Design, Construction and Performance Evaluation of Box And Parabolic Solar Cookers

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Abstract:- In this study, two types of solar cookers namely; box-type, and parabolic solar cooker were designed and constructed using locally available materials. The primary goal of the research was to look at the thermal performance of the solar cookers that were constructed. To evaluate the thermal performance of the designed solar cookers, the water boiling, cooking power and temperature variation testwas used. The tests were carried out on the constructed cookers in Zomba (Malawi) throughout the monthsof May and June 2019. The results of thermal performance indicated that the parabolic solar cooker obtained a maximum temperature 146^{0}C on average, followed by the box-type solar cooker at 96*℃*. Also included are the findings of the solar cookers, the efficiency of the parabolic cooker, and the box-type cooker were found to be 38.6% and 71.7 % respectively.

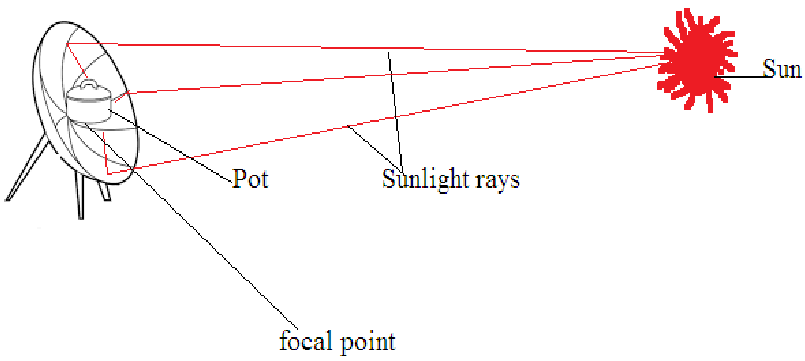
Keywords:- *Solar energy, parabolic solar cooker, Box solar cooker, thermal performance.*

I. INTRODUCTION

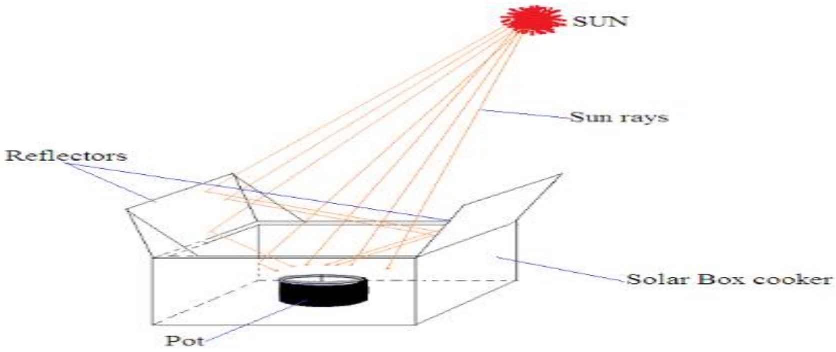
Cooking energy accounts for the majority of energy usage in most African nations, including Malawi. Because wood is the primary fuel for cooking in these nations, deforestation rate is very high. The rising need for fuel, along with a paucity of other sources, is a key contributor to deforestation. Over 75% of the population in Malawi live in the rural areas where electricity is mostly unavailable [19], hence there is high dependency on charcoal and fuel wood as a means of energy for cooking, which in turn has resulted in high deforestation rate [20,21]. Malawi being one of the Sub-Sahara African countries receives sunlight, with high intensity approximately to 5.4kWh/m^2, almost throughout the year, hence making cooking using solar energy convenient and possible[9,10].

