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RECENT NATIONAL SOLAR THERMAL TEST FACILITY ACTIVITIES, IN PARTNERSHIP WITH INDUSTRY

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ABSTRACT

The National Solar Thermal Test Facility (NSTTF) at Sandia National Laboratories in Albuquerque, New Mexico, USA conducts testing of solar thermal components and systems, funded primarily by the US Department of Energy. Activities are conducted in support of Central Receiver Technology, Distributed Receiver Technology and Design Assistance projects. All activities are performed in support of various cost-shared government/industry joint ventures and, on a design assistance basis, in support of a number of other industry partners.

KEYWORDS

Solar Thermal Energy, Central Receivers, Distributed Receivers, Heat Engines, Parabolic Dishes, Solar Oven, Solar Icemaker

CENTRAL RECEIVER TECHNOLOGY

In past years, the NSTTF has conducted testsof three 5 MW_t molten salt receivers[1,2,3], as well as heat transport, thermal storage, and steam generator systems. The Molten Salt Pump and Valve Test [4,5] was the final step in proving the molten salt technology. All of these tests provided the foundation for conversion of the Solar One plant, a once through water to steam boiler receiver technology to molten salt technology by the Solar Two consortium, a collection of US utilities and industry in conjunction with the US Department of Energy. Currently, the facility is performing a number of smaller-scale tests in support of the Solar Two consortium, addressing specific component and instrumentation issues[6].

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Additional Heliostats and Replacement Facets for Solar Two

The Solar Two project requires additional heliostats as well as replacement of failed facets in the existing field. An approach for replacing missing facets on the Solar One heliostats at Solar Two has been identified. The approach involves using the flat-glass facets from Carissa Plains [7] and a progressively adaptable bracket to replace missing facets with larger Carissa Plains glass facets. Results from beam quality testing were transmitted to Bechtel, the Solar Two Consortium member who is the Architect and Engineer for the project.

The temperature-curvature effect for the flat Carissa Plains facets was measured in an environmental chamber. The effect is important because if heliostat facets become convex at relatively high temperatures, the heliostats' effectiveness is compromised. The results showed that the modules tended to become globally convex at temperatures below 20-40°F [8]. The modules were generally concave at temperatures above this range. These effects became more pronounced as the temperature extremes were approached. The individual facets changed shape only slightly as a function of temperature, implying most of the overall shape change in the modules occurred at the juncture between facets. A heliostat made by the LUGO Co. with flat glass from Carissa Plains is proposed as one possible solution to installing additional heliostat area at Solar Two. Sandia assembled and tested a LUGO-like heliostat tracker with 16 flat glass mirror modules from Carissa Plains. The heliostat was assembled first with all the individual facets in a horizontal orientation. One quarter of the facets were later remounted in a vertical orientation. This remounting was more a test of the mounting procedure, than to evaluate the beam quality. It is believed that mounting in the vertical requires less modification to the framework. The beam qualities of each orientation indicate acceptable performance. Test results, along with recommendations have been submitted by Sandia to Bechtel.

Panel Preheat Options

In a molten-salt central receiver it is desirable to minimize the startup time and complexity. One way to reduce the start up time is to flow salt through a "cold" receiver and piping. "Cold" is some temperature below the salt freezing temperature, about 220 °C. During startup, the receiver is preheated using heliostats to bring the panel up to the molten-salt temperature. Because of non-uniformities of the heliostat beams, especially close to dawn and because of uneven convective loss, the receiver temperature may vary drastically. We conducted almost 20 panel experiments, with varying levels of preheat, to determine the operating conditions that will allow the panel to fill without trapping air or experiencing frozen salt plugs. We used heliostats in a dynamic mode of operation to preheat the panel. However, there were significant variations in the measured tube temperatures, as much as ±66°C.

The results indicate that there will probably be areas on the receiver panel that will be significantly below the salt freezing temperature despite efforts to uniformly heat the panels. Extrapolating from these would indicate that salt flow can be started through a Solar Two receiver panel with tube temperatures as low as

93°C. There is additional interest in flowing salt through cold manifolds and cold safe ends (the transition tubes between the headers and the receiver tubes). The manifolds are typically heat traced which can significantly add to the parasitic power consumption of the plant. Therefore, it is desirable to start the headers at reduced temperatures as well as cold. We conducted several experiments on manifolds that had cooled overnight to near ambient temperature. Although the data from these tests indicate that starting flow with cold headers and pipes is possible, the resulting thermal stresses could result in premature failure of the components. Additional work is needed in this area.

