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COMPARATIVE STUDY ABOUT THE BAKING CAPACITY OF TWO BOX TYPE OVENS, PRODUCED FROM APACKING CASE USED TO EQUIPMENT TRANSPORTATION

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Abstract. *It is presented a comparative study about the baking capacity of two box type ovens, produced from a packing case used to equipment transportation. The two ovens have different internal settings, with the greenhouse effect and the concentration of incident solar radiation as the main parameters of differentiation. The main features of the ovens are the low cost, the reuse of materials, the manufacturing and assembly processes simplified, the easy management and the ability of baking a variety of foods simultaneously. The manufacturing and operation of the ovens can be handled by any social and intellectual level of people. The feasibility of the ovens to bake the tested foods was proved with success, ensuring the supremacy of the mirrored oven. The results obtained for both ovens were competitive even with the conventional gas oven, producing the baking of three cakes with 750g in just 80 minutes. The most viable oven was mirrored.*

Keywords: *Solar energy, box-type solar cooker, baking food, low cost.*

1 INTRODUTION

Around one third of the world population (more than 2 billion people) depends on the use of wood for their power (energy) supply for cooking and heating of food. In the last national power balance, Brazil uses 12.989 x 103 tons oil equivalent for food cooking, out of which aside from natural gas and GLP, there is also the use of wood and vegetal coal, (EMPRESA DE PESQUISA ENERGÉTICA - EPE, 2014).

Studies that make possible the use of solar ovens through optimization of their construction processes and the levels of temperatures generated, as well as users' convenience must be prioritized and are indispensable for policies that fight ecological imbalance, ease the power matrix. It must contribute for the settlement of people in the rural areas and give them options of income generation through construction of solar ovens for future commerce, (TSUR; ZEMEL 2000).

In the following studies, two box-type solar cookers made from a box of wood were studied. These recipients are used for the transportation of machines and equipment. The wooden box was divided and two cookers were obtained. The comparative study had its main parameters – inner temperature of the absorber and the air, the outer surfaces temperature, the time for cooking of some types of food such as bread, cake, pizza and pastry.

The main characteristics of these type of cookers are low cost, the reuse of materials, easy construction and mounting and simple operability. People in any social and intellectual level can learn the construction and operability of the cookers. Another feature of the cooker is the capacity of cooking of several types of food simultaneously. That shows a great advantage about the available solar cookers today. It can even cook up to three 800g-cakes in the best performance cooker.

The main innovation of this study is the comparison between two types of solar oven in the same solar energy capitation area. One type of oven uses reflection mirrors inside to concentrate solar rays in a focal region. The other type has a darkened metallic absorber used for the cooking. In the mirrored oven, there is a concentration of reflected rays that reach the oven. In the darkened oven, there is a combination of concentration and the greenhouse effect.

2 MATERIALS AND METHODS

The models proposed were made from a wooden box that had been disposed of. The box was divide in two parts for two solar ovens. The comparison between the devices was done using the same area of solar energy capitation for two different types of cooker configuration: **mirrored solar oven and dark solar oven.** Both configurations had internal space of 0.64m², and reflecting external surface area of 0.45 m²; inner volumes had 50.2 liters for the mirrored and 43.3 liters for the dark.

Figure 1 shows a sketch in *SolidWorks* and some steps of the process of construction of the mirrored solar cooker from a wooden box for the transportation of equipment.

Figure 1. Sketch and steps of the construction of the mirrored oven.

The dark solar oven is the most common type. It was constructed as a reference for this study. The comparative tests with both ovens. The Figure 2 shows a sketch in *SolidWorks* and some steps of the process of construction of the dark cooker from a wooden box used for transportation of equipment.

Figure 2. Sketch and some steps of the construction process of the dark oven.

The Figure 3 shows the last steps of the construction process and the attachment of the outer reflecting surfaces of the ovens.

Figure 3. Last steps of the construction of the ovens.

