

# DEVELOPMENT OF HIGH CALORIFIC VALUE BLENDED LOCAL SUGARCANE BAGASSE – MAIGANGA COAL BRIQUETTES FOR DOMESTIC APPLICATION

Garkuwa, Y.A.<sup>1</sup>, Usman, A.M.<sup>2</sup>, Bello, A.A.<sup>3</sup> and Habou, D.<sup>4</sup>

<sup>1</sup>Department of Automotive Engineering, Air Force Institute of Technology Kaduna, Kaduna State, Nigeria

<sup>2</sup>Department of Mechanical Engineering, Modibbo Adama University Yola, Adamawa State, Nigeria

<sup>3</sup>Council for the Regulation of Engineering in Nigeria (COREN) Abuja, FCT, Nigeria

<sup>4</sup>Department of Automobile Engineering, Abubakar Tafawa University Bauchi, Bauchi State, Nigeria

Corresponding email: [amugfuty@gmail.com](mailto:amugfuty@gmail.com)

## ABSTRACT

*Sugarcane bagasse has reasonable calorific value but due to its high porosity, and lowers mass and energy densities render it unsuitable for most domestic application. There is a need for improving such properties by briquetting technology. The study aimed at developing high calorific value briquettes using bagasse blended with coal. 42g of bagasse was used as control sample after which 5% (2.1g) was replaced with coal and mixed with stoichiometric ratio of calcium hydroxide equivalent to Sulphur content in the coal. The samples were tagged BC0, BC5, BC10, BC15 and BC20 with ration of 42:0:0, 39.9:2.1:0.08, 37.8:4.2:0.1, 35.7:6.3:0.26, 33.6:8.4:0.34 for bagasse, coal and calcium hydroxide respectively. The mixed samples were compressed with 50MPa. Proximate and ultimate analyses, calorific value (CV), burning rate of the fuel (BR), heat transfer efficiency (HTE) and flame temperature (FT) of the samples were determined. The proximate analyses show better result in BC20 with low VM of 50%, MC of 6.1% and high FC 17% contents but with high AC of 11% as compared to all the samples. The sample BC20 also show better performance in the ultimate analysis with high carbon content of 68.11% and low Oxygen content of 23.32% even though with higher Sulphur content of 0.79%. The CV increases from BC0 as the quantity of coal in the sample increases, up to maximum of 22.40MJ/kg in BC20. The HTE and BR are optimum when BC20 and clay stove was used. For all the samples, clay stove show better performance as compared to metallic and then three stones stoves. The sample with highest FT of 520°C is obtained with BC20 followed by 495°C with BC15 after exactly 18min. The CV, HTE, BR and FT attained by all the samples were suitable for domestic application and commercialization.*

**Keywords:** Briquette, Calorific value, Coal, Sugarcane bagasse

## 1 INTRODUCTION

The availability of energy for domestic use in Nigeria continues to pose a challenge, especially with the high cost of cooking gas and kerosene. Furthermore, there are environmental problems associated with using firewood, charcoal, and scarcity and financial implication associated with using electric energy [1, 2]. Energy systems are required to simultaneously deal with rising energy demand and mitigating greenhouse gas (GHG) emission and other polluting gases. Renewable energies were an ally to sustainable development in relation to technologies that enable energy efficiency and development. One of the oldest known and used sources of renewable energy is biomass which has fixed carbon that is essential to meet various fuel requirements. If these biomasses

