Composite Briquettes of Banana and Rice Husk Residue as an Alternative Fuel Energy

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Abstract

The study aimed to evaluate banana residues mixed with rice husk for briquette production to meet rural Pakistan's energy demands. Banana leaves and rice husk were collected, sun-dried, shredded, and combined in different ratios for briquetting. Fine particle ratios included T1 (Banana 75% and Rice 25%), T2 (Banana 50% and Rice 50%), T3 (Banana 25% and Rice 75%), Coarse particle size T4 (Banana 75% and Rice 25%) and T5 (Banana 50% and Rice 50%) and T6 (Banana 25% and Rice 75%). Results showed maximum density (0.67 g/cm^3) in T1, followed by T2 (0.65 g/cm^3) and T3 (0.62 g/cm^3) for fine particles. Higher banana leaf content led to denser briquettes. Maximum ignition time (74 sec) was recorded in coarse T3, followed by T2 (67 sec) and T1 (64 sec). Briquettes with more rice husk ignited more slowly. Maximum ash content (16.14%) occurred in fine T3, followed by T2 (14.33%) and T1 (12.25%). Briquettes with higher banana leaf content had more ash. Burning rates were highest in coarse T1 (0.23 g/min), followed by T2 (0.19 g/min) and T3 (0.17 g/min), with rice husk contributing to faster burning. Calorific value peaked in coarse T3 (16,725.1 J/g), followed by T2 (16,552.1 J/g) and T1 (16,231.1 J/g). Higher rice husk content increased calorific values. Volatile matter was highest in coarse T1 (74.31%), with rice husk dominating. Fine T3 had the most fixed carbon (16.04%), with banana leaves contributing more carbon. Conclusion: The findings of this research emphasize the necessity to develop low-cost, accessible briquette production technologies, particularly in rural and developing locations with limited energy resources. With additional research and optimization, composite briquettes could be a feasible alternative to fulfil rising energy demands, prevent environmental damage, and increase the economic value of agricultural waste.

Keywords: Briquettes, Banana Residues, Rice Husk, Energy Sustainability, Energy Demand.

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Introduction

The availability of firewood is decreasing in many developing countries due to population growth and limited resources. The researchers have suggested that it is necessary to efficiently utilize the agricultural residue for energy demand, especially in rural areas by Demirbaset al., (2001). Plenty of biomass residues exist in many agricultural countries like Pakistan, India, China, etc. The agricultural residues include those fractions of agricultural crops that are excluded from the crop yield, such as straw and husk of different crops, roots, leaves, and pruning by Madanayakeet al., (2017).

Biomass briquette created from agricultural waste is considered an expected hotspot for sustainable power sources because of its supportability, positive effect on condition, and cost-adequacy. Through this chance, numerous analysts developed a new plan for transforming the waste item into a briquette. Briquette is nowadays generally utilized in domestic life as a heating material for non-renewable energy conservation and power production by Oladej et al., (2015). Briquette, likewise, identified as a fire starter, will go over densification measures, including compaction of free ignitable substantial and decrease of dampness in an unvarying shape by Yahaya and Ibrahim et al., (2012). Biomass is one of the hotspots of energy production carrying the best development latent in the coming years and can be effectively acquired as of farming creation in which it produces much waste. The utilization of rural or agro-mechanical squanders as a fuel produced by biomass for power production is by and large progressively contemplated and could be an elective answer for the issues identified with them. Therefore, these squanders can benefit from pellets and briquettes for burning and gasification measures in power production units by Sellinet al., (2013). The idea of utilizing the wastes from the agricultural sector either as primary or secondary energy resources is considered attractive. This is because they are available and abundant. Among the numerous types of biomass capitals, agricultural remains/wastes-sawdust, corn stover, bean husk, rice husk, groundnut husk, cotton stalk, etc. can be converted as one of the most auspicious choices as fuels for cooking due to their vast availability in substantial quantities as wastes annually. Though most biomass residues are not appropriate to be used directly as fuel without further processing, this is quite challenging. This could be attributed to their low energy density per volume, sporadic burning, high moisture content, and excessive amount of smoke they generate by Amaya et al., (2007). Various reserves of biomass-based energy differ all through the globe. These identical sources are fundamentally obsessed by four modules as Agri-biomass, forest-biomass, energy crops, and wastes. (NRG Expert Energy Intelligence, 2018). Agricultural remainders, of which the waste of bananas goes, can be demarcated as one of the biomass-based energy foundations that comprises agricultural harvests and remains. Crops like corn (maize), wheat, sugar cane, sorghum, vegetables, and contained oil-contained crops (e.g., sunflower, soybean, and rapeseed) are used in the production of molten fuels or biodiesel by Altun et al., (2003). However, misuse or mistreatment of such crop taking as energy supply contends along the industries of food. In disparity, agricultural remainders, or their byproducts, such as plants, straws, husks, pseudo stem, stalks, and shells. These remains could be the crop wastes that endured by harvest (such as pseudo stem and banana leaf) of the crop treating production units (groundnut shell and rice husk). This trash is ordinarily tilled over in soil, consumed, or brushed by routine They could be used in the manufacture of solid fuel if they are not used for energy.

