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Direct Absorption Receiver

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DIRECT ABSORPTION RECEIVER

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Three major goals of the receiver research effort of the Solar Thermal Research Program are to lower the cost of receivers, achieve higher working temperatures, and improve durability. Toward that end the Solar Energy Research Institute is investigating a novel receiver concept that has the potential to meet these three goals. This concept, the Direct Absorption Receiver (DAR), is based on flowing a thin film of molten salt down a flat, absorbing surface and directly exposing this film to concentrated solar flux from a heliostat field. This paper describes a research task aimed at evaluating the technical feasibility of this concept during FY 1984 and FY 1985. First, the concept and its potential benefits and problems are discussed. Then, the long- and short-term goals of the task are described. Finally, the paper explains the analytical and experimental elements of the task in general terms and gives the conclusions drawn to date.

DIRECT ABSORPTION RECEIVER CONCEPT

The DAR concept contrasts with a conventional system in which salt is pumped through a manifold into multiple tubes that are irradiated with concentrated solar energy (see Fig. 1). With direct absorption a more uniform heat flux is being applied to the salt flow than to the tubes. Figure 1 shows that the radiation impinging on the periphery of the tubes is not uniform.

There are several advantages of the DAR concept. First, there is no temperature drop across a tube wall. This gives a higher delivered salt temperature for a given flux, resulting in higher thermodynamic efficiencies for processes using solar energy. Another advantage is a higher heat flux because of the more uniform distribution of energy on the film. This leads to smaller cavities and, therefore, lower radiation and convection losses. The direct absorption receiver is easier to fabricate because it is simply a plate that uses gravity to generate the flow as opposed to multiple tubes that must be welded to manifolds. This simpler construction means initial costs and maintenance costs will be less. Also, there should be fewer thermal problems since there are no tubes or tube welds.

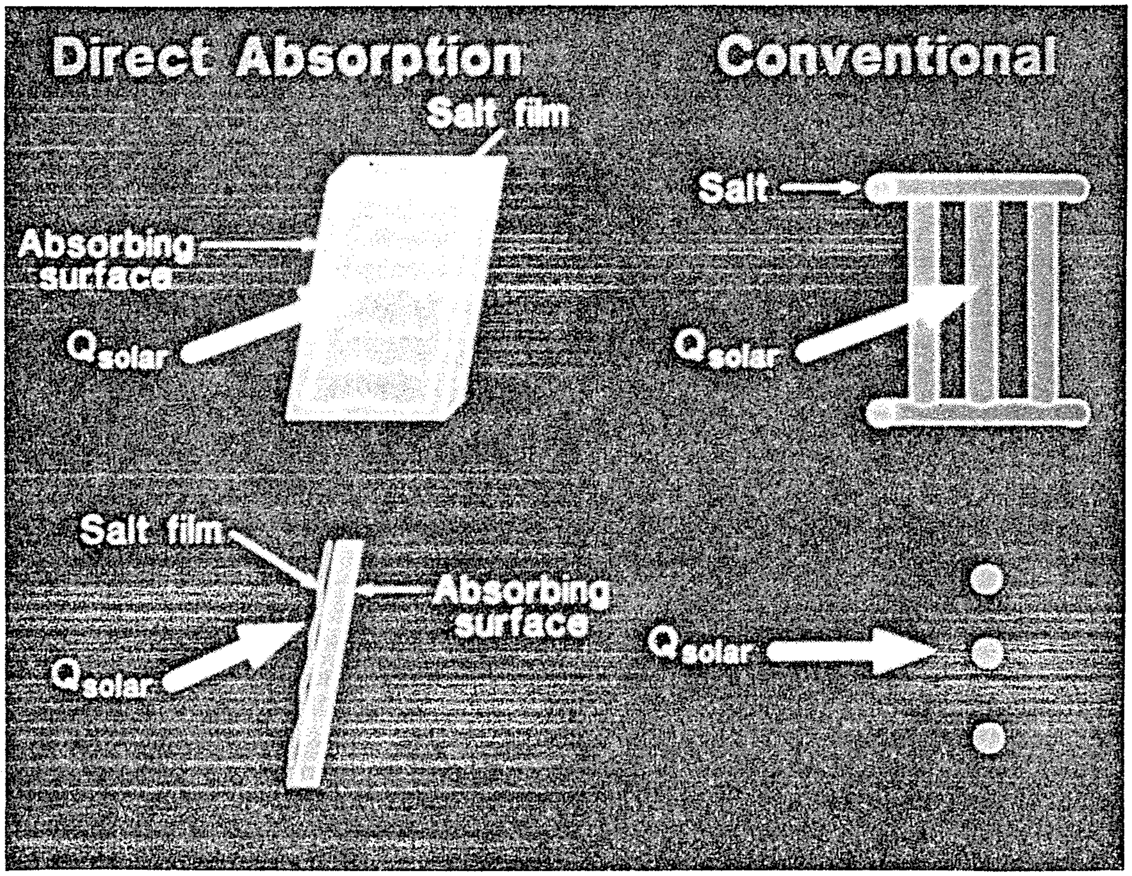

Figure 1. Comparison of Conventional Tube-Type Receiver with the Direct Absorption Receiver

On the other hand, the concept is an advanced one, requiring research to enable a characterization of the following processes and parameters:

- Film stability
- Heat transfer
- Materials lifetime and salt degradation
- Operation and control considerations.