Solar cookers are widely classified into three types: parabolic, box-type, and panel-type [3, 4, 7]. However, this research focused on parabolic and box type solar cookers. The box type solar cooker is an enclosed container with multiple or single glass (or other transparent material) covers [1,3,4]. The box-type of solar cooker is based on the "greenhouse effect," in which transparent glazing allows shorter wavelength solar radiation to pass through but is opaque to much of the longer wavelength radiation emitted by relatively low temperature heated materials[3, 4, 7,28, 31].In the box-type, mirrors are used to direct more sun radiation into the cooking chamber. Parabolic solar cookers, on the other hand, are direct concentrating cookers with a dish-type reflector that directs the majority of collected solar light to a point of focus [3, 4, 7].Dish-type concentrators require direct sunlight to work and must be frequently turned towards the sun. High cooking temperatures are one of the advantages for the parabolic solar cookers. The working principle of parabolic and box solar cooker is summarized in

Fig. 1. For the parabolic solar cooker, the direct solar radiation is reflected by the parabolic reflector to a focal point where high concentration is achieved and this results in in high pot temperatures which are suitable for cooking. On the other hand, the solar box cooker, the interior of the box is heated by the solar radiation. In this case, both direct and reflected solar radiation enters the solar box through the glass or plastic top cover which is then turnedinto heat energy when it is absorbed by the dark absorber plate and cooking pots.



(a)



(b)

Fig. 1: The schematic diagrams (a) show schematic diagram and working principle of parabolic solar cooker and (b) shows schematic diagram and working principle of box solar cooker.

Various types of solar cookers have been invented and tested all around the world. Recently, there has been a lot of interest in the design, development, and testing of several types of solar cookers. The methods used to assess the effectiveness of solar cookers include identifying one of the following: firstly, the cooking efficiency, time taken to heat a certain amount of water to the boiling point (water boiling test) and finally the temperature of the stagnation plate during an unloaded test. The second and third approaches are often used to assess the effectiveness of solar cookers. A common test approach for box-type solar cookers was proposed byAkoyand Ahmed [1].

Solar energy has grown in prominence in recent worldwide talks about energy and the environment. There have been a few attempts in the past to develop and promote solar cookers in Malawi. For instance, in some aspects only thermal efficiency was studied unlike time taken to heat a specific amount of any liquid [30]. In some aspects general problems on energy situation was studied even though solutions were proposed the researchers did not proceed further with their study [1, 7, 30].Based on the following, this study aimed at (i) fabricatingtwo different types of solar cookers and (ii) assessing the performance of the constructed solar cookers using the standard approach for testing solar cookers.

II. METHODS

This research was carried out in Zomba city, in Malawi which falls between latitudes, 15.3766° South and longitudes, 35.3357° East, and an altitude of 949m above the sea level. Locally available materials were used to construct the Parabolic and Box type solar cookers. card board box, aluminum foil, metal sheets, sawdust, nails, iron rod, and glue were some of the materials used.

A. The Design and Construction of the Box-Type Solar Cooker

The box-type solar cooker was made up of five components: a wooden container, an absorber plate (heat collector), a reflector, a glass lid, and a heat insulator (**Fig.** 2**).** A basic box container (0.8m x 0.8m) with a front height of 0.2m and a back height of 0.3m was fabricated. An absorbermetal plate with a dimension of 0.7m x 0.7m was fabricated out of a metal sheet coated black on the top surface to absorb the directed and reflected solar radiation. Paper Mache with a thickness of 5 cm was employed as an insulator and was deposited at the bottom side of the cookers between the absorber plate and the container, as well as on each side between the collector and the container. As a reflector, all of the interior walls of the box were coated with aluminum foil. A clear perplex glass, a 4mm thick (0.75m x 0.75m) was fixed to the top of the created box. To reflect more solar energy, a 0.75m x 0.75m reflector hinged at the top of the cooker was employed. For tracking, an adjustable lever was utilized.