The banana leaves are mostly utilized for wrapping food. However, this will eventually turn into waste after it has served its purpose. Banana plants can be used as a source of biomass energy in tropical countries due to their availability, fast-growing characteristic characteristics, carbon neutrality, and the fact that each banana plant bears only one stem of fruit by Tock et al., (2010). Some researchers have demonstrated the potential of banana residues for energy generation and these studies are based on the production of biogas from the digestion process (Ilori et al., 2007; Clarke et al., 2008), briquettes by Maia et al., 2014) and generation of ethanol from banana residues by Gabhane et al., (2014).

Therefore, this study was conducted to analyze the effectiveness, performance, and burning characteristics(combusting) of the briquette produced from the densification of the blend of rice and banana waste (banana leaves and pseudo stem) using starch gel as a binder.

Materials and Methods

The following methodology was adopted to achieve the results of set objectives.

Experimental Site and Material Collection

The present study was carried out in the laboratory of the Department of Energy and Environment, Faculty of Agricultural Engineering, Sindh Agriculture University, Tandojam, Pakistan. Bio-composite briquettes as a source of fuel were prepared and evaluated using locally available materials.

The biomass complex briquette includes rice and banana residue. Samples of banana leaves and pseudo stem were obtained from plants that had been cut for acquiring leafy foods breaking down in the dirt. The banana residue was kept for drying under the shortest daylight (ambient temperature) for about 72 to 96 hours to decrease the dampness (or moisture) content 8%.

Rice husk samples were collected from the rice mill for this study. Both samples of banana residue and rice were milled in milling machine (E-5001, Pakistan) individually into a fine and coarse powder with a particle size of <4 mm and >4 mm, respectively. Corn starch (5Kg) was bought from the market as a binding material for briquette production.

Making of biomass-composite briquette

The size of the banana residue and rice was reduced using a grinder (juicer) machine. The grinder material sieved into two fine and coarse sizes i.e. <4 mm and >4mm, respectively and the ground material was mixed at three different proportions 75% Banana residues 25% (T1), 50% fine rice 50% fine banana residue (T_2) and 25% fine rice 75% fine banana residue (T_3). Similarly, the other set of mix proportions were as 75% coarse rice, 25% coarse banana residue (T_4), 50% coarse rice, 50% coarse banana residue (T_5), and 25% coarse rice and 75% coarse banana residue (T_6). Each proportion was mixed with dried cornstarch as a binding material; hot boiling water was added and stirred thoroughly to form a semi-solid paste. Each batch of material proportion was then compressed with the manually operated hydraulic briquetting apparatus (constructed machine in the laboratory of energy and environment, SAU Tandojam) with a cylinder-shaped mold dimension of 5.0 cm x 5.0 cm, after which it was oven-dried for 24 hrs. at 105 °C and cooled at room temperature. The flow chart of the methodology is given in Figure 1.

