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SOLAR COOKER WITH CONCENTRATION PARABLE MADE FROM COMPOSITE PIAÇAVA

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Abstract. *This paper presents a model of solar cooker concentration for cooking food for residential, urban and rural, whose parable was manufactured of composite material that uses the piaçava bark fiber, alternative natural enhancement to polymeric compounds using fiber glass, applied on a ceramics mold. Will be presented thermal parameters of the characterization of the composite and the processes of manufacture and assembly of solar cooker studied. Will be demonstrated the thermal feasibility of solar cooker manufactured and tested and their competitiveness with other solar cookers shown in the literature to solar cooking food and even with a conventional gas. It should be noted that this study has a social connotation important and a core aspect, which is fighting environmental damage provided by the use of firewood, even on a large scale, for the cooking of food.*

Keywords: *solar energy, piaçava fiber composite, solar cooker*

1. INTRODUCTION

The energy in its various forms is essential to the survival of the human species. More than survive, man has always tried to evolve, finding sources and alternative forms of adaptation to the environment in which he lives and meet their needs.

Nevertheless, the increased energy needs of modern society and the importance of the impact of the policy adopted for society and the environment leads us to choose a power supply that can meet the needs of humanity so inexhaustible and serve as a basis for sustainable development.

Several countries are already investing in solar option, since investigating the flow characteristics of radiation that reaches the Earth to the technology required to support in technical and economic terms, the use of this energy. Brazil also participates in this 'race' for future studies, such as evaluating the effectiveness of small solar modules in remote and mapping of solar energy potential in the country, which is indispensable to the establishment of a national policy for the sector .

In this perspective, an application of thermal simplest solar cooker is used to cook food. Your job application is in the rural area of arid and semiarid regions of Brazil where the extraction of firewood for energy thermal assumes significant values. Considering the population in rural northeastern estimated at 17,000,000 inhabitants (IBGE, 2000), the use of solar cooker would represent a significant reduction in the extraction of firewood for cooking food. It is noteworthy that only 30% of this population employ solar cooker, this would mean an annual reduction of 5.37 million meters cubic of wood from Brazilian rainforests.

For the solar cooker can really take its place in society is necessary first of all to spread its use, showing the advantages and disadvantages of their use and the care that he should be released so you can actually operate

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satisfactorily. Therefore, it is necessary to research and development of methods to establish technical and economically viable solutions for the use of renewable resources by sectors most distant from large centers that economically unable to purchase equipment offered by the formal market, remain outside the economic and social development.

The glass fiber widely used for fabrication of prototypes used in solar has a major disadvantage that its unhealthy working. The worker is enough to handle the fibers, with serious consequences for their health. Intend to use a natural fiber that does not offer risks to which the handles.

The purpose of this work is through the availability and prior selection of piaçava bark fiber, preferably residues and by commercial, develop a polymeric composite shell piaçava at low cost, given that these residues are currently burned or thrown in trash.

How applicability intends to demonstrate its feasibility for manufacturing equipment, solar collectors, dryers, stills, cookers and ovens, can also be applied in furniture, shelves, and automotive components. As main application directs the study for making a solar cooker to the concentration for the cooking of food, cooking and baking, to be used mainly in the countryside.

The main features of the solar cooker are designed and built to ease of manufacture and assembly, the low cost and simplicity in handling and monitoring mechanism of direct sunlight. Despite a relatively large area of your weight are not significant and parabolic segments and the structure can be dismantled for easy transportation.

2. REVIEW

2.1. Solar cookers in LMHES

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. The following table shows the history of this line of research in LMHES.

Souza, in 1986, built a solar cooker with the concentration parabola reflector formed by segments of sheet steel. Although the focus of significant temperature studies showed a significant loss of energy concentrated in focus due to a level of absorbency of steel much larger than the mirror, despite its good reflectivity.

Queiroz, in 2005, studied in the Dissertation at PPGEM-UFRN, a solar cooker concentration consisting of four mirror segments constituting a parabola obtained by the use of glass fiber applied on a cast ceramic cooking food intended for residential purposes urban and rural. The mirror of the parable was obtained by use of multiple planes of mirror segments 2 mm thick. We obtained temperature levels equal to those of a conventional oven gas at around 800°C, with cooking times very close to the peak hours of radiation days with very low clouds. It was shown that it is possible cooking of food for two meals for a family of four people.

