

DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF SMART SOLAR BOX COOKER WITH SODOM APPLE FRUIT FIBRE/WASTE PAPER MIXTURE AS AN INSULATOR

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ABSTRACT

Fiberglass, mineral wool, and foam assemblies, are prevalent but hazardous for environmental and health reasons because of the nature of their constituents. Local alternatives developed from agricultural produce such as mesocarp from Sodom apple pods would open a sustainable way of utilizing the harnessed local resources to make useful products. This work is based on the development of smart solar cookers from Sodom apple fruit fiber mixed with waste paper. The major aims of this study are to develop insulating composites, design an IoT-based smart monitoring system, and make and test a solar box cooker's performance. There were careful collections, cleaning and sorting of materials for the experiment followed by some standard tests such as SEM, EDX, density testing, moisture content analysis, absorption tests, thermal conductivity measurement, TGA and compressive stress testing. The Bureau of Indian Standards uses two figures of merit, F1 and F2, for evaluating these metrics relative to cooking power measurements done by Association for Biological Agricultural Engineering are employed for the performance evaluation of the developed smart solar box cooker. A real-life situation showed that it did work effectively, as was shown during the field tests conducted in northeastern Nigeria at the Faculty of Engineering Teaching workshop, University of Maiduguri. The results for no-load tests (F1) read 0.12 on May 22nd, 26th and 24th 2024 respectively. Load tests (F2) May 25th, 26th, and 27th 2024, respectively. Lad as following second figure of merit: 0.72, 0.76, and 0.61, respectively. These findings agree with BIS classification for A Class Cookers. Next, $P_s = 0.874 \Delta T + 18.72$ is the regression equation for standardized cooking power, whereby $R^2=0.759$ indicates that with an increased temperature difference at a constant rate, cooking power will rise correspondingly. Given the promising findings of this study on Sodom apple fruit fiber, more uses for this kind of fibers must be examined to reduce heat in different fields. Moreover, it is indicated capacity of the fiber in sound absorption taking into account its properties.

Keywords: Sodom apple, insulator, Solar, Cooker, Figure of Merits

1 INTRODUCTION

It's estimated that about two billion people around the world suffer from domestic energy shortages. Most of these problems are situated in the rural and semi-urban areas of Africa where the scarcity of fuel wood has been a feature in the last couple of decades. The problem includes social, economic, technical, health, and environmental dimensions [1]. Solar energy technology is getting increasingly efficient as fossil fuel prices have risen globally in the last few years. Moreover, other than

numerous advantages using solar energy for food cooking, e.g. clean energy, low cost, health and safety benefits and infinite energy source, solar cooking is a new approach to cooking in many parts of the world. These cookers usually take a longer time to cook food compared to standard ovens [2]. With very high solar energy potential, Nigeria stands at 5×10^{12} kWh of annual solar energy influx. It has all over its geography some mean daily radiation of between 15.4 and 22.6 MJ/m²/day, the average daily sunshine ranges from 3.5 to 7.0 hours, while the average daily overcast period is in the range of 1.5 to 5.5 hours. Such ideal conditions, more favored by locations in the northern parts, have motivated local research to tap it efficiently [3]. Solar cooking directly utilizes the energy of the sun in heating and preparing food, hence eliminating the use of traditional fuels such as wood, charcoal, gas, or electricity. In this research, this smart solar box cooker is integrated with a monitoring system for real-time data visualization. There are sensors that turn on alarms and notify the user's mobile phone of warming and cooking times. It had a metered visual display unit showing the absorber plate temperature, oven temperature, water temperature, and ambient air temperature. Interest has in the past been focused on developing sustainable, biodegradable, and high-quality products using natural fibers by scientists, researchers, and practitioners around the world. Natural fibers obtained from renewable and ecologically acceptable sources have been, throughout history, the most critical materials used for the survival of human civilization. They have many advantages over synthetic fibers, which include low density, lightweight, inexpensive, biodegradable, nontoxic to health during processing, abundant, and easy to source. They reduce production cost, less energy consumption, and reduced CO₂ emission. Their attributes make natural fibers an attractive substitution to the synthetic fibers like glass or carbon in composite materials [4, 5]. The innovative insulation materials from the Sodom apple fruit fiber offer a number of environmental advantages over the traditional synthetic methods of insulation. These advantages include the reduction of carbon emissions, preservation of forests, improvement in air quality, conservation of natural resources, mitigation of climate change, and cost saving. The project tackled challenges in efficient cooking through environment-sensitive ways that propagated renewable and sustainable resources for supporting the conservation of natural materials. The rising concern for developing eco-friendly materials has driven researchers to find renewable and biodegradable materials to replace traditional sources of materials. [6]. Recycling farm fibrous wastes into insulation materials would not only rescue the environment but will reduce overdependence on high-tech insulation materials that mostly come from importation. [7] This is because, among many other essential attributes, natural fibers have high tensile strength under static loading, good particle orientation, and superior thermal insulation properties; this makes them advantageous over other materials. The efficiency of thermal insulation is mainly designed to minimize or limit the transfer of heat between objects or their radiant areas. All such materials available on the Nigerian market, including fiberglass, mineral wool, and foam assemblies, are prevalent but hazardous for environmental and health reasons because of the nature of their constituents. Local alternatives developed from agricultural produce such as mesocarp from Sodom apple pods would open a sustainable way of utilizing the harnessed local resources to make useful products. In this work, Sodom apple tree pods will be sourced locally to harvest mesocarp fiber/waste paper for developing efficient insulators of smart solar box cookers. The results are expected to prove the feasibility and performance of the Sodom apple fiber/waste paper as insulation material in thermal systems, targeting a reduction in production costs against their imported alternatives. If successful, this could further improve livelihoods associated with the agricultural production and processing involved. The project, therefore, shall be concerned with developing natural and sustainable Sodom apple fruit fibre/waste paper insulation and the design of a smart solar cooker, which shall be constructed with a view to evaluating the performance concerning improved thermal efficiency, cooking capability, and overall effectiveness. For example, [8] provided a review of the advancements in solar cooking technology over the past decade. The innovations reviewed pertain to cooker designs, materials, and tracking systems. Also noted therein was a trend towards integrating automated tracking and thermal storage solutions into such cookers to make them more practical and efficient. Performed a detailed empirical analysis of the performance evaluation for different solar cookers in. In this study, various designs and materials were considered to establish which has a better

