CONSTRUCTION AND EVALUATION OF THE PERFORMANCE OF A CONCENTRATION SOLAR COOKER USING URUPEMAS AS PARABLE REFLECTOR

Luiz Guilherme Meira de Souza, lguilherme@dem.ufrn.br
Universidade Federal do Rio Grande do Norte – Natal/RN

Ricardo Eugênio Barbosa Ramos Filho, **ricardoeugeniofilho@yahoo.com.br**
Universidade Federal do Rio Grande do Norte – Natal/RN

Iverton Rodrigo Barbosa Gomes – ivertonufrn@yahoo.com.br
Universidade Federal do Rio Grande do Norte – Natal/RN

Aldo Paulino de Medeiros Júnior - aldo.paulino@yahoo.com.br
Universidade Federal do Rio Grande do Norte – Natal/RN

Aroldo Vieira de Melo –aroldovmelo@hotmail.com
Universidade Federal do Rio Grande do Norte – Natal/RN

Luiz Guilherme Vieira Meira de Souza – lguilherme_souza@hotmail.com
Universidade Federal do Rio Grande do Norte – Natal/RN

Abstract. *The present project is about a concentration solar cooker composed of one urupema as parable inserted in a dismountable PVC structure that has mobility of movements for apparent solar correction. The urupema has a surface with several mirror pieces with 2 mm of thickness made through of cuts, using professional diamond. Your diameter is near 54 cm, with 10 cm of depth and 0,23m² of surface area. The main characteristic of the present cooker is the possibility of cooking foods in a focal region using an artesian object founded in popular marked, became easy the access for the population. Moreover it's a cheap structure because of the urupema and PVC softly. The other advantage is your practice construction so the parable not needs to be made. This kind of cook has a primordial aspect of use viable renovable clean energy for the society, opposing of the damage ecologist by utilization in scale large of firewood for cooking foods. Some care should be used for the preparation and utilization of the cooking with the sun rays and the cut of the mirror. Preliminary tests had shown the viability of the considered cooker for the attainment of temperature levels in the focal region around 300°C. It will be presented the cooking times for some types of foods showing its competitiveness with the cooks that uses conventional gas and the firewood. This cooker will can cook foods twice for day to a four people family.*

Keywords: keyword 1, keyword 2, keyword 3 *urupema, concentration solar cook, alternative reflective parable, food cooking, low cost.*

1. INTRODUCTION

The burning of firewood for cooking of food is 29.3% of the total wood produced, which equates to 26,564 x 103 tons, once within the Brazilian residential energy matrix, this value is 38% for data 2005 (National Energy Balance, 2006).

Overall, the burning of firewood for cooking foods reached 2.5 billion of people, which 23 million are Brazilian (World Energy Outlook, 2006). The use of firewood for cooking inside home leads to death of 1.6 million of people due to pollution indoor environments (World Health Organization, 2005).

The wood 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 (National Energy Balance, 2006).

About 40% of firewood produced in Brazil is transformed into charcoal. The residential sector consumes more firewood (29%), after coal industry. Usually it is for cooking food in rural areas. A eight people family requires approximately 2.0 m³ of wood per month to prepare their meals. The industrial sector comes after with about 23% of consumption. The main consumers industries of firewood in the country are from food and beverages, ceramics and paper.

These data show the massive use of wood, putting at risk the planet health, suggest the need for a politic of mass for use of solar cooker for cooking foods as a way to preserve the nature and even mitigate the ecological imbalance by indiscriminate use of firewood, beyond minimize the emission of pollutants gases to the atmosphere.

The use of solar energy for cooking and roasting foods is one of the oldest and most widespread applications of this energy source, and has as main characteristic social function. In northeastern backlands affected by drought, the country person suffer wiht hunger and thirst due to the severity of the sun on their land arid. The use of stoves / ovens in the solar drylands promises reverse or at least soften it allowing to country person a better life condition.

