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THE SOLAR MOLTEN SALT ELECTRIC EXPERIMENT

JOHN T. HOLMES
DIVISION 6222
CENTRAL RECEIVER TEST FACILITY
SANDIA NATIONAL LABORATORIES
ALBUQUERQUE, NEW MEXICO 87185, U.S.A

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The solar Molten Salt Electric Experiment (MSEE) is now being brought to operational status at the Central Receiver Test Facility (CRTF) near Albuquerque, New Mexico. We use a molten nitrate salt as its solar receiver and thermal storage heat transfer fluid and water/steam as its electric power generating fluid. The sodium nitrate (60 percent) and potassium nitrate (40 percent) salt melts at about 220 C (430 F). Because it is chemically stable in air and has a low vapor pressure at high temperatures, it is an ideal medium for storing heat for use when the sun is not shining. It is transported in pipes and contained in vessels that are made from common construction materials and have low pressure design requirements. In the MSEE, we will integrate the existing CRTF heliostat field, a 5 MWt solar receiver, a 7 MWH thermal storage system, a new 3 MWt steam generator, a 0.75 MWe turbogenerator and a digital process control system. Figure 1 is a photo of the CRTF indicating the location of the major MSEE subsystems. The amount of electricity produced by the MSEE is sufficient for about 250 homes.

1.1 Project Organization

The organization and funding of the MSEE is unique. Our program is a cooperative venture that combines government, electric utility and industrial funding, materials, design efforts, and operational expertise. The participants are:

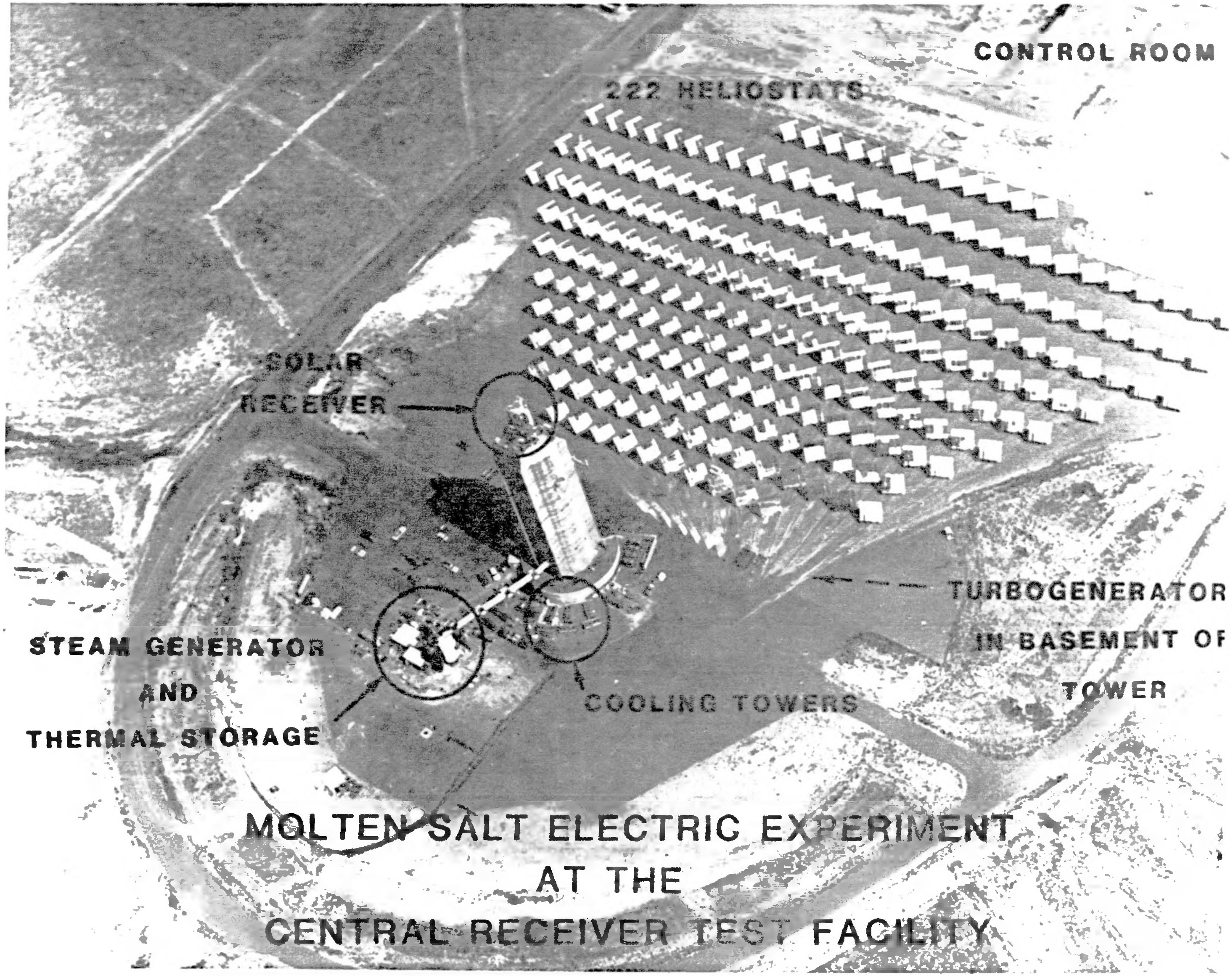
Babcock and Wilcox Nuclear Equipment Division
Black and Veatch Consulting Engineers
Electric Power Research Institute with
- Arizona Energy Commission
- Arizona Public Service
- Olin Chemicals Group
- Pacific Gas and Electric
- Southern California Edison

