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LOW COST SOLAR OVEN MADE WITH REUSABLE MATERIALS

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Abstract. *It presents a solar oven made from a scrap of freezer intended for baking foods such as pizzas cakes, breads, lasagna and more. It will be presented the processes of manufacture and assembly of solar oven, whose main characteristic is its low cost, giving the baking multiple foods at once. The main characteristic the solar oven is its low cost, producing multiple food cooks at once. It will demonstrate the thermal viability the solar oven proposed. The baking times for the foods tested were very competitive with other solar ovens already manufactured and tested in UFRN and other solar ovens mentioned in the literature for baking food. The ability to bake several foods the same time proved to be very viable and this characteristic gives the solar oven offered an advantage over other solar ovens been studied.*

Keywords: *solar, solar oven, reuse of materials, low cost, energy socialization.*

1. INTRODUCTION

The firewood is probably the oldest energy used by man and still has great importance in the Brazilian energy matrix, participating with about 10% of primary energy production.

About 40% of wood produced in Brazil is transformed into charcoal. The residential sector is the most expensive wood (29%). Usually it is to cook food in rural areas. A family of eight requires approximately 2.0 m³ of wood per month to prepare their meals. The sector Industrial comes next with about 23% of consumption. The main industries that consume fuel in the country are food and beverages, ceramics and pulp and paper (National Energy Balance, 2014 - www.mme.gov.br).

These data show that the massive use of wood, endangers the health of the planet, point to the need for a policy of mass use of solar cooker for cooking food as a way to preserve nature and also to lessen the ecological imbalance the indiscriminate use of firewood, while minimizing the emission of polluting gases into the atmosphere.

The use of solar energy for cooking and baking food is one of the oldest and well-known energy source, and its main characteristic its social function. It's wonderful to see that people in Africa use solar ovens and strongly contributes to a policy of non-use of wood, which contributes to the environmental imbalance of our planet. In the northeastern hinterland plagued by droughts, the interior suffers from hunger and thirst due to inclement sun on their barren lands. The use of solar ovens in the solar caatinga promises to reverse or at least mitigate this situation by allowing backcountry better living conditions.

Cookers box type may have different numbers of external reflectors, flat or slightly concave. Characterized by allowing obtaining a maximum temperature of 150 ° C, slow to heat up and its operation generally is not easy. On the other hand have the advantage of being able to work with virtually no user intervention, keeping food warm for a long time. Produce no harmful effects to the user nor by contemplation or reflection. Are stable and do not present risks for the production of flame does not therefore generate susceptibility to sunburn.

This work aims to study and making a solar oven that uses the sun as an energy source. The oven box type will be produced from a carcass (scrap) freezer. Will be presented results of tests for the baking of some foods, which demonstrate the feasibility of using such an oven that can be an element of social and combat imbalance ecologic .A main difference positive compared to many other models of solar ovens now studied is its ability to bake while various foods, due to large premises of the oven.

2. MATERIALS AND METHODS

The proposed solar cooker is the box type, made from a scrap upright freezer with about 250 liters. To improve its efficiency, decreased up this initial volume to 44 liters in an indoor corresponding 0.63 m². The baking enclosure has 0.07 m height.

They were used three segments of mirrors with 46 x 50 cm, totaling an area of 0.69 m^2, glued on the door of the freezer using contact adhesive. This configuration allows obtaining greater efficiency: a greater surface area absorbing or reflecting increased surface area the solar oven.

Throughout the oven interior was painted with black matte paint for better absorption of solar radiation and filled with polystyrene to decrease the volume without having a relative increase in weight. The aluminum plates which served as the freezer trays were reused as a support for the forms containing the food, but before they were painted with flat black to increase absorption of radiation.

As coverage of the oven we used three segments glasses 03 mm, for the promotion of the greenhouse effect, which aids in cooking food.

The manufacturing and assembly process of the solar oven studied consisted of seven steps outlined below.

