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DEVELOPMENT OF BOX–TYPE SOLAR COOKER FROM LOCALLY SOURCED MATERIALS

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Abstract: In this study, a solar box–type cooker was developed using locally available materials with the aim of investigating the thermal performance of the constructed solar cooker using standard test procedure. Several tests were conducted on the constructed cookers under Jalingo (Nigeria) prevailing weather conditions during December 2021. The thermal performance of the solar cooker revealed that it attained a maximum average temperature of 77.1 ^{o}C for boiling test and 67.7^{o}C for cooking test. Also, the results of the thermal efficiency for the constructed cooker during boiling test and cooking test were maximum at 9.00 hour (73.01%) and 15.30 hour (95.54%) respectively while cooking power during boiling test and cooking test were maximum at 13.30 hour with values of 0.472 and 0.83J respectively. However, it can be concluded that the use of solar energy in cooking is capable of protecting the environment and reducing health risks

Keywords: Solar cooker; temperature; time; cooking power; thermal efficiency

INTRODUCTION

Cooking plays a very essential role in human life because of the very existence of humans who depend on the food for survival. This food can be cooked in different ways (Yuksel et al., 2012). Lim and Seow (2012) have revealed that approximately 2.4 billion people depend on wood, dung charcoal and other biomass fuels for cooking and most of this population cook on open fires, which burn incompletely thereby leading to low fuel efficiency and high pollution missions. Zenebe et al. (2018) have also reported that approximately 4 million people die annually through cooking with traditional cook stoves and fuels, which mainly consist of firewood and charcoal.

The authors also revealed that most of these victims are women and children. Hence, the World Health Organization (WHO) suggested that indoor air pollution resulting from indoor burning solid fuels in poorly ventilated conditions causes diseases such as asthma, cancer, heart disease, chronic bronchitis and tuberculosis (WHO, 2009). Also, Ajibola et al. (2020) have also observed that conventional traditional methods of cooking poses a lot of hazards such as the alarming rate of climate changed, increased number of deaths and health hazards and deforestation.

Therefore, there is need to find an alternative source for fuel for indoor cooking. Solar cooker is a device which uses energy of direct sunlight for cooking (Tiba et al, 2010). This cooker allows Ultra–violet (UV) light rays in and thereafter converting them to longer infrared light rays that cannot escape (Uhuegbu, 2011). Solar Cookers currently in use are relatively expensive and considered as low–tech devices. However, some are powerful and expensive as traditional stoves, and advanced. Though, large–scale solar cookers can cook for hundreds of people. Moreover, fossil resources have dominated the energy market for a long period of time and the pressure on global energy resources is on the increase (Adegbola et al., 2012).

Solar energy technology is not conceptually new and many efforts have been made over the years to developed different solar cookers which have been tested by researchers at several geographic locations and under unique climate and physical conditions (Klemens and Maria, 2008). Uhuegbu (2011) have reported three different types of solar cooker, which include; box type solar cooker, parabolic solar cooker and panel solar cooker.

The box–type cooker is an insulated container with a single or multiple glass cover and relies on the greenhouse effect in which passage of shorter wavelength solar radiation is permitted by transparent glazing. However, it is opaque to longer wavelength radiation coming from moderately small temperature heated objects. Hence, mirrors are sometimes used for reflecting additional solar radiation into the cooking chamber.

Also, the parabolic solar cookers consist of a dish–type reflector which direct intercepted solar radiation to focus point. This type of cooker must be frequently oriented towards the sun, as a result, it is also referred to as direct concentrating cookers consisting of dish–type concentrators which needs direct sun light to perform optimally (Elamin and Abdalla, 2015). In addition, the panel solar cookers incorporate the features of both parabolic cookers and box–type (Muthusivagami et al., 2010). However, the box–type solar cooker is the most inexpensive and common of the three solar cooker types as it very easy to construct and are made of low cost materials (Klemens and Maria, 2008). Solar energy has gained high importance in the current global discussions on energy and environment. Hence, several attempts have been made to introduce and popularize the use of solar cookers in Nigeria (Uhuegbu, 2011). Therefore, in this study, a box–type solar cooker is been developed using locally sourced material. The performance of the developed cooker was evaluated through cooking test (using Yam) and boiling test (using water) by determining the cooking power and thermal efficiencies at constant time interval.

