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The Effects of Additional Solar Reflection on Increasing the Temperature in the Cooking Chamber of a Box Solar Cooker

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***Abstract*—** *Globally energy demand is expanding with rapid population growth. Almost 1.4billion people of our planet face daily shortage of energy. Therefore, the need for alternative source of energy for food preparation has given rise to the use of box type solar cooker for cooking. Though use of box solar cooker is not new and have even been commercialised in some countries like India there is still need for research to improve its cooking efficiency by increasing the temperature in the cooking chamber. To achieve this movable additional plane mirror reflector was introduced as an improvement to the system in addition to the one already attached to its side. Stagnation temperature test was carried out in the afternoon under solar radiation level of 1085W/m^{2}and ambient temperature of 35.7°C. Comparing the solar box cooker with that improved, the result showed that the average maximum temperature of 112.3°C was recorded from the unimproved box solar cooker while at the same time the improved cooker showed a temperature of 126 .2°C.That indicated a temperature increase of 13.9^{o}C hence justifying the improvement on this type of system.*

***Keywords*—** *Solar cooker, Stagnation temperature, Solar radiation, Ambient temperature.*

I. INTRODUCTION

Traditionally, the sun has provided energy for practically all living creatures on earth. Plants absorb solar radiation and convert it into stored energy for growth and development. Scientists and engineers today seek to utilize solar radiation directly by converting it into useful heat or electricity (Lewis Nathan S.Carabtree *et al.*, 2005). Two main types of solar energy systems are in use today namely photovoltaic and thermal. However there is still need to improve the available technology and increase the utilization, efficiency of solar thermal energy systems being used for cooking. (G.K Singh, 2013). A booster mirror is quite significant for solar cooking since it allows illumination intensity falling on the transmitting surface of the cooker hence higher working temperature which enhances the efficiency. Ibrahim and Elreidy (1995) investigated the performance of a solar cooker integrated with a plane booster mirror reflector and realised increase in its performance. Other researchers have also conducted various experiments geared at increasing the temperatures and cooking time reduction in box type solar cookers. Addition of plane mirrow reflectors (Ugwuke, et al.,) and double glazings (Kumar,) effects were so far investigate and still there is room for improving the performance of box type solar cookers. Therefore this work was conducted in order to improve the cooking efficiency of the common box type solar cooker by provision of additional reflectors to direct solar radiation in to the cooking chamber of the cooker. Results showed a temperature difference of over 13.9^{o}C due to this improvement without using concentrator, under sunshine radiation level of 1085W/m^2.

II. METHODOLOGY

This section covers description of the systems and the description of the methods employed in the system performance evaluation.

2.1 Description of the Dual Axis Plane Mirror Reflecting Booster Experimental Set up.

The dual axis plane reflecting booster was constructed at the Sokoto Energy Research Centre, Usmanu Danfodiyo University, Sokoto, Nigeria. It was constructed in such a way that it could allow unrestricted rotation along its horizontal and vertical axis enabling its adjustment to direct sun rays received by the reflecting surface to the cooking chamber of the box solar cooker. This configuration is as shown in Figure 2.1. Each of the two booster mirrors has an area of 142cm length and 104cm breadth. Also the two cookers used had effective area of 60cm x 60cm each. The cooking chambers which were covered with double glazing were of 20cm depth each.

2.2 System Performance Evaluation Theory

Solar collectors and **s**olar cookers have been the topic of research for several years ago, and most widely accepted standard test procedure for thermal rating of flat plate collectors in different countries has been based on ASHRAE standard 93-77. However, Garg and Mullick et al have come up with an expression for evaluating the box type solar cookers based on two figures of merit, termed as F1 and F2. The values for first figure of merits (F_1) can be determined by conducting the stagnation temperature test that is without load or any item loaded to be cooked in the cooker. The second figure of merit F_2 can be determined by sensible heating of known amount of water. Each of these performance indicators are explained below:

2.2.1 First Figure of Merit

The first figure of merit (F1) of a box type cooker is defined as the ration of the optical efficiency and overall heat loss coefficient, U of the box type solar cooker; (Purohit.,

2005) BIS, 2000 and Mullick *et al* (1987). It is mathematically defined as:

$$F_1 = \frac{\eta_0}{U_L} \quad (1)$$

The above expression can experimentally be represented as:

$$F_1 = \frac{T_{ps} - T_{as}}{H_s} \quad (2)$$

Where: T_{ps} is the plate stagnation temperature,(°C), T_{as} is the ambient temperature at stagnation (°C) and H_s, is the solar radiation intensity at stagnation (W/m^2).

