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# DEVELOPMENT OF A DC STOVE PROTOTYPE FROM LOCALLY AVAILABLE COMPOSITE MATERIALS FOR THE USE OF RURAL FARMERS

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## ABSTRACT
The locally crafted DC heater stoves signify a groundbreaking initiative in the realm of household items in Nigeria. The need to mitigate the greenhouse effect and to reduce deforestation coupled with the increase in the cost of cooking fuels like gas, kerosene and even firewood has necessitated the consideration of alternative means through the use of solar modules for direct generation of heat (without conversion of electricity from DC to AC) using DC heaters. These stoves were developed in conjunction with local artisans who have limited understanding of engineering principles. A prototype DC heater stove was designed, featuring a cylindrical composite material casing with iron sheet for ease of handling. This stove was developed and evaluated at the Department of Agricultural Technology, Engineering Section, Farm Mechanization Unit, Federal College of Freshwater Fisheries Technology in New Bussa. The testing utilized a modified version 4.12 of the University of California water boiling test (WBT). The performance results of the DC heater stove were compared to those of an AC heater stove. The cold start test revealed that the solar heater stove required an average of 35 minutes to bring 1 liter of water to a boil, while the AC heater stove achieved this in 25 minutes. Furthermore, the thermal efficiency of the DC heater stove was measured at 67%, significantly surpassing the 16% efficiency of the AC heater stove, thus making it a recommended option for use.

**Keywords**: Composite materials, Solar Panel, DC heater, Stove, Thermal

## INTRODUCTION
The energy from the sun is so enormous that humans usually do not harness up to 1% of its daily supply. In fact, the energy that the sun radiates daily is more than energy we need in a year. Access to reliable, clean energy for cooking remains a critical challenge in many rural farming communities across the globe (Sawin, 2017). A large proportion of rural households still rely on traditional biomass fuels—firewood, charcoal, crop residues, and dung—burned in open fires or inefficient stoves (Ogundana *et al.,* 2024). This reliance has multiple negative consequences: high indoor air pollution that causes respiratory and cardiovascular illnesses (disproportionately affecting women and children), significant time and labor spent collecting fuel, pressure on local woodlands and ecosystems, and low thermal efficiencies that waste scarce energy resources (Boafo-Mensah *et al.,* 2020).

In recent years, distributed renewable energy—particularly small-scale solar photovoltaic (PV) systems paired with batteries—has enabled new opportunities to provide electrical cooking devices in off-grid and weak-grid communities (Ademe, 2016). Devices designed to run directly on DC (direct current) are especially attractive for these settings. A DC stove that operates directly from a PV-battery DC bus avoids inverter losses and the extra capital and maintenance costs of AC conversion, improving overall system efficiency and reducing cost and complexity (Adria and Bethge, 2013). DC appliances can therefore provide meaningful cooking power within the limited energy budgets typical of household solar systems, enabling faster, cleaner and more controllable cooking than traditional biomass stoves while integrating with local renewable energy sources (Wilson *et al.,* 2016).

In Nigeria however a number of DC stove models are designed and fabricated by local artisans using locally available composite materials aims to bridge these considerations by creating an affordable, durable and efficient cooking device tailored to rural farming contexts.

## MATERIALS AND METHODS
### Study Area
Borgu Local Government is an administrative region in Niger State, Nigeria, with its headquarters in New Bussa as shown in Figure 1. It has a population projection of 296,500 according to the 2022 National Population Commission figures. Borgu Local Government has an area of 11,267 $Km^2$ with a density of 21.55 $Km^2$. It lies in the northwestern area of the state and covers the districts of Borgu, Dugga, Babanna, Karabonde, Konkoso, Malale, New Bussa, Shagunu, Wawa and Riverine areas as shown in figure 1. Borgu Local Government is bordered by Agwara, Mashegu and Mokwa Local Governments. Borgu Local Government Council controls the public administrative council makes law that governs the local government area.


