OPTICAL PROPERTIES OF THE COOKIT SOLAR COOKER

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ABSTRACT

The CooKit is a solar cooker of the panel-cooker type that has been distributed and replicated widely. This paper reports on a study of the optical properties of the standard CooKit geometry, for a variety of solar altitudes and azimuth angles. A laser beam at known altitude and azimuth angles was directed at the cooker and covered the entire surface while maintaining a constant solar angle. The areas of the panels that resulted in reflection to the pot were then identified. The entire CooKit surface was then mapped as to which regions resulted in direct or secondary reflection to the pot, or in no reflection to the pot. Knowledge of the relative importance of various regions of the panels could conceivably be useful for guiding design changes to the basic CooKit design, determining the solar optical efficiency at various sun angles, or optimizing the panel geometry for minimum panel area.

Keywords: CooKit, optical, laser

1. INTRODUCTION

The CooKit solar cooker is comprised of seven flat reflective

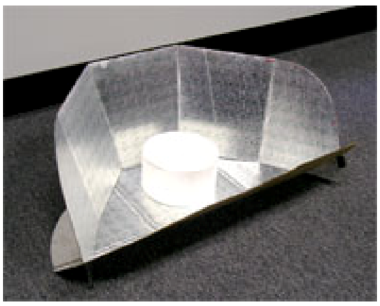

Fig. 1 Photograph of the CooKit

surfaces, which when folded into their working position, provide reflection of solar rays to a pot in the cooker.
The tilt angles, and azimuth angles (relative to the cooker axis of symmetry) are a function of the layout of fold and cut lines of the original flat sheet from which the CooKit is formed. The purpose of this study is to evaluate how well the various surfaces of the cooker reflect solar rays to hit the pot for several values of solar altitude and solar azimuth angles. A photograph of the assembled CooKit is shown in Fig. 1, with the simulated paper pot used in this project. Panels 1- 5 are at a tilt angle of 70 degrees. Panel 5 lies flat on the ground so the tilt angle is zero. The surfaces laid in a flat plane are shown in Fig. 2, which indicates the surface areas of the seven panels of the cooker.

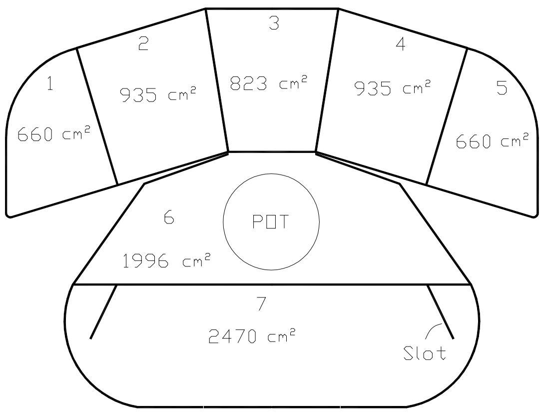

Fig. 2 CooKit surfaces in one plane.

2. BACKGROUND

Several thousand CooKits have been manufactured in the USA by Solar Cookers, Int., several tens of thousands manufactured in Africa, and smaller numbers replicated in

25 countries. In use, the pot is paced in a transparent bag and placed on the CooKit surface. Developed as a less expensive and less bulky alternative to the box cooker, the CooKit has proven to cook well in a variety of solar conditions. The pot is placed inside a transparent bag and placed on the cooker. The user adjusts the front flap surface (panel 7 in Fig. 2) to a suitable tilt angle. The cooker may occasionally be turned to follow the sun. The author's experience with observing users of the CooKit has been that the front flap is often kept constant during the entire cooking period, and often set at too high a tilt angle. A "rule of thumb" is often given as to set the front flap tilt so that the shadow under the front flap has a length of half the width of the front flap. In other words, if the shadow is very short, the flap is too high, and if the shadow is almost as long as the flap width, the flap is too low.

3. PROJECT

Except for the tilt angle of the front flap, the CooKit geometry is fixed by the construction. The only other variable open to the user is the solar azimuth angle, or how the user repositions the cooker as the cooking period proceeds. The reflective ability of the cooker would be a function of the front flap tilt, solar azimuth angle, and solar altitude angle. It would not be expected that the cooker reflects or concentrates solar rays equally well at different values of the relevant angles. This project seeks to provide information concerning:

1) the relative importance of each surface to delivering power to the pot
2) e the relative importance of solar azimuth (aiming the cooker)
3) the concentration ratio of the entire cooker surfaces.