1. Remove of the components from freezer - remove gas that performed the cooling of the freezer and have disconnected all cooling components. Initially, the compressor then the capillary tube and the aluminum tubes forming part of the evaporator, and finally the plates and supports the plates;
2. Filling the solar oven interior with foam - the oven cavity is filled with foam in order to decrease the working volume without an increase in weight occur, also reducing the time required to heat the solar oven;
3. Adaptation of the plates - plates containing aluminum tubes evaporators, these were removed and the plates adapted to be used as a basis for this work conformation used a hammer, a rubber mallet and a chisel, then the plates were painted black to better absorption of energy;
4. Painting - the painting was done from inside and outside the oven, using black paint; the color black was chosen because it has higher heat absorption;
5. Placing a wooden board 15mm for support of absorbing plates;
6. Mirrors glue - The three mirrors were cut with 46x50 cm each and glued on the door of the freezer through contact adhesive;
7. Setting wheel for changing position of the oven, made poor weld.

For the test without load was measured maximum temperatures reached by the absorbing plate and the air inside the oven solar manufactured and studied. We chose the period of highest solar radiation, between 10 and 14:00 hours to days of fine weather.

Were baked pizzas, cheese bread, cheese, cakes and breaded chicken measuring the baking time and the same levels of temperature as absorber and the air inside the oven. We also measure the temperature of the external surfaces of the oven to evaluate its thermal loss. The temperature data were measured with Chromel-alumel thermocouples, connected to a digital thermometer brand MINIPA MT-914 with a read range of -70 ° C to 1200 ° C within 0,1°C and a maximum error in about 2.0%. The global solar radiation was measured using a solar station installed in LMHES UFRN. Figure 1 shows the solar oven test.

Figure 1. Solar oven proposed in test in the Solar Energy Laboratory/ UFRN.

2.1. Thermal balance of solar oven

The solar incidents radiations over the top cover and about the mirrors external entering the solar oven of two ways: as solar radiation incident global about the glass cover and direct solar radiation reflected by the mirrors external. The energy balance equations are presented below.

a. Enters Energy in the solar oven (E_{ef})

The energy that enters the solar oven comes from two sources: of solar radiation incident global in coverage the solar oven and radiation direct solar reflected in the mirrors external situated above the solar oven. The equation 1 shows the total energy that enters in the solar oven.

$$E_{ef} = E_g + \mathrm{E}_{re} \tag{1}$$

E_{ef} = power that enters the solar oven (W); E_g = energy from of global solar radiation that falls directly on the solar oven (W); E_{re} = energy reflected from the mirror above of the solar oven (W).

To calculate the energy input in the solar oven was used the equations (2) and (3).

$$E_g = I_g.\tau_v.A_v \tag{2}$$

$$E_{re} = I_d.(A_{ue}/A_v).\rho_e.\tau_v.A_v \tag{3}$$

I_g = instantaneous global solar radiation entering the solar oven = 1000 W/m²; I_d = instant direct solar radiation entering the solar oven = 800 W/m²; ρ_e = mirror reflectivity = 0.95, τ_v = glass transmissivity = 0, 85; Av = glass area = 0,63 m²; A_{ue} = mirrors area = 0.69 m².

3.2 Energy lost by the side, bottom and the cover glass (E_{PF})

Considering the average temperature of the external surfaces of the oven shown in Figure 2, we calculated the convective heat loss from such surfaces and the ambient air. Ignored for radiation emitted to the external environment due to the low temperature gradient between the surfaces of trade. To calculate the convective exchange, used the equation (4).