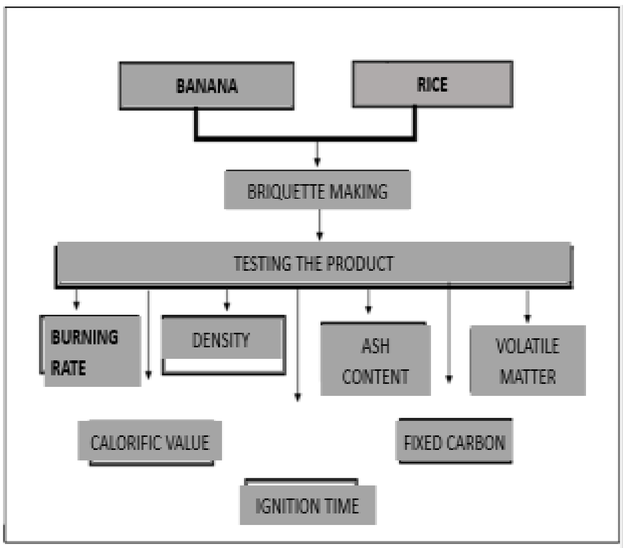

Figure 1 Flow chart of briquettes

Physical and Combustion Testing

The quality (eminence) of the briquette was determined by its combustion performance and physical properties. To check the quality, seven different physical and combustion tests were conducted, which examined the ignition time, density, calorific value, volatile matter, ash content, fixed carbon content, and burning rate of the briquette. Each composition of the trial was replicated thrice to obtain the maximum accuracy in results. The detail of determination methods of physical and combustion testing of briquettes is given below:

Density of briquettes

The density of the briquettes was measured immediately after the briquettes were discharged from the columns, and the density of the briquettes was determined by the ratio of the mass to the volume of the briquettes. The briquettes' mass was measured by using an electric balance (WT-N). Meanwhile, the volume of the briquette was measured by taking the linear dimension (length, width, and height) of the briquettes by using a Vernier caliper (50-101)-Misumi USA.

$$\boldsymbol{Densityb = \frac{Mb}{Vb}}$$

Where,

Db is the density of the briquette, Mb is the mass of the briquette and Vb is the volume of the briquette.

Ignition time of briquettes

The time taken by the briquette to ignite (ignition time) was calculated to evaluate the heat-up time of a briquette. The compound was burned at a free point and the required time for consumption to be ignited was noted to decide the ignition (burning) time. Once the spark began to ignite, the duration of the burning of the briquette was recorded.

$$\textbf{Ignition time} = t_1 - t_0$$

Where,

T_1 = Time the briquette Ignited (sec)

T_0 = time the burner was lighted (sec)

Calorific Value of briquettes

Calorific value, also known as the heat of combustion, is the measure of energy available from the fuel. The calorific value of the briquette was determined by using a calorimeter where the briquette was burned under an oxygen atmosphere in a closed vessel that will be surrounded by water and under controlled surroundings.

The calorific value was then displayed in Kj/kg after all briquette' samples were fully burned.

$$CV(J/g) = \frac{Measured\ value\ (J - Complete\ combustion(J)}{sample\ size\ (g)}$$

Ash Content of briquettes

This was an organic residue resulting from the inclination of organic matter (Onuegbu TU, 2011). Equipment used balance, crucibles, crucible tongs, desiccators, and the muffle furnace (HT-MF900, China). The procedure followed the Gravimetric Muffle Furnace Method (AOAC, 2005).

$$\boldsymbol{Ash\ Content} = \left(\frac{\boldsymbol{Mash}}{\boldsymbol{Mash\ briquette}}\right) \times \mathbf{100}$$

