SOLAR OVEN MANUFACTURED IN COMPOSITE LOW THERMAL CONDUCTIVITY

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Abstract. *Presents a low-cost solar furnace manufactured with composite blocks made from EPS powder, gypsum and cement. Will present the processes of manufacture and assembly of the furnace, which has as main feature the low cost of production. The oven works proposed greenhouse and concentration. Above the box solar oven is located a reflective surface to concentrate the incident rays, sending them to the oven. The blocks constituting the solar oven have low thermal conductivity, are lightweight and have good mechanical strength. Will be presented test results baking some foods that demonstrate the feasibility of using the oven, which can contribute to minimize the use of firewood, which brings significant damage to the environment. The proposed solar oven can help the poor in our region, constituting an option for generating employment and income.*

Keywords: *solar energy, solar oven, composite material.*

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 for cooking food in rural areas. A family of eight requires Approximately 2.0 m³ of wood per month to prepare their meals. The Industrial sector 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 2009 - www.mme.gov.br).

These data show the that massive use of wood, putting at risk 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 spread this energy source and its main characteristic its social function. It's wonderful to see that people in Africa use solar ovens and massively contributing 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 hinterland suffers from hunger and thirst due to inclement sunshine on their barren lands. The use of solar ovens in the solar scrub promises to reverse or at least mitigate this situation by allowing backcountry better living conditions.

The use of solar energy for the purpose of cooking and baking food is one of the oldest and most widespread applications of this energy source, and its main characteristic its social function. In northeastern backlands plagued by

droughts, the countryman suffers from hunger and thirst due to inclement sun on their arid lands. The use of stoves and solar ovens in the bush promises to alleviate this situation allowing the backcountry better living conditions

This paper presents a model of a solar oven designed to bake food, constructed from the use of a composite material, which has in its composition a recycled material, the EPS crushed. The solar oven proposed is intended for domestic use in rural and urban areas, from 9:00 to 14:00 hours, mainly for the operation of roasting foods, such as breads, cakes, pizzas and more.

2. REVIEW

The solar cooking food is one of the main research lines of the LMHES UFRN, having been the subject of numerous scientific papers published in various national and international conferences and eight Masters Dissertations.

Souza, in 1994, built and studied two solar ovens with reflective surfaces of flat mirrors. The first solar oven was square with three sides in two segments of mirrors and the other was also square with three mirror segments, ranging from manual angle. The tests showed the viability of solar ovens for obtaining temperature levels absorbing surfaces of the ovens of above 130 ° C.

Melo, in 2008, presented Master's thesis, in PPGEM PPGEM-UFRN about a solar oven made from a conventional gas stove. The location of the burners, served as the venue for the oven and was covered by a glass slide for the generation of greenhouse gases and had his back and side isolated by a compound of plaster and Styrofoam. Plane mirrors was placed on the sides of the oven for the concentration of radiation and a parabolic reflector was introduced into the backing compartment for the use of the incident radiation reflected inside the oven. The absorption average temperature was about 150 ° C and the air in the interior in the oven was 120 ° C.

Souza, et al., in 2008, showed in the V CONEM a model of solar cooker concentration used to heat an electric iron for ironing operation, saving up energy. The proposed solar iron presented viable for the purpose of replacing the iron in the task of ironing. The results obtained with the solar iron are similar to those obtained with the conventional iron plates, confirming their viability.

Souza et al., in 2008, presented in the VI CONEM a solar oven made from blocks of composite material. The oven was proposed with the bottom inside surface with a parabola shaped in manual process and mirrors coated in small pieces to increase its internal temperature. The blocks constituting the oven has low thermal conductivity, were lighter and showed good mechanical resistance. Above the furnace was located a parabolic reflector to concentrate the incident rays, sending them to the oven.

Gomes, in 2009, presented Master's thesis, in PPGEM PPGEM-UFRN about solar oven of low cost and easy operation for baking and cooking, built from a scrap tire. We studied three configurations, with two types of reflective parables. The supporting structure of the solar oven movements necessary to keep the apparent motion of the sun was made using a swivel chair scrap. There was obtained a maximum temperature at absorbent of around 160°C to about 120°C of internal temperature.

Souza et al., presented in 2011, at the 21th COBEM a model of the solar oven for roasting, built from a scrap polyethylene drum. For presenting profile cylinder the focus of the parabolic reflecting was linear, allowing the use of up to three pans inside. The proposed solar oven was feasible for roasting operation, from 9:00 to 14:00 hours.