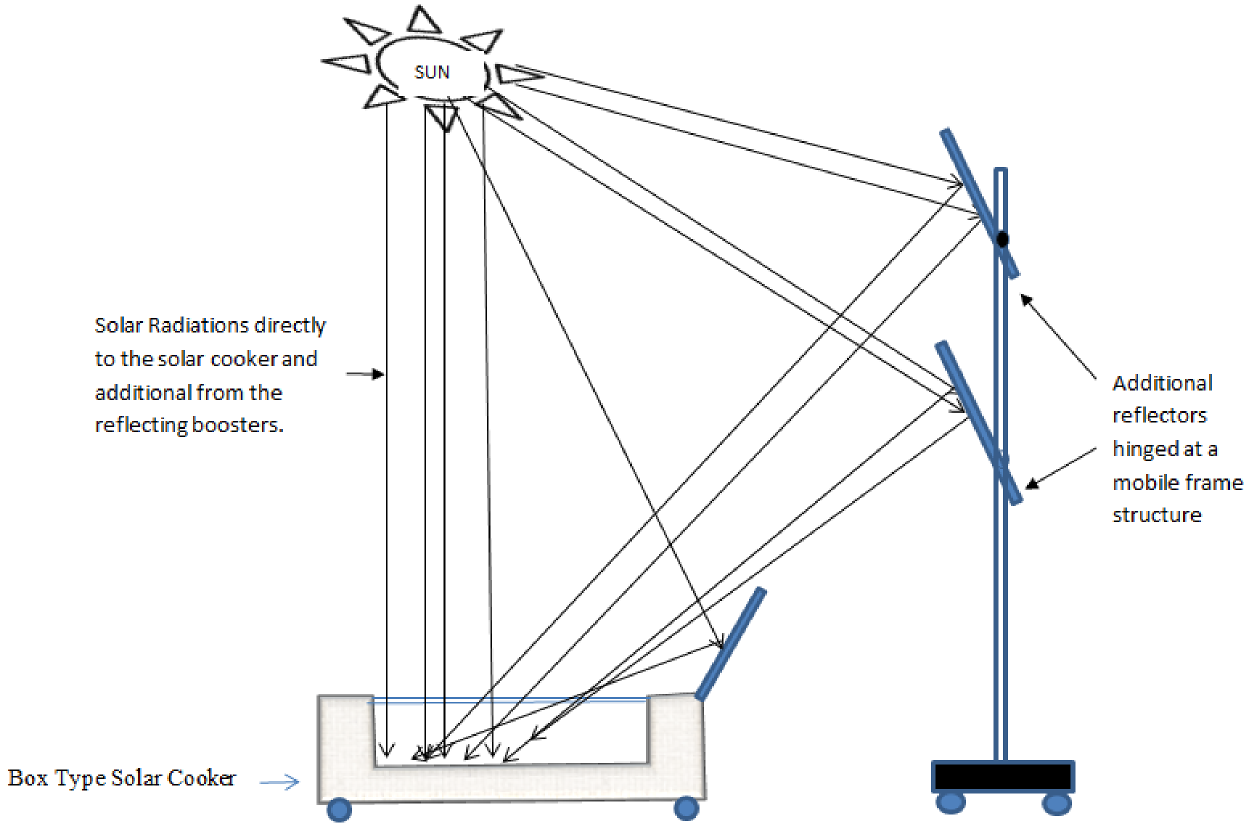

Figure 2.1: Arrangement of additional reflecting boosters on box type solar cooker.

2.2.2 Second Figure of Merit (F_2)

The second figure of merit (F2), of a box type solar cooker is evaluated under full load condition and can be expressed from the following expression: (Mullick et al. 1996) and (Bureau Indian Standard BIS, 2000)

(Subodh Kumar, 2005). This is presented here for further evaluations to be conducted on the system when tested under load.

$$F_2 = F_1 \frac{(M_W C_W)}{A_\tau} \ ln \left(\frac{1 - \frac{1}{F_1}(T_{W1} - T)}{1 - \frac{1}{F_1}\left(\frac{T_{W2} - T_a}{H}\right)} \right) \quad (3)$$

Where:

F_1 - represents the first figu re of merit,

M_w - the mass of the water, (kg)

C_w - specific heat capacity of water, (Kj/kgK)

T_a - average ambient temperature (^{O}C) over the period of time t

H - the average solar radiation incident on the aperture of the cooker (W/m^2)

T_{w1} - the initial water temperature,

T_{w2} - final water temperature,

A_t - the aperture area of the solar cooker;

t - the time differences in which water temperature rises from T_{w1} and T_{w2}.