Figure 1: Kainji Lake River Basin Area

**Design Analysis and Fabrication**

Stove dimensions: Overall stove dimension: L = 265, B = 265 and H = 285 mm

Lower surface of the combustion chamber is L = 127 and B = 127 mm

The upper surface of the combustion chamber is L = 150.7×B = 150.7 mm

The height of the combustion chamber is 124.5 mm

**Combustion chamber size**

***Cross-sectional area***

Cross-sectional area of the cylindrical combustion chamber, and height of the chamber are those formulated by Brydem *et al*., (2005).

Cross-sectional Area = $A_c = \pi \times r_c^2$ (1)

Where $A_c$ is the area, $\pi = 3.14$ and $r_c^2$ is the radius.

From the calculations the cross-sectional area of the combustion chamber is 12 cm

***Height of the combustion chamber***

Height of the combustion chamber Hc = 2 X π x r² (2)

The height ($H_c$) of the combustion chamber should be three times the diameter of the side opening. From Eqn.2 is: $H_c = 2 \times \pi \times 6 = 37.7$ cm

***Opening of the combustion chamber***

According to the recommendations of Bryden *et al.* (2005), a pot with a diameter of 30 cm is suitable for a family of five. The combustion chamber should feature a side opening of 12 cm, and it is essential to maintain a uniform cross-sectional area throughout the stove's structure. Consequently, using Equation 1, the calculated cross-sectional area of the combustion chamber is: Ac = π x 6² = 11.3 cm.

***Size of the combustion chamber***

The size of the combustion chamber depends on the size and the average number of solar heater used within the combustion chamber. The number of solar heaters required to fill the chamber is a function of the chamber volume, area of solar heater and height of solar heater mathematically derived and expressed according to Bello *et al.*,

$$n = \frac{v}{A.h_c} \quad (3)$$

where, n is the number of solar heaters required to fill the combustion chamber, A is area and V is the volume of the combustion chamber geometrically expressed by the expression according to Bello *et al.,* 2015.

$$v = n.\frac{1}{3}(A_1 + A_2 + \sqrt{A_1 + A_2})h \quad (4)$$

$A_1$, $A_2$ represent the areas of the lower and upper frustums and h is the height of the combustion chamber recommended a diameter-to-height ratio of solar heater of 0.75 mm i.e.:

d = 0.75 h

Therefore:

$$n = \frac{0.75v}{A.d} \quad (5)$$

The combustion chamber size requires the determination of area and number of solar heaters to be contained as follows.

**Lining (insulation) and surface area**

The material considered for insulation are clay, sand, white and grey cement which are readily available and has lower heat conduction. Equation 7 evaluates the *s*urface areas of one side of the clay lining:

$$A = \frac{1}{2\,(a+b)h} \quad (6)$$

where, A is surface area of clay lining (m²), a and b are lengths of lower and upper surfaces:

For four surfaces A = 4×½(a+b) h

= 4×½ (12.70+15.07) 12.45 = 691.47 cm²

**Heat transfer per unit area of composite lining**

$$\frac{q}{A} = \left(\frac{k}{s}\right)dT \quad (7)$$

where, q is heat transfer (W/hr), q/A is heat transfer per unit area (W/m²), k is thermal conductivity of clay lining material (0.15-1.8 W/mK), dT = ($T_1$-$T_2$) = temperature difference (°C) and s is wall thickness 25 mm:

$$q = \frac{1.8}{0.025}(31\text{-}100) \times 0.69147 = 3.435\,\frac{\text{kW}}{\text{h}}$$

**Coil Design**

For the purpose of the design, a market survey was conducted to source for the DC heater plugs to be used in the project. A typical diesel Dc Heater found is 100W and 9 pieces was used giving 900 W. This is the maximum power the DC heater can withstand without burning out. In this design, for robustness, it is being assumed to be 1000W and most time, it is being used on 1000W Alternative Current hotplate. This 1000 W DC stove is powered by DC Voltage of 12 V, 100 Ahm. With the DC Heater at full DC voltage, the heater on the stove become red hot which make it possible for people to use it to cook all manner of sizable dishes at home.

**Cable Design**

Another area of design is the minimum recommended thickness of the copper cable to be used for connection of the hot plate to the solar panel.

