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SERI/TP-333-427
UC CATEGORY: UC-59B

CONF-791024--7

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TWO CASE STUDIES OF THE APPLICATION OF SOLAR ENERGY FOR INDUSTRIAL PROCESS HEAT

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OCTOBER 1979

PRESENTED AT THE SOLAR INDUSTRIAL
PROCESS HEAT CONFERENCE,
OAKLAND HYATT HOUSE, OAKLAND, CALIFORNIA,
OCTOBER 31-NOVEMBER 2, 1979

PREPARED UNDER TASK NO. 3424.3

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A Division of Midwest Research Institute

Prepared for the
U.S. Department of Energy
Contract No. EG-77-C-01-4042

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ABSTRACT

Case studies of industrial process heat (IPH) have been performed by the Solar Energy Research Institute (SERI) on selected plants in metal processing, oil production, beverage container manufacturing, commercial laundering, paint (resin manufacturing), and food industries.

For each plant, the application of solar energy to processes requiring hot water, hot air, or steam was examined, after energy conservation measures were included. A life-cycle economic analysis was performed for the solar system compared to the conventional energy system. The studies of the oil production facility (oil/water separation process) indicate that it could economically employ a solar hot water system immediately. The studies of solar energy applied to the beverage container process (solar air preheat system with partial recycle of oven exhaust gases) indicate a 7.5-yr payback period, based on a solar system installation in 1985.

INTRODUCTION

Industry consumes about 36%-37% of the U.S. gross energy demand. Fifty to seventy percent of this demand is for industrial process heat (IPH) - the thermal energy used in the preparation and treatment of manufactured goods [1]. Since approximately 27% of the total IPH requirement is at temperatures below 288° C (550° F) [1], commercially available solar collectors could potentially be applied to this large market.

SERI is performing IPH case studies which include solar applications analyses for individual plants. The objectives of the program are: 1) to determine the near-term feasibility of solar IPH in selected industries; 2) to identify energy conservation measures and energy-saving process modifications; 3) to test SERI's solar IPH analysis software (PROSYS/ECONMAT) [2] and discover improvements; 4) to identify conditions of IPH systems affecting the potential use of solar energy; and 5) to disseminate information to the industrial community about solar IPH applications.

Solar IPH case studies were performed using PROSYS/ECONMAT for plants in several industries. A site visit and plant tour were first conducted. Then, during meetings between SERI and the plant staff, processes were chosen for study and data for heat and mass balances were gathered. Energy conservation and process reconfiguration measures (if any) were identified, solar systems designed by SERI were sized and priced, and economic analyses were conducted using PROSYS/ECONMAT. The results were then submitted to the plant staff for approval.

RESULTS

Two case studies of a crude-oil/water separation facility and an aluminum beverage container manufacturing plant are discussed in this paper. (Reference 3 documents all case studies of 1978.)

Oil/Water Separator

A case study was performed of a crude-oil/water separation facility (heater-treater) in Wyoming. The facility operates 24 h/d, 7 d/wk, year-round. A schematic of the separation process is shown in Fig. 1. The emulsion of crude oil and water, in a ratio of about 59 to 1 by volume, enters the separator tank at 27°C (80°F) from a nearby oil well at a rate of 329 kg/h (725 lb/h). The emulsion is heated in the separator tank to 57°C (135°F) by a propane burner system at a heat rate of about 2.1×10^7 J/h (2.0×10^4 Btu/h); this corresponds to an annual energy use of 1.85×10^{11} J (1.75×10^8 Btu). At 57°C the crude oil and water separate. The less-dense crude oil floats to the top of the tank, where it is drained off, and the water is drained from the bottom of the tank.

