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# PRELIMINARY OPERATIONAL RESULTS OF THE INDUSTRIAL PROCESS HEAT FIELD TESTS

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## ABSTRACT

There are currently six DOE-funded solar industrial process heat (IPH) field tests which have been operational for one year or longer. These are all "low temperature" first generation projects which supply heat at temperatures below 100°C--three hot water and three hot air. During the 1979 calendar year, personnel from the Solar Energy Research Institute (SERI) visited all of these sites; this paper describes the performance and cost results obtained for each project and discusses the operational problems encountered at each site.

## 1. PROJECT DESCRIPTIONS AND OPERATING EXPERIENCES

In this section a brief description of each of the six projects studied is given and the problems encountered at each site are summarized. More detailed project descriptions can be found in Ref. 1.

### 1.1 Campbell Soup Plant, Sacramento, CA

In this, the first of the six projects to become operational, a once-through system is used. Well water at approximately 21°C is pumped at $0.789 \ l \ s^{-1}$ through $413.9 \ m^2$ of flat plate collectors, then through $267.6 \ m^2$ of Acurex parabolic troughs, into a $71.9 \ m^3$ storage tank, and finally to a can washing line. A steam heat exchanger is used to supply the final boost to 91°C when needed.

One of the first problems encountered at this plant was an unexpected shutdown of the solar can washing line in order to change the type of soup. Since the solar system was dedicated to that one can washing line, it sat idle for several weeks.

Except for some condensation on the inside of the collector glazings, the flat plate collectors have held up well. Breakage of the glass tubes which cover the absorber pipes in the troughs has resulted from inadequate clearance for thermal expansion. This problem has been corrected in newer collector models.

Flow control and measurement have been major problems. The digital flow valve originally installed did not function properly due to surges in line pressure and was replaced with a valve that varies flow according to the time of day. The original flowmeters failed and were never replaced. In addition, the data logger and magnetic tape recorder failed due to excessive heat at their location in a sunlit stairwell. An exhaust fan was installed to cool the data logger, but the magnetic tape recorder has not been replaced until recently.

An effort is being undertaken to correct many of the problems that have occurred at this site. In addition, a data reduction procedure is being set up to ensure that data is reduced on a biweekly basis.

### 1.2 Riegel Textile Corp, LaFrance, SC

In this plant, a pressurized water/ethylene glycol mixture flows through $620.6 \ m^2$ of GE evacuated tube collectors at $4.7 \ l \ s^{-1}$ and the collected heat is transferred via two heat exchangers, first to storage and then to a dye beck. A $30.3 \ m^3$ storage tank is used to store heat when the beck is not operating.

Several problems have resulted in low energy delivery. Nighttime thermal losses from fluid in the collector loop have been high, resulting in an estimated 10% decrease in daily performance. The flow rate supplied by the pump has been approximately 75% of the design value, which has decreased collector efficiency by an estimated 5%. Additionally, the collector headers were not properly insulated, resulting in thermal short circuits to the collector frame. This problem has been aggravated by leaky collector grommets that have allowed insulation to get wet.

Approximately 1% of the glass tubes broke during installation. Another 3% broke when the collectors were thermally shocked with cold water during a stagnation condition. To prevent the collectors from being filled when they are overheated, an overtemperature indicator has been added and the circuit breakers which control the collectors' circulation pump have been relocated.

Other problems have included collector leaks and contamination of reflectors by boiler stack effluents. A program is currently underway to correct the existing problems.

### 1.3 York Building Products, Harrisburg, PA

In this project a water/ethylene glycol mixture is heated in 856.2 $m^2$ of AAI multiple reflector linear concentrators at a flowrate of 26.8 l $s^{-1}$. The heat is supplied via a heat exchanger to 189.0 $m^3$ of water in the underground "rotoclave" where concrete blocks are cured.

The most visible problem at this project has been the deterioration of the black chrome selective surface on the absorber pipes, which are exposed to the elements. Heavy rust has occurred in many places. It is believed that either the nickel substrate was of insufficient thickness or the selective surface was otherwise improperly applied. Other collector problems have included mirror cracking due to inadequate allowance for thermal expansion, and mirror desilvering. Modifications were needed to the type of grease used in the drive motors of the mechanical tracking mechanism. Also the drive motor wires were too thin for the long run lengths and were replaced with a heavier gauge.

A major problem occurred on January 13, 1979 when a reverse thermosiphon flow at night froze the heat exchanger, damaging the tube bundle. The heat exchanger was replaced within six weeks and check valves were added to prevent a recurrence. As with many of the other projects, there have been numerous problems with the data logger.

