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ORIGINAL RESEARCH ARTICLE

EFFECT OF COMPACTION PRESSURE AND BIOMASS TYPE (RICE HUSK AND SAWDUST) ON SOME PHYSICAL AND COMBUSTION PROPERTIES OF BRIQUETTES

M. Aliyu[1]*, I. S. Mohammed[1], H. A. Lawal[1], S. M. Dauda[1], A. A. Balami[1], M. Usman[1], L. Abdullahi[2], M. Abubakar[2] and B. Ndagi[2]

[1]*Department of Agricultural and Bioresources Engineering, Federal University of Technology, P. M. B. 65, Minna, Niger State, Nigeria*
[2]*National Cereals Research Institute Badeggi, P. M. B. 8, Bida, Niger State, Nigeria.*
**Corresponding author's email address: aliyu.mohd@futminna.edu.ng*

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ABSTRACT

In this study, a simple manually operated briquetting machine suitable for use in rural community with no access to electricity supply was fabricated. A three (3) tone hydraulic jack and a pressure gauge were installed to allow for pressure variation. Some physical and combustion properties such as the compressed density, shatter index, hydrophobicity, combustion rate and ignition time of the produced briquettes were determined at the three (3) different compaction pressures of 420.4 kN/m² , 525.5 kN/m² and 630.6 kN/m² . Rice husk (RH), sawdust (SD) and composite briquettes of rice husk and sawdust (RH/SD) were produced using cassava starch as a binder. The developed biomass briquetting machine had a minimum and maximum production capacities of 20 kg/hr and 30 kg/hr respectively. The results showed that the physical properties improved at an increasing compaction pressure. All the produced briquettes at different compaction pressures from the different biomass exhibited over 90% shatter index while the briquette produced from RH at compaction pressure of 525.5 kN/m² had the highest combustion rate. The RH/SD briquette moulded at compaction pressure of 630.6 kN/m² had the least combustion rate. The ignition time of the briquettes increased with increasing compaction pressure from 1.28 to 1.58. However, this study found that the RH biomass briquette exhibited a superior solid fuel quality property compared to the other briquette samples. Therefore, this study recommends the RH briquette as a sustainable source of solid biofuel

1.0 Introduction

Energy is one of the necessities for human existence (Olajedi and Oyetunji, 2013). Currently, fossil fuel is the major source of energy from which the commonly used fuel products like kerosene and cooking gas are obtained (Aliyu *et al.*, 2020; Mohammed *et al.*, 2020). However, the non-renewability and the negative impact of fossil fuel on the environment such as the greenhouse gas emission has become a global concern (Lang *et al.*, 2019). Also, in recent years, Nigeria and other countries in the sub-Sahara have faced the problem of forest degradation due to increased fuel-wood consumption among other causes (Leach and Mearns, 2013; Yahaya *et al.*, 2020). Out of the total energy demand in Nigeria, fuel-wood use account for about 37% (Oyedepo, 2014). In Ngeria, large quantities of agricultural residues such as the rice husk (RH) and sawdust (SD) are mostly dump in waste sites unutilised and recycling of these Agricultural wastes are rarely practiced which has led to environmental problems such as pollution (Thliza *et al.*, 2020). Figures 1a and 1b shows a typical dump sites for SD and RH in Niger State, Nigeria.

Figure 1: (a) Sawdust and (b) Rice husk dump sites

Therefore, it is imperative to pay more attention to renewable energy sources such as biomass from agricultural residues to reduce the problem of environmental pollution and deforestation (Tembe *et al*., 2014; Bach and Skreiberg, 2016). However, direct use of biomass as a sustainable energy resource constitutes some disadvantages due to its high moisture, low energy value, heterogeneity and low density (Wang *et al*., 2018). One of the simple techniques that is currently used to overcome some of the limitations to the direct usage of biomass as energy source as mentioned above is briquetting.

