EVALUATION OF THE EFFICIENCY OF A SOLAR BOX COOKING MADE BY RECYCLABLE MATERIAL

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Abstract. *Solar cooking can be used in remote areas where there is not availability of gas for conventional cooker. The wood cooker constantly consuming material to work. The advantage of solar cooker is that it need not matter to consumption and can be installed in the space of a conventional cooker. In this paper, a cooking was made with recycled material and evaluate their efficiency over time. The useful efficiency is the ratio of direct solar radiation by the rate of heat that heats a water container inside the cooking. The rate of solar radiation varies with time of day and his efficiency also varies with the time. An energy balance in cooking was made and were determined the parametes with high influence. The lost power convective and radiative are the most influency the accurancy of results.*

Keywords*: solar cooker, box cooker, efficiency*

1. INTRODUCTION

The major problems of world community are the degradation to the ozone layer and the Global warming. Since the 1980's happens discuss global climate change in the international sphere and a series of events began with the Toronto Conference on the Changing Atmosphere, Canada (October 1988). The IPCC's First Assessment Report in Sundsvall, Sweden (August 1990) was created. The IPCC (Intergovernmental Panel on Climate Change) is an indicator of climate change as a statistically significant variation in a parameter mean climatic and his variability. In June 1992 happened at Rio de Janeiro, Brazil, the Convention Nations Framework Convention on Climate Change (UNFCCC) on ECO-1992. In 1997, the United Nations created The Kyoto protocol, an international treaty with more stringent commitments to reduce gases emissions that exacerbate global warming. The world efforts are to appropriate utilization of source energy, reduce deforestation process and CO_2 emission, and many actions. One of these is the developing of equipments with low ambient impacts like the solar cooking.

According Wetter (2006) the solar cookers are an important contribution towards halting the deforestation process and thereby preserve the environment. At the same time they help in fighting poverty. 500 solar cookers save 5,500 tons of wood a year, which translates into 1,000 hectares of woodland in the south of Madagascar. There is no CO_2 emission, which is the main agent responsible for climate change. The population will become less dependent on wood and charcoal. Besides environmental reasons there are also economical and practical reasons to favour the solar cooker. Families spend a lot less money on wood and charcoal. There is a pay back on the investment after only 6 months of using the solar cooker.

The solar cooking was invented in Switzerland in 1767 by naturalist Horace de Saussure. The cooking took spend centuries to be broadcast throughout the world. Fornosolar (2009).

Solar cooling has three main categories: Box Ovens, Parabolic Cooker and Panel Cookers.

Box Ovens: Are the most common type of solar oven, and their use is widespread, particularly in developing countries. Hundreds of thousands of box ovens are used in India alone. Box ovens or cookers typically are square or rectangular and have a clear glass lid. Panel reflectors inside conduct heat throughout whatever is being cooked. Box ovens tend to cook at moderate to high temperatures, and they are primarily used for slow cooking.

Parabolic or curved concentrator solar cookers use concentrated sunlight. They typically have a large, dish-shaped design and a reflective surface. The parabolic cookers are useful for cooking foods quickly at high temperatures. They can be used to prepare individual meals or for large-scale institutional cooking. One of the primary disadvantages of a parabolic cooker is that must be monitored and adjusted frequently to ensure that the correct amount of sunlight is being directed toward the surface. Parabolic cookers also present a higher risk for fires or burns.

Panel Cookers combine elements of two categories. They are the easiest of the three to construct and use. They typically feature a pot that rests inside a plastic or glass enclosure and is surrounded by three to five reflective panels. Panel cookers generally cook food at much lower temperatures, making it much more difficult to overcook or burn food. Their lower cooking temperature does limit the types of foods you can prepare, and they typically work best with foods that have a higher moisture content. Unlike parabolics, panel cookers do not require constant monitoring or adjustment. After the January 2010 Haiti earthquake was donated hundreds of solar Painel cookers kits to Haiti.

The three categories of solar coking are showed at figure.

(a) (b) (c)

Figure 1. The three categories of solar coking: (a) Box Ovens, (b) Parabolic Cooker and (c) Panel Cookers.

