

# Maximizing Heat Absorbption from Sunlight Via Blackening the Entire Inner Surface of a Modified Solar Box Cooker in Barnawa, Kaduna State

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## Abstract

This study reports the increase in thermal efficiency of a modified solar box cooker at a project site in Barnawa, Kaduna state, Nigeria. The study also presents hourly variations in five distinct temperature measurements, alongside standard water heating tests and controlled food cooking tests, conducted between September 8<sup>th</sup> and 14<sup>th</sup> 2023 (seven days). The result of this investigation showed that a maximum temperature of 90 °C was attained for the water heating tests. The controlled cooking tests results also revealed that, the device took 1 hour 30mins and 2 hour 20mins to cook egg and rice respectively. The efficiency of the device was calculated to be 43.13 %. This value of thermal efficiency is lower than that of the previously reported work by Bello et-al in Illorin, However, if the same initial temperature condition of about 65 °C and 62 °C were considered; an efficiency of 52.22 % would have been obtained which is higher than that of the previously reported work. The high performance can be attributed to the black paint applied to the inner surface of the solar box cooker. Given its effectiveness, I recommend utilizing this device as a cooking solution and a viable alternative to firewood.

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## Introduction

With current energy problems Nigeria is facing which encompasses gradual decrease in the availability of wood fuel in the rural areas and the problems attributed to the use of wood fuel for cooking purposes, irregular availability of fossil fuels (like kerosene, methane gas etc) and lack of steady supply of electricity to use electric stoves for cooking; the obvious alternative is to use solar energy to heat and cook our food in order to meet the need of cooking food for nourishment which is indeed a fundamental need. This is the best option for Nigerians since Nigeria is blessed with abundant amount of sunshine. Since solar cookers are powered by energy from the sun and which is obtainable virtually always and free of charge, they can be used therefore as alternative cooking devices.

Bello et al, (2010) assert that in almost all the rural homes in Nigeria, the traditional and most popular sources of energy for cooking is firewood. The demand for fire wood leads to the indiscriminate cutting down of trees which in turn leads to deforestation; the attendant ecological hazards attributed to deforestation are glary obvious which encompasses erosion, desert encroachment etc which indeed are particularly devastating in Nigeria. Also the use of firewood for cooking produces smoke which irritates the lungs and the eyes and can cause diseases such as

asthma etc. A solar cooker is powered by energy from the sun and can be used as an alternative cooking device so as to reduce the overdependence of the rural people and even many of the urban dwellers on fuel wood.

The project site of this study is Barnawa, a central city of Kaduna State which is located in the North western part of Nigeria. The coordinates of Barnawa are: Latitude  $12^{\circ} 27' 10''$ N and Longitude  $8^{\circ} 32'$ E and altitude 107.4m above sea level (Shamsuddeen 2017).

### **Materials used**

The materials used for the conduct of this research work are mahogany planks, saw dust, black paint, transparent glass, Plane mirrors, aluminium sheets, crown white wool, glasswool, hinges/rollers, tempered glass, thermocouple, Campbellstokes recorder, PCMs, flat plate, linear focus, central focuss collectors, valtzsun photometer pyre geometer, pyradiometer, shading-ring,pyranometer, moving shadow-bar phyrheliometer, black paint, nails, hinges, screws, shelf pins, perforated iron bar, glue, mercury-in-glass thermometer, stop watch screws and inclinometer.

### **Construction procedure**

As earlier mentioned, this work is a modification of the solar box cooker constructed by Bello et al (2010) and other researchers. In the original design only the absorber plate below the box was painted black, the inner walls of the box were left reflecting. However, in this work, the researchers painted the entire inner surface of the box black. A trapezoidal shaped inner box of dimension of 30cm x 30cm x 20cm bounded by an outer box measuring 80cm x 60cm x 30cm was constructed for the study. The two boxes are made from mahogany plank. Aluminium sheet of thickness 0.5mm is glued to the inner box, the aluminium sheet is painted black so that it may significantly retain the heat needed for cooking in the sunny periods, and a heat storage tank for storing phase change chemical material is attached to the inner box in order to store heat from the collectors for cooking at night. Finned absorber plate are used for heat transfer to the food in the cooking vessel, For the insulation of the cooker, saw dust used to fill in the space between the inner and the outer boxes, so also, glass wool and crown white wool are used for insulating the side walls of the cooker and reducing heat losses from the absorbing plate to the environment respectively. For the glazing, two transparent glass panes of thickness of 4.0mm each are fitted on top of the cooker with a space of 10mm between them so that green house effect which is the basis of operation of the solar device is created. A big plane mirror of thickness 4.0mm with measurement of 60cm x 60cm is used as reflector. The reflector consists of wooden frame which was sized to form a cover for the box when not in use. The box was inclined at a suitable angle of inclination to ensure that maximum irradiation falls on it.