Taking advantage of the energy that comes from the sun, the stove / oven converts solar radiation into heat for the preparation of food, reducing the effort of the swing in search of firewood, and also contributing to the preservation of nature, enabling the increase in removing carbon dioxide from the atmosphere and reducing the concentrations of this greenhouse gas.

In LMHES (Laboratory of Hydraulic Machines and Solar Energy) has been built several generations of solar stoves and ovens, using conventional and alternative materials. This paper presents a model of the solar concentration cooker to cook food, built from the use of urupema (sieve of indigenous origin), acquired at the fair free to the cost of $ 12.00. Will be present the process of manufacture and assembly of the solar cooker that uses this parable already defined.

The stove is a proposed prototype solar average concentration of working with the concentration of rays incident on the parabolic reflector in a region called off focus and is intended for domestic use in rural and urban areas in the period from 9:00 to 15:00 hours.

The main innovation of this work was the use of parabolic reflector urupema as the stove, which facilitates the processes of manufacture and assembly of the stove to the merger. These processes can be passed technologically easier for low-income communities, which could use it and / or making it to generate employment and income.

2. STATE OF THE ART

Facing the world scene that global warming is fact, due to continuing emissions of carbon dioxide and methane in the Earth's atmosphere, many studies and debates have been conducted around the world, targeting to mitigate the factors that influence the overall environmental impact.

In CONEM IV (National Congress of Mechanical Engineering) performed in Belém - Pa, in 2004, Souza et.al. published a paper on the use of a solar cooker adjusted concentration for use in camping and rural communities, for cooking of foods .

In the 18th COBEM - International Congress of Mechanical Engineering, Ouro Preto - MG, 2005, Souza et. al., published an article under project Optimization of the constructions and efficiency analysis of a solar cook for food cooking, which studied a solar cooker for cooking the concentration of food.

In CONEM V - Mechanical Engineering Congress permformed in Recife - Pe, in 2006, Souza et.al., published a paper about the use of a alternative solar cooker with a low cost, object of this work, for the operation of roast foods.

In the 19th COBEM - International Congress of Mechanical Engineering, Brasília-DF, 2007, Souza et. al., published an article about Bifocal concentration solar cook for direct cooking, about the results of a solar cooker of two focus for cooking foods, comparing its results with those obtained by conventional concentration solar cooker with one focus

In the international sphere, the Solar Energy Spanish Association and the Society Solar Energy promoted in Vigo, Spain, in June 2008, the XIV Congreso Ibérico and IX Congreso Iberoamericano de Energia Solar, in which researchers from around the world, presented the following works about the use of box type solar cookers:

- Analysis of reducing carbon dioxide emission from the replacement of firewood by the use of box type solar cooker (Neto, JGC et. Al.)
- Designing the building of an experimental solar cooking school in Sergipe (Teixeira, OA, et. Al.)
- Low-cost solar cooker using a tire as base (Souza, LGM et.al.);
- Solar cooker for low income population in Brazil - Vital Brazil, OA et. al.)
- La cocina solar tolokatsins 3 - Ricon, EA, Lentz, EA
- Cocinas solar, the models of transfer - Chile and Portugal (Serrano, RP; Ruivo, CR).

Bodies such as UNESCO develop and finance projects aimed at the use of solar cookers in African countries like Zimbabwe and Kenya.

In Kenya, the Solar Cooking International (SCI) funded a program that allowed the purchase of solar cookers for over 15,000 families living in refugee camps. A program of building solar cookers in Peru uses the workforce of 100 children providing assistance to families in health and education.

Concentration solar cookers are used in real situations, in various parts of the world as seen in Figure 1.

Figure 1. Several types of concentration solar cookers in use worldwide such as USA figure a, b, c, d, f and g; Quênia: figure h; Índia: figure I; and Brasil: figures j and k both produced in LABSOLAR UFRN.

3. MATERIALS AND METHODS

The concentration solar cooker studied was constructed from an urupema acquired by the public market only $ 6.00, avoiding the construction of a mold and a parabolic surface. The urupema diameter measured was 0.54 m with an area equivalent to 0.23 m². Figure 2 shows the urupema used for the manufacture of concentration solar cooker.

