



Full Paper

DEVELOPMENT AND EVALUATION OF A MULTI-REFLECTOR DOUBLE EXPOSURE BOX-TYPE SOLAR COOKER

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ABSTRACT

Solar cookers are known to present an alternative energy source for cooking but, there is need for new designs to overcome some of its setbacks. A multi-reflector double exposure box-type solar cooker was developed with a surface dimension of 670 mm × 670 mm and a collector area of 0.264 m². It comprised an outer and inner box; a double glazing; an absorber plate (painted black); aluminium foil reflectors; saw dust (insulator) and aluminium pots (with reed-like protrusions added to the inner surface of the pot cover). The cooker was subjected to stagnation, water heating and cooking tests. The cooker's thermal performance was analysed by estimating the heating power and the sensible heat efficiency. Results reveal a maximum stagnation temperature of 102 °C, rising at an average rate of 5.0 °C per 15 min. The maximum water temperature attained while heating 1 and 2 kg of water was 92.3 °C and 80.0 °C respectively. A maximum heating power of 32.4 W and 26.0 W was observed for 1 and 2 kg of water, respectively while their respective maximum heat efficiencies were; 14.0% and 21.2% respectively. This study reiterates the usability and suitability of solar cookers in a tropical region.

Keywords: *Stagnation, water heating, heating power, heat efficiency and double exposure*

1. INTRODUCTION

One of the major applications of solar thermal energy is solar cooking. Solar cooking is not a new technology and has been improved over the years leading to various designs. Excluding the fact that solar cookers are simple and easy to use, it has the advantage of preserving the nutritive value of food (because the cooking is done at low temperature) and preserving the environment (because it is pollution free). There are several classifications of solar cookers in the literature but prominent

among them is that of Kundapur (1998) in which they are classified into two i.e. Direct solar cookers and indirect solar cookers.

In an indirect solar cooker, the pot is physically displaced from the collector and a heat transferring medium is required to convey the heat to the cooking pot. On the other hand, direct solar cookers have their pots in the same position as the collector hence; a heat transfer medium is not required to convey heat to the cooking pot. There are three types of direct solar cookers: i.e. panel, box and parabolic solar cookers.

A box-type solar cooker depends on the greenhouse effect in which the transparent glazing permits the passage of shorter wavelength solar radiation, but it is opaque to most of the longer wavelength solar radiation (Sedighi and Zakariapour, 2014). Attempts have been made by several researchers to improve the performance of the box-type solar cooker. Modifications have been done in terms of sun tracking, type of aperture, size, heat storage, auxiliary heating, pot design, etc. All these modifications and adaptations were directed towards overcoming some factors limiting the performance of solar cookers (e.g. sun movement, varying solar intensity, wind, pot thickness, cloud, etc.) thereby improving its efficiency. Al-Azab et al. (2009), Adedipe and Abolarin (2011) and Rikoto and Garba (2013) attached fins to the body of the cooking pots in a solar cooker. The fins added increased the thermal efficiency of the entire design. Al-Azab et al. (2009) observed that the thermal efficiency of the finned pot was 3% higher than that of the unfinned pot. Aremu (2004) developed a cooking pot with reed-like projections attached to the underside of the pot's lid to ensure faster conductive heat transfer from the top of the lid to the food. Uhuegbu (2011) observed that reflectors increased the amount of solar radiations getting into a box-type solar cooker. Martin et al. (2006) reported that the peak air temperature of a cooker with four reflectors was approximately 20°C higher than the cooker with only one reflector. Increasing the size of the reflectors also increases the net energy available to the cooker. (Mohurle, 2011). According to an experimental investigation carried out by Arabacigil et al. (2014), the optimum angle for the outer reflector of a box solar cooker is 30°.

Apart from the modification of various components of the box-type solar cookers, the entire box designs have been modified by several researchers. Nahar et al. (2009) developed a larger box solar cooker capable of containing twelve pots at a time. The cooker can be used twice a day for about 254 days. Mohammed et al. (2013) developed a truncated pyramid box-type solar cooker which is different from the usual rectangular box cookers. They observed a plate stagnation temperature of 145°C. Saravanan and Janarthanan (2014a) developed and evaluated the thermal performance of a

double exposure solar box cooker. The double exposure solar cooker has been found to be efficient in both summer and winter in terms of energy and exergy analysis (Saravanan and Janarthanan, 2014b).

The double exposure solar cooker developed by Saravanan and Janarthanan (2014a) was completely exposed at the base; making it to lose more heat to the environment. It does not have any reflector at the top of the cooker thereby not fully utilizing its capacity. Based on all these, this paper is aimed at developing and evaluating the performance of a multi-reflector double exposure box-type solar cooker.

