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THERMAL PERFORMANCE OF A DEVELOPED SOLAR BOX COOKER FOR AWKA METROPOLIS

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Abstract

The predominant use of fossil and wood energy sources in Nigeria has contributed immensely to environmental pollution and related health challenges; this has prompted an increasing demand for other cleaner and sustainable energy sources such as solar cookers. In this study, design and thermal evaluation of solar box using cheap locally available waste materials was carried out. The experimental investigations were carried out in Aroma, Awka, Anambra State with geographical coordinates of Latitude $6^{o}12^{1}25^{11}N$ *and* $7^{o}04^{1}04^{11}$*East, South Eastern Nigeria on 31st March and 1st April, 2016. Mullick Figures of Merit was used to test for the thermal performance of the cookers. The first figure of merit* F_1 *calculated for the constructed box cooker was 0.123, which is within the recommended range of 0.12–0.16* $m^{2o}C/W$ *for a functional cooker. The second figure of merit* F_2 *was calculated for the constructed solar box cooker as 0.285 which is also within the prescribed range of 0.254-0.490*$m^{2o}C/W$*, while delay observed in cooking time is attributable to the roughness in the foil, dirt and myth of overcast skies. The delay in boiling time was due to poor weather and instability in solar radiation.*

Keywords: Design, Solar, Energy, Irradiance, Transmittance, Figure of merits.

1. Introduction

Fossil fuels constitute the primary energy resource that has been used to power human technological advancement since the industrial revolution. Studies show that the pollution these fossil fuels cause on air quality is very high (Okonkwo et al. 2015; Dzioubinski and Chipman, 1999). Many scientists have pointed out the relevance of alternate renewable sources of energy to overcome 'Energy Crisis'. Among the renewable sources of energy, solar energy offers a practical solution for the energy problem which is clouding the prospect of mankind (Krishnan and Balusamy, 2015). Solar box cooker is the simplest type of solar cooker available because it is relatively cheap, low-tech device (Adewole et al, 2015).

In Nigeria, Fuel wood is the most widely used, supplying over 80 percent of household energy, while less than 20 percent is supplied by the other sources and complemented by small quantities of coal and charcoal (Audu, 2013). Fuel wood is often collected from the local environment in rural areas or purchased through markets in urban areas. Deforestation in the developing countries has been linked to massive exploitation of trees for use as wood fuel. Deforestation is discouraged world over because it weakens the planet earth's capacity to regulate its biosphere (Dzioubinskiand Chipman, 1999). Electric cookers are excellent sources of heat energy, unfortunately the high cost of electric energy generation and distribution added to erratic power supply as witnessed in underdeveloped economies constitute obvious drawbacks.

Nigeria as well as other countries in the tropics is readily blessed with abundant supply of solar energy which can conveniently be harnessed to fill this gap, over the years, researches developed different technologies for this purpose. Okafor (2008) conducted feasibility Study on the provision of solar energy in rural area using solar panel. As it concerns solar box type cookers, Saxena et al (2011) conducted thermodynamic review on solar box type cookers. Harmim et al., (2010) experimentally investigated a box-type solar cooker with a finned absorber plate. Similarly, Negi & Purohit (2005) investigated a box type solar cooker employing a non-tracking concentrator. El-Sebaii & Ibrahim (2005) tested a box-type solar cooker using the standard procedure of cooking power. Regarding thermal performance of solar cookers, Kumar (2004) carried out performance evaluation of box type solar cooker from heating characteristic curves; Sharma et al (2005) carried out thermal performance of a solar cooker based on an evacuated tube solar collector with a phase change material (PCM) storage unit and Kurt (2008) undertook an experimental investigation of thermal performance of hot box type solar cooker. The works of Harmin et al as it concerns thermal performance of a box type cooker is quite insightful. Also, Chen et al (2008) conducted numerical heat transfer studies of phase change materials (PCMs) used in a box-type solar cooker. In all the reviewed literature, there is paucity of information on solar box type cookers characteristics and the used of cheap locally available waste materials in Nigeria for the fabrication of the cookers. This is necessary for developing solar energy as an appropriate policy for reducing the dependence on imported energy and promoting environmental protection in the metropolis (Algifri, 2001).The solar box cooker developed in this study converts solar radiation from the sun to heat for thermal applications. In order to perform this function the solar box cooker is basically made up of the component that allows it to trap the solar radiation, convert it to heat and retain the heat within the stagnant chamber for cooking and other heating purposes. In line with the studies of Ogunwole (2006) and Khan (2008), the inner part of the box is painted black in order to maximize the heat generation.

2.0 Material and methods

A solar box was designed, simulated, and its performance evaluation was carried out using Mullick first and second figures of merit. The experimental investigations were carried out in Aroma, Awka, Anambra State with geographical coordinates of Latitude $6^o12^125^{11}$N and $7^o04^104^{11}$East, South Eastern Nigeria on 31st March and 1st April, 2016.
The solar box consists of the following components: Double wall glass cover, box frame, absorber plate and reflector.

