AIMS Energy, 6(1): 146–169.
DOI: 10.3934/energy.2018.1.146
Received: 03 November 2017
Accepted: 19 January 2018
Published: 25 January 2018

http://www.aimspress.com/journal/energy

Research article

Design, construction and performance evaluation of aBox type solar cooker with a glazing wiper mechanism

Zeleke Ademe* and Sameer Hameer

Bahir Dar Energy Research Center, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia

* **Correspondence:** Email: zeleke928@gmail.com; Tel: +251910169273.

Abstract: This research work describes the performance evaluation of a double-glazed box-type solar oven with three reflectors and with a vapor wiper mechanism fabricated using locally available materials. The box cooker has external box dimensions of 600 mm × 600 mm × 250 mm and pyramidal internal box dimensions of 460 mm × 460 mm top face and 300 mm × 300 mm bottom face with depth of 150 mm. The thermal performance was tested as per the ASAE International Test procedure and Bureau of Indian Standards (BIS) for testing the thermal performance of a box-type solar cooker. The obtained test results after employing required calculations were figures of merit F_1 = 0.123 Km^2/W, F_2 = 0.540, the standard cooking power P_{50} = 36 W and the cumulative efficiency to be 22%, whereas with the application of the wiper mechanism, it was found that F_1 = 0.123, F_2 = 0.827, the standard cooking power (P_{50}) = 51 W, and the cumulative efficiency to be 31.4%. The standard boiling time of 1.43 kg of water was calculated to be 53.54 and 88.84 minutes for the cooker with and without the application of wiper mechanism respectively. The thermal distribution of the cooker was modeled using interior box geometry as a boundary condition with ANSYS 15.0. The temperature distribution inside the box was simulated and the maximum wall temperature was found to be 139 ℃. This was lower than the experimental results by 22 ℃. The method of modeling and simulation of the cooker with and without a wiper mechanism is similar except for the variation of the transmittance of the glass due to shading of vapor which can be deducted from the cumulative efficiency for the latter case. The results show that using the vapor wiper mechanism increases the cumulative efficiency by 9.4% and reduces the boiling time by 35.3 minutes. Finally, the techno-economic analysis shows that the cooker with a vapor wiper mechanism has a good reliability for outdoor cooking of food and is economically feasible.

Keywords: solar energy; solar cookers; thermal performance; box type solar cooker; wiper mechanism; modeling; ANSYS

Nomenclature: A_{ap}: Aperture area [m^2]; pp: Payback period (year); Tas: Average ambient temperature (°C); Re: Reynolds number; I_{av}: Average solar power (W); F2: Second figure of merits; Tamb: Ambient temperature (°C); C_p: Specific heat capacity of water [J/Kg °C]; Pi: Cooking power (W); tboil: Standard boiling time (s); η_n: Cumulative efficiency; P_s: Standard cooking power [W]; ρ: Density (Kg/m^3); Tps: Stagnation plate temperature (°C); Td: Temperature difference (°C); Tf: Final temperature [°C]; ΔT: Temperature difference(°C); F1: First figure of merits (Km^2/W); K: Thermal conductivity [W/m K]; G: Global radiation [W/m^2]; Hs: The intensity of solar radiation(W/m^2); G: Gravitational constant, = 9.81 m/s^2; UL: Total heat loss coefficient (W/m^2 K); Cv: Heat capacity(4186 J/[kg K]); T: Time[s]; Ti: Initial temperature [°C]; τ: Time interval (s); M: Mass of water [Kg]; V : Velocity/speed (m/s); NPV: Net Present Worth (ETB)

1. Introduction

The use of solar energy for the purpose of cooking food presents a viable alternative to the use of fuel wood, kerosene, and other fuels traditionally used in Ethiopia. While certainly solar cookers cannot entirely halt the use of combustible fuels, it can be shown that properly applied solar cooking can be used as an effective mitigation tool with regards to global climate change, deforestation, and economic debasement of the world's poorest people. Solar collectors convert solar radiation into heat and they rely on an energy source that is free, abundant and renewable, but the reason that they are not widely spread as needed is because of the drawback that cooking must be done when, and where the sun is shining [1]. Currently, an estimated 2.7 billion people, which is 38% of the global population, put their health at risk through reliance on the traditional use of solid biomass for cooking [2]. About 5 million children in the developing world die each year from respiratory ailments and a further 5 million are estimated to die from diseases associated with contaminated drinking water [3]. In rural areas of Africa, 80% of the total available energy resource is utilized for cooking [4]. However, this situation causes some serious ecological problems such as deforestation [5–10]. Ethiopia's forest cover (FAO definition) was 12.2 million hectares (11%) in 2010 and 15.11 million hectares (13.65%) in 1990. This shows that 2.65% of the forest cover was deforested [11]. Renewable resource technologies in Ethiopia are not well known and not widely used; this results in increased fossil fuel dependency to satisfy its energy demand [12]. The global horizontal insolation of most developing countries including Ethiopia is in the range of 5–7 kWh/m^2 with more than 275 sunny days in a year [13,14]. Solar energy has the greatest potential of all the sources of renewable energy and if only a small amount of this form of energy is used, it will be one of the most important supplies of energy [1]. The facts speak in favor of solar energy, that world's reserves of coal, oil and gas will be exhausted within a few decades. Nuclear energy involves considerable hazards and nuclear fusion has not yet overcome all the problems of even fundamental research [15]. Research to resolve problems related to energy is quite significant since life is directly affected by energy and its consumption [16]. Fossil fuel-based energy resources still predominate with the highest share in global energy consumption accounting 78% [17]. However, clean energy generation is important due to the growing significance of environmental issues. Exploiting other available and renewable energy resources at local level through appropriate designs of energy technologies seems a more sustainable solution [18–21]. Box cookers consist of an insulated box with reflective surfaces, a transparent top face, and a black painted bottom, where a black pot is located [22]. They heat up slowly, because the sunrays are not concentrated on the pot. Because of their insulation, they work satisfactorily in the presence of wind, intermittent cloud cover, and low air temperature [23]. Manual azimuth tracking is required at least twice a day, [24] even if some models do not require any tracking [25,26]. The box type solar cooker has the Achilles heel of slow heating rate, low temperature delivery and low cooking efficiency. One of the drawbacks of the cooker is attributed to partial shading of water vapors on the inner surface of the glazing, which dampens the intensity of radiation. This kind of cooker depends on the greenhouse effect in which the transparent glazing permits the passing of shorter wavelength solar radiation but is opaque to radiation coming from relatively low temperature heated objects [27]. The main objective of this research work is to design, construct and evaluate the thermal performance of a box type solar cooker with a glazing wiper mechanism.

2. Methodology

2.1. Principles of solar box cooker design

The design parameters considered includes the energy requirements for cooking and daily average insolation. The energy requirement for cooking per person as explaind in [28] is about 900 kJ of fuel equivalent per meal. A solar box cooker as discussed in [29] should be sized in consideration of the largest amount of food commonly cooked, if the box needs to be moved often, it should not be so large so that this task is not too difficult and the box design must accommodate the cookware that is available or commonly used.In order for the box to get higher interior temperatures, the walls and the bottom of the box must have good insulation (heat retention) value. There are hundreds of different designs of solar box cookers in use. These vary in size, material, insulation and components used [30]. The general methodology used for the research work is as shown below on Figure 1.

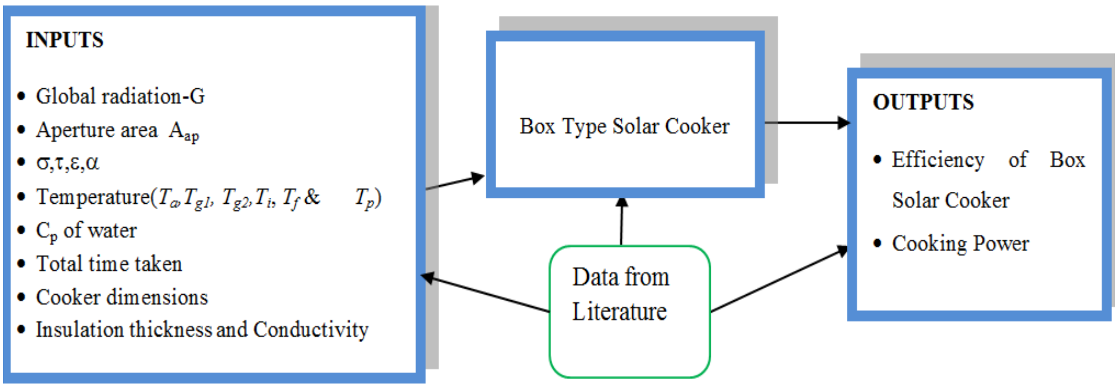

Figure 1. Flow chart showing inputs, process and the output of the methodology.