Figure 2. Urupema used for the manufacture of solar cooker studied from popular marked in Natal.

For the construction of the proposed solar cooker were used the following procedures:

1. Application of polyester resin on urupema surface to increase its rigidity;
2. Cutting of mirrors to form the reflector surface - used a pattern segment, composed of 36 segments of mirrors. The number of segment was ten . Was used a professional diamond tool for the cutting of mirrors.
3. Setting of the mirrors - was used contact glue for wood and other materials for fixing the pieces of mirror on the parabola surface.
4. Construct the structure - the structure of the solar cooker was constructed using PVC pipes and connections. It has a turntable structure for follow the apparent movement of the sun and has main characteristic the ease of construction and assembly.
5. Painting of the structure - the structure of the solar cooker was a painting to protect it from the weather and thereby minimize the effects of degradation of their exposure to natural phenomena.
6. Lateral coating of the absorber pot by composite material for minimization of thermal losses.

It was carried tests with the prototype built for determinate the maximum temperature reached in the focus, where the pot was located in the focal region, after guide by the apparent sun movement. It was not performed an ideal number of tests for measuring the temperature and estimate the cooker performance by cooking food, due to the weather inadequate conditions on the last two months in our city. Intend present on the final review of work more data with show a best performance of alternative concentration solar cooker.

The data of solar radiation were measured using a radiometer built at the LMHES UFRN, coupled to a digital multimeter. The data of temperature were measured with a thermocouple attached to a digital thermometer as can see at Figure 3.

Figure 3. Solar cooker at test in LMHES/ UFRN.

According to Figure 4, the process of converting solar energy into heat energy, to achieve is through some stages, (QUEIROZ, 2005), as follows:

1. In the first stage the solar radiation is captured by a collection of surface and reflected by the stage of absorption and conversion of solar radiation into heat energy.

2. In the second stage the solar radiation is absorbed and transferred to the working fluid can be water, oil, salt etc. It circulates through pipes appropriate, or simply an absorber whose income depends on the shape and thermal properties of the material used, such as the emissivity (ε) and absorption measure (α) that are design parameters which has limiting role.

Schematically, the system conversion cycle can be represented according with the diagram in Figure 4

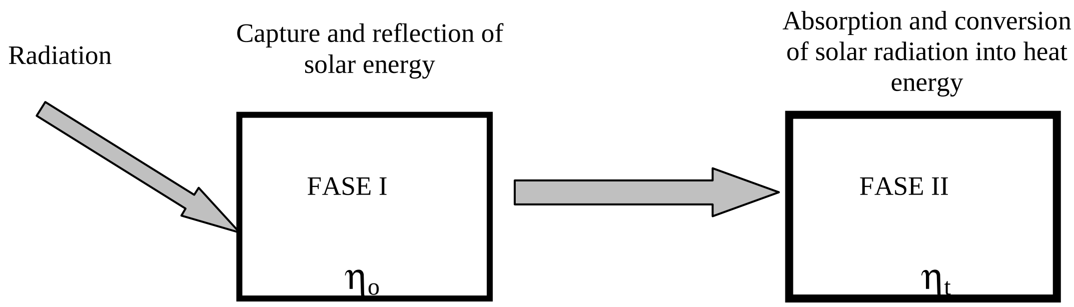

Figure 4. Overall scheme of the process of converting solar energy into heat energy.

As shown in the diagram above is noted that the first stage of the process depends on a factor, the optical efficiency, **(η_o).** Depending of the material and the accuracy degree that is built the capture surface of the optical efficiency system is a variable with the limiting characteristics of the overall system results jointly with the thermal efficiency, **(η_t)** in the second phase of the process. Another important factor to be considered in any project of radiant energy by conversion into another form of energy relates to the variation of radiation intensity on the basis of geographical location and other factors associated with weather, time of year and air pollution.

