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REDUCING FUEL USAGE THROUGH APPLICATIONS OF CONSERVATION AND SOLAR ENERGY

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NOTICE

ABSTRACT

Solar thermal technology, coupled with aggressive conservation measures, offers the prospect of greatly reducing the dependence of industry on oil and natural gas. The near-term market for solar technology is largely in industrial processes operating at temperatures below 288° C (550° F). Such process heat can be supplied by the relatively unsophisticated solar equipment available today. The major part of process heat is used by industries operating high-temperature processes, such as the manufacture of iron and steel. However, a majority of industrial establishments use process heat below 288° C. The inherent diversity of circumstances allows favorable matches between solar technologies and industrial processes. The problems involved with the installation and maintenance of conservation and solar equipment are similar and place additional demands on the plant engineer's time. Both compete for scarce investment capital, and each complicates industrial operations and increases maintenance requirements. The government can stimulate each technology through tax incentives, research programs, and the dissemination of information. Technological innovations requiring new types of equipment and reducing the temperature requirements of industrial processes favor the introduction of solar hardware. The industrial case studies program at the Solar Energy Research Institute has examined technical, economic, and other problems facing the near-term application of solar thermal technology to provide industrial process heat. The plant engineer is in the front line of any measure to reduce energy consumption or to supplement existing fuel supplies. The conditions most favorable to the integration of solar technology are presented and illustrated with examples from actual industrial plants. Such information provides guidance to plant engineers assessing the feasibility of solar applications for their plants. It is also of value in planning long-term investments that might permit the easy retrofit of solar systems when suitable economic circumstances arise.

INTRODUCTION

The vast majority of enterprises using process heat in the manufacture of industrial goods use such heat at temperatures below 288°C (550°F). Typical applications include hot water for washing and heat for evaporative and drying processes. Industrial plants requiring process heat at temperatures greater than 288°C are few in number but extremely energy intensive. Figure 1 illustrates the breakdown of industrial process heat (IPH) use according to temperature (InterTechnology Corporation 1977). The petroleum refining industry is the predominant user of industrial process heat in the temperature range of 288° to 593°C (550° to 1100°F). At temperatures above 593°C, users of IPH include the iron and steel, stone, glass, and cement industries.

