemical Engineers; in some cases quite closely, but the majority have been left to work for considerable periods of time on their own initiative.)

Following the first year which is built around the core of basic engineering subjects Engineering Science (physics), Electricity, Chemistry, and Mathematics, two major themes are developed supported by two minor themes

Mechanical Subjects

The mechanical subjects provide the main structure of the program and include courses on Steam Systems, Instrumentation, Building Environmental Services, Manufacturing Processes, and Building and Systems Maintenance. Combustion and Feedwater Chemistry are also included in this section. The objective of these courses is to produce a generalist who understands the basic principles, knows current practice, can check operating conditions and can identify the steps which may be necessary to assure efficient energy utilization. In some cases he may undertake corrective actions himself; in other instances he would report to his supervisor and/or call in specialists from within the organization or from outside. Representative activities in this field undertaken by Energy Systems students on their co-operative work terms are the following:

(i) Specifying, selecting, justifying and preparing working drawings for the installation of retrofit set-back thermostats in a commercial complex containing a warehouse, an office and a retail store.

(ii) Preparing an inventory of all energy-handling equipment in an office building and compiling a building operator's manual.

(iii) Preparing a feasibility study for the installation of a high volume, low temperature heat recovery system in a manufacturing plant.

Electrical Subjects

The electrical subjects in the program constitute the second main theme. These courses are Electric Power and Machines, Utility Metering and Billing (principally electric), and Lighting. The same basic approach is used in the treatment of these subjects since a technologist must know not just "what?" but "why?" It is quite possible that, in a particular job, a graduate could work exclusively in the mechanical or in the electrical field. This could result in him becoming quite specialized, but the program has been designed in a multi-disciplinary way so that he can view the total energy picture with understanding and be capable of working in both areas.

Typical work-term activities are:

(i) Validating utility bills and preparing suitably normalized energy consumption profiles for an institution or for a plant.

(ii) Determining the electrical demand profile of an institution, identifying and classifying the loads, and preparing a schedule of operation for controlling peak demand. This may include a study of the feasibility of installing automatic load scheduling equipment.

(iii) Carrying out a lighting survey and preparing working drawings for a de-lamping, or re-lamping, program. Alternatively, a comparative lifetime assessment of different lighting systems complete with specifications and preliminary design drawings could be undertaken, if appropriate.

Computer Subjects

These courses are intended to identify the computer as a machine for accumulating, processing, and storing data and also as a device capable of controlling systems and processes. They are not intended to develop experts in computer programming or hardware.

Computer subjects include Computer Concepts, BASIC Programming, Advanced Programming, Process Instrumentation, and Computer Control. Students rarely perform "computer" tasks but quite often make use of small machines and scientific programmable calculators in order to assist them with their work. Activities have ranged from programming a detailed heat loss calculation to facilitate a very long, but essentially simple problem, to adding more

points to a computer used to control building systems and manufacturing processes to reduce energy consumption and demand.

Communications Subjects

This aspect of the program is stressed and "Communications" is interpreted literally in such courses as Communication Skills, Humanities, Report Writing and Presentation Skills, which are designed to develop skills in written and verbal communication. It is also interpreted more generally in courses such as Engineering Drawing, Schematics, Management Accounting, and Management of Human Resources which have been designed to enable the Energy Systems students to communicate effectively with those around them.

Special laboratory facilities are being developed to support the program. The energy laboratory contains various systems using industrial equipment wherever possible. These include air handling, heat recovery, steam, hot water, pumps, electric power and lighting systems.

The program of studies contains few courses which are unusual in themselves: it is the grouping into a multi-disciplinary program with this career orientation which makes it different. The most innovative courses may be those in lighting, utility metering and billing, presentation skills and the three course credits for experiential learning called "practicum."

EXPERIENTIAL LEARNING

Experiential learning is a non-traditional method of education. In *sponsored* experiential learning, the student gains academic credit for what he learns off-campus while registered with an educational institution. This is contrasted with *prior* learning when credit is awarded for what the student has learned before attending the institution.

Energy Systems Technology is a fully integrated sponsored experiential program in which the students must gain academic credit for what they have learned off-campus during the three paid experiential semesters (work terms), in order to meet the requirements for graduation.

This means that the college must find a sufficient number of suitable placements in which the students will be able to identify appropriate learning objectives, usually within the tasks assigned by their supervisors.

Co-operative placements are sought in companies where these opportunities occur and the students are visited by a faculty member shortly after the work term has started in order to identify suitable learning objectives for the student. To facilitate this process, a list of generalized learning objectives is being compiled. These are in the areas of visual assessment, energy consumption profiles and reports, H.V.A.C., electric power, lighting, process, and research and development. In most cases the supervisors allow the students to keep copies of all of their reports, including calculations, drawings, quotations, etc., which are used to document their learning objectives that are submitted for academic credit after validation by the supervisor.

A system has been developed to measure how much has been learned and how well it has been learned. This culminates in an assessment committee meeting at which the faculty evaluators meet each student and discuss their appraisal of his work. The resulting practicum grades form part of the student's college record and appear on his transcript together with the grades for more traditional courses.

We have concluded that the model developed at Mohawk College for measuring sponsored experiential learning is general enough that it could be adapted for use in any valid, career-oriented program provide

that there are sufficient suitable placement opportunities.

CO-OPERATIVE EMPLOYMENT EXPERIENCES

Co-operative education is generally considered to be a highly desirable feature in college and university programs. At the outset it was decided that co-operative education is essential in Energy Systems because a graduate without practical field experience would be a liability on any energy manager's staff. A student technologist can be forgiven for not instantly recognizing a flash tank or a synchronous motor but a graduate who also lacked the skills and experience necessary to gain the co-operation of the men on the shop floor would have a great of difficulty in establishing the working relationships at all levels necessary to be successful in his new and occasionally threatening activities.

By adopting the co-operative education program model, a student normally completes twelve to fourteen months of related working, and learning, experience before graduation. Statistics have shown that about half of the students find their first employment as graduates among their co-operative employers. We anticipate that this will also be true with this program.

The co-operative education component of Energy Systems Technology started in the summer and fall of 1978 and has now operated continuously since May 1979. Initially about half of the placements were in the institutional/commercial sector and one quarter were in the industrial sector. The "energy-bus", which was developed at Mohawk in 1975 and then operated for four years under contract to the Ontario government, has provided a number of the "instant audit" type of placements which made up the remaining quarter of the jobs obtained during the early stages of the program.

More recently a proportionally greater interest has been shown by the industrial sector and we now have sixty percent of our students with manufacturers while the remainder are in institutional/commercial placements. As this program is unique in Canada, we regularly have students working in the Maritime (Atlantic) Provinces and right across the country to the west coast.

Employers have expressed great satisfaction with the ability, skills, initiative and enthusiasm shown by our students. We have sought feedback on the content of the program from the employers and from the students, in both cases asking them at the end of the work term. This has enabled us to validate many of the initial decisions and to add, shift emphasis or delete topics occasionally as required. We encourage student participation and involve them, as well as our advisory committee, in the curriculum development work of the department.

Energy Systems Technology started in September 1977 and has, through co-operative education, already established itself, and the role of the energy technologist, before the first class graduates in June 1980. We hope that these technologists and the experience that we have gained in developing the program will be of value as we all seek to make our contribution towards the eventual solution of our energy problems.

TRAINING FOR ENERGY MANAGEMENT: EXPERIENCE IN ONE STATE

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ABSTRACT

This paper examines the need for energy management education in the industrial sector, and focuses on the cooperative efforts of federal and state governments and educational organizations/institutions to fulfill that need. The roles of government and educational organizations and their respective capabilities in energy education are discussed, with emphasis on the role of the professional society. Two specific programs are described: the "general" workshop, designed to promote energy conservation awareness and present fundamentals of establishing and managing a program in an industrial facility; and, in greater detail, the "industry-specific" workshop, in which the specific methods for applying energy-saving technology and management techniques to an industry's processes and equipment are presented in detail. The industry-specific workshop is discussed in the context of one state's effort to transfer these methods to private industry.

INTRODUCTION

This paper describes just one small part in the current effort to educate the American public about our energy crisis and to promote among them conservation as one means to solving the energy problem.

Last year, then Deputy Secretary John F. O'Leary of the Department of Energy offered his view of how Americans perceive the energy dilemma and how leaders in various walks of life must go about altering that perception. In an address to a group of business leaders and educators, Mr. O'Leary said that we in the United States "have no national sense of what the problem really is and what it really takes to solve it." (9) However, Mr. O'Leary did not try to force his own view of the problem on his audience. What he did do was suggest that the first step in solving the problem is to understand it as you yourself see it, and not accept the placebo that, in his words, "there is plenty of oil and gas out there and solar is right behind us and all we have to do is go for divestiture and we will solve the problem or that Mexico will solve it for us." As the means to achieve that understanding, Mr. O'Leary pointed to a massive education effort to be carried out by the education, business, and labor communities.

In fact, all segments of our society are touched in one way or another by the energy problem, and therefore bear some share of the burden for solving it -- not only business, labor, and education, but the consumer, community leaders, and public leaders as well. Each of these societal components makes its voice in such matters heard through a variety of media, often through one or more representative professional societies. And it is this medium's role in energy education that this paper addresses.

SHARED RESPONSIBILITIES FOR ENERGY EDUCATION

Because various energy issues are not equal ly important for all sectors of the public, a variety of organizations and channels are required

to deliver energy education: educational institutions, governmental organizations, corporations, organizations representing special groups, mass media, and the like. All of these share the responsibility for energy education, but because each has a different constituency -- sometimes overlapping -- their roles are not the same.

In terms of the availability of resources to fund programs, the Federal government is probably the most important agency in this process. Most federally funded energy education programs accomplish their goals through outreach mechanisms such as information, technical assistance, exhibits, demonstrations, workshops, and direct funding of state and other agency or organization programs. Often, an individual program will use multiple media to achieve its objectives. Furthermore, in many Federal programs, energy education is only one of their many components. And finally, the in-house delivery capability of Federal agencies is frequently limited, and therefore they often must rely on outside contractors. Thus, while the Federal government must be and is a leader in energy education, its role is frequently restricted to the establishment of requirements and the provision and coordination of resources.

Conversely, state governments have limited funds as well as personnel, and they often depend on Federal "pass-through" monies which they use to contract outside help to execute their own or federally mandated programs.

In the public sector, schools, colleges, and universities are uniquely qualified to dispense energy education, and great strides have been made. In the public schools, curricula have been developed and are being implemented. In higher education, excellent professional programs in energy have been developed -- such as at the University of Pittsburgh, and at Coastline Community College in California -- but their beneficiaries are still few in number. In the main, although they reach an "extension" audience, the education community's programs are more long-term and their full impact is yet to be felt. And, as with the states, these programs are frequently underwritten, in whole or in part, by Federal subsidies.

Elements in the private sector, too, use Federal programs as a basis to pursue energy education within their own constituencies, but in a different way. They see them as healthy stimuli for activity in their own service or product areas, and draw upon them as resources to develop their own programs. Private sector firms make major contributions in providing conservation assistance to the public, as well as in designing, manufacturing, installing and servicing energy-efficient and renewable fuel devices. (8)

The role of the professional society, too, is defined by the constituency it serves. But in the case of one society -- the American Management Associations -- that constituency includes many, varied sectors of interest; it is the rather broad and amorphous "management community." AMA is dedicated to the training and personal development of people, in both the public and private sector, to better enable them to contribute to the effective management of their organizations. And this includes better energy management.

AMA "GENERAL" WORKSHOPS

In its First Report to Congress on Federal energy education, extension and information activities, the Department of Energy identified 63 Federal programs that, in some way, fall in this category. Interestingly, only about 10 percent of these reflect the workshop or seminar as their principal delivery mode. But it is this proven medium that AMA, as an educational institution, has chosen to use as the primary means to educate business and the public sector in energy conservation. In its not-for-profit status, AMA takes no position on any public issue, speaks for no group, and espouses no cause other than that of better management -- in this case, energy management.

To date, AMA has offered two types of energy management workshops. In 1977, as part of an FEA-sponsored effort to create an awareness of the energy dilemma among the American public and specifically within the business community, AMA conducted a series of 190 one-day Industrial Energy Conservation Workshops across the country. These were primarily management-oriented, and were designed to enhance the participants' understanding of the need to conserve energy, and to

teach them, mainly in a non-technical way, how to identify and evaluate energy-saving opportunities. During a one-year period, these workshops reached over 4,000 plant managers and engineers in 44 states and Puerto Rico.

INDUSTRY-SPECIFIC WORKSHOPS

Fortified with the success of these workshops, and having concluded that industry was in need of and actively seeking solutions to energy conservation problems, AMA undertook to develop a follow-on program that would be more technically-oriented while maintaining a management framework. This "industry-specific" workshop would continue to stress awareness and motivation, but also focus on decisionmaking techniques and specific technical solutions. AMA offered this program initially to several state energy offices, and after some modifications in the program's scope AMA entered into a contract with the State of New Jersey to design and deliver it.

Concept

These workshops are designed to assist plant managers, plant engineers, energy coordinators, process engineers, and other plant operating personnel to increase energy efficiency by better management of their technical resources. The target audience was further narrowed by focusing on small- to medium-sized plants with, say, a work force of from 50 to 500 personnel. AMA experience relfects that it is these firms which generally lack an in-house capability to evaluate their energy-savings opportunities, and thus they may not make appropriate and timely investments to remain competitive.

The New Jersey Department of Energy selected the five most energy-intensive industries in the State -- excluding petroleum -- for concentration. Through a demographic process, AMA developed, for purposes of building individual workshops, 10 subgroups among the five industries. (Table 1) Each selected subgroup of an industry (in two cases, the industry as a whole) is addressed in a separate workshop.

INDUSTRY GROUPINGS

SIC	Industry	Groupings
20	Food	Baking
		Canning, Bottling, and Other Food Preparations
		Frozen and Dehydrated Foods
26	Paper	
28	Chemical	Drugs
		Soaps and Toiletries
		Heavy Chemicals
32	Stone, Clay and Glass	
33	Primary Metals	Mills
		Foundries

Table 1

The program is designed to deliver 17 two-phase workshops. Phase I consists of a two-day session which focuses on key concepts of an energy management program, audits, the identification and analysis of industry-specific opportunities, and how to maintain the program. This phase terminates with the participants committing to specific conservation actions which they reasonably believe can be implemented in their plants within the succeeding three to six months. Phase II consists of a single, problem-oriented, follow-up day approximately six months after Phase I, and is based on the participants' experience in implementing the knowledge and ideas gained from the first two days. This Phase II session will be designed from survey data collected between the two phases. The training load for each workshop is 25-30 participants, based on AMA's experience that the greatest value of such sessions is gained from group discussion and the knowledge of other participants; this size group has proved to be the optimum for a meaningful exchange.

One of the innovations of this particular workshop is the use of "technical assistants." These are engineers, selected from the specific industries of concern in New Jersey, and who have a detailed knowledge of and hands-on experience with energy in their industries, who assist the principal workshop leaders as resource persons in the classroom. The technical assistants

answer industry-specific questions about energy conservation and manufacturing processes, inject comments and examples pertaining to industry-specific energy conservation opportunities and measures, and informally present one or more short presentations during the course of the workshop as to how energy has been saved in the industry. Also, within their capabilities, the technical assistants lead the principal part of the discussions on heat recovery, recycling, cogeneration and process changes.

AMA's mainstay for guidance during workshop design was a State Advisory Council, composed of 14 highly knowledgeable technical representatives of the five industries of concern, and eight representatives of the broader business and industry community in New Jersey. These 22 people were invaluable in helping to break down industries into logical groupings for workshop delivery, in verifying the target audience, in providing guidance as to which topics to stress in each industry, and in validating the overall workshop design and content. Two members of the Advisory Council are also serving as technical assistants. The design team was also aided by five memebers of the American Institute of Plant Engineers, drawn from the five industries.

Methodology

Before describing the workshop curriculum itself, a word or two about the methodology followed in constructing the workshop would be in order. It uses a systems approach, both methodologically and in content. To begin with, energy management is portrayed as only one component of a plant's total system. Then, as will be shown, energy management is itself treated as a system, with many interrelated and interlocking component parts, and, although it is broken into its components for instructional purposes, considerable emphasis is placed on the linkages between the various parts. Minimum time is devoted to the lecture method of presentation, but rather a variety of group interaction techniques are introduced to stimulate interest and discussion. Supporting the instruction are a Participant's Workbook, organized by major topic and containing numerous examples and case studies; a Technical Reference Manual, with pertinent articles and papers as backup reading; and a Leader's Guide. The three workshop leaders were carefully chosen for their expertise in energy management and their platform skills, and received further training conducted by the AMA staff. Evaluation of the workshops is based on detailed critiques submitted by the participants, as well as on the observations of the workshop leaders and AMA staff. These provide both a qualitative and quantitative assessment of the curriculum structure and content and the instructional methods, which can be measured against previously established performance standards. Another important mechanism in the evaluative process, and one that allowed early adjustments in the curriculum, was the pilot workshop which was held last July.

Curriculum

The curriculum follows the same general outline for each industry, with about 60 percent of the subjects being common. However, because each industry has unique characteristics of process, energy sources, equipment and the like, about 40 percent of the materials and the discussion are specific to that industry and even to the industry subgroup. In particular, industry-specific emphasis is placed on the areas of greatest savings in the heat generating, heat distributing, and heat end-use systems, and on heat recovery, waste recycling, cogeneration and process change to the extent that each applies to the industry being addressed. The more routine "housekeeping" measures such as insulation, lighting levels, repair of steam traps and the like are discussed only in passing unless participants wish to pursue them in greater depth.

The industry specificity is built into the workshop through a modular approach. Each selected industrial grouping -- a total of 10 -- is addressed in a separate workshop. The curriculum is divided into nine segments, not including the evaluation. (Table 2) The Participant's Workbook is divided correspondingly, with the sequence of instruction following the Workbook organization. (In the Workbook, Program Maintenance is a discrete section.) The common module for all the workshops consists of all the notebook segments except the Introduction and

major portions of the Detailed Audit and Identification of Opportunities. The Detailed Audit and the Identification of Opportunites are different for each of the five basic industries, and the Introduction is different for each of the 10 groupings. The introduction includes material on energy use and conservation options in the specific subgroup (for example, Heavy Chemicals or Soaps and Toiletries). However, sequentially, this material is deferred to the discussion of opportunities on Day 2.

WORKSHOP COMPONENTS

	Time (Hrs)
Introduction	1.5
Overview of Energy Management Program	0.5
Basis of Energy Audit	1.5
Preliminary Audit	1.5
Detailed Audit	1.5
Identification of Opportunities	3.25
Analysis, Implementation, Program Maintenance	2.5
Action Plans	0.5
Evaluation	0.25
TOTAL	13.0

Table 2

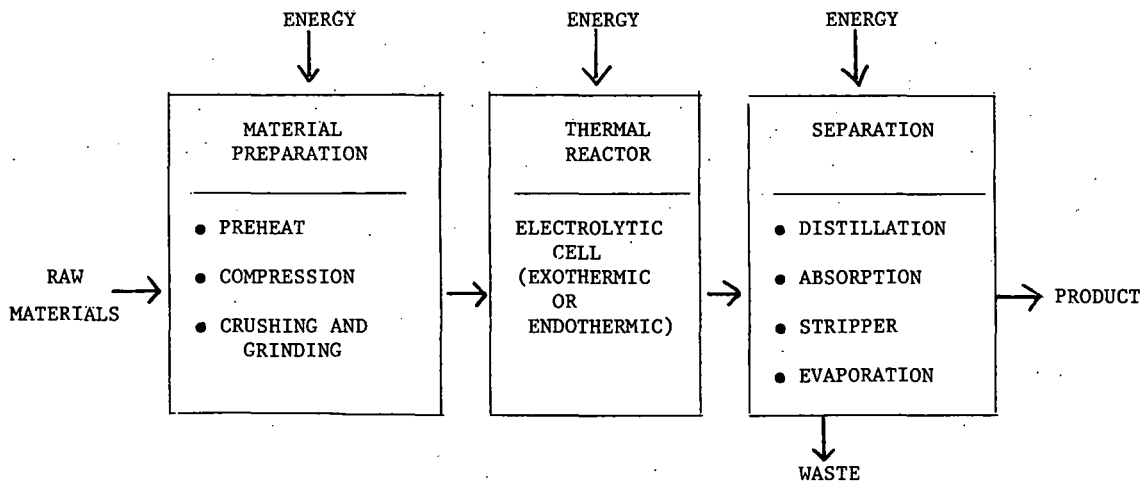
Some examples from the Heavy Chemicals workshop might help illustrate these points.

In Section I, a typical chemical process and its energy-using systems are described as th basis for understanding the future discussion of energy flow and balance (Figures 1, 2, 3)*

Section II discusses the components of an energy conservation system, as well as such basics as the need for top management commitment, the importance of establishing policies and procedures, and functions of an energy coordinator. (Figure 4).

Section III begins to address the substance of the workshop: the components of and the steps in the audit process, how to find the efficiency of transfer systems, and the use of Btu/unit of product to measure the performance of end-use systems. (Figures 5, 6, 7). It also discusses the difference between the value and cost of energy.

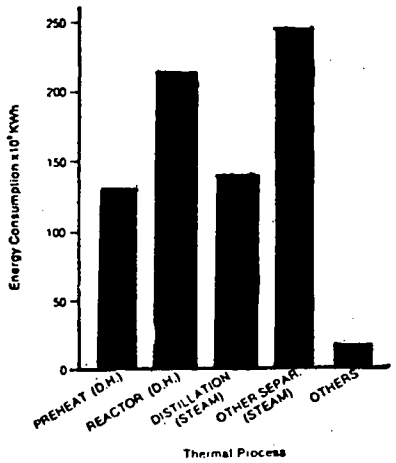
In describing a preliminary audit, Section IV focuses on data collection, types of energy, and division of a facility into cost centers. A substantial portion of this section is devoted to an example of a preliminary audit (Figure 8) and analyzing its results.



COMPONENTS OF A CHEMICAL PROCESS

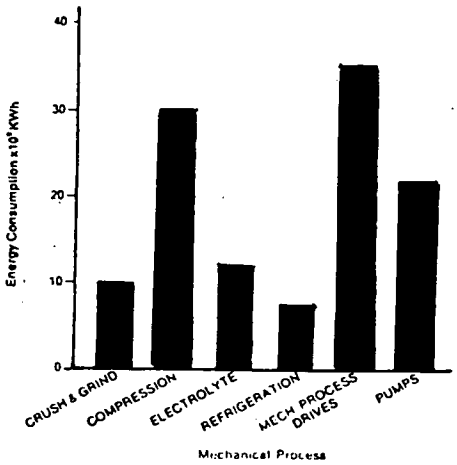
Figure 1

* Figures 2 and 3 have been adapted from Reference 3.



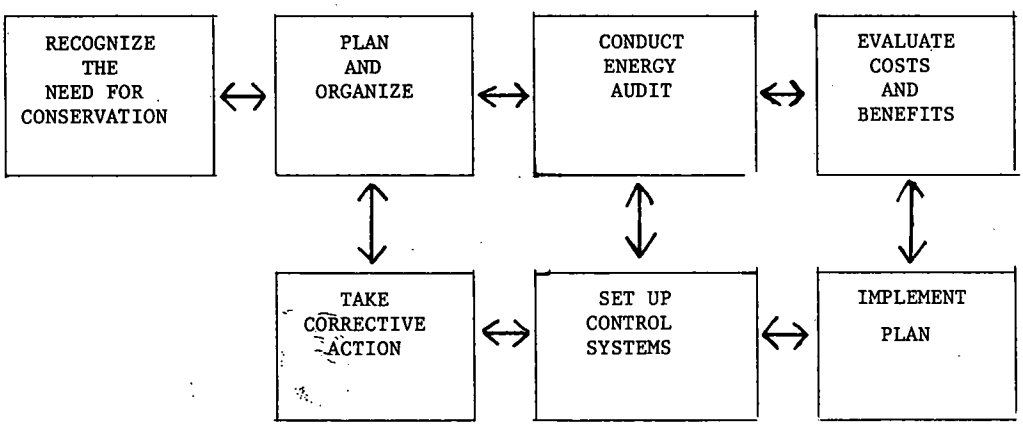
ENERGY USED IN THERMAL PROCESSES

Figure 2



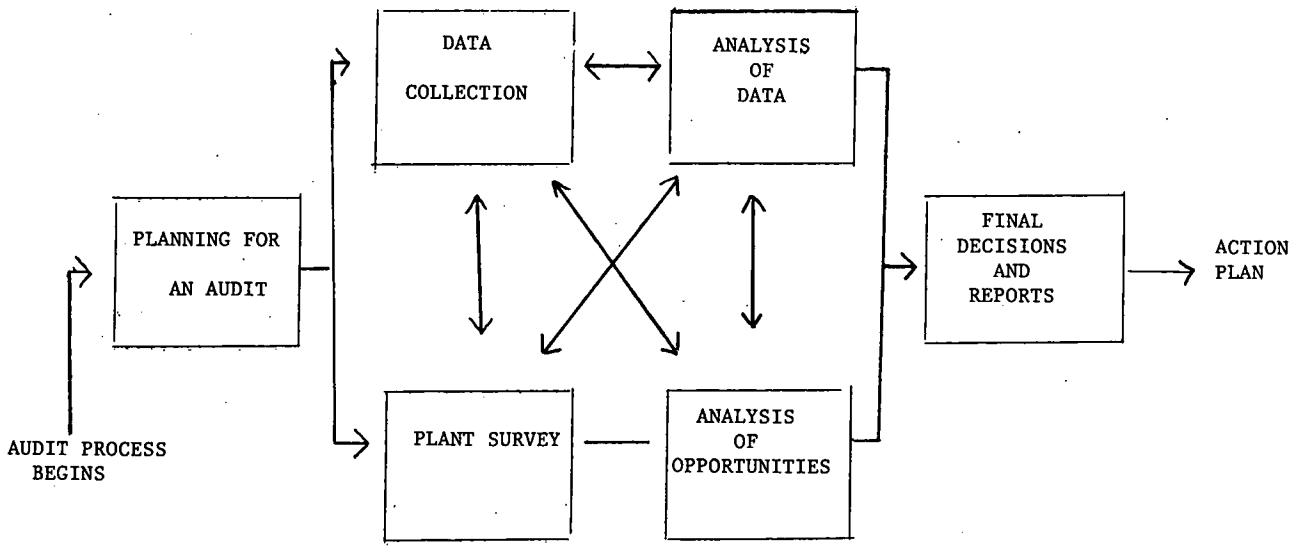
ENERGY USED IN MECHANICAL PROCESSES

Figure 3



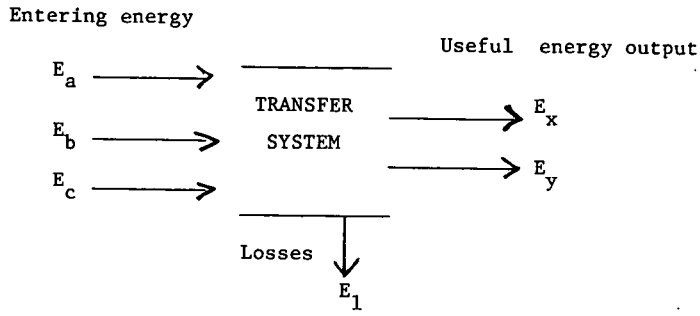
ENERGY CONSERVATION SYSTEM

Figure 4



AUDIT PROCESS

Figure 5

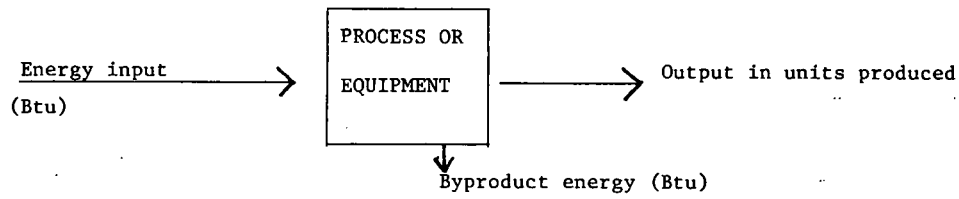


Energy balance equation: $E_a+E_b+E_c+E_x+E_y+E_l$

System Efficiency = $\frac{\text{Useful energy output}}{\text{Energy input}}$

TRANSFER SYSTEM

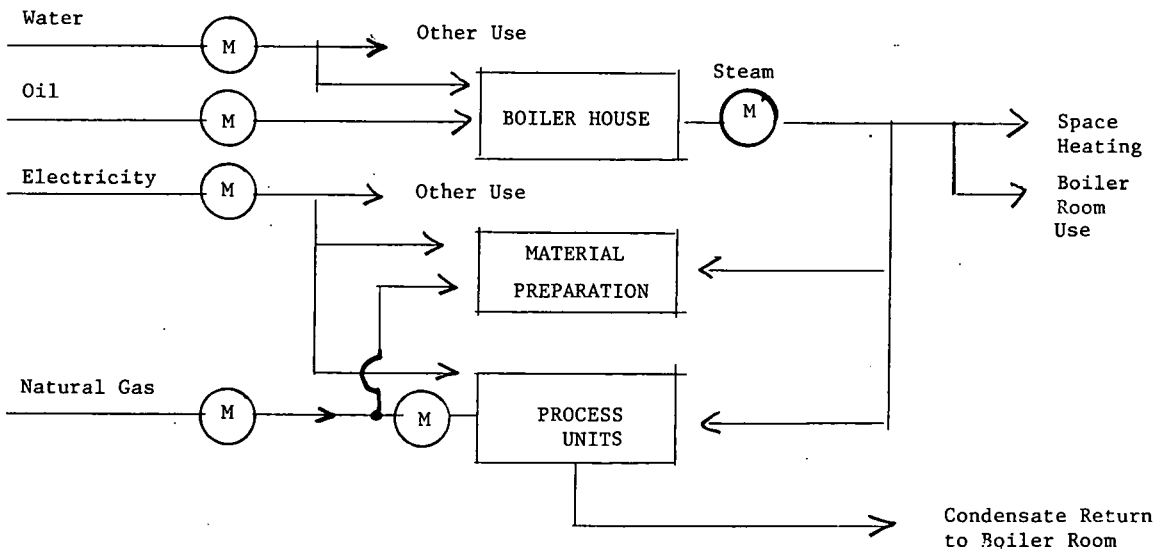
Figure 6



Energy content per unit of production = $\frac{\text{Energy input - Byproduct energy}}{\text{No. of units produced}}$

END USE SYSTEM

Figure 7



PRELIMINARY AUDIT OF A PLANT

Figure 8

Section V is the heart of the workshop. After tracing the flow of each fuel through a cost center to specific equipment, the concept of energy balance (Energy in = Useful Energy + Energy Waste) is introduced. The selection of data for an energy balance is discussed, as are battery limits, the estimation of losses, and how to conduct and analyze an energy balance and calculate system efficiency. The section concludes with participants conducting a detailed audit of a chemical plant.

In Section VI, the importance of conducting an energy balance is underscored by showing how it leads to the identification of specific equipment on which attention should be focused and how, in turn, a detailed analysis of this equipment will reveal specific energy conservation actions. Having deferred the industry-specific discussion of energy conservation opportunities from Section I it is integrated here in Section VI, with concentration on the opportunities available from the equipment, systems, and processes appropriate to the specific industry subgroup. The section is concluded with a discussion of how to calculate energy savings for any suggested improvement.

The remainder of the workshop deals with the techniques for conducting a cost-benefit analysis and how to establish a system of energy conservation maintenance and management control, and concludes with participants developing their own action plans and with the expectation that they will actively pursue the improvements to which they commit in those plans. Their success, failure, and areas in between will form the basis for Phase II of the workshop.

One might well ask, "How can such an ambitious agenda be fit into a two-day session?" The answer is: through judicious planning (which is not without its pitfalls), careful selection and prioritization of course material, and the selection of skillful workshop leaders who understand and are committed to fulfilling the workshop objectives. As difficult as it was to design such a complex modular structure spread across five industries and 10 groupings in those industries, the most difficult task was culling of the most pertinent and timely material from the great body of literature available, integrating it with substantial original work, and molding the composite, with due regard for the educational process, into a compact, workable, and meaningful curriculum. This involved an enormous expenditure of manhours in research, telephoning, conferring, writing and production. Some of the most useful materials were found to be the energy conservation self-study modules and case studies prepared under the aegis of MIT's Project PROCEED.

CONCLUSION

What is the current status of the program? After almost two years of planning, design and testing, the first workshop in the series has just now -- last week, in fact -- been held. The delay was caused by defects in the marketing plan and in its execution, which led to initial registration too low to justify holding the sessions. The importance of proper identification of the target audience, the construction of accurate lists, the development of an attractive and meaningful medium that clearly outlines the tangible benefits to be derived from the program, and a tested system for delivering that medium to the target audience cannot be stressed enough. Complementing the marketing effort must be a solid public relations campaign. The need for workshops of this type is evident, but without a system to "sell" them the best planned workshops will fail.

The industry-specific workshop is only one of many means available to encourage consumer adoption of energy-saving measures and renewable fuel technologies, and the variety between the means indicates that no single program or program approach is necessarily the best. In all probability, the best approach is a pool of programs from which to select the most appropriate one or ones for any given objective. Likewise, there is no one organization or agency that is the "best" delivery mechanism; each has its own characteristics and constituency. What is evident, however, is that qualified organizations in all sectors -- government, public, private -- have a continuing, legitimate role and a shared responsibility for energy education wherever their own unique capabilities can have the greatest impact. They can enhance those capabilities and achieve a degree of cohesiveness between each other's

programs by frequent and open communication among themselves and sharing resources and lessons learned. The professional society has a very distinct part to play in this process.

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OPTIMIZING THE MASS FLOW AND TEMPERATURE DIFFERENCE IN A COOLING SYSTEM FOR ENERGY CONSERVATION

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ABSTRACT

Conventional wisdom in recent times has been to raise the chilled water temperature to conserve chiller power. This is an effective and well-proven conservation strategy; however, it may be less optimal than other available alternatives. Reducing the fan speed and therefore the amount of circulating air in most cases is more energy efficient than raising the chilled water temperature. Either alternative is viable only if the system was originally over-designed or the refrigeration load has been reduced by alterations such as reduced illumination.

The removal of energy from a space or product is typically the function of a mass flow times a temperature difference. To reduce the rate of heat removal either the mass flow rate or temperature difference can be diminished. In most applications, greater energy savings are associated with reducing the mass flow rate. This is the result of the inefficiency associated with fans and pumps compared with the relatively good efficiency (C.O.P.) of a chiller. This paper develops an optimization strategy for specifying the mass rate and temperature difference for given heat loads to minimize energy consumption.

INTRODUCTION

Conventional wisdom has suggested to most building operators that raising the chilled water temperature would be a good energy conservation action. In fact, the U.S. Government has recommended this in their Emergency Building Temperature Regulation (EBTR) Compliance Guidelines for systems which simultaneously heat and cool. However, more energy savings may be accomplished in most cases by maintaining a lower chilled water temperature and reducing the air flow rate. The reason is that the auxiliaries (fans and pumps) consume more energy annually than the chiller in many medium to large-size buildings (over 80,000 square feet), and the fan and pump power is much more sensitive to flow rate than chiller power is to chilled water temperature. In many existing buildings cooling capacity can be reduced because of oversized equipment and/or energy conservation efforts which have reduced the peak loads. Slowing fan speed instead of raising chilled water to affect this capacity reduction could make a substantial impact on national energy consumption.

Operational parameters of heat exchangers are very significant in the overall energy efficiency of heating and air conditioning systems. For minimizing energy consumption in buildings there are optimum flow rates and temperatures for circulated air, chilled water, condenser water, and cooling tower air. This paper explores the potential for energy conservation in optimization of easily controllable heat exchanger parameters such as flow rates and temperatures.

The discussion is intended primarily for existing buildings; however, it implies that similar considerations would be useful in new design. Of course, in designing new systems there are many more variables, and this makes optimization vastly more complex. The point is that there is much to be gained by considering the transport energy cost associated with pumps and fans when computing the life cycle cost of a particular system design.

TECHNICAL DISCUSSION

Air conditioning of commercial buildings

typically requires heat exchangers from each of three categories.

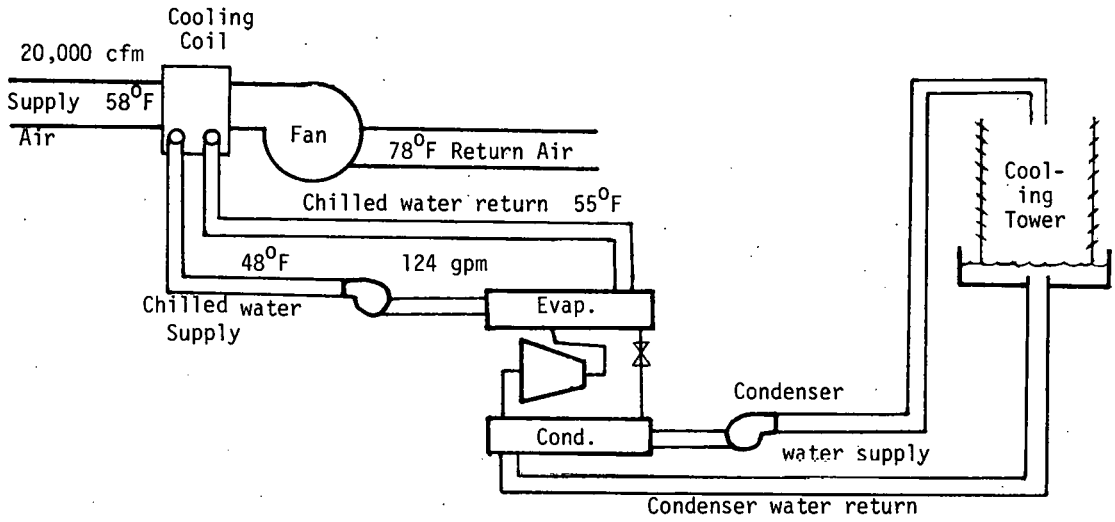
(1) There are air to water exchangers (fans and coil units) which transfer heat from circulated air into a chilled water loop.

(2) There are also exchangers which take the heat out of the chilled water by boiling a fluorocarbon refrigerant at a low temperature evaporator. Similar exchangers reject heat to cooling water by condensing the refrigerant at a higher temperature (condenser).

(3) Finally, the heat is rejected from the condenser water to the ambient air through an evaporative cooling tower.

A simplified energy balance for an air handler is shown in Figure 1. This simplified energy balance demonstrates the transfer of heat from the building space to the outside air. Good performance of these heat exchangers will reduce the temperature difference between the evaporator and condenser. For a given heat load the amount of work input to the refrigeration machine increases as the temperature difference between the evaporator and condenser increases. Therefore, it is desirable to have good heat exchanger performance, i.e., low temperature differential exchangers.

Heat exchanger "efficiency" is really a misnomer in that efficiency usually denotes a ratio



$$Q_{air} = Q_{water}$$

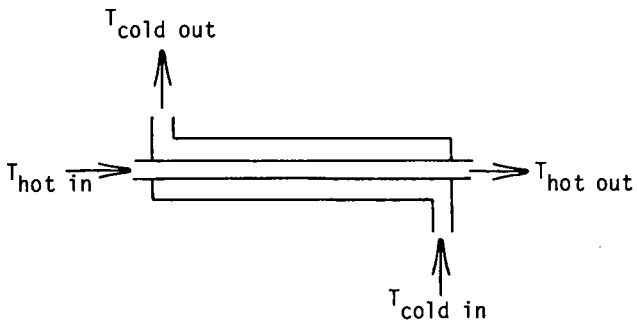
$$432{,}000 \quad Q_{air} = 20{,}000 \frac{ft^3}{min.} \times 60 \frac{min.}{hr.} \times .075 \frac{lb.}{ft^3} \times 0.24 \frac{BTU}{lb^oF} \times (78^oF - 58^oF)$$

$$432{,}260 \quad Q_{water} = 124 \frac{gal.}{min.} \times 60 \frac{min.}{hr.} \times 8.3 \frac{lb.}{gal.} \times 1.0 \frac{BTU}{lb^oF} \times (55^oF - 48^oF)$$

AIR HANDLER ENERGY BALANCE

FIGURE 1

of useful output to required input. For example, the efficiency of a heat engine is defined as the shaft energy output divided by the heat energy input. However, in a heat exchanger where a "hot" fluid transfers heat to a "cold" fluid, essentially all of the heat which leaves the hot fluid is transferred to the cold fluid regardless of the merits of the heat exchanger. At most, only a small fraction is lost or gained through the outer shell of the exchanger. A more appropriate method of rating heat exchanger performance is by effectiveness. Effectiveness, ε, is defined as the actual heat transfer divided by the maximum possible heat transfer for a given pair of streams. The mathematical expression for ε varies for different heat exchanger configurations. A counterflow exchanger is shown below as an example.



$$\varepsilon = \frac{m_{hot} c_{hot} (T_{hot\ in} - T_{hot\ out})}{(mc)_{min} (T_{hot\ in} - T_{cold\ in})}$$

Where:

- m = mass flow rate
- c = specific heat
- hot = hot fluid
- cold = cold fluid
- $(mc)_{min}$ = the lesser of $m_{hot} c_{hot}$ and $m_{cold} c_{cold}$

The actual hardware design of a heat exchanger is not the only factor that determines its performance in an installation. Other important factors are fluid properties (viscosity, specific heat, density), flow characteristics (velocity, laminar or turbulent flow, boundary layer thickness, entry lengths), and scaling conditions. The flow related factors are controllable to a large extent in that air and water flow rates can be changed. By adjusting the flow rates, the associated fan and pump power consumption will also be changed.

One might ask: if no energy is lost even in a poor heat exchanger, then why is it important to have a high effectiveness? The reason is that poor heat exchanger performance results in large temperature differences between the two streams, and large temperature differences adversely affect the thermodynamic efficiency of the refrigeration cycle.

A measure of refrigeration cycle efficiency is coefficient of performance (C.O.P.). It is defined as the ratio of energy removed from the conditioned space to energy required to drive the machine. The maximum theoretical coefficient of performance of a vapor compression refrigeration cycle can be expressed as a function of the condenser and evaporator temperatures.

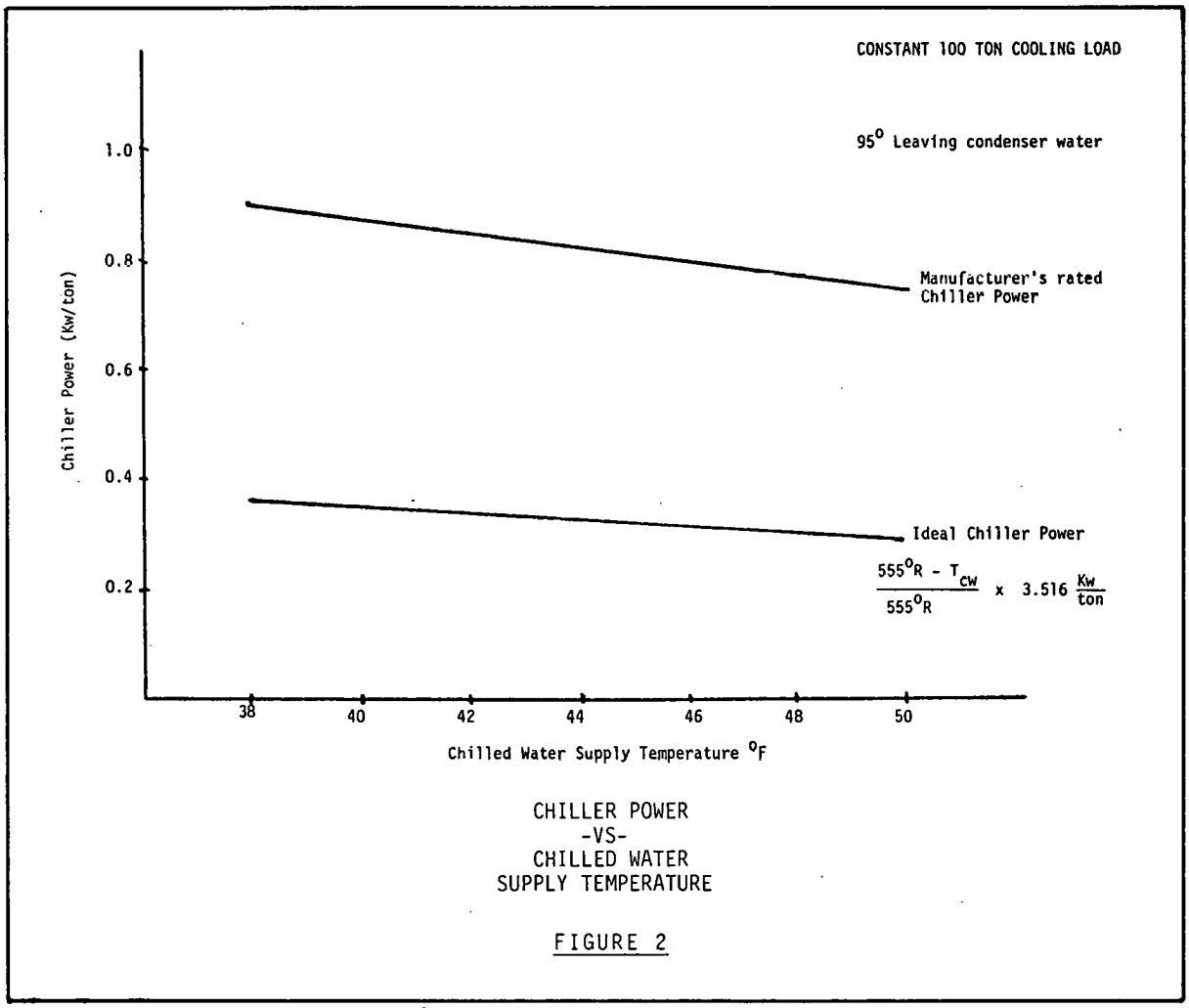
$$C.O.P._{ideal} = \frac{T_{cond}}{T_{cond} - T_{evap}}$$

Where:

- $C.O.P._{ideal}$ = the maximum possible coefficient of performance of a refrigeration cycle
- T_{cond} = the absolute temperature of the condenser
- T_{evap} = the absolute temperature of the evaporator

Figure 2 shows ideal refrigeration cycle performance over a typical chilled water temperature range. On the same graph is the actual performance of one manufacturer's refrigeration machine as a function of chilled water temperature at a constant condenser water temperature of 95° F. The curves predictably follow the same trend.

It is apparent from the figures that better chiller performance can be achieved by raising the chilled water temperature. A popular rule of thumb is that 1½% chiller power is saved for each 1° F temperature rise. Thus at first thought it would appear that this represents a good way to save energy under circumstances where reduced capacity



CHILLER POWER
-VS-
CHILLED WATER
SUPPLY TEMPERATURE

FIGURE 2

is of no consequence (reduced temperature difference between the conditioned space and the chilled water causes a corresponding decrease in capacity). But, to minimize the temperature difference across the chiller requires low temperature differences across all heat exchangers. This results in a trade-off between chiller power and fan power. High flow rates help reduce temperature differentials, but the problem is that fans require a large amount of power. In typical commercial buildings, the auxiliaries (fans and pumps) may consume more energy than the chiller. This is illustrated in the sample energy distribution in Table 1, which was derived from several Central Texas facilities our firm has analyzed.

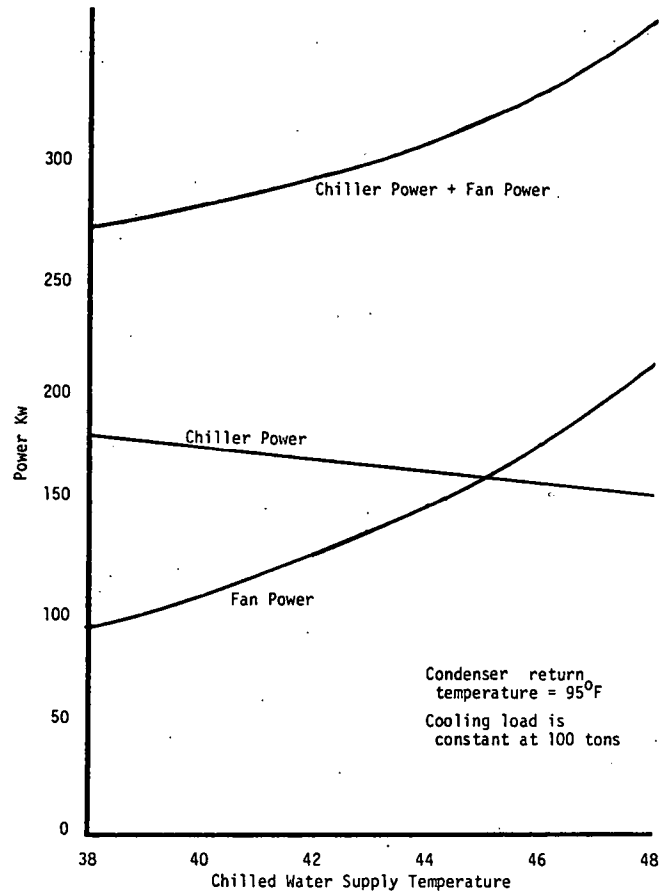
As can be seen from this limited data, the auxiliaries can consume a significant portion of the total annual electrical energy.

TABLE 1

PERCENTAGE OF ANNUAL ELECTRICAL ENERGY CONSUMPTION FOR TYPICAL MULTI-STORY OFFICE BUILDINGS

	Building A	Building B	Building C
Lighting	28	31	33
Chiller	29	25	29
Auxiliaries (fans & pumps)	37	39	34
Miscellaneous	6	5	4
Total square footage	104,000	95,000	91,000
Total No. of Floors	4	7	4

In Figure 3 the fan power and chiller power requirements are plotted for a constant 100-ton cooling load. The plot assumes a constant effectiveness of the chilled water coil and constant



CHILLER AND FAN POWER CONSUMPTION
-VS-
CHILLED WATER SUPPLY TEMPERATURE

FIGURE 3

condenser water temperature and neglects the potential for varying pump power requirements. The optimization of this simplified example is obtained by plotting the total power and determining a minimal point on the curve.

Note that while the chiller power appears almost linear over this temperature range, the fan power, being a function of the volume flow rate cubed, is quite steep. Thus, the sum of chiller and fan power is dominated by the fan power curve. The figure clearly indicates that reducing fan speed would be the most beneficial way to reduce capacity and energy consumption in this particular example. If a facility has excess capacity due to over-design or reduced internal load, a simple plot of the two most easily modified variables can provide valuable information in inexpensively retrofitting the facility. Slowing down the fans is usually as easy as changing the motor shieve. The chilled water can still be raised during light load conditions and even be put on a microprocesser controller or manually reset daily.

All variables should be considered in saving energy; lowering condenser water temperature provides a good opportunity to improve chiller performance. However, a minimum differential must be retained between chilled water and condenser water temperatures for proper operation and lubrication of centrifugal chillers.

The optimization of any system is dependent on the system components. All energy users need to be evaluated; not only the heat rejection equip-

ment, but the transport energy devices such as fans and pumps. Loads and energy consumption on chillers vary daily and seasonally in most cases; however, most pumps and fans are constant volume and have the same load all the time. New designs are frequently variable pumping and variable air volume systems. These systems should have control strategies and devices which properly utilize the flexibility of the components to minimize the transport energy requirements.

A simplified example of the magnitude of energy savings possible by reduced air volume and reduced chilled water temperature is shown in the following example.

Example

A 4-story building with 100,000 square feet has 25,000 square feet per floor; each floor has two air handlers with 20,000 cfm. The temperature and flow rates are the same as shown in Figure 1. The fans are operating at 6 $in._{WG}$ static pressure and therefore require 30 horsepower.

$$\text{Power} = \dot{V} \times \Delta \text{ pressure}$$

$$= 20{,}000 \frac{ft^3}{min} \times 6\ in._{WG} \times .03613 \frac{lb_f/in^2}{in._{WG}}$$

$$\times \frac{144\ in^2}{ft^2} \times \frac{HP\ min.}{33{,}000\ ft.\ lb_f}$$

$$= \frac{18.9\ HP}{.70\ \text{eff. fan} \times .9\ \text{eff. motor}}$$

$$= 30\ HP \times .746\ Kw/HP$$

$$\text{Power} = 22.38\ Kw$$

$\therefore$ for eight air handlers the power = 179.0 Kw

Assuming a C.O.P. equal to 3.0 for a water chiller, it will require

$$\frac{432{,}000\ BTU/hr \times 8\ A.H.U.}{3\ C.O.P.} = 1.152 \times 10^6 \frac{BTU}{hr.}$$

of electrical energy or 337 Kw.

The chiller peak load of 337 Kw will actually vary during the day and during the season to reflect an average 50 to 60 percent of peak load. Therefore,

337 Kw x .55 load factor = 185 Kw
average chiller power

If the fan speed were reduced 10%, the volume flow rate would be reduced 10% to 18,000 cfm. If no reduction in capacity could be tolerated to maintain the same heat removal, the supply air temperature would have to decrease 2.4° F; and, therefore, the chilled water temperature would also have to decrease.

The fan power is proportional to the volume flow rate cubed; thus a 10% reduction in volume yields a 27% reduction in power ($1^3 - .9^3 = 0.27$).

The chiller power increases $\approx$ 1.5% per degree F of chilled water temperature reduction.

$\therefore$ Fan power savings = 179 Kw x .27
= 48.33 Kw
Increase chiller power = 185 Kw x 2.4 x .015
= 6.6 Kw
Net savings = 41.73 Kw

Assuming an average distribution of power as shown in Table 2, the average demand would be 600 Kw and the net savings would be 41.7 Kw or approximately 7%.

TABLE 2

SAMPLE AVERAGE DEMAND DISTRIBUTION

Chiller	30%	185 Kw
Fans	30%	179 Kw
Lights	30%	179 Kw
Pumps & Misc.	10%	57 Kw
		600 Kw

To relate this example to dollar savings you need to assume total operating hours per year. If this facility operated 4,000 hours per year, the net savings would be approximately 166,800 Kwh, or $5,000 at $.03 per Kwh.

CONCLUSION

Chilled water temperature is easy to set in t applications, thereby making it cost effective to be reset seasonally; therefore, many have already begun to take advantage of this savings.

The success of many operators in raising the chilled water temperature demonstrates that many buildings were originally over-designed or that reduction of internal loads such as lighting have reduced the peak cooling demand. These buildings are usually excellent candidates for fan speed reduction. Fan speeds can be changed at relatively little cost by replacing the motor shieve and/or fan shaft shieve to achieve the desired speed ratio, and chilled water temperature can be varied to supply the needed capacity.

We recommend that, before modifying the chilled water temperature, a study be made to determine whether more energy could be saved by reducing air volume and lowering chilled water temperature. Measurements should be made to accurately determine the energy consumption of all major HVAC equipment. Then manufacturer's performance specifications can be used to predict energy consumption after any changes are made.

In new design projects, the designer should consider the sizing of piping, ducting, and equipment to minimize its life cycle cost of operation of not only heating and cooling equipment but also the associated transport energy devices.

INDUSTRIAL HVAC AIR-TO-AIR ENERGY RECOVERY RETROFIT ECONOMICS

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ABSTRACT

Retrofitting air-to-air energy recovery equipment is relatively simply to design and easy to install. Additionally, HVAC energy recovery is almost risk free when compared to process retrofit. Life cycle cost analysis is the best way to illustrate the economic attractiveness of retrofitting HVAC industrial energy recovery equipment.

HVAC air-to-air energy recovery applications are often overlooked for larger and more complicated process applications. Process applications however often require the need to design for corrosion, particulates, and condensibles in the heat exchanger. The result is that although the savings look attractive, the risk in reliably recovering process waste heat can often be substantial.

In contrast, retrofitting air-to-air energy recovery equipment to industrial heating and ventilating (HVAC) systems is relatively simply to design and install as well as being economically attractive. Typical industrial HVAC applications requiring substantial amounts of exhaust air which can benefit from the use of air-to-air energy recovery are:

Plant Heating and Ventilation
Laboratories and Test Facilities
Paint Spray and Welding Booths

Interest in energy recovery in many retrofit situations is not initiated solely on the basis of fuel savings. Relieving high negative building pressure can also be a significant factor. Often this negative pressure tends to increase as the building ages due to the ever increasing numbers of exhaust openings without the corresponding increase in the air handling unit supply volume. Negative building pressure results in employee discomfort due to drafts as well as causing higher heating bills.

In industrial HVAC applications up to 100,000 scfm, a factory built packaged energy recovery rooftop system is often the most cost effective means of retrofitting energy recovery. These units contain one of the four basic types of air-to-air heat exchangers used for HVAC applications: heat wheel, plate, heat pipe and coil loop.

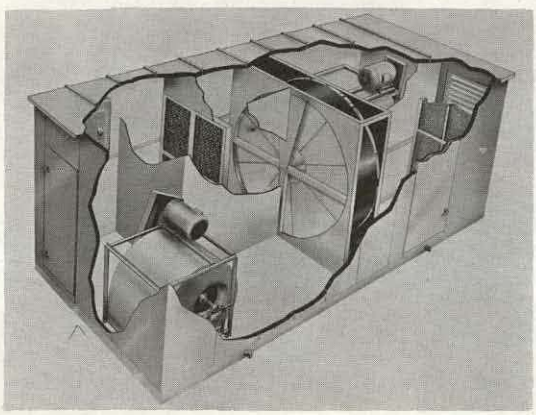


Figure 1: Wheel System

Fans, filters, heating coils, electrical wiring, and system controls can also be included in these exterior packages. Typical costs for a wheel system including a heat wheel, supply and exhaust fans, filters, and electrical wiring are shown in the graph below:

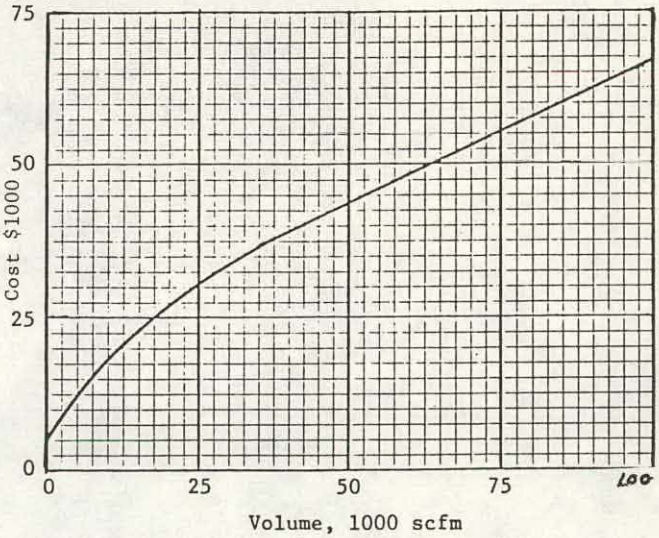


Chart 1: Wheel System Cost

Using the exterior energy recovery package, the plant engineer's task is reduced considerably. His prime concerns in the energy recovery retrofit project are providing adequate roof supports, lifting the unit into place, flashing the unit curbing into the roof, as well as making the ducting, plumbing and electrical connections. These responsibilities are usually sub-contracted to a local contractor with costs generally running approximately 50% of the energy recovery system cost.

Since the annual HVAC fuel savings utilizing an air-to-air exchanger depends on the climatic conditions of the plant location, the modified degree day procedure is used to approximate the annual heating savings.

STEP 1: The first step in these calculations is to determine the efficiency of the air-to-air exchanger from the manufacturer's published data. Shown below is the typical performance data for a heat wheel.

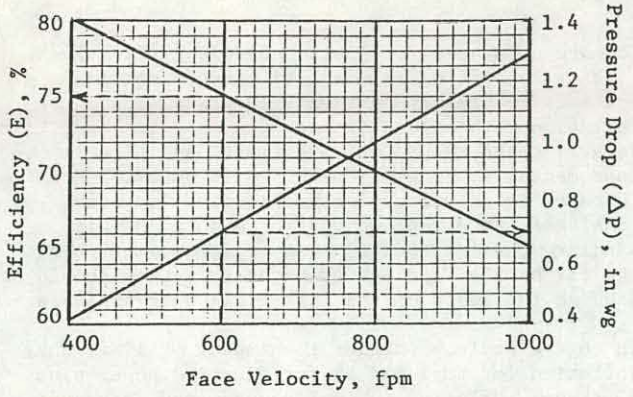


Chart 2: Wheel Efficiency & Pressure Drop

STEP 2: Based on the local winter design dry bulb temperature (T_1), the exhaust air temperature from the building (T_3), and the exchanger effectiveness (E), calculate the supply air temperature leaving the exchanger (T_2):

$$T_2 = T_1 + E\ (T_3 - T_1)$$

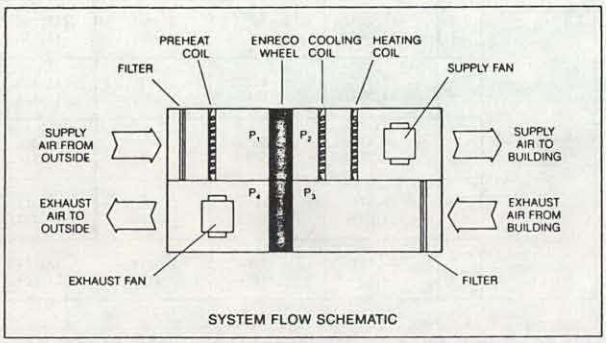


Figure 2: System Flow Schematic

STEP 3: Calculate the maximum hourly sensible heat (Q_s) in BTU/hr recovered and returned to the plant using the supply air volume (V_1) in scfm:

$$Q_s = 1.08\ (V_1)\ (T_2 - T_1)$$

STEP 4: Calculate the annual heating savings in dollars based on the ASHRAE modified degree day formula described in Chapter 43 of the 1976 ASHRAE Systems Handbook.

$$\text{Natural Gas Heat Annual Savings} = 0.000234 \times \frac{Q_s \times D \times C_D}{(T_3 - T_1)} \times h \times F$$

$$\text{\#2 Fuel Oil Heat Annual Savings} = 0.000259 \times \frac{Q_s \times D \times C_D}{(T_3 - T_1)} \times h \times F$$

where: Q_s = hourly energy recovered, BTU/hr
D = degree days
h = operating hours per week
F = fuel cost, $/1000 BTU
C_D = load correction factor

T_1	-20	-10	0	10	20	30
C_D	.57	.64	.71	.79	.89	.99

STEP 5: Calculate the additional fan power expense required to overcome the pressure drop across the air-to-air exchanger:

$$\text{Fan Power Annual Expense} = 0.00764 \times [(V_1)(\Delta P_1) + (V_3)(\Delta P_3)] \times h \times E$$

where: V_1 = supply volume, scfm
ΔP_1 = supply pressure drop across exchanger, in wg
V_3 = exhaust volume, scfm
ΔP_3 = exhaust pressure drop across exchanger in wg
h = hours per week the system operates
E = cost of electricity, $/KWH

STEP 6: Calculate the maintenance and insurance costs to operate the system. As a rule of thumb, annual maintenance and insurance costs can be estimated at 1 1/2% of installed equipment cost.

STEP 7: Calculate the net operating savings of the energy recovery system:

$$\text{Net Operating Savings} = \text{Fuel Savings} - \text{Electric Power} - \text{Maintenance \& Insurance}$$

For example a plant in Milwaukee is exhausting 19,000 scfm at 75°F on a 2 shift, 90 hr/week basis. The winter design conditions for Milwaukee are -4°F and 7,635 degree days. Current energy rates are $ .0393/KWH for electricity and $ 0.0055/1000 BTU for #2 fuel oil at 77¢/gallon. From Chart 1, the equipment cost is determined to be $26,000. Assuming a 50% additional cost for materials and installation, the installed equipment cost would be $39,000.

Using a nominally selected 600 fpm air-to-air exchanger from Chart 2 with a 75% effectiveness and 0.70 in wg pressure drop across the media, the net operating savings is calculated as follows:

T_2 = -4°F + 75% (75°F - (-4°F))

= 55°f

Q_s = 1.08 (19,000 scfm) (55°F - (-4°F))

= 1,210,680 BTU/hr

Oil Heat Annual Savings = 0.000259

$$\times \frac{(1{,}210{,}680 \text{ BTU/hr})\ (7{,}635 \text{ degree days})\ (.68)}{(75°F - (-4°F))}$$

x 90 hr/week x $0.0055

= $10,200/yr

Fan Power Annual Expense = 0.00764 x [(19,000 scfm) (0.70 in wg) + (19,000 scfm) (0.70 in wg)] x 90 hr/week x $\frac{\$0.0393}{KWH}$

= $718/year

Since the system operated only during the heating season, the fan power expense for 6 months would be:

$359

Maintenance & Insurance = ($26,000 + 13,000) x 1 1/2%

= $587/year

Net Operating Savings = $10,200 - $359 - $587

= $9,254/year

Historically to determine if this is a good investment, the simply payback technique would be used:

$$\text{Payback} = \frac{\text{Installed Equipment Cost}}{\text{Net Operating Savings}}$$

$$= \frac{\$39{,}000}{\$9{,}254/\text{year}}$$

= 4.2 years

Although a 4 year payback would be considered attractive, this analysis fails to consider inflation as well as the timing of cash flows. The significance of rising energy costs is illustrated in Chart 3. For example, if fuel escalates at 10% per year and the cost of capital is 15%, for every $1 of fuel saved toady, $9 can be expended for energy recovery equipment.

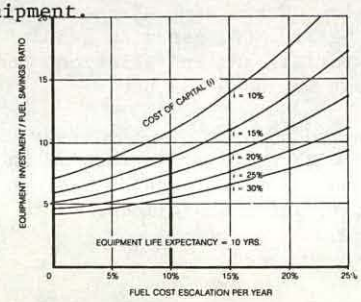


Chart 3: Energy Recovery Investment

To more accurately evaluate economic alternatives, life cycle costing is used. Life cycle costing combines the impact of fuel, electrical and labor inflation with taxes, depreciation and tax credits to determine the return on investment. Additionally an incremental costing approach should be used. For instance if an energy recovery system is being considered as a replacement for a worn out air handler, the incremental cost difference between a new air handler and energy recovery system should be used as the basis of the life cycle cost analysis.

In this example, consider the impact of 10% annual inflation for fuel and 8% for electric power plus 7% annual inflation for maintenance and insurance. For example, if the savings is $10,200 today, five years from now the savings will be $16,427 as a result of 10% annual inflation compounded over that period. Chart 4 also shows the effect of inflation on maintenance, insurance, and electric power.

Base Year Inflation Rate		Fuel Savings $10,200. 10%	Electric Power $ -359. 8%	Maintenance & Insurance $ -587. /%	Net Operating Savings	
Year	1	$11,220.	$ -388.	$ -628.	$10,204.	1
	2	12,342.	-419.	-672.	11,251.	2
	3	13,576.	-452.	-719.	12,405.	3
	4	14,934.	-488.	-769.	13,676.	4
	5	16,427.	-527.	-823.	15,076.	5
	6	18,070.	-570.	-881.	16,619.	6
	7	19,877.	-615.	-943.	18,319.	7
	8	21,865.	-664.	-1009.	20,192.	8
	9	24,051.	-718.	-1079.	22,254.	9
	10	26,456.	-775.	-1155.	24,526.	10

Chart 4: Incremental Operating Savings/Expenses

In addition to inflation, financial factors such as depreciation, taxes and tax credits must also be considered. These factors depend on the type of energy recovery application as shown in Chart 5

Application	Type Construction	Financial Consideration			
		Taxes	Depre-ciation	Investment Tax Credit	Energy Tax Credit
Commercial Industrial HVAC	Retrofit(1)	X	X		X
	New	X	X		
Gov't, Charitable Institution HVAC	Retrofit				
	New				
Industrial Process	Retrofit(1)	X	X	X	X
	New	X	X	X	

Note 1: HVAC systems and industrial processes existing prior to October 1, 1978.

Chart 5: Financial Considerations

The new Energy Tax Act of 1978 now permits a 10% energy tax credit for retrofitting energy recovery equipment to commercial or industrial HVAC systems as well as industrial processes existing prior to October 1, 1978. If the equipment is used in conjunction with a new or existing industrial proce: a 10% investment tax credit applies. Retrofit industrial processes are therefore entitled to a 20% total tax credit for application to processes existing

ior to October 1, 1978.

For industrial HVAC retrofit applications, income taxes must be paid on the net operating savings. The federal income tax rate for corporations is approximately 48%. Income taxes however are partially offset by depreciating the installed cost of the energy recovery system:

$$\text{Taxes} = \text{Tax Rate} \text{ (Net Operating Savings - Depreciation)}$$

Sum of the years digits depreciation can be used for energy recovery equipment, since it provides the earliest depreciation allowable by the Internal Revenue Service and consequently, a more attractive return on investment. Sum of the years digits is an accounting procedure whereby the number of useful years is totaled i.e. if the useful years is 3, the total would be 1 + 2 + 3 equals 6. The first year's depreciation would be 3/6, the second 2/6, and the third 1/6. This accelerates depreciation to the earlier years. Deducting taxes from the net operating savings, we obtain the net cash flow:

$$\text{Net Cash Flow} = \text{Net Operating Savings} - \text{Taxes}$$

For this industrial HVAC retrofit example, assume that a 48% tax rate applies and that the building existed prior to October 1, 1978 which entitles the project for an energy tax credit:

Year	Net Operating Savings	Sum of the Years-Digits Depreciation	Taxes @ 48%	Energy Tax Credit	Net Cash Flow	
Acquisition	$-39,000.	$ 3,545.	$ 1,702.	$ 3,900.	$-33,398.	
1	10,204.	6,736.	-1,665.		8,540.	1
2	11,251.	6,027.	-2,507.		8,744.	2
3	12,405.	5,318.	-3,402.		9,003.	3
4	13,676.	4,609.	-4,352.		9,324.	4
5	15,076.	3,900.	-5,365.		9,712.	5
6	16,619.	3,191.	-6,446.		10,174.	6
7	18,319.	2,482.	-7,602.		10,717.	7
8	20,192.	1,773.	-8,841.		11,351.	8
9	22,254.	1,064.	-10,171.		12,083.	9
10	24,526.	355.	-11,602.		12,924.	10

Chart 6: Tax and Depreciation Impact

For example in year 5 the net operating savings is $15,076 and equipment depreciation is $3,900. Taxes are calculated as 48% of $15,076 less the $3,900 depreciation which is $5,364. The net cash flow would then be the net operating savings of $15,076 less $5,364 in taxes which is $9,712. These same calculations are carried out for each of the 10 years.

Since the net cash flow will be occurring over a ten year period, it is necessary to consider the time value of money using present value analysis. Simply stated, $1 saved 10 years from now is worth considerably less than $1 in the pocket today. The reason being, that the $1 in hand today could be put in the bank at a compounded interest rate and be worth considerably more in ten years. The amount today's $1 is worth in the future depends on two things, the period of time and the interest rate. Conversely, $1 saved in the future, can be discounted to its present value in the same manner:

$$\text{Present Value} = \frac{\text{Future Value}}{(1 + i)^n}$$

where: i = annual interest rate
n = period in years

In this life cycle costing analysis, the annual interest rate (i) is really the after tax return on investment (ROI). Determining the ROI is a trial and error procedure, which equates the installed equipment cost to the sum of the present value of the net cash flow:

$$\text{Installed Equipment Cost} = \sum_{n=1}^{10} \frac{1}{(1 + i)^n}$$

For this example, assume (i) or (ROI) to be 25% and calculate the present value net cash flow:

Year	Present Value Net Cash Flow	$\frac{1}{(1+i)^n}$ i=25%	Future Value Net Cash Flow By Year (n) 1	2	3	4	5	6	7	8	9	10
Acquisition	$-33,398	1.0000										
1	6,832	0.8000	$8,540									
2	5,596	0.6400		$8,744								
3	4,610	0.5120			$9,003							
4	3,819	0.4096				$9,324						
5	3,182	0.3277					$9,712					
6	2,667	0.2621						$10,174				
7	2,248	0.2097							$10,717			
8	1,904	0.1678								$11,351		
9	1,622	0.1342									$12,083	
10	1,388	0.1074										$12,924
Sum of Present Value	$ 470											

Chart 7: Present Value Net Cash Flow

For example, in year 5 the net cash flow will be $9,712. Based on a 25% return on investment, the discount factor is 0.3277 for year 5. The future net cash flow of $9,712 is discounted to its present value by multiplying by 0.3277 which is $3,182. Each of the 10 years are discounted to their present value in the same manner. The sum of present values including the

acquisition in this case is $470. Since the sum is a relatively small positive number, the assumed 25% ROI is slightly lower than the actual. The exact ROI is reached when the sum equals zero.

In this case the after tax return on investment (ROI) is slightly over 25%. Whether or not the ROI is an attractive investment, is determined by the individual company's expected return on its capital. Typical returns on capital for various industries are shown below:

Industry	Industry Median
Personal Products	13.6%
Aerospace & Defense	11.2%
Information Processing	11.2%
Leisure	12.4%
Health Care	13.6%
Electronics & Electrical Equipment	11.6%
Energy	11.3%
Wholesalers	12.5%
Chemicals	11.3%
Construction - Contractors	11.0%
Industrial Equipment	12.0%
Forest Products & Packaging	10.4%
Utilities - Natural Gas	7.7%
Food & Drink	10.5%
Finance - Insurance	13.2%
Automotive	10.0%
Finance - Consumer Finance	7.9%
Supermarkets	8.8%
Multicompanies - Conglomerates	8.8%
Multicompanies - Multi-Industry	9.7%
Household Products	9.2%
Retail Distribution	9.4%
Finance - Banks	10.4%
Construction - Building Materials	8.7%
Utilities - Electric & Telephone	6.2%
Transportation - Surface	6.5%
Metals	7.5%
Steel	8.4%
Apparel	8.7%
Transportation - Air	5.9%
All Industry Medians	10.2%

Source: Forbes Magazine, January 8, 1979

Chart 8: Typical Returns after Tax on Total Capital

One other factor must be considered to determine whether or not the ROI is attractive, and that is risk. The actual after tax ROI's shown in Chart 8 include risk, or in other words, the end result of projects which succeeded and others which failed. As discussed in the beginning of this article, retrofitting air-to-air energy recovery to industrial heating and ventilationg (HVAC) systems is relatively simple to design and install. As a result, the typical minimum after tax ROI for HVAC energy recovery projects is in the 15% range.

In this example, a 25% after tax return would be considered a very attractive return on investment for any industry. In addition to a 25% ROI, the qualitative benefits can be equally as important. For instance relieving high negative building pressure can improve productivity by eliminating employee discomfort due to drafts.

Fuel curtailments are another important consideration If shortages, curtailments or quotas for fuels occur, reduced consumption obtained through the use of an HVAC air-to-air exchanger can be the difference between operating, curtailing or shutting down a plant. In some cases HVAC energy recovery may be the only means of overcoming the fuel allocation limit in a plant expansion.

Retrofitting air-to-air exchangers in industrial HVAC applications is a sound economic decision, and life cycle costing is the best means of proving that point.

"PLANT-WIDE ENERGY-CONSERVATION PROGRAM YIELDS IMPRESSIVE RESULTS"

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Teledyne Continental Motors
Muskegon, Michigan

Alan J. Zupko, P.E.
Roy F. Weston, Inc.
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ABSTRACT

Teledyne Continental Motors, Industrial Products Division (IPD), presently has 752,300 square feet of manufacturing area located on 59 acres in downtown Muskegon, Michigan. Fifty percent of the buildings were constructed between 1917 and 1921, with the balance built between 1941 and 1968. Extensive machining and assembly facilities are located there for the production of a variety of water-cooled, internal combustion engines.

In September of 1977, IPD retained Roy F. Weston, Inc. to provide an in-depth survey of energy use at the facility with the specific objective of recommending cost-effective means of reducing energy costs to augment Teledyne's ongoing conservation efforts. Boiler operations, steam distribution and condensate return systems, heating and air conditioning systems, building shell, and other available opportunities for energy usage reduction were evaluated.

By a series of process changes, HVAC revisions, and other cost-effective conservation measures, Teledyne has reduced energy consumption by 380,000 MBtu per year, a decrease of 65 percent based upon 1974 consumption. Energy savings coupled with reduced associated fixed costs are equivalent to a total cost avoidance of over $1,200,000.

This paper presents the results of Weston's energy survey and system designs, Teledyne's progressive implementation of energy conservation techniques, and actual plant performance to date in achieving energy savings.