The box cooker has external box dimensions of 600 mm × 600 mm × 250 mm and pyramidal internal box dimensions of 470 mm × 470 mm top face and 300 mm × 300 mm bottom face with a depth of 150 mm. Kundapur [31] suggested that the depth of the inner boxshould not be more than 10–15 cm. This depth is a critical parameter since a greater depth would introduce a shade effect, but the width andbreadthcould be of any dimension. The space between the two boxes was 6.5 cm at the top and 8.5 cm at the bottom. The inner side of the box waspaintedblack and made of 1.5 mm thick iron sheet. For this study Iron sheet was used for the interior box as an absorber plate and walling, Chip wood sheets for the external box and saw dust as insulation in between the two boxes.

The most important property of glass isits transparency to visible light and short wave infrared radiation but opaque to long wave infrared radiation [32]. Glass does not degrade in sunlight and if protected from thermal shocks and impacts, it is more durable than most plastic glazing, even those that are treated against degradation by ultra-violet rays [33]. Glass remains the most frequently used cover material because it transmits as much as 90% of the incoming short wave solar radiation, while, particularly for glass with low iron content, little of the long wave thermal radiation emitted by the absorber is transmitted out of the collector [34]. Two clear window glass panes with 4 mm thickness and 0.50 m × 0.5 m area were fixed over the box with an openable wooden frame with a separation 20 mm in between. The space between these two panes of glass is critical [28]. The air gap also acts as an insulator. Three 10 mm thick plane card boards covered with thin alumunium foils and with dimensions 500 mm by 500 mm were fixed on the same side of the box adjacent to each other. The cooker was always kept facing the equator [35]. The reflectors wereheld in position by fixed nails and adhesive tabs and with adjustible hinges which can be tracked in 15–30 minutes interval or when shadows appear on the absorber plate [36]. The reflectors concentrate solar radiation on the receiver which increases the efficiency, and hence the reliability of the box cooker [37]. The absorber area covered 0.22 m^2. The opening edges of the interior box have groves, which were designed to support the ends of a 450 mm long, 25 mm wide and 15 mm thick foam strip glazing wiper. The foam strip is sretched over a very thin plywood. The wiper was designed so that it can wipe the lower glazing surface by moving back and forth with a very thin string of 1 mm thick and attached at the two sides of both ends. Figure 2 shows the arrangement of the wiper inside the box.

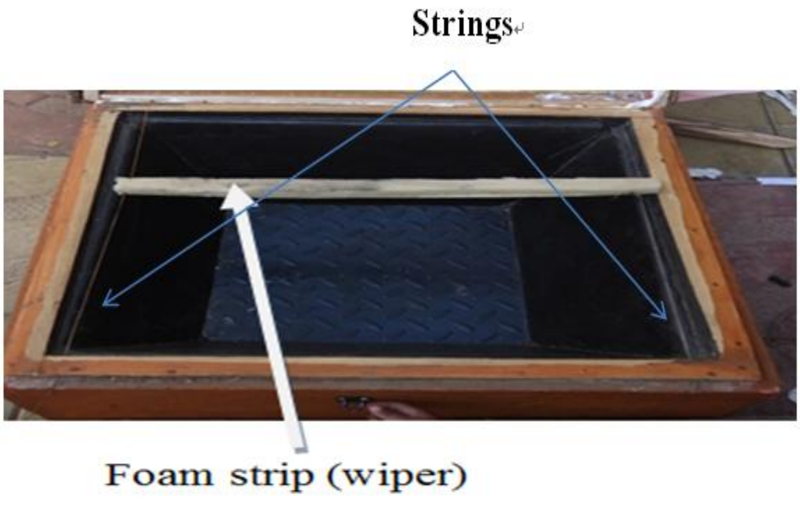

Figure 2. Glazing wiper mechanism.

The cooking vessel used in this study was bought from the local market, it is made of stainless steel in a parabolic dish shape and painted black which allows for high absorption of solar radiation [19]. It has a diameter of 12 cm and a depth of 7 cm. The vessel can contain 1.43 litter (Kg) of water. According to [36] Cookers canproduce 7,000 grams potable water per square meter. The cooking vessels used for this study has a maximum capaciy of 1.55 litter (Kg) of water. Figure 3 below shows the cooking vessel used for the research work.

Figure 3. Cooking vessel with water.

2.2. Construction of the box-type solar cooker

After going through the literature review of previous research works, trends used and experimental standards for the design, construction and testing of box type solar cookers, the design dimensions and materials used for the prototype were decided upon. The design components of solar box cooker with their corresponding dimensions are shown in the schematic of Figure 4.

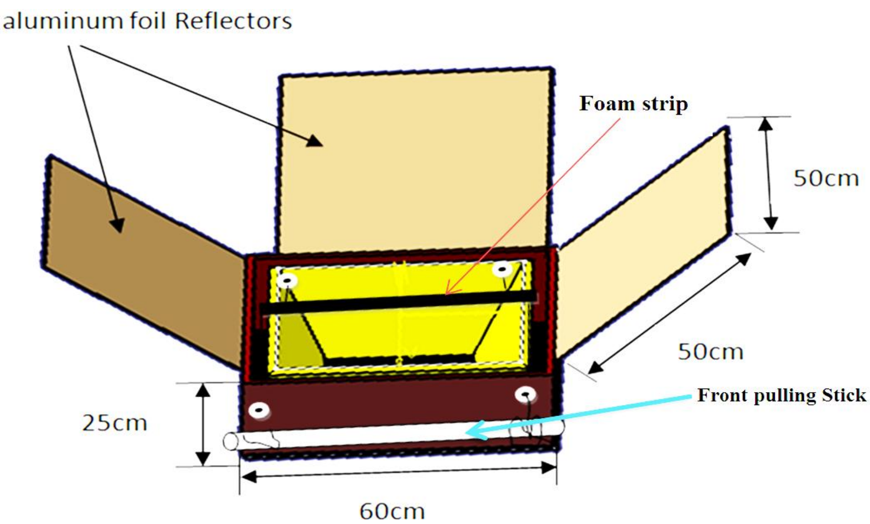

Figure 4. Schemaic of Box type solar cooker.

2.3. Description of the solar box cooker (prototype)

The cooker consists of 50 mm single walled cardboard box.The inner box was constructed using iron sheet 1.5 mm thick. The space between the outer box and inner box is filled with compressed sawdust (insulator) of 50 mm thick. Based on the above dimension, the volume of the cooker (the cooking space) is calculated to be 0.0306 m^3.The solar box cooker employs three reflectors, mounted on the box of the cooker to reflect incidence radiation onto the base and side of the absorber plate. The inner parts of the reflectors were constructed with1.5 mm thick iron sheet. The tilt of the reflectors was adjustable from the horizontal plane of the box cooker. The cooker has a mechanical interior glazing wiper mechanism which can be operated manually by attaching the foam strip in contact with the glazing to the exterior by very thin threads to the back and front side wooden sticks. When the cooker works the back and front sticks can be pulled back and forth alternatively so that the foam strip wipes the vapor off the glazing surface. The prototype of the box solar cooker described above is shown below in Figure 5.

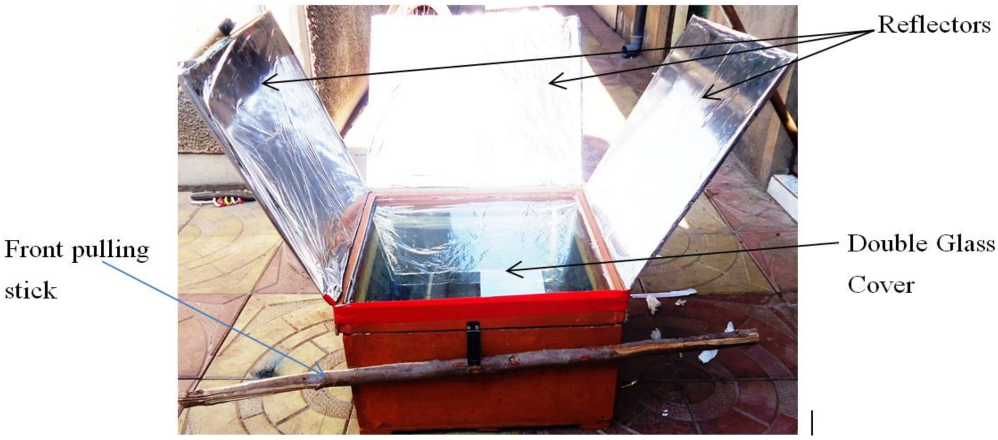

Figure 5. Solar box cooker used for the experiment.

2.4. Experimentation

This study was conducted in Bahir Dar city, Amhara Regional State capital, situated on the southern shore of Lake Tana, the source of the Blue Nile (or Abay). The city is located approximately 578 km north-northwest of Addis Ababa, having a latitude of 11°36′ N and longitude of 37°23′ E and an elevation of about 1,800 meters (5,906 feet) above sea level.