Experiments were conducted to measure the effects of thawing a panel that was frozen full of nitrate salt. The 60%-sodium/40% potassium nitrate salt has a freezing point of approximately 220°F, and expands about 4.6% by volume upon melting. A major concern with thawing a panel is when the panel is heated in the center with frozen plugs on each end. The salt will expand in the heated zone causing yielding of the receiver tubes. Five 'freeze-thaw' cycles on the panels installed in the molten salt loop were completed. In each case the panels were filled with molten salt and allowed to freeze. Heat trace on the headers and the safe ends kept them above the freezing point. Heliostats were used to melt the salt by heating the panel from the bottom. We measured the tube diameters and compared them to the pretest values. Every tube experienced some yielding, which resulted in a permanent strain from 1% to 4% after two cycles. In the design of commercial central receivers, permanent deformation due to thawing should be accounted in the life time prediction.

Therefore, to further understand the thaw procedure we designed a test to melt the salt under several conditions to determine if the tubing can be thawed without damage.

The test consists of two freeze/thaw chambers made from 30.5 cm diameter (12 inch) pipe and heated with band heaters. Two $^3/_4$ inch stainless steel tubes, .12 cm (.049 in) wall thickness, are inserted in each oven. A thermally insulating baffle is placed at the halfway position in each chamber. This allows the top and bottom of each tube to be at significantly different temperatures, that is, the salt in the top of a tube could be frozen while the salt in the bottom is molten and vice versa. By freezing the lower section while keeping the upper section hot simulates the upper header. Conversely, freezing the upper section while keeping the lower section hot simulates the lower header. To date, we have completed freeze/thaw cycles in what we consider the worst case scenario, that is, having the lower section frozen and the top hot then melting the lower section while the top remains hot. After each cycle the outside diameter of each tube is measured at six inch interval and recorded. In addition, we completed a best case, and mid-range freeze/thaw cycle. Test results indicate that the tube will rupture after 12 cycles.

Component Thermal Shock and Pressure Cycle Tests

Hardware such as flanges and check valves proposed for use in the Solar Two molten-salt system are being tested in a molten-salt loop at the NSTTF to verify the use and reliability of these components. Flanges are being tested because they are necessary but they have a tendency to leak in molten salt service. We have conducted a total of 150 thermal shocks of four types of flanges by flowing 288°C

(550°F) salt through them while they were at either 38 or 150°C (100 or 300°F). These cycles are typical of overnight shut down and cooling. The flanges experienced minor leaking but have not failed. In addition, total of 300 pressure cycles on a check valve are complete. The check valves did not fail [9].

Material Corrosion Tests in Molten Salt

Southern California Edison (SCE) requested Sandia to conduct experiments to determine the suitability of less pure molten nitrate salts for use in central receiver systems. Salts with chloride levels greater than the 0.3%, by weight, were tested. The motivation for these experiments is the interest in less refined nitrate salt, which may be significantly cheaper (as much as 40% cheaper) than the current salt source, but have a relatively high levels of chlorides. Eight different salts were tested. Each at two different temperatures, 580 °C and 315 °C, simulating "hot" and "cold" salt respectively in a system. Therefore, fourteen "salt pots" each containing approximately 9 kg of salt were tested. The eight different salts are different grades of sodium and potassium nitrate and contain different levels of impurities. Coastal Chemical and Chilean Nitrate Salt Corp. provided the salt. The pots contain metal coupons for corrosion analysis. The coupons are A36 carbon steel, as well as 304 and 316 stainless steel. Coupons and salt samples were removed for analysis at approximately 100, 200, 400, 800, 1600, 2800, 4000 and 7000 hours. Scientists at Sandia compiled the results [10] and found that all salts and all steels produced corrosion rates within acceptable limits for the design of Solar Two and commercial plants.

The isothermal experiments to determine corrosion rates on chromium-molybdenum materials for the steam generator continue. Three different materials have been exposed to three different salt mixtures at 460 °C for almost 7000 hours, this corresponds to about 2.5 yr. of operation at Solar Two. The materials tested are 9-Cr, 1-Mo and $2^1/_4$-Cr, 1-Mo steel alloys. The 9-Cr, 1-Mo is being tested at two silicon levels. Corrosion is very slow for all material in each salt mixture except $2^1/_4$-Cr, 1-Mo. This alloy is severely corroded in a salt mixture that has a high chloride concentration. Also silicon seems to inhibit corrosion. Our preliminary conclusion is that corrosion will not be an issue on the salt side of the steam generator if it is made of the 9-Cr, 1-Mo alloy.