Briquetting is the mechanical compaction of dry, loose and tiny particle size materials with or without the addition of an additive to form a regular shaped solid through the application of pressure (Osarenmwinda and Ihenyen, 2012; Orhorhoro *et al*., 2017). Compaction pressure plays a vital role in increasing the energy density and the combustion characteristics of a briquette, given the fact that denser solid fuel tends to burn for a longer time and more durable for handling and transportation (Orhevba *et al.,* 2016).

Briquettes have been produced from various agricultural residues and other waste materials (Tembe *et al*., 2014; Thabuot *et al*., 2015; Rajaseenivasan *et al*., 2016; Garrido *et al*., 2017; Krizan *et al*., 2018; Kongprasert *et al*., 2019; Thliza *et al*., 2020). However, to the authors knowledge, no literature has reported the production of briquette from RH, SD and a combination of RH/SD at varying pressure. Therefore, the aim of this study was to produce briquettes from RH, SD and RH/SD at varying compaction pressure and to determine some physical characteristics of the produced briquettes using a simple manually operated briquetting machine.

2. Materials and Methods

2.1 Materials

The materials used for the study include mild steel plates, angle iron, galvanize pipe, RH, SD, RH/SD (ratio 1:1), hydraulic jack, pressure gauge, electric oven, and cassava starch as binder. All the materials were sourced locally from Minna, Niger State, Nigeria. The manual briquetting machine was designed to produce four (4) briquettes at a time. Total area to which the compaction pressure acts, and the applied compaction pressure were calculated using Equations 1 and 2. The initial pressure was calculated from a hydraulic jack of 3 tonnes (Osarenmwinda and Ihenyen, 2012). The machine production capacity at varying compaction pressure was calculated using Equation 3 by considering the total time from loading, compaction, ejection, and the mass of the produced briquettes (Obi *et al*., 2013). The fabricated machine is shown Figure 2.

Corresponding author's e-mail address: aliyu.mohd@futminna.edu.ng

$$Total\ area = n \times \frac{\pi}{4} d^2 \quad (1)$$

Where n = Number of moulds

$$Applied\ pressure = \frac{F_a}{A_t} \quad (2)$$

$$Machine\ capacity = \frac{M_b}{T_t} \quad (3)$$

Where; F_a = Applied force (kN/m^2), A_t = Total area (m^2), M_b = Mass of briquette produced (kg)
T_t = Total time taken (hours)

Figure 2: The fabricated briquetting machine

Each of the raw biomass and the blend were mixed with cassava starch as a binder at a ratio of 3:1. The mixture was fed into the mould of the briquetting machine. It was ensured that all the moulds were fed to approximately equal level, to ensure equal distribution of pressure during compaction. The briquettes were ejected after compaction and were dried in an electric oven for 24hours at 120 °C to a constant mass.

2.1 Determination of physical properties of the produced briquettes

2.1.1 Determination of the compressed density

Four (4) briquettes were randomly selected from each production batch at the varying compaction pressure for the determination of the compressed density. The mean compressed densities of the briquettes were determined immediately after removal from the mould as a ratio of measured mass to the volume (Obi *et al*., 2013). The mass of the produced briquettes was determined using a digital weighing balance (OHAUS CORP AR3130 Model – China), while the average external and internal diameters, and height of the briquettes were measured using a vernier calliper. The measured diameters were subsequently used to calculate the volumes and the densities using Equations 4 and 5 (Olorunnisola, 2007; Kamruzzaman *et al*., 2008; Tembe *et al*., 2014; Aliyu *et al*., 2017; Aliyu *et al*., 2020).

$$V_b = \frac{\pi}{4}\left(D^2 - d^2\right)h \quad (4)$$

$$Compreesed\ density = \frac{M_b}{V_b} \quad (5)$$

Where; V_b = Volume of the briquette (m^3), D = External diameter of the briquette (m), d = Internal diameter (m) of the briquette and h = Height of the briquette (m)