In the previous tests, the cookers were placed on a platform, side by side, as shown in Fig. 3, and their thermal pairs inside (one in the absorber and another equally distant between the absorber and the glass cover in harmony with Harmim *et al.* (2010)).

We collected temperature data from the absorbing panel and from the inside of the ovens. The temperatures were noted between intervals of 1 (one) second through a data Thermometer/Register from 10:00h to 14:00h. This procedure was necessary in order to avoid failure caused by the zenithal angle.

The data from the temperature were measured with thermo pairs of type K cromel-alumel, attached to the OMEGA model RDXL4SD digital thermometer. It had reading range between -50.1°C to 1,700°C (it depends on the type of thermo pair) and resolution of de 0.1°C. This real time data register saves the temperature measures in four channels along with time information (year, month, minute, second). The data is store in an SD card in a spreadsheet and can be viewed using EXCEL software. The global solar radiation data were measure with Davis meteorological station - Weather Envoy set up on LMHES at UFRN.

2.1.1 Tests without load (Stagnation Test)

Initially, we carried out tests without any food for both cookers in order to verify the behavior of each device and their maximum temperatures.

2.2 Tests with Load

After the cookers were heat to their cooking temperatures, the food (pizza, nugget, bread, cake, crumbed chicken and lasagna) was put inside. We measured the baking time and the level of temperature inside the ovens. In addition, water-heating tests were done. The same amount of distilled water was put inside each cooker. Then, they were placed by the sun light.

2.2.1 Water-heating test.

As anticipated by Mullick *et al.* (1987), the best way to compare solar cookers is the heating of water. Some variables are excluded from the tests and the author's subjectivity and others about the state of cooking will be eliminated.

2.2.2 Calculation of Cooking Power

According to Funk (2000), to evaluate the baking power of a solar cooker, we must verify the difference of the water temperature during the intervals of 10 minutes and multiply this figure by the mass (kg) and the specific heat (4,186 J/K.Kg) of this fluid divided by the time (600s). The results of this equation will be the cooking power in Watts, as follows:

$$\mathrm{P} = \frac{(MC)_w(T_{w2}-T_{w1})}{600} \tag{1}$$

For the calculation of the equipment power, we must use the equation (1), but we must alter the intervals of time for the equivalent temperature change from 65ºC to 95ºC. This is necessary in order to have an area where thermal losses are more perceptible, as follows:

$$\mathrm{P}_{(65-95)} = \frac{30(MC)_w}{\Delta t} \tag{2}$$

Mahavar *et al.* (2015) declare that, generally, the utilization efficiency (η_u), for box-type solar cookers, is calculated using the following relations:

$$\eta_u = \frac{(MC)_w(T_W-T_a)}{\bar{I}_s A_p \Delta t} \tag{3}$$

T_W represents the maximum temperature of the water load and T_a is the ambient temperature. Δt is the time needed to reach the T_W, and $\bar{I}_s$ is the average solar radiation.

The calculation of the cooker performance must be done with the same range of temperature used for the cooking power (65ºC -95ºC), as follows:

$$\eta_{(65-95)} = \frac{30(MC)_w}{\bar{I}_s A_p \Delta t} \tag{4}$$

3 RESULTS AND DISCUSSIONS

3.1 Tests without load.

Both the cookers were tested without loads for three days. The correspondent 03/09/2014 presented the best results about the level of inner temperatures.

The cookers were placed under sunlight at 10:00h. The temperature of the absorber and the air inside corresponded to 25ºC for the dark cooker and 25ºC for the mirrored cooker. The ambient average parameters of the test were ambient temperature: 27ºC, thermal sensation: 29ºC, relative humidity: 85%, global solar radiation: 891 W/m^2 and direct solar radiation: 712 W/m^2. There was very little interference by the clouds just a brief clouding blocking the sun at around 11:50. The day had good weather in terms of clouding.