Volatile Matter of briquettes

This was the carbon content that had gone under combustion. In other terms, it was the % left escaped after analysis of Ash content. The Gravimetric Muffle Furnace Method was used (AOAC, 2005).

$$\boldsymbol{Volatile\ Matter}\ \% = \left(\frac{\boldsymbol{wi - wf}}{\boldsymbol{wi}}\right) \times \mathbf{100}$$

Burning Rate of briquettes

As stated by Chaegba *et al.* (2011), the burning rate was the ratio of the mass of the fuel burnt (in grams) to the total time taken (in a minute). This was the time from ignition up to when the fire flame went out.300 grams of briquettes from each blend will be burnt and the initial time (ignition time) to the final time of burning (flame extermination) will be recorded using a stopwatch. Burning Rate helps to how much fuel briquette mass a person should require burning under normal conditions in a specific given time.

$$\boldsymbol{Burningrate} = \frac{\boldsymbol{Mass\ of\ fuel\ consumed(gm)}}{\boldsymbol{Total\ time\ taken}\ \mathbf{(sec)}}$$

Fixed Carbon Content of briquettes

The fixed carbon content of briquettes was recorded in triplicates per treatment and used for the linear regression model in its raw form without aggregation. However, the table below shows the results of the mean values of fixed carbon content per treatment.

$$\%\ Fixed\ Carbon = 100\% - (\%VM + \%AC)$$

Where,

VM = volatile matter of the sample

AC =Ash content of the sample

Results

Density of briquettes

Statistical analysis showed a significant effect of material size and material ratio on the density of the Composite briquette. The maximum density (0.67g/ cm^3) was recorded in T_1 followed by T_2 (0.65 g/ cm^3) and then T_3 (0.62 g/ cm^3). Utilization of a higher percentage of banana leaves showed a higher density of composite briquette as compared to rice.

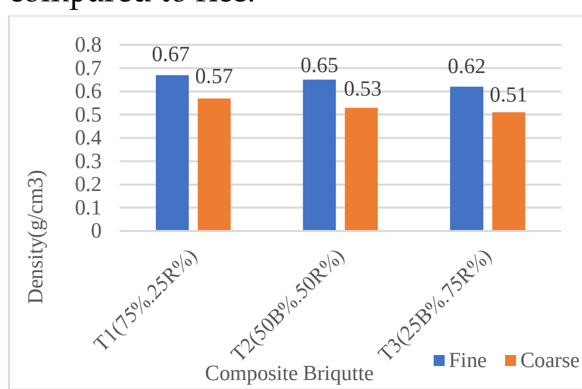

Figure 3.1 Mean of Density of composite briquettes under the impact of particle size and mixing ratio of materials

Ignition Time of briquettes

Statistical analysis showed a significant impact of material size and material ratio on the Ignition Time of Composite briquette. The maximum Ignition time (74 sec) was recorded in T_3 followed by T_2 (67 sec) and then T_1 (64 sec). Utilization of a higher percentage of rice showed higher

Ignition of composite briquette as compared to banana leaves.

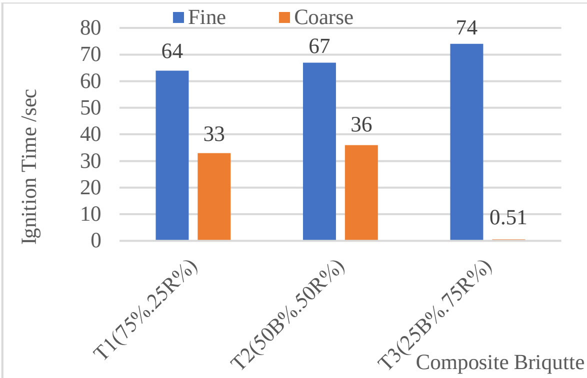

Figure 3.2 Mean of ignition time of composite briquettes under the effect of particle size and mixing proportion of materials

Ash Content of briquettes

Statistical analysis showed a significant effect of material size and material proportion on the Ash Content of Composite briquette. The maximum Ash Content (16.14%) was recorded in T_3 followed by T_2 (14.33%) and then T_1 (12.25. Utilization of a higher percentage of banana leaves showed higher Ash Content of composite briquette as compared to rice. The fine particle size of banana leaves and rice showed a maximum Ash Content of composite briquettes than the coarse size of banana leaves and rice.