are used sustainably, they can supplement much of the world's energy needs and sources. Even though biomass is the only renewable resource that can be used directly as fuel through combustion processes but they are not recommended as an energy source due to their precarious characteristics. These characteristics include low bulk density, high moisture content and low energy density, causing high transportation, storage and handling costs [2, 3]. Among the several kind of biomass available, agricultural residues have become one of the most promising choices for local cooking and heating source in Nigeria. Some agricultural wastes such as wood and shrubs can be directly utilized as fuel. Nevertheless, a majority of them are not suitable apparently because they are bulky, uneven, and porous and have low energy density. All these characteristics make them difficult to handle, store, transport and utilized in their raw form [2, 4, 5]. However, scientific studies have concluded that a lot of potential energy abounds in these residues [3]. Also, these residues could be used to generate heat for domestic and industrial cottage applications [1, 4, 6]. Hence there is need to subject them to conversion process in order to mitigate the problems [4, 5]. One of the promising solutions to these problems is the application of briquetting technology [3, 5, 7]. Bagasse is a fibrous by-product of perennial grass usually sugarcane that require frost-free climate with sufficient rainfall to grow. As sugarcane grows, it converts sunlight and nutrients into chemicals and energy which are stored inside the plant tissue in the form of sucrose (the juicy component). After the straw, trash and the juicy components were removed, the remaining residue is a potential energy source called sugarcane bagasse with high calorific value of 17 MJ/kg to 19 MJ/kg dry mass basis [8, 9, 10]. Olorunnisola [1], Mahmud and Anannya [10], and Usman *et al.* [11] reported bagasse having proximate analyses containing fixed carbon of 20.10%, volatile matter of 75.8%, ash content 4.2% and higher heating value (HHV) of 18 MJ/kg. It also has an ultimate analysis of 44.1% carbon, 5.26% hydrogen, 44.4% oxygen and 0.19% nitrogen. Coal is a natural material obtained as result of long time decomposition (over millions years) of organic matter under anaerobic condition. Due to its high calorific value, it is considered as fuel for domestic, electricity generation and other industrial application [12, 13]. Usman [12], Rahman *et al.* [13], Bowen and Irwin [14] reported that generally coal has moisture content of 2 to 60 %, ash content of 3 to 60%, and volatile matter of 20 to 31 %. While the ultimate analysis reveals 98 to 40 % carbon content, 0.1 to 1.3% Sulphur content and a calorific value of 4000 to 2200 kJ/kg. The physical properties of coal include density of 1500 to 1100 kg/m<sup>3</sup> for coal grades from anthracite to lignite coal. According to Usman [12] and Folahan *et al.* [15], there are several deposits of coal in Nigeria some of which are Onyema, Okpara, Okaba, Iva, Chikila, Lafia obi and Jankwashankodi. Average Nigerian coal as reported by Folahan *et al.* (2012) have 72.46% carbon, 6.07% hydrogen, 1.63% nitrogen, 1.41% Sulphur, 18.43% oxygen and calorific value of 30.52 MJ/Kg from ultimate analysis. They also reported a proximate analysis moisture content of 5.14%, volatile matter of 40.73%, ash content of 14.94%, fixed carbon of 39.18% and 17.25% mineral matter. Among the various coal deposits in Nigeria, Maiganga coal was selected for this study. Usman [12] reported that Maiganga coal has average property moisture content of 4.18%, ash content of 49%, volatile matter of 31.11%. While the ultimate analysis reveals fixed carbon of 15.64%, Sulphur content of 0.92% and a calorific value of 2283 kJ/kg. Briquettes is a compressed block of coal dust or other combustible biomass material to form a high energy and mass density, high calorific value and low moisture fuel which are easier to handle, store and transport. Biomass to be used for briquetting, pelleting and dinking include saw dust, wood chips, peats, paper, seed husks and shells and agricultural trashes. Briquettes produced under different conditions have been reported to have different better handling characteristics. These characteristics are found to be strongly affected by raw material properties [2, 3, 6, 16]. For biomass briquettes to be efficiently used as fuel, energy density and calorific value are the most important factors as they determine the thermal applicability, efficient usage and timing. Even though there are other important parameters such as the moisture content, ash content, mass density, volatile matter, high crushing strength and hydrogen and impurities content etc. The most important agro-waste for use in briquetting with reasonable calorific value but low energy and mass density is bagasse due to its fiber and sucrose (juice component) residue content which is a hydrocarbon [2, 3, 16, 17]. The availability of coal deposits and local sugarcane bagasse in north east Nigeria were the study was conducted make it possible for easier sourcing of raw material. The study will determine the effect of Maiganga coal on the thermal characteristics of local sugarcane bagasse.