2. THEORETICAL DEVELOPMENT

2.1. Design Considerations

The factors considered for the design are;

- i. Cooking Temperature: The cooking temperature should be adequate to cook various foods. For health and safety, the required cooking temperature for food is a minimum of 75°C (SGV, 2014) with a danger zone of 5°C - 60°C.
- ii. Absorber: The collector (usually a black body) should have high absorptivity so as to be able to capture sunlight. This will be the basis for the selection of the material to be used.
- iii. Reflector: The reflectors are to have a high reflectivity coefficient and durability.
- iv. Glazing: The materials used for the glazing window should have high optical transmission coefficient so as to allow the sun rays to easily transmit unto the collector. Heat loss reduction through this medium is also an important consideration. More than one glazing will reduce heat loss.
- v. Insulation: The cooker should be well insulated and the insulation materials should be stable at the working temperature.

2.2. Material Selection

Based on the design considerations above, the following materials were selected;

- i. Glazing: A double glazing of tempered glass was selected and used with 30 mm clearance from pot. It has a thickness of 3 mm, optical transmission coefficient (τ) of 0.92 and an overall heat transfer coefficient (U_w) of 2.8 W.m⁻².K⁻¹
- ii. Absorber plate: Mild steel (painted black) was selected based on its low cost. It was coated black to boost the emissivity/absorptivity above 0.9 and also to protect the surface from corrosion.
- iii. Plane and Parabolic Reflectors: Aluminium foils were used due to its good balance of cost, reflectivity, durability and ease of replacement. It has a reflectivity of 0.88 (Chapin et al., 2011).
- iv. Insulator: Saw dust whose thermal conductivity is 0.042 W.m⁻¹.°C⁻¹ (Akinwale, 2006) was selected due its performance, availability and the need to reuse waste products.
- v. Cooker Frame and support: Drum wood ($\dot{\sigma}m\dot{\sigma}$) (*Cordia millenii*) was used for the outer box due to its ease of workability, finishing, good gluing, resistance to termites, rapid drying and expected service life of 8-25 years (Jiofack, 2010). It was used to enhance the isolation of the internal surface of the cooker from the environment. Mahogany was used for the stand due to its good strength to weight ratio and good workability (Anonymous, 2008).

- vi. Cooking pot: Aluminium was selected for its high thermal conductivity (205 W/mK). It was painted black on the outside for good heat absorption.

2.3. Assumptions

The design assumed an ambient temperature (T_a) of 30 °C and a solar intensity (I_o) around 850 W/m² for Ibadan (Aremu and Akinoso, 2013). The room water temperature (T_w) was also assumed to be 25 °C. It was also assumed that the maximum attainable temperature of the cooking pot and absorber (T_p and T_{ab}) was 180 °C while the percentage of heat loss by side walls and bottom of the cooker (q_l) was taken to be 7% of I_o (Ekechukwu and Ugwuoke, 2003) i.e. 60 W/m². The cooker was designed to serve a family of four; hence, the pot used has a depth (H_p) of 90 mm and diameter (D_p) of 210 mm.

2.4. Determination of Collector (Inner box) Area

The design was carried out in accordance with the steps given by Nofziger (2008) and the theoretical basis given by Çengel (2004). The power available/incident (P_{inc}) to a solar cooker of aperture area A_s under an insolation of I_o is given as;

$$P_{inc} = I_o A_s \tag{1}$$

A fraction of this power is transmitted through glass coverings and it depends on the transmission coefficient (τ) of the glazing window. This is given as;

$$P_{trans} = \tau P_{inc} \tag{2}$$

For n number of glazing,

$$P_{trans} = \tau^n I_o A_s \tag{3}$$

This transmitted power reaches the absorber, but the amount absorbed will depend on the absorptivity of the absorber (α); hence, the power absorbed is;

$$P_{abs} = \alpha P_{trans} \tag{4}$$

With the addition of reflectors, the power absorbed will also be a factor of the reflectivity of the reflecting materials (r) and a gain factor (G); hence, the absorbed power is given as

$$P_{abs} = \alpha \times P_{trans} \times G \tag{5}$$

Where for N reflectors with dimension $u \times v$, G is given as:

$$G = 1 + \left[N \cdot r \left(\frac{u}{v} \right) \sin \left(\cos^{-1} \left[\frac{\frac{u}{v} \sqrt{\left(\left(\frac{u}{v} \right)^2 + 8} \right)}}{4} \right] - 90 \right) \right] \tag{6}$$

$$\Rightarrow P_{abs} = \alpha \cdot \tau^n \cdot I_o \cdot A_s \cdot G \tag{7}$$

Where: G is the Power gain factor due to the reflectors (unit less); N represents the number of reflectors; r , the reflectivity of the reflector (unit less), while u and v are the length and width of the reflector, respectively (m). I_o is the solar intensity (W/m²); A_s is the area of the aperture (m²); α is the absorptivity of absorber (unit less); τ is the optical transmission coefficient of glazing material (unit less); P_{abs} is the power absorbed (W) while P_{trans} represents

the power transmitted (W) through the glazing and n , the number of glazing.