Souza et al., in 2011, presented at the 21th COBEM a solar oven for roasting food, built from a box thermal EPS. The main innovation of this work was the use of Styrofoam cooler, widely-available, low cost and with a structure already defined and built, avoiding makes a mold to obtain the box. The times for pizza and lasagna baking proved competitive with other models already tested and shown in the solar literature to food roasting.

Souza et al. in, 2012, presented at the VII CONEM a solar oven made from a scrap of freezer intended for baking foods such as pizzas, cakes, breads, lasagna and more. This oven provided the baking of various foods simultaneously. Were shown their thermal and economic viabilities, by getting of the cooking times competitive with other solar ovens already tested in the world, the high temperatures of the absorber and internal and its large area of reflection of solar radiation and consequent concentration.

Figure 1 shows the various types of solar ovens have already been manufactured and tested in LMHES / UFRN.
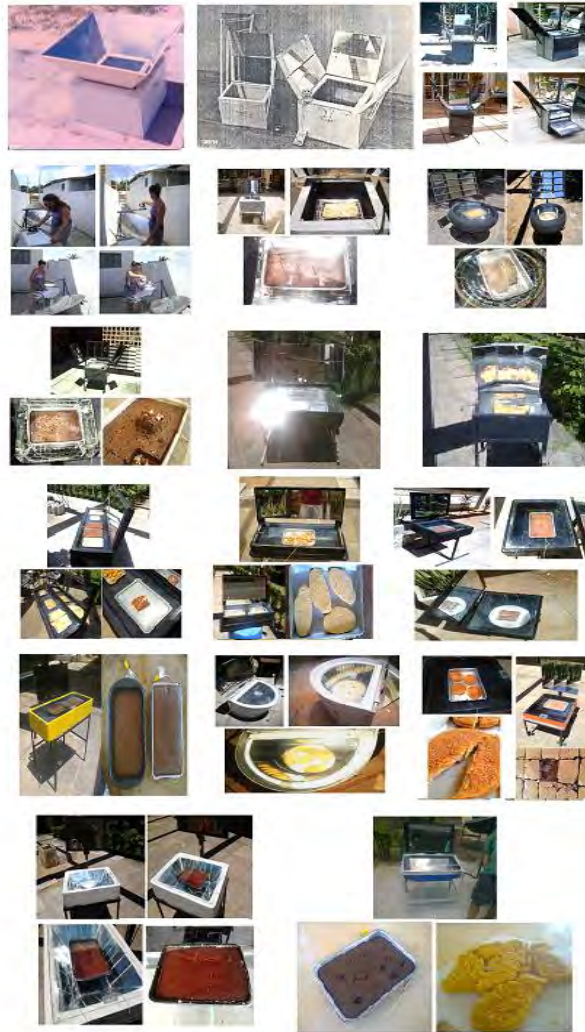
Figure 1. Solar ovens manufactured and tested in LMHES / UFRN.

3. MATERIALS AND METHODS

The solar oven was constructed from four blocks made of composite material. The plates were placed to form a square, and then added to the composite material inside it, forming the bottom of the oven. The proportions by volume of the composite material in the mixture were: 1.0 part gypsum, 2.0 parts triturated EPS, 1.0 part cement to 0.3 parts water relative to the total volume of the mixture.

The solar oven proposed had the following dimensions:
- external - Length: 0.60 m, width 0.50 m and height: 0.17 m;
- internal - length: 0,50 m, width: 0,40 m, height: 0,115 m.

The external area corresponds to 0.30 m² and the external volume 0.051 m³, internal area corresponds to 0,20m² and the internal volume of 0.023 m³. The reflective surface above the solar oven has catchment area of solar radiation corresponding to 0.2 m². Inside the solar oven were painted with synthetic enamel paint black to greater absorption of solar radiation.

Was used as a cover the solar oven a transparent flat glass 3 mm thick. The glass is seated in the composite and moves to facilitate loading and unloading of food offered for cooking. The solar oven structure was fabricated using angles and provides rotational movement to facilitate the handling of the oven.

Assays were performed without load for determining the temperature of the absorber and the interior of the box-type solar oven studied. Were also measured solar radiation incident on the prototype, using a Weather Envoy meteorological station installed in LMHES / UFRN. The temperatures were measured every five minutes and every one minute radiation. The tests were conducted for the period from 10:00 to 14:00 hours.

Tests were also performed to load a pizza baking 460g, breaded chicken and 300g, 500g kibe and a cake 700 g, determining the time required for this purpose. We also measured the temperatures of the outer surfaces of the solar oven to evaluate the heat loss. The temperatures of the internal air and the absorber were measured with Chromel-

alumel thermocouple Type K coupled to a digital thermometer. Figure 2 shows the solar oven made of composite material test.