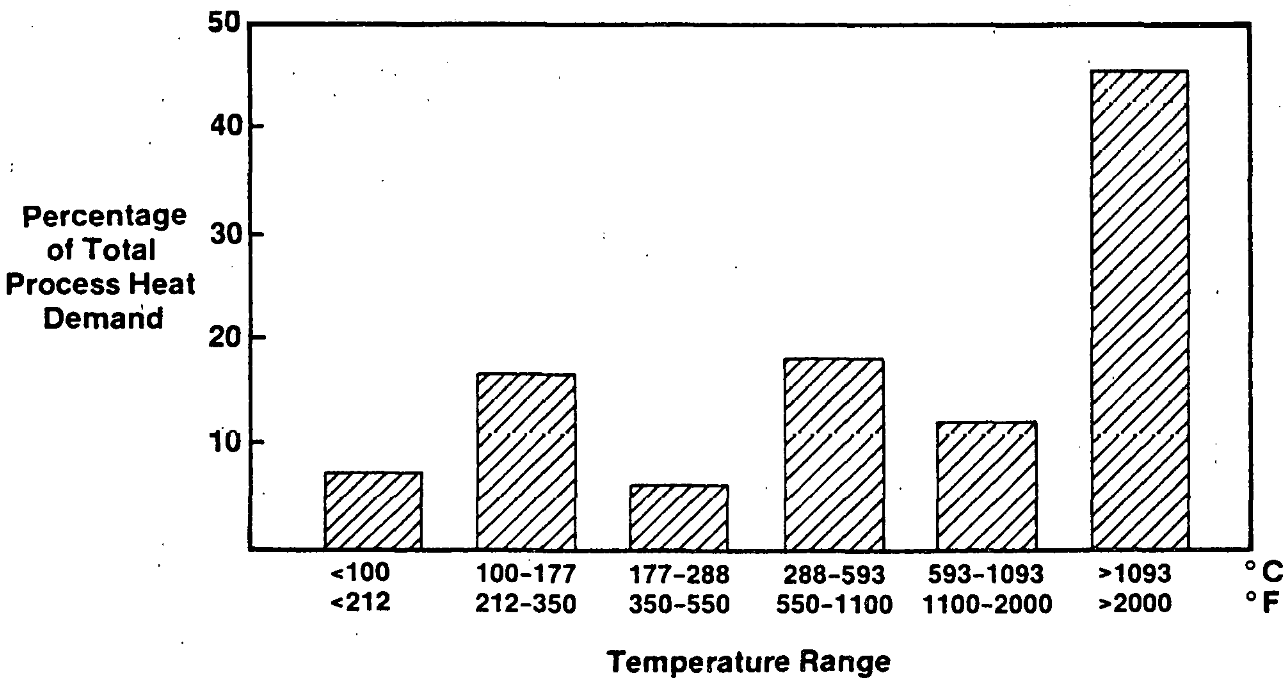


Figure 1. Distribution of Industrial Process Heat Demand by Temperature Range (1974)

Commercially available solar equipment, such as parabolic trough collectors, can produce temperatures up to about 288°C. Evacuated-tube collectors can operate to about 149°C (300°F) while flat-plate collectors and solar ponds can provide heat up to about 82°C (180°F).

To produce temperatures in excess of 288°C, solar technologies achieving high concentration ratios must be used. Point focus, parabolic dish collectors are under development and a demonstration project to test the central receiver "power tower" concept for electric power generation is planned for construction in Barstow, California. Difficult technical problems must be overcome before such technologies are commercially available to generate high-temperature process heat. At temperatures above 371°C (700°F), exotic heat transport media, such as molten salts or metals, are required for energy transport.

High-temperature operations require the resolution of problems associated with creep and thermal fatigue of receiver materials. Thus, in the short term, the major industrial potential of solar thermal technology is to provide heat for the vast number of plants running low-temperature processes, using commercially available and relatively well-proven solar components. The realization of this potential would have a large impact on the U.S. energy supply. The plant engineer will obviously play a leading role in any such development by influencing management decisions regarding solar energy investments and by operating and maintaining installed solar systems.

CONTROLLING ENERGY COSTS

In a period of rapidly rising costs of oil and natural gas, substantial economic benefits can be derived from reduced energy consumption. First-generation steps, generally nothing more than housekeeping measures, entail minimum expenditures and can produce large energy savings. Second-generation steps, perhaps involving the installation of heat recovery equipment, require more substantial capital investments and greater engineering inputs, yielding longer, but still attractive paybacks. Yet, such measures do not sufficiently compensate for rising energy costs. For example, a packaging plant in the midwestern United States cut energy consumption by 30% between 1972 and 1979. Nevertheless, total energy costs rose by 163%. The unit costs of electricity and natural gas increased by 222% and 409%, respectively. The trend in energy prices for the next few years looks as bleak, and further reductions in energy consumption are becoming increasingly difficult. Third-generation energy conservation measures involve technological changes in the industrial process. Thus, an industrial manager, after incorporating all feasible conservation measures, is faced with the choice of passing along increased energy costs to the consumer and risking the rejection of his product in the marketplace, or making the necessary expenditures to enable the use of a more economical source of energy.

In comparison to oil and natural gas, the availability and delivered price of coal is quite attractive in many areas of the United States. However, the cost of installation of a coal-burning furnace complete with fuel storage and solid-handling equipment can be up to eight times the cost of a similar furnace burning fluid fuels (Solar Thermal Test Facilities Users Association 1978, p. II-4). Environmental barriers are also major obstacles to the use of coal, particularly for small users or industries in urban areas.

Many industries have found that energy can be derived economically by burning biomass. For example, the pulp and paper industry meets a large fraction of its energy requirements by burning wood waste. Some food companies have been particularly innovative in deriving process heat from waste products such as peach pits, spent coffee grounds, and corn cobs.

The use of solar thermal technology to generate process heat is another alternative. Given the tremendous variety of plant engineering applications, favorable combinations of circumstances can arise such that solar thermal technology becomes at least marginally attractive, even at today's fuel prices.

In the past, cheap supplies of fuel oil and natural gas available to industry have not encouraged investments in energy-efficient equipment. These supplies are no longer cheap. However, financial problems face any means of reducing oil and natural gas consumption, including the application of solar thermal technology, since all such alternatives involve considerable capital expenditures.

