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ASSESSMENT OF MOLTEN-SALT SOLAR CENTRAL-RECEIVER FREEZE-UP AND RECOVERY EVENTS

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ABSTRACT

Molten salt used as a heat transfer fluid in central-receiver solar power plants has a high freezing point (430°F (221°C)). It is very likely during the life of the plant that the receiver will accidentally freeze up due to equipment malfunction or operator error.

Experiments were conducted to measure the effects of a molten salt receiver freeze-up and recovery event and methods to thaw the receiver. In addition, simulated freeze/thaw experiments were conducted to determine what happens when salt freezes and is thawed in receiver tubes and to quantify the damage caused to candidate receiver tube materials. Fourteen tube samples of various materials, diameters and wall thicknesses were tested to destruction. Results of these tests are presented in this paper.

BACKGROUND

In a molten salt solar central receiver, large tracking mirrors focus sunlight onto a receiver on top of a centrally located tower. Molten salt at 288 550°F (288°C) is pumped from a storage tank to the receiver where it is heated to 1050°F (565°C) in the receiver by the absorbed solar energy. The "hot" salt is stored in a tank where it can be withdrawn and pumped through a steam generator to produce steam to power a turbine and make electrical power [Chavez, Kolb, and Tyner, 1995]. Molten salt was chosen as the heat transfer fluid because of its high heat capacitance, low cost, and chemical stability at the upper operating temperature. Its disadvantage is its high freezing point (approximately, 430°F (221°C) [Cook and McMordie, 1989].

In the receiver there are multiple drain valves which allow the salt to drain back the storage tanks. During the nightly shut down of the receiver, there exists the possibility that a drain valve will fail to actuate. Based on a valve failure rates, a valve could fail to actuate more than once in a thousand times [Brookhaven National Laboratory], a receiver - which has 14 drain valves (such as the Solar Two 10MW$_e$ solar central receiver located in Daggett, CA [Chavez, Kolb, and Tyner, 1995]) - will fail to drain approximately once every two and a half months. That does not mean a panel will freeze that often. Only if this failure is not detected in time and corrective action (such as manually opening the valve) is not taken will the salt trapped in the associated panels freeze. Since the volume of salt increases when it goes from the solid to the liquid state (approximately 4.6%), damage can occur to the receiver tubing if the salt is thawed in a section of tubing or piping which is constrained at both ends.

Considering the multiple drain valves in the receiver, the likelihood that a panel could fail to drain during nightly shut down is high over the life of the receiver. In addition, a panel could freeze up during morning startup if areas of the receiver are below the salt freezing temperature. In previous receiver experiments, detailed assessments of freezing and thawing of the panel tubes had not been conducted. The Martin Marietta molten salt receiver, tested at Sandia National Laboratories, became frozen with salt during morning start up and was successfully thawed, though no data on tube deformation was available [Tracey, 1995]. In addition, during a test to determine the potential of cold filling a molten salt receiver in the external configuration, the receiver was partially frozen [Bergan, 1986].

In this paper we describe freeze / thaw experiments conducted with a receiver panel where we intentionally let salt freeze in the receiver panels. The objectives of these tests were to understand the freezing phenomenon under non-flowing (stagnant) conditions and quantify the deformation that takes place in an actual receiver panel. We also wanted to determine the procedure required to thaw a receiver panel if it became frozen with salt and to determine what amount of damage was done to the receiver tubes during the thawing process.

In addition to the panel freeze/thaw tests, we assessed the damage induced in various potential receiver tube materials under simulated freeze/thaw conditions in an oven. We conducted four series of these tests to understand the freezing/thawing process. We froze and melted salt sequentially in tube samples using a two-chamber oven to determine if the tubing can be thawed without damage. A fifth series of tests was conducted to quantify the damage that occurred to 14 samples of tubing (5 materials, 3 diameters and 3 wall thicknesses - not every combination was tried) under the most severe freeze/thaw

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