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OPERATION AND DESIGN OF SELECTED INDUSTRIAL PROCESS HEAT FIELD TESTS

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INTRODUCTION

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 industrial process heat requirements. To date, 26 studies or actual installations have been funded utilizing technologies ranging from flat plates to line-focus concentrators (a series of six similar project studies on central receiver industrial systems is not discussed here). 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. Figure 1 shows the construction and operational dates for the full series, also giving the industrial application, field test location and generic system type. Note that the 10000 ft^2 array series proceeded from hot water and hot air systems to steam systems of increasing temperature and pressure. The 50000 ft^2 array series is intended to examine the economics of scale and to utilize design information and lessons evolving from the earlier tests.

The early hot air and hot water projects, as well as two steam projects, are operational and providing important feedback to the design of current systems. The operational systems on the whole have shown good reliability and lower than predicted system thermal efficiency (Ref. 1). An examination of the causes 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) has been a continuing problem. Operational data from later field tests will be available for a number of projects in 1981.

PROJECT EXPERIENCE

In order to focus on specific operational experience and design approaches, this paper discusses four selected projects: Lamanuzzi and Pantaleo (L&P) Foods in Fresno, California, designed and constructed by California Polytechnic State University, San Luis Obispo; Johnson and Johnson Co., Sherman, Texas, designed and constructed by Acurex Corp.; Ore-Ida Co.,

10,000 ft² Arrays

System Type	Application	Location	Operational Date
Hot Water 135-270°F	Soup can washing	California	November 1977
	Textile dyeing	South Carolina	June 1978
	Concrete block curing	Pennsylvania	September 1978
Hot Air 140-210°F	Onion drying	California	September 1979
	Soybean drying	Alabama	May 1978
	Kiln drying (lumber)	Mississippi	November 1977
	Fruit drying	California	August 1978
Steam 85-150 psia	Commercial laundry	California	Early 1981
	Gauze bleaching	Texas	January 1980
	Orange juice pasteurizing	Florida	January 1981
	Fabric drying	Alabama	September 1978
Steam 140-300 psia	Latex production	Georgia	Early 1981
	Brewery	Texas	Early 1981
	Potato processing	Oregon	Early 1981
	Oil refinery	New Mexico	Mid 1981

50,000 ft² Arrays

System Type	Application	Location	Operational Date
Steam 150-165 psia	Corrugated board production	Texas	Late 1981
	Chemical plant polystyrene	Ohio	Late 1981
Hot water 235°F	Parts washing	California	Late 1981
Hot water 120-210°F	Fruit juice pasteurizing	Puerto Rico	In design stages
	Leather processing	California	In design stages
	Sodium alginate processing	California	In design stages
	Meat processing	Iowa	In design stages
	Poultry processing	Tennessee	In design stages

Figure 1. Evolution of DOE solar IPH field tests

Ontario, Oregon, designed and constructed by TRW; and Nestle Enterprises, Santa Isabel, Puerto Rico plant, designed by Nestle, General Electric Co. and Sunmaster Corporation. Design data for these projects is given in Figure 2. The following brief summaries discuss these systems and the experience gained to date on these projects.

L&P Foods: This system consists of 1950m^2 (21,000 ft^2) of air collectors that supply hot air to a 396 m^3 (14,000 ft^3) storage bin and 1 of 14 dehydration tunnels for raisins and prunes (Ref. 1). A 3.7-m (12-ft) diameter heat recovery wheel transfers heat from the tunnel exhaust to the fresh-air collector inlet. During the drying season, prunes and raisins are stacked on trays and move through the gas-fired dehydration tunnels with a residence time of 24 hours.

As is typical of food-drying operations, the plant operation is seasonal, limiting the cost effectiveness of a solar system. In this case the typical drying season is from August to February. Single-glazed (Lexan) flat-plate collectors for this project were constructed on site at a cost of \$263/m^2 (\$24.50/ft^2). The heat recovery unit, installed as part of the solar system retrofit, supplies about 2-1/2 times more energy to the air than the solar system at a much lower cost, pointing out the economy of routine energy conservation techniques.

Only minor operational problems exist at the site. The Lexan glazings have visibly yellowed, but collector array efficiency has not markedly decreased. Data acquisition system failures, rain leakage into the damper motor housings, and minor operational difficulties decreased system availability to about 75%. Some performance degradation resulted from non-uniform flow through the rock storage bed. Due to this and other losses, thermal system efficiency is about 25%, with an 18% net system efficiency after deducting the thermal equivalent of the high parasitic power requirements to circulate air through the system.