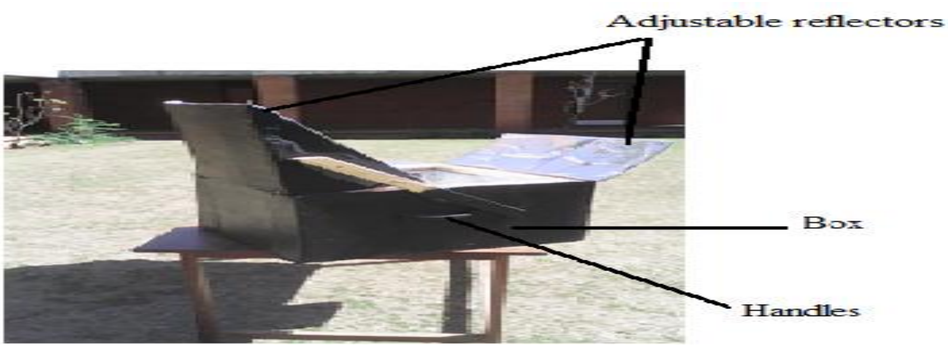


Fig. 2: Shows the constructed box solar cooker

B. The design and Construction of Parabolic Type Solar Cooker

The parabolic solar cooker is based on the parabolic dish reflector (model SK-14) that is used as a direct solar cooker and that is commercially available in many African countries[1, 6, 8. 31]). The advantage of this design is that it is easy to assemble and to maintain. The reflector of this cooker is a parabolic dish made of 24 identical reflecting petals that are interchangeable. Each petal is made of a reflecting galvanized sheet, instead of the usual anodized aluminum sheets, because galvanized sheets are locally available in Malawi. **Fig.** 3(a) shows a schematic diagram of one of the reflecting petals. Each petal consists of seven holes. The hole at the vertex of the petal (hole A) is where the bolt that attaches all the petals together is placed. The holes labelled B are used to fix the petals to a circular metal bar that forms the circumference of the Preliminary Design Review (PDR). The petals bend outwards and overlap when attached to the vertex and the circular metal bar. The holes labelled C are used to join the petals together so that the reflector of the solar cooker is rigid and maintains its parabolic shape. The reflector of the cooker has an aperture diameter of 1.364 ± 0.006 m, a depth of 0.440 ± 0.006 m and assuming a trueparaboloid shape, this gives a calculated focal length of 0.264 ± 0.006 m. **Fig.** 3**(b)** shows a photograph of the PDR. This is not a point-focus PDR but a fuzzy focus PDR.

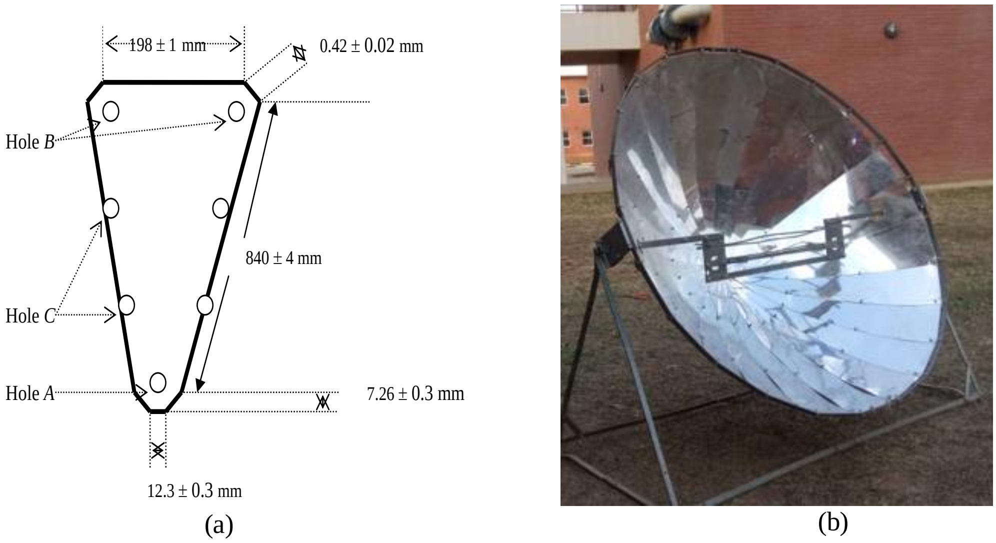


Fig. 3: (a) A schematic of a PDR petal with dimensions and (b) the PDR assembled using all the 24 petals

The focal point of the constructed parabolic dish was determined by making use of ray tracing technique [2]. The ray beam of light from laser source was let to hit the petals inside the dish at an angle (angle of reflection), then the point was determined where the reflected rays of light were meeting. This converging point of lesser light upon reflected was considered as the focal point, this is a point where the pot was made to be put when cooking with this constructed parabolic solar cooker.