BACKGROUND

Teledyne Continental Motors, Industrial Products Division (TCM-IPD) presently occupies 59 acres in downtown Muskegon, Michigan with 752,300 square feet of manufacturing area. Approximately 50 percent of the existing buildings are saw-tooth roof construction, built between 1917 and 1921; the remaining facilities were constructed piecemeal fashion between 1941 and 1968. Extensive machining and assembly facilities are located at IPD for the production of a wide variety of water-cooled internal combustion engines.

Energy conservation became the "watch word" at IPD as a spin-off of a plant consolidation program begun in 1974. A shortage of space at that time led to the relocation of a major product line and left plant management with an oversized facility for the remaining products and support services. Given the opportunity to assess these facilities, plant engineers realized that they were dealing with old buildings, outdated equipment, and deteriorating utilities services. An immediate program was undertaken to reduce the size of the facilities by internal rearrangements, sale, and demolition and to improve the efficiency and flexibility of the remaining production and support services. Between 1976 and 1979: 370,000 square feet were sold for urban renewal projects; 71,840 square feet were demolished; and 79,000 square feet were abandoned in place. In addition, 12 major production operations and office areas were relocated to increase productivity.

PROGRAM

The reduced, streamlined facility led to an examination of the utilities systems in 1976 with particular emphasis on the power house. Built originally in 1920, the power house consisted of eight coal-fired boilers with a combined steaming capacity of 700,000 pounds per hour. Until 1964, it generated electric power for the IPD facility. Two boilers, each rated at 90,000 pounds per hour of steam, had previously been converted to natural gas firing in 1970. In 1976, these two units alone provided space heating and process steam for the entire facility.

In the summer months, only one boiler was operated at approximately 15-percent capacity in order to supply the process steam requirements.

During the winter of 1976-1977, IPD's limited non-space heating demands were converted to other energy sources and processes modified to improve energy efficiency. Electric or gas heating units were installed at 22 locations for parts washing, derusting, plating, and metal treating. Complete conversion to ambient temperature metal treating solutions was not successful; however, some solutions were changed and temperatures as low as 80°F proved satisfactory. Separate domestic hot water heaters in 20 plant locations eliminated a wasteful central hot water system. These modifications have eliminated the need to operate the central boiler(s) and the deteriorated steam distribution/condensate return systems during the summer months since 1977 and have saved approximately 70,000 MBtu (1) annually.

In September 1977, IPD retained Roy F. Weston, Inc. of West Chester, Pennsylvania to provide an in-depth survey of energy usage and efficiency at the Muskegon facility. Boiler operations, steam distribution, condensate systems, HVAC requirements, building shell and other available opportunities for reducing energy needs were evaluated on technical and economic merits. A central objective of the study was a detailed analysis of the plant heating systems considering the following conditions:

- Peak steam requirements had been reduced to less than 50 percent of the capacity of a single boiler.
- Much of the steam and condensate systems were 60 years old, had been extensively patched, and in many areas were deteriorated beyond the point of cost-effective repair.
- Five central steam-coil fan rooms served the saw-tooth building sections, and individual unit space heaters supplied the balance.
- Temperature control was attempted by varying steam supply pressure up to a maximum of 5 psig or manually starting/stopping the fan room blowers.
- Shop space temperatures at the work level varied between 60° and 85°F during the heating season, and opening windows was a common practice to provide some comfort control and air balancing.

Three options were defined as cost-effective alternatives to the existing heating systems. Table 1 shows that the first option involved abandoning the existing field-erected boilers and installing new dual-fuel, packaged boilers. Improved condensate return, thermostatic heater controls, off-hour set-back, and fan room drive changes completed this alternative. Savings of $365,000 per year (120,000 MBtu per year) were estimated to pay back the required capital of $593,000 in 1.6 years. This alternative had the advantages of fuel supply stability due to the oil-gas firing option and elimination of the operation and maintenance for an outdated power house. However, the disadvantages were keeping the existing stream distribution, heaters, and fan rooms in service with their maintenance and reliability problems.

TABLE 1

HEATING SYSTEM - OPTION NO. 1

Description	Energy Savings $/year	Capital $	Payback years
Thermostatic Heater Control and Automatic Set-Back	215,000	198,000	0.9
Install Package Boilers and Abandon Existing Power House	110,000	290,000	2.6
Return Fan Room Condensate	29,000	65,000	2.2
Change Fan Room Drivers	11,000	40,000	3.6
TOTAL	$365,000	$593,000	1.6

The second option, presented in Table 2, involved upgrading plant heating and condensate systems and retaining the existing power house and steam distribution network. This alternative was estimated to save $255,000 per year (122,000 MBtu per year) and pay back the required capital of $303,000 in about 1.2 years. The advantages of lower capital requirements, rapid implementation, and improved boiler efficiency were offset by the high maintenance, labor costs, and reliability problems already experienced in the existing power house and steam distribution facilities.

TABLE 2

HEATING SYSTEM - OPTION NO. 2

Description	Energy Savings $/year	Capital $	Payback years
Thermostatic Heater Control and Automatic Set-Back	215,000	198,000	0.9
Return Fan Room Condensate	29,000	65,000	2.2
Change Fan Room Drives	11,000	40,000	3.6
TOTAL	$255,000	$303,000	1.2

Table 3 shows that the third option involved, abandoning the existing power house, steam distribution and condensate systems, and the fan room/unit

(1) MBtu equals millions of BTu's.

heaters and installing infra-red heaters. This alternative was estimated to save about $435,000 per year (143,000 MBtu per year) with a capital requirement of $517,000 paid back in 1.2 years.

TABLE 3

HEATING SYSTEM - OPTION NO. 3

Description	Energy Savings $/year	Capital $	Payback years
Install Infra-Red System and Abandon Existing Power House and Auxiliary Facilities	435,000	517,000	1.2

This option had one major uncertainty to resolve, i.e., the status of a reliable, economic supply of natural gas for the infra-red heaters. Michigan Consolidated Gas Company, supplier of natural gas to IPD, assured plant management that no curtailments were anticipated in this area and that industrial space heating priorities were ranked quite high in their allocation program. With these problems resolved, IPD management chose to install the infra-red heating system in April 1978.

It was decided to embark on an expedited schedule to design and install the system and avoid use of the old power house during the 1978-79 heating season. In order to meet the tight schedule, IPD authorized Weston to proceed with design while the scope and engineering costs were being refined. The implementation schedule for the fast-track project was:

Milestone	Schedule
Decision to Proceed	24 April 1978
Design	1 May to 14 July 1978
Contractor Bid and Review	July 1978
Contract Award	August 1978
Installation	August to November 1978
Operation	November 1978

In making its decision, IPD management and Weston realized that this would be the largest radiant heating system installed as a single package in the United States to date. The system comprised the following elements:

Number of Units	Energy Source	Capacity per Unit Btu per hour	Type
375	Natural Gas	125,000	Panelbloc Low Intensity
15	Natural Gas	63,000	Panelbloc Low Intensity
30	Natural Gas	30,000	Re-Verber-Ray High Intensity
12	Electric	24-34,000	ILG (Carrier Corp.)

The Panelbloc heaters were manufactured by the Bettcher Manufacturing Corp. and the Re-Verber-Ray heaters were manufactured by Detroit Radiant Products. In addition, a new natural gas supply and distribution system was installed. The heating system has 39 individual zones, each with a time clock to schedule the temperature set-back and an employee override switch to accommodate overtime activities. The thermostats are mounted 10 feet from floor level to shield them from direct radiated heat, prevent tampering, and minimize damage. It was decided to utilize individual, local controls rather than a centralized management system in light of the tight implementation schedule. However, both IPD and Weston concluded that, had additional construction time been available, microprocessor type mini-control systems would have been both practical and economical.

Venting individual heaters, where necessary, was accomplished by permanently closing selected skylights and replacing panes of glass with prefabricated ducts designed to fit the angled window frames. Metalbestos stacks with Breidert caps were passed through these ducts and rain shields attached.

The successful completion of this project was the result of very close coordination and cooperation among IPD plant engineering, Phoenix Contracting, Bettcher Manufacturing, and Weston. Detailed construction planning successfully avoided delays and interference with on-going manufacturing operations. Employee acceptance was high after initial pessimism. Drafts were eliminated, machines and floors warm, and a fairly uniform shop temperature maintained. In a few locations where operations are less physically demanding or near frequently used doors or poorly sealed windows, the thermostats were slightly raised above the 65°F norm. Negative pressure in the plant drew outside air into the shop through the now abandoned central heating system via make-up air vents. The buildings have been substantially sealed to eliminate these problems, and additional energy savings as well as improved working conditions have resulted.

Actual project completion for the new heating system was October 1978 at a total cost of $625,000. The increase in actual investment over that projected was due to a combination of factors: original estimate of $517,000 was based on mid-1977 dollars; four percent increase in heated area; premium (overtime) labor costs for early completion, etc. Actual savings for the 1978-79 heating season were 129,000 MBtu of natural

gas; at an average cost of $2.27 per MBtu, this was equivalent to $293,000. Electrical savings from abandoning the power house were offset by the additional motor load for compressed air due to the loss of a steam turbine driven compressor. Salary and related cost savings of $160,000 were realized since the power house was manned around the clock. Therefore, total savings of $453,000 per year were realized from this project.

Weston's energy survey of plant facilities also yielded conservation opportunities as shown in Table 4.

TABLE 4

ADDITIONAL ENERGY CONSERVATION OPPORTUNITIES

Description	Energy Savings $/year	Capital $	Payback years
Insulate Windows in Walls	28,000	29,000	1.0
Insulate Roof Glass	146,000	333,000	2.3
Insulate Walls of Main Buildings	15,000	38,000	2.5
Install Weather Stripping	4,600	500	0.1
Modify Paint Booth Air Systems	1,900	7,500	3.9

The generous payback estimated for insulating windows, walls, and roof sections led to a detailed investigation of roofing systems. Test sections of urethane foam insulation were applied in 1978; and in 1979, 127,300 square feet of roof area were coated with one inch of urethane and 3M Scotch Clad Roof Coating, resulting in an overall R-value of 8.7. Extensive leaking and deterioration were halted, and energy savings of 14,800 MBtu per year are expected. It is important to note that energy savings for this roofing system would have been substantially greater had there still been a conventional heating system in the shop with its inherent stratification.

Small projects when grouped together can have a significant impact on energy conservation. At the Muskegon IPD plant, the following low cost improvements have been accomplished during the past five years:

- Over 1,600 linear feet of deteriorated industrial window sash have been replaced. While insulation of these areas was not judged cost effective, savings are accrued by eliminating air infiltration.
- Covering the windows of a temporary office area with insulation eliminated the need for an additional 5 tons of air conditioning with negligible lighting load increase.
- Use of economizer cycles for air conditioned spaces reduced annual cooling requirements and eliminated air balancing problems.
- Steam loads were reduced prior to heating system and process changes by installing improved boiler control systems and initiating operator training programs.
- When rebuilding heat treating equipment, ceramic fiber insulation was used, yielding reduced heat losses and faster warm-up times.
- Two motor-generator sets providing 110 VDC and 220 VDC power were eliminated and local rectifiers used for machine controls and other direct current uses.
- Loading docks have been fitted with inflatable dock seals and air locks to accommodate full-size trailers.
- A 3 percent reduction in electric power was effected through an employee awareness program. This provided the requested reduction during a 1978 temporary power shortage.

RESULTS

An impressive and consistent reduction in energy usage at IPD in Muskegon, Michigan is shown in Table 5 from 1974 through 1979, and projected for 1980. It is important to note that production levels were approximately equal in 1974 and 1978 and higher in 1979. In 1979, energy consumption was 205,086 MBtu compared to the 1974 total of 584,644 MBtu - a reduction of 65 percent. Unfortunately, the rising costs of energy have outstripped these savings. From 1974 to 1979, the unit costs for electric power and natural gas have risen 48 and 350 percent, respectively, for this plant.

Comparing 1974 to 1979, energy savings in terms of cost avoidance were $1,018,900 per year. This savings is based upon the difference between 1974 energy consumption at 1979 unit energy costs versus actual 1979 energy consumption at unit energy costs for 1979. This method balances the effects of energy price increases and energy consumption decreases from a base year at equivalent production rates. Additional savings from decreased labor, improved maintenance, reduced taxes and insurance, etc. (i.e., non-energy related costs or fixed expenses) for 1979 are $192,000. Therefore, total cost avoidance for 1979 is $1,210,900.

TABLE 5

ANNUAL ENERGY CONSUMPTION - IPD (Muskegon, MI)

Year	Electric Power MBtu	Natural Gas MBtu	Total MBtu	Percent Reduction (1974 Basis)
1974	72,560	512,084	584,644	0
1975	56,636	401,775	458,411	21.6
1976	49,837	391,900	441,737	24.4
1977(1)	53,944	317,570	371,514	36.5
1978(2)	57,512	222,430	279,942	52.1
1979(2)	61,571	143,515	205,086	64.9
1980(3)	68,240	134,030	202,270	65.4

(1) Summer boiler shut-down initiated in 1977.

(2) Infra-red heating installed prior to 1978-79 heating season.

(3) Projected.

SOLAR ROOF COOLING BY EVAPORATION

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ABSTRACT

Evaporation is nature's way of cooling. By spraying a light film of water in the form of a mist for thirty seconds, then turning the sprays off for five minutes while evaporation takes place, the roof temperature can be reduced from 165° to 88°. Roof air conditioning load is reduced by 85% to 90%. The cooler roof also protects and extends roof life.

My presentation today will cover an old, old technique -- one that has been gaining in prominence in recent years, due to the energy shortage and the increased cost of electricity -- Solar Roof Cooling by Evaporation.

Evaporation is nature's way of cooling. When we get overheated, we perspire, and as the perspiration evaporates, our body is cooled. The same principle applies in cooling the roof of a building by spraying a thin film of water in the form of a mist on the roof of a building for 15 to 30 seconds, then turning the sprays off for three to six minutes while the evaporative process takes place. Results -- the roof temperature is reduced from as high as 165° to 88°. This reduces the roof air-conditioning load 85% to 90%, and at the same time completely eliminates the radiant heat.

Now, let's take a look at some basic facts -- as a gallon of water evaporates, it will absorb 8,652 Btu of heat; thus, we can see that a gallon and a half of water will provide the equivalent cooling effect of a ton of air conditioning.

As we reduce the roof temperature from 165° to 88°, the under-roof temperature is reduced from 120° to 84°. Thus, the roof air-conditioning load is virtually eliminated.

Now before we go any further, I want to mention the cost of a solar roof cooling system. Depending on the conditions, of course, the cost will run between 28¢ and 35¢ per square foot, and generally speaking, it will show a payback of 18 to 24 months. As one plant manager said, "I pay more than that each year, just to sweep my floors."

While my presentation today will be primarily with air-conditioned buildings. it is well to keep in mind that dramatic comfort cooling can also be realized in non air-conditioned buildings by completely eliminating the radiant heat. The human body, at 98°, absorbs radiant heat from the hot underside of a dry roof when the roof exceeds 98°. At 120° under-roof temperature, the radiation of the long-wavelength heat showers down upon the personnel and produces heat stress that is so detrimental to men and materials. When, however, the under-roof temperature is 84° to 86°, the radiant effect is reversed and absorbs heat from the workers and materials within the building, and for all practical purposes becomes a giant cooling panel. This condition occurs in both air-conditioned and non air-conditioned buildings.

Let's now take a look at where the major applications of evaporative roof cooling make sense.

1. Older buildings dating back to the 1960's and before. On these we find little or no insulation.
2. Expanded buildings. Many applications of solar roof cooling have been made where buildings have been expanded or new equipment added and the air-conditioning equipment

ment is insufficient to meet design criteria.

3. And finally, on New construction. With "U" factor of .10 and below, substantial savings in original air-conditioning cost can be achieved, plus lower energy usage.

Over a period of the last forty years, hundreds of articles have appeared in publications explaining solar evaporative roof cooling. Such publications include Heating, Piping and Air Conditioning, Plant Engineering, Architectural Forum, Industrial Maintenance etc., to mention only a few.

NORTH CAROLINA STATE UNIVERSITY published a 28-page Bulletin entitled "A Report on Sprayed Roof Cooling Systems" in 1958, primarily keyed to the Textile Industry. Copies of this are available upon request.

In 1940, the AMERICAN SOCIETY OF HEATING AND AIR CONDITIONING ENGINEERS ran extensive tests on the heat penetration into the building of a dry roof versus a sprinkled roof. The results were subsequently published in the Guide and Data Book, which is the heating and air-conditioning engineers' bible. They found that at 3:00 p.m. in the afternoon, 18 Btu per square foot per hour was penetrating into the building with a dry roof. When the roof was sprayed with a light film of water, it was found that only 1 Btu penetrated into the building. Thus, the roof load was virtually eliminated.

Another thing I want to emphasize in this slide is that the dry roof continues to pour heat into the building until 11:30 p.m., due to the build-up and retention of heat in the roof long after the sun has gone down. Note that the sprayed roof crossed the zero point of heat penetration at 6:00 p.m., a savings of five and one-half hours of air-nditioning roof load time, and this is particularly important when your plant is on a two or three-shift operation.

Generally speaking, the roof is divided into zones with each zone a maximum of 10,000 square feet. Each zone is controlled by a low voltage solenoid valve which is activated by a master control. A thermostat, which is imbedded in the roof in Zone 1, energizes the controller when the roof temperature reaches 90°. If you have this picture in your mind, we now go into the sequence of operation. The master control has timers for the days of the week, the hours of the day, and a series of cam timers that control the solenoid valves in each zone. The sequence of operation is as follows:

> The controller is energized at 8:00 o'clock in the morning and set to turn off at 6:00 o'clock in the evening. When the temperature on the roof in the morning reaches 90°, the controller is activated and Zone 1 sprays for a period of 10 to 30 seconds, then turns off as Zone 2 comes on. This sequence follows until all zones have been sprayed, at which time the cycling starts over again if the thermostat is again calling for cooling.

The major reason for laying the system out in zones is that we can reduce the gallons per minute required and the psi necessary to get adequate coverage. If we take, for example, a 100,000 square foot building, we would divide this up into 10 zones of 10,000 square feet each, which would require 45 Gpm at 50 psi at roof level to assure adequate coverage for the zones sprayed. Incidentally, an ordinary garden sprinkler will put as much water on the roof in fifteen minutes as a properly engineered evaporating cool system will use in a day.

In the past, attempts were made to use

spray nozzles, but it was found that the tiny serrations in the spray head, which were necessary to put a minimum amount of water on the roof, clogged up and required flushing out about every two weeks. A number of years ago, a method of machine piercing the copper tubing was developed. The piercing produced a diamond-shaped opening in the copper tubing and this created a rapidly diverging fan-shaped spray that turns into a mist after it leaves the tubing. The copper tubing is pierced at 10:00 o'clock and 2:00 o'clock thirty inches apart.

A word of caution in selecting an evaporative roof cooling system for your plant: While PVC has many excellent applications, it should not be used where it is continuously exposed to the sun's ultra-violet rays and extremes of heat and cold. We tried it many years ago, with near disastrous consequences.

Let's take a look at how we figure the roof load reduction using evaporative roof cooling:

We have a 100,000 square foot building, built up tar and gravel roof with 1" of insulation, .23 "U" factor, located in the south, with 2200 hours of annual air-conditioning usage. The electric rate is 5¢ per KW. This is an average, using direct energy cost and peak demand charge cost. Water cost is 50¢ per 1000 gallons.

Dry Roof - 100,000 sq. ft. X (140^{0} average roof temperature - 78^{0} inside temperature) 62^{0} = 6,200,000 X .23 "U" factor = 1,426,000 ÷ 12,000 (ton of AC) = 119 tons dry roof load.

Evaporative Cooled Roof - 100,000 sq. ft. X (88^{0} - 78^{0}) 10^{0} = 1,000,000 X .23 "U" factor = 230,000 ÷ 12,000 = 19 tons sprayed roof.

Savings -- 119 tons (Dry Roof) - 19 tons (Sprayed Roof) = Savings of 100 tons = 1 ton per 1,000 sq. ft.

KW & Dollar Savings - 100 tons X 1.5 KWH per ton = 150 KW X 2200 hours = 330,000 KWA X 5¢ per KWH = $16,500 energy savings.

Water Cost - 100,000 sq. ft. X .015 gal. per hr. sq. ft. = 150 gallons X 2200 hours = 4,200,000 gallons annual usage X 50¢ per 1000 gallons = $2,100 annual water cost.

Summary of Savings = $16,500 (Energy Savings) - $2,100 (Water Cost) = Savings of $14,400.

Thus, with a cost of $30,000 for a Solar Roof Cooling System, and $14,400 in annual savings, the payback would be 25 months. If waste water is available, the payback would be reduced to 22 months, and if the plant is on a two-shift operation, the air conditioning hours would be increased to 2900 hours for a payback of 17 months.

These paybacks are well below the Industry standards of 36 to 42 months for energy conservation.

Let's turn now to some actual installations and the results: This slide is of an 84,000 square foot textile plant in South Carolina, and the installation was not completed until early October so that we were unable to get a test on energy reduction. However, it was noticed that the air conditioning came on at 2:30 p.m. on the day before the roof sprays were activated. The outside temperature was only 71^{0}, the roof temperature had risen to 117^{0}, and the inside plant temperature was 80^{0}; thus, the air conditioning came on.

The evaporative roof cooling system was turned on the next day at 10:30 a.m. to check it out and adjust the sprays and timing. At 2:30 p.m. temperatures were again checked, and it was found then that the outdoor temperature was 75^{0} (some 4^{0} higher than the pre-

vious day), with the roof temperature holding at 78°, and inside plant temperature was 76°. The air conditioning never came on the entire day. Conclusion -- Solar roof cooling, by eliminating roof load in spring and fall, can cut air-conditioning run time, even in normally non air-conditioning weather.

Let's look at another installation. An evaporative roof cooling system was installed last spring on a portion of this plant. Immediately adjacent was another building that was an exact duplicate, both having been built at the same time. At 2:15 p.m. on August 5, tests were conducted by the plant engineer and SOUTH CAROLINA ELECTRIC AND GAS COMPANY engineers. The outdoor ambient temperature was 87°, with a wet bulb of 71°. The dry roof temperature was 154° whereas the sprayed roof was only 86°. Under-roof temperatures were then taken, and it was found that under the dry roof, the temperature was 117° but was only 85° under the sprayed roof. The engineers then went one step further and covered the thermometer probe with a dark material to determine the radiant heat. The inside temperature of the plant was at 76° at working level. The thermometer rose to 83° in the dry roof area whereas the sprayed area only went up to 78°. It was assumed that the 2° heat rise in the sprayed area was due to radiation from inside the plant. The 5° differential (83° - 78°) under the dry roof was assumed to be coming from the roof. Taking it a step further, from a comfort standpoint the thermostat could be set at 81° and still maintain the same relative worker comfort.

And finally, let's look at one more plant, located in Clearwater, Florida. Tests were conducted by the corporate energy engineers out of Connecticut, and the results were furnished to us together with their compilations of the energy savings. Thirty days before the solar roof cooling system was installed, a tape recording ammeter was installed on the chiller, and the run time was recorded. A daily check was made of the outside temperature and humidity, and this was also recorded.

The results, with an average outside temperature of 87.4°, showed a chiller average run time of 85.7% during the thirty-day period. On September 6, the roof sprays were activated and again monitored for thirty days. The average outdoor temperature was 86.2°; however, the chiller only ran 58.8% of the time, for a reduction of 31.4%! This exceeded the original estimate of energy savings which had been calculated at 24%. An Energy Release Bulletin was sent out to over 100 plant managers in the company to immediately investigate the potential savings by installing a solar roof cooling system on their plants.

Another important plus in evaporative roof cooling is roof protection. By holding the temperature to a maximum of 88°, as opposed to 170°, expansion and contraction is virtually eliminated. The volatile oils retain their plasticity and will not boil out and become hard and brittle. I am sure you have seen blisters or bubbles on the roof of a building such as shown here. This can be attributed directly to the high summer-time temperature.

This plant in Forest City, Arkansas was built in 1964 and incorporated solar roof cooling in its original design. Not only did they eliminate 250 tons of air conditioning on this 244,000 square foot plant, but in addition, the roof is laying as smoothly as the

day it was installed. In sixteen years they have had no leaks or problems with their roof. The plant engineer stated that he attributes the condition of the roof to the Roof Spray system.

A properly engineered evaporative roof cooling system will only spray about 10 ounces of water per 100 square feet every 6 minutes. This light film of water is completely evaporated and will not produce ponding or water runoff.

How about water? Virtually any water can be used as long as it is relatively clean. Water from ponds, rivers, waste water from condensors and air compressors, wells, and of course city water can be used. In about 50% of the installations, waste water has been available, and this eliminates water cost. A solar roof cooling system will use about 150 gallons of water per day for 1,000 square feet of roof surface. Even with city water, at 80¢ per 1,000 gallons, the cost will usually run less than 10% of the savings in electrical cost.

I want to mention two other ancillary benefits that are inherent in an evaporative roof cooling system.

1. The controller is equipped with a manual fire switch that overrides the thermostat and sprays the roof continuously in the event of a fire.
2. The copper tubing serves as an excellent lightning arrestor.

Finally, maintenance is negligible as mechanically very little can go wrong. The non-clogging features of the spray openings in the pipe are self-cleaning, and the low voltage solenoid valves have a life expectancy of a minimum of ten years.

As W. O. Kind, P.E., of I.T.T., said in an article that appeared in Heating, Piping and Air Conditioning,

> "The type of spray selected was one consisting of pierced pipe, for which the manufacturer claimed no cleaning would be necessary. This turned out to be the case; in four years of operation, no time has been spent in cleaning."

For the winter months, we provide drain valves at the end of each lateral, and also drains at low points in the main lines. Our experience has shown that a 100,000 square foot building can be completely winterized by one man in about three hours. The same would go for the start-up in the spring.

To summarize, evaporative solar roof cooling has been used successfully here in the United States for over forty-five years, and it is now assuming its rightful place in the field of industrial air conditioning and comfort cooling.

Roof air-conditioning loads can be reduced by an average of one ton of air conditioning per thousand square feet of roof surface.

Average payback of a solar roof cooling system usually runs between 18 and 24 months -- well below the industrial average of 36 to 42 months.

Radiant heat is totally eliminated as the under roof is converted to a giant cooling panel.

Roof life is extended and maintenance is reduced by holding the temperature to a cool 88^{0} versus a hot 165^{0}.

Finally, the system will provide fire protection and a lightning arrestor.

In closing, I quote the comment from a plant manager upon seeing the results of a solar roof cooling system on his plant, "Pat. you have reinvented the wheel."

HIGH-TEMPERATURE HEAT-RECOVERY SYSTEMS USING CERAMIC RECUPERATORS

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ABSTRACT

Ceramic shell and tube recuperators capable of providing up to 1800°F (980°C) preheated combustion air and operating at process gas inlet temperatures of up to 2800°F (1540°C) have shown themselves to be cost effective waste heat recovery devices. Full utilization of the heat recovered by such ceramic recuperators requires burners designed to accept combustion air preheated to recuperator design levels and economical high temperature ducting. Energy savings, product development, and maintenance experience on installations in the steel forging industry are discussed. Packaged furnace systems and non-forging applications of such recuperators are discussed.

1.0 RECUPERATIVE HEAT RECOVERY SYSTEMS

Frequently more than 60% of the total energy input to a high temperature furnace is wasted up the stack. The largest single improvement that can be made in such high temperature processes is to reduce the amount of energy lost in furnace exhaust gases.

Hague International specializes in high temperature energy conservation hardware for fossil fuel fired processes. In 1973 a local forge shop asked Hague to examine their operation and suggest practical steps they could take to reduce their fuel costs. Recuperative waste heat recovery was clearly desirable. Since forging furnace stack gases are normally about 2500°F (1370°C), Hague decided to use a ceramic rather than a metallic recuperator. This decision was made in part to obviate the necessity for dilution fans and dilution controls.

Eliminating dilution fans and dilution controls from a waste heat recovery system provides two advantages.

First, dilution of process gas entering the heat exchanger limits the fuel savings possible by recuperation. The increase in heat transfer area made possible by the use of cheaper metallic materials does not compensate for the decreased fuel savings resulting from the increased dilution required to prevent process gas inlet temperatures from exceeding the temperature limits of the metallic materials. No increase in heat exchanger effectiveness makes up for the need to increase dilution air (Reference 1).

Second, dilution fans and dilution controls present operational and maintenance problems. A single temperature excursion due to malfunction of a blower or control can result in severe damage to or the destruction of a metallic recuperator.

When designing a recuperator for forge furnace application, Hague discovered that no appropriate ceramic tubes could be purchased. Hague began an intensive development effort that resulted in ceramic heat exchanger tubes manufactured by Hague International of a proprietary silicon carbide material.

In 1974 Hague had an operational recuperator. The CERHX® ceramic heat exchanger consists of ceramic tubes mounted in an insulated steel frame. The CERHX® accepts undiluted process gas at temperatures up to 2800°F (1540°C) and provides air preheated to 1800°F (980°C).

When recuperator design tests first began providing combustion air preheated to temperatures of 1200°F (650°C) and above, it became quickly evident that conventional hot air burners were at best marginally adequate in terms of their ability to interface with the CERHX® in high temperature applications. Hague developed the Transjet® burner, which has high temperature ceramic parts, to accept combustion air preheated to the temperature levels that the CERHX® can provide.

To take the preheated combustion air from the hot air header of the recuperator to the burners, Hague

developed a light weight ceramic lined steel ducting. This shop prefabricated pipe comes in spools that weld and bolt together, minimizing the time needed for field erection.

At approximately the same time, Hague developed a closed loop oxygen sensing fuel/air ratio trim controller. This device keeps combustion conditions close to stoichiometric by compensating for naturally occurring variations in fuel temperature, pressure, specific gravity, and calorific value, as well as naturally occurring variations in air temperature, barometric pressure, and humidity. These factors cause excess air variations that frequently run to 10% daily and 25% seasonally.

The recuperator, burner, ducting, and controls have been assembled into retrofit packages suitable for application on high temperature fuel fired furnaces. These retrofit packages have been in commercial operation since the middle of 1978. The technology of the retrofit packages has been incorporated, along with other design innovations, into new design high performance slot and box furnaces for forging. Such furnaces have been in commercial operation since the middle of 1979. As of this writing there are a dozen commercial installations incorporating these high temperature technologies.

2.0 THE CERHX® RECUPERATOR

A typical CERHX® recuperator consists of five components (Figure 1):

(a) two rows of smooth walled tubes and their ceramic adapters;

(b) three rows of finned tubes and their ceramic adapters;

(c) a cold air header;

(d) a hot air header; and

(e) an insulated structural steel frame.

2.1 The Tubes

The smooth walled tubes are high temperature screen tubes that can look directly at a flame or radiant heat load. Two rows of smooth tubes are used for these applications with heavy radiative heat loads on the recuperator and process gas inlet temperatures over 2000°F (1093°C). These smooth tube rows are nearest the furnace.

Behind the rows of smooth-walled tubes are rows of finned tubes. The finned tubes accept high temperature gases carrying heat by convection. These tubes are 48 inches (122 cm.) long, including the ends. Each finned tube has approximately 10 square feet (.93 square meters) of exterior surface area. The fins increase the efficiency of heat transfer b increasing the surface area of each tube. The insi-- of each tube has a 1.5 inch (3.8 cm.) diameter flow channel. Both ends of the tube are ball and socket jointed.

The tubes mate with ceramic adapters at both the cold air header and the hot air header end.

2.2 The Tube String, Cold Air Header, and Hot Air Header

The tube string (consisting of the cold end adapter, the tube, and the hot end adapter) is spring loaded. The springs, which provide compression loading for thermal expansion and maintenance purposes, are located at the cold air header end of the recuperator. High temperature gaskets are sandwiched between the tubes and the ceramic adapters. This spring loaded ball and socket design reduces overall leakage to less than 2% when the recuperator is used with a single stage blower at 28" of water (6,970 newtons per square meter). The tubes themselves accept internal pressures in excess of 120 psig (8.44 kilograms/cm^2).

The cold end ceramic adapters support the tubes and insure uniform spacing between the rows of tubes. The tube end of the ceramic adapter forms one end of the ball and socket joint with the tube. The adapter also provides insulation (a refractory wall protecting the metal inlet and outlet tubes). The gaskets insure that there is a good seal in the ball and socket joints.

The hot air header assembly consists of a hot air plenum (Figure 1). The hot air plenum is where the air from the individual tubes is collected before being ducted to the burners.

2.3 The Structural Steel Frame

The recuperator's structural steel frame is lined with ceramic insulation. The frame holds the cold air header, the preload spring assembly, the ceramic adapters, the ceramic tubes and the hot air header in place. When mounted on top of a furnace so that the tubes are horizontal, the standard recuperator is 31" (7.9 cm.) high and 130" (330 cm.) long. If overhead space restrictions are severe, the recuperators can be mounted on transition pieces attached to the side of a furnace. The width of the recuperator will vary depending on the number of tubes needed to accommodate a specified thermal input.

CROSS SECTION OF CERHX® CERAMIC RECUPERATOR

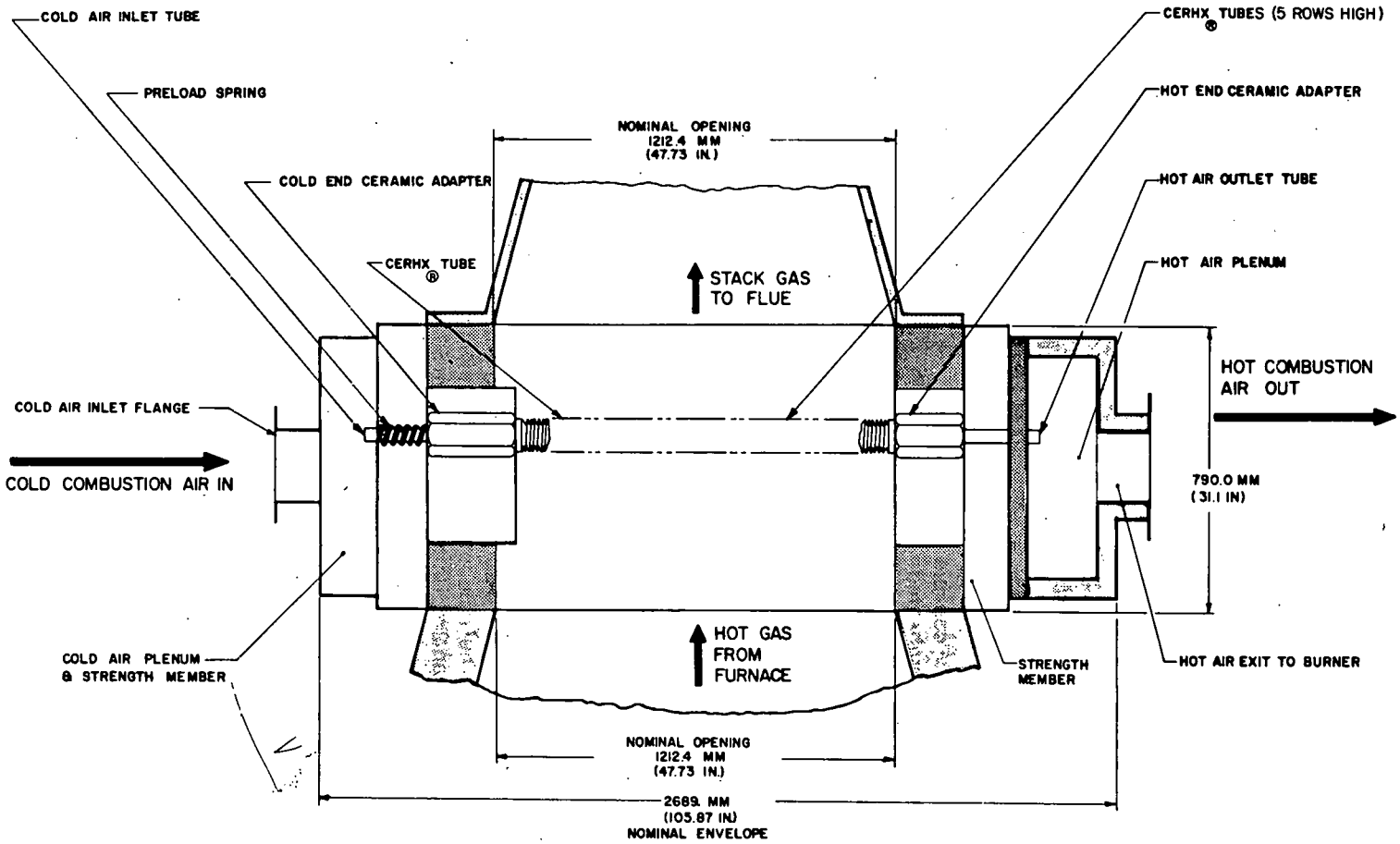


FIGURE 1

HAGUE INTERNATIONAL
3 ADAMS STREET
SOUTH PORTLAND, MAINE 04106
207/799-1580 207/799-7347

2.4 Operation of the CERHX® Recuperator

The CERHX® recuperator is a single pass shell and tube heat exchanger. It has no moving parts and no mortared joints.

Ambient air is blown in the cold air inlet flange, through the cold air plenum and through the CERHX® tubes (Figure 1).

Hot gases from the furnace flow around the outside of the ceramic tubes, heating the cold air inside the tubes. The air in the tubes passes through the hot end ceramic adapters and through the hot air outlet tubes. The preheated combustion air from each tube is gathered in the hot air plenum, and is then ducted to the burner(s) by insulated hot air ducting.

Standard recuperators have a ΔP on the gas (flue) side of approximately .3 inches of water (75 newtons per square meter) and a ΔP on the air side (through the tube) of approximately 3.15 inches of water (785 newtons per square meter).

The CERHX® tubes exhibit good resistance to thermal shock. Unloaded furnaces equipped with CERHX® recuperators are commonly brought to forging temperature (approximately 2350°F; 1290°C) in less than an hour, without adversely affecting the thermal or mechanical characteristics of the tubes.

3.0 THE TRANSJET® COMBUSTOR

The Hague International Transjet® combustor is a low emissions, recirculating burner, rated for use with combustion air preheated up to 1800°F (980°C). The Transjet® has internal parts made of high temperature ceramic.

The Transjet® recirculates hot gases from the furnace cavity back into the flame zone. This results in an extremely clean burning, highly radiant flame. The Transjet® produces little smoke and low levels of emissions. No external ducts or blowers are required for recirculation: the entire process is contained within the burner.

The Transjet® burns a variety of fuels including natural gas, light oils, heavy oils, and coal/oil mixtures (Reference 2). To change the burner's fuel configuration requires changing the burner core. This procedure can be accomplished in a matter of minutes.

4.0 HIGH PERFORMANCE FURNACES

The recuperators, burners, ducting, and controls that constitute retrofit systems have been incorporated into new design high performance slot and box furnaces for forging. These complete furnace packages incorporate a number of other design innovations.

The furnace walls are made of light weight castable insulation with a thermal mass about half th of conventional brick lining. The use of low thermal mass insulation diminishes the amount of fuel required to bring the furnace chamber up to temperature by reducing the amount of heat absorbed by the furnace walls. The exterior wall temperature of Hague furnaces is generally lower than that of conventional furnaces. As well as saving some fuel, this makes them more comfortable to work around.

The entire furnace is enclosed in and supported by a cold structural steel frame. This frame fixes the relationship between base, wall, and roof. The cold frame construction facilitates interior maintenance as the walls and roof can be individually removed and recast.

The high performance slot-forge furnaces have improved door closures. These closures can reduce overall heat loss by as much as 10% on a slot forge furnace.

Hague's high performance furnaces come prepiped and prewired and are skid mounted for quick installation.

Conventional fuel fired slot forge furnaces, operated according to best industry practice, require on average at least 3,000 Btu per lb. (6.98×10^6 joules per kg.) to bring carbon steel to forging temperature. Most furnaces actually use at least 4,000 Btu/lb. (9.3×10^6 joules per kg.). Hague's high performance furnaces, in commercial operation since the summer of 1979, have demonstrated their ability to bring steel to forging temperature at rates of 1000 Btu/lb (2.33×10^6 joules per kg.) and less.

5.0 INSTALLATION HISTORY

5.1 Retrofit Packages

The first commercial applications of Hague's energy conservation systems were retrofits on box furnaces. At the Clinton, Wisconsin plant of the Scot Forge Company an energy conservation system with an 8 MMBtu/hour (2,345 kw) installed burner capacity was retrofitted onto a box furnace in June, 1978. The external dimensions of the furnace were 21 feet (6.4 m) long; 13 feet (3.96 m) wide; and 9 feet (2.74 m) high.

Robert Ploog of Scot Forge made base case measurements of energy consumption over a six month period from December, 1977 through May, 1978. Pl reported that the average fuel consumption for the

furnace before retrofitting was 3.4 cubic feet of natural gas per pound of steel processed (3,400 Btu/); 7.9 x 10^6 joules/kg) (Reference 1). From June through November, 1978, after the installation of the retrofit package, fuel consumption was reduced to 2 cubic feet of natural gas per pound of steel processed (2,000 Btu/lb; 4.66 x 10^6 joules/kg). This represents a fuel reduction of 40% (Reference 1).

In December, 1978 a drop in combustion air temperature and increase in the time required to bring the normal 40,000 pound (18,145 kg) charge of billets to heat were noted. These billets usually were brought to heat in 5-6 hours and then soaked prior to forging. On a normally scheduled weekend shutdown, the system was examined. Hague technicians discovered that four tubes in the first row of the recuperator had cracked. The failed tubes were removed and the tube sheets were fitted with ceramic plugs to prevent the loss of combustion air into the furnace cavity. The furnace continued to operate without appreciable change in performance. No unscheduled downtime occurred. At a convenient time, the furnace was shut down and the lower course of tubes replaced.

The removal and replacement of the first row of tubes in a CERHX® recuperator can be accomplished in less than a day after the recuperator is cool enough to work on. Maintenance of the recuperator and burner's ceramic parts, including the cost of labor, equals 5-10% of the annual fuel savings.

The experience at Scot Forge led to the development of the smooth walled tube to provide a radiation shield for the recuperator. In April of 1979, the new recuperators were placed on the Scot retrofit, and in June of 1979 the first row of finned tubes was replaced with smooth walled tubes. From June of 1979 to the time of this writing (April, 1980), there has been no significant maintenance required.

Energy conservation packages incorporating the CERHX® recuperator and Transjet® burner have been placed on carbottom furnaces and ladle preheaters as well as box furnaces. These packages have ranged in size from 4 MMBtu/hour to 15 MMBtu/hour (1,170 kilowatts to 4,400 kilowatts).

5.2 High Performance Forging Furnaces

High performance slot forge furnaces have been in commercial operation since the summer of 1979. A high performance box furnace incorporating similar fuel saving features is currently being installed.

In November 1979, a slot forge furnace with an installed burner capacity of 4 MMBtu/hour (1,170 kilowatts) was placed at the Tube Turns Division of Chemetron Corporation in Louisville, Kentucky.

The United States Department of Energy is funding a six month demonstration program on this furnace to augment data previously gathered on the performance of Hague International's energy efficient slot forge furnaces. The Hague furnace at Tube Turns has been fully instrumented to measure temperatures, pressures, fuel flow rates, stack oxygen levels, and whether or not the slot is open. In parallel, a nearby conventional furnace has been monitored for fuel flow rates. The amount of fuel each furnace requires to process a mass unit of steel to heat has been calculated.

Preliminary data indicate that the conventional furnace requires 3,122 Btu per pound (7.26 x 10^6 joules per kg), and the Hague furnace requires 775 Btu per pound (1.8 x 10^6 joules per kg). These early data indicate that the Hague furnace uses approximately 25% of the fuel required by the conventional forging furnace.

6.0 ECONOMICS AND PAYBACK

Forge furnace retrofit systems reduce fuel consumption an average of 40%; high performance slot forge furnaces reduce fuel consumption an average of 60% compared to conventional, non-recuperated furnaces.

Paybacks average two years and under. Payback will depend upon system performance parameters, base energy costs, steel throughput, hours of operation per week, and weeks of operation per year. Fully detailed return on investment and payback schedules taking into account investment tax credits, energy saving tax credits, a conservative estimate of energy cost inflation, general inflation and realistic maintenance cost expectations are computed for each installation from after tax cash flows using double declining balance depreciation.

7.0 OTHER APPLICATIONS

Hague International is now completing preliminary evaluations of waste heat recovery systems based on the CERHX® recuperator in a variety of nonferrous applications. An installation on an aluminum remelt furnace is pending; applications on glass melting furnaces are being evaluated; and research and development efforts on exhaust fired gas turbine cycles incorporating modified CERHX® recuperators continue. Multi-pass, high pressure, and high

temperature recuperator programs are currently in progress.

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INDUSTRIAL WASTE-HEAT RECOVREY

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ABSTRACT

One hundred fifty reports were reviewed along with interviews of some twelve recuperator manufacturers and research organizations. Of the reports reviewed, the consensus was that the majority of recuperators used in the U.S. are constructed of 300 and 400 series stainless steels which generally limit the recuperator temperatures to less than 1300°F. After reviewing the literature and from our discussions with recuperator manufacturers and research organizations, a general conclusion was that the upper material temperature limit of 1500°F is state-of-the-art for recuperators operating in an oxidizing environment produced by the combustion of Diesel No. 2.

A full size counter axial flow metal heat exchanger test module has successfully completed 50 test hours with exit temperatures of 1650°F and firing temperatures of 2050°F. Performance monitored during the tests was well within predicted limits. Less than 5°F circumferential temperature gradients were measured in the axial flow section of the test module. Also, reduction in thermal gradients across tube to header connection was achieved.

Nine materials were tested in a 1700°F environment produced by the combustion of natural gas and Diesel No. 2 and also subjected to furnace oxidation tests. On the basis of these tests, promising heat exchanger tube alloys were identified.

Eighteen materials, coated and uncoated, were tested in a water economizer environment below the acid dewpoint temperature produced by the combustion of natural gas and Diesel No. 2. On the basis of these tests, promising low temperature heat exchanger tube alloys and coated surfaces were identified.

INTROUCTION

Recovering waste heat from the flue gases of gas-fired industrial proceses and using this energy in the process or for other industrial applications can significantly conserve gas. In many cases waste-heat recovery systems cannot be economically justified because of high hardware costs associated with technical limitations such as:

- Limited temperature of outlet air in pre-heating systems
- Corrosion limits in low temperature water/ heating systems
- Corrosion limits of process or standby alternate fuel contaminants at high temperatures
- Limited flexibility of many devices and systems in all temperature ranges to fouling and corrosion from process contaminants

Solar Turbines International (STI) proposes to reduce the above limitations by examining the technological advantages of an axial counter flow recuperator.

Program Objectives

Greater conservation of gas through application of advanced technology heat recovery techniques is the primary objective. Specific objectives are delineated below:

- Provide a comprehensive literature and industry survey of heat recovery devices in the low, medium and high temperature ranges. The objective of this assessment will be to determine the current state-of-the-art and advancements that could be anticipated in the near term through application of advanced technology.
- To identify critical technology problems limiting application of more extensive use of heat recovery devices.
- Based on recommendations obtained in the above critical technology assessment, develop plans for experimental and/or analytical evaluations to resolve technology road blocks.
- To improve methods of industrial heat recovery.
- To develop advanced production recuperators for waste heat recovery
- To work with the users of this equipment in subsequent years to implement this technology

in gas conserving applications.

Recuperator Concept

The recuperator design being advanced by this work combines the advantages of a pure axial-counterflow tube bundle and a cross flow tube bundle. The design is shown conceptually in Figure 1. This design uses a finned crossflow tube bundle in the low temperature region to increase overall compactness of the unit and uses bare tubes orientated parallel to the flow in the high temperature regions.

After comparing cross flow configurations (with horizontal tubes) to axial flow geometries the following reasons are presented for the selection of a vertical axial flow configuration for the recuperators' hot end.

- Reduces material's maximum-mean temperature variation; therefore, allows the unit to increase its maximum operating temperature.
- Pure axial flow eliminates circumferential thermal gradients and strain caused by crossflow.
- Minimizes large tube temperature variations between tubes connected to the same header.
- Reduces bending stress in tubes caused by tube weight over a long horizontal span.
- Reduces bending stress in tubes caused by aerodynamic loading of tubes (in crossflow configuration)
- Has potential of reducing fouling accumulation due to lower catch efficiency and self washing flow. The deposition will also be more symmetrical preventing "insulation" by deposits and consequent tube buckling.

The purpose of this design is to allow the recovery and delivery of the highest quality gases that is possible with a metal recuperator. The axial-counterflow section of the recuperator reduces tube stress in an area where, due to the high material temperatures, small thermally and mechanically induced stresses in structural components may add up to present a serious problem when operating at or near the unit's maximum capability. Also, since the purpose of this design is to allow the use of metal components at or near their maximum thermal capability, it is essential to minimize thermal excursions from the mean maximum material operating temperature.

As shown in Figure 1, the hot gases must flow into the tube bundle at the recuperator's hot end. This flow will contain a small crossflow component. To reduce its influence on tube material temperature

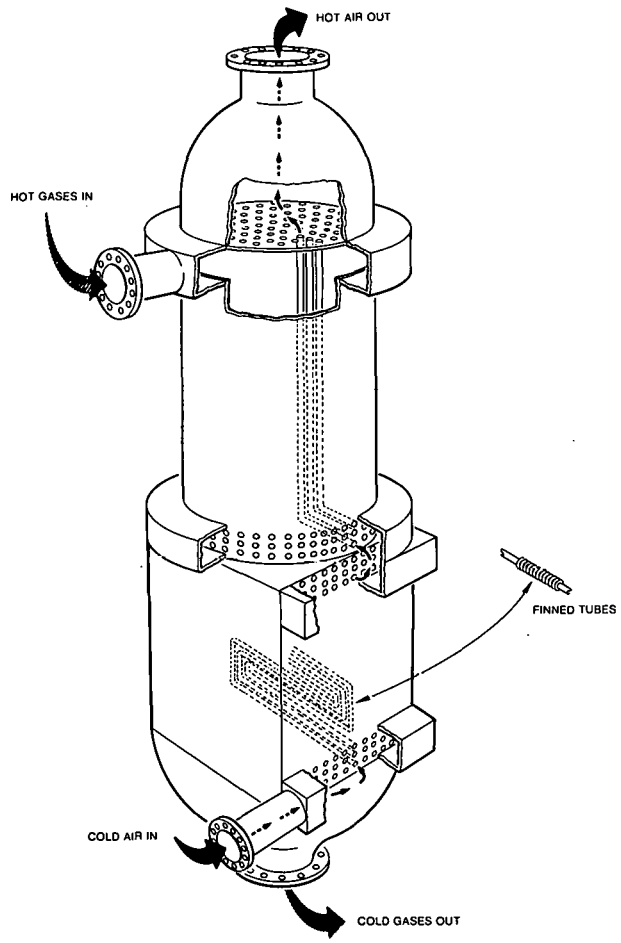


Fig. 1. High Temperature Recuperator

variation in this entrance region, individual tube shields may be required depending on manufacturing and cost design requirements.

TECHNICAL PROGRESS

The work completed towards the advancement of high temperature waste heat recovery equipment; industrial demonstration of a full size high temperature recuperator and commercialization included:

- Analysis of present recuperator state-of-the-art
- Critical design evaluations for high temperature heat recovery
- Environmental rig material/fuel interaction evaluation
- Low temperature critical experiments

Present Recuperator State-of-the-Art

One hundred fifty reports were reviewed along with interviews of some twelve recuperator manufacturers and research organizations. Of the reports reviewed, consensus was that the majority of recuperators used in the U.S. are constructed of 300 and

400 series stainless steels which generally limit the recuperator temperature to less than 1300°F.

r reviewing the literature and from our talks with the organizations interviewed, it was concluded that the upper limit for a recuperator operating in an oxidizing environment produced by the combustion of Diesel No. 2, was 1500°F.

Critical Design Evaluations for High Temperature Heat Recovery

The full size counter axial flow metal recuperator test module, as shown in Figure 2, has successfully completed 50 test hours with exit temperatures of 1650°F and firing temperatures up to 2000°F. Performance monitored during the tests was well within predicted limits. Less than 5°F circumferential temperature gradients were measured in the axial flow section of the test module with slightly higher gradients directly downstream of the hot header (Fig. 3). This increase in circumferential temperature gradient was a result of the small cross-flow component of the hot gases as the hot gas flowed around the header into the axial flow section of the test module.

An attempt to reduce circumferential temperature gradients directly downstream of the hot header was accomplished.

A 50 percent reduction was achieved by encompassing an instrumented section of tube #1 directly downstream of the hot header with a metal shield (Fig. 4). The shield reduced force convection heat transfer directly onto the tube. Free convection and radiation became the primary mode of energy transfer between the shield and the tube. Without the shield, the geometric orientation of the tube to the shell walls resulted in circumferentially maldistributed radiant heat transfer between the tube bundle and the shell. With the shield, the radiant energy was uniformly distributed around the tube's circumference. A maldistribution still existed between the shield and the shell, but since the shield temperature was very close to the shell wall temperature, any maldistribution that did occur was minimized by the low exchange of energy. The majority of the energy input to the shield was by forced convection.

Shielding is one possibility with which to prevent circumferential temperature gradients. The functional use of shielding is that it reduces the effects of forced convection directly on the tube and uniformly distributes radiative heat transfer circumferentially. This results in a reduction of thermal gradients. However, shielding may be impractical due to installation problems and environmental effects on shielding materials. Shields constructed from ceramic materials (SiC) may be required for high temperature service.

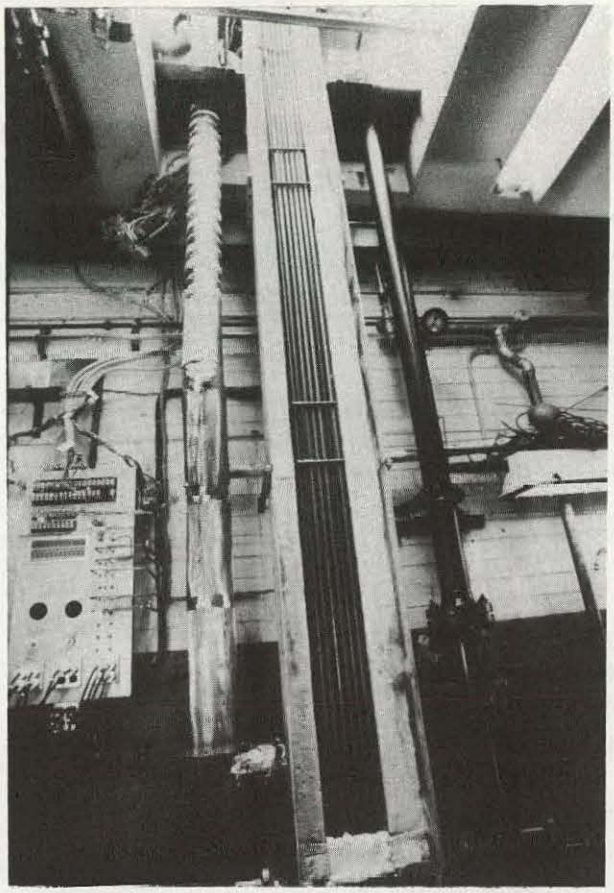


Fig. 2. STI/GRI Metal Axial Counterflow High Temperature Recuperator

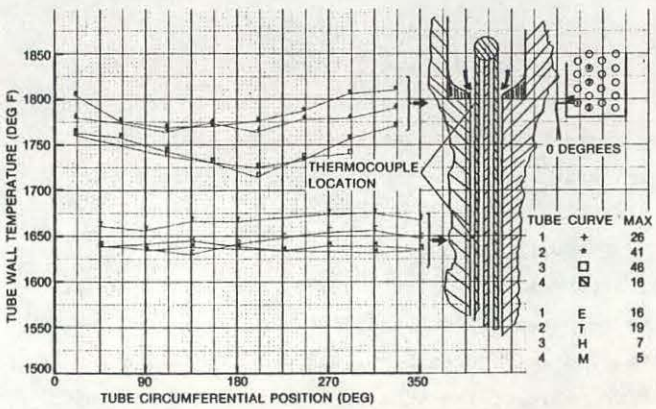


Fig. 3. Circumferential Thermal Gradients on Selected Tubes During a Steady State Condition (1615°F Air Outlet Temperature and 2000°F Gas Inlet Temperature)

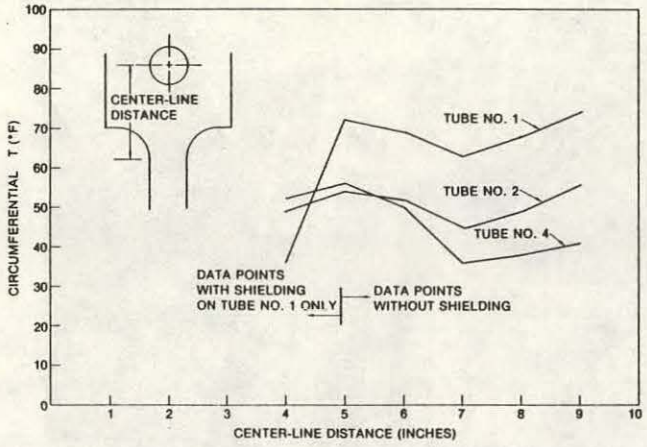


Fig. 4. Graph of Circumferential ΔT Versus Center-line Distance as Measured on STI/GRI High Temperature Recuperator Test Module

Tube circumferential thermal gradients are expected to occur in the area of the tube to header connections. These temperature gradients are undesirable because they increase the maximum material temperature. If the purpose of this metal recuperator is to provide the highest outlet temperature that can be obtained from a metal unit, these temperature gradients will reduce the maximum achievable result. These gradients will in effect reduce the thermal effectiveness and/or increase the size of such units. Therefore, if a cost effective process is found to prevent these circumferential thermal gradients, then the most effective and smallest size recuperator design can be achieved.

Part of the successful operation of the full size recuperator test module was a major reduction of the thermal gradients at the tube to header joint which will significantly increase the recuperator's cyclic life.

Thermal transient tests were conducted and thermal data recorded. The results, transient temperature response of selected instrumented tubes, are presented in Figures 5, 6, and 7. Figure 5 shows the response of the tube to header weld joint which results from the thermal isolation design. Note the low thermal gradient across the weld joints, thermocouples 65 and 81 and thermocouples 82 and 90. However, the tube which was directly welded to the hot header had a much higher thermal gradient across its tube to header weld joint as shown in Figure 6. A comparative plot of thermal gradients across the tube to header weld joints during the thermal transient is shown in Figure 7. The difference between the tube directly connected to the header and the tubes which are connected using the thermal isolation design

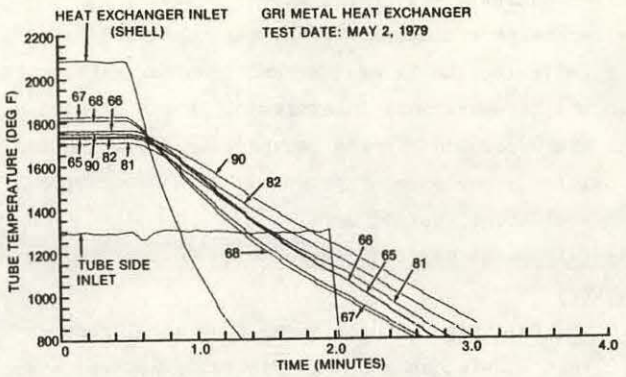


Fig. 5. Axial Thermal Gradients on a Selected Tube at the Hot Header During Transient Condition (at 30 Seconds, Air Outlet Temperature Equalled 1635°F)

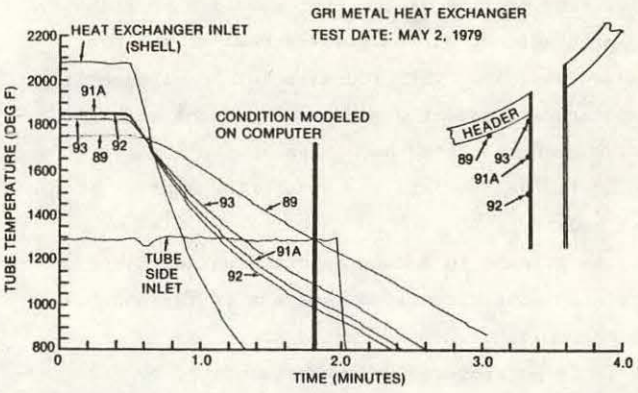


Fig. 6. Axial Temperature Gradients on a Selected Tube at the Hot Header During a Transient Condition (at 30 Seconds, Air Outlet Temperature Equalled 1635°F)

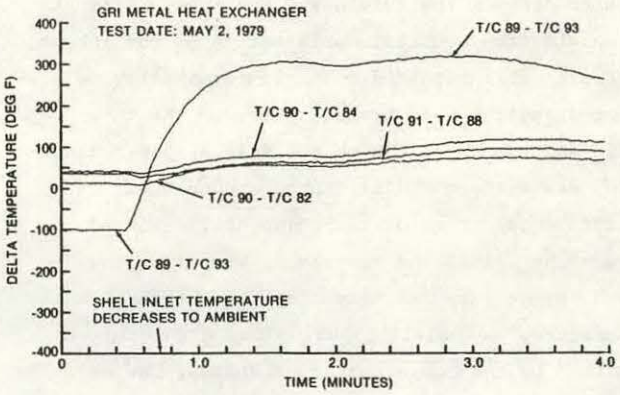


Fig. 7. Temperature Gradient (ΔT) Across Tube to Hot Header Weld Joint During Transient Condition (at 30 Seconds, Air Outlet Temperature Equalled 1635°F)

during a thermal transient was approximately 200°F. The thermal gradients measured across the weld joint the thermal isolation technique appear to be with- acceptable bounds.

Acceptable bounds are defined as a thermal gradient which does not create stress in the joint (at the weld) sufficient enough to cause permanent deformation and failure. All weld joints appear to be acceptable. However, with its characteristic high thermal gradient, the weld joint which connects a tube directly to the header is questionable. An assessment of the severity of the thermal stress that will result from the thermal gradients must be made with the aid of a computer model of this joint.

A computer element-nodal stress model was created of a header/tube intersection. A quarter segment of a tubular header and tube was modeled in order to investigate stress concentrations at the tube-header weld joint during thermal transients of a tube directly connected to the header. The three dimensional model of a right angle intersection between a tube and header is shown in Figure 8. As mentioned previously, the purpose of this model is to assess the severity of the thermal gradient that was measured during tests performed on the full size test module.

The conditions used for the model were those measured during a thermal transient test made on the full size module (Fig. 5). The results, summarized in Figure 9, indicate that equivalent element stresses will exceed 4000 psi at the weld joint between the tube and header during the transient condition shown in Figure 6. Complete stress maps of the tube and header are provided in Figures 10 and 11. When comparing these values to the creep or yield strength of a few superalloys, it can be seen that these stress levels predicted by the computer model for a tube directly connected to a header during a thermal transient condition are not acceptable. If the design requires less than one percent creep in 10,000 hours, then peak stresses should not exceed 1500 psi for Incoloy 800-H at 1700°F. The conditions simulated in the model were for a high pressure heat exchanger (internal pressure of 100 psi). For an atmospheric recuperator experiencing similar thermal transients at the header/tube weld joints the stress in the weld joints would still be unexceptable. The stress values that would exist during a thermal transient condition in a low pressure recuperator would be the difference between the uniform temperature and temperature gradient case shown in Figure 9. Header stress can be obtained by subtracting 650 psi from the values shown in the stress map, Figure 10. Peak stresses occurring at the weld joint still exceed 3000 psi for a low pressure recuperator.

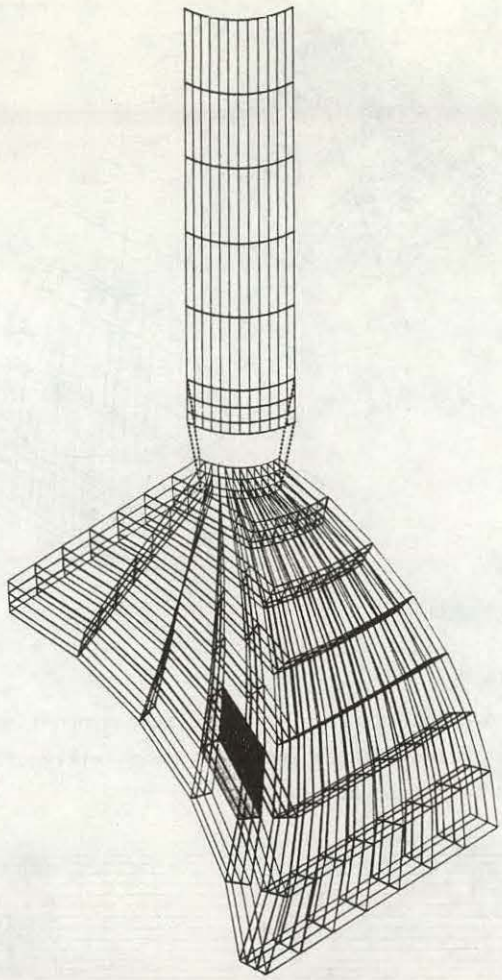


Fig. 8. Computer Stress Model of a Right Angle Tube to Header Intersection

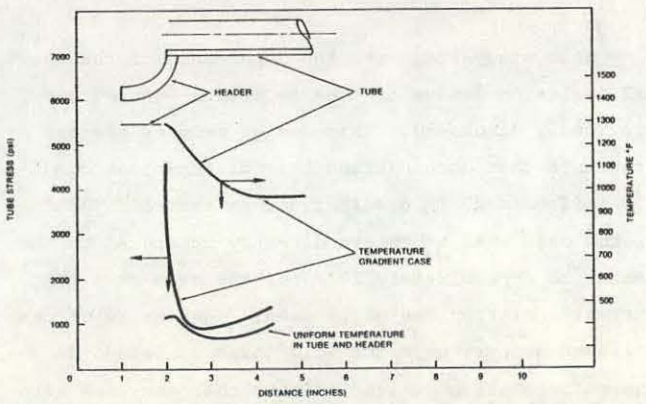


Fig. 9. Results from Computer Stress Model of a Right Angle Tube to Header Intersection; Tube Stress

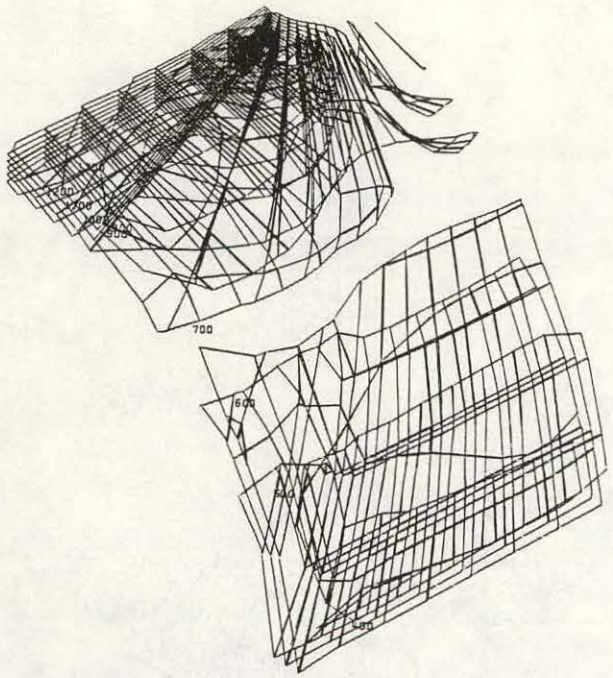


Fig. 10. Results From Computer Stress Model of a Right Angle Tube to Header Intersection; Header Stress

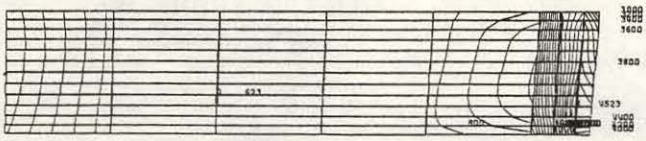


Fig. 11. Results From Computer Stress Model of a Right Angle Tube to Header Intersection; Tube Stress

This study indicates the importance of the thermal isolation design of tube to header connections previously discussed. This design reduces thermal gradients that occur during thermal transient conditions (from a 200°F gradient across the weld joint in the case when tubes are directly connected to the header to approximately 50°F for the case when the thermal isolation design is used). Estimates of peak stresses occurring in the weld joint contained in the thermal isolation design indicate that they are within acceptable design limits for Incoloy 800-H.

Environmental Rig Material/Fuel Interaction Evaluation

Nine materials were tested in a 1700°F environment produced by the combustion of natural gas and Diesel No. 2 and also subjected to a furnace oxidation test. The results are summarized in Tables 1 and 2 and Figure 12.

Table 1

Relative Amounts of Recession

(500 Hrs; 1700°F Environments)

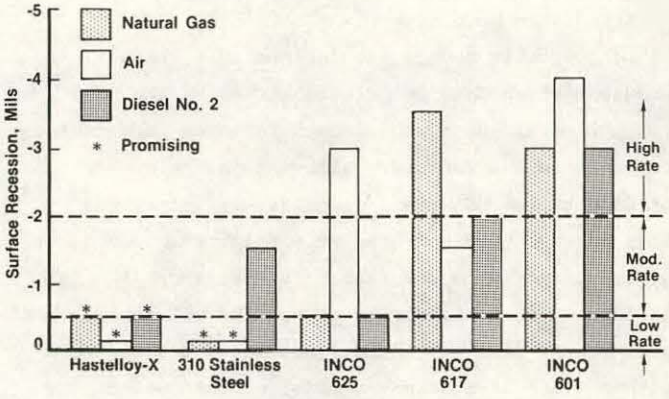
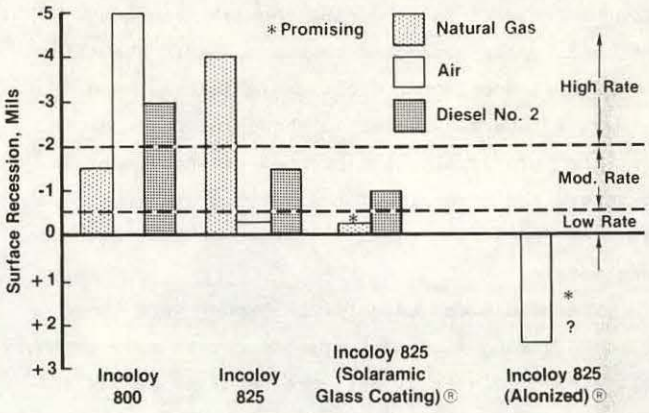


Table 2

Relative Amounts of Recession

(500 Hrs; 1700°F Environments)



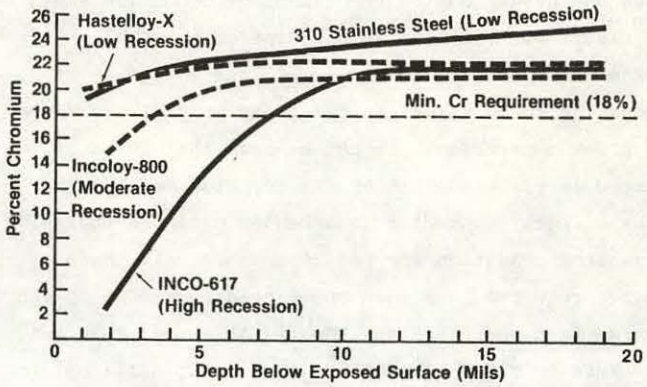


Fig. 12. Subsurface Chromium Reservoirs (SEM/EDX Analysis) (Natural Gas Combustion; 1700°F, 500 Hrs)

On the basis of rig testing results and furnace oxidation results, the most promising recuperator ›e alloys were found to be:

Natural gas combustion products (1900°F gas temperature, 1700°F material temperature) and air environment (1700°F)	Hastelloy X Type 310 SS
Diesel No. 2 combustion products (1900°F gas temperature, 1700°F material temperature) and air environment (1700°F)	Hastelloy X

These alloys were considered superior in terms of minimal wall recession, alloy depletion and microstructural changes.

Both high temperature glass coatings and Alonized® (aluminized) alloys may prove to be a more economical solution for high temperature recuperator applications. Used in conjunction with a relatively inexpensive and readily obtainable alloy such as Incoloy 800 material, costs could be decreased by as much as 60 percent. However, test results indicated that the Solaramic® coating may have a limited service life due to oxygen diffusion through the coating and thinning of the coating with longer exposures to the high temperature environments. Although the Alonizing process is most promising, it too must undergo further testing to characterize its oxidation stability over longer periods of time.

Low Temperature Critical Experiments

A review of available manufacturers' literature on acid corrosion resistant materials led to the conclusion that there were no metal alloys fully resistant to all concentrations of sulfuric, sulfurous, carbonic and hydrochloric acid over the full range of operating temperatures. The most corrosion resistant alloys appeared to be Hastelloy G, Hastelloy C-276, and Carpenter 20. However, the high cost of these alloys may limit their actual applicability and make plastic and glass coatings a more viable alternative.

A corrosive acid environment was created burning both natural gas and Diesel No. 2 in a special test rig. Although phosphoric, sulfurous and sulfuric acid were detected in condensate samples, the quantities and concentrations of these acids were not sufficient for comparing the acid resistance of the better alloys (e.g., Hastelloy-G, Inconel 825, etc.). Quantitative data was, however, obtained for the carbon steel baseline material. The corrosion rate of carbon steel in Diesel No. 2 exhaust gas was higher than that in natural gas combustion products, reflecting the effect of sulfur content on the corrosiveness of the exhaust gas.

Although corrosion rates could not be determined for the coated materials, it was observed that there were no gross failures of any of the coatings (Ryton®, Teflon® and porcelain). During the initial stages of each test, the hydrophobic nature of the plastic coatings were evidenced by fine droplet formation during condensation (see Figs. 13 and 14). Degradation of the surface tension properties of these coatings during the course of the tests resulted in a more indistinct fluid film on these surfaces by the test's conclusion. It is not clear at this time whether this degradation in surface properties has an effect on the corrosion resistance of the coatings.

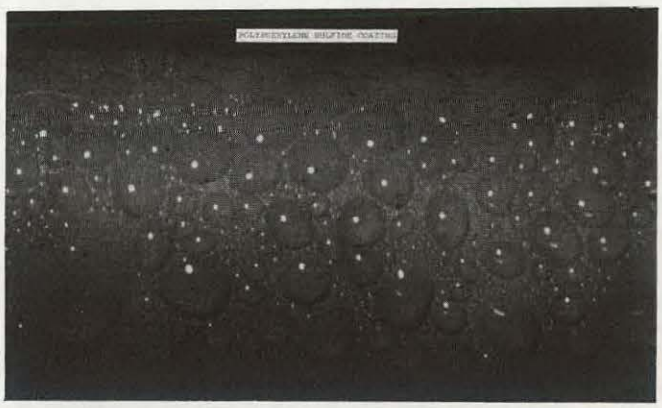


Fig. 13. Condensation on Surface of Ryton® Coated Tube During Natural Gas Acid Corrosion Test

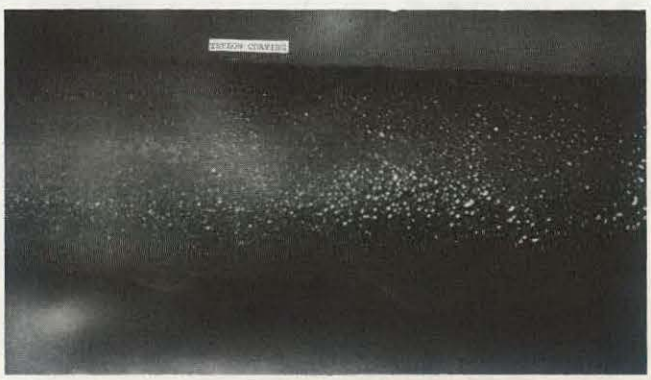


Fig. 14. Condensation of Soot Covered Teflon® Coated Tube During Diesel No. 2 Acid Corrosion Test

RECOMMENDATIONS

This effort was the first year of a three-year plan to advance metal recuperators for delivery of high quality air with the highest practical effectiveness. Its objective is to provide the technology base for the advancement of high temperature waste heat recovery state-of-the-art. This is being accomplished by increasing the recuperator's maximum material operating temperature.

The first year phase did demonstrate the advantages of a recuperator design which reduces thermal gradients during steady state and transient operation. With its successful operation at outlet temperatures of 1650°F, key technology areas were identified. To further the advancement of high temperature waste heat recovery, the following areas are considered primary for technology advancement and demonstration. The original three year field demonstration plan is still considered viable and supported by STI. The following is recommended.

