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SURVEY OF INDUSTRIAL DRYERS FOR SOLIDS

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PREPARED BY AEROJET NUCLEAR COMPANY FOR
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
IDAHO OPERATIONS OFFICE UNDER CONTRACT E(10-1)-1375

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ABSTRACT

A study was directed toward obtaining data for an estimate of the current and anticipated energy demand for industrial drying operations for solid materials.

Twenty-seven dryer types, including those utilizing both direct and indirect heat sources, were identified and are described. Results of an analysis made on 17 dryer types and based on data obtained from several of the largest solids dryer manufacturers indicate that industrial dryers for solids currently consume about 1.3 x 10^{18} J (1.2 quads) of energy. This represents nearly 4% of the total United States industrial energy use.

Several examples of steps being taken by industry to reduce energy requirements for solids drying are included. Still further action to reduce energy consumption of dryers is possible; implementation will depend upon the extent to which incentives are provided by fuel scarcity, fuel costs, and the perfection of new technology by industry alone and in programs with the Federal Government.

SUMMARY

At the request of the Energy Research and Development Administration (ERDA) Washington, the Energy Conservation Branch of Aerojet Nuclear Company (ANC) at the Idaho National Engineering Laboratory (INEL) has initiated a series of studies on several energy-intensive unit operations to determine their energy use patterns and their potential for energy conservation measures. This report summarizes the result of the first of these studies, the subject being industrial dryers for solids.

Basically, this study was directed toward obtaining data for an estimate of the current and anticipated energy demand for industrial drying operations and toward attempting to pinpoint the opportunities for conserving energy in this unit operation.

Some 300 domestic manufacturers of dryers for solids were identified. Each of these manufacturers produces from one to ten different dryer types, with as many as 68 companies making dryers of a single type. Altogether, 27 different dryer types were identified. During the course of the survey, information was obtained from leading manufacturers covering 17 of the major dryer types.

Dryers are classified primarily as either "direct" or "indirect," depending on whether the drying heat source is allowed to contact the material being dried or is separated from it by a barrier through which the heat must be transferred. Additional classifications of "infrared" and "dielectric" are included as separate items.

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SURVEY OF INDUSTRIAL DRYERS FOR SOLIDS

I. INTRODUCTION

Industrial energy consumption and the potential for more efficient energy use by industry have been the subjects of several impressive studies by contract researchers, government agencies, university staff members, trade associations, and the technical staff members of many of the nation's larger industrial companies. Most of these energy use studies have taken an industry-by-industry approach, because (a) economic and fuel consumption data are available on this basis, (b) individual plants are usually producers for a single industry, and (c) individuals who have done the studies are usually most knowledgeable about energy use from the standpoint of individual industries in which they have had long-term experience.

There are examples of studies which have not been concerned solely with energy consumption in particular industries but rather on a more general basis, such as those which have addressed the potential of using process steam first for power generation, followed by its use as a heating medium. Also, the use of heat pumps, heat pipes, and recuperators can be adapted to process steam and space heating applications, no matter what the industry. These might be called equipment-oriented or operation-oriented studies, as contrasted with industry-oriented studies. It can be argued that the cause of energy conservation may be well served if the second approach, operation-oriented studies, is given increased emphasis. The basic question is: Can we make faster and more certain progress in our energy-oriented systems analyses if some of the studies are oriented by unit operations rather than by industries?

The origin of the term "unit operation," introduced in 1915 by Arthur D. Little, would assert an affirmative answer to the question. Little pointed out that "any chemical process, on whatever scale conducted, may be resolved into a coordinate series of what may be termed unit operations, such as pulverizing, drying, roasting, crystallization, filtering, evaporating, and distillation. The number of these basic unit operations is not large, and relatively few of them are involved in any particular process." The unit operations concept has been invaluable in chemical engineering education, and not only the principles but even the details concerning many of the unit operations are directly applicable to many major industries outside the chemical processing field. These include many aspects of mining, ore processing, heavy metals production and refining, pulp and paper processing, plastics processing, food processing, heating, ventilating, air conditioning, pharmaceutical manufacture, transporting fluids, and managing waste.

The Division of Industrial Energy Conservation within ERDA's Office of Conservation has recognized the importance of both approaches to the analysis of energy use patterns and the planning of energy conservation programs. Branches of the division have had their programs structured in accordance with the following responsibilities:

(1) Unit operations and equipment efficiency

(2) Process analysis and modification

(3) Alternative fuels, materials, and processes

(4) Agriculture and food processes.

At an ERDA-sponsored workshop on February 5 and 6, 1976, the approach to analyzing industrial energy conservation potential from the unit operations standpoint was the subject of extensive exploration by some 35 representatives of chemical, petrochemical, primary metals, and other industries; process equipment manufacturers; and energy-oriented government agencies and laboratories. One of the conclusions reached was that industrial drying of solids was probably one of the most energy-intensive of the unit operations and also one of those applicable to the greatest number of different industries. In order to obtain a basis for understanding and acting on the energy conservation possibilities offered by industrial dryers, it was decided by ERDA, Industrial Conservation, that a survey and report on industrial dryers for solids should be prepared.

The Idaho National Engineering Laboratory was given this assignment, and this report is the product of the survey and study conducted in response to that assignment. It has been prepared by utilization of the following information sources:

(1) Text books and handbooks which describe technical details of numerous different solids dryer types

(2) Product literature from about a dozen manufacturers of industrial dryers

(3) In some cases, direct contact with manufacturers of industrial dryers

(4) Pertinent journal articles obtained as a result of on-line computerized literature searching through ERDA's RECON service and Lockheed's DIALOG service.

Basically, a solids-drying operation involves the two mechanisms of heat transfer and mass transfer (both unit operations, each in its own right). Heat must be supplied to the material in order to vaporize the liquid to be removed, and then the vapor must be transferred from the solid into a carrier gas stream. The rate at which moisture can be vaporized from a solid is governed by three factors: first, the rate at which heat is applied to the surface; second, the rate at which moisture can diffuse from inside (and from the surface of) the material being dried; and, third, the ability of the carrier gas stream to absorb and remove the vaporized moisture at the operating temperature. The theoretical minimum requirement is that which corresponds to the latent heat of vaporization of water, about 2,324 J/kg (1,000 Btu/lb) at atmospheric pressure. The closeness of approach to this value is one measure of the thermal efficiency of any drying process.

From the standpoint of fuel economy it would be desirable to discharge moisture-laden carrier gas from the solids dryer at its saturation point. To avoid condensation difficulties and to maintain an effective driving force, however, a solids dryer is usually operated so that a relative humidity (RH) of 50 to 80% prevails in the waste stack gas. Thus, a considerable portion of the heat utilized to raise the temperature of the carrier gas and the material being dried to the desired level of required drying temperature is lost. If 80% RH is satisfactory for maintaining an effective driving force, a substantial, but presently indeterminate, amount of fuel could probably be saved by conducting all dryer operations with carrier gas at this humidity level, rather than down in the neighborhood of 50% RH.

The combined effects of increased fuel costs and questionable availability, particularly of the most versatile fuels, prompt the need for studies aimed at energy conservation in the utilization of industrial solids dryers. The study reported here has had the dual objectives of (a) obtaining data for an estimate of the current and anticipated energy demand for industrial solids drying operations, and (b) identifying opportunities for conservation of energy in this unit operation.

The report is the first in an expected series which will cover a number of unit operations, with the first emphasis being applied to those which are most energy-intensive.

II. CLASSIFICATION AND DESCRIPTION OF DRYERS[1,2]

Solids drying equipment may be classified in several ways. The two most common classifications are based on (a) the method of transferring heat to the wet solids, and (b) the handling characteristics and physical properties of the wet material. The first method delineates differences in dryer design and operation, whereas the second method is more often used in the dryer type selection for a particular drying problem.

For the purposes of this study, dryer design and operation are of paramount importance, since these are the factors most likely to show potential for energy conservation. Consequently, the results of this survey are presented on that basis, with little or no regard for physical properties of the material being dried.

The types of industrial solids drying equipment investigated in this survey are categorized as shown in Table I.

TABLE I

TYPES OF INDUSTRIAL SOLIDS DRYERS INVESTIGATED IN SURVEY

Direct Dryers		Miscellaneous Dryers	Indirect Dryers	
Continuous	Batch		Continuous	Batch
Tower	Through Circulation	Infrared	Cylinder	Agitated Pan
Flash	Tray	Dielectric	Drum	Freeze
Tray	Fluidized Bed		Screw Conveyor	Vacuum Rotary
Sheeting	Centrifuge		Rotary	Vacuum Tray
Conveyor			Vibratory Tray	
Rotary				
Spray				
Through Circulation				
Tunnel				
Press				
Fluidized Bed				
Centrifuge				

The following sections are brief descriptions of each of the dryer types shown in Table I. Drying efficiency is defined as the ratio of evaporation actually obtainable to that theoretically possible from that portion of the energy supplied to the system which is available for evaporation. An indication of drying efficiency is given for those dryer types for which such information could be obtained or calculated from available data.