The solar cooker with three reflectors was exposed to solar radiation from March 31 to April 6, 2017 and a minimum of 30 records were taken each day [36]. Measurements were taken at intervals of 10 minutes. Plate temperature, air mass temperature, water temperature in the cooking pot, glass cover temperature, ambient temperature, wind velocity, and solar radiation intensity over the glass cover were measured. Some constants which cannot be measured directly were taken from literature. Measurement of test variables was conducted when wind speed was less than 1.0 m/s, taken at the elevation of the cooker and within ten meters of it. To keep this condition the location where the tests were conducted was ideal; that is it had a wind brake surrounding and almost the collected data was within the recommended range [36]. Tests were also conducted when ambient temperatures were between 20 and 35 °C and data recording was done while cooking vessel contents (water) were at temperatures between 5 °C above ambient and 5 °C below local boiling temperature. The solar intensity recorded during the test was in the range of 450 W/m^2 to 1,100 W/m^2. The experimental setup of the research is shown in Figure 6.

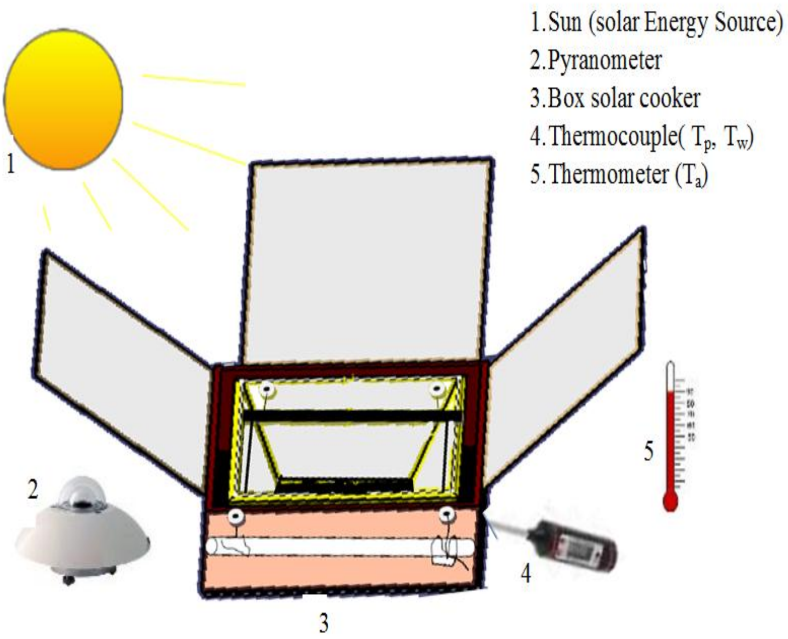

Figure 6. Schematic of experimental setup.

2.4.1. Performance testing

The three major testing standards for evaluating solar cookers throughout the world are: American Society of Agricultural Engineering (ASAE) Standard S580, the standard developed by the European Committee on Solar Cooking Research (ECSCR) and the Bureau of Indian Standards, based on work by [38]. Indian standards provide testing standard based on thermal test procedures for box-type solar cookers. The performance of the reflector based solar box cooker implemented in this study was done based on the Society of Agricultural Engineering (ASAE) Standard S580 and BIS. These Standards were intended to:

(1) Promote uniformity and consistency in the terms and units used to describe, test, rate, and evaluate solar cookers, solar cooker components, and solar cooker operation;
(2) Provide a common format for presentation and interpretation of test results to facilitate communication and;
(3) A single measure of performance so that consumers may compare different designs when selecting a solar cooker.

The scope of these Standards includes all solar powered batch-process for food and water heating devices (solar cookers). The Standards specify that test results be presented as cooking power, in Watts, normalized for ambient conditions, relative to the temperature difference between the cooker contents and ambient air, both as a plot and as a regression equation for not fewer than 30 total observations over seven different days [36].

2.4.2. Stagnation test

A number of tests without load were conducted on the cooker to determine its stagnation temperature and also to check the rise in temperature inside the cooker. The stagnation temperature, ambient temperature (T_a) and absorber plate temperature (T_p) were measured at different times of the day from 10:00 and 14:00 solar time [23]. Temperature was measured using type K, mineral insulated grounded junction, 1.6mm diameter thermocouple with Eli digital thermometer (LX-6500) capable of reading temperature between –50 ℃ and 750 ℃. A thermo anemometer (PROVA instrument, AVM 01) was used to measure wind speed(v) and solar irradiance (GHI) was measured using a Pyranometer (TENMARS TM-207).

2.4.3. Load test

The loading test was done by placing a water-filled oval shaped pot covered by a lid in the cooker. The test was conducted for four days with 1.43 kg of water without using the wiper mechanism in the first and third day; the same mass of water with the application of the wiper mechanism in the second and fourth day. Each test was carried out on a sunny day between 10:00 and 14:00 solar time as recommended by [36]. The absorber plate temperature (T_p), ambient temperature (T_a), water temperature (T_w), solar radiation (H_s) and wind speed (v) were measured using the instrumentation as described in section 3.2.2. The cooking vessel used for the experiment was painted black and made air tight during measurement of water temperature.

2.4.4. Performance measures

The performance evaluation of the solar box cooker involves estimation of the following parameters: First figure of merit (F_1), Second figure of merit (F_2) and cooker's efficiency (η).

2.4.5. First figure of merit

The first figure of merit (F_1) of a solar box cooker is defined as the ratio of optical efficiency (η_o) and the overall heat loss coefficient (U_L) [39]:

$$F_1 = \frac{\eta_o}{U_L} \tag{1}$$

Experimentally,

$$F_1 = \frac{T_{ps} - T_{as}}{H_s} \tag{2}$$

2.4.6. Second figure of merit

The second figure of merit (F_2) is evaluated under full load condition and can be expressed by the expression given by [40], as follows:

$$F_2 = \frac{F_1(M_w C_w)}{At} ln \left\{ \frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_a}{H}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{H}\right)} \right\} \quad (3)$$

In calculating the value of F_2, [12] reported that some flexibility is allowed in the choice of T_{w1} and the time interval (t). A valueof $T_{w1} > T_a$ was recommended by [41] while values of T_{w2} lower than the boiling point was recommended by [41]. The criteria for F_2 value according to the Indian standard should be greater than 0.42.

2.4.7. Standard boiling time

The time, t, for sensible heating from initial ambient temperature T_{amb} to a temperature T_{w2} can be obtained from:

$$t = -\frac{F_1 M_w C_w}{F_2 A} ln \left[1 - \frac{(T_{w2} - T_{amb})}{F_1 G}\right] \quad (4)$$

The time for sensible heating from the ambient temperature to boiling point, which is also known as the standard boiling time t_{boil}, is obtained by replacing T_{w2} with 100 °C and is calculated as:

$$t_{boil} = -\frac{F_1 M_w C_w}{60 F_2 A} ln \left[1 - \frac{(100 - T_{amb})}{F_1 G}\right] \quad (5)$$

2.4.8. Cooking power and standardized cooking power

The cooking power, P, is defined as the rate of useful energy available during the heating period. It is obtained by multiplying the change in water temperature for each time interval by them as sand by the specific heat capacity of the water contained in the cooking pot.

$$P = \frac{(M_w C_w)(T_{w2} - T_{w1})}{\tau} \quad (6)$$

The standardized cooking power, P_s, is obtained by correcting the cooking power P, to a standard solar radiation of 700 W/m^2. This is done by multiplying the interval cooking power by 700 W/m^2 and dividing the product by the interval average solar radiation intensity recorded during the corresponding time interval [42].

$$P_s = \frac{(M_w C_w)(T_{w2} - T_{w1})700}{G\tau} \quad (7)$$

A temperature difference is mathematically obtained by subtracting the ambient temperature for each interval from the water temperature for each corresponding time interval:

$$T_d = T_w - T_a \quad (8)$$

A linear regression line of the form $P_s = a + bT_d$ is then plotted to find the relationship between the standardized cooking power and the temperature difference in terms of the intercept a and slope b. The coefficient of determination, R^2, or proportion of variation in cooking power that can be attributed to the relationship found by the regression should be greater than 0.75 [41]. A single measure of performance is then obtained by computing the value of standardized cooking power (P_s) for a temperature difference (T_d) of 50 °C.