### 1.4 Gold Kist Soybean Plant, Decatur, AL

At this site, 1217.4 $m^2$ of Solaron flat plate air collectors supply 12.7 $m^3$ $s^{-1}$ of combustion air to a soybean dryer house which requires a total of 212.4 $m^3$ $s^{-1}$ of air.

The most frustrating problem at this site has been the collection of soybean chaff and oil on the collector glazings. This residue evidently polymerizes in the sun into a gummy substance that is difficult to remove. An automatic washing system has been instituted, which appears to be capable of maintaining the collectors in a clean state.

One surprising problem was caused by plant operating practices. Maintenance on the dryers is performed for about 6 hours every two days during which time the dryers are shut off. After collector installation, this maintenance continued to be performed during the day. Since there is no storage, no energy could be collected during these maintenance periods. This situation continued for several months, but was eventually corrected.

Other problems have included a data logger failure when a heater failed, water seepage into the duct insulation, and fan belt slippage causing low flowrates in the collectors.

### 1.5 J. A. LaCour Kiln Services, Canton, MS

Although considered a hot air project, this system circulates water from a 234.1 $m^2$ array of Chamberlain flat plate collectors to a 18.9 $m^3$ storage tank. A finned tube heat exchanger is used to provide heat to two hardwood lumber kilns. The sawtooth collector array includes an additional 223 $m^2$ of reflectors.

A serious problem occurred at this plant soon after the solar system became operational. During a period of low heat usage the storage tank overheated, causing failure of the CPVC pipe connecting the storage tank to the collectors. The PDP-11 computer was sprayed with hot water and steam, and took several months to repair. To prevent a recurrence, all of the CPVC pipe was replaced with steel pipe, a high temperature pump cutoff was installed, and a larger pressure relief valve was installed.

Another problem has been a poor turndown ratio on the gas burner in one of the kilns. The solar system is designed to add heat only when the gas furnace and blower are operating. Since one burner can only be turned down to 58.6 $kW_t$, solar energy can only supply heat in excess of this minimum. The contractor hopes to install new gas valves which will provide better turndown ratios.

Other problems at this plant have included collector manifold connection leaks due to overtightening, failure of flowmeters, and poor collector array drainage (solved by propping supports under piping). In April of 1979, a flood caused serious damage to the data acquisition system, which is still being repaired.

### 1.6 Lamanuzzi and Pantaleo Foods, Fresno, CA

This system consists of 1951 $m^2$ of flat plate air collectors that supply hot air to a 396 $m^3$ rock storage bin and to 1 of 14 dehydration tunnels for prunes and raisins. In addition, a 3.66 m diameter heat recovery wheel transfers heat from the tunnel exhaust to the fresh air collector inlet.

The most visible problem at this site is the condition of the Lexan glazings on the collectors. The 0.051 cm (0.020 in.) Lexan cover plates have visibly yellowed, and many have cracked due to compression failure. Reduction of collector array efficiency has not been observed, however, and analysis of a piece of glazing returned to SERI indicated a transmissivity of 80%--much better than a visual inspection might suggest.

A problem peculiar to this site is vandalism. Local gangs of youths have periodically come to the plant at night and caused damage. This has included striking the glazings with boards and carving initials in the duct insulation.

Other problems have included non-uniform flow in the rock bin due to uneven settling, damage of damper motors by rainwater, and electrical problems with the data acquisition hardware.

## 2. PERFORMANCE RESULTS

Data acquisition systems have generally been unreliable for these projects; the number of days of data available for each project is given in the first column of Table 1. For this study, energy values for each project have been summed and divided by the number of days over which the parameters were measured to yield an average "per day" value for each parameter. To make efficiencies more comparable, all are based on the total insolation incident on the plane of the collector array.

In comparing the projects one must keep in mind that a number of uncontrolled variables are involved. If one project recorded data only during cold months or cloudy days, and another has data available only for warm months or sunny days, comparing energy collected per day for the two projects is misleading. Type of collector, site location, process temperature, load profile and state of repair also have important impacts.

Referring to Table 1, the utilization column refers to that fraction of time the solar system was used by the process during the time that the solar system was operable. The availability refers to that fraction of time the solar energy system was mechanically available to supply energy to the process. Specifically,

$$\text{Utilization} = \frac{\text{Period of Solar System Operation}}{\text{Total Period of Study} - \text{Solar System Downtime}}$$

$$\text{Availability} = \frac{\text{Total Period of Study} - \text{Solar System Downtime}}{\text{Total Period of Study}}$$

Table 1 indicates that, in general, availability of the solar energy systems has been good. For three of the plants, however, utilization has been somewhat lower. The seasonal nature of drying operations is reflected in the utilization values for L & P and Gold Kist. The Campbell Soup utilization figure of 82% is due in part to the shutdown of the solar can line.