## 2 METHODOLOGY

The raw materials used were coal, sugarcane bagasse, calcium hydroxide and water. The coal sample used was collected from Maiganga coal deposit, located at Maiganga village (8km off Gombe-Yola road immediately after Kumo town) in Akko Local Government Area of Gombe State, Nigeria. The sugarcane bagasse was collected from a local sugarcane squeezing factory for making local chocolate located at Jambil Village in Tafawa Balewa Local Government Area of Bauchi State. The coal sample was crushed into a powdered form and then washed with water to reduce the pyritic Sulphur content by 70% as reported in literatures. The washed coal was dried before packing in to the container while the sugarcane bagasse was chopped into smaller sizes, sun dried before grinding into powder and packed. The study makes use of calcium hydroxide collected at no cost from a road side gas welding shop (product of reacting calcium carbide and water) as de-sulphurising agent. Forty-two grams of bagasse was use as control sample and subsequently 2.1g of coal was used to replace the bagasse up to four different replacements and tagged as BC0, BC5, BC10, BC15, and BC20. Meaning the samples has 0%, 5%, 10%, 15% and 20% of coal respectively. These raw materials were thoroughly mixed with de-sulphurising agent at a mass ratio (g) of 42:0:0, 39.9:2.1:0.08, 37.8:4.2:0.1, 35.7:6.3:0.26, 33.6:8.4:0.34 for bagasse, coal and calcium hydroxide respectively. As sugarcane bagasse contains enough lignin that binds the raw materials together hence the study did not used any type of binder. The mixture was compressed to a pressure of 50MPa using 3000 MPa capacity compression machine and a dwelling time of 30s was observed. Proximate and ultimate analyses, calorific value and fuel burning and consumption characteristics analyses when boiling 1litre of water were carried out on the developed samples. Proximate analyses determined the percentage volatile mater (VM), ash (AC), fixed carbon (FC) and moisture contents (MC) of the samples. Ultimate analyses determined the percentage carbon (C), hydrogen (H), Nitrogen (N), Sulphur (S) and oxygen (O) content in the briquettes samples. The calorific value determined the total heat content on the produce briquettes samples according to ASTM standard E711-87. Burning rate (*BR*) of fuel and percentage heat utilized (*PHU*) or heat transfer efficiency ( $\eta$ ) in boiling 1ltr of water using clay stove, stones and metallic stove were determine using equation 1 and 2 respectively [18, 19, 20]. The flame temperature was also measured at an interval of 3m during boiling litre water using the three stoves.

$$BR = \frac{m_f}{t} \quad (1)$$

$$\eta = \frac{m_w c_{pw}(T_b - T_0) + m_c L}{m_f cv_f} \quad (2)$$

Where  $m_f$  is mass of fuel burnt(kg),  $t$  is the time taken to burn fuel (s),  $m_w$  is mass of water,  $kg c_{pw}$  is specific heat capacity of water, kJ/kg.K,  $T_b$  is boiling temperature of water(K),  $T_0$  is initial temperature of water (K),  $m_c$  is mass of water evaporated(kg),  $L$  is latent heat of vaporization of water(J/kg) and  $cv_f$  is calorific value of fuel(kJ/kg). In addition, other equipment used includes digital bomb calorimeter (model C-5000), oven, ceramic fibremuffle furnace MXBAOCHENG and 3000 capacities compression machine. Others are AE Adam digital weighing balance, infrared thermometer (GM900); FGA4000XDS exhaust gas analyser, Endecott's test sieve shaker and Pots.

## 3 RESULTS AND DISCUSSION

### 3.1 Proximate Analysis

The result of proximate analysis of sugarcane bagasse- coal briquette is shown in Figure 1.

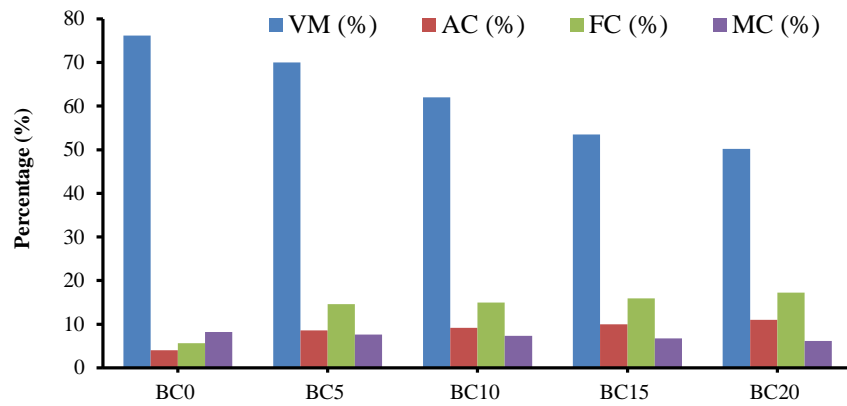


Figure 1. Variation of proximate analyses parameters in the bagasse coal croquettes samples