Many larger oil wells produce natural gas, which is used as the fuel for the separators. Small wells, such as the one under consideration, produce little or no gas; propane is the sole fuel for the separator under study. As of March 1979, the firm was purchasing propane at 14¢/l (52¢/gal.), which is equivalent to \$5.33/GJ (\$5.62/10^6 Btu). Approximately 5190 l/mo (1370 gal./mo) of propane are used by the separator, resulting in an annual propane energy input of 1.57×10^{12} J(1.49×10^9 Btu). Since 1.85×10^{11} J/yr (1.75×10^8 Btu/yr) are required for heating the crude-oil/water emulsion, the net energy utilization efficiency is about 11.7%.

The low efficiency results from the design of the separator tank; this design has little potential for additional energy savings. Additional insulation could be added to the tank to reduce the losses [estimated to be 3.6×10^6 J/h (3.4×10^3 Btu/h) at -17.8°C (0°F)], but an insignificant amount of energy would be saved compared to the amount lost in the burner exhaust gases. Insufficient information was available to estimate how much of the burner exhaust gases, if any, could be recycled to the burner to reduce the propane usage.

The computer codes PROSYS/ECONMAT were used to analyze applications of solar energy for heating the separator tank. Three systems were examined: 1) an oil-through-collector system in which the crude-oil/water emulsion is sent from the well directly to the collector field, heated to the process temperature, and then sent to the separator tank; 2) an external heat exchange system in which the crude-oil/water emulsion is heated to the process temperature before entering the separator tank via heat exchange with a closed-loop liquid collector system; and 3) an in-tank exchange system in which the crude-oil/water emulsion is sent to the separator tank from the oil well and is heated to the process temperature by a closed-loop liquid collector system via a heat exchanger inside the separator tank.

The external exchange system shown in Fig. 2 is preferred because it avoids, for example, the necessity for system draindown each evening or modification of the separator tank assembly. The PROSYS simulation for this system indicates that 18.0 m^2 (193 ft^2) of a commercially available parabolic trough collector is the most cost-effective solar system. The parabolic trough collector is preferrable to a flat-plate collector because of the increased average collector temperature in the external exchange system (58° C, 137° F) as compared to the oil-through-collector system (47° C, 117° F): the thermal efficiency of the parabolic trough is higher than a flat plate at the increased operating temperature.

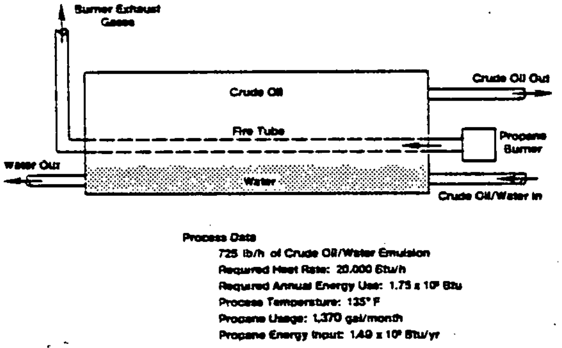


FIG. 1. CRUDE OIL/H_2O SEPARATOR TANK

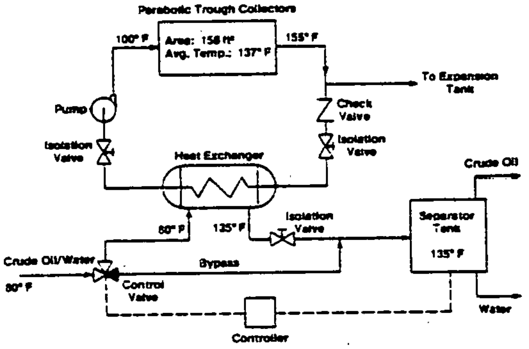


FIG. 2. CRUDE OIL/WATER SEPARATION FACILITY: EXTERNAL HEAT EXCHANGE SYSTEM

The external heat exchange system was sized to displace about one-third of the process energy requirement during a typical year (6.8 x 10^{10} J or 6.4 x 10^7 Btu). The solar system displaces 5.8 x 10^{11} J (5.5 x 10^8 Btu) of propane energy because of the low propane utilization efficiency.