(.Mohods *et. al.*, 2011).And (Subodh Kumar 2005).

III. Results and Discussions

The experiments were performed at the Sokoto Energy Research Centre, Usmanu Danfodiyo University Sokoto State, Nigeria. The tests on both the solar box cooker and improved solar box cooker with dual axis plane mirror reflecting booster were carried out simultaneously under the same solar radiation level. Main performance parameter monitored in the test was the stagnation temperature in the respective cooking chambers. Their increase with corresponding increase in solar radiation and ambient temperatures were periodically recorded.

3.1 Stagnation Test Result

Stagnation tests were conducted on the solar box cookers. The temperature in the cooker, solar radiation, ambient temperature of the environment which were the most important parameters were observed The maximum solar radiation recorded was 1085W/m^2at 12:30 Hours of that day. The data were recorded, plotted and presented in Figure 3.1a. As can be seen temperatures rising in all the cookers as well as ambient continue to rise in direct proportion to the increase in daily solar radiation. The maximum temperature of 126.2^{o}C was recorded from the cooker with additional reflecting booster (T_{Boost}) while at the same time the solar cooker without additional booster ($T_{NoBoost}$) attained maximum temperature of 112.3^0C as indicated in Figure 3.1b.

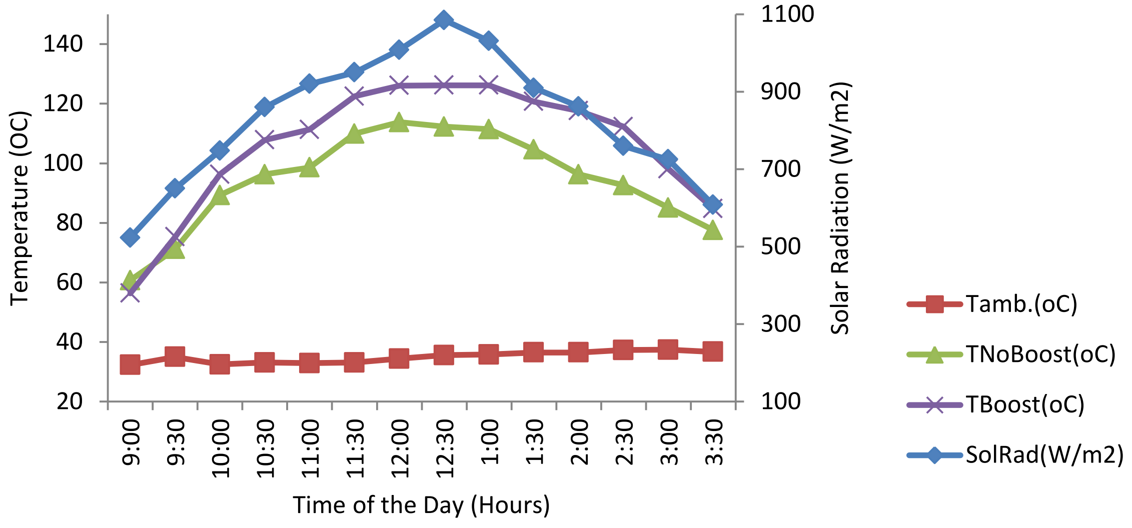

Figure 3.1a: Diurnal Variations of Ambient Temperature, Solar Radiation and Temperatures Attained in the Cooking Chamber of Each Cooker