On the other hand, from Stefan Boltzmann's law, the radiation emitted by a black body per unit area is given as;

$$E_b = \sigma T_{ab}^4 \quad (8)$$

and the heat energy radiated by the absorber is;

$$Q_{rad} = E_b A_s \Delta t \quad (9)$$

The power radiated is therefore;

$$P_{rad} = E_b A_s \quad (10)$$

But this power is limited and it depends on the absorptivity¹ (α) of the absorber; hence,

$$\Rightarrow P_{rad} = \alpha \sigma T_{ab}^4 A_s \quad (11)$$

Where: P_{rad} represents the power radiated (W); σ stands for Stefan-Boltzmann constant ($5.67 \times 10^{-8} \text{ Wm}^{-2} \text{ K}^{-4}$); T_{ab} is the temperature of the absorber (K) and Δt , the time difference (Sec).

According to Kirchhoff's law, the radiation incident on any point of the surface of the small body is equal to the radiation emitted by a blackbody at temperature T . i.e. $P_{abs} = P_{rad}$

Practically, for the entire cooker, there will be power loss through the glass cover and through the insulation at the sides and bottom of the cooker.

$$\Rightarrow P_{abs} = P_{rad} + P_{loss} \quad (12)$$

The losses through the insulation at the walls and bottom of the cooker was assumed to be 7% of the insolation for a total area of 1m^2 (Ekechukwu and Ugwuoke, 2003) while the loss through the circular opening at the bottom is assumed to be negligible since a parabolic reflector is to heat the absorber from below. There will also be losses through the glazing window at the top of the cooker. This loss is given as;

$$P_w = U_w \cdot A_s \cdot \Delta T \quad (13)^2$$

Where: P_w is the power loss through glazing window (W); U_w represents the overall heat transfer coefficient of the glazing window ($\text{Wm}^{-2} \text{ K}^{-1}$) and ΔT , the difference in temperature between the absorber and the ambient ($^{\circ}\text{C}$).

The total power loss, P_{loss} , can be expressed to be;

$$P_{loss} = U_w \cdot A_s \cdot \Delta T + 0.07 I_o \quad (14)$$

Substituting Equations (7), (11) and (14) into Equation (12)

$$\Rightarrow \alpha \cdot \tau^n \cdot I_o \cdot A_s \cdot G = \alpha \sigma T_{ab}^4 A_s - (U_w \cdot A_s \cdot \Delta T + 0.07 I_o) \quad (15)$$

From Equation (15) above, the area of the absorber surface can be computed from;

$$A_s = \frac{0.07 I_o}{[(\alpha \cdot \sigma \cdot T_{ab}^4) - (U_w \cdot \Delta T) - (\alpha \cdot \tau^n \cdot I_o \cdot G)]} \quad (16)$$

For ease of construction let $u = v$; hence, from equation (16),

$$G = 1 + \left[N \cdot r \left(\frac{v}{l} \right) \sin \left(\cos^{-1} \left[\frac{1 - \sqrt{((1)^2 + 8)}}{4} \right] - 90 \right) \right] = 1 + [3 \times 0.88(1) \sin(12 - 90)] = 2.32$$

Substituting the value of G and other variables into Equation (16),

$$A_s = \frac{0.07 \times 850}{\left[(0.9 \times 5.67 \times 10^{-8} \times 453^4) - (2 \times (180 - 30)) \right] - (0.9 \times 0.92^2 \times 850 \times 2.32)}$$

The collector (inner box) area A_s is therefore, 0.264 m^2

If the dimension of the inner box is $l \times w$, let $w = l$ for ease of construction,

$$\Rightarrow l = \sqrt{0.264} = 0.512 \approx 520 \text{ mm}$$

In order to give space for the absorber, 530 mm was used; hence, $l = w = 530 \text{ mm}$

Figures 1 and 2 show the absorber plate and the inner box respectively.

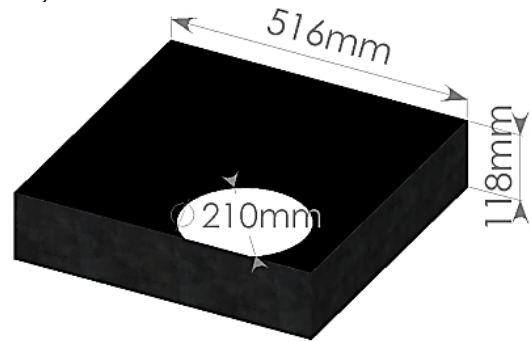


Figure 1: Absorber plate

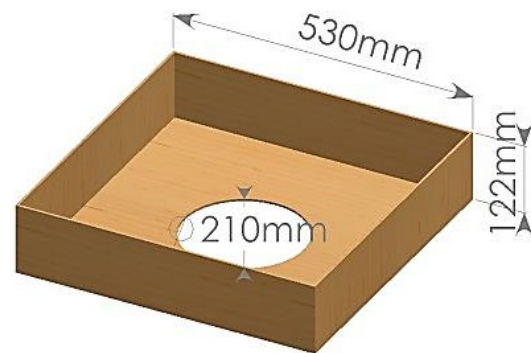


Figure 2: Inner box

2.5. Determination of the Thickness of Insulation Material

From Fourier's law of thermal conduction, for a given insulator with thermal conductivity, K , the thickness, x , needed to limit heat loss to, q_L , given a temperature change of ΔT is;

$$x = \frac{K A_{sb} \Delta T}{q_L} \quad (17)$$

¹ Or emissivity (ϵ)