From the result shown in Figure 1, the amount of volatile matter in the samples kept decreasing as the percentage of coal is increased in the samples. The sample having the highest quantity of VM is the control sample i.e. BC0, while the least is the sample containing 8.4g of coal i.e. BC20. This shows that blending coal with biomass improves the characteristics of the bagasse-coal briquettes produced. The results of ash content show that the amount of ash contained in the samples increases with increase in the amount of coal as can be seen in Figure 1, the least value of about 3.99% was obtained in BC0, while BC20 has the highest value of 11.00%. This agrees with the results obtained by Bemgba [21] and shows that blending coal with biomass reduces the amount of ash deposited which is not desirable. Fixed carbon is the solid fuel left in the furnace after volatile matter is distilled off. It consists of mostly carbon, but also contains some H, O, S, and N driven off with the gases. It gives rough estimate of calorific value of fuel. From the result shown in Figure 1, it can be seen that the value of fixed carbon increase with an increase in the percentage of coal in the samples, from BC0 to BC20 which agrees with the result obtained by Jauro *et al.* [22] and Siahdashti *et al.* [23]. The results of moisture content show that the sample BC0 has the highest moisture, the value kept reducing, the least being the sample BC20. Higher moisture content decreases the heat content per kg of fuel, typical range is 0.5 to 10%. Moisture content above 10% might lead to explosion as a result of dissociation Mani *et al.* [24], also an increase in moisture content may not be favorable to the compaction process, and it provides more resistance to the formulation of briquettes. The result show that the quantity of FC content in the samples increases while that of VM decreases as the coal replacement increases. The result describes in this study conformed with results of Arachchige [2], Marreiro *et al.* [3], Mulindwa *et al.* [5] Asamoah *et al.* [16], and Siahdashti *et al.* [23] eventhough some studies used different biomass.

### 3.2 Ultimate analysis

The result of ultimate analysis of bagasse-coal briquettes showing elemental compositions in different briquettes samples are shown in Figure 2.

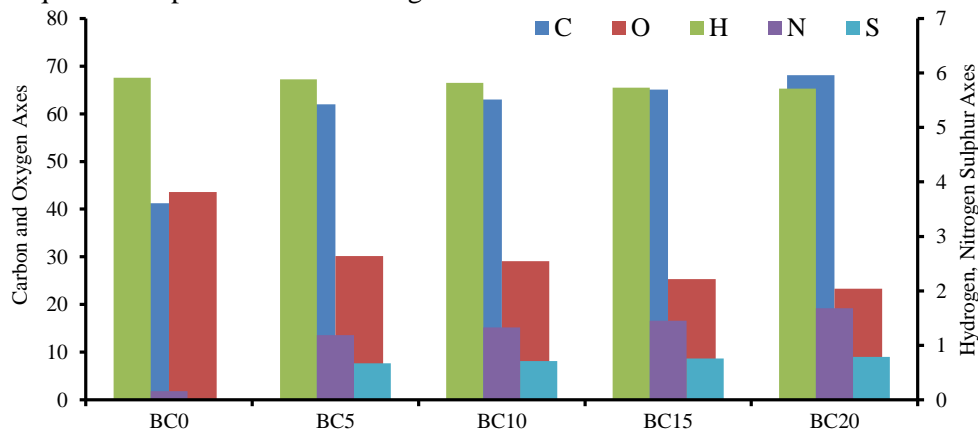


Figure 2. Ultimate analysis of sugarcane bagasse-coal briquettes.

Ultimate analysis is the determination of the elemental composition of a material, in this case fuel briquette. Usually the elements are carbon, hydrogen, oxygen, nitrogen, Sulphur and other metals. From the results obtained, the higher the amount of carbon, the higher the calorific value. The most interesting element in this research is carbon and Sulphur as they contribute to the calorific value of the coal as well as the briquette produced. Even though Sulphur contributes to the calorific value of coal during combustion, it produces acids of  $SO_2$  and  $SO_3$  which corrode equipment and also causing atmospheric pollution. The maximum acceptable limit of Sulphur in coals is between 1.5 - 1.6% by weight. Thanks to the low Sulphur content of Maiganga coal which is far below the acceptable limits, this can be seen from the results of the ultimate analysis reported by Usman [9], the highest value occur in sample BC20 is 0.79% as can be seen in Figure 2. Figure 2 also show that the carbon content increases with increasing coal in the sample up to 8.4g in BC20 with carbon content of 68.11% and calorific value of 22.4 MJ/kg in Figure 3. Hydrogen and Oxygen content reduces while Nitrogen content increases as the coal content increases in the produced samples as can be seen from Figure 2. Asamoah *et al.* [16] used municipal solid waste and Suttibak and Loengbudnark [17] used sugarcane bagasse, cassava rhizomes and water hyacinth and reported similar result.

### 3.3 Calorific Value

The result of the calorific value (MJ/kg) of the bagasse-coal briquette samples containing varying percentage of coal at pressure (50MPa) is shown in Figure 3.

