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Solar Cooking for Human Development and Environmental Relief

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Procedure for determining the directivity of a solar cooker

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Introduction

One of the goals of solar cooker performance standardization is to provide measurement methods that are independent of location on the earth. This will provide reproducibility of results for the power and efficiency of a solar cooker as measured by any testing facility.

One challenge in obtaining reproducible measurements comes from the fact that the angles of solar radiation vary from day to day and as a function of latitude. Unless such variations are accounted for in the experimental method, in general the results will not be reproducible.

Figure 1 shows the situation in the case of a box or panel cooker that is resting on the ground at three different locations. Note that the input solar radiation hits the cooker at different angles depending on latitude, as well as season and time of day. In general, a solar cooker reflector's optical performance varies with vertical angle, so its input power will vary accordingly. To account for this in the method, the cooker base will need to be tilted, or the power measurement will need to be adjusted, or both.

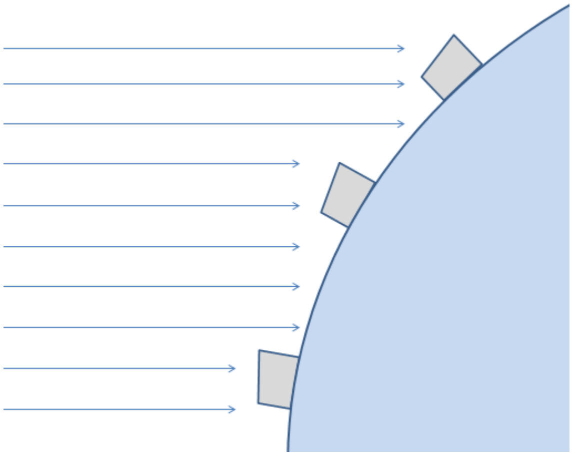

Figure 1. Latitude effect on vertical angles of solar radiation

This issue is not relevant to parabolic solar cookers, because their usage requires continuous steering to track the sun's position. But other types of solar cookers that rest on the ground, such as panel cookers and box cookers, are low-power devices that are turned infrequently or not at all.

The solar radiation intercepted by any solar cooker is proportional to the cosine of the angle relative to the angle of maximum intercept area. For panel or box solar cookers, this implies that the input power depends on the latitude of the test. But in addition, due to the complex shape of these cookers' reflectors, their efficiency in use of solar input is also affected by the specific shape of the reflector.

For designers of panel or box cookers, for maximum performance the reflector should be designed to maximize radiation onto the cooking pot for the latitude where the cooker is to be used. The design may be even further optimized by providing an adjustment to maximize the radiation to the pot depending on the season of the year, because the solar noon altitude angle varies +/- 23.5 degrees over the year. (Jim LaJoie's "All Season Solar Cooker" is designed this way (1)).

But what are the angles of maximum performance? Little information is available on this, for common types of solar cookers. Hence guidance to designers is needed. In this report we show a general method for measuring solar cooker reflector directivity, and the results of using this method to measure various common solar cooker types.

Optical reciprocity method

The "directivity" of a solar cooker describes how its output power depends on the vertical and horizontal angles of incoming solar radiation. Direct determination of the power vs. angle is difficult. To do it directly would require a series of measurements repeated at a wide range of horizontal and vertical angles. This would require many days of measurements under clear sky conditions.

There is an easier method, using a "reciprocity" technique to measure the optical directivity pattern of the solar cooker. In this method, a light source is substituted for the cooking pot and light meter readings from a remote sensor are recorded as the cooker is moved through a range of angles. This measurement must be made in darkness, avoiding any significant light from other sources. (We make the assumptions that angles of optical radiation to or from the reflector are reciprocal, and light concentration is proportional to cooker power).

Determination of horizontal directivity

We define horizontal angles relative to zero at the midline of the reflector when aimed in the sun direction. Vertical angles are relative to zero at the base of the cooker.

To collect data for the horizontal angles, a simple platform can be used; the light meter is fixed at a particular vertical angle while the platform is rotated in the horizontal. This generates a series of horizontal directivity curves as a function of vertical angle. This information can guide manufacturers in recommending how frequently the solar cooker should be turned toward the sun in order to maintain nearly maximum performance.

Determination of vertical directivity

Directivity measurements in the vertical direction would require a vertical semicircular track on which to place a light sensor. In order to minimize parallax effects, this track would have to be several meters away from the device under test, with no other obstructions or reflections in the vicinity. Such a rig would be difficult to construct.

An easier way to collect data for measuring the vertical angle directivity is to place the cooker on its side, on a base platform, and rotate the base horizontally. Measurements at least every 10 degrees in each dimension are generally adequate to determine the angle of maximum brightness, which equates to the angle of maximum power.

For our preliminary experiments, the Haines panel cooker (2) was measured in this way. Three plywood panels were arranged to support the reflector for these measurements. Angles were marked on the lower panel to guide the measurements (Figure 2).

Figure 2. Rig for measuring vertical directivity

For the first set of measurements, a bare 100W incandescent light bulb was used to provide a calibration of the directivity of the light source. The light bulb brightness was measured at night from a distance of more than 6 meters using an LX-1330B lux meter mounted on a tripod. A laser pointer was used to aim the light meter exactly at the source.

Figure 3. Rig for measuring bare bulb directivity.

In the second set of measurements, the Haines reflector was mounted in the rig with the reflector turned sideways. The reflector was fastened in place to maintain the proper shape. Black cloth was placed on the ground near the reflector to eliminate possible extraneous reflections. Then the lux meter values were collected for each 10 degrees of rotation.

Figure 4. Rig for measuring vertical directivity of Haines solar cooker reflector.

