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SOLAR PROCESS HEAT TECHNOLOGY IN ACTION: THE PROCESS HOT WATER SYSTEM AT THE CALIFORNIA CORRECTIONAL INSTITUTION AT TEHACHAPI

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ABSTRACT

Solar process heat technology relates to solar thermal energy systems for industry, commerce, and government. Applications include water preheating and heating, steam generation, process hot air, ventilation air heating, and refrigeration. Solar process heat systems are available for commercial use. At the present time, however, they are economically viable only in niche markets. This paper describes a functioning system in one such market.

The California Department of Corrections (CDOC), which operates correctional facilities for the state of California, uses a solar system for providing hot water and space heating at the California Correctional Institute at Tehachapi (CCI/Tehachapi). CCI/Tehachapi is a 5100-inmate facility. The CDOC does not own the solar system. Rather, it buys energy from private investors who own the solar system located on CCI/Tehachapi property; this arrangement is part of a long-term energy purchase agreement. United Solar Technologies (UST) of Olympia, Washington is the system operator.

The solar system, which began operating in the fall of 1990, utilizes 2677 m^2 (28,800 ft^2) of parabolic trough solar concentrators. Thermal energy collected by the system is used to generate hot water for showers, kitchen operations, and laundry functions. Thermal energy collected by the system is also used for space heating. At peak operating conditions, the system is designed to meet approximately 80 percent of the summer thermal load.

1.0 INTRODUCTION

This paper describes a successful commercial application of solar process heat technology in the government market. The system described provides service hot water for the California Correctional Institution (CCI) at Tehachapi, California.

Solar industrial process heat systems for water preheating and process hot water applications are available commercially. At the present time, however, they are economically viable only in niche markets.

Since 1988, the California Energy Commission (CEC) and the California Department of Corrections have been investigating the technical and economic feasibility of using solar process heat technology to provide hot water for bathing, cooking, laundry functions, and sanitation operations in state prisons. One prison for which the technology had the potential to be economically viable was the California Correctional Institution in Tehachapi, California (CCI/Tehachapi), a facility housing 5100 inmates. Tehachapi is located in the mountains between Bakersfield and Mojave at an elevation of 4000 feet.

Rather than purchase and operate a solar process heat system for meeting the hot water requirements at CCI/Tehachapi, the California Department of Corrections, assisted by CEC, entered into an agreement to buy energy supplied by an on-site solar system that is privately owned and operated. United Solar Technologies (UST) of Olympia, Washington, the project developers, negotiated the energy purchase agreement. Under this agreement, CCI/Tehachapi will purchase energy produced by the solar system over a 30-year period. Solar energy delivery is monitored with a Btu meter and is purchased at a cost 5% below the commercial rate for natural gas heating.

UST contracted Industrial Solar Technology (IST) of Denver, Colorado, to: (1) design the system; (2) manufacture the solar collectors; and (3) install the system. Also, IST has a contract with the system owner to perform system maintenance.

2.0 SOLAR SYSTEM DESCRIPTION

Figure 1 is a schematic of the system. The system utilizes IST parabolic trough solar collectors. Thermal energy collected by the system provides heat to a pressurized high-temperature water loop that distributes energy throughout the institution for showers, kitchens, laundry functions, and space heating. Domestic hot water is produced using a separate secondary loop. No thermal storage is provided. The collector outlet temperature is 147°C (296°F) at design conditions. At peak solar conditions, the system is designed to meet about 80% of the summertime thermal load.

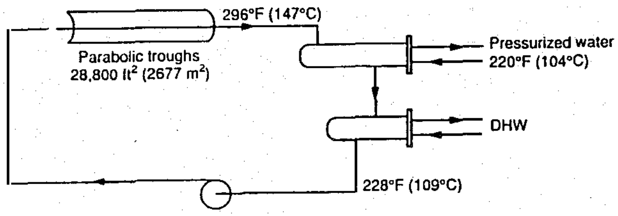

Figure 1. Schematic of the Solar Process Heat System Delivering Thermal Energy to the California Correctional Institution at Tehachapi

The systems utilize an advanced solar concentrator developed by IST that is different from conventional glass mirror designs. Each parabolic trough module is manufactured entirely of aluminum in a light-weight rigid design that uses reflector films produced by the 3M Company. A 150-square-foot collector module weighs just 160 pounds. The design lowers the installed cost of the system so that it is competitive with conventional fuels. The majority of the collector field uses 3M's SA-85 aluminized reflective film. NREL provided some of 3M's latest silvered film ECP-305, which has a greater reflectance, for the project for real-time testing on a few collector modules. The solar collector array uses 2677 m^2 (28,800 ft^2) of parabolic troughs arranged as 16 collector rows oriented along a rotational axis that is 35° off true north-south, or 10° from north-west/south-east. An innovative module drive system requires only eight motors to track the entire field. Peak output from the solar collector field is over 4 million Btu per hour.

