Available online

JOURNAL OF CONTEMPORARY RESEARCH (JOCRES)

RESEARCH ARTICLE VOL. 1 (2) ISSN:2814-2241

www.unicrossjournals.com

Date Accepted: 30th Dec, 2022

Pages 125--138

ALTERNATIVE FUEL FOR COOKING STOVES USING BRIQUETTES PRODUCED FROM WOOD AND AGRICULTURAL WASTES

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ABSTRACT

Energy demand for cooking stoves has been on the increase throughout the world. In Nigeria about 60% of the population depends on fire wood and charcoal for cooking. The threats posed by fossils fuels and the inefficient use of biomass, can be mitigated by effective utilization of biomass waste when converted to briquettes through densification and effectively used with domestic stoves. Design, production and evaluation of two types of cooking stoves using alternative fuels produced from sawdust, wood shavings and rice husk as briquettes was done. Weight of briquette burnt (kg), % char produced, fuel consumption rate (kg/hr), thermal efficiency (%), power input and output (kW) and specific fuel consumption (PHU) was evaluated. It was revealed that in both stoves, sawdust briquette had the highest power output (kW), 30365.27 kW, followed by the wood shavings briquette, 22225.77 kW and rice husk briquette with power output of 14968.21 kW. Thus the thermal efficiency of sawdust briquette was highest, 74.22%, followed by that of wood shavings briquette, 71.44% and rice husk briquette, 67% respectively in both stoves. Hence future researchers should intensify works on using different types of waste materials in the production of briquettes as fuels for use with domestic stoves.

Keywords: Stoves, Briquettes, Fuels, Agricultural, Wood, Waste

1.0 Introduction

Energy demand has been on the increase due to growth in human population (Kpalo*et al.*, 2020). Fossil fuel such as petroleum products, coal and natural gas are the most widely used, supplying about 80% of the global primary energy requirements (Sansaniwal *et al.*, 2017). According to Tursi (2019) the increasing usage of fossil fuel, biomass and wood fuel, especially in cooking has led to the increased level of pollution and consequent degeneration of public health (Kpalo*et al.*, 2019). Annenberg *et al.* (2013) reported that 3 billion people around the globe are exposed to health challenges due to their reliance on fuel wood, coal, charcoal or animal dungs for cooking and heating and most of these people are predominately found in developing countries (Jetter, 2009, MacCarty, 2010).

According to Nahar (2016) about 2 million annual deaths of women and children in developing countries are linked to indoor air pollution due to exposure to carbon monoxide and volatile (benzene and formaldehyde) release in the form of smoke. Furthermore, about one third of the global population live without access to healthy, clean and sustainable cooking fuel. Biomass energy is the third largest energy resource in the world, and about 69% of Africa population relies on biomass fuel as a source of energy. And in Nigeria about 60% of the population depends on fire wood and charcoal for cooking and other domestic energy needs (Olorunisola, 1999). In developing countries, three-quarter of the population relies on biomass (Geyer *et al*., 2007, Kumar and Singh,2017*,* Baqir *et al.*, 2018). In Ghana for instance, traditional biomass burning supplies over 64% of its energy consumption, in Ethiopia over 92% (Asresu*et al.*, 2017), 70% in Kenya and in Nigeria 78 %(Agbro*et al.*, 2012).

The threats posed by fossils fuels and the inefficient use of biomass, can be mitigated by effective utilization of biomass wastes when converted to briquettes through densification (Tripathi *et al.*, 1998, Sunday *et al.*, 2020, kpalo, 2020). Bello *et al.* (2019) stated that the use of Briquettes as domestic fuel is gradually taking over conventional use of firewood and charcoal in most parts of developing countries. The production and use of this biomass briquettes are considered environmentally friendly, fuel efficient, high thermal efficiency, readily available and cheaper than fossil fuel.