2.1 Components and Materials used

2.1.1 Double wall glass cover -The design of the double wall glass cover was done according to the method of Aremu and Akinoso, (2013). Tempered, float glasses were used as window covers because of its low solar absorptivity hence its transparent are mostly colourless in nature (Aremu and Akinoso, 2013).
2.1.2 Box Frame-The frame of the box was made of hardwood (MDM) plywood of thickness ¾ inches (1.905cm) constructed in square form with outer sides of length 53.81cm. Hardwood plywood was used because of its increased stability, high-impact resistance, chemical resistance and high strength-to-weight ratio; it has cross-laminated structure and is durable through drastic temperature and moisture changes. The bottom of the box is made of china plane wood of thickness ¼ inches (0.635cm) and dimensions of 500 x 500mm. This material was used because it has rot resistance (non-durable to perishable regarding decay resistance), it is susceptible to insect attack. Has no characteristics odour, cheap and good workability (i.e easily with both hand and machine tools). The underside battens, four in number were 75mm high were made from Afara wood (Terminaliasuperba) with sectional dimension of 60 x 60mm. The space housing the insulating materials was sealed with four pieces of plywood noggins (Aremu and Akinoso, 2013).
2.1.3 Absorber Plate-This is the cooker floor which is painted black; it is the part that collects the sunlight and converts it to heat being a blackbody. It is made of Aluminium sheet. The design of the absorber plate was one according to the method of Ogunwole (2006). Aluminium was chosen because it is smooth, odourless (hygienic), ductile, malleable, high resistant to corrosion. Its specific gravity, melting and boiling point are 2.7, 658^{o}C and 2057^{o}C respectively, which make it to possessed good conduction of heat. The absorber was coated with matte black paint of 1mm thick to serve as good absorber of radiation. Three layer of coating were applied in order to ensure that the plate was completely hidden under the paint.
2.1.4 Reflector-The fabrication of the reflector was done according to Adewole et al, (2015).The inner parts of the reflectors were constructed with 1 mm aluminium sheet. Aluminium foil was used as the reflector because it is readily available, effective, has excellent good compatibility, high reflectance/transmittance, resistant to degradation, good thermal insulation, good secularity, impermeability to water vapour and gases as well as low cost.

2.3 Description of Solar Box Cooker- The solar box cooker is framed of hardwood (MDM) plywood of thickness 3/4 in (1.905 cm). The box frame is constructed in square form with outer sides of length 53.81 cm. The bottom of the box is made of China plane wood of thickness 1/4 in (0.635 cm). The inner surfaces of the box are lined with Aluminium foil. The Aluminium foil helps to retain heat within the box as it will rebound thermal energy that makes its way to the inner surfaces of the wooden box. The solar absorber is made from 0.54mm thick smooth Aluminium. It is constructed in the form of inverted square pyramidal frustum as shown in fig.1 with dimensions. The slant height of the absorber box can be calculated as slant height $(s)=\sqrt{(r^2+h^2)}=\sqrt{h^2+\frac{1}{4}a^2\cot^2\left(\frac{\pi}{n}\right)}$, substituting the value into the equation gives a slant height of 16.77cm. The absorber area of the box was calculated using the equation $A_{abs}=r+\frac{1}{2}p.l$.The inner base of the wooden box is covered with helical/spiral shaped wooden chips. The chips are waste products of chiselling process. Sawdust is them poured on the chips to serve as insulation layer of 5cm. The space between the slanting sides of the absorber and the inner side surfaces of the wooden box is filled with composition of chiselled wooden chips and saw dust. The solar box cooker consists of two main sub-systems; the box and the cover. The box is a frame made of wood holding insulation and absorber in place while the cover is also frame made of wood but holding the glasses and the reflector in place as shown in fig.2.