The collector fluid is a glycol/water anti-freeze mixture that is circulated in a closed loop. Two heat exchangers deliver solar energy to a pressurized water loop and a domestic hot water load. The major pressurized water load transports heat at up to 240°F throughout the institution for domestic hot water, kitchens, laundries, and space heating.

The solar system is controlled by the Honeywell Fluxline control system, manufactured by IST under an exclusive license. This microprocessor-based system has demonstrated outstanding reliability in field applications for more than 10 years. The system has a master controller that monitors sunlight intensity, wind speed, flow and other safety parameters such as system temperature, pressure, and fluid level in the expansion tank. If all parameters are within acceptable bounds, the master controller sends an authorization signal to the local controllers that control the actual tracking of the collectors to maintain focus on the sun. The local controllers have their own internal logic. On receiving the authorization signal, and if no unsafe conditions exist, the local controllers drive the collectors from face-down stow position to focus on the sun. The local controllers maintain the collectors in focus as long as the authorization signal is provided by the master controller. The collectors return to the stow position at night or when any unsafe condition is detected. In the stow position, wind exposure is minimized. Also, soiling of the collector surfaces is reduced.

The system although privately owned and operated, is physically located in the CCI/Tehachapi facility. Consequently, it is a retrofit system and required that interface equipment be located within a crowded area among existing equipment. Thus, the main heat exchanger is mounted on the boiler room wall 5.5 m (18 ft) above the floor. From the solar field to the boiler room there is a 122 m (400 ft) piping run of which 76 m (250 ft) is overhead. Sandia's Design Assistance Center assisted in the design of the heat exchanger mounting configuration and the piping run. The Design Assistance Center also provided for a weather station that is installed adjacent to the solar field, and the system was instrumented to measure performance. Data gathering on a regular basis started in February 1991.

As mentioned earlier, the system is privately owned. Revenues from the sale of solar-produced thermal energy flow back to the owners to repay their investment and provide a return on that investment. UST provided bridge financing to build the system assisted by a small business loan from the State of California. The installed cost of the system was $604,800. Normalized in terms of dollars per square meter, the system cost \$226/m^2 (\$21/ft^2).

Since the system is new, data are not yet available regarding actual energy delivery. However, the system was designed to deliver approximately 7160 million Btu annually through the Btu meter. Summary data regarding the system are provided in Table 1.

Table 1. Summary Data Regarding the Solar Process Heat System for the California Correctional Institution—Tehachapi, California

Inmate population	5,100
Solar collector type	Parabolic Trough
Collector area	28,800 ft^2 (2677 m^2)
Reflector material	Aluminized Polymer Film
Field area	2 acres
Load temperature (pressurized water)	220°F (104°C)
Peak solar energy delivery	4 million Btu/hr (1172 kW)
Expected annual energy delivery	7160 million Btu
System installed cost	$604,800 (1990$)
System developer	United Solar Technologies (Olympia, WA)

3.0 SYSTEM STARTUP AND OPERATION

System performance monitoring is being performed by Southwest Technology Development Institute (Las Cruces, NM), under contract to Sandia National Laboratories. The data acquisition system uses a Campbell Micrologger and allows for remote interrogation of the performance data via modem. System performance reporting began in March 1991, while the system was in its shakedown, or startup, period.

During March, several operational problems were encountered as startup continued. Also, March was both windy and wet. A peak wind speed of 75 mph was recorded by the wind anemometer in the solar field. At a standard 10-meter measurement height, this wind speed corresponds to about 85 mph. In addition, much precipitation occurred in the form of rain and snow. The snowfall from a storm on March 21, 1991 was so great that the system was not operated for several days—until enough snow had melted so that the collectors could be rotated without driving through snow drifts.