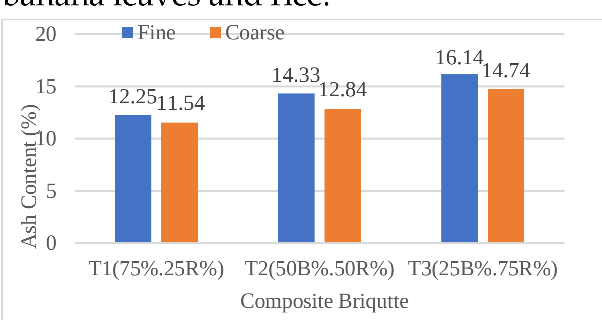

Figure 3.3 Mean of Ash content of composite briquettes under the impact of particle size and Mixing ratio of materials

Burning rate of briquettes

Statistical analysis showed a significant impact of material size and material ratio on the Burning rate of Composite briquette. The maximum Burning rate (0.23g/min) was recorded in T_1 followed by T_2 (0.19 g/min) and then T_3 (0.17g/min). Utilization of a higher percentage of rice showed a higher Burning rate of composite briquette as compared to banana leaves.

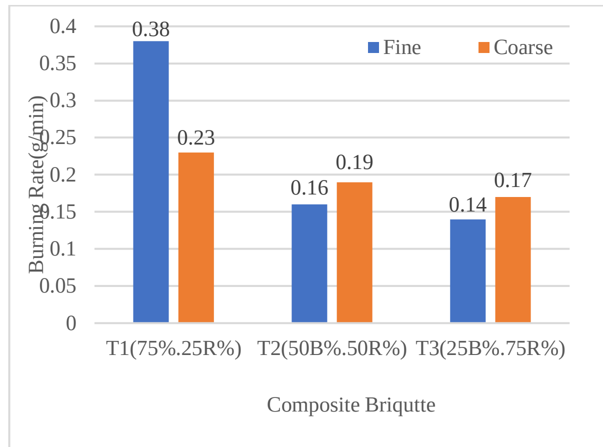

Figure 3.4 Mean of Burning Rate of composite briquettes under the effect of Mixing ratio and particle size of materials.

Calorific Value of briquettes

Statistical analysis showed a significant effect of material size and material ratio on the Calorific Value of Composite briquette. The maximum Calorific Value (16231.1 J/g) was recorded in T_3 followed by T_2 (16552.1J/g) and then T_1 (16725.1 J/g). Utilization of a higher percentage of rice showed a higher Calorific Value of composite briquette as compared to banana leaves.

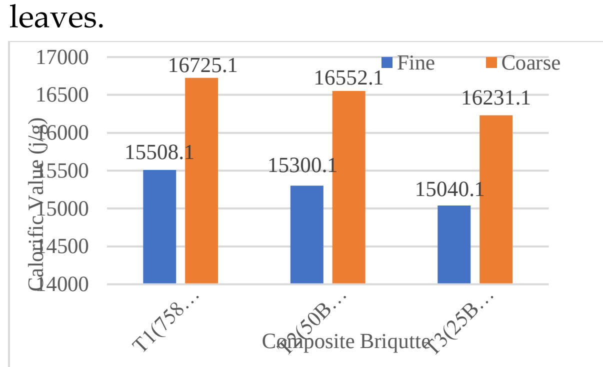

Figure 3.5 Mean of Calorific value of composite briquettes under the effect of Mixing ratio and particle size of materials.