2.1.2 Determination of shatter index

The durability of briquettes was determined in accordance with the shattering index. This was done by dropping the briquette sample repeatedly from a height of 1.5 m on a solid surface. The fraction of the briquettes retained was used as an index of briquette breakability. The percentage mass loss of briquettes was expressed as a difference between the initial mass and the mass after impact with the solid surface, divided by the initial mass. The shatter index was obtained by subtracting the percentage mass loss from 100 as expressed in Equations 6 and 7 (Ghorpade *et al.,* 2006; Suparin *et al.,* 2008; Sengar *et al.,* 2012; Tembe *et al.*, 2014).

$$Percentage\ mass\ loss\ (\%) = \frac{M_1 - M_2}{M_1} \times 100 \quad (6)$$

Where;

M_1 = Initial mass (g), M_2 = Final mass after shattering impact (g)

$$Shatter\ index = 100 - Percentage\ mass\ loss \quad (7)$$

2.1.3 Hydrophobicity test

Hydrophobicity is a measure of percentage of water gained by a briquette when immersed in water. Each briquette was immersed in 150 mm of water column at room temperature for 30 s. The percent of water absorbed by the briquettes were recorded and calculated. These values were, thereafter, subtracted from 100% to obtain the approximate average hydrophobicity in percentage using Equations 8 and 9.

$$\text{Water absorbed by briquette (\%)} = \frac{W_2 - W_1}{W_2} \times 100 \quad (8)$$

Where;

W_1 = Initial mass of briquette (g) and W_2 = Mass of wet briquette (g)

Hydrophobicity (%) = 100 - water absorbed by briquette (9)

2.2 Determination of combustion properties of the produced briquettes

2.2.1 Determination of the combustion rate of the produced briquettes

Briquette burning rate was determined according to the method reported by Onuegbu *et al.* (2012). The insulator, Bunsen burner, tripod stand, and wire gauze were arranged on the balance and their weights were recorded. Briquette sample of known weight was placed on wire gauze and the burner ignited. This was positioned on top of a weighing balance to facilitate instantaneous measurements of the mass every 10 seconds throughout the combustion process using a stopwatch, until the briquettes were completely burnt, and constant weight was obtained. The weight loss at specific time was computed from the expression in Equation 10.

$$Combustion\ rate\ (g/min) = \frac{M_d}{T_d} \quad (10)$$

Where;

M_d = Mass of burned briquette (g), T_d = Total time taken (minutes)

2.2.2 Determination of ignition time

Ignition time was determined according to the method described by Onuegbu *et al.* (2012). Each briquette was ignited by placing a Bunsen burner on a platform 4 cm directly beneath. Bunsen burner was used to ensure that the entire base of the briquette was ignited simultaneously after adjustment to blue flame. Caution was taken to avoid flame spread in the transverse direction. The burner was left until the briquette was well ignited and had entered its steady state burn phase.

3.0 Results and Discussion

3.1 Production capacity of the manually operated briquetting machine

The produced briquettes and the result of the machine capacity at different densification pressure is shown in Figures 3 and 4.

Figure 4 showed that biomass type had a noticeable influence on the production capacity or rate of the machine. On the contrary, the compaction pressure showed not much influence on the capacity. The composite biomass briquette RH/SD had the highest production rate which may be attributed to the differences in the biomass composition in the mixture and consequently led to a higher capacity. RH at 420.4 kN/m^2 had the lowest production rate with 20 kg/hr while the samples produced at 525.5 kN/m^2 and 630.6 kN/m^2 showed no differences in production capacity. The observed production capacity of the composite (RH/SD) briquette at increasing compaction pressures was 30 kg/hr. This implies that there were no changes in the observed capacities at the different compaction pressures. Obi *et al*. (2013) reported 43 kg/hr for SD briquette, the observed differences may be attributed to the differences in the sizes of the moulds used, production technique and the procedure.