Figure 3 presents monthly performance data for three drying seasons, which run from August through February. This data has yet to be analyzed to fully explain the significant decrease in efficiency over the season, and to identify all the factors contributing to the efficiency increase in 1980-81.

Johnson & Johnson: Low pressure steam is generated by a solar system employing 1070 m^2 (11,520 ft^2) of Acurex Model 3001 parabolic trough collectors in which pressurized water circulates directly through the collectors, reaching temperatures as high as 216°C (420°F) before being throttled into a flash boiler (Ref. 2). Water in the boiler flashes to steam to supply the plant steam main at 125 psi. This simple plant interface typifies solar steam production. For this application, process steam is used in the manufacture of surgical dressings.

Initial system checkout began in November 1979, with normal operation commencing in January 1980. System availability has been excellent (97% through June 1980). Minor early operational problems resulted from difficulties such as flow switch and control pressure gage failures, and improper sizing of collector flex hoses. Performance of the system has been promising with net system efficiencies on the order of 35% under good insolation conditions. On the average, however, system efficiency has ranged from 25-35%, approximately ten percentage points less than

Firm	Location	Process	Status 12-1-80	Working Fluid	System Delivery Temperature	Collector Type	Array Size
Lamanuzzi & Pantaleo Foods	Fresno, California	Raisin Drying	Operating	Air	145°F (63°C)	Flat Plate	21000 ft² (1950 m²)
Johnson & Johnson	Sherman, Texas	Gauze Bleaching	Operating	Steam 125 psia	345°F (174°C)	Parabolic Trough	11520 ft² (1070 m²)
Ore-Ida Co.	Ontario, Oregon	Potato Frying	Construction	Steam 300 PSI	417°F (214°C)	Parabolic Trough	9500 ft² (883 m²)
Nestle Enterprises	Santa Isabel, Puerto Rico	Fruit Juice and Nectar Pasteurizing	Design	Water	210°F (99°C)	Evacuated Tube	50000 ft² (4645 m²)