C. Experiments

In order to evaluate the performance of the fabricated solar cookers, solar radiation was measured, stagnation temperature test for the unloaded box solar cooker, water boiling test and controlled cooking test were carried out on both parabolic and box solar cookers. The tests began at 9:00 a.m. and lasted until 16:00 p.m.

a) Measurement of solar radiation
In order to measure solar radiation, Eppleypyranometer, a standard instrument for measuring Global Solar radiation (GSR)[16], was connected to Campbell CR10, the data logger. The average solar radiation was recorded by the data logger at the interval of four minutes.

b) Stagnation temperature test
This test was carried out on the box solar cooker.This was done to test temperature distribution inside the box solar cooker before cooking with it. Three K-type thermocouple wires with a precision of ± 0.1 ^{o}Cwere connected to Campbell CR10,data logger, were positioned at various points inside the box solar cooker. The temperature for the battery powering the data logger was set as reference temperature (ambient temperature). The data logger was set to be recording temperature and time at the interval of four minutes.

The first thermocouple wire, labeled 1, inside the box solar cooker was let to touch the metal black plate forming the base of the box solar cooker. This was to test the temperature change due to the conduction of heat by the metal plate. The second thermocouple wire, labeled 2, was suspended in the air inan area where there was shading inside the box solar cooker.Since the test was conducted in winter not all areas were exposed to the sun since the sun was not overhead. The third thermocouple wire, labeled 3, was left hanging to the side where the box solar cooker was receiving light directly from the sun.

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c) Water boiling test
To assess the thermal performance of the solar cookers, water boiling test was used.Mercury glass thermometer was used to measure temperature change of water, beam balance was used to measure mass of water. Initial water temperature, maximum water temperature, and boiling water temperature were all measured and recorded using. The recorded data was utilized to calculate the thermal performance and efficiency of the solar cookers that were constructed.

d) Thermal efficiency
The following equation was used to calculate thermal efficiency (reference).

$$\eta_{\mu} = \frac{M_f C_f \Delta T_f}{I_{av} A_c \Delta T}$$

Where

$$\eta_{\mu} = overall\ thermal\ efficiency\ (\%)$$

$$M_f = mass\ of\ cooking\ fluid\ (kg)$$

$$= specific\ heat\ of\ cooking\ fluid\ \left(\frac{j}{kg}.K\right)$$

ΔT_f =difference between the maximum and ambient air temperature.

$$I_{av} = Average\ sun\ intensity\ \left(\frac{W}{m^2}\right) throughout\ the\ time\ interva$$

$$A_c = is\ the\ aperture\ area\ (m^2)\ of\ the\ cooker.$$

ΔT =time required to achieve the maximum temperature of the cooking fluid (s).

e) Cooking Power
The following equation was used to compute the cooking power of the constructed solar cookers.

$$P = \frac{Tw_2 - Tw_1}{t} m_w C_{pw}$$

Where

$$P = cooking\ power(w)$$

$$Tw_2 = final\ water\ temperature\ ^\circ C$$

$$Tw_1 = initial\ water\ temperature\ ^\circ C$$

$$t = time\ (s)$$

$$m_w = mass\ of\ water\ (kg)$$

$$C_{pw} = water\ heat\ capacity\ (4.168\ kJ/kg\ K).$$

f) Controlled cooking test
Cooking times for cooking various common local foodstuffs such as dry beans, rice, cassava, baking, and frying eggs were recorded. This was done to get the real-time effectiveness of the cooker's ability to cook local foodstuffs.Time taken to cook different common local foodstuffs so that they can be served on the table was recorded.