2.4.9. Cooker efficiency

The overall thermal efficiency of the solar box cooker is expressed mathematically by [9,43] and reported by [12] as follows:

$$\eta_u = \frac{M_W C_W}{I_{av} A_c} \frac{\Delta T}{\Delta t} \tag{9}$$

2.5. Navier-stokes equations

The Navier-Stokes equations describe the flow of an incompressible fluid with a system of partial differential equations, the momentum equation and the continuity equation. They can be derived from mass and momentum conservation. The fluid particles are not handled individually, but are grouped and represented by a field of velocity vectors $\vec{u}$ and a pressure field p at a time t. Since the fluid is incompressible the density is assumed to be constant [44]. The behavior of a fluid is influenced by body forces $\vec{g}$, e.g., gravity, and the Reynolds number Re. A low Reynolds number is used for viscous fluids, and high Reynolds numbers for non-viscous fluids, e.g., air. Temperature distribution and air circulation in the box cavity are governed by conservation equations. The system of partial differential equations is:

$$\frac{\partial \rho}{\partial t} = -\left(\frac{\partial}{\partial x}\rho v_x + \frac{\partial}{\partial_y}\rho v_y\right) \tag{10}$$

Momentum conservation equation:

$$\frac{\partial}{\partial t}\rho v_x = -\left(\frac{\partial}{\partial x}\rho v_x v_x + \frac{\partial}{\partial_y}\rho v_y v_x\right) - \left(\frac{\partial}{\partial x}\tau_{xx} + \frac{\partial}{\partial_y}\tau_{yx}\right) - \frac{\partial \rho}{\partial x} + \rho g_x \tag{11}$$

$$\frac{\partial}{\partial t}\rho v_y = -\left(\frac{\partial}{\partial x}\rho v_x v_y + \frac{\partial}{\partial_y}\rho v_y v_y\right) - \left(\frac{\partial}{\partial x}\tau_{xy} + \frac{\partial}{\partial_y}\tau_{yy}\right) - \frac{\partial \rho}{\partial x} + \rho g_y \tag{12}$$

Energy conservation Equation:

$$\rho c_p \left(\frac{\partial T}{\partial t} + v_x \frac{\partial T}{\partial x} v_y \frac{\partial T}{\partial y}\right) = k\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right] + 2\mu\left[\left(\frac{\partial v_x}{\partial x}\right)^2 + \left(\frac{\partial v_y}{\partial y}\right)^2\right] + \mu\left[\left(\frac{\partial v_x}{\partial y} + \frac{\partial v_y}{\partial x}\right)^2\right] - \frac{2\mu}{3}\left[\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y}\right] \tag{13}$$

2.5.1. Analysis with ansys

Ansys geometry handling solutions include best-in-class Cad integration technology in an industry-leading, Cad-neutral, Cae integration environment. Inside the solar cooker physical phenomena, such as evaporation and condensation are common. The type of Ansys feature suited to analyze evaporation-condensation phenomena is Fluent (fluid flow)-Cfd.

2.5.2. Modeling details

Simple modeling of the interior box surface temperature distribution was validated by the measured experimental outputs for the maximum plate temperature. The computational domain used for this analysis was two dimensional. The procedures used for solving the problem included: (a) creating the geometry, (b) Setting the material properties and boundary conditions and finally, (c) Meshing the domain. The geometry taken for the analysis was the tetrahedral control volume.Box face dimensions: top face-glazing with 470 mm × 470 mm and 4 mm thickness, bottom face-plate with 300 mm × 300 mm and the four walls with trapezoidal faces of 470 mm and 300mm bases and 22.67 mm height and made of iron sheet 1.5 mm thick. Similar ambient temperature and thermal conductivities were used. The physical geometry used for modeling is shown in Figure 7.

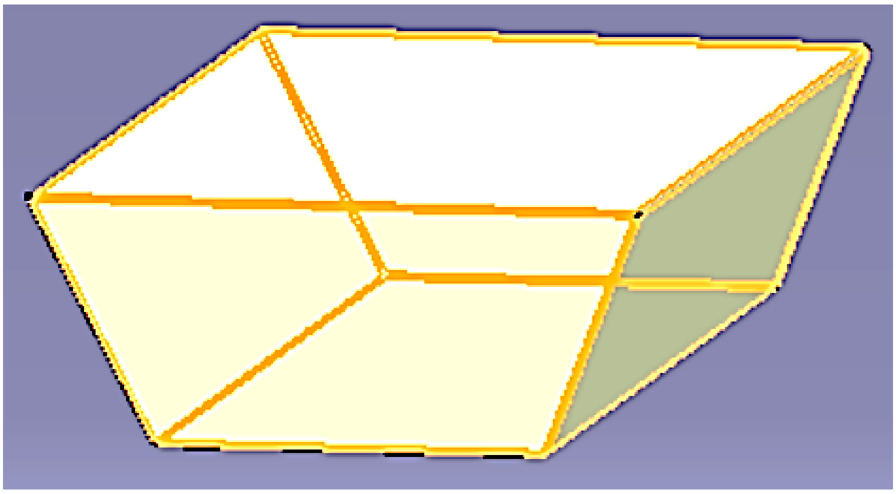

Figure 7. Geometry used for the analysis.

The modeling of the thermal disribution of the box type solar cookerwas done to see the comparative results with the experimental outputs discussed in the previous sub-sections.The boundary conditions used for the analysis were the interior box surfaces: Front wall, Back wall, two side walls, the glass and for the heat transfer mechanisms: Convection and Radiation coefficients with zero heat flux. Iterations have been done by the system based on the data input to get the Cfd analysis results.

3. Results and discussion

3.1. Stagnation temperature test

The result of stagnation temperature under no load condition is shown in Figure 8. The graph reveals the variation in the solar radiation and ambient temperature and their effects on the stagnation temperature observed in the absorber plate of the solar cooker. The average ambient temperature for the test was 31.2 ℃. The maximum absorber plate temperature of 161.7 ℃ was obtained after 3 hours 30 minutes at 13:30. The corresponding insolation value was 1,083 W/m^2. In the report discussed in [45], with a truncated pyramid solar thermal cooker, a maximum plate temperature of

131 °C was attained after 2 hours and 20 minutes. The thermal performance of a reflector based solar box cooker implemented in Ile-Ife, Nigeria reported a temperature of 76 °C [9] and 100 °C was attained for a finned absorber plate box cooker as discussed in [35]. The result shows that the absorber plate temperature was retained for a longtime. This is desirable for heating water since the major mode of heat transfer to the cooking vessels is by conduction from the absorber plate. The plate temperature, ambient temperature and insolation versus time are plotted in Figure 8.

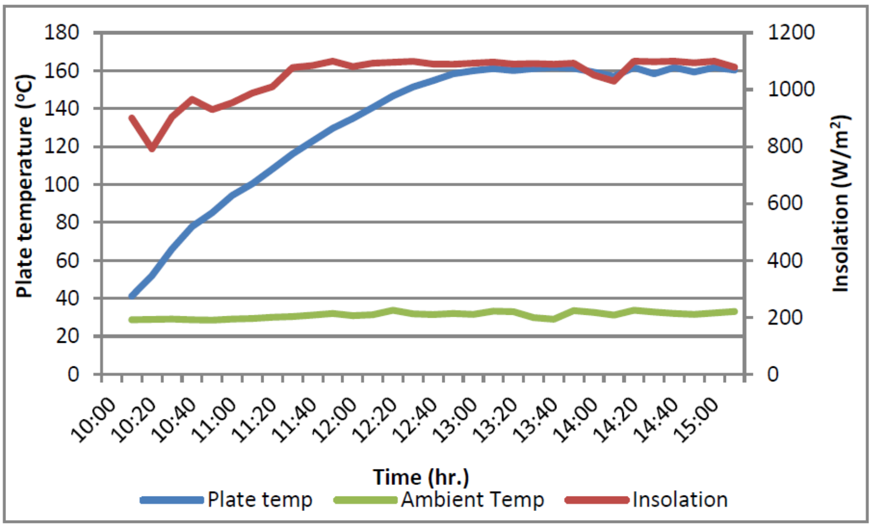

Figure 8. Thermal performance under stagnation test condition.

3.2. Sensible heat test

Variation in solar insolation, ambient temperature, plate temperature and plate water temperature during sensible heat test of 1.43 kg (1.43 liter) of water without and with the application of the glazing wiper mechanism are shown in Figure 9. These results validate the statement that using a wiper mechanism for the interior glazing allows solar energy to pass through the glazing without a barrier. Periodic weather overcast causes fluctuation in the solar insolation. The maximum insolation of 1,087 W/m^2 and minimum of 840 W/m^2 were recorded during the test. The average solar radiation and ambient temperature observed during the period of test were 1,019 W/m^2 and 31.1 ℃ respectively. The highest pot water temperature of 99.1 ℃ and 102.1 °C was observed within 2 hours and 40 minutes and 1hour and 50 minutes for without and with the application of the glazing wiper mechanism respectively. The test done by Ibrahim Ladan Mohammed in Kaduna Polytechnic, Kaduna State, Nigeria [45] obtained a 100 °C and pool boiling commenced after 3 hours 15 minutes. El-Sebaii AA, Domanski R, Jaworski M reported that most food can be fully cooked at the temperature range of 60–90 ℃ [46].