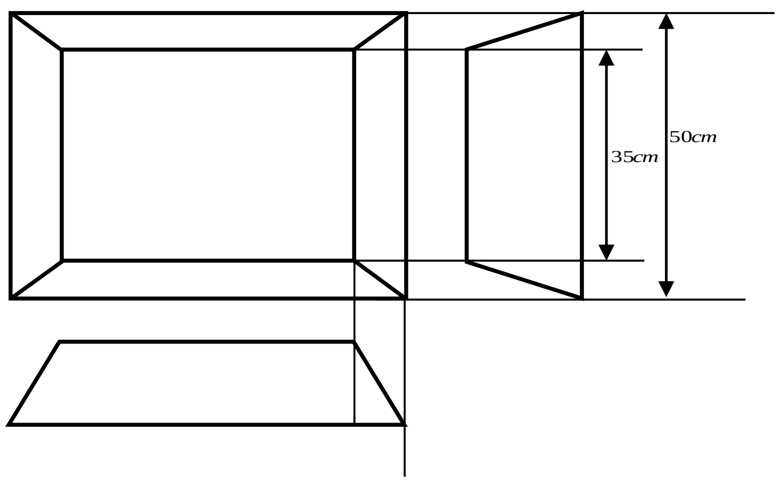

Fig.1 Pyramidal Frustum

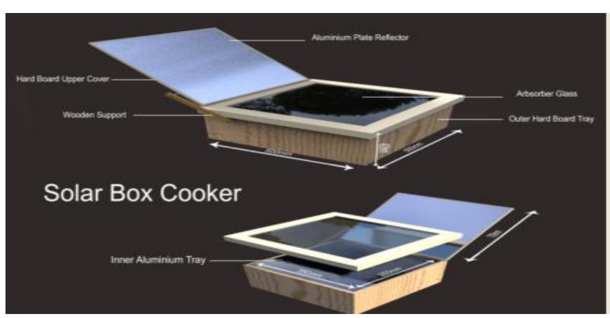

Fig.2 Designed Solar Box Cooker in 3D

2.4 Thermal Analysis using ASHRAE (2008) Model

2.4.1 Solar Energy Striking the Glass Cover - Generally, the glass covers of solar cookers are exposed to solar radiation. The solar radiation incident on the horizontal glass cover of a solar cooker is of three parts; the beam solar irradianceI_b, diffuse solar irradiance I_d and reflected solar irradianceI_r. Therefore the total solar irradiance is

$$I_T = I_b + I_d + I_r \tag{2.1}$$

The total solar irradiance I_T is what remains of extraterrestrial solar radiation after it has suffered atmospheric extinction. The empirical forms given by ASHRAE (2008) for the components of I_T under clear sky are

$$I_b = Ae^{-(\frac{B}{\sin\alpha})}\cos\theta_g \quad (2.2)$$

$$I_d = ACe^{-(\frac{B}{\sin\alpha})}\cos\theta_g \quad (2.3)$$

$$I_r = (\rho_r cos\theta_{rg})Ae^{-(\frac{B}{\sin\alpha})}\cos\theta_r \quad (2.4)$$

Where A, B and C are constants determined for average days of the months as presented in table 1.

Table 1: Standard Constants values of A, B and C used to calculate total solar irradiance I_T

Month	A [W/m^2]	B	C
January	1230	0.142	0.058
February	1215	0.144	0.060
March	1186	0.156	0.071
April	1136	0.180	0.097
May	1104	0.196	0.121
June	1088	0.1205	0.134
July	1085	0.207	0.136
August	1107	0.201	0.122
September	1151	0.177	0.092
October	1192	0.160	0.073
November	1221	0.149	0.063
December	1233	0.142	0.057

(ASHRAE, 2008)

It is assumed in eqn. 2.1-2.5 that the surface is completely covered, the reflector-glazing exchange factor, defined as the area of the glazing that is exposed to the reflected radiation is one (this is ensured by close monitoring and adjustment of the reflector), the length, width and area of the reflector and cooker glazing are equal and the cooker is oriented southwards. The α is the solar altitude angle while its complement θ_g is called the zenith angle. The θ_g is the angle of incidence. Therefore $\alpha + \theta_g = 90^o$. The θ_r and θ_{rg} are respectively the angle of incidence of beam solar radiation on the inclined reflector and the angle of incidence of the reflected solar radiation on the glass cover of the cooker. The ρ_r is the reflectivity of the reflecting material (Aluminium foil in the current case) on the reflector. According to Hanlon, (1992).The reflectivity of bright aluminium foil is 88% while dull embossed foil is about 80% .The glass incidence angle θ_g is given by

$$\cos\theta_g = \cos l \cos\delta \cos\omega + \sin l \sin\delta \quad (2.5)$$

The l, δ and ω are respectively the latitude angle, the declination and the hour angle of the glass surface. The latitude angle l is a geographical data that can be gotten from atlases, the declination δ can be calculated for each day of the year while the hour angle ω can be calculated for every hour of every day. An approximate equation by Cooper for declination is

$$\delta = 23.45\sin\left[\frac{360}{365}(284+n)\right] \quad (2.6)$$

Where n is the day of the year in a system in which first day of January is numbered 1 while the last day of December is numbered 365. The angle of incidence of beam radiation on the reflector θ_r is given by:

$$\cos(\theta_r) = \cos\alpha\cos\beta_s\sin\beta + \sin\alpha\cos\beta \quad (2.7)$$

where β and β_s are respectively the tilt and solar azimuth angle given by

$$\beta_s = \frac{\cos\delta\sin\omega}{\cos\alpha} \quad (2.8)$$

The angle of incidence of the reflected solar radiation on the glass cover of the cooker can be calculated using eqn. 2.9