Three types of efficiencies are given in Table 1: $\eta_c$, collector array efficiency; $\eta_T$, system thermal efficiency; and $\eta_s$, net system efficiency. These are defined as follows, where $I_T$ is the total insolation:

$$\eta_c = \frac{\text{Energy Collected}}{I_T}$$

$$\eta_T = \frac{\text{Energy Delivered}}{I_T}$$

Table 1. System Performance of the IPH Field Tests

| Project | No. Days Data | System Utilization (%) | System Availability (%) | $\eta_c$ Collector Array Efficiency (%) | $\eta_T$ Thermal System Efficiency (%) | $\eta_s$ Net System Efficiency (%) | Parasitic[a] Fraction (%) |
|---|---|---|---|---|---|---|---|
| Campbell Soup | 62 | 81.5 | 82.0 | 31.5 | -- | -- | 4.2 |
| Riegel Textile[b] | 3 | 97.0 | 97.6 | 18.3 | 9.7 | 8.1 | 3.4 |
| York Building Products | 233 | 100.0 | 91.2 | 11.9 | 9.9 | 8.7 | 3.8 |
| Gold Kist | 242 | 61.3 | 100.0 | 26.4 | 25.0 | 19.1 | 8.3 |
| LaCour Kiln Services | 180 | 100.0 | 94.0 | 36.3 | 33.5 | 32.5 | 1.0 |
| L & P Foods | 123 | 33.7 | 100.0 | 27.3 | 24.6 | 17.5 | 9.6 |

[a] [Parasitic energy (GJ) ÷ Energy Collected (GJ)] × 100%.

[b] Performance results available for this site are included for information, but poor statistical basis should be noted.

$$\eta_s = \frac{\text{Energy Delivered} - (\zeta \times \text{Parasitic Energy})}{I_T}$$

The energy collected is calculated from the rise in temperature of the fluid across the collector array. The energy delivered is defined as the energy supplied to the process from the solar system. It takes into account all the other losses in the system.

The factor $\zeta$ in the equation for net system efficiency is the ratio of the efficiency with which the on-site boiler would utilize displaced fossil fuel to the overall efficiency with which a central electric generating plant would utilize that fuel [2]. A value of 2.7 was used in this study.

Table 1 shows collector array efficiencies varying from 11.9% at York to 36.3% at LaCour. The very low array efficiency at York is due mainly to the fact that this site has experienced hazy weather, and the concentrators collect only direct radiation. Also, the deterioration of the absorber coating has decreased collector performance. A major factor in the high efficiency for LaCour is the large area of planar reflectors used. The efficiency is calculated based on the insolation striking only the collectors, so the result is high. The reflectors are much cheaper than the collectors, however, and do not increase the roof area needed to accommodate the sawtooth collector array, so this is probably a fair basis for calculation.

The Campbell Soup efficiency is based on hand calculations with no direct collector flow measurements, and errors are estimated at 10% or more. The collector array efficiency for L & P (27.3%) would be higher if the air supplied to the collector inlet were not preheated by the heat recovery wheel. The somewhat low (18.3%) collector array efficiency for the Riegel evacuated tubes can be attributed partly to the lower-than-expected flow rate and contamination of the reflectors. Also, the collector outlet temperatures have been as high as 132°C.

For several projects, thermal system efficiencies are on the order of three to five percentage points less than array efficiencies, this being the result of both operating and overnight thermal losses. The Riegel plant, however, shows a considerable drop from 18.3 to 9.7%. Although reduced data is limited, we believe this is an indication of sizeable overnight losses due to the large fluid inventory in the collector piping.

When parasitic power is taken into account the systems using liquid collectors show relatively small drops in efficiency. The two systems using air collectors, however, exhibit a high parasitic power penalty because of their fan power requirements. Gold Kist and L & P show a drop from thermal system efficiency to net system efficiency of 5.9 and 7.1 percentage points respectively. If a direct electrical energy equivalent (i.e. $\zeta = 1$) is used, the parasitic energy for these projects represents 8.3% and 9.6%, respectively, of energy collected compared to values of less than 5% for the other projects. The particularly low efficiency for L & P is due in large part to pressure drop across the rock bin.