Bello *et al.* (2019) stated that briquettes are products developed from engineered mechanical compaction of loose natural products such as wood wastes and agricultural residues, and tiny particle size materials with or without binder into different shapes and sizes to enable usability (Muazuand Stegemann,2015). The use of Briquettes as domestic fuel is gradually taking over conventional use of firewood and charcoal in most parts of developing countries. Briquettes are used domestically and industrially for heat and power generation (Bello *et al., 2019; Bello, 2020,* kaplo, 2020). The production and use of these biomass briquettes are considered environmentally friendly if the practice meets certain environmental sustainability indicators which are classified into broad categories related to land use, air and water quality. (Abel *et al.,* 2014; Christoforou *etal*., 2019; Agidi*et al.*, 2019; David, 2019; Kpalo*et al*. 2019).

The effects of smoke around the cooking environment from the inefficient stoves such as the traditional cook stoves and most biomass stoves, has made these existing stoves uncomfortable during cooking and environmentally unfriendly (Bello, 2020). Despite the significant progress in the development process of improved stoves, it remains a challenge to design stoves that are fuel efficient, reduce emissions and are easy to use by women and children (Annenberg *et al.,* 2013; Orhevba and Chinedu, 2015; Begum, 2016). Biomass energy is a renewable and sustainable source of energy for producing electricity, heat and other forms of power (Danjuma *et al.*, 2013). Biomass energy is the third largest energy resource in the world. In Nigeria, about 60% of the population depends on fire wood and charcoal for cooking and other domestic energy needs (Olorunisola, 1999). In developing countries, three-quarter of the population relies on biomass (Geyer *et al*., 2007, Kumar and Singh*,* 2017*,* Baqir *et al.*, 2018; Sunday *et al.*, 2020). In Ghana for instance, traditional biomass burning supplies over 64% of its energy consumption, in Etophia over 92% (Asresu*et al.*, 2017), 70% in

Kenya and in Nigeria 78 % (Agbro*et al.*, 2012).

The objectives of the study are: (1) Design and fabricate domestic stoves, (2) produce briquettes from wood and agricultural wastes and (3) evaluate the performance of the stoves using briquettes as alternative sources of energy.

2.0 Materials and Method

This work was accomplished in four different phases. The first phase involved the Design and fabrication of a cook stoves, the second phase was the sourcing and preparation of wood and agricultural waste for briquetting. The third phase was the production of briquettes. While the final phase was the evaluation of briquettes on the fabricated stove.

2.1 Design Consideration for Cooking Stoves

Design of cooking stoves for the test considered a number of factors such as: Strength of materials for the fabrication, durability of the stoves, thermal conductivity of the materials for stoves construction, cost of the required materials, expected life span of the design, cost of maintenance of the design and availability of replaceable parts, combustion chambers, ability to burn different types of materials, The design considered among others the work of the following authors: Olalekan and Olalusi (2009); Kabir*et al.* (2018); Bello *et al.* (2015, 2019); and Eze-Iiochi and Oti (2019).

2.2 Materials Consideration for Stoves Design and Briquettes Production

2.2.1 Materials Consideration for Stoves Design

Materials selection is crucial to the design of cooking stoves and briquette production considering the desired performance requirements such as thermal conductivity, heat resistance, heat retention and so on. Assurance of high-quality standard is needed, hence materials with the appropriate engineering properties were selected with varying degrees of heat exchange, malleability, ductility, capacity to withstand high tensile stress and strength. Some of the materials needed are galvanized sheet materials, mild steel, alloy cast iron, cast aluminum and a host of others. Major components of the stove included:

i. Combustion Chamber: This is where burning would take place for generation of heat. It would consist of ash grill, pot stand and lining. It will be fabricated with high strength material such galvanized metal and securely lined with clay material.

ii. Outer casing: This would be constructed with galvanized iron for easy heat dissipation. This section would provide and enclosed environment for primary air supply to the combustion chamber.

iii. Stove Stand: This would be constructed with galvanized steel; it is the base that is responsible to withstand the total load of the stove.

iv. Briquette Spout: This is the briquette holder during operation of the stove. It would be constructed using galvanized steel.

v. Briquettes: Different types of briquettes would be produced from wood and agricultural wastes materials for use with the stoves. These would be produced from highly compressed materials and forced through an extruder to produce high density, wood-like carbonated substance that burns with less smoke compared to charcoal and wood. The following materials were used in the production of briquettes: saw dust, wood shavings and rice husk (Asersu, 2017).