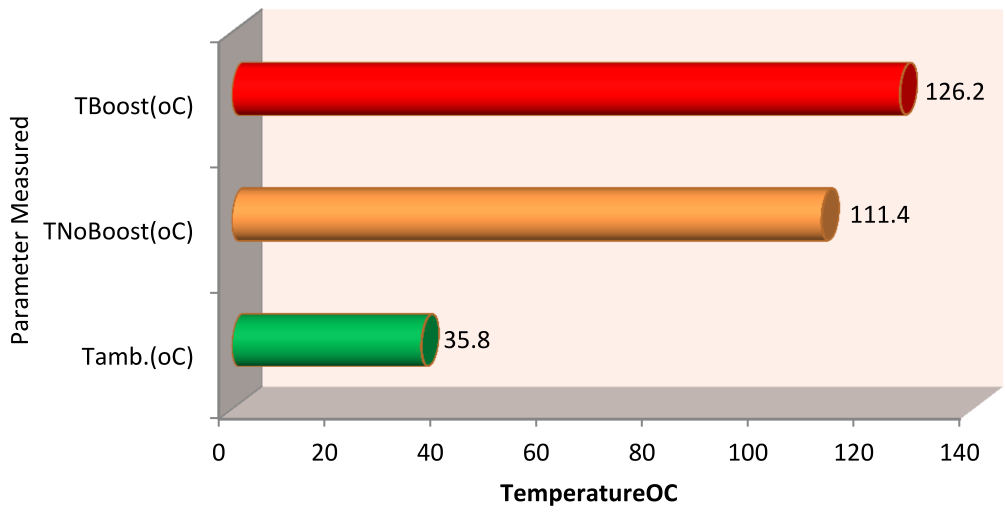

Figure 3.1b: Maximum Temperatures From Cookers at a Given Ambient

The temperature difference between the ambient each of the two solar cookers started to be observed shortly after the beginning of the experiment. At any time the difference was obtained using simple arithmetic subtraction as in equation (4) below:

$$\Delta T_{Cooker\&Amb.} = T_{cooker} - T_{Amb} \qquad (4)$$

Where:

$\Delta T_{Cooker\&Amb.}$ – is the temperature difference between cooker and ambient (^OC).

T_{cooker} - is the temperature attained by the solar cooker (^OC)

T_{Amb} - is the corresponding ambient temperature. (^OC)

As shown in Figure 3.2 at any time the difference between the cooker with booster and the ambient was higher when compared with the difference between the temperature in the cooker without booster and the ambient. The maximum temperature differences of 91.7^oC and 79.4^OC were observed between the cooker with booster and between ambient, and between the cooker without booster and ambient, respectively. Similarly differences of temperatures between the cooker with booster and one without the booster were observed. Here also

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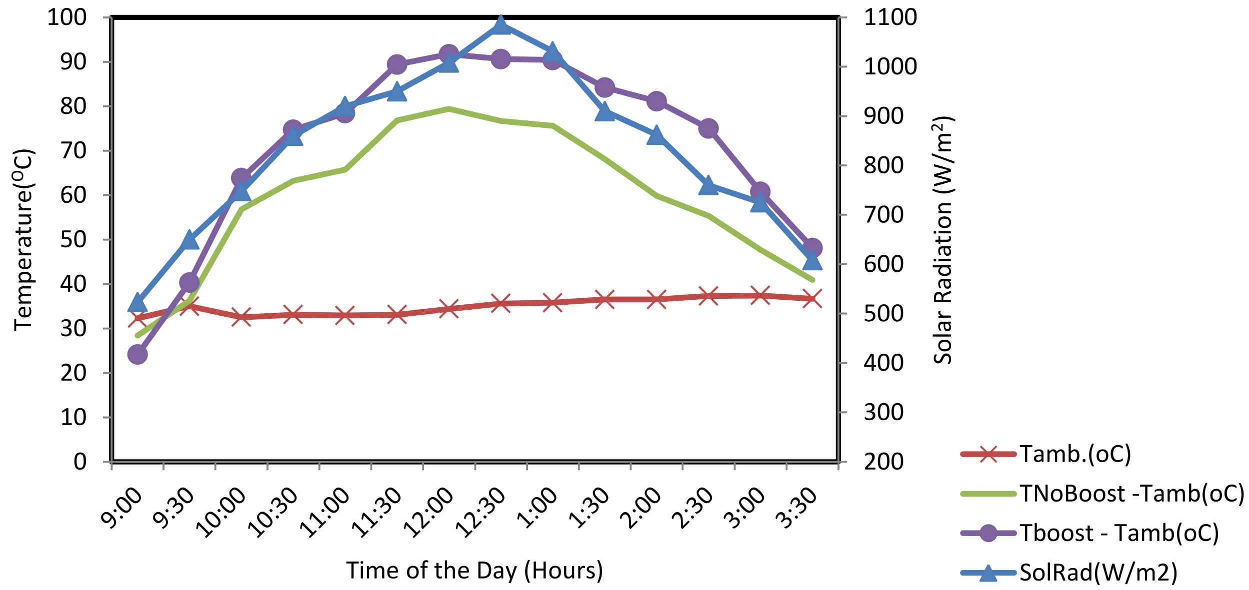
the difference at any time was obtained by subtracting the temperature of the cooker without booster from the one with booster also using simple subtraction equation (5). The temperature difference as can be observed in Figure 3.3. As a result of the additional booster a maximum temperature increase of 13.9^{O}C was realised.