- Continue waste heat recovery program (3-year plan) with work on Phases II and III
- Identify current markets and market economics for high temperature waste heat recovery
- Identify a possible field test site
- Continue high temperature material/environmental interaction studies in order to
  - choose recuperator build of material
  - assess the materials life at maximum temperature
  - assess the materials capability to withstand sulfidation
  - assess an Alonized® low cost superalloy (Incoloy 800 H) compatibility with the recuperator environment including life predictions and economics incentives
- Fabrication of full size modularized recuperator test unit
  - examine tube bundle aerodynamic effects on tube temperature distributions in a multi-module recuperator
  - measure the radiation effects on tube temperature distributions and performance in a multi-module recuperator
  - assess the viability of radiation shields
  - assess the design and cost benefits to reducing total pressure drop below what is obtainable with a simple design
  - check the effects of multi-module combined axial flow - finned cross flow construction on calculated performance parameters
  - detailed examination of the tube to header joint area in order to guide the proper material choice and structural design
- Design necessary controls for field test unit
- Design and field test of a prototype full size high temperature (1600°F outlet) recuperator
  - six month field test evaluation
- Perform long term accelerated material-environment interaction tests of coated and uncoated low temperature water economizer tubes utilizing catalyzing agents to promote SO_2 to SO_3 conversion
- Investigate the acid corrosion resistance and economic advantages of coated and uncoated finned tubing
- Construct a small scale water economizer utilizing the best material from the long term environmental tests.

A CROSS-FLOW CERAMIC HEAT RECUPERATOR FOR INDUSTRIAL HEAT RECOVERY

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ABSTRACT

With increasing fuel costs, the efficient use of fuel is very important to the U.S. process heat industries. Increase in fuel usage efficiency can be obtained by transferring the waste exhaust heat to the cold combustion air. The metallic recuperators currently available suffer from problems of creep, corrosion and oxidation, particularly at high temperatures. The Department of Energy and GTE Products Corporation have pursued a jointly funded venture, Contract No. EX-76-C-01-2162, to establish performance criteria and demonstrate a cross-flow ceramic heat recuperator for high temperature industrial heat recovery applications.

The immediate goals of the ceramic recuperator project were to demonstrate a heat exchanger capable of handling high temperatures (1600-2400 °F), that is compact with a high surface area and with costs comparable to the lower temperature metal heat exchangers.

This paper describes the basic GTE Products Corporation design and details the design basis, the predicted recuperator performance, the ceramic and housing materials, the recuperator design procedure and the fabrication and assembly. The data provided includes NTU-Effectiveness and flow friction and heat transfer ("f" and "J") plots.

INTRODUCTION

During the past five years, GTE Products Corporation has been developing the technologies to fabricate a cross-flow recuperator. The initial investigations concerned themselves with material identifications for regenerative types of heat exchangers for turbine applications. This technology was applied to the fabrication feasibility of cross-flow heat exchangers. Ultimately, the final product was to accomplish a simple task, decrease the fuel consumption for a process. This paper concerns itself with the various stages of design necessary to develop a ceramic waste heat exchanger.

In 1976 a contract was entered with the Department of Energy to demonstrate industrial feasibility of the recuperator. A knowledge of the combustion process is necessary to the effect that recuperated or preheated air can have on a system when heat is transferred from the waste gas to the combustion air. The focal point for our effort was utilization of preheated air directly in the combustion cycle, not for low quality preheated air that is used in a secondary process such as drying, make up air units, etc. After discussing the design of our heat exchanger from an engineering standpoint, a theoretical model will be presented for a cross-flow recuperator, with both fluids unmixed (our present design). Finally a case history of a particular application will be presented along with a discussion on combustion control utilizing preheated air.

ENERGY SAVINGS WITH WASTE HEAT RECOVERY

When a fuel is burned, energy is released. For perfect combustion to take place with fossil fuels, precise volumetric controls of the reactants must be controlled. In the case of burning natural gas, outlined below, we have assumed that it is 100% CH_4. This is a close enough approximation to demonstrate the energy evolved in a process in the form of waste heat. Table I shows the relationship of the reactant temperature to that of flame temperature. In each case the gas is at ambient temperature (60 °F) but is shown as the temperature of the air mixed with the gas. Combustion air of increased temperature results in an increase in flame temperature and energy input. The effect of stoichiometry is also shown. Perfect combustion (approximately 10.1:1, air to gas by volume) always yields the highest flame temperature. Equation (1) shows the combustion equation for natural gas (assumed to be 100% methane) with oxygen.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{heat} \quad (1)$$

Industrial furnaces generally utilize air as the basic source of oxygen. Assuming that air is 20% O_2 and 80% N_2 by dry volume, we find equation (2).

$$CH_4 + 2O_2 + 8N_2 \rightarrow CO_2 + 2H_2O + 8N_2 + \text{heat} \quad (2)$$

Table I*

Reactant (fuel)	Reactant (oxidizer)				
Type	Type	Temp, °F	Equiv Ratio	% Excess Air	Temp, °F
Natural Gas	O_2	60		0	5120
Natural Gas	Air	60	.86	10	3300
Natural Gas	Air	60	1	0	3562
Natural Gas	Air	60	1.11	≈10% Rich	3400
Natural Gas	Air	600	1	0	3800
Natural Gas	Air	900	1	0	3920
Natural Gas	Air	1100	1	0	4000
Natural Gas	Air	1400	1	0	4100
Natural Gas	Air	1400	1.11	≈10% Rich	4070

BTU content of gas approximately = 1020 BTU/cu ft^3

*Reference 1 = Pg. 10, Table 1.9

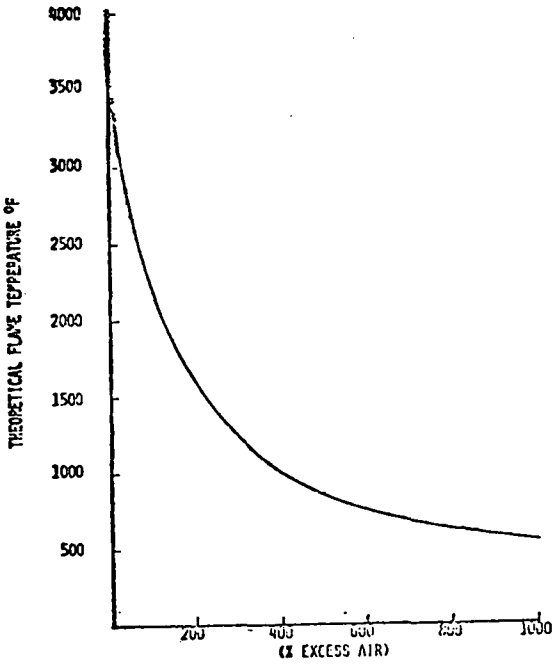
As shown in equation (2), nitrogen does not take part in the combustion process. Its primary function is simply lowering the flame temperature. This relationship makes it easy to understand why the available heat to load ratio decreases as temperature increases (Figure 2). Equation (3) shows that approximately 74% of the mass of the combustible mix is N_2.

$$\begin{aligned} 8N_2 + 2O_2 + CH_4 &= CO_2 + 2H_2O + 8N_2 \\ 8(28) + 2(32) + (16) &= 44 + 2(18) + 8(28) \\ 224 + 64 + 16 &= 44 + 36 + 224 \end{aligned} \quad (3)$$

$$\text{or } \%N_2 = \frac{224}{224 + 16 + 64} = \frac{224}{44 + 36 + 224} \text{ approx. } 74\%$$

To maintain the temperature of a particular load requires a fixed amount of energy. When combustion occurs the energy is present in the chamber only as long as it takes for the gases to travel through the chamber. The longer they remain, the more heat they can transfer. However, the speed at which they travel is a function of the input rate of the furnace. The particular heat balance necessary for a process is governed by this relationship. The Shankey diagram (Figure 4) depicts this situation. When one realizes that most of the volume input into a chamber is N_2, the surprisingly small percent available heat at elevated temperature is predictable.

Figure 1



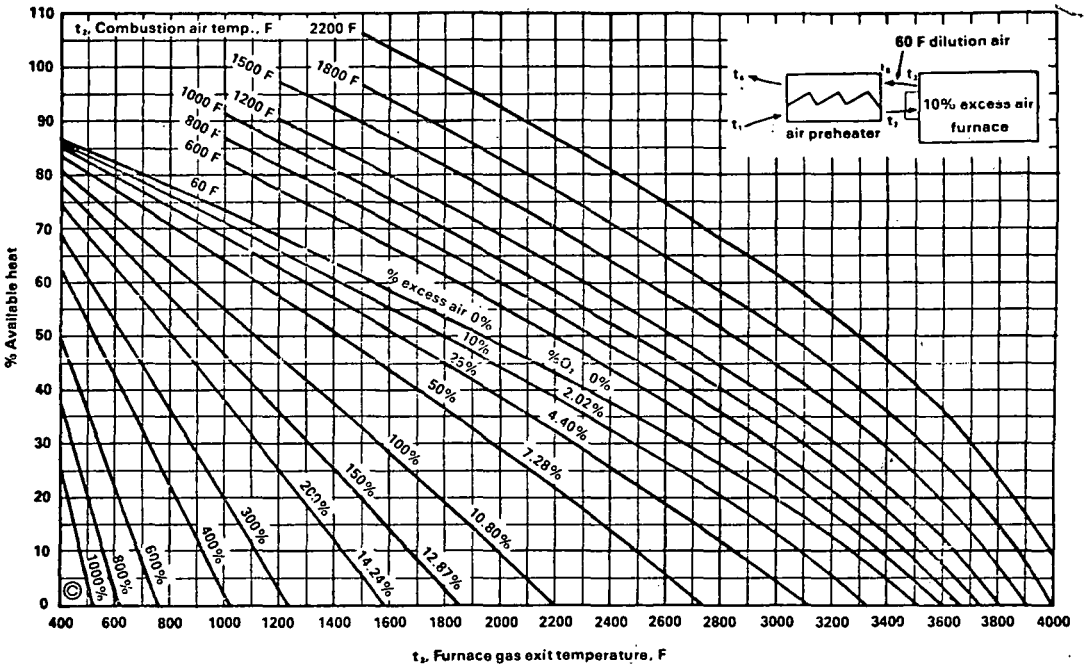
Theoretical Flame Temperature
of Natural Gas With Excess Air Combustion

Now that it is understood that most of the energy input in a process is lost as waste heat, it becomes apparent that the transfer of this heat to combustion air is a logical method of improving system efficiency, as is shown in Figure 2. An increase in the thermodynamic efficiency of the furnace also results. Factors contributing to this are the increase in available heat, the flame velocity and its temperature. A decrease in mass flow (necessary to maintain equilibrium) will result in a partial reduction in the forced convection heat model. Overall it can be shown, and it is accepted that for every BTU recovered in the form of preheated air, 1.1 BTUs are realized. Figure 3b depicts the Shankey diagram when recuperation is utilized. The resultant is the reduction of fuel necessary to maintain the same load shown in the Shankey diagram in Figure 3a.

GTE DESIGN AND ENGINEERING CONSIDERATIONS

The two basic recuperator designs considered here were shell and tube and cross-flow plate. The shell and tube system, either counter-flow or cross-flow, becomes large and expensive due to size and material requirements. Good conductive material, such as metals, is necessary in shell and tube construction due to the relatively low heat transfer surface. To attain relatively high temperatures (1500 to 1800 °F), superalloys must be utilized whose cost, size, weight and fabrication problems can limit usage. Lack of corrosion resistance also severely limits this type construction in many applications.

Figure 2*

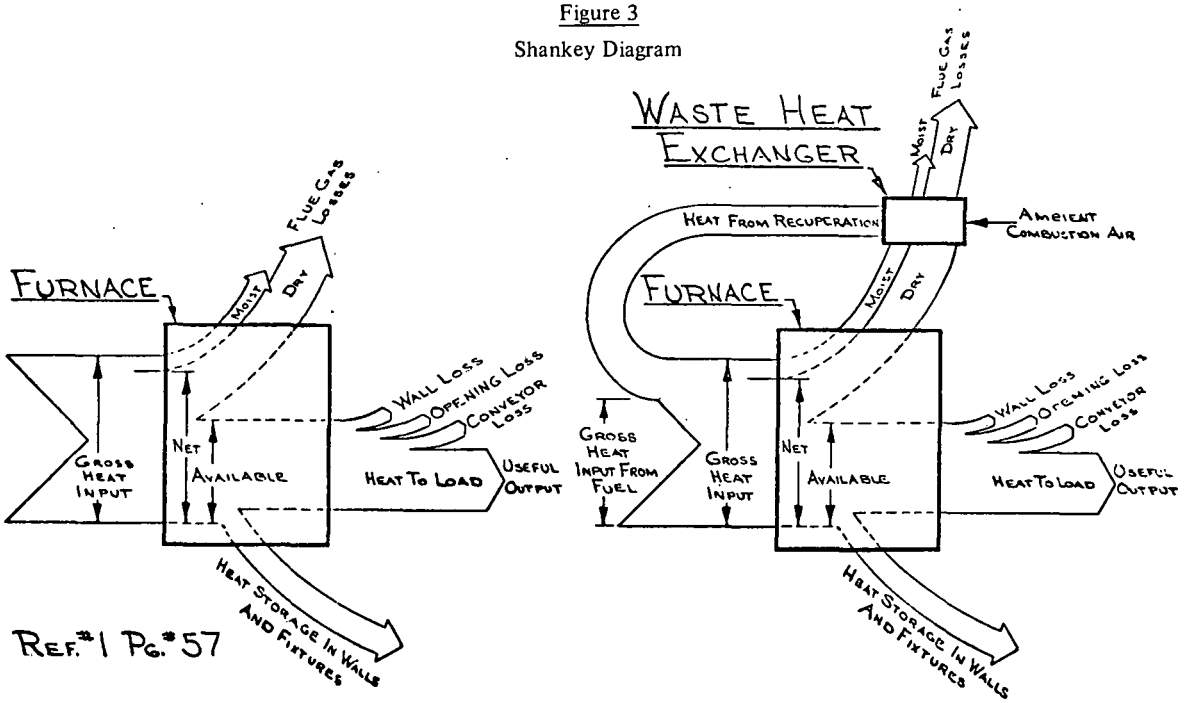


Available Heat: Flue Gas Analysis

*Reference 1

Figure 3

Shankey Diagram



a. No Recuperation

b. With Recuperation

Until recently, the recuperators utilized the most for gas to gas heat exchange were made of metals fabricated into plates or finned tubes for cross-flow applications. These metallic recuperators are useful at relatively low temperatures but limited when used for higher temperature processes (temperatures in excess of 1600 °F). An expensive and elaborate overtemperature protection system of make-up air is often needed to stay within the temperature capability of the metals. The metallic systems are also limited in design since they must be made resistant to the high temperature cyclic creep characteristics of most metals. Thus, high temperature applications require that cold air, water or steam be injected into the hot waste gases upstream from the metallic recuperator in order to reduce the waste gas entry temperature to a level that is safe for the metal. This type of dilution severely restricts the amount of energy that can be recovered in high temperature installations.

It was immediately apparent that a ceramic cross-flow type of heat exchanger with a large heat transfer surface area and a capability of handling high temperature furnace exhaust (in excess of 1600 °F) could be a dramatic improvement over metallic units currently available on the market. Many ceramic materials have been developed that have a potential for fabrication into high temperature heat exchangers. The key design criteria is thermal shock resistance (TSR). The largest design constraint affecting TSR is thermal expansion. Low expansion rates, high temperature strength, resistance to fracture and corrosion resistance are all properties exhibited by silica, lithium aluminum silicate (LAS), magnesium alumina silicate (MAS), silicon nitride, silicon carbide, and various zirconia compositions that make these particular ceramics prime recuperator candidates. Magnesium alumina silicate (MAS) was selected because of its ease of fabrication, relatively low thermal expansion, good thermal shock resistance and its good corrosion resistance. MAS limitations involve some difficulty in firing due to a narrow material firing range.

A recuperator, whether ceramic or metallic, must exhibit relatively low leakage. During the first stage of design, goals were placed at leakages under 25 percent, based upon maximum flow and ratings at maximum flow. (It should be noted that present designs are exhibiting leakages at less than 5 percent based upon maximum rating and maximum flow.) The negative effects of leakage on recuperator effectiveness are shown in Figure 4.

Figure 4

$$E = \frac{Tao - Tai}{Tei - Tai} \quad \frac{C_1 \text{ air}}{C \text{ min}}$$

E = Effectiveness

Tao = Temperature of Preheated Air Out

Tai = Temperature of Preheated Air In

Tei = Temperature of Exhaust In

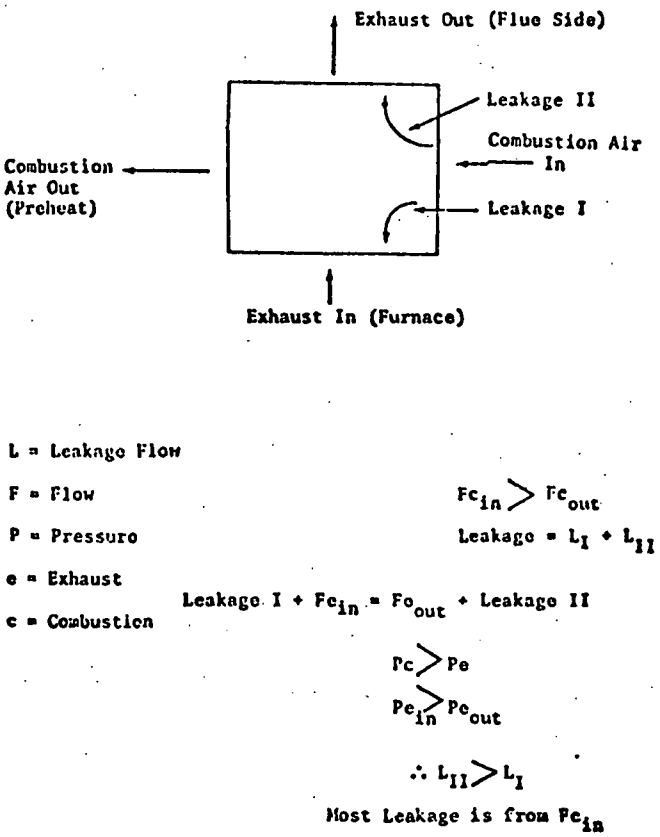
C air = Specific heat of the air.

C min = Minimum specific heat of the air or gas (C min is always C air) $\therefore \frac{C \text{ air}}{C \text{ min}} = 1$

Definition of Recuperator Effectiveness

This has been determined by experimentation. Since the leakage will occur from the higher pressure (combustion air side) towards the exhaust, the result is a cooling of both fluids. The primary leakage will be into the flue side (exhaust) since a negative pressure often exists here due to the low pressure in the exhaust stack and a positive pressure in the furnace itself. See Figure 5.

Figure 5



Recuperator Leakage

This figure demonstrates the general trend exhibited by the leaking fluid (gas in this case). For combustion to take place it will be necessary to develop a pressure of approximately 16 oz/ at the burner. The matrix will then have to be designed to acce

$\frac{16 \text{ oz}}{\text{in}^2}$ + pressure drop across the matrix (max. = $\frac{1 \text{ oz}}{\text{in}^2}$)

In each application the matrix must accept at least 12 oz/in^2. Pressure drop was the next design criteria. It was decided that combustion pressure drops can be accepted easily (use of a high pressure fan); however, exhaust pressure drops must not exceed 0.3 in. of water column (W.C.) in our particular application. To achieve this, the matrix was designed to allow a much greater open window area in the exhaust direction (Figure 2).

The larger size hydraulic diameter of the exhaust channels also reduces the chance of difficulties due to fouling of the matrix. Combustion gases are at approximately 70 °F entering the cube while exhaust gases at 1,400 °F have expanded four times as shown in Table II. The increased velocity will also increase the frictional factors causing very large pressure drops. This points out that a greater relief (percent open window) is necessary in the exhaust direction, unless ejectors of exhausters are to be utilized as an integral part of the system.

One other factor that must be taken into consideration when designing a recuperator system is the exhaust gas environments. Furnace exhausts can contain corrosive materials such as acids (sulfuric), fluorides, chlorides and vanadium as well as particulate which can cause fouling and could present cleaning requirements. Ceramics stand up quite well to most of the corrosive materials present in furnace exhausts; however, it is suggested that a 6 in x 6 in x 6 in test piece of the ceramic matrix be suspended in the furnace exhaust for two months to determine if in fact a specific combination of corrosives could deteriorate the matrix. Fouling of the ceramic matrix by extremely "dirty" furnace exhaust particulate can be minimized by design consideration for the exhaust holes. For example, smaller exhaust holes provide a greater heat transfer area, but produce a higher pressure drop through the matrix and hence a greater propensity to plug. Thus, the exhaust holes can be enlarged to such a size to minimize plugging.

Table II

Temperature °F	G, Gas Gravity	Density lb/ft^3	Volume Expansion Ratio(λ)	Volume of 1 lb Dry Air, ft^3	Heat Content of Dry Air Btu/lb	Heat Content of Dry Air Btu/ft^3 stp air	% Volume of Water Vapor in Saturated Air at 1 atm	Absolute Viscosity, lb/ft-sec	Thermal Conductivity Btu/ft ft^2 hr °F
60	1.000 0	0.076 5	1.000	13.07	0.000	0.000 0	1.744	0.000 012 06	0.014 67
80	0.963 4	0.073 7	1.038	13.57	4.863	0.372 0	3.452	0.000 012 42	0.015 17
100	0.928 1	0.071 0	1.078	14.08	9.719	0.743 5	6.467	0.000 012 76	0.015 67
200	0.788 2	0.060 3	1.269	16.58	34.03	2.603	78.45	0.000 014 43	0.018 08
400	0.605 2	0.046 3	1.652	21.60	83.05	6.353		0.000 017 40	0.022 53
600	0.490 2	0.037 5	2.040	26.67	129.5	9.907		0.000 020 04	0.026 56
800	0.413 1	0.031 6	2.421	31.65	184.1	14.08		0.000 022 41	0.030 27
1000	0.355 6	0.027 2	2.812	36.76	231.8	17.73		0.000 024 58	0.033 71
1200	0.313 7	0.024 0	3.188	41.67	280.5	21.46		0.000 026 59	0.036 91
1400	0.279 7	0.021 4	3.875	46.73	330.2	25.26		0.000 028 49	
1600	0.252 3	0.019 3	3.964	51.81	380.7	29.12		0.000 030 41	
1800	0.230 1	0.017 6	4.346	56.82	455.2	34.82		0.000 031 93	
2000	0.211 8	0.016 2	4.721	61.73	507.7	38.84		0.000 033 54	
2200	0.195 5	0.015 0	5.115	66.87	560.9	42.91		0.000 035 08	
2400	0.181 7	0.013 9	5.504	71.94	614.9	47.04		0.000 036 55	
2600	0.169 9	0.013 0	5.886	76.92	694.4	53.12		0.000 037 97	

Note: Volume of one cubic foot of dry stp air at the listed temperature = 1/G.

Properties of Air at Elevated Temperatures

Table III illustrates the range of exhaust hole sizes available. Should the matrix become plugged several cleaning methods have been proven successful. Since the ceramic matrix is quite resistant to thermal shock, cold compressed air can be blown on the stack side of the exhaust holes and any buildup can be simply blown off. It was found in actual testing that exhaust particulate buildup seemed to be heaviest at the top (cooler) side or stack side of the exhaust holes and thus lent itself to removal by high pressure (100 psi) air. A second method of cleaning the matrix was also investigated. Here combustion air through the matrix was shut off allowing the total ceramic matrix to heat up and the particulate buildup to volatilize.

Table III

.750 in x .125 in
.200
.250
.300
.350
.500
.600

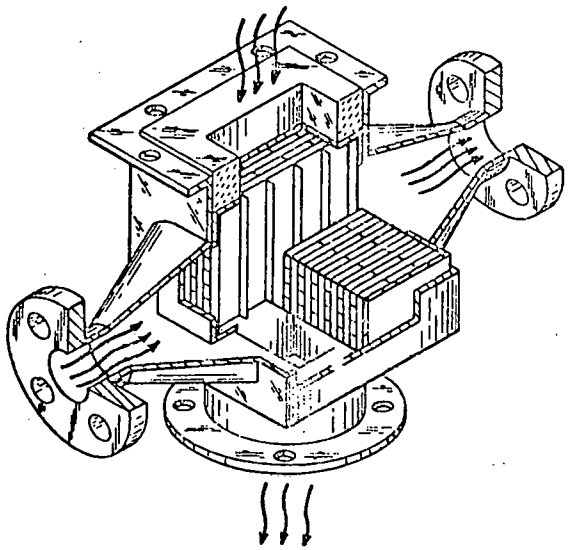
Air/Exhaust Hole Sizes Available

This last method is dependent upon exhaust temperatures, independency of the combustion system and the type and nature of the particulate buildup.

The general basic design that has evolved after years of testing and trial is a cross-flow configuration as illustrated in Figure 6 and 7. It should be noted that the additional side ribs on the cube edges allow for a 1 in. gasket window that enables the sealing of the cube in either a ceramic or metal housing with a minimum of leakage. The ceramic cube is shown installed in an actual housing in Figure 8. The total assembly then consists of the ceramic matrix, the refractory resilient seal and the housing itself. This housing design is as important to the successful system operation as the ceramic matrix itself. The housing keeps the ceramic in compression over a wide temperature range and it seals against the ceramic to prevent leakage. It has a refractory core to enable it to withstand high temperatures and it provides an easy hookup to other parts of the system, (i.e. pipes, flues and stacks).

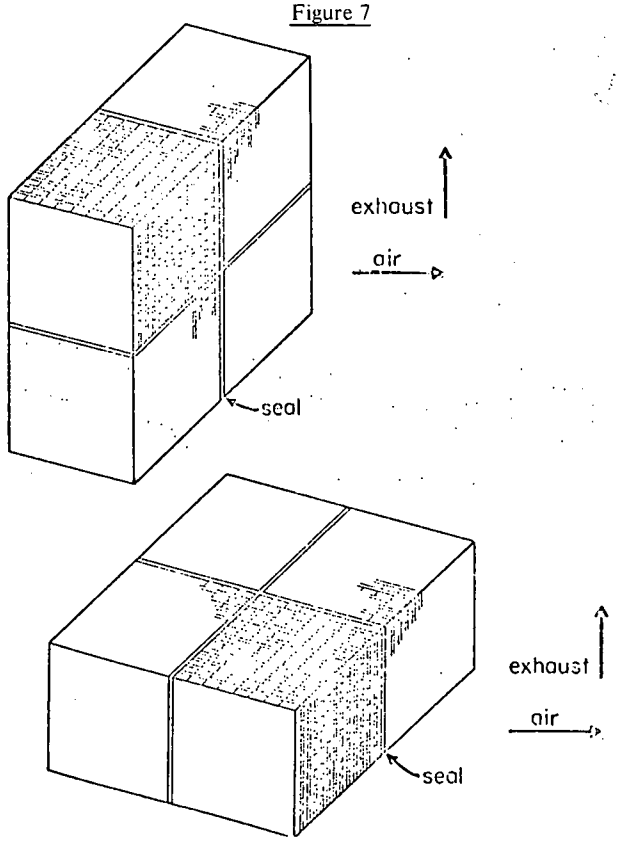
The ceramic matrix is sealed into the refractory lining by the 1 in. edge refractory seal. This unit also utilizes high temperature springs that keep the higher pressure (combustion air) side in compression thus allowing for a slight thermal expansion and assuring a constant and uniform seal. The spring loading also allows easy replacement or removal of the ceramic matrix from the unit for cleaning and maintenance.

Figure 6



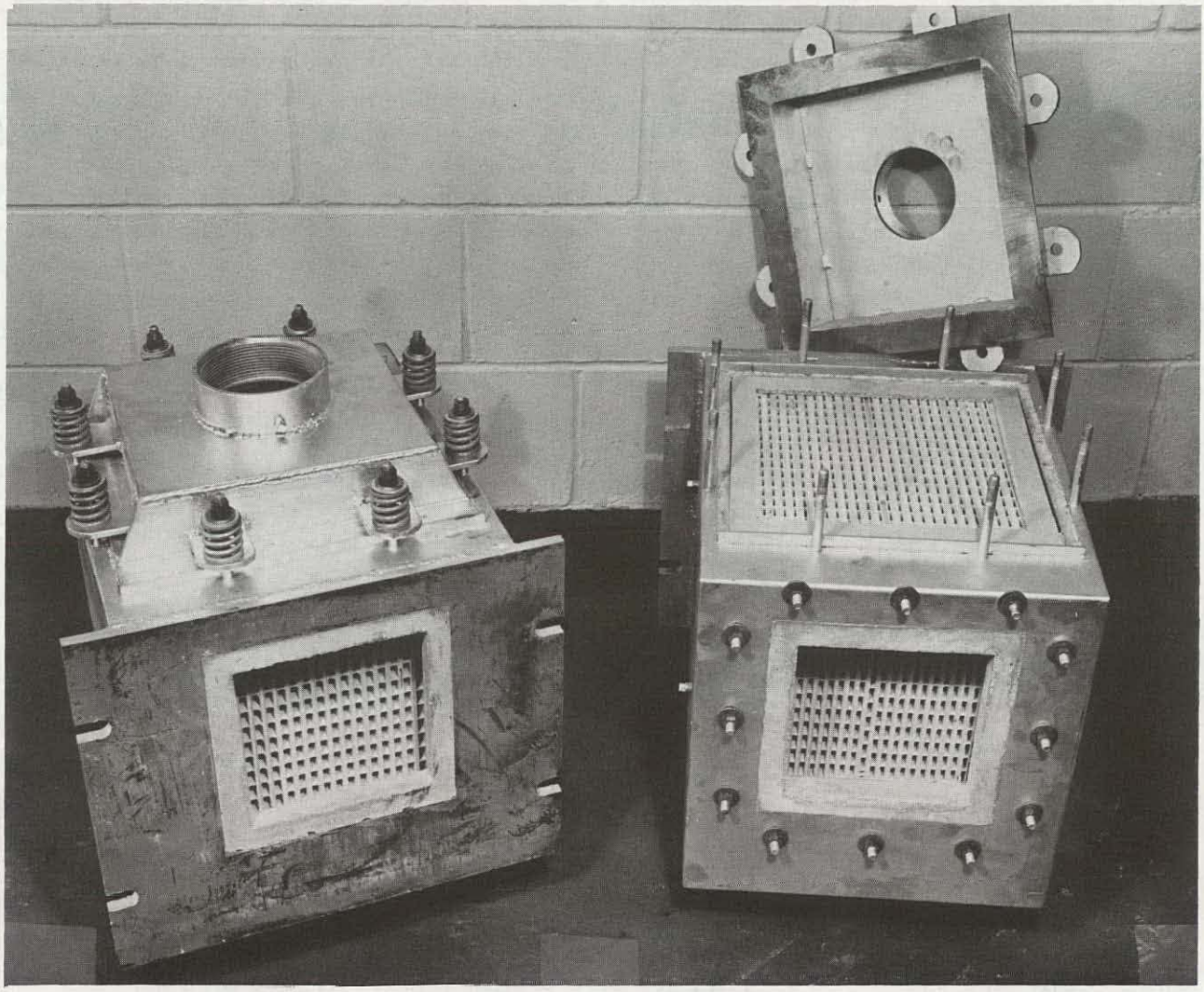
GTE Products Ceramic Recuperator

Figure 7



Grouped Heat Exchangers

Figure 8



Cast Steel Ceramic Housing

The ceramic cross-flow matrix itself can be manufactured in a variety of standard sizes. Table III lists some of the standard hole sizes available for preheat air and exhaust passages. Table IV lists the sizes of the cubes that have been developed as standards.

Table IV
Standard Size Ceramic Cubes

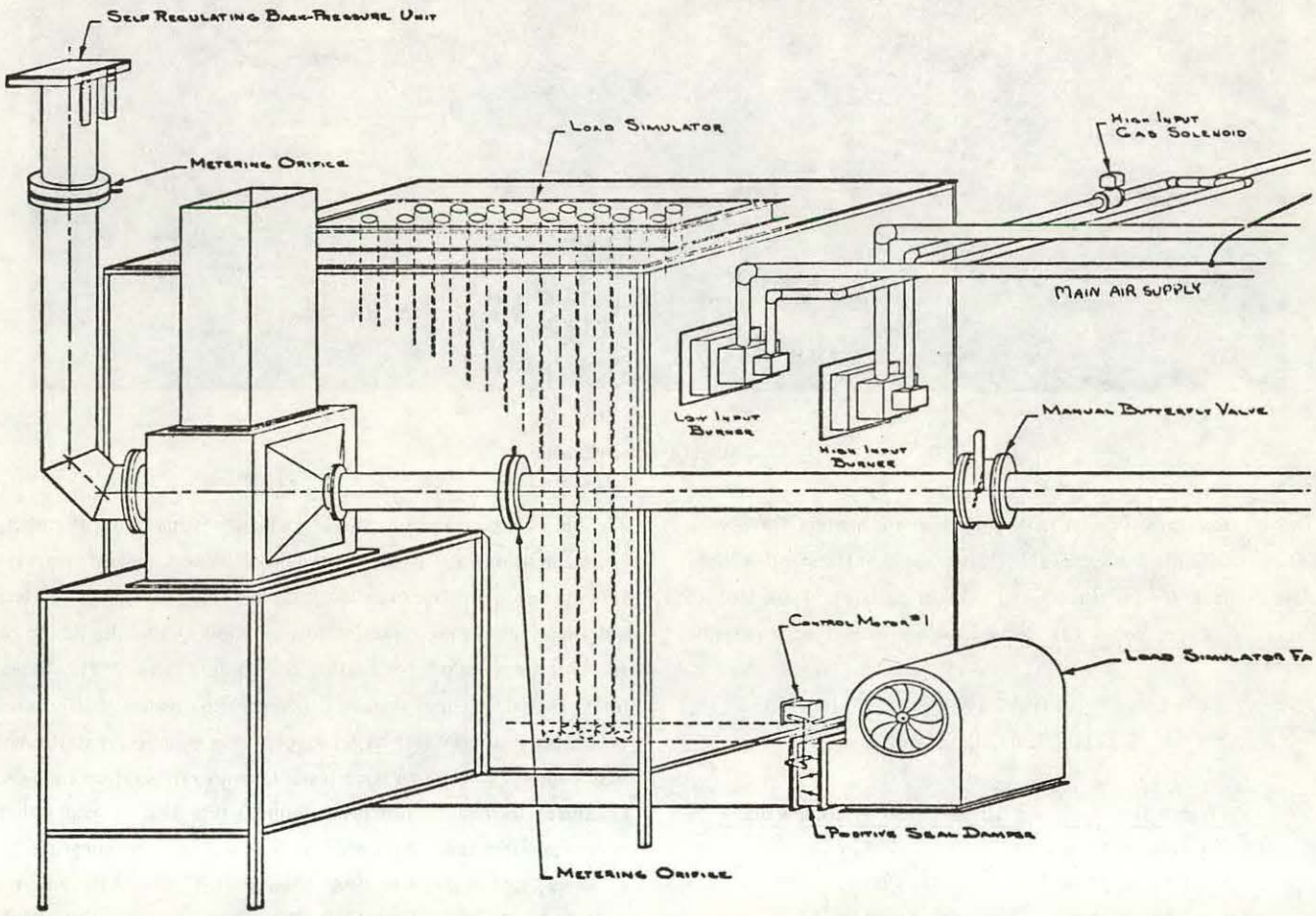
Overall Size	Useable Heat Transfer Volume
10 in. x 10 in. x 10 in.	512 $in.^3$
12 in. x 12 in. x 12 in.	1,000 $in.^3$
12 in. x 12 in. x 18 in.	1,600 $in.^3$
12 in. x 12 in. x 24 in.	2,200 $in.^3$
18 in. x 18 in. x 18 in.	4,096 $in.^3$
17 in. x 18 in. x 34 in.	7,680 $in.^3$

The life of a recuperator can vary widely depending on the operating conditions and process variability. Under constant temperature operation with clean exhaust, the ceramic recuperator can last indefinitely. During typical industrial applications, the design of the units must allow for heating and cooling rates of 212 °F per hour (100 °C). These designs, however, must realize that failures of furnacing systems due to gas supply, blower or power shutdown may expose the cube to large instantaneous temperature changes. Complete testing has not been done to this date to insure that units can withstand shutdown with any degree of consistency. However, operable units have been cycled repeatedly and no damage has been evident. When flow changes were varied simultaneously in the exhaust and preheat directions (closed loop), few problems arose below 2,250 °F. However, more data is necessary to quantify parameters governing catastrophic failure.

PERFORMANCE CHARACTERISTICS

The determination of performance characteristics on a test furnace (Figure 9 and Table V) provided data to optimize design parameters that are required to maximize system performance. The methods involved were two-fold, first core geometries were designed by computer models. Figure 10 shows the NTU-Effectiveness relationship for various ratios of capacity rate (C) for the air/gas. A gas/gas heat exchanger running between .1-1.2 equivalent ratios (1,000% excess air - 20% excess gas) with flows balanced to ±20% yields a range of capacity rate ratios. (C min/C max) of .75-.95. It can be seen that to obtain an effectiveness of .6, it is necessary to have an NTU of approximately 1.5-1.8 (NTU = AU/C min). Optimization of other parameters, such as minimizing exhaust pressure drop, attempting to keep the unit a perfect cube, and maintaining combustion pressure drop less than 2" W.C. at 2,000 °F, yielded a matrix design shown in Figure
The core geometry and fluid flow data from the test furnac shown on the computer generated output in Table VI. This data represents a single data point presented on the curves shown in Figures 12 and 15. The data output here will be utilized to maximize the ratios of the air side heat transfer surface area (A air) versus the gas side heat transfer surface area (A gas). To do this the heat transfer coefficient (j) and friction factor (f) will be plotted as in Figure 12. At this point only this section of data has been determined, however, after the analysis is completed optimization can begin. Preliminary results however have allowed for system designs that have become operable. An example of the data obtained from the test furnace is shown in Figure 15.

Figure 9



Schematic of Test Furnace

Table V

Test Furnace - Specifications

Firing Chamber - 64 cubic feet

Insulation:	1" 3,000 °F Saffil board with 2" 2,600 °F sheet and 4" 2,300 °F sheet
Input:	200,000 - 4.4 mm BTU/hr. - Gas - 4 burners
Fans:	1) combustion 96,000 scfh at 32 osi pressure 2) exhaust 33,000 scfm at 6" sc 3) load simulator 1800 scfm at 6" wc
Noise:	<85 db at max fire
Temp Range:	With load simulator 0-2,270 °F Without load simulator 0-3,000 °F
Control:	Automatic - Programmable over full range Method: hard cam and PAT controls Secondary control → variable at fixed points
Ignition:	Interrupted and/or continuous pilot with auto purge, ignition and monitoring
Indications:	Potentiometric - strip charts, circular chart, LED unit and digital with 12 point selector
Wall Losses:	40,000 BTU/hr at 3.4 mm BTU/hr at 2,000 °F
Load Simulator:	Removes 10,000 to 800,000 BTU/hr at 2,000 °F i.e., at 1 mm BTU T is controllable between 1,300 to 2,250 °F

In short, a 1 cubic foot recuperator - Model R 1000 with a core of .125 x .300 will obtain a temperature rise of 800 °F with exhaust air of 2,100 °F when the flows are 11,000 and 12,000 SCFH respectively (Figure 12). The exhaust pressure drop at 2,200 °F at 12,000 SCFH will be approximately .4" W.C. and the air side pressure drop will be approximately 2.5" W.C. If the furnace exhaust pressure drop called for a max of .25" W.C., another core may be selected. Perhaps a larger unit, or simply a change in the ratio of hydraulic diameters will be necessary.

The flexibility of a unit that is 1 cubic foot is controlled by the particular core geometry. Table VII shows the broad spectrum of operation of that unit. The optimization of heat transfer can only take place after the limitations of the system on which it will operate are satisfied.

Data Collection

1) Flows (Q) -
   - Air and gas at each burner
   - Air and gas total
   - Total pilot air and gas
   - Flow of preheat air in
   - Flow of preheat air out
   - ΔP exhaust
   - ΔP preheat
   - Absolute furnace pressure
   - Absolute hot and cold preheat pressure
   - Oxygen analysis of combustion products

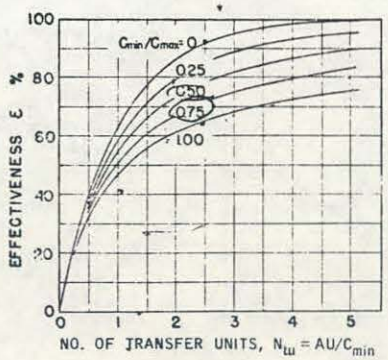
Simulations Available

Any burner may be simulated up to a 4 mm BTU/hr unit from 4 to 20 osi.

Modes of Simulation:

1) Continuous - ΔT by load response auto programmable control of simulator load
2) Continuous - balanced (closed loop furnace without sudden draft changes)
   a) cycle control with air and fuel
   b) cycle control with fuel only (excess air)
3) Continuous & Periodic - unbalanced (primary heat used in remote process - openlook or sudden variations in flow induced by sudden changes in draft
   a) cycles variable by all of above
4) Periodic - Balanced
   a) cycles with air and fuel
   b) cycles with fuel only

Figure 10



Effectiveness as a function of NTU, and capacity rate ratio; cross-flow recuperator with both fluids unmixed.

Table VI

CROSSFLOW RECUPERATOR PROBLEM - 12. X 12. X 12. MATRIX

GEOMETRY OF THE CROSSFLOW RECUPERATOR MATRIX

PREHEAT WINDOW = 10.0 X 10.0 = 100.00 (SQ.IN.)
EXHAUST WINDOW = 10.0 X 10.0 = 100.00 (SQ.IN.)

DISTANCE OF AIR TRAVEL IN MATRIX = 12.0 (IN.)
DISTANCE OF GAS TRAVEL IN MATRIX = 12.0 (IN.)

	RIB TCKNESS (IN)	RIB HGT (IN)	DIST BTWN RIBS (IN)	# OPENINGS	TCKNESS PLTE (IN)
PREHEAT	0.029	0.112	0.676	301.155	0.039
EXHAUST	0.029	0.281	0.676	301.155	0.039

	FRE FLO AREA (SQ IN)	HYDRL DMTR (IN)	SRFC AREA (SQ IN)	PRESSURE PSI	PRES DRO INWC	L/HD
PREHEAT	22.801	0.192	5695.434	15.740	0.740	62.45
EXHAUST	57.206	0.397	6916.918	14.766	0.140	30.23

ANALYSIS OF THE FLUIDS

	FLOW SCFH	SP. GR. AIR=1.	MASS FLOW LB/HR	DENSITY LB/CUFT	CH4 WT%	C2H6 WT%	O2 WT%	N2 WT%
GAS BIRMNHM	500.0	0.6000	22.950	0.0459	83.25	8.67	0.0	8.08
AIR	5090.0	1.0000	389.385	0.0765	0.0	0.0	23.14	75.53
COMB PRODTS	5531.5	0.9578	405.308	0.0733	0.0	0.0	1.68	87.38

ANALYSIS OF THE COMBUSTION PRODUCTS (EXHAUST FLUID)

	CO2	H2O	O2	CH4	N2	TOTAL
SPECIFIC HEAT	0.2990	0.5530	0.2617	1.0988	0.2727	0.3003
THERMAL CONDUCTIV	0.0405	0.0540	0.0427	0.1007	0.0374	0.0398
PRANDTL #	0.7577	0.979	0.747	0.755	0.752	0.779
VISCOSITY	0.1026	0.0956	0.1220	0.0692	0.1031	0.1025
% MASS	14.3615	11.4202	1.5939	0.0	72.6845	100.0000
MASS (LBS)	58.2302	46.4987	6.4899	0.0	295.9438	407.1624
DENSITY @S.T.P.	0.1162	0.0476	0.0845	0.0424	0.0740	0.0733
VOLUME	498.93	973.16	76.47	0.0	3982.96	5531.52
% TOT VOLUME	9.02	17.59	1.38	0.0	72.00	100%
% DRY VOLUME	10.95	0.0	1.68	0.0	87.38	100%

**NOTE VOLUME OF H2O IF IT EXISTED AT STP AS AN IDEAL GAS

THERMODYNAMIC PROPERTIES OF FLUIDS (AT AVERAGE TEMPERATURES)

AVERAGE PREHEAT TEMP = 511.5 (DEG. F) (539.4DEG. K)
AVERAGE EXHAUST TEMP = 1427.0 (DEG. F) (1048.0DEG. K)

	TEMP IN DEG F.	TEMP OUT DEG F.	FLOW SCFH	FLOW ACFH	SPEC HEAT
PREHEAT	80.0	943.0	5090.0	5285.8	99.1308
EXHAUST	1864.0	990.0	5531.5	24721.6	124.9472

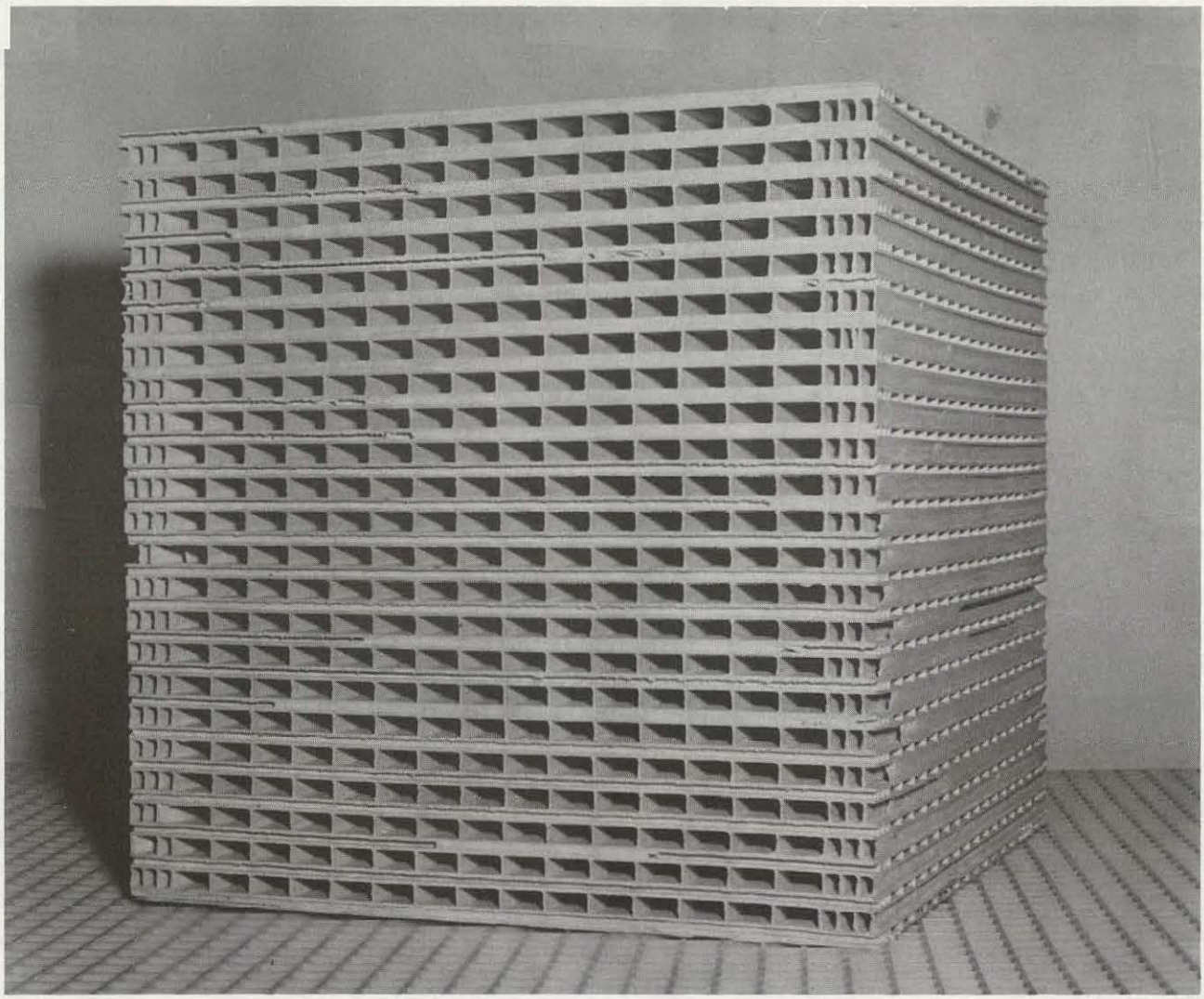
CMIN/CMAX 0.79338
LOG MEAN TEMP DIFFERENCE 477.66162

	FLOW SCFH	VELOCITY FT/SEC	MASS FLOW LB/FT**3	DENSITY LB/FT**3	SPEC HEAT BTU/LB F	VISCOSITY LB/HR FT
PREHEAT	5090.00	9.273	389.38	0.0409	0.255	0.0690
EXHAUST	5531.52	17.286	405.31	0.0201	0.308	0.1025

	AVG TEMP F	THER CND BTU/HR FT F	EFFCTNSS	HT TRNS BTU/HR	THER CNDCTNC	RENLDS #
PREHEAT	511.50	0.0244	0.4837	85549.9	4.5293	570.72
EXHAUST	1427.00	0.0398	0.6175	-109203.8	4.7596	329.44

	NTU	PRANDTL #	STANTON #	HT TRANS COEF	FRICTION FACTOR
PREHEAT	1.807	0.719	0.014952	0.011999	0.087235
EXHAUST	2.306	0.779	0.030889	0.026152	0.097679

Figure 11



Ceramic Matrix (Model 1000)

Table VII

Ceramic Recuperator Performance

Per Ft^3 of Matrix

Effectiveness, E	-	Min.	30 - 50%
	-	Max.	60 - 70%
Air Flow, (Recommended)	-	Min.	3,000 scfh
	-	Max.	20,000 scfh
BTU (Recommended)	-	Min.	300,000 BTU
	-	Max.	2,000,000 BTU
Cost (11/1/79)	-	Min.	$1,400
	-	Max.	$2,000

INDUSTRIAL UTILIZATION OF A RECUPERATOR

Experimentation with various control systems on various types of furnaces is taking place. Continuous furnaces are the simplest challenge for a ceramic cross-flow recuperator. In a control system, the input range varies slightly, minimizing the need for rapid air flow rate changes. The ability to maintain precise stoichiometric ratios is clearly optimized here.

Oxygen analysis, digital flow controllers linked with differential pressure tranducers, & furnace pressure control, are all methods under investigation for control over wide ranges of input. Another system result is a flow sensitive control system. In this system, a double diaphram regulator receives a flow signal (pressure) from an orifice plate downstream of the recuperator. The multiplied signal is then (from the smaller diaphram side) transmitted to the

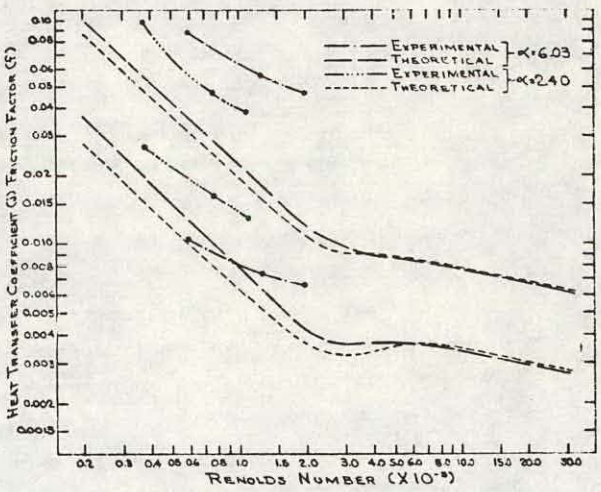
ratio regulator on the gas line. The simplicity of this system, allows for easy modification of kiln systems, making the retrofit market feasible. Figures 14a and 14b compare a system with bias control (multiplying regulator) and a recuperator, to a system without recuperation. Figure 13 compares the results of each system. A 44% reduction of fuel was observed. This data was generated after six months of service, without any "tune up." A torch test showed that minimal O_2 was available in the exhaust products proving that controlled stoichiometries of approximately 2% excess air had been maintained. The furnace shown is a 900 pound capacity aluminum melting furnace. The furnace was fabricated and designed by Hamilton Thermal Specialties Ltd., of Hamilton Ontario, Canada. The recuperator is a 1 cubic foot unit with a matrix as described in Figure 11, 14, 15 and Table VI.

CONCLUSION

The design of a compact heat exchanger, utilizing the most sophisticated ceramic processing and materials has been completed by GTE Products Corporation. Industrialization of the units is now proceeding. The predicted increase in systems economy has been demonstrated in various applications, one of which is the aluminum pot melting furnace. Control systems for maintaining stoichiometries are somewhat more elaborate than standard control system, however, in many applications they can still be simple and accurate when recuperators are implemented. The increased cost of a 1 mm BTU system can range from $2,500 (recuperator and bias regulator and orifice) to $8,000 (digital control of flow with furnace pressure and O_2 analysis). However, payback periods can still range from as little as three months to two years for complete system improvements. The ultimate goal, however, is the reduction of fuel input necessary for processing and/or increases in production rate.

The optimization of the heat transfer coefficient (j) and friction factor (f) for each process can be accomplished through the interaction of GTE's test furnace and computer simulations. The t of the product's integirity has been completed and with proper design, the potential impact of waste heat recovery on energy conservation is vast.

Figure 12



Gas Flow Inside a Rectangular Tube;
Experimental Data

Figure 13

Two 900 pound crucible type, aluminum melting furnaces were commissioned at Brampton Foundries Ltd. in Brampton Ontario in July, 1979. The furnaces are identical except as shown on the diagram. After six months of service, a comparison test was performed under everyday foundry conditions. No "tune-up" of the equipment was done. A torch test showed minimum excess air in the waste gas from either furnace.

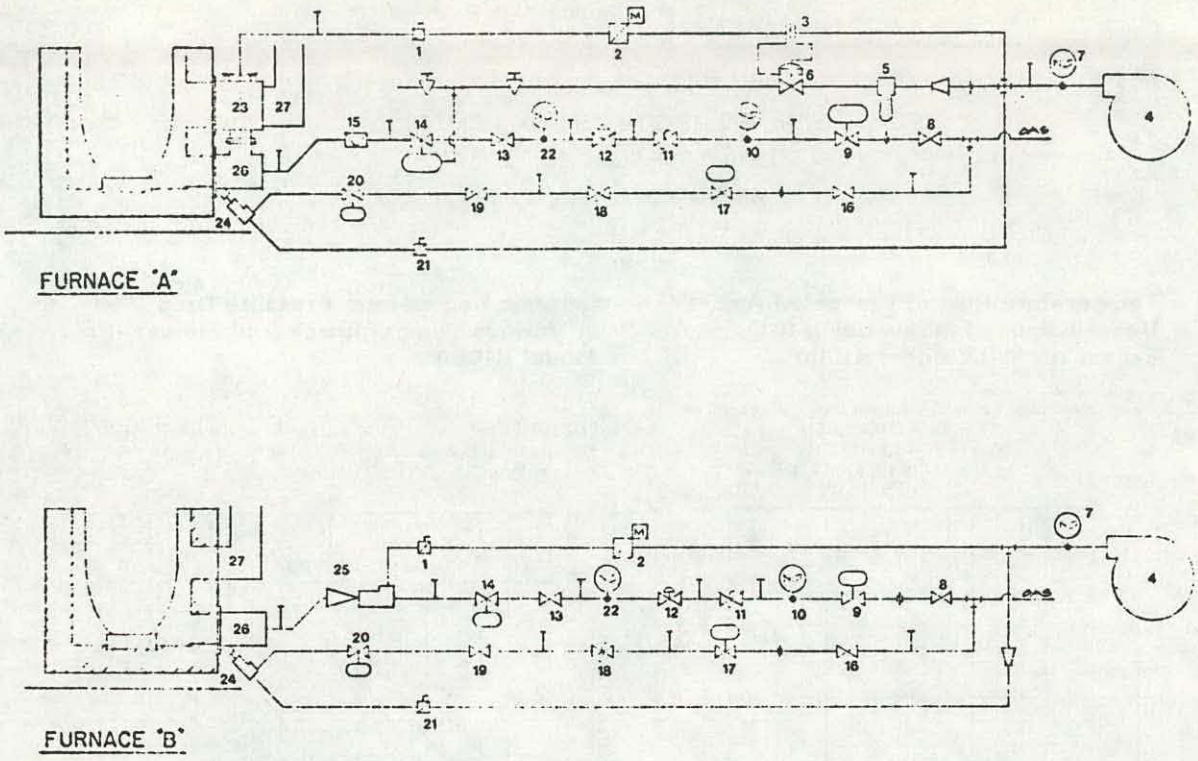
NOTE: The test consisted of weighing ingot aluminum into each cold furnace, starting the furnaces and recording fuel use and time.

The "Reclaimer" equipped furnace, utilizing hot combustion air as recuperated from the waste gases, outperformed the other furnace as shown in the table below.

	melting furnace "A"	melting furnace "B"
burner	hot air nozzle mix	premix
burner capacity	850,000 btu/hour	1,000,000 btu/hour
fuel	natural gas	natural gas
crucible capacity	900 lbs.	900 lbs.
test charge	380 lbs. aluminum	379 lbs. aluminum
time to melt from cold	185 min.	247 min.
natural gas to melt	2137 cu.ft.	3830 cu.ft.
heat recovery	"RECLAIMER"	none
gas saving	3830-2137=1693 or 44.2 %	none
time saving	247-185=62 or 25.1 %	none

Comparison of Recuperated (A) and Unrecuperated (B) Aluminum Melt Furnace

Figure 14



1. Manual shut off valve
2. Motorized shut off valve
3. Orifice
4. Combustion blower
5. Air filter
6. Multiplying air regulator
7. Air pressure switch
8. Lubricated plug valve
9. Gas regulator
10. Gas pressure switch
11. Solenoid valve
12. Manual gas valve
13. Lubricated plug valve
14. Atmospheric regulator
15. Limiting orifice
16. Lubricated plug valve
17. Pilot regulator
18. Pilot solenoid
19. Lubricated plug valve
20. Pilot zero governor
21. Manual shut off valve
22. Gas pressure switch
23. Reclaimer
24. Pilot mixer
25. Aspirator mixer
26. Burner
27. Flue

Furnace A - 1) Utilizes a recuperator to preheat air.
2) Recuperator is mounted directly to the burner.
3) Ratio control is flow sensitive because of the multiplying air regulator (6) attached to the downstream air orifice (3). The signal (pressure) from the multiplying air regulator then goes to the atmospheric ratio regulator (14) on the main gas line.
4) Burner is a nozzle mix type.

Furnace B - 1) Standard control scheme utilizing a premix type burner (25 and 26).
2) No recuperator; direct exhaust of waste gas.

Control Systems of Recuperated (A) and Unrecuperated (B) Aluminum Melt Furnace

Figure 15

Specifications

Size: 1 cubic foot

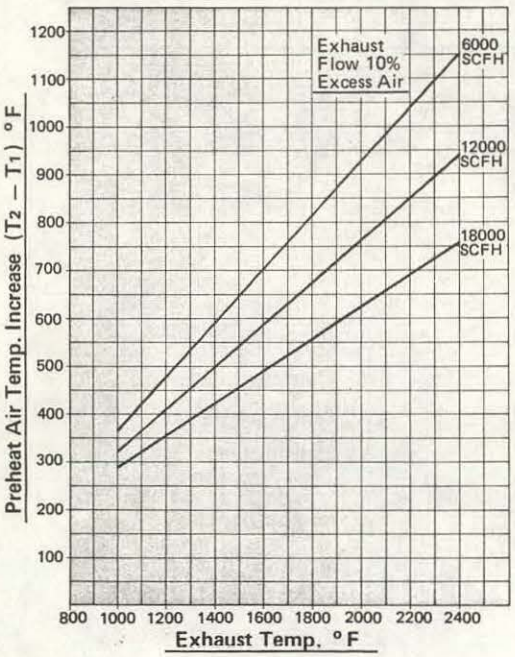
Recommended BTU: 500,000-1,500,000

Exhaust Hole Size: .300" x .750"

Air Hole Size: .125" x .750"

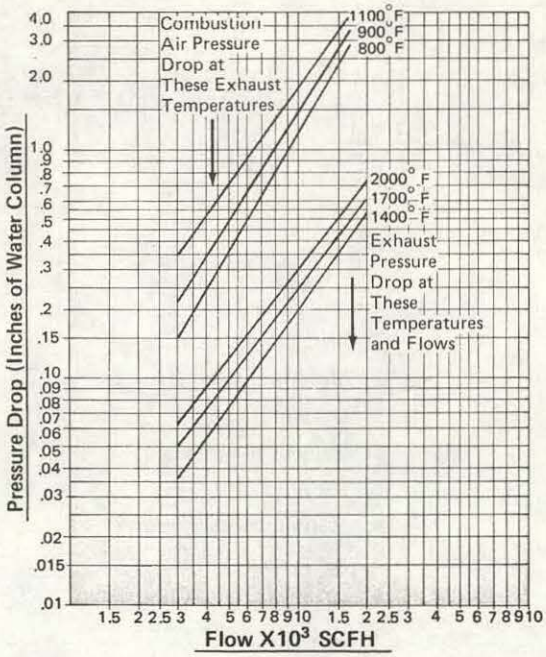
Temperature Rise of Preheated Air Under Balanced Flows Using 10% Excess Air With Model R1000

Example: 1 mm BTU Burner using 10% excess air.
Air Flow = 11000 SCFH
Gas Flow = 1000 SCFH
Exhaust Flow = 12000 SCFH



Ceramic Recuperator Pressure Drop at Various Temperatures And Flows – Model R1000

Preheated Air Temp. at 2000°F Exhaust =770+RT(70)=840°F
Pressure Drop Exhaust .35" H_2O Column
Pressure Drop Air 1.3" H_2O Column



Recuperator Performance

A 1 Cubic Foot Matrix (Model 1000)

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ESTIMATION OF FUEL SAVINGS BY RECUPERATION OF FURNACE EXHAUSTS TO PREHEAT COMBUSTION AIR

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ABSTRACT

The recovery of waste energy in furnace exhaust gases is gaining in importance as fuel costs continue to escalate. Installation of a recuperator in the furnace exhaust stream to preheat the combustion air can result in considerable savings in fuel usage. These savings are primarily the result of the sensible heat increase of the combustion air and, to some extent, improved combustion efficiency. The amount of fuel saved will depend on the exhaust gas temperature, amount of excess air used, the type of burner and the furnace control system. These fuel savings may be accurately measured by metering the energy consumption per unit of production before and after installation of the recuperator.

In the design of a waste heat recuperation system, it is necessary to be able to estimate the fuel saved by use of such a system. Standard industrial practice refers to the method described in the North American Combustion Handbook with its curves and tables that directly predict the percentage fuel savings. This paper analyzes the standard estimation technique and suggests a more realistic approach to calculation of percent fuel savings. Mass and enthalpy balances are provided for both methods and a typical furnace recuperation example is detailed to illustrate the differences in the two methods of calculating the percent energy saved.

INTRODUCTION

Most industrial processes for heat treating and reheating of materials employ furnaces that are fueled with natural gas or oil. In such applications, the furnaces are required to heat the materials uniformly and furnaces are designed to ensure a uniform temperature distribution. One method of achieving temperature uniformity was to use large amounts of excess air. The stoichiometric air fuel ratio for natural gas is approximately 10:1. In some steel industrial furnaces operating from 700 °F to 2200 °F, excess air use could be as high as 600 percent at the low temperature to approximately 50 percent at the higher temperature. Thus, temperature uniformity was achieved with the use of large excess air values but required increased fuel usage. Therefore, one way to obtain energy savings in these applications would be to substantially reduce the quantities of excess air used while still maintaining temperature uniformity through appropriate furnace design.

Another method of obtaining energy savings is to use recuperators to preheat the combustion air to the furnace. The fuel saved would primarily result from the increase in sensible heat of the combustion air. An added advantage would be the improved efficiency of the combustion process itself. Recovery of waste heat normally exhausted into the atmosphere is now getting serious consideration as one of the most viable methods of energy conservation. The price and supply of all

forms of energy is now demanding that processes be run as effectively as possible and preheating combustion air by waste gas recuperation can save up to 40-60% of the fuel previously used. The amount of fuel saved will depend on control systems, amount of excess air, type of burner and temperature of the furnace exhaust. The higher the temperature of the furnacing operation, the greater the amount of energy that is lost up the exhaust stack to the atmosphere. Furnaces that run at temperatures of 1800 °F or above lose about 50% of their energy input through their flue gas exhaust.

Experience has shown that furnace operators do not follow set furnace operating specifications and fuel and excess air usages vary considerably depending on each individual application and the particular furnace load. Furnace operators are more concerned with meeting production targets and will do so by adjusting fuel and air inputs to the burner so as to obtain the best operation conditions in the furnace irrespective of fuel economy. The ideal system for determining the energy savings resulting from recuperation of furnace exhausts would be to meter the fuel input to the furnace before and after the use of the recuperator. However, in many industrial plants, fuel usage in individual furnaces may not have been monitored on a continuous basis. Therefore, base line energy consumption, per unit of time or per unit of production, may not have been established prior to installation of the recuperator.

Thus, if no prior fuel usage data is available, it becomes necessary to be able to calculate the fuel consumption per unit of time for given furnace operating conditions. When a recuperator is designed and sized for the given application the fuel consumption may likewise be calculated so as to obtain the energy savings when a recuperator is used. The remainder of this paper deals with the standard technique for estimating fuel savings by recuperation and suggests a more conservative approach in calculating energy savings.

MASS AND ENERGY BALANCES

Before detailing the methods used to calculate energy savings, it would be desireable to review the basic mass and enthalpy balances around the furnace and recuperator. For the basic calculations dealing with the combustion of a fuel with air, reference may be made to any standard text on thermodynamics. The example discussed in this paper uses methane as the fuel for simplicity of calculations. The stoichiometric air/fuel ratio for methane is 9.52 $ft.^3$ air/$ft.^3$ methane or 17.27 lbs. air/lb. methane. The lower heating value of methane is 910 BTU/$ft.^3$ or 21,500 BTU/lb. and the adiabatic flame temperature is about 4025 F. For the case of 10% excess air, used in the subsequent example, the air fuel ratio is 10.47 $ft.^3$ air/$ft.^3$ methane or 18.97 lbs. air/lb. methane and the resulting flame temperature, without losses, is 3340 F.

Before Installation of a Recuperator

In a typical furnace operating without a recuperator, the combustion products enter the furnace, transfer energy to the material in the furnace with some losses through the furnace walls and openings. They exit from the furnace at approximately the furnace temperature and are exhausted up the stack. A system schematic without a recuperator is depicted in Figure 1.

A mass balance can be performed on the system as follows:

$$m_1 + m_2 = m_3 = m_4 \qquad (1)$$

Where

m_1 = mass of methane entering burner (point 1)

m_2 = mass of air entering burner (point 2)

m_3 = mass of products entering furnace (point 3)

m_4 = mass of exhaust gas exiting the furnace (point 4)

The equivalent energy balance equation for the furnace configuration in Figure 1 is:

$$m_1h_1 + m_1\Delta H_R + m_2h_2 = m_3h_3 = m_4h_4 - Q_L \qquad (2)$$

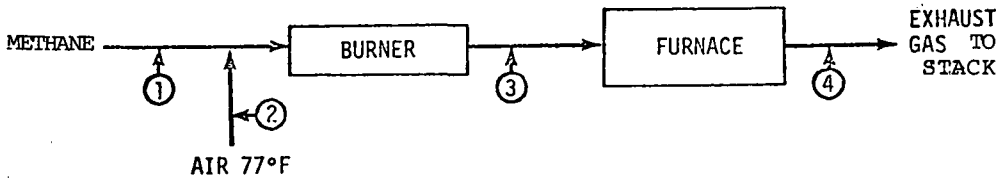


Figure 1 System Schmatic Without Recuperator

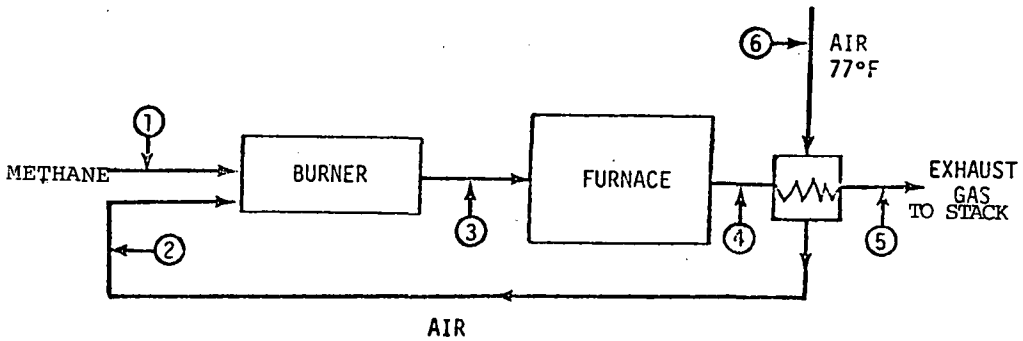


Figure 2 System Schematic With Recuperator

Where

m = mass rate of flow (lb/hr)

h = enthalpy (BTU per pound)

ΔH_R = heat of combustion of fuel

Q_L = heat lost in furnace to heat the load and to account for losses

After Installation of a Recuperator

Now consider a ceramic recuperator installed in the exhaust gas stream (Figure 2) that preheats the combustion air.

A mass balance for the overall system would give the following equations:

$$m_2 = 18.97\ m_1 \text{ (with 10\% excess air)} \quad (3)$$

$$m_1 + m_2 = m_3 = m_4 = m_5 \quad (4)$$

$$m_2 = m_6 \quad (5)$$

An energy balance would give the following three equations:

$$m_1h_1 + m_1\Delta H_R + m_2h_2 = m_3h_3 = 19.97\ m_1h_3 \quad (6)$$

$$Q_L + m_3h_3 = m_4h_4 \text{ or } Q_L = 19.97\ m_1(h_4-h_3) \quad (7)$$

$$m_2h_2 - m_6h_6 = m_4(h_4-h_5) = 19.97\ m_1\ (h_4-h_5) \quad (8)$$

Where m = mass rate of flow (lb/hr)

ΔH_R = lower heating value of the fuel for methane ΔH_R = 910 BTU/ft^3=21,500 BTU/lb)

Q_L = furnace load and losses

STANDARD METHOD FOR CALCULATING FUEL SAVINGS (METHOD 1)

If the methane input to the burner (m_1) and the stack gas temperature (t_4) are given for a specific application, the total enthalpy input to the furnace (m_3h_3), the furnace load and losses (Q_L) and enthalpy lost through the stack (m_4h_4) may be computed by using equations (1) and (2). The temperature of the combustion products (t_3) may be calculated from equation (2) by assuming a value of t_3 and balancing equation (2) in an iterative process. The iterative procedure may be avoided by referring to a standard combustion text for a plot of the theoretical flame temperature versus excess air for the specific fuel. For the purposes of this paper, figure 3 may be used if the combustion product enthalpy (h_3) in BTU/lb. is calculated from equation (2).

When a recuperator is now installed in the furnace exhaust stream to preheat the combustion air

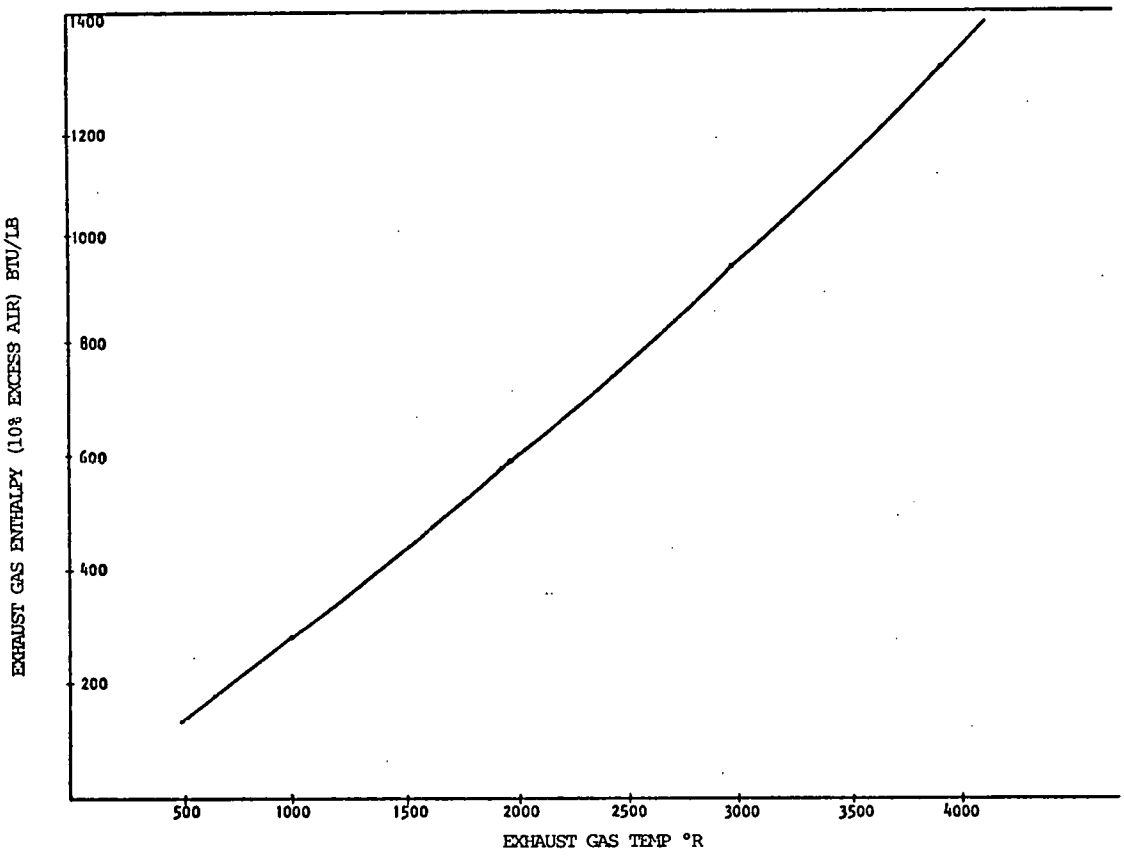


FIGURE 3 - ENTHALPY FOR A GIVEN EXHAUST GAS TEMPERATURE WITH 10% EXCESS AIR

TABLE I

% FUEL SAVINGS AT VARIOUS FURNACE
EXHAUST TEMPERATURES & COMBUSTION AIR PREHEAT

Furnace Exhaust Temp °F	Preheated Air Temperature °F						
	600	800	1000	1200	1400	1600	1800
2800	37	45	51	56	60	64	67
2600	30	37	43	48	53	56	60
2400	26	32	38	43	47	51	54
2200	23	29	34	39	43	47	50
2000	20	26	31	35	39	43	46
1800	18	24	28	33	37	40	--
1600	17	22	26	30	34	--	--
1400	15	20	24	28	--	--	--
1200	14	19	23	--	--	--	--
1000	13	18	--	--	--	--	--

Fuel - Natural Gas @ 10% excess air.

(see figure 2), and the exhaust gas inlet (t_4) and outlet (t_5) and air inlet (t_6) and outlet (t_2) are now known, the following questions need to be answered:

- What are the mass and energy balance relationships?
- How much energy is now lost up the stack with the recuperator?
- How much fuel is saved by using the recuperator?

These questions may be answered providing the following assumptions are made:

Assumption 1: The furnace load and losses are the same as before, i.e., without the recuperator (or Q_L is kept constant).

Assumption 2: The exhaust gas temperature leaving the furnace is the same as before, i.e., without the recuperator (or t_4 is kept constant).

Assumption 3: Burner excess air is the same.

The first assumption seems logical because it is imperative, in any industrial application, that furnace load be maintained or that production should not decrease when a recuperator is used. The second assumption is logical because the furnace operating temperature should be the same even if a recuperator is in use.

Calculations to determine the methane usage with a recuperator and hence the fuel savings, may be performed using equations (3) through (8). First the enthalpy of the combustion products (h_3) is determined by using equation (6) modified as below (for 10% excess air):

$$m_1 h_1 + m_1 \Delta H_R + 18.97\ m_1 h_2 = 19.97\ m_1 h_3$$

With h_3 known, the combustion product temperature (t_3) may be determined from figure (3). Equation (7) may now be used to determine the methane flow rate (m_1) because of the assumptions that Q_L and t_4 were the same as before the recuperator was used. The percent fuel saved is now calculated based on the difference in methane usage with and without recuperation.

