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The SUNTASTE, a new cork based solar box cooker

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Abstract: *Following the experience with the SUNCOOK [1], a plastic based box type solar cooker incorporating non imaging optics as a way to produce a certain degree of solar energy concentration (a factor of 2.0 X concentration on average) while retaining it stationary for full operation for periods as large as 3 hours, the idea came for developing a new cooker, the SUNTASTE [2], with an improved geometrical configuration and ease of operation (stationarity), this time based on a natural material: cork. The choice of cork offers the possibility of having it both as the structural element for the whole box, and at the same time taking advantage of the fact that it is highly insulating.*

Two versions of the SUNTASTE with different sizes but essentially with the same optics, were produced and tested according to the method defined in [3,4]. The tests of both versions were carried out in several consecutive high DNI days and also included a SUNCOOK for the sake of a direct comparison. The paper provides a brief description of the new cooker and presents the testing results of the two prototypes of each size produced. It can be reported that preliminary measurements show that is fair to expect for the new product, a performance in many regards comparable to that of the SUNCOOK.

Keywords: Solar Cooking Performance, Solar Cookers.

1. INTRODUCTION

Solar box cookers have known a continuous development since they were proposed [5] as early as in the sixties of the previous century. Simple box designs, with cooking plates at the bottom, augmenting mirrors placed in cover lids, side mirrors to enhance stationarity under operation or to providing extra solar irradiance concentration, have been proposed and tested. Tilted covers have also been a fixture of some of the models proposed and many of these cookers have been used all over the World, either as products to be purchased on the market or produced by their users directly, built according to plans provided by solar cooking promoters, individuals and organizations [5,6].

One cooker has been particularly successful, incorporating inside the box, non-imaging optic concentrators [7], thus enhancing its thermal and optical performance [1]. This solar cooker was a truly industrial product, fabricated in plastic (different kinds of plastic, pending on temperature and their location within the cooker) with a substantial input from the Portuguese plastics and plastic molds industry [8,9].

The use of plastic is certainly interesting from the point of view of product manufacturing and quality assurance, but also from the point of view of potential low cost, quite beyond those already achieved (under development). However, and in the meantime, new directions are being explored and one of them is the basis of the efforts reported in this paper.

The idea is to use another abundant material, cork as the main material in the cooker. Cork is a natural material with excellent thermal properties, a natural insulator (k= 0,045 W/mK) and at the same time strong enough to be, by itself, the structural material of the cooker. It is easy to form/machine to the necessary shape, and, thus it is an excellent base for solar cooker production. There is also top manufacturing experience of cork products in Portugal, quite besides the fact that Portugal is the primary World producer of cork.

This paper describes briefly such a cooker, the SUNTASTE, presently produced in two models (Compact and Large). It then presents results of measurements made during the fall of 2017. Because, during the fall, the sun has already a low altitude in the sky at the latitude at which the cooker was tested, it was thought interesting to compare it with the SUNCOOK, referred above, to give a measure of its highest available performance at other times of the year. The paper ends with some brief conclusions.

2. SUNTASTE DESCRIPTION

A photograph of the cooker can be seen in Fig.1, showing the two versions (Compact and Large) side by side. As can be seen, cork is used for the side walls, front and back wall. The lid is manufactured in aluminum. The cooker has a double glass cover with the bottom glass slid into place and the top glass glued to the cork. The cover is tilted to an angle of 17º chosen to minimize condensation accumulation on the bottom glass surface (condensed water will slide down truly minimizing negative effects of the cover on transparency).

The cooking plate is a black anodized aluminum (2,5 mm thick) plate, laying at the bottom, which can be removed for cleaning. Dimensions of both cookers can be seen in Table 1.

Table 1- Dimensions of SUNTASTE COMPACT and SUNTASTE LARGE.

SUNTASTE	External dimensions (cm)	Plate area (cm)	Cover area (cm)
COMPACT	52×43×32	36×30	44×36
LARGE	66×43×32	50×30	58×36

The rectangular shape was chosen to reduce the effects of longitudinal (E-W) losses of incoming solar irradiance and its dimensions were chosen as a function of practical considerations [2] of the manufacturer, production and commercial ones, related, for instance to the number and size of pots and pans that are provided or recommended to be used with the SUNTASTE.

The choice made in terms of geometry and dimensions correspond to an average concentration value (A_n/A_p) of approximately 2X.

Figure 1 - The SUNTASTE, (COMPACT and LARGE) front and back view.

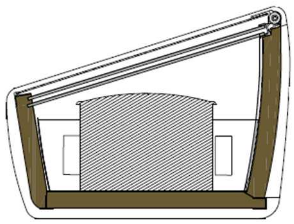

Figure 2 - cross section on transversal plane of the SUNTASTE.

Acceptance angles of the SUNTASTE (COMPACT and LARGE) and hours of stationarity provided, can be seen in table 2. Cork thickness for bottom and side walls can be seen in table 3.

Table 2 - Acceptance angles of the CPC walls and hours of stationarity provided.

Element	Acceptance angle θ_a (deg)	Stationarity time (h)
Front CPC	59.8	4.0
Side CPC	48.6	3.2

Table 3 - Wall thickness.