As a result of the static tests conducted on the first phase of steel coupons all participants (SAIC, Bechtel, SCE Coastal Chemical, Chilean Nitrate Corp. and Sandia) agreed that thermal cycling tests are crucial for reliably predicting the life of solar receivers. Four salt pots and four different salt mixtures (chosen based on the results from the static test) were tested at 570°C. Each contained twenty-four coupons (twelve 304 and twelve 316 stainless steel). The coupons were automatically lifted from the molten salt three times daily and slowly re-immersed. Samples were removed and analyzed at approximately 100, 200, 400, 800, 1600 2400 and 4000 hours. The tests demonstrated that thermal cycling is not a factor even for the most impure grades of salt. As a result of the test we identified corrosion allowances and specifications for the concentrations of impurities in the salt. We were able to relax the constraints on salt impurity levels to the point where the Solar Two project and commercial plants should realize substantial savings in the purchase of salt.

Flux and Temperature Measurements

Two tests of particular significance to the design of the Solar Two receiver evaluated the use of photometers and infrared (IR) cameras to aid in the control of the receiver and measurement of flux and temperature. During panel preheat experiments two infrared cameras were used to view the temperature profiles of the heated panels and to determine the applicability of the IR camera to the instrumentation needs for central receivers. The IR cameras were Inframetrics brand, one operating in the 3-5 μm wavelength range and the other in the 8-12 μm band. These cameras proved to be extremely useful in determining the temperature profiles across the receiver during preheat and for finding tubes where there was flow blockage .[11]

Several experiments with photometers were conducted to determine if they can be used to measure flux on a central receiver to provide feed-forward control of the molten-salt flow. The impetus for this investigation is to determine if more reliable, lower cost alternatives to flux gages exist that are easier to maintain. Flux gages used in the Solar One receiver accounted for 6.6% of the outages caused by the receiver. Experience at the NSTTF and at Solar One indicates that flux gages last approximately six months before needing re-calibration or replacement. Because photometers would be mounted below the receiver, out of the high flux, they do not experience the severe environment that flux gages do. Therefore, they should be more reliable. Similar photometers have been in use in our weather station for nearly three years without any problems.

The principle behind the operation of the photometers is basic: they measure reflected light off the black receiver panel. The greater the incident flux, the more intense the reflected light will be. If the absorptivity of the black paint changes, so will the reflectivity but during normal operation these changes occur slowly and can easily be accounted for in a calibration technique or tuning of the controller.

Results for experiments conducted with a glycol cooled panel mounted on the solar tower indicate the photometers followed the flux gages well and could be calibrated to measure incident power. Figure 1 shows a result of one of the tests where groups of heliostat beams were brought on the panel 16 at a time, increasing the incident power. We have conducted test with fluxes up to 750 kW/m^2 using as many as 157 heliostats. Rockwell, the receiver vender for Solar Two is enthusiastic about these results and will integrate photometers into the receiver control system.

Wind Damage

On August 1, 1994, a storm with peak winds measured at 52 mps (114 mph) at 10 meters damaged several solar concentrators at the NSTTF. Fortunately, the storm affected only selected areas at the facility and no personnel were at the site during the storm. Some analysis indicates that the storm may have included a cyclone, which would account for the intermittent damage.

Significant damage at the site was limited to the far west side and an east-west strip in the middle of the site. Three heliostats, two parabolic dishes and several line focus troughs were damaged in the storm from the wind.

Along the west edge of the site, the wind damaged the line focus troughs and two dishes. A portable staircase was thrown over 50 meters and a house trailer, used as a work/storage area, was moved 15 cm (6 in) off of its foundation. Most of the damage to the trough was limited to the mirror panels. The light weight foundations were not damaged and appear to be functional. The design point wind load for the trough in the stowed position is 40 mps (90 mph). An elevation drive jack screw on one of the parabolic dishes failed in tension. All components are undergoing further analysis.

The damage to the east-west strip in the middle of the site included the loss of three heliostats. A fourth heliostat, in-between the three damaged heliostats, does not appear to have sustained any damage from the wind. The drives failed on all three of the damaged heliostats. The heliostats had a design wind load of 40 mps (90 mph).