MATERIALS & METHODS

This study was conducted at the Faculty of Engineering, Taraba State University, Jalingo–Nigeria, lies between latitudes, 8.90° North and longitudes, 11.32° East.

Materials

The material utilized for this study include; 2cm plywood, glass lid (0.3mm) mild steel (0.4mm), screw and hinges (metal) mirror (0.3mm), rollers (plastic), paint (black). These materials were sourced locally from commercial shops in Jalingo – Nigeria. Also, the performance of the developed cooker was evaluated using water, slices of yam a thermometer and a silver painted pot weighing 20.80grams. In addition, the solar radiation intensity for the test period was measured using a Pyrheliometer (DR03, sensitivity: 10 x 10–6V/{W/m²}, operating temperature: –40 – 80°C, Response time: 2sec)

Methods

Solar cooker construction

The box–type solar cooker constructed comprised of five components, this includes; wooden box which serves as container, heat insulator, glass cover, absorber plate (heat collector) and reflector. The isometric, sectional and orthographic view of the box–type solar cooker are shown in Figure 1, 2 and 3 respectively. A box container (1.15m height) with outer box, 0.45 x 0.45 x 0.3 m and inner box 0.35 x 0.35 x 0. 295 m. The entire inner and outer surface of the box were painted black for better absorption of solar energy. In addition, the absorber plate with 0.4m × 0.4 m made of metal sheet was also installed and was painted black (upper surface) so as to absorb the sun rays. A plane mirror 3mm thick (0.76 x 0.25m) was placed trapezoidal on to the wooden frame at an angle of 30° to ensure that maximum irradiation falls on it and was used as reflector. However, inner sides of the box were covered with aluminium foil in order to also serves as reflector. In addition, a transparent adjustable glass sheet 5mm thick (0.48m x 0.48m) was fitted at the top of the constructed box between the reflector and the absorber to serve as transparent cover and to ensure that greenhouse effect which is the basis of operation of the solar device is created. The developed box–type solar cooker is presented in Figure 4