² The surface area of the absorber is approximately equal to the area of the glazing window

$$A_{sb} = \text{Area of 4 sides} + \text{Area of base} - \text{Area of opening} = 4(l \times H) + (l \times w) - \frac{\pi D_p^2}{4}$$

$$D_p = 210 \text{ mm}$$

$$H (\text{wall height}) = \text{Pot height (90 mm)} + \text{Clearance between glazing and pot (30 mm)} = 120 \text{ mm}$$

$$A_{sb} = 4(120 \times 520) + 520^2 - \left(\frac{\pi \times 210^2}{4}\right) \approx 4.85 \times 10^5 \text{ mm}^2$$

$$= 0.485 \text{ m}^2$$

$$\Rightarrow x = \frac{0.042 \times 0.485 \times (180 - 30)}{60} \approx 0.05 \text{ m} = 50 \text{ mm}$$

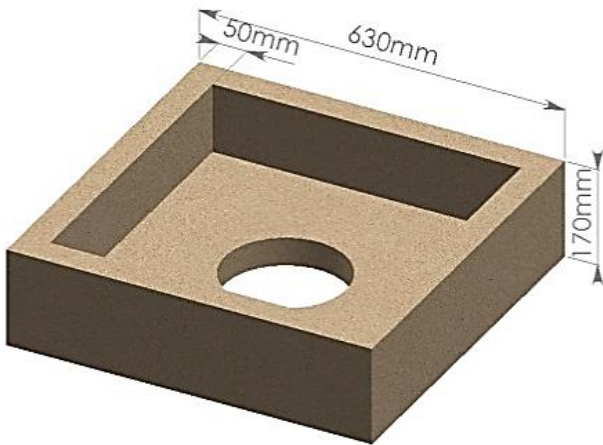


Figure 3: Saw dust (the shape it forms in the solar cooker)

2.6. Pot Cover Design

In order to enhance heat transfer from the top of the pot to the pot contents, reed-like protrusions were added to the inner surface of the pot cover which extends outwards towards the inner surface of the pot. The area of the pot cover is 0.0346 m² hence, given an insolation of 850 W/m², the power absorbed by the pot cover is;

$$0.0346 \times 850 \times 0.9 = 26.469 \text{ W}$$

This implies that each of the four reeds will transfer heat of 6.6 W. The reeds were made of aluminium whose thermal conductivity is 205 W/m.K; hence, a reed of 70 mm long and 10 mm wide will be adequate to transfer 6.6 W of heat.

Figure 4 shows the details of the pot cover and pot assembly.

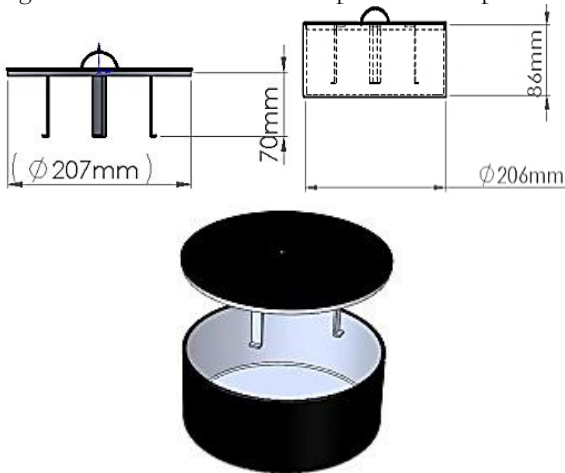


Figure 4: Pot cover and pot assembly

2.7. Dimension of Parabolic Reflector

The height of the cooker was designed to allow the user work with the back remaining at a neutral position. The acceptable height of a work table for light work is 5 to 10 cm below the elbow height i.e. about 85 to 110 cm (CCOHS, 2008). Based on these, the height (H_c) selected was 90cm.

The focal point (F) of the bottom reflector should be at the bottom of cooking pot located at z = 50 mm from the bottom of the box; hence,

$$F = H_c - z \tag{19}$$

$$F = 900 - 50 = 850 \text{ mm}$$

To get the diameter of the parabolic reflector (D_{pr}), it is required that the reflector be foldable up to the height of the cooker. Taking the height of the reflector stand, R_s as 200 mm;

$$D_{pr} = H_c + H - R_s = 900 + 120 - 200 = 820 \text{ mm}$$

The depth of the parabolic reflector is;

$$d_{pr} = \frac{(D_{pr}/2)^2}{4F} \tag{20}$$

$$d_{pr} = \frac{(820/2)^2}{4 \times 850} = 49.4 \text{ mm} \approx 5.0 \text{ cm}$$

The dimensions of the parabolic reflector are; Focal length: 85 cm; Diameter: 82 cm and Depth: 5 cm. Figure 5 shows the dimension of the bottom reflector frame.