2.2.2 Design of Open and Enclosed Single Spout Stoves

The stove was designed using SOLIDWORKS 2021 3D Computer Aided Design (CAD)SOLIDWORKS is a solid modeling computer-aided design (CAD) and computer-aided engineering computer program. It is an auxiliary tool, which helps to obtain simple analysis results quickly in the design process. The AutoCAD software was utilized in the design, modelling construction of different parts of the stoves.

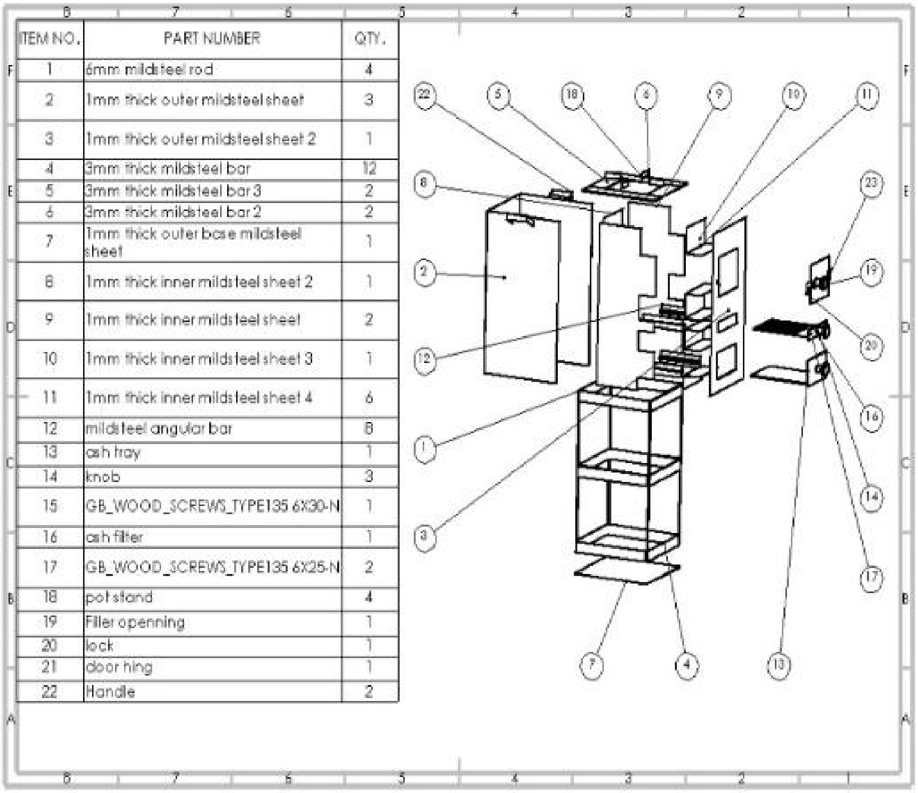

Figure1. An Exploded View an Enclosed Single Spout Stove

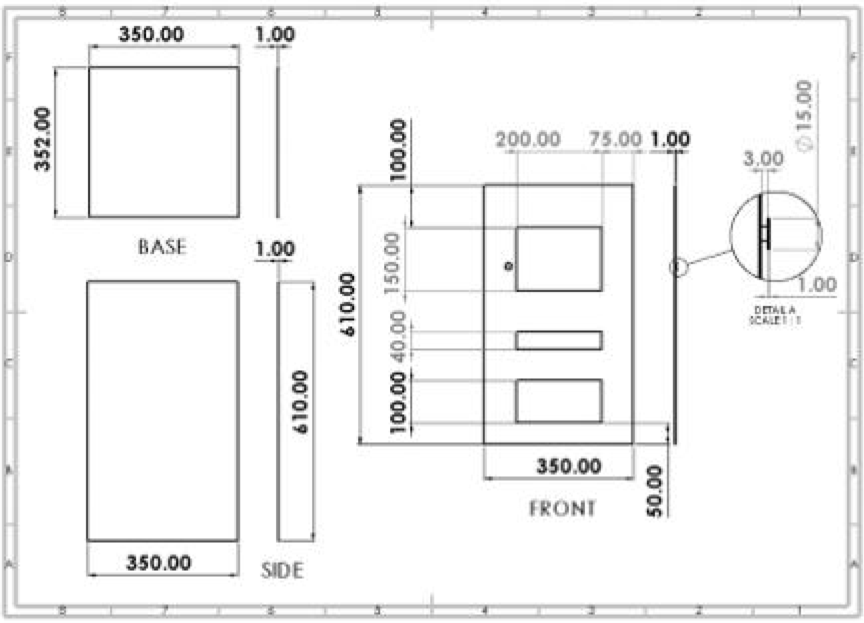

Figure 2. Orthographic Projection of Enclosed Single Spout Stove