Figure 2. Solar oven proposed test in Solar Energy Laboratory UFRN.

3.1. Thermal balance of solar oven

The solar incidents radiations over the top cover and about the mirrors external entering the solar oven of two forms: 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.

$$E_{ef} = E_g + E_{re}$$
(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).

$$E_g = I_g.\tau_v.A_v$$
(2)

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

I_g = instantaneous global solar radiation entering the solar oven = 850 W/m²; I_d = instant direct solar radiation entering the solar oven = 680 W/m²; ρ_e = mirror reflectivity = 0.95, τ_v = glass transmissivity = 0, 85; Av = glass area = 0,255 m²; A_{ue} = mirrors area = 0.20 m².

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

Considering the average temperature of the oven external surfaces was calculated 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 exchange surfaces. To calculate the convective exchange, used the equation 4. They performed several measurements in the temperature of the external surfaces for the period of highest incidence of solar radiation between 11 and 12 hours.

$$E_{pf} = Q_{convec} = h_c.A_{se}.(T_s - T_{amb})$$
(4)

E_{PF} = Energy lost by the solar oven (W) h_c = transfer convective coefficient between the outer surfaces of the oven and air (W/m.K); A_{se} = area of the external surface of the oven temperature (m²), T_{se} =external surface of the solar oven (°C); T_{amb} = ambient temperature (°C).

3.1.3. 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 5.

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

(5)

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

4. ANALYSIS OF RESULTS

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.

ENERGY	WATTS
Energy entering the furnace	322.0
Energy absorbed by solar oven	224.3
Energy lost by the oven	97.7
Internal efficiency the solar oven	70.0%

The efficiency of the solar oven studied was around 70%, since the energy lost corresponded to 30% of the energy that went into the enclosure of the oven. This efficiency demonstrates the feasibility of thermal solar oven studied, which resulted in the good efficiency of the insulation used. Subsequently, baking times also demonstrated good thermal efficiency of the furnace studied.

4.1. Test results for baking food in the oven solar

Table 2 shows the average results of the test evaluated the temperature of the absorber surface and the internal environment of the solar oven studied. The solar oven was placed in sunlight sunning 09:00 hours. The average ambient temperature was 29°C and sensation of 33°C during testing.

Table 2. Hourly average results of the test without load.

Time (hour)	$T_{absorber}$ (°C)	$T_{internal}$ (°C)	I_g (W/m²)	I_d (W/m²)
9h-10h	63.5	92.1	727.0	581.6
10h-11h	77.2	115.3	826.0	660.8
11h-12h	80.2	120.5	832.0	665.6
12h-13h	83.5	115.7	793.0	634.4
13h-14h	90.2	110.5	711.0	568.8
Average	**78.9**	**110.8**	**778.0**	**622.4**

The absorber maximum temperatures the solar oven corresponding to 125.3°C and 91.3 ° C, respectively, were significant and suitable to provide the baking of foods. The average temperatures for these parameters during the test duration, at around 110.8°C and 78.9°C, respectively, are also suitable for obtaining the desired end.

The test was conducted to solar excellent conditions, with maximum global radiation of 880W/m² and maximum direct solar radiation 704W/m². The average temperature was 29.5°C, the thermal sensation of 33.5 ° C and humidity average of 66%.

Despite temperatures of the absorber and internal air the solar oven are well below conventional gas oven with internal temperatures up to 250°C, the solar ovens previously fabricated and tested reached levels similar to those achieved in the solar oven study and enabled the cooking of foods such as cakes, pizzas, cheese bread, pasta, rice, meat.

Depending on the experiments performed with several other stoves, projected to feasibility of using such an oven designed to achieve the desired end, namely, the cooking of food for a low income family, minimizing the harmful effects of the use of wood to the environment and life.

Tests with box type solar cookers have already shown their greater viability for baking food. Then broke for testing for baking of some foods whose results are shown below.

A pizza was baked and the results of the measured parameters in this test are shown in Table 3. The complete pizza baking 460 g was obtained in 20 minutes. The test was started at 11:15 hours with absorber temperatures of 107°C and the internal air the solar oven at 70°C. The environment temperature during the test was on average 30.5 ° C, the thermal sensation 35.3 ° C and relative humidity of 66%.

Table 3. Results of the measured parameters in the test to bake a pizza.