design configuration for different climatic conditions. This analysis found that only optimized design parameters can result in maximum thermal efficiency. Proposed some kind of low-cost, simplified IoT-based system for monitoring energy by [9] Real-time information for energy consumption and efficiency is provided by the system. This could turn out to be very vital in the optimization of the performance of solar cookers. Probably, some refinement in a solar cooker by integrating such monitoring systems could make it efficient and reliable. [10] tried to use stearic acid in a double-compartmented solar box cooker for storing solar thermal energy. Stearic acid, as PCM, depicted effective thermal storage capacity since it would hold the cooker at a desired cooking temperature for a longer period. This design solved the problem relating to continuous temperature required for cooking in case of cloudy weather or when the sun had already set.

2 MATERIAL AND METHOD

Materials used in this work include Sodom apple fruits, which were collected from the outskirts of University of Maiduguri campus. The fibre extraction and laboratory preparation were carried out at the Faculty of Engineering Teaching Workshop. The waste paper was sourced within the campus and cassava starch as (binder), while plywood and nails for mould making were easily sourced through the local market in Maiduguri. A rubber gasket was sandwiched between the glass cover and the smart solar box cooker to minimize leakage from the box to the outside. The cookware vessels used in this study were procured from the local market, made of aluminum alloy in a cylindrical shape, and painted black in color to allow a high absorption of solar radiation so that cooking could be efficient. Clear window glass panes were used, and the inner receivers were made of aluminum painted dull black to absorb maximum solar energy.

2.1 Smart System Configuration

This section of the book details hardware and software components for implementing Smart Refrigeration. The hardware setup for the Smart Solar Cooker module consisted of a power supply unit, Arduino Uno board—ATmega328p, LM35 Precision Centigrade Temperature Sensors, GSM module, LCD display, and Buzzer—ABI-009-RC. These were designed to alert users when the unit reached a warm temperature or when water was boiled. A temperature sensor, mounted at a point inside the solar box cooker, measured internal temperatures. The signals from Arduino communicated with the GSM AT Commands, indicating whether the oven was warm or the food is cooked. Examples of the notifications that were sent to the user's cell phone through the GSM module included "the oven is warm" and "the water is boiled." Alternatively, if the user did not have a phone, an installed buzzer provided an audible alert. This interface would allow connectivity with an Arduino Uno using GSM AT Commands MTCBA-G-F1/F2 and the Node MCU platform as the WiFi module. In addition, it used LM35 and PT100 as temperature sensors in measuring the ambient temperature and internal box cooker temperature, respectively [10]. In this design, the Arduino UNO acted as the central processing unit. It gathered data from the sensors to obtain optimal cooking times. GSM AT Commands MTCBA-G-F1/F2 played a major role in developing secure communication channels between the Arduino processor, the user's phone, and the buzzer. For real-time monitoring, critical metrics such as ambient temperature, absorber plate temperature, water temperature, and oven temperature were continuously displayed on an LCD screen. In reaching the set temperatures both of the oven and water, and the cooking is complete, it immediately sends simultaneous notifications to the user's phone via GSM AT Commands MTCBA-G-F1/F2, and an alarm through the buzzer. This makes it easier to monitor the Solar Box Cooker [10]. The whole system was powered by DC battery power for an effective continuous energy supply. This battery acted as a kind of energy tank in providing the required continuous supply to the system operation. This strong IoT interface strengthened supervision and control in the Solar Box Cooker through temperature monitoring, real-time data visualization, remote notifications, and a reliable DC battery power supply system. This power IoT interface strengthens supervision and control of the Solar Box Cooker through integration of temperature monitoring,

real-time data visualization, remote notifications and reliable power supply system DC battery as illustrated by the circuit diagram in Figures 1 and 2.

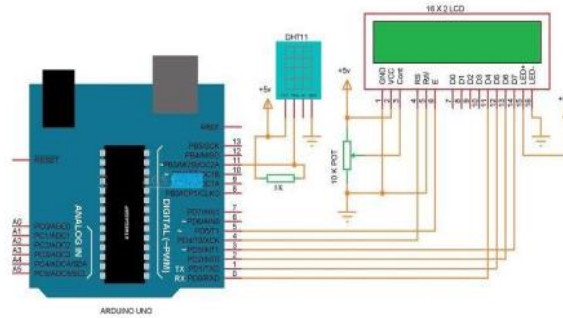


Figure 1. circuit diagram of Arduino uno with LCD

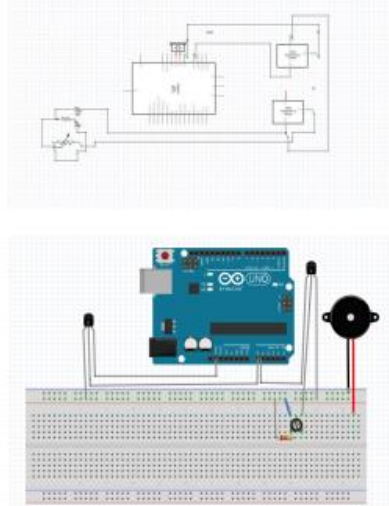


Figure 2. circuit diagram of Arduino uno with Buzzer.