The project is primarily experimental. A red laser beam was set up at fixed elevation (altitude) angle on a bench. All the cooker surfaces were ruled into 461 small areas, mostly small squares 2 cm on a side. With the cooker set at a known azimuth and elevation, the laser was directed to each small area and an observation made as to whether or not the reflected laser hit the pot. If the laser reflected to hit another spot of the cooker and then reflected to the pot, this was noted as a secondary reflection. The pot was simulated by a paper cylinder 22 cm diameter and 11 cm high, representative of a typical pot; however, people often use larger pots.

The setting of the front flap tilt angle followed the rule of thumb stated above, resulting in the following:

Elevation angle degrees	Front Flap Tilt degrees
30	15
60	34
90	60

The laser reflection tests were performed for elevation angles of 30, 60, and 90 degrees and azimuth angles of 30 and 60 degrees, for a total of five scenarios. Note, for elevation angle of 90 degrees (sun overhead) the azimuth angle is not relevant.

Figs. 3-7 show the cooker surfaces laid flat in a plane with areas showing where reflection to the pot occurred. Narrow cross hatching represent reflection to the pot, and wide cross hatching represent secondary or tertiary reflection (more than one reflection) to the pot. Hatched areas on the figures are not proportional to the amount of solar power reflected to the pot however, since each area has a different incidence angle, i, between the solar (laser) ray and the perpendicular to the area. When the incidence angle is zero, the rays are perpendicular to the surface, and the surface intercepts the most power.

For each combination of elevation and azimuth, the region of each panel that gave reflection to the pot, from any number of reflections, was measure using a computer graphics program, and called the panel effective area. These are the narrow hatched regions in Figs. 3-7.

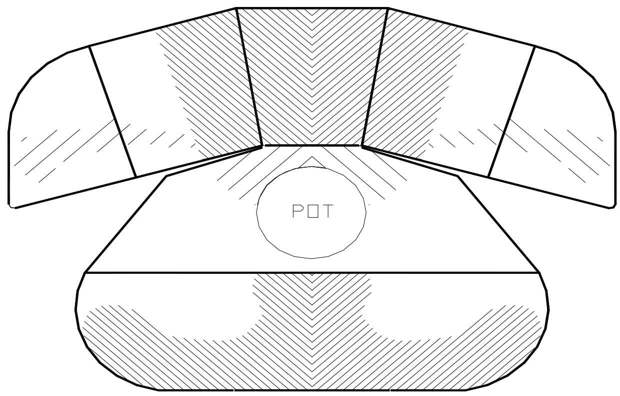

Fig. 3 Elevation angle 90 degrees.

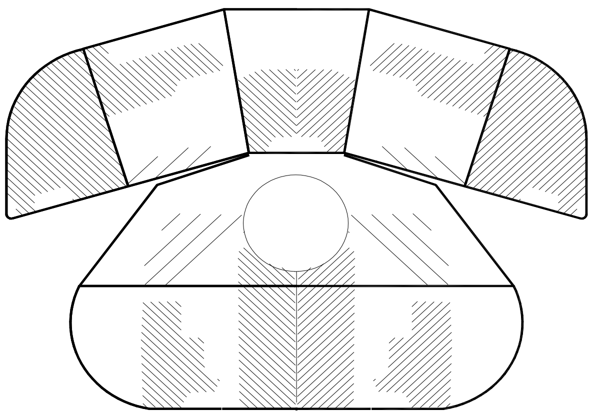

Fig. 4 Elevation angle 60 and azimuth 0.