Volatile Matter of briquettes

Statistical analysis showed a significant outcome of material size and material proportion on the Volatile Matter of Composite briquette. The maximum Volatile Matter (74.31%) was recorded in T_1 followed by T_2 (70.03%) and then T_3 (64.32%). Utilization of a higher percentage of rice showed higher volatile matter of composite briquette as compared to banana leaves.

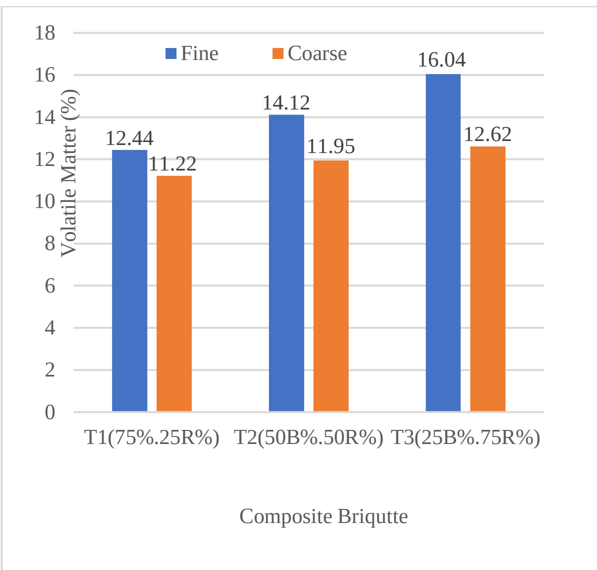

Figure 3.6 Mean of Volatile matter of composite briquettes under the effect of Mixing ratio and particle size of materials.

Fixed Carbon of briquettes

Statistical analysis showed a significant effect of material size and material ratio on the Fixed Carbon of Composite briquette. The maximum Fixed Carbon (16.04%) was recorded in T_3 followed by T_2 (14.12%) and then T_1 (12.44%). Utilization of a higher percentage of banana leaves showed higher Fixed Carbon of composite briquette as compared to rice.

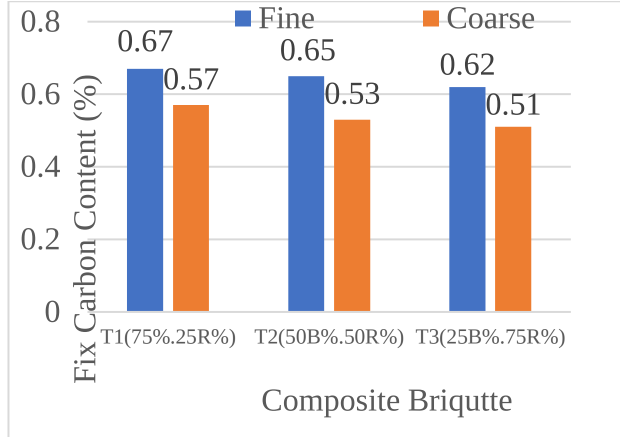

Figure 3.7 Mean of Fixed carbon of composite briquettes under the effect of Mixing ratio and particle size of materials

Discussion

Density of briquettes

The maximum density (0.67g/ cm^3) was recorded in T_1 followed by T_2 (0.65 g/ cm^3) and then T_3 (0.62 g/ cm^3) from fine material as compared to briquette prepared from coarse material. Utilization of a higher percentage of banana leaves showed a higher density of composite briquette as compared to rice. The fine particle size of banana leaves and rice showed the maximum density of composite briquettes than the coarse size of banana leaves and rice. Similarly, such findings are by the existing research literature. (Ajnani, 2015). This was due to the smaller size molecule that can occupy the voids spaces and consequently improve the compaction of the briquette. Therefore, the reduction of particle size provides a larger contact surface area and thus lowers the porosity of the composite briquette. This was because smaller-sized molecules can occupy void spaces, thereby improving the compactness of the briquette. Therefore, reducing the particle size can provide a larger contact surface area, thereby reducing the porosity of the composite briquette. This indicates that the adhesion of adjacent particles increases with the increase of the collective banana residue. This was possible because the banana residue contains 3% starch as a binder. Briquette was bonding improved by adding the banana residue and upholding their compacting procedure after the densification procedure (Borowski *et al*., 2007)

