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Direct Absorption Receiver

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Introduction

The Solar Energy Research Institute (SERI) is conducting research for high-temperature solar thermal receiver concepts. A good candidate for a receiver heat transport and a thermal storage medium is molten salt, and molten carbonates are the primary candidate salts for applications requiring temperatures of 850°C (1562°F) or higher. The receiver absorbs concentrated solar radiation directly on a salt film flowing down a wall in a cavity.

The molten salts being investigated are carbonates and chlorides. Although sodium hydroxide is the cheapest medium, it has the highest corrosion rate on containment materials and, thus, does not warrant further study at this time. Chlorides have low corrosion rates on ceramics but high rates on metals, and carbonates have low or modest corrosion rates on both metals and ceramics. A ternary eutectic of lithium, sodium, and potassium carbonate has been selected as the primary salt mixture for the direct absorption receiver and thermal storage system concept.

Figure 1 illustrates the receiver concept. Low-temperature salt at 425°C is pumped to the receiver in the riser, and a manifold distributes that salt over the top of the absorber surface. The molten salt runs down the absorber surface and is heated by the concentrated solar flux to a temperature of 900°C. The salt then returns to ground level through the downcomer, a metal pipe. Solar radiation enters the cavity through an uncovered opening and is absorbed in either a blackened salt or a black surface with a relatively clear salt.

Objectives

Our research objective is to provide the scientific and technical base for the design of a direct absorption and thermal storage system for high-temperature solar thermal applications, thus, demonstrating the technical feasibility of the system concept. At this stage the research is generating data from which we can design commercial-scale central receiver systems and assess the economic potential. The research currently emphasizes modeling of the direct absorption process and measurements of liquid-film flow characteristics. We will also perform experiments on thin films and molten carbonate salt.

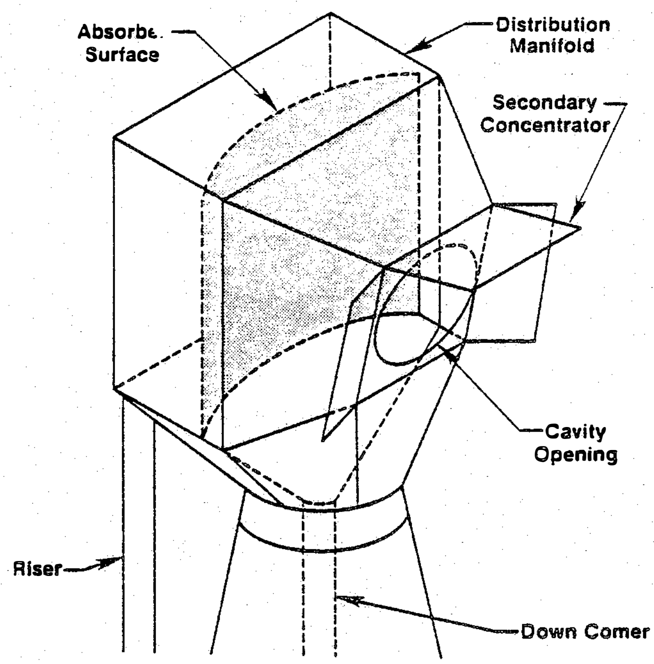

Figure 1. 50-MW_t DARTS Receiver

Accomplishments

We chose a 50-MW_t receiver based on the Boeing design [1] to be our baseline size. We selected this size because several other receiver designs are available for comparison, and the data generated can be converted to reflect larger and smaller sizes.

Flow Regimes

Figure 2 illustrates the shape of the absorber surface for the baseline design with an average receiver flux of 500,000 W/m^2. All three configurations are curved in the z-direction to maintain constant flux in that direction; the figure illustrates the surfaces as if they were flat. For the nominal case (100 m^2) active absorber surface the flow is turbulent in the presence of maximum insolation and laminar for minimum insolation, which results from viscosity changes with salt temperature. An all-laminar configuration can also be defined, but as illustrated, it has an odd shape and may have flow distribution problems. An all turbulent configuration also has an odd shape and requires pumping of the salt back to the top of the absorber surface; once after being heated to 617°C and a second time after being heated to 783°C.

An apparatus to evaluate film thickness and flow characteristics in water was constructed. Experiments to date indicate that under some flow conditions dry spots can develop, which could cause local overheating and damage to the absorber surface. Rough, wetting surfaces distribute the flow well, avoiding dry spots. Additional tests are in progress to measure film thickness and velocity with water.

A molten salt loop to evaluate flow and heat transfer effects is being designed. SERI is designing and constructing the absorber, blackener addition (graphite), and preheater for the molten carbonate salt. The Georgia Institute of Technology (GIT)

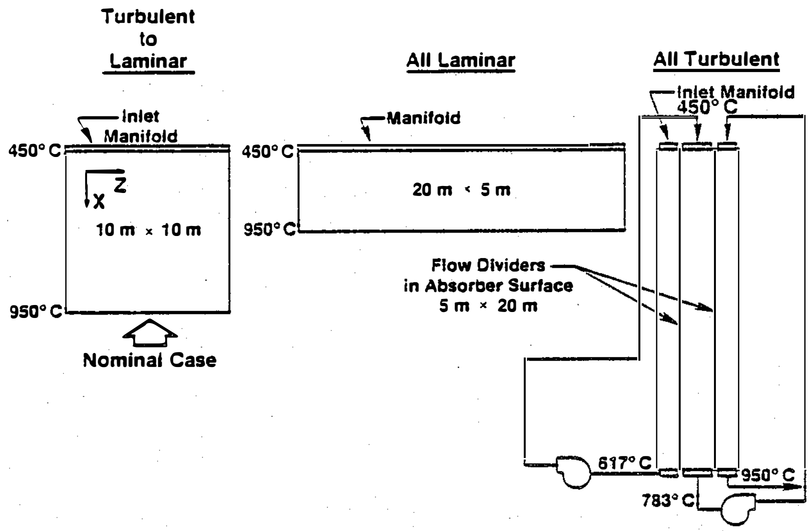

Figure 2. Flow Geometry, 50-MW_t, 100-m^2 Absorber

is designing the remainder of the flow loop. Figure 3 illustrates a schematic of the system. The apparatus will first be used in a ground test (isothermal salt flow) and later in a solar heat experiment at the Advanced Components Test Facility (ACTP) and GIT.