Lion, in 2007, presented in the Dissertation at PPGEM-UFRN the concentration of solar cooker consists of two mirror segments, forming two semi-parabolas obtained by the use of glass fibers applied over a ceramic mold, intended for food cooking purposes residential, urban and rural. Proved that it is possible to simultaneously cooking food from two different meals for a family of four, with cooking times competitive with other solar cookers shown in the literature to solar cooking food. The maximum temperature of the absorber was about 550 ° C and average around 450 ° C.

Souza et al., in 2008, showed the V CONEM a model of solar cooker concentration used to heat an electric iron for ironing operation, saving up energy. Great importance of this project is to educate the poorest communities in regard to waste energy and increase your income. . 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 were similar to those obtained with the conventional iron plates, confirming their viability.

Souza et al., in 2008, presented at the VI CONEM a solar cooker concentration constructed from a scrap of satellite dish. The solar cooker has extremely low manufacturing cost since it can be built with scrap materials, with the exception of the mirrors that cover the reflective surface of about 0.3 m². The maximum temperature obtained with the solar cooker corresponded to 560 ° C and average temperature for the study period, around 413 ° C, was in the level conducive to cooking. The test was performed for solarimétricas excellent condition. It was noticed that the temperatures reached are extremely significant, but due to the small area of the parable scavenging and reflective of direct solar radiation, the power that reaches the cooking pan prevents adequate amounts of food for a family, necessitating therefore an increase thereof.

Souza et al., in 2009, presented at the 20th COBEM a model of the solar cooker to cook food for concentration, constructed from the use of a urupema (sieve indigenous origin), acquired at the open at a cost of £ 12.00. The main innovation of this work was the use of urupema as a parable reflecting the stove, which facilitates the process of manufacturing and assembling the stove concentration. These processes can be more easily transferred technology to low-income communities, who could use it and / or manufacture it for generating employment and income. The main features of this stove were therefore its low cost and its easy construction and assembly processes. Due to its small catchment area of solar radiation, 0.23 m² The cooked food did not appear feasible, despite having reached a maximum temperature of 337.4 ° C. focus

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Filho, in 2010, presented Master's thesis in PPGEM-UFRN on a solar cooker concentration consists of two parables elliptical reflector made from reused scrap TV antenna of 0.28 m² covered by multiple mirrors 2mm thick mounted on a metal frame made with the reuse of scrap, having a mobility correction of apparent motion of the sun. The tests show that the cooker has reached the maximum temperature of 740 ° C, for boiling water in an average time of 28 minutes, cooking various foods like potatoes, rice and pasta in an average time of 45 minutes and still working as a solar oven , doing the baking pizza and meat. Proved the feasibility of using the stove to cook or bake in two daily meals for a family, still presenting conditions to improve their performance with the addition of new materials, equipment and techniques.

Neto, in 2010, presented Master's thesis in PPGEM-UFRN on a solar cooker with the concentration parabola reflector constructed of composite material. We used a concrete mold with parabolic profile obtained through modeling. The solar cooker concentration main characteristic is its low cost, being produced from a composition of reusable materials, such as cement, gypsum and crushed EPS and tires. Presented catchment area of 1.0 m² and his parable was covered with mirrors segments of 25 cm ². watch to focus better temperature to 650 ° C. Demonstrated the feasibility of this solar cooker for cooking various types of foods such as beans, potatoes, rice, yams and macaroni and can be used in two meals for a family of four.

Souza et al., in 2012, presented at the 20th CBECIMAT better allocation and utilization of waste hair, generated by salons, avoiding their disposal in the environment. It should be noted that the decomposition of hair has an unlimited time, which accentuates the ecological problems arising from disposal at landfills. It was manufactured from a composite grinding waste hair. The matrix of the composite was orthophthalic resin. We constructed a parabola with 0.65 m², used to manufacture a solar cooker concentration. The highest temperature reached in the focus of the parabolic concentration cooker was 401 ° C. The boiling time 1.5 liters of water occurred at 345 minutes and the 250g of pasta cooking in 18 minutes after boiling water. It was demonstrated, therefore suggested the feasibility of the stove for the purpose of cooking food in spite of the small area of the parabola.

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

Figure 1. Solar cookers manufactured and tested in LMHES / UFRN.

2.2. The composite-based piaçava

Meanwhile, the search for alternative sustainable materials has a growing demand to replace the commonly used materials due to growth of environmental problems caused by the use of oil from the oil industry. Consequently, the study of composite materials corresponds to an area of materials science is becoming increasingly widespread.

In this context, the natural fibers are an excellent alternative to synthetic fibers, they have great social and ecological, help create jobs, prevent the rural exodus, are biodegradable, have relatively low cost when compared to synthetic fibers, plus the fact cause less wear on the equipment during processing and manufacture of composites.