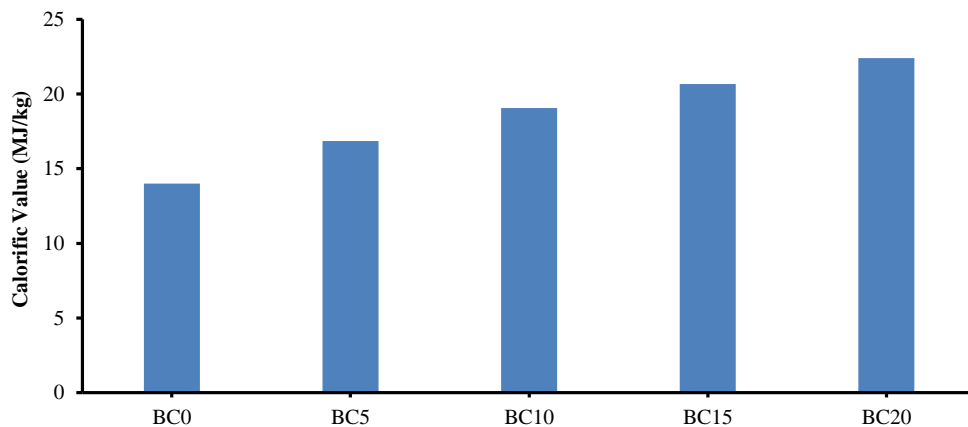


Figure 3. Calorific values of sugarcane bagasse-coal briquettes

The amount of energy in the briquette represents the raw materials calorific value. According to the above information, lower moisture content, lower volatile matter and less ash content, higher fixed carbon content, and bulk density are essential to produce efficient fire briquettes [2]. Calorific value is the most important indicator of fuel chemical quality [5]. Therefore, the results obtained in Figure 3, showed that the calorific value increases as the amount of coal in the sample increases, the highest value obtained is 22.40MJ/kg in a sample (BC20), while the lowest value is 14.01MJ/kg in a sample (BC0). These can also be seen from lower moisture content, lower volatile matter and less ash content and higher fixed carbon content of BC20 sample described in Figure 1. Arachchige [2] reported 13–16 MJ/kg while Mulindwa *et al.* [5] reported 16–22 MJ/kg which are similar to present study. Even though Arachchige [2] used agricultural crop residue and industrial waste while Mulindwa *et al.* [5] used carbonized maize cobs, Bamboo and charcoal dust. Suttibak and Loengbudnark [17] reported 27.73 MJ/kg using bagasse, 27.50 MJ/kg using cassava rhizomes and 17.44 MJ/kg when water hyacinth was used.

### 3.4 Burning and Consumption Characteristics

The result of percentage heat utilized (PHU) or thermal transfer efficiency, burning rate and flame temperature were shown in Figure 4 to 6 respectively.