1. DIRECT DRYERS

Heat transfer for drying is accomplished by direct contact between the wet solid and hot gases. The vaporized liquid is carried away by the hot gases.

1.1 Continuous

Operation is continued without interruption as long as wet feed and hot gases are supplied.

1.1.1 Tower. Material to be dried flows by gravity over a series of baffles while heated drying air flows, concurrently, countercurrently, or crossflow through the material. Drying efficiency: 20-40%.

1.1.2 Flash. Material to be dried is dispersed rapidly by injection into the heating medium in the form of small, wet, solid particles. Drying occurs rapidly, and many heat sensitive materials can be safely handled. Separation of the dried particles from the gases is accomplished in a cyclone separator. Drying efficiency: 50-75%.

1.1.3 Tray. Material to be dried is placed on trays which in turn are loaded on continuously moving metal belts. Hot gases flow over and around the trays, thus heating the material and causing vaporization of the liquid phase.

1.1.4 Sheeting. Material to be dried passes, as a continuous sheet, through the dryer either as a festoon or as a taut sheet stretched on a pin frame. Drying efficiency: 50-90%.

1.1.5 Conveyor. Material to be dried is conveyed through a chamber, in which it is contacted by high temperature high-velocity gases, to a cyclone separator. Drying efficiency: 40-60%.

1.1.6 Rotary. Material to be dried is conveyed and tumbled inside a rotating cylinder through which hot gases flow. Drying efficiency: 40-70%.

1.1.7 Spray. Material to be dried is usually in solution. Dryer feed is atomized through either a nozzle or a high-speed rotating centrifugal disk. Hot gases flowing through the dryer remove the liquid from the atomized droplets. Drying efficiency: about 50%.

1.1.8 Through Circulation. Material to be dried is conveyed through the dryer on a perforated screen; hot gases are blown through the screen and around the particles being dried.

1.1.9 Tunnel. Material to be dried is loaded into trucks which are moved through a tunnel. Hot gases flow either concurrently, countercurrently, or across the tunnel around the truck. Drying efficiency: 35-40%.

1.1.10 Press. Material to be dried is loaded into a press in which most of the water is squeezed out. A water getter, such as alcohol, is then pumped through the pressed cake to remove the remaining moisture.

1.1.11 Fluidized Bed. Material to be dried is held in suspension by a flow of hot gas in a stationary vertical tank. Dried material is removed through an overflow system at the top of the tank. Drying efficiency: 40-80%.

1.1.12 Centrifuge. Material to be dried is fed as a slurry into a short vertical rotating perforated cylinder. A blast of hot gases is blown through the material as centrifugal force causes it to contact the screen. Spiral baffles direct the flow of dried material toward the discharge end.

1.2 Batch

Dryers are designed to operate on a batch of wet feed of predetermined size for given time cycles. In batch dryers the conditions of moisture content and temperature continuously change during the drying cycle.

1.2.1 Through Circulation. Material to be dried is held on screen-bottomed trays in a closed chamber. Hot gases are blown through the material.

1.2.2 Tray. Material to be dried is held on solid bottomed trays on either trucks or shelves in a closed chamber. Hot gases are blown over the material on the trays. Drying efficiency: about 85%.

1.2.3 Fluidized Bed. Material to be dried is held in suspension by a flow of hot gas in a stationary vertical tank. After a prescribed period of time, the flow of hot gas is stopped, and the material is removed from the bottom of the tank. Drying efficiency: 40-80%.

1.2.4 Centrifuge. Material to be dried is fed as a slurry into a short rotating perforated cylinder. A blast of hot gases is blown through the material as centrifugal force holds it against the screen. Removal of the material is accomplished after the hot gas flow and the cylinder rotation have been stopped.

2. INDIRECT DRYERS

Heat for drying is transferred to the wet solid through a retaining wall. The vaporized liquid is removed independently of the heating medium. Rate of drying depends on the repeated contact of the wet material with heat transfer surfaces.

2.1 Continuous

Drying is accomplished as material continuously passes through the dryer in contact with a hot surface.

2.1.1 Cylinder. Material to be dried is in the form of a continuous sheet which is held in close contact with an internally heated cylinder or series of cylinders. The drying of pulp to form paper is the most outstanding and most energy-intensive example of this dryer type. Drying efficiency: 90-92%.

2.1.2 Drum. Material to be dried is deposited as a thin film of slurry or solution onto the surface of one or more internally heated horizontal cylinders or drums. The dried material is scraped from the surface of the drum by means of an adjustable blade after less than one complete revolution. Drying efficiency: about 85%.

2.1.3 Screw Conveyor. Material to be dried is fed into one end of a horizontal or nearly horizontal, heated, stationary or slowly rotating cylinder equipped with vanes on the internal cylinder walls or a stationary or slowly rotating, internally heated shaft equipped with vanes or a variety of paddles so designed as to convey the material being dried toward the discharge end of the cylinder.

2.1.4 Rotary. Material to be dried is loaded into one end of a horizontal or nearly horizontal rotating cylinder equipped with internal vanes. Rotation of the dryer causes the material to be tumbled, thus assuring intimate contact with the heated internal walls of the dryer. Moisture is removed by means of a small flow of gas through the dryer. Drying efficiency: 75-90%.

2.1.5 Vibratory Tray. Material to be dried is loaded onto trays which are vibrated in such a manner as to gently transport the particles from one end of the trays to the other. Heat is supplied through the heated hollow bottom of the trays.

2.2 Batch

Dryers are designed to operate on a batch of wet feed of predetermined size for given time cycles. Material to be dried is usually heat sensitive and subject to contamination. Heat is supplied through solid barriers, and frequently these dryers are operated under vacuum.

2.2.1 Agitated Pan. Material to be dried is loaded into a shallow circular jacketed vessel with a flat bottom. A slowly moving internal agitator keeps the material being dried in motion and allows uniform repeated contact with the heated surface. This type of dryer can be operated either at atmospheric pressure or under vacuum. Drying efficiency: about 90%.

2.2.2 Freeze. Material to be dried is usually loaded onto trays, placed in the dryer, and then frozen. Drying is accomplished by imposing a high vacuum on the vessel containing the trays and controlling the heating medium in the hollow tray bottoms so that sublimation rather than vaporization of the moisture occurs.

2.2.3 Vacuum Rotary. Material to be dried is loaded into a closed jacketed vessel, usually conical in shape. Vacuum is applied to the vessel, and a heating medium is passed through the hollow walls of the vessel. Rotation of the vessel insures intimate contact of the material being dried with the heated surface. Drying efficiency: up to 70%.

2.2.4 Vacuum Tray. Material to be dried is loaded onto trays which are then loaded on shelves in a closed cabinet-type container. The container is placed under vacuum, and heat is applied to the shelves.

3. INFRARED

Materials to be dried are loaded onto trays, moving belts, or other mechanisms such that a shallow layer can be exposed to radiant heat. Vaporization occurs as a result of generation, transmission, and absorption of infrared rays. Drying efficiency: 30-60%.

4. DIELECTRIC

Materials to be dried are placed in a chamber and are then exposed to a high frequency electric field so that heat is generated within the solid. Drying efficiency: about 60%.

III. INDUSTRIAL DRYER UTILIZATION

The utilization of solids drying equipment is quite widespread; however, the majority of uses can be generally categorized into nine groups identified by their two-digit Standard Industrial Classification (SIC) numbers. Table II is a matrix which indicates the major areas of industrial dryer use as determined by this survey. Appendix A lists the major group description quoted from the 1972 printing of the Standard Industrial Classification Manual issued by the U.S. Office of Management and Budget[3]. Following each major group description are examples of typical generalized and specific products currently being dried by the manufacturers contacted.

