

Study on Receiver Shape for Beam-Down Solar Concentrator

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Abstract- Solar thermal energy is one of the most promising types of renewable energy. Concentrating Solar thermal collectors are used to increase the temperature of collection where the direct normal irradiance of sunlight is low. The tower type of concentrating solar thermal collectors generates the highest temperature of all types of concentrating solar thermal collectors. To effectively use concentrated sunlight, a converter that changes the sunlight into heat—a receiver—is necessary. This study aims to investigate the relationship between receiver shape and temperature. A small-scale model experiment using a solar simulator was conducted, followed by temperature measurements with a full-size receiver using the beam-down tower type of concentrating solar thermal collector. The inner surface of the receiver was measured using a multicolor changing type of thermopaint, which revealed the temperature distribution on the receiver. Consequently, it was found that the maximum temperature of the receiver was over 1270°C and a side wall of the cavity type receiver did not contribute to the reception of concentrated sunlight, but was effective for heat exchange.

Keywords – Solar Energy, Beam-Down Solar Concentrator, Receiver, Temperature Measurement

I. INTRODUCTION

Solar thermal energy is a promising candidate for renewable energy source. Concentrating solar thermal collectors are used to increase the temperature of collection where the normal direct irradiance of sunlight is low. Tower-type concentrating solar thermal collector [1-3] generates the highest temperature of all types of concentrating solar thermal collectors, which is used not only for driving heat engines for electricity generators but also for producing hydrogen through a thermochemical reaction. To effectively use concentrated sunlight, a converter that changes the sunlight into heat, also called a receiver, is important. This research aims to investigate the relationship between receiver shape and temperature. To outline the characteristics of receiver shape, after designing the shape by simplified ray-tracing, a small-scale model experiment using a solar simulator was conducted, followed by temperature measurements with an full-size receiver using a beam-down solar collector.

II. EXPERIMENTAL DEVICE

A. Solar Simulator and Small-Scale Model

To effectively use concentrated sunlight, a converter that changes the sunlight into heat, also called a receiver, is necessary. In investigating the relationship between receiver shape and sunlight-heat exchange, constructing a full-

size receiver for an actual solar concentrator is a bulky and expensive task, so a small-scale solar simulator is employed. The solar simulator (Fig. 1) comprises two main parts. One is a main frame that supports the equipment. The frame is made of a 40-mm-thick readymade aluminum frame. The other part is the optical equipment to simulate the beam-down type of solar collector.

The optical setup of the solar simulator (Fig. 2) comprises two main parts. One is a 500 W xenon short arc lamp used as a light source. Its wavelength characteristics are similar to those of sunlight. The other is an elliptical mirror with two focal points. A beam that passes through the first focal point is reflected by the elliptical mirror and collected at the second focal point. Therefore, the light-emitting part of the xenon lamp is set at the first focal point and a receiver is set at the second focal point. Therefore, the light-emitting part of the xenon lamp is set at the first focal point and a receiver is set at the second focal point.

