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DEVELOPMENT OF A SOLAR THERMAL RECEIVER FOR HIGH TEMPERATURE APPLICATIONS

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ABSTRACT

A thermal receiver for point focus collectors is being constructed. Its design, which is based upon experience with a commercial receiver, employs the advantages of that receiver and improves some of its features. The new receiver uses as a buffer between the cavity surface and the heat transfer fluid a thermal mass, which with a very small temperature drop penalty smooths the heat flux distribution to eliminate hot spots. Maximum operating temperature range was extended from 620°C to 870°C and receiver efficiency was improved. The design of the receiver enables significant spillage flux at the receiver to be used. Thus, lower quality optics can be employed in applications not requiring very high temperatures. Design and construction features of the receiver are presented and the testing program is described.

FOREWORD

This report documents progress on the advanced thermal receiver project (Copper Receiver) in the Solar Thermal Conversion Branch, Task 3457.11. A presentation based on this report was given at the Advanced Solar Thermal Technology Program, Phoenix, Ariz., December 1979.

INTRODUCTION

Several high temperature receiver concepts were recently proposed for point focus application. Such applications include electric power generation, process heat, and fuels and chemicals production. For example, in the June 1979 Review of Advanced Solar Thermal Power Systems two receiver concepts for Stirling engine application were presented [1].

Interest in fuels and chemicals production in the SERI Solar Thermal Conversion Branch has led to the development of a high temperature point focus receiver. Primarily a research tool for field testing of thermochemical receiver concepts, the point focus receiver may prove to be practical for other high temperature applications.

Some of the design features of this receiver are based on our experience gained from a commercially available, point focus receiver/concentrator [2]. We learned three key design features of that system. First, the optical matching between the concentrator and the receiver was relatively poor. Second, the receiver was limited to an operating temperature well below our range of interest. Third, a thermal mass would be needed for many applications, especially for thermochemical receivers.

In this paper we describe the design features, construction details, and proposed testing plan for the high temperature receiver currently under development.

DESIGN FEATURES

This receiver design uses the thermal mass concept. In the attached figure the thermal mass is the cast copper part of the receiver (the receiver is axisymmetric). The purpose of the thermal mass is to give both temporal and spatial smoothing to the heat flux impinging upon the cavity surface to minimize the chance of coolant tube burnout and add thermal inertia to the entire system. Tube burnout may be a significant problem for receivers used to heat endothermically reacting fluids because local heat transfer rates may vary significantly along the tube length.

The thermal mass concept compared with exposed tube receivers has two disadvantages. First, in tracking concentrators, the framework, tracking controls, and tracking motors must support the additional mass. The second disadvantage is the temperature difference from the cavity surface to the heat transfer fluid—a loss of second law efficiency. However, if the thermal mass has a high thermal conductivity, this temperature difference will be small compared with the absolute operating temperature of the mass.

A second design feature is seen in the figure. The flat portion of the thermal mass is exposed to spillage flux at the receiver aperture plane. Our work with the commercial concentrator/receiver indicated a poor match between the 6-m concentrator and the 10-cm receiver aperture; i.e., a significant portion of focussed energy spilled outside the receiver aperture. One solution is to increase the cavity aperture diameter at the expense of more reradiative losses at high operating temperatures. Our approach was to retain the 10-cm receiver aperture and absorb spillover flux on the exposed face of the receiver. For the optical quality we have at the Advanced Component Research (ACRES) facility [1], this face will be exposed to a significant spillover flux, perhaps as much as half the total energy crossing the receiver aperture plane. A significant fraction of this spillover energy can be used depending on the solar absorptance of this face. In addition, thermal gradients in the mass can be minimized to allow a higher average operating temperature. Reradiation from the face is insignificant at the expected operating temperatures.

In many applications in which very high temperatures are not required, high precision optics are unnecessary; therefore, an approach such as this may be one method of employing a relatively large solar image. If the optical accuracy at the ACRES facility were improved, the exposed face could be insulated and only the cavity portion of the receiver used.

CONSTRUCTION DETAILS

As seen in the attached figure, the thermal mass consists of a copper shell cast around a helical stainless steel cooling coil. A castable insulation is used on the outside to the shell that, in turn, is surrounded by a ceramic wool layer. The insulation is protected by a stainless steel shell. The cast copper portion is held in the receiver in such a way that interchanging these parts will be simple and will provide experimental flexibility. We chose to use a spherical cavity to facilitate analysis.

The more important dimensions are:

Receiver aperture diameter	10 cm
Cavity inside diameter	12.5 cm

Exposed face outside diameter	20 cm
Cooling tube	1/4" outside diameter, .049" wall
Copper casting weight	22.7 kg
Support frame weight	13.6 kg

Most problems encountered in the construction of this receiver arise from the use of copper and the desire to operate at relatively high temperatures. We chose copper because of its high thermal conductivity, relatively low cost, and because it extends the operating temperature well above that of the commercial receiver we tested. The two major problems in using copper are the casting process itself and the need to protect exposed surfaces of the receiver from oxidation during high temperature operation.

Casting pure copper is difficult because voids tend to form throughout the casting. One technique to overcome this problem is to add 3% to 5% zinc to the copper melt. One of our recent castings using 3% zinc was cut in half to expose any voids. Compared with some initial castings on small samples the result looked very promising. In addition, bonding between the copper and the stainless steel cooling tube was very good. It should be noted that adding 5% zinc reduces thermal conductivity of the mass to about 70% that of a pure copper thermal mass.