One may determine the percent fuel saved with recuperation by following the graphs and tables presented in the "North American Combustion Handbook" published by the North American Manufacturing Company, Cleveland, Ohio. The percent fuel saved is defined in terms of "Available Heat" which is the gross heat released within the combustion chamber less the stack losses. The fuel savings calculations are presented in tabular form similar to Table I presented here. This table presents the results of energy balances based on the same three assumptions listed above and may be used to directly obtain the energy savings with recuperation. Performing the detailed calculations using the above equations, however, gives the engineer a better feel for what happens around the system when a recuperator is used.

RECOMMENDED METHOD FOR CALCULATING FUEL SAVINGS (METHOD 2)

It has been the experience of the authors that in some instances, the percent fuel saved, as presented in Table 1, is difficult to achieve in a practical application. This is particularly so in cases where the furnace operator has tuned the furnace to operate efficiently and where the furnace design is such that convective heat transfer plays an important role in transferring heat to the furnace load. An efficiently operated furnace is indeed a rare occurrence in practice mainly because the furnace variables are not carefully monitored. It is common practice that only when a recuperator is installed, are the operating parameters adjusted and the furnace fine tuned. This often results in actual fuel savings greater than predicted by Table I partly because the use of preheated air requires less fuel and partly because the furnace itself is operating more efficiently due to the adjustments made.

It may be appropriate at this stage to briefly analyze what happens to the system when a recuperator is used. Obviously, the furnace itself does not see what is happening downstream from it. However, it does know the energy input, the quality

of that energy and how it was designed to transfer that energy to the load. The use of preheated air to the burner results in a small improvement in combustion efficiency, especially if oil is used as fuel, a change in the characteristics of the flame front and a higher temperature of the products of combustion. The furnace sees a quantity of gas entering at a higher temperature but at a reduced mass flow rate (as less fuel is combusted with the same air/fuel ratio). The higher temperature increases the heat transferred by radiation while the reduced mass flow rate decreases the heat transferred by convection. It is difficult to determine quantitatively the increase in radiation and decrease in convection for a generalized furnace configuration unless the specific furnace design is known. Thus, it is difficult to quantitatively predict the change in the furnace efficiency resulting from the use of preheated air.

Since the furnace does see the total energy input to it and the furnace design remains the same when a recuperator is installed, it is safe to assume that the production load will be maintained (this is of extreme importance) provided the total energy input to the furnace is held constant. This assumption forms the basis of the recommended method of calculating the fuel savings and is presented below:

Assumption 1: The total furnace energy input is the same as before the recuperator was installed (i.e., $m_3 h_3$ is kept constant)

Assumption 2: The exhaust gas temperature leaving the furnace is the same as before the recuperator was installed (t_4 is kept constant).

Assumption 3: The burner excess air is held constant.

The calculations use the same basic equations (1) through (8) as presented before. The first step is to use equation (6) to calculate the specific enthalpy (h_3) at point 3 (refer to Figure 2). The temperature of the combustion products (t_3) may now be determined from figure (3). The total energy input to the furnace (H_3) assumed the same as before the recuperator was installed, is now used to determine the mass of methane used (m_1), thus $19.97\ m_1 h_3 = H_3$.

The savings in methane is now determined and the stack losses and other parameters determined as before using equations (1) through (8). Note that the furnace load and losses are now calculated by using equation (7).

ILLUSTRATIVE EXAMPLE

The differences in the two methods for estimating energy savings are best illustrated by considering a practical application.

Problem:

A furnace on a galvanizing line is fired by natural gas with 10% excess air. The fuel input to the burner is 3.8 MM BTU/hr. The gases leave the furnace at 1500 F and are exhausted out of the stack. Because of restrictions on fuel usage and rising fuel costs, a decision is made to install a recuperator to preheat the combustion air. A quotation from a recuperator manufacturer sizes a unit and estimates the operating characteristics of their unit as follows:

Exhaust gas temperature entering the recuperator = 1500 F.
Exhaust gas temperature leaving the recuperator = 885 F.
Ambient temperature = 77 F
Preheated combustion air temperature = 650 F.
How much fuel is saved by the use of the recuperator?

Solution

For simplicity, methane will be assumed as the fuel. The excess air, 10%, will also be assumed to be constant. The amount of methane currently used is directly obtained from the given burner input. Equations (1) and (2) are then used to calculate the furnace input, the energy exhausted out of the stack and the furnace load including losses (Q_L). When the recuperator is installed,

TABLE II

SUMMARY OF ILLUSTRATIVE EXAMPLE RESULTS

FURNACE/RECUPERATOR PARAMETERS	WITHOUT RECUPERATOR	WITH RECUPERATOR INSTALLED STANDARD TECHNIQUE METHOD 1	WITH RECUPERATOR INSTALLED RECOMMENDED TECHNIQUE METHOD 2
Mass Flow Rates - lb/hr.			
Methane	177	146.5	160
Air	3358	2779.0	3030
Exhaust Gas	3535	2925.5	3190
Temperatures °F			
Methane	77	77	77
Air	77	650	650
Combustion Products	3280	3610	3610
Furnace Exhaust	1500	1500	1500
Stack Gas	1500	885	885
Fuel Input to Burner MM BTU/hr.	3.800	3.150	3.440
Enthalpy Input to Furnace - MM BTU/hr.	4.291	3.935	4.291
Furnace Load & Losses			
MM BTU/hr.	2.223	2.223	2.424
% of Furnace Input	51.81	56.50	56.50
Exhaust Gas Enthalpy Entering Recuperator			
MM BTU/hr.	-	1.711	1.866
% of Furnace Input	-	43.50	43.50
Stack Gas Enthalpy			
MM BTU/hr.	2.068	1.126	1.228
% of Furnace Input	48.19	28.61	28.61
Heat Transferred from Exhaust Gas in Recuperator - MM BTU/hr.	-	0.585	0.638
Heat Transferred to Combustion Air in Recuperator - MM BTU/hr.	-	0.389	0.424
% Fuel Savings	-	17.25	9.6

equations (1) through (8) are used to calculate the operating parameters by methods 1 and 2. The results of the calculations are summarized in Table 2.

In method 1, the furnace load and losses of 2.223 MM BTU/hr have been assumed to be the same and the fuel input to the burner and the enthalpy input to the furnace calculated. Note that the combustion product temperature has increased to 3610 F and the furnace efficiency increased. The fuel savings amounts to 17.25%. While the calculations are consistent with the first law of thermodynamics, whether or not the furnace production can be maintained in practice, with the decreased flow and decreased energy input to the furnace, will depend on the specific furnace design.

In method 2, the energy input to the furnace is kept the same as before recuperation and the increased combustion product temperature ensures that the furnace production will be met. Note the increase in furnace load and losses to 2.424 MM BTU/hr. This small increase may be attributed to the increase in radiation losses due to the increased combustion product temperature. The estimated fuel savings is now 9.6%.

CONCLUSION

It is recommended that method 2 be used in estimating fuel savings from recuperation of furnace exhausts. It is a more conservative approach and ensures that the furnace production will be maintained after the recuperator has been installed. The estimation of fuel savings is more realistic, particularly in cases of furnace designs that transfer heat, in large part, by convection.

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THE USE OF INFRARED SCANNING IN THE FOOD AND FIBER INDUSTRY

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During the nineteenth century came the discovery that all objects absorbed and re-emitted heat and that the color of the object determined the amount of absorption that would take place. This phenomenon was discovered by an English astronomer who was attempting to find a material to reduce the glare in telescopes. Today it is known as the infrared spectrum of the electromagnetic spectrum.

On the micron scale photographic film would appear in the 0.4 to 0.7 range, while infrared film is available in the 0.7 to 0.9 range. So, true invisible infrared starts on the scale at about 1, and the instruments in use today go as high as 14 microns. Space age technology makes it possible to detect this invisible energy. By using the fields of physics and optics, technologists can convert this radiation to an electronic signal and manipulate it to solve problems.

There are a number of scanning devices with differing capabilities on the market. The equipment that appears to be the most versatile and accurate is that manufactured by AGA Corporation. It is accurate to 0.2°C. at +30°C. with an object temperature of -20°C. to 900°C., with special filters as high as 2000°C. This instrument has a viewing screen on which a polaroid camera can be attached to reproduce an image. The photograph provides a permanent record with information that assist in determining the temperature rise of an object.

In the food and fiber industry two extremes exist: (1) very dusty (2) extremely clean.

Feed mills, flour mills, and grain elevators, for instance, constantly fight the problem of dust which in itself is dangerous when exposed to heat. Malfunctions occur in Dust Systems, Switch Rooms, Hydraulic Pump Rooms and Conveyor Systems to mention a few.

The other extreme can be found in food processing plants where water at 180°F. is used in abundance, creating corrosion in electrical and mechanical equipment. Problems have been found in Boiler Rooms, Freezer Rooms and Ovens to give a few examples. In both instances infrared scanning can detect a malfunction before a critical situation arises.

Infrared scanning serves as an excellent tool to identify inefficiency through poor design, inferior workmanship, or operational failure of equipment or material. An infrared inspection can provide equally accurate information about electrical switch gear, distribution systems, power transformers, ovens, boilers, pumps and bearings. One technician should be capable of covering approximately thirty-five to forty major pieces of equipment in one day.

External inspection of a building may reveal information about its construction failure, such as damaged insulation brought about by a leaky roof. A sidewall inspection may reveal insulation

problems, poor structural design, inadequate or improper heating or cooling.

An infrared inspection initially defines the areas in which a heat differential exists. Management can then study the photographs and temperature information to set priorities for corrective maintenance. Critical areas can be spotted and attended to immediately, while areas with lesser temperature rise can be treated as time and manpower permit. Time is not wasted on checking materials or equipment with no temperature rise. Thus, costs are reduced because certain preventive maintenance need not be performed on an entire system.

Another advantage of an inspection is reducing costly lost production time. Minor problems can be corrected before they become major ones, and men and machinery are not idle because of malfunction. Some firms are also finding that they can reduce the man days required for their preventive maintenance programs. Infrared scanning is efficient, precise and cost effective.

ENERGY RECOVERY FROM POTATO-CHIP FRYERS

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ABSTRACT

The design, operating characteristics, and energy savings from an energy recovery system employed on a potato chip fryer which became operational in December, 1979, is discussed. The design incorporates a modification to an odor control system which permits heat recovery from the fryer cooking fumes. The fumes consist primarily of water vapor (11 psia) and air (3.7 psia) at a temperature of 275°F. About 10% of the available energy is dissipated in a scrubber which removes particulate material and reduces the mixture temperature to about 195°F. This flow is passed through a water-cooled condenser. The heat absorbed in the water-cooled condenser coils is in excess of 11.5MM BTU/hr. for a 4200 lb/hr potato chip fryer. A majority of this heat is transferred to the building water-glycol heating system. Back-up heating during periods of non-operation, or as supplemental heat on extremely cold days, is provided by a conventional steam-water heat exchanger.

This reclaimed energy is estimated to save 76,000 gallons of No. 6 fuel oil annually by using the heat recovery system rather than conventional steam heat. At current prices, this represents more than $36,000 per year compared to an installed cost of $81,000 for the modified system.

SNACK FOOD PROCESS PLANTS PROVIDE MANY ENERGY RECOVERY OPTIONS

Snack food plants provide many energy conservation opportunities both through improvements in process equipment and because of the nature of the processes themselves. Fryers and toaster ovens utilized in production of potato chips and tortilla chips in current use still have much in common with equipment originally designed when fuel was cheap and engineering time by comparison was expensive. In addition, the importance of taste and the difficulty in quantifying taste or changes associated with equipment changes has tended to inhibit implementation of modifications which would otherwise have been immediately accepted because of energy efficiency improvements.

In the preliminary design for a new snack food nt at Charlotte, N.C., we investigated alternative energy recovery approaches. This study included evaluation of techniques related solely to HVAC, such as heat wheels and heat pipe heat exchangers, as well as recovery opportunities associated with process equipment. In this paper we will concentrate on recovery from process applications.

The nominal energy use allocation shown in Figure 1 illustrates the major end use of the energy consumed in our typical plants both for process and HVAC. The process uses currently are almost completely associated with convective losses from equipment which are released to the kitchen and energy released through stacks to the atmosphere. The convective losses can be substantially reduced through improved equipment design and are not readily collectable as recovered energy.

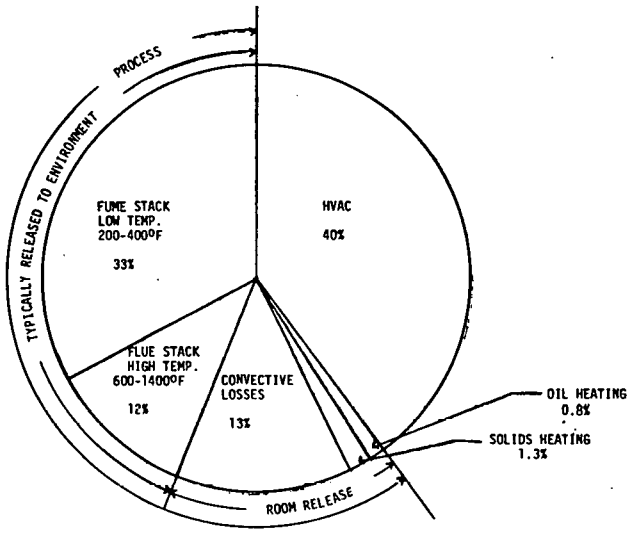


Figure 1. Nominal Energy Use

Energy recovery options are summarized in Figure 2. Both sources (Flue stack, Fume stack, and ventilation exhaust) and uses (Process heating to space heating) are listed in order of decreasing temperature available or required. Where heat is recovered from a process, the most desirable use is the same process. This permits independence and precludes the need to operate two processes concurrently solely because of energy considerations. The connecting bars illustrating applicability show unfortunately that process heating requires the highest quality source, although, in some cases, combustion air preheat could utilize a lower temperature source and maintain connection between the source and use.

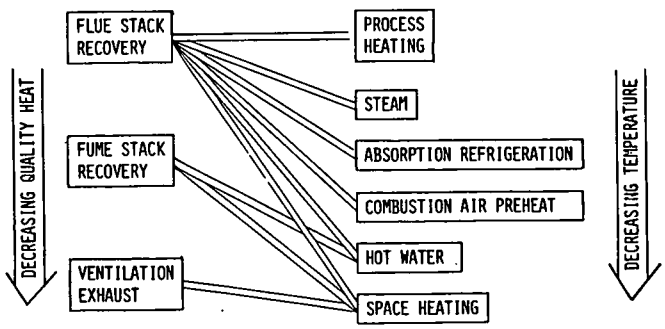


Figure 2. Energy Recovery Options

RECOVERED PROCESS FLUE HEAT HIGH QUALITY BUT UNECONOMIC

There are two major process wasteheat sources, exhausted combustion products and process fumes. It is convenient to designate these as flue heat and fume heat respectively. The quantity of flue heat available is a measure of the inefficiency in the combustion process and inefficiency in removing heat from the combustion products. Fume heat, that heat associated with a water vapor which is removed from the product being cooked, is one of the basic byproducts of the cooking process. While waste flue heat can be reduced considerably through improved equipment design, the fume heat is a necessary part of the cooking process. In our review of energy conservation options, we examined the possibility of recovering heat from flue stacks using stack mounted heat exchangers and a fluid circulation system connecting all of the various cookers, ovens and boilers. Although this approach was estimated to be capable of providing about 3,000,000 Btu's per hour of high quality heat, it was rejected as a viable alternative because it would have complicated our combustion controls, the majority of which operate with natural draft. Further, it would have been only marginally cost effective because of the large number of heat recovery units required.

The low temperature of the fume stack exhaust makes it a dubious source for energy recovery. The sheer volume of energy available from the fumes of a large potato chip fryer, however, makes consideration of the use of this heat very worthwhile. A nominal energy and potato balance for such a unit is illustrated in Figure 3.

Note that the potato chip yield is about 25 percent of the potato weight entering the fryer. The loss is water which is vaporized in the cooking process. The great majority of the heat obviously goes into the fume exhaust. Interestingly enough, the physical process superheats the water vapor substantially.The typical stack temperature of the water vapor air fume mixture is about 275°F. Th corresponds roughly to a mass energy balan obtained by superheating the water evaporated from

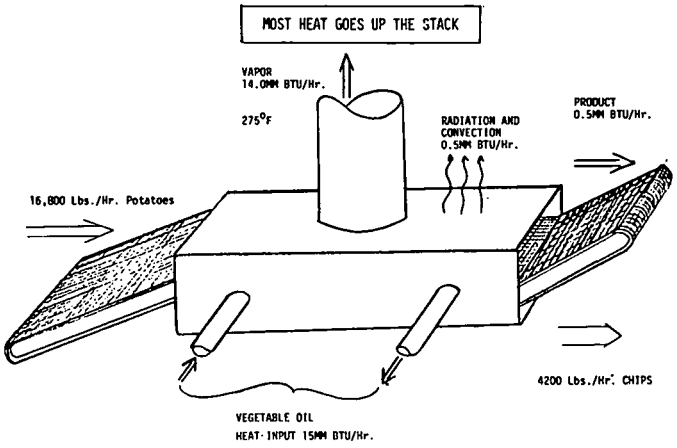


Figure 3. Potato Chip Fryer Energy Balance

the potato slices to the oil temperature and mixing that energy with air ingested as part of the draft process. The partial pressure of the water vapor amounts to about 11 psia.

The 275°F temperature would appear to offer substantial potential for moderate temperature applications, such as, absorption refrigeration. The distribution of the heat between sensible and latent heat, however, limits such applicability. This is shown graphically in Figure 4. Less than 10% of the heat content is removed by cooling the fumes from 275°F to 195°F. In that range only sensible heat is removed. Below the saturation temperature, the heat removed rises rapidly as the temperature falls but this heat is available at too low a temperature for use in an absorption refrigeration unit.

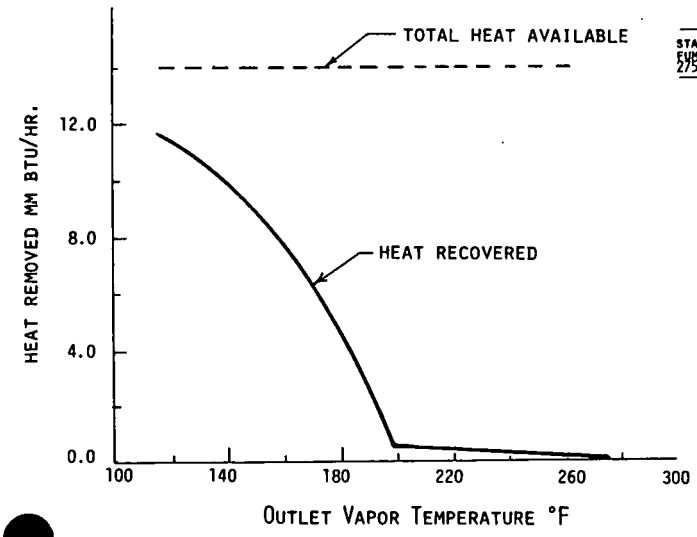


Figure 4. Recoverable Heat Shows Strong Temperature Dependence

When we initially considered recovering the energy in this steam, we found the process to be somewhat unconventional. Manufacturers of condensers for boilers shudder at the thought of condensing from a mixture which is 25% air. On the other hand manufacturers of HVAC equipment are not comfortable with air mixtures containing 75% water. Fortunately, technology has been developed around particulate and odor control which addresses such condensation. A conventional approach outlined in Figure 5 has utilized a cyclone particulate removal system to eliminate oil and other particles which may have been carried aloft with the fumes. This process removes most of the sensible heat in the mixture leaving a scrubbed saturated mixture with a temperature in the 191° - 195°F temperature range. One approach used to reduce odors is to mix the non-condensable components with combustion air and burn them after first condensing most of the water vapor. The condenser section removes water vapor from the mixture. In the system shown, heat removed from the fumes is dissipated in a cooling tower with no particular effort being made to achieve high temperature. In fact, the 132°F outlet temperature is too low for recovery use.

CONVENTIONAL ODOR CONTROL PROVIDES INADEQUATE TEMPERATURE

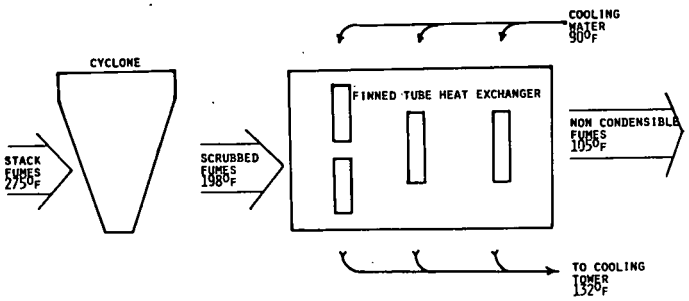


Figure 5. Conventional Scrubber Condensor System

Review of this design showed that by rerouting the coolant water flow through the condenser and changing the fin sections to accommodate the different flow, water could be heated to temperatures high enough to use in a building heating system while still retaining outlet saturated air temperatures of about 105° F, the original fume control design point. Equipment was fabricated and is now in use in accord with this design principle. Appropriate design temperatures and flows are shown in Figure 6.

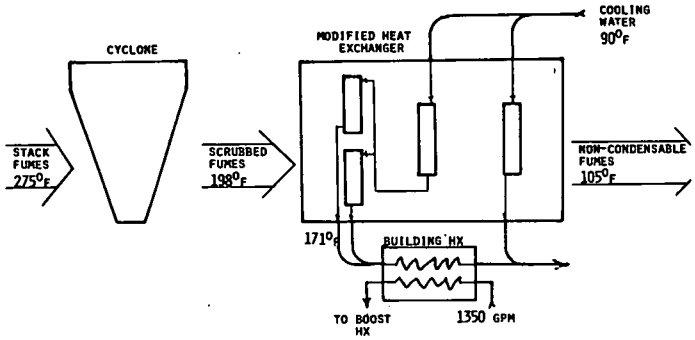


Figure 6. Modified Heat Exchanger Provided Usable Heat

The coils employed in the final condenser design are standard gas-to-liquid direct exchange units with a double circuit flow configuration. All the units have 5/8 inch copper tubing with 1-3/8 inch fins on a eight-to-an-inch spacing. The three coils which heat water for the building heating system have an effective face area of 12.3 square feet and include a total of 44 tubes, while the final coil is somewhat larger with a 15.6 square foot face area and a total of 54 tubes.

The system including odor control and heat recovery units was assembled by Heat and Control, Inc. incorporating our design requirements. Coils were fabricated by Aerofin.

The condenser design point selected actually represents an extrapolation of the manufacturer's data from a conventional regime. Operationally, it is performing satisfactorily.

PRELIMINARY ECONOMICS FAVORABLE

At the time energy conservation alternatives were being examined, preliminary estimates of building heating requirements based on Charlotte weather conditions were made to determine the practicality of using the recovered heat. Coupling this information with nominal Charlotte design weather data calculations showed that the recovery system assuming constant building coolant loop return temperature could provide the heating equivalent of 76,000 gallons of No. 2 fuel. At current prices this amounts to an annual savings of $36,000 compared to a nominal installation cost of $81,000.

SYSTEM CAPABILITIES SOMEWHAT SENSITIVE TO WEATHER

The basic design approach combines the heat energy recovery system with a steam heater back up. This steam heat is modulated to provide a constant outlet temperature of the building glycol loop. On cold days, more heat is removed from the glycol and the inlet glycol temperature to the energy recovery heat exchanger is lower than when the weather is warmer. This provides a feedback loop of sorts to the energy recovery system. There are effectively three regimes of operation which are illustrated in Figure 7. If the outlet temperature of the building water-glycol loop falls below 145°F, steam backup will be required. With one heat recovery unit (HRU) operating, such backup would be expected only for ambient temperatures below 40°F. If the HRU can supply more heat than is required, the building water-glycol temperature will rise. If it would rise above 170°F the additional heat is dumped to the cooling tower.

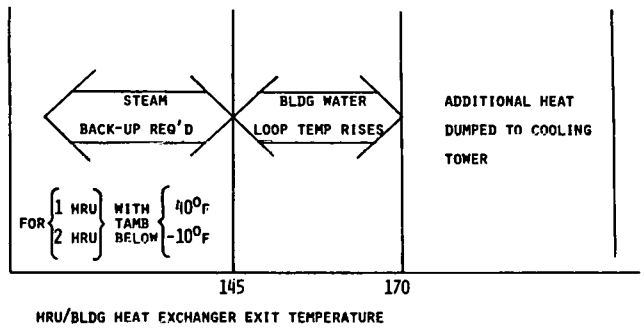


Figure 7. Recovered Heat Used In Three Regimes

PRELIMINARY OPERATIONAL DATA PROMISING

The system has now been operating on a limited basis for a few months using a single fryer. Measured energy recovery data is shown in Figure 8 superposed on the preliminary building design requirements. Each point shown represents several measurements averaged to reduce variation associated with building heater demand variations and potato chip production variations. The data agrees very well with predicted requirements.

To date, operation has been satisfactory but with some minor problems. One of the circulation pumps

failed in one of the heat recovery unit systems ···sing shutdown for a period of time.

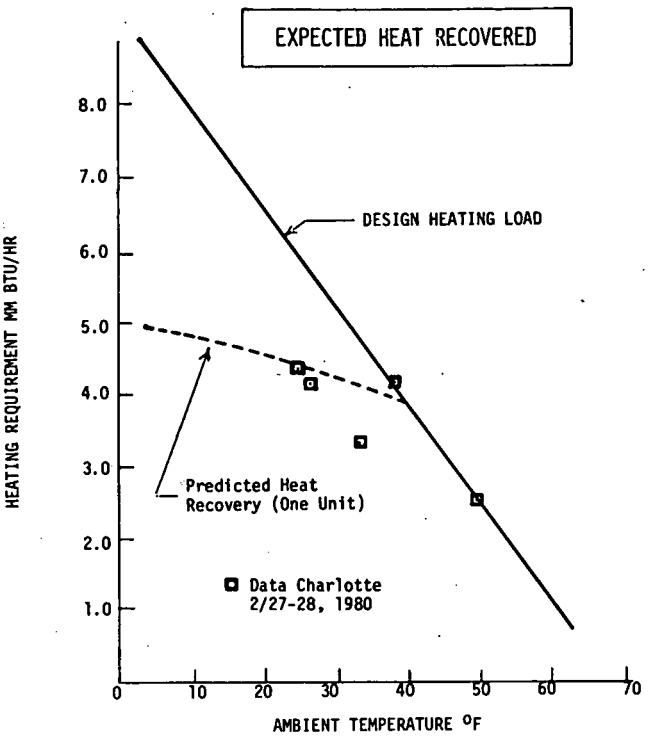


Figure 8. Energy Recovery - Charlotte Data

Although systems are protected with a freeze protection capability consisting of circulation pump designed to maintain flow through the coils, one unit has suffered a freeze failure.

DESIGN IMPROVEMENTS ARE POSSIBLE

Several design changes are possible which would increase the recoverable heat capacity. The design selected employing the scrubber upstream of the condenser heat exchanger is obviously less efficient thermally than would be a unit using a heat exchanger condenser system first. The configuration selected was done primarily to choose a conservative approach which would provide the least risk of contaminating the fin tube surfaces with deposits of particulate material. We are conducting preliminary experiments at the current time to determine whether this step is necessary or whether adequate clean-in-place systems can be provided to permit condensation or to scrubbing.

In addition, the utilization of a fluid-fluid heat exchanger between the heat recovery unit and the building heating system reduces the heat which can be removed. It does provide total system isolation, however, which prevents any cross-coupling between heat recovery unit and building heating system malfunctions. Currently, control options for a future unit in which direct connection would be provided are being investigated.

BUILDING HEAT APPLICATION FOR PROCESS HEAT RECOVERY EFFECTIVE

Long term operational data is still being collected. From the data currently available, however, the use of a normal process residue, waste process heat, even at comparatively low temperature, is proving to be an effective method of energy conservation.

WASTE ENERGY ANALYSIS & RECOVERY FOR A TYPICAL FOOD PROCESSING PLANT

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ABSTRACT

An energy analysis made for the Joan of Arc Food Processing Plant in St. Francisville, Louisiana indicated that a significant quantity of waste heat energy was being released to the atmosphere in the forms of low quality steam and hot flue gases. Additional analysis, measurements, and observations over a period of 12 months resulted in an evaluation of the losses as well as recommended methods for the effective recovery of the waste heat energy. The waste energy recovery results in significant savings in energy costs as well as a reduction in the consumption of scarce fuel.

The research was supported by the Louisiana Department of Natural Resources, College of Engineering, Louisiana State University, and the Joan of Arc Company, St. Francisville, Louisiana.

INTRODUCTION

In 1978, Louisiana State University together with the then Department of Conservation, Natural Resources and Energy Division, joined in a study to reduce natural gas, oil, and electric power consumption within the food industrial sector. Since the food industry is a significant consumer of energy in Louisiana, that particular SIC classification (20) was chosen for a demonstration project.

Accordingly, in the summer of 1978 the subject project was initiated. More specifically, in the SIC 2033 category, "Canned Fruits, Vegetables, Preserves, Jams and Jellies", there exist in Louisiana twelve plants. As of 1978, these twelve plants were primarily dependent on natural gas as the source of power for their process. Recognizing that these industries account for approximately 1500 direct labor jobs and countless other agricultural employment which feed their products to these industries, the State of Louisiana correctly deemed that it is to the interest of the state to assist these employers in alleviating energy problems which, if they became acute, could cause widespread unemployment.

The primary thrust of the research centered around a demonstration project where an investigating group would look at the profile of the energy uses for a chosen installation, evaluate various approaches towards energy conservation, and extrapolate the savings therefrom for the state.

For the demonstration site, the Joan of Arc Canning Company in St. Francisville, Louisiana was chosen. This plant (Figure 1) is primarily an operation which cans sweet and irish potatoes and potato salad.

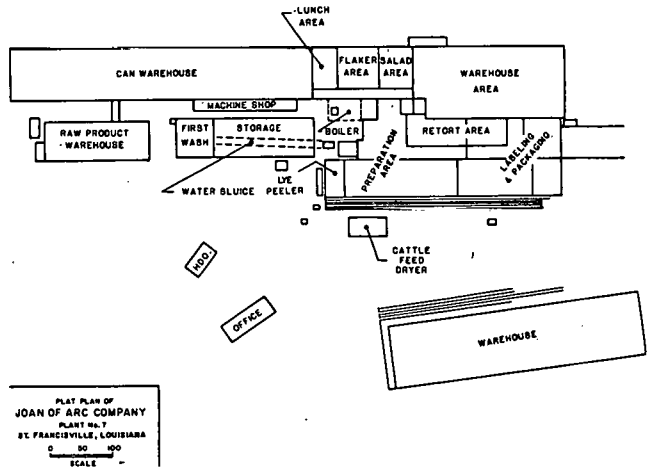


Figure 1. Plant Layout

ORGANIZING A WASTE ENERGY MANAGEMENT PROGRAM

Every plant has some waste energy. A waste energy management program is a systematic study of the sources of energy in a plant and opportunities for its use. This would normally be undertaken as part of a comprehensive energy conservation program. Obviously, a viable waste energy management program implemented in the initial design phases of a new plant would result in greater savings than will a retrofit program. This is not to suggest that significant energy savings are not available in a retrofit program.

The organization and management of a waste energy recovery program is an integral part of the overall energy conservation program. The rewards in the form of reduced energy costs may be great and this constitutes the incentive for committing resources to waste energy recovery.

IMPLEMENTING WASTE ENERGY MANAGEMENT

The first steps taken were to survey the plan process units in order to discover opportunities for recovering and using waste energy. The results of

engineering and economic studies for each process unit were evaluated and are summarized, using appropriate itional information and proposals from manufacturers of waste energy recovery equipment. Although the individual processes were not properly submetered for fuel consumption measurements, Special instruments and observations were used to monitor equipment performance. If full benefit is to be obtained from the capital investment, it is essential that all the equipment be kept in optimum operating condition and this can be assured through adequate instrumentation and an active testing program. One must realize that past metering systems were utilized, not so much as an analysis tool, but as a means for accounting personnel to document receipt of the fuel or energy; however, this should no longer be the prime function of metering and instrumentation.

SOURCES OF WASTE ENERGY

An examination and study of the entire St. Francisville plant revealed several sources of waste energy. Further study and analysis indicated that significant quantities of waste energy could be recovered from several of the sources. It should be noted that the scarcity of fossil fuels as well as a 15 fold increase in its cost now makes economically feasible recovery systems that could not have been considered five years ago.

The principal sources of waste energy which will be considered are:

1. Boiler furnace stack gases
2. Cooking retort surface heat
3. Waste steam from the condensate tank
4. Steam box exhausts
5. Retort purging

Each of the above waste energy sources will be treated as a separate item; however, items 3 through 5 will utilize some of the same equipment for the recovery process.

RECOVERY OF FLUE GAS HEAT

In this section, the economic feasibility of an energy recovery device that preheats combustion air with recovered flue gas energy is determined.

The temperature of the flue gas is approximately 435°F. The diagram below illustrates about the best possible situation which can be realized with an energy recovery unit and an average ambient air ---perature of 70°F. The combustion air is preheated 250°F which represents an increase of $\Delta T = 190^{\circ}F$. The change in exhaust stack gas temperature from 435° to 225°F (well above the dew point for stack gases) is 210°F. The recovery level represents an efficiency of 90% in the preheater system which is readily attainable (Figure 2).

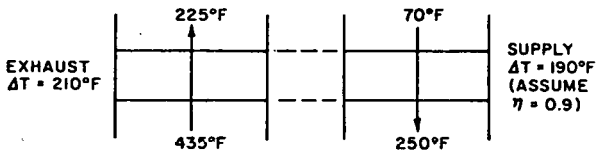


Figure 2. Preheating Combustion Air - Heat Pipe

Calculating the energy saved by preheating the combustion air by $(210^{\circ}F)(\eta) = (210)(0.9) = 190^{\circ}F$:

$$Q = C_{P(air)} (\Delta T) = 0.24(190) = 45.4 \text{ BTU/lbm}$$

In order to calculate the savings per year, gas consumption at 87,785,000 ft^3/yr with 25% excess air is assumed.

The yearly consumption of air was determined using the pressure and temperature metering base for gas as 15.025 psi and 60°F as supplied by the local utility company.

The yearly savings from the stack gas heat recovery are as follows:

Savings = Air MM lbm/yr x Q BTU/lbm x $MM BTU

= 81.9 x 45.4 x $2.50

= $9,296/yr.

The only manufacturer of heat pipe (Figure 3) flue gas energy recovery units estimated the total installed cost of a heat pipe unit to be $40,000. Thus, the investment would be recovered in 4.3 years.

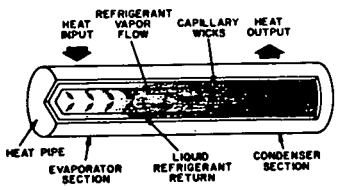


Figure 3. Heat Pipe

Use of a "heat wheel" type of recovery system (Figure 4) would permit the same type and level of energy recovery at a significant reduction in initial cost. Heat wheel applications have been in operation for many years with a very high degree of reliability. It is recommended that the rotating type of heat wheel be utlized since it requires a minimum of maintenance (only minimal surface cleaning during each cycle) when compared to the alter-

nate channel system requiring two hot gas channels and a valve system operating to divert the hot gases. A brief calculation indicates that the stack head loss due to passage over the heat wheel system would be very small. Hence, there would be no need for any draft augmentation system.

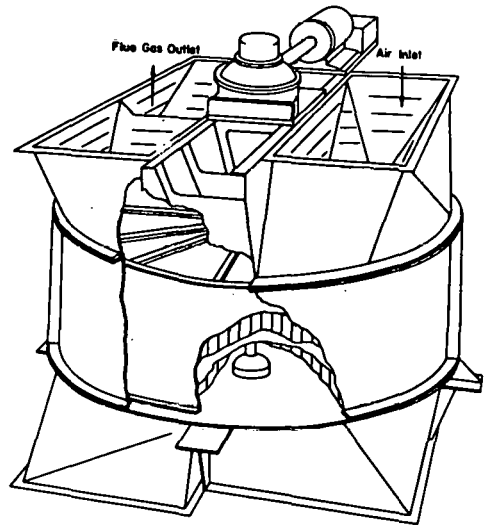


Figure 4. Heat Wheel

Although a firm cost estimate was not available for the rotary regenerative preheater, it is expected that the total cost of this device installed in the St. Francisville plant would not exceed $22,000. With yearly savings from stack gas energy, investment recovery would occur in less than 2.4 years.

From a purely economical viewpoint, the rotary regenerative preheater for combustion air is the better investment; however, further study is necessary to ascertain the required maintenance and cleaning costs for each of the systems to establish the "long term" installation and operational costs. Certainly the reliability of this system has been established by its use in several systems.

INSULATION OF COOKING RETORTS

The retorts are not insulated, therefore energy is lost during the cooking process, and the energy loss has been calculated to determine the feasibility of insulating those vessels. Although this is indicated as energy recovery, it is really a prevention of a present loss which is even more efficient than that which could be obtained by recovery methods.

The retorts are essentially horizontal cylinders of varying lengths and five feet in diameter. The outer surfaces are coated with aluminum paint (emissivity = 0.4) and, at cook condition, the surface temperature is 210°F.

Energy is lost through the cylindrical surfac as well as the ends of the retorts. The curvature of the ends is not known; however, it is small; hence, it will be assumed that the heat flux from the ends is relatively the same as from the cylindrical surface. Energy loss through the cylindrical surface is calculated by relations for free convection from the horizontal cylinder.

The total surface area of all 12 retorts is calculated as follows:

$$A = \pi DL_{tot} + 24\pi D^2/4$$

$$= 5\pi[36 + 9(25) + 2(18.5)] + \frac{24\pi(5)^2}{4} = 5152 \text{ ft}^2$$

In order to compute the energy loss per year, the following calculations are made:

average retort surface area = 62.8 ft^2/basket

From the data provided by Joan of Arc personnel, the following two values were determined:

number of baskets per year = 42,881

average cook time = 54 minutes per retort charge

Therefore the energy loss per year was calculated to be 521.6 MM BTU/yr.

Assuming a boiler efficiency of 70% and fuel costs of $2.50/MM BTU, the estimated cost of the lost energy is $1,862/yr.

After contacting companies in the area, the lowest bid offered a water resistant insulation capable of containing 260°F with less than 2% heat loss at the price of $1.75/$ft^2$.

Further analysis indicates that should six of the twelve retorts be insulated and these six retorts be utilized to fullest extent possible, the effectiveness of the retort insulation would be increased. It is not possible to effect a detailed analysis for this option because the FDA regulations do not permit any significant "holding time" which would be necessary to accomplish the queuing arrangement to achieve, say, 5 or 6 cooks per day in the first six retorts. Extensive observation of the system in operation does lead one to believe that insulation of the first six retorts would cost approximately $5000 and the savings in energy loss would be approximately $1400/yr. These data show that the investment would be recovered in 3.6 years.

WASTE STEAM

Items 3 through 5 will be considered in this section. Although these specific sources are not

the same, the required handling and recovery methods for the waste energy will be similar.

Figure 5 shows a schematic diagram of the steam system for the St. Francisville plant. As can be seen from the schematic, the steam used in the processes of heating, purging, cooking and exhausting is exhausted to the atmosphere. The principal energy loss in the actual cooking process in the retorts has been covered in a previous section.

Although the process steam has served its primary function of providing heat at a specific location in the food processing operation, it still contains a significant amount of energy which is lost or wasted when the steam is exhausted or vented to the atmosphere. This waste results in added fuel consumption and costs. Recovery of this waste energy would provide significant savings in the amount of scarce fuel consumed as well as reducing the cost of operation.

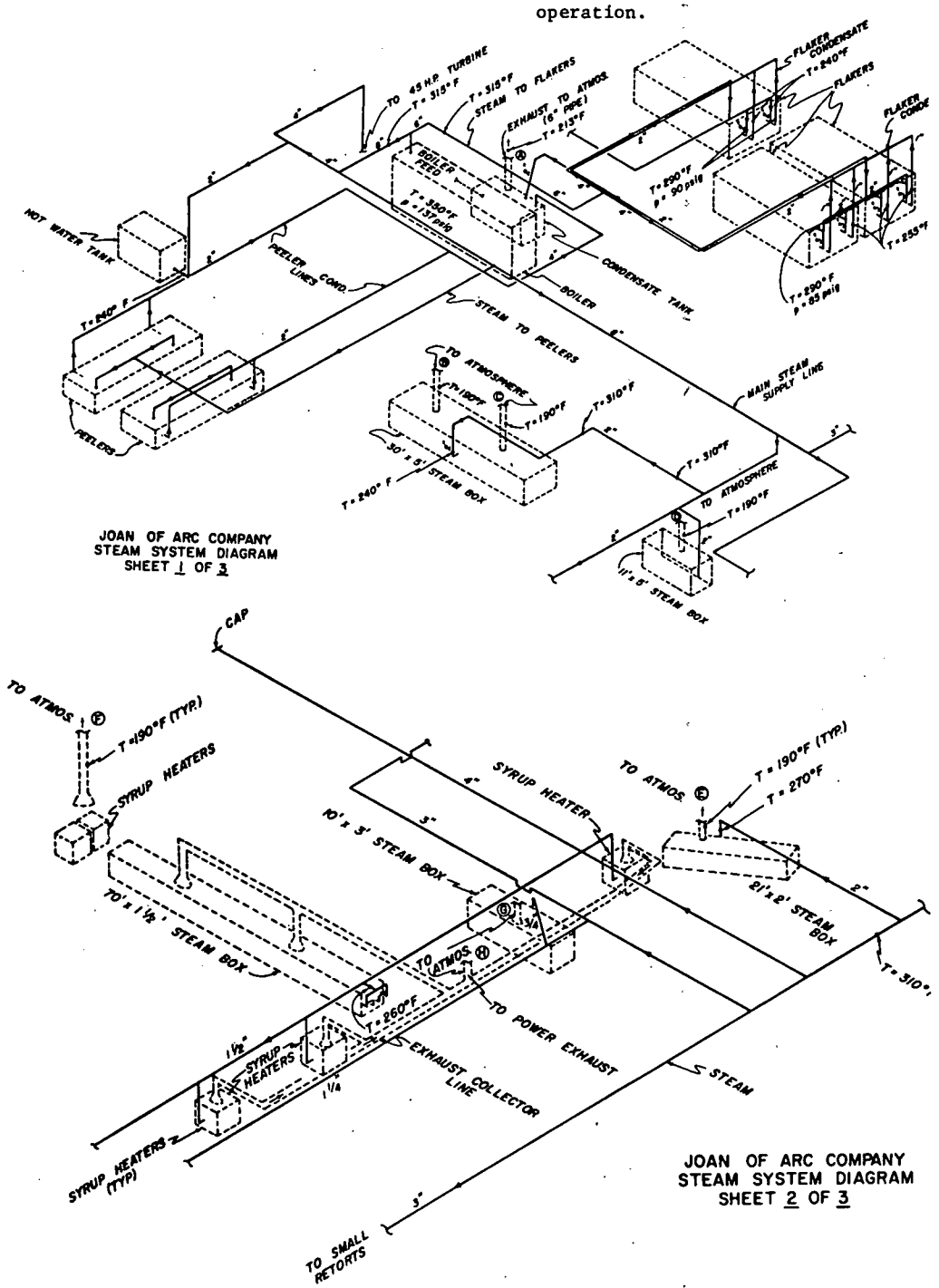


Figure 5. Steam System Layout

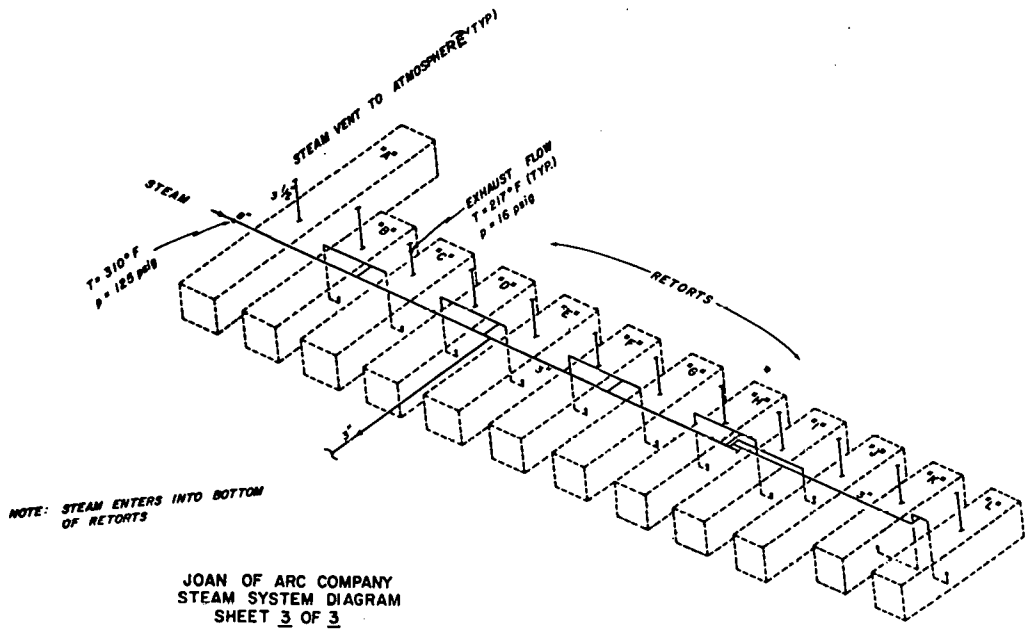


Figure 5. Steam System Layout (continued)

The sources of waste steam energy fall into two broad categories:

1) Continuous flow of waste steam
   a) Exhausting boxes - steam is used to exhaust adsorbed gases from the product and syrup prior to sealing
   b) Syrup heaters
   c) Closure heaters
2) Intermittent flow of waste steam
   a) Steam used to purge the air from the retorts prior to cooking.

The waste steam, although of such low quality that it could not be directly used for processing, does in fact contain a significant amount of energy. The waste steam from the several sources listed varies in pressure, temperature and "quality" among the several sources. Two examples will briefly illustrate this fact.

a) The purging steam from the retorts exits as a vapor at approximately 217°F and a pressure of 16 psia.
b) The steam from the exhausting boxes exits at approximately 15 psia in the form of very finely divided water droplets suspended in a vapor. The temperature was found to vary from 190°F to 200°F.

An evaluation of the waste energy exhausted from the condensate tank, [item A, Figure 5, sheet 1] results in a loss of 4.05 MM BTU/hr. during the operating day. This flow is uncondensed "condensate" which could be used directly as boiler feed water once it has been condensed. The flow escapes as finely divided water droplets and vapor at a temperature of 213°F and a pressure only slightly above atmospheric.

The waste energy exhausted to the atmosphere from the exhausting boxes and heater systems, [items B through H, Figure 5, sheets 1 and 2] results in a loss of 28 MM BTU/hr. during the operating day. This flow escapes as finely divided water droplets suspended in some vapor. The temperature varies from 190°F to 200°F and the pressure is essentially atmospheric.

All of this waste energy could be recovered in the form of hot water which could be used directly as boiler feed water since it has not been contaminated. The problem of condensing the vapor and collecting the finely divided water droplets is discussed in the next section entitled condensing chamber.

It is well to note that the exhausting boxes also produce a significant quantity of very hot water; however, it is contaminated by materials on

the exterior of the filled cans; hence, its potential has not been developed.

The waste energy exhausted from the retorts during the purging [Figure 5, sheet 3] process is intermittent; however, during a normal process day proper management of the processes could produce a condition where the retorts would be purged in a sequence such that there would be an almost continuous flow of the purging steam.

Measurements made at the plant indicate that the purging flow consists primarily of vapor at 217°F and a pressure of 16 psia. There are some finely divided water droplets suspended in the vapor flow. The waste energy exhausted from the retorts during the purging process results in an energy loss of 4.9 MM BTU/hr. for the process day.

The recovery of the retort purging flow poses an additional problem not encountered for any of the other systems. This problem results from a FDA rule which states that there shall be no back pressure on the retort vent line; hence, the vented flow must be captured without producing any restriction to the flow. This requirement, while further complicating the capture procedure, does not preclude capture of the waste energy flow.

CONDENSING CHAMBER

The condensing chamber will exert a slight vacuum on all of the sources of waste steam for two basic reasons: (1) to satisfy the FDA rule of no back pressure on the retort vents and (2) to produce a pressure gradient resulting in the flow of the waste steam from the source into the chamber. The ducts along which the steam flows must be well insulated to conserve the energy. The ducts must also have a slight inclination toward the condensing chamber such that all of the waste steam (including that which condenses to hot water in the ducts) will flow into the condensing chamber. For normal operation, it is expected that an excess of 99% of the flow will be condensed into water in the chamber; hence, the blower required to produce the slight negative pressure will be small. In the final design the capture and condensing systems must operate in the continuous flow and/or intermittent flow modes in a fail-safe manner with no back pressure on the retorts.

A summation of all sources indicates that the duct system from the continous sources to the condensing chamber must be capable of handling 262.7 cubic feet per second for a mass flow rate of 27,580 lbm/hr. The intermittent flow provided by one purging retort produces 4.9 MM BTU/hr. of available energy in a flow of 30.7 cubic feet per second for a mass flow rate of 4,230 lbm/hr. It should be noted that the intermittent flow exits the retort at 217°F and 16 psia; hence, an expansion of the flow within the recovery ducting must be included in the design of the system.

The condensing chamber may be designed to accomplish the condensation of the waste steam to produce hot water at any one of several temperature levels. The selection of a temperature level is dependent on the planned use for the hot water.

At the Joan of Arc plant there is need for hot water for several purposes: heating, boiler feedwater, cleaning purposes, etc. In the analysis of the condensing chamber an efficiency of 95% will be assumed since there is no external work except for the small energy consumption for the fan used to slightly reduce the chamber pressure.

Of the total 45,000 lbm/hr. of boiler feedwater, the presently recovered condensate contributes 11,000 lbm/hr.; hence, the make-up water required is 34,000 lbm/hr. Further analysis of the entire plant indicates the need for 30,000 gallons of hot water each day for clean-up purposes which is a consumption of 250,250 lbm/day. With the assumption of an 8 hour process day, the accumulation of 250,250 lbm of clean-up water requires that 31,280 lbm/hr. be produced.

Further analysis and design may be employed to somewhat reduce the quantity of water produced in the condensing process by making use of the condensing screen technique whereby the "wetting" characteristic of the fluid may be utilized to achieve condensation. Preliminary estimates indicate that approximately 75% of the waste steam may be condensed in this manner. The system is not presently a commercially available item; however, the research development and design of a system would not be overly expensive or difficult. The development of this new condensing system would significantly improve the efficiency of an energy recovery system.

Estimates indicates that a basic condensing system to achieve 180°F hot water would cost approximately $20,000. The fuel savings resulting from the energy recovered in the form of hot water is $58,000/year.

It is immediately obvious that the recovery

system is attractive from an economic consideration provided all the hot water generated by the heat recovery system can be effectively utilized.

CONCLUSIONS

The results of the studies and analysis made for the Joan of Arc Company plant in St. Francisville permit several specific conclusions as concerns the conservation and/or recovery of waste energy:

1. Significant savings in fossil fuel can be accomplished by the recovery of waste energy by the conversion of low energy steam to hot water.
2. The recovery of a portion of the energy from the stack gases would pre-heat the combustion air.
3. The exterior of the large retorts should be insulated to conserve energy losses.
4. The exterior of the larger steam lines should be better insulated.
5. The "waste" energy recovery system could be utilized to produce the hot water needed for plant operations without the costly use of steam to heat the water.
6. The thermal "pollution" of the area could be significantly reduced by some of the recovery systems.

RECOMMENDATIONS

As a result of the studies made to date there are several changes and/or additions which have l recommended for the Joan of Arc Company in St. Francisville:

1. It is recommended that the amount of pertinent instrumentation in the plant be significantly increased and that some of the existing instrumentation be improved.
2. A system to recover "waste energy" from the exhausted low energy steam should be designed and installed. The hot water produced would be used as boiler feed water and as "clean-up" water.
3. A heat exchanger system should be installed to recover energy from the stack gases and the recovered energy used to pre-heat the combustion air.
4. The first seven of the large retorts should have exterior insulation applied to conserve energy during the processing cycle.

STACK-GAS HEAT RECOVERY FROM 100 TO 1200 HP BOILERS

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ABSTRACT

With newspaper reports of March 1980 fuel price increases at as much as a 110% annualized rate, energy users are becoming more keenly aware of the urgency of conserving energy--and energy dollars. It is becomming increasingly more difficult for business to remain competitive while "passing through" fuel cost increases to consumers. As energy becomes an increased percentage of the budget, energy conservation will have an increasing impact on profitability.

While at the time of this writing our nation appears to be blessed with a generally expanding energy supply, not too many months ago commercial and industrial energy users in some parts of the country had experienced energy rationing or even curtailment. In certain industries, this resulted in reduced production and caused personnel layoffs.

U.S. Government reports indicate that roughly 20% of all fuel is consumed in boilers. A savings in boiler fuel comsumption can have a positive impact on energy conservation, and become an important component in the solution of our nation's "energy crisis."

BACKGROUND

Peabody Gordon-Piatt, Inc. having manufactured combustion equipment for the efficient, economical use of energy in boilers since 1949, began looking more closely at boiler stack gas heat recovery for energy conservation in 1975.

Our investigation verified by initial installations, showed that fuel savings of 4% to 15% were attainable from boiler stack gas heat recovery (see figure 2). Where applicable, simple payback of one to four years is typical. In many situations, early positive cash flow can be obtained when the heat recovery equipment is financed on a leased basis.

Boiler industry history reports the use of stack gas economizers (gas-liquid heat recovery to preheat boiler feedwater) as far back as 1910. Their use was limited to utility and large industrial boilers for many years because of the availability of low cost fuel.

As fuel costs increased, boiler stack gas heat recovery became cost effective for boilers in the 100 to 1200 HP size range (Peabody Gordon-Piatt manufactures combustion equipment for boilers of this size).

Research led to the develpment and patenting of Peabody Gordon-Piatt's packaged gas-liquid boiler heat recovery unit, trade marked the HEATMIZER. The unit was "packaged" as a system for ease of application and predictable performance.

APPLICABILITY

Boiler stack gas heat recovery is applicable to steel watertube and firetube as well as cast iron boilers.

Energy recovered can be used to preheat boiler feedwater, to heat water for process, potable or hydronic heating purposes.

With energy cost in the $2.00 to $7.00 per million BTU range, most applications have been to boilers operated in excess of 3,000 hours per year (boilers used for other than strictly winter space heating applications), to provide a reasonable payback of investment.

Typical applications have been in the food processing, textile, metal working, institutional

(hospital), mining, and pulp and paper industries.

DESCRIPTION

The HEATMIZER packaged "passive" type boiler stack gas heat recovery unit consists of: (see figure 1)

A. A counterflow, plate and tube type, ASME stamped heat exchanger, with stainless steel tubes and 1/8" thick aluminum plate. A 50:1 extended heating surface ratio adds approximately 1/3 to boiler heating surface (at 5 square feet of heating surface per boiler horsepower).

B. The heat exchanger is arranged in a stack bypass in a "passive" relationship with the boiler. Energy is recovered when available (flue gases flowing) and when a suitable "heat sink" exists on the liquid side (water flowing). During other periods, such as start-up when boiler feedwater is not flowing, flue gases are automatically bypassed. (Boiler operation is uninterrupted when HEATMIZER is being cleaned, inspected, maintained, etc.)

C. An induced draft fan and draft control system to maintain the same static condition at the boiler breeching as exists without the HEATMIZER (additional boiler pressurization and burner fan static not required).

D. Integral cleaning system. Soot is washed to a drain (not blown into the atmosphere).

E. Corrosion resistant construction throughout. In addition to stainless tubing and aluminum extended surface, a stainless steel fan and Cor-Ten A steel casing is provided. Construction is suitable for operation below the flue gas dew point when natural, L.P. gas, or No. 2 fuel oil is used (operation above flue gas dew point is recommended when fuel is No. 4, 5, or 6 oil).

F. A control panel from which the induced draft fan and draft-control system are programmed and essential functions are monitored.

G. Temperature and pressure indicators.

HEAT RECOVERY SYSTEM BENEFITS

Properly applied, this boiler stack gas heat recovery system can reduce fuel consumption--or extend boiler performance--in the range of 4 to 15 percent. This savings can result in a one to four year payback, particularly when used in conjunction with process boilers or heating boilers which are

TYPICAL HEATMIZER PACKAGED BOILER HEAT RECOVERY UNIT ARRANGED TO RECOVER BOILER STACK GAS ENERGY TO PREHEAT BOILER FEEDWATER

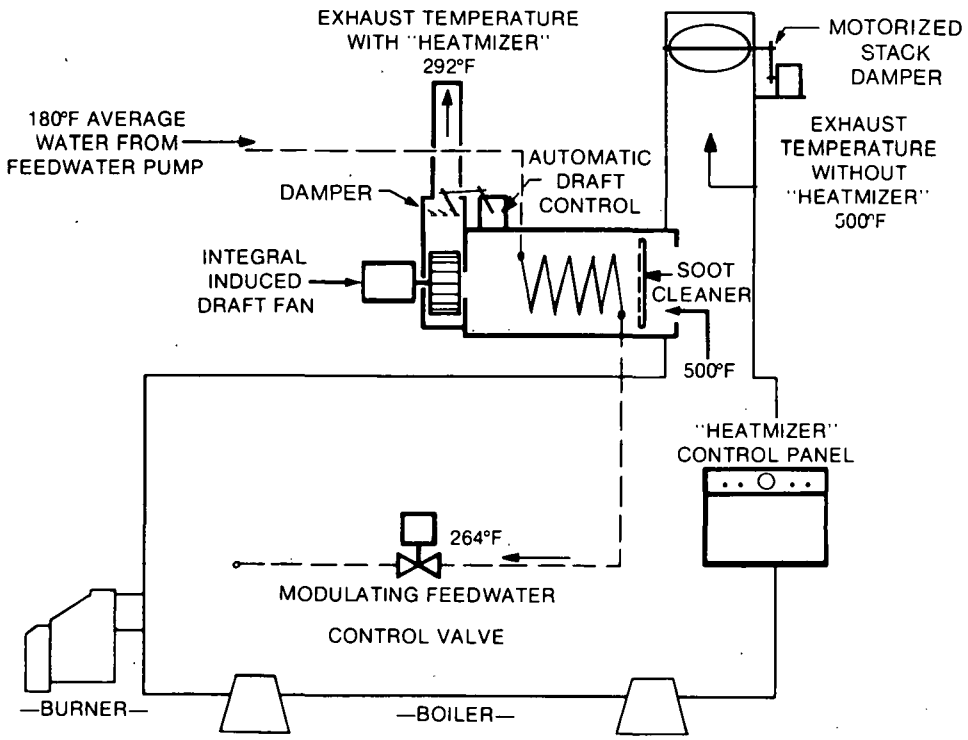


Figure 1

operated to provide absorption airconditioning, summer reheat, etc.

The following specific results can be accomplished:

Reduction of fuel consumption and cost while producing the same amount of steam (or hot water) with reduced fuel burner input.

B. Extension of boiler performance by producing more steam (or hot water) with the same fuel burner input. The user may be able to live within a fuel allocation and extend boiler performance--reducing fuel cost per pound of steam or BTU of hot water produced.

C. A combination of categories A and B can be produced, providing the burner-boiler units are allowed to modulate.

The burner-boiler unit operating at high fire provides extended performance--more steam or hot water when needed (often required for process start-up, the "up to temperature" cycle, or peak loads).

When the extended performance is not required, the modulating controls lower fuel burner input, reducing consumption.

D. Boiler maintenance is decreased as preheated feedwater reduces "thermal shock."

DETERMINING FUEL & DOLLAR SAVINGS

Five key survey factors will generally allow determination of savings and feasibility of a HEATMIZER boiler stack gas heat recovery application:

1. Boiler (size, type, average input)
2. Annual hours of operation
3. Average gross stack temperature
4. Temperature of water to be heated (feedwater, process, potable, or hydronic heating water)
5. Fuel consumption and current cost (therms, gallons, etc.)

Procedure for estimating savings (figure 2):

Example:

A 600 HP process boiler running at rated input

Fuel Consumption: 252 Therms/hour of natural gas @ $.35/therm

Gross Stack Temperature: 500°F

Water Temperature Entering HEATMIZER: 100°F

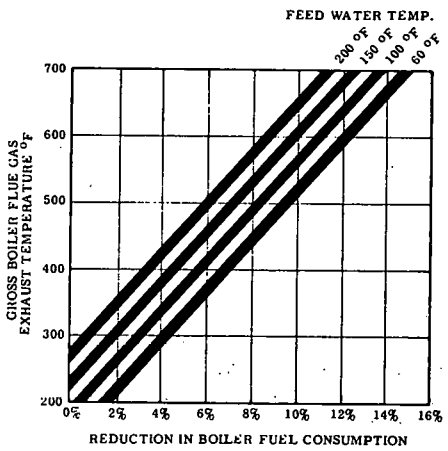
Annual Hours of Operation: 6,000

1. 8.3% fuel savings can be determined from figure 2 (assuming 30% excess air)
2. Hourly fuel savings are 252 Therms x .083 = 20.916 Therms/hour
3. Annual fuel savings are 20.916 Therms/hour x 6,000 hours/year annual operations = 125,496 Therms of natural gas saved annually
4. Annual natural gas dollar savings are 125,416 Therms x $.35 = $43,923.60
5. Electrical consumption for the induced draft fan (15 HP) and controls would be 15KWH x 6000 hours = 90,000 KW/year. With a power cost of $.04 per KWH, annual expense would be $3,600
6. Net annual dollar savings = gas savings $43,923.60 - electrical power cost $3600 = $40,323.60

When fuel savings are compared with the estimated installed cost of the heat recovery equipment (because of varying systems and construction costs, the installed equipment cost estimate is best left to a specialist), the payback can quickly be calculated.

HEATMIZER stack gas heat recovery system users confirm actual fuel savings meeting or exceeding pre-installation projections. At today's energy costs--and looking ahead to tomorrow--stack gas heat recovery does not cost, it pays!

EFFECT OF
HEATMIZER BOILER STACK GAS HEAT RECOVERY UNIT
ON BOILER FUEL CONSUMPTION



Fuel savings possible with varying boiler flue gas and feedwater temperatures.

NOTE

Chart based on burning natural gas with 30 percent excess air. For other fuels and excess air amounts, fuel savings can be adjusted with the savings multipliers shown.

PERCENT EXCESS AIR	SAVINGS MULTIPLIERS	
	NATURAL GAS AND #6 OIL	#2 OIL
0	.80	.77
10	.87	.84
20	.93	.91
30	1.00	.97
40	1.07	1.04
50	1.14	1.11
60	1.20	1.18
70	1.27	1.24

Figure 2

ENERGY AUDITS IN PROCESS UNITS

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ABSTRACT

Emphasis is placed on practical considerations in the effective organization and execution of a successful in-house energy audit of a process unit, based upon experience gained in several such audits of Gulf Coast petrochemical units.

Staffing requirements, membership qualifications, probable time span for the audit, cost-benefit ratios, and necessary line management commitment are discussed. The scope and importance of pre-audit preparation and related responsbilities are explained. Activities of the Audit Team are likely to fall naturally into six general phases, each of which is reviewed in detail.

INTRODUCTION

For the purposes of this presentation, an energy audit is defined as:

> "A formal in-depth review of a process unit, a professional study by competent engineers and specialists, to develop and evaluate ideas for improving energy efficiency."

There are some key words in this definition; the first is "in-depth". An audit of this sort is not a superficial review; it does require a considerable degree of in-depth study. The phrase "to develop and evaluate" is also important. It is not sufficient for the energy audit merely to list ideas for saving energy or for using it more efficiently. Instead, the proposals must also be developed and evaluated to a point where selected ones can be presented to management with some degree of confidence that they are the most cost-effective options available and will prove to be practical and economically justified. They need not, however, be developed by the audit team to the degree of precision that is required in a formal request for funding. The recommendations of an audit team will typically take the form of: a change of operating conditions, the replacement or modification of equipment, procedural changes, training needs, or (in some relatively few cases), a recommendation for further study.

MANAGEMENT PLANNING

Time Span

In planning for such an audit, it is well that management be aware of the time frame most likely to be involved. In general, an audit of this kind can be expected to require roughly 12 months of time lapse between its start and finish, if it is assumed that the members of the audit team are devoting 30-50% of their time to this responsibility. This will vary considerably, however, with the size and complexity of the unit, the degree of commitment of management and team members, etc.

An alternative to this time schedule exists; it might be called an "intensive" alternative. In this instance the members of the team devote their full time to the task and complete the audit in a fairly brief time span of perhaps four to six weeks duration. This particular alternative will be discussed in detail this afternoon by Mr. R. D. Korich of our Seadrift Plant; however it is well to note briefly at this time some of the pros and cons for such an approach. The chief advantages of the "intensive" audit lie in the requirement that the full audit team be involved for only a limited length of time. As a result it is easier to maintain continuity of membership on the team (often difficult or impossible over longer periods). The total manhours required may also be less, in some cases. Offsetting these

two advantages, however, are two disadvantages, e being that it places a great deal more emphasis upon the thoroughness of preparation required prior to the audit. The adverse effects of any deficiency in this preparation are magnified, and the quality of the audit results may be adversely affected. This makes the "intensive" alternative much more difficult to carry out with an old unit than with a new one, which may have more complete records and may include computer models and other such helpful tools. Secondly, in the "intensive" audit, the time constraints usually make it a great deal harder to "dig below the surface" and to make the audit a truly in-depth evaluation of ideas. There is a tendency to be superficial and to recommend "more study" more often.

Commitment

A high degree of commitment throughout the entire organization is essential to the effectiveness of an energy audit. In a sense, this commitment must "start at the top" with corporate management and extend down thru the local plant management to the specific unit being audited. Not only must the necessary funding and manpower be provided, but also a receptive environment must be made to exist such that audit team proposals are viewed in a truly objective manner. Steps must be taken by management to minimize the turnover of its members during the life of the team. Commitment of the maintenance organization is vital in providing prompt response to the audit team's needs in troubleshooting, providing improved metering, etc.

Staffing

Normally, an audit team is comprised of from four to six members. Ideally, one or two of these should have previous energy audit experience. Each should be a recognized authority in his "specialty". Audit team membership is not for neophyte engineers.

One of the members of the team should be a representative of the unit being audited. He should have a recognized level of operating experience over the entire unit such that his judgment in issues can carry "the weight of experience". His participation is essentially full-time in the audit, especially during the early phases. Because he is responsible for the preparation of the pre-audit package of information the unit representative is usually the first team member to be named. When the team is first organized, he acts as the "educator" for team members who are not familiar with the details of the unit technology. Later he acts as an interface, a liaison, between the audit team and the unit being audited.

Another member of the audit team is usually a process engineer who has a breadth of experience in the design of the process units, as well as in one or more areas of related technical engineering expertise, such as heat exchangers, computer modeling, ete. He also acts as an interface between the audit team and other engineering skill centers or other engineering personnel who may be called upon for specialized input.

A representative of the Energy Systems of the plant should also be included as a member of the audit team. He should bring to the team a breadth of experience and knowledge in these plant systems so that he can act as an interface between the audit team and these systems. He should be able to "speak for" the Energy Systems group and he should be able to evaluate the impact of audit team proposals upon them. In some fortunate instances he may also be able to contribute specific technical expertise to the audit team in such areas as prime movers, furnaces, electric power distribution, etc.

The fourth member of the audit team should properly be a disinterested production engineer. He should be recognized for his good judgment and be an acknowledged authority over a wide range of production operations. He should have a breadth of production experience, yet he should not be involved directly with the unit under audit. He brings to the team a degree of objectivity and innovation, as well as a "fresh" look and the ability to ask "embarrassing" questions.

Other supplementary members of the audit team may be added as fits the particular features of the unit being audited. In particular, if a major unit operation, such as reaction kinetics mass transfer, or furnace operation is involved, that area might very well be represented by an expert as a full member of the team. Alternatively, such areas of expertise can be provided by individuals who are not full members of the team, but are merely available for consultation.

The leader of the audit team is usually one

of the above members, but in order to maintain the team's objectivity, it is recommended that he not be the unit representative or the Energy Systems representative. He should be experienced in team leadership and interaction, but he need not necessarily be strongly process or production oriented. The leader should also have a credibility with management such that will make it easy to expedite the team's activity and progress, escalating issues should the need ever arise.

PRE-AUDIT PREPARATION

A great deal of preparation is required before the energy audit team itself can function effectively. This preparation can be divided into three main pieces. The Unit representative team member is responsible for this preparation.

Current "Base Case" Data

The first piece of the pre-audit preparation is current "base case" data, which can be defined as "the necessary current material and energy balances required to predict quantitatively and accurately the effect of audit team proposals." Several key points should be noted as regards these "base case" data. First, there is an optimum degree of "perfection" in these data. It is unlikely that balances will close perfectly or that all the other minor details can be provided without some omissions, even with the assistance of computer models and even in new units where design documentation is relatively complete and available. It is worth noting, however, that in most cases, the "base case" data tend to be significantly deficient.

Second, there should be acceptably good closure of the energy balances around not only the overall unit being audited, but also around major portions of the unit (such as the refining section or the reaction section) and around what we might call "energy hogs" in the process. These "energy hogs" can be defined as any piece of equipment, such as a distillation column, which consume as much as five percent of the total energy used by the unit.

Third, the "energy level" should be specified at the "source" where it is available to the unit and at the point where it is actually used in the process. For a steam supply to a heater this would mean the pressure and temperature at the header where it enters the battery limits of the unit as well as at the point within the heater where condensation occurs.

Fourth, the data should include all of the dominant operating modes. Usually one mode will be operation at full rates at some specified product mix; another mode might be at some reduced operating rate and/or alternative product mix at which the unit is called to operate for significant portions of the year. It is usually true that energy usage depends greatly upon production rate, but this relationship is frequently not linear and occasionally is discontinuous at one or more points.

Fifth, emphasis should lie with the major energy supplies (e.g. steam, power, cooling water, fuel, etc.). Some of those used in trivial amounts can best be ignored in the interests of maximizing the "productivity" of the audit team.

Sixth and last, the need may arise to carry out special tests to develop accurate data for the necessary material and energy balances. Where possible such special tests should be limited to fairly short duration (24-48 Hrs) and encompass relatively small, easily controlled portions of the unit (e.g. a reaction system, a furnace, a distillation train, etc.). Experience indicates that prolonged balances around entire units are much more likely to be frustrated by circumstances beyond the control of the audit team. The effort-to-benefit ratio is often disappointingly high if too much equipment or too large an area is included in such a special test. It is almost a "last resort" to try to carry out such a 24- or 48-hour balance around a total unit as part of the preparation for the base case data.

Pre-Audit Package

The second piece of the preparation for an audit is the "pre-audit package," an assembly of basic reference data for the unit. A part, distributed (along with the previously described "Base Case" data) to each team member for his study before they meet for their initial organization meeting, should include such items as: the organizational structure of the unit being audited, (personnel names and their responsibilities), unit plot plans, overview description of the process technology (including simplified flow-

heets), and an overview of the history and future plans for energy conservation in that unit.

An assembly of other more detailed information should also be made available to the team at its first meeting or very shortly thereafter. This should include such things as design reports, equipment files, major performance test data on individual equipment, operating procedures, cost sheets, production plans for the present year and for future years, physical properties of the materials in process, computer data (historical data logs), results of earlier audits (should there by any) and a "laundry list" of energy conservation ideas (obtained from the operating staff and from hourly personnel in the unit being audited).

Physical Facilities

The third and last piece of the "pre-audit" preparation includes providing the physical facilities necessary for the Team to function. These may range from elemental to elaborate. At one end of the spectrum, an office for occasional team meetings may suffice; while at the other, for the "intensive" alternative audit schedule previously mentioned, it might include a temporary trailer with several offices, telephones, and secretarial service.

One final word about "pre-audit" preparation: Don't underestimate either the time and effort required for the Unit representative to do the job properly or its importance to the team's effectiveness.

TEAM KICK-OFF MEETING

A number of items should be included on the agenda for the first meeting of the audit team.

First, some time spent in basic "team building" should be considered, especially if the members of the audit team have not worked closely together in the past. Team building methods are generally well known and need not be discussed in detail here, but they serve to acquaint each of the members with the other to assure the effective interaction of team members, and to build a commitment of the team along desired lines.

Second, it is appropriate that a team leader be selected if one has not already been named. It is also helpful for the team members among themselves to agree to certain "internal standards" to maximize their efficiency; Figure I lists some examples which have proved helpful.

- SOME TYPICAL INTERNAL STANDARDS - FOR AN AUDIT TEAM

MEETING SCHEDULES	1.	Meetings of the full team membership are held at monthly intervals. Shorter intervals do not provide adequate working time for significant progress; longer ones foster procrastination.
	2.	Meetings should be scheduled far ahead, beginning early in the audit.
EFFICIENT MEETINGS	3.	One week before each meeting, each member mails to the other team member an informal update of progress on all his projects--including all findings and recommendations to be discussed at the meeting.
	4.	Each member "does his homework" before the meeting..mailing out the progress reports mentioned above and fully digesting those received.
	5.	An agenda is mailed to each member the week before the meeting; it includes, among items (A) review of the status of all projects, and (B) review and update of all schedules.
"INSIDE" COMMUNICATION	6.	Secretarial duties should be rotated among members. Minutes are required for each team meeting and are to be completed and mailed within one week (only to team members, plus a critical few outsiders).
	7.	Full, open, informal communication is maintained among members of the team and "supplementary" personnel on a one-to-one basis. Informal communication between team members and their respective supervisors is as necessary.
	8.	Formal, "official" team correspondence is issued only over the signature of the team leader when addressed outside of team.

"OUTSIDE" COMMUNICATION

9. Liaison with the unit is maintained through the unit representative for needed shutdown, repairs, etc.

10. "Early" formal recommendations are issued by the team when possible in order to expedite implementation of projects clearly justified. This not only benefits the corporation, but is also "good press" for the team. Judgment is required to avoid "changing our mind" on recommendations, however.

FIGURE I

Third, the audit team "proposal" should be agreed to and documented. This proposal is in effect the team's "contract" with management; and it clearly states the objectives of the team, a tentative schedule for the team's activities, and notes any needs for special support (e.g. additional team members) needed for the effective operation of the team.

A fourth subject which needs to be addressed in the initial organizational meeting might be called the "evaluation mechanics." This includes the bases the team is to use in evaluating the unit: the production plans for the present and future years, usage factors and cost pers (including each energy source, raw material, etc), and energy equivalent information, (i.e. the Btu equivalent of each lb of product and raw material).

The team should also seek to define and agree upon the format to be used in its final report. It may seem premature to devote time to this subject at the first meeting, but it will tend to reduce the time spent later in rewriting and recalculating team results. Instead each proposal can be drafted in the final reporting format when it is first presented to the team for review (see "Opportunity Evaluation Phase").

"TECHNOLOGY EDUCATION" PHASE

Following the first team meeting, the members will, in most cases, require a period of time for them to become more familiar with the technology of the unit being audited. The Unit representative takes the lead at this point and in effect, educates the other members in the details of his unit. This is really a continuation of the "Pre-Audit Package" and includes such things as "chalk-talks," unit tours, etc. During this period, the team should test the adequacy of the "Pre-Audit Package" data and determine the need for any confirming or supplemental operating data, computer logs, etc. It is essential to do this early enough to enable an appropriate response by Maintenance Department for additional metering or whatever else may be necessary to obtain data of the necessary quality.

"OPPORTUNITY DEVELOPMENT" PHASE

During this period, the team focuses its attention on conceiving, developing, refining, and evaluating energy conservation ideas. A starting point is often a review of the previously mentioned "laundry list" of ideas suggested by unit personnel, on perhaps a review of the findings and recommendations of previous energy audits. Interviews with hourly operating personnel may be helpful, and "brainstorming" and "Value Analysis" techniques may be used. Input from technology specialist (e.g. distillation, heat transfer, power distribution, etc.) can be extremely helpful at this time. Identification and analysis of the "energy hogs" in the unit not only determines if they are operating at design or better, but also ascertains if attractive new technology is available to replace them. A "sinks and sources" listing for sensible heat may be helpful, but all major energy usage elements should be considered in this phase, not just heat.