<u>TABLE II</u>

INDUSTRIAL DRYER UTILIZATION

Industrial Dryers Users (2-digit SIC Identifiers)	Solids Dryers																				
	Direct											Indirect								Misc.	
	Continuous										Batch	Continuous				Batch					
	Tower	Flash	Tray	Sheeting	Conveyor	Rotary	Spray	Through Circulation	Tunnel	Fluidized Bed	Tray	Drum	Screw Conveying	Rotary	Cylinder	Agitated Pan	Freeze	Vacuum Rotary	Vacuum Tray	Infrared	Dielectric
20 Food and Kindred Products	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X
21 Tobacco Manufacturers			X		X			X													
22 Textile Mill Products					X			X		X		X								X	X
24 Lumber and Wood Products			X						X												
26 Paper and Allied Products					X										X					X	X
28 Chemicals and Allied Products		X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
30 Rubber and Miscellaneous Plastics Products		X	X	X	X		X	X	X	X	X	X									
32 Stone, Clay, and Glass Products					X	X	X			X											
49 Electric, Gas, and Sanitary Services					X	X	X	X													

IV. SOLIDS DRYER MANUFACTURERS

As pointed out in a previous section, categorization of industrial solids dryers for this survey was based on dryer design and operating characteristics. A search was made using several catalogs[4,5,6] to determine names and locations of the major companies which manufacture the various types of solids dryers outlined in Table I. Results of this search revealed a total of 301 manufacturers of industrial solids dryers scattered through 31 of the 50 states. Major concentrations of solids dryer manufacturing plants are to be found in New York, New Jersey, and Pennsylvania in the East and Ohio and Illinois in the Midwest. California and Massachusetts may also be classified as major solids dryer manufacturing states. Table III summarizes the location of these manufacturers' plants by states.

Most solids dryer manufacturers build dryers of more than one type. Table IV indicates the number of identified solids dryer manufacturers in the United States by dryer type. As can be seen from this table, as many as 68 different companies manufacture a single type dryer. Each company, of course, has its own specifications and recommendations for dryer design and operation. As a result, vastly different dryers are actually included in many of the dryer types cataloged. In some instances, hybrids of two or more dryer types have been developed; this further complicates the categorization and selection process.

Concentration of manufacturers of the various solids dryer types included in this survey by location of their main manufacturing facilities is shown in Table V.

TABLE III

NUMBER OF SOLIDS DRYER MANUFACTURERS' PLANTS BY STATES

Alabama	1	Montana	0
Alaska	0	Nebraska	0
Arizona	0	Nevada	0
Arkansas	0	New Hampshire	0
California	12	New Jersey	39
Colorado	2	New Mexico	0
Connecticut	9	New York	42
Delaware	0	North Carolina	2
Florida	4	North Dakota	0
Georgia	4	Ohio	39
Hawaii	0	Oklahoma	4
Idaho	1	Oregon	2
Illinois	33	Pennsylvania	34
Indiana	9	Rhode Island	1
Iowa	2	South Carolina	1
Kansas	4	South Dakota	0
Kentucky	6	Tennessee	0
Louisiana	0	Texas	4
Maine	1	Utah	1
Maryland	5	Vermont	0
Massachusetts	16	Virginia	0
Michigan	9	Washington	0
Minnesota	3	West Virginia	1
Mississippi	0	Wisconsin	6
Missouri	4	Wyoming	0

TABLE IV

NUMBER OF SOLIDS DRYER MANUFACTURERS BY DRYER TYPE

Direct		Indirect	
Continuous		**Continuous**	
Tower	4	Cylinder	41
Flash	22	Drum	39
Tray	51	Screw Conveying	12
Sheeting	2	Rotary	22
Conveyor	68	Vibratory Tray	8
Rotary	64	**Batch**	
Spray	22	Agitated Pan	2
Through Circulation	4	Freeze	33
Tunnel	48	Vacuum Rotary	36
Press	11	Vacuum Tray	33
Fluidized Bed	51	Infrared	57
Centrifuge	20	Dielectric	8
Batch			
Through Circulation	1		
Tray	14		
Fluidized Bed	3		
Centrifuge	16		

TABLE V

LOCATION OF SOLIDS DRYER TYPE MANUFACTURERS BY STATES

	Solids Dryers																										
	Direct																Indirect									Misc	
	Continuous												Batch				Continuous					Batch					
State	Tower	Flash	Tray	Sheeting	Conveyor	Rotary	Spray	Through Circulation	Tunnel	Press	Fluidized Bed	Centrifuge	Through Circulation	Tray	Fluidized Bed	Centrifuge	Cylinder	Drum	Screw Conveying	Rotary	Vibratory Tray	Agitated Pan	Freeze	Vacuum Rotary	Vacuum Tray	Infrared	Dielectric
Alabama						1												1									
California		1			2	4					1	2					2	2	1	2			1			1	
Colorado					2				1										1	1					1		
Connecticut						1			2		4	1		1			1	1						1		2	
Florida		1				3												1								1	
Georgia						3																					
Idaho												1															
Illinois		3	11	1	10	12	4	1	5	1	9	1		5	1	2	3	5	1	3	1		5	6	3	6	
Indiana	1				2	1			1		2							3						3		4	
Iowa		1				2														1							
Kansas			1			1	1				1					1	1	1									
Kentucky		1			2	2	1				4										1				1		1
Maine						1											1										
Maryland		1	1			3	1	1		1	1						1		1	2			1	1	1		
Massachusetts		1	3		4	2	1		3	3	3	3		1		3	5	2	1				1	1		3	3
Michigan		1	1		2	1	1			1	1	1						3			1		2		1	2	
Minnesota		2	1		2	1	2		1		2					1	1	1	1	1			1	1	2		
Missouri		1									1	1				1							2				
New Jersey		3	6		10	2	5	2	5	2	6	2		2	1		6	1	1	2	2	1	4	4	5	9	
New York	1	1	7		5	2	3		5		3	2				3	3	3		1	1		6	9	10	7	2
North Carolina					1	2			1	1						1		1		1							
Ohio		2	9		12	5			14		3	2				1	7	5	2	1	1		2	2	2	13	1
Oklahoma					1	1																					
Oregon					1				1								2				1					2	
Pennsylvania	2	3	10	1	9	9	2		6	2	9	4	1	5	1	2	5	7	3	6		1	7	5	7	5	
Rhode Island									1																	1	
South Carolina					1				1																	1	
Texas			1		1	1					1												1				
Utah																								1			
West Virginia						1										1											
Wisconsin					1	3	1		1								2	2		1							

V. SUMMARY OF DATA OBTAINED FROM MANUFACTURERS

In order to obtain data on which to base a statistical analysis of solids dryer use, several of the largest solids dryer manufacturers were presented with a series of 25 questions; Appendix B lists the questions asked. A discussion of studies of work underway aimed at energy conservation is included as Section VII of this report. Summarized economic and operational data obtained from these manufacturers on 17 of the 27 solids dryer types cataloged in this survey are presented in Appendix C. As can be seen from these tables, wide variations occur in nearly all categories of data collected.

The following paragraphs are addressed to those generalized questions which are not included in Section VII or the economic and operating summaries of Appendix C.

1. SELECTION OF SOLIDS DRYER TYPE

In most instances, the desired quality and physical and chemical characteristics of the dried product are the most important considerations in the selection process. These are followed by such characteristics as fragility, heat sensitivity, required cleanliness, required processing rate, initial and final moisture content, as well as many other items of less importance. In the majority of cases, the potential solids dryer customer is requested to submit samples of his material to be dried by selected dryer manufacturers. Essentially all manufacturers maintain pilot plants or test laboratories in which drying tests are conducted. In the selection process, the manufacturer and the potential customer perform the necessary trade-off studies to determine what dryer type and what modifications to standard designs are required to accomplish the desired drying result. Although most dryer manufacturers advertise standard dryer types, in fact, the vast majority of industrial solids dryers sold today are custom designed, based on basic principles and standardized hardware.

2. EFFECT OF AIR AND WATER POLLUTION CONTROL REQUIREMENTS

The majority of dryer manufacturers indicated that air and water pollution control requirements would probably double the investment in equipment necessary for industrial solids drying installations. Essentially all dryer effluents contain moisture and finely divided particulate matter. Removal of these pollutants has greatly complicated the industrial solids dryer business.

3. ALTERNATE ENERGY SOURCE POTENTIAL

Indirect dryers, in which the drying energy source is not in direct contact with the material to be dried, can generally use any fuel. Direct dryers generally require a cleaner drying energy source, since the drying medium is in direct contact with the material being dried. Most industrial solids dryers currently use natural gas, liquified petroleum gas (LPG), or No. 2 fuel oil as the primary energy source. Conversion to coal, wood, heavy oil, lignite, or other organic fuels is under consideration by many manufacturers; however, economic considerations associated with such conversions have limited the applications made to date.

The U.S. pulp and paper industry is a notable exception. According to the American Paper Institute[7], the anticipated 1976 energy requirement for the industry as a whole is 2,470 x 10^{15} J (2,340 x 10^{12} Btu). Of this total 985 x 10^{15} J (984 x 10^{12} Btu) or 42% of the total energy requirement is satisfied by generating steam in boilers using as fuel waste products from the industry itself. These waste products include bark, hogged wood, and spent pulping liquor.