However the useful efficiency of the cycle can be represented through the relationship, equation (1):

$$\eta_u = \eta_o \cdot \eta_t \quad (1)$$

The optical efficiency (η_o) of the system, is given by the following equation (2):

$$\eta_0 = \rho . k_{rd} . \alpha_p \quad (2)$$

The thermal efficiency, (η_t) the system is given by the ratio between the useful energy (Q_u) and net flow of energy collected, **($A_c I_c \eta_o$).** Thus such as the equation (3):

$$\eta_t = \frac{Q_u}{I_c \cdot A_c \cdot \eta_0} \tag{3}$$

The factor of concentration (C) is defined as the ratio of (A_c) - the surface area of solar energy collection and (A_r) – illuminated area of the absorber, according to the equation (4):

$$C = \frac{A_c}{A_r} \tag{4}$$

The useful power of the system in (W), is given by the difference between the absorbed power and lost power, according to the equation (5):

$$P_{útil} = P_{abs} - P_{loss} \tag{5}$$

The power absorbed by the pot is given by the equation (6):

$$P_{abs} = I_c \cdot A_u \cdot \rho \cdot k_{rd} \cdot \alpha_p \text{ or } P_{abs} = I_c \cdot A_u \cdot \eta_0 \tag{6}$$

Where:

I_c - instantaneous radiation collected by the system to capture solar energy W/m2
A_u - Useful area hub. (m2)
r - Reflectivity of the concentrator (%)
k_{rd} - Fraction of reflected radiation that is absorbed by the pot (%)
a_p - Absorptivity of the pot (%)
P_{abs} - Maximum power absorbed by the pot (W)

Considering that radiative loss of the pot to the medium is negligible, the total loss is convective give for equation (7):

$$P_{loss} = h_{ce} \cdot A_{lp} \cdot (T_{ep} - T_a) \tag{7}$$

Where:
h_{ce} -Convection coefficient between the external surface of the pot and the ambient air. (W/m². °C)
A_{lp} - Area side of the pot (m²)
T_{ip} - Temperature outside of the pot (°C)
T_{ep} - Ambient Temperature (°C)

The convection coefficient can be given by equation (8), shown below.

$$h_{ce} = \frac{K_{ar}}{L} . C_K . R_{a_L}^n \tag{8}$$

Where:
K_{ar} - thermal conductivity of air (W/m². ° C).
L - height of the pot
$R_{a_L}^n$ - Number of Rayleigh

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

4. RESULTS AND DISCUSSIONS

Using equating described in the previous chapter it was estimated the parameters which diagnose the efficiency of a solar cooker, as the next procedure.

4.1. Determination of the maximum thermal power absorbed by the pot

Through eq. (6) the maximum power which is absorbed by the pot from the following data:
- $I_c = 600$ W/m^2
- Au = 0.23 m^2
- $\rho = 0.95$
- $K_{rd} = 0.90$
- $\alpha p = 0.9$

Replacing it the values in equation (3), below, are:

$$P_{abs} = 106.2W$$

4.2. Determination of useful power

The power loss is calculated by eq. (7), showing the amount $P_{loss} = 33.9W$
The useful is power calculated by eq. (5), having a corresponding value:

$$P_{useful} = 106.2W - 33.9W = 72.3W$$

4.3. Determination of concentration factor

By eq. (10) calculate the concentration factor by using A_c = 0.23 m² and A_{focus} = 0.002 m² resulting in C = 115

4.4. Determination of optical efficiency.

$$\eta_0 = \rho . k . \alpha_p = 0.95 \times 0.9 \times 0.9 = 0.77$$

4.5. Determination of thermal efficiency

$$\eta_t = \frac{P_u}{I_c \cdot A_c \cdot \eta_0} = \frac{72.3}{600 \times 0.23 \times 0.77} = 0.68$$

Emphasized were neglected the absorber thermal losses by radiation, according the same be being covered with a composite insulator.