Foster Wheeler Solar Development Corp.
Martin Marietta Aerospace
McDonnell Douglas Astronautics Co.
Public Service Company of New Mexico
U.S. Department of Energy and Sandia National Laboratories

The government (Department of Energy) is providing half of the cost of the project and the use of the CRTF, through Sandia National Laboratories.

1.2 Project Implementation

Overall technical management of the MSEE is provided by Sandia National Laboratories. Our design effort was started in mid 1982. Design requirements were defined by Martin Marietta, the system integrator. Detailed designs for construction were provided by Black and Veatch. In order to meet a timely start up schedule, we performed much of the construction as design details were completed. Construction activities were monitored by resident engineers from Martin Marietta, Black and Veatch, Public Service Company of New Mexico, and Babcock and Wilcox.



MOLTEN SALT ELECTRIC EXPERIMENT
AT THE
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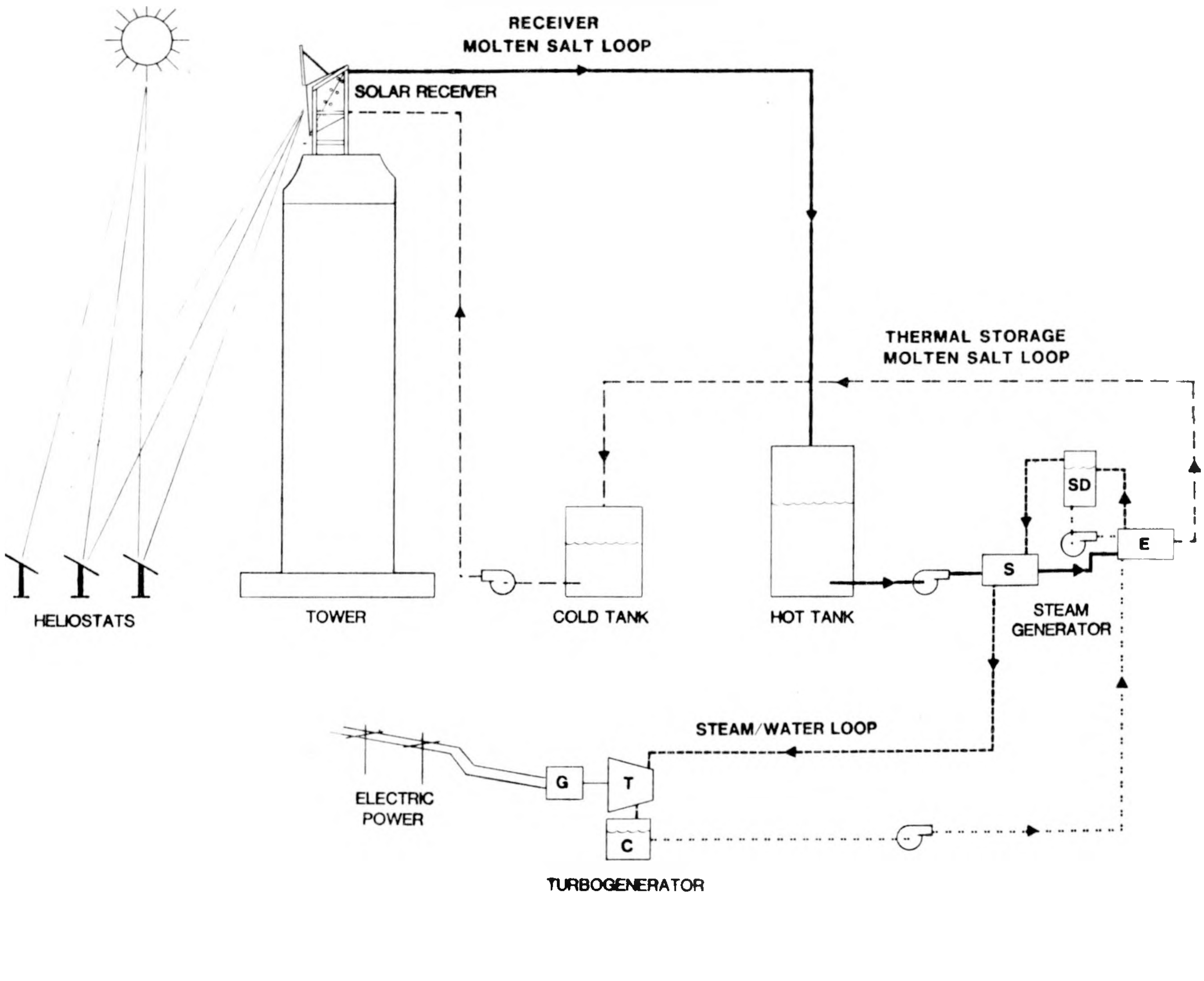
A previously operated solar receiver and a thermal storage subsystem were both refurbished after having been stored for over one year. A new steam generator was designed, built, and installed by Babcock and Wilcox. We located a surplus turbogenerator, refurbished it, and installed it at the CRTF. Olin Chemical provided the salt inventory. The existing CRTF heliostats and a distributed, digital process control system were provided by Sandia.