SUNTASTE	Thickness bottom walls (cm)	Thickness side walls (cm)
COMPACT	2.5	3.1
LARGE	2.5	3.1

3. MEASUREMENTS AND RESULTS

The two SUNTASTES were tested side by side with the SUNCOOK [1]. The idea for doing so came from the fact that this cooker was well characterized then and the comparison made here, will allow for extrapolations of results to be expected at other times of the year. This procedure highlights once more the need for universally accepted standards, which will facilitate cookers comparison in the future. In any case two Figures of Merit F_1 and F_2 discussed in [4] are calculated and one result is derived from them, time from ambient to boiling, is presented. F_1 is given by

$$F_1 = \frac{\eta'_0}{U_L} = \frac{A_p}{A'} \frac{(T_{ps} - T_{as})}{I_{hs}} \quad (1)$$

$$A' = \left[A_c \times \frac{\cos(\theta - \delta)}{cos\theta} + \left(\frac{A_n}{cos\theta} - A_c \times \frac{\cos(\theta - \delta)}{cos\theta}\right) \times \rho\right] \quad (2)$$

$$A_n = A_H \times \cos\theta \times \left(\frac{\cos(\theta - \delta)}{cos\theta}\right) \quad (3)$$

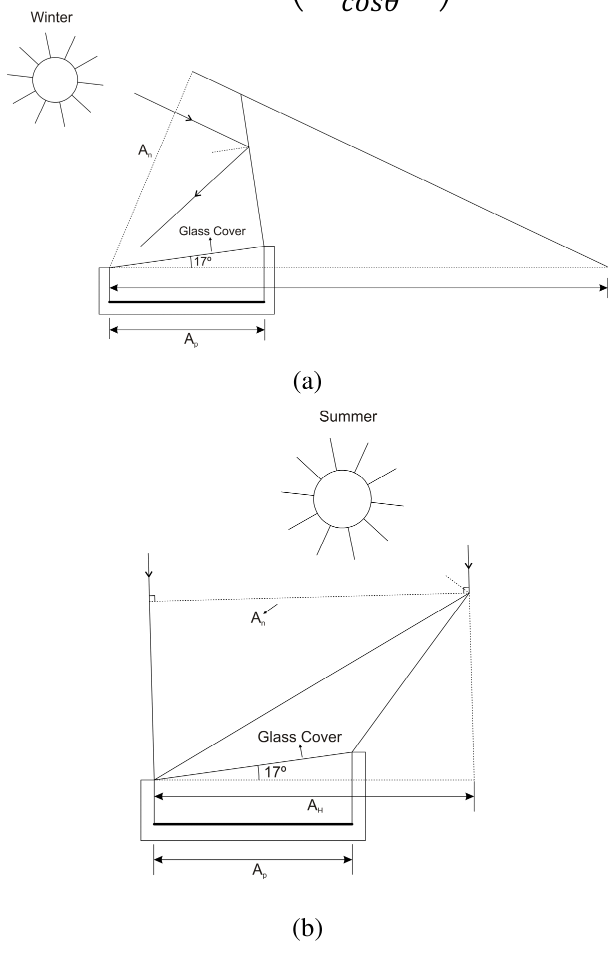

Figure 3 - Solar cooker: (a) – Tested in winter; (b) – Tested in summer.

And F_2 by

$$F_2 = \eta'_0 \times C_r = F_1 \times \frac{(MC)_w}{A' \times \tau} \times \ln\left[\frac{\left(1 - A_p \times \left(\frac{T_{w1} - T_a}{A' \times F_1 \times I_h}\right)\right)}{\left(1 - A_p \times \left(\frac{T_{w2} - T_a}{A' \times F_1 \times I_h}\right)\right)}\right] \quad (4)$$

Time to boiling is calculated according to

$$\tau_0 = -\frac{F_1}{F_2} \times \frac{(MC)_w}{A'} \times \ln\left[1 - \frac{A_p \times (99.2^1 - T_a)}{A' \times F_1 \times I_h}\right] \quad (5)$$

Where, η_0 is the optical efficiency, U_L the heat loss factor, T_{ps} the plate temperature at stagnation, T_{air} the ambient temperature at stagnation, A_p plate area, I_{hs} irradiance on horizontal plane at stagnation, A_c is the cover area, A_n normal area to incoming beam irradiation, Θ the zenith angle, δ the mirror tilt, ρ the mirror reflectivity, A_H projected area by the lid on the horizontal plane (see Figure 3), $(MC)_w$ is the product between mass of water and its specific heat capacity, τ time between T_{w1} and T_{w2}, T_{w1} initial water temperature value (40ºC), T_{w2} final water temperature value (80ºC), T_a average ambient temperature and I_h average insolation on a horizontal plane between T_{w1} and T_{w2}.

With A_n =0,244 m^2, A'= 0,458 m^2 for SUNTASTE COMPACT and A_n=0,318 m^2, A'= 0,597 m^2 for LARGE, the results are as follows. $(MC)_W$ was calculated according to $(MC)_{WCOMPACT}$ = 1.463[2]kg×4186 J/kg.K and to $(MC)_{WLARGE}$ = 1.911kg×4186 J/kg.K.