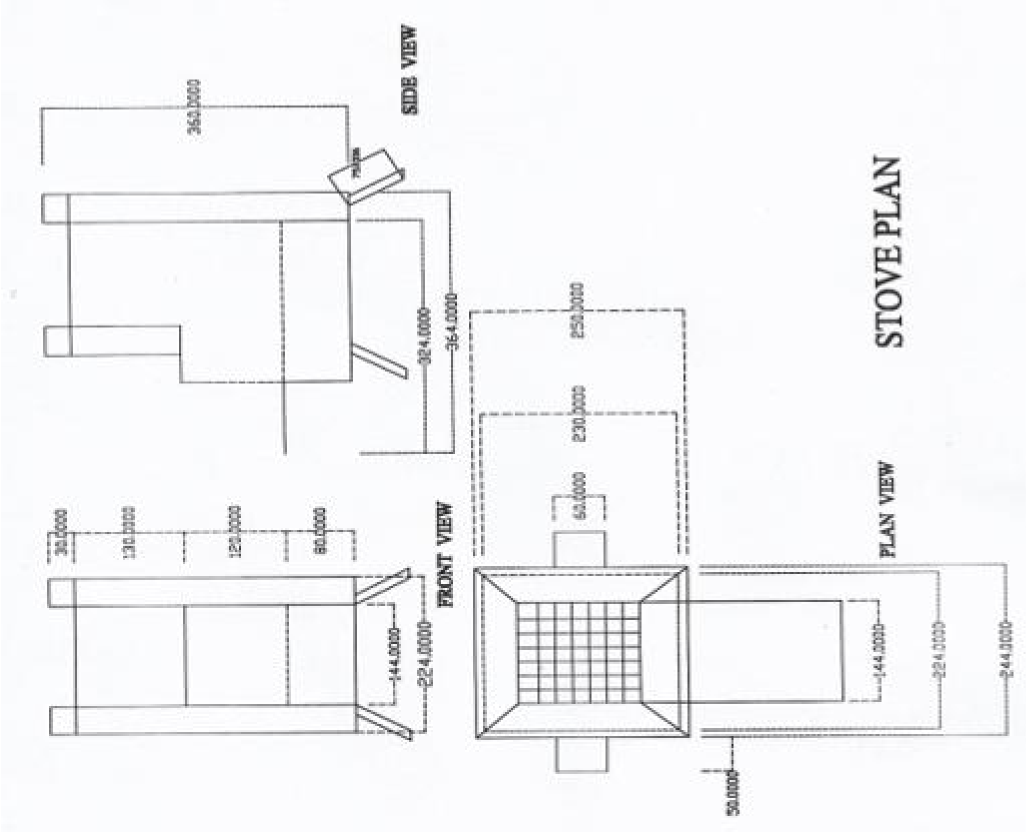

Figure 3. Plan of Open Single Spout Stoves

2.3 Fabrication of stoves and Briquette production

2.3.1 Fabrication of Stoves

Fabrication of the 2 types of stoves including (i) Enclosed single spout stove and (ii) Open single spout stove was carried out in the department of Mechanical Engineering Workshop.Various components of the stoves were fabricated according to specifications using hand held and machine tools. Various equipment including center lathe, milling, drilling and welding machines, electrodes, electric power generator as backup and other machines were used to carry out different operations during prototype production of the stoves.