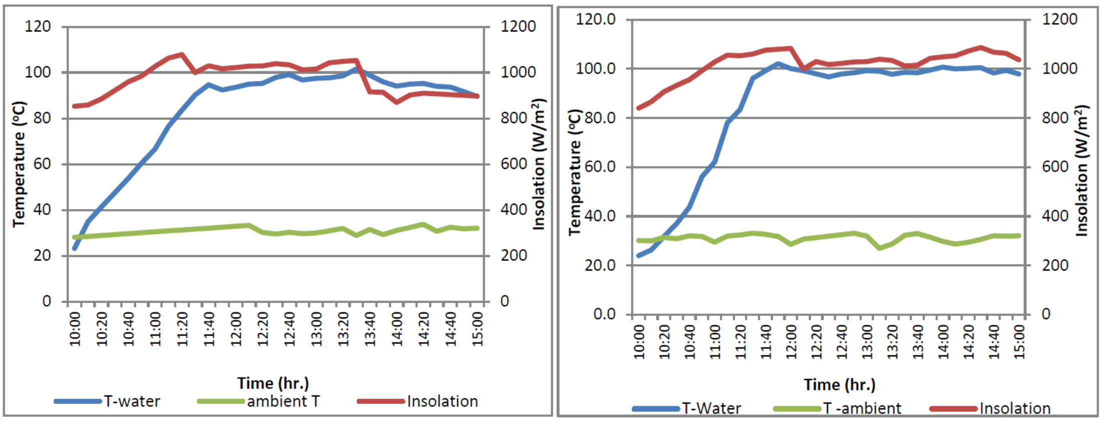

Figure 9. Temperature variation curve during sensible heat test Without wiper (left) and with wiper (right) mechanism.

3.3. Performance rating

3.3.1. First figure of merit

The first figure of merit (F_1) was calculated from equations (2.1 & 2.2) to be 0.123 at stagnation, with a value of T_p = 161.7 °C, T_a = 29 °C and H_s = 1,083 W/m^2. This corresponds to the maximum plate temperature of 161.7 °C attained by the cooker during stagnation test. The first figure of merit obtained was found to be higher than the multi reflector solar cooker (0.09) made with cardboard in India [11] and equal to that of the test done by Ibrahim Ladan Mohammed in Kaduna Polytechnic, Kaduna State, Nigeria [45]. It is also within the range or slightly higher compared to commercial box cooker which is from 0.11 to 0.12 [40]. Based on Indian standards, any designed solar box cooker with F_1 greater than 0.12 and above is classified as grade A and if otherwise, it is classified as grade B [38]. The high value of first figure of merit is as a result of high optical efficiency and high insolation, as well as low convection and radiation loses from the cooker.

3.3.2. Second figure of merit

The second figure of merit of the cooker (F_2) which corresponds to heat transfer efficiency of the cooker at low heat capacity of cooker was calculated from sensible heat test (water heating test) of 1.43 kg of water in the cooker using equation (3.3). In calculating the value of F_2, [41] reported that some flexibility is allowed in the choice of T_{w1} and the time interval (t). A valueof $T_{w1} > T_a$ was recommended by [47] while values of T_{w2} lower than the boiling point was recommended by [48]. The time required to raise the temperature of 1.43 kg of water from 60.5 ℃ to 94.3 ℃ was about 50 minutes which corresponds to the second figure of merit (F_2) calculated from equation (3.3) to be 0.540 without the application of glazing wiper. The time required to raise the temperature of 1.43 kg of water from 62.1 ℃ to 96.1 ℃ was about 30 minutes which corresponds to the second figure of merit (F_2) calculated to be 0.827 with the application of glazing wiper. These values are greater than 0.42 and the cooker has met BIS requirements in terms of the first and second figures of merits. The F_2 value for the test done by Ibrahim Ladan Mohammed in Kaduna Polytechnic, Kaduna State, Nigeria was 0.402 [45].

3.3.3. Standard boiling time

The time for sensible heating from the ambient temperature to boiling point, which is also known as the Standard boiling time t_{boil}, was calculated to be 88.84 minutes and 53.54 minutes for without the application of the wiper mechanism and with the application of wiper mechanism respectively. The result shows that the water boiling time of the cooker with a glazing wiper is reduced by 35.3 minutes to that without a wiper mechanism. In addition to the standard water boiling test food cooking was done by the cooker. It was shown that 250 g of white rice were cooked in 91 minutes, 500 g of potato were boiled in 95 minutes and 250 g of wheat bread were baked in 155 minutes. In the report discussed in [45] a Truncated Pyramid Solar Thermal Cooker could cook 2.0 kg of rice in 2 hours 45 minutes; 1.2 kg of beans in 3 hours; 2.0 kg of yam in 2 hours; 2.0 kg of sweet potato in 1 hour 45 minutes; 1.6 kg of potato 1 hour 45 and 6 pieces of chicken egg in 1 hour.

3.3.4. Calculating cooking power

The change in water temperature for each ten-minute interval shall be multiplied by the mass and specific heat capacity of the water contained in the cooking vessel (s). This product shall be divided by the 600 seconds contained in a ten-minute interval, and the analysis was done for each interval temperature. The instantaneous maximum and minimum power obtained were 118 W and 2 W, and 291 W and 2 W without and with the application of the wiper mechanism respectively.

3.3.5. Standardizing cooking power

Cooking power for each interval shall be corrected to a standard insolation of 700 W/m^2 by multiplying the interval observed cooking power and dividing by the interval average insolation recorded during the corresponding interval as recommended in [36]. Figure 10 and 11 show the adjusted cooking power plotted over the temperature difference and the resulting regression line for the two cases without and with the wiper mechanism.

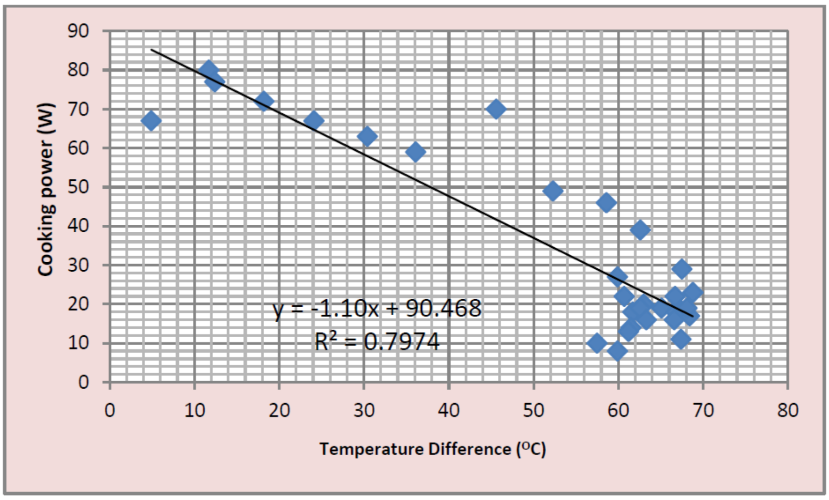

Figure 10. Cooking power vs temperature difference and the resulting regression line for the non-wiper cooker.

The equation was: $P_s = 90.5 - 1.1T_d$, and the standard cooking power for a 50 ℃ temperature difference was: $P_s(50)$ = 36 W. The general trend of the scatter diagram is that as temperature difference increases, standardized cooking power decreases. Correlation analysis shows that the correlation coefficient, R, was 0.893 and the coefficient of determination, R^2, was 0.797. This means only about 79.7% of the variation of standardized cooking power can be attributed to temperature difference.

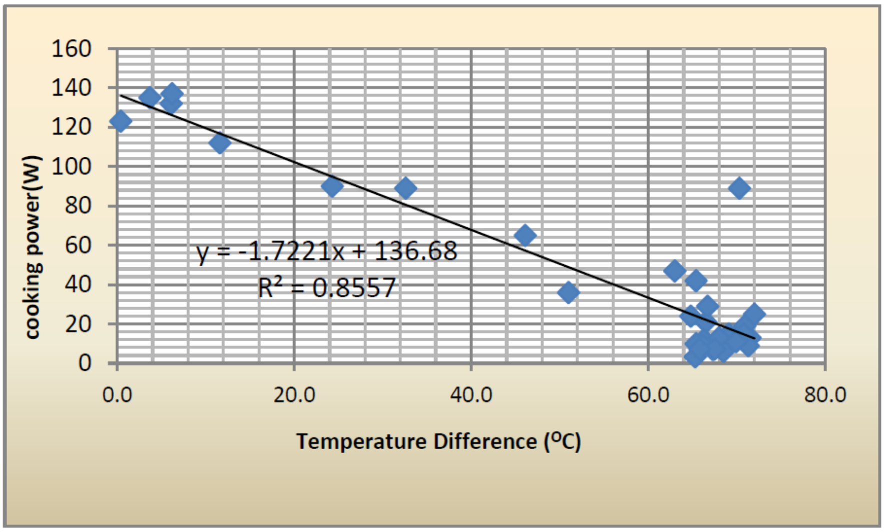

Figure 11. Adjusted cooking power vs temperature difference and the resulting regression line for wiper mechanism using cooker.