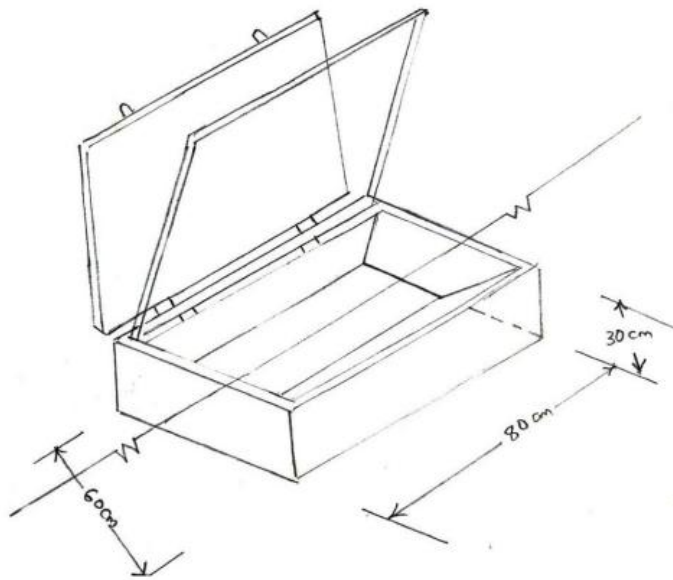


Fig 1a : Isomeric view of the solar box cooker

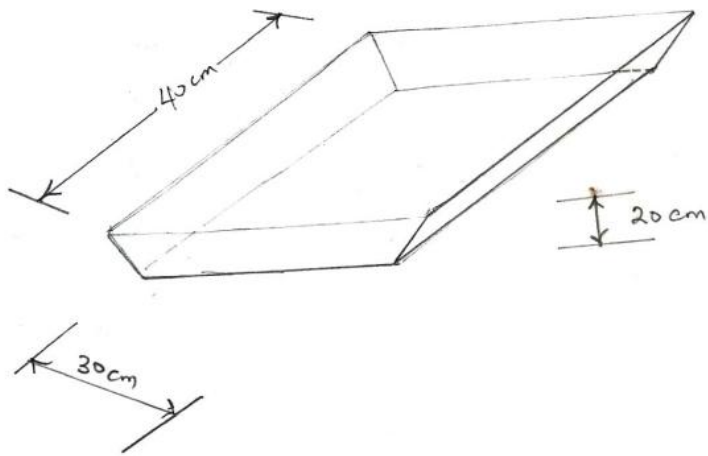


Fig. 1b: Inner absorber tray

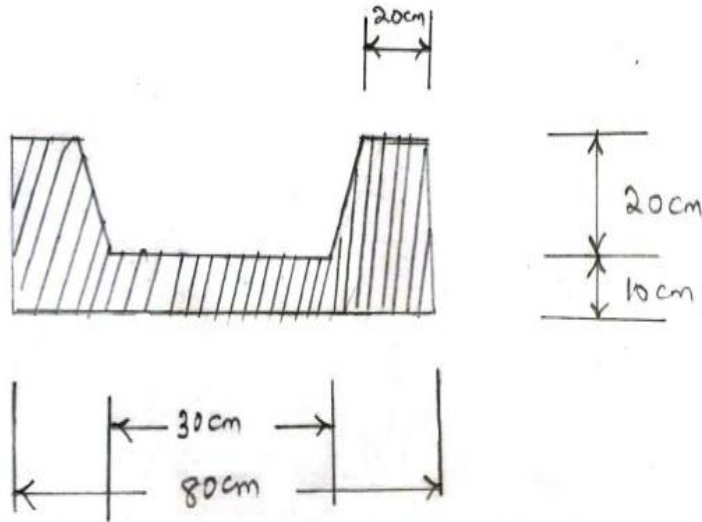


Fig. 1c: section X-X



Fig. 2.2: Outer view of the solar box cooker

## Experimental Procedure

The solar cooker was positioned in an open space at Isa Kaita College of education Dutsin-ma, Katsina State. The thermal system was placed facing southwards where there were no tree shade of any sort so as to maximize the solar radiation falling on it. The cooking device was allowed to heat for about 10 minutes before inserting the load. The device was exposed to direct sunlight to allow incident solar energy fall on it while the reflector was adjusted manually at regular intervals of 30 minutes to ensure that the reflected rays covered the entire glazing surface.

The performance tests conducted were: (i) water heating tests which involves temperature tests which involve temperature measurements connected with photo-thermal system for the period it takes to heat the water as well as (ii) controlled cooking tests. During the experimentation on the cooking and water heating tests, the following temperature readings were observed and recorded: ambient temperature,  $T_a$   
insulator temperature,  $T_i$   
working fluid (water) temperature,  $T_w$   
absorber plate temperature,  $T_p$  and  
cooking chamber temperature,  $T_c$ .

For the water heating tests, a black painted aluminium pot of mass 0.2kg containing 500cm<sup>3</sup>(0.5kg) of water was placed on the absorber plate of the solar box cooker and placed out door for observations. Similarly, for the controlled cooking tests, the food to be cooked plus 750cm<sup>3</sup> of water contained inside the black painted pot were placed in the box and the unit was placed outside for necessary measurements to be observed and recorded. The various temperature and time measurements were measured on hourly basis from 11:00 hours to 17:00 hours using mercury-in-glass thermometers and a stop watch throughout the period of the study.

## RESULTS AND DISCUSSION

### Results

The results of the hourly variations of temperature measurements observed in the period between 8<sup>th</sup> and 17<sup>th</sup> September 2023 using the modified solar box cooker are presented in tables 3.1 to 3.10:

Table 3.1: Results of temperature measurements observed with time using the modified solar box cooker on 8<sup>th</sup> september, 2023.