The enclosed single spout stove had a height and width of 601mm and 350mm respectively with the following basic features:

i. **Combustion chamber:** This is the heart of the stove where the briquettes are burnt.

ii. **Air inlet chamber:** This consist of vents on the cylinder wall of the combustion chamber, on the briquette loading door and the air entry space.

iii. **Spout/Grate:** This is where the briquettes are loaded

iv. **Insulated stove wall:** This insulated wall is designed to reduce convective and radiation losses of heat energy from the combustion chamber.

v. **Removable ash collector:** It is a light ash tray with a handle to enhance ash removal from the stove during combustion for immediate disposal even when the fire is still on.

Figure 4. Fabricated Enclosed Single Spout Stove

Figure 5. Fabricated Open Single Spout Stove

2.3.2 Production of Briquettes

Production of briquettes were carried out in the departments of Wood Products Engineering Workshop and Civil Engineering Laboratory. The materials used for the production of the briquettes includes: rice husk gotten from Idomi in Yakurr Local Government Area. While saw dust and wood shavings were collected from the Akim Timber Market, Calabar. Production process of each of the briquettes was sorting, shredding, mixing, binding, compacting and drying.5.0kg each of the materials was measured, sorted and sundried for three days to further reduce the moisture content.

Waste paper, matrix binding was used for the process. The waste papers were shredded and soaked in water for two (2) days before conversion into pulp by crushing in a grinder (Roy *et al.* (2015). The paper pulp was used as the matrix material because it an effective binder with good combustion property. The paper pulp and each of waste materials were combined at percentage proportions of 100:0, 90:10, 80:20, 60:40, and 50:50 as samples before densification. Physical observation and shatter index of the different ratios showed that a ratio of 90:10 mixture of material to binder gave the best densification.

Production of briquettes was carried out from each of the samples viz - sawdust, wood shavings, and rice husk in turn. Manually operated hydraulic piston-press at the Civil Engineering department, CRUTECH was used in compacting the mixture. The mixture was fed into a mould with 51mm inner diameter and a height of 48mm. Three different pressures of 5.5, 10.5 and 15.5 MPa were applied during compaction at ambient temperature of 28C^o. Compacted briquettes were held in residence for at least 60 s before ejection from the mould. The produced briquettes were kept in a room with adequate ventilation and left to dry for at least 5 days. The produced briquettes were then subjected to different tests after drying.

2.3.3 Moisture content

Moisture content was determined by using oven-dried methods. Each briquette was weighed and then oven-dried at 105 ± 3 C^o to constant mass in 24 hrs. The loss in mass, expressed as a percentage of the final oven-dried mass, was taken as the moisture content of the briquettes. The moisture content was calculated by the equation:

$$MC = \frac{W_1 - W_2}{W_2} \times 100$$

where MC = moisture content, W_1 = wet weight, and W_2 = weight after drying.

2.3.4 Density

The briquette density was calculated by dividing the mass of the briquette by its volume. A Vernier caliper was usedto measure the diameter and the height of the sample, while an electronic balance was used to measure the weight. The density of the biomass briquette sample was calculated by the equation:

$$q = m/v$$

where q = Density, m = mass of biomass briquette, and V = volume of biomass briquette.

Figure 2. Mould of briquette.

2.3.5 Shatter index

Shatter index was measured according to ASTM standards D440-86 (1998). The initial mass of each briquette sample was weighed and recorded by using digital electronic weighing scale. The briquette sample was subjected to the fall of gravity and dropped on concrete floor from a constant 2-meter height for three (3) times. The disintegrated briquette was sieved through a sieve of size 2.36 mm. The mass of the briquette retained on the sieve was recorded. The shatter index of each briquette was calculated by the equation

$$K = B_z/B$$

Where K = shatter index, B_z = weight of briquette after shattering and B = weight of briquette before shattering.