Such fibers are abundant in agricultural countries like Brazil, and among the many fibers that have the potential of being used, you can highlight the fibers of palm fiber, which is a natural fiber extracted from various palm trees.

In Brazil, Bahia is responsible for 95% of the total national production. Exploiting piaçaveiras is a purely extractive activity, so there is a need for a rational management for their survival is guaranteed. [Vine, S. G. Apiaçaveira and associated vegetation in southern Bahia, 1997].

The type of piaçava scientifically known as Attalea funifera Mart, found in Bahia, grows well in warm (24 ° C) and always humid (relative humidity above 80%), belonging to the species of palm trees and having the advantage of be impermeable to conserve its elasticity when moistened and form long fibers [Vine, S. G. 1997].

In southern Bahia, are on average until 1670 piaçaveiras per hectare. Moreau, MS Occurrence, management, productivity, and marketing channels piaçaveira in Bahia. Thesis (Ph.D.) - State University of Santa Cruz, UESC, Ba, 1997.

Currently, palm fiber is used in brooms, brushes, ropes for ships, baskets, mats and roofing. It is estimated that the percentage of waste in industries, working with this fiber is about 20%.

One of the main characteristics of palm fiber is its adaptation to low fertility soils and unsuitable for other crops. The collection fiber is made only once, at any time of year. Each foot yields up to 8 to 10 pounds of fiber per year. The lifetime of a piaçaveira is up to 20 years. Once gathered, the fibers are stretched and placed to dry in terraces, and often crimped to obtain a uniform drying. When dry, they are clean and beats so that waste is removed. The product is tied in bundles, and can then be cut when for the specific industry. The fibers reach up to 4 feet long and have about a millimeter thick.

3. MATERIALS AND METHODS

The material was a composite consisting of randomly arranged fibers with average lengths approximately 2.0 cm orthophthalic resin impregnated.

The fibers used as reinforcement in composite originated in the city of Ituberá, the Lower South of Bahia, a major producer of palm fiber. The fibers used are called palm fiber and shell is largely used in the coverage of beach huts. For the manufacture of composite specimens for characterization followed the procedure.

1. Washing the fibers;
2. Drying in solar dryer;
3. Cutting the fibers using a manual cutter for cutting paper, 2 cm length;
4. Treating the fibers with 3% NaOH with soaking for one hour;
5. New solar drying in the dryer;
6. Mixing the fibers and the polyester resin and catalyst;
7. Placing the mixture in a glass mold.

3.1. Characterization of fiber piaçava sludge

The fibers of the dregs of palm fiber were characterized by scanning electron microscopy analysis (SEM), test X-ray diffraction (XRD), thermogravimetry (TG) and differential thermal analysis (DTA).

3.2. Mechanical tests on composites

The mechanical behavior of the composite was determined by the uniaxial tensile test and three-point bend. They were conducted at ambient temperature (25 °C) in an equipment Time Group WDW-300E, see figure 3.6. The specimens (CPs) were cut and the sides sanded and polished according to the techniques of metallography.

The dimensions of the CPs and specifications to perform tests followed the ASTM D3039-00 and ASTM D790-96 for the uniaxial tensile tests and three point bending, respectively.

The mechanical properties of strength, rigidity (modulus) and elongation at break were determined for both tests. In the case of the same elastic moduli were measured before the start of the damage.

3.3. The composite thermal tests

The thermal behavior of the composite was determined through testing differential scanning calorimetric (DSC) and thermal conductivity. We also determined the percentage of water absorption.

3.4. Manufacturing processes and assembly of solar cooker proposed

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Mastered the technique of obtaining the composite broke for the manufacture of the parable of the solar cooker concentration obeying to the following procedures;

1. Design dimensions of the paraboloid - Area - 1.0 m², diameter - 1.14 m, focal length - 0.57 m;
2. Use of the composite fiber and resin blurs the palm fiber for the construction of parabolic orthophthalic - placing a layer of fiber blend of palm fiber sludge orthophthalic resin in a proportion of 10% fiber by weight; positioning the structure of the parabola was obtained in one piece fiber with a high degree of perfection, after the time necessary for a perfect drying of the composite. Before starting the process of making the parabola mold was covered with a plastic undercut to facilitate the composite structure built;
3. Cutting the mirrors - The pieces of mirrors were obtained by cutting a sheet measuring 2 mm thick using a diamond cutting tool;
4. Attachment of mirrors used to contact adhesive to wood and other materials (glue Formica) for fixing the pieces of glass on the surface of the parabola;

5. Fabrication of the structure - the structure of the solar cooker was designed made from scraps. Have movements that permit monitoring of the apparent motion of the sun and its main characteristic is the ease of construction and assembly;
6. Fixing the frame connection between structure and parable using resin orthophthalic;
7. Painting of the structure - the entire structure solar cooker received a painting to protect it from the weather and thus minimize the degradation effects of their exposure to natural phenomena.