The solar cooking has very advantages, as:

- Equipment inexpensive and easy to make and use,
- Reduces the use of fuels such as butane or kerosene, firewood and charcoal,
- Reduce air pollution and deforestation, erosion and soil depletion, water pollution, the reduction of rain and oxygen from the air and the advance of desertification,
- The workload of cooking: the food does not burn,
- Can be built small and lightweight, easy to transport,
- Promotes better health because the food cooks slowly and at lower temperatures, preserving the nutrients,
- Reduces eye disease in the lungs caused by smoke from the burning of firewood in the kitchen
- Does not cause fires or burns. It is safer,
- Enables pasteurize water and milk, canning and dehydrating fruits and seeds, breads, cakes and biscuits baked in the sun, increasing the sources of family income.

Some disadvantages are they do not work in the morning or at night, on rainy days. Have low efficiency on cloudy days

For a high efficiency, a solar cooking should be used in areas that have high incidence of sunlight. The regions near the equator are usually the best for your use.

The international solar ovens have released a list of the twenty countries with the greatest potential for using these. And the criteria were taken in the ranking: the highest average incidence of solar, fuel shortages and population size. The Brazil is in 13 th in the list. The 10 top list are:

1. India; 2. China;3. Pakistan;4. Ethiopia;5. Nigeria;6. Uganda;7. Sudan;8. Afghanistan;9. Tanzania;10. South Africa.

There is little application in Brazil. Some studies evaluating their efficiency as Moura (2007), Oliveira and Damasceno (2009). However there is fails methodology therefore do not consider the input power or energy is not useful to evaluate warm some food. Therefore this work was performed with a defined methodology.

2. METODOLOGY

The estimative of solar cooking useful efficiency is similar a solar collector efficiency. Duffie (1991) presents an energy balance in the solar collector. The direct solar irradiation reaches the set (cooking and mirror) (I_{dir}). One part is lost to the environment by optical losses (P_o) as diffuse energy reflected from mirror. The power that arrives in the box (P_{box}) is composed for the useful power (P_u) and lost power (P_p). The lost powers are composed by the convective and radiative lost. Cavalcanti and Souza (2010) showed the energy balance on the collector at the figure.

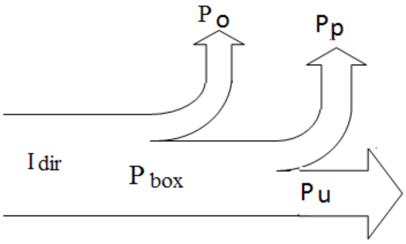

Figure 2. Energy balance of the solar cooking.

The useful efficiency is the relation of the useful output energy and the input energy. The useful energy is the energy to heat and evaporate the water in recipient composed by sensible and latent heat. The input energy is the product of solar rate to area perpendicular to sun's rays.

Due the losses there are the optical, thermal and useful efficiencies. The useful efficiency of collector may be estimated by optical efficiency of collector and thermal efficiency of collector:

$$\eta_u = \frac{P_u}{I_{dir}} = (\eta_o) \times (\eta_t) = (\frac{P_{box}}{I_{dir}}) \times (\frac{P_u}{P_{box}}) \qquad (1)$$

Some definitions of solar angle: the Solar altitude angle (β) is the angle measured from a horizontal plane on earth up to the sun. The solar azimuth angle (ϕ) is the angle measured between two vertical plane, between the sun's rays and the north. Their angles vary with latitude, hemisphere, solar time and month's day, (Stoecker, 1985). The collector orientation and the solar angles are in figure with (in red) the projected area of ray's sun.

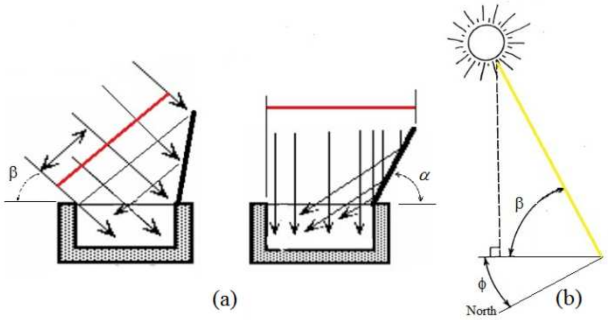

Figure 3. (a) Orientation of collectors with sun's rays (b) The Solar Angles β and ϕ.