4.6. Determination of useful efficiency

$$\eta_u = \eta_o \cdot \eta_t = 0.77 \times 0.68 = 0.52$$

The values reflect a good optical efficiency, high thermal efficiency and a significant overall efficiency of the mirror segments of the small area which produced a uniform mirror surface, adapting to the urupema parabolic profile, although there are plans and needed use a thermal insulation in Pot absorber.

The maximum theoretical temperature obtained by the solar cooker for two days tested was 337.4 ° C. Table 1 shows the average temperature of the absorber for a day of testing and present the test results to evaluated the temperature of the solar cooker absorber surface studied and the graphs of Figure 5 and 6 shows the behavior assumed by these parameters. The solar cooker was put in solar exposure from 09:00 hours.

Table 1. Time of heating of the pot in function of the absorbed temperature and direct solar radiation.

Time (Hour)	T absorber (°C)	Direct solar Radiation (W/m²)
09:15	132,5	544

09:30	202,2	560
09:45	215,2	560
10:00	225,3	568
10:15	235,1	568
10:30	249,2	576
10:45	250,5	576
11:00	261,3	584
11:15	272,2	592
11:30	281,1	600
11:45	291,2	600
12:00	301,4	600
12:15	311,1	600
12:30	319,8	600
12:45	337,4	600
13:00	327,7	584
13:15	331,2	592
13:30	313,5	584
13:45	291,2	560
14:00	282,5	560

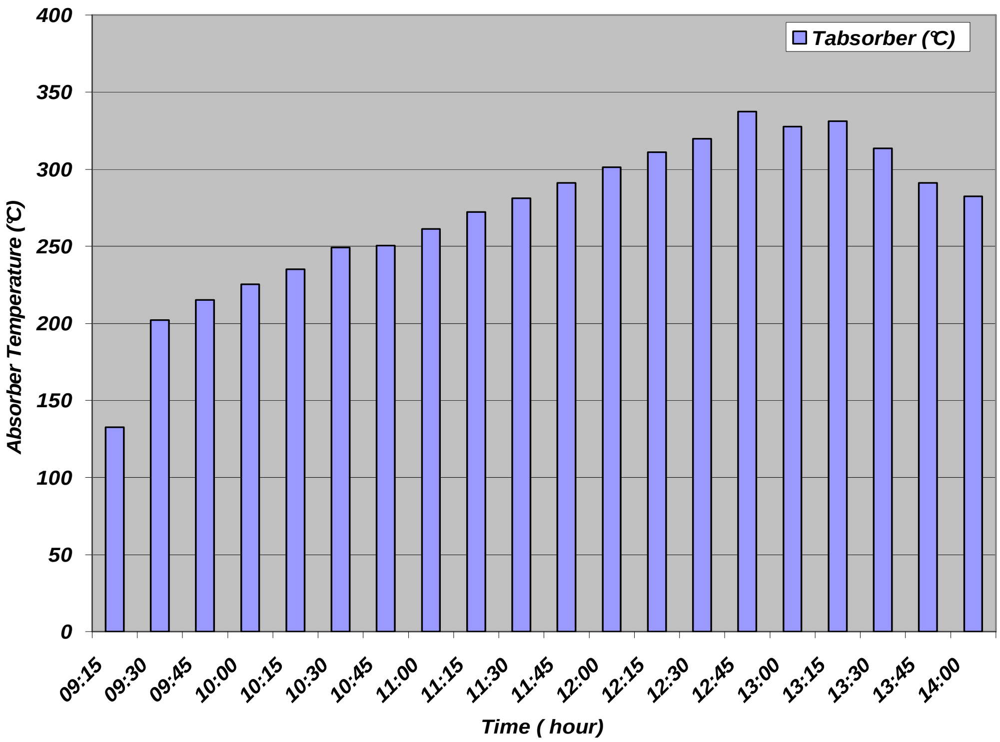

Figure 5. Behavior of the absorber temperature in function of the time.