Ignition time of briquettes

The maximum Ignition time (74 sec) was recorded in T_3 followed by T_2 (67 sec) and then T_1 (64sec) from coarse material as compared to a briquette prepared from fine material. Utilization of a higher percentage of rice showed higher Ignition of composite briquette as compared to banana leaves. The Coarse particle size of banana leaves and rice showed maximum Ignition time of composite briquettes than the fine size of banana leaves and rice. However, the outputs are within the permissible values of 66.61 to 107.92 seconds for Water-Hyacinth Briquettes with a fastener proportion of 10 to 50% R.M, Davies *et al.* (2013). The observed trend in ignition time indicates that the ignition time decreases as the mass of the briquette increases. The way may be attributable to the high porosity displayed, which due to the low binding force, makes it easy for oxygen to permeate and cause the combustion mass to flow out. However, this value was within the corresponding value of 19-186 seconds in a bio-coal briquette prepared by mixing 10-50% elephant grass and spear grass with coal in different concentrations by Davies *et al*., (2013).

Ash content of briquettes

The maximum ash content (16.14%) was recorded in T_3 followed by T_2 (14.32%) and then T_1(12.25%) from fine material as compared to briquette prepared from coarse material. Utilization of a higher percentage of banana leaves showed higher Ash Content of composite briquette as compared to rice. The fine particle size of banana leaves and rice showed a maximum ash content of composite briquettes than the coarse size of banana leaves and rice. Such findings are with existing research literature by Nayara *et al*., (2016). The results showed that the addition of banana pomace reduced the ash content of the composite briquettes.

Burning rate of briquettes

The maximum burning rate (0.23g/min) was recorded in T_1 followed by T_2 (0.19g/min) and then T_3 (0.17g/min) from coarse material as compared to briquette prepared from fine material. Utilization of a higher percentage of rice showed a higher Burning rate of composite briquette as compared to banana leaves. The Coarse particle size of banana leaves, and rice showed a maximum Burning rate time of composite briquettes than the fine size of banana leaves and rice similarly reported by Sumrit and Vijitr, (2016). For the banana peel charcoal briquette and banana bunch charcoal briquette, the peak burning time was obtained, respectively. Thus, the burning rate was one of the important characteristics showing the mass of the briquette. It was the amount of material that undergoes burning in a period. The obtained burning rate trend shows that the burning rate increases with the increase of the briquette biomass. The highest burning rate may be due to the high porosity between the particles or due to the low binding force, which makes the oxygen easy to permeate and causes the briquette to flow out.