Figure 2. Selected data for four solar IPH projects

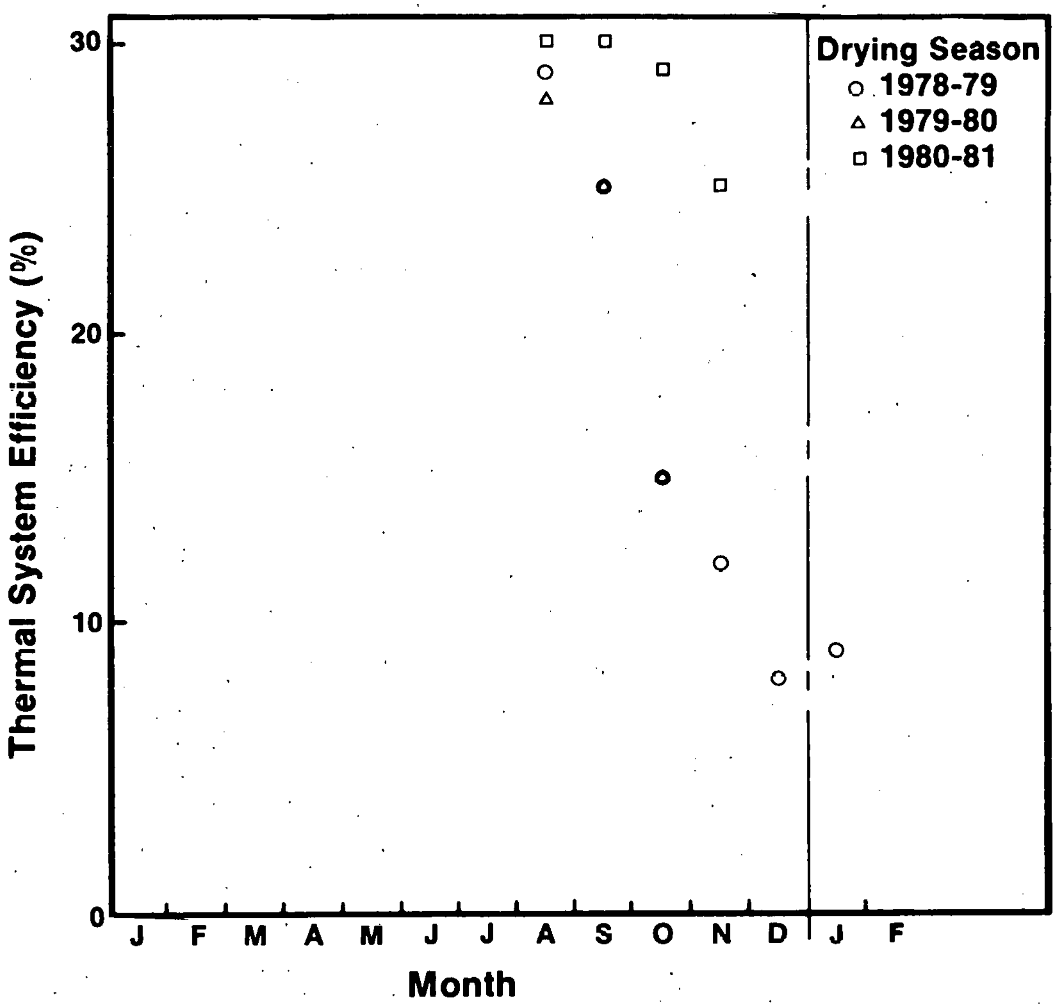

Figure 3. Performance of the L&P Foods system

prediction. System energy delivery is being compared to prediction for actual insolation and weather conditions in order to gain a more complete understanding of system performance. Thermal line losses are higher than design values, and the parasitic losses inherent in a flash system are significant. In addition, steam trap losses in the flash tanks and abnormal thermal losses associated with freeze protection have been identified. The performance data for March through October (1980) are given in Figure 4.

Ore-Ida: This application, currently under construction, utilizes solar-produced 200 psia steam at 214°C (417°F) to heat oil, through a heat exchanger, to fry potatoes. Line-focus Suntec parabolic troughs in a 883 m^2 (9500 ft^2) array generate hot water at 249°C (480°F) and 600 psia, which is then flashed to operating conditions in a flash tank. The steam from the flash tank interfaces with the plant process steam through a simple connection into the steam main.

The conceptual design reviewed three methods of producing the steam. These included use of a heat transfer fluid in the first alternative. FDA regulations, however, preclude the use of silicone oil to produce process steam without an intermediate unfired steam generator, adding to the cost and complexity of the system. Given this constraint, the two pressurized water systems had an edge on technical and cost merits, with the flash system being chosen as marginally superior in this particular case. In general, FDA and USDA regulations warrant careful attention in the introduction of solar process heat into the food industry.

The original design for this project called for a roof-mounted collector field. Subsequent analysis determined that, in fact, the roof was inadequate to withstand the collector loading and a ground-mounted array was more attractive than attempting to strengthen the existing roof. In contrast to the selection of the flash steam system in this and the J&J project, other conceptual designs for IPH steam systems have also chosen to generate steam in an unfired boiler heated by a heat transfer fluid which passes directly through the collector field.

Nestlé Enterprises: This hot water system (Ref. 3) is being designed primarily for fruit juice and nectar pasteurizaiton at 99°C (210°F). Secondary uses of the collected energy are boiler preheat and cleanup operations. Pasteurization is normally accomplished in an APV pasteurizer with steam-heated hot water; with solar, the hot water supplied via hot water storage (75,000 gal.) will be connected directly to the APV water loop. A schematic of the system is shown in Figure 5.

Located in Puerto Rico, this site is characterized by high ambient temperature, good insolation, and a moderately high diffuse/direct insolation ratio. Both evacuated tube and parabolic trough collectors appeared suitable for this application on the basis of the cost of delivered energy. However, the strong interest of the industrial partner in the use of low maintenance nontracking collectors at this more remote location led to the recommendation of evacuated tube collectors for the 4645 m^2 (50,000 ft^2) array. The large hot water storage system in this design is typical of food processing solar system requirements. An unusual feature, however is that the storage water level will drop slowly during the week due to the direct use of storage water for end-of-day cleanup. The tank will be replenished and heated over the weekend during plant shutdown. The solar system is designed to provide almost 60% of the