From the Ohm's law V = IR (8)

But the resistance of a wire is directly proportional to its length and inversely proportional to its cross-sectional area, mathematically

$$R = \rho \frac{l}{A} \quad (9)$$

Where R is the resistance of the Wire, l is the length and A is the cross-sectional area of the wire. $\rho$ is the resistivity of the wire (Robertson, 2008).

$$A = \rho \frac{l}{R}$$

Substituting equation 5 into equation 6 in order to eliminate R

$$A = \rho \frac{l}{V/I}$$

$$A = \rho \frac{U}{V}$$

Where I is the maximum current expected to flow in the wire during the usage of the DC stove and V is the allowable voltage drop between the solar panels and the DC stove.

With negligible loss in the circuit breaker, the expected loss along the cable is calculated as follows. The voltage drops across the cable (both positive and negative) is given as:

$V = 2IRph$ (13)

The maximum current expected to pass through the cable is $I = 33.33$A

$Ploss = VI = 1 \times 33.33$ (15)

$Ploss = 33.33$W

Therefore, the maximum power expected from the panel is

$Ppanel = Ploss + Ph$

Where Ppanel is the watt peak of the solar panel array required, Ploss is the power loss in the cable and Ph is the rated power of the hot plate.

For Ph of 900W and Ploss of 33.33W as calculated above,

$Ppanel = 33.33 + 900 = 933.33Wp$

Assuming a panel of $P1 = 220Wp$,

**Electrical connections**

The connection is done as shown below. All the positive terminals are connected together and all the negative terminal are connected together as shown in figure 2.

**Panel Specification**

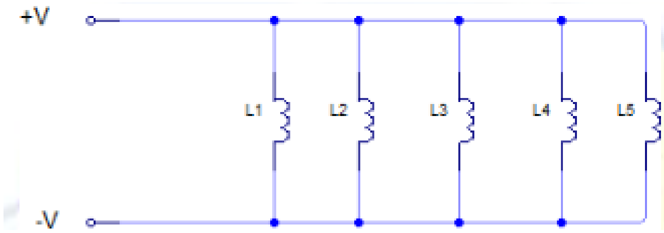


Figure 2: Circuit Diagram of the element

The expected current to be drawn by all the elements is taking into consideration so that the copper wire is not heated up thereby consuming substantial amount of energy generated by the solar modules. The termination of the copper wire is done on the body of the DC stove with the help of two copper pins of diameter 3mm protruding from the body of the DC stove. The ends of the two copper terminals are provided with high quality copper connectors for easy termination with the solar panels.

**Fabrication of solar heater stove**

The casing is constructed from a 2mm metal sheet, forming a cylindrical frame that encloses the combustion chamber, with its base sealed using the same material. A circular opening measuring 12.4cm is created on one side of the casing to serve as the access point for the combustion chamber. Additionally, tripod prongs, each 20cm in length and made from a metal bar, are positioned within the base to securely support the combustion chamber (Ogundana *et al.,* 2020).

**Combustion Chamber**

The combustion chamber was made from a composite materials mixture. Clay, sand, white and grey cement were mixed in ration 5:3:1:1 were used to cast the cylindrical combustion chamber. The chamber was allowed to dry for four days.

**Stove Description**

The DC heater stove designed and fabricated at the engineering section, farm mechanization unit, Federal College of Freshwater Fisheries Technology, New Bussa, Niger State, Nigeria. The stove has hot plate section lagged with a composite material. The hot plate chamber has a top diameter of 12 cm. The DC heater stove is designed to contain 9 pieces of solar heater, 50 mm in diameter and 55 mm in height, respectively. During the day when the sun impinges on the solar panel array, the solar energy is converted to electrical energy. the amount of energy to be realized per unit time depend on several factors such as the solar irradiance, solar panel efficiency, incident angle of solar energy impinging on the panel, the overall wattage of the panel arrays, the cleanliness of the panel surfaces and the quality, length and size of the cable being used. The cable, both positive and negative terminals from the solar panel array is connected to a circuit breaker. This breaker performs dual purpose of protection in case of any short circuit and also regular isolation when the hot plate is not in use. The output of the breaker is then terminated on the DC stove as shown in the figure 3.