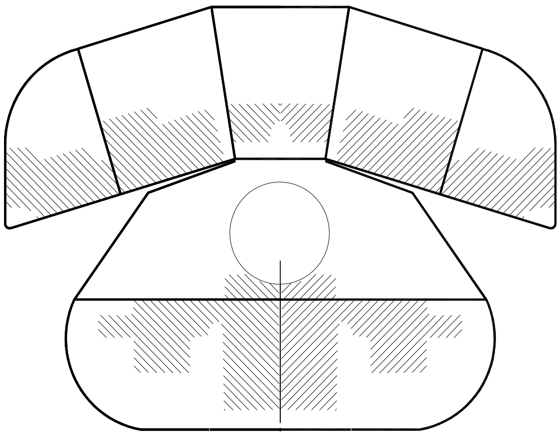

Fig. 5 Elevation angle 30 and azimuth 0

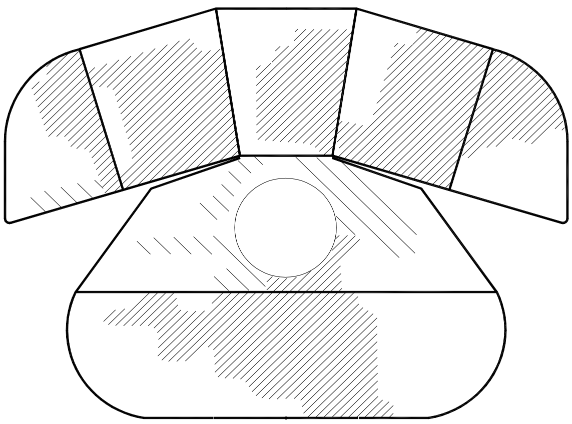

Fig. 6 Elevation angle 30 and azimuth 30.

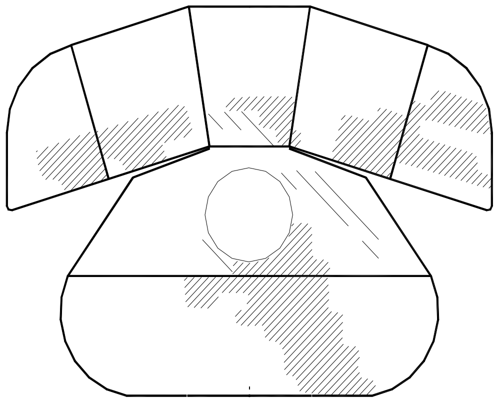

Fig.7 Elevation angle 30 and azimuth 30.

Tables 1-5 give the numerical values of the effective areas for each panel.

The incidence angle i was calculated for each panel for all elevation and solar azimuth angles using trigonometry relations. Note, the azimuth angles of panels 1,2,4, and 5 relative to the cooker axis are not zero and must be included in the geometry calculation. With azimuth defined positive in the counterclockwise direction looking down on the cooker, the azimuth angles of the *panels relative to the cooker axis* are:

Panel	Azimuth, degrees
1or 5	60 or -60
2 or 4	44 or -44

Tables 1-5 also give the cosine of the incidence angles. Multiplying the effective area by the cosine of incidence angle gives the area of solar rays intercepted; that is, the area of solar rays perpendicular to the solar ray.

It is desired to find the actual power (watts) delivered to the pot from each panel for the cases tested. However, the solar power flux (w/m^2) normal to the solar ray (solar normal flux) depends on the elevation angle. When the elevation is 90 degrees, solar rays travel through one air mass of the atmosphere; when the elevation is less than 90 degrees, the path length through the atmosphere is larger, giving less solar flux. Furthermore, the normal solar flux depends on the annual variation of atmospheric conditions, changing earth-sun distance, and clearness. The power reflected to the pot for each panel was calculated and given in the last column of Tables 1-5. In order to incorporate the lower solar normal flux at elevations less than 90 degrees, an average solar normal flux of 958 w/m^2 was taken for 90 degree elevation, and the solar flux for lower elevation angles reduced by a factor accounting for atmospheric conditions and larger air mass. (See Hsieh, J.S., Solar Energy Engineering, Prentice Hall, 1986 or ASHRAE Handbook of Fundamentals for a discussion of this procedure.) The average annual solar normal flux for the three elevation angles are 958, 933, and 807 w/m^2 for elevation angles of 90, 60, and 30 degrees, respectively. Note that these values pertain to clear cloudless days and refer to *beam* radiation, as opposed to diffuse solar radiation. On a clear day, most of the radiation is beam; on an overcast day, diffuse radiation becomes a larger portion.

Based on these values of solar normal flux, the power to the pot was included in Tables 1-5 as the last column, with the total given for all panels plus the direct power to the pot. Note that the direct solar power to the pot varies with elevation because of the variation in top and side areas exposed to the sun as well as the effect of air mass.