Figure 2 shows the constructional details of the structure conceived and built.

Figure 2. Some steps of the manufacturing and assembly of the solar cooker studied.

3.5. Theoretical

According to Figure 3, the process of converting solar energy into thermal energy for achieving passes through several stages as follows:

1. In the first stage the solar radiation is collected by a collection surface and reflected to the stage of absorption and conversion of solar radiation into thermal energy.
2. In the second stage the solar radiation is absorbed and transferred to the working fluid can be water, oil, etc. salts. flowing through appropriate pipes, or simply a heat absorbing element whose yield depends on the format and properties of the material used, for example, emissivity (ε) and the absorptivity (α), which are design parameters that take part limiting.

Schematically, the overall conversion cycle system can be represented in accordance with the diagram of figure 3.

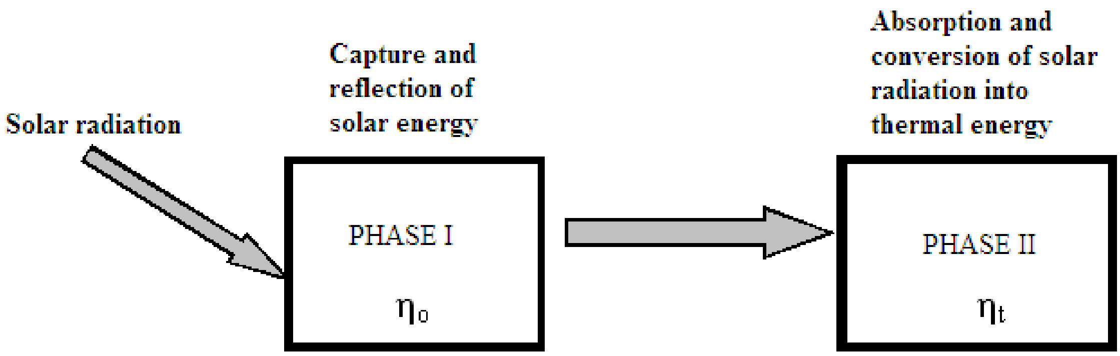

Figure 3. Overall scheme of the process of conversion of solar energy into thermal energy.

As shown in the above diagram is noted that the first phase of the process depends on a factor, the optical efficiency (**η_o**). Depending on the material and the degree of precision that the surface is constructed pickup optical system efficiency represents a variable restrictor on the overall characteristics of the system together with the thermal efficiency ((**η_t**) in the second stage. Another important factor to be considered in any design conversion of radiant energy into another form of energy with respect to the variation of radiation intensity as a function of geographic location and other factors associated with climate, season and atmospheric pollution. However, the useful efficiency of the cycle can be represented by the relationship equation (1):

$$\eta_u = \eta_o - \eta_t \tag{1}$$

According to the configuration of the model, Figure 4 shows a more detailed exemplification in order to better explain what happens in systems that operate according to the concentration and the radiation conversion efficiency of radiant energy into thermal energy. As a first possibility we suggest that thermal losses in the absorber are radiative in nature only, and Figure 4 shows the complete cycle from the same and proceeds to an energy balance of the system.

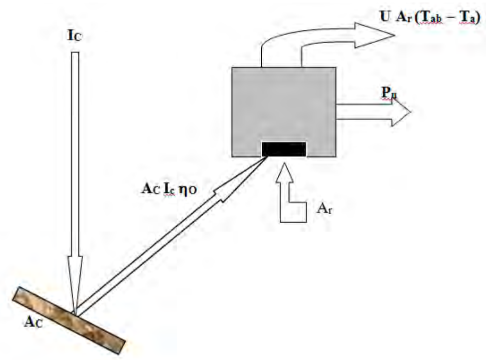

Figure 4. Energy flow-capture system converting solar radiation into heat energy.

where:

P_u - useful thermal power (W), A_c - surface area of solar energy (m^2), I_c - instantaneous radiation collected by the system of solar energy (W/m^2), η_o - optical efficiency of the capture system solar energy; η_t - thermal conversion efficiency, U - total loss coefficient ($W/m^2.\,^\circ C$) - air illuminated area of the absorber (m^2), and T_{ab},Ta - temperature of the fluid in the absorber and the environment (^oC), η_u - useful efficiency of conversion; Ɛ - emissivity of the absorber, σ - Stefan-Boltzmann constant whose value is 5,67 x 10^{-8} W/m^2K^4

Thus, according to the diagram in Figure 4, the power output of the system, (W) is given by the difference between the input power and lost power in accordance with the equation 2:

$$P_{útil} = P_{abs} - P_{perdas} \tag{2}$$

The power absorbed by the pot is given by the equation 3:

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$$P_{abs} = I_c.A_u \rho.k_{rd}.\alpha_p \tag{3}$$

where:

I_c - instantaneous radiation collected by the system of solar energy W/m²; Au - Hub Area (m²), r - Reflectivity concentrator (0.95); krd - fraction of reflected radiation that is absorbed by the pot (0 90); A_p - Absorptivity of the pot (0.85); P_{abs} - Maximum power absorbed by the pot (W)

Considering that radiative loss from the pan to the medium is negligible, the total loss is convective, given by equation (4):

$$\mathrm{P_{perdas}} = \mathrm{h_{ce}} \cdot \mathrm{A_{lp}} \cdot \left(\mathrm{T_{ep}} - \mathrm{T_a}\right) \tag{4}$$

where:

H_{ce}-convection coefficient between the outer surface of the pan and the ambient air (W/m². °C); A_{lp} - side area of the pan (m²); T_{ip} - External temperature of the pan (°C); Tep - Ambient temperature (°C).

The convection coefficient can be given by equation (5) shown below.

$$h_{ce} = \frac{K_{ar}}{L} \cdot C_k \cdot R_{a_L}^n \tag{5}$$

where:

K_{ar} - Thermal conductivity of air (W/m²°C); L - Height of pot (m); $R_{a_L}^n$; - Rayleigh number.

The coefficient Ck and the exponent n depends on the range of Rayleigh number, where: for n = ¼ flow is laminar and n = 1/3 the flow is turbulent.

To find the values of thermal efficiencies, optical and useful (total) using the equations described below 6:

$$P_u = A_c \cdot I_c \cdot \eta_o - h_{ce} \cdot A_p \left(T_p - T_a\right) \tag{6}$$

The optical efficiency (η_O) system is given by the following equation 7:

$$\eta_o = \rho.k_{rd}.\alpha_p \tag{7}$$

The thermal efficiency (η_t) of the system is given by the ratio of useful energy (Qu) and the net flow of energy collected, (**A_c I_c η_o**). is calculated by the following equation 8:

$$\eta_t = \frac{P_u}{I_c \cdot A_c \cdot \eta_o} \tag{8}$$

With respect to the final yield called conversion efficiency (η_U), which is given by the ratio of useful energy (Qu) and the collected energy flow (**A_C I_c**) thus represents the equation 9:

$$\eta_u = \frac{P_u}{I_c A_c} = \eta_o - \frac{h_{ce}}{I_c} \cdot \frac{A_r}{A_c}\left(T_p - T_a\right) \tag{9}$$

So, knowing that the concentration factor (C), is defined as the ratio (Ac) - surface area of solar energy collection and (Ar) - illuminated area of the absorber, we have the equation 10:

$$C = \frac{A_c}{A_r} \tag{10}$$

Therefore, the equation (11) after the substitutions can be written as:

$$\eta_u = \eta_o - \frac{h_{ce}}{I_c} \cdot \frac{1}{C}\left(T_p - T_a\right) \tag{11}$$

Equation (11) has a validity field, which requires some conditions that are described below.

- A concentration factor with high value,

- Index radiation with high value,
- Low loss coefficient,
- Efficiency optics with high value.

It is possible to establish a relationship between the concentration, the temperature and the energy dissipated by radiation in the focus of a hub, for values of (C) that varies in a range of 1: n.

3.6 Testing methods

The tests consisted in measuring the focal temperature, determining the maximum and average values, in the time to boil a liter and a half liters of water in the cooking of some foods and baking a cake.

Meteorological data of solar radiation, temperature, wind chill, wind speed, relative humidity was obtained from a meteorological Central Davis Weather Envoy located in LMHES / UFRN. The temperature data was measured for three days of test with low levels of cloudiness, every fifteen minutes, by measuring the period from 10h to 15h to verify the point of highest temperature in the pan to be placed. We used a pair of cromel-alumel thermocouple attached to a digital thermometer.