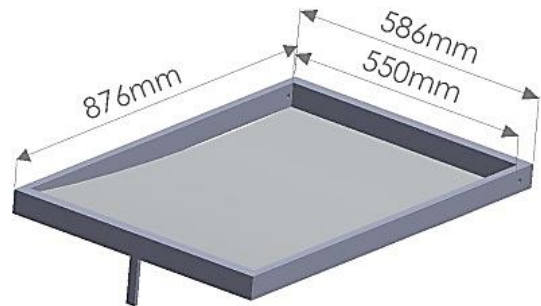


Figure 5: Bottom reflector

Generally, the dimensions of the cooker is

$$\text{length of frame} + \text{insulator} + \text{absorber} = (25 + 25) + (50 + 50) + 520 = 670 \text{ mm}$$

which was the same dimension with the plane reflectors as shown in Figures 6 and 7. Figure 8 shows the complete assembly of the cooker.

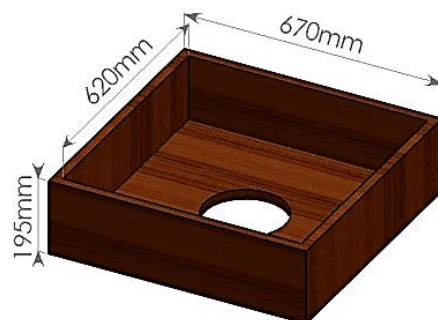


Figure 6: Outer box of one of the solar cooker

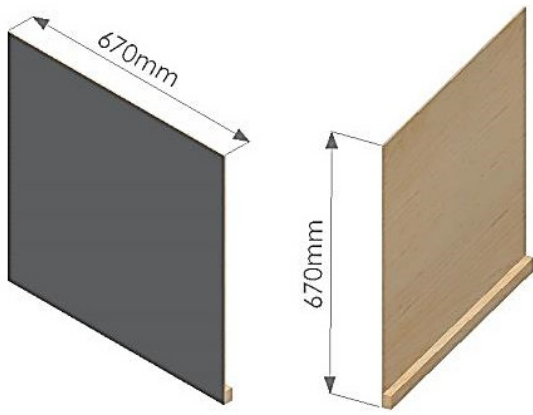


Figure 7: Plane reflector

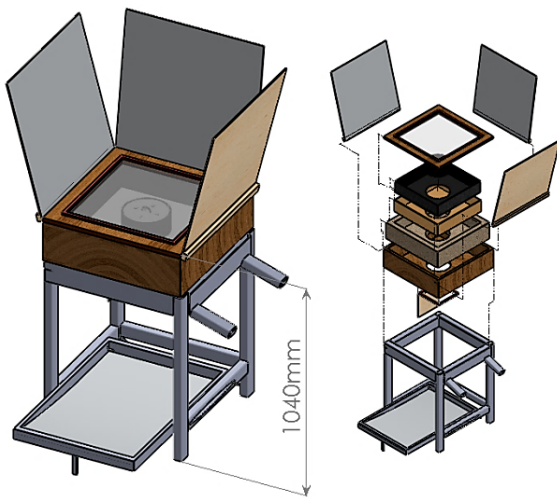


Figure 8: Exploded view of the solar cooker



Figure 9: Solar cooker setup under solar radiation

The thermal performance of the solar cooker was evaluated by estimating the heating power and sensible heat efficiency using equations (21) and (22), respectively.

$$\dot{Q} = \frac{M_w C \Delta T}{\Delta t} \quad (21)$$

$$\eta = \frac{\dot{Q}}{I_0 A_s} \quad (22)$$

Where; M_w is the mass of water heated (kg), C is the specific heat capacity of water (J/kg K), ΔT represents the difference between an initial and final water temperature ($^{\circ}\text{C}$) and Δt is the time difference (sec).

3. EXPERIMENTAL PROCEDURES

In evaluating the cooker, stagnation, water heating and cooking tests were carried out. The instruments used for these tests include; k-type thermocouples, multi-channel temperature logger (REED Thermometer SD-947) and indicator (Supco EM60), solar meter (Dr Meter Solar Power Meter SM206) and digital weighing balance (METRA TL-5000). The cooker was set up in an open area (figure 9) with its reflectors facing the direction of the sun. Care was taken to ensure that shadow was not casted on the surface of the cooker. The hot junction of the thermocouples was fixed at the absorber plate and inside the pot, while the other ends were connected to the multichannel temperature logger and indicator.

During the stagnation (no load) test, the temperature of the empty pot, absorber plate and the ambient temperature were recorded at 30 sec interval using the multichannel temperature logger and indicator while the intensity of solar radiation was measured using a digital solar meter. Average values of these measurements were estimated for each 15 min interval. The experiment lasted till the intensity of solar radiation dropped below 400 W/m^2 . Similar measurements were taken for water heating and cooking. For water heating, 1 kg and 2 kg of water were heated on separate days while the water temperature was recorded with a temperature logger at 30 sec interval and an average measurement over a 15 min interval was estimated. For the cooking test, 500 g of water was used in cooking four eggs while, 260 g of water was used in cooking 200g of jollof rice.