Figure 3: Developed DC heater stove

**Performance evaluation of the developed charcoal stove**
The evaluation was carried out by activating the solar heater integrated into the stove. The performance of the stove was assessed using the standard water boiling test (WBT) procedures outlined by Bello *et al.,* (2015). This method is appropriate for assessing stove optimization and provides a rough estimate of relative energy savings when laboratory or field testing is not feasible. For the water boiling tests, 1.2 kg of water was placed in a pot and positioned on the hot plate to heat the water to 100°C in a controlled environment. Temperature measurements were recorded at atmospheric pressure and at 15-minute intervals until the water reached its boiling point, utilizing a mercury thermometer with a range of 0-360°C, produced in India. Once the water boiled, the remaining volume in the pot was weighed and documented along with the final temperature of the water. Additionally, a controlled experiment using an electric hot plate was established for further analysis.

**Controlled cooking tests (CCT)**
This test stimulates the cooking of a typical meal in an ideal kitchen situation to determine specific stove parameters. Locally processed rice and beans were used in the control-cooking test (CCT) to evaluate the stove performance using solar energy. The test was performed by boiling the foods with a recorded temperature in the stove chamber. A Samsung stopwatch recorded the cooking time and the cooked yam weighed with an SF-400 digital scale. Stove performance variables employed in stove tests according to Nhuchhen and Afzal procedures include the following measured variables:
Time taking to boil water in the pot ($\Delta C_c$)
Time spent in cooking food (hr/kg)

$$\frac{Total\ time\ spent\ in\ cooking\ (T_s)}{Total\ weight\ of\ cooked\ food\ (T_{wc})}\left[\frac{h_r}{k_g}\right] \qquad (10)$$

iv. Time to use stored power.
v. Stove thermal efficiency ($n_t$): The percentage of the work done in heating and evaporating water and the energy consumed.

$$\eta_{ih}(100\%) = \frac{(P_{ci}-p_f)\times(T_{ci}-T_{cf})+2260W_{cv}}{LHV\times f_{cd}} \qquad (11)$$

## RESULTS AND DISCUSSION
Development of solar heater stove shows the designed specifications. The combustion chamber has a total volume of $2.41\times10^2$ $cm^3$ with a capacity to contain 9 pieces of solar heater with 60.00 mm height. The stove's mean fuel consumption varied between 0.56 and 0.68. increased the thermal efficiency of the stove.

**Water boiling and cooking tests**
Figure 4(a-c) shows the experimental setups of the water boiling (Figure 4a) and cooking tests conducted to evaluate the performance of the solar stove. The water boiling test, WBT) was used to compare the time required to heat water temperature to 100 °C.

Figure 4(a-c): WBT and CCT showing setup and products, (a) Cook beans (b) Boiling water (c) cook rice

The control cooking test results revealed 3.435 kW/hr thermal output per unit surface area within the surface area. The stove thermal efficiencies varied between 31.47 and 39.89% in the morning, 17.13, 38.52% in the afternoon and 23.84 and 39.89% in the evening respectively. The mean energy used to cook 259 g of rice (Figure 4c) and 245 g of beans (Figure 4a) increased from 0.718 to 0.745 in cooking rice and beans, respectively.

**Comparative performance advantages over existing stoves**

The developed stove performance indices showed good performance with thermal efficiency values obtained for different solar radiation level within the 35% thermal efficiency reported as suitable for energy-efficient solar stove with 75A/12V battery bank. The developed stove is eco-friendly and portable with great potential for improving indoor air quality. The solar stove cooked beans of 245 g for 35 minutes, one litre of water was boiled to 100 $^{o}$C at 15 minute and rice for 30 minutes compared with existing biomass stove that take longer duration of cooking.

**Economics of production**

The major factor that influences the economics of production is the cost of materials for construction and technology. The major materials of construction include low-cost mild steel plates sourced from the open junk market and the clay, sand, gray and white cement for the lining of solar hot surface area. Table 1 contains the materials of construction and cost. Technology involvement includes simple designs, portability and ergonomic considerations. The stove is relatively cheap N157,000 compared to most improved stoves of 300,000 and above depending on model. The stove has a comparative advantage in cost of production, user preference and efficient performance over other conventional stoves.