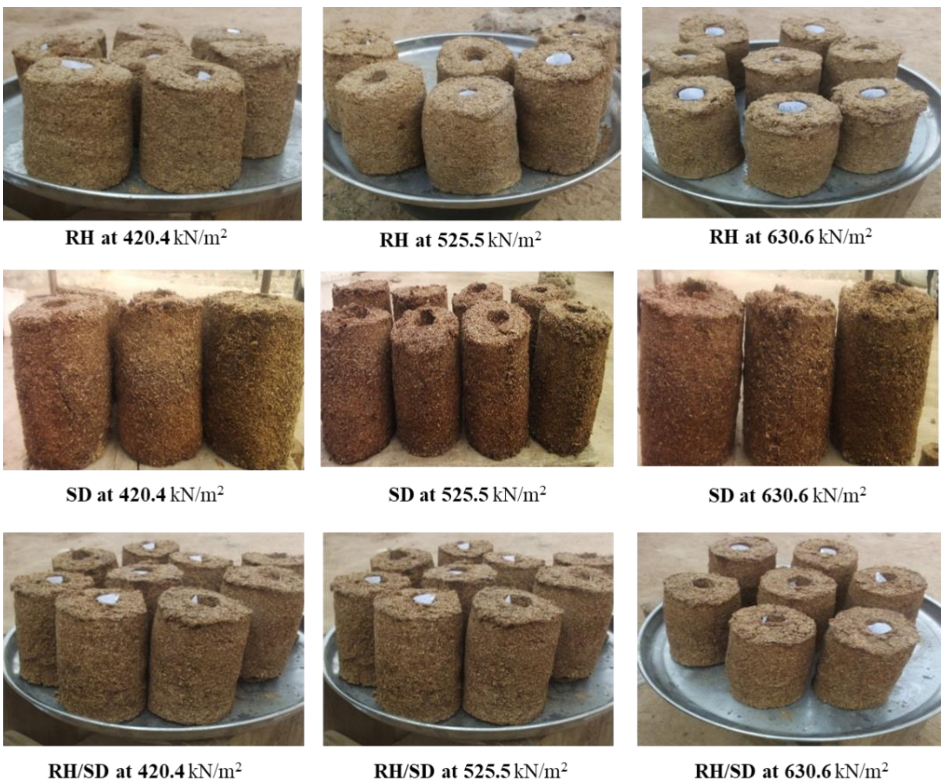

Figure 3: The produced briquettes at the different compaction pressures

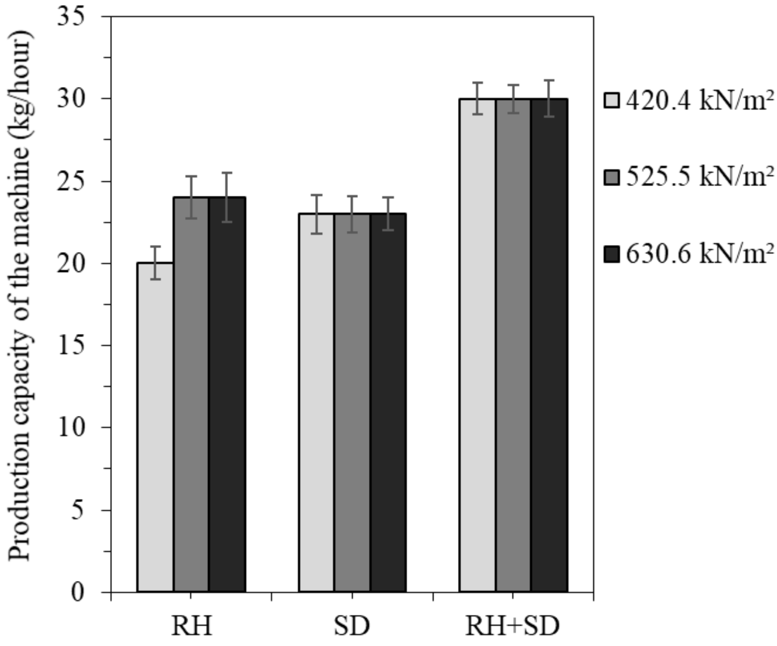

Figure 4: Production capacity of the manually operated briquetting machine

3.2 Compressed density of the briquettes

In this study, density was determined from the measured average mass and volume of the produced briquettes and the result is shown in Figure 5. The briquette produced from composite of RH/SD sample had the highest density of 8.26 g/m^3 at compaction pressure of 525.5 kN/m^2. This suggests that it would burn for a longer duration compared to the other briquette samples. The RH briquette sample had the lowest density of 7.14g/cm^3 at compaction pressure of 420.4 kN/m^2. However, in this study the compressed densities were much lower than the 726900 g/m^3 reported by Obi *et al.* (2013) for SD briquette. The difference in the observed values was due to the differences in the size of the briquetting mould and the production technique used.

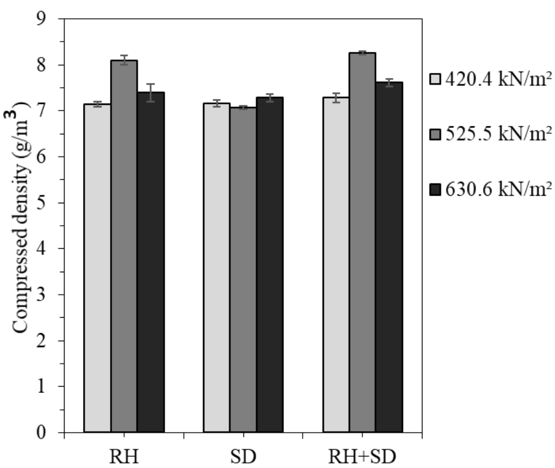

Figure 5: Compressed density of the produced briquettes

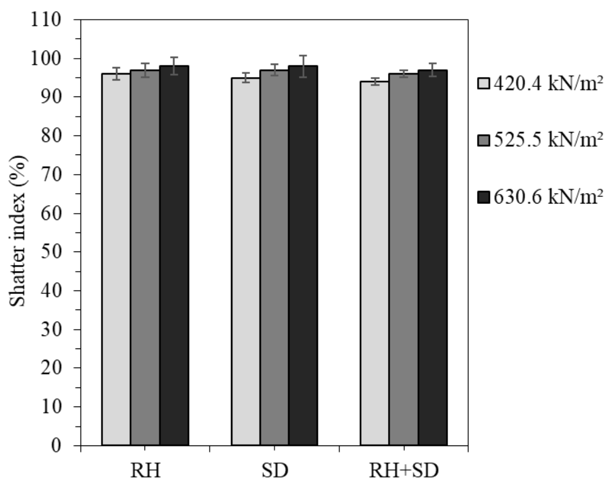

Figure 6: The shatter index of the produced briquettes

3.3 Shatter index of the produced briquettes

This test was conducted to determine the durability of the briquettes for handling during transportation and storage. Figure 6 shows the shatter index of produced briquettes at the three (3) different compaction pressures. The Figure revealed that over 90% of all the briquette mass, irrespective of the biomass type, were retained after the shatter index test. Result revealed that the shatter index increased as the compaction pressure was increased. This indicates that the production pressure had a