Time (hour)	$T_{absorber}$ (°C)	$T_{internal}$ (°C)	I_g (W/m²)	I_d (W/m²)
11:20	60.0	65.0	875.0	700.0
11:25	61.0	65.0	880.0	704.0
11:30	63.0	66.0	880.0	704.0
11:35	66.0	69.0	885.0	708.0
Average	**62.5**	**66.2**	**880.0**	**704.0**
		baking time	**20 minutes**	

Although the internal temperature and the absorber are well below the levels achieved in a conventional oven gas, again evidenced the viability thermal oven proposed for obtaining pizza baked in 20 minutes, although this time is well above the time required for the same order in an conventional oven, about 12 minutes. This is explained by the combination of energetic contributions of the greenhouse effect and concentration that leads to a condition suitable for obtaining baking of food,

Other ranges tested had already baking time for the pizza same between 15 and 25 minutes, similar to levels of radiation. The global solar radiation maximum was 900W/m² and direct radiation averaged 702W / m². Figure 4 shows the pizza baked in the solar oven proposed.

Figure 4. Baking a pizza in the solar oven study.

Another test with the solar oven was baking a cake 700g chocolate flavor. Table 4 shows the results of the temperatures inside the oven and the absorber and global solar radiation. The test began at 11:00 hours. The temperatures before placing the cake were 113°C for the temperature of the absorber and 76°C for the temperature of the air inside the oven. The average temperature was around 30.8°C during the test, the thermal sensation of 36.4°C and relative humidity of 68%. The complete baking the cake happened in fifty minutes.

Table 4. Test results for baking a cake in the oven proposed.

Time (hour)	$T_{absorber}$ (°C)	$T_{internal}$ (°C)	I_g (W/m²)	I_d (W/m²)
11:05	56.0	61.0	840.0	672.0
11:10	61.0	63.0	859.0	687.2
11:15	65.0	64.0	866.0	692.8
11:20	67.0	64.0	845.0	676.0
11:25	70.0	67.0	867.0	693.6
11:30	71.0	67.0	850.0	680.0
11:35	73.0	68.0	856.0	684.8
11:40	75.0	75.0	876.0	700.8
11:45	78.0	73.0	893.0	714.4
11:50	80.0	78.0	905.0	724.0
Average	69.6	67.8	866.0	692,8
		baking time	50 minutes	

The internal temperature of the oven and were well below the absorber achieved with a conventional oven gas. However, considering that the time of baking a cake in a conventional oven gas happens in about 40 minutes, the solar furnace built was very feasible to bake this food, especially for its low cost. Solar radiation levels were of great magnitude, reaching maximum values for global and direct solar radiation of 920 and 736W/ m². Figure 5 presents the cake baking and after roasted in proposed solar oven.

Figure 5. Cake baking in the oven solar study.

Another test with the solar oven was baking the breaded chicken, three in number, and each with a mass of 100g, 300g total. Table 5 shows the results of the temperatures inside the oven and the absorber of solar radiation and direct solar radiation. The test began at 11:55 hours. The temperatures before placing the nuggets were 107 ° C for the temperature of the absorber and 73°C for the temperature of the air inside the oven. The average temperature was around 30.3°C during the test, the thermal sensation of 35.3 ° C and relative humidity of 67%. The complete baking the breaded happened in twenty minutes.

Table 5. Test results for baking Breaded chicken in the oven proposed.

Time (hour)	$T_{absorber}$ (°C)	$T_{internal}$ (°C)	I_g (W/m²)	I_d (W/m²)
12:00	70.0	64.0	885.0	708.0
12:05	71.0	70.0	880.0	704.0
12:10	70.1	70.0	885.0	708.0
12:15	71.0	70.0	885.0	708.0
Average	71.0	68.5	884.0	707.0
		baking time	20 minutes	

The internal temperature the solar oven and the absorber were once again well below achieved with a conventional oven gas. However, considering that the time of baking the batter in a gas conventional oven happens in about 15

minutes, the solar furnace built was feasible to bake this food, especially for its low cost. Solar radiation levels were of great magnitude, reaching maximum values for global and direct solar radiation of 884 e707W/m². Figure 6 presents the empanadas on baking in the oven solar proposed.

Figure 6. Breaded chicken baking in the oven solar study.

Another test with the solar oven was the baking of kibes (10 units), each with a mass of 50g, 500g total. Table 6 shows the results of the temperatures inside the oven and the absorber and global solar radiation. The test began at 12:45 hours. The temperatures before placing the kibes were 105°C for the absorber temperature and 68 ° C for the temperature of the air inside the oven. The average environment temperature was around 30.3° C during the test, the thermal sensation of 35.3° C and relative humidity of 67%. The complete baking of kibes happened in an hour.

Table 6. Test Results for oven baking of kibes proposed.