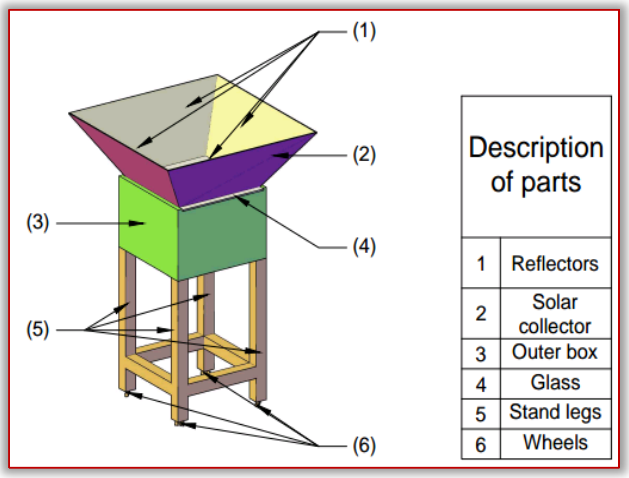

Figure 1: Isometric view of the developed solar cooker

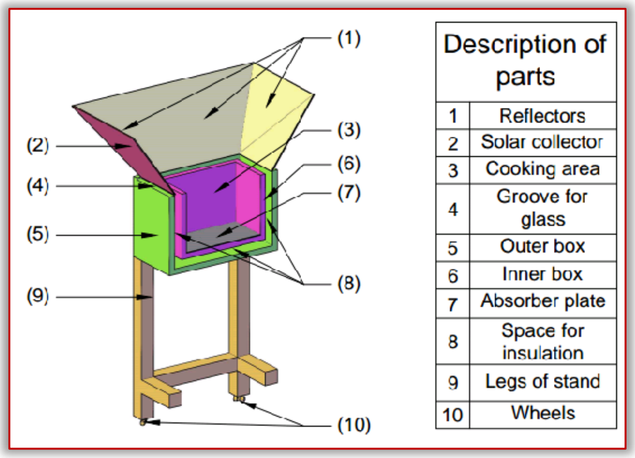

Figure 2: Sectional view of the developed solar cooker

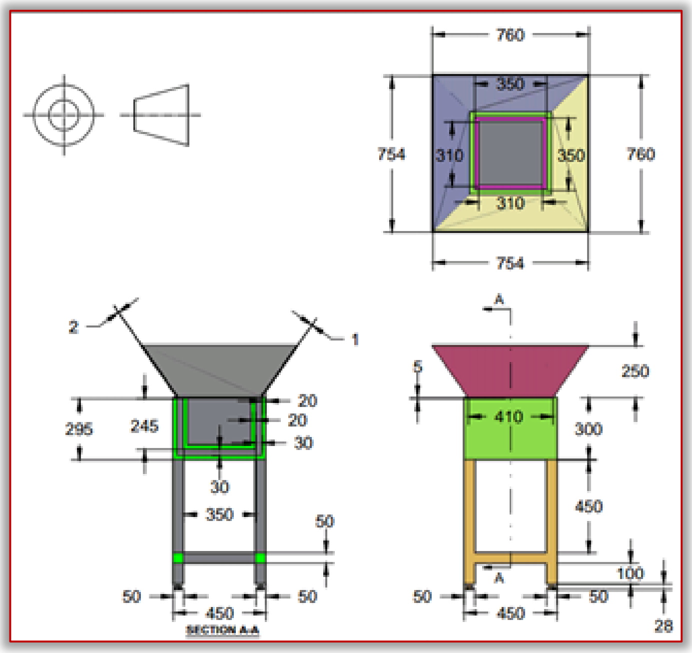

Figure 3: Orthographic view of the developed solar cooker

(a)

(b)

Figure 4: Developed box–type solar cooker: (a) Complete view, (b) Top view

Performance Evaluation

a. Boiling and cooking tests

The performance of the constructed solar cooker was evaluated through boiling test (using water) and cooking test (using water and yam). These tests were conducted in accordance with procedure outlined by (Elamin and Abdalla, 2015).

However, tests were conducted for five days between 1st December, 2021 and 5th December, 2021 from 9:00 to 16:00 hours daily for boiling test and five days between 6st December, 2021 and 10th December, 2021 from 9:00 to 16:00 hours daily at the premises of the Faculty of Engineering, Taraba State University, Jalingo (Annex) using digital thermometers (Temp. range: 0–300°C), slices of yam and silver–painted cooking pot. During the experiment, the ambient temperature and the temperature at the different parts of the cookers (the test sample, reflector and the absorber plate) was measured and recorded at 30 minutes intervals.

Also, a digital weighing balance (TAPSONS™, Accuracy: 0.001) was used to measure the mass of water, pot and yam slices. However, the measured variables were: ambient temperature, the temperature of the water in cooking pot, the reflector and the absorber plate temperature. The recorded data was used to determine the thermal efficiency and cooking power of the constructed solar cooker.

b. Thermal Efficiency

The overall thermal efficiency (ŋ) of the cooker was calculated using Eqn. 1 (Saxena and Karakilcik, 2017). The maximum projected area of a solar collector represent the aperture area through which the unconcentrated solar radiant energy is admitted.

$$\eta = \frac{m_w \ x \, C_w \ x \, \Delta T_w}{I_{av} \ x \, A \ x \, \Delta t} \qquad (1)$$

where;

m_w = mass of water (kg)

C_w = specific heat of water (4.168 kJ/kg K)

ΔT_w = Temperature difference between the maximum and ambient air

I_{av} = average solar intensity (W/m^2) during the time interval.