It is important during this opportunity development phase not to be overly "selective" or critical of ideas; rather, it is important to create an atmosphere whereby new ideas can be proposed and often themselves become the raw material for still better proposals. It is important to build upon early ideas, concepts, and suggestions. One idea may very well lead to another of an improved quality.

The team should always be prepared to recycle briefly at a later date to this "Opportunity Development" Phase when new ideas arise. The development of opportunities for saving energy conservation will probably occur frequently during the rest of the team's life.

"OPPORTUNITY EVALUATION" PHASE

During this phase, the team identifies the most promising of the proposals and then analyzes them in more depth.

First, each of the proposals developed in the previous phase is assigned to a Team member for preliminary screening. His review seeks to categorize the proposals, based upon his very rough estimate of the cost of implementing the proposals and of the savings likely to be realized, e.g.,

COST ($M)		Savings ($M/yr)
<50	"Good"	>200
50-200	"Average"	50-200
>500	"Poor"	<50

In addition he should estimate the probability that the Audit Team will be able, within the time allotted to it, to endorse the proposal and recommend that it be pursued further.

These preliminary screening results for each of the proposals provide a basis for the team to prioritize the list and to select the "critical few" for more detailed analysis. Exactly how many proposals are included in this "critical few" will vary, but usually the initial list of ideas from the "Opportunity Development" Phase will be reduced to 15 to 30 sufficiently promising to warrant a closer look.

(It is desirable at this point that proposals which are not included in the "critical few" be documented and the reasons for their being discarded be summarized. This information can be most useful to subsequent audits.)

The selected "critical few" proposals are then reassigned among the individual team members who define them more carefully and develope estimates of capital costs (± 50%) and savings. Their findings are presented for review and acceptance by the entire team in a formal draft suitable for inclusion in the final report of the Audit Team. This draft should include a one-page summary of all the indices and factors likely to be of interest to management later in acting on the recommendations of the team. An example of the format which might be used in the "Executive Summary" is shown in Figure II. Note that after a concise description of the "mechanics" of the proposal, the effect upon the energy balance

EXECUTIVE SUMMARY FORMAT

DEFINITION

TITLE (FEW WORDS: INCLUDE ANY "PROJECT NUMBER", ETC)

SCOPE/OBJECTIVE (SIMPLE, CONCISE STATEMENT OF CHANGES TO BE MADE TO EQUIPMENT OR PROCEDURES: 3 LINES.....)

ENERGY

ENERGY IMPACT (@ FULL RATES) REDUCES ..... BY ..... PER HR
INCREASES ... BY ..... PER HR

NET REDUCTION IN ENERGY USAGE FACTOR .....MMBTU/MLBS

NET REDUCTION IN PLANT ENERGY USAGE .....MMBTU/HR

(.....MMMBTU/YR AT 1980 PLAN)

ECONOMICS

ANNUAL SAVINGS	PLANT BASIS	DEPARTMENTAL BASIS
1980	$---M	$---M
1985	---	---
PAYBACK PERIOD (1980)	--- YRS	--- YRS
RETURN ON INVESTMENT (BEFORE TAX)	--- %	--- %

ESTIMATED INSTALLED COST $ ..... M (± 50%), 1980

OVERALL PRIORITY

PRIORITY INDICES

_____ ECONOMIC

_____ TECHNOLOGY

_____ RISK/FEASIBILITY

_____ % PROBABILITY OF ACHIEVING ESTIMATED SAVINGS. **

** OVERALL TEAM JUDGMENT

FIGURE II

is listed, first in terms of changes in specific usage rates at full production (e.g. Mpph steam, MKW power, etc.) and then in terms of appropriate indices at the planned operating rate. In the next section, the economic impact is summarized in terms of how it will affect the plant (or corporation) as a whole, as well as how it will affect the costs of the Unit being audited. Finally the judgment of the Audit Team is summarized in four indices described fully in Figure III.

PRIORITY INDICES

DEFINITIONS

PRIORITY INDICES	ECONOMICS	TECHNOLOGY	RISK/FEASIBILITY
"A" (GOOD)	WELL-DEFINED AND ATTRACTIVE	PRESENT "T" ADEQUATE AND CONFIRMED BY CORPORATE EXPERIENCE	NEGLIGIBLE RISK, VERY FEASIBLE
"B" (MAYBE)	WELL-DEFINED BUT ONLY MARGINALLY ACCEPTABLE	ONLY MINIMAL ADVANCE OF EXISTING "T" NEEDED: OR WE SIMPLY LACK ANY CONFIRMING EXPERIENCE	MINOR OPERATIONAL RISKS AND/OR FEASIBILITY DOUBTS
"C" (HOLD)	EITHER POORLY DEFINED OR MARGINALLY UNACCEPTABLE	PRESENT "T" INADEQUATE BUT MAY BE EASILY ADAPTED	POORLY DEFINED RISKS AND/OR DOUBTFUL FEASIBLITY
"D" (NO!)	CLEARLY UNATTRACTIVE	REQUIRES MAJOR "T" BREAKTHRU	HIGH RISKS OR SERIOUS FEASIBILITY PROBLEMS.

FIGURE III

The team reviews all of these formal drafts and assures that they truly represent the judgment of the entire team.

"FINAL SELECTION" PHASE

In this phase the team selects from the list of proposals it has formulated those which are sufficiently attractive to recommend to management that they be implemented and sequences them in the best order for implementation.

It is not uncommon to find that some of the proposals in an energy audit will interact with each other. Either they may both tend to claim the same savings, or one may be a prerequisite for (or merely enhance) another. Up to this point in the audit the proposals have been viewed more or less independently, but now it is essential that any interaction be recognized and quantified. Where duplication in savings exist, appropriate choices must be made.

The first step in this "Final Selection" Phase is therefore to identify those proposals which do not interact significantly with any of the others. These are then sequenced in what the team judges to be the most attractive order considering the ease of implementation, the economic attractiveness, potential risks, etc. Those proposals which do not meet the necessary minimum criteria are discarded, but the details of the team's investigation are documented and retained so as to be available to others in the future.

Each of the other team proposals is then grouped with those with which it does interact. Each proposal within each group is then examined to determine its economics if the other proposal(s) in that group are implemented first. It is not uncommon to find one or more proposal in each group simply cannot be justified if the others are pre-existing. In this manner the most cost-effective combination (and sequence) of proposals are identified for each group, and those which are clearly much less attractive can be discarded.

During this entire process the team should be alert for any attractive new proposals which might be generated by these studies.

Finally the group(s) of those selected proposals which do interact are integrated with the group of proposals which do not interact, yielding a specific sequence which the team recommends to management. The formal draft describing each proposal and its energy and economic impact,

written in the earlier "Opportunity Evaluation" ise, is revised to reflect its merits as it appears in this sequence recommended by the team. Appropriate summary tables are compiled, such as those in Figures IV and V.

By way of review, Figure VI outlines the progress of a typical energy audit team through the "Opportunity Development", "Opportunity Evaluation" and "Final Selection" Phases.

SUMMARY OF BATTERY LIMITS USAGE CHANGES AFTER INTEGRATION IS COMPLETED - AT FULL RATES

Project	200-lb Steam (Mpph)	70-lb Steam (Mpph)	Elect Power (MKW)	Conden-sate (MGph)	Added Prod (Mpph)
#12 Feed Clr Bypass	2	(6)	-	(0.3)	-
#21 Feed Points	4	4	-	0.1	(6)
#24 Raw Mtl Hx	(18)	(7)	-	-	-
#5 Vacuum Pump	(2)	-	0.1	-	-
#10 200-lb Cond Tank	(10)	(10)	-	(0.05)	-
#20 Feed Temp	-	(10)	-	1.2	-
TOTAL CHANGE	(24)	(29)	(0.1)	1.5	(6)

FIGURE IV

SUMMARY OF IMPACT AFTER INTEGRATION

RECOMMENDED PROJECTS, LISTED IN ORDER OF RECOMMENDED IMPLEMENTATION
(1980 Basis)

	Incremental Impact						Cumulative Impact			
Project	$Saved $M/yr Plant	$Saved $M/yr Dept	Fuel Saved M^3Btu/yr	Installed Cost $M	Payback Yrs.	Prob'ty Achiev'g Savings %	$Saved $M/yr Plant	$Saved $M/yr Dept	Fuel Saved M^3Btu/yr	Installed Cost $
#12 Feed Clr Bypass	80	85	40	-0-	0.0	100	80	85	40	-0-
#21 Feed Points	180	300	62	-0-	0.0	90	260	385	102	-0-
#24 Raw Mtl Hx	500	600	300	20	0.1	50	760	985	402	20
#5 Vacuum Pump					3.6	95				
#10 200-lb Cond Tank	300	40		309	1.0	95				
#20 Feed Temp					0.4	90				
							1270	1150	680	590
Probability Adjusted Total							1025	930	530	

FIGURE V

DEVELOPMENT OF TEAM RECOMMENDATIONS FOR PROCESS CHANGE

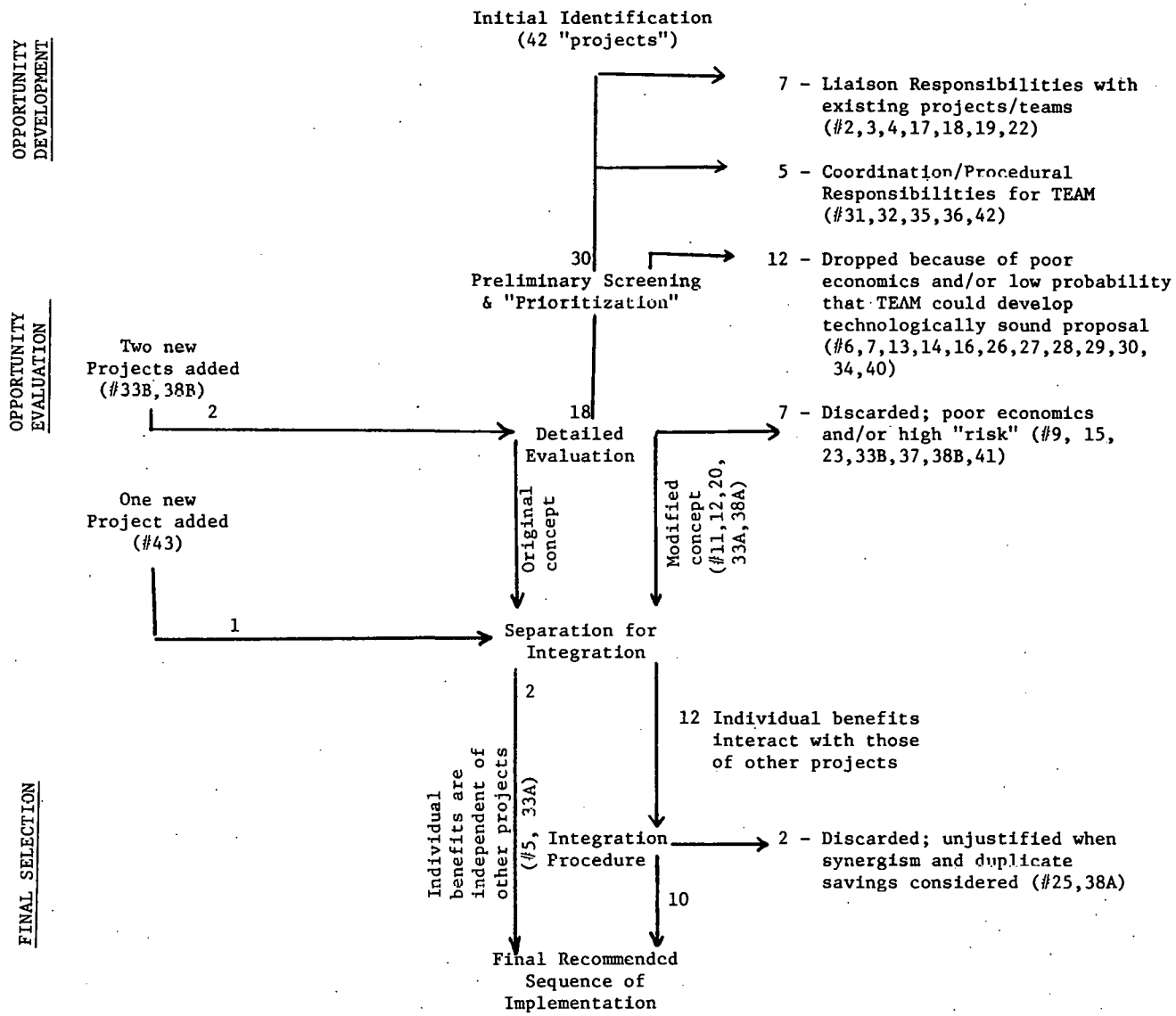


FIGURE VI

REPORTING PHASE

This last phase of the audit team's operation deals with the documentation and formal written presentation of the team's findings. The drafting of this document can be done either by a single individual or by several individuals within the team. If the team has performed in the way described earlier, portions of the final report will have been written before the team reaches the point of drawing all its findings together in a single document. Those individuals responsible for the development of data on each specific proposal will have already written up those particular proposals during the earlier phases. In any event, however, the final document must be carefully reviewed and have the full approval and agreement of all team members.

It is recommended that the report be split into two major portions: One, a summary report for wide distribution to management, containing perhaps 15 to 25 pages and a second, an appendix of limited distribution, including all the details of the team's deliberation. The former would include for each recommended proposal only the "executive summary" page; the latter would include details for each proposal considered by the team (those discarded as well as those recommended).

It is also recommended that the report include

a self critique of the team's operation. It is very likely that this audit team will not be the last one that is carried out in your particular organization, and its findings and recommendations on the manner in which the audit team carries out its work can be very valuable to future teams.

FOLLOW-UP

In closing, it should be noted that nothing has been said about follow-up on the team's recommendations. This has been intentionally ommitted as part of the audit team's responsibility, because the audit team is viewed as a staff function, responsible for making appropriate recommendations but not responsible for the carrying them out. After reporting its finding and recommendations, the audit team's jobs is complete. Line management, that of the unit and the plant involved, has the responsibility for implementing those recommendations which it chooses to accept.

It is recommended that management respond to the audit team's recommendations by acknowledging them promptly and by preparing the appropriate action plans in a timely manner. The audit team should be advised of progress toward meeting these recommendations. These action plans should be included in a quarterly review of the performance of the department involved, and the audit team should be advised of progress at regular intervals.

In many cases, the proposals recommended by the team may require some further refinement, including more precise cost estimating, before the funding process can be started. In other instances the energy conservation measures recommended by the team may not be readily translated into a fuel (or other purchased energy) saving for the plant without some other accompanying change being made elsewhere in the plant and outside the Unit being audited. These and other conditions byond the scope of an energy audit of a process unit should not be a source of frustration for team members, nor should they be allowed to detract from the credit due the team. If it has correctly identified and has enabled management to focus upon the most attractive ways to use energy more efficiently in the process unit it audits, and if it has provided accurate information for management decisions, then the team has done its job well!

DEVELOPMENT OF AN ENERGY-CONSUMPTION MODEL AT A MULTI-PRODUCT CHEMICAL PLANT

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ABSTRACT

A plant-wide energy model is being developed to be used primarily as a planning tool to evaluate the impact of energy conservation projects and plant expansions on the total plant energy balance. Statistical analysis of historical data from each production unit has generated regression equations which correlate the various energy utilities with production rate and other variables. The form of the model varies from unit to unit. Startups, shutdowns, and unit interruptions are simulated using a Monte Carlo technique. In some units, energy consumption does not correlate with production rate, which indicates that energy savings may be possible through better control of energy usage. The model should also lay the framework for an on-line energy management program.

INTRODUCTION

As you are all aware, over the past several years and even more so during the past year, there has been a dramatic increase in energy costs. This increase has affected the operating costs of petrochemical plants as it has costs of all other users of energy.

Fuel costs for the Texas City Plant have risen from $0.19/MMBTU in 1972 to about $2.50/MMBTU in 1980. This amounts to a tenfold increase in the cost of fuel.

Because of this dramatic climb in energy costs, a corporate goal to reduce energy consumption per pound of product by 15 percent from 1972 levels before 1981 has been established. Figure 1 shows the variation of the energy index from 1972 to the present, and the projected values through 1985. The Texas City Plant has an internal commitment to reduce the index by 40 percent from 1972 levels before 1985. To achieve these stated goals, a variety of energy conservation and reduction programs have been established. These have ranged from miscellaneous housekeeping projects, energy audits, major process revisions, replacement of energy inefficient equipment, and the establishment of an overall Plant Energy Management Program (PEMP).

Objectives of the PEMP include: 1) monitoring and control of daily energy usage and efficiency, 2) monitoring of projects before approval for energy efficiency, and 3) long-range evaluation of future major Plant additions from an energy standpoint. One of the tools needed to achieve these objectives is an energy consumption model of the Plant. This afternoon, I would like to give you an idea of the approaches we have tried in developing this model, and some things we are considering for the future.

BACKGROUND

Before I start discussing the development of the energy consumption model, it will help to give a basic overview of the Plant.

The Plant consists of essentially nine major operating units, and an Energy Systems Unit. Each unit makes anywhere from one to 30 different chemicals. Some units operate batch-wise while others are continuous. At any given time, the product mix from a multiple product unit will vary, and with it, the energy needed per pound of product. More on this later.

Various utilities are needed to operate the production units. Major utilities include electricity, 1000 psi steam, 600 psi steam, 200 psi steam, 70 psi steam, cooling water, compressed nitrogen, compressed air, and fuel gas. As shown in Figure 2, utilities to a unit are provided by Energy Systems or from another unit. As more emphasis is being placed on the utilization of low level waste heat, this interconnection between units will increase in the future.

The Energy Systems Unit provides for most of the Plant's needed utilities. It consists of three powerhouses with complex power generating systems utilizing gas turbines, back pressure and condensing steam turbines as prime movers that operate in a variety of energy cycles of varying efficiencies.

A general picture of the energy cycles is depicted in Figure 3. As shown, the major electrical generators exhaust into waste heat boilers to produce steam for the Plant. Main-

taining the proper balance in this steam/power energy cycle is very critical. An on-line computer program called BOMP has been implemented to maintain this balance, while at the same time assuring that the most energy efficient turbines are operated.

This has now layed the groundwork for the discussion of the consumption model. Since an optimization program (BOMP) exists for the Energy Systems Unit, the model will treat this unit as a black box and focus on the nine major operating units.

DEVELOPMENT OF A PLANT ENERGY CONSUMPTION MODEL

Two approaches were considered for the development of the model. I will refer to these as the "detailed" and the "empirical" approaches.

The "detailed" approach requires a model of energy consumption as a function of operating variables for each major piece of equipment. The necessary information would be gathered by performing a simulation or unit test around each major piece of equipment. The equipment models would be linked together to form the individual production unit models and likewise to form the overall Plant model. It was decided that this approach was more involved than what was needed for a "first crack" at a Plant energy consumption model. From a time standpoint, with the resources available, a simpler approach was needed. This led to the "empirical" approach. The remainder of this paper will discuss this approach.

Much historical data on the energy consumption of operating units is available. The "empirical" approach involves the statistical analysis of this data. A multiple linear regression program is used to determine statistically significant variables. Regression equations which correlate the various energy utilities with production rate and other variables are generated for each production unit. A Plant consumption model can then be determined from the collection of equations.

EMPIRICAL APPROACH - FIRST ATTEMPT

In the generation of the model, many factors had to be considered:

1. Energy usage usually varies with production rate, sometimes in a non-linear relationship.
2. Other variables besides production rate affect energy usage -- what are these variables?
3. The Plant operates both continuous and batch operations.
4. Some units depend on other units for part of their energy requirements.
5. Steam production and electrical requirements need to be balanced since the Plant generates most of its electricity from steam.
6. Startups, shutdowns, and unit interruptions require different energy usages than normal operation.
7. The type and frequency of energy data vary from unit to unit. Some units have process computers that collect data frequently while at other units, the data is more difficult to collect. Some units have in-unit energy balances.
8. The product mix at some units is continually changing.

Each operating unit was looked as an entity all to itself and attacked one at a time. The procedure used was as follows:

1. A basic understanding of each unit was obtained from the unit energy conservation representative.
2. With the help of unit personnel, a unit was broken down into a series of blocks that would provide for the best model of that unit. Blocks were determined by such things as location of utility meters, process equipment, and product made.
3. The best variables to predict energy usage in each block were determined.
4. Utility usages into and out of each block and the independent variables chosen were tabulated for each day over the six month period from July to December, 1979. Data was obtained outside this interval for startups, shutdowns, or other abnormal conditions when needed, to simulate these occurrences.
5. A regression equation for each utility as a function of the independent variables was determined from a selected set of data points that covered the range of operation. Sometimes two or even three equations were needed to best simulate the entire range. Sets of equations were developed for the different products processed through the same equipment. Sets of equations were also developed to simulate startups and shutdowns.
6. When poor correlations were obtained, other independent variables were selected and steps 4 and 5 repeated.

The consumption model is generated from the equations. The model form of a unit is shown in Figure 4. When values for the independent variables, state of operation (startup, shutdown, etc.), and product being made are given, the equations can be used to produce a Plant balance on each utility.

To use the model for long-range planning, a Monte Carlo simulation is used. The method is displayed in Figure 5. A frequency distribution of each independent variable is made. The data is then organized into a cumulative distribution. The cumulative curve is then described by fitting it to an algebraic equation of the form $x=f(y)<0$ $y<1$. The simulation is then made by generating random numbers between 0 and 1 ($0<y<1$) from a computer program. For each random value of y, the value of x can be computed from $x=f(y)$. The value of x can then be substituted into the appropriate utility equation along with the other variables that have been generated by the same method,and a utility usage computed. A computer program to perform the simulation has been developed. By running hundreds of such experiments, a utility distribution is formed. The range and probability of the occurrence of a utility usage rate in a unit or for the Plant is then established. Included are the peak and lowest usages and the probability of occurrence. This information can be used for long-range evaluation of future major Plant additions with respect to energy impact.

EMPIRICAL APPROACH - FIRST ATTEMPT RESULTS

The heart of the model rests in the generation of good utility regression equations. A set of regression equations developed for one block of an operating unit is shown in Figure 6. As seen from this figure, accountability of data (r^2 value) ranged from 40 to 85 percent. The small t is a measure of the confidence on a coefficient (coefficient value divided by its standard error). These results were typical for other blocks that were modeled.

From a statistical standpoint, we feel that a good model should give greater than 90 percent accountability on utility usages. Reasons why we believe this was not obtained on the first attempt include:

1. Accuracy of utility meters.
2. Not enough meters in the right places.
3. Lack of resources to fully understand the workings of a unit and consequently define the needed independent variables.
4. Carry-over effect of daily data.
5. Use of historical data sometimes does not allow for the determination of the independent effect of a variable - independent variables correlate highly with each other.
6. Energy usage is truly independent of operating variables, due to equipment design.

Some valuable information did come out of the first "crack" at a model. In some units, there was no correlation with certain utilities and production rate, indicating that energy savings may be possible through better control of energy usage. Also, an indication of what variables affect energy usage were obtained, and these will be monitored more closely in the future.

CONSUMPTION MODEL - THE FUTURE

At present, we are building a model based on monthly data. Data is being obtained from utility meters that are known to be accurate. Utility indexes (energy usage per pound of production) have been generated for each of the operating units, and regression equations are being obtained.

In the near future, a second attempt at a daily model will be made. Data will be gathered from the same meters used above for the monthly model. Correlations generated in the first attempt should be improved. As unit energy indexes change, new correlations will be generated to keep the model evergreen. The model should lay the framework for an on-line energy management program. Key variables will be monitored and adjusted on a day-to-day basis to optimize energy usage. The best mode of operation for each operating unit will also be determined at a given time to optimize energy usage.

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Internal Conversation with C. Hendrix, Union Carbide Corporation.

FIGURE I - TEXAS CITY PLANT ENERGY INDEX, 1972-1985

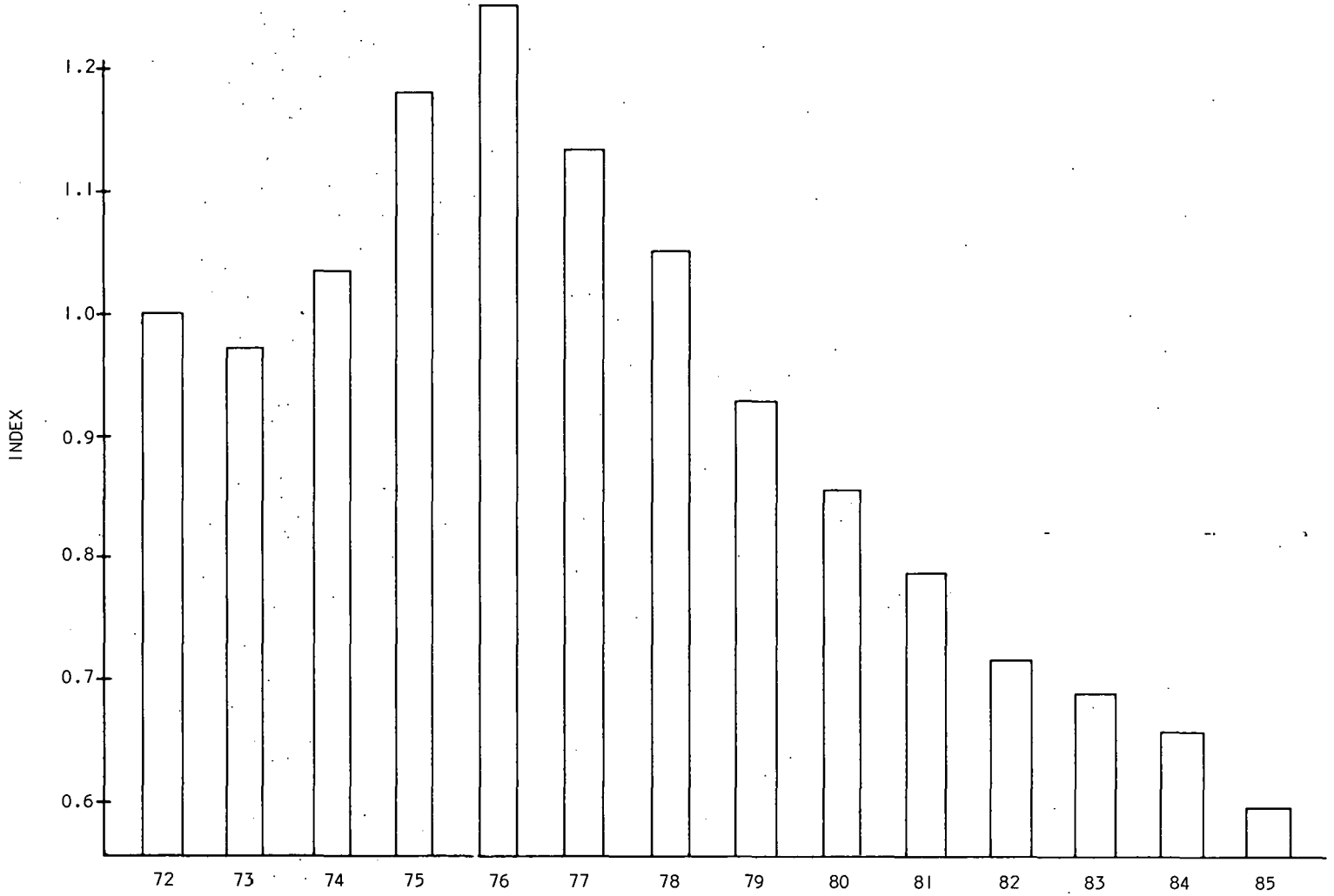


FIGURE 2 - P_ANT ENERGY EXCHANGE

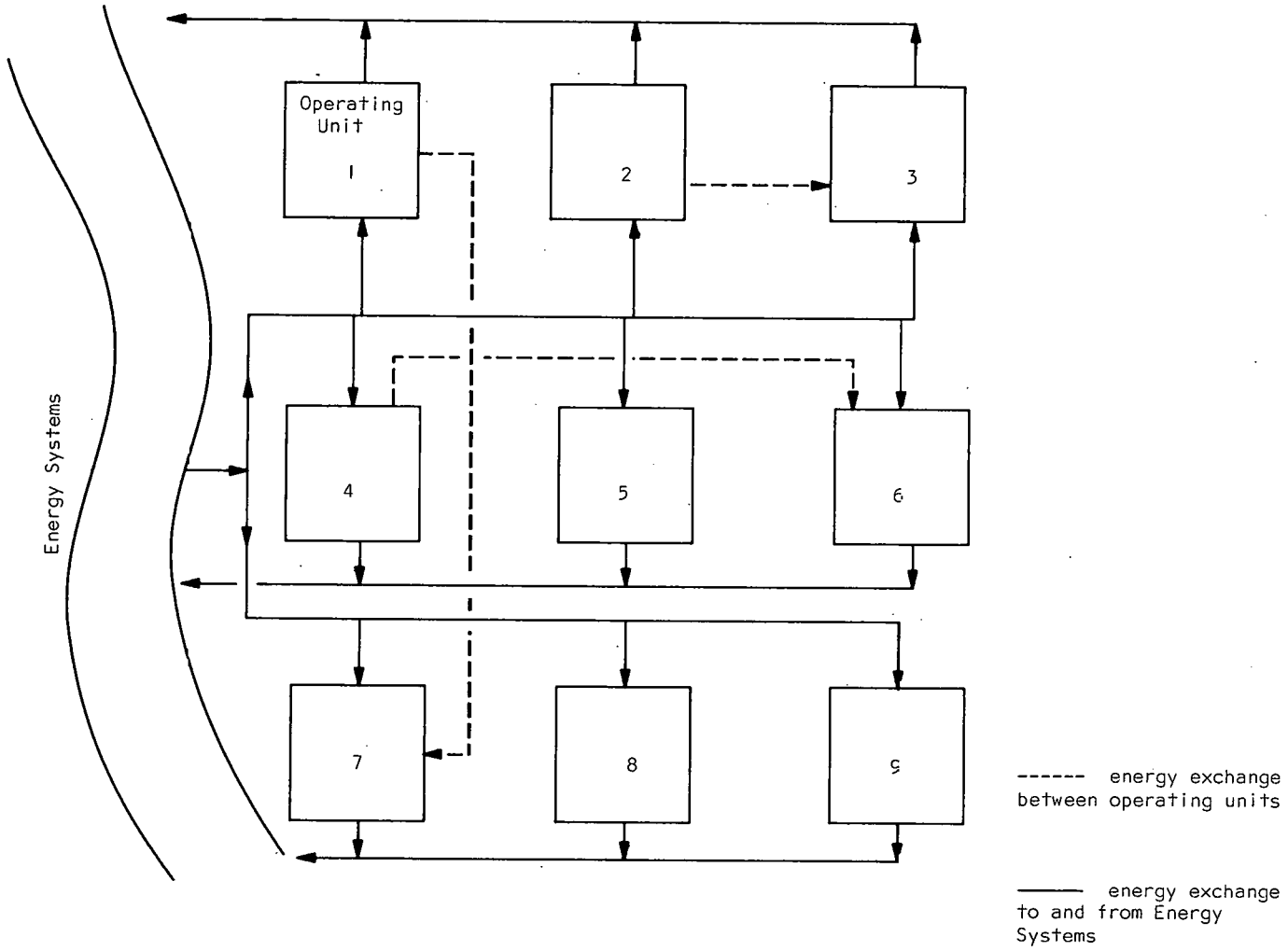


FIGURE 3 - GENERAL OVERVIEW OF TEXAS CITY PLANT ENERGY CYCLES

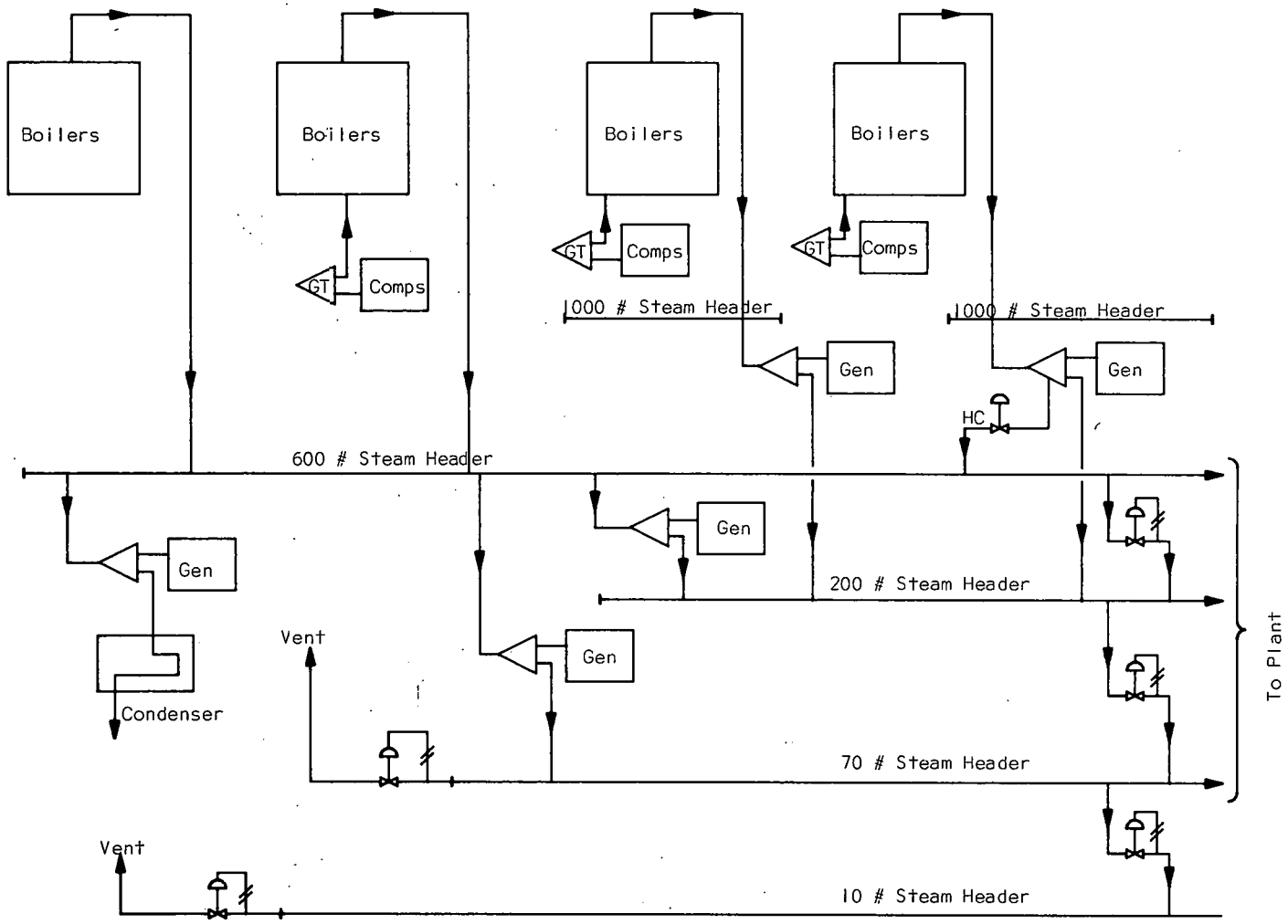
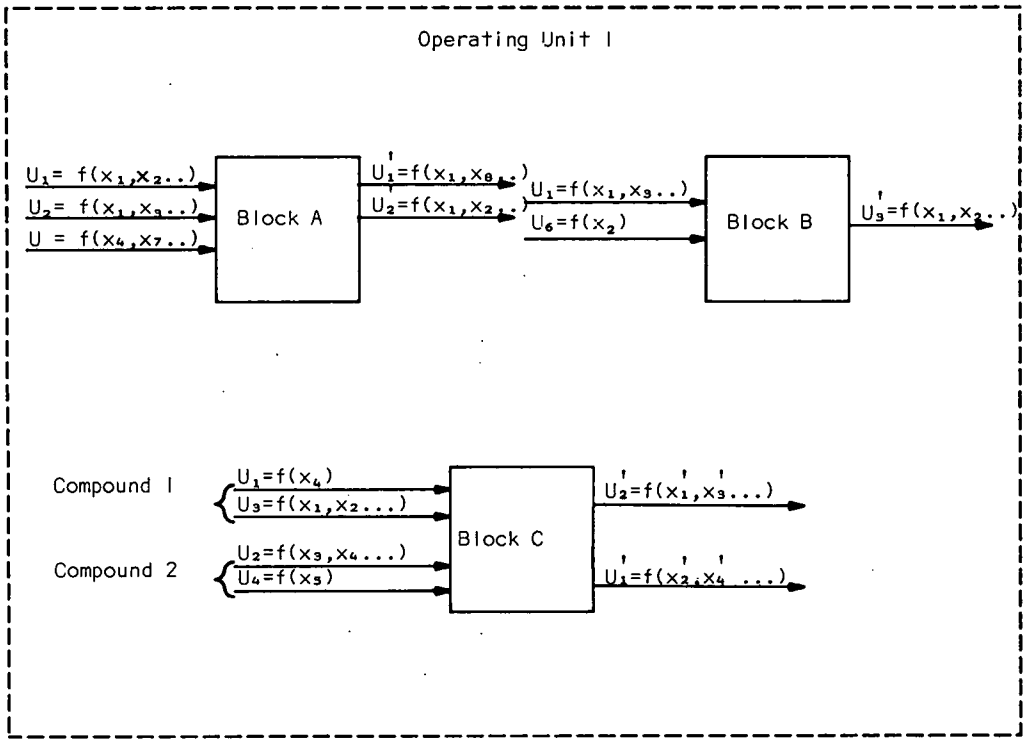


FIGURE 4 - FORM OF CONSUMPTION MODEL FOR AN OPERATING UNIT



Procedure:

1. Given status of operation, compound being produced, values for independent variables x_1, x_2...xn.
2. Select proper inlet and export utility equations for each block.
3. Compute inlet and export utility rate.
4. Tie to rest of plant balance.

Normal Operation:
Un = Inlet utility rate, utility n (may be from Energy Systems or from another unit.
Un' = Exported utility rate, utility n (may be to Energy Systems or another unit).
xn = Independent variable n.

*A different set of equations would exist for each block to simulate startup, shutdown, or other abnormal situations. Note Block C, when compound I is being produced, equations U_1, U_3, and U_2 are used. When Compound 2is being produced, equations U_2, U_4, and U_1' are used.

FIGURE 5 - DEMONSTRATION OF MONTE CARLO SIMULATION

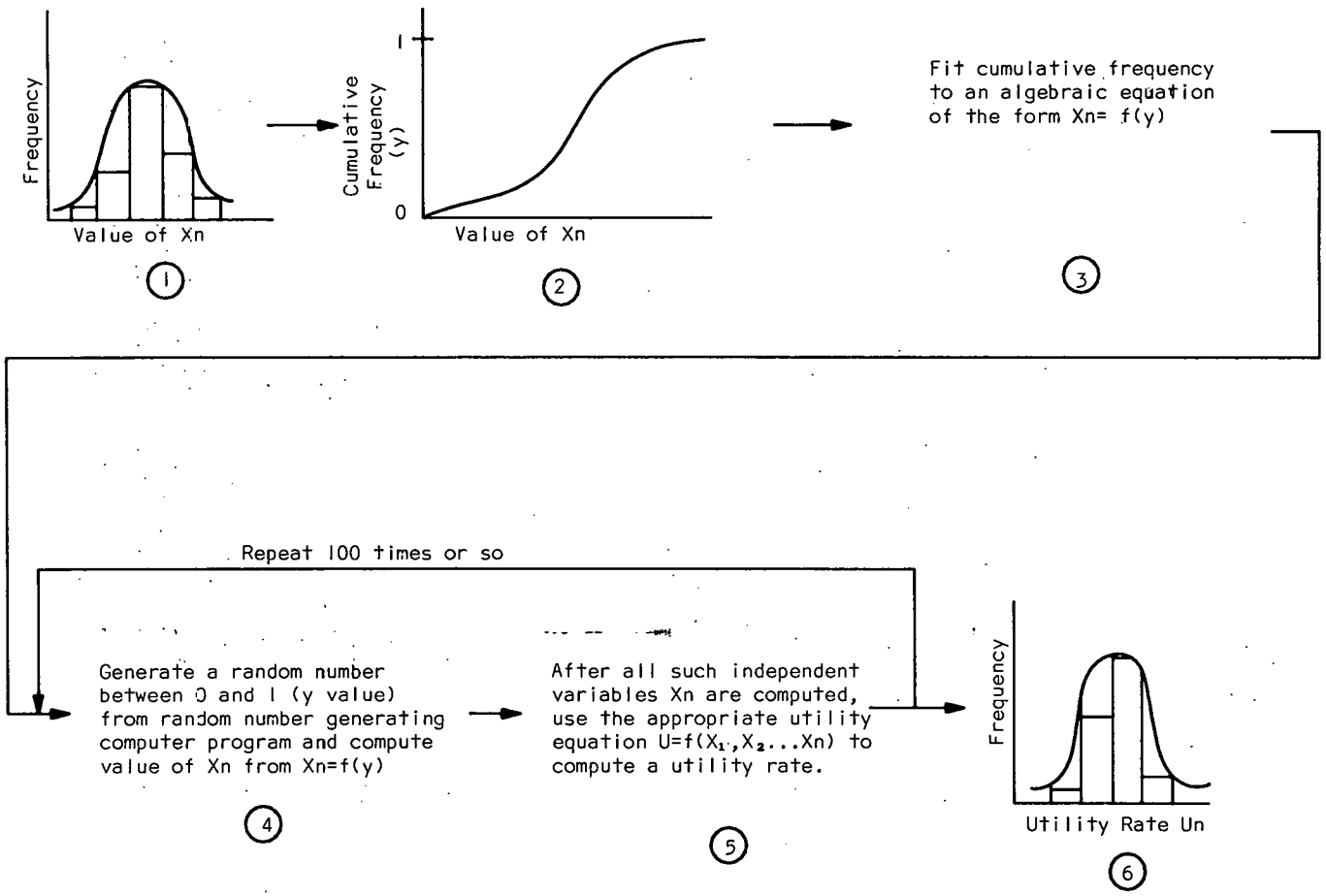


FIGURE 6 - UTILITY REGRESSION EQUATIONS DEVELOPED FOR BLOCK A, OPERATING UNIT I

Utility Equation	r^2	t values
$U_{1000} = -500 + 1.11\ P + 17.64T$	.852	$t_p = 9.78$ $t_t = 3.07$
$U_{200} = 871 + 0.64\ P + 190\ M$	.703	$t_p = 3.45$ $t_n = 1.61$
$U_{70} = -27 + 2.9\ T + 72\ M$	.418	$t_t = 1.81$ $t_n = 3.55$
$U_E = 1.17 \times 10^5$	.52	-

U_{1000} = 1000 # Steam lbs/day

U_{200} = 200 # Steam lbs/day

U_{70} = 70 # Steam lbs/day

U_E = Electricity KWH/day

P = Production, Mlbs/day

T = Ambient Temperature, °F

M = Inlet Feed Molar Ratio

ENERGY-GUIDELINE FACTORS PROVIDE A BETTER MEASURE OF REFINERY ENERGY PERFORMANCE

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Abstract

Exxon Company, U.S.A. refineries reduced energy consumption by 25% between 1972 and 1978 compared with an 18% reduction for the U.S. Petroleum Refining Industry over the same period. The Exxon approach to conserving energy in petroleum refining operations goes beyond energy conservation housekeeping measures and investments, and uses a comprehensive method to measure energy efficiency rather than energy consumption per barrel. It uses the Exxon Research and Engineering developed energy guideline factors, which are based on energy efficient designs and criteria, to

(1) Evaluate the energy efficiency performance of refineries of different complexity in a consistent manner.

(2) Compensate for changes in individual process unit throughputs and in unit operating intensity/severity.

(3) Identify and quantify areas of energy inefficiency.

(4) Regularly monitor and steward energy efficiency performance.

Effective conservation also requires the analysis of energy performance and setting goals for future improvement. The paper explains how this can be done...

Energy consumption represents about half of a refiner's operating cost; thus conservation efforts are a must to remain competitive. Conservation programs are well underway, spurred by the steep increase in fuel prices following the 1973 oil embargo and continuing. Emphasis should remain high in view of the recent reminder of vulnerability of energy supplies. Refiners reported through the API that energy savings of 18% had been achieved in 1978 over base year 1972 consumption. A goal of 20% savings by 1980 had been established. Continued escalation in energy prices will undoubtedly justify further reductions. By implementing energy conservation housekeeping measures and

stments and by using the Exxon Research and Engineering Company Energy Guideline Factors to monitor and steward progress, Exxon Company, U.S.A., attained a 25% energy savings in 1978 vs. 1972 and anticipates further improvement.

Typically the majority of the initial energy savings to date have come from no or low-capital investment/high return improvements including housekeeping measures such as furnace tuning, exchanger cleaning, and steam leak and trap repair. Future savings will come principally from investments in new or retrofitted operating equipment. In order to properly manage this multi-year conservation effort and predict how energy can be saved, refinery energy efficiency must be put into proper perspective. Goals which reflect continued

efficiency improvement should be set. Then an accurate method should be used to analyze energy efficiency and steward progress toward the efficiency goals.

Using the conventional refinery consumption indicator (MBTU/B)* can be misleading since effects of changes in feed slate, product mix, and operational intensity are lumped in with improvements in energy efficiency. A better method for measuring refinery efficiency is to compare actual energy consumption with an energy efficient base. Flexibility should be included to:

- measure energy efficiency of refineries with different complexity by using a set of common efficiency criteria.
- compensate for changes in intensity of operations such as high conversion summer operation compared with low conversion winter operation.
- identify areas of energy inefficiency and quantify the amounts of energy waste.
- provide a meaningful measure of quantifying energy savings (or losses).
- monitor progress in energy conservation.

These are the prime objectives of an Energy Guideline Factor (EGF) system developed by Exxon Research and Engineering Company. Its uses are further explained in this article.

Consumption Versus Efficiency

A distinction should be made between the terms "consumption" and "efficiency". Energy per barrel of processed input or typically MBTU/B*, is a measure of refinery energy consumption, not efficiency. Consumption expressed as a percent of an energy efficient "guideline" consumption, (%GL), is a measure of efficiency. Efficiency is the more important indicator when making comparisons between two time periods of operation for a given refinery, between two or more different refineries, or between the same type of process unit at two or more locations.

A refinery with a low consumption is not necessarily more efficient than a refinery with high consumption. A hydroskimming refinery with little downstream processing should not consume as much energy as a conversion refinery since their product slate and numbers and types of process units are quite different. Realistically this difference should be taken into account if comparisons of energy efficiency are to be made between refineries.

Consider the hypothetical hydroskimming refinery A, shown in Table 1. Consumption for this refinery is 225MBTU/B of crude and its efficiency is 150% GL. In contrast, consider hypothetical refinery B, a conversion refinery which has a number of additional process units for increased clean products yield. It has a consumption of 433MBTU/B. Its efficiency, however, is much better at 135% GL. Higher energy consumption by the conversion refinery is inherent because of the higher level of processing. This fact is evidenced by the higher energy intensity for refinery B, which is discussed later.

Likewise changes in product demand (for example, seasonal middle distillate demand) dictate different throughput and severities of operation of the

*Thousands BTU/Barrel of Input

TABLE 1

MEASURING CONSUMPTION VERSUS EFFICIENCY

Refinery A Hydroskimming Refinery	Major Processing Units	Refinery B Conversion Refinery
Atmospheric Pipestill		Atmospheric Pipestill
POWERFORMER		Vacuum Pipestill
Crude and POWERFORMER Light Ends (6 Towers)		Crude and POWERFORMER Light Ends
Naphtha, Kerosene, and Distillate Hydrofining		POWERFORMER
Sulfur Removal and Processing		Naphtha, Kerosene, Distillate Gas Oil Hydrofining
Offsites		Fluid Catalytic Cracker
		Catalytic Light Ends
		Alkylation
		Coker
		Hydrocracker
		Sulfur Removal and Processing
		Hydrogen Plant
		Offsites

ENERGY DATA

100	Processed Input, MB/D	100
22500	Total Energy Usage, MBTU/D	43300
225	Refinery Consumption, MBTU/B(1)	433
15000	Guideline Energy, MBTU/D	32100
150	Refinery Efficiency, % GL(2)	135
150	Refinery Intensity, GL-MBTU/B(3)	321

$M = 10^3$

(1) e.g., 43300/100 = 433
(2) e.g., (43300/32100) x 100 = 135
(3) e.g., 32100/100 = 321

Refinery A has lower consumption (MBTU/B), yet is less efficient (higher % GL).

---

refinery units as shown in Table 2. Consumption differs by 21 MBTU/B between winter and summer operations. Efficiency, however, remains constant at 135% GL. The efficiency is constant inasmuch as the EGF method automatically compensates for changes in operating severities and throughputs of the refinery units.

What is the EGF System?

The EGF system is based on a set of Energy Guideline Factors (EGF) for each process unit and normal offsite facilities. These factors specify the energy consumption of energy-efficient designed and operated process units. The guideline factors set a standard against which consumption for specific units are compared.

The factors were developed using design information from actual refinery units and adjusting them to common energy efficiency criteria. The selected criteria are achievable in favorable economic climates and establish a low level of energy usage. The guideline factor for the unit is expressed in energy/bbl of representative divisor, usually feed rate. The guideline factor is constant for some units, but for others is correlated to major process

TABLE 2

ACCOUNTING FOR DIFFERENCES IN OPERATING SIGNALS

REFINERY B

Summer Operation		Winter Operation
100	Processed Input, MB/D	100
335	Intensity, GL MBTU/B	321
486	Consumption, MBTU/B	465
145	Efficiency, % GL	145

variables which affect energy consumption. Figure 1 illustrates a typical relationship between guideline energy and a major unit variable.

The efficiency measure itself is a percent of guideline, which is the energy consumed by a particular, real processing unit divided by that unit's guideline energy.

$$\%\ GL_i = \frac{\text{Energy Consumed by Unit}_i}{\text{Guideline Energy for Unit}_i} \times 100 \quad (1)$$

The weight average efficiency of a refinery is the energy consumed by all the processing units and other operations divided by the guideline energy of all of these units.

$$\%\ GL = \frac{\text{Energy Consumed by All Units}}{\text{Guideline Energy of All Units}} \times 100 \quad (2)$$

The denominator of eq. 2 is the refinery guideline energy based on the processing objectives for the particular refinery in question. It can also be thought of as the energy that refinery would use operating at the standard efficiency of 100% GL. This guideline energy is determined by the configuration of the refinery in question and its major operating parameters. Thus it is "tailor made" to fit that individual refinery. The guideline energy for refinery A (Table 1) is based upon guideline factors for those processing units only. The conversion refinery B has much higher guideline energy, based upon the guideline factors for its processing units.

The refinery guideline energy per barrel of processed input is defined as energy intensity and is a measure similar to the Nelson complexity

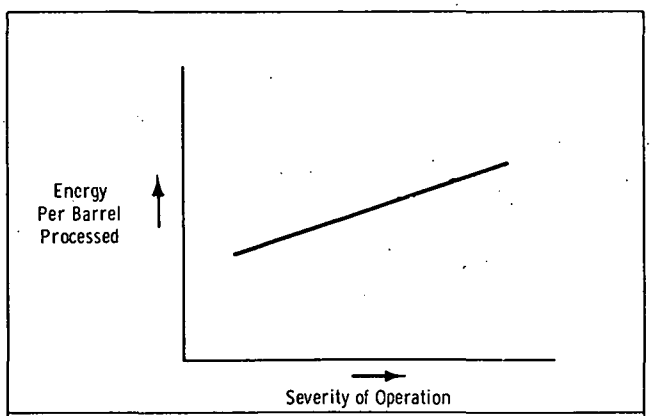


Figure 1
ENERGY REQUIRED VS. OPERATING SEVERITY

index.[1,2] There is a major difference, however. As stated earlier, the guideline factor for some process units is a function of major operating variables. Therefore, as operating signals, crude and product slates change, the guideline energy and energy intensity of a given refinery will vary although the processing configuration of the refinery may not be changed. Intensity is related to refinery efficiency by eq. 2a.

$$\% \text{ GL} = \frac{\text{Actual Consumption}}{\text{Intensity}} \times 100 \quad (2a)$$

By using the EGF system to define the efficiency of a given refinery, we have (1) compared the refinery's energy to a stringent technologically achievable standard of energy efficiency, and (2) have developed this standard based on those processing units and operating variables of that particular refinery.

Use of the EGF System for Energy Loss Analysis

The guideline energy sets a standard for comparison of a given refinery process unit's energy consumption. This enables one to carry out an energy loss analysis or energy audit of the unit. The analysis is made by comparing key data on the given unit to guideline criteria. Standard engineering techniques are used to identify (1) where energy is being lost, (2) how much of it is technically feasible to recover, and (3) what portion of the losses will support capital investment for recovery. Three major areas of losses in most refinery units are: excess furnace stack heat losses, loss of excess lower level heat to air or water coolers, and inefficient drivers, such as condensing steam turbines. Energy loss analysis may also highlight less-than-optimum processing schemes.

Part A of Table 3 shows the result of a typical energy loss analysis for Unit E which operates at 145% GL. It consumes 45% more energy than the highly efficient or standard unit would use, i.e. 100% GL. For the analysis of losses, shown, stack heat losses are determined by comparing furnace efficiency at the guideline stack temperature and excess O_2 with the actual furnace efficiency of Unit E. Loss of usable heat to cooling water that could be recovered by better unit heat integration is determined in a similar manner. Actual compressor power consumption is compared to the efficient unit's consumption.

Part B of Table 3 shows the results of energy conservation efforts on Unit E. Efficiency can be improved from 145 to 141% through tighter operations, i.e., no investment required. The 141% GL level is defined as the operational target, i.e., the best operation within the current hardware limitations on the unit. Another point is evident: through implementation of all economically attractive energy projects, listed in Table 3, Unit E efficiency can be improved to 115% GL. The additional 15% GL inefficiency above 100% is unattractive to recover under today's economic circumstances in a retrofit situation.

Use of the EGF System in Measuring Long Range Conservation Performance

As conservation efforts are implemented, the results will be reflected in better refinery efficiency. Total consumption in MBTU/B, however, may show a different trend. As heavier crudes are run, and

TABLE 3

ENERGY LOSS ANALYSIS

A. Energy Loss Analysis Unit E.

	% GL	MBTU/B
Guideline Energy,	100	200
Measured Energy Consumption		290
Efficiency	145	-
Potential Recoverable energy	45	90
Analysis of Losses:		
Base	145	
Non-Optimum Operations	4	
Operational Target	141	
Losses requiring capital investment to recover		
Excess Furnace Stack Losses	12	
" Low Level heat lost to Cooling losses	15	
Compressor consumption due to recycle	8	
Misc. and unidentified	6	
Guideline	100	

B. Energy Conservation Program

Base Consumption	145
Optimize Operations	4
Efficiency attainable without investment	141
Attractive Projects	
Furnace Air Preheat	10
Add more preheat exchangers	6
Install variable speed driver	6
Improved instrumentation and control program	4
Efficiency attained through attractive projects	115
Unattractive to recover	15
Guideline	100

environmental considerations require more severe processing, refinery consumption will increase. These increases should be isolated before evaluating the results of conservation efforts. Efficiency can be improved in two ways: Reducing real energy consumption on processing units for given constant operating conditions, and installing new energy efficient processing capacity. If the latter case involves new downstream units, the refinery MBTU/B may increase but % GL will decrease.

Figure 2 illustrates measuring the long term energy efficiency of a refinery. The base year 1972 represents pre-oil embargo energy performance. The low cost energy conservation programs and minor projects which were put in service in late 1973, 1974 and 1975 are reflected in % GL and also in MBTU/B consumption.

In 1975 to 1976, more sour crude required increased sulfur recovery, catalyst was changed in major units, and additional Hydrofiners were added. Therefore, energy intensity increased reflecting the additional processing. Efficiency, as shown by a decline in % GL, continued to show improvement as energy conservation efforts were continued.

Consumption, however, remained constant as increased processing requirements offset conservation gains.

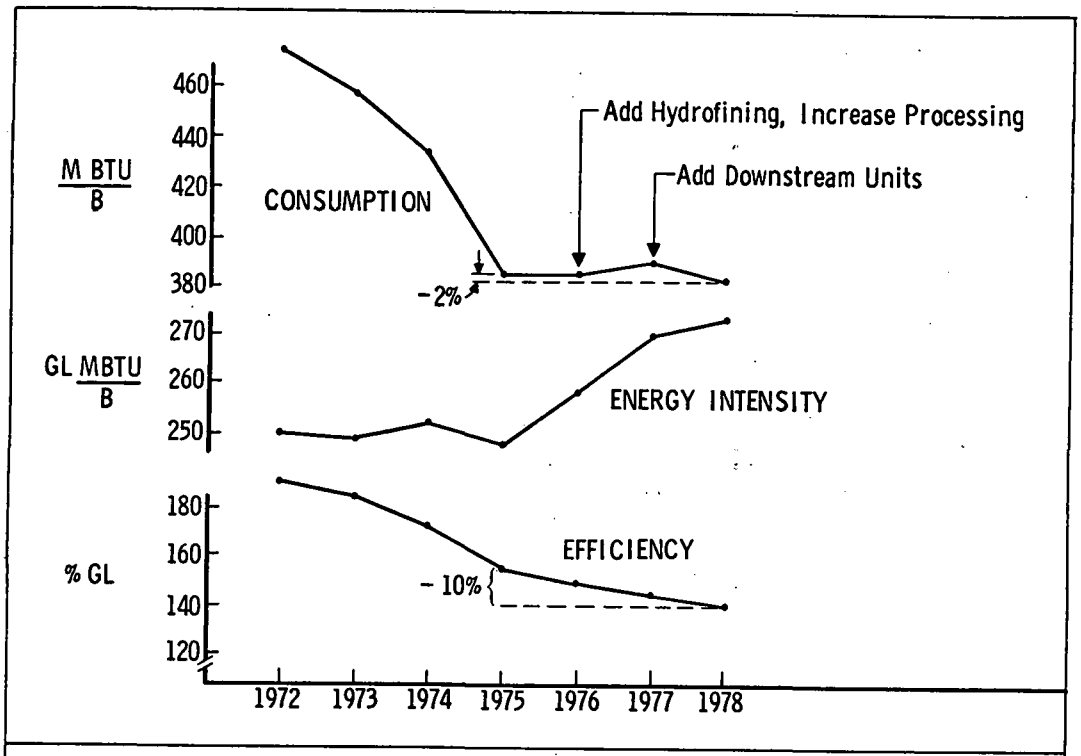


Figure 2
MEASURING LONG RANGE ENERGY CONSERVATION EFFORTS

In 1977, several additional processing units were added. Intensity again increased and consumption actually increased from 1976. However, since the energy efficient design considerations were used for these new units, their start-up improved the overall refinery efficiency as shown by a decrease in % GL.

Overall consumption was reduced only 2% between 1975 and 1978; efficiency however, was improved by 10%.

Use of the EGF Method for Monitoring and Stewardship

The bottom line results in energy performance depend on day-to-day, week-to-week monitoring and regular stewardship of performance vs. a set goal.

Individual Unit Monitoring

Monitoring should be done at each processing unit. It may, however, be desirable to group several units together within one identifiable processing zone. For example light ends processing may consist of an absorber/deethanizer, debutanizer, naphtha splitter and depropanizer each of which has a separate guideline factor. In this case weighted efficiency is calculated by dividing the process area real energy by the sum of the guideline energies for the individual towers.

Energy should be expressed as energy per day rather than energy per barrel since each tower has a different divisor.

A second useful indicator of efficiency is % of target which is the actual consumption of an individual unit divided by its target consumption (times 100).

Target consumption is obtained from a unit profile plot, a graph which shows best observed energy consumption for a particular operating unit as a function of its feed rate and operating variables. Fig. 3 is an example of such a plot. Percent of target is calculated by dividing the unit's actual energy consumption (at those same conditions) by the operation target read from the graph.

Percentage of target is a useful indicator for unit operating and technical personnel to gauge their efforts in conservation energy. By using the % of target indicator, effects of short term variations in feed rate and operating signals, normally outside the operators control, are factored out.

Stewarding Refinery Efficiency

The EGF method enables accurate analysis of overall refinery performance. Changes in energy intensity, i.e. differences in consumption due to more or less processing, are automatically compensated in the efficiency calculation.

The difference in refinery efficiency, $\triangle\%\ GL_{2-1}$, between two time periods (or between actual and forecast) is calculated by equation 3.

$$\triangle\%\ GL_{2-1} = \left[\frac{\text{Total measured energy}_2}{\text{Total guideline energy}_2} - \frac{\text{Total measured energy}_1}{\text{Total guideline energy}_1} \right] \times 100 \quad (3)$$

Total guideline energy (typically in $\overline{\text{MBTU/D}}$)* is the sum of all the guideline energies for each operating unit in the refinery. Guideline energy will vary between period 1 and 2 with changes in individual unit feed rates and operating signals.

With 1) total measured energy 2) individual unit divisors, usually feed rate, and 3) key operating signals, for both time periods, calculation of eq. 3 is straightforward.

However, since the total variance in equation 3 can represent several million dollars a year for a large refinery, further analysis should be made. This will enable managers to better understand all of the various effects reflected in $\triangle\%\ GL_{2-1}$ and will pinpoint areas for corrective action.

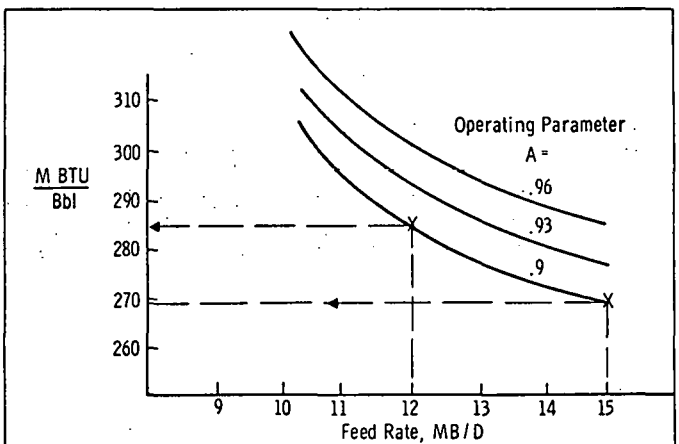


Figure 3
UNIT PROFILE CURVE - UNIT E

*Million (10^6) Btu per day

Forecast year average Operations 1978

Unit	D	E	Total Zone
Feed Rate MB/D	10.0	15.0	25.0
EGF MBTU/B - Guideline	85	205	-
Guideline Energy $\overline{M}$BTU/D	850	3,075	3,925
Energy Required, $\overline{M}$ BTU/D	1,300	4,035	5,335
Efficiency, % GL_1	152.9	131.2	135.9

Actual Year Average operation for 1978, Zone 1:

Unit	D	E	Total Zone
Feed Rate MB/D	10.0	12.0	22.0
EGF, MBTU/B Guideline	88	205	-
Guideline Energy, MBTU/D	880	2,460	3,340
Energy Required, MBTU/D	1,296	3,300	4,596
Efficiency, % GL_2	147.2	134.1	137.6

To illustrate such an analysis of $\triangle$% GL_{2-1}, consider the processing zone shown above. The zone is used here for simplicity; the principles apply also to the whole refinery.

The zone consists of two units, D and E, as shown:

By Equation 3:

$\triangle$% GL_{2-1} = 137.6 - 135.9 = +1.7, (Worse than forecast)

The zone supervisor was disappointed in the results inasmuch as he knew there were 1) diligent attention to operations during the year 2) as well as several unforecasted energy conservation projects put in service. Thus he performed further analysis.

Unit Mix: Units D and E were correctly forecasted to run at different individual efficiencies (152.9 and 131.2 % GL, respectively). Since actual feed rate and operating conditions were different than forecast, i.e. there was a different unit mix, zone efficiency would be expected to change.(3) This change would occur for the zone even if individual unit efficiencies did not change. Thus in order to isolate this effect, variance due to unit mix is calculated by equation 4.

Unit Mix Effect: $\triangle$% GL_{2-1} =

$$\left[\frac{\text{Energy Consumption at Forecast Efficiency and Actual Operations}}{\text{Guideline Energy at Actual Operations}}\right.$$

Minus

$$\left.\frac{\text{Energy Consumption at Forecast Efficiency and Forecast Operations}}{\text{Guideline Energy at Forecast Operations}}\right] \times 100 \qquad (4)$$

In this example unit mix affects zone efficiency +1% GL*, i.e. 1% worse than forecast.

* See footnote next page.

Energy Conservation: In addition to those in the forecast, four other conservation projects were put in service during 1978. These identified savings were calculated to be 140 $\bar{M}$BTU/D averaged over the year. The approximate effect of conservation savings are then calculated using equation 5.

$$\Delta\%\ GL_{2-1} = \frac{\text{Energy Effect}}{\text{Guideline Energy}_2} \times 100 \qquad (5)$$

In this example $\Delta\%\ GL_{2-1}$ energy conservation effect is -4.2% GL, i.e., better than forecast.

Turndown: Unit E operated at an average of 80% of its forecasted feed. Examining its unit profile curve, Fig. 3, shows that the best (lowest expected) consumption at 12,000 B/D is 285 MBTU/B instead of the 269 MBTU/B forecasted at 15,000 B/D feed.

This turndown effect represents 192 $\bar{M}$ BTU/D lost efficiency or by equation 5,

+ 5.7% GL (worse than forecast).

General Unit Efficiency

The closure of equation 3, total observed efficiency difference ($\Delta\%\ GL_{2-1}$), is derived from all other factors which influence energy efficiency including energy program maintenance, operator and technical attention, operating problems and any unidentified effects. For this zone, unit efficiency is calculated by difference.

$$\underset{\Delta\%\ GL_{2-1}}{\text{Total Variance}} = +1.7 = \underset{+1.0}{\text{Unit Mix.}} - \underset{4.2}{\text{Encon.}} + \underset{5.7}{\text{Turndown}} + \underset{X}{\text{General}} \qquad (6)$$

X = -0.8, or slightly better than forecast.

This result confirmed the supervisor's analysis of operator attention to conservation efforts. Any particular energy effect may be highlighted by quantifying the actual effects and then using eq. 5 to express it as incremental efficiency.

The above analysis could have been performed alternatively by looking at the actual energy effects (MBTU/D) only; however, for a large refinery with 20 - 70 different guideline units, such calculations can become complicated and confusing. Use of % GL simplifies these calculations by factoring out the effect of different energy intensity between the two periods.

Financial Reconciliation

Actual and forecasted energy cost for the whole refinery is calculated using projected costs and actual billings respectively, for fuel, steam and power. Reconciliation of the cost difference can be performed by expressing the energy cost as a product of guideline energy, efficiency, and unit price as shown in eq. 7.

$$\frac{\text{cost}}{\text{day}} = \left(\text{composite price}, \frac{\$}{\bar{M}BTU}\right) \times \left(\text{Guideline energy}, \frac{GL\bar{M}BTU}{D}\right) \times \left(\text{Efficiency}, \frac{\%GL}{100} \frac{\bar{M}BTU/D}{GL\bar{M}BTU/D}\right) \qquad (7)$$

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* Calculate unit mix effect as follows:

Guideline energy at actual operations and forecast efficiency:

$$10 \times 88 \times \frac{152.9}{100} = 1345.5 \quad \text{Unit D}$$

$$12 \times 205 \times \frac{131.2}{100} = 3227.5 \quad \text{Unit E}$$

$$\%\ GL_{2-1} = \frac{1345.5 + 3227.5}{880 + 2460} - \frac{3925}{5335} \times 100$$

$$= 136.9 - 135.9$$

$$= +1.0$$

Differentiation of eq. 7 to calculate variance yields three terms on the right hand side which are the price effect, operating program effect (crude run plus operating signals) and efficiency effect. The efficiency effect, as was illustrated in the earlier example, can be broken down further into individual effects such as were given in eq. 6. For example turndown debit for the year may be expressed in terms $\triangle$% GL efficiency (eq. 6) or in $/Day. (eq.7)

Summary

As energy savings become harder to capture and require larger capital expenditures, a better definition of energy efficiency is needed. Having a standard of energy usage (guideline) for a specific processing unit enables performing an energy loss analysis for that unit. This analysis provides a basis for evaluating the feasibility of energy conservation projects.

Rising energy costs require more precise reconciliation analyses in order to understand a refinery's energy performance and to accurately reflect conservation efforts.

Using the Exxon Research and Engineering Company Energy Guideline Factor system rather than MBTU/B to track energy efficiency provides a sounder basis for managing conservation efforts and stewarding performance.

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USE METERS TO PUT TEETH INTO YOUR CONSERVATION PROGRAMS

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The confluence of two trends is exerting ever greater pressure for sophisticated energy conservation programs. On the one hand, the cost of energy continues to rise at a rapid rate; on the other, the easy energy savings resulting from an era of energy affluence have been harvested. Overlaying these trends is the sobering realization that new energy sources will make little or no difference for decades, thus conservation has become the most available source of "new" energy. These trends are well established and the 1980's will be the decade of energy accountability and control in most industries.

As energy costs gallop out of sight, in-house conservation programs will be directed to determining how efficiently energy is used by various departments. What makes this a difficult task is the fact that most energy is provided to users in forms that make it very difficult to measure - red hot steam, high pressure air and nitrogen, and high velocity natural gas. Furthermore, the cost of shutting down a facility to install energy measuring devices is so exhorbitant that it precludes their wide-spread use.

This paper addresses the problems associated with assigning energy cost directly to in-plant users, either by department or by product. The solution is effective flow metering, but that is a difficult job even in more traditional applications. The problem is compounded by the fact that traditional metering concepts are inadequate for the unique problems presented by retro-metering for in-plant accountability. This paper brings the problem into a sharp, analytical focus and further offers some unique, new solutions. Finally, the experiences of companies who have committed to metering programs is investigated.

INTRODUCTION

It is well-known that the United States consumes a vastly disproportionate amount of the world's energy. Further, our useage of energy has been inefficient and wasteful when compared to the useage pattern of other countries (1). With the industrial section accounting for approximately 40 per cent of all fuel used in the United States, it has come under the spotlight of national energy conservation efforts. The rapidly growing library of regulations underscores the government's concern for more efficient use of energy.

Industry, however, needed little incentive to pursue programs aimed at saving energy. The rising cost of energy has had its impact on the profits of virtually every United States company. In some cases, this impact has been so significant that it has led to the termination of certain product lines or the shutdown of inefficient plants.

Two major trends will exert continuing pressure on industry to implement more sophisticated energy management programs. First, energy costs will continue to rise with no relief in sight and second, energy savings will become even more difficult to achieve as the "law of diminishing returns" applies.

These trends have already led to beneficial results. Industrial energy consumption has declined over the past few years while use by other sectors has increased. The big unanswered question is, can this trend be continued or are we witnessing the fruits of harvesting the easy savings?

The answer lies in the success of new and more sophisticated energy management techniques and systems.

The common thread unifying such programs will be the determination of energy useage at smaller and smaller ties. Beginning at the plant level, then departmental levels and finally to specific processes, the goal is to break down energy cost to controllable levels in the same way the labor and materials are controlled.

ACCOUNTABILITY AND CONTROL OF ENERGY COSTS

What has been suggested is that energy conservation, long thought to be the domain of the technologist, has a new mentor...the cost accountant and/or financial executive. When energy was cheap it could be neglected or treated as overhead. But in recent years, the cost of some utilities such as steam has increased by an order of magnitude. This has commanded attention from management to energy conservation in a myriad of ways.

Bottom Line Profits

In measuring the financial performance of a firm via periodic income statements, corporate executives have observed profits impacted by rising energy costs.

> "In 1973, energy costs comprised only one-half of one percent of the total operating costs of a typical fabricated metal company", reports the Department of Energy. "At present, these energy costs amount to about ten percent..."(2)

In other industries, the cost of energy has risen to as high as 25 per cent of the total cost of production. Energy conservation programs that are expected to produce savings of 9 to 24 per cent on an industry-wide basis are already underway (3). Such savings can represent hundreds of millions of dollars annually to a large manufacturing firm.

Cost Accounting

It is safe to say that all large manufacturing firms have extensive cost accounting systems for labor and materials. Now that energy has become a significant factor in the total cost of producing a product, it must likewise be accurately accounted for if sound pricing and profitability decisions are to be made.

At the Buick Motor Division of General Motors, an in-plant sub-metering system for steam, natural gas, compressed air and electricity has helped reduce the energy use per vehicle by 16.7 per cent in the last five years (4).

Identify Losses and Inefficiencies

In an era of energy affluence, inefficiencies and even sloven practices developed. Since Energy was cheap, who cared? There were bigger problems to worry about.

In recent years there has been a concerted effort to correct such practices. For example, leaks in utility pipes were found to be very expensive. Steam leaks could be easily identified because they could be seen. Not the case for "invisible" fluids such as air and natural gas. Such systems required metering in order to help identify losses. And while metering systems are expensive, their payback is very rapid (5).

Leaks are only one kind of inefficiency; wasteful practices that have crept into industrial operations are far more significant. General Motors has found that using energy meters to measure a manager's performance (and help determine the size of a manager's bonus) promptly produces energy savings of 5 to 10 per cent "because a manager is less likely to ignore the energy consequences of his decision" (6).

Segregate Energy Costs

Some firms have found it advantageous to be able to segregate process energy (energy used in the production of a product) from other uses. For example, in most states, process energy is not subject to sales tax, since it is considered part of the value added by a manufacturer. It is often necessary to demonstrate to a taxing agency exactly how much energy is used for process applications. This requires metering.

Incremental pricing is another area where it is advantageous to segregate energy costs. This procedure is rapidly becoming very complex and will not be detailed in this paper. The basic principle in all incremental pricing, however, is that certain energy forms, i.e., natural gas, will be allowed to reach a free market price level rather than a regulated price level. The exception being process energy. Thus, several firms right now find themselves with problems of having to segregate process energy from other uses because of significant price differences.

Government Reporting

The Department of Energy requires all major manufacturers to report their energy consumption patterns on a regularly scheduled basis (quarterly, monthly, etc.). The trend has been to require more and more

detailed reporting, both by energy commodity and by operating entity. This trend will continue and will thus require more accurate and more sophisticated metering.

FOCUSING ON THE PROBLEM

All of these requirements suggest more sophisticated energy management practices underpinned by accurate metering at smaller and smaller entities. This so-called practice of sub-metering can be illustrated in Figure 1.

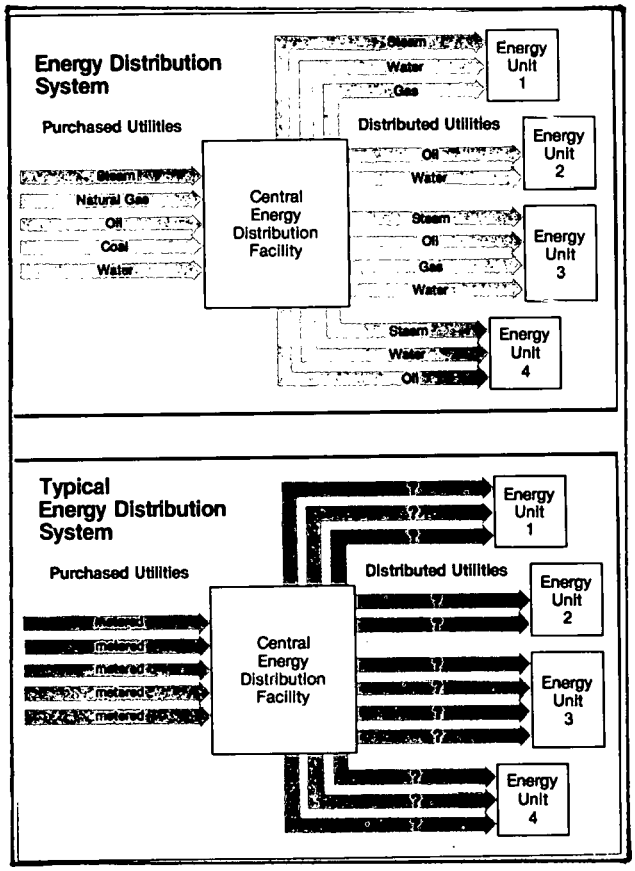


FIGURE 1. ENERGY DISTRIBUTION SYSTEM

As the figure suggests, accurate metering exists at a plant's doorstep because the energy commodity is being bought and sold. As the energy is converted and distributed to users within a plant, however, there is little known about its useage.