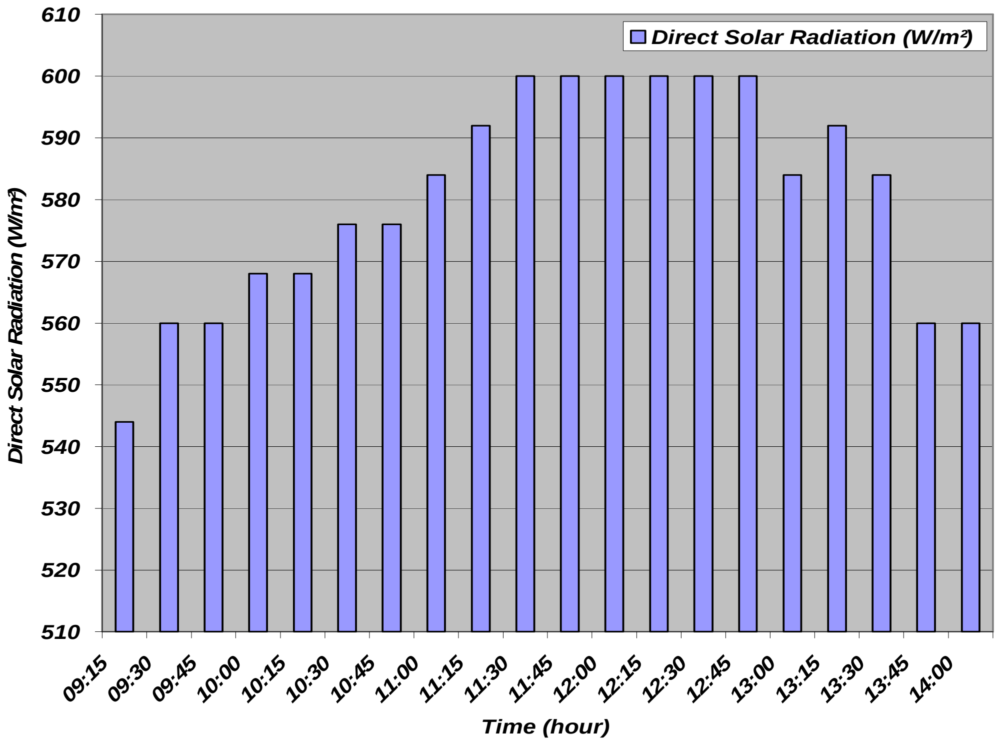

Figure 6. Behavior of the direct solar radiation in function of the time.

Table 2. Data average of the absorber temperature of the solar cooker in test.

TIME (Hour)	**Tabsorber (°C)**	**Direct Solar Radiation (W/m²)**
9:00 – 10:00	193,8	558,1
10:00 – 11:00	244,28	574,4
11:00 – 12:00	281,44	595,2
12:00 – 13:00	319,48	596,8
13:00 – 14:00	309,22	576,0
AVERAGE	269,6	580,1

The maximum temperature obtained with the solar cooker corresponding to 337.4 ° C being significant, to provide itself cooking of foods. The average temperature for the period studied, about 270.0 ° C, was also in the level conducive to cooking. The test was conducted at excellent solar conditions, with maximum direct radiation of 600W/ m² and a minimum of 558.0 W/m², with a variation of only 7.0%, which indicates nearly constant levels of radiation.

Initially was intended a solar cooker with two urupemas with a single focus. However due to focus of each urupema be very low it was not possible to handle it. The tests were made with only a urupema for a preliminary assessment, although it was imagined that because of its small catchment area and the reflection of direct solar radiation, temperatures of focus did not reach significant levels.

Bespeak a local craftsman to construct an urupema of 1.0 meters, to get a cooker built with much higher levels of temperature, capable of providing the cooking of food with more viability.

Emphasized the operations of the cooker studied were not operated according to the period of great solar instability in our city, when the end of its construction. It is expected the final correction of this work may be performed such tests and submit their results.