A_c = is the aperture area (m^2) of the cooker (0.1035m^2)

Δt = time required to achieve the maximum temperature of the water (s).

c. Cooking Power

The cooking power (P) of the solar cooker was calculated using Eqn. 2 (Elamin and Abdalla, 2015).

$$P = \frac{T_{w_2} - T_{w_1}}{t} x \, m_w \ x \, C_w \qquad (2)$$

where;

T_{w2} = final temperature of water in °C

T_{w1} = initial temperature of water in °C

m_w = mass of water in kg

t = time in seconds

C_w = heat capacity of water (4.168 kJ/kg K)

RESULTS &DISCUSSION

Boiling & cooking tests

The average experimental results obtained from water boiling and yam cooking test is shown in Table 1 and 2 respectively.

These results are represented in Figure 5 and 6 respectively. The experimental results revealed that the more heat was generated at the absorber plate during the water boiling and cooking test. The results also indicates that the radiation of the sun affects the heat and cooking performance of the solar system.

The ambient temperature and the temperature at the different parts of the cooker increases with time of the day. However, there was a gradual drop at the different part of the cooker from 14.30 hour to 16.00 of the day.

- Volume of water = 30.90ml
- Weight of yam = 26.90 grams
- Average solar radiation intensity for boiling test = 6.06 kWh/m^2
- Average solar radiation intensity for cooking test = 6.11 kWh/m^2

Table 1: Experimental results for water boiling test

Run	Time (sec)	Time of the day (hr)	Ambient temp. (°C)	Temp. of reflector (°C)	Temp. of test sample (°C)	Temp. of absorber plate (°C)	Thermal efficiency (%)	Cooking power (W)
1	0	9.00	28.2	35.3	34.6	37.2	73.01	–
2	1800	9.30	30.1	37.2	36.2	39.2	69.59	0.114
3	1800	10.00	36.5	39.2	38.6	42.7	23.96	0.172
4	1800	10.30	40.2	43.1	41.1	45.4	10.27	0.179
5	1800	11.00	43.2	46.6	44.5	48.2	14.83	0.243
6	1800	11.30	45.9	48.8	47.4	51.7	17.11	0.207
7	1800	12.00	48.1	52.0	51.3	55.4	36.50	0.279
8	1800	12.30	54.8	57.5	57.5	61.8	30.80	0.444
9	1800	13.00	59.3	62.3	63.8	67.7	51.33	0.451
10	1800	13.30	66.5	51.4	70.4	75.8	44.49	0.472
11	1800	14.00	68.1	53.1	72.2	77.1	46.77	0.129
12	1800	14.30	66.7	51.2	70.7	75.7	45.63	0.107
13	1800	15.00	65.3	50.7	69.5	73.8	47.91	0.086
14	1800	15.30	64.6	49.2	68.8	72.2	47.91	0.050
15	1800	16.00	63.9	47.9	68.3	71.6	50.19	0.036

Table 2: Experimental results for cooking test

Run	Time (sec)	Time of the day (hr)	Ambient temp. (°C)	Temp. of reflector (°C)	Temp. of test sample (°C)	Temp. of absorber plate (°C)	Thermal efficiency (%)	Cooking power (J)
1	0	9.00	28.8	32.5	31.3	32.9	24.62	–
2	1800	9.30	29.6	33.2	32.2	34.2	25.61	0.064
3	1800	10.00	35.9	39.2	38.6	39.7	26.59	0.458
4	1800	10:30	39.4	43.1	42.1	43.4	26.59	0.250
5	1800	11.00	42.4	46.6	45.5	40.2	30.53	0.243
6	1800	11.30	44.9	48.8	47.4	42.7	24.61	0.136
7	1800	12.00	47.3	51.4	50.3	45.4	29.55	0.207
8	1800	12.30	53.3	57.5	56.5	51.8	31.52	0.444
9	1800	13.00	58.7	62.3	62.8	57.7	40.38	0.451
10	1800	13.30	65.1	69.4	74.4	63.8	91.60	0.830
11	1800	14.00	68.4	72.1	77.2	66.1	86.68	0.200
12	1800	14.30	66.8	70.2	75.7	67.7	87.66	0.108
13	1800	15.00	64.9	69.7	73.5	65.8	84.71	0.157
14	1800	15.30	62.1	67.2	71.8	63.2	95.54	0.122
15	1800	16.00	60.9	65.9	70.3	62.6	92.59	0.107