Martin Marietta is providing the planning and on-site technical direction for the system check-out, initial operation, and characterization of the individual and integrated systems. McDonnell Douglas, as guided by the Electric Power Research Institute, will plan, train, and direct the MSEE activities in early 1984 when electric utility teams will reside at the CRTF for hands-on operating experience with this new technology. During all phases of the MSEE, Sandia's staff at the CRTF is providing operations and maintenance support.

2. MSEE SYSTEM DESCRIPTION

The MSEE system is shown schematically in Figure 2. It will demonstrate the conversion of solar energy to electricity using molten salt and water/steam

FIGURE 2. THE SOLAR MOLTEN SALT ELECTRIC EXPERIMENT



as the energy transfer fluids. The molten salt moves heat from the receiver through thermal storage to the steam generator and water/steam is the energy transfer medium from the steam generator to the turbogenerator. The receiver, located at the top of the CRTF tower, receives concentrated solar energy from 221 heliostats. Molten salt from a cold storage tank, located at ground level, is pumped up the tower piping and through the receiver. The salt is heated from 306 C to 566 C (580 F to 1050 F) in the receiver and returned to the hot salt storage tank. To generate steam, we pump salt from the hot tank through the steam generator and return it to the cold storage tank. We use the steam from the steam generator to drive a turbogenerator to produce 0.75 MW of electricity. The advantages of this molten salt solar system are that the steam generator and turbine are decoupled from the receiver by the thermal storage system; and, molten salt from the receiver is used directly as the thermal storage fluid.