2.2 Solar Cooker Design

These principles control the flow of heat, and within this solar box cooker, efficiency in thermal transfer and retention is attained. The considered design parameters include the energy requirements for cooking and the daily average insolation. The size of a solar box cooker shall be such that it can accommodate the normally used cookware and the largest quantity of food generally cooked. In the event that good insulation of the box is made at the walls and the bottom, then more heat will stay inside the box, and it will be hotter inside. The First Law of Thermodynamics states that the heat lost by one system must be transferred wholly to another. While the Second Law says that transfer occurs from a hotter depository system to the colder one, described in Equation 1. These, therefore, are some of the guiding principles in heat flow, which bestow on the solar box cooker efficient thermal transfers and retentions.

$$Q = MC\Delta T \quad (1)$$

If $MC\Delta T$ is the energy required to raise the temperature of the water from T_i to T_f (where) $\Delta T = (T_f - T_i)$ and I_s is the amount of solar energy available to boil the water, then the solar radiation collector area can be obtain by Equation 2.

$$A_s = \frac{MC\Delta T}{I_{av}t\eta} \quad (2)$$

The cooker wall insulation thickness x can be obtained from Fourier's law of conduction can be obtain using equation 3.

$$x = \frac{KA_l\Delta T_p}{q_l} \quad (3)$$

Where K is the thermal conductivity of the insulation material, A_l is the heat loss area, ΔT_p is the temperature difference between the absorber plate and the ambient, q_l is the desired maximum rate of heat loss through the cooker walls ($q_l = 7\%$ of incident insulation) [11].

2.3 Fabrication of Smart Solar Cooker

In the construction of this smart solar box cooker, highly effective insulation material was made from Sodom apple fiber (*Calotropis procera*) and waste paper. The collection of a well-prepared wooden mold and some Sodom apple fruit fibers with their impurities removed preceded the start of the process. Measurement and soaking of the fibers in water for 48 hours later, squeezing out water was the next step. Similarly, collection of waste paper, soaked in water for 48 hours, and then drainage of the water was carried out. The Sodom apple fruit fiber and the waste paper were mixed in a proportion and made into a paste that was poured into the prepared wooden mold of the required dimensions. This was then compressed under pressure and dried in the sun. The now sun-dried box was removed from the wooden mold. An aluminum plate was then molded to the size of the insulated box and placed inside the rigid box made from the Sodom apple fruit fiber and waste paper. The aluminum plate was painted black thereafter. The dimensions of the outer box are 600×300×250 mm, while the inner box measures 500×250×200 mm. According to [12] the depth of the inner box should not exceed 10-15 cm. This depth is critical because a greater depth would introduce a shade effect, although the width and breadth can vary. The inner side of the box was painted black. Two clear window glass panes, each 4mm thick, were fixed over the box with an openable wooden frame. The absorber area covered 0.1 m² (Plate 1). An accepted size for the cooking vessel was 19.5 cm in diameter and 10 cm in height. The cooking vessels used in this study were aluminum cylindrical containers with lids. The exterior of the pots.



Plate 1. Assembled solar box cooker

2.4 Solar Box Cooker Performance Measurement

[13], developed test procedures with evaluation equations for assessing the thermal performance of solar cookers, mainly box-type solar cookers. Their recommendations were later accepted by the Bureau of Indian Standards. Various results from these tests are given as factors of merit, the first figure of merit, F1, and the second figure of merit, F2.

First figure of merit (F1)

The First Figure of Merit, F1, is defined as the ratio of optical efficiency, η_o , to the overall heat loss coefficient, U_l . It is mathematically defined by equation 1.

$$F1 = \frac{\eta_o}{U_l} \quad (4)$$

Experimentally using equation 5.

$$F1 = \frac{T_{ps} - T_{as}}{H_s} \quad (5)$$

Where T_{ps} is the plate stagnation temperature ($^{\circ}\text{C}$) T_{as} is the ambient temperature at stagnation ($^{\circ}\text{C}$), and H_s is the solar radiation intensity at stagnation (W/m^2). The stagnation (steady state) condition is defined as the 10-minute period when (i) Variation in absorber plate temperature is less than $\pm 1^{\circ}\text{C}$, (ii) Variation in solar radiation is $\pm 20 \text{ W}/\text{m}^2$, (iii) Variation in ambient temperature is $\pm 0.2^{\circ}\text{C}$. The permissible solar radiation condition during testing is that it should always be greater than $600 \text{ W}/\text{m}^2$.

Second figure of merit (F_2)

The Second Figure of Merit, F_2 , takes into account the heat exchange efficiency of cookers and is obtained through the sensible heating of specified load of water ($8 \text{ kg}/\text{m}^2$ of aperture area). F_2 is evaluated through the following expression in equation 9.

$$F_2 = \frac{F_1(M_w C_w)}{A\tau} \ln \left[\frac{1 - \frac{1}{F_1} \left(\frac{T_{w1} - T_a}{H} \right)}{1 - \frac{1}{F_1} \left(\frac{T_{w2} - T_a}{H} \right)} \right] \quad (6)$$

Where F_1 is the First Figure of Merit, M_w is the mass of the water, C_w is the specific heat of water, T_{w1} is the initial temperature of water ($\equiv 60^{\circ}\text{C}$) T_{w2} is the final temperature of water ($\equiv 90^{\circ}\text{C}$), τ is the measured time difference in which the water temperature rises from T_{w1} to T_{w2} , T_a is the average ambient temperature over the time period τ , H is the average solar radiation intensity incident on the aperture of the cooker, and A is the aperture area of the solar cooker. In [14], recognized the need for an international standard for testing solar cookers, leading to recommendations later adopted by [13]. The average water temperature ($^{\circ}\text{C}$) of all cooking vessels in a cooker should be recorded at intervals not exceeding ten minutes, measured to the nearest tenth of a degree Celsius. Additionally, solar insolation (W/m^2), ambient temperature ($^{\circ}\text{C}$), and wind speed (m/s) should be recorded at least as frequently. The frequency of attended (manual) tracking, if any, should be noted and reported. The azimuth angle(s) during the test, the test site latitude, and the date(s) of testing should also be documented and reported.