$$\theta_{rg} = 180^o - \beta - \theta_r \quad (2.9a)$$

When the reflector is facing the beam radiation then

$$\theta_r = \beta - \theta_g \quad (2.9b)$$

But when the reflector is not facing the beam radiation then

$$\theta_r = \beta + \theta_g \quad (2.9c)$$

2.4.2 Solar Energy Transmitted through Glass Cover

The proportion of solar energy striking the glass cover that successfully pass through the glass and enters the cooking chamber is proportional to the transmittance of the glass cover to solar radiation. The transmitted solar radiation has the respective three parts; the beam transmitted solar irradianceI_{bt}, diffuse transmitted solar irradiance I_{dt} and reflected transmitted solar irradianceI_{rt}.

$$I_{bt} = \tau_{bt} A e^{-(\frac{B}{\sin\alpha})} \cos\theta_g \quad (2.10)$$

$$I_{dt} = \tau_{dt} ACe^{-(\frac{B}{\sin\alpha})} \cos\theta_g \quad (2.11)$$

$$I_{rt} = \tau_{rt}(\rho_r cos\theta_{rg}) Ae^{-(\frac{B}{\sin\alpha})} \cos\theta_r \quad (2.12)$$

Where τ_{bt}, τ_{dt} and τ_{rt} are respectively the transmittances of the glass cover to beam, diffuse and reflected solar radiation striking the glass cover. Generally, if the surface reflectivity and material absorptivity of the glass cover to radiation are r and a respectively then transmittance and absorptance through single glass are respectively given by

$$\tau_{t1} = a\frac{(1-r)^2}{1-r^2a^2} \quad (2.13)$$

$$\alpha_{t1} = r + ra^2\frac{(1-r)^2}{1-r^2a^2} \quad (2.14)$$

The transmittance when the cooker cover is composed of m identical glasses is

$$\tau_{tm} = \tau_t^m \quad (2.15)$$

Therefore, the total solar irradiance becomes

$$I_{Tt} = I_{bt} + I_{dt} + I_{rt} \quad (2.16)$$

2.4.3 Thermal Energy Generated by the Absorber

The solar energy in the cooking chamber is converted to heat by the absorber. The heat generated is proportional to the absorptance of the absorber to the various components of the transmitted radiation. The heat generated from the beam transmitted solar irradiance q_{bt}, diffuse transmitted solar irradiance q_{dt} and reflected transmitted solar irradianceq_{rt}.

$$q_{bta} = \alpha_{bt}\tau_{bt}^2 Ae^{-(\frac{B}{\sin\alpha})} \cos\theta_g \quad (2.17)$$

$$q_{dta} = \alpha_{dt}\tau_{dt}^2 ACe^{-(\frac{B}{\sin\alpha})} \cos\theta_g \quad (2.18)$$

$$q_{rta} = \alpha_{rt}\tau_{rt}^2(\rho_r cos\theta_{rg}) Ae^{-(\frac{B}{\sin\alpha})} \cos\theta_r \quad (2.19)$$

Where α_{bt}, α_{dt} and α_{rt} are respectively the absorptance of the absorber to beam transmitted, diffuse transmitted and reflected transmitted solar radiations within the box or cooking chamber. On the account of equation (2), the rate heat energy is generated by the cooker can thus be given as

$$q_T = q_{bta} + q_{dta} + q_{rta} \quad (2.20a)$$

$$q_T = \alpha_{bt}I_{bt} + \alpha_{dt}I_{dt} + \alpha_{rt}I_{rt} \quad (2.20b)$$

$$q_T = \alpha_{bt}\tau_{bt}^2 I_b + \alpha_{dt}\tau_{dt}^2 I_d + \alpha_{rt}\tau_{rt}^2 I_r \quad (2.20c)$$

Bringing in the ASHRAE empirical models in equation (2.15-2.16) gives the heat generated as

$$q_T = (\alpha_{bt}\tau_{bt}^2)Ae^{-(\frac{B}{\sin\alpha})} \cos\theta_g + (\alpha_{dt}\tau_{dt}^2)ACe^{-(\frac{B}{\sin\alpha})} \cos\theta_g + (\alpha_{rt}\tau_{rt}^2)(\rho_r cos\theta_{rg}) Ae^{-(\frac{B}{\sin\alpha})} \cos\theta_r \quad (2.21)$$

The products of absorptance and transmittance squares are put in brackets to highlight the total specular interaction of the solar box cooker with the solar radiation.