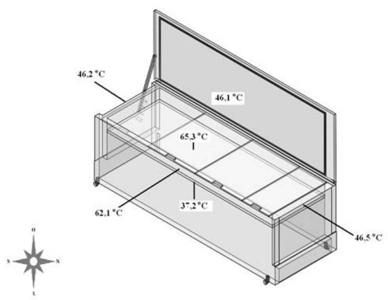

Figure 2. Temperatures on the external surfaces of the oven.

$$E_{pf} = Q_{convec} + Q_{rad} = h_c.A_{se}.(T_s - T_{amb}) + h_r.A_{se}.(T_s - T_{SKY}) \tag{4}$$

E_{PF} = Energy lost by the solar oven (W) h_c = transfer convective coefficient between the outer surfaces of the oven and air; h_c = transfer radiative coefficient between the outer surfaces of the oven and sky); A_{se} = area of the external surface of the oven temperature T_{se} =external surface of the solar oven; T_{amb} = ambient temperature.

The coefficient of heat transfer by convection between the external surface of the glass and the ambient air can seconds Duffie & Beckman (1991), may be determined by equation 5.

$$h_{c(ve-a)} = 2{,}8 + 3.v_v \tag{5}$$

This equation is valid for wind speeds between 0 and 7 m/s. At the place where the tests were done at medium speed was between 2.0 and 3.0 m / s.

The radiative heat transfer coefficient between the outer surface of the cover and the ambient, as Duffie & Beckman, 1991, is a function of the local weather conditions considered can be determined using equation 6.

$$h_{r(ve-a)} = 5{,}16.10^{-8}\,\frac{(T_{ve}{}^{4} - Tsky^{4})}{(T_{ve} - T_{a})} \tag{6}$$

where:
Tve = external temperature of the glass, in K.
Tsky = sky temperature in K.
Ta = ambient temperature in K.
Without incurring significant errors can obtain the value of Tsky from Ta by the equation (7).

$$T_{sky} = 0{,}0552.T_{a}{}^{1,5} \tag{7}$$

3.3. Internal Efficiency solar oven (η_{if})

The internal efficiency solar oven will be calculated by the ratio between the energy absorbed and available inside the oven and the total energy entering the solar oven by equation 8.

$$\eta_{if} = (E_{abs} / E_{ef}) \tag{8}$$

where: η_{if} = internal efficiency of solar oven; E_{ef} = Energy that enters the solar oven (W); E_{abs} = Energy absorbed by the solar oven (W).

3. RESULTS AND DISCUSSION

Table 1 shows the energetic contributions involved in the energy balance of the solar oven studied, and its thermal efficiency.

Table1. Energies involved in the energy balance of the solar oven studied.

PARAMETER	WATTS
Energy entering the solar oven	942.0
Energy absorbed by solar oven	536.8
Energy lost by the solar oven	405.2
Internal efficiency oven	57.0

The thermal efficiency of the solar oven demonstrated its feasibility in producing the baking of various foods simultaneously.

The greater the power loss of around 82% occurred cover glass, which was placed at a small height above the absorbing surface to accelerate the baking process. But it does not prevent the use of the proposed solar oven, since their baking time for the selected food were competitive with the cited literature for by solar cooking. The maximum temperature the glass reached 69°C and the average 65.3°C.

In baking test the great advantage it was the significant area of its baking enclosure, allowing the test with various foods at the same time. For the first test you have chosen the five baking cakes 700g each, making a total load of 3.5 kg. The flavors of the cakes were two of chocolate, one orange, one coconut and lemon.

Table 2 shows the average results of the test evaluated hours the temperature of the absorber surface and the internal environment of the oven solar studied. The solar oven was put on display in the sun 11:00 hours. The average ambient temperature was 29°C and sensation of 33°C during testing. When placing the cakes into the oven, at 11:35am, absorbing and internal air temperatures corresponded to 120°C and 90°C.

Table 2. Baking test results of five cakes simultaneously.