Calculating cooking power.

The change in water temperature for each ten-minute interval should be multiplied by the mass and specific heat capacity of the water in the cooking vessel(s). This product should then be divided by the 600 seconds in a ten-minute interval, as shown in Equation 7.

$$P_i = (T_2 - T_1)MC_v/600 \quad (7)$$

Where; P_i = cooking power (W), T_2 = final water temperature ($^{\circ}\text{C}$), T_1 = initial water temperature ($^{\circ}\text{C}$), M = water mass (kg), C_v = heat capacity ($4186 \text{ J}/[\text{kg}\cdot\text{K}]$).

Calculating interval averages

The average insolation, ambient temperature, and cooking vessel contents' temperature should be calculated for each interval.

Standardizing Cooking Power

The cooking power for each interval should be adjusted to a standard insolation of $700 \text{ W}/\text{m}^2$. This is done by multiplying the observed cooking power for the interval by $700 \text{ W}/\text{m}^2$ and then dividing by the average insolation recorded during that interval, as shown in Equation 8.

$$P_s = P_i(700/I_i) \quad (8)$$

Where P_s = standardized cooking power (W), P_i = interval cooking power (W), I_i = interval average solar insolation (W/m^2). Interval observed cooking power by $700 \text{ W}/\text{m}^2$ and dividing by the interval average insolation recorded during the corresponding interval.

Temperature difference

Ambient temperature for each interval is to be subtracted from the average cooking vessel contents temperature for each corresponding interval as in equation 9.

$$T_d = T_w - T_a \quad (9)$$

Where T_d = temperature difference ($^{\circ}\text{C}$), T_w = water temperature ($^{\circ}\text{C}$), T_a = ambient air temperature ($^{\circ}\text{C}$).

Regression

A linear regression of plotted points was performed to determine the relationship between cooking power and temperature difference, expressed as intercept $a(\text{W})$ and slope $b(\text{W}/^{\circ}\text{C})$ in the equation $P_s = a + b \times T_d$. At least 30 observations from three different days must be included. The coefficient of determination (R^2), indicating the proportion of variation in cooking power explained by the regression, should exceed 0.75 or be specifically noted.

Single measure of performance

The standardized cooking power P_s (W) will be calculated using the regression relationship found, specifically for a temperature difference T_d of 50°C .

3 RESULTS AND DISCUSSION

3.1 Smart System

The developed monitoring interface underwent comprehensive testing at Faculty of Engineering Teaching Workshop, University of Maiduguri, Borno state. Plate 2 showcases the smart system before coupling. Experiments were conducted using the IoT monitoring interface on solar box cooker as illustrated in plate 3. This improvement is attributed to a significant reduction in heat loss, primarily stemming from fewer interruptions caused by the reduced need to open the cooker for manual monitoring during the cooking process. The integration of the IoT monitoring interface yielded tangible benefits, notably enhancing the Solar Box Cooker's efficiency. By enabling remote monitoring, the interface effectively minimized heat loss, thereby streamlining the boiling process and reducing boiling times. The smart solar box cooker system ensures precise temperature monitoring, user alerts, and safety measures, enhancing the water boiling experience while promoting energy efficiency and sustainability.



Plate 2. Smart monitoring system with IoT interface before coupling



Plate 3. IoT monitoring interface on solar box cooker experiment

3.2 Solar Cooker Design

Design parameters are presented in Table 1.

Table 1. Design Parameters

Description	Symbol	Quantity
Mass of water	M	1.0 kg
Desired final water temperature	T _f	100oC
Specific heat capacity of water at constant pressure	C _p	4200 jkg/k
Desired water boiling time	T	7200 S
Average total insulation	I _{av}	700 W/m ²
Assumed overall efficiency	H	0.50%
Ambient air temperature	T _a	30oC (303k)
Anticipated absorber temperature	T _p	130oC (403k)
Maximum heat loss rate through the cooker walls	Q _l	7% (of I _{av})
Solar cooker surface area dimensions (calculated)	A _s	0.12 m ²
Thickness of wall insulation (calculated)	X	0.052 m

Insolation values, I_{av} of about 700W/m² are prevalent in the location during the dry season. Taking into consideration fluctuations in insolation which are usually minor during the season, an average insolation value of 650W/m² during the desired cooking time was used in the design. This gives a cooker surface area of 0.12m². For ease of construction cooker dimensions of 0.5m x 0.2m are chosen. The cooker wall insulation thickness x was obtained from Fourier’s law of conduction. This gives a cooker wall thickness of 0.052 m. For ease of construction, cooker wall thickness dimension of 0.050 m was chosen as shown in Figures 3 and 4.