4. RESULTS AND DISCUSSION

Table 1 shows the parameters of energy solar cooker studied.

Table 1. Energy parameters of the solar cooker studied.

PARAMETERS	VALUE
Direct solar radiation	800 W
Absorber energy	581,4W
Useful power	552,7 W
Concentration factor	90,9
η_o	0,73
η_t	0,95
η_u	0,69

The values reflect a good optical efficiency, a high thermal efficiency and a significant overall efficiency of the mirror segments of small area produced a uniform mirror surface, adapting the parabolic profile, even if planes and the utilization of the thermal insulation pan absorber. It should be noted that the tests were performed under ideal solar conditions.

The first test performed to assess the ability of the cooking hob study was to determine if the time required boiling a liter of water. This test measured the changes in water temperature minutes every minute until it reaches the boiling point. The global solar radiation average was around 900W/m², the average direct radiation around 720 W/m², ambient temperature of 32°C, the thermal sensation of 36.5°C and relative humidity of 62%. The water was placed in the pan 12:28pm and after placement of the water temperature was 35°C, since the pot was already exposed to the radiation dollar. Table 2 presents the results of this test.

Table 2. Data for boiling a liter of water in the solar cooker studied.

TIME (min)	T_{water} (°C)
0	35,0
2	44,6
4	58,5
6	70,5
8	79,6
10	85,2
12	94,2
14	101,3

Considering that the time for boiling a liter of water in a conventional oven is 8 minutes, it was concluded that the studied cooker has a boiling time 75% larger, but this result is significant and demonstrates the thermal efficiency of the prototype displacer solar fabricated and studied. It is noteworthy that uses a free energy, inexhaustible, widely distributed and environmentally friendly. Compared to other stoves already tested, and shown in the literature Solar for food cooking, the stove studied is very competitive. The comparison of boiling time presented by other solar cookers, always points times around 15-20 minutes, or demonstrates the competitiveness of the stove studied. Table 3 shows the results of this test.

Table 3. Data for boiling a liter of water in the solar cooker studied.

TIME (min)	**Twater (°C)**
0	33
1	41,6
3	49,8
5	59,6
7	63,3
9	71,9
11	77,6
13	82,8
15	87
17	92,3
19	96,1
21	100

Considering that the time for boiling 1.5 liters of water in a conventional oven is 12 minutes. Even having a boiling time much greater than that obtained with the gas stove, the wide feasibility study thermal solar cooker was demonstrated. It is noteworthy that uses a free energy, inexhaustible, widely distributed and environmentally friendly. Compared to other stoves already tested, and shown in the literature to solar cooking food, the stove has studied very competitive. For other solar cookers, literature always points times around 20-30 minutes, or demonstrates the competitiveness of the proposed stove. Figure 5 shows the solar cooker manufactured in the boiling water test.

Figure 5. Solar cooker proposed test for boiling water.

The following table shows the average values of temperature obtained at the bottom of the pan empty "without water", during the three tests climatic conditions substantially identical. These values are also shown in graphs for analysis of the behavior assumed by such parameters in the days of the tests where you can have a clearer idea comparative to the days of testing.

Table 4 shows the average results of tests for the determination of the temperature focus of the solar cooker studied.

Table 4. Average data of tests to determine the temperature in the focus of the solar cooker studied.

TIME (HOUR)	**T_{foco} (°C)**	**$T_{foco\ max}$ (°C)**	**I (W/m²)**	**I_d (W/m²)**
08:00 – 9:00	**350**	**405**	**650**	**520**
09:00 – 10:00	**425**	**458**	**823**	**658,4**
10:00 - 11:00	**487**	**501**	**917**	**733,6**
11:00 - 12:00	**514**	**530**	**981**	**784,8**
12:00 - 13:00	**505**	**512**	**965**	**772**
13:00 - 14:00	**485**	**503**	**906**	**724,8**
14:00 - 15:00	**420**	**456**	**753**	**602,4**

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Temperature levels achieved in the focus of solar cooker tested were quite significant, with an average maximum temperature in the focus of pan 480.7 and 455.1 average. The maximum temperature reached in the focus of the solar cooker was 615 ° C. This temperature was lower than other already obtained with other stoves manufactured and tested in LMHES / UFRN, but is explained by largest focus area for the stove studied due to the greater area of each mirror which formed the parable.

Despite this level of lower temperature, the cooking times were similar, because a larger area of the bottom of the pot was struck by the rays from the parable which led to a more distributed energy in the absorber, providing good result. It should be noted that the tests were performed under excellent solar conditions.