Calorific Value of briquettes

The maximum calorific value (16231.1 J/g) was recorded in T_3 followed by T_2 (16552.1J/g) and then T_1 (16725.1 J/g) from coarse material as compared to briquette prepared from fine material. Utilization of a higher percentage of rice showed a higher calorific value of composite briquette as compared to banana leaves. The Coarse particle size of banana leaves and rice showed the maximum calorific value of composite briquettes than the fine size of banana leaves, and rice course size of banana leaves and rice. These qualities are extensively higher when contrasted with 15.5 MJ/kg detailed by Abdullah *et al.*, (2010) for the banana pseudo stem, 19.4 MJ/kg for palm oil squanders (EFB) revealed by Abdullah *et al*. and are additionally higher than the calorific estimation of banana leaves of 17.1 MJ/kg announced by Sellin *et al.*, (1996). The calorific yield (estimation) of the briquettes was similarly inside the satisfactory range for consumable (or business) briquettes (>17.5 MJ/kg) DIN 51731, Abdullah *et al.*, (2010). The heating value of a fuel is an expression of the unit value of energy or heat, which was released when the unit value was burned in the air (Jones *et al.*, 2010). It was the amount of heat per unit of energy or the work that can be obtained from a unit of energy. This was an important parameter; it determines the quality of energy. As the biomass increases, the calorific value gradually decreases because the calorific value of coal is higher than that of biomass. This value was much higher compared to 15.5 MJ/kg reported by Abdullah *et al*. (2009) for the banana pseudo stem, 19.4 MJ/kg for palm oil wastes (EFB) reported by (Sellin *et al*. 2013) and are also higher than calorific value of banana leaves of 17.1 MJ/kg reported by (Deutsches *et al*. 1996). The calorific value of briquettes was also within the acceptable range of commercial briquettes (>17.5 MJ/kg) DIN 51731 by Abdullah *et al.*, (2010).

Volatile matter of briquettes

The volatile matter of different briquettes was observed. The Minimum volatile matter during burning was recorded as T_1 (74.31%) and then T_2 (70.03%), While the maximum was the maximum Volatile Matter T_3 (64.33%). Utilization of a higher percentage of rice showed higher volatile matter of composite briquette as compared to banana leaves. The Coarse particle size of banana leaves, and rice showed maximum volatile matter of composite briquettes than the fine size of banana leaves and rice similarly unstable issue decides if the material was ignited with great fire and maybe it was creating smoke, a substance with high instability was deliver extra smoke. Substantial with the highly unstable issue can undoubtedly be touched off and would ignite with long smoky blazes by O.A. Oyelaran *et al.*, (2018).

4.7 Fixed Carbon of briquettes

The maximum fixed carbon (16.04%) was recorded in T_3 followed by T_2 (14.12%) and then T_1 (12.44%) from fine material as compared to briquette prepared from coarse material utilization of higher percentage of banana leaves showed higher fixed carbon of composite briquette as compared to rice. The fine particle size of banana leaves and rice showed a maximum fixed carbon of composite briquettes than the coarse size of banana leaves and rice. Similarly, the carbon substance of the crude supplies and that of briquettes were delivered. In all two biomasses, the carbon content is low. The average content of banana leaves was 43.45%, the average content of fake stem was 38.33%, and the average carbon content of rice test was 83.51%., Oyelaran *et al.* (2018) and P.K. Nag *et al.,* (2002).

Conclusion

Statistical analysis showed a significant effect of mixing ratio and material size on the physical and combustion properties of composite briquettes. Briquettes prepared from coarse material size showed a higher value of time of ignition, burning rate, calorific value, and volatile matter with the lowest value of density, ash, and fixed carbon. Utilization of a higher percentage of banana leaves material prepared from showed higher density burning rate and volatile matter with minimum ignition time ash content Calorific value and fixed carbon of composite briquette as compared to coal. The banana material showed higher density and stronger bonding between the particles inside the briquette, which can reduce the crumble of the briquette during the combustion process. The composite briquettes prepared from banana residue and rice showed good potential as a solid fuel as an alternative to the present energy resources. as compared to briquettes prepared from fine material size.

Suggestions

In this study, the effect of different moisture contents of composite briquettes on their quality characteristics has not been investigated. Furthermore, a study should be conducted on different moisture levels of composite briquettes and their influence on burning characteristics. This study has considered the physical and combustion properties of composite biomass briquettes for their quality evaluation. However, there are chemical properties of the biomass that influence the combustion characteristics of the briquettes. Therefore, further studies are required to determine the effect of the chemical composition of different biomass materials on the burning characteristics of briquettes. In this work, coal and banana leaves were used as biomass material for briquette preparation. This study should be expanded to use other types of biomass materials in the preparation of composite briquettes for the effective use of agricultural residues with different binding agent ratios.

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