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D. FEASBY
D. KEARNEY

MASTER

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Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

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INDUSTRIAL PROCESS HEAT APPLICATIONS
FOR SOLAR THERMAL TECHNOLOGIES

David W. Kearney* and
David Feasby**

*Engineering Consultant, Del Mar, California 92014
**Solar Energy Research Institute
Golden, Colorado 80401

ABSTRACT

This paper presents an overview of selected solar industrial process heat (IPH) activities under development in the U.S. Included are a summary of the IPH field test program, status of solar thermal technologies, and results of specific technology/application matching and market studies. There is a large potential market for solar IPH in the United States. The near-term viability of solar technologies in the industrial sector is dependent upon both the economic and technical issues which vary depending on the application, plant site, and system selected.

KEY WORDS

Solar; industrial process heat; IPH field tests; market assessment; end-use matching; industrial applications.

INTRODUCTION

Current energy consumption in the United States is approximately 80.5 x 10^8 gigajoules (GJ) [76.3 Quads (Q)]: 28.8 x 10^8 GJ (27.3 Q) for residential and commercial buildings; 19.6 x 10^8 GJ (18.6 Q) for transportation; and 32.1 x 10^8 GJ (30.4 Q) for industry. Industry, the largest energy user, consumes 39% (Hooker and others, 1980) of the gross energy.

Industry is a diverse and complex market sector consisting of four subsectors--manufacturing, mining, construction, and agriculture. The energy use within the sector is unevenly distributed (i.e., manufacturing (78.8%), mining (8.4%), construction (7.2%), and agriculture (5.6%). Energy use within the manufacturing subsector is highly concentrated. 60% of all energy use in the subsector is accounted for by the 10 largest manufacturing industries.

Approximately half of the total industry energy consumption is for industrial process heat (IPH)--thermal energy used in the preparation and treatment of manufactured goods (Brown and others, 1980). This represents a significant market for solar thermal technologies designed to provide thermal energy in the form (e.g., hot water, hot air, or steam) and duty-cycle required for a particular type of application, provided that the economic and performance criteria of industry can be met.

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INDUSTRIAL USES

Large quantities of heated water at temperatures between 49°C and 100°C are used in industry for such processes as cooking, washing, bleaching, and anodizing. Hot water may be supplied by directly heating water in absorber tubes of flat-plate, evacuated tube, or concentrating collectors, and piping this water to the process. Alternatively, a separate fluid may be piped through the collector field and then used to heat potable water via a heat exchanger. Large solar ponds may also be used to provide large amounts of low-temperature hot water.

Many industrial processes require large quantities of relatively low-pressure saturated steam. Saturated steam at approximately 690 kPa, equivalent to a temperature of about 171°C, can be produced in a solar system in two ways: (1) pressurized water may be circulated in a collector field and then flashed into steam in a low-pressure chamber, or (2) a heat transfer fluid capable of higher temperature operation may be circulated in the collector field and then to a steam generator, where the fluid serves as a heat source to produce steam. Because of the higher temperature needed, industrial steam applications normally require tracking concentrating collectors, such as the parabolic trough, or certain types of nontracking high-performance collectors, such as the evacuated tube.

Low-temperature (less than 177°C) direct heat is used for crop drying and food processing as well as paint drying, curing, and mineral solution dehydration. Air may be heated directly in collector systems designed to handle air as the circulating fluid, or a liquid may be circulated through the collectors and pumped through a heat exchanger to heat ambient air.

High-temperature (greater than 288°C) direct process heat accounts for a large portion of all industrial heat needs. Industries such as petroleum refining, primary metals, Portland cement, and glass are the major users. Intermediate-temperature collectors (parabolic trough or evacuated tube) cannot be used for process heat at these temperatures. Other collector types, though, such as central receivers or parabolic dishes, have potential for direct solar heating in selected processes.