To finalize the proposed tests with the stove held trials cooks foods that constitute a basic meal typical of northeastern Brazil. We cooked the following foods: rice, pasta, meat, cassava and fish stew. rice, pasta, meat, fish and cassava.

The first food rice tested was in the amount of 500 grams. The pan was placed a quantity of water corresponding to 1.5 liter. The test for cooking rice began the 11:05 hours under optimum conditions solarimétricas. After boiling of water in 20 minutes, the rice was put in the pot and after a further 14 minutes gave the cooking of the food. The total time for the cooking of rice was 34 minutes.

Considering that the time for boiling a half liters in a conventional oven gas is 12 minutes and in 25 minutes preparing 500 g of rice, one realizes the good performance of the proposed solar cooker. Figure 6 shows the rice already cooked in the solar cooker studied.

Figure 6. Rice cooked in solar cooker proposed.

The second feed was tested in the pasta quantity of 250 grams. The pan was placed a quantity of water corresponding to 1.5 liters. The test for cooking began the 11:46 solarimétricas under excellent conditions. After the boiling water about 20 minutes, the pasta was placed in the pan after 11 minutes gave the cooking of the food.

Considering that the cooking time for the pasta in a gas is 25 min, the results achieved with a solar cooker study is significant, since with no energy expenditure and uses a clean, inexhaustible and widely available. After thorough cooking was also made in the cooking hob of a tomato sauce and added to the macaroni. Figure 7 shows the already cooked pasta and sauce added.

Figure 7. Pasta cooked in solar cooker studied.

The third test food was cassava, in the amount of 1,000 grams. The cassava was peeled for cooking. The amount of water placed in the pot was 1.5 liters. The test was performed with excellent solarimétricas. Room temperature was approximately 31.5 ° C.

After boiling water about 20 minutes, the cassava was placed in the pan and after 25 minutes gave up your cooking. Considering that the cooking time for cassava on a gas stove is 35 min, the result achieved with the solar cooker studied is significant. Figure 8 shows the cassava cooked in solar cooker fabricated.

Figure 8. Cassava cooked in solar cooker fabricated.

The fourth test food is meat, in the amount of 800 grams. The meat was cooked directly in the form of added stewed tomatoes, onions, garlic and green seasoning. The test was performed with excellent solarimétricas and began at 11:58. Room temperature was approximately 31.5 ° C. The cooking time was 50 minutes.

Considering that the cooking time for meat on a gas hob is 40 min, the result achieved with the solar cooker demonstrates its good thermal efficiency and feasibility of its widespread use. Figure 9 shows you meat cooked in the solar cooker tested.

Figure 9. Meat cooked in the solar cooker tested.

The fifth one was tested food fish stew, in the amount of 1.000 grams. The fish was cooked directly in the form of added stewed tomatoes, onions, garlic and green seasoning. The test was performed with excellent solarimétricas and began at 11:34. Room temperature was approximately 31.5 ° C. The cooking time was 36 minutes. Was also prepared one had shrimp stew cooking time like that relating to fish.

In a conventional oven gas cooking time of stew would be around 30 minutes. The solar cooker built and tested is competitive with the solar cooker gas and more with other solar cookers to the concentration already tested in LMHES and worldwide. Figure 10 shows the stew cooked in solar cooker tested.

Figure 10. Fish stew cooked in solar cooker studied.

The baking food is always operated in gas furnaces or solar. In an unprecedented way it was used in the solar cooker solar oven function to produce the baking of a cake. Depending on the temperature in the focal region is too high, the pan for baking the cake was comprised of two pans that have mated. The cake was placed inside the pan and was in the form of handling five minutes to avoid burning food by excessive exposure to high temperatures.

The sixth test food was a chocolate cake industrialized, wherein the prepared dough was placed in a rectangular shape, with a mass of about 700 grams. The test was performed with excellent solarimétricas and began at 11:08. Room temperature was approximately 31.5 ° C. The baking time was 50 minutes. That time is competitive even with the gas stove with baking time for this food between 45-50 minutes. Figure 11 shows the baked cake in the solar cooker tested.

Figure 11. Process of baking a cake in the solar cooker proposed.

The Table 5 shows the results of all the cooking times for all foods tested and times relating to solar cookers have tested and conventional oven gas.

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Table 5. Comparison between the cooking times of conventional and alternative solar cookers.