Time (hour)	$T_{absorvedor}$ (°C)	$T_{internal}$ (°C)	I_g (W/m²)
12:50	63.0	64.0	830.0
12:55	65.0	62.0	820.0
13:00	66.0	62.0	800.0
13:05	68.0	62.0	800.0
13:10	68.0	67.0	790.0
13:15	60.8	64.0	780.0
13:20	67.0	64.0	770.0
13:25	66.0	62.0	750.0
13:30	65.0	65.0	740.0
13:35	68.0	66.0	735.0
13:40	68.0	68.0	725.0
13:45	68.0	71.0	710.0
Média	**66.7**	**64.5**	**770.8**
	baking time	**60 MINUTES**	

The internal temperature the solar oven and the absorber were once again well below achieved with a conventional oven gas. However, considering the time of kibes baking in a gas conventional oven occurs in about 40 minutes, the solar oven built was feasible to bake this food, especially for its low cost. Solar radiation levels were of great magnitude, reaching maximum values for global and direct solar radiation of 850 and 680W / m². Figure 7 shows the kibes baked in the oven test.

Figure 7. Kibes of baking in the oven solar study.

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

Table 7. Average parameters measured in the tests chosen for baking food.

FOOD	Mass (g)	Baking time (min)	baking time in gas oven (min)	baking time in others solar ovens (min)	$T_{internal}$ (°C)	$T_{absorvedor}$ (°C)	I_g (°C)	I_d (°C)
PIZZA	460.0	20.0	10.0 – 15.0	15.0 - 30.0	66.2	62.5	880.0	704.0
STEAKS	300.0	20.0	30.0 - 40.0	20.0 - 25.0	68.5	71.0	841.0	672.8
CAKE	700.0	50.0	45.0 - 50.0	50.0 - 80.0	67.8	69.6	866.0	692.8
KIBES	500.0	60.0	30.0 - 40.0	60.0 - 80.0	64.5	66.7	770.8	616.6

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The tests operated with solar cooker under study for all foods tested demonstrated its viability and its 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

For the diagnosis of thermal loss from the oven temperatures were measured from their external surfaces. Figure 8 shows the mean values of temperatures measured during the test without load, at 11: 30 hours.
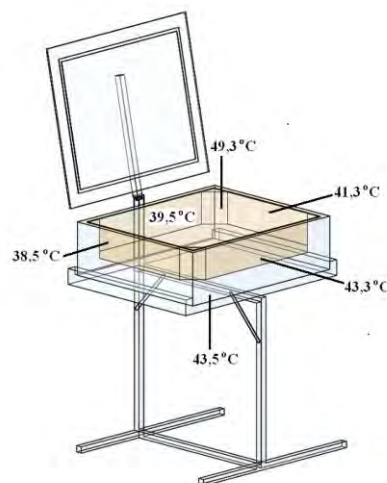

Figure 8. Disposal of measurement points in the external surface the solar oven proposed with their respective values.

The point of maximum glass temperature was in the external explained by the concentration of the rays from the reflecting surface placed above the oven addressed to the oven. As the temperature was around 31°C, an average temperature difference between the surfaces and external environment was about 10°C. It should be noted that these temperature levels are achieved also because of the external surfaces of the oven are painted black. The heat loss through the bottom could be minimized by reducing the internal volume of the oven by placing a thermal insulator between the inner bottom of the oven and the absorber plate. Despite this difference in temperature losses are not significant and do not constitute a factor that could prevent the thermal performance of the furnace proposed.

5. CONCLUSIONS AND SUGGESTIONS

1. The solar oven was feasible for the baking of foods tested;
2. The baking times for all foods tested were competitive with solar pointed out the literature for cooking food;
3. The composite used to manufacture the proposed oven provided a minimization of thermal losses as seen in the temperature levels of their external surfaces;
4. The times of baking top of foods tested were superior to those obtained with a conventional gas;
5. The largest contribution to the energy comes from the oven baking concentrated radiation incident radiation in external reflective surface;
6. The solar oven is easy to build, because the composite used in its manufacture is easy workability;
7. The process of assembly and disassembly of the furnace proposed are simple, requiring only prior training;
8. The proposed solar oven is capable of producing food preparation in the period from 9:00 to 14:00 hours, in good solar condition;
9. The manufacturing cost the solar oven offered is around 100 dollars, below the average range for such prototypes between 150 and 300 real, for purposes other than for-profit;
10. Perform tests for various types of food in all seasons to a more real performance of the proposed solar oven.
11. Decrease the internal volume of the oven and test it by comparing their results with the version already studied.

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