2.1 Collector Subsystem

The collector subsystem, or heliostats, concentrate sunlight onto the tower-mounted receiver. There are 221 two-axis tracking heliostats located north of the 61 m (200 ft) tall receiver tower. Under good insolation conditions, we can concentrate over 5 MWt onto the receiver. The details of the design, control, and operation of the heliostats were presented by Holmes [2].

2.2 Receiver

The receiver converts the heliostat beam energy into thermal energy in its molten salt working fluid. The receiver consists of the absorber panel, cavity enclosure, and associated vessels, piping and valves [3]. The receiver is located at the top of the CRTF tower.

We operated the receiver for about 500 hours at the CRTF in a previous component development program and now we have refurbished it for MSEE.

The receiver absorber panel uses a serpentine, up and down, flow pattern through 18 vertical passes that have 16 tubes per pass. The tubes are Incoloy 800 with 19 mm (0.75 in.) outside diameter and have a 0.17 cm (0.065 in) wall thickness. The panel is painted with a high temperature black paint. The overall size is 5.5 m (18 ft) wide by 4.0 m (13 ft) high.

An insulated cavity separates the panel from the square opening through which the heliostat beam is directed. The 2.7 m (9 ft) by 2.7 m (9 ft) square opening can be closed by an insulated door to retain heat when the solar beam is not directed at the receiver. The center of the opening is about 1.7 m (5.5 ft) in front of and 1.5 m (5.0 ft) below the center the absorbing panel.

2.3 Thermal Storage

The thermal storage system provides cold salt to the receiver and hot salt to the steam generator. This system includes the hot and cold salt storage tanks, salt pumps, and associated piping and valves [4].

The centrifugal salt pumps are a vertical cantilever design. The impeller and casing are suspended below the liquid level in a sump; the bearings are located above the liquid level and do not contact the salt.

The design of the hot salt storage tank is unique. We used a pleated Incoloy 800 liner to contain the hot salt and allow us to use carbon steel in the outer structural portions of the tank. We have fire brick insulation layer between the liner and steel outer shell. The hot tank is 7.2 m (23.6 ft) high and 3.7 m (12.3 ft) in diameter. The cold salt tank is carbon steel and does not require the internal liner due to its lower operating temperature. The cold tank is 3.7 m (12.3 ft) high and 3.7 m (12.3 ft) in diameter. The total inventory of salt is about 80,000 kg (175,000 lb) giving a thermal storage capacity of about 7 MWH when charged to 566 C (1050 F).

2.4 Steam Generator

The steam generator transfers sensible heat from the molten salt to produce superheated steam for the turbogenerator. The steam generator includes an evaporator, water recirculation pump, steam drum, superheater, and attemperator. The steam generator is the only major component which had not been operated prior to assembling the MSEE.

The evaporator and superheater are horizontal, U-tube, heat exchangers. Low pressure salt is on the shell side and high-pressure water and steam are on the tube side. We chose this configuration to minimize thermal stresses in the tubes and tubesheets. The evaporator is 2.25 Cr, 1.0 Mo steel. The superheater is 304 stainless steel.

A conventional steam drum, made of carbon steel is located above the evaporator. It separates water droplets from the steam before saturated steam enters the superheater. We have forced circulation of water between the steam drum and evaporator.

The steam outlet temperature of 504 C (940 F) is provided by attemperating the 538 C (1000 F) steam from the superheater with saturated steam from the drum. Our steam generator is rated at 3 MWt.

2.5 Turbogenerator

The electric power generation subsystem converts the enthalpy in the steam to electricity. This system includes the steam turbine, electric generator, condenser, cooling towers, and electric power control equipment.