The table 1 shows the maximum figures and the average radiation for test on the 03/09/2014. T_{n1} was the temperature in the absorber of the dark cooker, T_{n2} was the temperature of the air inside the dark cooker, T_{e1} was the temperature of the absorber in the mirrored cooker and T_{e2} was the temperature of the air inside the mirrored cooker.

Table 1. Maximum figures for the test on the 03/09/2014.

Parameters	**Local time (hh:mm:ss)**	**T(ºC)/ Rad (W/m^2)**
T_{n1}	11:38:28	162.8
T_{n2}	12:48:28	132.8
T_{e1}	12:36:28	148.7
T_{e2}	11:42:58	115.3
Rad	11:43:00	1,041
Average radiation		891.3

3.2 Tests with load

The first tests we did were the cooking of crumbed chicken. The objective was measure the time of cooking in order to compare authors from LMHES. Total cooking time was 20 minutes for both cookers. The 400g pizzas were cooked in 20 minutes.

The Figure 4 shows the crumbed chicken and the pizzas during and after the cooking process.

Figure 4. Cooking of crumbed chicken and pizzas.

3.2.1 Cakes

Three different cakes were cooked. For one cake, the cooking time was 29 minutes. For two cakes, the cooking time was 37 minutes and for three cakes the cooking time was 80 minutes. The time for cooking were so satisfactory that they can be compared to those of a conventional oven. We will detail the tests for the cooking of the three cakes.

The test started at 11:17h and ended at 12:38h. The temperatures of the absorber and the inner air were T_{n1}=153.7ºC and T_{n2}=113ºC for the dark cooker and T_{e1}=121.3 and T_{e2}=103.2ºC for the mirrored cooker. Each cooker had 2,400g load. The average ambient parameters were: T_a= 28.8ºC, thermal sensation = 33.1, Ur= 76% and global solar radiation = 923.7 W/m^2, direct solar radiation = 739 W/m^2. The graphic in Fig. 5 shows the behavior of the parameters taken.

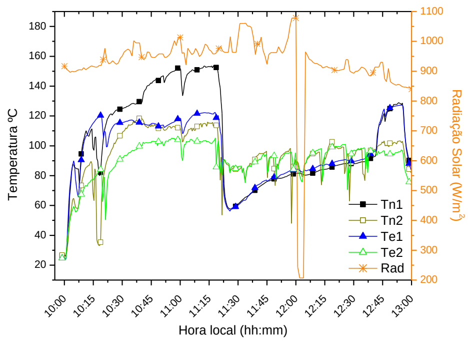

Figure 5. Graphic for the test on the 15/09/2014

We observed that for the 2,400g load, the total cooking time was one hours and twenty-eight minutes. Two chocolate cakes (in each device) were ready first (Fig. 6). After ten minutes, the coffee cakes were taken out of the cookers.

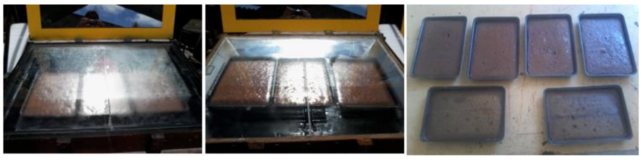

Figure 6. Cakes during and after the cooking process.

3.2.2 Bread

In order to diversify the tests, we put 850g of pre-cooked bread in each cooker. These tests happened on 22/09/2014. Figure 7 shows the parameters of inside temperatures T_{n1}, T_{n2}, T_{e1} e T_{e2}, and the solar radiation for the tests period.

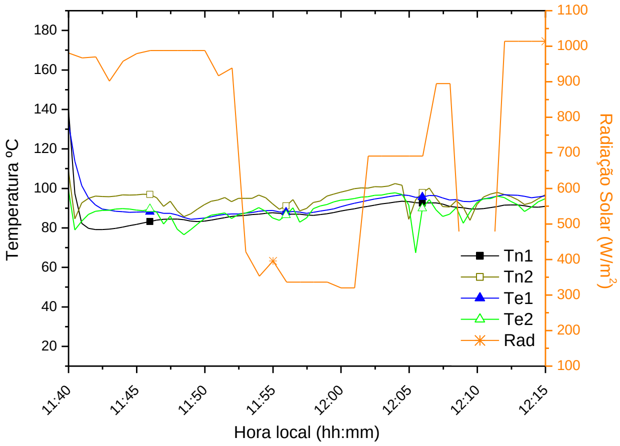

Figure 7. Graphic for test on the 22/09/2014.