The traditional use of payback period is inadequate in judging the value of long-term energy investments such as solar thermal IPH systems. Present-value-type calculations are required to gauge the worth of cash flows beyond the payback period. In addition, by allowing the deduction of fuel costs as an operating expense, the tax structure penalizes any measure taken to reduce conventional fuel use. Governmental action to equalize tax benefits could greatly stimulate energy conservation measures and the use of solar technology. When these factors are considered in a present value calculation, solar thermal systems may be more acceptable to industry.

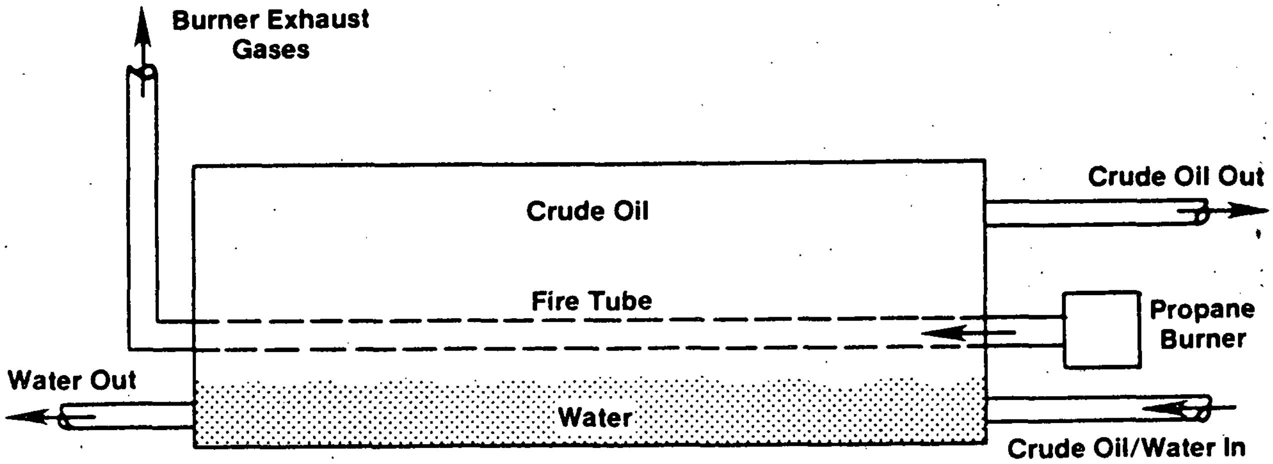
Reducing fluid fuel consumption, whether by substituting a forced-draft furnace with heat recovery for a natural-draft furnace, by installing a solar system, or by burning coal, will greatly complicate industrial operations. Increased maintenance costs and somewhat reduced operating flexibility are likely. Such technologies require not only substantial engineering design inputs but also considerable research and development. For instance, there is a great need to develop less expensive heat exchangers operating at low differential temperatures, and many materials problems involving corrosion need to be solved. The incorporation of these technologies into IPH systems will increase the responsibilities of the plant engineer.

CASE STUDY PROGRAM

As part of the IPH program carried out at the Solar Energy Research Institute (SERI), several industrial case study investigations have been performed (Hooker, May, West 1980). These studies are aimed at determining the near-term economic and technical feasibility of solar thermal technology to provide process heat. In addition, factors most favorable for solar energy applications have been identified, and some important insights have been gained regarding patterns of industrial energy use.

A crude oil dewatering facility is an example of a very simple process that can use solar energy economically. A schematic of the crude-oil/water separation facility is shown in Fig. 2. Propane is used to heat the emulsion from 27° to 57°C (80° to 135°F) in a very inefficient burner system via a fire tube through the middle of the tank. At 57°C, the emulsion separates into its individual crude oil and water components. This facility has several features that make solar energy attractive, such as:

- The required process temperature is low [less than 93°C (200°F)], favoring the use of relatively simple solar collectors (flat plates or parabolic troughs).
- Heating liquids, as opposed to generating steam or heating air, is a favorable solar application.
- The process operates 24 hours/day, 7 days/week, on a year-round basis.
- The propane used by the company is relatively expensive.
- The propane energy utilization efficiency is low.
- There is little potential for energy conservation because the equipment is not easily modified to enhance efficiency, and the tank is already sufficiently insulated.
- The process has built-in storage because the emulsion in the tank can be heated to 93°C by solar energy during the day, so that operation is extended into the evening hours before the emulsion temperature drops to 57°C and propane has to be burned.