The parabolic trough collectors used in the simulation of the external exchange system cost a total of $5900 in 1979. The remainder of the system costs are estimated to be $6800 [4,5,6], resulting in a total installed cost of $12,700. The life-cycle cost analysis, using ECONMAT, shows that the external exchange system has a positive net present value of $35,600 (assuming a 20-year solar system lifetime) when compared to the conventional propane system. Thus, the solar system is competitive with the propane system (which is expensive and inefficient) and has a payback period of less than 3.4 yr for a 1979 startup. Table 1 summarizes the solar system parameters.

Aluminum Beverage Can Manufacturing

An IPH case study was done of an aluminum can manufacturing line in Colorado. The process consists of shaping and trimming the can bodies, followed

Table 1. SOLAR SYSTEM PARAMETERS

Parameter	Crude Oil/Water Separator	Aluminum Can Manufacture
Collector	parabolic trough	parabolic trough
Collector area (m^2)	18.0	274
Process temperature (°C)	57	87
Average annual solar energy supplied (J)	6.8×10^{10}	1.7×10^{12}
Average annual energy displaced (J)	5.8×10^{11}	5.9×10^{12}
Collector cost (1979$)	5,900	140,000
Total system cost (1979$)	12,700	152,000
Net present worth (1979$)	35,600	27,000
Capacity cost (1979$/GJ/yr)	178	91
Delivered energy cost (1979$/GJ)	20	10
Payback period (yr)		
1979 startup	3.4	16.1
1985 startup	2.2	7.5

by washing and drying. The cans are printed and bottom coated, passed through a direct-fired oven to cure the ink and coating, and cooled. They are then coated internally, cured in a direct-fired oven, cooled, necked, pressure tested, and palletized.

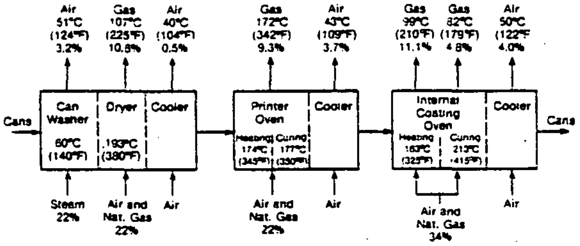
Process heat is supplied to heat the wash water, dry the cans after washing (direct-fired), and heat the printer oven and internal coater oven (see Fig. 3). The plant operating schedule is 7 d/wk, 24 h/d, year-round. With shutdowns, the average operating time is 24 h/d, 6.5 d/wk, 50 wk/yr.

Figure 3 summarizes the results of the energy balances and shows that some 48% of the estimated total energy input to the process of 4 GJ/h (3.8×10^6 Btu/h) leaves in the exit hot gases. The remainder leaves as heat of vaporization of water, heat losses to the building air, and sensible heat of the cans and can conveyor. The fuel currently used is natural gas at \$1.93/GJ (\$2.04/10^6 Btu) of heating value (Dec. 1978 price).

An energy conservation analysis indicated potential for substantial energy recovery in the dryer, ovens, and coolers in the form of the sensible heat of the exhaust gases. One means of recovery would be heat transfer between the exhaust gases and incoming air, but, since it is gas-to-air exchange, relatively large heat exchangers would be required. The most direct recovery of this energy would be to reuse the gases. Whether or not a solar system is employed, the air used to cool the cans should be used as a preheated air supply to the gas burners, saving 8.2% of the total IPH requirement. Some of the hot combustion product gases might be recycled. These alternatives were considered in the solar applications analysis.