Using the weighted annual energy requirements for industrial solids dryers, as shown in Table VI, 39% of all such dryers are shown to use heat from an indirect source. In most instances, heat for these indirect dryers can be supplied from a variety of alternate energy sources.

4. MARKETING OF INDUSTRIAL SOLIDS DRYERS

Because of the special design requirements and the need for pilot and/or laboratory tests on a customer's material to be dried, the great majority of industrial solids dryers are sold direct from the factory or through factory representatives. After fabrication many industrial solids dryers are too bulky to be shipped completely assembled to the customer's site and must, therefore, be shipped as components to be assembled after arrival. At least one manufacturer has limited his marketing area to the region immediately surrounding his manufacturing facility because of the difficulty and expense of component shipping and reassembly at the customer's plant location.

TABLE VI

WEIGHTED AVERAGE ANNUAL ENERGY REQUIREMENTS FOR INDUSTRIAL SOLIDS DRYERS

(Based on This Survey)[a] [$\sim 10^{15}$ J/yr (10^{12} Btu/yr)]

DIRECT		
Continuous		
Tower	137 ± 32	(130 ± 30)
Flash	528 ± 211	(500 ± 200)
Sheeting	2.8	(2.7)
Conveyor	1.9	(1.8)
Rotary	66	(63)
Spray	9.5	(9)
Tunnel	<1	(<1)
Fluidized Bed	23	(22)
Batch		
Tray	<1	(<1)
INDIRECT		
Continuous		
Drum	2.4	(2.3)
Rotary	53	(50)
Cylinder	427 ± 53	(405 ± 50)
Batch		
Agitated Pan	<1	(<1)
Vacuum Rotary	11	(10)
Vacuum Tray	<1	(<1)
INFRARED	<1	(<1)
DIELECTRIC	<1	(<1)
Total	1261 ± 105 x 10^{15} J/yr	(1195.2 ± 100 x 10^{12} Btu/yr or 1.20 ± 0.1 quad/yr)

[a] Weighted averages were obtained by using selective judgement based on conversations with dryer manufacturers.

VI. INDUSTRIAL SOLIDS DRYERS ENERGY USE

Based on an analysis of the economic and operating information obtained from the dryer manufacturers contacted, as well as estimates of the numbers of each dryer type currently in use, it has been possible to estimate total drying energy requirements for the 17 dryer types for which data were obtained. A display of the annual energy requirements for these industrial solids dryers is shown in Table VI. Despite uncertainties in the data and despite assumptions that had to be made, it is believed that the total of about 1.3×10^{18} J (1.2 quads[a]), as shown in Table VI, represents most of the actual energy consumed for industrial solids drying in the United States. The drying energy consumption is distributed among the nine major industrial classifications as indicated in Table II.

In September, 1975, J. T. Reding and B. P. Shepherd of the Dow Chemical Company, in reporting results of an energy conservation study sponsored by the Environmental Protection Agency[8], summarized energy requirements of the six most energy-intensive United States industries. They reported that these six industries consumed a total of about 19×10^{18} J (18 quads) per year, 5.9% of which was consumed in drying operations. United States industry as a whole consumes about 42% of the total U.S. energy of about 77×10^{18} J (73 quads), or about 32.4×10^{18} J (30.7 quads). If we assume that drying utilizes the same proportion of energy in all U.S. industry as in the six most energy- intensive industries, the total energy used for drying (as calculated from the Dow report) would amount to about 1.9×10^{18} J (1.8 quads). Since drying energy use in the paper industry is disproportionately high compared to the total energy requirement in this industry, an adjustment of the Dow reported energy summary was made, eliminating the anomaly of the paper industry and its associated drying energy requirements. Using this analysis, it was estimated from the Dow report that U.S. drying energy requirements would amount to about 1.6×10^{18} J (1.5 quads), including the paper industry.

Although a direct comparison cannot be made between the results of the Dow study and the results of this survey, it is interesting to note the similarity of the estimated dryer energy consumption in the major user industries.

From comments made by dryer manufacturers, it is anticipated that dryer sales may increase about 25% in the near term (to 1985). Unless energy conservation efforts are instituted, the industrial solids drying unit operation could conceivably consume as much as 1.7×10^{18} J (1.6 quads) of energy per year by 1985. With moderate energy conservation practices, the anticipated expansion of dryer utilization could be achieved with essentially no increase in drying energy.

[a] 1 quad = 1.055×10^{18} J (10^{15} Btu).

VII. EXAMPLES OF CURRENT INDUSTRY EFFORTS TOWARD ENERGY CONSERVATION

In the past several years many articles have been published concerning the potential for energy conservation in the industrial drying of solids. Computerized literature searching has revealed several hundred references relating to energy conservation in industry. Perhaps 200 to 300 of these articles are related to industrial dryers.

The following examples briefly describe some of the approaches currently being utilized or under consideration by U.S. industry to improve dryer operation economy through energy conservation.

1. WASTE HEAT UTILIZATION INVOLVING DRYER EFFLUENTS

Air and water pollution requirements have contributed or will contribute significantly to the conservation of energy in industrial drying operations. Most of the dryer manufacturers contacted for this survey expressed the opinion that these requirements, when applied to dryer effluents, would result in at least partial utilization of the contained waste heat either through recycling in the drying operation itself or in other inplant operations. Air and water pollution control requirements have significantly increased the market for certain types of dryers. For example, waste sludges from industrial operations have historically been wasted into sumps, lakes, rivers, and oceans. In addition to reduction of pollution, recovery of valuable chemicals is now being realized by the drying of these sludges.

2. USE OF GARBAGE AND SEWAGE SLUDGE AS FUEL

One example of energy conservation reported during this survey concerned the disposal of sewage and garbage in a large eastern U.S. city. A system is currently being installed in which modified rotary type dryers will be utilized to reduce the moisture content of raw sewage to about 15%. Heat for the dryer is obtained from steam generated by a garbage incinerator. The dried sewage has a heat content of about 24,400 x 10^3 J/kg (10,500 Btu/lb). Additional steam, which will be generated from incineration of both garbage and sewage sludge, will be piped to a number of buildings for heat. A significant net energy gain is anticipated.

3. ROTARY DRYER DESIGN IMPROVEMENTS

A number of dryer manufacturers have developed modifications to conventional horizontal or nearly horizontal rotary-type dryers to increase their energy utilization efficiency. Of major significance is the development of systems in which the shell of the dryer is held stationary while internally heated tubes, vanes, or paddles affixed to a hollow central shaft are rotated through the material being dried.

4. COMBINATION DRYER SYSTEM

A combination of hot air, infrared, and dielectric energy sources associated with a single conveyor-type dryer was reported by one dryer manufacturer. In this application, a slurry was to be dried to a small particle product. At the slurry inlet end of the conveyor, the greater part of the liquid was vaporized using an infrared source with a low flow of relatively cool air passing over the conveyor to remove the vapor. Surface drying of the product was accomplished in the second section of the conveyor dryer system by introducing a stream of hot air around the conveyor and over the surface of the wet particles. Internal moisture was then removed from the particles in a third step using dielectric or microwave energy. It was reported that a more uniform product was obtained through the use of this system and that a net energy savings was realized compared with the former method of hot air drying over an extended drying time.

5. TWO-STAGE DRYING

Another dryer manufacturer reported a two-stage drying technique to effect about a 25% net energy saving. In two-stage drying, the effluent gases from the combined process leave the system with a comparatively low residual energy level. More of the available energy is thus used for the removal of moisture. It was reported that combinations of spray-flash, flash-flash, and flash-fluidized bed have demonstrated the energy economy of two-stage drying.

6. GRAIN DRYING MODIFICATIONS

In drying of grains, at least two major dryer manufacturers have demonstrated through time-temperature studies that appreciable fuel economy can be achieved by reducing heated drying air flow and drying air temperatures. This approach causes a significant increase in drying time, but it has been demonstrated that the economic advantages far outweigh the throughput disadvantages. One of the manufacturers reported a fuel savings of from 1/3 to 1/2 of that required under conventional air flow and air temperature conditions.

Additional studies reported by grain dryer manufacturers have been successfully carried out to demonstrate that partial drying in a conventional high-temperature dryer followed by cooling and drying in a bin at lower air flows and temperatures will save significant amounts of energy without reducing yield and will actually improve quality through alleviation of stress cracking of the grain kernels. Successful experiments have also been conducted using solar energy to provide some or all the required heat for the bin-drying step.

One manufacturer of tower-type grain dryers has successfully demonstrated that 20 to 33% of the energy required to dry grain can be saved by recycling about half of the exhaust gases. These gases exit the tower at temperatures up to 50°C (122°F) and contain an appreciable amount of damp or wet fines and dust. Removal of the fines and dust has reduced an objectionable fire hazard so that a good portion of the exhaust gases can be fed back through the burners.