4. RESULTS AND DISCUSSION

4.1. Stagnation Temperature

Figure 10 shows the variation in the values of the ambient temperature (T_a), absorber plate temperature (T_{ab}), pot temperature (T_p) and solar intensity (I_0) with time. At an average temperature of 34.5°C and solar intensity of 778 W/m^2 the double exposure solar cooker attained a maximum absorber plate temperature of 102°C and a maximum pot temperature of 85°C . The absorber plate temperature rose from 48.4 to 102°C in 4 hours. This result is comparable to that of Saravanan and Janarthanam (2014a) who reported a plate temperature of $102 - 115^{\circ}\text{C}$ after 4 – 5 hours at a maximum solar intensity of 1122 W/m^2 and an ambient temperature of 37.5°C . It was also observed that within the first 105 min, the temperature of the absorber plate rose at an average rate of 5.0°C per 15 min. Within this period, the temperature rise varied from $1.0 - 11.6^{\circ}\text{C}$ depending on the intensity of the solar radiation. For the empty pot, the temperature rise was at a rate of 3.0°C per 15 min within the first 90 min of exposure to solar radiation. A maximum of rate of 8.0°C per 15 min was attained during this period.

4.2. Water Heating

Figures 11 and 12 show the variation in the values of water, absorber plate and ambient temperature alongside the solar intensity with time for 1 kg and 2 kg of water, respectively. It was observed that it took approximately 2 hours for the temperature of 1 kg of water to rise from $47.0 - 92.3^{\circ}\text{C}$ at an average solar