profound effect on the compaction of the briquettes. Similar observation was reported by Rajaseenivasan (2016) for briquettes produced from sawdust blended with neem powder using compaction pressure range of 7 to 33 MPa. The high shatter index recorded for the briquettes may have resulted from the ratio of biomass to binder used (3:1) in this study. Figure 6 also showed that the shatter index for the individual biomass was slightly higher than the mixed biomass. This indicates that there was more attraction force due to similar biomass particles than heterogenous or different particles. The shatter index indicates that the briquettes can withstand handling during transportation and storage.

3.4 Hydrophobicity of the briquettes

Figure 7 shows the result of the hydrophobicity test for the produced briquettes from RH, SD and RH/SD. It was observed that the production pressure increased the hydrophobicity of the briquettes. RH briquettes exhibited the highest hydrophobicity compared to the other briquettes. However, not much effect was observed in RH briquettes at the different production pressures. This indicates that the three (3) production pressures were good enough to produce a hydrophobic solid fuel from RH. Briquettes produced from the composite of RH/SD exhibited the least hydrophobicity at the three (3) different production pressures. This could be as a result of different particles from the composite not well attracted to each other, leaving more pore spaces for easy penetration of water. In general, the result of the hydrophobicity recorded for all briquettes implied that; short-term exposure to rain or high humidity during transportation and storage, would have little or no adverse effect on the ease of ignition of the briquettes.