A relation between the solar altitude (β) and reflector position angle (α) was estimated as:

$$\alpha = \frac{180 + 2.\beta}{3} \qquad (2)$$

A model of energy balance was elaborated to determinated the efficiency.

$$I_{dir}.\tau_{glas}.\left[A_{box} + A_{trans,mir}.\rho_{mir}\right] + \alpha.\sigma.A.T_{neig}^4 = h.A(T_s - T_\infty) + \varepsilon.\sigma.A.T_s^4 + m.c_p.\frac{\Delta T}{\Delta t} \qquad (3)$$

Where:

τ_{glas} is the glass transmissivity 0.79,

A_{box} is the box area =L.L.sin(β),

$A_{trans,\ mir}$ is the transverse area of mirror =L.L.sin(α-β),

L is the dimension internal (length and width) of cooker 0.44 m,

ρ_{mir} is the reflectivity of mirror 0.91,

α is absorptivity of cooker's surface 0.26 (white paint)

σ is the Stefan–Boltzmann constant 5,67x10^{-8} W/m^2K^4.

T is temperature

ε is the emissivity of surface (white paint) 0.90 and glass 0.94

m is mass of cardboard, steel, water and glass

c_p is heat specific of cardboard 0.064 kJ/kg K, steel 0.452 kJ/kg K, water 4.18 kJ/kg K and glass 0.84 kJ/kg K,

ΔT/Δt is the ratio temperature variation by time variation

Subscript: neig is neigborhood, s is surface, ∞ is air.

The property optical of mirror, glass and white surface and material's heat specific were utilizing the literature's values of Holman (1983) and Incropera (1998).

The neighborhood temperature is similar the sky temperature. According Retscreen (2004), the sky temperature is (T_{sky}) is the temperature of an ideal blackbody emitting the same amount of sky radiation. The sky radiation is radiation originating from the sky at wavelengths greater than 3 μm. It is required to quantify radiative transfer exchanges between a body and the sky. The sky radiation varies depending on the presence or absence of clouds.

According Incropera (1998), the effective sky temperature depends depends on atmospheric conditions, ranging from a low of 230 K unde a cold, clear sky to a high of approximately 285 K under warm, cloudy conditions.

The neigborhood or sky temperature were measured for the interection of radiation heat change of black painted metalic sphere with sun and neighborhood.

2.1 EXPERIMETAL APPARACT

The experiment was conduced in campus of UFRN, Natal, RN, with the follow regional characteristics.
Data 29 jan 2011
Latitude -05° 47'42"
Longitude -35° 12'34"
Height 30 m.

According Climatempo (2011) the atmospherically conditions were:
Test Conditions: Sun with very clouds during the day. Periods of cloudy, with rain at any time.
Air environmental temperature: 31 a 23 °C
Windy velocity: ESE 14km/h,
Cloudy and Relative Humid: 10 mm, 80%
Sunrise and Sunset: 05:22 hs and 17:45 hs.
An apparatus's representation of can be showed at figure

Figure 4. Experiment's apparatus of the solar cooking

During de test has very clouds during the morning until 11 hs, after was a sunny day,
Total irradiation solar range: 350 – 1050 W/m^2,
Wind velocity range: 0.1 km/h (0.028m/s) – 8.9 km/h (2.5 m/s),
Air environmental temperature: 26 a 30 °C,

2.2 Experimental procedure

The useful efficiency is the ratio of useful energy to input energy. The useful energy is energy used to heat and evaporated the water. Then this energy is measure by the variation of mass and temperature of water. The input energy is measure by pyrometer and the area perpendicular based at solar altitude angle (β) and reflector position angle (α).

The Measurements were collect from 8 to 15 pm each hour and calculated the daily average values. There were available the efficiencies of solar cooking using the instruments. The description of instruments used on experimental were showed at table below.