Process Data

725 lb/h of Crude Oil/Water Emulsion
Required Heat Rate: 20,000 Btu/h
Required Annual Energy Use: 1.75×10^8 Btu
Process Temperature: 135° F
Propane Usage: 1,370 gal/month
Propane Energy Input: 1.49×10^9 Btu/yr

Figure 2. Crude Oil/ Water Separator Tank

A possible solar system for this process is shown in Fig. 3. The system displaces approximately one-third of the process energy requirement during a typical year, with the existing propane system used as backup. A life-cycle cost analysis showed that this solar system has a payback period of about 6.5 years.

Two of the industries studied, fluid milk processing and meat processing, use large quantities of 60° C (140° F) water for cleanup. This process (see Fig. 4) is very favorable for solar application. It is a low-temperature use, and in nonfreezing climates water can be pumped directly through the collector field without the need for a heat exchanger. The fluid milk industry also uses heat for pasteurizing milk at a temperature of 74° C (165° F). The case study dairy is unusual in that the milk is heated using circulating hot water, which in turn is heated by exchange with steam. The liquid system allows more accurate temperature control than the conventional technique of using steam directly. The liquid system also allows an easy retrofit of a solar supplementary heat source.

The use of high-temperature water (HTW) systems is increasingly accepted by industry as an energy conserving measure. The universal use of package steam boilers seems to originate more from familiarity than from an actual need for steam. HTW systems eliminate the need for steam traps, greatly reduce water treatment costs, and are more thermally efficient because no heat is lost from blowdown or flash-off (Teller 1976). Increased use