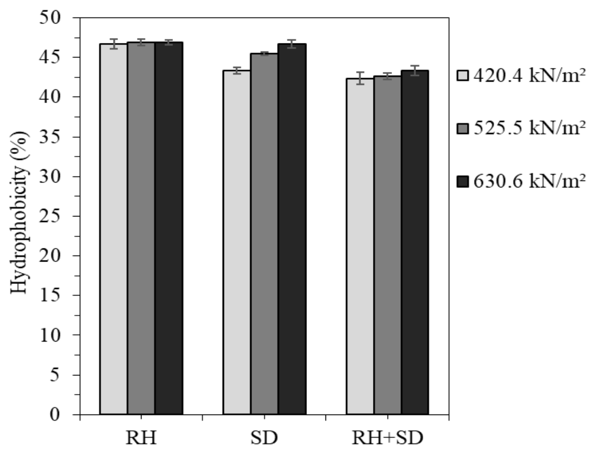

Figure 7: The hydrophobicity of the produced briquettes

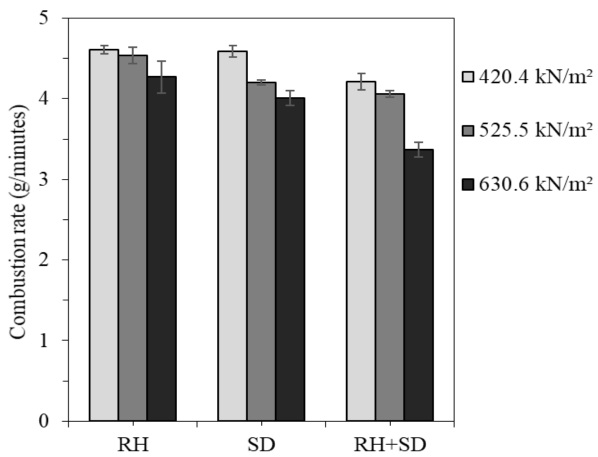

Figure 8: Combustion rates of the produced briquettes

3.5 Combustion rate of the produced briquettes

The average combustion rates of the produced briquettes are shown in Figure 8. RH briquette produced at a compaction pressure of 420.4 kN/m^2 exhibited the highest combustion rate while RH/SD briquette produced at a compaction pressure of 630.6 kN/m^2 has the least combustion rate. Figure 8 revealed that the compaction pressure and biomass type had a noticeable influence on the combustion rates of the produced briquettes. RH exhibited a relatively higher combustion rate at each compaction pressure compared to the other biomass types. However, it was observed that the combustion of the RH decreased at increasing compaction pressure. This observation could be attributed to decreased available pore spaces occupied by air that can enhance combustion reaction in the RH biomass. Similar combustion behaviour was observed for SD and RH/SD biomass at an increasing compaction pressure. However, RH/SD biofuel exhibited the least combustion rate which could be as a result of complex combustion reaction in the heterogenous mixture of the biomass briquette, this may have led to the lower combustion rate. Therefore, this implies that the briquette from the composite of RH/SD will burn for a longer duration compared to the other briquettes. The duration of combustion is also an important quality index of a solid fuel; hence, the composite of RH/SD biomass briquette will offer such advantage compared to the other individual briquettes. Similar observation was reported by Aliyu *et al.* (2020) for composite biomass briquette produced from corn cob and orange peels.