7. NO-DRY CORN STORAGE

Of interest to energy conservation studies is the process of storing grain without drying, thus saving 100% of the normal energy requirement. University research and the experience of 20,000 to 30,000 farmers have shown that wet grain, stored in an oxygen deficient atmosphere, will store equally as well as dried grain. Livestock feeding results with this ensiled grain have been consistently equal to or better than results with dry grain. About 6 to 7% of the nation's corn crop is currently being fed to livestock as high moisture grain ($\sim$25 to 30% moisture content).

8. RECYCLED EXHAUST GASES

In conveyor dryers from 70 to 85% of the exiting gases at temperatures up to 95°C (200°F) are successfully being recycled in some installations. The combustion of fuel is carried out to produce combustion products of a higher temperature than required for drying. These gases are then blended with the recycled exhaust gases to provide a drying gas of the desired temperature. Since the exhaust gases contain appreciable quantities of moisture, controlled rate of drying can be accomplished by adjusting the relative humidity of the drying gas that enters the dryer, through an adjustment of the recycle ratio.

9. HEAT RECUPERATORS IN DRYING SYSTEMS

Heat pipe, heat wheels, finned tube exchangers, and other indirect heat exchange systems are being utilized in some instances to recover up to 70% of the energy contained in wet or contaminated dryer exhaust gases. This energy is frequently used to preheat burner feed air to increase efficiency of the combustion process.

10. BURNER EFFICIENCY IMPROVEMENTS

The efficiency of fuel combustion to provide heat for drying operations is a prime consideration in determining overall energy efficiency of an industrial dryer. One burner manufacturer contacted during this survey has developed and is marketing burners for No. 2 fuel oil which have efficiency ratings in excess of 99%. This high efficiency is attained by injection of compresssed air through a series of mixing cones and special aeration plates where intimate contact is made with atomized fuel oil. Flame length is carefully controlled in a specially designed and shaped combustion chamber. Essentially complete combustion of the hydrocarbon is effected within the flame envelope; thus the products of combustion consist of carbon dioxide and water only. The purity of the hot exhaust gases is such that they can and are being used in direct contact with food products for human consumption, such as grains and snack foods.

11. PAPER DRYING CONSERVATION MEASURES

By far the largest user of energy for drying is the pulp and paper industry. In 1972 the industry established a goal of total energy use reduction of 10% by 1980. Most recent reports indicate that the industry as a whole will exceed this goal. The largest conservation effort undertaken has been the increased utilization of waste products from the mill (spent liquor as well as bark and hogged wood) as boiler fuel to generate steam. Steam is used in banks of 48 to 60 cylinder dryers to dry processed pulp to paper.

The paper industry is investigating ways to reduce moisture content of the wet paper fed to the dryer section from 60 to 55%. This would reduce the drying energy needs about 10%.

12. OTHER ENERGY CONSERVATION MEASURES

Additional energy conservation steps being studied or implemented by solids dryer manufacturers include:

(1) Boiler efficiency improvement

(2) Dryer insulation

(3) Improvement of materials of construction for heat transfer surfaces

(4) Fuel substitution, such as coal or wood for natural gas and oil

(5) Use of oxygen-enriched air in burners for dryers

(6) Supplemental energy from wind, solar, or geothermal sources.

VIII. POTENTIAL FOR ENERGY CONSERVATION

As indicated in Section VII of this report, a great many energy efficiency studies and demonstrations are currently under way among the various industrial dryer manufacturers and their customers. To identify a substantial fraction of them and to estimate their overall potential for energy conservation would be beyond the scope of this study and report. It would require surveying a majority of the 300 manufacturers of dryers, an effort which it was felt would not be worth its cost in time and money.

Suffice it to say that contacts made with major manufacturers show a high degree of awareness and sensitivity to the need for energy conservation on their parts. They know that the potential for conservation by design and operating changes in drying is significant, and many are doing something about it. From the survey made for this report and from technical considerations of dryer design, it is conservatively estimated that from 25 to 30% of the total energy utilized annually for solids drying, or about 0.3 x 10^{18} J (0.3 quad), could be saved if the industry would adopt currently known techniques.

The following paragraphs based on several of the studies and demonstrations discussed in Section VII are indicative of the potential for energy conservation.

(1) Grain drying in the United States currently consumes about 53 x 10^{15} J/yr (50 x 10^{12} Btu/yr)[9].

(a) Decreasing air flow and air temperature and increasing drying time could save from 18 x 10^{15} to 26 x 10^{15} J/yr (17 x 10^{12} to 25 x 10^{12} Btu/yr).

(b) Recycling of a portion of the exhaust gases from grain dryers could save from 11 x 10^{15} to 18 x 10^{15} J/yr (10 x 10^{12} to 17 x 10^{12} Btu/yr).

(c) Using the compressed air injection burner technique could save about 37 J/yr (35 x 10^{12} Btu/yr).

(d) Utilizing oxygen deficient storage for that portion of the grain harvest used for livestock feed probably could save as much as 42 to 47 x 10^{15} J/yr (40 to 45 x 10^{12} Btu/yr).

Economic and climatic circumstances would no doubt influence the degree to which each of these or other alternatives could be utilized; however, it is resonable to assume that about half of the energy currently being used for grain drying, or about 26 x 10^{15} J/yr (25 x 10^{12} Btu/yr), could be saved. This amounts to 1,907 m^3PDE (12,000 BPDE[a]).

(2) Drying of paper accounts for about 0.32 to 0.42 x 10^{18} J (0.3 to 0.4 quad) per year. Reduction of the moisture content of the paper prior to drying (through adjustment of press rolls) has been targeted by the industry to effect a 10% reduction in the drying energy requirement. This could result in a savings of about 2,701 m^3PDE (17,000 BPDE).

(3) It is reasonable to assume that the technique of compressed air injection on gas and/or oil burners could be applied to at least half of the "direct" dryers. This would result in an aggregate fuel savings of about 0.16 x 10^{18} J (0.15 quad) per year (based on the efficiencies indicated in Appendix C and the energy requirements shown in Table VI). These savings could amount to as much as 11,760 m^3PDE (74,000 BPDE).

(4) A logical extension in technology (and time of adoption) beyond that in the preceding paragraph would be represented by the use of oxygen-enriched air for burners for dryers. If an economical retrofit system for enriching air to 30% oxygen becomes available for the hundreds of thousands of burners in use, the gas and oil fuel savings could probably amount, in the mid-term period, to as much as 15,890 m^3PDE (100,000 BPDE).

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[a] 0.1589 m^3PDE (1 BPDE) = 5.86 x 10^9 J/yr (5.55 x 10^6 Btu/yr).
BPDE = Barrels (of oil) per day equivalent.

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APPENDIX A

STANDARD INDUSTRIAL CLASSIFICATION MAJOR GROUP DESCRIPTIONS[a] WITH TYPICAL PRODUCTS[b] BEING DRIED

[a] All major group headings and descriptions in Appendix A are quoted from Reference 3.

[b] The products listed are those indicated by the manufacturers contacted in this study.

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APPENDIX A

STANDARD INDUSTRIAL CLASSIFICATION MAJOR GROUP DESCRIPTIONS WITH TYPICAL PRODUCTS BEING DRIED[3]

Major Group 20. – FOOD AND KINDRED PRODUCTS

"This major group includes establishments manufacturing or processing foods and beverages for human consumption, and certain related products, such as manufactured ice, chewing gum, vegetable and animal fats and oils, and prepared feeds for animals and fowls."

Examples:

- Alfalfa
- Animal Blood
- Apples
- Applesauce
- Baby Foods
- Beans
- Bermuda Grass
- Berries
- Beverages
- Candy
- Cereals
- Cheese
- Citrus Pulp
- Coffee
- Corn
- Corn Starch
- Croutons
- Crumbs
- Eggs
- Fish
- Flour
- Gelatin
- Meat Meal
- Milk
- Milo
- Nuts
- Pet Foods
- Potatoes
- Puffed Candy
- Rice
- Rye
- Seeds
- Snack Foods
- Soup
- Soy Products
- Spent Brewers Grain
- Starch
- Sugar
- Vegetable
- Wheat
- Whey
- Yeast

Major Group 21. – TOBACCO MANUFACTURES

"This major group includes establishments engaged in manufacturing cigarettes, cigars, smoking and chewing tobacco, and snuff, and in stemming and redrying tobacco."

Major Group 22. – TEXTILE MILL PRODUCTS

"This major group includes establishments engaged in performing any of the following operations: (1) preparation of fiber and subsequent manufacturing of yarn, thread, braids, twine, and cordage; (2) manufacturing broad woven fabric, narrow woven fabric, knit fabric, and carpets and rugs from yarn; (3) dyeing and finishing fiber, yarn, fabric, and knit apparel; (4) coating, waterproofing, or otherwise treating fabric; (5) the integrated manufacture of knit apparel and other finished articles from yarn; and (6) manufacture of felt goods, lace goods, nonwoven fabrics, and miscellaneous textiles.