Mathematical Modeling

The direct absorption process has been modeled for both laminar and turbulent flow regimes [2]. A numerical analysis approach was incorporated into a computer program at SERI. This model was checked against previous models generated by Sandia for molten nitrate salt [3]. Good agreement was obtained with the earlier work, which was limited to conditions where the salt is isothermal in the y-direction. The SERI model is capable of predicting both x-direction and y-direction temperatures in the salt film. The model contains a number of simplifying assumptions, and additional work is in progress to incorporate more of the major variables.

The current model has been used to calculate temperatures in the salt film for solar fluxes in the range of 100,000 to 1,000,000 W/m^2. The data are being generated parametrically because a receiver can be designed for small or large solar fluxes by making the absorber surface large or small. Similarly, the flow regime can be designed to be laminar or turbulent by the shape of the absorber surface (see Figure 2).

Plans For Next 12 Months

SERI with GIT plans to complete the fabrication of a molten salt loop and to conduct a series of ground tests on several types of absorber surfaces. A metal, a ceramic, and a roughened absorber surface will be tested. The experiments will be isothermal with the inlet temperature set in the range of 425° C to 900° C.

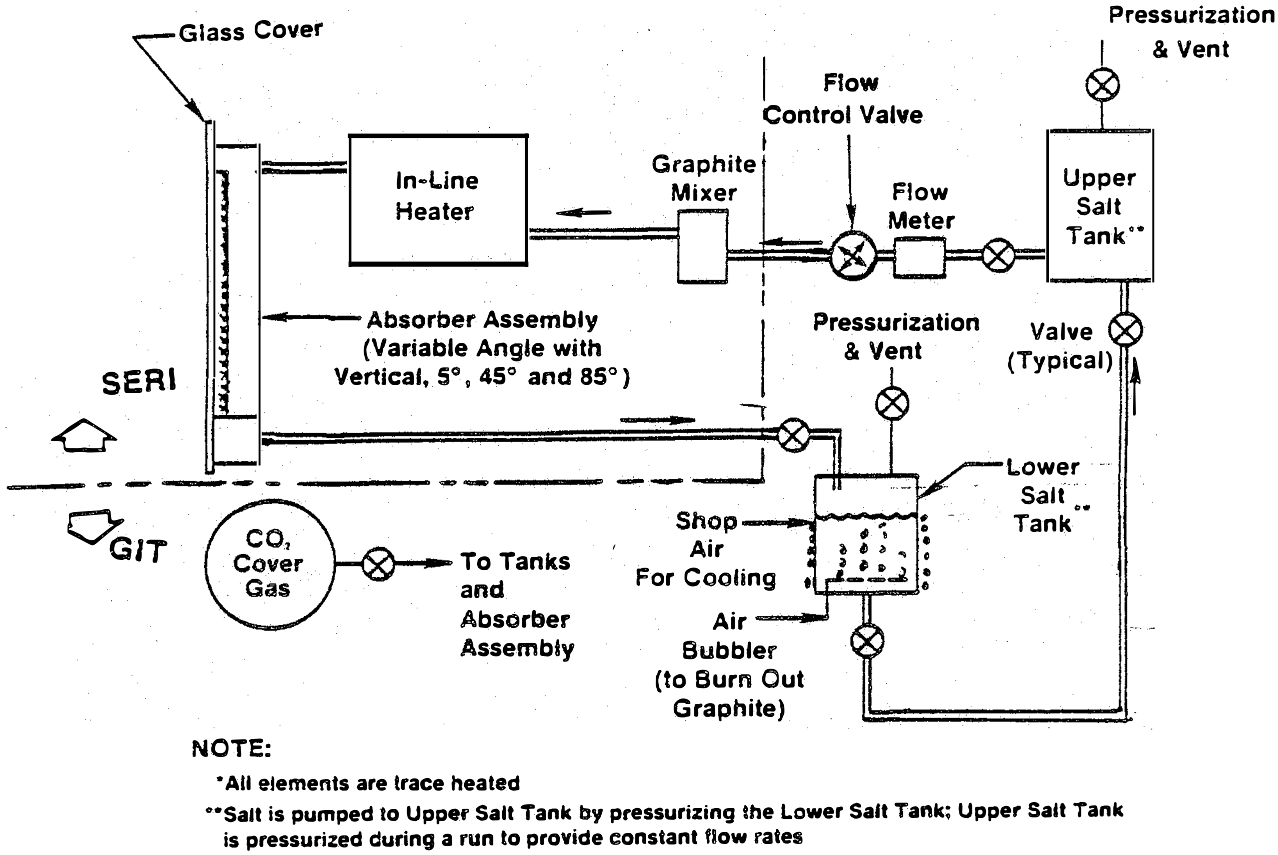

Figure 3. Molten-Salt Test Apparatus Ground Test Configuration

SERI also plans to continue the work on mathematical modeling and water films to develop a better understanding of the phenomena and to provide design data for commercial-scale receivers.

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