Testing was complete on all of the concentrators, with the exception of one of the heliostats. Therefore, the programmatic impact of the wind damage is minimal. The drives and foundations are being examined to determine more about the failure modes and possible improvements that could be made to the designs. Validation of the light weight foundations for the line focused troughs may be a significant benefit of the storm. Non Destructive Testing is being performed on other site heliostats to verify that they were not damaged in the storm.

DISTRIBUTED RECEIVER TECHNOLOGY

Work at the NSTTF on Distributed Receiver Technology projects [12] fall in three categories. 1) Concentrator Technology, 2) Dish/Receiver Technology, and 3)Dish/Engine Technology. Each area is discussed below.

Concentrator Technology

The objective of Concentrator Technology Development activities is to bring dish concentrator designs to commercial readiness for use in solar thermal electric systems. The parabolic dish designs will be used in dish/Stirling applications. Because of their importance in developing high performance and cost-efficient concentrator designs optical materials development is also an important part of concentrator development.

The facets on the faceted stretched-membrane dish have been realigned to a focal length of 9.9 meters from their original, design focal length of 9.0 meters to accommodate a design revision incorporated by SAIC into their concentrator for use in the Utility-Scale Joint-Venture Program.

Dish/Receiver Technology

Reflux receivers have the potential of improving the life and performance of dish-Stirling power generation systems. The reflux receiver provides a thermal "transformer" between the dish and engine, providing isothermal, uniform flux to the heater heads. This results in a higher average engine temperature, lower stresses, and fewer constraints on dish design. In addition, the two-phase heat transfer allows a smaller, cheaper, and more efficient receiver. The short-term objectives of the receiver development effort are the demonstration of reflux receiver technology on-sun at scales appropriate for current dish-Stirling projects and to directly compare the performance of a reflux receiver with a directly illuminated heater head through application to the STM PCS (Sterling Thermal Motors, Power Conversion System) package. In the longer term, the program will pursue high performance, low cost concepts, develop design tools, develop hybrid receiver technology, and transfer the resulting technology to industry for commercialization.

Two promising advanced wick structures, sintered metal powder and metal felt wick, are under development and test for application to future heat pipe receivers. Sandia's improved receiver wick modeling capabilities were used to evaluate options for Cummins. Additional limit testing of the Cummins 36-kWt receiver was performed on Sandia's Test Bed Concentrator and testing of the Thermacore 75-kWt heat pipe was completed in August..

Metal felt wick materials

Felt metals are now being explored as a potential wick structure for a solar receiver. Felt metals are typically made with fine fibers ($\approx 10\mu m$) that are loosely laid down to form a mat with a high porosity. Felt metals are commonly used in filtration applications. In an unsintered state, felt metals are extremely pliable so they can easily conform to the shape of a receiver dome.

Preliminary tests were performed on samples to determine the metal felt's permeability and effective pore size. The material can be compacted to alter the pore radius and permeability. Tests on the samples indicate that the wick properties of these metal felts could be several times better than any of the wick materials that have been tested to date.

Several felt metal samples have been sintered in Sandia's hydrogen oven. After sintering, the felts were found to form a good bond with stainless steel and Haynes 230 substrate materials. The felts tend to stiffen on sintering making them more durable, and they also shrink somewhat, which could aid in pressing the material to the convex surface of a receiver dome to improve bonding.

A contract has been placed to develop a receiver with a felt metal wick. The contractor has received domes for the construction of the receivers; they have also made several sintering runs to develop the techniques for bonding the felt metals to substrate materials. Sandia plans a development program for the felt metal wick structure.

Brazed powder wick

Sandia models of potential wick designs were used to select the most promising wick structure from samples provided by Friction Coatings Inc. Friction Coatings Inc. demonstrated the application of the selected wick structure to a small (5-inch diameter) sample dome. After the application process was fully developed, Sandia delivered several full-size Cummins-style domes to Friction Coatings Inc.

Cummins 36-kWt heat-pipe receiver

The Cummins 36-kWt heat pipe receiver was tested on Sandia's Test Bed Concentrator (TBC-1). The purpose of the test was twofold. First, the limit test would increase confidence in the Cummins design. In addition, the results could be directly compared to the Sandia/Thermacore wick model for model calibration.