STATUS OF THE TECHNOLOGY

Figure 1 shows the types of solar technologies that can be used to supply process heat over a broad range of temperature levels. Solar ponds offer the potential of very low-cost process heat up to temperatures approaching 100°C. A solar pond is a large area of water, 1- to 3-m deep designed both to collect and store solar energy. Thermal loss mechanisms that occur in natural bodies of water are greatly reduced in solar ponds either by using a salt gradient to suppress natural convection or by using inexpensive plastic glazings. The largest pond (2000 m^2) in the U.S. provides heat for a city's recreational building and swimming pool. Israel, which is particularly active in this area, has four ponds varying from 1100 m^2 to 6400 m^2 in area to provide energy for industrial processes and to produce electricity. Continued development of solar ponds is needed to find better, cheaper, and more reliable methods of maintaining a stable, nonconvecting layer, of extracting the heat, and of solving the problems associated with material lifetimes of liners and glazings.

Energy at somewhat higher temperatures can be supplied by flat-plate collectors (up to 93°C) or nontracking concentrating collectors (up to 177°C), such as evacuated tubes and compound parabolic concentrators. Flat-plate and evacuated tube collectors are most widely used for residential and commercial heating, and are continually being improved as a result of the experience gained in the field.

The required features of high-temperature collectors are the ability to track the sun on one or two axes and to concentrate its energy many times by reflecting

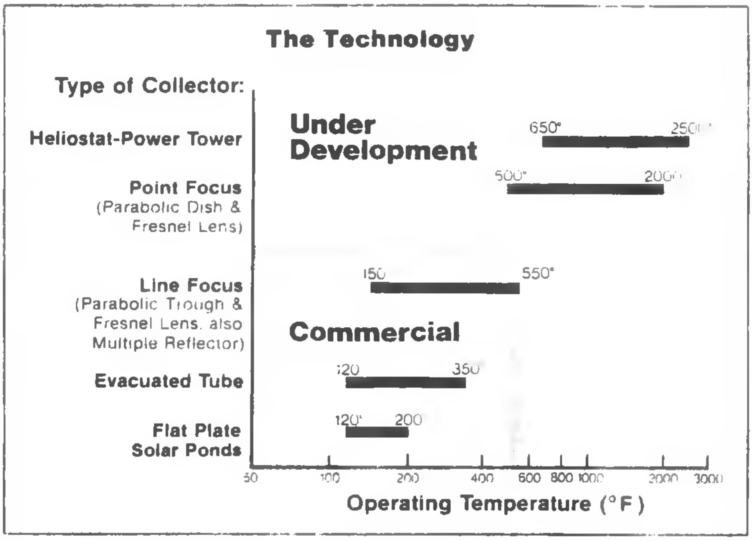

Fig. 1. Typical Operating Temperature Range of Solar Collectors

incident solar rays onto a receiver. The concentration ratio, defined as the ratio of collector aperture area to receiver area, can vary from about 40 for parabolic troughs to over 2000 for heliostat/central receivers.

Fresnel lens collectors, which focus light through refraction onto an absorber tube, and parabolic troughs or multiple reflector types, which concentrate by reflection, are used to supply energy with temperatures of up to 288°C. Parabolic troughs can yield higher concentrations than the Fresnel lens types and have been shown to operate at higher efficiencies than the multiple reflector types. As a result, they are the most common choice in the 154°C to 260°C intermediate temperature range. All of these must track the sun, however, and will not collect any significant amount of diffuse radiation. Because of the strict requirements on focusing accuracy, they are also relatively susceptible to contaminants such as dust. Most intermediate-temperature solar IPH applications today use parabolic trough concentrators, but Fresnel lens collectors are available for this market. The extensive use of parabolic troughs in DOE-funded field tests for steam applications, as well as a few commercial projects, has significantly improved the design features and performance of these systems.

The point-focusing distributed receiver can achieve very high temperatures using a parabolic dish concentrator to track the sun on two axes. This technology is less developed than line-focused collectors, though commercial products do exist and can produce thermal energy at high temperatures (ceramic designs are projected to operate as high as 1649°C).

High-temperature process heat requirements can also be met by a central receiver, in which a field of individually guided mirrors (heliostats) reflect incoming solar radiation to a single receiver mounted on a tower. The working fluid--air, helium, molten salt, liquid sodium, or water/steam--circulates through the receiver and transports the collected energy to the process.