Time (hour)	**T_{abs}** cake 1 **(°C)**	**T_{int}** cake1 **(°C)**	**T_{abs}** cake 2 **(°C)**	**T_{int}** cake 2 **(°C)**	**T_{abs}** cake 3 **(°C)**	**T_{int}** cake 3 **(°C)**	**T_{abs}** cake 4 **(°C)**	**T_{int}** cake 4 **(°C)**	**T_{abs}** cake 5 **(°C)**	**T_{int}** cake 5 **(°C)**	**I_g (W/m²)**	**I_d (W/m²)**
11:45	59	62	58	62	57	59	56	58	58	58	980	784.0
12:00	67	67	68	74	73	69	65	74	74	74	974	779.2
12:15	78	75	77	77	83	78	84	87	81	85	880	704.0
12:35	86,7	85,6	82	86,5	90	81,1	89	99,1	92,3	95	750	600.0
AVERAGE	72.7	72.4	71.3	74.9	75.8	71.8	73.5	79.5	76.3	78.0	896	716.8

The two chocolate cakes that were baked in less time, 65 minutes, which is explained by the greater absorption of heat for being darker. Then the 12:50pm was removed orange cake from intermediate color and the other two lemon and coconut cakes clear colorations were ready 01:00pm

The five baking cakes at the same time provide an advantage to the oven designed in relation other ovens to one food. This ability to produce baking multiple foods at the same time represents an option for generating employment and income for poor communities that could create a craft factory and trading for baking cakes.

Of all the tested already in the oven LMHES/UFRN and compared to those reported in the literature for cooking food solar furnace that had a higher viability, since the baking of a cake in a conventional oven at 250°C and held in a 40 minutes solar oven around 60-80 minutes. They were baked five cakes in only 90 minutes that demonstrated good thermal efficiency of the solar oven studied. Figure 3 shows the solar oven baking operation studied in five cakes simultaneously.

Figure 3. Solar oven baking five cakes simultaneously.

Another test operated on solar oven baking was studied four different foods simultaneously. A cake 700g, 500g breaded chicken, 500g of cheese rennet and a pizza 600g. The food was placed into the oven at11:20 am when temperatures absorber and air were respectively 130°C and 95°C. The Table 3 shows the results measured when performing the test described.

Table 3. Average results measured in baked test.

TIME (hour)	**$T_{absorber\ pan}$ (°C)**	**$T_{air\ internal}$ (°C)**	**I_g (W/m²)**	**I_d (W/m²)**
11:20	130	95	960	768.0
11:30	98	68	950	760.0
11:40	100	73,6	955	764.0
11:50	102	76,4	932	745,6
12:00	107	82	856	684,8
12:10	112	90	842	673,6
12:20	115	92	835	668.0
AVERAGE	**109.1**	**82.4**	**904.3**	**723.4**

The first baked foods were pizza and cheese, taken at 11:50am, thirty minutes after the start of the test. The breaded chicken were removed then the 11:55am and the cake 12:20pm. The times obtained were very competitive with other solar ovens manufactured and tested in LMHES/UFRN and others shown in the literature to solar cooking foods, which once again demonstrated good efficiency solar oven studied. Again it was proved that the advantage oven was compared to other solar ovens manufactured, which is its ability to produce a significant load of baking food varied simultaneously.

This is a highly significant difference and can bring important social benefits for poor communities. The transfer of technological solar oven construction may represent an option for generating employment and income for poor communities, and reuse an appliance that would be deposited in landfills, bringing ecological problems harmful to the environment.

Despite the oven temperatures are well below the temperatures for conventional gas oven, the baking times proved the competitiveness of solar oven made from a conventional, especially when taking into account the load roast. The use of clean energy to replace gas and wood represent another distinctive quality of life that this prototype solar can represent.

After removal of food is left exposed to microwave radiation for measuring the peak temperature of the absorber and the air inside the oven is reached 142.1°C and 134.1°C, respectively. These results indicate that the oven was manufactured and tested that reached the highest levels ever measured temperature, which confirms its excellent performance for the baking of various foods at the same time. Figure 4 shows foods baked.

Figure 4. Baked foods into the oven at the same time solar tested.

Table 7 presents the average parameters of the solar oven for all foods tested.