5. CONCLUSIONS AND SUGGESTIONS

Then, in line with these targets can be assumed to agree with the data obtained that:

1. The proposed solar cooker is feasible for the purpose of cooking food, can bring substantial economic and minimize problems in attack on ecology, especially as regards the use of deforestation for firewood;
2. It is easy to construct once it does not require the construction of parable in structure and was made of PVC, extremely easy to operate;
3. The processes of assembly and disassembly of the proposed cooker is simple, requiring only a previous training;
4. The size of various mirrors segments making up the parabola reflector was essential to obtain a temperature of greater focus;
5. The cooker is capable of cooking proposed in the period from 9 to 15 hours, in good solar conditions;
6. The cost of manufacture of the stove is proposed around 25 dollars, is well below the average range for such prototypes between 75 and 150 dollars, not intended for profit;
7. The support structure of the cooker needs to be optimized to allow greater stability in the operation of tracking to follow the apparent movement of the sun;
8. Use of an urupema with a larger diameter, facilitating the cooking of food, reducing the time for it to get ready;
9. Use of a structure with two urupemas in the same focus from increasing the focal length of the same
10. Multifocal build a stove that has the ability to cooking food for four at the same time;

6. REFERENCES

BEZERRA, A.M. Aplicações térmicas da energia solar,Editora Universitária – UFPB, 221 p. João Pessoa, 2001.

GIL, M. C.; SANTOS, A.C., Energía solar térmica de baja temperatura, CENSOLAR(Centro de Estudios de la Energia Solar), PROGENSA, Sevilla, 2001.

CENSOLAR, Cocinas Solares, CENSOLAR(Centro de Estudios de la Energia Solar), PROGENSA, Sevilla, 2001.

SOUZA, L.G.M, MELO, A.V., Fogão solar alternativo tipo caixa a baixo custo**,** V CONEM – Congresso Nacional de Engenharia Mecânica, Recife-Pe,2006.

SOUZA, L.G.M, QUEIRÓS, W.F., Optimization project of the construction and efficiency analysis of a solar cook for food cooking, 18 COBEM, International Congress of Mechanical Engineering, Ouro Prteo, MG, 2005.

INCROPERA, F.P., Dewitt, D.P., Fundamentos de Transferência de Calor e de Massa, Guanabara Koogan, 4ª edição, Rio de Janeiro, 2003.

VARELLA, F.K.O.M., Tecnologia solar residencial: inserção de aquecedores solares de água no Distrito de Barão Geraldo – Campinas, Dissertação de Mestrado da Faculdade de Engenharia Mecânica da UNICAMP, Campinas-São Paulo, 2004.

FILHO**,** J.R.S., **Projeto, construção e levantamento de desempenho de um concentrador solar cilíndro parabólico com mecanismo automático de rastreamento solar,** Dissertação de Mestrado do Programa de Pós-Graduação em Engenharia Mecânica da UFRN – Natal/RN, 2008.

LION, C. A. P. Q.**, Construção e análise de desempenho de um fogão solar à concentração utilizando dois focos para cozimento direto**, Dissertação de Mestrado do Programa de Pós-Graduação em Engenharia Mecânica da UFRN – Natal/RN, 2007.

MELO, A. V. Q.**, Projeto, construção e análise de desempenho de um forno solar alternativo tipo caixa a baixo custo.** Dissertação de Mestrado do Programa de Pós-Graduação em Engenharia Mecânica da UFRN – Natal/RN, 2008.

SOUZA et.al., ***Bifocal concentration solar cook for direct cooking***, 19th COBEM – International Congress of Mechanical Engineering, Brasília– DF, 2007.

SOUZA et.al., ***Forno solar de baixo custo utilizando como elemento base um pneu usado***, XIV CONGRESO IBÉRICO Y IX CONGRESO IBEROAMERICANO DE ENERGÍA SOLAR, España, 2008.

7. RESPONSIBILITY NOTICE

The author(s) is (are) the only responsible for the printed material included in this paper.