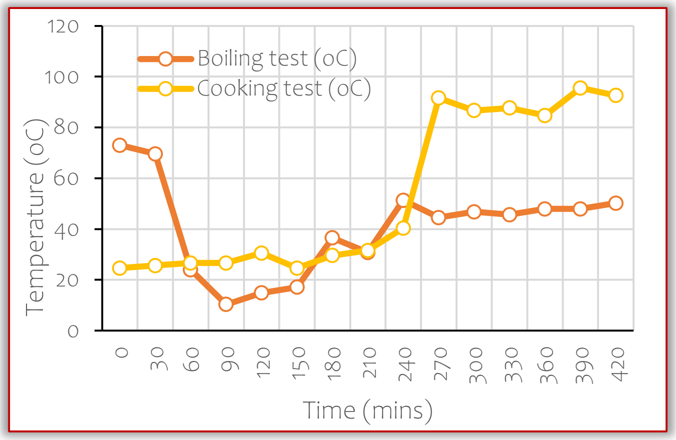

Figure 5: Temperature variation for water boiling test

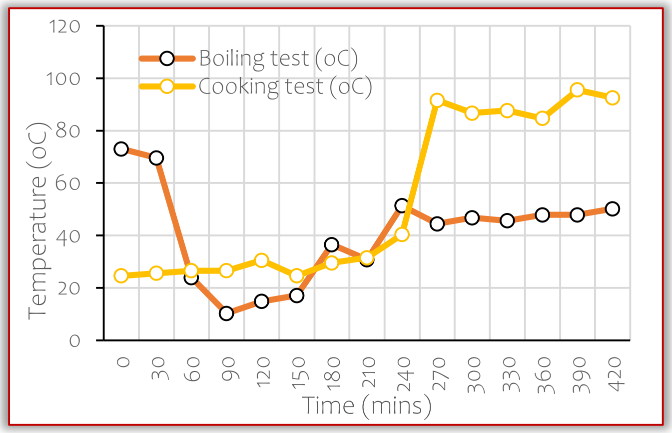

Figure 6: Temperature variation for cooking test

Thermal efficiency and cooking power

The thermal efficiency and cooking power calculated using Eqn. 1 and 2 are presented in Figure 7 and 8 respectively. The results presented in Figure 7 revealed that during the water boiling test, the developed box–type solar cooker attained the highest thermal efficiency (73.01%) at 9.00am and lowest thermal efficiency (10.27%) at 10.30am while the highest thermal efficiency (95.54%) was attained during the cooking test at 15.30hour and the lowest thermal efficiency (24.61%) was achieved at 11.30am.