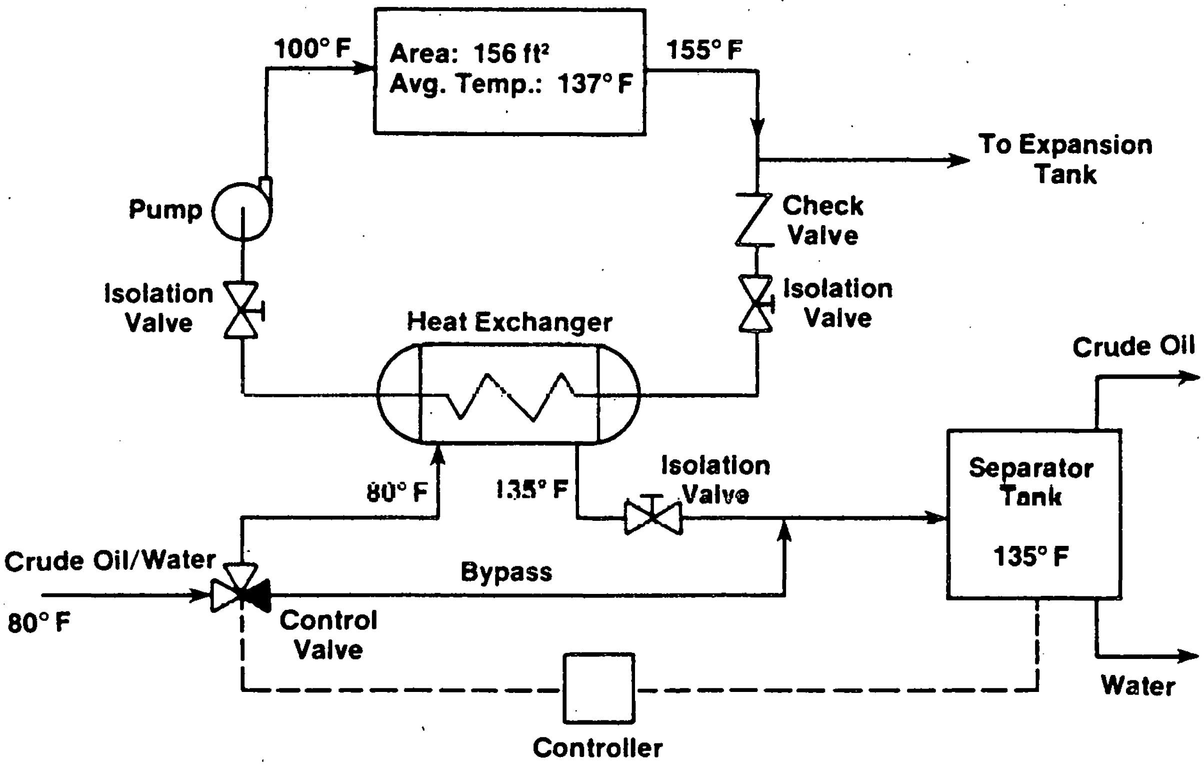


Figure 3. Crude Oil/Water Separation Facility External Heat Exchange System

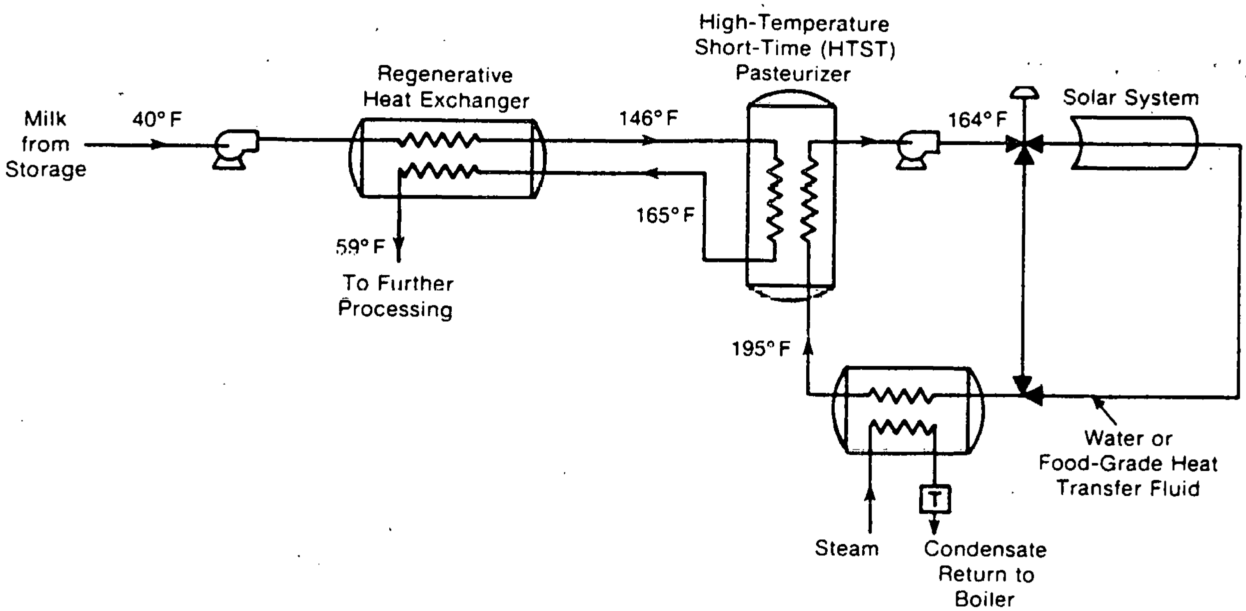


Figure 4. Milk Pasteurization Process

of HTW systems would enhance the possible use of solar technology. Collectors heating water can operate at temperatures much lower (and hence at higher efficiencies) than those required to generate steam.