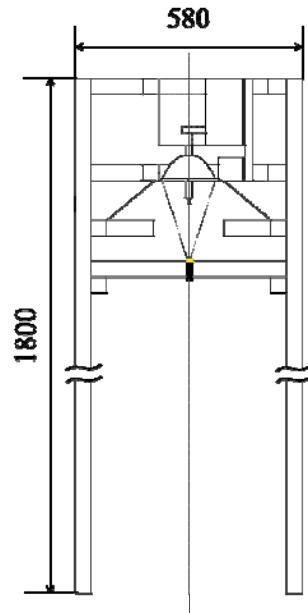


Figure 1. Solar simulator

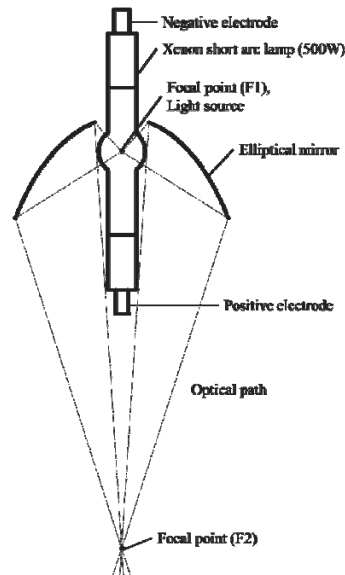


Figure 2. Optics of solar simulator

B. Beam-Down Solar Concentrator

The beam-down solar collector (Fig. 3), which is located at the University of Miyazaki, comprises 88 heliostats and an upper reflecting mirror. Each heliostat has 10 concave mirrors that are 500 mm in diameter. All of the heliostats are set on the ground. They follow the movement of the sun and reflect the sunlight to the primary focus of the upper reflecting mirror, which then reflects the beams to the secondary focus where they are collected. This point is where the maximum flux occurs.

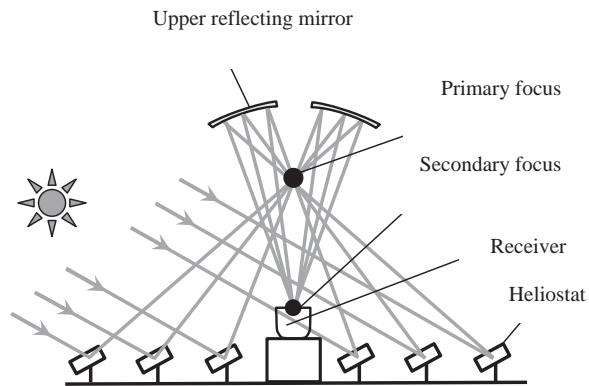


Figure 3. Beam-down solar collector

C. Design of Receiver

Before designing the receiver by ray-tracing, the following conditions are required. The reflected beam on the elliptical mirror must pass through the second focal point. Reflection on the surface of the receiver must be specular reflection. The energy distribution of the light must be uniform.

An example of ray-tracing is shown in Fig. 4. Beams running from the second focal point are reflected on the surface of the receiver. As a result of the ray-tracing, five types of receiver models were designed (Fig. 5).

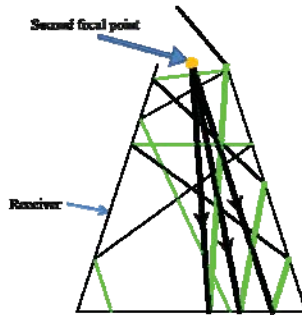


Figure 4. Example of ray-tracing

All models are made of 0.5-mm-thick steel plates. Receiver (a) has a conical shape with a cropped top and a flat bottom. The outer shapes of (b) and (c) are the same as (a) but have an inner cone. The height of the inner cone of (b) is half of the total height and that of (c) is two-thirds of the total height. Receiver (d) has a cylindrical shape. Its diameter and height are 20 and 46 mm, respectively. However, aperture is restricted by plate with 10 mm hole in diameter. Receiver (e) has a long cylindrical shape. Its diameter and height are 10 and 108 mm, respectively. The apertures of all models are 10 mm in diameter.