III. RESULTS AND DISCUSSION

This section presents and discusses the results of different measurements conducted in order to evaluate the thermos performance of the two constructed solar cookers. It has to be noted thatthroughout the test the minimum solar radiation was 100 W/m^{2}and the maximum was 540 W/m^2, which is consistent with the average solar radiation for Zomba for months of March to July [16].

A. Stagnation temperature test

The temperature of the absorber plate (thermocouple wire 1) and the ambient temperature are displayed against time in **Figure 4**. The maximum absorber plate temperature was found to be 136±0.005^{0}C during the middle of the day, as shown in the graph. The fact that solar radiation is variable throughout the day, reaching a maximum at noon when the insolation path length through the atmosphere is shortest, could explain the variation in absorber plate temperature during the day [1, 13]. Although the data collection was done in winter, clouds and rains could disturb, but from the findings, it can be extrapolated that during summer the graph should be curvature reach peak temperature at noon and slowly drop in the evening [1,9].

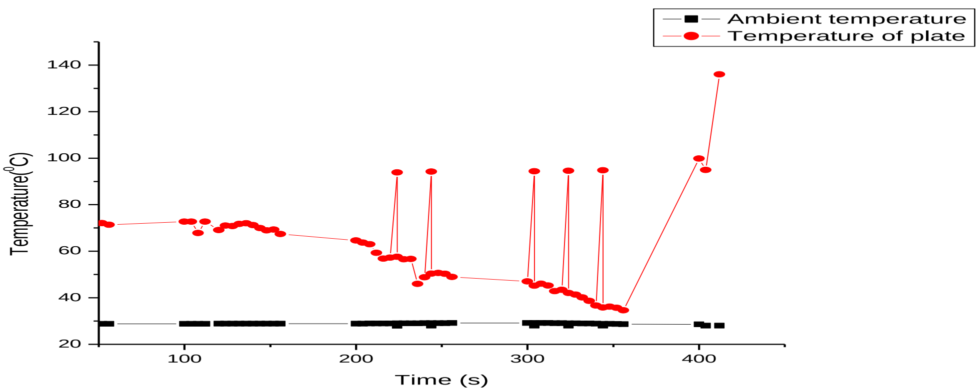
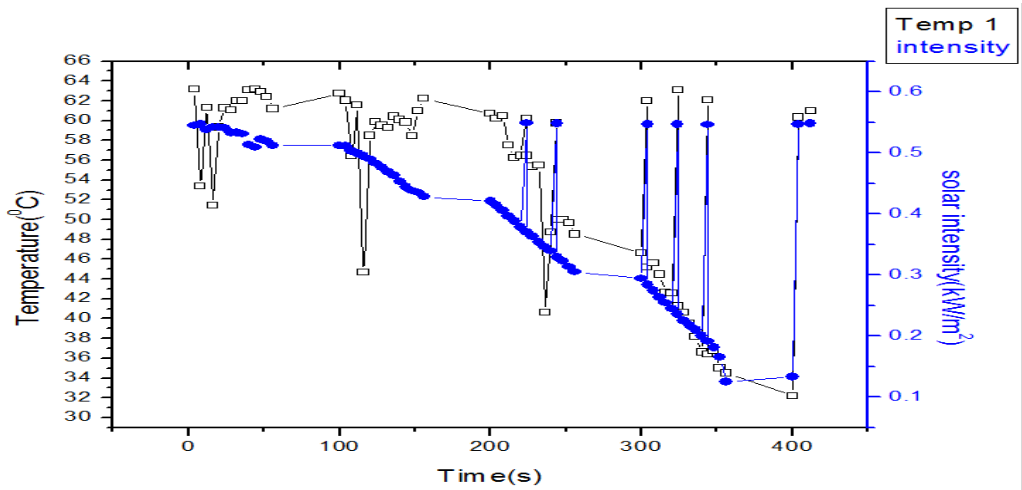
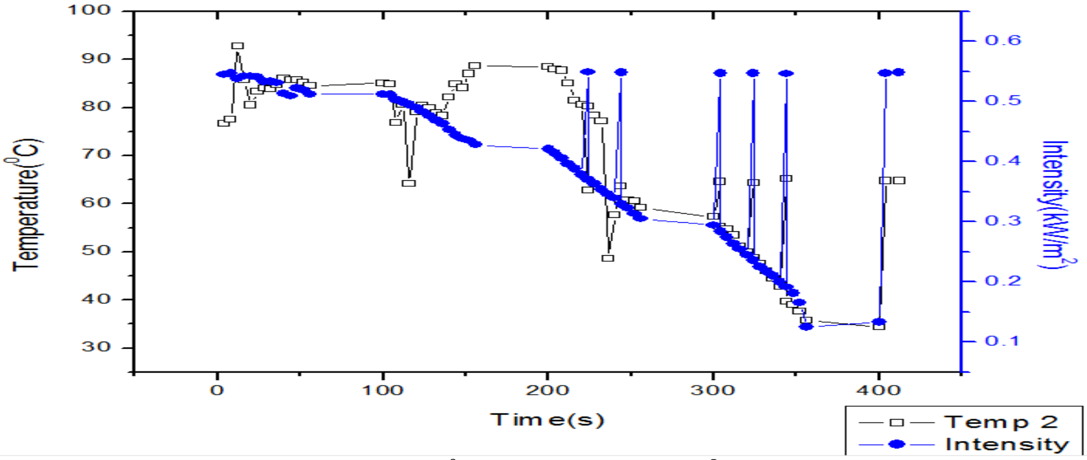