2.5 Test Procedure.

- Tests were started at around 10:00am and were stopped at around 6:00pm.
- The cookers were kept under shading before the start of the tests and brought to receive solar radiation simultaneously.
- Tracking of the cookers was done manually every ten minutes
- Thermocouples were attached to the center of the bottom absorber plate during the No-load (stagnation) test and were immersed into water during the boiling test.
- In the test, 1 litre of water divided equally between two identical pots was used at each start of the Load test (Sensible test).
- Results are recorded every ten minutes. The set-up for the test procedure can be seen in plate 1.

Plate 1: Setup of the Solar Box for stagnation and sensible test showing the multi-meters used in measuring the chamber, absorber and water temperatures

3.0 Results and Discussions

3.1 Energy Gain

Graphical forms of the energy gain to solar devices are usually generated to ease analysis and avoid lengthy calculations. In this work, the analytical methodology for solar energy gain is based on the ASHRAE (2008) models. Plots of the ASHRAE (2008) models of solar energy striking the cooker surface as given in equations (3.1-3.4) for March and April are shown in fig.3. March and April are considered first because they are the months the tests were carried out. The stagnation test was carried out on 31st of March while the sensible test was carried out on the 1st of April 2016, therefore the I_b for both 31st of March, 1st of April, are included in fig.3. The negative time represent the morning hours while the positive time represent the afternoon hours.
The noon I_b for both the whole of March and the whole of April are given in fig.3.

A transmittance value of $\tau_t = 0.9$ is adopted for the transparent glass used (Hanlon, 1992). It is assumed that the value of the transmittance of the glass cover is same for beam, diffuse and reflected solar radiation for all time of the day (Hanlon, 1992). Therefore the noon clear sky transmitted solar radiation; I_{bt}, I_{dt}, I_{rt} and I_{Tt} are plotted on same axis for both 31st of March and 1st of April in fig.4.
Adapting an absorptance of 0.95 for matte black paint on Aluminum sheet (Löf, and Tybout, 1972). It is assumed in what follows that absorptance of the absorber is same for beam, diffuse and reflected transmitted solar radiation for all time of the day. Therefore the rate of thermal energy generation; q_{bta}, q_{dta}, q_{rta} and q_T are plotted on same axis for both 31st of March and 1st of April in fig.6.

Fig.3 shows a graphical view of results of clear-sky beam solar irradiance obtained from ASHRAE (2008) models. -6 represents 6am in the morning, 0 represents 12noon, while 6 represents 6pm local time. It is deduced that the beam or direct solar irradiance travelling directly on a straight line from the sun to the surface of the earth increase rapidly from 6am to 12noon, after which it returns to its original position. Maximum beam solar irradiance occurred at 12noon. It is also observed that March has a high direct or beam solar irradiance than April based on the graph. Thus the cooking performance of the cookers in the Month of March will be higher than that of April.

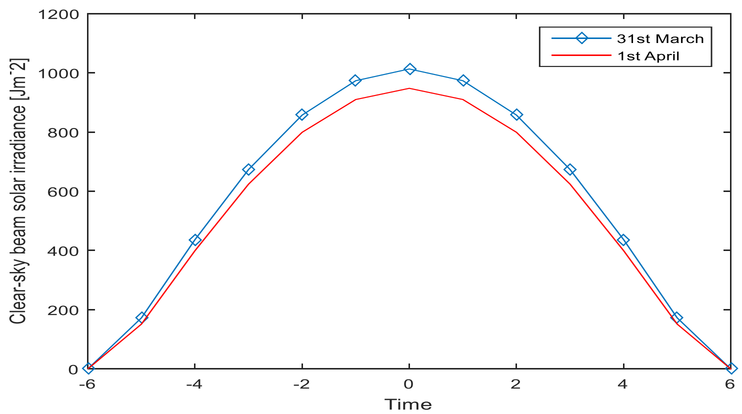

Fig.3: I_b for 31st March and 1st April obtained from ASHRAE models

Fig.4 shows a graphical view of results of Noon clear-sky beam solar irradiance obtained from ASHRAE (2008) models. January is the first day of the year that is 1 and end in 31st day, February 1st begins with 32nd day while March 1st is the 60th days and ends in day 90. April begins on 61st day and ends in day 120 as shown in fig.4. It is observed that the Month of March has the higher value of Noon-clear-sky beam solar irradiance when compare to April. The noon clear sky beam irradiance in the month of March 31st was 1010J/m^2, while that of April first was 950J/m^2. These values were used because stagnation test was conducted on 31st March, while the sensible test was done on 1st April, 2016.