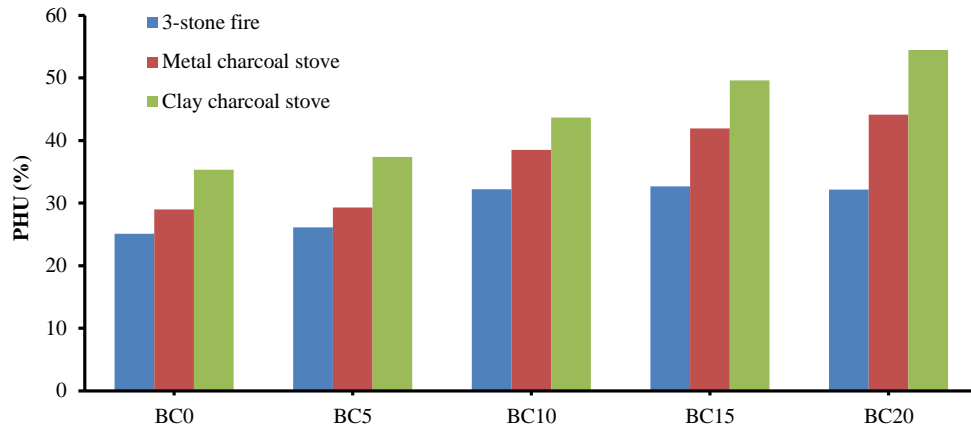


Figure 4. Percentage heat utilized by sugarcane bagasse-coal briquette samples

From the result obtained in Figure 4, were performed on three different local cooking stove, 3-stone fire, metal charcoal and clay charcoal stoves. It revealed that clay stove is the most efficient which utilized about 35.32% to 54.47% of the supplied heat using samples BC0 to BC20 respectively. This is due to the fact that heat lost to the surrounding by conduction in clay stove is minimum due to low thermal conductivity when compared with metal charcoal stove. For the metal charcoal stove, the highest value obtained is 44.13% in sample BC20 while the least value is 29.33% in a sample BC0 as the escaping to the surrounding reduces. The least efficient is the 3-stone fire which has the highest and lowest efficiencies of 32.15% and 25.11% in samples BC20 and BC0 respectively. This is because more heat is lost to the surrounding due to its geometry and the distance between the pot and the fuel's flame is higher compared to other types of stoves. These results to decrease in the amount of heat utilized, hence the low efficiency. Igboanugo *et al.* [25] reported thermal efficiency of 31% and 14% using wood and briquettes respectively while Omoniyi and Ojo[20] reported 15.1% and 15.3% using briquettes under cold and hot testing condition respectively. Djafar *et al.* [26] also reported efficiency of up to 73.66% on a clay- stove, 38.98% using steel stove, and 11.49% on an aluminum stove. Similar types of heat utilization variations were reported in previous studies of Odesola *et al.* [19], Ekouevi *et al.* [27], Lam *et al.* [28] and Wae-hayee *et al.* [29]. Even though some of these literatures used different types of fuels or combination of different fuels. Therefore, using the developed briquettes and the stoves, all the samples provides higher and better efficiencies.

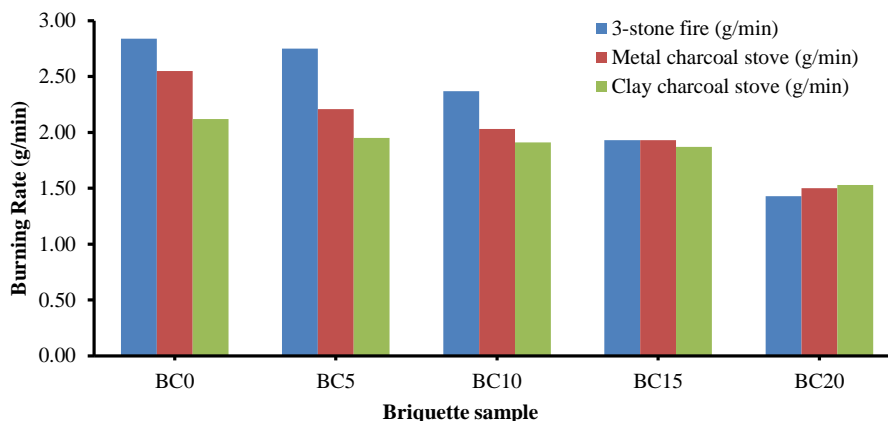


Figure 5. Burning rate of sugarcane bagasse-coal briquette samples

Burning rate determines the rate (how fast) a certain mass of fuel is combusted in air. The result in Figure 5, showed that as the percentage of coal in the samples increases, the burning rate decreases. This is because bagasse (biomass) contains more volatile matter than coal and it is more porous which allows for easy infiltration of air and outflow of combustion products. The lowest value of 1.43, 1.5 and 1.53 g/min was obtained in a sample BC20 using stones, metal and clay stoves respectively. The highest value of 2.84, 2.55, and 2.12g/min was obtained in a sample BC0 using the

three stoves respectively. In all the samples except for BC20, 3-stone firing has the highest burning rate due to excess supply of oxygen while the lowest rate was obtained using clay stove due to controlled supply of oxygen to the fuel briquettes. Komolafe and Awogbemi [18] reported burning rate of 6 g/min and 1.8 g/min when vent is fully opened and 2.18 g/min and 1.17 g/min when vent is halfway opened. This result was obtained when heating 2 kg of water for a period of 1 hr. using two different stoves and wood charcoal briquettes. Igboanugo *et al.* [25] reported 20 g/min when boiling 5 ltrs. of water which took the experiment 60 mins to complete. Also, Omoniyi and Ojo [20] reported burning rate of 9.63g/min and 9.65g/min when boiling 1kg of water under cold and hot testing condition. As compared to previous literatures, the present study briquettes samples performed reasonably better.

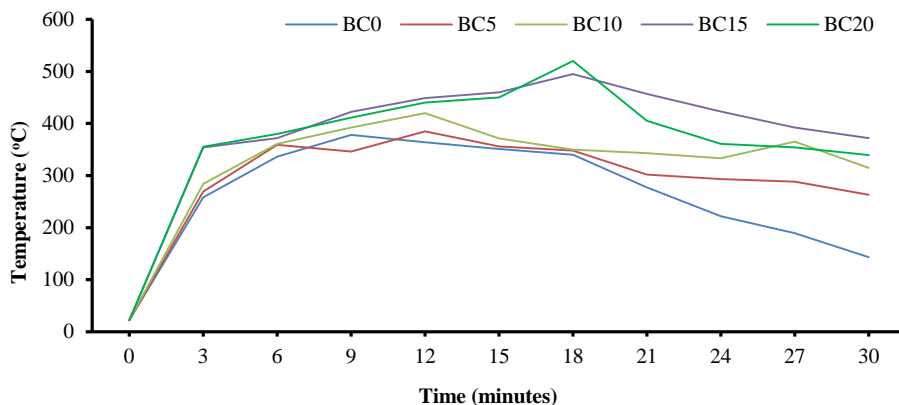


Figure 6. Flame temperature versus time of sugarcane bagasse-coal briquettes samples