Time(Hour)	$T_a$ (°C)	$T_i$ (°C)	$T_w$ (°C)	$T_p$ (°C)	$T_c$ (°C)
11:00	32.5	34.0	28.0	34.0	36.0
12:00	34.5	36.0	53.0	60.0	57.0
13:00	36.0	40.0	70.0	74.0	68.5
14:00	36.5	44.0	82.0	79.0	83.0
15:00	37.0	46.0	81.5	80.0	85.0
16:00	36.0	46.0	79.0	78.0	80.0
17:00	35.0	46.0	75.0	75.0	78.0

Table 3.2: Results of temperature measurements observed with time using the modified solar box cooker on 9<sup>th</sup> September 2023

Time(Hour)	T <sub>a</sub> (°C)	T <sub>i</sub> (°C)	T <sub>w</sub> (°C)	T <sub>p</sub> (°C)	T <sub>c</sub> (°C)
11:00	32.0	32.0	31.0	36.0	34.0
12:00	34.0	34.0	50.0	54.0	52.0
13:00	35.0	38.0	65.0	68.0	64.5
14:00	34.0	40.0	76.0	74.0	78.0
15:00	33.0	40.0	74.5	72.0	76.0
16:00	32.0	40.0	73.0	71.0	74.0
17:00	30.0	40.0	70.0	67.0	71.0

Table 3.3: Results of Temperature measurements observed with time using the modified solar box cooker on 10<sup>th</sup> September 2023

Time(Hour)	T <sub>a</sub> (°C)	T <sub>i</sub> (°C)	T <sub>w</sub> (°C)	T <sub>p</sub> (°C)	T <sub>c</sub> (°C)
11:00	33.0	34.0	30.0	38.0	36.0
12:00	35.0	36.0	51.0	56.0	53.0
13:00	36.0	38.0	64.0	69.0	65.5
14:00	36.0	42.0	77.0	77.0	78.0
15:00	35.0	40.0	75.0	74.0	77.0
16:00	33.0	38.0	72.0	71.5	74.0
17:00	32.0	38.0	69.0	68.0	70.0

Table 3.4: Results temperature measurements observed with time using the modified solar box cooker on 11<sup>th</sup> September 2023

Time(Hour)	T <sub>a</sub> (°C)	T <sub>i</sub> (°C)	T <sub>w</sub> (°C)	T <sub>p</sub> (°C)	T <sub>c</sub> (°C)
11:00	34.0	32.0	30.0	40.0	39.0
12:00	34.0	34.0	52.0	62.0	60.0
13:00	35.0	38.0	69.0	75.0	70.5
14:00	36.0	42.0	80.0	83.5	86.0
15:00	36.5	44.0	84.5	81.0	83.0
16:00	35.0	44.0	81.0	79.0	81.0
17:00	34.0	42.0	78.0	74.0	79.0

Table 3.5: Results of temperature measurements observed with time using the modified solar box cooker 12<sup>th</sup> September, 2023.

Time(Hour)	T <sub>a</sub> (°C)	T <sub>i</sub> (°C)	T <sub>w</sub> (°C)	T <sub>p</sub> (°C)	T <sub>c</sub> (°C)
11:00	32.0	32.0	29.0	40.0	38.0
12:00	33.0	34.0	49.0	52.0	50.0
13:00	35.0	36.0	64.0	68.0	64.5
14:00	36.0	38.0	75.0	72.0	77.0
15:00	34.0	40.0	73.5	70.0	75.0
16:00	33.0	40.0	71.0	67.0	73.0
17:00	30.0	38.0	68.0	64.0	70.0

Table 3.6: Results of temperature measurements observed with time using the modified solar box cooker 13<sup>th</sup> September 2023.

Time(Hour)	T <sub>a</sub> (°C)	T <sub>i</sub> (°C)	T <sub>w</sub> (°C)	T <sub>p</sub> (°C)	T <sub>c</sub> (°C)
11:00	31.0	32.0	30.0	41.0	40.0
12:00	35.0	34.0	62.0	73.0	70.0
13:00	36.0	38.0	76.5	80.0	80.0
14:00	37.0	44.0	86.0	84.0	87.0
15:00	37.0	46.0	90.5	86.0	91.0
16:00	36.0	46.0	87.0	84.5	88.0
17:00	34.0	46.0	84.0	81.0	85.0

Table 3.7: Results of temperature measurements observed with time using the modified solar box cooker 14<sup>th</sup> September, 2023.