The equation is: $P_s = 137 - 1.72T_d$, and the standard cooking power for a 50 ℃ temperature difference is: $P_s(50)$ = 51 W. The Correlation analysis shows that the correlation coefficient, R, is 0.927 and the coefficient of determination, R^2, equals to 0.86. This means that only about 86% of the variation of standardized cooking power can be attributed to temperature difference. The figure of standardized cooking power for the cooker with a wiper mechanism is comparative to the 73.9 W reported in [45] and obtained by other investigators such as Sharma et al. [49], Purohit et al. [46], and Aroma et al. [42] who reported higher figures of 62, 64.9, and 67.06 W respectively.

3.3.6. Overall cooker thermal efficiency

The Overall daily thermal efficiency of the solar box cooker (η_u) was calculated from equation 9 to be 22.0% without the application of glazing wiper mechanism and 31.4% with the wiper mechanism. The above result shows that with the application of the wiper mechanism has increased the efficiency compared to the case with no wiper mechanism. The variations of the solar insolation and the instantaneous efficiencies versus solar time for the cooker without wiper mechanism are presented in Figure 12.

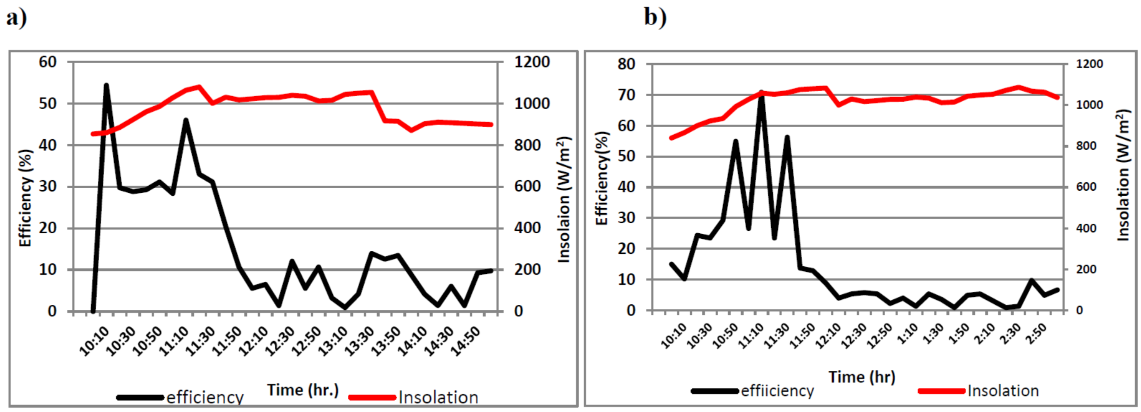

Figure 12. Efficiency and solar insolation versus time for (a) without wiper and (b) with the application of wiper mechanism.

3.4. Visualization of CFD output

The maximum and minimum temperature which can be attained inside the box and the thermal distribution are shown in Figures 13 and 14. The number of nodes and elements used for meshing the physical body were 115,920 and 108,460 respectively.

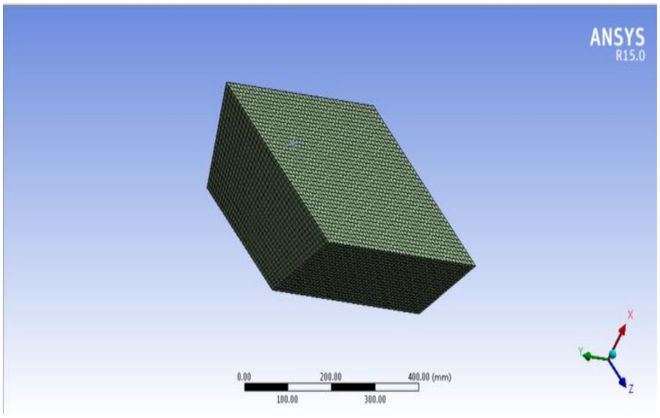

Figure 13. Meshing of the graphical body.

The highest temperature occurs at the bottom face of the cooker's plate, which is more exposed to direct solar rays than the walls. The thermal distribution on the box with the corresponding color code is displayed with temperature contours in Figure 14.

Computational fluid dynamics was used to model and simulate the solar box cooker plate temperature distribution. Natural convection, conduction and radiation mechanisms of heat transfer were used in the modeling and simulation.The comparison of the simulation results and the experiment shows that, the experimental result for the plate temperature was found to be greater by 13% to that of the simulation. This could be due to enviromental factors and the orientations of the cooker during the experimentation.

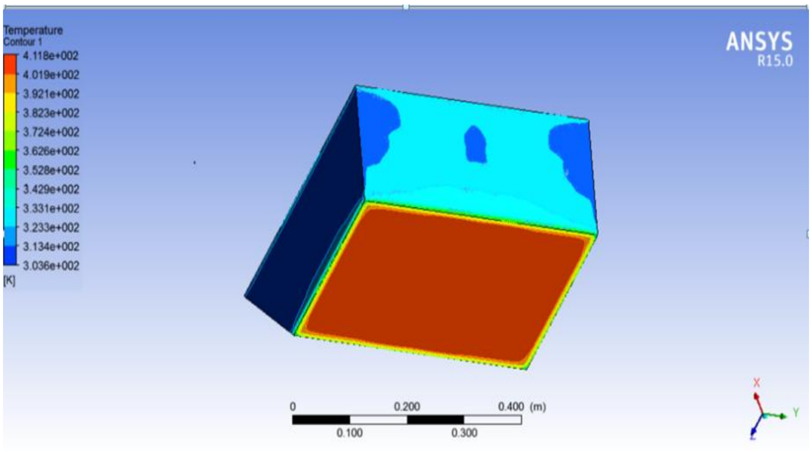

Figure 14. Bottom plate and wall tempetratude distribution.

3.5. Validation of results

Performance evaluation of a double-glazed box-type solar oven with reflector was done in Minna, Nigeria by Joshua Folaranmi [50]. The maximum plate temperature of 119 ℃, a cooking power of 23.95 W, and a water boiling time of 136 minutes were obtained. Nahar et al. [51] used a double reflector to improve the performance of the box-type solar cooker with transparent insulation material. The use of one more reflector avoided the tracking of the sun for 3 hours so that cooking operations could be performed unattended, as compared to a hot box solar cooker where tracking of the sun is required every hour. The efficiencies were 30.5% and 24.5% forcookers with and without a transparent insulation materiel respectively. Ammer et al. [52] discussed the experimental results on a double glazed box-type solar cooker, under similar operating conditions. The results show that the absorbers of the box type cooker and the double glazed cooker attain 140 ℃ and 165 ℃, respectively. The temperatures of the air inside the two cookers are 132 ℃ and 155 ℃, respectively. The time taken for cooking several foods and for boiling the same amount of water is obtained for the two cookers under the same conditions and at the same location. The double exposure cooker reduces the cooking time by about 30–60 minutes.

Negi and Purohit [50] conducted an experimental study of a box-type solar cooker with two non-tracking planar reflectors to enhance solar radiation in the box. The experimental results obtained show that the concentrator solar cooker provides a stagnation temperature 15–22 ℃ higher and it was also observed that the boiling point of water with the concentrator cooker was reached faster, by 50–55 min, than with the conventional box type cooker using a booster mirror.

3.6. Techno-economic evaluation of the cooker

The construction costs of a solar cooker vary widely, independently of the type. Production of solar cookers locally often becomes difficult because of materials like glass, mirrors, or reflective-coated aluminum is not easily available. The solar box cooker used for this research work was produced from locally available materials which can be manufactured and marketed by local shops and furniture manufacturers around Bahir Dar.