The following results were obtained for the vertical directivity of the Haines reflector:

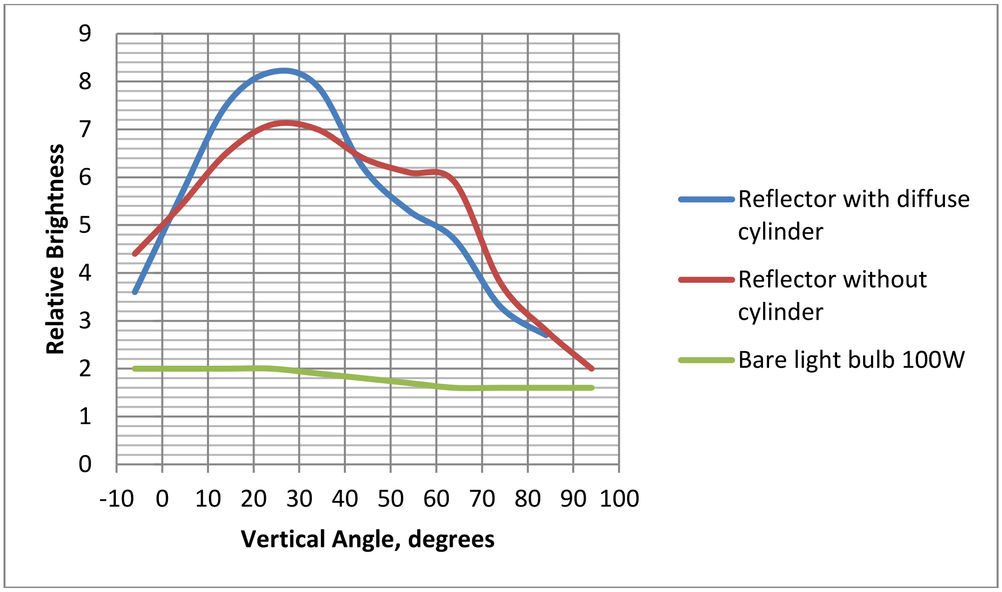

Figure 5. Relative vertical directivity of Haines reflector

Two conditions were measured for the Haines cooker: one with just the bare light bulb in the position where the center of the pot would be (blue), and a measurement where a light-diffusing cylinder (made of onionskin paper) to simulate the sides of a cooking pot (red).

It is evident that the bare light bulb is not perfectly omnidirectional. Therefore, an adjustment to the data was made to compensate for its directionality by subtracting the bulb brightness from the reflector data, and then adding 1. This converts the plot into a measurement of the optical concentration factor of the reflector.

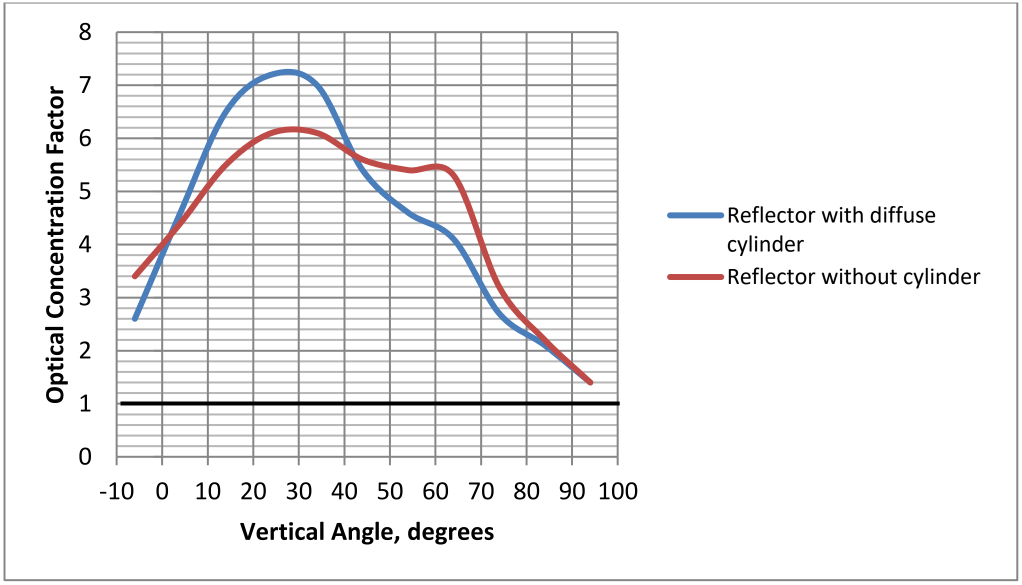

Figure 6. Optical concentration factor vs. vertical angle for Haines reflector.

The results show that the vertical angle of maximum optical performance is about 25-30 degrees in both cases. The diffuser, which represents light reflected onto the sides of a pot, shows a small increase at around 60 degrees, which represents light coming through a transparent glass lid on the pot. For this particular reflector design, it can be seen that the performance (cooking power) is strongly dependent on intercept angle of the sun on the reflector. For optimum performance, the reflector should be tilted to match the intercept angle to the angle of maximum performance.

This report illustrates how designers can use directivity information to optimize the tilt angle and shape of a reflector for use at a particular latitude and season of the year. To maximize performance for the user, the angle of maximum performance should be measured and noted in manufacturer's documentation.

This is the first time that such quantitative directivity measurements have been made, to the author's knowledge. (William Bradley did reciprocity tests using a digital image processing technique (3), but the experiments done here were direct physical measurements of light using a lux meter). In future research, we plan to conduct directivity measurements with a range of solar cookers.

References

1. All Season Solar Cooker, http://www.allseasonsolarcooker.com/

2. Haines Solar Cooker, http://www.hainessolarcookers.com/

3. Bradley, W., "Reciprocal photo test for measuring solar cooker performance", http://solarcooking.wikia.com/wiki/Earthbound_Technology