Film stability refers to the growth of dry spots on the absorber, resulting in overheating of the absorbing surface. Heat transfer questions concern whether or not enough heat can be removed with the film by convection or radiation between the film and the plate to keep the plate cool enough to prevent material degradation or damage to the plate. Another question is whether the salt will degrade when it is exposed to air. This and other materials problems must be considered along with the ongoing work on heat transfer and fluids mechanics. These film stability, heat transfer, and materials issues could also lead to special control requirements that could affect start-up and transient operation.

GOALS AND OBJECTIVES

The long-term goals for the direct absorption receiver program are to evaluate the technical feasibility of the concept and provide the engineering data necessary to design a receiver for a full size plant for process heat or for electricity generation. The near-term objective for FY 1984/FY 1985 is to evaluate the technical feasibility by

- Analytically modeling the film flow and heat transfer in the film
- Experimenting with a water film flowing down an inclined plate and investigating the effect of roughness
- Developing techniques for measuring film thickness in molten salt
- Fabricating an absorber plate out of Inconel and testing it in air up to 900°C
- Building and operating a 500°C batch salt apparatus for developing data on film stability and thickness
- Fabricating and operating a 700°C continuous flow salt loop
- Fabricating a 900°C test loop for testing at the Georgia Institute of Technology Advanced Component Test Facility.

MODELING

Film Stability

The analytical modeling work [1] sought to determine the controlling parameters for several potential phenomena that could affect the ability of salt to flow down the plate. One of these is film breakdown at low flow in which the salt film tends to break up into rivulets because of surface tension. This leaves dry spots and can cause overheating. The thermocapillary effect is caused by gradients in temperatures across the liquid film. These temperature gradients and resultant surface tension gradients tend to pull the film away from hot spots, leaving a dry area that could overheat the absorber plate.

Gas/liquid interaction may arise from either forced convection flows caused by wind or natural convection flows in the receiver cavity where the air flow would be counter to the liquid salt flow. The shear force could pull the film off the plate or initiate instabilities, which could result in dry spots and absorber plate overheating.

Understanding the effect of absorber plate roughness on the film is important because a metal absorber plate will eventually become rough because of corrosion on the surface, while a refractory surface would likely start out rough. Therefore, how this roughness affects the stability of the film flow needs to be determined.

Finally, there is a need to understand at what flow transition to turbulence occurs since it profoundly affects the heat transfer and film stability.

Heat Transfer

In the area of heat transfer analytical modeling was completed [2] that allows one to predict the temperature distribution in the film (from the air-liquid interface through the film to the liquid-absorber plate interface). The model allows either laminar flow or turbulent flow and also allows one to test the effect of adding darkener to the salt to increase its solar absorptivity. The model also allows one to test what effect reflectivity has on the absorber surface.

WATER FILM EXPERIMENT

Water film experiments [2] were performed at various angles of absorber plate inclination and various flow rates. These helped in developing a technique for measuring the thickness of the film and verifying that the measured thicknesses of the water film compared favorably with data and correlations found in the literature. This measuring technique is now being used to measure the thickness of the salt film. The experiment also helped in examining the flow of water over a rough surface and in developing a heat transfer model for flow over the rough surface.

SALT FLOW EXPERIMENTS

SERI has three salt flow experiments: the 500°C batch apparatus, the 700°C continuous flow loop, and the 900°C flow loop. The status and objectives of these experiments are listed in Table 1.

Figure 2 shows how all the various test loops cover the important flow rate ranges. It also shows various plant capacities at three turndown ratios. The 500°C loop covers the low end of the flow rate range; the 700°C loop goes well into the range of commercial interest; and the 900°C loop covers the entire range of flow rates of interest.

Figure 3 shows an end view of the absorber plate tested in the 500°C apparatus. This plate is a 6-in. x 30-in. x 2-in. thick slab of Inconel. There are 22 cartridge heaters placed in the sides and thermocouples that control the temperature of the absorber plate.

Figure 4 shows the absorber plate being tested at approximately 900°C. There was no salt flowing during this experiment; the test verified that the cartridge heaters and the control system can operate at the high temperatures needed.