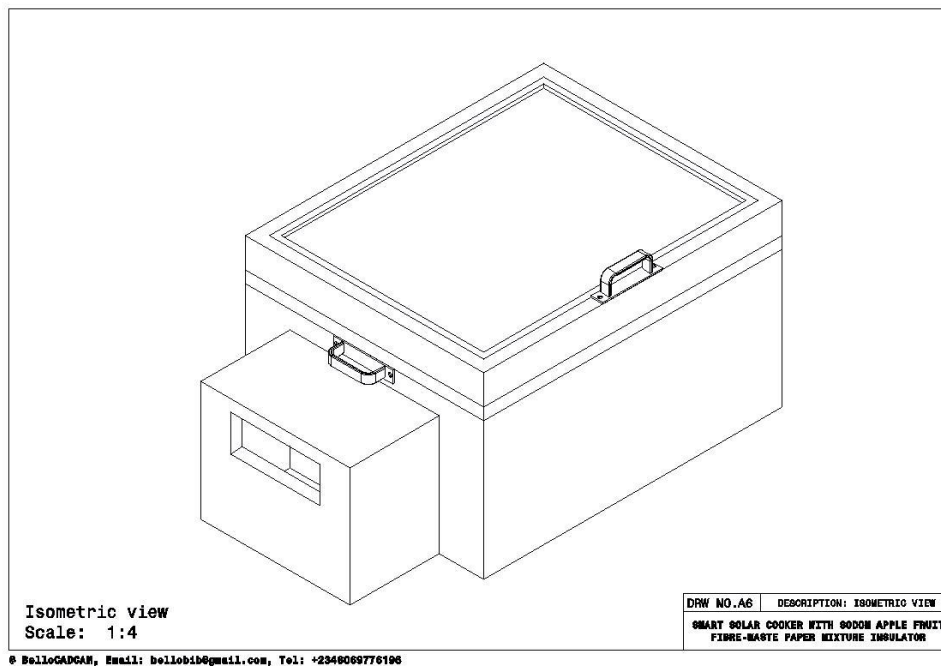


Figure 3. Isometric view

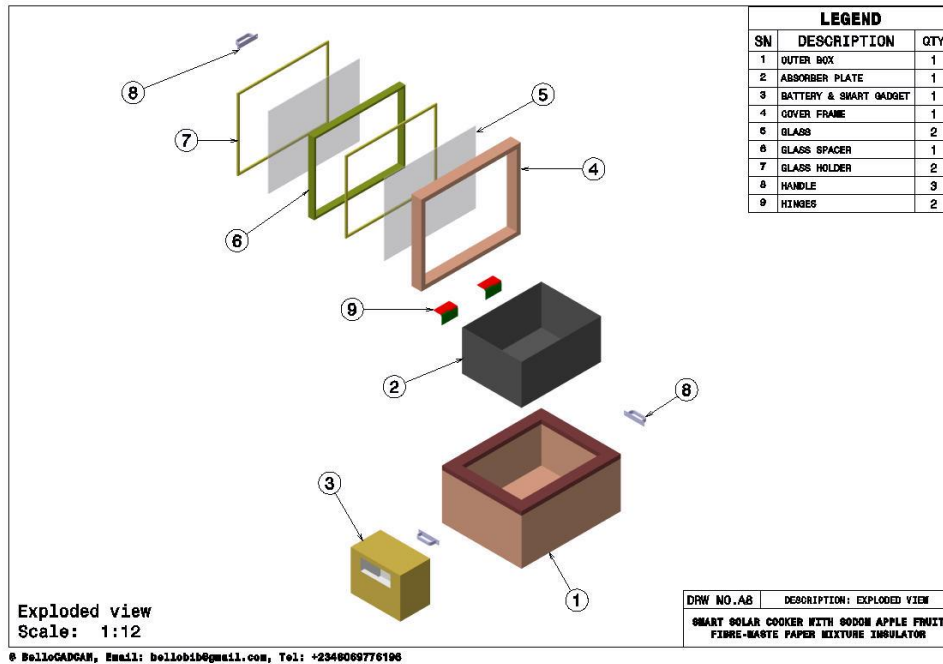


Figure 4. Exploded view

3.3 Experimental Results

The experiments were conducted at the Faculty of Engineering Teaching Workshop, University of Maiduguri, Maiduguri, Borno State. The latitude, longitude, and altitude of the University campus in Maiduguri are respectively, 11051'N, 13008'E, and 354m above the level. The field experiments were conducted in May 2024. The radiation intensity on a horizontal surface was calculated in all the experiments using a digital pyrometer SPM-1116SD with an accuracy of 0.1 W/m². In this context, temperature is measured at various cookers' locations using smart systems developed with a three-channel contact thermocouple with accuracy 0.1⁰C: fluid being cooked, absorber plate, and ambient air temperature. The aerometer, ABH-4224, measured the wind speed with an accuracy of 0.1 m/s. In addition, measuring cylinder was used for measuring the volume/mass of water. Ambient temperature, absorber plate temperature, initial water temperature, maximum water temperature, and boiling water temperature were measured and recorded. The data recorded was used in evaluating, both thermally, the performance of the constructed solar cooker according to Bureau of Indian Standard and Association of Biological and Agricultural Engineers. During each day, the temperature range and insolation of this solar box cooker met the requirements of international test standards. Typical variations in the applied weather conditions, namely insolation, wind speed and ambient temperature and the transient response of the solar cooker under no load condition are presented in Figures 5, 6 and 7 for the conditions. These results are only representative of a series of test undertaken.