Fig. 4: The graph of ambient temperature, plate temperature against time

Figure 5 shows temperature and solar intensity fluctuations plotted vs time for thermocouples wire 2 and thermocouple wire 3, placed in the shade d area and area receiving direct sunlight respectively, inside the Box solar cooker. (a)The graph of temperature (^{0}C) and intensity (kW/m^2) against Time (s)for thermocouple wire 2and (b) The graph of temperature (^{0}C) and intensity (kW/m^2) against Time (s) for thermocouple wire3. This was done to check if there is no temperature stagnation inside the box solar cooker [3, 6, 13].



(a) The graph of temperature (^{0}C) and intensity (kW/m^2) against Time (s)for probe 2



(b)The graph of temperature (^{0}C) and intensity (kW/m^2) against Time (s) for probe 3

Figure 5. The graph of temperature (^{0}C), solar intensity (kW/m^2) against Time (s).**(a)**The graph of temperature (^{0}C) and intensity (kW/m^2) against Time (s) for probe 2 and**(b)** The graph of temperature (^{0}C) and intensity (kW/m^2) against Time (s) for probe 3.

Probe 2 for the thermocouple wire 2, was hanged to the side which formed a shade inside the box solar cooker. Since the test was conducted in winter not all areas were exposed to the sun as the sun was not overhead, adjustments were made but still, some areas had shade [7, 14, 17, 19]. This is where probe 2 was put to measure temperature distribution. The results have been plotted as shown in **Figure 5 (a)**. The lowest temperature recorded was 32.5^{0}C and the highest temperature recorded was 63^{0}C, minimum solar intensity was 100W/m^2 and maximum solar intensity was 540W/m^2. Though probe 2 was suspended in the air and was placed in a region where there was a shed, still the temperature rose through the convention process within a short time[11, 16]. This gives hope that if this test is to be conducted in summer, the temperatures could rise so high within the same period of time.

Probe 3 for the thermocouple, the wire was placed in suspense to the side where the box solar cooker was receiving light directly from the sun to the box solar cooker, temperature, intensity, and time were measured. The results are shown in **Figure 5 (b),** whichreveals that the lowest temperature recorded was 32.5^{0}C and the lowest solar intensity was 100W/m^2. The highest solar intensity was 540W/m^2 while the highest temperature recorded was 95^{0}C. From this data, it has been seen that though probe 3 was suspended in the air and was placed in a region where there was direct sunlight, the temperature rose close to the boiling point of water through the convention process within a short time[11, 17].