The bread was put inside the devices in the following conditions: temperature of the absorber and the air inside T_{n1}=135.7ºC and T_{n2}=116.2ºC or the dark cooker and T_{e1}=138.8 and T_{e2}=102.6ºC for the mirrored cooker. The ambient parameters of the tests were: T_a= 29.3ºC, thermal sensation = 33.2, Ur= 79% and average global solar radiation = 688 W/m^2, direct solar radiation = 550.5 W/m^2.

Fig. 8 shows the load of bread inside the cookers. We can verify that there is condensation on the glass of botch devices. The load was placed inside the cooker at 11:42 and taken out of the oven at 12:02 (Figure 8). The whole process took 20min of preparation, but the bread was overcooked. They were similar to toasts. Thus, the cooking time can be reduced.

Figure 8. Breads on baking and baked after the study solar oven.

3.2.3 Tests with water

For a better accuracy in the comparison between both tested configurations, we performed a water heating tests described by Harmim *et al.* (2010). This test can express more accurately thermal losses and efficiency of the cookers.

Three tests were performed with water on the same day (26/01/2015). The load used was 0.5, 1.0 and 1.5Kg. They were placed in the testing recipients and put inside the cookers. We performed a more detailed and focused approach on the 1.0 Kg load.

The following chart presents the general data related to the tests with the 1.0 Kg load. For the calculations of the cooking power, the table 10 rectifies the superiority of the mirrored cooker, as well as for efficiency and time needed to reach from de 65ºC to 95ºC.

Table 2. Power and efficiency of the cooker for a 1.0 Kg load at a 30ºC ΔT.

Δt (min)	**$P_{(65\text{-}95)}$ (W)**	**$\eta_{(65\text{-}95)}$ (%)**	**Δt (min)**
Mirrored solar oven	78	14	26.5
Dark solar oven	41.17	5.9	33.5

We verified in Table 3, the time needed to reach the temperature intervals from T_{w1} to T_{w2}, the loads of H_2O, average radiation for the tests and the ambient temperature. We observed that we can relate the tests of food and water, for the times are very similar.

Table 3. Summary of the test results with water.

Oven	**Walter load (M) (Kg)**	**Rad (W/m^2) (average insolation)**	**T_a (ºC) (Ambient temp. correspond to Max. Tw)**	**T_{w1} (ºC)**	**T_{w2} (ºC)**	**Time Δt (min)**
Mirrored oven	0.5	941	29	60.9	92.9	12
Dark oven	0.5	946	29	60.7	92.9	19
Mirrored oven	1	944	29	60.9	91.2	31
Dark oven	1	919	29	60.2	91	24.7
Mirrored oven	1.5	649	29	59.7	93.2	64.5
Dark oven	1.5	667	29	59.6	93.2	69

As the temperature inside the solar cookers rises and differs from the ambient temperature, the radioactive loss increases faster. This is a fourth power function directly connected to the surface temperatures that interact with the ambient.

The explanation for the superiority of the mirrored cooker on the dark cooker can be observed at Fig. 9. We can see thermo graphical images of the equipment and their temperature gradients. More precisely, the illustration shows that the area of the dark oven has a much higher temperature than the mirrored one. Therefore, the radioactive losses for the mirrored oven are lesser than the dark cooker.