3.6 Ignition time

The result of the ignition time for the produced briquettes is shown in Figure 9. The result revealed that the ignition time of the briquettes increased with increase in the compaction pressure. The observed increase in the ignition time due to the increased pressure could be due to increased compaction of the briquettes thereby eliminating available pore spaces filled with air, that can promote ignition and subsequent combustion. RH briquette produced at the pressure of 630.6 kN/m^2 took the longest time of 1.58 minutes to ignite while SD briquette produced at a compaction pressure of 420.4 kN/m^2 took the shortest time of 1.28 minutes to ignite. The result also indicated that, it would be more difficult to ignite the RH briquette compared to the SD and RH/SD briquettes.

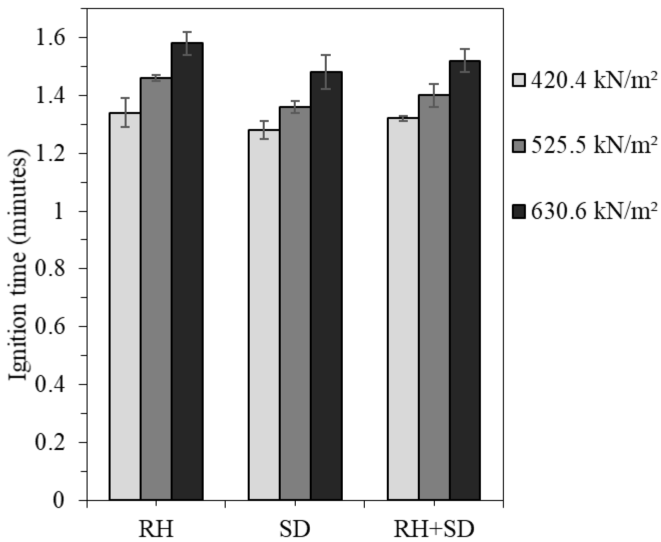

Figure 9: Ignition time of the produced briquettes

4. Conclusion

A simple and manually operated briquetting machine was constructed and a hydraulic jack was incorporated to allow for pressure variation. The constructed machine was used to produce briquettes at three (3) different compaction pressures monitored by a pressure gauge. The minimum and maximum production capacity of the machine was 20 kg/hr and 30 kg/hr respectively. All the produced briquettes at different compaction pressures from the different biomass exhibited over 90% shatter index while the briquette produced from RH at compaction pressure of 525.5 kN/m^2 had the highest combustion rate. The RH/SD at compaction pressure of 630.6 kN/m^2 had the least combustion rate. The ignition time of the briquettes increased with increasing compaction pressure. However, this study revealed that the RH biomass briquette has a superior solid fuel quality property compared to the SD and RH/SD briquette samples.

References

Aliyu, M., Dauda, SM., Balami, AA., Mohammed, IS. and Abdulfatai, Y. 2017. Engineering properties of luffa (L. cylindrica) seed relevant to the processing machineries. Agricultural Engineering International: CIGR Journal, 19(3): 47-55.

Aliyu, M., Mohammed, IS., Usman, M., Dauda, SM., Igbetua, IJ. 2020. Production of composite briquettes (orange peels and corn cobs) and determination of its fuel properties. Agricultural Engineering International: CIGR Journal, 22(2): 133-143.

Yahaya BS., EkpeEsor, E and Ochei, ES. Use of composite biomass briquettes as cleaner energy source. American Journal of Engineering Research (AJER), 9(10): 12-18.

Bach, QV., Skreiberg, Ø. 2016. Upgrading biomass fuels via wet torrefaction: A review and comparison with dry torrefaction. Renewable and Sustain Energy Review, 54: 665-677. https://doi.org/10.1016/j.rser.2015.10.014.

Garrido, MA., Conesa, JA., and Garcia, MD. 2017. Characterization and production of fuel briquettes made from biomass and plastic wastes. Energies, 10(7): 850.

Kamruzzaman, M., Hossain, MM. and Sarkar, MHT. 2008. Performance study of rice husk briquette machine: a case study in Muktagacha of Mymensingh district, Bangladesh. International Journal of BioResources, 5(1):7-11.