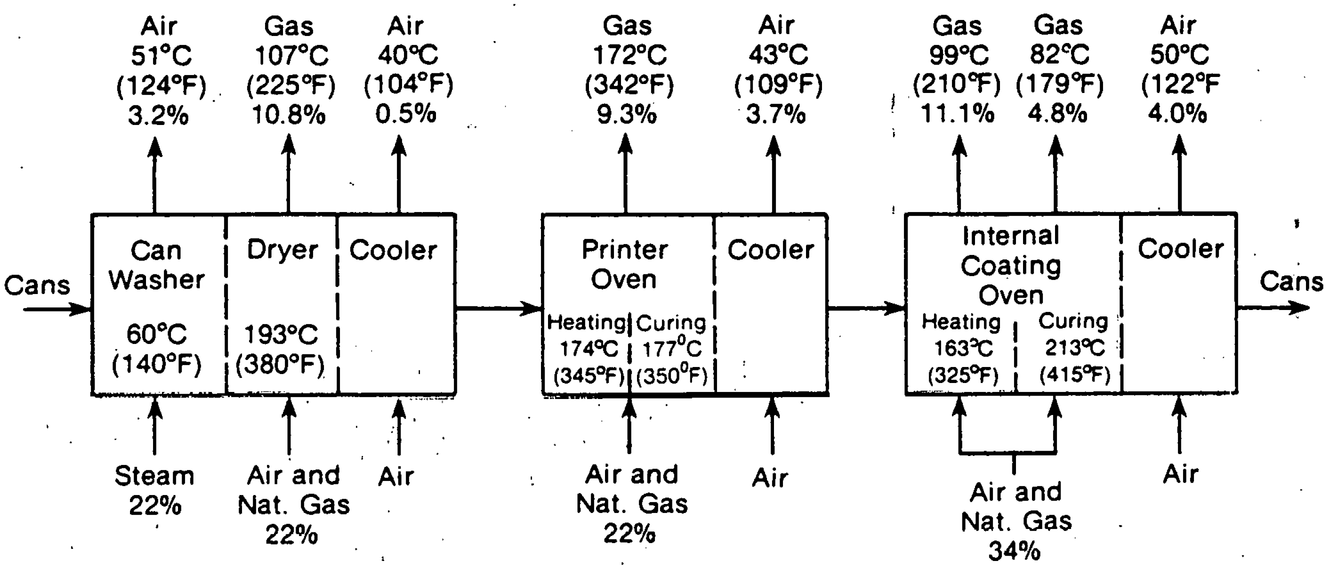
An analysis of solar systems to provide hot water for cleanup and pasteurization for the fluid milk plant showed them to be uneconomic at the present time. Although located in the southwestern United States, an area of high solar radiation, the plant uses natural gas costing only $2.38/10^6 Btu. The five-day-per-week operating schedule of the plant is also a very unfavorable factor. Sufficient storage cannot be economically incorporated to capture the entire output of the solar array during the weekend. Even a hypothetical scenario of the above natural gas price advancing about 10% per year in real terms, together with a combination of government incentives (federal and state) equivalent to about a 50% tax credit, shows a payback of about six years for a system designed to heat cleanup water and installed in 1985.

The urban location of the dairy highlights the problem of land availability for collectors. Although many industrial plants have sufficient roof space to provide a significant fraction of their process heat needs, these roofs are generally cluttered or incapable of supporting solar collectors. This problem of space could be the determining factor of the feasibility of a solar energy application. It is much more economic to anticipate the possible installation of solar collectors when building a new facility than to carry out all the modifications necessary for a retrofit.

An analysis of the meat packing plant, where process heat is used almost entirely for cleanup, produced results similar to results for the dairy. Again, the processing schedule is unfavorable: most heat use occurs overnight, five days per week. Extension of the operating hours of an industrial plant or the rescheduling of heat-requiring operations to the daytime enhances the applicability of a solar system.

An aluminum container manufacturing plant (Fig. 5) and a bakery (Fig. 6) use large quantities of process heat for air heating applications. The aluminum container plant uses air at temperatures up to 213°C (415°F) for the curing of inks and can coatings, while the largest single use of energy in the bakery is for heating ovens up to 232°C (450°F). In both plants, heat is supplied by the direct firing of relatively inexpensive natural gas. Using solar energy to heat air is generally not as cost-effective as using the energy to heat liquids. The efficiency of the air heating systems is lower and much parasitic power (electrical input) is required by the fans to move the air. In addition, both of these hot air applications are at relatively high temperatures. Thus, no near-term economical solar applications were identified for the current process configurations of either the container plant or the bakery.

Some interesting possibilities did arise, however, from a detailed study of the container manufacturing plant. This plant could save considerable energy by the common technique of recovering heat from the exhaust air to preheat air for the gas burners. Another, more efficient approach, which eliminates the need for heat exchangers at the expense of increased control and safety measures, is to recycle air partially depleted in oxygen back to the gas burners. Solar heating of the recycled exhaust gas stream would not affect its oxygen content. Consequently, the use of a solar system would allow a much greater fraction of the exhaust gas stream to be recycled before the gas entering the burner was deficient in oxygen. A system whereby a portion of the hottest off-gas streams from the ovens is recycled with exhaust air from the can coolers, which is further heated using solar energy, appears economically attractive.