**Table 1: Cost and Materials Analysis of Construction of Solar Heater Stove**

| Part | Description and dimensions | Quantity | Amount (NGN) |
|---|---|---|---|
| Combustion chamber | 2 mm MS plate 1219.2×609.6 mm | 1 | 6, 500.00 |
| Solar panel | 200/24v | 1 | 75,000.00 |
| Charger controller | 30amp | 1 | 27,000.00 |
| Paint | 1 litre | 1 | 2,000.00 |
| wire | 2mm | 1 roll | 7,000.00 |
| Solar heater | DC heaters | 9 | 27,000.00 |
| Grey, white cement | Portland cement | 5 kg | 5, 500.00 |
| Workmanship | | | 7 000.00 |
| | Total | | 157, 000.00 |

## CONCLUSION

The world has a lot of solar energy that can be used to benefit the hordes of people. Converting solar energy to fit our everyday needs while also making room for convenience is a problem. In order to address these issues, the solar DC stove was constructed. Energy waste that is typically caused by conversion efficiency (such as dc to ac conversion using an inverter) can now be reduced due to simple direct conversion. If the design is used in rural locations where firewood is the primary or only source of cooking fuel, it can be effectively utilized. In addition to helping to mitigate greenhouse gas emissions, this will lessen deforestation in our rural areas. When compared to conventional stoves, the study found that the new DC stove performance indicators performed well and used less energy. The thermal efficiency numbers fall within the range that is appropriate for energy-efficient stoves. The stove has a lot of potential to improve indoor air quality in home settings and is both eco-friendly and portable. A notable advance over current stoves is demonstrated by the full heating of hot plugs in the surface area with less heat loss because of the composite materials lining.

## REFERENCES

Ademe, R. (2016). Easing women's life with energy efficient cook stove. World Vision Report. Sub-City; Kebele 11, Addis Ababa, Ethiopia: World Vision Ethiopia. Retrieved from www.wvi.org/ethiopia

Adria, O., and J. Bethge. (2013). What users can save with energy-efficient cooking stoves and ovens. Wuppetral, Germany: Wuppertal Institute for Climate, Environment and Energy, Germany.

Agyei-Agyemang, A., P. O. Tawiah, and F. Nyarko. (2014). Efficient charcoal stoves: enhancing their benefits to a developing country using an improved design approach. International Journal of Engineering Trends and Technology, 15(2): 94-100.

Bello, R.S., T.A. Adegbulugbe and M.A. Onilude, 2015. Characterization of conventional cooking stoves in South Eastern Nigeria. AgricEngInt: CIGR J. Open Access, 17: 122-129

Boafo-Mensah, G., K. M. Darkwa, and G. Laryea. (2020). Effect of combustion chamber material on the performance of an improved biomass cookstove. Case Studies in Thermal Engineering, 21: 100688.

Bryden, M., D. Still, P. Scott, G. Hoffa, D. Ogle, R. Bailis, and K. Goyer. 2005. Design Principles for Wood Burning Cook Stoves. 80574 Hazelton Road, Cottage Grove: Aprovecho Research Center

Ogundana O. S., Abdulkadri A., Jubril D., Owa W. T (2020). Design and Construction of Electric Fish Smoking Kiln Using Locally Available Composite Materials. Journal of Engineering Research and Reports. 13(4): 15-21

Ogundana O.S., Adejumo B. A., Orhevba B. A., Bori I. (2024). Development of an automated dual powered kiln for drying and preservation of fish. Iconic Research and Engineering Journals. Vol. 7. Issue 10, ISSN: 2456-8880 P. 339-344.

Robertson C. R (2008). Fundamental Electrical and Electronic Principles, 3rd ed., Elsevier, Ed., Oxford: Newnes publications, 2008.

Sawin J. S, (2017). "Renewables 2017 Global Status Report," 2013, http://www.ren21.net/wp-content/uploads/2017/06/GSR2017 Ful.

Wilson, D. L., D. R. Talancon, R. L. Winslow, X. Linares, and A. J. Gadgil. (2016). Avoided emissions of a fuel-efficient biomass cookstove dwarf embodied emissions. Development Engineering, 1: 45-52.