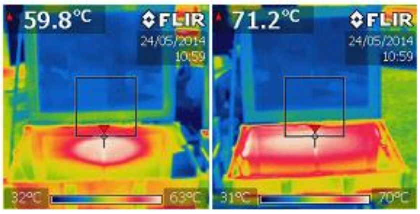

Figure 9 Thermal picture of the dark and the mirrored cooker.

Another important aspect it the absorbing recipient of the mirrored oven that is in the center of the device, isolated by the air-walls inside the cooker, whereas for the dark oven, the pan is directly touched by the absorber pan. This eases the loss for convection. It may be well observed in Fig. 10.

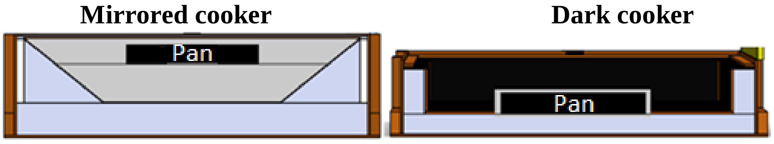

Figure 10. Recipients inside the cookers.

3.2.4 Comparison

This topic presents and discusses numbers referring to the cookers studied here and compared with different authors. In Table 4, the cookers in this study were compared to other models studied by Mahavar *et al.* (2012). The main conferring data is the stagnation temperature.

Table 4. Comparison among the stagnation temperatures from different authors.

Referrence	Test dates	Time (hh:mm)	Ambient Temp. (°C)	Solar Radiation (W/m^2)	Stagnation Temperature (°C)
Vaishya *et al*	23/09/1982	12:00	32	1020	122
Nahar	-	14:00	28	760	132(temp. do ar)
Negi; Purohit	Março de 2002	12:00	27	750	140
Kumar *et al.*	-	13:40	37	858	138
Mirdha; Dhariwal	-	13:30	37	-	163
Harmim *et al.*	23/07/2008	12:00	48	960	140
Purohit; Purohit	17/06/2009	13:30	35	945	144
Dark cooker	**03/09/2014**	**11:38**	**30.2**	**891.3**	**162.8**
Mirrored cooker	**03/09/2014**	**12:36**	**30.2**	**891.3**	**148.7**

About the table above, we observed that the mirrored and the dark ovens had results superior to almost every others. This is due to the different features of the projects (additional reflecting mirrors, capitation area, inner volume, absorber mass). The reaching of this position rectifies the quality of projects hereby developed.

Another important comparison was performed in the water heating. We verified that the ovens we developed had a superior performance compared to the oven by Mahavar *et al.* (2015), Table 5.

Table 5. Performance comparison for the water heating test with other solar cookers type box.

Oven	Walter load (M) (Kg)	Rad (W/m^2) (average insolation)	T_a (°C) (Ambient temp.)	T_{w1} (°C)	T_{w2} (°C)	Time Δt (min)
Dark oven	1	944	30.1	60.9	91.2	31
Mirrored oven	1	919	30.1	60.2	91	24.7
Mahavar *et al.* (2015)	0.8	783	36.1	60.3	91.1	60
Dark oven	1.5	649	30.1	59.7	93.2	69
Mirrored oven	1.5	667	30.1	59.6	93.2	64.5
Mahavar *et al.* (2015)	1.6	854	35.5	59.7	93.2	90

4 CONCLUSIONS

The solar ovens proposed, both configurations, are viable for cooking food from 10:00 to 14:00, under good solarimetric conditions;

The mirrored design is the most efficient for baking because of its lesser thermal loss;

The proposed solar cookers, both configurations, present a good cost x benefit ratio, mainly because of their low construction cost viable for low-money people;

The operability and the construction and mounting processes of the solar ovens proposed are simple and can be easily learned by communities that can use them;

The oven presented can be an alternative for food baking. It can contribute for the socialization of solar energy and fight hard ecological imbalance problems cause by the massive use of wood;

The dark oven shows an easier construction and mounting for it does not need mirror cutting and calculations for its positioning;

The risks for the users of these ovens are low. It requires but some precautions that can be easily learned.

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