Time(Hour)	T <sub>a</sub> (°C)	T <sub>i</sub> (°C)	T <sub>w</sub> (°C)	T <sub>p</sub> (°C)	T <sub>c</sub> (°C)
11:00	32.0	34.0	30.0	38.0	38.0
12:00	34.0	36.0	54.0	59.0	52.0
13:00	35.0	38.0	70.0	74.0	71.5
14:00	36.0	42.0	80.0	78.0	83.0
15:00	36.0	44.0	79.5	76.0	82.0
16:00	35.0	42.0	77.0	73.0	79.0
17:00	33.0	40.0	73.0	70.0	75.0

### 3.2 Efficiency of the Solar Cooker

The efficiency of the cooker is calculated using equation 1.22 i.e.

$$\eta_c = \frac{(m_p c_p + m_w c_w)(\overline{T_w} - \overline{T_a})}{A_c H_T t}$$

Where:

Mass of port,  $m_p = 0.27\text{kg}$

Mass of water in the pot,  $m_w = 0.5\text{kg}$

Specific heat capacity of pot,  $C_p = 920\text{Jkg}^{-1}\text{K}^{-1}$

Specific heat capacity of water,  $C_w = 4200\text{Jkg}^{-1}\text{K}^{-1}$

Average water temperature,  $\overline{T_w} = 70.25^\circ\text{C}$

Average ambient temperature,  $\overline{T_a} = 34.68^\circ\text{C}$

Aperture area of solar collector,  $A_c = 0.12\text{m}^2$

Average global solar radiation,  $H_T = 459\text{Wm}^{-2}$

Daily time period of investigation,  $t = 3600\text{s}$

$$\therefore \eta_c = \frac{(0.27 \times 920 + 0.5 \times 4200)(70.25 - 34.68)}{0.12 \times 459 \times 3600} = 42.13\%$$

Considering that same initial temperature conditions of the working fluid of about  $65^\circ\text{C}$  (in 15 March) and  $62^\circ\text{C}$  (in 17 March) were used as in the previously reported work, the thermal efficiency would have been:

Mass of pot,  $m_p = 0.27\text{kg}$

Mass of water in the pot,  $m_w = 0.5\text{kg}$

Specific heat capacity of pot,  $C_p = 920 \text{Jkg}^{-1} \text{K}^{-1}$

Average water temperature,  $\overline{T_w} = 79.41^\circ\text{C}$

Average ambient temperature,  $\overline{T_a} = 35.32^\circ\text{C}$

Aperture area of solar collector,  $A_c = 0.12 \text{m}^2$

Average global solar radiation,  $H_T = 459 \text{Wm}^{-2}$

Daily time period of investigation,  $t = 3600 \text{s}$

$$\underline{\eta_c} = \frac{(0.27 \times 920 + 0.5 \times 4200)(79.41 - 35.32)}{0.12 \times 459 \times 3600} = 52.22\%$$

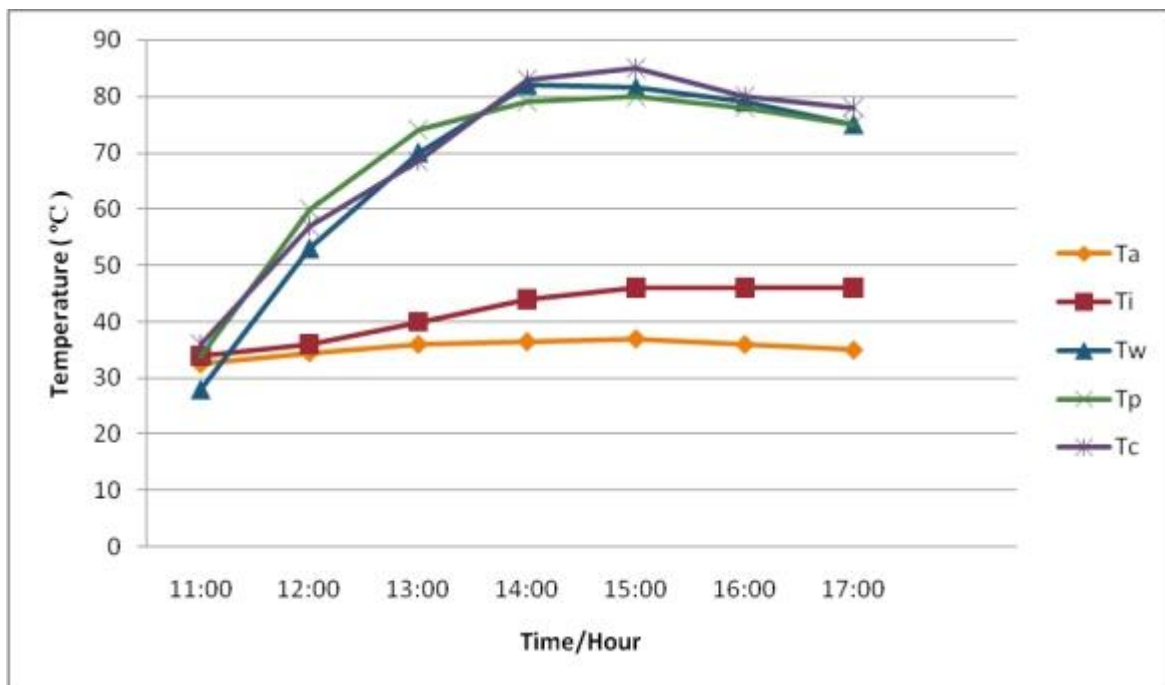


Figure3.1: Graph of temperature versus Time using the modified solar box cooker on 8<sup>th</sup> September 2023