"This classification makes no distinction between the two types of organizations which operate in the textile industry (1) the "integrated" mill which purchases materials, produces textiles and related articles within the establishment, and sells the finished products; and (2) the "contract" or "commission" mill which processes materials owned by others. Converters or other nonmanufacturing establishments which assign materials to contract mills for processing (other than knitting) are classified in nonmanufacturing industries. . . ."

Examples:

Blended Fabrics
Cloth
Coated Thread
Dyed Fabrics
Hair
Lace
Leather
Netting
Rayon Cake
Rugs and Carpeting
Skein Yarn
Synthetic Fibers
Tow and Staple Fibers

Major Group 24. – LUMBER AND WOOD PRODUCTS, EXCEPT FURNITURE

"This major group includes logging camps engaged in cutting timber and pulpwood; merchant sawmills, lath mills, shingle mills, cooperage stock mills, planing mills, and plywood mills and veneer mills engaged in producing lumber and wood basic materials; and establishments engaged in manufacturing finished articles made entirely or mainly of wood or wood substitutes."

Examples:

Particle Board
Sawdust
Wood Chips
Wood Fibers
Wood Pulp

Major Group 26. – PAPER AND ALLIED PRODUCTS

"This major group includes the manufacture of pulps from wood and other cellulose fibers, and from rags; the manufacture of paper and paperboard; and the manufacture of paper and paperboard into converted products such as paper coated off the paper machine, paper bags, paper boxes, and envelopes."

Examples:

Box Board
Insulating Board
Paper
Paper Capacitors
Paper Coatings
Paper Laminates
Wood Pulp

Major Group 28. – CHEMICALS AND ALLIED PRODUCTS

"This major group includes establishments producing basic chemicals and establishments manufacturing products by predominantly chemical processes. Establishments classified in this major group manufacture three general classes of products: (1) basic chemicals such as acids, alkalies, salts, and organic chemicals; (2) chemical products to be used in further manufacture such as synthetic fibers, plastics materials, dry colors, and pigments; (3) finished chemical products to be used for ultimate consumption such as drugs, cosmetics, and soaps, or to be used as materials or supplies in other industries such as paints, fertilizers, and explosives."

Examples:

Adhesives
Alumina Gel
Aluminum Oxide
Amino Acids
Lime
Metallic Powders
Nylon Chips
Organic Chemicals

- Battery Plates
- Catalytic Filters for Cars
- Charcoal Briquettes
- Coal
- Coke
- Dessicants
- Detergents
- Dyes
- Explosives
- Fertilizers
- Films
- Filter Cakes
- Fungicides
- Glues
- Gypsum
- Inorganic Chemicals
- Iron Oxides
- Perfumes
- Pesticides
- Pharmaceuticals
- Pigments
- Powders
- Rare Earths
- Resins
- Rocket Fuel
- Shellac
- Silica Gel
- Starches
- Stearates
- Sulfur
- Synthetic Vitamins
- Tear Gas
- Urea

Major Group 30. – RUBBER AND MISCELLANEOUS PLACTICS PRODUCTS

"This major group includes establishments manufacturing from natural, synthetic, or reclaimed rubber, gutta percha, balata, or gutta siak, rubber products such as tires, rubber footwear, mechanical rubber goods, heels and soles, flooring, and rubber sundries. This group also includes establishments primarily manufacturing tires. . . This group also includes establishments engaged in molding primary plastics for the trade and manufacturing miscellaneous finished plastics products."

Examples:

- Latex on Tire Cords
- Leatherette
- Linoleum
- Plastic Coatings
- Plastic Films
- Plastic Pellets
- Plastic Sheets
- Polyester Fibers
- Synthetic Rubber

Major Group 32. – STONE, CLAY, GLASS, AND CONCRETE PRODUCTS

"This major group includes establishments engaged in manufacturing flat glass and other glass products, cement, structural clay products, pottery, concrete and gypsum products, cut-stone, abrasive and asbestos products, etc., from materials taken principally from the earth in the form of stone, clay, and sand."

Examples:

- Bentonite Clay
- Cement
- Ceramic Beads
- Ceramic Extensions
- Fiber Glass
- Fire Clay
- Gravel
- Kaolin
- Mica
- Refractories
- Sand

Major Group 49. – ELECTRIC, GAS, AND SANITARY SERVICES

"This major group includes establishments engaged in the generation, transmission and/or distribution of electricity or gas or steam. Such establishments may be combinations of any of the above three services and also include other types of service such as transportation, communication, and refrigeration. Water and irrigation systems, and sanitary systems engaged in the collection and disposal of garbage, sewage, and other wastes by means of destroying or processing materials, are also included."

Examples

- Animal Wastes
- Industrial Wastes
- Sewage Sludge

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APPENDIX B

QUESTIONS PRESENTED TO DRYER MANUFACTURERS

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APPENDIX B

QUESTIONS PRESENTED TO DRYER MANUFACTURERS

1. What types of dryers does your company manufacture?

2. What types of materials are dried in each type of dryer you manufacture?

3. Over what temperature ranges does each type of dryer operate?

4. What industries are the major users of each type of dryer you manufacture?

5. How many of each type of your dryers are currently in use?

6. What is your sales volume for each type of dryer you manufacture?
   No. of units/yr for last five years.
   Anticipated sales/yr for next five years.

7. What percent of your sales are for:
   Catalog Items?
   Special Design Items?
   Hybrid Items?

8. What is the range of prices for each type of dryer you manufacture?

9. What is the anticipated operating life for each type of dryer you make?

10. What is the anticipated maintenance cost for each type of dryer you manufacture?

11. What range of capacities does each type of dryer you make have?

12. For what energy sources are the dryers you manufacture designed?
    Mechanical Energy?
    Drying Energy?

13. Can the dryers you manufacture be converted to other energy sources?

14. What are typical operating energy requirements for the types of dryers you manufacture?

15. What are typical heat transfer rates for each type of dryer you make?

16. What are typical drying efficiencies for the various types of dryers you make?

17. For batch drying operations, what are typical heat up-dry-cooldown cycles?

18. Who usually does the design or determines operating specifications of the dryers you manufacture and sell?

19. Are your dryers
    a. Shipped as complete assemblies? or
    b. Built/assembled on site?

20. What are the geographic limitations of your dryer marketing, and does this influence or is it influenced by the cost and availability of particular energy sources in different geographic areas?

21. Are your dryers sold through distributors, through dealers, direct from factory, or by other means?

22. Are your dryers used exclusively for water removal or are they adapted for solvent removal?

23. What do you consider the most important factors in determining the type of dryer to recommend for a particular use?

24. What have you done in the past five years or are currently doing or anticipate doing to your dryer line to achieve a significant reduction in energy requirements?

25. What effect will air and water pollution requirements have on design, first cost, energy requirement and/or operation features and operating cost of the types of dryers you manufacture?

APPENDIX C

ECONOMIC AND OPERATING INFORMATION OBTAINED ON 17 SOLIDS DRYER TYPES

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APPENDIX C

ECONOMIC AND OPERATING INFORMATION OBTAINED ON 17 SOLIDS DRYER TYPES

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Tower (Continuous – Direct)

Economic Information:

1. Price range: \$5,000 to \$200,000 per unit
2. Anticipated operating life: 10 to 20 years
3. Anticipated maintenance cost: 1 to 3% of cost of dryer per year
4. Sales volume:
   - Current: \$10 - \$15 x 10^6/yr for commerical units, no data for on-farm units
   - Projected: Expect to double sales volume

Operational Information:

1. Number of units in operation: 4,000 commercial, 30,000 on-farm units
2. Range of capacities:
   - Commerical: 16 to 265m^3 (450 to 7,500 bushels) of grain/hour
   - On-Farm: 3.5 to 70m^3 (100 to 2,000 bushels) of grain/hour
3. Range of operating temperatures: 66 to 204°C (150 to 400°F)
4. Energy sources:
   - Mechanical: Electrical
   - Drying: Natural gas, propane, No. 2 oil
5. Moisture removal capacity: No data
6. Energy requirements:
   - 0.30 to 0.45 x 10^9 J/m^3 of grain
   - (10 to 15 x 10^6 Btu/1,000 bushels of grain);
   - 420 to 630 x 10^3 J/kg grain (180 to 270 Btu/lb grain)
7. Heat transfer rates: No data
8. Drying efficiency: 20 to 40%
9. Used for water or solvent removal: Water only
10. Batch cycle times: Not applicable