A concentration ratio is calculated for each condition and defined as the total solar power to the pot divided by the solar power to pot in the absence of any panel reflection.

For this entire study, all radiation is assumed to be specular (mirror like) with perfect reflectance. In reality, some of the reflection is diffuse, and power, perhaps a few %, is not reflected. Also, solar radiation to the pot must pass through the transparent bag, where additional losses from absorption and scattering occur.

4. CONCLUSION

Some interesting observations can be made from the test results. It is seen from the tables that the power supplied to the pot via panel 7 (front flap) is relatively large. At zero azimuth, it provided 22 to 56% of the total reflective power. Even at 30 azimuth, it still provides approximately as much power as the highest panel (panel 2). This observation suggests that it may be worth paying attention to the tilt angle of the front flap during use for maximum heating.

The power values in the tables for panel 6 (the horizontal panel, or floor) are seen to be relatively low, suggesting that when reflective material is scarce, loss of reflection from this panel would not be critical.

Comparing Tables 2 and 4 for the same elevation of 60 degrees but at zero and 30 degrees azimuth, it is observed that the total power is approximately the same. This result indicates that for elevations of around 60 degrees, there is no gain in aiming the cooker axis at the sun. The cooker is very tolerant to azimuth angle.

As expected, low elevation angle produces lower power than higher elevation angle. Tables 4 and 5 indicate that at 30 degrees azimuth, the lower elevation of 30 degrees produces less than half the power at 60 degrees elevation. Cooking at this low an elevation angle poses limitations.

The maximum power of all cases was found to be for 60 degrees elevation and zero azimuth, or 33% more than for 90 degree elevation. So overhead sun, though stronger in solar flux, is less effective than sun at elevation of 60 degrees.

Concentration ratio is defined as the power to the pot divided by the pot power if no reflective panels were present. Concentration ratios in the tests ranged from 3.8 to 5.1 except for the lowest power case of low elevation of 30 degrees and 30 degrees azimuth, which gave a concentration of only 2.7.

TABLE 1 ELEVATION ANGLE 90 DEGREES

Panel	Effective Area, cm2	Cosine i	Power To Pot, watts
1	0	0.342	0
2	483	0.342	15.8
3	823	0.342	27.0
4	483	0.342	15.8
5	0	0.342	0
6	0	1.0	0
7	1566	0.5	75.0
Pot			38.
Total			172

Concentration Ratio = 4.5

TABLE 2 ELEVATION ANGLE 60 DEGREES, AZIMUTH DEGREES

Panel	Effective Area, cm2	Cosine i	Power To Pot, watts
1	318	0.531	30.6
2	294	0.634	17.4
3	374	0.766	26.7
4	294	0.634	17.4
5	618	0.531	30.6
6	142	0.866	11.5
7	1226	0.438	50.1
Pot			45
Total			229

Concentration Ratio = 5.1

TABLE 3 ELEVATION ANGLE 30 DEGREES, AZIMUTH 0 DEGREES

Panel	Effective Area, cm2	Cosine i	Power To Pot, watts
1	287	0.578	13.4
2	341	0.756	20.8
3	168	0.984	13.3
4	341	0.756	20.8
5	287	0.578	13.4
6	116	0.5	4.7
7	1172	0.259	24.5
Pot			40.
Total			151

Concentration Ratio = 3.8

TABLE 4 ELEVATION ANGLE 60 DEGREES, AZIMUTH 30 DEGREES

Panel	Effective Area, cm2	Cosine i	Power To Pot, watts
1	270	0.703	17.7
2	682	0.634	40.3
3	433	0.703	28.4
4	703	0.476	31.2
5	303	0.296	8.4
6	100	0.866	8.1
7	1038	0.476	46.1
Pot			45
Total			225

Concentration Ratio = 5.0

TABLE 5 ELEVATION ANGLE 30 DEGREES, AZIMUTH 30 DEGREES

Panel	Effective Area, cm2	Cosine i	Power To Pot, watts
1	164	0.985	13.0
2	214	0.961	16.6
3	101	0.876	7.1
4	210	0.395	6.7
5	293	0.171	4.0
6	145	0.5	5.9
7	641	0.289	14.9
Pot			40
Total			108

Concentration Ratio = 2.7