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Solar Total Energy At Sandia Labs

James A. Leonard
Supervisor, Solar Energy Projects, Division 5712, Sandia Laboratories, Albuquerque, New Mexico 87115

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This presentation describes the Sandia Laboratories' Solar Total Energy Program. This program consists of designing, building, installing, and operating a field of concentrating parabolic trough solar collectors which provide energy at 310°C, a 32-kW$_e$ organic Rankine cycle power plant, and the heating and cooling equipment to utilize the cascaded, low-temperature energy from the turbine/generator. Included in the presentation are descriptions of the total energy system, its components, its performance characteristics, a status report, and a discussion of future plans.

Total energy is an energy cascading concept in which the normally wasted heat from electrical power generation is used for heating and cooling of buildings and for domestic hot water. Thus, greater utility is made of the energy content in the fuel, be it fossil fuel, nuclear, solar, or an alternate energy form. In conventional electric power plants, about one-third of the energy in the coal pile or oil barrel is converted to electrical energy. In total energy facilities, about two-thirds of the energy is put to use. Thus, it would seem that the total energy concept would always result in energy conservation and superior economics. Unfortunately, such is not always the case. A small penalty in electrical conversion efficiency must usually be accepted in order to produce thermal energy at temperatures high enough to be useful for heating and cooling applications. This fact combined with the fact that thermal energy is difficult to store and transport means that the total energy concept is most practical for those applications where a market for thermal energy is physically close to the electrical generation site or vice versa.

The objectives of Sandia's Solar Total Energy Program are: 1) to provide a versatile solar total energy system which can be used as an engineering evaluation center or testbed for further development of alternative sub-systems and individual components, 2) to establish the feasibility of the solar total energy concept by constructing and operating a system to collect and evaluate performance data under a variety of conditions, 3) to encourage private sector participation in the program and in the development of components for the system, 4) to design a system of sufficient size to require realistic integration of all subsystems and to permit identification of those areas of research and development that warrant continuing effort, 5) to conduct a demonstration capable of attracting widespread public interest, and 6) to develop and validate a systems analysis computer program capable of evaluating the great number of possible combinations of solar total energy system configurations.

In pursuit of these objectives, a comprehensive hardware program, supported by aggressive systems analysis and materials and process development tasks, is underway at Sandia's Albuquerque Lab. The Sandia Solar Total Energy System, which underwent its initial operational tests in December 1975, is depicted in block diagram form in Figure 1. It will operate as follows: a heat transfer fluid, Therminol-66* (T-66), is pumped through receiver tubes located at the focus of a series of parabolic trough reflectors. The fluid is thus heated by reflected and focused solar radiation to a temperature of 310°C (590°F) and is then pumped to an insulated high temperature storage tank. As required, the hot T-66 is drawn from storage to a heat exchanger in which toluene vapor is boiled and superheated. The superheated toluene vapor is expanded through a 32 kW organic Rankin cycle turbine/generator after which it passes through a regenerator section, through a condenser and finally back to the heat exchanger where the cycle starts again. The spent T-66 is returned to the cool side of the storage tank and subsequently pumped back through the collector field to be reheated. The turbine condenser coolant, a water glycol solution, is collected in a low temperature storage tank and becomes the energy source for the

* Registered TM of Monsanto Industrial Chemicals Co.
heating and cooling components of the system.

Air conditioning will be provided by a lithium bromide absorption chiller which uses the water glycol solution at 88°C (190°F) fluid as its energy source. For heating the hot water will be used directly at a temperature of 70°C (158°F).

Fossil-fuel heaters and artificial loads are incorporated throughout the system so that any subsystem can be operated independently for engineering purposes and so that the entire system can be operated during sunless periods.

Figure 2 is a recent photograph of the Solar Total Energy Project. The system has been sized to meet the energy requirements of the Solar Project Building (visible in the background), an 1130 m² (12,200 ft²) office building which, in addition to other organizations, houses the solar engineering project staff. The building's electrical load is 32 kW for 11 hours per day, a daily total of 352 kW-hr. The cascaded energy from the turbine condenser will be sufficient to meet approximately 70 percent of the building's peak heating and cooling demand and will be supplemented by conventional means on peak load days.