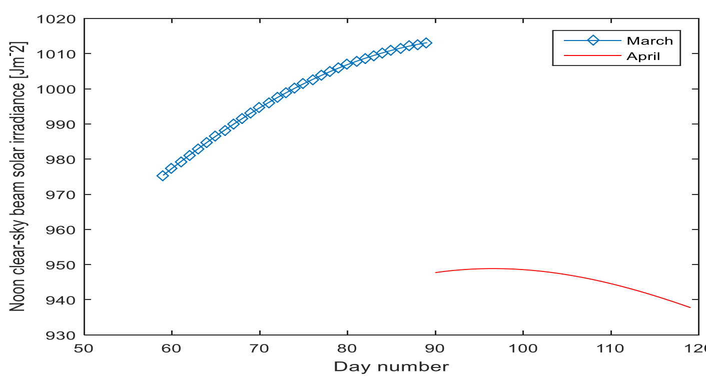

Fig.4: Noon I_b for both the whole of March and the whole of April obtained from ASHRAE models

Fig.5 shows the graph beam, diffuse and reflected of Noon clear-sky transmitted solar irradiance. It can be deduced that the beam transmitted solar irradiance increase gradually as the number of days increased. The reflected solar radiation decreased in the month of March and increased in the month of April. Also the diffuse solar transmitted irradiance slightly increases for both the month of March and April.

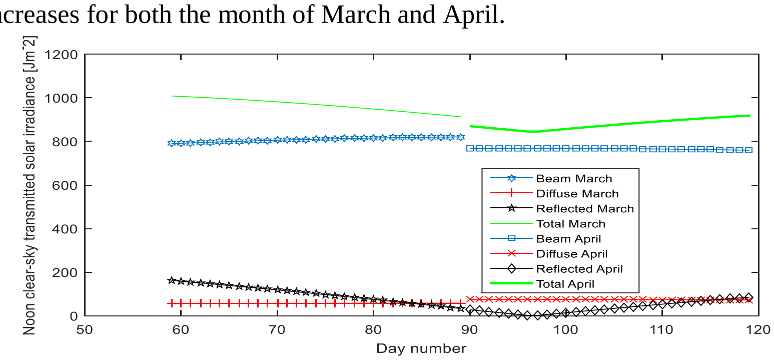

Fig.5: NoonI_{bt}, I_{dt}, I_{rt} and I_{Tt} for both the whole of March and the whole of April obtained from ASHRAE models

The noon clear-sky heat generation shows gradual increase in the month of March and April as for both the beam and diffuse heat generation shown in Figure 6.

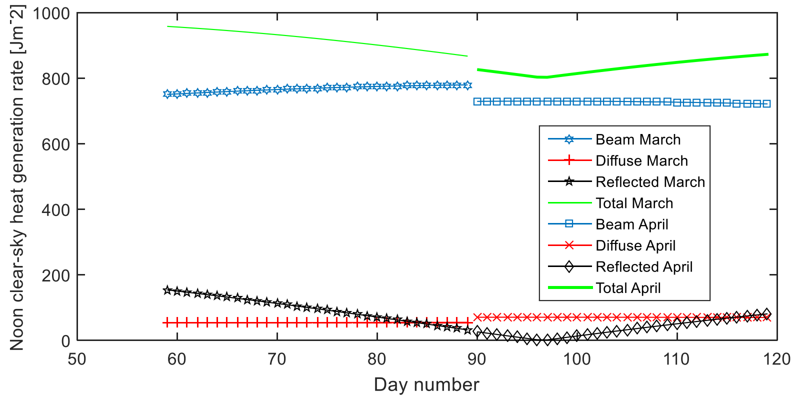

Fig.6: The Noonq_{bta}, q_{dta}, q_{rta} and q_T for both the whole of March and the whole of April obtained from ASHRAE models

3.2 Performance Evaluation Results

Fig.7 and 8 show graphical representation of clear-sky solar irradiance of beam, reflected and diffuse solar irradiance for stagnation and sensible tests. The beam solar irradiance is the solar radiation travelling on a straight line from the sun down to the surface of the earth, diffuse solar irradiance is irradiance that is sunlight that has been scattered by molecules and particles in the atmosphere, but that has still made it down to the surface of the earth, while reflected irradiance is the sunlight that has been reflected off of non-atmospheric things such as ground (www.ftexploring.com). It can be seen that the beam irradiance and diffuse irradiance are maximum at 12noon, while there was no reflected irradiance at 12noon. The reflectors are tilted in the direction of the sunlight until when it is 12noon. At this point, the plane reflector has no row to play as the irradiance travels directly into the solar box at 90^o.