3.6.1. Payback period of the cooker

Life Cycle Costing (LCC) is the sum of all costs associated with an energy delivery system over a selected period of analysis or over its lifetime. Life Cycle Saving (LCS) is the difference in the present worth between the LCC of conventional or alternative fuel system and the LCC of the solar energy system. These two were used in the economic analysis of the cooker. They are considered useful in economic analysis of solar energy systems [14]. More than 70% of Ethiopia's energy is directly supplied by fuel wood or charcoal [37]. Wood fuel provides 90% of rural households' energy requirement and 85% of urban households' energy requirement [53]. Charcoal and firewood were chosen as alternative sources of fuel. Considering the durability of materials used to construct the cooker it was estimated to have a life span of 10 years. The payback period was calculated by assuming a discount rate (d) of 10%; repair and maintenance (α) 5% of the capital cost of the cooker; number of meals in a year (n) 2 × 275 = 550 and a life span (t) of 10 years. Cost using alternative fuel was calculated using the following considerations: Daily energy requirement is 5.4 MJ, (6 × 900 kJ). Charcoal of calorific value of 28 MJ/kg at a cost of ETB 4/kg with an efficiency of 20% for institutional stoves and for every 1kg of charcoal 3 kg of wood is required. Charcoal requirement per day to meet the energy demand equals to 5.4 MJ/(28 MJ/kg × 0.2) = 0.96 kg of charcoal. Cost of charcoal to meet the daily energy demand = ETB 4 × 0.96 = ETB 3.86 per day. Annual cost of charcoal = ETB 3.86/day × 275 days = ETB 1,061.5. Equivalent amount of wood required to meet daily energy demand is given by 0.96 × 3 = 2.88 kg and annual wood requirement = 2.88/day × 275 days = 792 kg of wood. For a lifespan of 10 years about 7.920 tons of wood would be required. The payback period was computed using the following relation:
The net present worth can be calculated as follows:

$$NPV = \left(\frac{np - C_o\alpha}{d}\right)\left[\frac{(1+d)^t - 1}{(1+d)^t}\right] \tag{13}$$

The payback period (PP) can be calculated as follows:

$$pp = \frac{C_o}{(np - \alpha C_o)} \tag{14}$$

$$pp = \frac{4500}{(550 * 3.86 - 0.05 * 4500)}$$

$$= 2.37 \text{ years}$$

The benefits, operational costs and net cash flow of the cooker is shown in Table 1 below

Table 1. Cost analysis of the solar cooker.

Years from start of project development to the end of Life span of the cooker											
Year	0	1	2	3	4	5	6	7	8	9	10
Benefits	0	1725.5	3294	4720	6016.4	7194.9	8266.3	9240.3	10125.7	10930.6	11662.4
Investment	4500	2774.5	1206	-	-	-	-	-	-	-	-
Sum of Payments	4500	2774.5	1206	4720	6016.4	7194.9	8266.3	9240.3	10125.7	10930.6	11662.4
Net Cash Flow	–4500	–2774.5	–1206	4720	6016.4	7194.9	8266.3	9240.3	10125.7	10930.6	11662.4

The cost of purchasing and installing a solar cooking system is high in comparison to the conventional system it replaces. But the conventional system is energy intensive, that is, the annual energy costs are higher than an equivalent solar system [52]. Purchasers of solar systems expect the resulting fuel savings eventually to pay for the system and save on the cost of future energy needs. The net cash flow of the cooker for the intended period is shown in Figure 15 below.

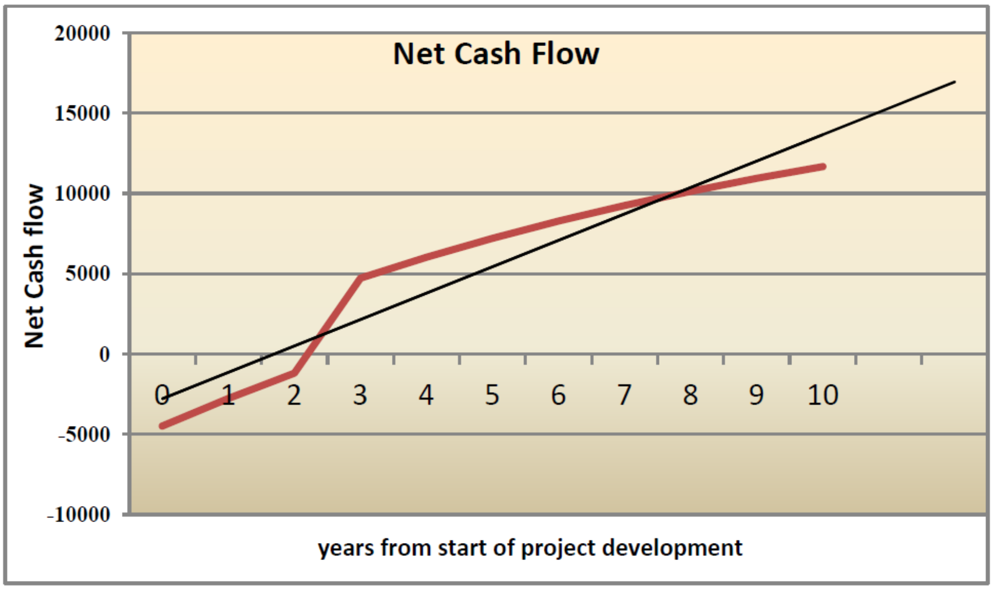

Figure 15. Net cash flow of the cooker.

According to Unisun Technologies (P) Ltd. [54], box solar cookers with different cooking capacities and components are manufactured and marketed worldwide within a cost range of 250–2000 US dollars. The box type solar cooker used in this study was manufactured from locally available and recycled materials with a total cost of ETB 4500 (196 USD). This result indicates that the cooker is low cost and can be purchased by people in the locality. Techno-economic and environmental impact analysis of a Passive Solar Cooker was done in Nigeria and reported for the cost of rectangular box type solar cooker which was constructed out of recyclable available materials. Table 2 shows the cooking capacity, total costs, monthly energy savings and payback period of the cooker [55].

Table 2. System payback period.

Cooking	System Cost	Monthly Savings	Payback Period
3 meals a day	£30.00	£7.50	4 months
2 meals a day	£30.00	£5.00	6 months
1 meal a day	£30.00	£2.50	12 months

4. Conclusions and recommendations

4.1. Conclusions

The Box Solar Cooker was designed and fabricated in accordance to the details available in journals and previous works. The following conclusions are given based on the results obtained from the research work.

(1) First figure of merit (F_1) to be 0.123 at stagnation, with maximum plate temperature of 161.7 ℃, at an ambient temperature of 31.0 ℃ and as per BIS the cooker was graded A and it is also in the range compared to commercial box cooker which are from 0.11 to 0.12 [40]. The second figure of merit of the cooker (F_2) which corresponds to heat transfer efficiency of the cooker at low heat capacity is calculated from sensible heat tests (water heating test). 1.43 kg of water found to be 0.540 without the application of glazing wiper and 0.827 with the application of glazing wiper. This is greater than 0.42 as per BIS.

(2) The overall daily thermal efficiency of the solar box cooker (η_u) was calculated to be 22.0% without the application of glazing wiper mechanism and 31.4% with the wiper mechanism. The above result shows that the box type solar cooker with the application of wiper mechanism has improved the efficiency of 9.4% to that of without wiper mechanism.

(3) The water boiling time from measured data was obtained to be 53.54 and 88.84 minutes for the cooker with and without wiper mechanism respectively. The result shows that water boiling time of the cooker with a glazing wiper is reduced by 35.30 minutes to that without a wiper mechanism. The standardized cooking power with a temperature difference of 50 ℃ was 36 W and 51 W for the cooker without and with wiper mechanism respectively.

(4) The thermal distribution of the cooker was also simulated using ANSYS 15.0. This result was validated with the experimental results. It was found that the amount of heat which is absorbed by the interior box is approximately equivalent to that of calculated from experimental results. The method of modeling and simulating of the cooker with and without wiper mechanism is similar except for the variation of the transmittance of the glass due to the shading of vapor. This can be deducted from the cumulative efficiency of the latter case.

(5) Finally the cost of the cooker was estimated to be ETB 4500 (196 US$) and the payback period was estimated to be 2.4 years.

4.2. Recommendations for further work

(1) Further work should be carried out on an integrated solar automated wiping mechanism and the simulation and modeling with detail parameters in different components and materials to get optimum results.

(2) The rate of vapor formation and the effect of vapor on the glazing surface that could affect the transmittance of the glazing and optimum rate of wiping that gives better results are not answered in research work.

Acknowledgements

This work would not have been possible without the financial support of Bahir Dar University Institute of Technology and Amhara Trade and Industry bureau and. I am especially indebted to Dr. Sameer Hameer Prof (asst.), Researcher and my advisor in Bahir Dar Energy center and lecturer in the department of Sustainable Energy Engineering, who have been supportive of my career goals and who worked actively to provide me with the protected academic time to pursue those goals. I am grateful to all of those with whom I have had the pleasure to work during this. Most importantly, I wish to thank my loving and supportive wife, Serawork Degu, and my Son, Esrael Zeleke who provide unending inspiration.

Conflicts of interest

All authors declare no conflicts of interest in this paper.