CURRENT APPLICATIONS

The U.S. Department of Energy has funded a series of field tests since 1977 to gain operational experience in the application of solar energy to IPH requirements. To date, 34 design studies or actual installations have been funded utilizing technologies that vary from flat plates to line-focus concentrators to central receiver industrial systems. The types of solar systems include hot air, hot water, and steam production applied to a broad spectrum of industrial processes.

Design studies for the first field tests were initiated early in 1977, with design and construction of subsequent tests continuing to the present. As a guide to the energy delivered by such a system, an array of 1860 m^2 located in Colorado, operating at 40% system efficiency, would deliver about 4641 million kJ/yr. Table 1 shows the construction and operational dates, the industrial application, field

TABLE 1. Summary of Solar IPH Field Tests and Design Studies

Location	Process	Collectors	Owner	Status
		Hot Water (60°–100° C)		
Sacramento, CA	can washing	flat-plate & parabolic	Campbell Soup Co.	operational (June 1978)
Harrisburg, PA	concrete block curing	multiple reflector trough	York Building Products	operational (Sept. 1978)
La France, SC	textile dyeing	evacuated tube	Reigel Textile Corp.	operational (June 1978)
		Hot Air		
Fresno, CA	fruit drying	flat-plate	Lamanuzzi & Pantaleo Foods	operational (Aug. 1978)
Canton, MS	kiln drying of lumber	flat-plate (liquid)	LaCour Kiln Services, Inc.	operational (Nov. 1977)
Decatur, AL	soybean drying	flat-plate	Gold Kist, Inc.	operational (May 1978)
Gilroy, CA	onion drying	evacuated tube (liquid)	Gilroy Foods, Inc.	operational (Sept. 1979)
		Low-Temperature Steam (100°–177°C)		
Fairfax, AL	fabric drying	parabolic trough	West Point Pepperell	constructed (Sept. 1978)
Sherman, TX	gauze bleaching	parabolic trough	Johnson & Johnson	operational (Jan. 1980)
Pasadena, CA	laundry	parabolic trough	Home Cleaning & Laundry	construction
Bradenton, FL	orange juice pasteurization	evacuated tube	Tropicana Products, Inc.	construction
		Intermediate-Temperature Steam (177°–260°C)		
Dalton, GA	latex production	parabolic trough	Dow Chemical	construction

TABLE 1. Summary of Solar IPH Field Tests and Design Studies (Concluded)

Location	Process	Collectors	Owner	Status
San Antonio, TX	brewery	parabolic trough	Lone Star Brewing Co.	construction
Ontario, OR	potato processing	parabolic trough	Ore-Ida Co.	construction
Hobbs, NM	oil refinery	parabolic trough	Southern Union Co.	construction
		Large-Scale Hot Water		
Santa Isabel, PR	fruit juice pasteurization	evacuated tube	Nestle Enterprises	design
Santa Cruz, CA	leather tanning and finishing	flat-plate	Salz Leathers	design
Oxnard, CA	sodium alginate processing	flat-plate	Stauffer Chemicals	design
Des Moines, IA	meat processing	parabolic trough	Oscar Mayer	design
Shelbyville, TN	poultry processing	evacuated tube	Tyson Foods	design
		Large-Scale Steam		
Haverhill, OH	chemical plant	parabolic trough	U.S. Steel	construction
Fort Worth, TX	corrugated board production	parabolic trough	Bates Container	construction
San Leandro, CA	pressurized hot water for washing	parabolic trough	Caterpillar Tractor	construction

test location, and generic system type. Operation of a large number of steam projects will begin in 1981, leading to a wealth of new operational data in 1982 and beyond.

Overall, the operational systems have shown good reliability but lower than predicted system thermal efficiency (Kutscher, 1980). An examination of the causes of lower efficiencies points to a need for better design to reduce thermal and parasitic losses, and for improvement of the solar/industrial process interface. Failure of routine nonsolar components (pumps, valves, controls) is a continuing problem. Results to date have also indicated that efficient and cost-effective reflector cleaning techniques must be developed for concentrating collectors to ensure good long-term performance.