The problem is further compounded by the fact that energy is provided to in-plant users in forms that make it very difficult to measure, or in locations that preclude a shut down to install meters. Following is a litany of some of the unique requirements that apply to in-plant sub-metering systems.

- o install all without shut down
- o universal meter (not dedicated to a specific line
- o accurate
- o wide range
- o low pressure drop
- o bi-directional
- o economical

With this as an overview, the dilemma to the plant engineer or energy "czar" becomes.."WHICH METER SHOULD I USE?"

This is a perplexing question to answer because there are so many different types of flow meters (7), (8). The dilemma is further compounded when, after careful examination of available alternatives, the technologist concludes that none are universally "satisfactory". As is often the case, such a dilemma calls into being new technological innovations (9). The following case history examines the experiences of a major chemical plant faced with this problem and what they did about it.

Case History of a Chemical Plant

The plant manager of a major chemical company refereed the contest between competing factions in his plant. On one side he was offered the argument that energy conservation efforts in the plant were being stifled by a lack of data on consumption patterns. From the other side came the challenge that "meters don't save energy", and the company resources could be better directed to proven systems.

When he voted in favor of an in-plant metering project, his primary justification was for better control. And he had in mind not only control of energy consumption, but the manufacturing processes as well. "Running an operation without proper controls is like driving a car by bouncing between guard rails", he said. "Without controls to indicate the direction of progress, no action is taken until the damage is done".

His experiences highlight the two major factors that impede the widespread use of meters in energy conservation programs:

- o meters by themselves do not save energy, thus justifying a metering program becomes a qualitative, rather than a quantative, exercise;
- o economic benefits from a metering progra require a "program champion". What this suggests is that energy savings will be realized only if the data provided by

energy meters is used by management and engineering personnel to make better decisions. tification for installing meters can thus be for direct economic reasons to reduce costs, or for process control purposes. The more explicit the operating parameters of industrial processes can be defined, the greater likelihood of manufacturing a consistent, quality product. This does not mean that control be absolutely precise, but it does mean that an acceptable band or tolerance should be defined.

Program Implementation

Once management has recognized the need and approved a metering project, there are four basic steps that follow:

1. Divide the total operation into meaningful subunits.
2. Define output in meaningful units.
3. Establish commitment from operating supervision.
4. Select hardware and install.

As mentioned earlier, there is generally good metering at the point of delivery, but this seldom gives an adequate indication of how subunits are performing. Exceptional performance in one area may go unrecognized due to poor performance in another. These subunits must be defined by the nature of the business For one location, this could be by one area of supervision; for another, it might be by product or department.

Particularly for manufacturing facilities, the output must then be related in meaningful units. Bulk measurement of utilities, such as cubic feet of gas, pounds of steam, or kilowatts of electricity, mean little unless related to volume of output. A steam reduction from 1000 pounds/hour to 900 pounds/hour can easily be misinterpreted if production has dropped from 100 units/hour to 75 units/hour. Actually, per unit consumption has increased from 1$\bar{M}$ Btu/CWT to 1.25$\bar{M}$ Btu/CWT.

Commitment from operations is easily overlooked in initial phases, but this will be the key element to a successful program. A posted speed limit has no significance if the drivers disregard it. Unless heeded by the vast majority of drivers, the signs are only an expense to the taxpayers. Production management is far from simple and unless this group perceives some advantage from meters, the meters will remain the property of the engineer that installed them. The list of benefits for production range from better production cost performance, to upper-management blackmail, to utility cutoff, to.....whatever.

Hardware selection, in many ways, becomes the simplest step in a metering project. Here the engineer can deal with quantifiable entities - for the most part. Experience in laying out one program generated a list of possible factors, shown in Figure 2, to consider.

MEASUREMENT FACTORS	COST FACTORS
Accuracy	Instrument Cost
Repeatibility	Piping and Material Cost
Turndown or Range	Installation Labor Cost
Reliability	Spare Parts for Inventory
MAINTENANCE FACTORS	**OTHER FACTORS**
Mechanical Reliability	Vendor
	Computer Compatible
Calibration Requirements	Space Requirement
Spare Parts	History and Experience
Availability to Maintenance	Pressure/Temperature Compensation
Capability of Workforce to Maintain	Output
	Reversible Flow

FIGURE 2. EVALUATION CRITERIA FOR ENERGY METERS

These groupings are general and intended only to reflect the spectrum of dimensions involved. The lists can be added to, or deleted from, for a specific situation. One note, electric meters fall pretty much in the same pile from our experiences, so they are not discussed. The particular utilities of focus are gas, steam and air.

Measurement or hardware factors are the simplest to obtain. Every supplier of this equipment has data or specifications related to his goods. Jargon may vary between manufacturers, but it offers valuable information that should be considered.

Cost factors are a little less obvious, but again are relatively simple to establish. Instrument, material and labor costs are easily obtainable, in most cases. If production must be interruped to install the meters, this cost should also be considered. Any

unique, or hard-to-obtain parts that must be inventoried add stock charges.

The long-range value of metering will require that the system be well-maintained, so these factors should be included at the time of purchase. The need for periodic maintenance and the availability of qualified personnel or test instruments will definitely affect system reliability. Also, the availability of the instrument for maintenance without interrupting production is vital in most cases.

The last category (Other Factors) is a catch-all for everything else that is important but may not fit in the other categories. These are the individual factors that apply in specific cases. One attribute not to be discounted is the vendor or manufacturer. The most important difference between several alternatives can be the service and responsiveness of the supplier to your specific problems.

Program Results

As support for the value of metering, the next section of the paper shows examples from actual situations experienced after the utility meters were installed. Not always were these results understandable when they first occurred. Only after the "guardrail" had been hit was it realized what the meters were telling.

The setting for the example is an energy intensive chemical processing plant that has set substantial energy reduction goals without reducing quality standards. The actual results of metering have included not only energy saving but also product quality improvements.

Figure 3 illustrates the energy efficiency for a drying operation. The data is plotted in units that illustrate energy per pound of product.

This figure clearly shows an unfavorable trend in energy per capita (0.10 in July vs. 0.27 in February.) The unusually low readings at the end of November and beginning of December represent a time when the meters were removed for service. Seasonal variation cannot account for this trend as the department is fully within the plant walls.

A review of total gas consumption by the department provided apparently meaningless results. As of this writing, the trend is unexplained, but efforts are underway to find the reason for the major change in process energy efficiency as indicated by the met

Figure 4 illustrates steam consumption per capita by the same department. This figure appears erratic, but was found to be the result of an unknown tie-in by another department. In the maze of the piping system, an adjacent department had been connected to this department's line. The peaks correspond to changes in demand at the "pirating" department. If this department had made only one product, the transgression might have gone unnoticed. But the peaks started a search that correlated them to product changeovers, then the piping connection.

A spin-off of benefit to this evaluation was the identification of unusually high energy losses caused by high steam velocities at peak demands. This has led to an evaluation of the cost savings that could be gained by changing to a larger pipe.

Figure 5 shows natural gas consumption per capita by yet another department. This figure illustrates the most dramatic and beneficial result of the metering program to date.

The sharp peak in September came just before a major burner failure. The peak in February corresponds to an unexplainable appearance of a gray coating on a pure white product. In both cases, certain maintenance costs could have been avoided given a better understanding of the message provided by metering data.

Summary

The use of meters in this chemical plant has opened up a panorama of insights which were heretofore unknown. More accurate and timely assessment of these insights will certainly develop over the years as experience is gained.

Needless to say, the firm has found that meters provide a valuable source of data not only on energy useage, but also on process efficiency. In every instance, the first observation turned out to be only the tip of the iceberg. Subsequent investigations continue to provide valuable new information on plant operations.

Conclusion

Metering alone does not produce energy savings.

Successful energy conservation requires a committed management, comprehensive programs and an effort by everyone in the plant. According to S. N. Choudhuri, "Energy conservation is 95 per cent management and only 5 per cent technical" (10).

In such an energy conscious environment, meters provide invaluable data for energy savings as well as efficient process control.

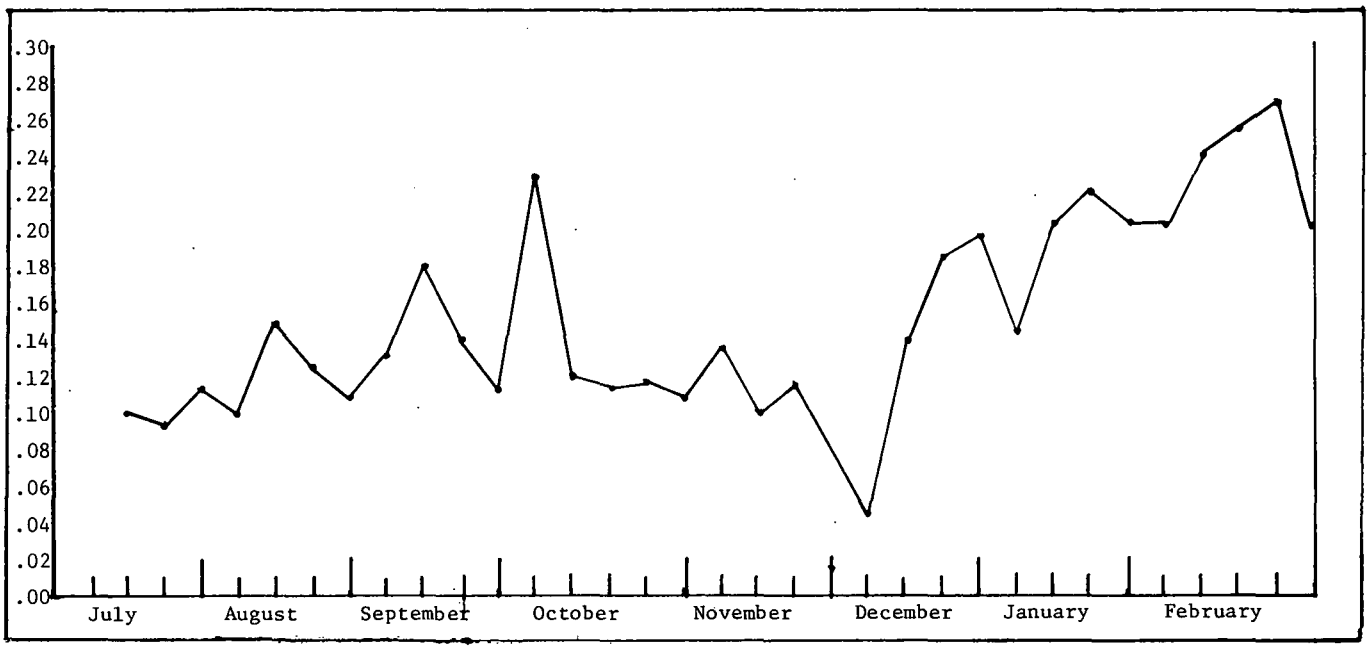


FIGURE 3. NATURAL GAS USEAGE - DEPT. "X"

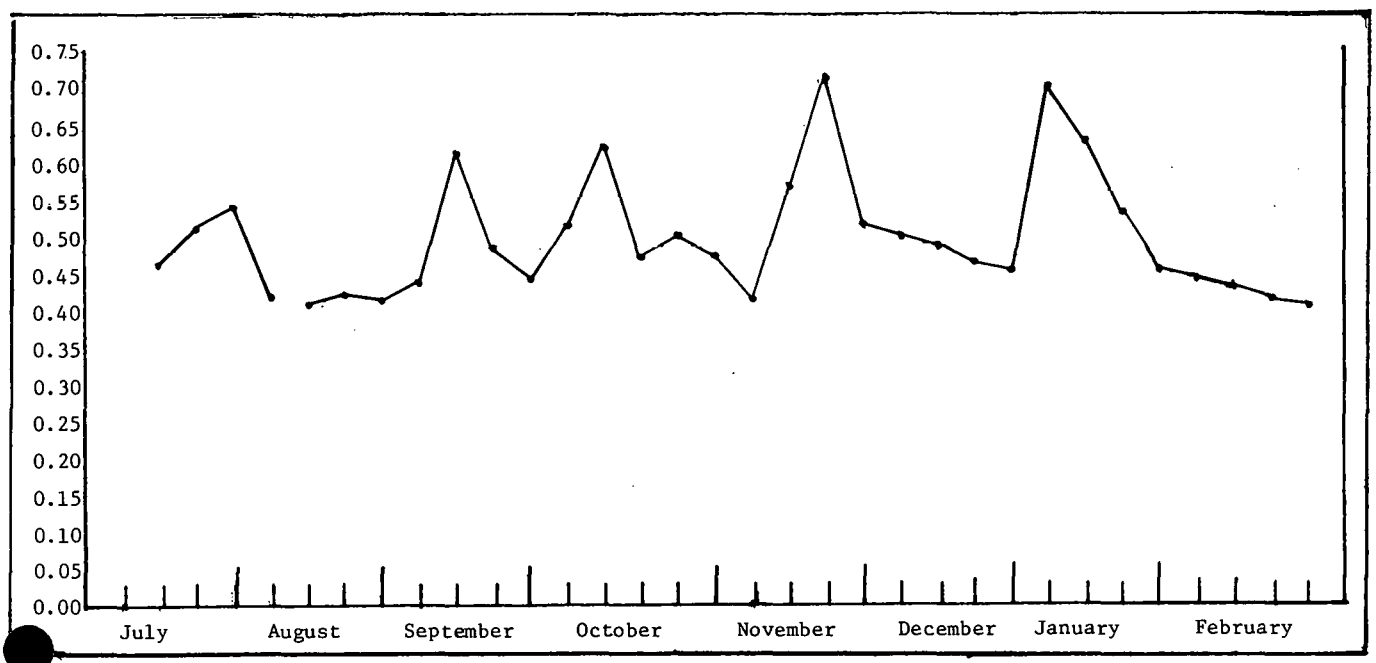


FIGURE 4. STEAM DEPT. - DEPT. "X"

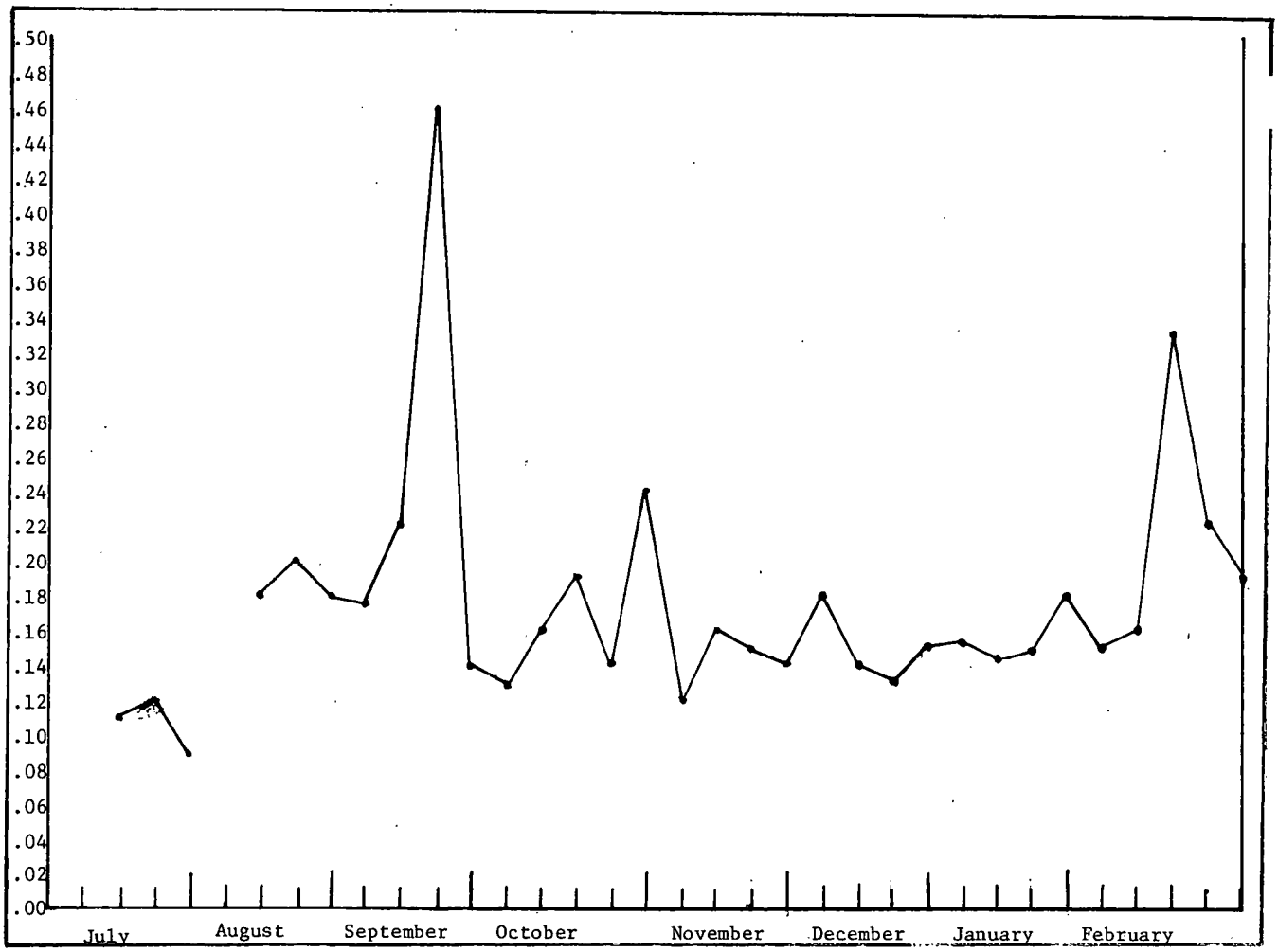


FIGURE 5. NATURAL GAS - DEPT. "Y".

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ONTARIO HYDRO MOTOR EFFICIENCY STUDY

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ABSTRACT

Electric motors consume more than one-half of the electrical energy produced by Ontario Hydro. In the residential sector, the major motor load is for refrigerators and freezers while packaged equipment dominate the motor load in the commercial market. However, this paper concentrates on the industrial market since 76% of this market's load is motors.

The polyphase integral horsepower motor is the "workhorse" of industry. The efficiency of the standard induction motor can be improved. The new "high efficiency" motor is described and the operating cost is compared to the standard motor. Payback for high efficiency motors is found to be about one year for continuous duty applications. Specific instructions are presented for use in industry.

INTRODUCTION

A survey conducted in 1974 by Ontario Hydro reported that 52% of the electricity produced that year was used to power motors. (See Fig. 1) This was more than twice the energy consumed by the second primary end use, heating. The magnitude of this load suggested to the Energy Conservation Division that electric motors deserved a close look to see if the energy was being used efficiently. The first step in the examination was to determine the energy use in different market segments.

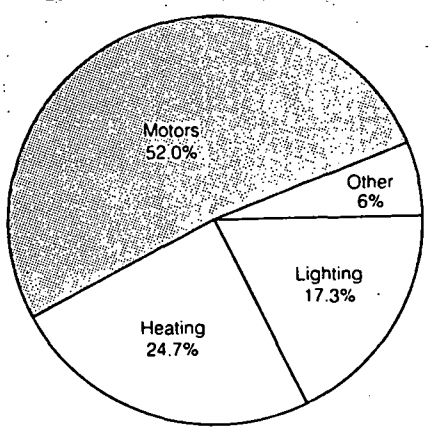


Figure 1
Distribution of Total Electricity Use

RESIDENTIAL

Motors account for 21% of the residential market load. (shown in Fig. 2) About 2/3 of the 21% is used by refrigerators and freezers. In both of these appliances, the motor is usually hermetically sealed with the compressor. A more efficient motor would not only use less electricity, but would improve the refrigeration cycle efficiency by contributing less heat to the refrigerant. However, the consumer who purchases the appliance never sees the motor, or is aware of the efficiency. Fortunately, the recently introduced "ENERGUIDE" program will make it possible to compare energy use of various makes and models of refrigerators. If consumers are attracted to refrigerators that use less energy the manufacturers will respond with design changes that will include higher efficiency motors if they are the most effective design change.

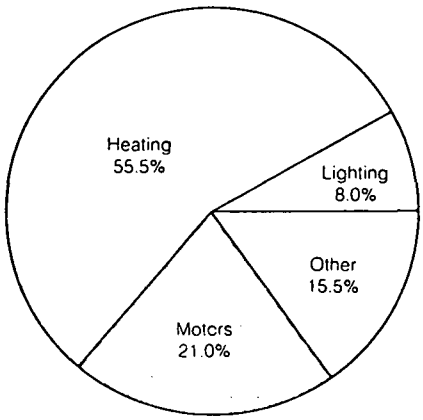


Figure 2
Distribution of Residential Electricity Use

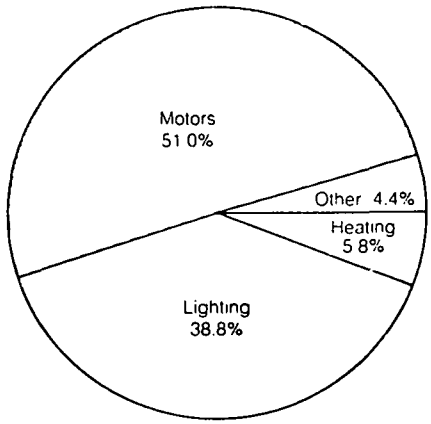


Figure 3
Distribution of Commercial Electricity Use

COMMERCIAL

Motors use 51% of electrical energy in the commercial market. (shown in Fig. 3)

Refrigeration and air handling equipment are major users of energy with smaller loads coming from elevators, moving stairways, electric doorways, etc. Once again, this market usually purchases packaged equipment, with the motor well hidden away. The purchaser is usually not aware of who manufacturers the motor and what the efficiency and power factor are. This situation is further complicated by the fact that the purchaser is not usually responsible for operating costs and therefore opts for the lower capital cost which may be at the cost of efficiency.

Progressive consulting engineers can play a key role in this market. They should be writing specifications that include the cost of operating equipment, awarding penalties to less efficient equipment. This will encourage the original equipment manufacturer to increase the efficiencies by proper design of the equipment and by the use of a higher efficiency motor. At the same time, the consultant must convince his client that an investment in high efficiency equipment can produce good returns.

INDUSTRIAL

76% of the industrial electrical load is motors. (shown in Fig. 4) If you are interested in reducing your electrical energy operating costs, higher efficiency motors could be a good bet. In this market, the user of the motor is usually the purchaser of the motor and is therefore aware of both capital and operating costs. He will be in a good position to respond to a product that is marginally more expensive but yet reduces operating costs significantly. It is time to re-examine old ways in this new era.

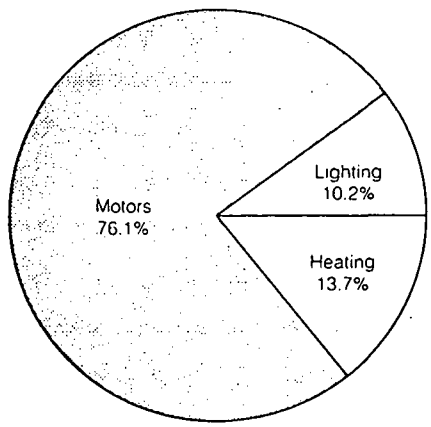


Figure 4
Distribution of Industrial Electricity Use

WHICH MOTORS CAN BE IMPROVED

The selection of a motor for a given application can involve many considerations. Often efficiency will be disregarded beca

of the over-riding importance of other motor characteristics (e.g.,efficiency may be sacrificed to limit starting current).

D.C. and synchronous motors are generally very large. Hence, motor losses would likely have been scrutinized in the design process, as is usually the case with large motors.

The efficiency of squirrel-cage induction motors can be improved. This is confirmed by the fact that some "high efficiency" induction motors have already been marketed, and all motor manufacturers admit that the efficiencies can be improved.

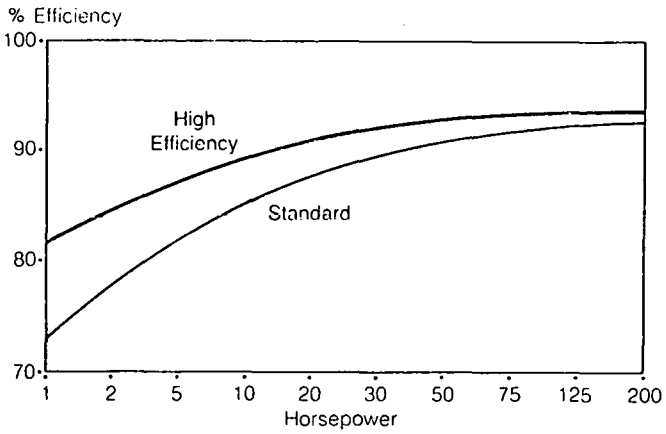


Figure 5
Motor Efficiency Comparison

Induction motors can be divided into three general categories. While the efficiency of single phase fractional hp motors can be improved, the wide variety of application and duty cycle makes a general effort in this area difficult. Polyphase induction motors greater than 200hp are generally (but not always) designed with efficiency in mind. However, the efficiency of polyphase induction motors in the 1-200hp range can be improved, since other operating characteristics are generally standardized.

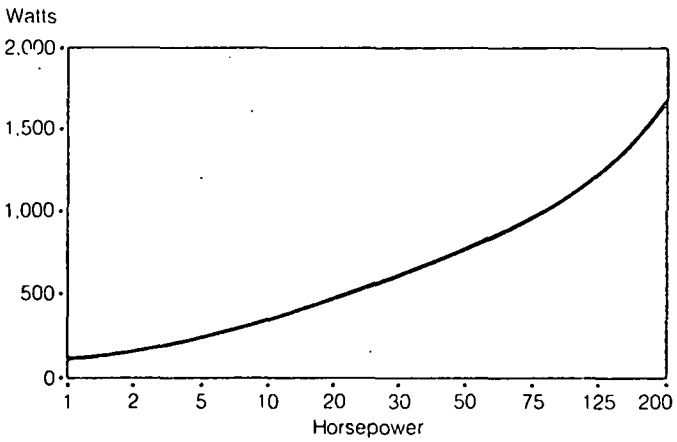


Figure 6
Typical Loss Reduction with High Efficiency Motors

HIGHER EFFICIENCY MOTORS

The induction motor is, by its nature, a highly efficient device. Large induction motors over 200hp are often purchased solely on the basis of first cost and availability. The efficiency of these motors can be improved! Existing losses can be reduced using more and better quality material in the motor. The range of improvement varies among manufacturers, but an approximation is given in Figure 5. Even though the percentage improvement in efficiency grows smaller in the higher hp ranges, the actual watt reduction increases as the horsepower increases (Figure 6). Therefore, the full 1-200hp range deserves attention.

COST OF OPERATION

The rate that you pay for electricity depends on various factors. A kW or demand charge is levied to pay for the equipment required to provide you with electricity. A kW.h or consumption charge is representative of the fuel used to produce the electricity while the power factor charge encourages a ratio of kilowatt to kilovolt ampere use of 0.9. Your electrical bill depends on the above factors and the various rates applied by your Utility or Hydro. However, an approximate average industrial rate that includes the above charges would be $0.02 per kW.h.

Using this rate, the cost of running motors with typical average efficiencies are shown in Figures 7 and 8. For higher duty cycles, the cost of running a motor can be several times the purchase price as shown in Figure 9. Obviously, operating costs should be considered when purchasing a motor.

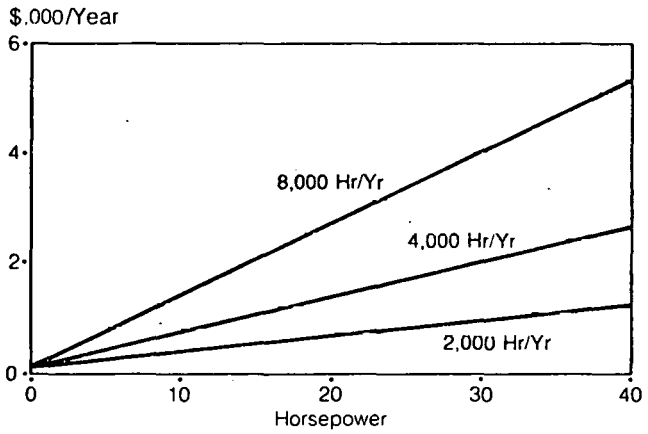


Figure 7
Typical Operating Cost of Induction Motors
1 to 40 HP (2¢/kW·h)

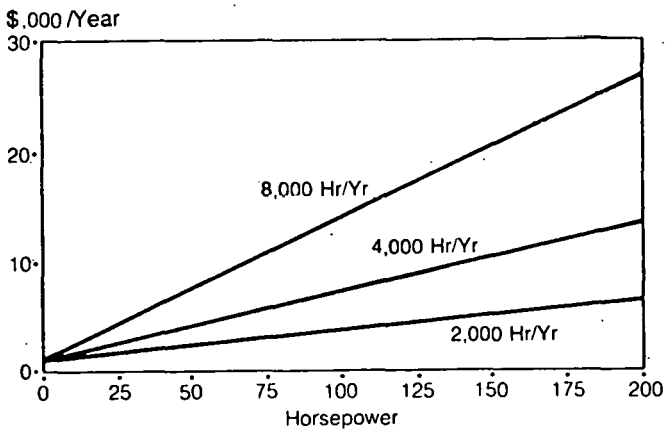


Figure 8
Typical Operating Cost of Induction Motors
1 to 200 HP (2¢/kW·h)

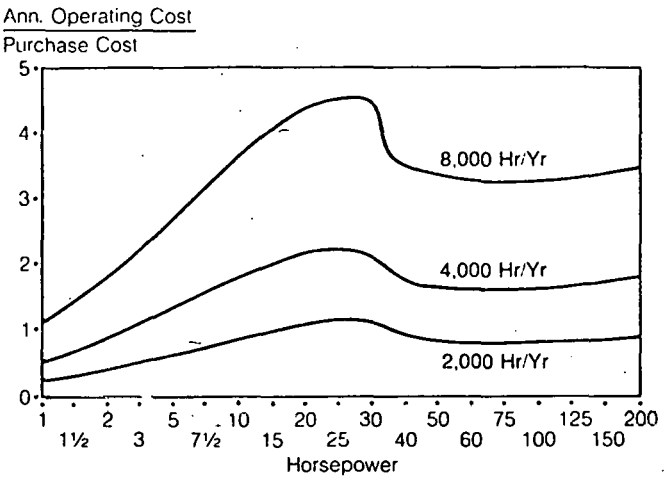


Figure 9
Comparison of Annual Operating Cost With Purchase Cost of Induction Motors
(1,800 RPM TEFC, 2¢/kW·h)

Figure 6 reported the watts reduction for typical improvements in efficiency. In order to put this into perspective, Figure 10 is presented to translate the efficiency improvement into dollars saved per year for various duty cycles. As energy rates increase, the savings will become even more significant.

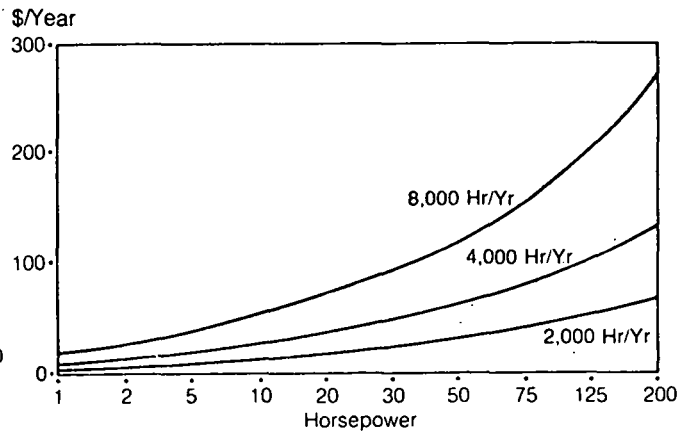


Figure 10
Typical Savings Achieved with High Efficiency Motors
(2¢/kW·h)

PAYBACK USING HIGHER EFFICIENCY MOTORS

The efficiency of a motor is improved mainly through the use of additional and/or better quality materials. Therefore, an increase in efficiency means an increase in

--st. The actual increase in cost varies considerably depending on marketing conditions. An order for a small number of high efficiency motors may carry a premium of 60% or more. This represents the cost of producing a "specialty" item since the market demand for high efficiency motors is still quite small. Indications are that if "production" runs of higher efficiency motors were made, the premium would be approximately 15% in the smaller hp sizes to 5-10% in the larger hp size. Payback is calculated by combining this premium with typical improvements in efficiency for various duty cycles according to the following formula:

$$\text{Payback} = \frac{\$\ \text{Premium}}{\text{kW} \times \frac{\text{hours}}{\text{year}} \times \frac{\$0.02}{\text{kW.h}}}$$

where

$$\text{kW} = \text{hp} \times .746 \times \left[\frac{1}{\text{std. eff}} - \frac{1}{\text{high eff.}}\right]$$

Figure 11 shows potential payback for 2,000, 4,000 and 8,000 hours of duty per year. In many situations, payback is well under 3 years!

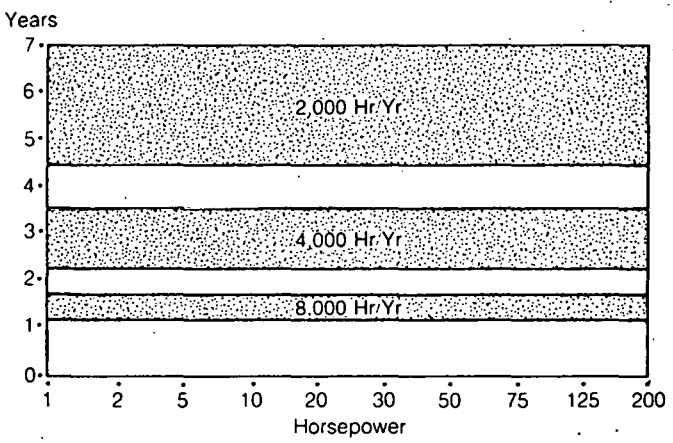


Figure 11

Typical "Payback" on High Efficiency Motors (2¢/kW·h)

A MESSAGE FOR INDUSTRY

The time has come for industrial motors to be of the highest possible efficiency. How can this be achieved?

When placing any large order for motors, the following steps should be taken:

1. determine size of motors
2. determine duty cycle of each size
3. determine your cost of power
4. when preparing a purchasing specification request the cost and efficiency of both "standard" and "high efficiency" motors
5. with the above information, do a "total" cost comparison using your company's particular accounting methods
6. buy the motor that is cost effective.

WRITING MOTOR SPECIFICATIONS - HOW TO INCLUDE EFFICIENCY

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ABSTRACT

The escalating cost of electric power coupled with the rapid depletion of our non-renewable resources makes consideration of motor efficiency good sense both from economic and conservation viewpoints.

The efficiency of an electric motor can be assessed during bid evaluation by applying loss penalties; however, the actual value can be influenced at an earlier stage by a careful review of what goes into the motor specification.

INEFFICIENCY - THE HIDDEN COST

The advertising style for new automobiles has undergone a noticeable change in emphasis recently. With the spur of legislated fuel consumption limits, manufacturers are now using the results from qualification testing as a focal point in their promotion of the new generation of smaller more efficient cars.

The lifetime feeding costs of our mechanical pets are being shown to be comparable with the initial capital investment. With electric motors the case is similar though somewhat easier to evaluate objectively since our needs are not clouded by emotion!

Taking the power output required from a motor as an accepted requirement and therefore a legitimate cost for the corresponding energy consumed, we should consider the additional 'cost' accruing to the losses dissipated whilst producing this useful work. A motor inefficiency of 6% and a capitalized loss value of $1000/kW equates to a first cost penalty of $60/kW or $45/HP - an amount certainly comparable to the initial cost of a typical motor. Nuclear applications having continuous duty can easily be double this amount.

EFFICIENCY AT ANY PRICE?

Having set the scene justifying our interest in good efficiency, I must emphasize that in a Utility application, and probably in many continuous production processes, efficiency considerations should always be subordinate to reliability requirements. The replacement fuel costs of using fossil units instead of a single 800 MW CANDU nuclear powered generator amounts to around $200,000 per day! Any motor unreliability contributing to unit unavailability exerts tremendous leverage in the evaluation assessment as discussed in an earlier paper (1).

Hence, a prototype motor design developed exclusively for high efficiency should be analyzed very carefully to ensure that any reliability claims derived from historical data are in fact valid and reasonable.

SPECIFICATION WRITING

After exposure to the assorted problems generated by the combined ingenuity of the world's leading motor manufacturers, there may be a temptation to write a specification that effectively states how a motor is to be designed. This must be avoided, and it is worthwhile looking at this through a supplier's eyes as well as the possible consequences to the buyer.

What does a manufacturer look for when confronted with a specification of interest to a specific industry or class of user? Primarily, he looks to see if the specification is drawn in such a form as to permit him to furnish his current line of machines without major problems. He also seeks assurance that he is free to introduce advanced state-of-the-art developments, or even novel approaches to old problems, within the context of the specification. (As a user, I reserve the right to place my own assessment on the value of any 'novel' solutions.) If these criteria are met, he then looks to the nature of the specification. Is it 'functional', or

is it 'design oriented' and does it indicate any credit for good efficiency?

One of the important qualities of a good specification, from a design engineer's viewpoint, is that it should be functional. A functional specification tends to tell the engineer what is expected from his machine or device, while a design-oriented specification takes a 'cook book' approach and tells him how to build it. Thus, the functional specification places the burden directly on the designer to provide a product that does what the customer expects it to do. If it fails to perform as specified, there can be no question that the responsibility lies with the manufacturer (assuming, of course, that the user has correctly set forth the necessary performance criteria and attendant conditions of operation). On the other hand, should a design-type of specification insist upon the use of materials or processes with which a manufacturer is unfamiliar, and the product fails to perform, the way is open for considerable controversy over the responsibility of correction.

TYPE OF MOTOR

The type of motor specified can have a significant impact on the resulting drive efficiency due to fundamental differences in operating characteristics. As with all things, a trade-off has to be made between first cost, reliability, efficiency and other required parameters. Although it is beyond the scope of this paper to review all their characteristics, the principle features of the major motor types will be noted.

Synchronous motors probably stand at the top of the efficiency chart - especially when operated at unity power factor. This motor type is often the first choice for large base load applications where frequent starting is not a requirement. The ability to provide reactive power back to the system when overexcited, to offset the reactive demand of induction motors, is often a prime factor in their selection, albeit at the expense of efficiency compared to operation at unity pf. Another feature of synchronous motors, which is not often given due prominence, is that starting and running characteristics can, within limitations, be designed independently of each other. For example, high starting torque can often be provided without detriment to the running efficiency. A major drawback, that prevents general application of synchronous motors within utility systems, is the inability to rapidly reclose onto an energized bus to maintain auxiliary support to a turbine generator after a supply service transfer.

Low cost, inherent simplicity and ruggedness have made the squirrel cage induction motor the 'work horse' of industry and the first choice for many applications. The efficiency is inherently lower than for a synchronous motor of similar rating due to the need to supply magnetizing power from the line and slip losses to the rotor. Recognition of the potential to improve the efficiency of these motors in the high volume, standard rating range was clearly shown by the authors of several papers at a recent symposium sponsored by Ontario Hydro (2).

Wound rotor induction motors overcome the disadvantage of high inrush current but are normally only applied where very severe starting conditions have to be met or variable speed operation is required. Generally efficiency is lower than for an equivalent squirrel cage motor and this, coupled with their higher cost and lower reliability, limits their use to special applications.

DC motors are probably the least efficient of all but are applied where their ability to provide precise speed control or rapid reversals is of paramount importance. In addition they are used in many emergency or backup applications where, supplied from batteries, they allow a safe and orderly shutdown of a system or process upon failure of the primary source of power.

VARIABLE SPEED DRIVES

The foregoing remarks on efficiencies are related to the motors alone when operating at essentially fixed conditions of load and speed.

Many applications require variations in output from the driven equipment, such as change in fluid flow for pumps or fans. The lowest cost way of achieving this - by means of a fixed speed motor in conjunction with valves or dampers - is also invariably the least efficient. Overall efficiency can be improved significantly in many cases by the use of a variable speed drive.

The well-established DC motor and slip coupling drives have been joined by sophisticated AC motor drives incorporating induction or synchronous motors

with solid state slip recovery or variable frequency convertors. The life cycle costs of these various alternatives must be established for each application including an evaluation of 'reliability credits'

In general, the more time that a drive system is required to operate below rated capacity, the more attractive a variable speed drive will appear.

MOTOR SIZING

Sophisticated calculation techniques coupled with improved materials have enabled motor designers to pack more power into a given frame size. Not only are motors usually produced with a higher insulation class than before but any margins on allowed temperature rises are smaller due to a better ability to predict actual performance. As a result, peak efficiency generally occurs below full load and to take advantage of this motors should be sized somewhat above the predicted load requirement. This approach is very attractive because it also gives better reliability and longer operating life.

Although the point of maximum efficiency varies depending on rating and speed, it is typically around 75% load. Motors operated at their maximum permissible or service factor load may do so at a significant efficiency penalty. By sizing a motor from 10 to 25% above the continuous load requirement not only will a small gain in efficiency be achieved but the service life of the motor should be increased. The current guidelines within Ontario Hydro for motors with a 1.0 service factor (i.e. equal to the nameplate rating - no overload permitted) is that the rating shall be at least 15% higher than the continuous load requirement and shall not be less than any short time loading condition.

It should be recognized, however, that excessive oversizing can result in severe loss penalties since the change in efficiency below the optimum load point is generally much steeper than above.

PERFORMANCE VERSUS EFFICIENCY

The foregoing remarks apply particularly to NEMA frame motors where there is an incentive to buy an essentially standard product with a view to short delivery and spares availability.

When specifying larger induction motors that may be custom designed, the opportunity exists to tailor performance to the specific application. However, care must be taken not to specify unnecessary requirements with the impression that additional assurance will automatically result. The design of motors is always a compromise between the various performance parameters and it is important to recognize that obtaining extra specific requirements can only be at the expense of others, including efficiency.

In particular, the requirements for high starting torque and/or low starting current are directly opposed to the goals of high efficiency. Where specific application demands or supply bus limitations require high starting torque or restricted inrush current, these should be applied only to the motors concerned and not as a general specification item.

Starting torques are clearly defined by NEMA, and these are adequate for most applications with few exceptions. General specifications which call up starting torques higher than NEMA are seldom justified, and the resulting extra cost is invariably accompanied by lower efficiency. Where higher than normal starting torque is required for a particular application, the additional cost and reduction in efficiency can be kept at a reasonable level provided locked rotor current is allowed to increase. This is usually possible on other than the largest ratings installed on a particular electrical system.

NEMA specifies locked rotor current values for ratings up to 500 HP. Above this there are no standards; however, actual values for standard designs rarely exceed 650% of full load current. Occasionally high locked rotor current may present a voltage dip problem, but this is only a real one insofar as the largest rating on the system is concerned. For a specified value of starting torque, limited locked rotor current is inherently associated with lower efficiency due to the increase in rotor losses. Ideally, peak motor efficiency should occur between 75% and 100% load. As locked rotor current decreases, the peak efficiency moves away from full load and can even be as low as 50% load.

EFFICIENCY EVALUATION

Unless advised otherwise, a motor manufacturer will not know that effiency is to be evaluated and as a result is likely to offer the least cost motc when tendering for a specific application. Hence it is important to identify what value is to be

placed on motor losses during tender comparison as this then allows the manufacturer to review his sign and offer the most economic motor.

Both the $/kW value and the load at which the evaluation will be made should be given as the losses may be significantly different between nameplate and actual operating load. In addition, where the number of motors specified includes some redundancy, the actual numbers subject to evaluation should be clearly identified. A motor manufacturer will offer as high an efficiency as possible consistent with the assessed value of losses exceeding the additional costs: his motivation will be strictly commercial rather than energy conservation per se!

On major applications the design changes leading to the improved efficiency should be carefully reviewed. Where extra copper has been added, this is good for lower temperatures, mechanical strength and resulting longer life. Beware of cases where the ventilation circuit has been extensively trimmed with resulting marginal temperatures as this can lead to premature failure.

Identifying a loss value for standard motor sizes will allow the manufacturer to offer a "High Efficiency" design if one is available. Otherwise he can assess whether offering the next larger frame size will be attractive depending on the relative values and load points for peak efficiency.

The proposal by NEMA to publish Efficiency Index Letters will provide more uniformity in and simplify the statement of efficiency on smaller motors. These Index Letters refer to a number of efficiency value brackets with each letter corresponding to a nominal efficiency and a minimum efficiency. A purchaser, in carrying out an evaluation, may choose to use either the nominal or minimum efficiency values associated with the Index Letters quoted.

LOSS VALUES

The actual $/kW rate to be assigned to the losses for evaluation purposes can be determined by various methods and degrees of sophistication.

Where return on investment guidelines require a relatively short payback period, a simple calculation ignoring interest rates and energy price escalation can be made, e.g.:

For a 3-year payback period, based on 4000 hrs/year operation and 2¢/kW.h energy cost:

Loss Value = 3 x 4000 x .02 = 240 $/kW

A more comprehensive assessment would include estimates of the variable interest rate and energy costs computed for each year being considered, with a present worth factor applied to bring each value to the evaluation year. The sum of products of the present worth factor and energy cost for each year results in a true present worth assessment of the value of losses over the whole evaluation period.

In Ontario Hydro, the worth is computed over the total projected life of the motor - typically 30 years for new generating stations. The present worth values used recognize that the in-service dates may start several years after the tender evaluation period. The energy costs used are a composite value based on the forecast mix of generation facilities, i.e. hydro, fossil and nuclear. In addition to the energy costs, the present worth value of the associated generating capacity to supply these losses is also included. Loss values approaching 2000 $/kW have been calculated for some recent applications, and as mentioned earlier, the resulting assessment is significant when compared to the actual capital cost.

Although it may not always be easy to 'collect' in the event of failure to meet a guarantee, a penalty at least equal to the evaluation $/kW can be specified to provide some assurance that the credit given at the tendering stage will in fact be realized. This is one of the main arguments against giving full credit for motor efficiency. When faced with paying a penalty, suppliers invariably take all possible steps to meet the guarantee including changes such as running bearing oil hotter, reducing fan sizes, blocking off ventilation ducts, plugging cooler tubes, etc. Whilst these may not drive other performance requirements outside specification, they generally push them to the limit with the result that reliability is reduced and the supplier's reputation is lowered in the eyes of the user. This is an industry problem that needs resolution to make efficiency evaluation more attractive to the user - hard not soft dollars.

Several major purchasers of motors have undertaken ambitious in-house testing programs to assess the credibility of efficiency values quoted by their various suppliers. The results from these tests may then be fed back into the evaluation procedure for new purchases to forestall potential commercial

wrangles arising from future deficiencies.

EFFICIENCY VERIFICATION

A specification should clearly state on what basis a motor's efficiency is to be quoted and how it is to be verified after manufacture. Although it is recognized that all standards may have their weaknesses in some areas, referring all bids to a common reference makes comparative evaluation valid.

The test method specified should take into account the limited facilities that may be available for testing larger motors. On critical applications, the ability of the various potential suppliers to fully test a particular motor should itself be an evaluation item. Where a rating exceeds the supplier's capabilities, tests based on equivalent circuit calculations must be accepted; however, these can be verified by electrical input and slip values taken when the motor is first run with the driven equipment.

It is not appropriate to review the deficiencies of the various standards here but it is worth pointing out some of the hidden variables that may equate to significant discrepancies when using high evaluation rates:

- copper losses quoted at different temperatures;
- stray load losses allowed as a fixed percentage of output versus calculated and tested values;
- allowance of a tolerance on efficiency quoted;
- conditions for inclusion of thrust bearing losses.

In general I feel that IEEE 112 and 115 are comprehensive specifications which offer adequate guidance for testing of induction and synchronous motors respectively. For large induction motors, Method E is recommended over Method F. Where a motor manufacturer has insufficient load capacity to take the required input readings, these can be recorded on site or at the driven equipment manufacturer's facility with the motor coupled to its intended load. These readings, together with no load and stray load loss data determined in the factory, allow calculation of the required efficiency.

CONCLUSION

It has been shown that consideration of efficiency during motor specification encompasses all stages, from initial selection of the motor type through to final testing.

By viewing the evaluation as a total procedure, maximum benefits will be achieved. Once motor manufacturers are aware that efficiency credits are being considered under clear 'rules' they will do their part in offering improved performance to remain competitive.

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ECONOMIC REALITIES AND ENERGY-EFFICIENT POLYPHASE INTEGRAL-HORSEPOWER ELECTRIC MOTORS

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ABSTRACT

Energy efficient polyphase integral horsepower electric motors are currently being vigorously promoted as a profitable method of conserving energy in many industrial and commercial applications. While the goal to be attained is indeed laudable, and must be tenaciously pursued, the economic realities of investment payback on increased efficiency versus cost of changeout, power factor, etc. must have a meaningful review before decision making. Actual savings on a discount cash flow basis must be documented, and validity of the claims for the energy efficient motor must be verified.

This paper develops the procedures used by the chemical manufacturing divisions of the Union Carbide Corporation in developing a long range plan for evolution from a motor population of standard efficiency units to one of higher efficiency and increased reliability. It notes statistics publicized by the U.S. Department of Energy, Union Carbide's overall electric equipment efficiency review, their own efficiency testing of sample small electric motors, and a pilot program to determine the number of lightly loaded motors in plant location. It further depicts an economic appraisal on the payback of replacing a standard efficiency motor with a higher efficiency unit and an action plan for purchasing energy efficient motors while simultaneously securing optimization of other parameters.

INTRODUCTION

Electric motor drives used in industrial and commercial facilities are said to be the greatest single identifiable consumer of electric power generated in the United States. Statistics compiled by Arthur D. Little in a report prepared for the U.S. Department of Energy note that the 1 to 125 HP polyphase motors are the predominant energy users. These motors - used primarily to drive pumps, compressor, and blowers - consume about 28 percent of the total electric power generated. The report continues by stating that, if the existing standard efficiency motors could be replaced with higher efficiency units, 5 percent of all electric power generated in 1990 could be saved for a dollar achievement of $1.5 billion or 60 million barrels of oil. These statistics are based on 1975 dollars. These are indeed impressive savings and positive response is certainly warranted from responsible segments of the industrial and commercial communities.

Much has been written in media outlets, and bills have been introduced in legislative bodies - all with the intent of defining the problem and suggesting corrective action. Some of this suggested corrective action has been the all inclusive and arbitrary replacement of standard efficiency electric motors with high efficiency units. It is unfortunate that many of the media articles were written without adequate appraisal and projected economic paybacks that are not achievable or realistic.

To achieve energy conservation goals, most large industrials and many commercials have established Energy Management Programs with the objective of identifying the areas of greatest unnecessary energy loss and determining how available capital can be most profitably spent. While the greatest energy savings can be achieved in disciplines other than electrical, the publicity and statistics quoted on electric motor energy consumption have caused this subject to be closely scrutinized.

Electric motor energy consumption, and what may be done to practically and economically reduce it, is not the only area under examination as a part of the electrical portion of the Company Energy Management Program. Specifications and procurement measurements have been issued for power transformers and lighting along with new standards setting criteria for consideration of I^2R losses in conductor sizing. Additional studies have been made for using strategically located capacitors for reducing feeder

and equipment I^2R losses due to the reactive flow required by utilitization devices.

The paramount issue, however, has been the evaluation of the impact of the "energy efficient" motor on the relatively large small motor populations now existing in plant facilities and how it should be judged in new or replacement needs.

Several basic questions or points arise when beginning such an evaluation.

1. How many motors are in service in the horsepower categories that are known to be the worst "energy losers" and what is the average of a location motor population?
2. What is the payback in buying new motors with higher efficiency ratings versus standard efficiency?
3. What are the economics and logistics involved in any proposal replacement program? Considering capital outlay - increased failures from new equipment and reconnection - loss of production, etc.
4. What is the economic feasibility of replacing a lightly loaded motor with a smaller high efficiency unit?
5. How do you determine that you are getting the motor efficiencies claimed by the vendor? What measurement methods are used?
6. Does this motor manufacturing evolution present an opportunity for increasing the reliability of the severe duty motor presently manufactured?

DISCUSSION

The last question becomes the first point of the discussion. Our review was coordinated with others in the chemical industry since there was substantial consensus that the standard "T-rated" motor, as manufactured by most, is a serious high magnitude offender in unplanned electrical outages of our various plant facilities. It was felt to be an opportune time to collectively suggest improvements in other facets of motor design and manufacture as well as efficiency. Bettered bearing quality - the single biggest cause of motor failure - along with acceptable power factor and noise levels, increased resistance corrosion, etc., were all considered and evaluated.

The result, developed under the auspices of a chemical industry trade association, was an informal guide specification that is presently being used as a procurement aid by many of the companies participating. In great part, it is an attempt to reestablish levels of reliability that have been lost in the evolution of the commercial "T-rated" motor.

Efficiency Testing

Concurrent with the collective effort through the chemical trade association, an in-company program was initiated to determine the validity of the efficiency claims of motors offered by a group of selective manufacturers. A group of three motors from each manufacturer was selected in 1800 rpm and 3600 rpm units of from 5 to 15 HP, and each supplying motors for testing was requested not to specially select the units sent but to pick the chosen rating at random off the production line. These were then tested in accordance with IEEE 112 Method B - with the dynamometer sized to within three times the smallest machine rating. Each test used the same dynamometers, the same circuitry and measuring instruments, and employed identical personnel. Even though the absolute accuracy could be off slightly, the relative accuracy in comparing the manufacturers' products was judged to be good. The following is a typical Form B data sheet depicting the data on one of the motors tested.

FORM B

Input-Output Test of _____ Induction Machine

Type TCE Design B Frame 254T Hp 15 Phase 3
60 Cycles 460 Volts 1000 Synchronous rpm
_____ Degrees C Temperature Rise _____ Time Rating
40° C Max. Ambient

Test Point	1	2	3	4	5	6
(1) Stator-winding temperature °C	71	65	61	61	49	
Ambient temperature	28	28	28	28	28	
Frequency	60	60	60	60	60	
Observed slip, in rpm	48	38	26	17	9	
*Corrected slip, in rpm	46.59	37.62	26.09	17.06	9.41	
Speed, in rpm	1753.41	1762.38	1773.91	1782.94	1790.59	
Torque, in lb-ft	54.77	43.22	31.36	18.91	9.01	
(1) Dynamometer correction	1.35	1.35	1.35	1.35	1.35	
(2) Corrected torque	56.12	44.57	32.71	20.26	10.36	
(3) Output, in hp	18.74	14.96	11.05	6.88	3.53	
Amperes input	23.60	18.33	14.13	10.22	7.82	
Percent power factor	83	84	81	70	48	
Observed watts input	15660	12290	9085	5710	3030	
(b) Stator I^2R loss at (t_1) degrees Centigrade	304.33	183.45	109.01	57.03	33.39	
(c) Stator I^2R loss at (1)	313.33	185.31	108.65	56.84	31.93	
(4) Input correction = (b) − (c)	-9.23	-1.86	0.37	0.19	1.46	
(5) Corrected watts input	15651.	12288.	9085.37	5710.19	3031.46	
(6) Percent efficiency	89.30	90.79	90.71	89.85	86.92	

Performance Curve # 3

Data Obtained from Performance Curve

Load	0	¼	½	¾	Rated Load	1¼
Percent power factor	0	49	72	81	84	83
Percent efficiency	0	87	90	91	91	9
Speed, rpm	1800	1791	1781	1772	1763	17
Amperes (line)	5.5	7.8	10.8	14.2	18.3	2

The results secured on one manufacturer's motors showed a significant variance, two to four points down from efficiencies listed in his data sheets. Another submitter's units tested very close to the values stated in his listing while yet another's offerings were strictly in accordance with the efficiencies noted in his literature. Information secured at a later date revealed that the latter manufacturer had indeed preselected and pretested the motors sent for test. Personnel conducting the dynamometer testing had commented on the absolute smoothness, lack of vibration, and quality of assembly on those units.

Quality Analysis Evaluation

In addition to the dynamometer testing of the motors submitted, each manufacturer was aware that the motors would be shipped to another location and subjected to our own "quality analysis" testing. This testing includes vibration and noise analysis, complete disassembly and measurement for tolerance, and general examination as to quality of hardware and assembly. The following is a sample report showing vibration and noise measurements together with associated quality control comments.

Motor "Y" Evaluation

1. Vibration Measurement

	Fan	Drive
5 HP	.020 IPS	.025 IPS
7-1/2 HP	.030 IPS	.035 IPS
15 HP	.045 IPS	.045 IPS

2. Bearing Noise

	Fan	Drive
5 HP	-6 db	-6 db
7-1/2 HP	+4 db	-4 db
15 HP	-6 db	-6 db

The above values are within acceptable limits although the +4 db value is nearing the upper limit of +6 db. Additional tests and inspections were conducted with the following comments.

5 HP - 1740 rpm 184-T Frame

1. During the operational check of this motor, the bearing emitted an unusual noise at a frequency capable of being detected by the human ear. Further inspection of the bearing and end bell housings found the fan end bearings measurement within tolerances but fan end bell housing bore exceeded the maximum tolerance by .0009 inch. This condition is not acceptable.
2. The drive end bearing measurement was within tolerance, but the drive end bell housing bore exceeded the maximum tolerance by .0006 inch. This condition is not acceptable.
3. During the efficiency tests, the stator winding had rotated in the motor housing because the stator was not secured properly to the housing.
4. The bearing shields, installed behind the bearings, make it difficult to remove bearings. The bearing shields are damaged during bearing removal and require replacement with each bearing change. This condition is not acceptable.
5. Pressed sheet metal fan cover and bolts do not appear to have sufficient material strength to withstand normal field service.
6. The junction box cover does not have sufficient contact surface area to provide a good seal. Also, combination screw driver head-hex screws that secure the junction box cover to the junction box are not acceptable.
7. Stator laminations are not uniform throughout the circumference of the stator.

Acceptable Manufacturers

The data secured from dynamometer testing, the information produced by the "quality analysis" conducted at one of our plant locations, the overall reliability criteria established by participation in the collective effort by chemical industry members, and data furnished by our plant maintenance groups all are combined with:

1. adherence to any other requirements of our basic motor specification,
2. documentation of the ability of the manufacturer to furnish a full range of needed sizes and speeds from stock,
3. prior knowledge of the manufacturer's ability to construct a quality motor and its acceptability to our plant locations,
4. the technical strength and depth of his

representatives,

5. and his acceptance of pricing agreement concept based on a major percentage purchase of requirements.

All the above was, and is, used as total criteria in selecting acceptable manufacturers for the supply of motors in the NEMA frame sizes. With the adoption of the new NEMA standard MG1-112.53b for providing uniform and guaranteed minimum efficiencies, the need for separate testing should not be required.

Replacing Existing Motors of Standard Efficiency

Based on information displayed in media publications, many inquiries come from plant location as to the economics of replacing motors. Proposals to replace existing standard efficiency but satisfactorily operating motors with higher efficiency ones are questionable, and in general, are not acceptable profitable alternatives. For illustration, an analysis for arbitrarily replacing a 40 HP, 1800 rpm, 460 volt, design B, TEFC motor with one of a higher efficiency is shown below.

1. A 2.3 percent increase in efficiency was used.
2. The discounted cash flow procedure for return on investment was used.
3. New motor cost plus changeout cost is calculated at $1600.00.
4. An 8 year project life with depreciation by sum of digits method is utilized.
5. Continuous running at 4¢/Kwh yields $400.00/yr savings.
6. A 15 percent discount rate was used.
7. An investment tax credit of 10 percent was used as differential.

The results of the above will show a positive cash flow at the beginning of the eighth year - a return on investment that is not acceptable. While the payback period will be decreased by increasing electric power rates, the immediate future is not likely to achieve an acceptable return except in locations that experience substantial increases from the 4¢/Kwh noted in the above example and associated increased investment tax credits for energy conserving equipment. Those smaller than 40 HP would show increased payback periods while those larger may, on an individual basis, show a decreased payback time.

Our chemical manufacturing operations are judged to have about 350 MW of consumption in the 1 to 125 HP polyphase motor area. Even when using an average gain of four points in efficiency, the return on investment using the discounted cash flow method does not justify the capital required for changeout.

However, the purchase of high efficiency motors for new projects or replacement of a failed unit with high associated repair costs is an economically acceptable alternative even with plant locations experiencing a relatively low Kwh rate. When coupled with the requirement for increased bearing reliability, bettered corrosion resistance, and monitoring of quality assembly, the totalized decision can be firmly justified and documented.

Lightly Loaded Motor

Another facet of electric motor energy conservation was also reviewed to determine the payback associated with the possible changeout of the lightly loaded electrical motor. Lightly loaded motors, operating at below 50 percent of nameplate horsepower, are known to be relatively inefficient with associated poor power factor. Published efficiency curves on the design characteristics of the average motor show a significant decrease in operating efficiency at positions below that 50 percent value and, if this operating point is confirmed, replacement with more suitably sized (and higher efficiency) motors may effect worthwhile energy savings.

As a basis for determining the feasibility of a full scale program for identifying lightly loaded motors, two pilot programs were instituted at two major plant locations. In one location, plant operating personnel selected 22 motors that were readily accessible and judged to be lightly loaded. At another location, 18 motors were designated for testing. Watts, voltage, and amperes were measured using portable indicating instruments. The testing was to determine the accuracy and practicality of the instruments used for measurement, the degree of safety risk in conducting measurements on energized and operating equipment, and to obtain sample statistics on just how many motors were likely to fall below the

50 percent loading category. Readings were taken only at normal operating load conditions.

At the first location, only two motors were found to be below 50 percent loading, and because of cyclic load requirements neither was a candidate for replacement. In the second location, two motors were found to be below the 50 percent loading criteria. Based on the method of known "worst case" solutions and the numbers developed by the pilot program, the cost of identifying lightly loaded motors was not judged to be worthwhile and the program was withdrawn.

Consideration of Power Factor

Any discussion on the energy conservation aspects of the electric motor would be lacking if it did not include the economics of power factor. Again, much of the data presented on today's higher efficiency motor treats only the energy losses associated with the motor and says little or nothing about the impact of the motor's power factor on the losses in the supplying system. This position is quite understandable when viewed from the motor manufacturer's role - he generally feels that design parameters should concentrate on improvement of the efficiency and that power factor can be corrected by external devices such as capacitors. It is also a design fact that some of the alternatives leading to increased efficiencies have attendant decreases in power factor.

One of the methods available to the user when attempting to evaluate the efficiency/power factor design balance of a given manufacturer is the use of "apparent efficiency" - the product of the efficiency and power factor in decimal form. While this has no absolute value, it does give an appraisal basis between motor vendor offerings on who may have optimized one value with too great a decrease in the other. All other factors being relatively equal, the "apparent efficiency" value may provide decision making information.

Within the majority of our company's divisions, small motor reactive needs are supplied by in-plant generation and/or by large synchronous drivers and the reactive requirements of the location's rate structure are generally the only basis for any power factor correction. Power factor correction at the utilization level can be justified only when release of system capacity dictates the need and not by rate structures or I^2R energy conservation criteria. One of our divisions, which uses large induction motors and associated synchronous condensers has, because of metering of the condenser, been able to construct charges used for kVAR cost penalty factors shown by the following table:

	INVESTMENT EQUIVALENTS	
	kW	kVAR
POWER RATE	COST	COST
$0.020/kWh	$1409	$28
0.021	1480	30
0.022	1550	31
0.023	1621	32
0.024	1691	34
0.025	1762	35
0.026	1832	37
0.027	1903	38
0.028	1973	39
0.029	2043	41
0.030	2114	42
0.031	2184	44
.032	2255	45
.033	2325	47
.034	2396	48
.035	2466	49
.036	2537	51
.037	2607	52
.038	2678	53
.039	2748	55
.040	2819	56
.041	2889	58
.042	2960	59
.043	3030	60
.044	3100	62
.045	3171	63
.046	3241	65
.047	3312	66
.048	3382	67
.049	3453	69
.050	3523	70

Differentials in correction kVARS required may then be used in formula form for judging each manufacturer offering. Most of our divisions use synchronous drivers for large motor drives, inherently self correcting, and consider the cost of the reactive supply to be so minimal as not to be a direct cost factor for evaluation. As previously

stated, the "apparent efficiency" is then used as an aid for judging the product power factor.

SUMMARY

The use of higher efficiency motors in the 1 to 125 HP range in commercial and industrial facilities will save a significant percentage of the electric power generated in the United States. That statement cannot reasonably be challenged and the implementation measures to achieve that goal should begin. However, as in the purchase of higher gasoline mileage motor cars, achievement of the goal requires a realistic time frame and prudent application of economic reality.

There are segments of the user industry who believe that, concurrent with the effort to achieve decreased losses, a companion effort should be initiated to achieve increased operating reliability. For these reasons, the implementation effort within our Company is structured to attain the goal of a higher efficiency motor population, do it within the constraints of acceptable economics, maintain awareness of the impact of power factor, and simultaneously stress other quality components that cause increased reliability.

As a part of implementing these goals, we have:

1. affirmed or denied the efficiency claims of a group of selected manufacturers,
2. looked at the economics of arbitrarily replacing existing standard efficiency machines and those in our motor population that are lightly loaded,
3. used the "apparent efficiency" as a guide in evaluating power factor in procurement decisions,
4. coordinated our efforts with others in the chemical industry to achieve reliability improvements in other motor parameters,
5. and, by the use of a purchasing agreement are buying only high efficiency motors for new projects and replacement needs.

Based on the average motor failure rates experienced across our locations, most of the plant motor populations will be replaced in 7 to 10 years. Electric power costs will continue to be monitored in higher cost locations as to economic feasibility of arbitrary changeout, but all present cost trends indicate that the evolution concept is, and will continue to be, the most economical alternative.

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ENERGY CONSERVATION THRU STEAM TRAP SURVEYS AND PREVENTIVE MAINTENANCE PROGRAMS

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This paper will deal with steam trap surveys and preventive maintenance programs and the energy savings that may be realized from such efforts.

Trap survey organization, flexibility, simplicity, and mechanics will be reviewed, including the economic justification for the survey program. Defective steam traps and their energy characteristics will also be discussed.

An on-going preventive maintenance program can be initiated from the information derived from the survey. Sustained energy efficiency of the plant's steam system is the maintenance program's primary goal. The scope and aggressiveness of such a program will be presented.

There's an old saying that goes "an ounce of prevention is worth one pound of cure." When refering to steam system efficiency, specifically steam trap performance, a small effort in terms of prevention is worth significantly more than one pound - of steam, that is!

Let's review the results of efficient steam trap operation. A new, properly applied and installed steam trap will consume a maximum of about 2 pounds an hour of steam. This 2 pounds is due to the amount of energy the trap requires to do its job and the radiation of heat off the trap's body. At $4.00 per thousand pounds of steam this good, peak performing piece of equipment is costing the user about $70.00 a year! As the trap ages and the internals begin to wear, the steam consumption of the trap can dramatically increase. This rise can be as little as 5 pounds per hour, or as great as 300 or more pounds a hour. A trap in such a condition can cost from $175.00 to $10,500.00 a year. The necessity to monitor the performance of the steam trap is obvious! And the mechanics and end result of a continuous steam trap preventive maintenance program must respond to these facts!

To demonstrate the solid economics of an aggressive PM program, an initial steam trap survey must be completed. This trap survey is performed with several goals in mind. The first, and probably foremost, is to quantify to management the monetary payback of a good PM program. For the program to succeed over the long run it must have management backing. To accomplish this it is necessary to determine the existing condition of the steam system and steam traps. What is the percentage of defective traps and what are these traps costing in terms of live steam waste? A secondary goal is to investigate the compatability of the existing trap stations with an effective, on-going PM program. Unions around the trap, 3-way valves on the inlet and outlet, strainers with blowdown valves, all make a PM program fairly easy and relatively painless!

The initial trap survey is the springboard to the trap maintenance program. It should collect enough information to start a PM program yet not so much data that the survey itself becomes a burden or that only a professional engineer can do it. Figure#1 shows an example of a simple, yet highly informative, steam trap survey sheet. The survey sheet itself sets the limits and guidelines for the survey. Areas of possible ambiguity have been minimized. More about the utilization of this sheet later.

The mechanics of the initial steam trap survey must be well organized before moving into the plant. This is done to avoid any confusion when assimulating the survey data and transforming into the necessary information for an effective PM program.

An engineering plot plan of the plant should be obtained. The plant should be broken into several sections or units and the boundries for such should be determined. Estimate the number of traps within each section and allocate an appropriate sub-heading for each of the trap tag numbers within that area. An example would be the crude unit of an oil refinery. All tag numbers allotted to that unit would have the prefix "CU".

Also determine a "travel sequence" thru the area.

After one trap is checked, where is the next one? This is essential for the establishment of the long-range PM program. The people who do the initial trap survey won't be necessarily performing the continuous trap PM program. Therefore, finding the next trap to be tested is all important!

There are several pieces of equipment that are "a must" for a good trap survey; a microsonic detector, a pyrometer, and a file. The microsonic detector enables one to listen to the operation of a trap when it is impossible to valve the trap to atmosphere and check it visually. The pyrometer and file will facilitate a fairly accurate reading (usually -5 to -15° F.) of the inlet and outlet temperature of each trap. Since mother nature provides a distinct steam temperature - pressure relationship, the inlet temperature will determine the service pressure of the trap, while the outlet temperature will indicate the amount of backpressure on the trap.

Now let's return to the actual survey sheet. The first column is headed "tag number". Every trap within the unit should be tagged. This creates the trap inventory for the maintenance program. Tagging materials vary greatly, but for the long range program, permanent metal or plastic tags are necessary. One of the handiest is the use of the stainless steel tags normally associated with an addressograph machine. Various trap manufacturers also have such tags available. The tags should be placed on the outlet side of each trap, just beyond the union and near the outlet valve. This minimizes burn hazards and prevents the loss of the tag during trap replacement.

The next heading is "trap location". This column is to note the piece of equipment, equipment number, or rack number that the trap is near. Some examples would be "below tower #750," "rack post 78-13", etc.

The following column contains three pieces of information concerning the existing trap; the pipe size of the trap, the manufacturer, and the particular model number. The pressure rating or orifice size may also be noted here. This data, in conjunction with long range testing, will help determine if that particular type trap is attaining a maximum service life for that specific application.

The "application" column is sub-divided into four basic classifications, into which all traps should fall. The first two, steam main drip and steam tracer service, are usually associated with fairly low loads (2 to 70 pounds per hour) and are usually small traps. The capacity range of such traps is limited because of their reduced orifices, and when they finally do fail, will waste only moderate amounts of live steam (5 to 80 pounds per hour). The second two applications are coil and process services. Both are usually larger load applications, in excess of 100 pounds per hour, and thus these traps have high capacities and large orifices. The steam waste due to a failed trap on these applications can be in excess of 300 pounds per hour. The "coil" catagory would include comfort heat radiators, forced air heaters, tank coils, etc. "Process" services would include areas where steam is used for production, such as large shell and tube heat exchangers, reboilers, jacketed kettles, etc.

The column designated "differential temperature" is for recording the inlet and outlet temperatures of each trap. Temperature is only a means of determining steam pressure. After filing the nipples on either side of the trap, the temperature readings can be taken. Caution must be used because the accuracy of contact pyrometers can vary, depending on how well the nipples are cleaned, the metal on which the reading is taken, and so forth. The inlet temperature will indicate the pressure the trap is applied to (superheated steam is the exception to this rule), while outlet temperature will show the pressure in the condensate return system, if one exists. An excessively high temperature at the outlet indicates a relatively high back pressure. This situation not only decreases the capacity of all traps (because of the low differential pressure across the trap) but also can have a detrimental effect on the efficiency and service life of certain type traps. One common misconception about temperature readings on both sides of the trap is that a large temperature differential across it will indicate a good trap. This may be true with high capcity (large orifice) traps, but with the smaller reduced capacity traps employed on drip and tracer applications, a significant temperature difference will always exist due to the pressure drop created by the small (approximately 1/8"diameter) orifices. This differential will be present whether the trap is good or failed open and blowing live steam.

The steam traps "condition" is recorded in the next column. This is really the essence of the ey, but is probably the most subjective area. The person determining the trap's condition must have a basic knowledge of different type steam traps, their methods of operation, and their characteristics under certain conditions. Training personnel on how to detect faulty steam traps must be done if your program is to be successful. Personnel should spend a sufficient amount of time checking various types of traps with a qualified teacher. As a training tool, some trap manufacturers provide training sessions and/or video tape presentations showing the principles of operations and methods of checking steam traps. The possibility of excess ambiguity when determining the trap's condition dictates the necessity for stringent guidelines. Thus, the operational condition is separated into four specific modes. Most traps will fall into one of the four.

The failed open (FO) or blow-thru condition exists when there is no cycle or throttling of the steam trap's orifice and live steam is constantly passing thru the trap. As a long-term effect, this steam will slowly erode the orifice, making it larger, and therefore blowing increasingly more live steam.

A rapid cycle or leaking (RC/L) trap is discharging condensate but also allowing some live steam to escape with each discharge. In this condition the steam waste may indeed be small, but excessive wear is taking place across the valve and seat. This wear can eventually lead to a failed open trap. A cycle rate of 15 to 25 cycles per minute is usually evidence of accelerated wear (10 cycles per minute is better than 5 million cycles per year).

A trap falling into the "cold" (C) catagory is obviously not wasting any steam, but can be just as costly as a failed open trap. Most likely the trap is failed closed due to debris clogging the orifice (filming amines, scale, rust, etc.). In this condition there is a build up of condensate behind the trap. Maintenance headaches occur when the ambient temperature drops below freezing and this condensate turns to ice, thus splitting or cracking the piping and/or the trap. But a cold trap may also be an indication that the trap is out of service and no steam is coming to it. Regardless, the reasons for this cold condition should be determined and the necessary corrective action taken.

A good or "OK" trap is operating as designed and is discharging condensate but closing before steam reaches the orifice.

The general heading "Piping" will indicate the existing pipe configuration around the trap. The goal of recording this information is to standardize the piping practices to facilitate easy trap testing and maintanence. The inlet and outlet valving is to isolate the trap for ease of replacement. If 3-way valves are used, the presence of steam to the trap can be tested at the inlet, while trap operation can be visually observed at the outlet valve. Visual observation is certainly a good method for testing traps, but it must be remembered that when a 3-way outlet valve is opened to atmosphere, the trap may no longer be in its normal operating situation. In condensate return systems a high back pressure may actually fail a trap. When the trap is valved to atmosphere the back pressure no longer exists and the trap may operate normally. Therefore caution must be taken when testing by the visual method. The options for inlet and outlet valving are: one 2-way valve. two 2-way valves in combination, a 3-way valve, and no valve.

The next piping sub-heading deals with the pressence or lack of a strainer before the trap. A strainer is actually a sieve for the steam system and can greatly reduce the amount of debris that can reach the trap and possibly fail it. Although not conclusive, a strainer may actually help extend the service live of the trap by reducing the amount of small, abrasive particles passing thru the orifice, therefore minimizing wear. The options available in the strainer column are; strainer, strainer with a blowdown valve, no strainer. Two things to note when dealing with strainers: One, if a blowdown valve is present, blow down the strainer after testing the trap. Two, all steam main drip applications should include a strainer because the steam separator or boot off the bottom of the main is a natural dirt collection pocket.

The final sub-heading under "Piping" shows where the condensate discharging from the trap ultimately drains. There are 5 options under the "Return" heading; over-head return, over-head return with a check valve, direct discharge to atmosphere or drain, discharge into a condensate return line that drains to a flash tank or knockout pot, and finally, discharge into a condensate return line that eventually

TAG NO.	LOC	TRAP			APPL				ΔT	CND	PIPING					OPTIONS	COMMENTS
		SZ	MNF	MDL	DRIP	TRACER	COIL	PROCESS			IN	STR	TRAP	OUT	RTN		
		3/8 1/2 3/4								FO RC/L C OK							

Figure #1

NO.		TRAP	SZ		DATE	TRAP CND				ACTION			TRAP CHG	DATE		
LOC			MNF			FO	RC/L	C	OK	O	CLN	RPL		SZ		
APP						FO	RC/L	C	OK	O	CLN	RPL		MNF		
P.IN	P.OUT		MDL			FO	RC/L	C	OK	O	CLN	RPL				
						FO	RC/L	C	OK	O	CLN	RPL		MDL		
						FO	RC/L	C	OK	O	CLN	RPL				

Figure #2

ends up draining to atmosphere at the end of the ıe.