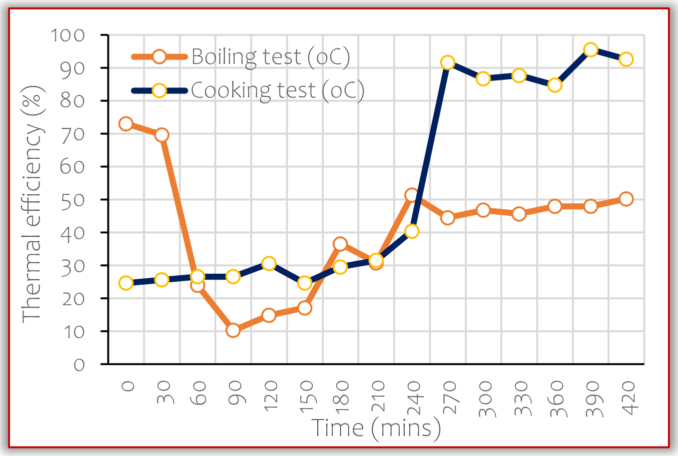

Figure 8: Thermal efficiency for water boiling and cooking test

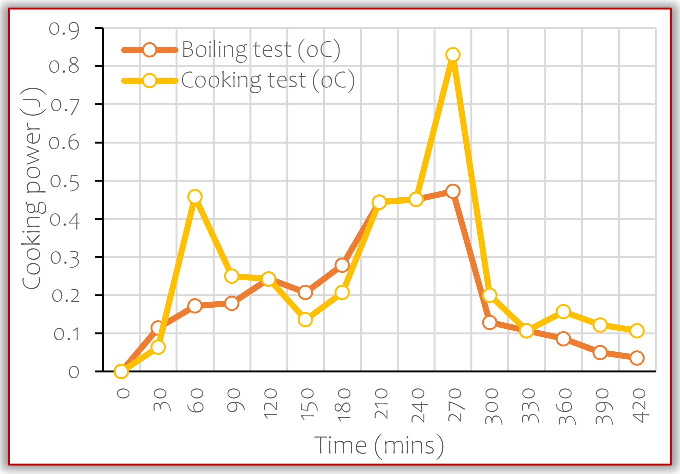

Figure 9: Cooking power for water boiling and cooking test

The differences in the thermal efficiencies could be attributed to heat losses to the surrounding as a result of the high temperature gradient (Elamin and Abdalla, 2015). Also, the high thermal efficiency of 95.54% obtained during the cooking test was attributed to the fact that the solar box cooker have retains sufficient heat inside the box for the cooking process. In addition, the calculated results of the cooking power of the constructed solar cooker presented in Figure 8 showed that of the cooking power is highest at 13.30 hour and lowest at 16.00 hour for both water boiling and cooking test. This explains that the solar collecting ability of the cooker increases with increasing solar radiation therefore, converted heat will be larger at higher solar radiation.

Table 1: Experimental results for Cooking power and thermal efficiencies

Run	Time (sec)	Time of the day (hr)	Water boiling test		Cooking test	
			Thermal efficiency (%)	Cooking power (W)	Thermal efficiency (%)	Cooking power (W)
1	0	9.00	73.01	–	24.62	–
2	1800	9.30	69.59	0.114	25.61	0.064
3	1800	10.00	23.96	0.172	26.59	0.458
4	1800	10.30	10.27	0.179	26.59	0.250
5	1800	11.00	14.83	0.243	30.53	0.243
6	1800	11.30	17.11	0.207	24.61	0.136
7	1800	12.00	36.50	0.279	29.55	0.207
8	1800	12.30	30.80	0.444	31.52	0.444
9	1800	13.00	51.33	0.451	40.38	0.451
10	1800	13.30	44.49	0.472	91.60	0.830
11	1800	14.00	46.77	0.129	86.68	0.200
12	1800	14.30	45.63	0.107	87.66	0.108
13	1800	15.00	47.91	0.086	84.71	0.157
14	1800	15.30	47.91	0.050	95.54	0.122
15	1800	16.00	50.19	0.036	92.59	0.107

CONCLUSIONS

Cooking plays a very essential role in human life as a result of the existence of humans who solely depend on the food for survival. A box–type solar cooker has been developed using locally sourced material and the performances were evaluated by investigating the thermal efficiencies and cooking power. Based on the results obtained, the following conclusion can be drawn;

- The constructed solar cooker was satisfactorily used to boil water. However, the cooking of slices of yam could not be completed on the first day but the yam completely cook on the second day.
- The ambient temperature and the temperature at the different parts of the cooker increases with time and there was a gradual drop at the different part of the cooker between 14.30 and 16.00 hour of the day.
- The developed box–type solar cooker attained the highest thermal efficiency (73.01%) at 9.00 hour and lowest thermal efficiency (10.27%) at 10.30 hour while the highest thermal efficiency (95.54%) was attained during the cooking test at 15.30 hour and the lowest thermal efficiency (24.61%) was achieved at 11.30 hour.
- Also, the cooking power of the constructed solar cooker power is maximum at 13.30 hour and minimum at 16.00 hour for both water boiling and cooking test
- The use of solar energy in cooking is capable of protecting the environment and reducing health risks.

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