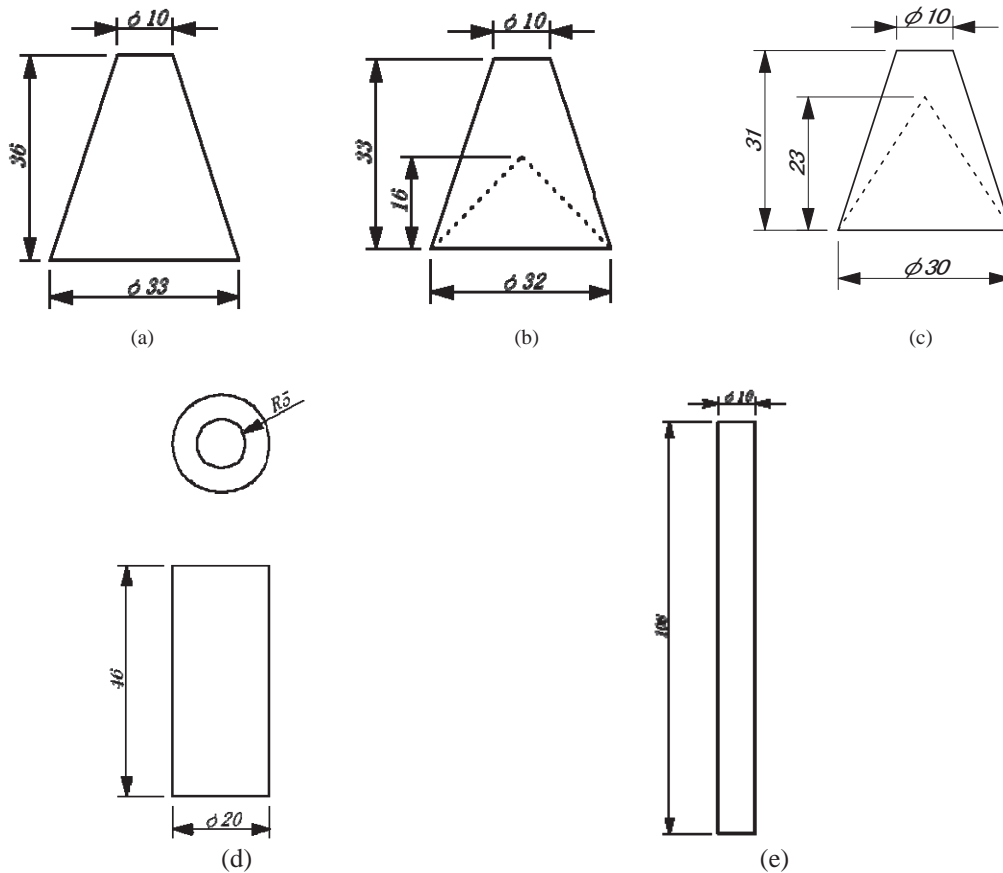


Figure 5. Small-scale models of the receiver

D. Full-Size Receiver for Actual Beam-Down Solar Collector

In the beam down solar collector, sunlight is collected at the secondary focal point, where the spot size is 400 mm in diameter. The receiver for the actual beam-down solar collector (Fig. 6) is designed for the heat exchange process in a steam generator, the details of which will be described later.

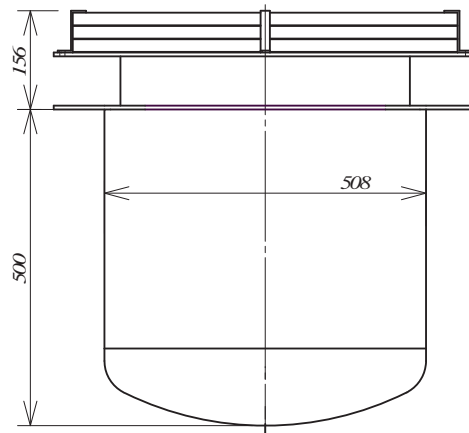


Figure 6. Receiver for beam down solar collector

III. EXPERIMENT METHOD

A. Small-Scale Model Experiment

In the small-scale model experiment, temperature history and distribution measurements were conducted for each of the model receivers. Temperature history was measured by a thermocouple. Measuring points were set to the surface by welding. Temperature data was recorded to a data logger at 0.5 s intervals. Meanwhile, temperature distribution was measured by thermography. The time resolution of thermography is relatively low because of the recording speed, so temperature distribution images were measured at intervals of approximately 1 min.

B. Temperature Measurements of the Full-Size Receiver for the Beam-Down Solar Collector

In the full-size experiment, the receiver was heated by the beam-down solar collector. The temperature of the inner surface was measured using a multicolor changing type of thermopaint applied to the inner surface (Fig. 7). To decrease the effects of heat loss, the outside of the receiver was covered by a 12.5-mm-thick ISOWOOL blanket, which had a maximum heat resistant temperature of 1400°C, and a 0.5-mm-thick galvanized iron sheet. When the temperature exceeds a threshold, the paint color changes in a stepwise manner. The temperature changes the color according to an eight-grade system.