3.4 No load test

Figure 5, 6 and 7 Depicts the corresponding solar radiation with absorber plate and ambient temperature recorded on 22nd, 26th and 27th May 2024 respectively. It can be seen from Figures 5, 6 and 7. The Cooker carried out step responses following closely the insolation pattern. This holds good in all the Thermal Performance Tests conducted under no-load condition. An increase in stagnation temperature led to an absorber temperature exceeding initial value of 39.6°C, to peak at 130°C at 1:30 pm with insolation reading of 815 W/m². The absorber plate temperatures remained above 80°C almost all the time insolation was reasonably high at 11h local time. This non-uniform rise in absorber temperature can only be related to the increased solar power and ambient temperature with respect to

efficiency of the box cooker in converting the sun's energy. The gradual rise in absorber temperature while reaching stagnation is an indication that this solar box cooker did well in terms of solar energy. The maximum temperature qualities are also indicative of a well-founded heat uptake and retention performance. Design features and technical properties crucial for the proper functioning of the solar cooker, depending on the climatic application and general environment of the area. It is evident that stagnation temperature is being approached at about 1.30 on daily routine. What follows is, of course, the bracket of time when peak solar irradiance normally occurs, ultimately leading to the highest operational efficiency possible with the solar cooker. The results of these three days show just how close such time and power tracking are to being the same in probably the same environment. This value of F_1 (0.12) obtained for solar box cooker conforms to the value suggested for F_1 [14]. Hence the cooker belongs to category A cooker. To calculate the first figure of merit (F1) for the solar box cooker using equation (4). First figure of merit for 22nd May 2024: $F_1 = 0.12$. First figure of merit for 23rd May 2024: $F_1 = 0.12$. First figure of merit for 24th May 2024: $F_1 = 0.12$.

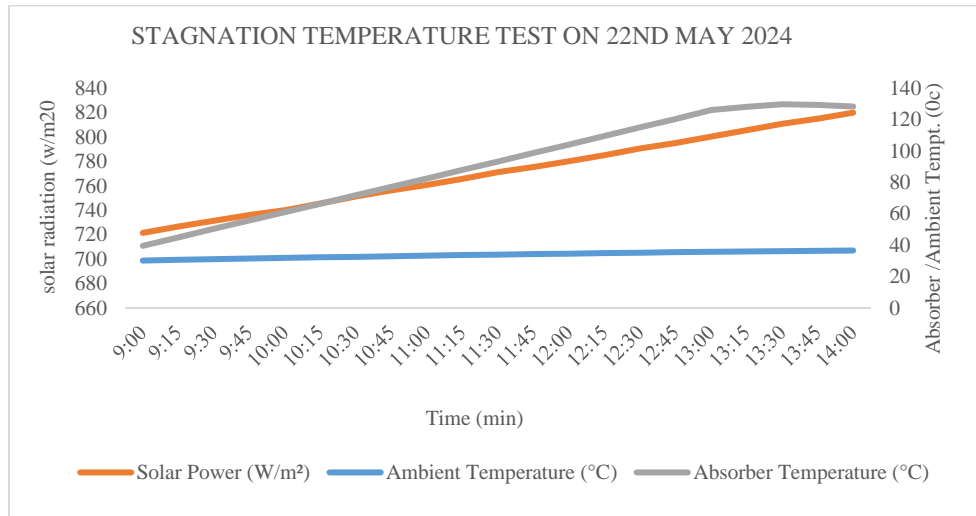


Figure 5. Corresponding solar radiation with absorber plate and ambient temperature recorded on 22nd May 2024

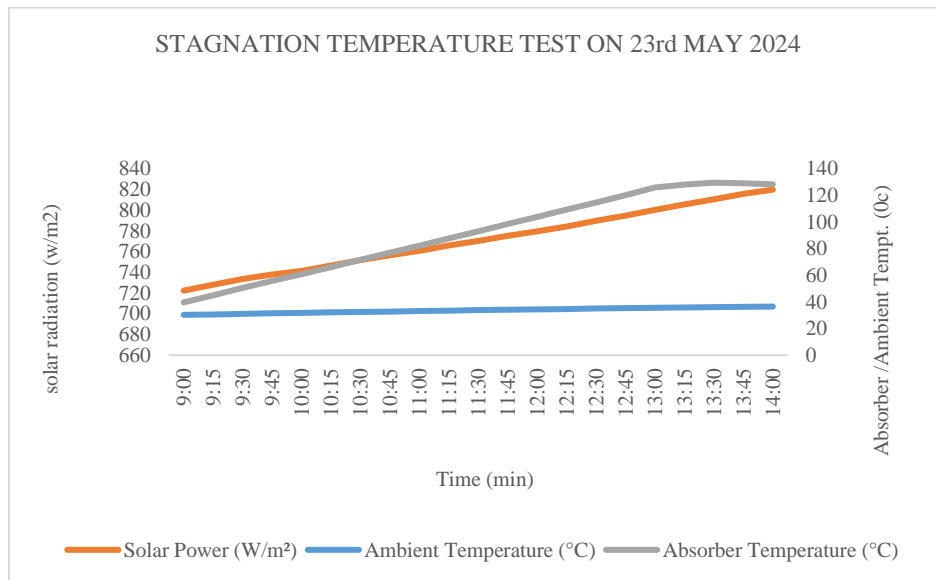


Figure 6. Corresponding solar radiation with absorber plate and ambient temperature recorded on 23rd May 2024

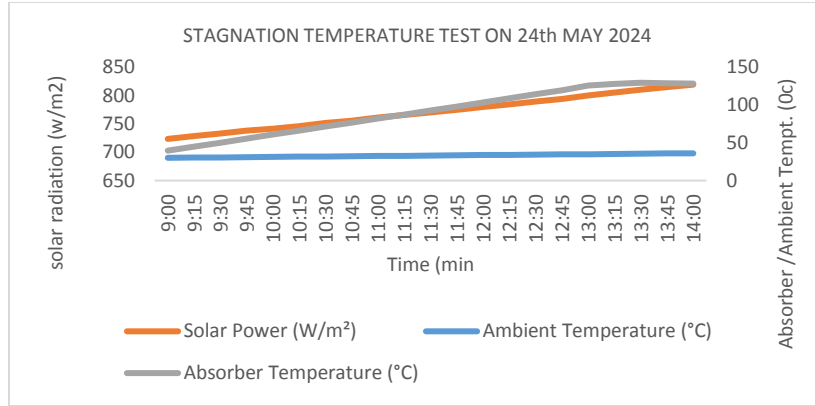


Figure 7. Corresponding solar radiation with absorber plate and ambient temperature recorded on 24th May 2024