The following primary heading is "Options". While doing the trap survey one has the unique opportunity to seek out other trouble spots not necessarily related to the steam trap. Some of these may be potential freezing problems due to low points in poorly designed tracers, steam leaks because of corroded pipes, nipples, elbows, flanges, etc., missing or wet and deteriorated insulation, and by pass valves around the traps which may have been inadvertantly left open. There is virtually a myrid of possible problems that can be investigated while doing the trap survey. To simplify the recording of these various trouble spots it is wise to give each a corresponding code number.

The final column on the trap survey sheet is "Comments". This is extra space for any miscellaneous information one may want to note. Anything dealing with steam distribution, use, and efficiency can be recorded in this section.

Now all the data necessary for a simple on-going steam trap preventive maintenance program is collected. Transforming this information to the mechanics of an effective PM program is the next step. Figure #2 is an example of the maintenance record for a trap. The conditions listed during the initial trap survey should complete the first two blocks on the maintenance record. The following block has a column for the date of inspection and the trap's condition at that time. The frequency of inspection will vary, but usually the determining factor is inlet or service pressure. The higher the pressure the greater the risk of extreme steam energy waste. An aggressive PM program would be based on the following inspection intervals:

(1). 0 to 30 psig - annually
(2). 30 to 100 psig - bi-annual
(3). 100 to 250 psig - quarterly or monthly
(4). 250 psig and above - monthly or weekly

The "Action" column indicates what corrective measures are taken after determining the traps operational mode. If the trap was "OK" and no corrective action was necessary, simply slash out the ". A trap that is back-flushed or dismanteled and cleaned, is recorded by marking the "CLN" column. If the trap was found to be defective and had to be replaced, mark the "RPL" column. The size, manufacturer, and model number of the new trap should be recorded in the "Trap Chg" block if it differs from the old trap.

The preceding has been an attempt to simplify the mechanics and logistics of steam trap surveys and preventive maintenance programs. Hopefully this clear, easy system will be the catalyst to initiate a PM program and capture energy savings throughout your steam system. Now get on with it and good luck!

STEAM AND CONDENSATE SYSTEMS

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In the late 60's and early 70's oil was plentiful and steam was relatively inexpensive. The switch to low sulphur fuel oil and the oil embargo suddenly changed the picture. The cost of steam rose from $.50 per 1,000# to today's cost of $4.00 or more.

Many see costs of $6.00/$7.00 in the near future. These tremendous increases have caused steam systems, steam traps and condensate systems to become a major factor in overall plant efficiency and profit.

There are many factors to consider in steam and condensate systems. The primary factors are:

1) Proper steam pressure
2) Adequate sized steam lines
3) Adequate sized condensate return lines
4) Utilization of flash steam
5) Properly sized and installed steam traps
6) A regular program of trap checking and maintenance

Selecting the proper steam pressure needed for the process is the initial step in designing an efficient steam system. Pressure above or below the process requirements can cause system inefficiency. Through the use of pressure reducing valves and/or desuperheaters, high pressure steam can be used for lower pressure/temperature requirements.

Adequate sized steam lines assure the process will be furnished with sufficient quantities of steam at the proper pressure. Steam lines that are undersized will have excessive pressure drops and may not be able to transmit sufficient quantities of steam at the required pressure. Oversized steam lines are more expensive to install and heat loss through radiation is increased.

Adequate sized condensate return lines are important to overall efficiency. Many times this portion of the system does not receive a great deat of attention and energy is wasted. These lines must be sized to handle the flash steam as well as the condensate. Inadequately sized return lines result in a system back pressure higher than desired, which can have a major effect on system efficiency. Particular attention should be paid to condensate systems during remodeling or plant additions.

Many plants utilize the heat in flash steam for low pressure applications such as building heat, low pressure heating coils, etc. Commonly, flash tanks or drums are used to separate flash steam from the condensate. If excessive lifts or elevation changes in the condensate line present a back pressure problem, you may want to consider a pumped system using a vented receiver and pumping the condensate back to the boiler area.

Properly selected, sized and installed steam traps may be the single most important factor in system efficiency. Unfortunately, there is no universal steam trap which is best for all applications and each application must receive individual attention.

There has been a great deal of discussion recently about steam loss through the various types of traps. Our data shows that most types have low losses when sized and installed properly.

Virtually any condensate removel device will waste steam or fail prematurely if improperly sized or installed. When selecting steam traps, factors such as inlet pressure, load, back pressure, return lines, ambient temperature, etc., must be considered. All of these factors will determine which type of trap is best suited for a particular service.

A failed steam trap can waste $2,000, or more, per year and it can fail prematurely due to improper selection or installation.

What is a steam trap? It is an automatic control valve that opens on condensate, air and non-condensable gases and closes on steam or hot condensate.

The basic types are:

THERMODYNAMIC

Operate on the principle of flash steam. The disc valve design is commonly used on steam main drips and tracers, the piston valve version is used for high pressure and the lever valve is used for the higher capacity process loads.

Advantages - 1) Near steam temperature discharge
2) Ease of repair and maintenance

Disadvantages - 1) Affected by rain and cold wind if not protected by a weather shield.
2) High back pressure can affect cycle rate.

THERMOSTATIC - Operate in response to inlet temperature and pressure. A corrugated metal bellows, diaphragm or a bi-metal element is usually the method used to open and close the valve. Depending on the design, these traps can discharge condensate at near steam temperature or highly sub cooled. These traps are used in drip and tracer and process applications. The recent introduction by a number of manufacturers of the sub-cooled version seems to be gaining favor as an efficient tracer trap with very little resultant flash steam.

Advantages - 1) Wide range of discharge temperatures
2) Operates against high back pressure

Disadvantages - 1) Bellows subject to water hammer
2) Bi-metal elements can "drift" or lose initial setting.

MECHANICAL _ Operate on the density difference between steam and condensate. The most common type is inverted bucket design. Float operated traps are also available for medium-high loads. The inverted bucket is used for drip, tracing and process services.

Advantages - 1) Proven design
2) Simple operation

Disadvantages - 1) Must select proper orifice for conditions.
2) Subject to freezing

FIXED RESTRICTION (ORIFICE) - These devices consist of a small hole which is sized to remove the condensate. They are used on non-fluctuating loads such as drips and tracers. Due to the small size of the orifice, the use of strainers is essential.

Advantages - 1) No moving parts

Disadvantages - 1) Subject to plugging
2) Difficult to size

With today's steam cost, it is essential that your steam traps are maintained at peak operating efficiency. A regular program of trap checking and maintenance pays large dividends. A study involving more than 250,000 steam traps showed:

Plants with only demand checking and maintenance show an average 50% failure rate.

Plants with annual checking and maintenance show an average 25% failure rate.

Plants with semi-annual checking and maintenance show an average 13-15% failure rate.

Plants with quarterly checking and maintenance show an average 6-7% failure rate.

Plants with monthly checking and maintenance show an average 2-3% failure rate. This study was conducted from 1974 to the present, and represented all types which were installed in services from very low pressure to a high pressure of 600 psi.

The average failure rate of all types was 43%. A failed trap can waste $2,000 per year or more, therefore the economic advantages of a regular trap checking and maintenance program are obvious.

There are three primary methods of checking steam traps: sight, sound and temperature measurement.

SIGHT - Observing the trap discharge cha teristics. In order to use this method, a trap must discharge directly to atmosphere or be provided with a downstream test tee. In a closed return system, the performance of a trap vented to atmosphere may be different than when discharging into a closed system.

SOUND - This method uses a stethescope or ultrasonics to listen to the trap operation. The advantage of this method is that you are listening to the operation of the trap under actual conditions. The disadvantage is this method requires trained personnel, and the results are very subjective.

TEMPERATURE MEASUREMENT - This method measures the pipe surface temperature before and after the trap. A lower than usual upstream temperature usually indicates a trap that is backing up condensate, and a high downstream temperature usually indicates that a trap is blowing steam. In order to use this method, you must accurately know the upstream and downstream pressure. Also, open by-pass valves or plugged strainers can give a faulty reading. Each method has advantages and disadvantages. It is recommended that at least two methods are used to insure accuracy. The important point is not which method is used but that some method is used.

In summary, the factors critical to steam and condensate efficiency are:

(1) Proper steam pressure
(2) Adequare sized steam lines
(3) Adequate sized condensate steam lines
(4) Utilization of flash steam
(5) Properly sized and installed steam traps
(6) A regular program or trap checking and maintenance

MANAGING AN EFFECTIVE LEAK-SEALING PROGRAM

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ABSTRACT

An on-line leak sealing program is an extremely effective method of cost savings to industrial plants. The dollars a plant saves can be direct and dramatic as in an avoided system shut-down or subtle and analytical as in a long term maintenance program. Either way, the cost savings are an important part of a complete leak sealing program; in addition, to dollars saved, noise is reduced, environment is safeguarded and energy is conserved.

INTRODUCTION

Leaks in steam and process systems represent considerable financial losses to industrial plants worldwide. These financial losses range from the waste of energy dollars to the staggering losses that occur when a forced shutdown of a process unit takes place. In addition to financial losses, leakage from any system may cause the potential dangers of fire, excessive noise, personal injury, and equipment damage caused by erosion and corrosion. To reduce the economic impact and eliminate the safety hazards of industrial leaks, it is imperative that plant management develop, implement and maintain a program to effectively deal with this problem.

The key to the success of such a program is proper management. As with any aspect of plant operations or maintenance, such a program will not succeed without sincere management interest. Often, leaking equipment is neglected until it becomes a crisis situation.

Process system leakage is inevitable — be it the result of inadequate design or installation procedures, inadequate maintenance, or equipment age. The effective way to deal with the problem is the formulation of a comprehensive, yet flexible plan which eliminates or minimizes the potential of a crisis situation. Plant management must establish the direction and controls necessary to ensure a successful energy saving program.

ECONOMIC INCENTIVES

The high costs involved with the operation and maintenance of an industrial plant are derived from a number of sources including: the high cost of labor (increasing at an annual rate of approximately 10%), imposition of environmental controls for pollution and noise reduction, increased fuel costs, etc.

The impact of fuel costs is evidenced by the dramatic increases experienced in 1979. While the price of all fuels rose a mere six (6) percent in 1978, the year 1979 witnessed a 45 percent increase, with petroleum prices increasing 90 percent. Although the incentives to invest in energy conservation measures appear to be overwhelming, necessary investment capital has become less accessible in

view of the current monetary crisis. With interest rates at 18 percent and climbing, major expenditures for capital equipment conversion have been hampered.

DIRECT ENERGY LOSSES

The most visible energy losses associated with the operation of an industrial plant are leaks from steam or process lines. The costs of these process leaks are difficult to ascertain, though for end products a direct correlation to the wholesale price index exists. To determine the cost of intermediate products it is necessary to analyze all influencing factors including energy inputs (electrical, fuel, steam), raw material costs, and product/by-product loss.

Steam leakage lends itself to a readily identifiable energy loss analysis. The first step involves the identification of the quantitative steam loss from a specific leak. Many studies have been performed to determine this type loss, though most have, unfortunately, related leaks to a specific size hole. For obvious reasons, the orifice size of a leak in progress cannot be measured. Two (2) important studies have been conducted which relate the total leakage to the "blow length" of a steam leak (Ref.: Warren E. Danekind, "Steam Management in a Refinery", Hydrocarbon Processing, December, 1976; David W. Wade and William G. Moran, "Steam System Energy Savers", Chemical Engineering, February 11, 1980). These studies provide a practical approach to quantitatively defining the mass flow rate loss from a specific leak. FURMANITE, INC. developed a Steam Loss Calculator as a handy tool for evaluating steam leakage in this manner. (See Figs 1, 2, and 3)

The second step necessary to economically quantify steam losses requires the plant to accurately determine the cost of steam production. For those plants which must purchase steam, this cost is already known. For those plants which manufacture their own steam, a cost analysis must be conducte Figure 4 depicts typical steam costs for various industries in the United States.

STEAM LEAK SURVEY

Having established a convenient way to measure the amount of steam lost from a specific leak and integrating this with actual steam cost, the plant can now evaluate the total monetary impact of steam leakage. This is best achieved through a program of steam leak surveys which can be conducted "in-house" or by a contractor specializing in on-line leak sealing.

A steam loss survey of a plant system is necessary to provide a factual record of each leak, recording such information as location, type of leak, leakage rate, and most important - Dollar Value of Energy Loss (DVEL). An example of such a survey is shown in Fig. 5. Having accumulated this information, plant management can evaluate each leak in relation to its economic impact.

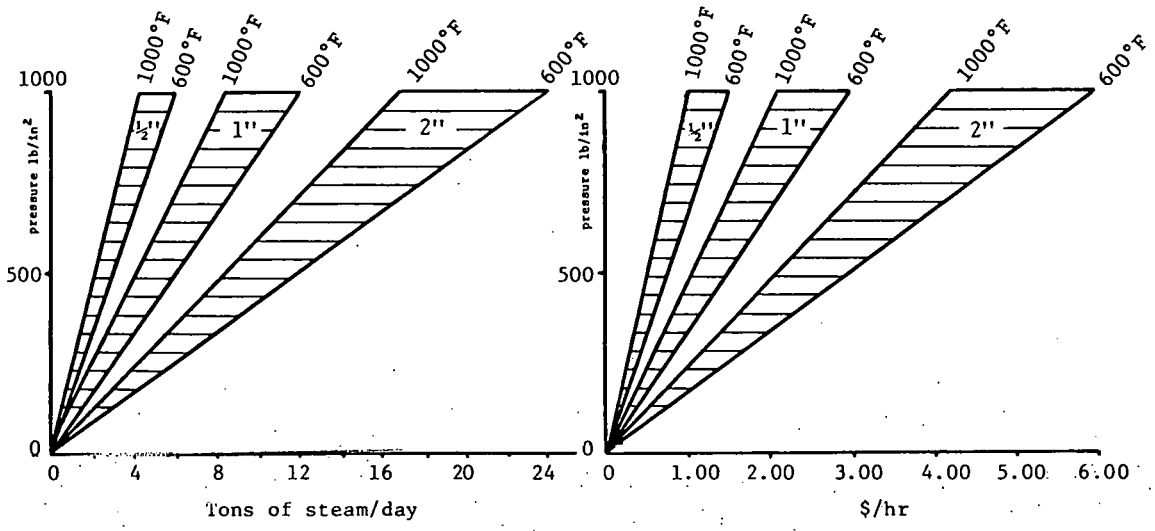
The inclusion of on-line leak sealing into a plant's maintenance program can result in impressive energy and cost savings. The advantage of using such a service is that payback of investment begins immediately as a leak is sealed; therefore, a plant can partially achieve its energy conservation goals without encountering the burden of more capital intensive projects. For example, in one large West Coast refinery, records were kept for a twelve (12) month period (1976). During that time, it was estimated that approximately nine (9) million dollars worth of energy was saved. The cost of the on-line leak sealing service was less than $250,000 - a payback of approximately 36 to 1. The payback of investment a result of using a leak sealing service, can be expected to improve if current economic trends

Blow Length Ft.	Steam Loss Lbs./Hr. (*)	Annual Steam Loss Lbs./Yr.	Annual Energy Losses $/Yr. (**)
2	17.5	153,000	505
3	31	270,000	890
4	54	473,000	1,560
5	95	836,000	2,758
6	167	1,463,000	4,828
7	295	2,584,000	8,527
8	518	4,538,000	14,975

* Data based on nominal 1/8" diameter hole, 150 psi saturated steam; effect of higher pressure or larger hole size roughly compensated in blow length.

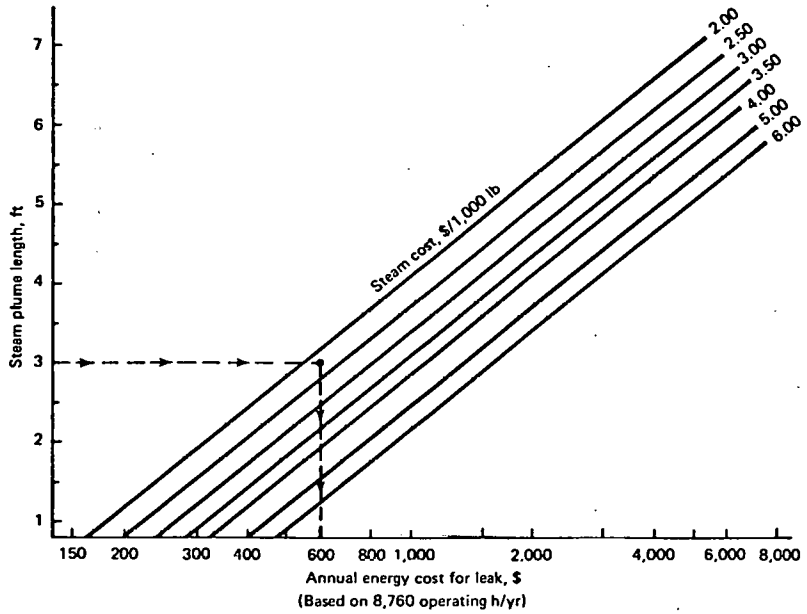
** Energy costs based on steam cost = $3.30/1,000 lbs.

Fig. 1 - STEAM LOSS/ENERGY COST ESTIMATION BASED ON VISUAL OBSERVATION OF LEAKS



Rate of steam leakage and cost for valves with spindle diameters 1/2", 1" and 2"

Fig. 2 - STEAM LOSS/ENERGY COST ESTIMATION OF TYPICAL VALVE SPINDLE PACKING LEAKS



STEAM LOSS ANALYSIS/BLOW LENGTH METHOD

Fig. 3

INDUSTRY	SOUTHEAST	SOUTH	MIDWEST	NORTHEAST
Paper	4.50 - 5.50	3.00 - 4.00	3.00 - 5.00	4.00 - 6.00
Power	5.00 - 6.00* 4.00#	4.50 - 5.00* 3.50#	4.00 - 7.00* 4.00 - 5.00#	6.00 - 8.00* 5.00#
Steel	5.00	–	–	5.00
Refinery & Chemical	3.50 - 4.00	4.50 - 5.00	5.00	4.00 - 6.00

*Oil/Gas #Coal

STEAM PRODUCTION COST

(Dollars/1000 lb_m Steam)

Fig. 4

STEAM LEAK SURVEY FURMANITE®

COMPANY NAME * SAMPLE *

LOCATION

DATE | FURMANITE REPRESENTATIVE:

#	LOCATION	TYPE	PSI	TAG	CLIP	BOX	SCAF	AIR	LBS./HR.	D.V.E.L.
1	DRAIN VALVE 2", RCVR F-201	PACKING	150	✓					52	1650
2	BLOCK VALVE 12" HDR NEAR CLMTE	FLANGE	150	✓	✓		✓		95	2900
3	MANWAY 20" TANK F-1203 STM DRM	FLANGE	150	✓					31	940
4	DRAIN LINE TO TRAP TP-774 1½"	UNION	850	✓					41	1350
AIR 1	UTILITY AIR LINE TO STA 4U-85	THR COUPLNG	-	✓					-	1572

Indicates field provision requirements for tagging, clip, box, scaffolding or mobile air compressor.

"DVEL" = Dollar Value of Energy Losses

SURVEY SHEET SAMPLE

Fig. 5

continue. This is due to the recent dramatic increases in fuel costs (the major cost factor in steam production) compared to the relatively smaller increases in labor costs (the major cost factor in on-line leak sealing).

INDIRECT ENERGY LOSSES

In addition to the direct energy loss from a steam leak, other losses occur simultaneously. These losses are represented by the cost of replacement condensate water (especially costly where treated feedwater is necessary) and the reduction in system efficiency which occurs through the heating of the additional makeup water to system temperature. A representative estimate of these indirect energy losses are as follows:

Steam System Pressure (psig)	Feedwater Cost ($/1000 lb_m)
600	0.60
150	0.40
15	0.25

Notes:
(1) Based on Fuel Oil at $25 per barrel
(2) Based on non-commercial supply of basic water

Steam and process leaks are not the only leaks that waste energy. Utility leaks, such as plant air, are additional energy problems. The economic effect of air leaks is tabulated in Fig. 6. The benefits of

utilizing on-line leak sealing in the elimination of compressed air leaks is typified by the results achieved in a medium sized West Coast refinery. A survey of air losses was estimated to cost $40,000 per month. The total cost of on-line leak sealing of these leaks was $8,100. The resultant payback on an annualized basis was approximately 60 to 1.

TYPICAL COSTS FOR AIR LEAKS IN A 100 P.S.I. SYSTEM
(BASED ON PRODUCTION COST OF $.15/1,000 CU.FT.)

DIA. OF LEAK	CU.FT./HR.	COST/DAY	COST/YEAR
1/32	75	$ .27	$ 98.00
1/16	299	1.07	391.00
1/8	1,197	4.31	1,572.00
1/4	4,788	17.24	6,292.00
3/8	10,748	38.69	14,078.00
1/2	19,152	68.95	25,165.00

FIG. 6

NOISE REDUCTION

The benefits of leak sealing in noise reduction programs have come somewhat as a by-product advantage, since the quantitative effects of noise reduction by this method are only just beginning to be measured broadly by industry. Results of a study performed by FURMANITE in 1977, and subsequently published in the Acoustical Industry Bulletin (May, 1978), demonstrated impressive noise reductions resulting from the repair of steam leaks in a typical steam distribution system. Actual in-plant studies have shown noise levels in operator locations near steam leaks to be over 115 dBA, a level at which no exposure, regardless of how short the duration, is permitted under OSHA regulations. Even in areas where the leaks are not in such close proximity to operator, it is common for personnel to be exposed to noise levels in the 100 to 105 dBA range. Typically, the elimination of leaks in this environment can resu in an immediate 15 dBA reduction, or to the normal equipment background level for the area.

The elimination of steam leaks generally results in large noise level reductions in the lower frequency bands, which are troublesome to safety engineers since low frequency noise is more difficult to attenuate than the higher frequencies (See Fig. 7). The noise limitations imposed by OSHA, especially for areas where operating personnel must have repeated or continuous access, can pose serious problems to plant management and can easily result in fines, plant shutdowns or costly acoustical controls or equipment changes.

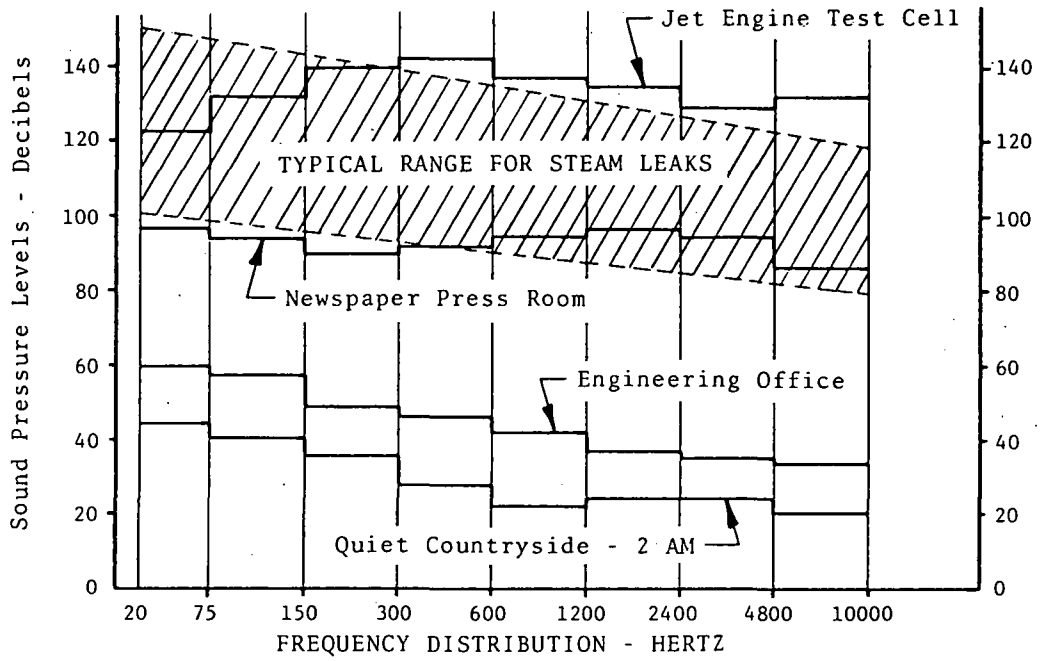
OSHA PERMISSIBLE NOISE EXPOSURES
(Without Hearing Protection)

Noise Level - dBA	Duration - Hrs./Day
90	8
92	6
95	4
97	3
100	2
102	1½
105	1
110	½
115	¼ or less

The ability to alleviate a major noise source without the need for unit shut-down or for capital modification of equipment can easily make leak sealing an attractive approach to noise reduction. Advantages such as these can make on-line leak sealing an effective part of any plant's safety and noise abatement program.

POLLUTION CONTROL

Recent regulations imposed by the EPA and local pollution control boards have made it mandatory that all point sources of specified hydrocarbon pollution be measured, recorded, and if beyond acceptable limits, repaired within a specified time period. The primary economic incentive to control these leaks can



FREQUENCY DISTRIBUTION/SOUND POWER LEVEL FOR TYPICAL NOISE SOURCES.

Fig. 7

only be related to the potential fines or shut-down costs which can be prevented through the use of an on-line leak sealing service.

LEAK PREVENTION PROGRAM

With energy saving objectives in mind, plant management must provide the proper direction to routinely deal with the leak situation. Leaks generally fall into the following categories:

(1) Emergency - System or plant shut-down imminent.

(2) Safety Hazard - Leak effects must be controlled for equipment or personnel safety.

(3) Major Leak - Leak which loses greater than 50 lb_m/hr.

(4) Minor Leak - Leak which loses less than 50 lb_m/hr.

(5) Nuisance Leak - Leaks which are generally housekeeping problems, not significant in reference to energy losses.

Leaks that fall in categories (1) and (2) obviously require immediate attention. Those leaks in categories (3) and (4) should be reviewed in light of plant operational commitments. Calculations should be performed that relate the anticipated energy loss until the next planned shut-down versus the cost of on-line leak sealing. In this manner, the economics of the situation are analyzed; however, it must be noted that economics cannot be the deciding factor alone. A decision to let leakage continue must be tempered with the understanding that resulting erosion can generate higher equipment repair costs.

Leak sealing is a valuable program which adds new dimensions to plant maintenance. Whether on-line leak sealing is used in emergency situations, routine maintenance, or noise abatement, a properly managed leak sealing program offers tremendous cost savings, energy conservation, and aid in meeting EPA and OSHA requirements and guidelines.

THE ENGINEERED APPROACH TO ENERGY AND MAINTENANCE-EFFECTIVE STEAM TRAPPING

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ABSTRACT

The engineered approach to steam trap sizing, selection and application has proven effective in significantly reducing a plant's fuel consumption, maintenance and trap replacement costs while improving thermal efficiency and overall steam system performance.

New field test procedures for measuring condensate load and steam loss have proven valuable in sizing traps and to determine which trap is the most energy efficient.

The combination of using the engineered approach to steam trapping, field tests to verify trap performance and good maintenance practices has contributed to a major reduction in energy consumption of 10-50% in many industrial plants.

Energy conservation projects in many industrial plants have bypassed the steam system in order to effect other economies in their processes. The chemical industry has reported an 18.2% reduction in fuel usage per unit of output in 1978 versus 1972. A recent report indicated that 3.7 million barrels of oil/day are used to produce steam which is 17% of all U.S. energy usage and 47% of all industrial energy usage.

While perpetual steam leaks were tolerated since they did not seriously affect a plant's operation and the magnitude of the cost was unknown, the steam system and its related equipment can no longer be ignored with the cost of fuel to produce steam averaging $4.50-$6.50/1000 lbs.

The efficient utilization of steam in the plant is an important economic consideration. It must be trapped and insulated properly to be thermally and functionally efficient. Energy operating targets should include an analysis of steam trapping practices and a monitoring of fuel consumption since the steam trap has an important bearing on the efficient operation of a plant. With proper selection and applying good engineering practices, any efficient trap can save energy dollars by allowing the steam system to come up to operating temperature rapidly, maintain optimum operating temperatures and perform at maximum capacities.

Steam traps have been proven to be wasters of large amounts of steam regardless of trap manufacturers' claims. Much of the waste can be attributed to improper selection, oversizing, wear or life cycle characteristics, effect of back pressure, orifice erosion, steam loss upon failing open and maintenance practices. Surveys of steam traps in a number of plants revealed that 20-60% of their traps were failed open blowing steam. Refer to Table 1 for an analysis of the cost of steam losses from failed open traps at today's fuel prices. Not included is the additional cost of make up water to the boilers and related chemical treatment of the feedwater. The steam loss from a leaking trap can cost more in one day than the replacement cost of the trap.

Trap manufacturers are claiming everything from no steam loss to a maximum 2 lbs./hr. during its life cycle. Tests performed in plant by many users have proven these claims to be erroneous. An effective trap consumes 1-2 lbs./hr. steam just to function properly. An inverted bucket trap loses 2-4 lbs./hr. and a thermodynamic disc trap 0.5-1 lbs./hr. just due to radiation loss.

Good engineering, careful selection and an awareness of the shortcomings of steam traps is vital to any plant's energy conservation program.

The Drain Orifice, a continuous condensate removal device, introduced commercially in 1974, has been a major driving force in making plant engineering and maintenance personnel aware of the need to use an engineered approach to steam trapping. Good application engineering must be applied to the Drain

A trap functions as an orifice and therefore flow equations for sizing control valves and orifices are valid for traps. C_V methods are being used by some manufacturers to size traps and estimate steam loss.

Operating requirements for trap sizing include:

1. Pressure at the trap inlet.
2. Pressure drop across the trap orifice.
3. Backpressure and lift head.
4. Maximum condensate load.
5. Ambient conditions of temperature and wind chill.
6. Other operating conditions of the process the trap is to drain which could vary the load by some degree.

In order to better understand the relationship between saturated steam and saturated condensate flow through a given orifice refer to Fig. 4. For example, at 100 PSIG, the maximum steam flow through the orifice is 5.4% of its condensate capacity. If the orifice has a condensate capacity of 100 lbs./hr., it can only pass 5.4 lbs./hr. of steam, if no condensate is present.

The difference is due to the large volumetric difference between steam and a reduced C_D for condensate.

Flexitallic has developed two methods for determining the correct orifice size for a specific application:

A. Compusize - where complete data is available or obtainable, a computer program offers an engineered approach to orifice sizing for each application. Also it includes efficiency and max-steam loss data to determine the suitability of the Drain Orifice for the application.

Note: Refer to Fig. 1 for a sample data sheet on tracers.

The program can also be used to prepare an orifice selection table for a given application.

Note: Refer to Fig. 2 for a sample orifice selection table for tracers.

B. Field Test Procedure for Determining Condensate Rates and Orifice Sizes Employing the Flexitallic Test Assembly.

Many times it is difficult to obtain the data required to calculate the condensate load. This leads to selecting a trap large enough to assure removal of the load which is the same as oversizing and all the problems associated with it.

The Test Assembly is shown in Fig. 3. It is designed to allow the user to connect it directly to the drain line in his plant. By selecting an orifice large enough to pass all of the condensate and using a contact-type temperature probe, data can be obtained to accurately calculate the condensate load at operating conditions. Then the correct orifice size can be calculated for that drain point.

Note: This procedure can also be used to determine the correct orifice size to use in any trap. However, orifice selection is limited by each type of trap's design compared to the infinite rangeability of the Drain Orifice.

Backpressure

Backpressure can exist if traps are connected to a condensate return system which may contain some pressure or may be due to lift head from elevating condensate to an overhead return line.

Backpressure must be included in trap orifice sizing because trap capacity is based on the differential pressure across the orifice. If not, you may not be able to get condensate back to the low pressure system or it may cause "water logging" of the process equipment.

The various types of traps have specific limitations in their ability to function against backpressure. For example:

Type of Trap	Backpressure Limit % of Inlet Pressure
Inverted Bucket	50%
Thermodynamic (Disc Type)	50%
Thermodynamic (Impulse Type)	30%
Drain Orifice	99%

Orifice before it can be effective and efficient in any steam system and the same applies to steam trapping in general. Plants which have applied the Drain Orifice properly are reporting reductions in fuel consumption of 10-50%, a substantial reduction in maintenance and replacement costs, and overall improvement in thermal efficiency and steam system performance.

The following parameters must be considered in engineering a steam trap for a specific application:

Selection

Selection of the wrong type and size of steam trap can cause high energy losses, premature failure and lower the operating and thermal efficiency of the steam system.

Selection has generally been an afterthought and a poor one. It is common practice in many plants to select a trap based on the drain line pipe size rather than on condensate load conditions. Too large a trap will operate sluggishly and waste steam while too small a trap will back up condensate lowering thermal efficiency and cause water hammer.

Each type of trap (inverted bucket, thermodynamic or the thermostatic) must be selected on the basis of its operating characteristics and how well suited it is for a specific application. Users are reporting that various types and makes of traps fall short of performance characteristics claimed by manufacturers.

The following parameters must be considered in the trap selection process:

1. Remove condensate, air and non-condensable gases as rapidly as they form to maintain steam temperature and optimum thermal efficiency with minimum steam loss.
2. Capable of performing at operating as well as changing pressures, temperatures and condensate loads.
3. Provide long life and dependable service.
4. Be corrosion resistant and free from dirt problems.
5. Freezeproof - traps subject to freeze-up can cause an unscheduled plant shutdown.
6. Operate against varying levels of back pressure. Many traps are limited to the amount of backpressure they can accept.
7. Fail safe in the open or closed position depending on the application.
8. Resistant to hydraulic shock or water hammer.
9. Good response to changes in operating conditions.

The Drain Orifice is the only type of steam trap that simplifies the selection process. It meets all of these parameters and can be applied to all applications except where there is wide variation in condensate load conditions at constant pressure, i.e. greater than 50% from design load. Using the engineered approach to trap selection, it can be determined during the selection process if the Drain Orifice can meet the application requirements. This is very difficult to do with all other types of traps, none of which can meet all of the desirable operating parameters.

Trap Sizing

Trap sizing errors contribute to poor trap performance and premature failure more than any other single factor. Oversized traps cause rapid cycling, excessive wear and erosion as well as increased steam venting. Undersized traps reduce operating efficiency.

A common misconception is that trap size be based on the size of the drain line or on condensate temperature when it should be a function of condensate load. Also a common practice is to size a trap based on warm-up condensate load instead of normal condensate production rate. This oversizing wastes large amounts of steam and causes premature trap failure.

ENERGY WASTED WITH VARIOUS SIZE TRAP ORIFICES

Trap Orifice Size (inches)	Steam Loss (lbs/mo) vs Cost/mo ($4.50/1000 lbs) Trap Failed Open-Discharge to Atmosphere							
	50 PSI	Cost	100PSI	Cost	150PSI	Cost	250PSI	Cost
1/32" (0.031)	1,340	$ 6.	2,376	$ 11.	3,413	$ 15.	5,479	$ 25.
1/16" (0.0625)	5,328	24.	9,504	43.	13,608	61.	21,888	98.
1/8" (0.125)	21,456	97.	38,016	171.	54,576	246.	87,840	395.
1/4" (0.250)	85,680	386.	151,920	684.	218,160	982.	350,640	1,578.
3/8" (0.375)	192,960	868.	342,000	1,539.	491,040	2,210.	789,120	3,551.
1/2" (0.500)	342,720	1,542.	607,680	2,735.	872,640	3,927.	1,403,280	6,315.

TABLE 1

Form C-TTH-F (Data)
Type 1-2-3

Flexitallic DRAIN ORIFICE
COMP-U-SIZE DATA SHEET

Tubular Trace Heating -- Field

Please Fill in ALL Blanks:

Steam Pressure 50 psig
Minimum System Product Temperature 40 °F
Design Pressure Drop 10 %
Maximum Backpressure 10 psig
Maximum Lift Head 10 feet
Standardization Desired: Yes (X) No ( )
Maximum Steam Loss: 1 lb/hr ( ) 2 lb/hr (X)

CUSTOMER _____

LOCATION: _____

Check Tracer Used and Application Type

TRACER SIZE			APPLICATION TYPE		
			AIR CONVECTION	CONDUCTION	
				CHANNEL TRACE	HAND TROWELED
TUBING	O.D. Specified	1/4"			
		3/8"			
		1/2"	X	X	X
		5/8"			
		3/4"			
		1"			
	Type K	1/4"			
		3/8"			
		1/2"			
		5/8"			
		3/4"			
		7/8"			
PIPE		1/4"			
		3/8"			
		1/2"			
		3/4"			
		1"			

FIGURE 1

Form-C-TTH-F-Air Convection

Flexitallic DRAIN ORIFICE
COMP-U-SIZE

Tubular Trace Heating -- Field

Customer _____
Location _____
_____
Sized by _____

Steam Pressure 50 psig
Minimum System Product Temperature 40 °F
Design Pressure Drop 10 %
Maximum Backpressure 10 psig
Maximum Lift Head 10 feet
Standardization Desired: Yes (X) No ( )
Maximum Steam Loss: 1 lb/hr ( ) 2 lb/hr (X)

TABLE #1
Orifice Required for Tracer
AIR CONVECTION TYPE

TRACER SIZE			ORIFICE
Copper or Stainless Tubing	O.D. Specified	1/4"	0.0260
		3/8"	0.0260
		1/2"	0.0280
		5/8"	0.0350
		3/4"	0.0420
		1"	0.0520
	Type K	1/4"	0.0260
		3/8"	0.0260
		1/2"	0.0330
		5/8"	0.0400
		3/4"	0.0465
		7/8"	0.0625
Iron or Steel Pipe		1/4"	0.0260
		3/8"	0.0310
		1/2"	0.0380
		3/4"	0.0520
		1"	0.0670

FIGURE 2

Form C-TTH-F-CONDUCTION (C)

Flexitallic. DRAIN ORIFICE

COMP-U-SIZE

Tubular Trace Heating -- Field

Steam Pressure 50 PSIG
Minimum System Product Temperature 40 °F
Design Pressure Drop 10 %
Maximum Back pressure 10 PSIG
Maximum Lift Head 10 FEET
Standardization Desired: Yes (X) No ( )
Maximum Steam Loss: 1 lb/hr ( ) 2 lb/hr (X)

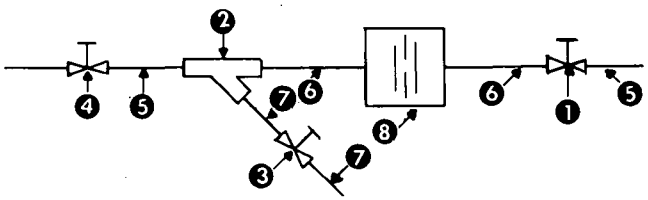
CUSTOMER _____
LOCATION _____
SIZED BY _____

TABLE #1
Orifice Required for Tracer
CONDUCTION TYPE-CHANNEL TRACE

Product	Copper or Stainless Tubing												Iron or Steel Pipe				
Pipe	O.D. Specified						Type K										
Size	1/4"	3/8"	1/2"	5/8"	3/4"	1"	1/4"	3/8"	1/2"	5/8"	3/4"	7/8"	1/4"	3/8"	1/2"	3/4"	1"
½ - 1½	0.0260	0.0260	0.0370	0.0465	0.0595	0.0670	0.0260	0.0350	0.0465	0.0595	0.0670	0.0860	0.0292	0.0400	0.0520	0.0670	0.0890
2	0.0260	0.0260	0.0350	0.0465	0.0595	0.0670	0.0260	0.0330	0.0430	0.0550	0.0625	0.0860	0.0280	0.0380	0.0520	0.0670	0.0860
2½	0.0260	0.0260	0.0350	0.0465	0.0550	0.0635	0.0260	0.0320	0.0430	0.0550	0.0625	0.0820	0.0280	0.0380	0.0520	0.0635	0.0820
3	0.0260	0.0260	0.0350	0.0430	0.0550	0.0625	0.0260	0.0310	0.0410	0.0520	0.0595	0.0810	0.0280	0.0360	0.0465	0.0625	0.0810
3½	0.0260	0.0260	0.0330	0.0420	0.0520	0.0625	0.0260	0.0310	0.0400	0.0520	0.0595	0.0781	0.0260	0.0360	0.0465	0.0625	0.0781
4	0.0260	0.0260	0.0320	0.0410	0.0520	0.0595	0.0260	0.0310	0.0390	0.0520	0.0595	0.0760	0.0260	0.0350	0.0465	0.0595	0.0760
5	0.0260	0.0260	0.0310	0.0400	0.0520	0.0595	0.0260	0.0292	0.0390	0.0520	0.0550	0.0760	0.0260	0.0350	0.0465	0.0595	0.0760
6	0.0260	0.0260	0.0310	0.0390	0.0520	0.0595	0.0260	0.0280	0.0370	0.0465	0.0550	0.0730	0.0260	0.0330	0.0420	0.0595	0.0730
8	0.0260	0.0260	0.0292	0.0370	0.0465	0.0550	0.0260	0.0280	0.0350	0.0465	0.0520	0.0700	0.0260	0.0310	0.0400	0.0550	0.0700
10	0.0260	0.0260	0.0280	0.0350	0.0420	0.0520	0.0260	0.0260	0.0330	0.0410	0.0469	0.0635	0.0260	0.0292	0.0370	0.0520	0.0635
12	0.0260	0.0260	0.0260	0.0310	0.0380	0.0465	0.0260	0.0260	0.0292	0.0360	0.0420	0.0595	0.0260	0.0260	0.0330	0.0465	0.0595
14	0.0260	0.0260	0.0260	0.0280	0.0350	0.0400	0.0260	0.0260	0.0280	0.0330	0.0380	0.0520	0.0260	0.0260	0.0310	0.0400	0.0520
16 & Up	0.0260	0.0260	0.0260	0.0260	0.0310	0.0360	0.0260	0.0260	0.0260	0.0292	0.0350	0.0465	0.0260	0.0260	0.0280	0.0360	0.0465

FIGURE 2A

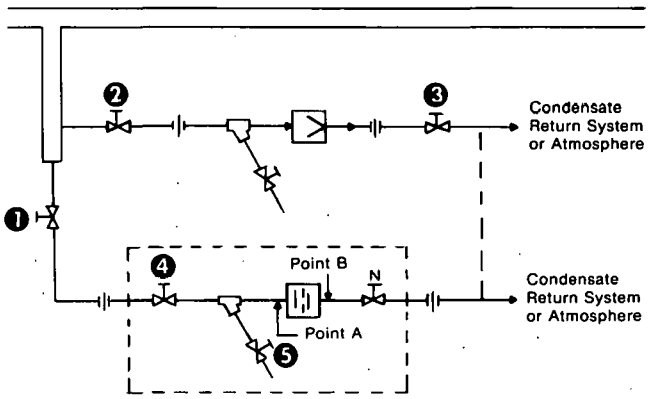
TEST ASSEMBLY (1/2" 600 PSIG TEST UNION ASSEMBLY)



ITEM NUMBER	DESCRIPTION
1	1/2" NPS— 600# Needle Valve
2	1/2" NPS - 600# Y Strainer with 0.020" Perforated Plate Basket
3	1/4" NPS - 600# Globe Valve
4	1/2" NPS - 600# Gate Valve
5	1/2" x 4" Nipple (Schedule 80)
6	1/2" x 6" Nipple (Schedule 80)
7	1/4" x 4" Nipple (Schedule 80)
8	Orifice Plate

FIGURE 3

TYPICAL DRIP LEG INSTALLATION OF TEST ASSEMBLY



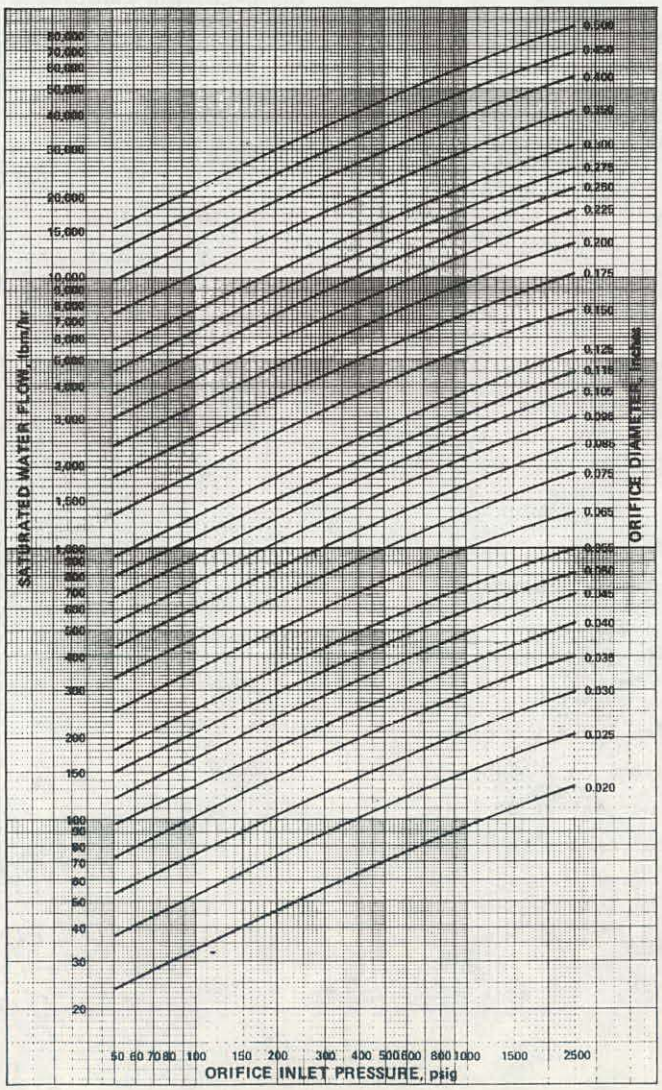
NOTES:
1. All connections outside of and to test assembly by Customer.
2. Drip leg should be blown down before test rig is installed.
3. "Y" Strainer ahead of steam trap may be blown down and test rig connected at strainer blow down point.

FIGURE 3A

Multiplier Chart for Orifice Diameter Sizing									
Multiplier	**Orifice ±0.001"**	**Multiplier**	**Orifice ±0.001"**	**Multiplier**	**Orifice ±0.001"**	**Multiplier**	**Orifice ±0.001"**	**Multiplier**	**Orifice ±0.001"**
1.00	0.0200"	4.41	0.0420"	21.85	0.0935"	51.84	0.1440"	91.20	0.1910"
1.10	0.0210"	4.62	0.0430"	21.94	0.0937"	54.02	0.1470"	93.60	0.1935"
1.26	0.0225"	5.40	0.0465"	23.04	0.0960"	55.87	0.1495"	96.04	0.1960"
1.44	0.0240"	5.49	0.0469"	24.01	0.0980"	57.76	0.1520"	99.00	0.1990"
1.56	0.0250"	6.76	0.0520"	24.75	0.0995"	59.29	0.1540"	101.00	0.2010"
1.69	0.0260"	7.56	0.0550"	25.75	0.1015"	60.99	0.1562"	103.12	0.2031"
1.96	0.0280"	8.85	0.0595"	27.04	0.1040"	61.62	0.1570"	104.04	0.2040"
2.13	0.0292"	9.76	0.0625"	28.35	0.1065"	63.20	0.1590"	105.57	0.2055"
2.40	0.0310"	10.08	0.0635"	29.86	0.1093"	64.80	0.1610"	109.20	0.2090"
2.43	0.0312"	11.22	0.0670"	30.25	0.1100"	68.89	0.1660"	113.42	0.2130"
2.56	0.0320"	12.25	0.0700"	30.80	0.1110"	71.82	0.1695"	119.57	0.2187"
2.72	0.0330"	13.32	0.0730"	31.92	0.1130"	73.87	0.1719"	122.10	0.2210"
3.06	0.0350"	14.44	0.0760"	33.64	0.1160"	74.82	0.1730"	129.96	0.2280"
3.24	0.0360"	15.24	0.0781"	36.00	0.1200"	78.32	0.1770"	136.89	0.2340"
3.42	0.0370"	15.40	0.0785"	39.06	0.1250"	81.00	0.1800"	137.35	0.2344"
3.61	0.0380"	16.40	0.0810"	41.28	0.1285"	82.81	0.1820"	141.61	0.2380"
3.80	0.0390"	16.81	0.0820"	46.24	0.1360"	85.56	0.1850"	146.41	0.2420"
4.00	0.0400"	18.49	0.0860"	49.35	0.1405"	87.89	0.1875"	151.29	0.2460"
4.20	0.0410"	19.80	0.0890"	49.42	0.1406"	89.30	0.1890"	156.25	0.2500"

TABLE 2

WATER FLOW, 50 TO 2500 psig



GRAPH 1

In all types, except the Drain Orifice, when the backpressure limit is exceeded, the trap will remain open causing excessive steam loss.

Where traps are connected to a return system, as they fail open they contribute to backpressure. When the backpressure limit is exceeded, all traps connected to the return system will fail open, overload the receiver and vent both live and flash steam.

The Drain Orifice can take a 10:1 turndown in ΔP across the orifice before its performance is seriously affected. As the ΔP across the orifice changes, the capacity of the orifice is reduced and is self compensating and will not contribute to increases in the backpressure of the return system or increase the steam loss.

Flash Steam

A percentage of the discharge of a trap turns to flash steam. The higher the backpressure, the lower the percent of flash steam.

Many plants use the heat in flash steam for lower pressure applications which is known as cascading. Flash tanks are used to separate flash steam from condensate.

Flash steam is the vapor that forms when hot condensate is discharged through an orifice from a higher to lower pressure. A trap which discharges condensate the fastest will also produce a larger percentage of flash steam but also prove to be the most efficient.

It is important to be able to recognize the difference between flash and live steam. If the trap discharge is colorless close to its point of discharge, live steam is being lost. An all-white discharge is usually flash steam mixed with condensate.

The Drain Orifice has proven to be the most efficient of any type of trap based on its operating characteristics and the higher percentage of flash steam formed when discharging condensate to a lower pressure.

Refer to Fig. 5 for details. The net result is a more stable, thermally efficient operating steam system.

Safety Factor

The safety factor is a load multiplying factor or oversizing factor which must be given serious consideration in trap sizing.

Trap manufacturers have established safety factors based on user experience or preference. Other factors considered in selecting a safety factor are:

- Warm-up load or load fluctuations during normal operation
- Capacity needed for air venting
- Lower operating pressure than normal resulting in lower trap capacity
- Inaccuracies in estimating condensate load.

All of the above lead to selection of safety factors which result in excessive oversizing and the related problems such as large steam losses and premature trap failure. Safety factors vary from 2 to 10 based on user experience.

Flexitallic has gone to great lengths to scientifically determine the safety factor for each application outlined as follows:

Application	Drain Orifice	Steam Traps
Main Steam Supply		
Outdoors	1.50	3.0
Indoors	1.25	3.0
Trace Heating	1.10	2.0
Space Heaters	1.00	2-3
Process Heaters	1.1-1.25	5.0
Hot Water Heaters	1.1-1.25	5.0
Fintube Radiation		
Above 75 PSIG	1.5	3.0
75 PSIG or less	2.0	3.0
Cylinder Dryers	1.5	8.0-10.0

TEST ARRANGEMENT FOR STEAM LOSS TEST

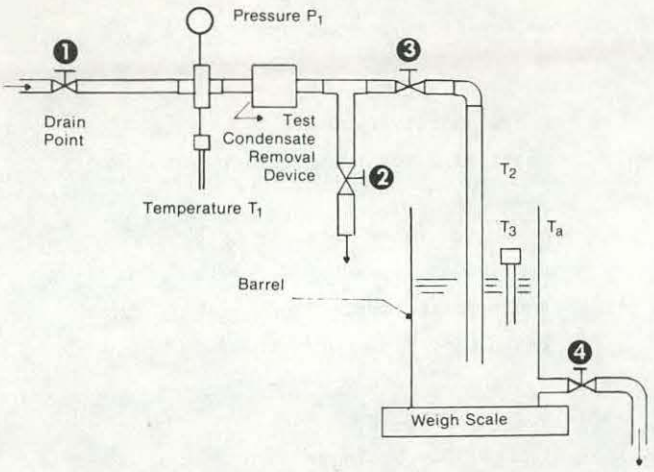


FIGURE 3B

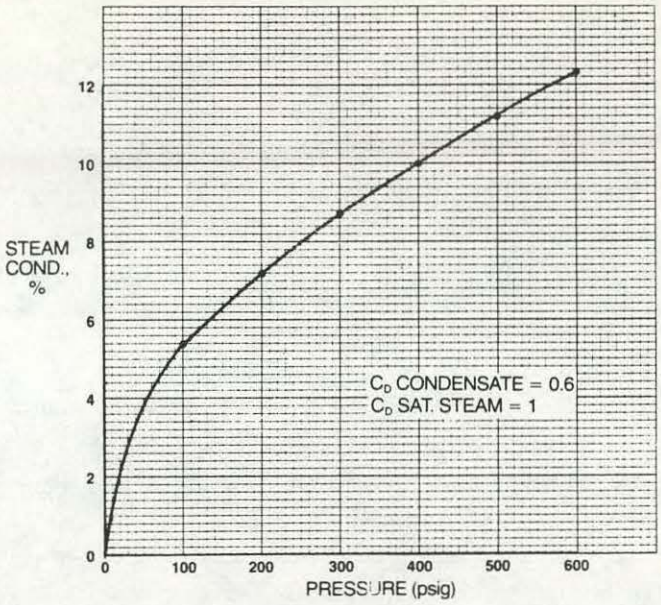


FIGURE 4

STEAM FORMED
WHEN DISCHARGING SATURATED CONDENSATE
TO A LOWER PRESSURE

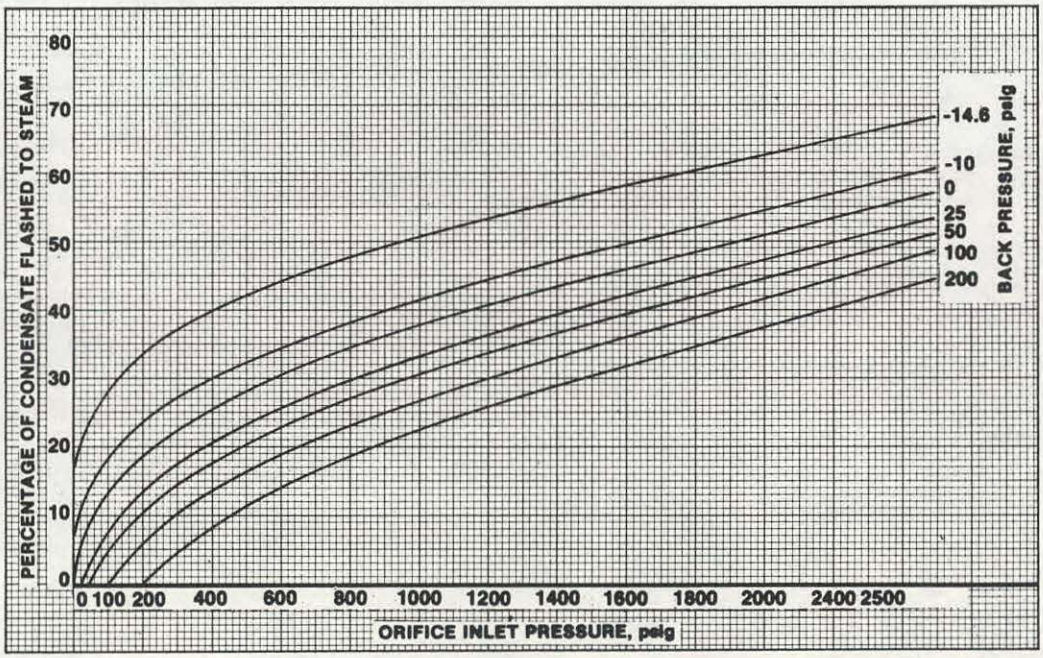


FIGURE 5

The effect of safety factor is directly related to the pressure turndown capability of an orifice.

Safety Factor	Pressure Turndown
2.0	30 to 1
1.5	15 to 1
1.25	6 to 1
1.10	2 to 1

The inlet pressure to the orifice can vary up to the limits of the pressure turndown with the orifice being self compensating and performing at high thermal efficiency.

The relationship between live steam flow when an orifice is passing a mixture, as when oversizing (safety factor) is employed and live steam flow when no condensate is present is illustrated in Fig. 6. For example, an orifice capable of passing 5.4 lbs./hr. steam at 100 PSIG, if no condensate is present, will pass only 0.704 lbs./hr. steam when condensate is present using a SF=1.5. The relationship may be calculated as follows:

$$SR = \frac{45.34}{SF} (SF - 1.0)^{1.212}$$

Where:

SR = Steam Ratio, %

$$SF = \text{Safety Factor} = \frac{\text{Orifice Capacity}}{\text{Condensate Load}}$$

The effect of steam ratio and safety factor on steam loss as a function of condensate flow is illustrated in Fig. 7. It is interesting to note that a safety factor of 1.5 produces a steam loss of 0.8% of condensate flow at 150 PSIG. Most Drain Orifice applications require safety factors of 1.25 or less, further reducing steam loss.

The following applications were selected to illustrate the importance of safety factor as related to steam trap performance and inherent steam loss. The actual applied safety factor is derived as follows:

$$SF = \frac{M \times A \times C_b \times C_p}{W}$$

Where:

SF = Actual Safety Factor

M = Multiplier for trap orifice (refer to Table 2)

A = Saturated water capacity of a 0.020 orifice at pressure (Refer to Graph 1)

C_b = Backpressure correction

C_p = Drain pipe size correction

W = Condensate load

Example No. 1

Main Steam Supply Drainage

Size of Main: 4" diam.

Steam Pressure: 100 PSIG

Ambient Temp.: 0°F

Length between Drip Legs: 200 ft.

Backpressure: OPSIG

Lift Head: OPSIG

Calculated Load: 41.3 lbs./hr.

Type of Trap	Capacity at 100 PSI ΔP (lbs./hr.)	Design S.F.	Orifice Diam (in.)	Actual S.F.	Steam Loss (lbs./hr.)
Drain Orifice	66.9	1.5	0.028	1.62	0.57
Inverted Bucket (Cast Iron)	350	2-3	5/64"(0.078)	12.61	19.87
Inverted Bucket (Stainless Steel)	640	2-3	7/64"(0.109)	24.74	47.27
Thermostatic (Bellows Type)	348	3-4	5/64"(0.078)	12.61	19.87
Thermodynamic (Disc Type)	810	1.2-2	Calculated 0.098	19.06	35.76

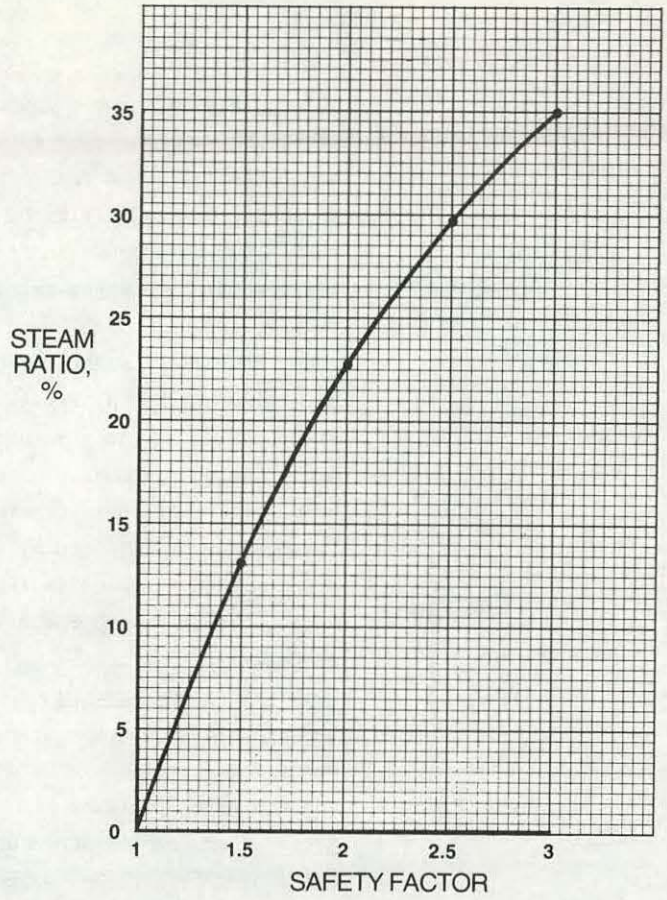


FIGURE 6

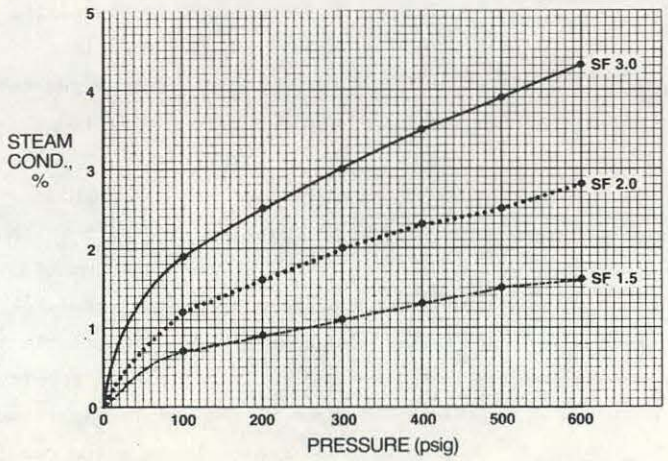


FIGURE 7

Example No. 2

Tubular Trace Heating

Product Temp: 140°F (min.)

Insulation: 1-1/2" Cal Sil

Ambient Temp: 0°F

Steam Pressure: 100 PSIG

Backpressure: 0 PSIG

Lift Head: 0 PSIG

Wind Chill: 20 MPH

Tracer: 1/2" O.D. Copper Tubing

Calculated Load: 14.71 lbs./hr.

Type of Trap	Capacity at 100 PSI ΔP (lbs./hr.)	Design S.F.	Orifice Diam (in.)	Actual S.F.	Steam Loss (lbs./hr.)
Drain Orifice	33	1.1	0.020	2.32	0.51
Inv. Bucket (Low Capacity)	710	2.0	#38R60 (0.036)	7.5	18.2
Thermostatic (Bellows Type)	348	3.0	5/64"(0.0935) Calculated	35.39	26.4
Thermodynamic (Disc Type)	300	2.0	Calculated (0.0595)	20.54	13.3
Thermodynamic (Disc Type)	370	1.2-2	Calculated (0.0658)	25.12	17.2

Example No. 3

Process Heater - Still Bundle, Boiling Process Amines

Condensate Load @ 350 PSIG Downstream of Valve = 4500 lbs./hr.

Condensate Load @ 25 PSIG Downstream of Valve = 500 lbs./hr.

Backpressure: 0 PSIG

Lift Head 0 PSIG

Type of Trap	Design SF	Max. Cond.			Min. Cond.	
		Orifice Diam (in)	Actual SF	Steam Loss (lbs./hr.)	Actual SF	Steam Loss (lbs./hr.)
Drain Orifice	1.1 to 1.25	0.180	1.11	13.27	2.82	17.8
Inv. Bucket (Cast Iron)	3	11/32" (0.3438)	4.10	739	10.28	128
Thermodynamic (Impulse Type)	1.2 to 2.0	Calculated (0.290)	2.90	412	7.3	81

In each example you can readily determine t effect of safety factor related to the trap orifice and potential steam loss. Example No. 3 clearly indicates the capability of a fixed orifice to handle variable loads and still operate more efficiently than steam traps.

Trap Testing

A variety of test methods have been used to determine whether a trap is performing properly and efficiently. Various methods are as follows:

Sight Method - visually observing the trap discharge to determine if it is passing hot condensate and flash steam or live steam.

Sound Method - use of an industrial stethoscope or ultrasonic device to check if the trap is cycling properly.

Temperature Measurements - checking the differential temperature across the trap by use of a contact pyrometer. Temperatures should correspond to the inlet and discharge pressure.

Note: Thermophotographic and infrared pyrometers are being used by a number of companies to measure the ΔT across the trap as well as photograph its operating condition.

The ΔT measurement has become the most acceptable method for determining steam trap performance industrywide. The closer to steam temperature that condensate is discharged is important in maintaining maximum energy efficiency. Causes of trap failure are misapplication, improper sizing, corrosion, inferior quality, inability to withstand the effects of freezing, and dirt in the system.

Several trap manufacturers are offering to perform laboratory tests on steam traps a customer is currently using in his plant. While such tests can be indicative of a trap's performance, they cannot compare to the results achieved by running such tests under actual operating conditions in a plant.

The Performance Test Code Committee Number 39.1, Condensate Removal Devices for Steam Systems

pproved the ANSI/ASME PTC 39.1 tentative draft of the Performance Test Code which has been sent to the membership for approval.

Flexitallic has developed its own Field Steam Loss Test Procedure which is similar to PTC 39.1 for any condensate removal device. It has been used by many customers to evaluate the steam loss from any steam trap in plant for a specific application.

Users are no longer accepting a trap manufacturer's claims of no steam loss or losses no greater than 2 lbs./hr. over the trap's life cycle. They are measuring these losses and making their own comparison tests. Results obtained from such a test is as follows:

Test No. 1

Application: Main Steam Supply

Steam Pressure: 150 PSIG

Condensate Load: 18.75 lbs./hr.

Type of Trap	Inlet Temp(°F)	Outlet Temp(°F)	Steam Loss (lbs./hr.)	Efficiency (%)
Drain Orifice (0.020")	340	202	0.25	98.6
TD-Disc Type (1")	328	325	26.25	41.6
TD-Disc Type (3/4")	320	318	9.25	66.9
TD-Disc Type (1/2")	323	253	7.25	72.1
TD-Disc Type (3/8")	319	242	9.75	65.7
Thermostatic (3/4")	330	294	11.25	62.5
TD-Disc Type (3/4")	320	302	18.24	50.6

Test No. 2

Application: Main Steam Drainage

Steam Pressure: 50 PSIG

Condensate Load: 16.75 lbs./hr.

Type of Trap	Temp(°F)	Temp(°F)	Steam Loss lbs./hr.
Drain Orifice (0.020")	270	205	0.25
Inverted Bucket (7/64")	265	205	7.25
Float/Thermostatic	265	210	18.25

Note: All traps provided by the customer were new and being used for this application. Each trap was the best available size for the pressure and load conditions.

Based on these results it is highly recommended you perform your own trap evaluation tests. It can result in a significant reduction in steam loss, improve the operating efficiency of the steam system and substantially reduce maintenance costs.

Maintenance

The job of finding and eliminating faulty steam traps must be high on the priority list of energy and cost conscious plant managers. It has already been demonstrated that steam traps waste a large amount of steam over their life cycle. Steam is vented with each discharge and with accelerated wear cause failures that further increase the steam loss.

Many plant maintenance programs put trap surveys and repairs or replacements low on their priority list because of a lack of manpower. The failure rate in many plants averages 43% with one large plant reporting Inverted Bucket Traps failing at an annual rate of 70%; Thermostatic at 43%, Thermodynamic at 33% and no failures of Drain Orifices. Another large chemical plant reported Disc Traps failing within 6 weeks to 3 months after installation.

It has been common practice to replace a defective trap with the same trap or any available trap that fits the drain pipe. This practice has led to excessive steam loss and process control problems created by poor thermal efficiency.

Steam trap inspection and maintenance costs are high but less costly than living with steam leaks at today's fuel costs. One refinery spent $80,000 in one year to evaluate traps and saved $500,000 by correcting trap steam losses on a steam load of 800,000 lbs./hr. There are many reports from other plants about similar saving$.

The engineered approach to steam trapping can eliminate or minimize the trap failure rates, maintenance and replacement costs to such a degree that it can be justified based on the return in investment.

The Drain Orifice installed with a proper class Y-Strainer has given 10 years of maintenance-free service to the US Navy and has required minimal maintenance in five years of industrial use. It is easy to check in-line by measuring the temperature difference across the orifice. Orifice erosion has increased the steam loss 0.5 lbs./hr. after 10 years of continuous service. There have only been a few instances of orifice plugging reported and no orifices have required replacement during this same period. No other steam trap can match this record of achievement.

Conclusion:

1. The engineered approach to steam trapping has contributed to large energy savings and has helped many plants achieve or exceed their energy conservation goals.
2. Proper selection and sizing of traps as well as taking into account the effects of backpressure, flash steam, safety factor and other operating parameters has resulted in:
   - Minimizing steam loss
   - Prolonging premature failure
   - Improving thermal efficiency
   - Lowering maintenance and replacement costs
   - Better process control
3. Field test procedures can be used to measure condensate load where data is not available for proper orifice sizing and measuring steam loss which is a function of trap efficiency and performance.
4. Contrary to popular belief that the Drain Orifice may only be used for constant load conditions, it can be oversized by a reasonable factor and still lose far less steam than any steam trap. Orifices may be sized for load variations to the extent permitted by the design safety factor.
5. Drain orifices can accommodate large changes in inlet pressure with high efficiency because they are self compensating.
6. Compared to steam trap maintenance, drain orifice maintenance requirements are negligible.
7. Energy savings can be significant, 10-50% of a plant's fuel cost to produce steam, with proper application of the drain orifice. Field test data has confirmed this in many plants.

In summary, effective steam trapping starts at the design stage using good engineering practices. The economic justification is based on steam savings, reduction in manpower required for maintenance, reduction in trap replacement and repair costs, improved steam system operation and process control.

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EXPANSION-JOINT CONCEPTS FOR HIGH-TEMPERATURE INSULATION SYSTEMS

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ABSTRACT

As high temperature steam and process piping expands with heat, joints begin to open between the insulation sections, resulting in increased energy loss and possible unsafe surface temperatures. Many different expansion joint designs are presently in use for both single and double layer insulation construction. However, due to the installation cost reduction associated with single layer systems and increased thickness capabilities of insulation manufacturers, much attention is being given to utilizing single layer construction as much as possible.

Thermal expansion is a phenomenon common to most structural materials. High temperature piping systems employ many and various expansion loop designs to deal with this occurrence while subjecting the piping to a minimum of stress. In furnace construction utilizing insulating firebrick, fibrous filler strips are used between wall sections to provide room for the brick to grow as the furnace rises in temperature.

The scope of this presentation will be confined to rigid pipe insulation such as Calcium Silicate applied to high temperature steam or process piping. Due to the fact that the pipe insulations, in general, do not exhibit significant thermal expansion, the discussion will center on dealing with expansion gaps that occur when the piping expands and the insulation remains the same dimension.

DEFINITION

The term "expansion joint" is really a misnomer when dealing with insulation since every gap that opens up between sections is actually an "expansion joint." The meaning here relates to the desire to deal with expansion by either forcing the gap to open at a predetermined location or by minimizing the effect of open joints all along the piping. So, the term "expansion joint concept" refers to any and all methods of dealing with the problem of open joints.

THE OPEN JOINT PROBLEM

Before striving to find a method to eliminate open joints, it is important to understand why such openings are of concern to the design engineer. First, when a gap opens and exposes bare pipe to ambient, the heat loss from the pipe will be increased. The amount of loss is obviously dependent on many factc such as pipe temperature, ambient

temperature, insulation thickness, pipe orientation, jacket type, and gap width. There is little data published on this issue and the work that has been done has not examined all of the variables in combination with each other.

The second concern with open joints is the possible effect on the insulation jacketing material. Organic jackets will discolor and/or scorch if the temperature gets to high. Metal jackets will withstand much higher temperatures, but personnel protection becomes a factor. Safe touch temperature specifications range from 130F to 160F with many standardized at 140F. As a maximum, the jacketing should not be allowed to rise above 160F in an area that is exposed to personnel.

TYPICAL EXPANSION JOINT DESIGNS

A review of the various expansion joint designs currently being specified by design engineers shows a very great diversity in both construction and placement. Some systems require only a slip joint jacket to cover the expansion gap while others have intricate multilayer support clips with fiber packing at each junction. Regarding placement, specifications vary from 6 feet to 20 feet on vertical lines and 12 feet to no requirement at all on horizontal piping.

The point is that present practice is not particularly standardized in the industry. This indicates one of two things: either the expansion gap issue is not a very serious problem and a wide variety of designs are acceptable, or the problem is so difficult that no one design is completely satisfactory so new concepts continue to be investigated. The writer's personal opinion is that the problem is not generally of serious concern to the design engineer and that little thought is given to improving systems presently in use. However, with the energy consciousness of owners increasing and techniques for checking systems for thermal leaks (i.e. infrared scanning) becoming more available, there may well be an increase in attention paid to expansion joint design.

Vertical Systems: Most of the expansion joint designs for vertical piping are tied into the insulation support rings. Due to the weight of the insulation, gaps do not generally occur between the insulation sections. Therefore, the entire expansion gap occurs beneath the insulation support ring.

In general, this cavity is filled with either bulk mineral fiber or strips of fiberglass mat tightly compressed in the cold state. As the gap enlarges, the fiber expands to fill the gap and thus

maintain the continuity of the system. With double layer construction, the outer layer is also usually tied to the support ring but a six-inch offset is employed to break the through joint. Some designs call for the second layer to be fiber packed like the first layer while other systems allow that joint to remain open. In all cases, both single and double layer, the jacketing material covering the joint is secured to the insulation above the support ring and not attached to the lower material. This allows the overlap to slip without binding and maintain a weather-proof orientation.

Horizontal Systems: Much less effort is spent on horizontal expansion joint designs and many specifications exempt horizontal systems from any requirement in this regard. The reason for this is that in the horizontal orientation, there is no impetus for the insulation to move one way or another. Hence, there is a much greater probability that expansion gaps will tend to open more evenly between sections rather than in one place as with the vertical line.

When joints are designed, they usually employ fiberglass or mineral wool at certain intervals along the run. Unfortunately, the only way this design will work is if the system can be forced to open at that packed joint. Present field practice does not assure that expansion will be restricted to specific joint locations.

On the other hand, if the designer could be assured that the horizontal expansion gaps would occur evenly between each insulation section, the problem would be minimized due to the small size of each gap. However, due to variations in insulation fit and band tightness, this even expansion may not occur and a larger gap may open somewhere along the line. Therefore, on high temperature horizontal work, a method must be devised to either force expansion at each section or else deal with a potentially large gap.

SINGLE LAYER VS. DOUBLE LAYER CONSTRUCTION

The use of staggered joint, double layer construction lends a safety margin to expansion joint design by separating the inner and outer layer joints to avoid potential bare pipe exposure. However, even standard double layer construction terminates both layers at ells and other fittings, thereby creating a straight through joint which may well open up with expansion. On vertical work, double layer construction is of very little value since both layers will tend to rest on the lower support rings.

There are rules of thumb which have eloped over the years indicating that double layer construction should begin at 600F. Some of the reasons were based on the use of outer layer products that could not be used above 600F. Others related to the organic jacketing materials that had lower temperature limits than the present metal systems. Finally, certain materials were historically only available in limited thicknesses and when temperature conditions required thicker material, double layering was the only option. The point is that double layering recommendations should continue to be reviewed in light of new insulations, new jacketing materials, and increased single layer thickness capabilities available in the industry.

Another factor to be considered is the general increase in overall insulation thickness due to energy conservation efforts. Here specifications which call for all insulation greater than 2 1/2 inches thick to be double layer are clearly inappropriate. It is very likely that economic thickness requirements will have lower temperature (traditionally single layer) lines with thicknesses into the arbitrary double layer range. This serves no practical purpose at all.

The greatest incentive for using single er construction wherever possible is the significant reduction of installation labor. It is estimated that the double layer labor cost can be reduced by 40% by going to single layer. In an economy with sky rocketing inflation, the owner needs to take advantage of every opportunity to reduce costs, and single layer construction is one such opportunity.

From the standpoint of the design engineer, there is added security in a double layer design. Since expansion gaps are somewhat unpredictable, especially on horizontal, the use of a second layer reduces (but does not eliminate) the possibility of a large through joint. Therefore, it is important for the design engineer to have a single layer joint design that will meet the performance requirements and still allow the cost reduction associated with single layer.

SINGLE LAYER EXPANSION JOINT DESIGNS FOR HIGH TEMPERATURE PIPING

Before describing the design concepts, it is in order to establish the magnitude of the expansion gap anticipated at various operating temperatures. Listed below is the calculated gap in inches for steel pipe at various lengths. The expansion is based on 70F installation temperature.