Exposed copper oxidizes at temperatures well below our desired operating temperatures. The oxide coating is not self-protecting because oxygen diffuses through the coating causing further oxidation at the copper/copper oxide interface. Because oxide coating very quickly spalls, a protective coating for the copper casting will be necessary. This coating should prevent diffusion of oxygen to the copper, should tolerate temperatures as high as 980°C, and on the exposed face of the receiver it should absorb a reasonable fraction of impinging solar flux.

Coatings being investigated in cooperation with the SERI Materials Branch include flame-sprayed coatings and nickel electroplating. The first flame-sprayed coating (a three-layer commercial coating) proved unsatisfactory as an oxygen barrier. Other flame-sprayed materials are being studied. Nickel electroplating oxidizes to produce a highly absorptive coating that is durable up to 704°C but appears to fail at higher temperatures.

TESTING PROGRAM

Because copper has a melting temperature of approximately 1066°C, we chose it in designing a receiver to replace the commercial receiver that is limited to a maximum operating temperature of 620°C. Because of the temperature difference from the center of the casting to the surface of the cavity, it is clear that operating temperatures (measured at the center of the casting) will be limited to well below 1066°C. Our first application for this receiver will require operating temperatures of at least 870°C. Assuming that a durable coating can be found, this does not appear to be an unreasonable goal for this receiver.

We will first employ optical efficiency measurements to determine if we have improved optical matching between receiver and concentrator. These experiments are carried out at a low operating temperature. Next, we will attempt operation up to 600°C with high pressure water/steam to compare this receiver efficiency with the efficiency of the commercial receiver previously tested at this temperature range. Also, the temperature distribution in the mass will be measured to determine if sufficient buffering of the solar flux has been accomplished. Finally, we will use a gas coolant to investigate operation above 600°C to determine durability of the protective coating and to explore other failure mechanisms.

REFERENCES

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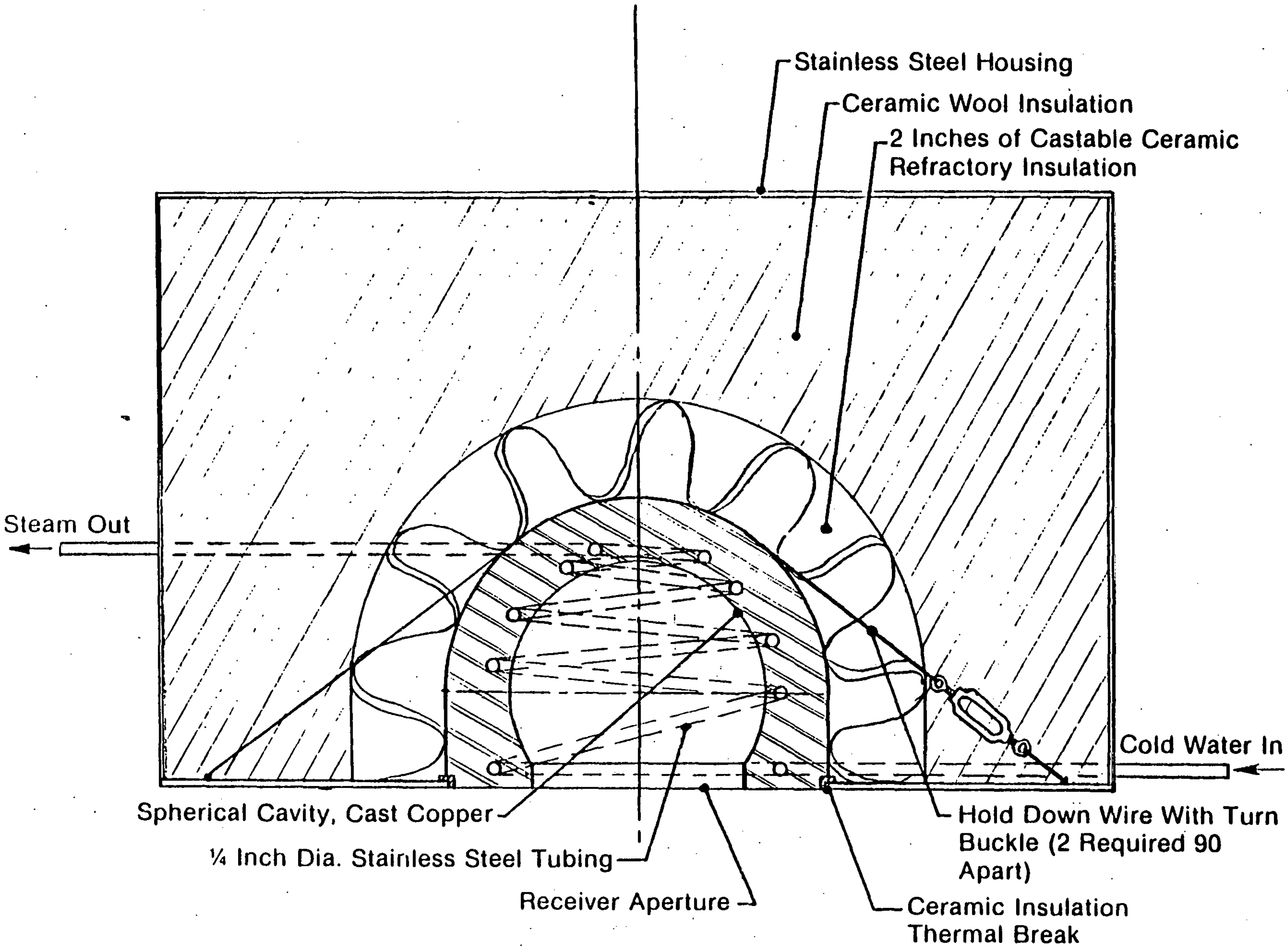

Crossection of Advanced Thermal Receiver