3.5 Boiling test

Figure 8, 9 and 10 Depicts the corresponding solar radiation with water temperature recorded on 28th 29th and 30th May 2024 respectively. Data shows that the water temperature started at 40.6°C and reached a temperature of 100°C about 12:30 PM at an insolation value of 730 W/m². The graphs therefore clearly deduce that peak water temperature occurs at solar noon while peak solar power levels occur at the same time. It is observable that the expectation for solar cookers to work best when the maximum solar radiation is received, consequently resulting in the highest temperatures, was met in this study. The temperature of the water finally went downward after 1:30 PM, which shows a decline in the availability of solar power. This also depicts the decrease in thermal efficiency of the cooker when the sun crosses its zenith position. Results from the water boiling test conducted on 25th, 26th, and 27th of May 2024 return this solar box cooker to raise and hold a high temperature of the water quite well. The data will show that the cooker is efficient in turning solar energy into thermal energy for practical application on the application of water boiling. The second figure of merit (F_2) was therefore calculated from the results of the boiling test parameters in Table 4.4 appendix 2 was found to be 0.72, 0.76 and 0.61 for 25th, 26th and 27th May 2024 respectively. The value of F_2 0.72, 0.76 and 0.61 are found to be similar to the work of [14]. The second figure of merit for solar box cooker was calculated using equation (5). The second figure of merit, F_2 , of box type solar cooker is to be evaluated under full load condition and can be expressed as: F_2 of 1 litre of water experimented on 25th may 2016.

$F_2 = 0.72$: F_2 of 1 litre of water experimented on 26th may 2016. $F_2 = 0.76$: F_2 of 1 litre of water experimented on 27th may 2016. $F_2 = 0.61$.

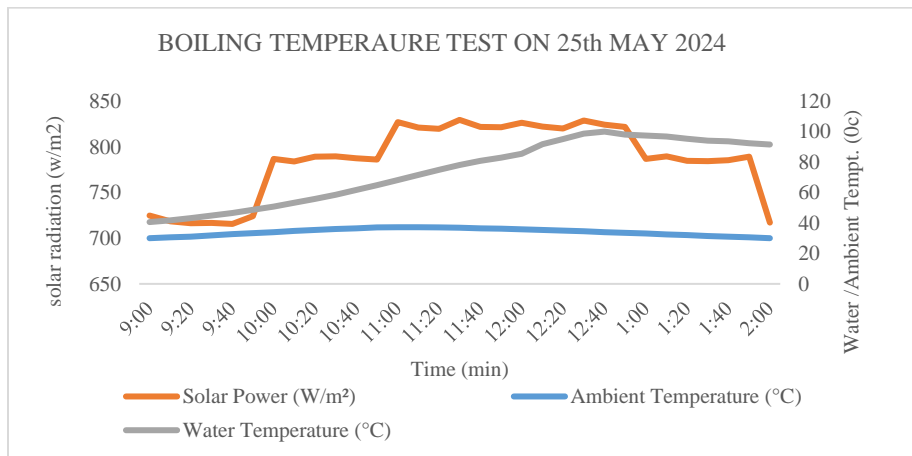


Figure 8. Corresponding solar radiation with water temperature recorded on 25th May 2024

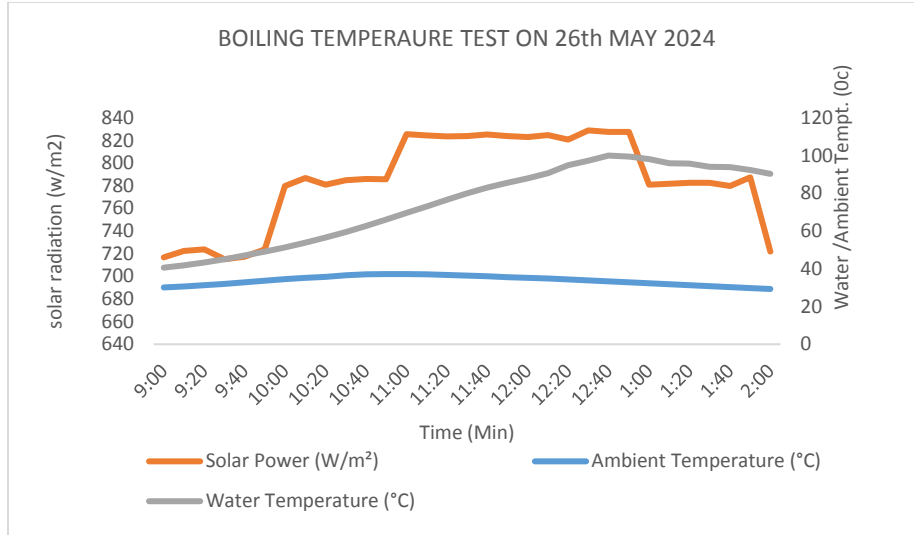


Figure 9. Corresponding solar radiation with water temperature recorded on 25th May 2024