Table 4 - Figure of merit F_1.

SUNTASTE	F_1 (m^{2}K/W)
COMPACT	0,054
LARGE	0,052

Fig. 4 shows the rise in plate temperature and Fig. 5 shows the water temperature. Testing was carried out in the middle of November, during high DNI days.

Analyzing Fig. 4, it can be seen that, the plate stagnation temperature is 131ºC and 137 ºC for COMPACT and LARGE SUNTASTE, respectively. It is to be noted that during the tests in plate stagnation temperature the sun was very low in the sky (Θ = 57.48º).

[1] Boiling water temperature at the place where the tests carried out [10].
[2] According to [11], the water mass M obtained considering 6 kg/m^2 of A_n.

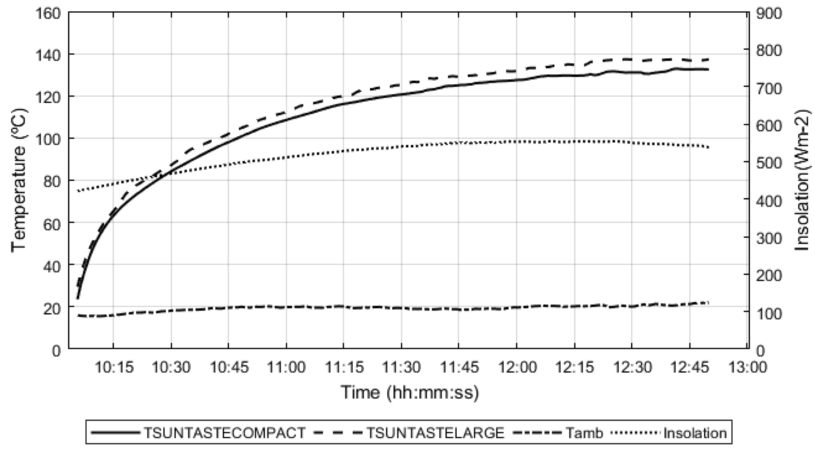

Figure 4 - Rise in plate temperature with tracking every 15min (November 15th).

Table 5 – Figure of merit F_2 and boiling time of water for the testing day.

SUNTASTE	F_2	τ_0 (min)
COMPACT	0,096	129
LARGE	0,092	157

According to the measurements (Fig. 5), the time for water to go from ambient temperature to boiling are 145 and 177 minutes for SUNTASTE COMPACT and LARGE, respectively. These values are not so distant from τ_0 presented in table 5, but they are not quite the same because during the test initial water temperatures in both SUNTASTE were higher than ambient temperature. As in the test quoted earlier, the sun was very low in the sky (Θ = 58.67º), thus the incoming irradiance was close to the minimum in a sunny in our latitude.

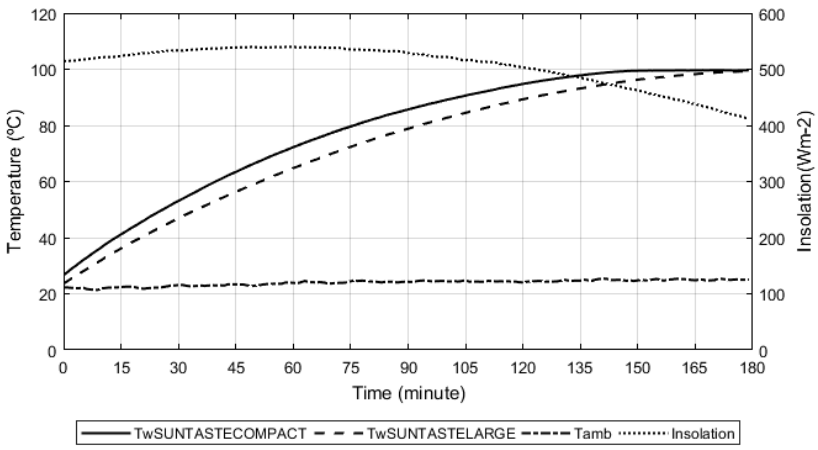

Figure 5 - Rise in water temperature with tracking every 15min (November 16th).

4. CONCLUSIONS

The test of solar box cookers is an extreme important issue, since it allows to evaluate their performance, as well as to relate cost/benefit between different alternative, according to the needs of the users.

The use of non-imaging optics enables higher temperatures and, in turn, higher performance. It does not require sophisticated solar tracking, so SUNTASTE can be used without user intervention.

Although the tests were carried out in November, it can be seen that the SUNTASTE solar cookers reached still high stagnation absorber/plate temperature and are close to SUNCOOK stagnation plate temperature. Regarding tests with water, the time the water takes to go from ambient temperature to the local boiling temperature (99.2 ºC) is over two hours, 146 minutes and 177 minutes, for SUNTASTE COMPACT and LARGER, respectively.

It was clearly confirmed that the tilted glass cover on the SUNTASTE greatly reduces the condensation formation on the interior side of the cover, providing better transparency of the cover and thus transmission of incoming sunlight.

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