- 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

Figure 5. Metal Container Process Energy Flow Diagram

The largest energy user studied in the case study program so far is a midwestern United States corn wet-milling plant. This study revealed the variety of options open to the large energy user. A skilled technical staff at the plant supervises the housekeeping measures to reduce energy consumption. The staff has instigated major process changes, such as increasing the number of effects for an evaporative process, using vapor recompression cycles, and increasing animal feed drying temperatures. The possibility of increasing the quantity of on-site electrical generation is being investigated, and measures are being taken to burn more coal. Although this plant uses large quantities of low-temperature process heat, its location and use of coal preclude any economical solar application. Land is also a major constraint. To make a significant energy contribution, the collector field would have to cover hundreds of acres. For very large fields, energy is probably delivered most economically using the "power tower" system. A central receiver eliminates many of the delivery problems inherent in pumping fluids through large fields of collectors (thermal losses and high electric power consumption). However, the central receiver, as mentioned previously, is only in a preliminary stage of development.

CONCLUSIONS

The solar IPH case study program at SERI has been useful in evaluating the potential of solar technology to supply industrial process heat. Only by examining specific cases of IPH applications can the unique problems and requirements of solar energy systems be identified. Although the case studies performed to date by SERI are not numerous, some

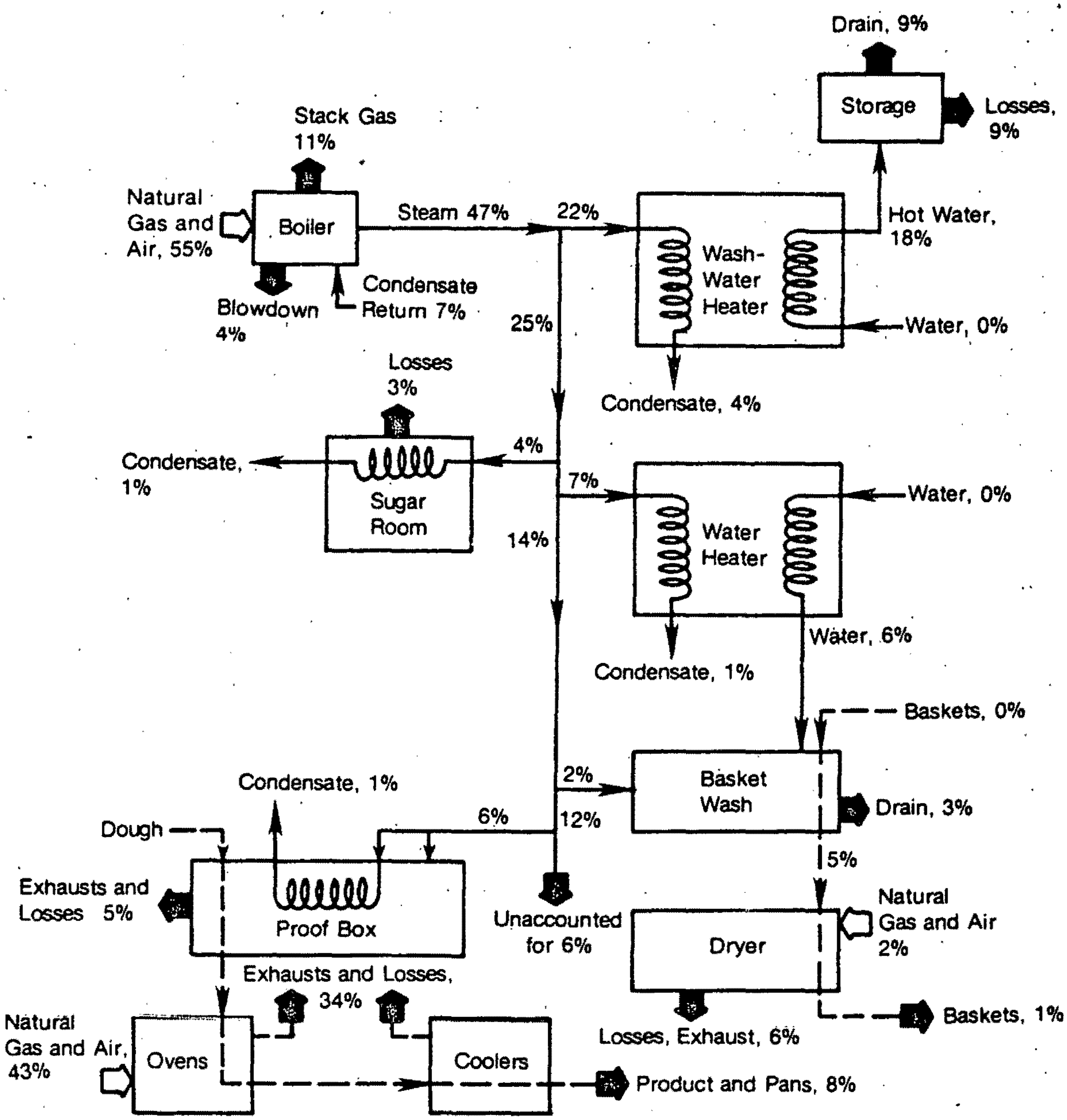


Figure 6. Bakery Energy Flow Diagram

The percentages are shown as percents of the total process input energy of 15.2 GJ/h. All energies are with respect to 15° C (60° F).

important conclusions about the use of solar energy for IPH have been reached. Factors favoring the application of solar thermal technology to supply IPH are listed in Table 1. By evaluating these factors, the plant engineer can make an initial assessment of the near-term technical and economic feasibility of using such technology in his plant. A favorable assessment should lead to more detailed analysis.

In addition, the plant engineer should be aware that the trend toward increased energy conservation could foster solar energy installations. This could arise, for instance, from developments leading to reduced processing temperatures or from the installation of a HTW system. Solar energy and conservation technologies also require similar research and development, such as the development of inexpensive heat exchangers to transfer heat efficiently at small temperature differences. Conservation is the first step in saving oil and natural gas at any industrial plant, and much work remains to be done in this area. Once this potential is exhausted, however, solar energy is one of the few alternative sources of energy for IPH applications.