Kongprasert, Wangphanich, NP. and Jutilarptavorn, A. 2019. Charcoal briquettes from madan wood waste as an alternative energy in Thailand. Procedia Manufacturing, 30:28-135.

Križan, M., Krištof, K., Angelovič, M., Jobbágy, J. and Urbanovičová, O. 2018. Energy potential of densified biomass from maize straw in form of pellets and briquettes. Agronomy Research, 16(2): 474-482.

Lang, Q., Zhang, B., Liu, Z., Chen, Z., Xia, Y., Li, D., Gai, C., 2019. Co-hydrothermal carbonization of corn stalk and swine manure: combustion behaviour of hydrochar by thermogravimetric analysis. Bioresources Technology, 27(1): 75-83. https://doi.org/10.1016/j.biortech.2018.09.100.

Leach, G. and Mearns, R. 2013. Beyond the wood fuel crisis: people, land, and trees in Africa. Routledge, London, 23-47.

Mohammed, IS., Aliyu, M., Abdullahi, NA. and Alhaji, IA. 2020. Production of bioenergy from rice-melon husk co-digested with cow dung as inoculant. Agricultural Engineering International: CIGR Journal, 22(1): 108-117.

Obi, OF., Akubuo, CO. and Okonkwo, WI. 2013. Development of an appropriate briquetting machine for use in rural communities. International Journal of Engineering and Advanced Technology (IJEAT), 2(4): 578-582.

Olorunnisola, A. 2007. Production of Fuel Briquettes from Wastepaper and Coconut Husk Admixtures. Agricultural Engineering International: the CIGR E-journal. Manuscript EE 06 006. Vol. IX. February.

Orhevba, BA., Musa, U., Isah, AG., Bilyaminu, S., Mohammed, UG., Nwatu, E. 2016. Synthesis of Composite Biomass Briquettes as Alternative Household Fuel for Domestic Application. Proceedings of the world congress on engineering and computer science, San Francisco USA, October 2016, (2):19-21.

Orhorhoro, EK., Chukudi, OM., Oghenekevwe, O. and Onogbotsere, M E. 2017. Design and Fabrication of an Improved Low-Cost Biomass Briquetting Machine Suitable for use in Nigeria. International Journal of Engineering Technology and Sciences, 4(2): 128-138.

Osarenmwinda, JO. and Ihenyen, OI. 2012. The preliminary design and fabrication of a manually operated briquetting machine. Journal of Applied Sciences and Environmental Management, 16(2): 167-170.

Olajedi, TJ. and Oyetunji, OR. 2013. Investigation into physical and fuel characteristics of briquettes produced from Cassavas and Yam Peels. Journal of Energy Technologies and Policy, 3(7): 40-47.

Rajaseenivasan, T., Srinivasan, V., Qadir, GSM. and Srithar, K. 2016. An investigation on the performance of sawdust briquette blending with neem powder. Alexandria Engineering Journal, 55(3): 2833-2838.

Tembe, ET., Otache, PO. and Ekhuemelo, DO. 2014. Density, Shatter index, and Combustion properties of briquettes produced from groundnut shells, rice husks and saw dust of Daniellia oliveri. Journal of applied biosciences, 82(1):7372-7378.

Thabuot, M., Pagketanang, T., Panyacharoen, K., Mongkut, P. and Wongwicha, P. 2015. Effect of applied pressure and binder proportion on the fuel properties of holey bio-briquettes. Energy Procedia, 79: 890-895.

Thliza, BA., Abdulrahman, FI., Akan, JC., Chellube, ZM. and Kime, B. 2020. Determination of Compressive Strength and Combustibility Potential of Agricultural Waste Briquette. Chemical Science International Journal, 29(1): 30-46.

Wang, T., Zhai, Y., Zhu, Y., Li, C. and Zeng, G. 2018. A review of the hydrothermal carbonization of biomass waste for hydrochar formation: Process conditions, fundamentals, and physicochemical properties. Renewable and Sustainable Energy Reviews, 90: 223-247., https://doi.org/10.1016/j.rser.2018.03.071.