Table 1. Status and Objectives of the Three Salt Flow Experiments

Apparatus	Status	Objectives
500°C	Operational	Gain experience in molten salt handling
		Look at safety issues
		Develop film thickness measurement capability
		Determine film thickness and stability over limited flow range, tilt angle
		Measure viscosity of molten carbonate salt
700°C	Operational	Test at near vertical position
		Check flows from 3:1 turndown; 25 MW_{th} to full capacity, 50 MW_{th}
		Moniter continuous flow for steady state operation
		Cover transition regime, laminar to turbulent
900°C	In fabrication	Test with solar flux input
		Cover full flow range

CONCLUSIONS

The analytical models have shown that there are questions about the applicability of some of the correlations and property data, such as surface tension, contact angle, and viscosity. However, within these limits the modeling shows that the film should be stable except at very low flow rates.

There is a need for experiments on low flow rate ranges. The effect of hot spots (local areas of high solar flux) needs to be investigated to determine if the thermocapillary effect will produce dry areas and overheating. The interaction of gas flows with the liquid salt flow needs to be examined. Also, the effect of roughness on the absorber needs to be looked at. Low flow stability and the effects of hot spots and turbulent flow will be investigated in FY 1985.

The heat transfer modeling shows that turbulent flow provides a uniform temperature across the film and is the preferred mode of

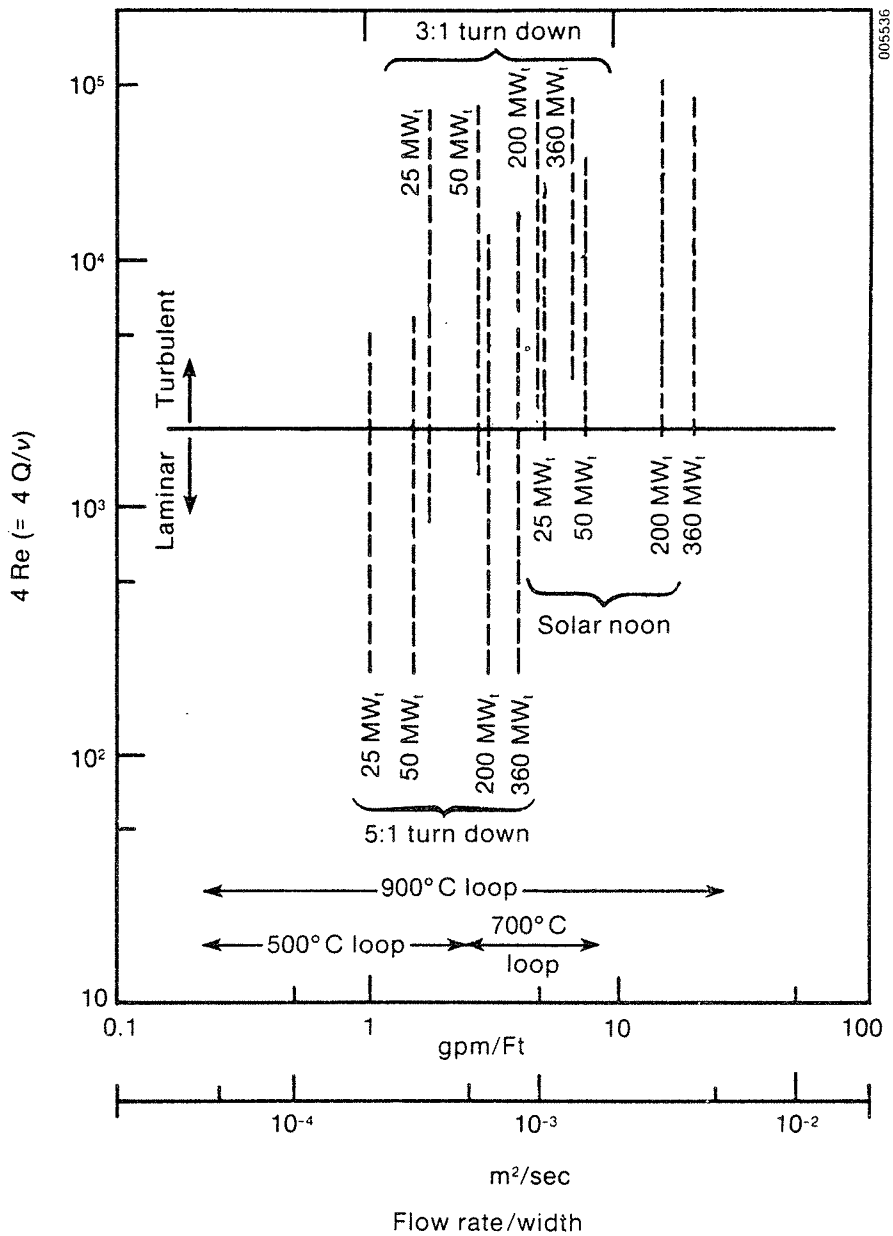

Figure 2. Comparison of Flows Required for Full Scale and Experimental Capability

operation. It also shows that adding darkener to the salt flow is not necessary if the absorber plate is an oxidized metal. If this is not the case, then it might be necessary to add darkener to the salt. This research task does not include testing the effect of salt darkeners during FY 1985.