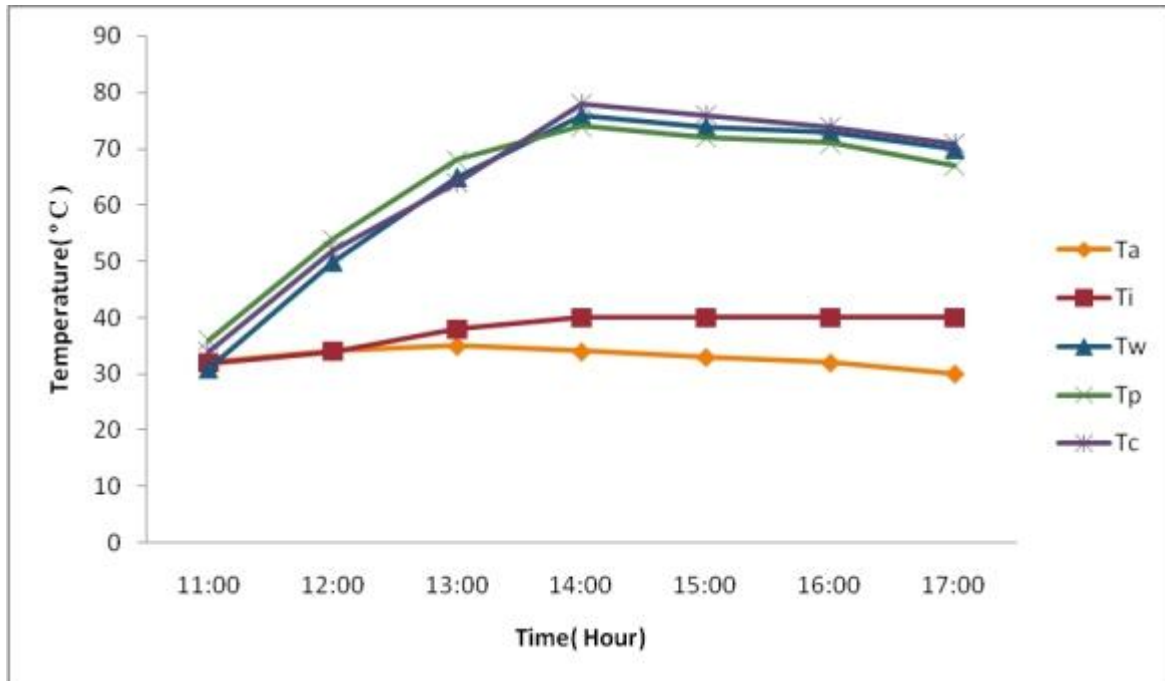
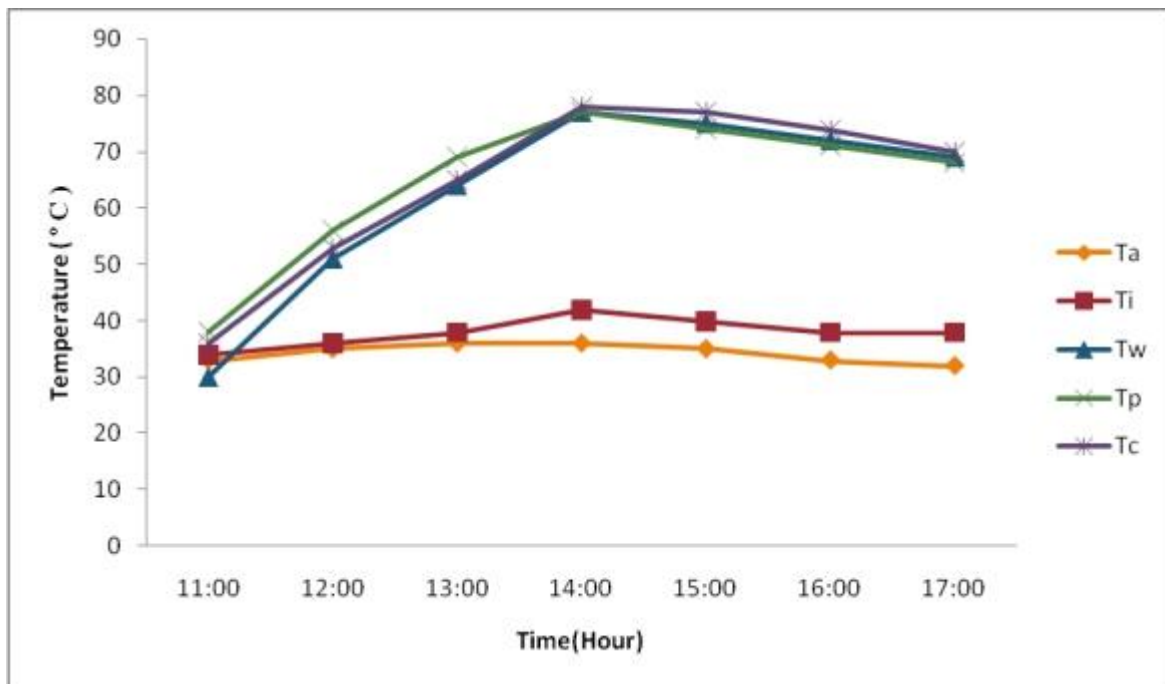
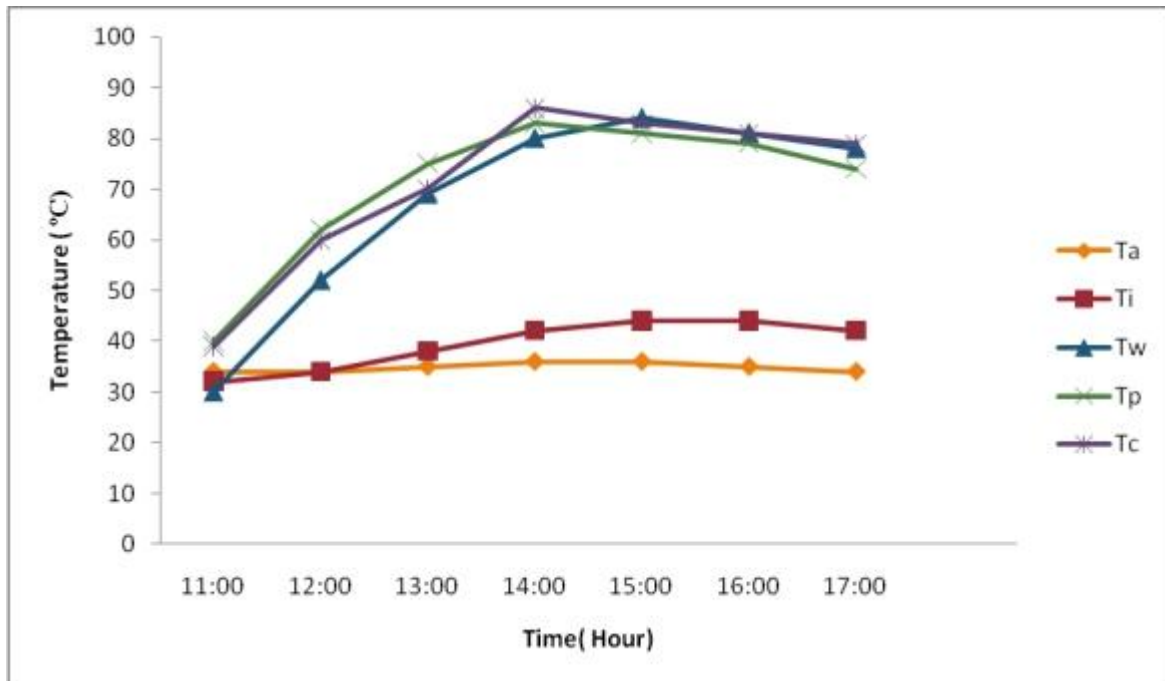