The energy collection will be accomplished by about 800 m² (8,600 ft²) of collectors, a partial field of which are shown in operation in Figure 3. The collector field will produce 8.7 kJ/day (8.2 MBtu/day) on winter solstice, the shortest day, and 9.8 kJ/day (9.3 MBtu/day) on summer solstice. At present, about 25 percent of the collector field is installed. These consist of 20 2.7 x 3.7 m (9 x 12 ft) parabolic trough concentrating reflectors oriented in the east-west direction. The collectors operate in ganged groups of five. Each group of five collectors is controlled by a single tracking and drive system which keeps the plane of symmetry of the parabolas aligned with the sun so that reflected solar radiation will converge on the receiver tubes which are located at the parabolic focus.

The reflectors in Figure 3 are constructed of 18 mm (3/4 in.) marine plywood laid up and bonded in a parabolic press. The plywood shell is bonded to a plywood rib structure for stiffness. This assembly in turn is bolted to a frame of steel pipe, flat steel end plates. Each collector assembly is supported on plate steel pylons which also house the drive mechanism and which permit the collectors to rotate through an angle of almost 180°. The reflective surface installed at present is a second surface aluminized teflon bonded to a mylar substrate. The film laminate is bonded to aluminum sheets which are mechanically attached to the parabolic shell structures. This film has a specular reflectance value of 0.83.

The receiver tube, Figure 4, through which the T-66 is pumped consists of a selectively coated steel tube enclosed in an evacuated borosilicate glass envelope. An expansion bellows end closure is provided to allow for differential thermal expansion. The length of each receiver tube, 3.7 m (12 ft), coincides with the length of the reflector. Adjacent receivers are joined by sealed flanges so that the T-66 can flow continuously through a series of collectors. A support post attached to each reflector end plate holds the receiver tubes in position. The selective coating on the absorber tube is electrodeposited black chrome which has high absorptance (a = 0.97) and low emittance (ε, H = 0.25) in the infrared spectrum.

The nominal temperature of the T-66 as it emerges from the collector field is 310°C. This temperature must be maintained within 10°C to preserve the stability of the thermocline in the high-temperature stratified storage tank. The fluid outlet temperature is controlled by varying the pumping rate as solar radiation levels fluctuate. For instance, if solar intensity is low, then the pumps are slowed so that the fluid takes longer to traverse the collector field and thus has more time to gain temperature. The control strategy used is a predictive, feedforward, feedback system implemented by a minicomputer. In the predictive aspect of the system, a normal incidence pyrheliometer is employed to monitor continuously the solar radiation level. Based on this data, the minicomputer calculates a nominal fluid flow rate and transmits an appropriate command to the pump. This initializes the system at approximately the right flow rate. The feedback aspect is as described above—the computer compares the output temperature of the collector field with the desired temperature and commands changes accordingly. The feedforward aspect is used to reduce the response time lag in the system. At one or more points in mid-field, the fluid temperature is monitored and compared with precalculated setpoints. In this way, an unacceptable output condition can be anticipated and the appropriate pumping adjustments made. The control strategy has been developed and a wide variety of hypothetical situations, including transients and collector field start-up, have been examined with the aid of a specially written computer program, called CONTRL.
The 32 kW turbine/generator is a derated, modified version of a 100 kW gas-fired total energy turbine/generator power plant which is being developed by Sundstrand Aviation. The turbine/generator operates on a superheated organic Rankine cycle and uses toluene as the working fluid. Toluene was chosen because it is a member of a family of high-molecular-weight organic fluids, the vapor states of which have the property of becoming more superheated as they expand. This precludes the problem of liquid droplets (which can cause damage) forming in the turbine rotor. Also, the high molecular weight results in a low nozzle spouting velocity which permits the turbine to be run at a lower speed and to accomplish the entire expansion in a single stage. A major modification to the gas-fired system was the replumbing of its toluene boiler. This boiler, which is integral to the turbine/generator chassis, is used in the solar application as an auxiliary heater for the T-66. In situations where high-temperature storage is depleted, the auxiliary heater can furnish hot T-66 to the toluene heat exchanger or to the high-temperature storage tank and the balance of the downstream system will operate normally.

This concludes the description of the Solar Total Energy System as presently configured. This solar-to-electric portion of the system is in the operational phase and system testing is being conducted. In the next phase of the program, which is now in progress, the size of the collector field and storage tank is being expanded to about 800 m² (8600 ft²) and 20,000 liters (5200 gallons), respectively. These additions will be largely through the output of several development contacts. In addition, the low-temperature components for the heating and cooling portions of the system will be added and the modifications to the Solar Project Building to ready it for its demonstration role will be accomplished. The initial demonstration of the Solar Project Building will take place in mid-1977 with a partial collector field. Full operation as a Solar Total Energy System Test Facility should begin late in 1977.

Figure 1