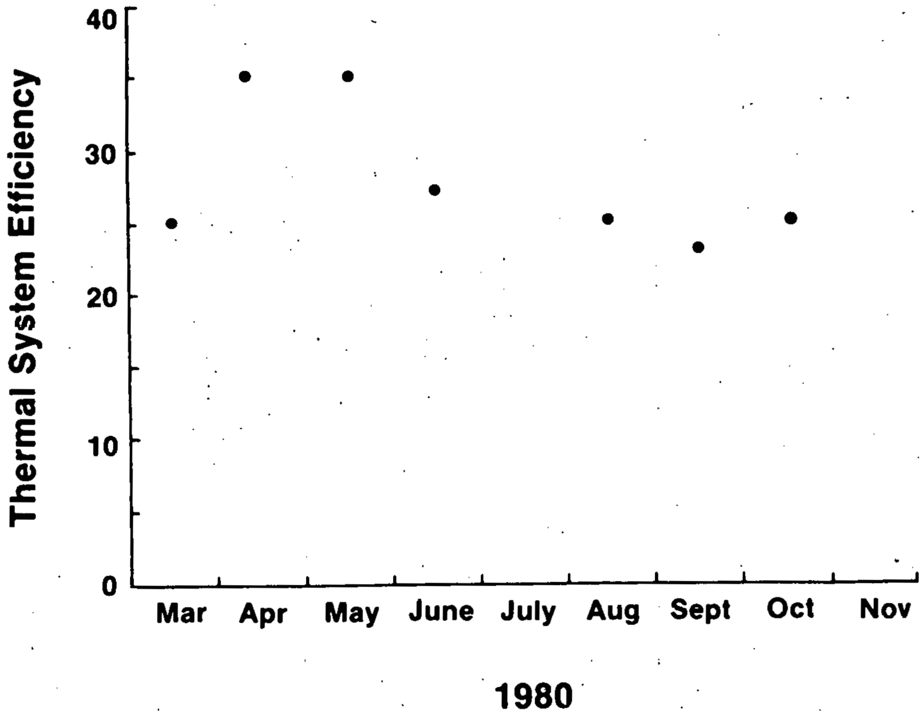

Figure 4. Performance of the Johnson & Johnson system

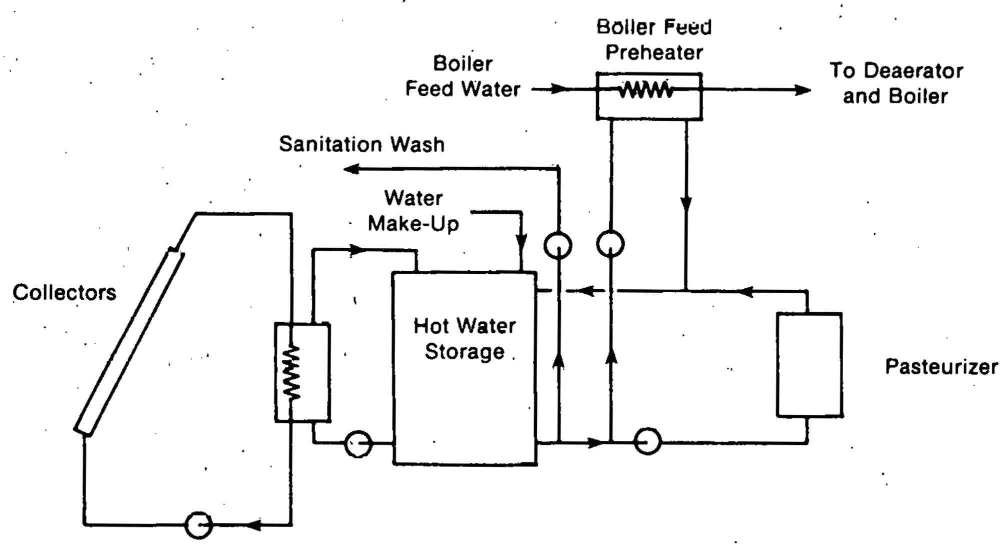

Figure 5. Solar System schematic of the
Nestle Enterprises, Santa Isabel Plant, P.R.

the annual needs, an important contribution in a locale fully dependent on imported oil.

For low-temperature applications such as this, it is apparent that a variety of collector technologies-parabolic trough, Fresnel lens, evacuated tube, flat plate-should be considered in the temperature range from 140°F to 200°F, and numerous competing and important design issues must be carefully weighed in the light of specific project requirements.

SUMMARY

The DOE program of solar industrial process heat field tests has shown solar energy to be compatible with numerous industrial needs. Both the operational projects and the detailed designs of systems that are not yet operational have resulted in valuable insights into design and hardware practice. Typical of these insights are the experiences discussed for the four projects reviewed in this paper. Future solar IPH systems should benefit greatly not only from the availability of present information, but also from the wealth of operating experience from projects due to start up in 1981.

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