THERMAL STORAGE EXPERIENCE AT THE MSSTF AND PLANS FOR THE FUTURE*

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SUMMARY

The purpose of this presentation is 1) to review the background of thermal storage development at the Midtemperature Solar Systems Test Facility (MSSTF) at Sandia Laboratories, 2) to define the problems which have been encountered, 3) to outline a course of action for resolving these problems, 4) to determine scaling effects of going from laboratory models to full-size applications, and 5) to apply the lessons learned to thermal storage needs in near-term solar projects.

MULTIPLE TANK THERMAL STORAGE

The Multiple Tank Thermal Storage subsystem shown in Figure 1 was designed at Sandia to provide thermal storage for the testing operations and to evaluate the multiple tank concept in an operating environment. A three-tank design was chosen because the operating strategies and control problems are representative of those encountered in the field with a larger system.

The basic design requirement for the multiple tank subsystem is to store 860kWh (2.935×10^6 Btu) thermal energy between the temperature limits of 241° to 309°C (467° to 588°F). The heat transfer and storage medium is Therminol 66®. A volume of 22.62 m^3 (6 000 gallons) of Therminol 66® will satisfy this requirement. The subsystem was designed so that any two of the three identical tanks could hold a volume of 23.24 m^3 (6 140 gallons). Allowing for 10% ullage, the volume of each tank is 12.78 m^3 (3 377 gallons).

The subsystem was required to deliver thermal energy at a rate of 283 kW (0.966 Btu/h) and to receive thermal energy at a rate of 502 kW (1.713×10^6 Btu/h). To facilitate pumping of the storage fluid, a gas pressure of 110 kPa (16 psi) is maintained inside the tanks. Because of this pressure the tanks were designed to meet ASME pressure vessel standards.

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The specific dimensions and shape of the tanks and the choice of type and thickness of tank insulation were determined with the aid of a computer program developed at Sandia. This program predicted heat loss through the tank surfaces for the daily operating cycle of typical winter or summer days, given tank shape and insulation types and thicknesses. After the tank shape was established, the criterion for selection of insulation thickness and type was minimum cost. The total estimated cost, using current prices, was computed for various thicknesses and types of insulation. Added to this was the cost of extra collector area to compensate for heat loss. The most economical choice for material is intermediate service fiberglass. The optimum thickness is 0.4 metre (15.6 inches). Since the cost increases only slowly as thickness increases, the thickness finally chosen for the tank insulation was 0.533 metre (21 inches).

Each tank contains instrumentation for sensing both temperature and liquid level. At the bottom of each tank, a 45-cm (18-inch) diameter "well" is provided so that nearly all the liquid in each tank can be drained. All lines for filling and draining the tank enter at the wells.

The significant problems encountered were 1) the need for a complex control system, 2) an energy loss of about 50% in excess of design calculations, and 3) accumulation of low temperature fluid in the bottom of the tank.

The control complexity arises from the 500 or more possible combinations of the many parameters involved in the operation of a three-tank system. The reasons for the high thermal losses are still under review, but apparently include 1) loss of hot inert gas from ullage, 2) improper installation and subsequent degradation of insulation, and 3) convection, or thermal siphoning, of heat transfer fluid along horizontal pipes leading to closed valves. After a period of storage, these losses result in the accumulation in the bottom of the tank of up to 1.9 m^3 (500 gallons) of fluid which has cooled below the usable temperature. This cool fluid is the first to be delivered from the tank and special operating strategies are required to deal with it.

THERMOCLINE THERMAL STORAGE

The first thermal storage subsystem installed in the MSSTF was the thermocline subsystem shown in Figure 2. This system was used to evaluate the storage of thermal energy in water at temperatures up to 232°C (450°F), or in Therminol 66® at temperatures up to 320°C (608°F). The volume of the tank between the diffusers is 5 m^3 (1 563 gallons). The theoretical energy storage capacity is 292 kWh (10^6 kJ) for Therminol 66® between the temperatures 243° to 311°C (470° to 592°F). The subsystem is composed of five elements:

1. A low-carbon-steel pressure vessel, fabricated to ASME Pressure Vessel Codes, with 2.5-cm (1-inch) thick walls,
2. Vacuum foil insulation around the vertical walls of the tank,
3. Diffusers at the top and bottom of the tank to minimize flow disturbances when fluid is pumped in or drawn out of the tank,
4. Two "T" valves to allow injection of fluid at 310°C (590°F) into the top of the tank while simultaneously withdrawing fluid at 243°C (470°F) from the bottom of the tank, and vice versa, and
5. A temperature probe to measure the vertical temperature profile of the fluid within the tank.

The major disadvantages in this thermocline storage subsystem are 1) the thermocline region initially occupies 20% of fluid volume, 2) the thermocline enlarges with time, 3) energy in the thermocline region is usually not usable because of low quality, 4) thermal energy losses are in excess of design calculations. The advantages are 1) control is simplified, 2) withdrawing hot fluid from the top of the vessel gives high assurance that it will be at the proper temperature, 3) the subsytem is adaptable to multi-medium storage, and 4) the subsystem is 20% less expensive than a multiple tank system of the same thermal storage capacity. Because of these advantages, Sandia is concentrating future evaluation effort on the thermocline concept.