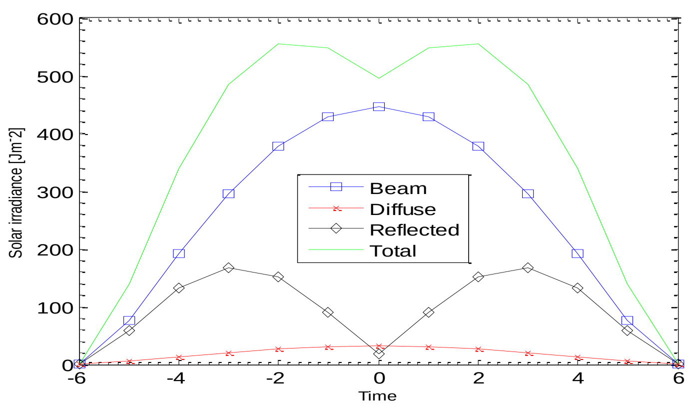

Fig.7. Clear-sky solar Irradiance during stagnation test on 31st March, 2016

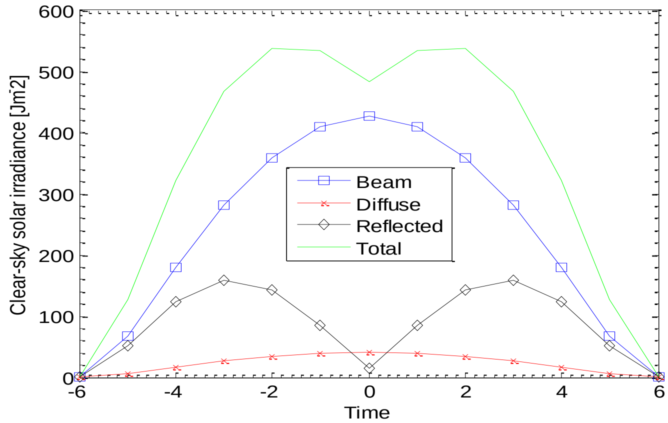

Fig.8. Clear-sky solar irradiance during sensible test on 1st April, 2016

It can be seen from fig.9 that the temperature change of the absorber and the cooker chamber follow closely the clear-sky transmitted irradiance for 31st of March in fig.7. The non-smooth nature of the absorber and the cooker chamber temperatures in fig.9 was due to poor, non-clear and random weather of 31st March. Maximum absorber plate and chamber air temperatures of 115.1°C and 104.9°C respectively. These maximum values were recorded at 13:30h local time. The ambient temperature at this time is 32.19ºC. The absorber temperature is consistently higher than the chamber temperature. This is expected as the absorber is the source of heating of the chamber.

The variations in the ambient, absorber and water temperatures during the sensible heat tests for the cooker are shown in the figure 10. The high variability of the temperatures in figure 3.8 was due to poor, non-clear and random weather of 1st of April. Maximum absorber plate and water temperatures were 113.4°C and 100°C respectively. These maximum values were recorded at 12:30h local time. The absorber temperature was consistently higher than the water temperature during heating but consistently lower than the water temperature during cooling after 2:00 h local time. This is expected as the absorber is the highly conductive source of heating of the water.

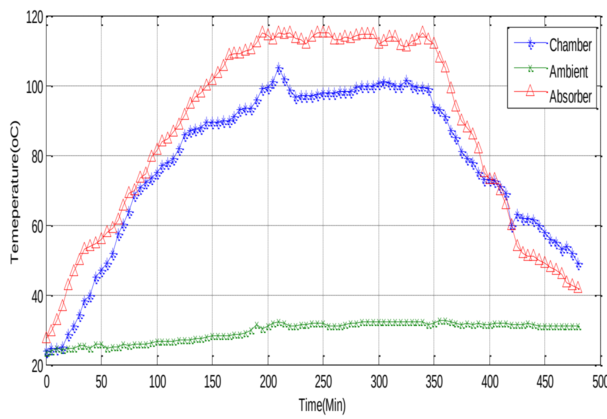

Fig.9: Temperatures during Stagnation Test on 31st March, 2016

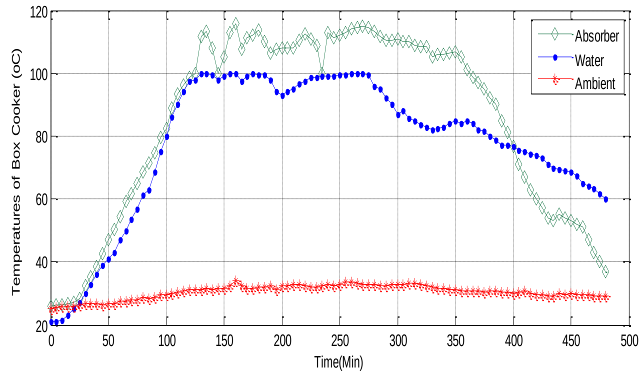

Fig.10: Temperatures during sensible test on 1st April, 2016

3.3 Cooker Test Performance using Mullick el at figure of merit

Considering the experimental results obtain in Aroma, Awka, Anambra State with coordinates $6^{o}12^{1}25^{11}N7^{o}04^{1}04^{11}E$ on 31st March, and 1st April, 2016. The first figure of merit given in equation (3.1) considers I_{Ts}, as the irradiance on a horizontal surface at stagnation. The theoretical horizontal irradiance given in equation (3.1) and plotted in figure 8 is for the clear-sky conditions. In applications, weather conditions are rarely clear as stipulated in the ASHRAE (2008) models.