A word should be said about energy conservation in these plants. In most cases, no detailed energy conservation measures were taken in conjunction with the installation of the solar system. The L & P dehydration plant is a notable exception. Data indicates that the heat recovery wheel has provided more than two and one half times as much energy to the dehydrator as the solar system and has a payback period of less than one year. There are several other energy conservation measures that could be used in this plant and which would provide rapid payback. Indications are that, in this respect, the L & P plant is not unusual. It is evident that energy conservation should precede solar implementation in commercial industrial applications; precisely the same principle has been recognized in building heating and cooling applications for some time.

## 3. COSTS

Costs for the design and construction of each project are summed to give total capital cost in column 1 of Table 2. Since future privately funded projects would incur considerably lower design costs and would not employ detailed data acquisition systems, column 2 lists construction costs minus data acquisition costs. Values of $\$(\text{GJ yr}^{-1})^{-1}$ and $\$\text{m}^{-2}$ are presented in Table 2, based on each of these cost figures.

The values of energy delivered per day from the performance calculations have been extrapolated to obtain the quantity of energy which would have been collected during a year of operation, assuming that the systems would perform at all times as they did during the periods for which data was available. The values of GJ $\text{yr}^{-1}$ thus obtained are given in column 3 of Table 2. Note that for Riegel Textile in particular, a large extrapolation was required.

Referring to columns 4 and 5, the least expensive project based on energy delivery is L & P, due to the low cost of its collector array (see below). Riegel had the highest cost in terms of energy delivery due to its low system efficiency. The York energy cost is high, due to very low collector array efficiency. The Gold Kist plant has a high cost, due largely to its expensive collector support structure.

Table 2. Costs of the Low Temperature IPH Field Tests

| Project | Total Capital Cost ($) | (Construction Cost)-(Data Acquisition) ($) | Extrapolated $GJ(yr)^{-1}$ | Extrapolated[a] $ $(GJ\ yr^{-1})^{-1}$ | Extrapolated[b] $ $(GJ\ yr^{-1})^{-1}$ | $(\$\ m^{-2})^a$ | $(\$\ m^{-2})^b$ |
|---|---|---|---|---|---|---|---|
| Campbell Soup | 785,150 | 549,005 | -- | -- | -- | 1152 | 805 |
| Riegel Textile | 868,660 | 568,735 | 389 | 2233[c] | 1462[c] | 1399 | 916 |
| York Building Products | 563,200 | 394,510 | 393 | 1433 | 1004 | 658 | 461 |
| Gold Kist | 1,034,670 | 733,810 | 785 | 1318 | 935 | 850 | 603 |
| LaCour Kiln Services | 357,100 | 219,555 | 390 | 916 | 563 | 1528 | 938 |
| L & P Foods | 813,890 | 517,000 | 1197 | 680 | 432 | 418 | 265 |

[a] Based on total cost.

[b] Based on construction cost minus data acquisition cost.

[c] Cost results for this site are included for information, but poor statistical basis should be noted.

The costs of these projects in terms of $ $m^{-2}$ are shown in columns 6 and 7 of Table 2. Most noticeable is the very low cost for the L & P project. The contractor on this project was a university professor. He and his students built the collectors themselves and assembled them on-site. Students were paid standard union wages, but overhead and material costs were very low. Note that the exclusion of data acquisition and design costs in column 7 greatly reduces the cost of the LaCour project. Since this project has such a small collector area, design and data acquisition constitute a large fraction of the cost.

Since these were first-round projects, future prices can be expected to drop considerably. For example, in the first three rounds of government-funded solar heating/hot water projects for commercial buildings, average costs (excluding design and data acquisition) dropped from $1313 $m^{-2}$ to $517$m^{-2}$ [2]. Also, privately funded projects can be expected to be lower in cost than government-funded projects, due to lower overhead and indirect costs, and more conventional construction scheduling and management techniques.

## 4. CONCLUSIONS

Based on the available data, some preliminary conclusions can be drawn that should prove useful in future projects. These are:

- Degradation of collector absorber surfaces and glazings is still relatively common.
- Problems similar to those encountered in the solar heating and cooling of buildings program occur in IPH applications. Better education in system design engineering and installation is needed.
- Parasitic power has been a major factor in the low system efficiency of the two systems employing air collectors.
- Thermal losses from piping, both during operation and overnight, can seriously degrade system performance.
- Data acquisition systems have generally been very unreliable.
- Environmental contaminants can seriously affect solar collector performance.
- Certain adjustments in plant operation schedules, hardware, and control logic are often needed to optimize the utilization of a solar energy system.
- Energy conservation opportunities are abundant in industry. Just as in the solar heating and cooling of buildings, energy conservation should precede solar implementation.

Further information can be found in Ref. 3.

## 5. REFERENCES

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