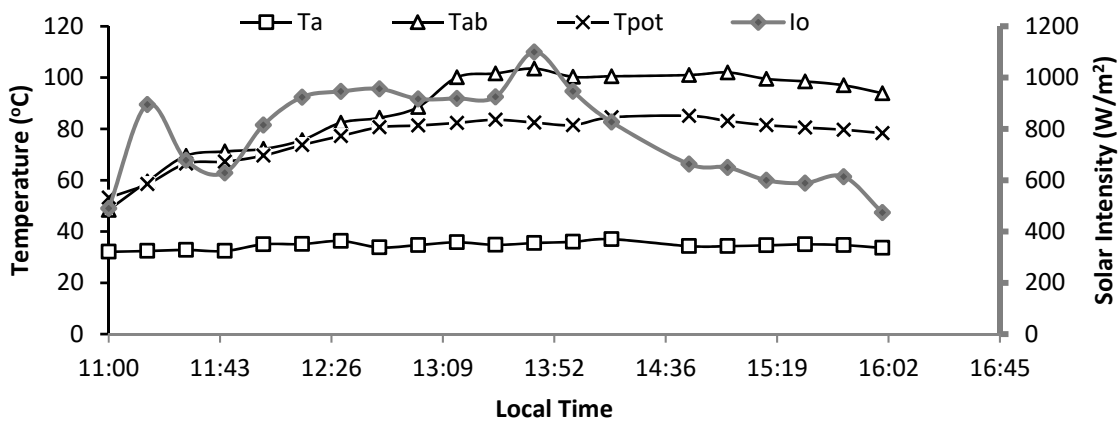


Figure 10: Performance of cooker under no load

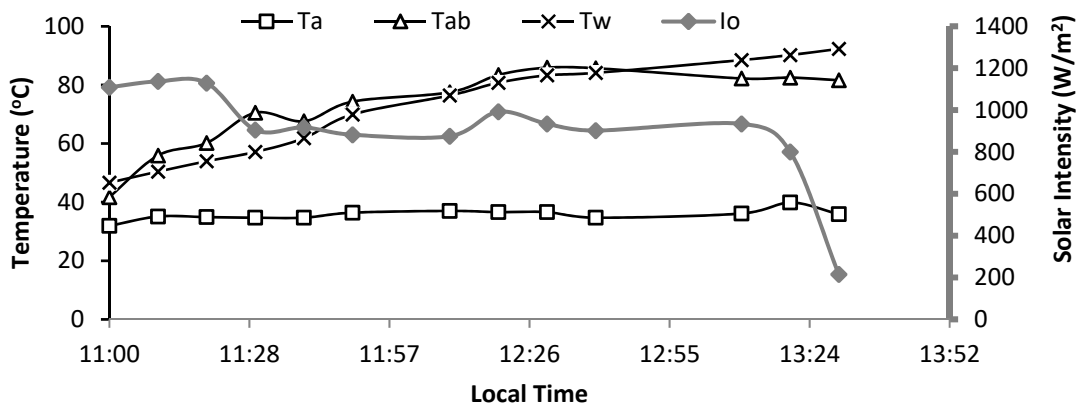


Figure 11: Performance of solar cooker in heating 1 kg of water

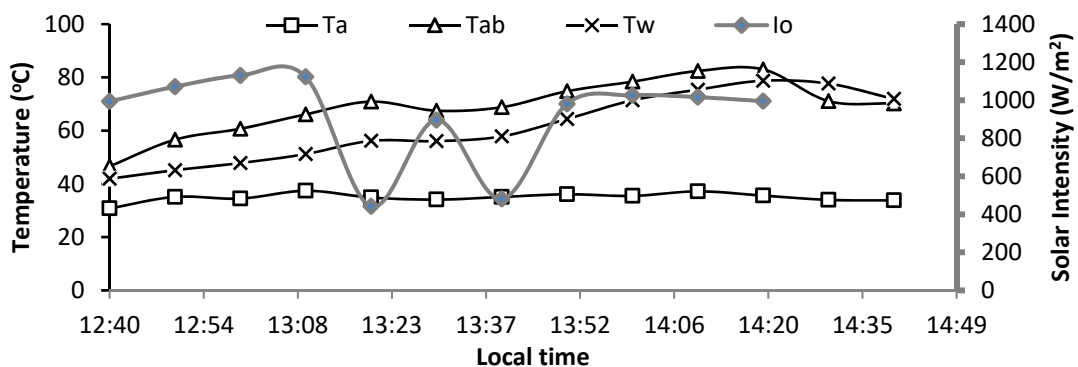


Figure 12: Performance of solar cooker in heating 2 kg of water

intensity of 765 W/m² and average ambient temperature of 35.7 °C. For 2 kg of water, it took 100 min for the temperature to rise from 42.0 °C to close to 80.0 °C at an average solar intensity of 923 W/m² and average ambient temperature of 35.0 °C. It was also observed that for 1 kg of water, an average temperature rise of 3.8 °C per 10 min was observed. During the first 60 min, the average rate of temperature rise was 5.0 °C for each 10 min. This drop in rate was due to the drop in solar intensity. Similarly for 2 kg of water, there was an unstable rate of temperature rise. An average rise of 3.7 °C per 10 min was observed but, within the first 60 min, a lower rate of 2.67 °C per 10 min was observed; hence, the amount of water to be heated influenced the rate of temperature rise, especially during start up.

4.3. Cooking Tests

Table 1 summarizes the performance of the solar cooker in cooking two different food items. Figure 12 shows one of the cooked foods. This result is better than that of Saravanan and Janarthanan (2014a) who reported 60 min and 85 min for 4 eggs and 250 g of rice respectively given a higher peak solar intensity of 1122 W/m².

4.4. Thermal Performance

Figures 14 and 15 show the heating power and heat efficiency of the solar cooker for 1 and 2 kg of water respectively. It was observed that a maximum heating power of 32.4 W and heat efficiency of 14.0% was attained within 50 min while heating 1 kg of water. For 2 kg, a maximum heating power of 26.0 W was attained

after 90 min but a maximum efficiency of 21.2% was attained after 40 min. The thermal performance is affected by the quantity of water and the intensity of solar radiation. It was observed that the heating power for 1 kg of water was higher than that of 2 kg of water due to the reduced load. On the other hand, the higher efficiency observed for 2 kg of water was due to a higher solar intensity.

5. CONCLUSION

A multi-reflector double exposure box-type solar cooker was developed and evaluated. The solar cooker had a collector area of 0.264 m² and an outer surface dimension of 670 mm X 670 mm. During stagnation, the cooker attained a maximum absorber plate temperature of 102 °C, rising at an average rate of 5.0 °C per 15 min, at an average temperature of 34.5 °C and solar intensity of 778 W/m². For water heating, a temperature of 92.3 °C was attained for 1 kg of water during an average solar intensity of 765 W/m² and 80.0 °C was observed during an average solar intensity of 923 W/m² for 2 kg of water. The maximum heating power was 32.4 W and 26.0 W for 1 and 2 kg of water respectively. The basic



Figure 13: Cooked Jollof Rice

improvement required for this design is increment in size. A larger size will ensure a higher surface area and energy input. Better insulators can also be adopted to give a higher thermal performance. This study reiterates the usability and suitability of solar cookers in a tropical region.

Table 1: Summary of solar cookers' performance in cooking

Average Solar Intensity (W/m ²)	Average Ambient Temperature (°C)	Mass of Water (g)	Food Item	Quantity	Cooking Time (min)
827.4	33.5	500	Eggs	4	50
511.0	36.1	260	Jollof Rice	200 g	120