$$\Delta T_{Cookers.} = T_{Booster} - T_{NoBooster} \quad (5)$$

Where:
$\Delta T_{cookers}$ - Temperature difference between the two cookers (^{O}C)
$T_{Booster}$ -Temperature of the cooker with additional reflecting booster (^{O}C)
$T_{NoBooster}$ -Temperature of the cooker without additional reflecting booster (OC)



Figue 3.2: Variations of Temperatures Between Ambient and the Cooking Chanbers of the Cookers With Solar Radiation

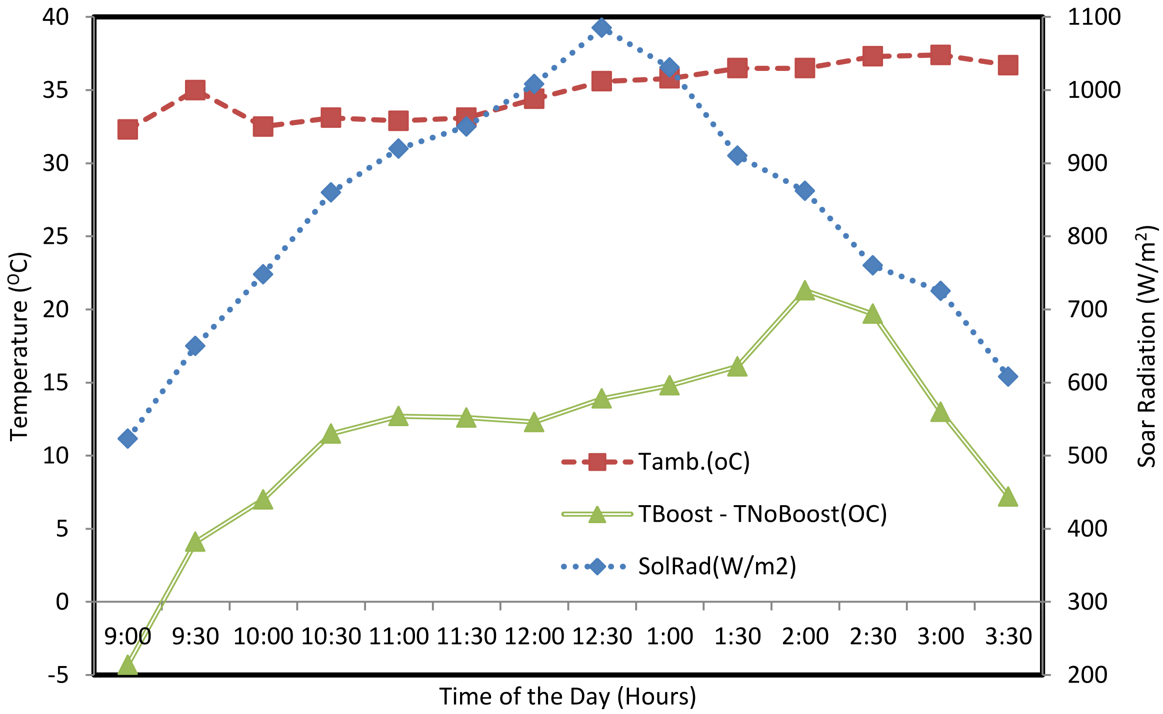


Figure 3.3: Profiles of Temperatures Differences Between the Cooker with booster and One without Booster

3.2 First Figure of Merit

Results obtained on the comparative stagnation temperature tests between the two cookers enabled the First figure of merit for each cooker to be calculated using equation (1) and plotted as shown in Figure 3.4. From the figure it can be seen that the value of F1 of the cooker with additional reflecting booster has always been higher than that without reflecting booster.