The receiver was subjected to the full TBC-1 dish power from sunrise, using the natural insolation ramp to increase power. The receiver demonstrated successful operation at 56-kW_t throughput with 67-kW thermal input from the dish. This is a new record for on-sun heat-pipe receiver throughput. The thermal losses were high because a wide open aperture was used, allowing receiver protection with an infrared (IR) camera. The throughput was limited by the dish power and the calorimeter capabilities, both of which reached their limits while the receiver continued to operate.

Artery-free receiver

Thermacore developed an artery-free receiver design for application to the Dish/Stirling Joint Venture Program (DSJVP) project. This has the potential of reducing the receiver costs significantly. On-sun operation of the Cummins/Thermacore artery-free receiver continued on a regular basis throughout the quarter. Cummins has accumulated 1000 hour operation on-sun with this receiver. The receiver continues to operate without difficulties or maintenance. Operation will continue based upon dish availability.

Cummins/Thermacore 75-kWt heat-pipe receiver

Cummins in cooperation with Thermacore developed a 75-kW heat-pipe receiver under contract with Sandia. The receiver will be applied to the STM engine package after direct illumination testing is completed. Thermacore has extended the 36 kWt technology and constructed several receivers designed for at least 65 kWt throughput [13]. They enlarged the dome to 20 inches, incorporated directed refluxing, and use a circumferential artery. The receiver was designed for use on Sandia's TBC and for eventual integration with the Stirling Thermal Motors 4-120 25 kWe motor. The initial receiver operated well at about 60 kWt throughput, but exhibited difficulties during startup. During the initial startup of the day, the receiver had hotspots just above the pool in high-flux regions. Subsequent restarts and rapid

startups did not exhibit this behavior. The receiver performed well during one frozen-sodium start with full dish power incident on the receiver.

A second Thermacore high-power receiver has just been tested at Sandia, and the startup problems have been eliminated. Several key design changes contributed to the improvement. The wick structure permeability has been improved such that the design tools predict performance in excess of 120 kWt, compared to 75 kWt on the first receiver. The gap between the absorber and the aft support dome was quadrupled to eliminate vapor pressure drops. Finally, the receiver was thoroughly baked out while monitored with a residual gas analyzer, until the hydrogen and water peaks were minimized. It was theorized at Sandia that free hydrogen in an improperly cleaned system forms hydrides as the receiver cools to ambient. Upon startup, the pressures generated hy decomposing hydrides would be sufficient to de-prime the wick structure, causing hot spots. This second receiver operated well to the limit of the dish, and demonstrated a throughput of over 65 kWt to a gas-gap calorimeter. This, we believe, is currently the record for a solar-driven heat pipe receiver.

Sandia has been actively identifying and testing potential high performance wicks, both to improve upon Thermacore's capabilities, and to provide a secondary technology in case problems are identified. Sandia has identified a stainless steel felt supplied by Porous Metal Products of Texas. This felt is very uniform in appearance, and has properties that exceed powder metal technologie.

Nickel wick mechanical properties

An effort is underway to determine the strength requirements of a thick nickel wick. This is in support of (1) Sandia's collaboration with Thermacore to develop a 75-kWt heat-pipe receiver and (2) the Dish/Stirling Joint Venture Program. In the present period, mechanical properties of a representative wick have been measured, finite element stress analysis has been performed, and a contract for creep characterization has been issued.

The room-temperature wick yield strength, ultimate tensile strength, fracture strain, and elastic modulus are all on the order of 10% to 20% of wrought-nickel values. We have scaled accordingly the temperature dependent wrought-nickel elastic modulus in our finite-element stress analysis. Predicted stresses in the wick of a prototype heat-pipe receiver are near the measured value for yield at room temperature. While they are compressive, reversal probably will occur as a result of creep. Repeated tensile cycling of this magnitude could lead to early fatigue failure. To address this scenario, a contract has been issued to creep-test nickel-wick samples at elevated temperature, and a total of 18 samples have been wire-EDM cut from the first Sandia/Thermacore 75-kWt heat-pipe receiver.

Bench-scale pool-boiler receiver durability test

The durability bench-scale pool boiler developed a very small leak at a condenser thermowell after about 7500 hours total lamp-on time. The recorded behavior was normal until the last 12 hours of operation.