C. Rice husk briquette A. Sawdust briq

Figure 6. Samples of Briquettes produced: (A) Sawdust briquette, (B) Wood shavings briquette and (C) Rice husk briquette

2.4 Evaluation of the Stoves and Briquettes.

Performance evaluation of the constructed stoves and briquettes produced were carried out between November 15-28, 2022 at the department of Wood Products Engineering Workshop. Among the tests conducted were the Water Boiling Test (WBT), percentage of char produced, fuel consumption rate, burnt rate and other vital tests. Each briquette produced was used in the test procedure, with the use of charcoal in the control experiment. Dry weights of experimental materials like pot and stove were taken. The initial known weight of pot filled with water was recorded and maintained throughout the experiment. The test was conducted under two varying conditions such as (i) open and (ii) closed environment. Stopwatch was utilized to monitor the time taken for cycle of operations. Weighing balance was used to record weights at different intervals (Mapereka *et al.*, 2017; Modestus and Otanocha, 2018).

Each of the briquettes produced from sawdust, wood shavings and rice husk were tested by burning on the stoves simultaneously. During evaluation of the stoves, each of the briquettes was evaluated independently. The briquette was weighed and place on the spout before slotting it into the stove. The briquette was then ignited using a lighter. And the pot containing the cook material (water) was placed on the stove. A stopwatch was used in measuring the start and finished time for each operation. The following properties were tested.

2.4.1 Fuel Consumption Rate (FCR), (kg/hr)

This is the amount of briquette(fuel) used in operating the stove divided by the time taken

$$FCR = \frac{\text{weight of briquette used (kg)}}{\text{operating time(hr)}} \quad (1)$$

2.4.2 Specific Fuel Consumption (PHU)

This is the amount of briquette (fuel) used in achieving a defined task divided by the weight of such task. This is expressed thus,

$$PHU = \frac{\text{mass of consummed briquette (kg)}}{\text{total mass of cooked food (kg)}} \quad (2)$$

2.4.3 Percentage Char Produced

This is the ratio of the amount of char produced and amount of briquette burnt.

$$\% \, char = \frac{\text{weight of char (kg)}}{\text{weight of briquette used (kg)}} \times 100 \quad (3)$$

2.4.4 Burn Rate (kg/hr)

This is a measure of the rate of fuel consumption.

$$r_{cb} = \frac{\text{weight of briquette consumed (kg)}}{\text{time taken (hr)}} \quad (4)$$

where r_{cb} = burnt rate

2.4.5 Thermal Efficiency (%)

This is the ratio of burnt rate over specific fuel consumption.

$$\eta_{th}\,(100\%) = \frac{\text{Burnt Rate}}{\text{PHU}} \quad (5)$$

2.4.6 Power Input

This is the amount of energy supplied to the stove based on the amount of briquette consumed.

$$P_t = 0.0012 \times FCR \times HV_f \quad (6)$$

Where,
P_t = power input, kW
FCR = fuel consumption rate (kg/hr)
HV_f = calorific heat value of fuel, Kcal/kg (3765.23 k Cal/kg for sawdust and rice husk)

2.4.7 Power Output

This is the amount of energy released by the stove for cooking.

$$P_o = FCR \times HV_f \times T_E \quad (7)$$

Where,
P_o = Power Output (kW)
FCR = Fuel Consumption Rate (kg/hr)
T_E = Thermal Efficiency, %

3.0 Results and Discussion

3.1 Water Boiling Test

Table 1. Water Boiling Test Results for Stoves and Briquettes

	Enclosed Single Spout Stove			Open Single Spout Stove		
	Sawdust Briquette	**Wood Shavings Briquette**	**Rice Husk Briquette**	**Sawdust Briquette**	**Wood Shavings Briquette**	**Rice Husk Briquette**
Initial Weight of Briquette (kg)	0.420	0.494	0.447	0.420	0.494	0.447
Weight of water evaporated (kg)	0.093	0.113	0.167	0.086	0.105	0.162
Weight of briquette/fuel burnt/consumed (kg)	0.067	0.120	0.105	0.058	0.118	0.101
Time used (min)	7.5	6.3	6.7	9.6	8.1	7.8
Time used (hr)	0.125	0.105	0.112	0.16	0.135	0.13
Max temp increase of water from initial value (28^{0}C)	88	93	98	92	96	94

Table 1 shows the results of data gathered the during the water boiling tests for the enclosed single spout and open single spout stoves using the different briquettes produced from sawdust, wood shavings and rice husk. The initial weight of briquette (kg), weight of water (kg), weight of briquette consumed (kg), time (hr) used and the maximum temperature increase in ^{0}C from the initial temperature of (28^{0}C) are shown. Maximum temperature of 98 ^{0}Cwas achieved by rice husk briquette in enclosed single spout stove, while a temperature of 96 ^{0}C was achieved for wood shavings briquette using the open single spout stove. The weight of briquette used during the two instances were 0.105 kg and 0.118 kg respectively.