Experimental work to date shows that roughness does not change the water film stability and can enhance heat transfer. However, the roughness needs to be carefully applied to the surface, as the roughness can trap air bubbles resulting in hot spots on the absorber plate.

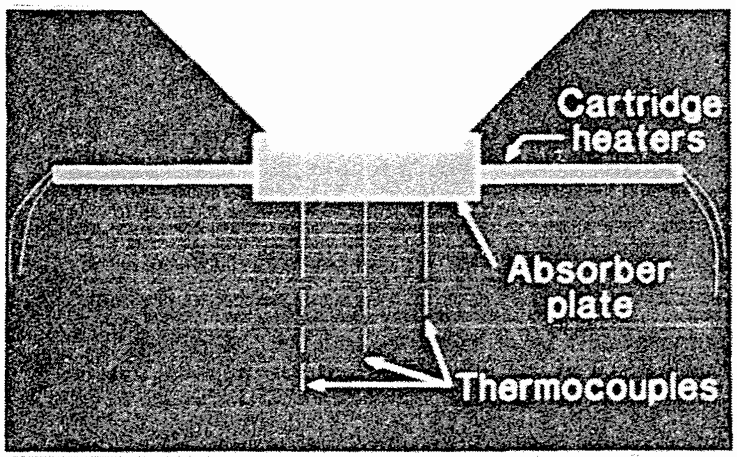

Figure 3. Absorber Panel/Test Fixture End View

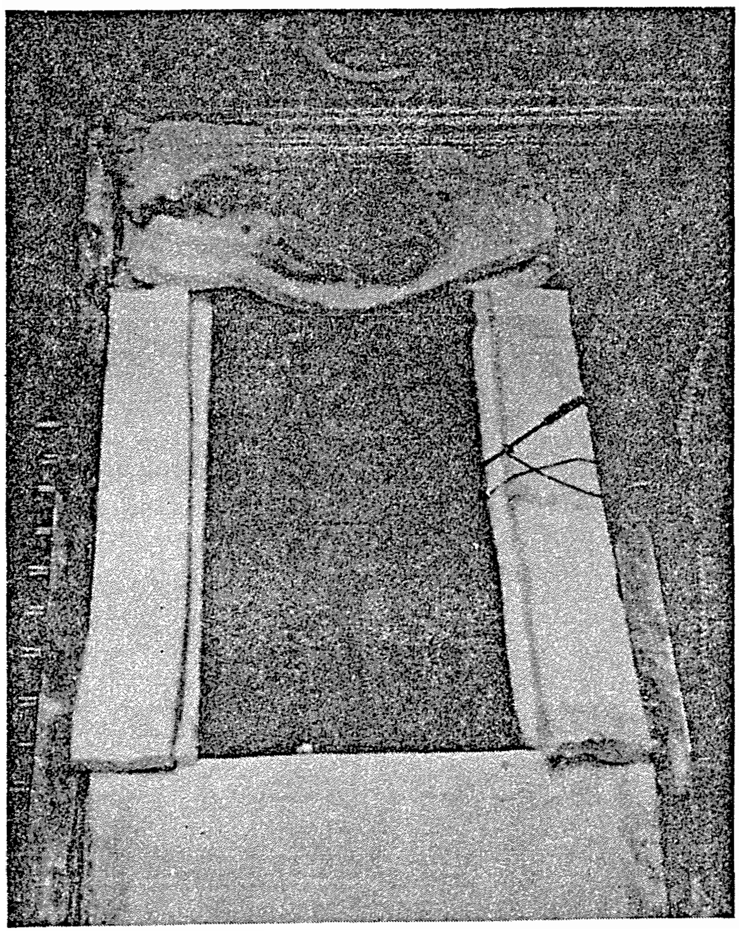

Figure 4. Absorber Plate Being Tested at 900°C

The work on salt flowing on an absorber at 5 degrees from horizontal shows that the salt film very easily wets the surface. This is primarily because of the low contact angle and the high surface tension. The flow rate range in the 500°C apparatus is restrictive; however, the salt film is stable at both ends of this flow range. At the lowest flow, which is an extremely low flow rate, and at the highest flow, which is just below the transition point, the film appears to be stable.

Further work in FY 1985 will demonstrate film stability at the more practical near-vertical absorber orientation as well as at turbulent flow rates and with actual solar input. These tests will be used with the analytical models to determine if a commercial-scale DAR is technically feasible.

ACKNOWLEDGMENTS

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