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Flash (Continuous – Direct)

Economic Information:

1. Price range: \$2,000 to \$200,000 per unit
2. Anticipated operating life: 8 to 20 years
3. Anticipated maintenance cost: Less than 5% of dryer cost per year
4. Sales volume:
   - Current: No data
   - Projected: No data

Operational Information:

1. Number of units in operation: 3,500
2. Range of capacities: 4,500 to 18,000 kg (5 to 20 tons) of material per hour
3. Range of operating temperatures: 38 to 700°C (100 to 1,300°F)
4. Energy sources:
   - Mechanical: Electrical
   - Drying: Steam, natural gas, No. 2 oil, coal, wood
5. Moisture removal capacity: No data
6. Energy requirements:
   3.7 to 9.3×10^{12} J/kg (0.8 to 2×10^{6} Btu/ton); 3,720 to $8{,}715 \times 10^{3}$ J/kg (1,600 to 3,750 Btu/lb) water evaporated; 930 to $2{,}325 \times 10^{3}$ J/kg product (400 to 1,000 Btu/lb)
7. Heat transfer rates: No data
8. Drying efficiency: 50 to 75%
9. Used for water or solvent removal: Both
10. Batch cycle times: Not applicable

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Sheeting (Continuous – Direct)

Economic Information:

1. Price range: Up to $250,000 per unit
2. Anticipated operating life: 25 to 30 years
3. Anticipated maintenance cost: 5% of dryer cost per year
4. Sales volume:
   - Current: $250,000 per year
   - Projected: No data

Operational Information:

1. Number of units in operation: 50
2. Range of capacities:
   - 12 to 15m (40 to 50 ft) of sheeting/hour;
   - 3,630 to 4,535 kg/hour (8,000 to 10,000 lb/hr)
3. Range of operating temperatures: Up to 204°C (400°F)
4. Energy sources:
   - Mechanical: Electrical
   - Drying: Natural gas
5. Moisture removal capacity: No data
6. Energy requirements:
   - 15.8×10^9 J/hr (15×10^6 Btu/hr);
   - $3,486 \times 10^3$ J/kg product (1,500 Btu/lb)
7. Heat transfer rates: No data
8. Drying efficiency: 50 to 90%
9. Used for water or solvent removal: Generally solvent
10. Batch cycle times: Not applicable

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Conveyor (Continuous – Direct)

Economic Information:

1. Price range: \$15,000 to \$600,000 per unit
2. Anticipated operating life: 8 to 25 years
3. Anticipated maintenance cost: Up to 10% of original dryer cost per year
4. Sales volume:
   Current: \$500,000 per year
   Projected: Anticipate doubling the sales during next 5 years

Operational Information:

1. Number of units in operation: About 500
2. Range of capacities:
   227 to 45,350 kg/hr (500 to 100,000 lbs/hr);
   up to 183 m/min (600 ft/min) paper
3. Range of operating temperatures:
   38 to 427°C (100 to 800°F)
   [special cases up to 870°C (1,600°F)]
4. Energy sources:
   Mechanical: Electrical
   Drying: Natural gas, propane, steam, hot oil, No. 2 oil, infrared, dielectric
5. Moisture removal capacity: No data
6. Energy requirements:
   2.3 to 13.9 x 10^6 J/kg (1,000 to 6,000 Btu/lb)
   water evaporated
7. Heat transfer rates: No data
8. Drying efficiency: 40 to 60%
9. Used for water or solvent removal:
   Mostly water; minor use for solvent removal
10. Batch cycle times: Not applicable

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Rotary (Continuous – Direct)

Economic Information:

1. Price range: \$20,000 to \$1.5 x 10^6 per unit
2. Anticipated operating life: Up to 10 years
3. Anticipated maintenance cost: Up to 5% of original dryer cost per year
4. Sales volume:
   - Current: No data
   - Projected: No data

Operational Information:

1. Number of units in operation: About 35,000
2. Range of capacities:
   45 kg/hr to 54 x 10^4 kg/hr
   (100 lb/hr to 600 tons/hr)
3. Range of operating temperatures: 95 to 1,315°C (200 to 2,400°F)
4. Energy sources:
   - Mechanical: Electrical
   - Drying: Natural gas, No. 2 oil, heavy oil, coal, wood
5. Moisture removal capacity:
   0.98 to 48 kg water/hr·m^2
   (0.2 to 10 lb water/hr·ft^2)
6. Energy requirements:
   4.1 to 8.1 x 10^6 J/kg (1,750 to 3,500 Btu/lb)
   water evaporated
7. Heat transfer rates: No data
8. Drying efficiency: 40 to 70%
9. Used for water or solvent removal: Both
10. Batch cycle times: Not applicable

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Spray (Continuous – Direct)

Economic Information:

1. Price range: \$1,800 to $\$10^6$ per unit
2. Anticipated operating life: Up to 25 years
3. Anticipated maintenance cost: 1 to 2% of original dryer cost per year
4. Sales volume:

   Current: No data

   Projected: No data

Operational Information:

1. Number of units in operation: About 2,000
2. Range of capacities:

   Up to 27,000 kg (30 tons) of water evaporated/hr
3. Range of operating temperatures:

   95 to 700°C (200 to 1,300°F)
4. Energy sources:

   Mechanical: Electrical

   Drying: Natural gas, hot oil, steam, coal, waste heat
5. Moisture removal capacity:

   1.6 to 48 kg water/hr·m^3

   (0.1 to 3.0 lb water/hr·ft^3)
6. Energy requirements:

   3.7 to 11.6 x 10^6 J/kg (1,600 to 5,000 Btu/lb) water evaporated
7. Heat transfer rates: No data
8. Drying efficiency: 50%
9. Used for water or solvent removal: Both
10. Batch cycle times: Not applicable

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Tunnel (Continuous – Direct)

Economic Information:

1. Price range: $25,000 to $250,000 per unit
2. Anticipated operating life: Up to 30 years
3. Anticipated maintenance cost: 2 to 5% of original dryer cost per year
4. Sales volume:
   - Current: About 5 units/year
   - Projected: No data

Operational Information:

1. Number of units in operation: About 50
2. Range of capacities: No data
3. Range of operating temperatures: Up to 150°C (300°F)
4. Energy sources:
   - Mechanical: Electrical
   - Drying: Natural gas
5. Moisture removal capacity: No data
6. Energy requirements: No data
7. Heat transfer rates: No data
8. Drying efficiency: 35 to 40%
9. Used for water or solvent removal: Both
10. Batch cycle times: Not applicable

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Fluid Bed (Continuous – Direct)

Economic Information:

1. Price range: \$10,000 to \$300,000 per unit
2. Anticipated operating life: Up to 25 years
3. Anticipated maintenance cost: Up to 5% of original dryer cost per year
4. Sales volume:
   - Current: \$300,000 to \$500,000/year
   - Projected: Anticipate large increase

Operational Information:

1. Number of units in operation: About 300
2. Range of capacities:
   45 to 27,000 kg/hr (100 lb/hr to 30 tons/hr)
3. Range of operating temperatures:
   38 to 540°C (100 to 1,000°F)
4. Energy sources:
   - Mechanical: Electrical
   - Drying: Natural gas, steam, coal, waste heat, No. 2 oil, electricity
5. Moisture removal capacity: No data
6. Energy requirements:
   Up to 21×10^9 J/hr (20×10^6 Btu/hr)
7. Heat transfer rates: No data
8. Drying efficiency: 40 to 80%
9. Used for water or solvent removal: Both
10. Batch cycle times: Not applicable

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Tray (Batch – Direct)

Economic Information:

1. Price range: \$3,000 to \$30,000 per unit
2. Anticipated operating life: Up to 30 years
3. Anticipated maintenance cost: About 1% of original dryer cost per year
4. Sales volume:
   Current: No data
   Projected: Anticipate moderate expansion

Operational Information:

1. Number of units in operation: About 7,000
2. Range of capacities: No data
3. Range of operating temperatures:
   38 to 290°C (100 to 550°F)
   [special application up to 870°C (1,600°F)]
4. Energy sources:
   Mechanical: Electrical
   Drying: Steam, natural gas, No. 2 oil, electricity
5. Moisture removal capacity:
   0.10 to 12.2 kg water/hr·m^2
   (0.02 to 2.5 lb water/hr·ft^2)
6. Energy requirements:
   2 kg steam/kg water (2 lb steam/lb water) removed
7. Heat transfer rates: No data
8. Drying efficiency: 85%
9. Used for water or solvent removal: Both
10. Batch cycle times:
    No heat up time required. Drying time varies from 15 minutes to 12 hours. Normally unload hot, no cool down

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Cylinder (Continuous – Indirect)