Table 7. Average parameters in the tests with solar oven proposed.

FOOD	Mass (g)	baking time (min)	baking time in gas oven (min)	baking time in others solar ovens (min)	$T_{air\ internal}$ (°C)	$T_{absorber\ pan}$ (°C)	I_g (°C)	I_d (°C)
PIZZA	600	30	15 - 20	25 - 35	**75**	**100**	880.0	704.0
STEAKS	500	35	30 - 40	20 - 25	**75**	**100**	841.0	672.8
CAKE	700	60	45 - 50	50 - 80	**75**	**100**	866.0	692.8
CHEESE	500	30	15 - 20	30 - 40	**75**	**100**	770,8	616.6

The tests operated with solar cooker under study for all foods tested demonstrated their viability and their massive use can be of great significance in a social policy to generate employment and income for poor communities, which could produce cakes at a low cost and using clean energy, environmentally friendly and promoting sustainable development, contributing to reducing the use of wood as an energy source.

Her baking times were competitive with solar ovens already studied in LMHES/UFRN and other solar ovens solar mentioned in the literature for baking food. Was the solar oven that had the highest levels of the absorber temperature and the indoor air of all solar ovens already studied in UFRN, providing greater speed in baking.

For the diagnosis of thermal loss from the oven temperatures were measured from the external surfaces of the proposed solar oven. Figure 5 shows the mean values of temperatures measured during the test without cargo, 11:30 am.

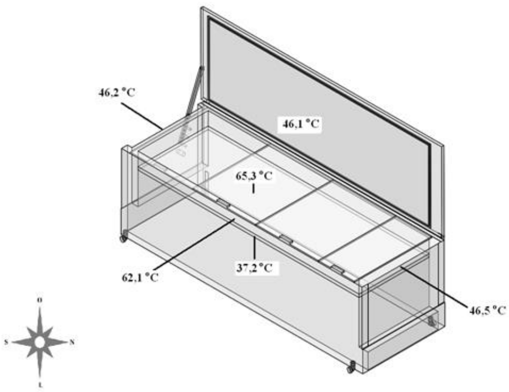

Figure 5. Arrangement of measurement points on the external surfaces of the proposed solar oven with their values.

The point of highest temperature was in the outside glass, explained by the intense exchanges convective and radioactive inside the oven, due to its low height and small volume, plus a warming due to absorption of radiation concentrated sent glass from the mirror surface external reflector. The outer surface which achieved higher temperature was the variable receiving radiation from the outer reflective surface, the surface during in the morning and east in the afternoon the surface west. Despite the significant loss through the glass, the furnace efficiency was still very good.

The solar oven must have proposed period of operation with higher efficiency 10 to 15 hours, and may be up to three loads baked foods. Therefore, it is possible to baking of cakes to 15 daily or a greater efficiency, a total of 10 daily cakes. One can manufacture various baking ovens and much larger payloads, and can be produced on a larger scale for a pilot project to manufacture handmade cakes.

4. CONCLUSIONS AND SUGGESTIONS

1. The baking times of the tested foods were competitive with those achieved by other solar ovens have studied and cited by solar literature for cooking food;
2. The solar oven proved to be feasible to produce baking food in the period from 9:00 to 14:00 hours, in good solar condition; may bring savings and minimize attack problems of ecology, particularly with regard to deforestation for use firewood;
3. The studied solar oven has the capacity to produce baking multiple foods simultaneously, their main features, besides its low cost;
4. The baking times of all foods tested were up to those obtained with a conventional gas;
5. The ability to bake several foods at the same time gives the solar oven studied differential quality and viability over other solar ovens already tested;
6. The operation of the solar oven only requires some technical expertise and some care with the radiation reflected from the mirror surface located above the enclosure of the solar oven;
7. The manufacturing and assembly of the solar oven proposed are simple, requiring only prior training;
8. Perform tests for various types of food in all seasons to a more real performance of the proposed solar oven.

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