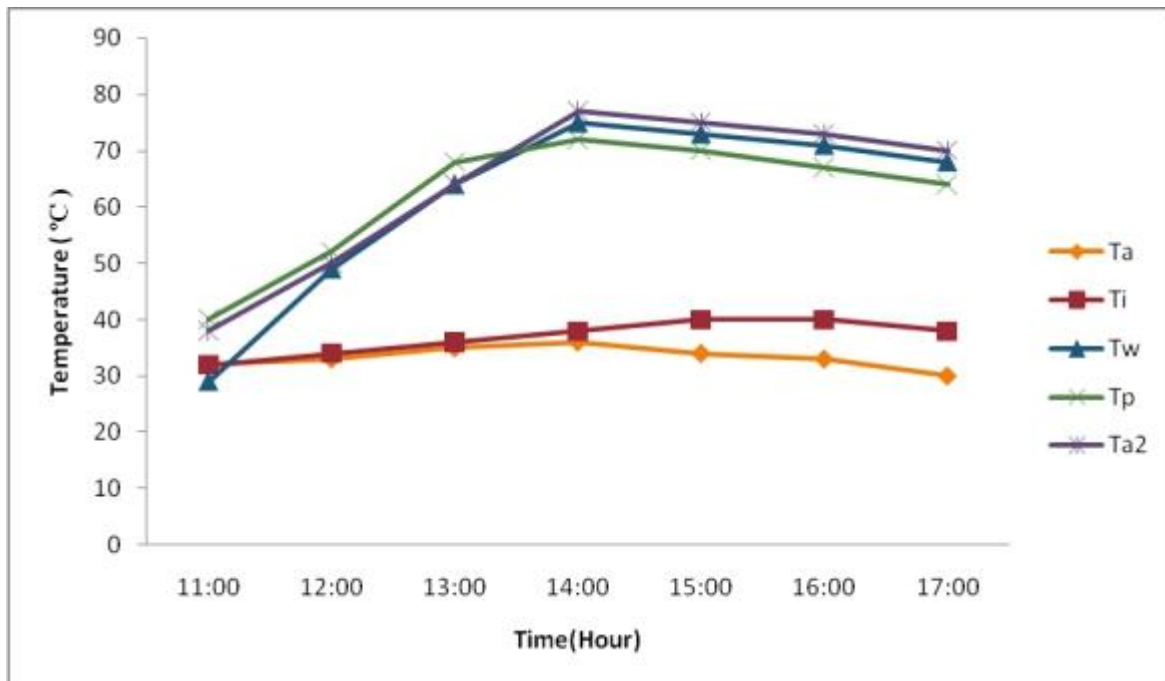
Figure 3.2: Graph of Temperature versus Time using the modified solar box cooker on 9<sup>th</sup> September 2023.