Economic Information:

1. Price range: \$150,000 to \$2 x 10^6
2. Anticipated operating life: 20 years
3. Anticipated maintenance cost: No data
4. Sales volume:

   Current: No data

   Projected: No data

Operational Information:

1. Number of units in operation: Approximately 2,000
2. Range of capacities:

   4,500 - 1.36 x 10^6 kg (5 - 1,500 tons) paper/day

   [average 9 to 13.6 x 10^4 kg (100 to 150 tons) per day] [10]
3. Range of operating temperatures: Up to 175°C (350°F)
4. Energy sources:

   Mechanical: Electrical and steam

   Drying: Steam
5. Moisture removal capacity:

   Up to 48.8 kg water/hr·m^2

   (10 lb water/hr·ft^2)
6. Energy requirements:

   0.4 to 0.8 kg steam/kg (2 to 4 lb steam/lb) paper product;

   4.6 to 9.2 J/kg (2,000 to 4,000 Btu/lb) paper product
7. Heat transfer rates: No data
8. Drying efficiency: 90 to 92%
9. Used for water or solvent removal: Water
10. Batch cycle times: Not applicable

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Drum (Continuous – Indirect)

Economic Information:

1. Price range: $6,000 to $100,000
2. Anticipated operating life: Up to 10 years
3. Anticipated maintenance cost: About 5% of original dryer cost per year
4. Sales volume:
   - Current: $2.5 to 5 x 10^6 per year
   - Projected: No data

Operational Information:

1. Number of units in operation: 600
2. Range of capacities:
   - 45 kg/hr (100 lb/hr) to several thousand kg/hr
3. Range of operating temperatures:
   - 175 to 540°C (350 to 1,000°F)
4. Energy sources:
   - Mechanical: Electrical
   - Drying: Steam, hot oil, molten salt
5. Moisture removal capacity:
   - 7.3 to 39 kg water/hr·m^2
   - (1.5 to 8.0 lb water/hr·ft^2)
6. Energy requirements:
   - 1.3 to 2.5 kg (lb) steam kg (lb) water evaporated
7. Heat transfer rates:
   - 28 - 400 W/m^2 K (5 - 70 Btu/hr·ft^2·°F)
8. Drying efficiency: 85%
9. Used for water or solvent removal: Both
10. Batch cycle times: Not applicable

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Rotary (Continuous – Indirect)

Economic Information:

1. Price range: \$20,000 to \$600,000
2. Anticipated operating life: Up to 30 years
3. Anticipated maintenance cost: Up to 10% of original dryer cost per year
4. Sales volume:
   Current: No data
   Projected: No data

Operational Information:

1. Number of units in operation: About 7,000
2. Range of capacities: 91 kg/hr (200 lb/hr)
3. Range of operating temperatures:
   66 to 204°C (150 to 400°F)
4. Energy sources:
   Mechanical: Electrical
   Drying: Steam or hot water
5. Moisture removal capacity:
   13.2 to 65.9 kg water/hr·m^2
   (2.7 to 13.5 lb water/hr·ft^2)
6. Energy requirements:
   Up to 22.7×10^6 J/m^2 (2,000 Btu/ft^2)
   of heated surface
7. Heat transfer rates:
   11.3 to 56.8 W/m^2·K (2 to 10 Btu/hr·ft^2·°F)
8. Drying efficiency: 75 to 90%
9. Used for water or solvent removal: Both
10. Batch cycle times: Not applicable

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Agitated Pan (Indirect – Batch)

Economic Information:

1. Price range: $15,000 to $150,000 per unit
2. Anticipated operating life: Up to 15 years
3. Anticipated maintenance cost: Up to 5% of original dryer cost per year
4. Sales volume:
   Current: No data
   Projected: No data

Operational Information:

1. Number of units in operation: About 400
2. Range of capacities:
   Up to 3 m^3/hr (800 gal/hr) of slurry
3. Range of operating temperatures:
   Up to 315°C (600°F)
4. Energy sources:
   Mechanical: Electrical
   Drying: Steam, hot water, hot oil, molten salt
5. Moisture removal capacity:
   2.4 to 14.6 kg water/hr·m^2
   (0.5 to 3.0 lb water/hr·ft^2)
6. Energy requirements:
   1.3 to 1.8 kg (lb) steam/kg (lb) water evaporated
7. Heat transfer rates:
   28.4 to 341 W/m^2·K (5 to 60 Btu/hr·ft^2·°F)
8. Drying efficiency: 90%
9. Used for water or solvent removal: Both
10. Batch cycle times: No data

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Rotary (Indirect – Batch – Vacuum)

Economic Information:

1. Price range: $12,000 to $200,000
2. Anticipated operating life: Up to 30 years
3. Anticipated maintenance cost: Less than 5% of original cost of dryer per year
4. Sales volume:
   Current: No data
   Projected: No data

Operational Information:

1. Number of units in operation: Several thousand
2. Range of capacities:
   450 to 1350 kg/hr (1,000 to 3,000 lb/hr)
   (some much larger)
3. Range of operating temperatures:
   150 to 540°C (300 to 1,000°F)
4. Energy sources:
   Mechanical: Electrical
   Drying: Steam, hot water, oil
5. Moisture removal capacity:
   0.5 to 14.6 water/hr/m^2
   (0.1 to 3.0 lb water/hr/ft^2)
6. Energy requirements:
   22 to 75 x 10^3 W (30 to 100 hp) steam;
   1.3 to 3.0 kg (lb) steam/kg (lb) water evaporated
7. Heat transfer rates:
   5.7 to 200 W/m^2·K
   (1 to 35 Btu/hr·ft^2·°F)
8. Drying efficiency: Up to 70%
9. Used for water or solvent removal: Both
10. Batch cycle times: 0.5 to 20 hours drying time. Normally loaded and unloaded with no cooldown between batches.

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Tray (Indirect – Batch – Vacuum)

Economic Information:

1. Price range: \$20,000 to \$100,000
2. Anticipated operating life: Up to 30 years
3. Anticipated maintenance cost: 1 to 2% of original cost of dryer per year
4. Sales volume:
   Current: About \$5 x 10^6 per year
   Projected: Anticipate doubling in next 5 years

Operational Information:

1. Number of units in operation: About 1,000
2. Range of capacities:
   0.18 to 92.9 m^2 (2 to 1,000 ft^2) of heated surface
3. Range of operating temperatures: Ambient to 150°C (300°F)
4. Energy sources:
   Mechanical: Electrical
   Drying: Steam or hot water
5. Moisture removal capacity:
   2.4 to 14.6 kg water/hr/m^2
   (0.5 to 3.0 lb water/hr/ft^2)
6. Energy requirements:
   1.3 to 2.0 kg (lb) steam/kg (lb) water evaporated
7. Heat transfer rates:
   Approximately 5.7 W/m^2 K(1.0 Btu/hr·ft^2·°F)
8. Drying efficiency: No data
9. Used for water or solvent removal: Both
10. Batch cycle times: Drying time from 1/2 hour to several days. Normally no cooldown between cycles.

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Infrared

Economic Information:

1. Price range: $10,000 to $300,000 per unit
2. Anticipated operating life: Up to 30 years
3. Anticipated maintenance cost: 5% of original cost of dryer per year
4. Sales volume:
   - Current: No data
   - Projected: No data

Operational Information:

1. Number of units in operation: About 6,000
2. Range of capacities: Up to 183 m (200 yards) of material per minute
3. Range of operating temperatures:
   82 to 260°C (180 to 500°F)
4. Energy sources:
   - Mechanical: Electrical
   - Drying: Electrical
5. Moisture removal capacity:
   [0.025 x kW output] kg water evaporated/min
6. Energy requirements: No data
7. Heat transfer rates: No data
8. Drying efficiency: 30 to 60%
9. Used for water or solvent removal: Both
10. Batch cycle times: No data

INDUSTRIAL DRYER SURVEY DATA SUMMARY

Dryer Type: Dielectric

Economic Information:

1. Price range: $30,000 to $500,000
2. Anticipated operating life: No data
3. Anticipated maintenance cost: 5% of original cost of dryer per year
4. Sales volume:
   - Current: No data
   - Projected: No data

Operational Information:

1. Number of units in operation: About 400
2. Range of capacities: Up to 183 m (200 yards) of material per minute
3. Range of operating temperatures:
   82 to 260°C (180 to 500°F)
4. Energy sources:
   - Mechanical: Electrical
   - Drying: Electrical
5. Moisture removal capacity:
   [0.025 x kW output] kg water evaporated/min
6. Energy requirements: 10 to 700 kW
7. Heat transfer rates: No data
8. Drying efficiency: 60%
9. Used for water or solvent removal: Both
10. Batch cycle times: No data

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