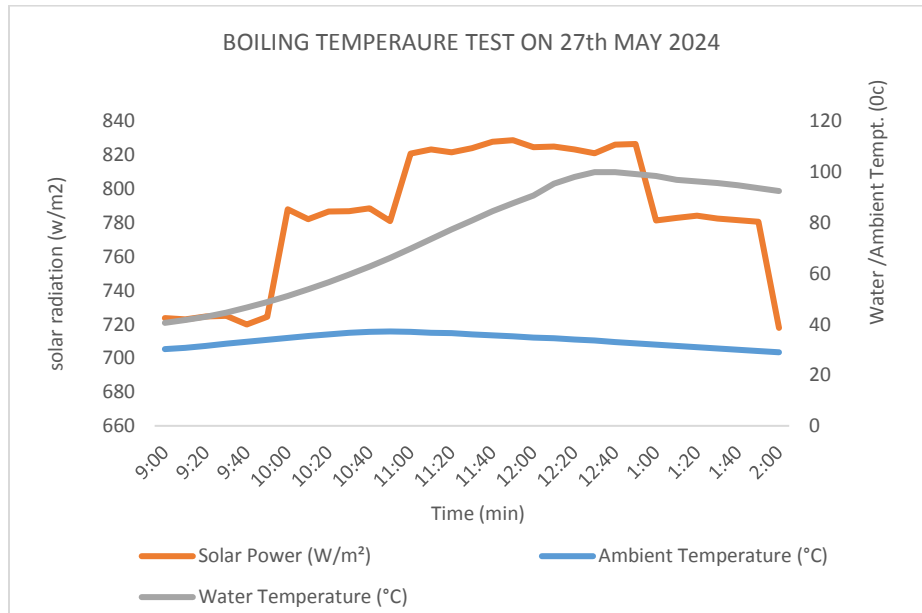


Figure 10. Corresponding solar radiation with water temperature recorded on 27th May 2024

3.6 Cooking power

This graph illustrates the relationship of the cooking power with temperature difference for a solar box cooker. The experimental data is fitted with a linear regression line. The equation for this line is $y = 0.8741x + 16.32$, with a coefficient of determination R^2 of 0.759. This means there is a positive linear relationship between these two variables. According to the linear equation $y = 0.8741x + 16.32$, a rise in temperature difference by one unit results in an increase of approximately 0.8741 units in the cooking power of the solar box cooker. The y-intercept, 16.32, gives the baseline cooking power when the temperature difference is zero. The positive slope and y-intercept indicate that as temperature difference increases, the cooking power of the solar box cooker increases. This result is similar to the findings of [15], which reported that the coefficient of determination (R^2) or proportion of variation in energy output that can be attributed to the relationship found by regression should be better than 75%. The value for standardized cooking power, W_{in} , was computed for a temperature difference of 50°C using the above

determined relationships for the solar cooker. It was estimated that, at a temperature difference of 50°C, the standardized cooking power would be 60.02W for the solar cooker.

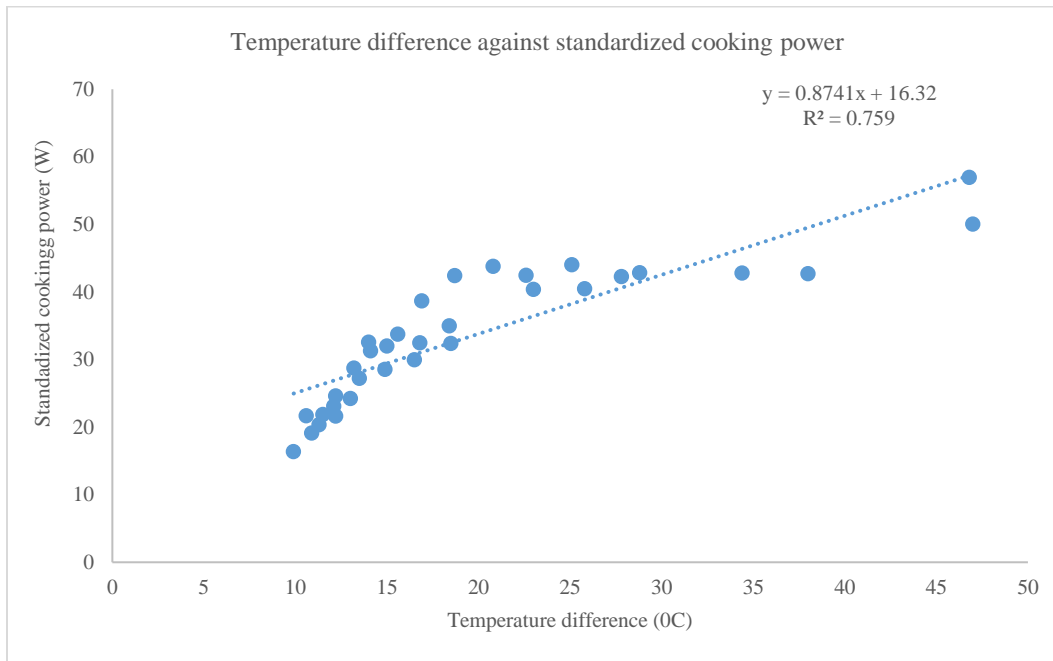


Figure 11. Standard cooking power against Temperature difference

4 CONCLUSIONS

The research on smart solar box cooker development using a mixture of Sodom apple fruit fibers and waste paper has come up with significant findings and advances. Some of the key conclusions are given below. Designing a Natural Composite Material: The researchers here have developed a new natural composite material by combing Sodom apple fruit fiber and waste paper. This new composite is given to turn into a dependable alternative to manmade materials for ecological advantages. Progress in IoT Integration: This industry of solar box cookers completely turned into an IoT-based, smart system and added several functionalities related to improvement in user experience efficiency. It is a giant step toward more convenient cooking with sunlight.

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