During April 1991, fewer operational problems were experienced. System reliability improved to the point that energy was produced and delivered on 21 out of 30 days. Performance data for April are shown in Table 2.

During May 1991, the solar system was available for energy collection for the entire month. It operated on 27 out of 31 days. On the other 4 days, the levels of direct normal insolation were not sufficient to start up the solar field. Performance data for May are shown in Table 3.

In June 1991—the last month covered in this paper—the system was available for energy collection for the entire month. It ran every day except for one cloudy day. After IST engineers corrected a solar collector misalignment problem (caused by the massive March snowstorm), energy delivery increased substantially. During June, energy delivery averaged 25 million Btu per day and peaked at over 34 million Btu per day. Performance data for June are presented in Table 4. Figures 2 and 3 show energy delivery and system efficiency, respectively, for the 3-month period. They demonstrate dramatic increases in performance over this period.

Table 2. Tehachapi System Monthly Summary—April 1991	
Insolations	
Direct normal per unit area	56,324.61 Btu/ft^2
Total direct normal	1,622.15 MMBtu
Plane of array per unit area	49,891.95 Btu/ft^2
Available in collector plane	1,436.89 MMBtu
Horizontal per unit area	54,350.18 Btu/ft^2
Diffuse per unit area	14,743.63 Btu/ft^2
System Produc	
Energy output	205.86 MMBtu
Weather	
Average ambient temperature	47.46 Fahrenheit
Average relative humidity	68.64 Percent
Average wind speed	6.06 mph
Peak wind speed	28.20 mph
Source: Southwest Technology Development Institute (Las Cruces, NM)	

Table 3. Tehachapi System Monthly Summary—May 1991	
Insolations	
Direct normal per unit area	74,089.97 Btu/ft^2
Total direct normal	2,133.79 MMBtu
Plane of array per unit area	67,292.65 Btu/ft^2
Available in collector plane	1,938.03 MMBtu
Horizontal per unit area	68,477.32 Btu/ft^2
Diffuse per unit area	13,900.17 Btu/ft^2
System Production	
Energy output	378.15 MMBtu
Weather	
Average ambient temperature	52.56 Fahrenheit
Average relative humidity	59.08 Percent
Average wind speed	6.62 mph
Peak wind speed	30.70 mph
Source: Southwest Technology Development Institute (Las Cruces, NM)	

Table 4. Tehachapi System Monthly Summary—June 1991	
Insolations	
Direct normal per unit area	90,303.48 Btu/ft^2
Total direct normal	2,600.74 MMBtu
Plane of array per unit area	82,034.90 Btu/ft^2
Available in collector plane	2,362.61 MMBtu
Horizontal per unit area	76,400.03 Btu/ft^2
Diffuse per unit area	11,754.03 Btu/ft^2
System Production	
Energy output	749.96 MMBtu
Weather	
Average ambient temperature	63.00 Fahrenheit
Average relative humidity	41.93 Percent
Average wind speed	5.54 mph
Peak wind speed	25.33 mph
Source: Southwest Technology Development Institute (Las Cruces, NM) tion	

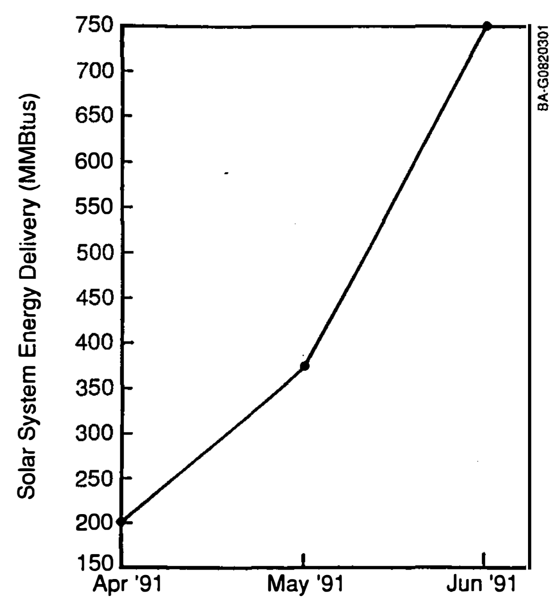

Figure 2. Actual Energy Delivery by the Solar System for the 3-Month Period

System clear-day performance is shown for June 15 in Figure 4. This particular day was virtually cloudless and had a peak insolation of just over 1000 W/m^2 near solar noon. The solar system began operating about 6:35 a.m. PST and began producing useful energy within about 15 minutes. By 8:00 a.m., the collector system outlet temperature was over 240°F. The peak collector system outlet temperature for the day was just over 270°F and occurred near normal incidence, just after 1:00 p.m. PST. Wind speeds at this time reached 18 mph. Collector system efficiency at normal incidence was 52% and the energy collection rate was 4.0 million Btu per hour. The system operated until about 4:20 p.m. for a total operation time of 9.75 hours. Energy production for the day totalled about 32 million Btu.