Table 1. Characteristics of Instruments for measures

Instruments	Description/Characteristics
thermocouples	Tipo K, range -40 °C a 204 °C, accuracy ±1.0°C, resolution 1.0°C
Digital Temperature Indicator	Coel, model CLCD2, range -50 °C a 50 °C, accuracy ±0.6°C, resolution 0.1°C
Spring Dynamometer	Range: 0 a 10 kg, **Resolution**: 0.1 kg
Pirometer	Instrutherm, model MES 100, Gauge: 0 - 2000 W/m^2, resolution 1 W/m^2, accuracy 10 W/m^2.
Digital vane anemometer	Instruterm, model TAD-500, resolution 0.1 m/s ou 0.1 km/h, accuracy ±3%

At 30 min before the measurement, the cooking was adjusted with the sun position (solar azimuth angle), and the reflector angle was adjusted according solar altitude angle. This procedure is to reduce the shadow at cooking and avoid reducing his efficiency

At each hour, to measure:

- the global and diffuse irradiation,
- Solar azimuth and solar altitude angles,
- Mass, temperature of water in recipient,
- Air temperature and velocity
- Surface temperature at 2 points and glass surface temperature
- Neighborhood temperature

2. RESULTS

The solar irradiation or global solar irradiation is composed for direct and diffuse irradiation. The global irradiation was measured by pirometer and the diffuse irradiation was measure with the same instrument but utilizing um surface opaque to block the direct irradiation. The values of the direct, diffuse and global (sum) solar irradiation of data test for hour were showed at figure.

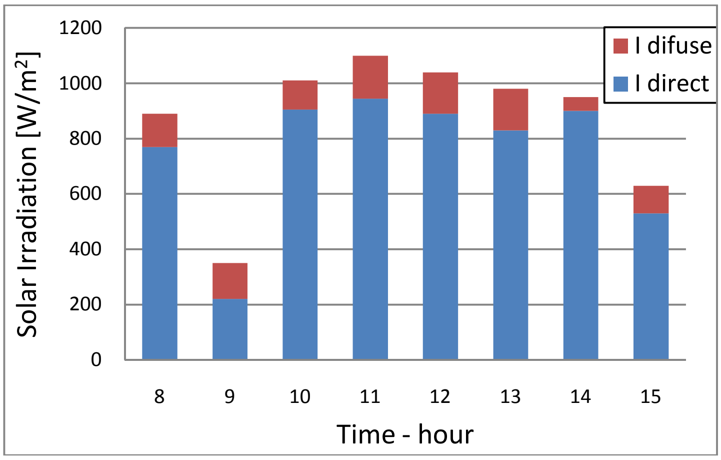

Figure 5. Solar Irradiation versus hour

The irradiation's measure varied widely at each seconds. The accuracy was impaired due a measure at each hour not guarantee that this value correspond the exact value at time. At 9 am the solar radiation value was very low due the presence of clouds.

The estimative of solar cooking efficiency is necessary estimate three solar power: The direct (I_{dir}), in box (P_{box}) and the useful power (P_u) according the energy balance on the collector at the figure.

The direct irradiation that reaches the cooking and mirror was determinate by transversal area of ray's sun and the direct solar irradiation showed at figure 2 and 3, respectably. The values direct irradiation were determinate at each hour range, by the means at each hours and the projected area of ray's sun were determinate by equation 3 utilizing the hourly means of angle (α and β), as equation 3.

The irradiations that arrive in the box (P_{box}) were determinate by the difference of the direct irradiation and the optical losses (P_o) which is affected by the optical property (reflectivity) of glass and (transmissivity) of mirror. The optical property were considering diffuse.

The useful power (P_u) were determinate by sensible and latent heat of water. The change of mass and temperature of water were measured utilizing temperature Indicator and spring Dynamometer.

As much as all experimental data were estimated at each range of hour, the heat transfers were showed at end of hour for each range, begging at 9 hs and finishing at 15 hs.