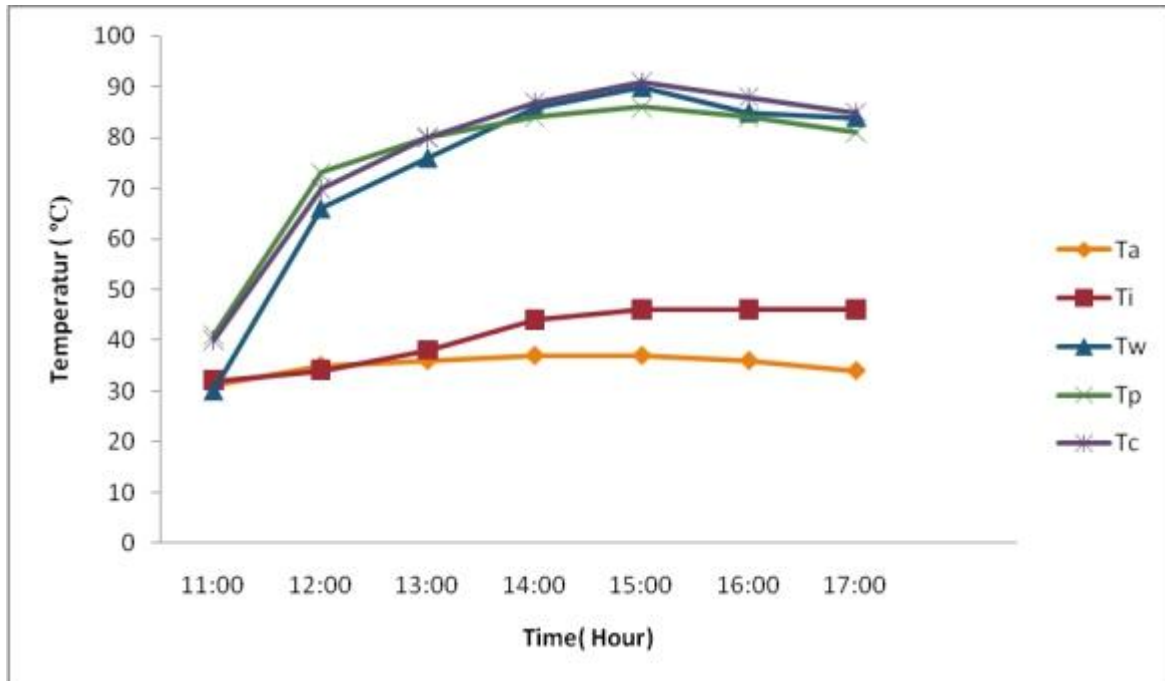
3.3: Graph of Temperature versus Time using the modified solar box cooker on 10<sup>th</sup> September 2023



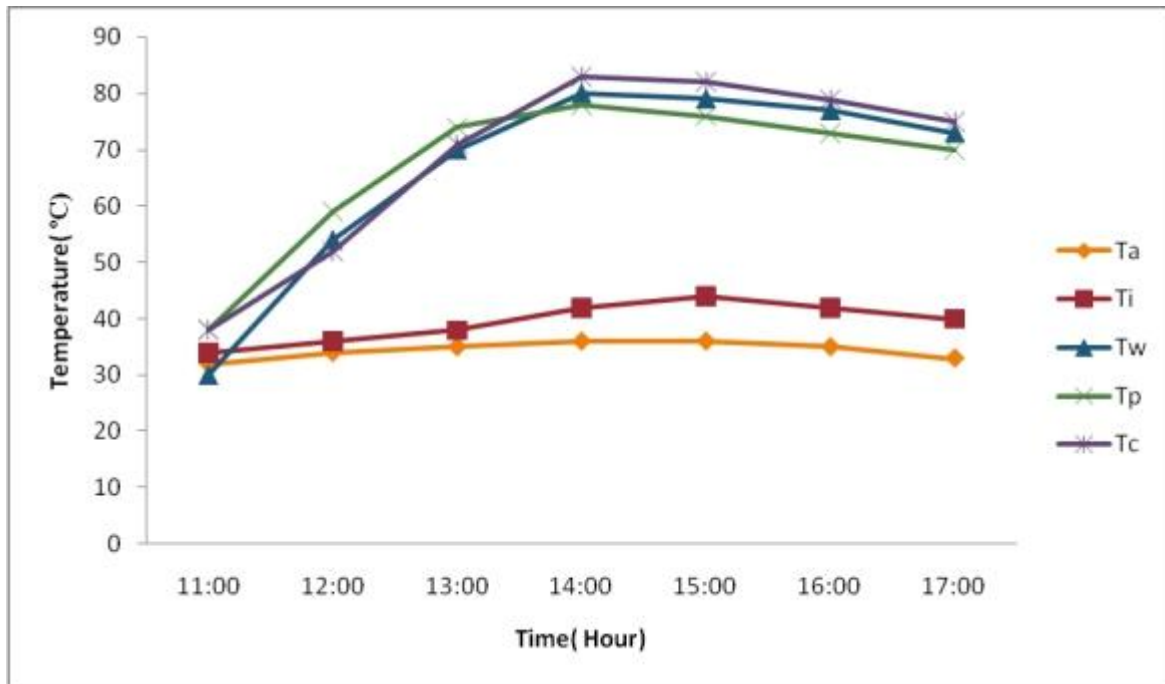
3.4: Graph of Temperature versus Time using the modified solar box cooker on 11<sup>th</sup> September 2023.