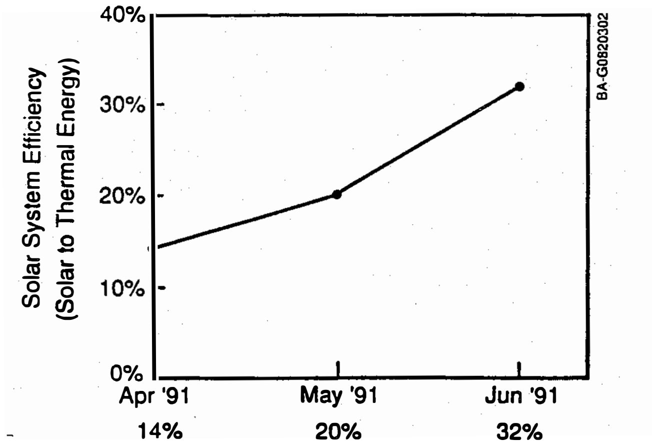

Figure 3. Solar-to-Thermal Energy Efficiency of the Solar System for the 3-Month Period

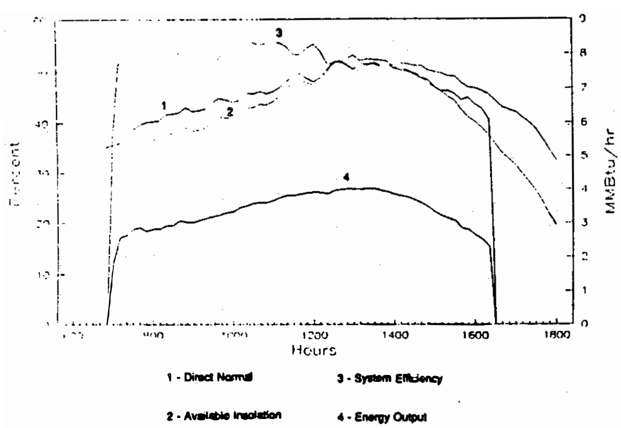

Figure 4. Tehachapi System—15 June 1991 Performance Data (Source: Southwest Technology Development Institute, Las Cruces, NM)

While performance continues to improve during this shakedown period, one additional engineering problem involving the flex hoses has been identified and is in the process of being resolved. Flex hoses are used to transfer the thermal fluid in and out of the solar collectors. Each flex hose connector consists of two separate hoses—an inner hose that carries the thermal fluid and an outer hose designed to restrict bending of the inner hose. Engineers found that the angular motion of the outer hoses become restricted as the solar concentrators track the sun from east to west. Because of this restricted motion, the solar collectors are prevented from tracking the sun in the western sky for approximately the last two hours each day in the summer. This results in the loss of collectable energy. The project engineers have designed new flex hoses to solve this problem. Plans call for installing and testing them in the system in December 1991.

4.0 CONCLUSIONS

This new solar process heat system, while in the shakedown period, is generating revenue for the private owners.

While initial startup problems have been encountered, they have been or are being resolved by the project engineers. The most significant problems were:

- Damage to the solar collector field due to unusually severe weather in the early spring of 1991 (high winds and unusually heavy snows).
- Flex hose problems that cause the solar collectors to return to the end-of-day stow position up to two hours earlier than scheduled each day.

The structural problems have been corrected. The engineers expect to resolve the flex hose problem with a newly-designed flex hose assembly. Testing and evaluation of the new hoses in the solar field is scheduled for December 1991.

System reliability and performance are continuing to improve. For example, solar-to-thermal energy conversion efficiency has increased from 14 percent in April 1991 to 32 percent in June 1991. This system is an example of the possibilities for the cost-effective utilization of solar process heat technology in local/state/federal facilities and operations.