A surplus, General Electric turbogenerator that was used aboard the USS Norfolk from 1951 to 1974 will produce the electrical output of the MSEE. It has a 0.75 MWe capacity. We cool the condenser by a 7 MWe dry cooling tower system, using a mixed water - ethylene glycol cooling fluid. The electrical output is fed into the local grid and is sufficient to power about 250 households.

2.6 Master Control System

MSEE is controlled by a distributed digital process control system manufactured by the EMC Company and by Bailey Controls. This process control system integrates all of the thermal and electrical processes. Our operator interfaces are provided by four video displays and keyboards in the CRTF control room. Three displays are used for the process controls and one for heliostat controls. The process controller has a host computer in the control room and four, independent control modules located near the system hardware. The fourth video display provides the heliostat operating interface. Heliostat control is not integrated into the overall MSEE process control scheme at this time. The MSEE controls are supported by a hard-wired, relay-logic system that automatically provides for safe shutdown in the event that the control computers, critical hardware components, or operating electrical power fails.

Data acquisition and data storage is performed by a digital mini-computer system. Both real-time and after-test data are available for characterization of system performance.

3. SYSTEM OPERATIONS

Each of our major MSEE systems is being brought into operational status separately. That involves component by component checkouts, manually controlled process operations, tuning of automatic control loops, and finally automatic operation of each system. In early 1984, we will integrate all of these separate systems to give a fully operational MSEE.

Our operational status as of December 1, 1983 is as follows:

Receiver - We have achieved operation at about 70 percent of rated power. Flow, level, and temperature control loops are tuned but require additional operational testing.

Thermal Storage - All phases of operation have been checked out and tested. The cold salt boost pump performs as designed to pump 630 kg/min (1380 lb/min) of salt from ground level through the receiver located about 70 m (230 ft) above on the tower. Automatic level control loops have been tuned.

Steam Generator - We have generated steam at about 70 percent of rated conditions (490 C, 60 kg/min, 7.6 MPa). Automatic process control has been partially implemented.

Turbogenerator - Mechanical, electrical, and instrumentation checkouts of this system are in progress. The first electrical output to the local grid is expected in January, 1984.

4. ELECTRIC UTILITY TRAINING PROGRAM

When we complete the first phase of MSEE operation and testing, all anticipated modes of operations, normal and faulted, will have been demonstrated and CRTF operators will be qualified to run the system. From then on, the McDonnell Douglas Astronautics Co. will direct the utility training program. This phase of MSEE operation will have the following major goals and objectives.

a. Provide a hands-on operating experience for teams of utility power plant engineers and technicians.

b. Receive and document feedback from these teams about this technology and its potential applicability to commercial power generation.

c. Completely characterize system performance and document information and data that is appropriate for scale up and commercial use of the technology, including the indentification of remaining problems and unresolved technical issues.

This phase of the MSEE will start in early 1984. Approximately nine utilities are planning to send teams for the hands-on experience. McDonnell Douglas will conduct a one week class room and control room training session. This will be followed by two-to-three weeks of the teams actually operating the MSEE through a selected set of operating modes including:

a. Steady state operation at both rated and derated conditions

b. Cloud transient operation

c. Simulated faulted and emergency conditions

5. CONCLUSIONS

For the first time, we are using the molten salt heat transfer working fluid in an integrated system that uses sunlight to generate electricity. The power produced will be fed into the local utility grid. Previously, the solar receiver and thermal storage systems were separately tested at the CRTF. These systems have now been integrated with a new salt-heated steam generator that provides steam to generate electricity in a turbogenerator.

This program is a cooperative venture that combines government, utility and industrial funding and expertise. A number of participants have contributed materials, design efforts, operation expertise and have assisted by integrating the subsystems into the total MSEE. The government (Department of Energy) is providing the use of the CRTF, through Sandia National Laboratories. The Department of Energy will support the operation and maintenance of the MSEE through the characterization and training programs. In 1984, operations engineers and technicians from commercial utilities will operate the MSEE.

Our primary goal for the MSEE is to provide the participants a realistic look at this new technology so that decisions can be made regarding the future development needs and potential for use of molten salts as an improved power tower heat transfer fluid.

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