3.2 Performance of Briquettes with stoves

Table 2. Fuel consumption rate (kg/hr), specific fuel consumption (PHU), thermal efficiency, power output and input of stoves

	Enclosed Single Spout Stove			Open Single Spout Stove		
	Sawdust Briquette	**Wood Shavings Briquette**	**Rice Husk Briquette**	**Sawdust Briquette**	**Wood Shavings Briquette**	**Rice Husk Briquette**
Weight of briquette/fuel burnt/consumed (kg).	0.167	0.120	0.105	0.158	0.118	0.101
% Char Produced.	43	38	35	45	39	37
Total operating time fuel was consumed (hr)	0.125	0.105	0.112	0.16	0.135	0.13
Fuel/briquette consumption rate (kg/hr)	1.336	1.143	0.938	0.988	0.874	0.777
Specific fuel consumption, PHU	0.018	0.017	0.019	0.019	0.021	0.021
Thermal Efficiency (%)	74.22	71.44	67.00	58.12	51.41	43.17
Power Input (kW)	6.04	5.16	4.24	4.46	3.95	3.51
Power Output (kW)	30365.27	22225.77	14968.21	16606.50	12995.32	10270.85

Table 2 shows values of results for weight of briquette burnt (kg), % char produced, total operating time (hr) fuel was consumed, fuel consumption rate (kg/hr), thermal efficiency (%), power input and output (kW) and specific fuel consumption (PHU)of stoves using different types of briquettes. The results from the table revealed that in both stoves, sawdust briquette had the highest power output (kW), followed by the wood shavings briquette and rice husk briquette. Thus the thermal efficiency of sawdust briquette was highest, followed by that of wood shavings briquette and rice husk briquette respectively in both stoves. Though the performance of enclosed single spout stove was higher than that of the open single spout stove. This could have been as a result of the fact that the enclosed single spout stove had better design criteria than the open single spout stove. Thus, the enclosed single spout stove is designed with an insulated wall to reduce convective and radiation losses of heat energy from the combustion chamber.

4.0 Conclusion and Recommendation

Design, production and performance evaluation of two types of cooking stoves using alternative fuels/briquettes produced from sawdust, wood shavings and rice husk was carried out. The values for weight of briquette burnt (kg), % char produced, total operating time (hr) fuel was consumed, fuel consumption rate (kg/hr), thermal efficiency (%), power input and output (kW) and specific fuel consumption (PHU) of stoves using different types of briquettes. It was revealed that in both stoves, sawdust briquette had the highest power output (kW), 30365.27 kW, followed by the wood shavings briquette, 22225.77 kW and rice husk briquette with power output of 14968.21 kW. Thus, the thermal efficiency of sawdust briquette was highest, 74.22%, followed by that of wood shavings briquette, 71.44% and rice husk briquette, 67% respectively in both stoves.

Briquettes as domestic fuel is gradually taking over conventional use of firewood and charcoal in most parts of developing countries. The production and use of this biomass briquettes are considered environmentally friendly, fuel efficient, high thermal efficiency, readily available and cheaper than fossil fuel. The threats posed by fossils fuels and the inefficient use of biomass, can be mitigated by effective utilization of biomass waste when converted to briquettes through densification. Hence it recommended that future researchers should consider using different types of waste materials in the production of briquettes for use with cooking stoves.

Acknowledgement

This research was sponsored/funded by Tertiary Education Trust Fund (TETFund) Institution-Based Research (IBR) of the Cross River University of Technology (CRUTECH), Calabar (now University of Cross River State (UNICROSS), Calabar), Nigeria. We are highly grateful to the Vice Chancellor and Management of CRUTECH/UNICROSS through which the TETFund IBR Grant was sourced using the Directorate of Research and Development of the University.

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