From the result of flame temperature versus time shown in Figure 6, it can be seen that the highest temperature recorded is 520°C in a sample containing 20% coal (BC20) followed by 495°C, 420°C, 385°C and 378°C for BC15, BC10, BC5 and BC0 respectively. The result shows that samples reached their highest temperature at different times. The samples BC0 TO BC20 reached maximum temperatures after 9 mins, 12 mins, 12 mins, 18 mins and 18 mins respectively. The results also show that as the percentage of coal increases in the samples, the longer it takes to reach its maximum temperature. This is because the hardness of the samples increases as the quantity of porous bagasse in the samples is replaced with harder coal sample which reduces the burning rate Figure 5. These consequently increase the time it takes to reach the maximum temperature. These variations were also shown in previous studies of Wae-hayee *et al.* [29] and Djafar *et al.* [26].

#### 4 CONCLUSIONS

At the end of this study, it was concluded that the samples were successfully made without adding any binder as the bagasse contain lignin which serve as a binder. Proximate and ultimate analyses, calorific value (heating value), burning rates, heat transfer efficiency and flame temperature of the produced samples were successfully determined. Proximate analysis shows that the fixed carbon and ash content increase while VM content decreases as the quantity of coal replacement in the sample increases. The better sample is the BC20 as it contained the highest FC content and low VM even though with highest ash content. Ultimate analyses (UA) show that carbon and oxygen are the highest in the samples. Also, carbon increase while oxygen content decreases as the coal content in the samples increases. The better sample according to UA is BC20 with highest carbon content of 68%.The calorific value increases as the amount of coal in the sample increases; the highest value obtained is 22.40MJ/kg in a sample (BC20), while the lowest value is 14.01MJ/kg in a sample (BC0). These can be seen from lower MC, lower VM and AC and higher fixed carbon content of BC20 sample. The heat transfer efficiency and burning rate are the optimum in BC20 sample and using clay stove. For all the samples, clay stove show better performance as compared to metallic and then three stones stoves. The sample with highest flame temperature of 520°C is obtained with BC20 followed by 495°C with BC15 after exactly 18min. The flame temperatures reached by all the samples were suitable for domestic application. The sample BC20 is the optimum sample among the entire produce sample.

## REFERENCES

1. Olorunnisola, A. (2007). Production of Fuel Briquettes from Waste Paper and Coconut Husk Admixtures. *Agricultural Engineering International: the CIGR Ejournal, Manuscript EE 06 006 vol. IX*, pp. 1-11.
2. Arachchige, U.S.P.R. (2021). Briquettes Production as an Alternative Fuel. *Nature Environment and Pollution Technology-An International Quarterly Scientific Journal*, vol. 20, no. 4, pp. 1661-1668.
3. Marreiro, H.M.P., Peruchi, R.S., Lopes, R.M.B.P., Andersen, S.L.F., Eliziário, S.A. and Rotella Junior, P. (2021). Empirical Studies on Biomass Briquette Production: A Literature Review. *Energies*, vol. 14, pp. 1-40.
4. Mulindwa, P., Egesa, D., Osinde, A. and Nyanzi, E. (2021). Production of Fuel Briquettes from Bamboo and Agricultural Residue as an Alternative to Charcoal. *Journal of Sustainable Bioenergy Systems*, vol. 11, pp. 105-117.
5. Wilaipon, P. (2007). Physical characteristics of maize cob briquettes under moderate die pressure. *American journal of applied science*, vol. 4, pp. 995-998.
6. Oladeji, J.T. (2010). Fuel characterization of briquettes produced from corn cob and rice husk residues. *Pacific Journal of Science and Technology*, vol. 11, no. 1, pp. 101-106.
7. Oladeji, J.T. (2010). Pyrolytic conversion of sawdust and rice husk to medium grade fuel. In *Proceedings of 2010 conference of Nigeria institute of industrial engineers, Ibadan*, pp. 81-86.
8. Usman, A.M., Raji, A., Waziri, N.H. and Hassan, M.A. (2014). A Study on Silica and Alumina Potential of the Savannah Bagasse Ash. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, vol. 11, no. 3, pp. 48-52.
9. Usman, S.O. (2014). Chemistry of Maiganga coal deposits, upper Benue Trough, north eastern Nigeria. *Journal of Geosciences and Geomatics*, vol. 2, no. 3, pp. 80-84.
10. Asamoah, B., Nikiema, J., Gebrezgabher, S., Odonkor, E. and Njenga, M. (2016). Resource Recovery and Reuse Series 7: A Review on Production, Marketing and Use of Fuel Briquettes. *International Water Management Institute (IWMI) and World Agroforestry Centre*, 43p.
11. Suttibak, S. and Loengbudnark, W. (2018). Production of charcoal briquettes from biomass for community use. *IOP Conf. Series: Materials Science and Engineering Series*, vol. 297, pp. 1-9.
12. Mahmud, M.A. and Anannya, F.R. (2021). Sugarcane bagasse - A source of cellulosic fiber for diverse applications. *Heliyon*, vol. 7, pp. 1-14.
13. Onesippe, C., Coutrin, N.P., Bilba, K. and Arsene, M.A. (2010). Thermal properties of treated bagasse fibres reinforced cement composites. In *International Inorganic-Bonded Fiber Composite Conference*, pp. 130-139.
14. Rahman, R., Widodo, S., Azikin, B. and Tahir, D. (2019). Chemical composition and physical characteristics of coal and mangrove wood as alternative fuel. *Journal of Physics: Conference Series*, vol. 1341, pp. 1-11.
15. Bowen, B.H. and Irwin, M.W. (2008). Coal Characteristics. *Indiana Center for Coal Technology Research, Indiana*, 28p.
16. Bemgba, B.N. (2000). Physicochemical characterisation of low rank Nigerian coals. *Center for Hydrogen Energy, Institute of Future Energy, University Technology Malaysia, Johor*, 200p.