The incorporation of certain conservation measures and solar energy systems will probably complicate the operation of IPH systems. The plant engineer will be responsible for managing these changes. However, it appears inevitable that industry will have to make changes in order to cope with drastically increasing energy prices and potential energy shortages. Through continuing research, development, and demonstration efforts, reliable solar IPH systems are being developed and can be used by industry to slow the energy price escalation and provide protection against energy curtailments.

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Table 1. FACTORS FAVORING THE APPLICATION OF SOLAR THERMAL IPH SYSTEMS

Environmental Factors

- High insolation levels—either total or direct, depending on the solar technology proposed
- High ambient temperatures—to reduce thermal losses (particularly for nonconcentrating collectors) and to allow the use of water as a heat transfer fluid
- A pollution-free microclimate—so as not to dirty or corrode collector surfaces
- A polluted macroclimate or area with strict air pollution regulations—where no additional air pollution emissions are allowed and where such controls are a restraint on levels of production

Process Factors

- Low-temperature process—so that the cheapest type of collector, operating at a high efficiency, can be employed
- Continuous, steady operations (24 h/day, 7 days/week) where exact temperature control is not critical
- Liquid heating application as apposed to air or steam heating
- Built-in process storage—which helps even out fluctuations in the thermal output of the collectors, and which can act as a reservoir of heat produced by the solar system (during the weekend, or long summer evenings)
- Easy retrofit of the the solar system—so as to minimize costs
- Inefficient fuel usage, not easily rectified—so that energy delivered from the solar system replaces more than the equivalent Btu content of fossil fuel

Economic Factors

- High and rapidly escalating fuel costs
- Uncertainties regarding fuel supplies—such as interruptible natural gas contracts
- Sufficient capital to finance investments in a solar energy system
- Long payback periods or demand for low rates of return on energy investments
- High federal, state, or local tax incentives for solar investments
- Energy-intensive industrial operation and energy costs representing a large fraction of value added
- All economical energy conservation measures already incorporated
- Cheap land or a strong roof available close to the delivery point of the required energy; salt available at little or no cost, if a salt pond is a solar option
- Low labor costs — because solar installations are labor intensive
- New plant—allowing a solar system to be incorporated from the beginning

Company Factors

- Desire to install a solar system and an enthusiastic work force from top management down
- A skilled maintenance and engineering work force—so that the solar system can be run and maintained at maximum efficiency
- Progressive management—which gives some recognition to the noneconomic but social values of solar energy, such as public relations, security of long-term supply, and reduced air pollution, leading perhaps to the application of less stringent payback criteria to investments in solar systems

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16. Abstract (Limit: 200 words)
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