$$F_1 = \frac{(T_{ps} - T_{as})}{C_{INs} I_{0s}} \quad (3.1)$$

Where C_{INs} is the clearness index at stagnation; the ratio of real irradiance to the theoretical extraterrestrialirradiance I_{0s}. At the stagnation time of 13:30 h local time, the I_{0s} is calculated as 1366.7Wm^{-2}. The clearness index reported for the months of March and April by Ezeonuegbu (2015) is 0.501 and 0.50 respectively. Substituting T_{ps}= 116.1°C, T_{as}= 32.19°C, I_{0s}=1366.7Wm^{-2} and C_{INs}= 0.501 gives F_1=0.123. It was noted that a functional cooker performance would require F_1 in the interval 0.12–0.16 m^{2o}C/W. This means that the constructed cooker will guarantee the medium. This is expected as the absorber is the highly conductive source of heating of the water.

The second figure of merit is calculated using equation 3.2. Introduction of clearness index makes the equation to have the form

$$F_2 = \frac{-F_1 (Mc_p)_w}{tA_s} In \left\{ \frac{\left[1 - \frac{1}{F_1}\left(\frac{T_{w2} - \bar{T}_a}{C_{INs}\bar{I}_{0s}}\right)\right]}{\left[1 - \frac{1}{F_1}\left(\frac{T_{w1} - \bar{T}_a}{C_{INs}\bar{I}_{0s}}\right)\right]} \right\} \quad (3.2)$$

The mean ambient temperature in the sensible test is $\bar{T}_a$=30.50°C. The mean extraterrestrial irradiance in the sensible test is $\bar{I}_{0s}$=1366.7Wm^{-2}. The extraterrestrial irradiance does not vary significantly with time of the day. Then using F_1=0.129, M=1kg, c_p=4200 J/kg/K, A_s= 0.473×0.473= 0.2237m^2, the time interval t is read off from the curves of figure 4.13 to correspond to heating the water from T_{w1} =47.0 to T_{w2}=100 as t=12:15-11.00=1.15h=69mins. The second figure of merit becomes F_2= 0.285. Even though the weather under which the experiment was carried out is highly random and overcast most of the time, the calculated second figure of merit becomes F_2= 0.285 which falls in the recommended range of 0.254–0.490.

4.0 Conclusion

A functional solar box cooker was designed and constructed in this work. The constructed experimental solar cookers were made of two main sub-systems; the box and the cover. The box is a wooden frame holding insulation and absorber in place while the cover is also a wooden frame but holding the glasses and the reflector in place.

One of the primary considerations in the design and construction of functional solar box is insulation or lagging. Some of the measures that ensured functional insulation include that the inner surfaces of the box were lined with Aluminium foil. All the space between the absorber and the wooden box is filled with mixture of chiselled wooden chips and saw dust. Considering the plane, the total incident solar irradiance was estimated using the ASHRAE (2008) empirical models for solar radiation. By considering surface reflectivity, material absorptivity of the glass cover to radiation and multiplicative transmittance of multiple glazing, it was possible to estimate the total transmitted solar irradiance using the ASHRAE (2008) empirical models. By considering the absorptance of the absorber to the various components of the transmitted radiation, it was possible to estimate the total rate of heat generation for the constructed box.

The first figure of merit F_1 derives from no-load stagnation tests which evaluate the relative strengths of cooker optical efficiency and insulation. The first figure of merit F_1 calculated for the constructed box cooker is 0.123, which is within the recommended interval of 0.12–0.16 $m^{2o}C/W$ for a functional cooker. The second figure of merit F_2 derives from load tests which evaluates the strength of heat exchange between the cooker and the cooked item. This figure of merit is indicative of cooking time. The second figure of merit F_2 is calculated for the constructed solar box cooker as 0.285, which is also within the recommended range of 0.254–0.490. The time it will take to boil 1.8 litres of water is calculated from the first and second figures of merit as 2hrs for parabolic cooker and 2h.45mins for the solar box cooker. The reason for the prolonged time for boiling is the very poor weather which was highly fluctuating such that no time of the day was clear. And the clearer intervals never lasted more than few minutes without going overcast again.

5.0 Recommendation

- Since the ratio of chamber to absorber temperatures is always above 0.75 and on a sunny day the cooker absorber is expected to attain higher temperatures than 126.5 ^oC, the cooker can be serve as a solar oven that can be used for roasting purposes and cooking.
- The result that solar box cookers installed in Aroma, Awka even in a random weather can sustain ratio of water to absorber temperature above 0.75 during the pre-boiling heating process means that the cookers can be recommended for use in sterilization.

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