17. Jauro, A., Agho, M.O., Abaye, O., Obaje, N.G. and Abubakar, M.B. (2008). Petrographic studies and coking properties of Lamza, Chikila and Lafia Obi Coals. *Journal of Industrial Chemistry*, vol. 44, pp. 11-18.
18. Mani, S., Shahabaddine, S.B.X. and Anthony, T. (2006). Economics of producing fuel pellets from biomass. *Applied Engineering in Agriculture*, vol. 22, no. 3, pp. 421-426.
19. Siahdashti, M.S., Talaeipour, M., Khademieslam, H. and Bazayar, B. (2022). Investigation of Physical and Thermal Properties of Fuel Briquettes Made of Bagasse. *BioResources*, vol. 17, no. 2, pp. 2053-2073.
20. Wae-hayee, M., Yaranee, K., Suksuwam, W. and Nuntadusit, C. (2021). Effect of burner-to-plate distance on heat transfer rate in a domestic stove using LPG. *Case Studies in Thermal Engineering*, vol. 28, pp. 1-9.
21. Lam, N.L., Upadhyay, B., Maharjan, S., Jagoe, K., Weyant, C.L., Thompson, R., Uprety, S., Johnson, M.A. and Bond, T.C. (2017). Seasonal fuel consumption, stoves, and end-uses in rural households of the far-western development region of Nepal. *Environmental Research Letters*, vol. 12, pp. 1-11.
22. Ekouevi, K., Kennedy, K. and Soni, R. (2014). Understanding the Differences Between Cookstoves. *World Bank Group Supported by Energy Sector Management Assistant Program*, pp. 1-8.
23. Odesola, I.F., Ige, E.O. and Yunus, I.O. (2019). Design and Performance Evaluation of Energy Efficient Biomass Gasifier Cook Stove Using Multi Fuels. *Journal of Energy Research and Reviews*, vol. 3, no. 4, pp. 1-7.
24. Djafar, Z., Suluh, S., Amaliyah, N. and Piarah, W.H. (2022). Comparison of the Performance of Biomass Briquette Stoves on Three Types of Stove Wall Materials. *International Journal of Design & Nature and Ecodynamics*, vol. 17, no. 1, pp. 145-149.
25. Omoniyi, T.E. and Ojo, O.O. (2022). Development and Performance Evaluation of a Briquette Cooking Stove. In *43rd Annual Conference of Forestry Association of Nigeria (FAN), Akure*, pp. 390-404.
26. Igboanugo, A.C., Ajieh, M.U. and Azi, S.O. (2015). Performance evaluation of a biomass stove using particulate matter and carbon monoxide emission from briquette & fuel wood. *Nigerian Journal of Technology*, vol. 34, no. 3, pp. 484-490.
27. Komolafe, C.A. and Awogbemi, O. (2010). Fabrication and Performance Evaluation of an Improved Charcoal Cooking Stove. *The Pacific Journal of Science and Technology*, vol. 11, no. 2, pp. 51-58.