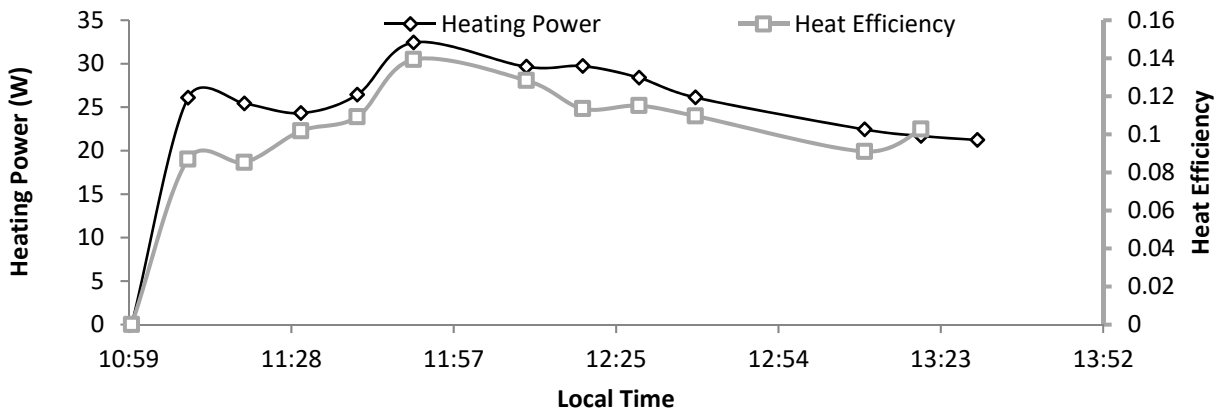


Figure 14: Thermal performance in heating 1 kg of water

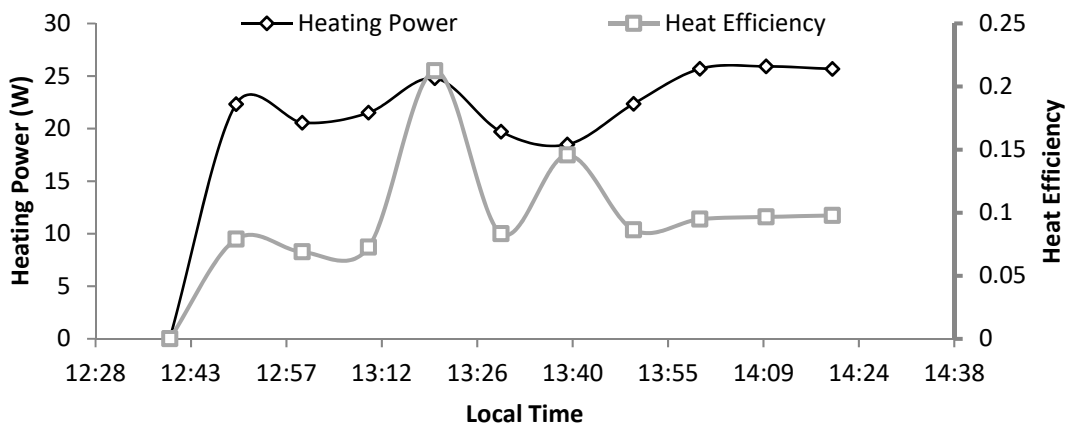


Figure 15: Thermal performance in heating 2 kg of water

NOTATIONS

E_b : Emissive power of a blackbody per unit area (Wm^{-2})
 σ : Stefan-Boltzmann constant ($5.67 \times 10^{-8} Wm^{-2}K^{-4}$)
 Q_{rad} : Energy radiated (J)
 P_{rad} : Power radiated (W)
 P_{abs} : Power absorbed (W)
 P_{trans} : Power transmitted (W)
 P_{inc} : Incidence Power (W)
 P_w : Power loss through glazing window (W)
 P_{loss} : Total power loss (W)
 \dot{Q} : Heating power (W)
 η : Heat efficiency (unit less)
 G : Power gain factor due to reflectors (unit less)
 U_w : Overall heat transfer coefficient of the glazing window ($Wm^{-2}K^{-1}$)
 Δt : Time difference (Sec)
 A_s : Area of the aperture (m^2)
 A_{sb} : The heat loss area (bottom + side walls) (m^2)
 ΔT : Change in temperature ($^{\circ}C$)
 T_p : Pot temperature ($^{\circ}C$)
 T_a : Ambient Temperature ($^{\circ}C$)
 T_w : Water temperature ($^{\circ}C$)
 T_{ab} : temperature of the absorber plate (stagnation) ($^{\circ}C$)
 α : Absorptivity of absorber (unit less)
 τ : Optical transmission coefficient of glazing material (unit less)
 n : Number of glazing
 N : Number of reflectors
 r : Reflectivity of the reflector (unit less)
 I_o : Incident insolation (W/m^2)
 u : The length of the reflector (m)
 v : The width of the reflector (m)
 l : The length of the inner box (m)
 w : The width of the inner box (m)
 H : Wall height of cooker (m)
 D_p : Diameter of cooking pot (m)
 H_p : Height of cooking pot (m)
 H_c : Height of cooker (m)
 R_s : Height of base reflector stand (mm)
 z : Distance between pot bottom and box base (mm)
 F : Focal point of parabolic reflector (m)
 d_{pr} : Depth of parabolic reflector (m)
 D_{pr} : Diameter of parabolic reflector (m)
 x : Thickness of insulation material (saw dust) (m)
 K_{sd} : Thermal conductivity of saw dust (Wm/K)
 A_{sb} : The heat loss area (bottom + side walls),
 q_l : The desired maximum rate of heat loss through the cooker walls.
 M_w : Mass of water (kg)
 C_w : Specific heat capacity of water ($kJ kg^{-1} K^{-1}$)

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