The leak symptoms were (1) decreased boiler thermal-power throughput and (2) a single lower-than-normal indicated temperature. The internal pressure was near-normal, indicating that very little air leaked into the boiler. The test was operator-terminated, the test vessel was drained, and the residual liquid metal was distilled out under vacuum. The vessel was sectioned and metallurgical examination has started.[14]

Initial results of the metallurgical examination are encouraging, although it must be kept in mind they are tentative. As suspected, the leak is in a material and in a boiler feature (the IN600 thermowell) that would not be part of a commercial receiver. Equally important, the condition of the Haynes Alloy 230 and the heated-surface powder-metal coating appear to be good. Some surface recession and grain-boundary grooving of the Haynes Alloy 230 are apparent, but appear to be slight. Better characterization will be possible after completion of cross-sections and analysis of NaK for Haynes Alloy constituents.

Hybrid receivers

Stirling Technology Company (STC) of Richland, Washington, has been under subcontract to NREL since April 1992 in a two-phase program to demonstrate the feasibility of a 10-kWt_h hybrid liquid-metal pool-boiler receiver for dish/Stirling application. Cummins Power Generation (CPG) continues work on their hybrid heat-pipe subcontract. CPG is planning to start on-sun testing soon.

Dish Converter Solarization (Dish/Engine Technology)

In cooperation with industry, Sandia has been engaged in a program to solarize, test, and evaluate power conversion devices that have the potential to be utilized in commercial solar thermal electric point-focus systems. The goals of the program are to engage in projects that directly support on-going commercialization efforts; to develop solar thermal power conversion systems that are candidates for commercialization; to identify and respond to solarspecific design issues; and to increase the general industry knowledge base on system integration, packaging, and system testing techniques.

Stirling cycle power conversion system

A project is currently in progress at the NSTTF to develop solarized versions of existing engines. The project involves solarization and on-sun testing of engines developed primarily for co-generation applications. The on-sun testing is designed to verify the predicted power conversion system (PCS) performance and determine the suitability of the engines for solar applications.

Phase 1 of a cost-shared project with Detroit Diesel (DDC) and its sub-contractor, Stirling Thermal Motors (STM), is complete. This project consisted of integrating a 25-kWe Stirling engine (an upgraded STM4-120) with a direct illumination receiver, an engine cooling system, an induction

generator, and an engine control system into one package. This integrated package is called a power conversion system (PCS).

Prior to delivery to Sandia, the engine was tested with gas-fired heater heads, and then the entire PCS was tested using quartz lamps for the heat input to the receiver. The engine performed quite well during these tests.

Testing of the PCS is to be done in three phases. Phase 1 is complete and consisted of system checkout and debugging. Power and temperature levels started out relatively low (600 °C). Two of the specific objectives of this phase are to verify control stability and to verify a reasonable temperature distribution on the direct illumination receiver. An infrared camera system is used to view the receiver's temperature distribution. For this reason, the 220-mm aperture is removed. This increases thermal losses tremendously, but allows a full view the receiver during these shakedown tests. The infrared system has been a great asset in these tests. After all personnel involved are satisfied with these tests, the 220-mm aperture will be reinstalled and the engine will be operated at full input power.

Phase 2 consists of performance mapping the PCS. Power output, PCS, and system efficiencies will be mapped as a function of power input (mirror area) and receiver temperature.

Phase 3 is optional and will be performed only if time and resources permit. The purpose of this phase is to map the PCS at different cycle pressures and to identify anomalies in performance because of less than ideal conditions such as cloud transients and dish tracking errors.

Phase 2 of the project, which consists of performance mapping of the STM engine, was initiated in January. Several difficulties occurred during this testing. First, the maximum power that could be achieved from the engine was 16.5 kWe. This power level was achieved under conditions where the expected power level was 22 kWe. It is currently believed that this reduced power level is the result of a faulty set of piston rings in one of the engines four cylinders. All of the piston rings will be replaced to determine if this is the actual cause of the reduced power level.

A second difficulty arose during a test sequence in early March. During start-up, the engine controller "locked up" before the alternator was hooked up to the grid. As a result, the engine heater head was overheated. The front side of the heater head tubes went to at least 1025°C; the pressure in the engine working fluid was at 6 MPa. The heater head ruptured in four locations, one associated with each of the four quadrants in the heater head. The engine was removed from the Test Bed Concentrator for examination and repair. STM is currently producing another four heater heads to replace the ones that failed. SNL added software and hardware shutdowns to the back up the STM controller. Also, this opportunity will be used to replace the piston rings to determine if they are the cause of the reduced power level.