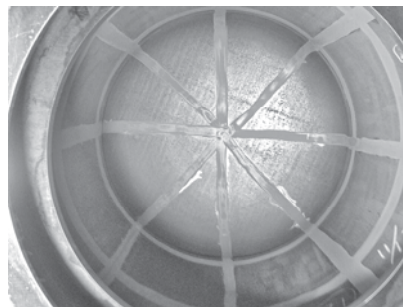


Figure 7. Multicolor change thermopaint

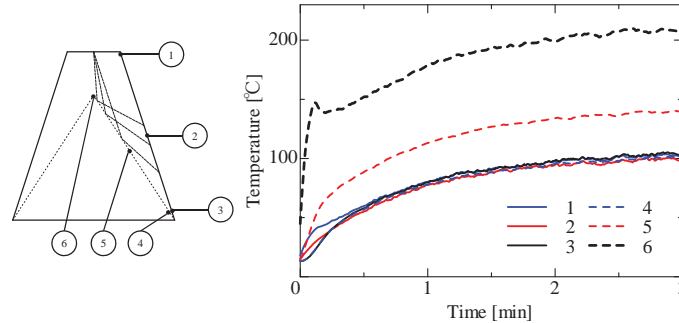
IV. RESULT AND DISCUSSION

A. Results of Small-Scale Model Experiment

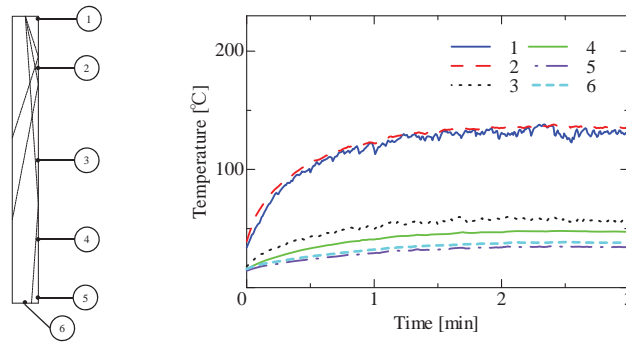
The temperature history of receivers (c) and (e) are used as typical examples of the small-scale model results (Fig. 8). The temperature rapidly increased at the top of the inner cone, but the temperature of the outer wall, which was heated by reflected light, increased slowly (Fig. 8(a)). The maximum temperature was approximately 210°C at point 6. Regarding receiver (e), points 1 and 2 were rapidly heated and the temperatures of the other points slowly

increased (Fig. 8(b)). These results indicate that areas exposed to direct light are rapidly heated and the heating effects of reflected light are minimal. Furthermore, the maximum temperature is decreased by heat loss and conduction.

Thermography images are shown in Fig. 9. Regarding (a), (b), (c), and (d), the temperature increases with time from bottom to top in each shape. Initially, the bottom or inner cone is heated by direct light. The other parts are then heated by reflected light and heat conduction. Regarding (e), the temperature increases from top to bottom. This result is the same as the result of temperature measurements by the thermocouple. Both show that the area receiving direct light is rapidly heated and the heating effects of reflected light are small.

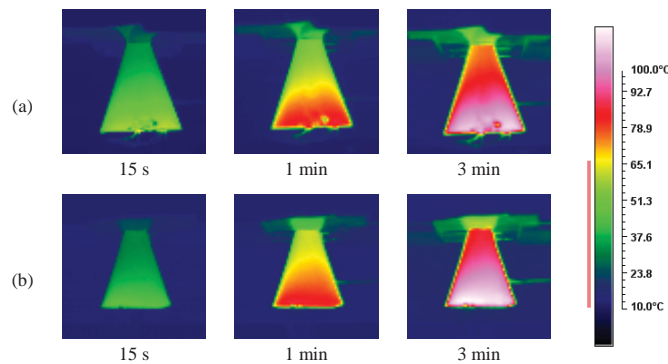


(a) Measured points on conical receiver with 2/3-height inner cone (Fig. 5(c)) and corresponding temperature distributions



(b) Measured points on cylindrical receiver (Fig. 5(e)) and corresponding temperature distributions

Figure 8. Temperature distributions for two select small-scale receiver shapes (Fig. 5(c) and (e))