	Inches of Pipe Expansion			
		Length of Pipe		
Oper. Temp	100'	20'	12'	3'
1000F	8.77"	1.75"	1.05"	.26"
900F	7.66"	1.53"	.92"	.23"
800F	6.60"	1.32"	.79"	.20"
700F	5.58"	1.12"	.67"	.17"
600F	4.60"	.92"	.55"	.14"
500F	3.65"	.73"	.44"	.11"

Vertical Designs for Single Layer: Single layer insulation on vertical lines should be fully acceptable on lines up to 1000F. Due to the weight of the product, the full gap will occur just below the support ring, as discussed earlier. Based on a 12' support spacing, the maximum gap will be 1.05". To fill this space, it is suggested that the spacing actually be 12'1" to allow for a fibrous filler strip. For example, 1 1/2" thick refractory fiber blanket can be doubled over to 3" thickness and compressed into the 1" space. Upon expansion to a total width of 2.05", the fiber blanket will expand to fill the gap. Utilizing a fold in the filler strip provides additional force causing the blanket to expand and fill the cavity. Also, since the support ring only extends about half way into the single layer thickness, using a folded filler strip equal to the insulation thickness will also fill around the support ring and contact the bottom of the insulation supported by the ring, thus totally closing the gap.

The above discussion is based on a 1000F line which is higher than the majority of industrial steam and process temperatures. At lower temperatures, either the distance between supports can be increased, or the amount of gap to fill decreased. The latter approach is preferred.

Horizontal Designs for Single Layer:

To safely utilize single layer construction on horizontal work, one of two approaches must be used. The first method seeks to have the expansion occur evenly between each section. Tightly banding the sections to the pipe or perhaps even utilizing a high temperature adhesive or lugs on the pipe to secure each section to the pipe will allow the gaps to form evenly. Then, if the resulting gaps (as shown above with the 3' pipe length) are too large, a thin fiber gasket can be applied to one end of each insulation section to fill the small void. In many cases, the gap width will probably be small enough to ignore, especially with large insulation thicknesses and jacketing to reduce both the convection and radiation losses.

The second approach parallels the vertical design in that it seeks to have all of the expansion take place at one point. Here, horizontal pipe supports or collars are used to limit the total gap possible, similar to the vertical design. For example, horizontal collars at 20' intervals at 700F would allow a maxi total gap of 1.12 inches. Now, a method

must be devised to secure all the intermediate insulation sections together

the entire system "floats" between the two collars. One technique employs "U" shaped nails driven into adjacent sections thus pinning them together. Another approach is to use extra long jacketing screws which penetrate the insulation. If applied across two sections, the tightly secured jacketing will serve to hold the insulation sections together as a unit. Finally, with the insulation together, a fiber filler strip similar to that used in the vertical design can be used at each end of the insulation unit next to both collars. In this way, whether the insulation "floats" or stays tight to one collar, the expansion gap will be filled with insulation.

It appears that this second approach fits more closely with present field installation practice and utilizes a concept already established in vertical work. However, regardless of which approach eventually becomes the norm, it is assured that owners will want and need to take advantage of the expanded single layer capabilities and greatly reduce their installation labor costs.

ENERGY SAVINGS BY VENEERING

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With the Oil Crisis of 1972-1973, the attitude by Industry on fuel usage and conservation began an evolutionary change in attitudes. This change in attitudes was brought about by three strong motivators for conservation: rising prices, availability of fuel, and government voluntary energy improvement program for the 10 largest fuel consuming industries by 1980. While each region of the United States has its own particular set of inflationary fuel costs, the experience at our Babcock & Wilcox plant in Augusta, Georgia is probably a very typical example of the cost rises experienced by Industry since the 1972-1973 period.

1.	Electric Power Increase	190% per KWH
2.	Natural Gas Increase	320% per Therm
3.	No.2 Oil Increase	271% per Gallon
4.	No.4 Oil Increase	339% per Gallon
5.	Propane Increase	250% per Gallon

Price increases of 50% to over 100% are conceivable in the next five years, plus the availability of fuels may also be a matter of serious concern.

The escalating cost and temporary shortages have rapidly increased the acceptance and usage of Ceramic Fiber as a furnace lining material to 2750°F to 2800°F under some fairly severe environments. Alumina-silica,*SAFFIL®, and Unifelt®, a combination of SAFFIL and Ceramic Fiber, have a proven record of fuel savings when used as total lining material for furnaces and kilns. Typical savings have averaged between 15% and 20% with some documented cases of 50%. The exact percentage realized is dependent on cycle, past lining practice, and furnace operation.

The energy savings being experienced with Ceramic Fiber linings are due to the material's unique physical properties.

1. Low Thermal Conductivity
2. Low Heat Storage
3. Excellent Resistance To Thermal Shock
4. High Reflectivity

From 1964, the use of Ceramic Fiber as a total furnace lining material has gained widespread Industry acceptance in heat treating, heating, re-heating furnaces, and ceramic kilns.

In the 1974-1976 period, it became evident that even with the rapidly increasing fuel cost, it was not economically justifiable in many instances to replace a serviceable conventional lining or install a new furnace with a total Ceramic Fiber lining. As an economically justifiable alternative to realize fuel efficiencies on both conventional existing linings and new conventional linings, hot face veneering has gained increased utilization and acceptance.

TYPES OF VENEERING

There are two types of veneering being utilized. The first is a wallpaper treatment where the blanket is held to the existing refractory with metal studs. Due to the use-limit limitation on the studs, wallpaper veneering should only be utilized to 2150°F. The second type is modular veneering in which 12"x12" specified thickness modules are mortared to the existing refractory surfaces. At the present, there are two types of veneering modules available.

1. Blanket strips of Ceramic Fiber or SAFFIL fiber that are bonded together parallel to form the 12x12 modules. The module is held together in compression with netting.
2. Unifelt strips that are bonded together parallel to each other to form 12x12 modules. These modules are also held together with nylon netting. The vacuum formed strips are formulated using blends of 95% alumina fiber and Ceramic Fiber to achieve the

desired physical properties.

th module types are supplied with use-limits of 2300, 2600, and 3000°F.

THICKNESS

Veneering both wallpaper and modular can be accomplished in a range of thicknesses from 1-1/2" to 6" and over. However, based on computer studies, the optimum thickness is 2.5" to 3" thick. A number of veneers have been done at 4" to 6" thick and have provided an adequate payback. For modular veneering, we would recommend a maximum thickness of 6". As a minimum thickness, 1-1/2" modules have been used, but thicknesses below 3" prove to be difficult to install.

THE PURPOSE OF VENEERING

1. Energy Savings

Veneering provides hot face insulation which reduces heat loss, heat storage, and loss due to openings in the refractory structure.

2. Reduced Refractory Maintenance

By the addition of a protective lining which shields the original lining from destructive furnace conditions and lowers the lining mean temperatures, refractory maintenance is reduced.

3. Increased Production

There is more available heat for product output.

4. Temperature Uniformity

Veneering maintains a more uniform temperature profile within each zone of the furnace.

JUSTIFICATION PROCEDURE

To justify the cost of a veneer lining which can range from several thousand dollars to over $150,000 per furnace, depending on size and grade of material required, a furnace analysis should be undertaken by the company that will be supplying the veneer.

The furnace analysis will incorporate the following:
1. Review the operating conditions of the furnace, furnace operating data, and refractory construction.
2. Analysis is made with the aid of a computer to allow for the recommendation of the most thermally and cost effective veneer lining. The analysis mpares the thermal effectiveness of the existing and proposed linings on the basis of furnace operation and fuel consumption and fuel cost. From this comparison of fuel savings, the veneered lining costs are calculated to present the customer a return on investment estimate consistent with the available operating conditions.

The experience to date has shown that with the program utilized for the computer analysis of the return on investment, the calculations have been proven to be very accurate projections of actual savings to the over-stating of the payback period by 50%. In these few cases, further analysis of the particular furnace showed that by veneering, the furnace was made tighter reducing radiation loss and hot gas loss through cracks in the refractory. These variables could not be factored into the program with any degree of reliability. But it is a pleasant surprise to find that the actual payback is more rapid than calculated.

In a few instances, actual payback periods have exceeded the calculated period. Generally, upon close investigation of these cases, the longer payback period could be attributed to furnace operational changes or improper furnace operation.

INSTALLATION

Wallpaper - The installation of the wallpaper type system is fairly straightforward requiring a drill, preferably an impact drill, to drill a hole into the existing refractory. The barbed stud is then placed into the hole and mortared into place. The mortar may be placed around the stud by the use of a modified caulking or grease gun. The blanket is then impaled on the studs and held into place with either an SS washer or a ceramic cuplock.

Modular - In affixing the modules to the existing refractory, the refractory surface should be fairly clean, free from excessive slag type build-up, dust free, and solid. Care must be taken to fully work the mortar into the module. The mortar must be placed under the nylon netting to facilitate spreading and penetration into the fiber surface. In placing the module to the refractory surface, sufficient force must be placed on the module to cause the mortar bed joint to flow out. Lateral compression also should be provided to develop a tight veneer job. The lack of adequate compression in the lateral direction can reduce the material

insulation effectiveness significantly. Mortar consistency is very important. The consistency should be between a dipping mix and a troweling mix.

CASE STUDIES

A number of case studies covering application in the Ceramic, Iron & Steel, Non-Ferrous and Chemical Process areas will be shown with operational results.

Ceramic

Sewer Tile Producer - Firebrick crown of 40' diameter beehive kiln was veneered using the wallpaper system 1"8# plus 2"4#. The customer is reporting 12% fuel savings in his operation. The calculated savings were 10%.

Face Brick Manufacturer - The burning zone of a tunnel kiln was veneered with the wallpaper method using 1" of 8# density Ceramic Fiber blanket. The customer experienced 5% fuel cost reduction versus a calculated 4%. Due to better temperature distribution in the kiln, his saleable production increased approximately 250,000 brick per year. With the increase in production, in addition to the fuel savings, the customer is realizing a 10% savings.

NON-FERROUS

A Titanium Reheat Furnace operating at 2250°F was veneered with 5" 2600°F Ceramic Fiber modules. The existing roof was 10 years old plastic refractory in fair condition. To date, this furnace has been in operation 2-1/2 years and has lost only one module. The cold face prior to veneering was measured at 404°F. The current cold face with the veneer is 200°F. While no calculated payback was ever done on this furnace, the customer is more than pleased with the results. This furnace was the first modular veneer done in the U.S. to our knowledge.

FERROUS HEATING

An 80' diameter rotary hearth furnace operating at 2450°F was veneered over existing insulating firebrick with SAFFIL modules. In this furnace, the roof, sidewalls, and burner walls were veneered. This unit has been in operation for approximately 2 years. Initial payback calculations predicted a payback of 18 months for material and installation. Due to the additional insulation and resultant improved sealing, the actual payback was placed at 8 to 9 months. In the first year of operation, the customer estimates that he realized $340,000 in fuel savings. These savings are continuing.

A walking beam slab reheat furnace 110x40x12 fired with coke oven gas and No.6 oil operating at 2300°F preheat zone, 2500°F heating zone, and 2350°F soak zone was veneered. The Unifelt 3000 veneer was installed over a semi-silica suspended roof which was 1 year old with some glaze build-up. Also, the discharge curtain wall was veneered. This curtain wall was a maintenance problem having to be repaired every two months.

The calculated payback was 13 months. While no actual payback has been developed by the customer due to recuperator problems, they do report a uniform lowering of the cold face temperatures of the roof from 462°F to 302°F. The 160°F drop realizes a theoretical savings of $103,300/year for a 10 month payback.

The veneer to the discharge curtain wall has completely eliminated the maintenance of this area.

A greater number of modules have been lost from the roof than had been anticipated. It is felt that some improper installation, expansion of the semi-silica, burner misalignment and water leakage have caused these problems and efforts are underway to solve these problems.

Specialty steel manufacture activated an unused rolling mill. As part of the program, a Rust 3 zone pusher furnace was rebuilt. Due to the anticipated rolling schedule projected over the coming 2 to 3 years of one 10 hour turn, 4 days/week, the customer was in need of a furnace lining construction that could withstand rapid thermal cycling with low heat storage.

It was decided to utilize insulating firebrick for the suspended roof and IFB sidewalls with a 3" veneer of Unifelt 3000 and Unifelt 2600 modules as the working lining. The thermal analysis indicated this lining would show a payback of 1.2 years as compared to a plastic refractory construction typical for this type of furnace.

To date, after 9 months of operation, no fuel costs

are available, but it has been stated that the heating cost per ton of steel is the lowest in the .S.

The customer is now activating the second furnace and has chosen the same basic construction techniques with the exception that the soak zone will be constructed with suspended high temperature IFB and veneer modules.

Some problems have been experienced with brick modules shearing in the heating zone, but with the use of a stronger grade of IFB, the problem appears to have been alleviated.

CHEMICAL PROCESSING

To effect a rapid repair on the refractor of a crude heater, a wallpaper veneer was installed with satisfactory results. At a later date, it became necessary to do further repair and modular veneer was installed. The veneer of the heater has stabilized the refractory and the customer has realized a 14% saving.

CONCLUSION

Veneering with Ceramic Fiber in Ceramic, Ferrous Heating, Reheating and Heat Treating furnaces, Non-Ferrous heating and Chemical Process furnaces can produce a very adequate return on investment by decreasing fuel usage, prolonging refractory life and reducing maintenance cost. Prior to a veneering program, a detailed furnace analysis and computer study should be undertaken to determine if veneering is economical.

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*SAFFIL® is a registered trademark of Imperial Chemical Industries Ltd. for inorganic fiber. SAFFIL fiber is distributed by the Babcock & Wilcox Company.

LINING OVER REFRACTORY TO CONSERVE ENERGY & CAPITAL

by

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INTRODUCTION

Companies operating industrial heating equipment find themselves coming under more and more constraints every day. Environmental regulations dictate what can be emitted from these units. Occupational safety procedures require special conditions and provisions for equipment operators. Energy suppliers are limiting the type and quantity of energy available for furnace operators. And, the financial community places restrictions on expenditures to upgrade or improve existing industrial furnaces and heaters. These factors can be dealt with, to a great degree, by utilizing modern refractory practice and expertise.

The use of ceramic fiber insulation has been gaining in popularity in recent years as a highly effective energy conservation measure. The use of ceramic fiber insulation has proven itself as an efficient method for conserving energy, increasing furnace productivity, and providing more uniform temperature within a unit. The maximum benefits are obtained when the existing refractory lining is removed and replaced with a total lining of ceramic fiber insulation.

As the cost of borrowing money increases, furnace operators find it more difficult to justify removal of refractory linings having several years of remaining useful service. Replacing such linings with ceramic fiber usually requires a significant capital expenditure. This can sometimes be difficult to finance, even though resulting energy savings normally provide a relatively quick payback.

The LOR (Lining Over Refractory) technique has been used for a number of years as an effective means for improving existing furnace efficiency. The technique is simple, requiring a minimal capital investment.

Advantages

By using the LOR technique, one can gain many of the same advantages found in using a total ceramic fiber insulating lining. First is the reduction in heat losses during furnace operation. Heat loss reduction is a key to energy saving capabilities. The added insulation provided by a ceramic fiber LOR substantially reduces the rate of heat loss through a refractory lining.

An added benefit is the reduction in the cold face temperature associated with reduced heat loss. The cold face temperature reduction provides more comfortable working conditions around furnaces in operation.

Due to the low heat storage associated with ceramic fiber insulation, the LOR approach reduces the overall heat storage of the refractory lining. Ceramic fiber insulation, when applied to the hot face of a refractory lining, reduces the mean temperature through the refractory. This, in turn, substantially reduces the heat storage of the entire lining. Heat storage is critical to a cyclical furnace. The application of a ceramic fiber LOR thereby reduces the time and energy required for both furnace heat-up and cool-down. In cyclical furnaces (periodic kilns, heat treating units, etc.), significant increases in furnace production can be achieved. In refinery heaters, continuous heat treaters, etc., a great deal of valuable time can be saved during turnaround due to faster cool-down and heat-up.

Ceramic fiber insulation is completely immune to thermal shock and can, therefore, be heated at a very rapid rate. When used as an overlay in a furnace, ceramic fiber provides a thermal cushion for the existing refractory lining, thereby allowing the

furnace to be heated rapidly without fear of thermal shock to the refractory back-up.

Temperature uniformity within the furnace will be vastly improved. Since the ceramic fiber insulation is applied over the entire hot face of the refractory lining, all cracks and crevices, developed over years of operation, are sealed, creating both uniform internal and external unit temperatures. Sealing of heat leaks reduces heat loss and provides for improved furnace operating efficiency.

Finally, a ceramic fiber LOR typically reduces lining maintenance and significantly reduces exterior unit sound levels.

Lining Over Refractory Methods

A lining over refractory installation is fast and can be accomplished using semi-skilled labor. An LOR can be done using either a layered or modular approach.

A - Layered Technique - When using the layered technique, the first task is to lay out a stud pattern on the surface of the existing refractory lining by means of a chalk line. Typically, anchors are located on 10 inch horizontal and 12 inch vertical centers for walls and on 10 inch x 10 inch centers in the roof.

Holes are then drilled at the chalk line intersections in the refractory lining using an electro-pneumatic hammer drill. The holes are usually drilled to a depth of about 3 inches with a 1/4 inch diameter carbide drill bit. If the existing refractory is lightweight, such as insulating firebrick, a 3/16 inch masonry bit can be used with a conventional electric hand drill. As a rule, 3-4 holes can be drilled per minute and each drill bit is good for approximately 100-250 holes. The life of the drill bit will, of course, vary depending on the hardness and density of the refractory lining. Holes in the arch or roof should be drilled at about 30 degrees from perpendicular to provide more purchase for the mounting studs.

After drilling, each hole is easily cleaned of drill dust using compressed air. Next, a high quality air setting mortar is used to fill each hole and barbed alloy studs are installed.

Finally, the desired layers of ceramic fiber blanket are impaled over the studs with staggered joints between individual layers to prevent heat leaks to the refractory. The ceramic fiber lining is held securely in place using either an alloy or a ceramic retainer locked to the stud on the hot face.

B - Module Technique - Ceramic fiber modules are made of strips of either folded or edge stacked ceramic fiber blanket. The blanket strips are compressed and wrapped in a nylon scrim material. The resulting structure is a block 12 inches by 12 inches square having the desired thickness for the LOR to be installed.

Before application of the modules, the refractory should be cleaned of any loose dust or spalled particles. Surface glaze should also be removed, if present. This can be done with a chipping hammer, a regular masonry hammer, or by sandblasting. If modules are installed over glazed refractory and the glaze reaches its softening temperature, the bond between the mortar and the glaze would be destroyed.

After surface cleaning, the existing refractory is moistened with water by use of a spray bottle or ordinary brush. This will prevent premature drying of the bonding mortar. A 1/16 to 1/8 inch thickness of special air setting mortar is applied to the refractory surface. The mortar should be applied to a surface area no greater than can be effectively installed with modules in a 3 to 5 minute time period. Otherwise, setting of the mortar will occur causing a poor bond between the modules and the refractory.

Finally, mortar is applied to the back side of the mdoules and the modules are set in place. The modules should be pushed firmly against each other and against the refractory to insure against heat leaks and provide a secure bond. Typically, modules are installed in a parquet pattern and the scrim covering each module is left in place. The nylon scrim will burn off during the initial firing. An electric carving knife can be used to trim modules around flues, burner blocks, etc.

Layered vs. Module Techniques

Figure I illustrates the change in heat flow of a furnace wall. There is a 45°F drop in the cold face temperature with a reduction in heat loss of 134 BTU/ft.^{2}/hr. This is based upon the insulating firebrick being in excellent condition. Usually, the existing refractory lining is in partially deteriorated condition and the resultant cold face and heat loss reductions with a ceramic fiber LOR are

substantially greater.

FIGURE I

Parameters

Existing Lining:	9" of 2300°F insulating firebrick
Hot Face temperature:	1800°F
External ambient temperature:	80°F
External wind velocity:	0 MPH
Emissivity:	0.9

Layered Technique

3 inches 8 lb./ft.^{3} needled ceramic fiber blanket

Modular Technique

3 inches 8 lb./ft.^{3} ceramic fiber module

HEAT FLOW COMPARISON

	Existing Lining	Layered or Module LOR	Reduction
Cold Face, °F	228	183	45
Heat Loss, BTU/ft.^{2}-hr.	361	227	134
Heat Storage, BTU/ft.^{2}	5763	4576	1187

Figure II shows the comparative installed costs of the layered vs. module LOR. As shown, the module LOR costs approximately 20 percent more. The actual comparison in a specific furnace is highly dependent on the uninterrupted surface area.

FIGURE II

Layered Costs/Square Foot

Material (2 layers of 1-1/2" thick 8 lbs./ft.^{3} blanket)	$3.42[1]
Anchors ($1.75 per squre foot, 330 alloy 6" long)	1.52
Labor to install studs.	0.58[2]
Cost of drill bit	0.15[3]
Cost of mortar.	0.02
Labor to install blanket	1.60[4]
TOTAL	$7.29/sq. ft.

Module Costs/Square Foot

Material (3" thick module 8 lbs./ft.^{3}	$6.73
Mortar (3-4 lbs. per module).	1.00
Labor (surface preparation and module installation)	1.00[5]
TOTAL	$8.73/sq. ft.

1) Based on blanket cost of $1.71/sq. ft.
2) Based on $20.00/man hour and 2 holes/min.
3) Drill bit cost of $17.00 each and 200 holes/bit.
4) Based on 25 layer sq. ft./man hour and $20.00/man hour.
5) Based on 20 sq. ft. (20 modules)/man hour and $20.00/man hour.

Payback of the LOR technique can range from few weeks to as much as several years. In cycled furnaces, payback time can be appreciably less than in units of a continuous nature. A number of benefits can be realized with a ceramic fiber LOR in addition to reduced fuel costs. Maintenance costs are usually less. Downtime or turnaround time can be substantially reduced. And, in most units, production or throughput can be increased. Following are a few actual case histories of furnaces upgraded by the use of ceramic fiber LOR.

Hardening and Draw Furnaces

An East Coast manufacturer of trailer axles operates a 34 ft. long by 13-3/4 ft. wide x 6 ft. high draw furnace lined with 13 inches of refractory firebrick. A layered LOR using 2 inches of 8 lbs./cu. ft. ceramic fiber blanket was installed in the hardening furnace. A 3 inch LOR of 6 and 8 lbs./cu. ft. blanket was employed in the draw furnace.

The total fuel savings in the two furnaces was a measured $35,000 the first year. This resulted in a 7 month payback in fuel savings alone. In addition, the hardening furnace can now be brought to temperature (1650°F) in just half the time previously required. The ceramic fiber LOR also reduced the noise level around the furnace by more than 2 dba.

Bottom Forge Furnace

A Pennsylvania forge shop chose a module LOR for one of their bottom forge furnaces. These furnaces typically operate at a temperature of 2300°F. A 3 inch thick module LOR was installed in the 20 ft. long by 11 ft. wide by 9 ft. high furnace resulting in a documented fuel savings of 13-1/2 percent.

Petrochemical Feed Heaters

A Southeastern chemical company installed a layer LOR in two feed heaters. The gunned castable linings were cracked causing significant heat leaks and a cold face temperature nearly 75°F over original design temperature.

A 2 inch layered LOR of 6 lbs./cu. ft. ceramic fiber blanket dropped the shell temperature well below the original design cold face. Payback in fuel savings alone was calculated at approximately 9 months. In addition, over 2 days were saved in periodic turnarounds due to a lower heat storage, unit output was increased, and lining maintenance has been greatly reduced.

Conclusions

Ceramic fiber linings over refractory have proven themselves capable of substantial fuel savings with a minimal capital outlay. LOR's are easily installed in most refractory lined furnaces and provide additional benefits of increased output, reduced lining maintenance, lower skin temperatures, protection of the existing refractory, and reduced unit noise levels.

COST-ENERGY DYNAMICS OF THERMAL INSULATION:

POTENTIAL ENERGY SAVINGS AND POLICY RECOMMENDATIONS

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Abstract

This paper looks at extra insulation for saving energy from the viewpoint of a decisionmaker. Public and private decisions are distinguished. Profitability and process analyses are combined to obtain a simple trade-off relationship between the extra cost and extra energy saving. Due to higher costs of energy at present and in the foreseeable future, good oppportunities exist to retrofit existing thermal enevelopes with extra insulation. Potential costs and savings in the residential, commercial and manufacturing sectors are assessed. A hypothetical $10 billion insulation budget is determined to save 0.5 quad/yr of energy for the next 10 to 15 years, resulting in conservation energy costing less than $2/MMBtu. It is argued that public subsidies to energy conservation and energy supply technologies should be weighed so that the worth of each unit of resultant energy at the point of use is the same.

INTRODUCTION

This paper attempts to look at the cost and benefit of adding insulation from the viewpoint of a planner. Although heat transfer, material properties, and insulation have to be considered, we shall incorporate them in such a manner that will be easily handled by decision makers. We are interested in the following questions:

1. If heat lost through existing insulation is to be reduced by, say 50 percent, what is the extra cost?
2. How much is "conservation energy" worth, and what is the payback period for the extra investment?
3. How much energy can each sector of the economy (residential, commercial, industrial) save through increased insulation?
4. What is the role of the government in encouraging extra insulation, and what is the effectiveness of its measures?
5. Would too much insulation require more energy to produce than the energy it is expected to save?

The methodology used in answering these questions is called cost-energy dynamics (CED). It combines profitability analysis and process engineering to arrive at a simple relationship between the variable investment and variable energy consumption of a system at a fixed level of output. CED aggregates industrial energy consumption by unit processes, considers energy embodied in the investment, considers the trade-offs between cost and energy, and distinguishes bases for decisionmaking in the public and private sectors. Below we will first unfold the elements of CED as applied to thermal insulation before attempting to answer the questions posed earlier.

COST-ENERGY DYNAMICS EQUATIONS FOR INSULATION

Cost-energy dynamics is a method that relates investment cost and energy consumption for the purpose of studying their trade-offs. The general formulation of CED has been explored elsewhere[1]. For thermal insulation, we let K designate costs in dollars and E designate energy in MMBtu (million Btu). Subscripts used are T for total, I for investment, E for process energy, and o for constant values independent of changes in capital or process energy. A "dot" superscript over a quantity designates the annual rate. Then, for an insulation project, the total life-cycle cost and life-cycle energy requirement are

$$K_T = K_o + K_I(\dot{E}) + K_E(\dot{E}) \qquad (1)$$

$$E_T = E_o + E_I(\dot{E}) = E_E(\dot{E}) \qquad (2)$$

The implicit assumption in Eqs. (1) and (2) is that capital and energy are substitutable while other factors of the operation--namely labor and materials--are additive. This is quite acceptable in the case of thermal insulation. The energy loss through insulation $\dot{E}$ obviously decreases as the thickness of insulation increases (beyond the critical radius in the case of cylindrical insulation).

We note that the structure of Eqs. (1) and (2) sets the stage for an optimization process to

minimize K_T (life-cycle cost) and E_T (life-cycle energy requirement). K_o and E_o are ...ed terms independent of design points $\dot{E}$. The functions $K_I(\dot{E})$, $K_E(\dot{E})$, $E_I(\dot{E})$, and $\dot{E}_E$ are determined as follows:

1. Life-cycle cost of lost energy

The life-cycle cost of lost energy is simply the present worth of the product $p\dot{E}$, where p is the cost of each unit of energy. Since at the point of end use, the cost of energy is only slightly higher than the price of energy at that point, we shall designate p as price for simplicity. If p_o is the price at "present," y is the escalation rate, x is the effective cost of money used for discounting, and N is the life cycle, $K_E(\dot{E})$ is

$$K_E(\dot{E}) = \sum_{i=1}^{N} \frac{p_o(1+y)^i \dot{E}}{(1+x)^i} = NZ_E p_o \dot{E}, \quad (3a)$$

where Z_E is a factor defined as

$$Z_E = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{1+y}{1+x}\right)^i \quad (3b)$$

Table 1 shows some values of Z_E which can also be interpreted as the levelized factor or the weight of the energy price when the entire life-cycle N is taken into account. Z_E is low when fuel costs escalate only slowly, but is high when fuel costs escalate fast. Typical values of Z_E in the era of cheap energy are smaller than 1. When fuel escalates at rates exceeding 10 percent per year, a value of Z_E between 1 and 2 is more realistic.

2. Life-Cycle Cost of Investment

The life-cycle cost of investment is the present worth of all costs associated with servicing the investment I. In cost analysis[2], the levelized annual fixed charge is used for ...t purpose, and $K_I(\dot{E})$ is

$$K_I(\dot{E}) = \sum_{i=1}^{N} \frac{\bar{\phi} I(\dot{E})}{(1+x)^i} = Z_I I(\dot{E}) \quad (4a)$$

Where $\bar{\phi}$ has been given in Reference 2 as

$$\bar{\phi} = \frac{CRF(x, N)}{1-\tau} - \frac{\tau \bar{d}}{1-\tau} + \pi \quad (4b)$$

and

$$Z_I = \sum_{i=1}^{N} \frac{\bar{\phi}}{(1+x)^i} = \bar{\phi}/CRF(x, N) \quad (4c)$$

In Eq. (4), $CRF(x,N) = x/[1-(1+x)^{-N}]$ is the capital recovery factor for rate x in N years; τ is the effective income tax rate (e.g., 50 percent taxable income); $\bar{d}$ is the levelized depreciation charge rate using an allowed schedule (e.g. sum-of-the-years' digits) and π is the local tax or ad-valorem charge rate.

Table 2 shows some values of CRF(x, N), $\bar{d}$, $\bar{\phi}$, and Z_I for typical values of x between 6 percent/yr. and 14 percent/yr. and N between 10 and 30 years. Similar to Z_E, the quantity Z_I can be viewed as a weighting factor for the investment I. The value is typically between 1 and 2 when the income tax rate is around 50 percent. Ignoring the effect of income tax, such as is often done in planning by the government, has the effect of reducing the importance of investment. This is a basic difference between public and private sector decisions on capital projects.

How does the investment I relate to energy loss $\dot{E}$? We can determine this relationship through the thickness of insulation t. For a flat plate insulation, we have

$$\dot{E} = a/t \quad (5)$$

$$I = b_1 + b_2 t \quad (6)$$

and therefore

$$I = b_1 + b_3 \dot{E}^{-1} \quad (7)$$

where a has the unit of MMBtu in.; b_1, dollars; and b_2, \$/in. the quantity b_1 is sometimes the same order of magnitude as $b_3\dot{E}^{-1}$, but for convenience, we shall assume here that $b_1 \ll b_3\dot{E}^{-1}$. Thus, if a reference insulation thickness has been decided upon (e.g., the economic thickness of insulation), a slight departure from that thickness would result in a slight change in the energy loss $\dot{E}$ from the value $\dot{E}_{Ref}$. This change results in a change in investment following the relationship

$$I/I_{Ref} = (\dot{E}/\dot{E}_{Ref})^{-1} \quad \text{(flat plate)} \tag{8}$$

For insulation around a pipe, the heat loss is basically inversely proportional to $\ln(1 + z)$ where z is the ratio of the insulation thickness to the pipe diameter; i.e., $z = t/R$. The insulation cost is basically proportional to the insulation volume, or $z^2 + 2z$; but business practice is that it is very frequently proportional only to the insulation thickness because the cost of insulation material is often small compared to the cost of selling and engineering. Hence, for piping insulation

$$\dot{E} = \frac{a'}{\ln(1 + z)}$$

$$I = b_1' + b_3'(z^2 + 2z) \quad \text{when cost is proportional to insulation volume} \tag{10}$$

$$I = b_3''z \quad \text{when cost is proportional to insulation thickness} \tag{11}$$

In Eqs. (9) through (11), a', b_1', b_2', b_3', and b_3'' are constants with proper units and $z = t/R$. Combining Eqs. (9) and (10) or (9) and (11), we obtain the power function relationship between I and $\dot{E}$. The results are

$$I/I_{Ref} = (\dot{E}/\dot{E}_{Ref})^{-c} \tag{12a}$$

$$c = \beta/\alpha \tag{12b}$$

$$\alpha = \ln[\ln(1 + z)/\ln(1 + z_{Ref})]/\ln(z/z_{Ref}) \tag{13}$$

$$\beta = 1 \quad \text{when cost is proportional to thickness} \tag{14a}$$

$$\beta = \ln[(z/z_{Ref})(2 + z)/(2 + z_{Ref}]/\ln(z/z_{Ref}) \tag{14b}$$

when cost is proportional to volume.

Table 3 lists values of α, β and c for typical values of z_{Ref} and z/z_{Ref} and for two cases: when cost of insulation is proportional to thickness and cost of insulation is proportional to volume. Figure 1 and 2 plot these data. The following observations are noted:

1. c is not 1 as in the case of flat plate insulation, but larger than 1. It increases with increasing insulation. As Eq. (12) gives $\ln(I/I_{Ref}) = -c \ln(\dot{E}/\dot{E}_{Ref})$, this indicates that when insulation is already thick, the marginal cost of saving energy is steep (i.e., the return is diminishing).

2. The area of interest is around z_{Ref}, and is related to answering the question: How much is the additional cost if energy loss is further reduced by 10 percent? We are interested in this case at values of c corresponding to $z_{Ref} \simeq z_{Kopt}$, and z/z_{Ref} between 1 and 2.

3. Eq. (9) captures the essence of piping insulation and has neglected the thermal resistance by interfaces and by pipe wall. This is justified by example 1.

Example 1: Compare the relative magnitudes of heat transfer resistance by fluid-pipe interface, pipe wall, insulation thickness, and insulation air interface for a 6" pipe, 1/16" thickness, carrying a 600°F fluid, and surrounded by 7" of calcium silicate. The data and results are shown in Table 4.

3. Life-Cycle Energy Requirement

The life-cycle process energy need is simply $N\dot{E}$ where N is the lifetime of the insulation and $\dot{E}$ is the energy loss through it per year. But it takes more than 1 MMBtu to deliver 1 MMBtu of fuel at the point of loss. We capture this fact by the coefficient $\varepsilon_1 = \varepsilon/\eta$ where ε is the Bullard coefficient [3] and η is the efficiency of conversion from fuel at the end use to heat at point of loss.

$$E_E(\dot{E}) = \varepsilon_1 N\dot{E} \tag{15}$$

Bullard et al.[3] have made an input-output computation for ε based on the 1967 economy. Some values are

Energy Carrier Fuel	ε(MMBtu/MMBtu)
Coal	1.01
Crude petroleum and gas	1.06
Natural gas	1.12
Refined petroleum	1.22
Electricity	4.07

Typical values of heat generation efficiency are as follows:

Conversion Mode	(MMBtu/MMBtu)
Electricity to heat	1
Fossil fuel to heat	0.95
Fossil fuel to steam	0.90

For our purposes, ε_1 probably does not need more than 2 significant digits. We expect ε to decrease as conservation is increasingly more important, but changes from the above value will not be statistically significant.

4. Embodied Energy

The energy embodied in the investment I is also captured by a coefficient, δ, which converts a dollar of investment to the energy that is spent to realize the physical deed that the investment represents. Thus

$$E_I(\dot{E}) = \delta I(\dot{E}) \qquad (16)$$

The values of δ have been computed by Bullard et al.[3] for the 1967 U.S. economy. Table 5 illustrates some representative values. They range from 0.02 MMBtu/1967$ for banking to 0.518 MMBtu/1967$ for cement. As a rule, the more sophisticated the product or service, the less embodied energy there is in it because the value added predominates. In terms of 1980 the values of δ in Table 5 should be appropriately decreased by a factor reflecting the value of the 1980 dollars compared to the 1967 dollars. The industrial price index increased more than a factor of 2 between 1967 and 1980.

COST OPTIMIZATION, ENERGY OPTIMIZATION, AND IMPLICATION ON ENERGY CONSUMPTION

1. Optimum Insulation

When the expressions for K_I, K_E, E_I and E_E are in place in Eqs. (1) and (2) and when these equations are differentiated with respect to $\dot{E}$, we obtain $\dot{E}_{Kopt}$ and $\dot{E}_{Eopt}$, the cost and energy optimum design:

$$\dot{E}_{Kopt}/\dot{E}_{Ref} = (cK_{I,\,Ref}/K_{E,\,Ref})^{1/(c+1)} \qquad (17)$$

$$\dot{E}_{Eopt}/\dot{E}_{Ref} = (cE_{I,\,Ref}/E_{E,\,Ref})^{1/(c+1)} \qquad (18)$$

In the above equations, the subscript "Ref" refers to a reference thickness of insulation with respect to which the optimization is made; $K_{I,\,Ref} = Z_I I_{Ref}$, $K_{E,\,Ref} = NZ_E p_o \dot{E}_{Ref}$, $E_{I,\,Ref} = \delta K_{I,\,Ref}$ and $E_{E,\,Ref} = N\varepsilon_1 \dot{E}_{Ref}$. Since the reference design represents a vertical line intersecting the $\dot{E}$ axis at $\dot{E}_{Ref}$, it can be chosen precisely at either $\dot{E}_{Kopt}$ or $\dot{E}_{Eopt}$. (Figure 3) We obtain the first characteristic of c

$$c = \left.\frac{\text{(life cycle) energy requirement}}{\text{(life cycle) cost of insulation}}\right|_{\substack{\text{at energy}\\\text{optimum}\\\text{design}}} \qquad (19)$$

and

$$c = \left.\frac{\text{(life cycle) energy requirement}}{\text{(life cycle) embodied energy}}\right|_{\substack{\text{at energy}\\\text{optimum}\\\text{design}}} \qquad (20)$$

The ratio of Eq. (18) and Eq and (17) yields $\dot{E}_{Eopt}/\dot{E}_{Kopt} = (Z_E \delta p_o/Z_I \varepsilon_1)^{1/(c+1)} = R^{1/(c+1)}$ which is always smaller than 1 for realistic values of Z_E, δ, p_o, Z_I and ε. For example, for a ten-year life cycle (N=10), cost of money at x=0.14, price of energy at $4/MMBtu and rising at 15 percent/yr, δ of insulation at 0.04 MMBtu/$ (1980) and η=0.9 for steam, we obtain Z_E=1.05

(Table 1), Z_I=1.48 (Table 2), R=0.063. For flat plate insulation, $\dot{E}_{Eopt}$ is 25% of $\dot{E}_{Kopt}$; for pipe insulation system with c=1.5, $\dot{E}_{Eopt}$ is 33% $\dot{E}_{Kopt}$. The usefulness of Eqs. (17) and (18) and of c can further be illustrated in the following example.

Example 2: It is estimated that 100 MMBtu of heat is lost through the ceiling of a commercial property. Determine the thickness of insulation if it is optimized for N=10years, p_o=\$3/MMBtu (1980), y=10 percent/yr, x=10 percent/yr and the cost of insulation at 265t where t is thickness in inches.

In this case, c=1; Table 1 gives Z_E =1.00; Table 2 give Z_I=1.42; Eq. (19) gives

$$K_{I,Kopt} = Z_I I_{Kopt} = K_{E,\,Kopt}/c = (10x1.0x3x100)/1=3000$$

Hence

$$I_{Kopt} = 3000/1.42 = 2113$$
$$t_{Kopt} = 2113/265 = 8 \text{ inches}$$

Should we be interested in the minimum energy requirement, we can compute R = 0.063 and $\dot{E}_{Eopt} = 0.25\,\dot{E}_{Kopt}$. Since $\dot{E}/\dot{E}_{Ref} = (t/t_{Ref})^{-\alpha}$ with $\alpha = 1$, we have $t_{Eopt}/t_{Kopt} = (\dot{E}_{Eopt}/\dot{E}_{Kopt})^{-1/\alpha} = 0.25^{-1} = 4.0$ or $t_{Eopt} \approx 32$ inches.

2. Overinsulation and Underinsulation

Figure 3 shows the relative positions of the cost optimum and energy optimum. The region of interest to a private firm is to the right of $\dot{E}_{Kopt}$ while that of the government is to the left of $\dot{E}_{Kopt}$.

We suspect that underdesign (to the right of $\dot{E}_{Kopt}$) is most commonplace in our economic system. This is due the fact that private firms are often short of front-end capital, hence tends to give more weight to Z_I. Often the designer (or seller) is not also the user of the system (hence does not have to pay the operating cost), and he tends to design only for low first cost. This is most commonly seen in the level of insulation of new houses and apartment buildings.

An overdesign (to the left of $\dot{E}_{Kopt}$) is sometimes necessary when the designer places great emphasis in reducing heat loss $\dot{E}$. For example, since insulation materials can be manufactured with the assist of abundant coal resources, an extra use of insulation to save on oil and electricity is justified. If σ_E is the relative energy saving, σ_I the relative extra cost, and σ_T is the relative extra total cost, we obtain for an over insulation

$$\sigma_E = (\dot{E}/\dot{E}_{Kopt})-1 \quad \text{(negative; a saving)} \tag{21}$$

$$\sigma_I = (I/I_{Kopt})-1 = (1+\sigma_E)^{-c}-1 \quad \text{(positive, an extra cost)} \tag{22}$$

$$\sigma_T = (K_T/K_{T,Kopt})-1 = \frac{\sigma_I + c\sigma_E}{H+c+1} \quad \text{(positive; an extra cost)} \tag{23}$$

In the above equations, H is the ratio of K_o to $K_{I,Kopt}$ and is assumed relatively unchanged.

3. Retrofit

Figure 4 shows an insulation system that was optimized for an energy price p_1 when after a few years, it was obvious that the life cycle energy price became $p_2 = \nu\, p_1$. (ν>1). Retrofit is the effort to add insulation to attain the new economic optimum, $\dot{E}_{Kopt,2}$. Eq. (17) gives

$$\dot{E}_{Kopt,2}/\dot{E}_{Kopt,1} = \nu^{-1/(c+1)} \tag{22}$$

Inspection of Eq. (22) leads to the conclusion that $\xi = -1/(c+1)$ behaves very much like the price elasticity of demand because it is the percentage change in energy use for every percent increase in price. Indeed, we have for a retrofit

$$\sigma_E = \frac{\dot{E}_{Kopt,2}}{\dot{E}_{Kopt,1}} - 1 = \nu^{\xi} - 1$$

$$\sigma_I = \frac{I_{Kopt,2}}{I_{Kopt,1}} - 1 = \nu^{-c\xi} - 1 \tag{24}$$

$$\sigma_T = \frac{K_{T,Kopt,2}}{K_{T,Kopt,1}} - 1 = \frac{\alpha_I + \nu c\sigma_E}{H + 1 + \nu c} \tag{25}$$

Example 3: Should the life cycle price of energ in Example 1 increase by a factor of 1.5, determine the new level of insulation.

$$\sigma_E = 1.5^{-(1/2)} - 1 = -0.18$$

$$\sigma_I = 1.5^{(1/2)} - 1 = 0.22$$

$$\sigma_T = \frac{0.22 + (1.5)(1)(-0.18)}{0.1 + 1 + (1.5)(1)} = -0.02$$

Since $\dot{E}_{Kopt,2}/\dot{E}_{Kopt,1} = (t_{Kopt,2}/t_{Kopt,1})^{-\alpha}$ with $\alpha = 1$, we have

$$t_{Kopt,2} = t_{Kopt,1}(1+\sigma_E)^{-1/\alpha} = (8)(1.22) = 9.75 \text{ inches}$$

A retrofit of 1.75 inches of insulation would, therefore, save 18 percent of energy and 2 percent of overall cost. We have assumed, however, that the retrofit cost is strictly proportional to the thickness of the extra insulation.

4. Economic Payback Period of a Retrofit

By definition, there is no economic payback period when the insulation is larger than the economic thickness of insulation, t_{Kopt}. However, if the design was optimized for the life-cycle energy price p_1 which becomes $p_2 = \nu p_1$ due to unexpected price increases, then a retrofit to the new cost optimum would save an amount of energy $\Delta\dot{E} = \sigma_E \dot{E}$ but would require an extra investment of $\Delta I = \sigma_I I$. The economic payback period of the retrofit is

$$PBP_K = \frac{N}{\nu c} \frac{\sigma I}{\sigma_E} \qquad (26)$$

where σ_I is given by Eq. (24), and σ_E by Eq. (23).

Example 4: A 6-inch pipe carrying a hot fluid has an economic thickness of insulation of 7 inches. A few years into its ten-year life cycle, the cost of energy is estimated to increase by a factor of 2. How much insulation must be added and how long is the economic payback period? Use $c = 1.5$.

Equation (23) gives $\sigma_E = 2^{-(1/2.5)} - 1 = 0.24$

Equation (24) gives $\sigma_I = 2^{(1.5/2.5)} - 1 = 0.52$

Equation (26) gives $PBP_K = \frac{(10)(0.52)}{(2)(1.5)(0.24)} = 7.2$ yrs.

Since $\dot{E}_2/\dot{E}_1 = (t_2/t_1)^{-\alpha}$ and $\alpha = \beta/c = 1/1.5$, we have $t_2/t_1 = (\dot{E}_2/\dot{E}_1)^{-1/\alpha} = (0.76)^{-1.5} = 1.51$

The insulation thickness that must be added is therefore 3.6 inches. If the remaining life of the system is less than 7 years and if the fixed cost of retrofit is significant, it may be economic to add less that 3.6 inches or sometimes, nothing at all.

5. Energy Payback Period

For a retrofit with extra investment ΔI, the extra embodied energy is $\delta\Delta I$ where δ is the conversion factor from dollars to energy. The energy saving is $\Delta\dot{E}$ per year to the system and $\varepsilon_1 \Delta\dot{E}$ to the economy. The energy payback period PBP_E is

$$PBP_E = \frac{\delta\Delta I}{\varepsilon_1 \Delta\dot{E}} = \frac{NR\sigma_I}{c\sigma_E} = \nu R\ PBP_K$$

Since ν is, for all practical purposes, between 1 and 2, and $c > 1$, Eq. (27) indicates that $PBP_E < PBP_K$. In other words, for a retrofit that is economically attractive, the energy payback period is always smaller than the economic payback period.

Would there be an energy payback for overinsulation when economically such is not attractive? With an extra investment of ΔI, the payback period for an overdesign is

$$PBP_E = \frac{NR\sigma_I}{c\,\sigma_E} \qquad (28)$$

where $\sigma_I = (1 + \sigma_E)^{-c} - 1$

An extreme case of over insulation would be to reduce heat loss to $\dot{E}_{Eopt}$, the energy optimum. At this level of insulation, we have from Eqs. (17) and (18) $\dot{E}_{Eopt}/\dot{E}_{Kopt} = R^{1/(c+1)}$; therefore $\sigma_E = R^{1/(c+1)} - 1$ and $\sigma_I = R^{-c/(c+1)} - 1$.

In Example 2 where $R = 0.063$ and $c = 1.0$, the numerical values are $\dot{E}_{Kopt}/\dot{E}_{Eopt} = 0.25$, $\sigma_E = -0.75$, $\sigma_I = 4.0$ and $PBP_E = 3.6$ years.

In this case, the extra investment is \$8452; the extra energy saving is 750 MMBtu over 10 years. The equivalent cost of each MMBTU of energy saved is $Z_I \Delta I/\Delta E = \$16.0$.

Thus, an over-insulation all the way to the energy optimum still saves energy but is not economically attractive.

ASSESSING ENERGY SAVING AND EXTRA INVESTMENT COST

The above development of cost-energy dynamics uses a specific insulation system (with a reference insulation thickness) as the subject of analysis. Below we shall expand such system to an aggregation of options so that the costs and benefits of policies covering thermal insulation can be studied. Our final aggregated system is the U.S. economy. We are also interested in determining an optimum method for allocating insulation funds so that their combined effect is to maximize energy saving.

1. Three Sectors of the Economy

In 1978, the United States consumed approximately 78 quads (78×10^{15} Btu) of energy in various forms: fossil fuels, nuclear energy, hydroelectric energy, and others. The economy is conventionally subdivided into four sectors: residential, commercial, industrial, and transportation. Only the first three sectors use insulation material extensively to prevent heat loss.

Table 6 shows an approximate disaggregation of energy use and heat loss in the three sectors. The residential sector, which consists of approximately 75 million dwelling units, consumed 18 quads in 1978, 60 percent of which is for space heating and air conditioning and 15 percent for water heating. Space heat is lost from the dwelling unit through air infiltration (25-30 percent), window (23-27 percent), floor (14-23 percent), roof (12-14 percent) and walls and doors.[4] (15-17 percent). Although adding insulation to the attic is the easiest and most talked about method of residential conservation, it can contribute only about 1 quad/yr. at the maximum. More significant savings can be obtained by insulating walls, floors, and by reducing air infiltration; but those measures are more difficult and expensive to carry out.

There are approximately 36×10^9 square feet of space in the commercial sector. This includes space in hospitals, schools, public buildings, office buildings, and shops. The total energy use in 1978 was approximately 12 quads, of which 42 percent was for space heating, 11 percent for air conditioning and 24 percent, lighting. The heat flow from commercial buildings are assumed to follow the same paths as those in dwellings; that is, through air infiltration and through the thermal envelope.[5]

The manufacturing sector used approximately 20 quads of energy, 12 of which were in the form of process heat and 8, electricity.[1] Approximately 30% of the industrial process heat is applied at 100-100°C, 30 percent at 200-1000°C and 30 percent above 1000°C. Donnelly et al[6] estimated that approximately 1.6 quads/yr. of heat were amenable to be saved by insulation in 1976. We assume that by 1980, extra insulation efforts have reduced this to 1.3 quads/yr. Reducing heat loss to zero is impractical, of course, because that would require an infinite amount of insulation.

2. Aggregating The Technology Parameter

The majority of insulation cases in the residential and commerical sectors deal with flat insulation for which the technology parameter c is 1. However, what can we say about the technology parameter of insulation for the industrial sector? Table 7 illustrates the six components of heat loss classified according to temperature range. The third column of the Table (assigned c) is determined by using Figures 1 and 2 with z_{Ref} = 1 to 2. We also reason that a most appropriate value of z/z_{Ref} is around 1 to 2. For example, it appears that most heat loss through walls at temperature range above 1000°C takes place at large furnaces for which walls can be considered flat; hence $c \approx 1$. Similarly, processes that take place at 200-350°C could take place in tanks or in pipes. The insulation thickness could be 6-8 inches; the addition of insulation could be 2-4 inches. We choose $c \approx 1.5$ which corresponds to $z_{Ref} \approx 2$ and $z/z_{Ref} = 1.5$ in Figure 1.

The aggregated technology parameter for the industrial sector is computed as follows:[1]

$$c^+ = \sum_i S_{E,i} \cdot c_i \simeq 1.4,$$

where $S_{E,i}$ is the energy share of the contribution i and c_i is its technology parameter.

3. Estimating The Worth of Existing Insulation

ıe way to estimate the monetary worth of insulation in place is to add the value of all insulation shipments in the past few decades. There we run into the problem of inadequate data, insulation retirement, and changes in value of the dollar. Cost-energy dynamics allows an alternative method of estimation on the strength of a single assumption: insulation is installed to minimize total cost as perceived by the decision-makers. As c is the ratio of the (life-cycle) operating cost to the (life-cycle) capital cost at the point of cost optimum, we have

$$I_{Ref} \approx K_{E,\ Ref}/cZ_I = NZ_E p_o \hat{E}_{Ref}/cZ_I \qquad (29)$$

We assume that the planning horizon (service life) for insulating the residential sector, commerical sector, and industrial sector is 15 years, 10 years, and 10 years, respectively. Table 8 lists the assumptions for x, y, and p_o and the computed values of Z_E and Z_I for the three sectors. Equation (29) yields a worth in 1978 of $\$34 \times 10^9$, $\$ 14 \times 10^9$, and $\$ 9 \times 10^9$ for in-place insulation in the residential, commercial, and industrial sector, respectively.

4. Heat Saving, Cost Saving and Extra Investment

Changes in energy prices are assumed to be $\nu = 2.5$, 2.5 and 2.67 for the residential, commercial and industrial sector, respectively. The energy savings, extra investments, and total cost savings are computed by Eqs. (21) through (23) as follows:

	Residential	Commerical	Industrial
Energy saving (σ_E)	-0.37	-0.37	-0.34
Extra Investment (σ_I)	0.58	0.58	0.77
Totat cost saving (σ_T) (assuming $H \simeq 0.2$)	-0.10	-0.10	-0.03

5. Cost of Conservation Energy

Assuming a benefit of 15 years of service in the residential sector and 10 years of service in the commercial and industrial sectors after the retrofit, the costs of conservation energy are also shown in Table 8 for the three sectors. In all cases, they are lower than the current cost of purchased energy. The differences of conservation energy cost in the three sectors is not significant in view of the fact that it depends on assumptions on insulation capital stock.

6. Motivations and Barriers to Adding Insulation

When delivered energy costs \$5/MMBtu and more, it appears that a strong incentive exists for homeowners and firms to add insulation because such measures "produce" conservation energy at an investment cost of less than \$2.5/MMBtu. The incentive is not so strong, however, when we view the total cost at about \$3.1/MMBtu and the overall cost saving of less than 3%. These overall figures are often glossed over by conservation proponents who do not count the tax effect of self-initiated conservation measures.

There are other barriers to voluntary conservation. In the building sector, the owners are often not the occupants or are likely to move within a time span shorter than the payback period. Sometimes there is no reliable information nor reliable service. In many cases, shortage of front-end capital is a real problem. These barriers can only be overcome with coordinated federal and state programs to make capital available to enhance technology transfer, and to train a new technical cadre dedicated to energy productivity. Where there is a natural difference between perceptions of owners and occupants, manufactures and consumers, regulations would be effective to bridge the gap.

7. Allocating Funds for Maximum Energy Saving

Let T be the total fund made available by the firm or by the government to be distributed among many insulation programs. Let the program i be represented by a capital stock of I_i, energy consumption $\dot{E}_i$, and a technology parameter c_i. The linear programming problem is finding the fund $\Delta I_i = I_i \sigma_{I_i}$ allocated to program i such that the total energy saving of all programs is maximum. The results to second order approximation are as follows:

$$\sigma_{I,i} = \kappa_T^{c_i/(c_i+1)} - 1$$

$$\sigma_{E,i} = \kappa_T^{-1/(c_i+1)} - 1,$$

where

$$\kappa_T = 1 + \gamma$$

$$\gamma = \frac{b-[b^2-4aT/I^+]^{0.5}}{2a}$$

$$a = \sum_i \frac{(I_i/I^+)c_i}{2(c_i+1)^2}$$

$$b = \sum_i \frac{(I_i/I^+)c_i}{(c_i+1)}$$

$$I^+ = \sum_i I_i$$

Table 9 shows the allocation of 10 billion of federal funds earmarked for insulation. The lion's share, $6.8 billion, goes to the residential sector primarily because of a large quantity of heat being lost through the thermal envelope. Since the heat lost through walls of industrial equipment is only 1.3 quads/yr, a share of only $0.4 billion is given to the industrial sector. The total energy saved in this $10 billion program is 0.5 quad/yr. The equivalent cost of conservative energy to the government is about $1.5/MMBtu, a very attractive figure compared to the cost of new energy supply.

CONCLUSIONS AND RECOMMENDATIONS

We can recapitulate below several conclusions that are results of the above analysis.

1. The costs and benefits of retrofitting thermal envelopes with extra insulation can be easily estimated with the assistance of the technology parame c which is 1.0 for the building sector and about 1.4 for the manufacturing sector.
2. The economics of over-insulation is the real barrier to such action, not the net energy problem.
3. Assuming life-cycle energy prices have increased by a factor of 2.5 over and above those prices used to optimize the insulation thicknesses, a saving of 37 percent in energy and 10 percent in total cost can be achieved by adding approximately 60 percent of the original insulation. This translates into a saving of 1.33 quads/yr at a cost of $35 billion, or less than $2.5/MMBtu. In the long run, much more energy can be further saved by improving the thermal envelopes besides the ceilings of structures.
4. A simple method can be devised on the basis of the parameter c to allocate an insulation budget for maximum national energy savings. The lion's share of the budget would go to the building sector due principally to their low values of c and the large heat losses from their thermal envelopes.

The relationship $I/I_{Ref} = (\dot{E}/\dot{E}_{Ref})^{-c}$ reflects the fact that the more one wishes to save on energy, the more expensive each resultant unit of energy would cost. This is in contrast with energy supply technologies when the next unit of energy is generally cheaper than the previous one. But saving energy through insulation can be brought about faster than producing energy through new technologies. It appears, then, logical to solve the energy problem through both the supply and demand sides. As the United States in embarking on a massive program to produce synthetic fuels with a heavy federal subsidy, a similar subsidy should be provided to conservation. If the level of subsidy is put at $ 2.5/MMBtu, it can be seen from Table 8 that 1.33 quads/yr can be saved in a very short time, and up to 5 quads/yr can be saved in the longer run at a total cost not exceeding $150 billion. This, we believe, should be viewed together with the synthetic fuel program.

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ACKNOWLEDGMENTS

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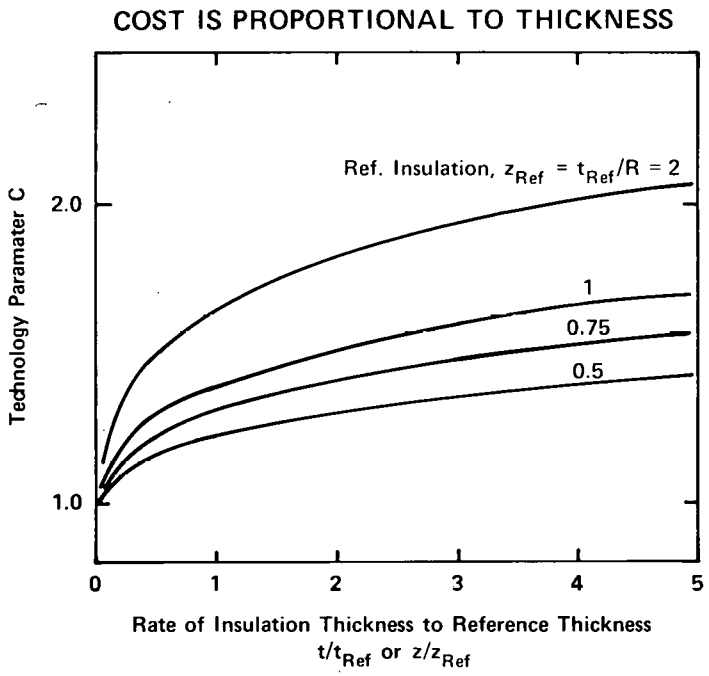


FIGURE 1: TECHNOLOGY PARAMETER c FOR PIPE INSULATION: Case 1 — Cost is Proportional to Thickness

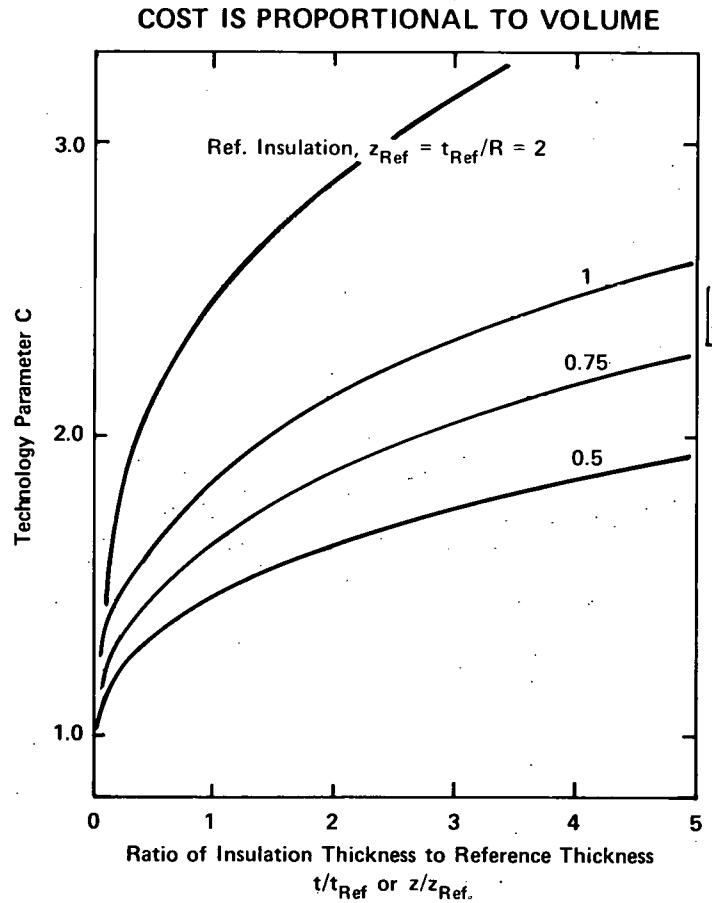


FIGURE 2: TECHNOLOGY PARAMETER c FOR PIPE INSULATION: Case 2 — Cost is Proportional to Volume

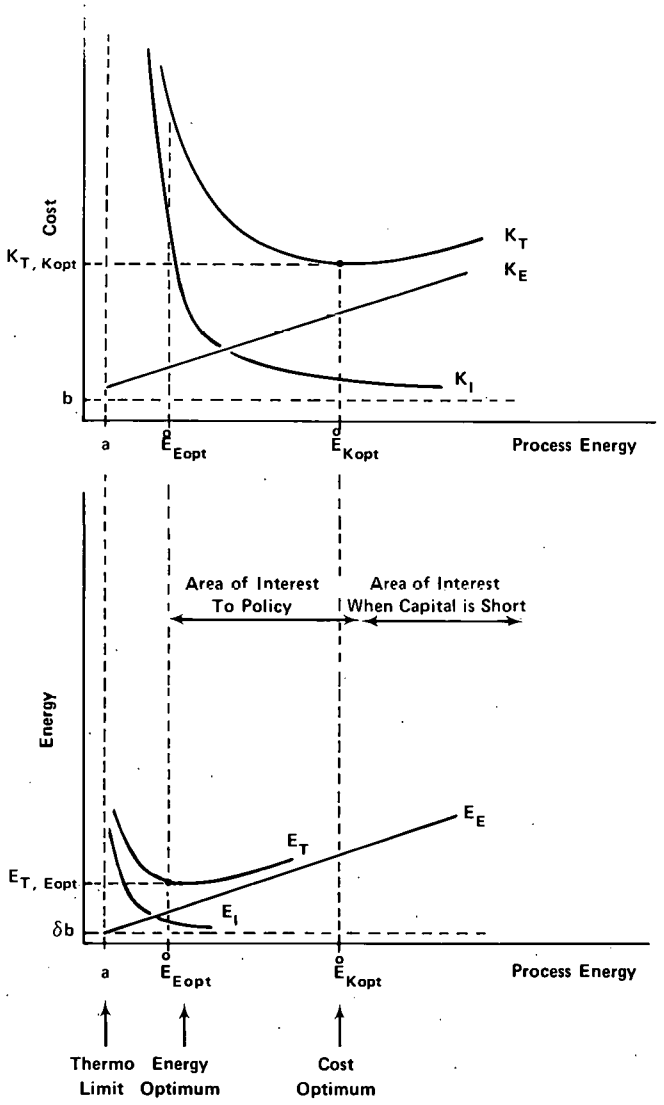


FIGURE 3: COST OPTIMUM AND ENERGY OPTIMUM

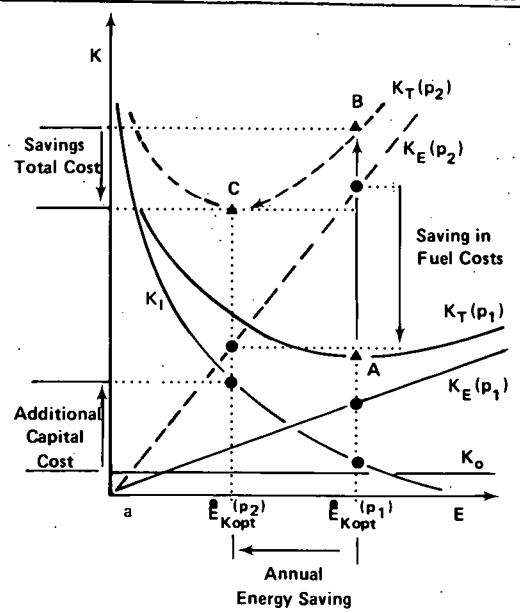


FIGURE 4: RETROFIT FOR BOTH ENERGY AND TOTAL COST SAVING

TABLE 1

TYPICAL VALUES OF Z_E

el price factor is defined as $Z_E = \frac{1}{N} \sum_{1}^{N} \left(\frac{1+y}{1+x}\right)^i$

where

N = planning horizon

x = effective discount rate

y = annual fuel escalation rate

Planning Horison N (years) and Effective Discount Rate x (yr^{-1})	Z_E for y (yr^{-1}) of Price Escalation			
	y = 0.06	y = 0.10	y = 0.15	y = 0.20
N = 5				
x = 0.06	0.972	1.119	1.285	1.473
x = 0.08	0.920	1.057	1.212	1.387
x = 0.10	0.872	1.000	1.145	1.308
x = 0.12	0.827	0.948	1.083	1.236
x = 0.14	0.787	0.900	1.027	1.169
N = 10				
x = 0.06	0.950	1.233	1.609	2.106
x = 0.08	0.859	1.108	1.436	1.868
x = 0.10	0.781	1.000	1.287	1.665
x = 0.12	0.713	0.907	1.160	1.490
x = 0.14	0.654	0.826	1.050	1.340
N = 20				
x = 0.06	0.907	1.509	2.621	4.695
x = 0.08	0.754	1.219	2.063	3.613
x = 0.10	0.636	1.000	1.433	2.819
x = 0.12	0.544	0.832	1.335	2.231
x = 0.14	0.471	0.702	1.097	1.790
N = 30				
x = 0.06	0.866	1.868	4.484	11.522
x = 0.08	0.666	1.346	3.056	7.530
x = 0.10	0.527	1.000	2.142	5.041
x = 0.12	0.428	0.766	1.546	3.462
x = 0.14	0.356	0.603	1.148	2.439

TABLE 2

TYPICAL VALUES* OF Z_I, $\bar{\phi}$, CRF (x,N)

Discount Rate x (yr^{-1}) and Planning Horizon N (years)	CRF (x,N)	$\bar{d}_{SYD}$	$\bar{\phi}$	Z_I
N = 5				
x = .06	.2374	.2078	.287	1.21
x = .08	.2505	.2104	.311	1.24
x = .10	.2638	.2127	.335	1.27
x = .12	.2774	.2150	.360	1.30
x = .14	.2913	.2174	.385	1.32
N = 10				
x = .06	.1359	.1088	.183	1.35
x = .08	.1490	.1114	.207	1.39
x = .10	.1627	.1141	.231	1.42
x = .12	.1770	.1166	.257	1.45
x = .14	.1917	.1191	.284	1.48
N = 20				
x = .06	.0872	.0590	.135	1.55
x = .08	.1019	.0617	.162	1.59
x = .10	.1175	.0642	.191	1.62
x = .12	.1339	.0666	.221	1.65
x = .14	.1510	.0687	.253	1.68
N = 30				
x = .06	.0726	.0422	.123	1.67
x = .08	.0888	.0448	.153	1.72
x = .10	.1061	.0469	.185	1.75
x = .12	.1241	.0488	.219	1.77
x = .14	.1428	.0504	.255	1.79

* The definitions of Z_I, $\bar{\phi}$, CRF (x,N and $\bar{d}_{SYD}$) are as follows:

$$CRF\ (x,N) = \frac{x}{1 - (1+x)^{-N}}$$

is the capital recovery factor for the effective discount rate x over the planning horizon N.

$$\bar{\phi} = \frac{CRF\ (x,N)}{1 - \tau} - \frac{\tau}{1 - \tau}\ \bar{d} + \pi$$

is the annual levelized fixed charge rate for capital-related services, τ is the effective income tax rate, $\bar{d}$ is the levelized depreciation rate (schedule dependent), and π is the ad-valorem charge rate. We use the sum-of-the-years' digit schedule (SYD) for $\bar{d}$ and the value of 0.02 for π.

$$\bar{d}_{SYD} = \frac{2\ [N\ CRF\ (x,N) - 1]}{N\ (N+1)\ x}$$

is the SYD depreciation charge levelized with discount rate x over period N, and

$$Z_I = \frac{1}{1 - \tau} - \frac{\tau}{1 - \tau}\ \frac{\bar{d}}{CRF\ (x,N)} + \frac{\pi}{CRF\ (x,N)}$$

is the present worth factor for all charges related to capital.

TABLE 3

VALUES OF α, β, AND c FOR PIPE INSULATION*

	z_{ref} (reference insulation thickness/pipe radius)											
	0.5			0.75			1.00			2.00		
Value of z/z_{Ref}	β	α	c	β	α	c	β	α	c	β	α	c
A. Cost is proportional to thickness												
0.5	1.000	0.861	1.161	1.000	0.814	1.229	1.000	0.773	1.293	1.000	0.665	1.503
0.9	1.000	0.826	1.211	1.000	0.778	1.285	1.000	0.731	1.368	1.000	0.617	1.621
1.2	1.000	0.812	1.232	1.000	0.751	1.331	1.000	0.708	1.413	1.000	0.592	1.689
2.0	1.000	0.773	1.293	1.000	0.711	1.406	1.000	0.665	1.504	1.000	0.551	1.815
3.0	1.000	0.742	1.348	1.000	0.678	1.475	1.000	0.631	1.585	1.000	0.521	1.919
5.0	1.000	0.701	1.427	1.000	0.636	1.572	1.000	0.590	1.694	1.000	0.415	2.062
B. Cost is proportional to volume												
0.5	1.151	0.861	1.337	1.212	0.814	1.490	1.202	0.773	1.633	1.416	0.615	2.130
0.9	1.192	0.826	1.443	1.270	0.778	1.633	1.323	0.731	1.811	1.490	0.617	2.415
1.2	1.220	0.812	1.503	1.289	0.751	1.717	1.357	0.708	1.916	1.523	0.592	2.573
2.0	1.262	0.773	1.633	1.347	0.711	1.895	1.416	0.665	2.130	1.505	0.551	2.077
3.0	1.306	0.742	1.760	1.396	0.678	2.059	1.465	0.631	2.322	1.633	0.521	3.134
5.0	1.366	0.701	1.948	1.458	0.636	2.292	1.526	0.590	2.586	1.682	0.485	3.468

*For flat plate insulation, α = 1, β = 1, and c = 1. The exponent α is defined such that heat loss is proportional (thickness). The exponent β is defined such that cost is proportional to (thickness). The technology parameter is c = β/α and is useful for the direct trade-off between energy loss and insulation cost; $I/I_{Ref} = (E/E_{Ref})$.

TABLE 4

RELATIVE HEAT RESISTANCES OF PIPE WALL, INSULATION AND FLUID-SOLID INTERFACES

Resistance Area	Heat-Transfer Coefficient	Heat-Transfer Resistance	
Fluid-pipe	h_f = 1,000 Btu/hr ft² °F	$1/h_f$	=0.0010
Pipe wall	k_w = 26 Btu/hr ft² °F	$(r1/k_w)\ln(r_2/r_1)$	=0.0002
Insulation	k_i = .047 Btu/hr ft °F	$(r1/k_i)\ln.(r_3/r_2)$	=6.3276
Insulation-air	h_a = 1.0 Btu/hr ft °F	$(r1/r_3)h_a$	=0.2981

TABLE 5

SELECTED VALUES OF THE ENERGY INTENSITY OF GOODS AND SERVICES

SIC	Industrial Sector Description	δ* (MMBtu/$ (1967)
20.02	Sawmills	0.076
20.09	Wood products	0.083
24.01;02	Pulp mills, paper mills	0.221
27.01	Chemicals	0.303
28.01	Plastics	0.243
28.02	Synthetic rubber	0.329
30.00	Paint	0.136
35.01	Glass	0.112
36.01	Cement	0.518
36.02	Bricks	0.037
36.14	Gypsum	0.171
36.17	Asbestos	0.119
36.20	Mineral wool	0.168
37.01	Steel	0.282
37.02	Steel foundries	0.104
37.04	Primary metal	0.157
38.04	Primary aluminum	0.428
40.03	Heating equipment	0.079
40.04	Fabricated structural steel	0.137
42.05	Fabricated wire products	0.169
42.08	Pipes	0.082
43.01	Steam engines	0.079
43.02	Internal combustion engines	0.069
44.00	Farm machinery	0.079
45.01	Construction machinery	0.075
48.01	Food product machinery	0.057
48.02	Textile machinery	0.066
48.04	Paper industry machinery	0.068
49.01	Pumps, compressors	0.061
49.03	Blowers	0.069
49.06	Industrial furnaces	0.079
49.07	General industrial machinery	0.071
53.07	Carbon products	0.167
58.01	Storage battery	0.108
61.07	Transport equipment	0.109
65.01	Rail transportation	0.098
65.03	Truck transportation	0.058
69.01	Wholesale trade	0.040
69.02	Retail trade	0.038
70.01	Banking	0.023
78.04	Federal government enterprises	0.040

* These values were selectively extracted from Bullard et al.[3] conversion of K_I to E_I usually requires a combination of a spec δ and those of the trade margin. For 1980 $, the values for δ are appreciatively less than half the values in this table.

TABLE 6

ENERGY USE AND POTENTIAL HEAT SAVINGS BY INSULATION*

Economic Sector	Total Energy (quads/yr)	Process Heat (quads/yr)	Potential Heat Savings by Insulation (quads/yr)	
			Ceiling	Entire Thermal Envelope
Residentials	17.2	10	1.4	7.6
Commercials	12.1	5	1.0	5.4
Industrial	29.2	11	—	1.3

* References:

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TABLE 7

ESTIMATE OF TECHNICAL PARAMETER FOR INSULATION

	Process Temperature Range	% Process Heat	Assigned c
A. Manufacturing			
	100°C	11.1	2.0
	100-200	30.3	1.7
	200-350	13.6	1.5
	350-550	8.9	1.1
	500-1000	8.1	1.1
	1000°C	28.0	1.0
		100.0	$c^+ \approx 1.4$
B. Residential			
	100°C	100.0	1.0
C. Commercial			
	100°C	100.0	1.0
D. Transportation:	Thermal insulation not considered.		

TABLE 8

ESTIMATE OF BENEFITS AND COSTS OF RETROFIT INSULATION

	Residential Sector	Commerical Sector	Industrial Sector
A. Assumptions			
1. Heat to be further saved by extra insulation (quads/yr.)	1.4 (ceiling) 7.6 (total envelope)[a]	1.0 (ceiling) 5.4 (total envelope)	-- 1.3
2. Healthy capital stock growth (%/yr)	1.5	2.5	2.5
3. Insulation - technology parameter, c	1.0	1.0	1.4
- service life (years)	15	10	10
4. Capitalization - cost of money (%/yr)	10	14	14
- income tax rate (%)	20	30	50
5. Prices of energy - 1980 $/MMBtu	5.0	5.0	4.0
- escalation (%/yr)	20	12	15
- old price at time of optimization ($/MMBtu)	2.0	2.0	1.5
B. Computed Values			
1. Operating cost factor Z_E	1.00	0.91	1.05
2. Capital cost factor[b], Z_I	1.25	1.27	1.58
3. Price increase factor, v	2.50	2.50	2.67
4. Worth of insulation ($ 10^9)[d]	34	14	9
5. Potential extra saving (quads/yr)	-0.52[e] -2.81[f]	-0.37 -2.00	-- -0.44
6. Extra investment (10^9)	20[c] <105[d]	8 <44	7
7. Cost of conservation energy[e] - investment ($/MMBtu)	2.5	2.2	1.6
- total ($/MMBtu)	3.1	2.8	2.5
8. Payback periods (yrs) - economic	9.4	6.3	8.5
- energy	1.1	0.7	0.5

(a) Total envelope includes ceiling, walls, windows, and floors.
(b) In the residential sector, no depreciation and ad-valorem charges are included.
(c) The extra cost is computed with the assumption that insulation cost remains the same in constant-dollar terms
(d) This is computed by the formula $\Delta I = NZ_E(p_o\dot{E}_{Kopt,2} - p_1\dot{E}_{Kopt,1})/Z_I c$ where for the residential sector, p_2 is $5/MMBtu, p_1 = $2/MMBtu, $\dot{E}_{Kopt,2}$ = 4.79 quads/yr, $\dot{E}_{Kopt,1}$ = 7.6 quads/yr.
(e) This calculation is for attic insulation only.
(f) This calculation is for the entire thermal envelope.

TABLE 9

ALLOCATION OF FUNDS FOR OPTIMUM ENERGY SAVINGS

	Residential Sector	Commercial Sector	Industrial Sector
Heat loss through thermal envelope (quads/yr)	1.4[a] 7.6[b]	1.0 5.4	- 1.3
Worth of Insulation ($10^9)	34[a] 185[b]	14 76	- 9
Technology Parameter, c	1	1	1.4
Optimum Allocation Funds ($ 10^9)	6.8	2.8	0.4
Energy Savings (quads/yr)	0.27	0.19	0.04
Cost Conservation Energy ($/MMBtu)	1.7	1.5	1.0

(a) Computed for attic only.
(b) Computed for the entire building envelope. The bulding envelope includes attic, walls, floor, windows, and doors; not all of these can be interpreted in terms of insulation.