STM performed many tests to pinpoint the problem. First, this particular engine had a lubrite process eliminated; a process that reduces friction between parts. It was thought that this process was not

needed due to a change in materials on the bearing surfaces. However, this was not the case, and lubriting the crossheads significantly increased the engine efficiency. Additional lack of power appears to be related to the generator. The efficiency dropped as soon as the engine was placed in the package instead of on the dynamometer. Further investigation showed the generator, which is actually a motor running in reverse, is not as efficient as the motor rating suggests. STM is planning more tests on the motor/generator. The package was returned to SNL and is being retested.

DESIGN ASSISTANCE ACTIVITIES

Under the design assistance program the NSTTF conducts tests of products that are generally developed without significant solar thermal program funding. Two parabolic troughs manufactured by Industrial Solar Technology have been tested in several configurations. Both were tested on the rotating platform at the NSTTF. One of the troughs uses ECP305 reflective film and the other uses aluminized SA85 film. Two receiver tubes were tested on each trough. One tube is made of Pyrex and the other will use sol-gel and AR (antireflective) coated glass. The purpose of the test program was to compare the various trough upgrades. The baseline case, aluminized trough reflector with a black chrome receiver covered with Pyrex glass envelope, had an optical efficiency of about 66%. The advanced trough system, ECP305 trough reflector with a black nickel receiver covered with a sol-gel coated envelope, had an optical efficiency of 77%. Writing of the complete report is underway.

Solar Ice Maker

The facility has worked with Energy Concepts Co. to test the Mini- and Full-ISAAC (Intermittent Solar Ammonia Absorption Cycle) ice maker. The system is composed of a parabolic solar collector, an absorber cooler and an auxiliary heating coil. The solar collector has a concentration ratio of 1.8 and yields 100°C, the temperature required for ammonia vapor desorption. The concentrated solar energy is directed into a generator/absorber (G/A) vessel. Thermal energy boils -- or "generates" -- ammonia vapor from an aqua-ammonia solution contained in the vessel. The ammonia vapor is routed up to the condenser/receiver vessel where it condensed into liquid. The receiver collects liquid ammonia during the day. When the sun goes down a valve is turned and the cycle changes from 'generate' to 'ice-making'. During ice-making the liquid ammonia flows to the evaporator where a unique thermosyphon cools the G/A vessel and thereby lowers the pressure. As the pressure decreases the liquid ammonia begins to evaporate through a pressure reducing valve, drawing heat from the refrigerator/freezer compartment and ice is made. The ice maker is capable of producing 40 kg of ice per day. The ice-maker is being tested for Energy Concepts to aid in improving the system design and to asses its long-term performance and operation.

Solar Oven

Also tested at the facility is a solar concentrating oven developed by Burns Milwaukee. The oven called a Villager Sun Oven has a 0.6 m^2 cooking surface, has been tested and is ready for domestic and international markets. The purpose of the tests is to quantify the oven's performance activities such as heat up time, tracking requirements, cooking capabilities, and alternative use. When testing the oven on clear days, heat up of the oven to 150°C (300°F), took about 20 minutes at a direct normal insolation of 1000 W/m^2. Early morning heat up of the oven (less than 700 W/m^2 direct normal) took about 40 minutes. The oven was capable of maintaining cooking temperatures (greater than 120°C (250°F)) under partly cloudy conditions as long as the direct solar insolation did not drop below 600W/m^2 for more than 15 minutes. The oven was used to cook a variety of foods including, various meats, vegetables, breads and drying of fruit. Also, the oven was used for boiling water for sterilization purposes. During the operation of the oven it was determined that the oven tracking could be adjusted every 30 minutes without any noticeable drop in heat collection, and could maintain stable temperatures with very little drop in heat collection when adjusted every hour.

American SunCo. Parabolic Trough Collector

The American SunCo. parabolic solar trough concentrator is a two axis tracking collector for heating water for hot water usage, and small scale industrial usage such as laundry hot water or adsorption air conditioning. The purpose of this test program is to check the functionality of the collector system, qualitatively analyze the tracking system, determine hot water heating capabilities, analyze the trough optical characteristics, and checkout the overall system performance. The system provided by American SunCo is a two axis tracking parabolic trough that is powered by a photovoltaic array. The system includes the following:

One 50 ft^2 parabolic reflector with a 2 inch receiver
One two axis tracking controller
One two axis optical sun sensor
Two 12 volt actuating motors for elevation & azimuth
Mounting chassis and mounting hardware for the actuating motors
DC pump and fluid hoses
Photovoltaic panel for powering the system

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