B. Water boiling tests

Figure 6 indicates the maximum achievable water temperature for water boiling tests done under the same test circumstances on the two solar cookers. The highest achievable water temperature of tested parabolic and box-type was determined to be 105± 0.1^{0}C and 78± 0.1^{0}C respectively. The results show that the parabolic solar cooker performed best in terms of water heating than the box solar cooker, these results are in agreement with the findings of other researchers elsewhere [1, 21, 28].

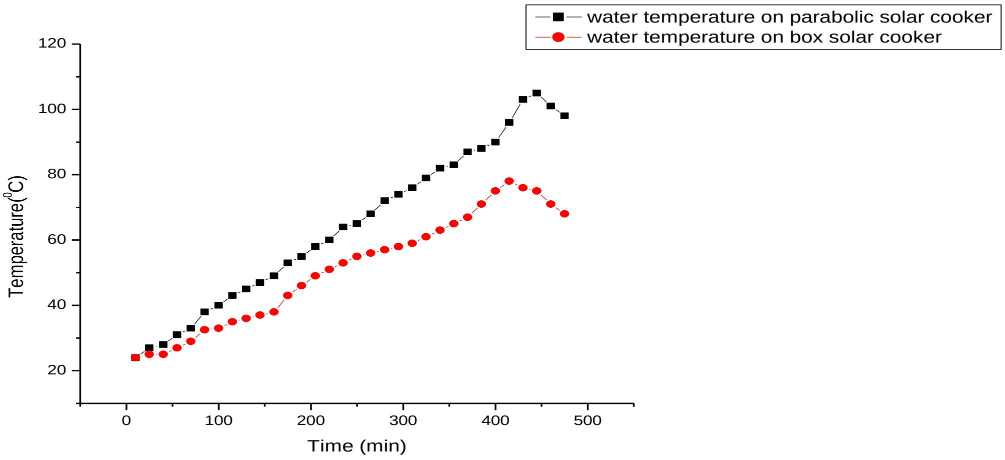


Fig. 6: Water temperature variation on the two solar cookers.

a) Solar cookers Efficiency

From the data as shown in **Figure 6,** solar cookers efficiency was calculated for 2 kgof water, it has been found that box type solar cooker attained high efficiency of 71.7% than a parabolic solar cooker 38.6% this is due to the fact that heat losses to the surroundings as a result of a high-temperature gradient. Another reason is that the solar box cooker maintains heat inside the box, whereas other forms of cookers are open and lose heat [1].

C. Controlled cooking test

The Box solar and parabolic solar Cookers have been tested for different foodstuffs and the time it takes to cook such food was recorded during the winter season in Malawi. Cooking dried beans on the box Solar cooker took three hours without adding the spices while cooking the dried beans on the parabolic solar cooker took one hour 30 minutes including the addition of spices making it ready to be served on a table. Boiling 1 liter of water on the parabolic solar cooker takes 10 minutes while on Box solar cooker 1 liter of water takes 50minutes. Cooking rice on the parabolic solar cooker took 15minutes. These findings show that cooking using box solar and parabolic solar cookers is possible with all activities which are done when one is using an electric stove, gas, or charcoal only that when using solar cookers, the source of energy is the sun.

D. Solar Cookers power

From the data calculated it was found that a parabolic solar cooker has a cooking power of 52.5 W while a box type has a cooking power of 19.5 W This explains that an increase in the area of the solar cooker increases the sun gathering ability, the converted heat will be greater [1, 6, 32].

IV. CONCLUSIONS

Based on the results obtained from the study the following conclusions were drawn firstly the solar cookers that were constructed performed admirably in terms of water heating. Secondly the constructed parabolic solar cooker can easily boil water, the solar cookers that were constructed were used to cook most local Malawian food stuffs. And finally, the use of solar energy in cooking is intended to help the environment while also lowering health concerns.

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