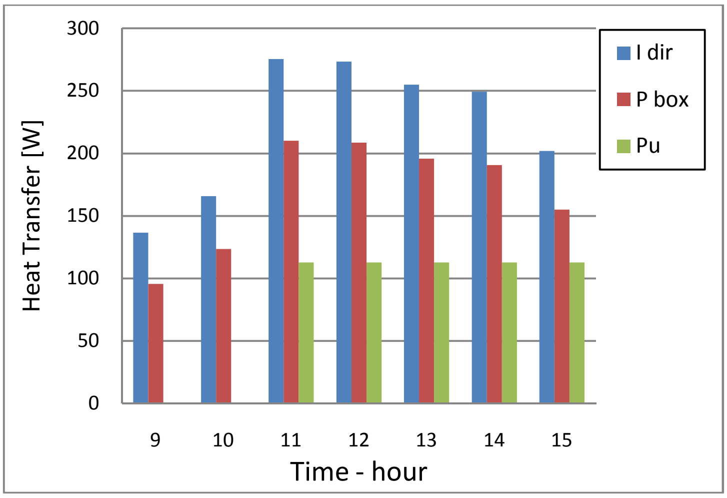

Figure 6. Power heat transfer versus hour

The optical, thermal and useful efficiencies were estimated like equation 1. His values also were estimated at each range of hour like showed his values at figure.

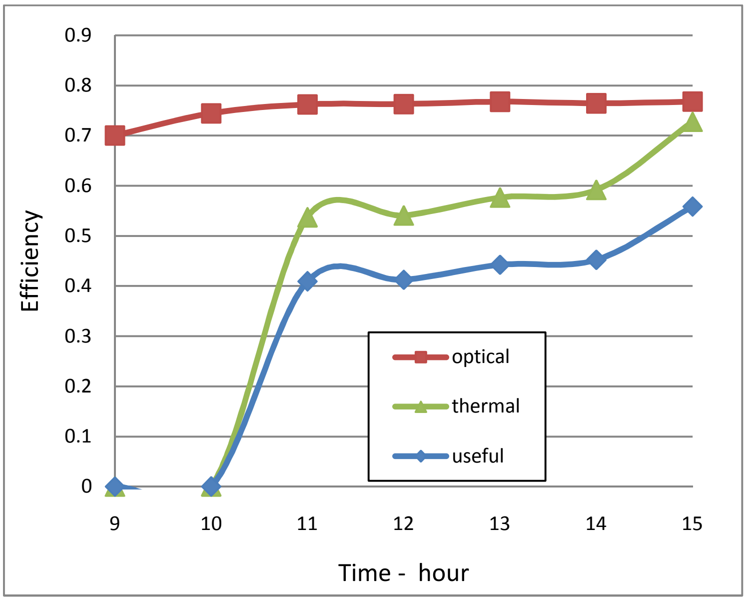

Figure 7. Efficiency versus hour

The optical efficiency depends of transversal area, altitude solar angle and property optical of mirror and glass. Their values are almost constants, the low variations occur due a low variation of transversal area with altitude solar angle (β)through the hours.

The sensible heat of water is very low compared with latent heat of evaporation. Beginning the water only has sensible heat by the temperature increase. At 11hs observed an water evaporation by reduction of water mass. This energy is very significative and can be noticed an elevation of thermal and useful efficiencies. The two efficiency are related with useful power. As time observed an low increase of this two efficiency. The useful power are constant until 15 hs, but the direct irradiation (I_{dir}) and power box (P_{box}) have the maximum value at 11 hs and after that begging the reduce his values due the reduce at solar irradiation. The effect can be observed at figure 6 and 5.

The lost power can be estimated by two methods. One for the energy balance by the difference of the power box (P_{box}) and the useful power (P_u) as like figure 2 and the other for the literature correlations of convection heat transfer and liquid radiative transfer. The seconds methods depends on the velocity of wind to estimate the convection coefficient, and the optical property as absorptivity of cooker's surface (α) and the emissivity of surface (ε) according at equations 3. The convective heat transfer is forced and not natural, the comparison can be realized by dimensionless parameter Gr/Re^2. His low value means the dominant convection is forced, otherwise his high value means the dominant convection is natural. The value near 1 means occur mixed convection. The range experimental value of this parameter were 0.021 to 0.0000017 means the dominant convection is forced. The range forced convective coefficient for surface estimated for correlations changing by 0.84 to 7.9 W/m^2 ^{o}C.

The comparion of values of lost power were strong discrepancy. The variation of wind velocity at time and the lack of accuracy of value of optical property of cooking made by cardboard milk carton have significant effect of lost power. The emissivity of surface (ε) was adjusted from 0.9 to 0.5 for reduce the difference among the two methods. The comparion of values of lost power determinated by two methods and his value difference for emissivity of surface (ε) 0.5 can be showed at figure.