3.5: Graph of Temperature versus Time using the modified solar box cooker on 12<sup>th</sup> September 2023.



3.6: Graph of Temperature versus Time using the modified solar box cooker on 13<sup>th</sup> September 2023.



3.7: Graph of Temperature versus Time using the modified solar box cooker on 14<sup>th</sup> September 2023

## DISCUSSION

Figures 3.1-3.7 shows the hourly variations of the ambient temperature ( $T_a$ ), insulator temperature ( $T_i$ ), working fluid (water) temperature ( $T_w$ ), absorber plate temperature ( $T_p$ ), and cooking plate temperature ( $T_c$ ) observed for 10 different days of performance tests in the months of September 2023. As shown in the figure 4.1, a maximum temperature of the working fluid of about 82°C was attained around 14:00 hours (2pm) on this day of investigation in September (17/09/2023). According to figure 3.2 and 3.3, maximum temperature of the working fluid of about 76°C and 77°C were attained respectively around 14:00 (2pm) again. On 11/09/2023 (Figure 3.4), it can be seen that a maximum temperature of the working fluid of about 84°C was reached somewhat later in the e day around 15:00hours (3pm). Figure 3.5 indicates that a maximum temperature of the working fluid of about 75°C was recorded around 14:00 hours (2pm). However, figure 3.6 shows that a peak temperature of the working fluid of about 90°C was attained around 15:00 hours (3pm). In figure 3.7, a maximum temperature of the working fluid of about 80 °C was reached around 14:00 hours (2pm) by the constructed solar cooker. And on 14/09/2023 (Figure 3.8), maximum temperature of the working fluid of about 78 °C was attained around 15:00 hours (3pm). Figure 3.9 and 3.10 show that, maximum temperature of the working fluid of about 75.5 °C and 86 °C were attained around 14:00 hours (2pm) and 15:00 hours (3pm) respectively. From the results, it can therefore be observed that maximum temperature of the working fluid of about 90 °C was attained in (13/09/2023).

In general, it can be observed that, at the early hours of the day, the temperatures increased rapidly. For the second hour, the rate slows down, peak temperatures were mostly attained around 14:00 hours (2pm) th 9<sup>th</sup> and 11<sup>th</sup> while in 13<sup>th</sup> and 14<sup>th</sup> peak temperatures were mostly attained around 15:00 hours (3pm). The temperature of the cooker begins to drop gradually after the peak temperature. Also, it is evident that, the differences between the absorber plate temperature,  $T_p$  and cooking chamber temperature,  $T_c$  is not quite significant. This is possible a reflection of the good emittance and selective surface properties of the absorber plate.

Bello et al (20) reported that the required minimum food cooking temperature is 82°C. The result of the performance tests carried out in this work suggest that, this temperature was attainable during the periods of investigation in 13<sup>th</sup> and 14<sup>th</sup> September. This therefore indicates that the constructed solar box cooker is quite good for optimum use during these periods in the Area of study.

After the experimentation on the water heating tests, controlled cooking tests were carried out to examine the effectiveness of the cooker. The device was used to cook egg and rice (0.180kg). The tests were conducted from 11:00 hours 15:hours and it took 1hour 30minutes (11:00am – 12:30pm) to cook egg and 2 hours 20 minutes(12:40 – 3:00pm to cook rice which is comparable to the result obtained by Bello et al (2010)

The efficiency of the modified solar cooker has been calculated based on the results of the water heating tests conducted. The efficiency was calculated to be 42.13%.

## Conclusion

The following conclusions have been made from this study:

The performance evaluation of the modified solar box cooker showed that the cooker can heat water to a maximum of 90°C which is higher than the value of 88°C obtained by Bello et al in 2010.

The time taken by the solar device to cook egg and rice (0.180kg) was respectively found to be 1 hour 30 minutes and 2 hours 20 minutes while that of Bello et al in 2010 took 1 hour 30 minutes and 2 hours 30 minutes to cook the same quantity of egg and rice respectively. The device took a long time to cook the egg due to weak intensity of solar radiation in the early hours of the day.

The thermal efficiency of the solar cooker was found to be 42.13% which is lower than the value of 47.56% obtained by Bello et al (2010) for a similar cooker in the Guinea Savanna Region of Nigeria. However if the same initial temperature condition of the working fluid of 65°C in (September 15) and 62 °C in (September 17) were used as in the previously reported work, a thermal efficiency of 55.22% would have been obtained. This therefore implies that painting the entire inner surface of the solar box cooker black will give a better performance than painting only the absorber plate below box black.

Since this device can cook food in the time stated above, and with the aforementioned value efficiency; it can be concluded that the device could be used as alternative to firewood for avoidance of indiscriminate cutting down of trees which is the main objective of the research.

## Recommendations

Based on the results of this study, the following recommendations are made:

For the better performance of the device, one or more reflectors should be included as part of the cover to increase amount of insulation on the solar collector.

Light materials like plywood should be used to construct the box so as to reduce the weight of the box.

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