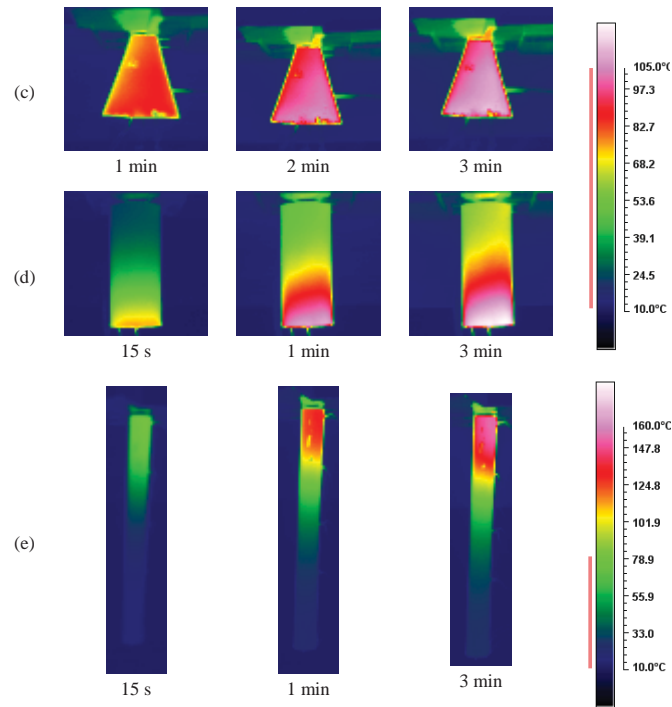


Figure 9. Thermography images for the small-scale receivers

B. Results of Temperature Measurements of the Full-Size Receiver for the Beam-Down Solar Collector

The temperature distribution of the inner surface of the full-size receiver is shown in Fig 10. The upper portion of Fig. 10 shows the side view of the receiver, the bottom left portion shows the bottom view, and the bottom right portion is the legend detailing colors and corresponding temperature ranges. The bottom of the receiver, especially the northern section, was strongly heated, and the maximum temperature in this region exceeded 1270°C . According to the heat flux measurements, the peak heat flux is located near the center of the concentrated spot on the secondary focus, but it is shifted to the north side after the focus because of the distribution of the heliostats. Therefore, the high-temperature area is heated by direct concentrated light. Conversely, the maximum temperature on the side wall is $800\text{--}900^{\circ}\text{C}$ and does not exceed the temperature of the bottom. Moreover, the temperature gradually decreases from bottom to top. This means that side wall is primarily heated by heat conduction and the reflected light less effective in heating.

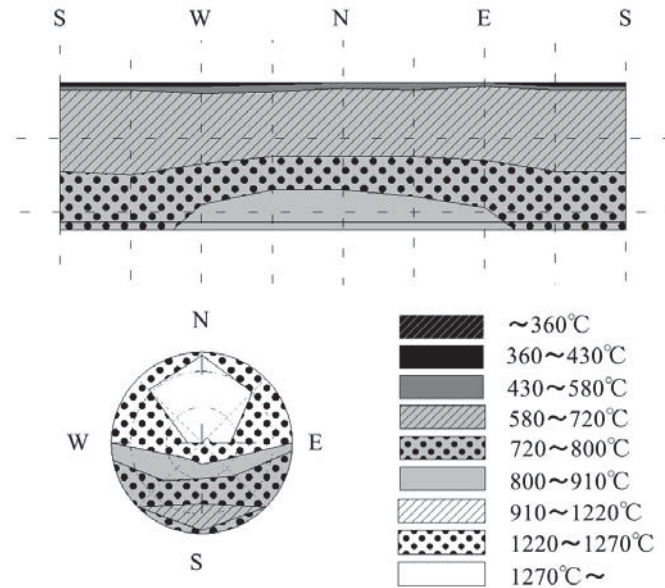


Figure 10. Temperature distribution of the receiver
Top: side view, Bottom left: bottom view, Bottom right: legend

V. CONCLUSION

In this paper, the following results were obtained.

- 1) Direct concentrated light heated the wall strongly, but reflected light was not as effective in heating.
- 2) Heat conduction caused decreases in the maximum temperature. However, it is assumed to be effective for heat exchange in a boiler.
- 3) The full-size receiver was affected by the distribution of heliostats because of its depth.

VI. ACKNOWLEDGMENT

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