References

1. Concentrating Solar Power, Global Outlook 09, Greenpeace USA. Solar PACES and ESTELA, 2009. Available from: http://www.greenpeace.org/international/Global/international/.../2009/.
2. World Outlook Energy 2015, Executive Summary, International Energy Agency. Available from: http://www.iea.org/publications/freepublications/publication/WEO2015.pdf.
3. Solar Cookers: Technology and Development. Available from: http://www.appropedia.org/Solar_Cooking_and_the_Box_Cooker:_T.
4. Sedighi M, Zakariapour M (2014) A review of direct and indirect solar cookers. *Sustain Energ* 2: 44–51.
5. Brinkmann K (2012) Analysis of landscape transformation processes in and around four west African cities over the last 50 years. *Landscape Urban Plan* 105 (1–2): 94–105.
6. Food and Agriculture Organization. Global forest resources assessment database, 2015. Available from: http://countrystat.org/home.aspx?c=FOR.
7. Food and Agriculture Organization. Global forest resources assessment 2010: main report. Rome, 2010. Available from: http://www.fao.org/docrep/013/i1757e/i1757e.pdf.
8. Hambidge M, Miller L, Krebs NF, et al. (2012) An assessment of deforestation and forest degradation drivers in developing countries. *Environ Res Lett* 7: 189–190.
9. International Journal of Energy Engineering 2015, DOI: 10.5923/j.ijee.20150505.02-ResearcgGate, Available from: http://www.scimagojr.com/journalsearch.php?q=26677&tip=sid.
10. Mandelli S, Barbieri J, Mattarolo L, et al. (2014) Sustainable energy in Africa: a comprehensive data and policies review. *Renew Sust Energy Rev* 37: 656–686.
11. Research Journal of Agriculture and Environmental Management. 4: 216–224, 2015. ISSN 2315-8719© 2015. Available from: http://www. apexjournal.org/rjaem/index.htm.
12. Institute for Population Research-National Research Council (Irp-Cnr) Roma, Italy.
13. SOLANKI, Singh C (2009) Renewable energy technologies: A practical guide to beginners. Available from: https://www.kopykitab.com/ebooks/2016/06/7379/sample/sample_7379.pdf.
14. Solar Thermal Process, Duffie AJ, Beckmann NJ (1991) 3rdedition, New York, John Wiley. Available from: http://www.studyres.com/doc/.../energy-engineering---kalasalingam-univers.

15. Ercan-Ataer Ö, Energy Storage systems-Vol I, Gazi University, Mechanical Engineering Department, Malteps, 06570, Ankara Turkey.
16. Sahin AD, Dincer I, Rosen MA (2007) Thermodynamic analysis of solar photovoltaic cell systems. *Sol Energ Mat Sol C* 91: 153–159.
17. Cuce E, Cuce PM (2013) A comprehensive review on solar cookers. *Appl Energ* 102: 1399–1421.
18. Colombo E, Masera D, Bologna S (1997) Renewable energies to promote local development. In: Colombo E, Bologna S, Masera D, Eds. *Renewable Energy for Unleashing Sustainable Development*. Springer International Publishing: Switzerland, 3–25.
19. Legros G, Havet I, Bruce N, et al. (2009) The Energy Access Situation in Developing Countries: A Review focusing on the Least Developed Countries and Sub-Saharan Africa. New York. Available from: http://www.undp.org/content/dam/undp/library/Environment and Energy/Sustainable Energy/energy- access-situation-in-developing-countries.pdf.
20. Oduori SM, Rembold F, Abdulle OH, et al. (2011) Assessment of charcoal driven deforestation rates in a fragile rangeland environment in north eastern Somalia using very high resolution imagery. *J Arid Environ* 75: 1173–1181.
21. Panwar NL, Kaushik SC, Kothari S (2011) Role of renewable energy sources in environmental protection: a review. *Renew Sust Energ Rev* 15: 1513–1524.
22. Saxena A, Varun, Pandey SP, et al. (2011) A thermodynamic review on solar box type cookers. *Renew Sust Energ Rev* 15: 3301–3318.
23. Funk PA, Larson DL (1998) Parametric model of solar cooker performance. *Sol Energy* 62: 63–68.
24. Hren S, Hren R (2010) The Carbon-Free Home: 36 Remodeling Projects to Help Kick the Fossil-Fuel Habit. Chelsea Green Publishing: Chelsea, Vermont.
25. Nahar NM (1998) Design, development and testing of a novel non-tracking solar cooker. *Int J Energ Res* 22:1191–1198.
26. Pande PC, Thanvi KP (2010) Design and development of a solar cooker cum drier. *Int J Energ Res* 12: 539–545.
27. Sedighi M, Zakariapour M (2014) A review of direct and indirect solar cookers. *Sustain Energ* 2: 44–51.
28. Nahar NM (2009) Design development of a large size non- tracking solar cooker. *J Eng Sci Technol* 4: 264–271.
29. Bowman TE, Blatt JH (1978) Solar cookers, history design fabrication test and evaluation. First International Symposium of Engineering, Florida.
30. Thermodynamic Review of Solar Box Cookers (Excerpted from the thesis of Petri Konttinen for the Helsinki University of Technology. Submitted September 25th, 1995). Available from: http://www. solarcooking.org/research/fi/petrithe.htm.
31. Kundapur A (1998) Review of solar cooker designs.TIDE8-1: 1–37.
32. Boyle G (2004) Renewable energy, Oxford University Press Ink (New York). Available from: http://oro.open.ac.uk/3044/.
33. Wikipedia (2011) Glazing-Solar/Cooking. Available from: http//solarcooking.wikia.com/wiki/Glazing.
34. Norton B (2006) Anatomy of a solar collector. *Refocus* 7: 32–35.

35. International Journal of Advanced Research in Engineering and Technology (IJARET). Article ID: IJARET_06_07_001. 2015, 6: 01–06. Available from: https://www.slideshare.net/iaeme/ijaret-06-07001.
36. ASAE S580 JAN03 Testing and Reporting Solar Cooker Performance, 2003. Available from: http//www.solarcooking.org/asae_test_std.pdf.
37. Bhagavan MR, Karekezi S (1992) Energy management in Africa. African Energy Policy Research Network (AFREPREN) Zed Books Ltd.
38. Mirdha US, Dhariwal SR (2008) Design optimization of solar cooker. *Renew Energ* 33: 530–544.
39. Design, Construction and Performance Evaluation of a box type solar cooker, Anonymous., Indian standard for box type solar cooker specification. IS 13429 (Part 3), Bureau of Indian Standard 2000, 2006. Available from: https://issuu.com/zeleke1/docs/design.docx.
40. Duffie JA, Beckman WA, Mcgowan J (1994) Solar engineering of thermal processes. *J Sol Energ Eng* 116: 549.
41. Hasan MA, Sumathy K (2010) Photovoltaic thermal module concepts and their performance analysis: A review. *Renew Sust Energ Rev* 14: 1845–1859.
42. Aremu AK, Akinoso R (2013) Potential use of box type solar cooker in developing countries. *J Assoc Prof Eng Trinidad Tobago* 41: 11–17.
43. Kuhnke K, Renbar M (1997) Solar cookers in the third world. Available from: http://www.detlef-schwefel.de/119-Schwefel-Kuhnke-solar-cookers.pdf.
44. Fundamentals of the Finite ElementMethod for Heat and Fluid Flow. John Wiley & Sons, Ltd, 2004.
45. International Journal of Renewable Energy and Environmental Engineering ISSN 2348-0157, 2015, 3: 105–110. Available from: http//www basharesearch.com/IJREEE.html.
46. El-Sebaii AA, Domański R, Jaworski M (2014) Experimental and theoretical investigation of a box-type solarcooker with multi-step inner reflectors. *Energy* 19: 1011–1021.
47. Szulczewski M (2016) Lasting impacts of a solar cooker project. Available from: http://static2.wikia.nocookie.net/__cb20111229184529/solarcooking/images/e/ec/Lasting_Impacts_of_Solar_Cooker_Projects.pdf.
48. Mullick SC, Kandpal TC, Saxena AK (1987) Thermal test procedure for box type solar cooker. *Sol Energy* 39: 353–360.
49. Sharma SD, Iwata T, Sagara K (2004) Thermal performance of box type solar cooker: a study in Japan climate. *J Japan Sol Energ Soc* 30: 49–54.
50. Folaranmi J (2013) Performance evaluation of a double-glazed box-type solar oven with reflector. *J Renew Energ* 2013.
51. Nahar NM (2001) Design, development and testing of a double reflector hot box solar cooker with a transparent insulation material. *Renew Energ* 23: 167–179.
52. Ammer EH (2003) Theoretical and experimental assessment of double exposure solar cooker. *Energ Consers Manage* 44: 2651–2663.
53. Ikiara M, Mwakubo S, Mutua J, et al. (2006) Integrated assessment of energy policy with focus on the transport and household energy sector. Available from: https://www.researchgate.net/publication/275208387_Kenya_Integrated_assessment_of_the_Energy_Policy_With_focus_on_the_transport_and_household_energy_sectors.

54. UNISUN TECHNOLOGIES (P) LTD.No 7, Ist Floor, Kodava Samaja, Vasanthnagar, Bangalore-560052, INDIA. Web: ISSN: 2455-5304. Available from: https://books.google.it/books?isbn=8188234265.
55. Techno-Economic and Environmental Impact Analysis of A Passive Solar Cooker for Application in Nigeria, The International Journal of Engineering And Science (IJES), December–2014, ISSN (e): 2319–1813 ISSN (p): 2319–1805, Available from: https://heijes.com/papers/v3-i12/Version-3/B03120306011.pdf.