FOOD	MASS (g)	COOKING (min)	COOKING SOLAR COOKERS (min)	COOKING GAS OVEN (min)
RICE	500	34	30 a 40	25-30
NOODLES	250	31	30 - 40	20-25
CASSAVA	1000	45	45 a 55	30 a 35
MEAT	800	50	50 a 60	35 a 40
MOQUECA	1000	36	55 a 45	20 a 25
CAKE	700	50	50 a 80	35 a 45

All foods tested in the solar cooker studied showed competitiveness, and often supremacy over other stoves manufactured in UFRN and shown in relation to the solar literature.

The times obtained for cooking were always higher than those obtained with a conventional gas, but for some foods the times were very close. It should be noted that the use of solar cookers and contribute to a policy of using new energy sources, bringing alternatives to the Brazilian energy matrix, eliminating the use of harmful wood, can also help trim a source of generating employment and income for poorest communities through the construction and marketing of such stoves.

The use of a clean and can be used in a decentralized manner by the poor population would be the main component of the prototype implementation working with the solar conversion of solar energy into thermal energy.

5. CONCLUSION AND SUGGESTIONS

1. The proposed solar cooker was feasible for the purpose of cooking food, and can bring substantial savings and minimize attack problems of ecology, with regard to deforestation for firewood use;
2. The process of assembling and disassembling the stove proposed are simple, requiring only prior training;
3. The stove has proposed cooking capacity in the period from 8 to 15 h, in good condition solarimétricas;
4. The cooking times of foods tested are competitive with the cooking times in the literature for solar cooking food;
5. The solar cooker study showed also feasible to produce the baking of food, and may be controlled by the distance of the pot relative to the focal point, or using dual pan;
6. The solar cooker offers cost-effective when compared to a gas stove and one wood stove.
7. The composite base of palm fiber and resin orthophthalic was suitable for the manufacture of the parable absorbing and reflecting solar energy with good quality standard;
8. The composite processability has studied much more appropriate than the glass fiber which causes damage the health of the handler.

6. REFERENCES

DUFFIE, J.A., BECKMAN, W.A., **Solar Engineering of Thermal Processes**, New York, John & Sons, 1991.

FILHO, R.E.B.R., Análise de desempenho de um fogão solar construído a partir de sucatas de antena de tv, Dissertação (Mestrado em Engenharia Mecânica) Programa de Pós Graduação em Engenharia Mecânica, Universidade Federal do Rio Grande do Norte, Natal, 2011.

LION F., Carlos Alberto Pereira de Queiroz, Construção e análise de desempenho de um fogão solar à concentração utilizando dois focos para cozimento direto, Dissertação (Mestrado em Engenharia Mecânica). Departamento de Engenharia Mecânica, Programa de Pós-Graduação em Engenharia Mecânica, Universidade Federal do Rio Grande do Norte, Natal, 2007.

NETO, M.C.M., Análise de desempenho de um fogão solar com parabola fabricada em material compósito **,** Dissertação (Mestrado em Engenharia Mecânica) Programa de Pós Graduação em Engenharia Mecânica, Universidade federal do Rio Grande do Norte, Natal, 2011.

QUEIROZ, William Fernandes, Construção de um fogão solar à concentração para cozimento direto e indireto. Dissertação (Mestrado em Engenharia Mecânica) Departamento de Engenharia Mecânica, Programa de Pós-Graduação em Engenharia Mecânica, Universidade Federal do Rio Grande do Norte, Natal, 2005.

ISSN 2176-5480

SOUZA, L. G. M. et al. **Bifocal Solar Cook for Direct Cooking**, 9th International Conference on Sustainable Energy Tecnologies. Anais da 9th International Conference on Sustaintable Energy Tecnologies, v. 1, p 1-8, 2010.

SOUZA, L. G. M. et al. Solar Cooking Built in Composite Material. 20th COBEM, Gramado-RS, 2009.

SOUZA, L. G. M.; RAMOS FILHO, R. E. B. et.al. **Fogão solar com parábola reciclável de antena.** VI CONEM 2010, Campina grande – PB.

SOUZA, L.G. M. RAMOS FILHO, R.E. B. et al. **Construction and Evaluation of the Performance of a Concentration Solar Cooker Using Urupemas as Parable Reflector**. 20th COBEM, Gramado-RS, 2009

SOUZA, L.G.M et.al. **Bifocal Concentration Solar Cook for Direct Cooking**. 19th COBEM, Brasília, UNB, 2007.

SOUZA, L.G.M.; QUEIRÓS, W.F. **Optimization project of the construction and efficiency analysis of a solar cook for food cooking**. 18th COBEM, Ouro Preto, MG, 2005.

7. RESPONSIBILITY NOTICE

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