TECHNOLOGY/APPLICATION MATCHING

Although it would appear that the best potential markets for solar energy in industry would be the highest energy-consuming industries, there are other consid-

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erations (e.g., temperature requirements, solar system development, plant location, and conventional energy costs) that preclude these from being viable near-term markets. Within the U.S. industrial market sector, there are hundreds of different processes spread over 350,000 manufacturing plants and 450 different four-digit Standard Industrial Code (SIC) industries. Additionally, industrial plants are widely distributed over the U.S. so that the performance of solar thermal systems varies considerably due to the geographic variations in insolation. Therefore, there is a need to match solar thermal technologies to specific types of plant and process requirements to help assure satisfactory system performance and economics.

Care must be taken to select a proper interface between the solar system and the industrial process. From a technical viewpoint, the interface should simplify the control system, minimize thermal storage requirements, and permit continuous solar system operation whenever the insolation level is sufficient.

To match solar thermal technologies to a specific industrial process, an analytical method and feasibility analysis model has been developed and implemented at the Solar Energy Research Institute (SERI). The model (PROSYS/ECONMAT) is a combined performance and economic model that is flexible and fast-calculating

TABLE 2. Factors Favoring the Application of Solar IPH Systems

Environmental Factors

- High insolation levels
- High ambient temperatures
- A pollution-free microclimate
- A polluted macroclimate or area with strict air pollution regulations

Process Factors

- Low-temperature process
- Continuous, steady operations (24 h/day, 7 days/week)
- Liquid heating application
- Built-in process storage
- Easy retrofit of the solar system
- Inefficient fuel usage, not easily rectified

Economic Factors

- High and rapidly escalating fuel costs
- Uncertainties regarding fuel supplies
- Available capital
- Long payback periods or low rates of return requirements
- High federal, state, or local solar tax incentives
- Energy-intensive industrial operation and high energy costs
- Energy conservation measures already incorporated
- Close, cheap land or a strong roof available
- Low labor costs
- New plant

Company Factors

- Desire to install a solar system
- A skilled maintenance and engineering work force
- Progressive management

(Stadjuhar, 1981). The performance element calculates the long-term annual energy output for several collector types including flat-plate, nontracking concentrators, one-axis tracking concentrators, and two-axis tracking concentrators. The economic element of the model provides solar equipment cost estimates, annual energy capacity cost, and optional net present value analysis.

The PROSYS/ECONMAT model has been used in a variety of in-depth analytical studies, specific plant case studies, and generic system studies. Case studies (Hooker and others, 1980) consisted of selecting and visiting a variety of industrial plants in different locations to collect detailed process data, to test the model on actual industrial plant applications, and to assess the viability of solar technologies for these applications. One of the results of the case studies was to develop a set of factors (Table 2) that favor the application of solar IPH systems. A solar IPH application advantageously meeting the majority of factors in Table 2 is potentially economical and may warrant a more detailed analysis.

Processes investigated for the case studies included crude oil production (dewatering), aluminum container manufacturing, corn wet milling, polymeric resin manufacture (paint production), fluid milk processing, and meat processing. Based on plant location, process energy requirements, and the solar thermal system selected, the economic viability varies considerably. Note that although a variety of industries were investigated, without substantial screening, there were two cost-effective applications out of thirteen case studies completed.

NEAR-TERM SOLAR IPH MARKETS

Several market assessments and studies (Battelle, 1977; Insights West, 1980; Intertechnology, 1977) have been completed for industrial processes to try to match the solar thermal technologies to specific IPH applications. As a result of these efforts, selected four-digit SIC industries have been ranked as near-term IPH markets (DeAngelis, 1980) and are shown in Table 3. These industries have little potential for use of extensive waste heat recovery and have temperature requirements that match available solar thermal technologies.

A computer mapping technique (DeAngelis and others, 1981), similar to the type used for land management studies, is currently under development at SERI to determine near-term geographic markets for solar IPH. Factors (e.g., conventional fuel costs and availability, collector performance, air pollution data, state tax credits, etc.) that favor the use of solar energy by industry are compiled state by state. These can be weighted as desired. Then composite maps of the United States are generated to identify the geographic markets.