The application of solar energy to can manufacture was examined in three ways: 1) by using solar collectors to supply one-third of the total annual energy required for the dryer and ovens (i.e., 1/3 of 22 TJ/yr) via hot air at the maximum required process temperature of 213°C (415°F); 2) by employing individual collectors to supply energy via hot air or water to each unit at the maximum temperature required; and 3) by applying a reconfigured process air flow for make-up air preheating in the coolers and by recycling a portion of the hot exhaust gases (solar energy further preheating the make-up air). Solar energy is not competitive with efficiently used natural gas if the solar system supplies the same amount of energy as that supplied by the displaced natural gas [conditions (1) and (2)]. However, when solar energy is used together with air preheating and partial recycle of hot off-gases, one solar system has a 7.5-yr payback with a 1985 system startup (see Table 1). This design recycles the hottest half of the off-gas streams, using the can coolers to preheat incoming air and employing solar collectors to further preheat this air.

Figure 4 presents the final air flow configuration. In this configuration, incoming air passes through the can coolers. The hottest air, that from the internal-coating oven can cooler and about one-third of that from the print oven can cooler, is circulated to solar collectors where it is heated to 87° C (189° F). The off-gas from the print oven and the can washer/dryer, and about two-thirds of the off-gas from the internal-coating-oven heat section are mixed with the solar preheated air. This mixed gas stream is then used as preheated combustion air for the gas-fired units: the can washer/dryer, the print oven, and the internal-coating oven.



- Estimated Total Energy Input 4 GJ/h
- Percentages are Sensible Heat in Gas (Relative to 31°C, 88°F) as % of Total Energy Input
- Sensible Heat of Off-Gases Accounts for 48% of Energy Input. Balance is Due to Water Evaporation and Heat Losses

FIG. 4. FLOW DIAGRAM OF RECYCLING HOT GASES AND SOLAR PREHEAT

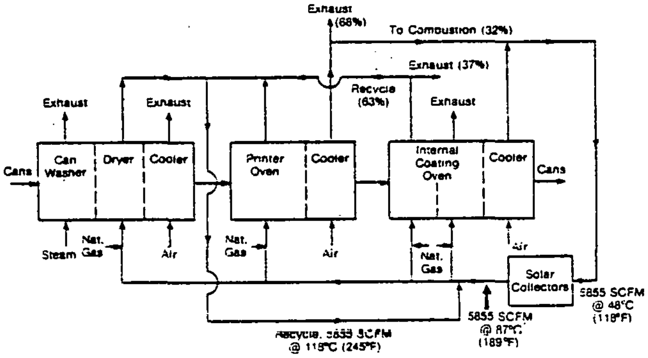


FIG. 3. METAL CONTAINER PROCESS ENERGY FLOW DIAGRAM

The can coolers supply 5% of the total process energy requirement (for an average of 10 of the 24 operating hours per day), solar energy provides 12%, and the recycled gases supply 27%. The remaining 56% is supplied by burning natural gas. The energy recovery from the can coolers and some of that from the recycle of hot gas can be achieved without the solar system. However, more oxygen-depleted gas can be recycled with the solar system because the solar-heated portion of the air stream has not been oxygen-depleted by combustion.

The advantage of this configuration is that although the solar system supplies 0.48 GJ (0.45 MBtu)/h, the natural gas displaced is equivalent to 1.8 GJ/h (1.7 MBtu/h).

CONCLUSIONS

Based upon the solar IPH case studies, the following conclusions have been reached:

- For solar energy applications to be competitive over the next 10 years, one or more of four conditions should be met: 1) fuel costs for the existing IPH system are much higher than typical, or 2) the system uses fuel very inefficiently, or 3) solar collector/system costs are substantially reduced from present levels, or 4) the solar system displaces much more fuel energy than it supplies to the process. [This last condition can sometimes be achieved in direct gas-fired heating processes. Hot, oxygen-depleted exhaust gases can be recycled when solar energy is used (depending on process requirements) because less gas needs to be burned and, thus, less makeup oxygen must be supplied. Solar energy is best used in such cases to preheat the incoming makeup air before it mixes with the recycle air.]
- Near-term solar IPH potential is greatest for low-temperature applications in which solar system efficiencies are higher.
- Because of the great potential for industrial use of solar-heated air, additional R&D is needed for air collectors and air system components.

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