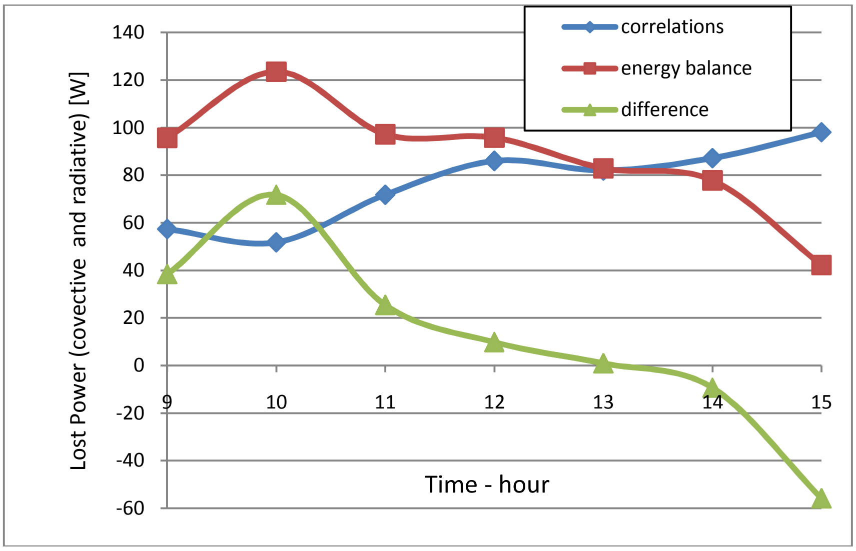

Figure 8. Comparion of Lost Power for emissivity of cooking surface (ε) of 0.5

The equation 3 has the right side composed for the input energy from direct solar and absorptivity's neighborhood and the left side composed for the output energy from convective, radiative's emissivity and stored energy.

The comparion of the input energy, output energy and his difference for value emissivity of surface (ε) 0.5 can be showed at figure.

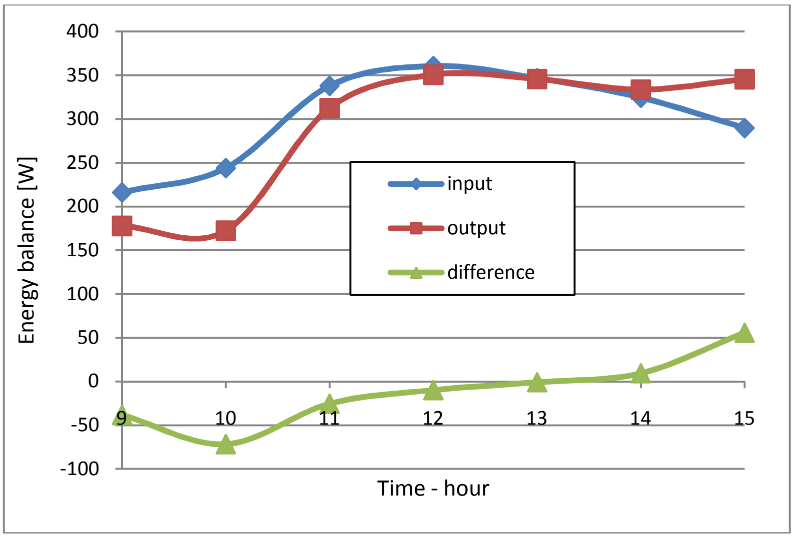

Figure 9. Comparion of input and output energy from equation 3.

The input and output energy have values almost equals. If the emissivity of surface was not change, the energy difference will be for all time positive.

3. CONCLUSION

A cooking was builded with cardboard box and were evaluated useful, optical and thermal efficiency over time. The efficiencies change with the hour. Also there were estimated the direct (I_{dir}), in box (P_{box}) and the useful power (P_u).

An energetic balance were performed at cooking and the lost power were determined by two methods. The results indicated that the convective and radiative lost have the high discrepancy. The imprecision of air velocity and the property optical of surface have strong influence at his values. The dominant convection is forced.

Some adjust of emissivity of surface was made to reduce the discrepancy.

4. ACKNOWLEDGEMENTS

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