The mapping technique, together with the market assessment data, will identify four-digit SIC industries in specific locations that are target near-term markets for solar IPH. Feasibility analysis tools (e.g., PROSYS/ECONMAT) can then be used on a plant-specific basis to evaluate the viability of solar energy.

SUMMARY

There is a large potential market for solar IPH. The near-term viability of solar technologies in the industrial sector is dependent upon both economic and technological issues that vary widely according to the application, plant site, and the system selected. The DOE-sponsored Solar IPH Field Test Program has been instrumental in getting solar systems tested in a variety of applications.

Certain criteria have been developed which, if met, favor solar IPH application. Also, analytical matching tools such as PROSYS/ECONMAT are available to perform preliminary feasibility analyses. Technology/application matching combined with

TABLE 3. Potential Near-Term IPH Market for Solar Thermal Technologies

Below 288°C	2895 - Alumina *
2048 - Prepared Feeds	2823 - Cellulosic Man-Made Fibers *
2051 - Bread/Bakery Products	2834 - Pharmaceutical Preparations
Below 177°C	2951 - Paving Mixtures/Blocks *+
2062 - Cane Sugar Refining +	3275 - Gypsum Products *+
2063 - Beet Sugar *	395 - Ground/Treated Minerals *
2075 - Soybean Oil Mills	Below 100°C
2077 - Animal/Marine Fats/Oils	2011 - Meat Packing
2085 - Distilled/Blended Liquor	2022 - Natural/Processed Cheese +
2421 - Sawmills/Planing Mills*	2261 - Finishing Plants - Cotton *+
2611 - Pulp Mills *+	2262 - Finishing Plants - Synthetic *+
2621 - Paper Mills *+	2435 - Hardwood Veneer/Plywood
2631 - Paper Boards Mills *+	2436 - Softwood Veneer/Plywood*
2653 - Corrugated/Solid Fiber Boxes +	2511 - Wooden Furniture +
2661 - Building Paper/Board Mills *+	2824 - Noncellulosic Fibers *+
2812 - Alkalies/Chlorine *	3271 - Concrete Block/Brick *+

*Industries with the largest energy costs as compared to their value of product shipments.

+Industries that are the largest users of petroleum.

market assessment data and geographic market data have established near-term solar IPH markets for specific four-digit SIC industries. However, even after the preliminary feasibility has been determined, there is a need to investigate the viability of solar IPH at the plant site because of factors such as process requirements, available insolation, and land constraints.

REFERENCES

Battelle Columbus Laboratories (1977). Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat. National Technical Information Service, Springfield, VA.

Brown, K. C., D. W. Hooker, A. Robb, S. A. Stadjuhar, and R. E. West (1980). End-Use Matching for Solar Industrial Process Heat. SERI/TR-34-091. Solar Energy Research Institute, Golden, CO.

DeAngelis, M. (1980). Market surveys: potential solar IPH applications. Solar Industrial Process Heat Conference Proceedings and Presentations. Houston, TX.

DeAngelis, M., A. K. Turner, and J. Weber (1981). A geographic market suitability analysis for solar IPH systems. Solar Rising, The 1981 American Section of the International Solar Energy Society Proceedings. University of Delaware, Newark, DE.

Hooker, D. W., E. K. May, and R. E. West (1980). Industrial Process Heat Case Studies. SERI/TR-733-323. Solar Energy Research Institute, Golden, CO.

Insights West (1980). Solar-Augmented Applications in Industry. Gas Research Institute, Chicago, IL.

Intertechnology Corporation (1977). Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Process Heat. National Technical Information Service, Springfield, VA.

Kutscher, C. F., and R. L. Davenport (1980). Preliminary Operational Results of the Low Temperature Solar Industrial Process Heat Field Tests. SERI/TR-632-385. Solar Energy Research Institute, Golden, CO.

Stadjuhar, S. A. (1981). PROSYS/ECONMAT User's Guide-Solar Industrial Process Heat Feasibility Evaluation. SERI/TR-733-724. Solar Energy Research Institute, Golden, CO.