Based on the various tests conducted and applying the internationally accepted expressions for evaluating the performance of box type solar cookers it was found that additional reflecting booster enhances the increase in temperature of solar cooker as well as the first figure of merit.

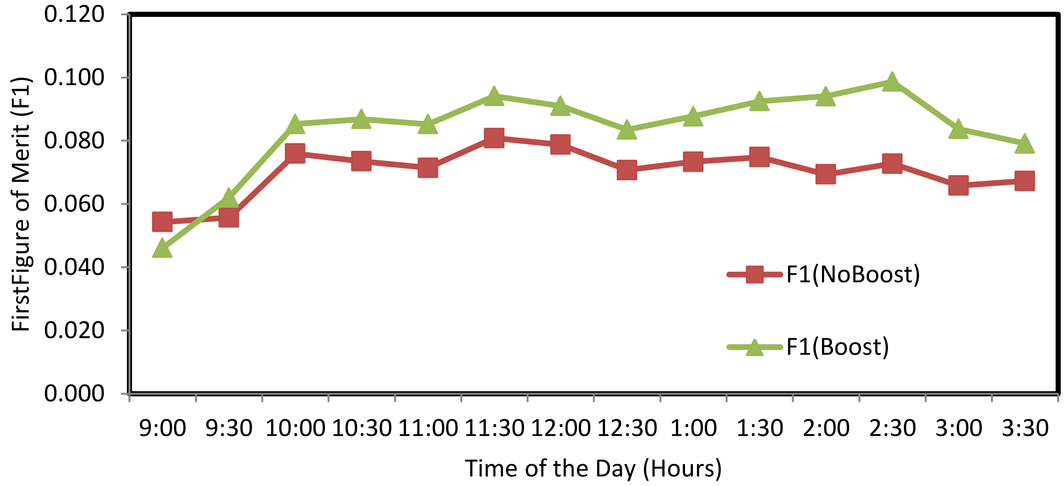


Figure 3.4: Profiles of First Figures of Merit (F1) obtained by each Solar Cooker

IV. Conclusion

A dual axis plane mirror reflecting booster was developed and constructed using the available material and used as an additional solar radiation booster to the conventional box type solar cooker. Its performance was evaluated in comparison with conventional box type solar cooker based on standard test procedures. The stagnation tests were done which enabled the temperature rising without any load to be studied. From the test results obtained it can be concluded that the development and construction of the dual axis plane mirror reflecting booster had improved the cooking efficiency of a box type solar cooker. Temperature increase of over 14^{o}C can reduce the cooking time and justified the use of additional reflecting booster on the conventional box type solar cooker.

References

[1] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) adopted ASHRAE Standard 93–77 1978 International Solar Energy Society. Published by Elsevier Ltd.

[2] Bureau of Indian Standard Bureau of Indian Standards (BIS) IS 13429: 2000.

[3] Funk P.A. (2000). "Evaluating the International Standard Procedure for Testing Solar Cooker Performance". *Solar Energy, Vol. 68, No. 1*, pp 1-7.

[4] Ibrahim SMA, Elreidy MK. (1995). The performance of a solar cooker in Egypt. RenewEnergy;6(8):1041–50.

[5] Lewis, Nathan S. Carabrartree, Geoge (2005). Basic Research Needs for Solar Utilization report of Basic Energy sciences workshop on solar energy Utilization volume 53 page 1-13.

[6] Mohod, A.G. and Poar, A.G. (2011). Development and evaluation of mulit reflector foldable type solar cooker, *Agricultural Engineering International CICR Journal manuscript no* 109 vol. (1).

[7] Mullick S.C., Kandpal T.C., and Kumar S. (1996). "Testing of Boxtype Solar Cooker Second Figure of Merit F2 and its Variation with Load and Number of Pots". *Solar Energy, Vol. 57, No. 5*, , pp 409-413.

[8] Mullick S.C., Kandpal T.C., and Saxena A.K. (1987). "Thermal Test Procedures for Box-Type Solar Cookers". *Solar Energy, Vol. 39, No. 4* , pp 353-360.

[9] Ugwuoke N.T (1998). Designed and measured performance of a plane reflection augment of box type solar cooker M. Engr project department of mechanical engineering, UNN.