Other thermocline subsystems are being evaluated by Sandia. The subsystems installed at the Willard, NM, and Coolidge, AZ, Irrigation Projects are part of large solar systems and are not instrumented for thorough evaluation of the thermal storage subsystem. Nevertheless, some useful information is being obtained.

FUTURE ACTIVITIES

The problems defined in the two existing thermal storage subsystems at the MSSTF cannot be solved using these facilities, either because instrumentation is lacking or because of the difficulty of modifying existing hardware. The thermal storage subsystems at Willard and Coolidge are instrumented for analysis of gross operational effects and not for the study of macroscopic events which occur in a thermocline storage facility. For these reasons a new thermocline tank was designed.

A new thermocline tank is presently being installed in place of the old one at the MSSTF (see Figure 3). The objective is to produce useful design information for the installation and efficient operation of thermocline storage subsystems for use with line-focusing solar collectors used in total energy and industrial process heat applications. It will be operated as a single-media, direct storage thermocline tank. The capacity will be 4.5 m^3 (1 179 gallons). The tank is made of 4.76-mm (3/16-inch) low carbon steel with stainless steel legs to minimize conduction. Multiple ports at the top and bottom give access for plumbing and instrumentation. The entire top can be removed if required for internal modifications or changes in instrumentation. A 45-cm (18-inch) diameter hatch provides personnel access. The installation of stainless steel legs and of the thinnest walls possible is a result of past experience.

Various diffuser designs can be installed for evaluation. The tank is instrumented with 350 temperature sensors. Two vertical thermocouple probes will be installed inside the tank to measure the temperature at 5-cm (2-inch) intervals. Also, thermocouples will be attached to both the inside and outside walls of the tank, and there will be thermocouples between each layer of insulation. A displacement-type gage will measure fluid level. Four turbine flowmeters will measure rate of flow of hot and cold fluid into and out of the tank. The data from the sensors are acquired and stored by a minicomputer. Plumbing connections allow hot fluid to be received from either the solar collectors or from the Multiple Tank Thermal storage subsystem. The tank legs will rest on a 5-cm (2-inch) pad of load-bearing insulation. The tank will be insulated with 38 cm (15 inches) of fiberglass.

Subscale models of diffuser designs will be tested in the laboratory and then fabricated full scale for testing in the system. The first design has been completed and the diffuser fabricated.

Subscale tests are also being conducted to investigate the stability of thermoclines. Full-scale testing of the new tank will begin early in 1980. Testing will include 1) heat loss measurements under steady-state flow conditions at temperatures of 200°, 260°, and 315°C (400°, 500°, 600°F); 2) static heat loss tests with initial temperature at these same levels; and 3) tests of thermocline stability and duration under static conditions, at various charge and discharge rates, and at various temperatures. All these tests will be done both with the tank completely filled using an auxiliary tank to accomodate expansion, and then with ullage space in the tank.

The difference in performance between laboratory scale models and resulting components of the new thermocline tank will provide a measure of scaling effects.

One cutput of the evaluation will be a design handbook for the installation and efficient operation of storage concepts for industrial process heat and other solar applications.

REFERENCE

1. Harrison, T. D., et al.: Solar Energy Test Facility Results, High Temperature Thermocline Storage Subsystem. SAND77-1528. Sandia Laboratories, Albuquerque, NM, April 1978.

Figure 1. The Multitank Thermal Storage Subsystem

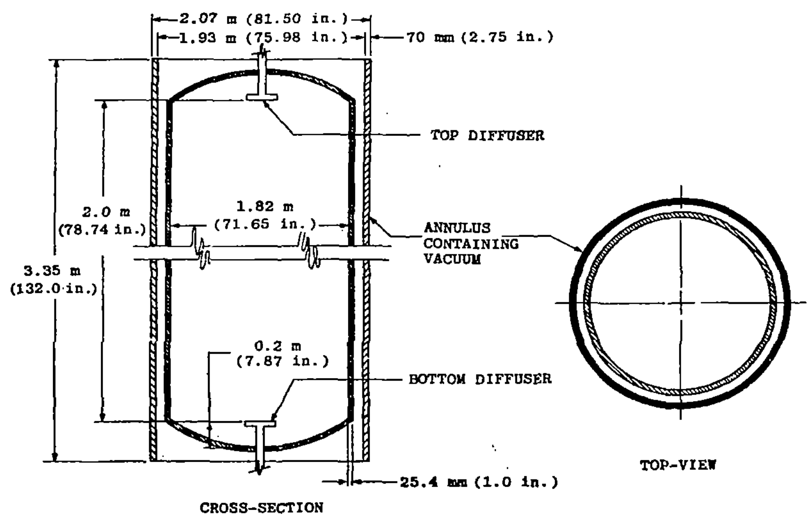

Figure 2. Cross Section and Top View of High-Temperature Storage Tank

Figure 3. The New Thermocline Thermal Storage System