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Value addition of coal fines and sawdust to briquettes using molasses as a binder

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ABSTRACT

In this study, the co-briquetting of coal fines saw dust and molasses as a binder is explored as an option for value addition of the wastes generated in the various industries. The effect of the saw dust concentration and the molasses concentration was investigated through measuring the briquette's calorific value, fixed carbon, compressive strength and shatter index. Addition of $Ca(OH)_2$ was done to effect removal of sulphur from the briquette. Measurements of the briquettes physicochemical properties such as moisture content, ash content and sulphur content were measured using the standard methods. As the saw dust and the molasses concentration increased, the calorific value, fixed carbon and compressive strength increased by 16%, 8% and 50% respectively. Whereas, the shatter index decreased by 146% as the saw dust and the molasses concentration increased in relation to the coal fines. Addition of the saw dust and the molasses are therefore critical in the production of a high quality coal-saw dust-molasses briquette which does not shatter.

1. Introduction

The usage of briquettes as an alternative source of solid fuel for several applications in boilers and industrial use is having increased attention. (Wang et al., 2014, 2016). In South Africa alone, the coal mining and processing process generates about 10 million tons of waste in the form of coal fines that can be a source of pollution to the environment if not properly managed (Venter and Naude, 2015; Ibeto et al., 2016). Coal fines being of particulate nature if inhaled have potential to cause pneumoconiosis and other health related conditions; furthermore these contain high sulphur which results in acid rain. On the other hand, there are several initiatives on the briquetting of these coal fines that have been explored so that they become a source of solid fuel (Kim et al., 2001; Venter and Naude, 2015).

The stand-alone briquettes from coal alone have been reported to be highly brittle and easily shattered due to the nature of the coal fines as they cannot easily agglomerate (Kwong et al., 2007). Previous studies have reported that waste biomass and binders can actually be introduced as part of the briquette composition so as to increase the strength and calorific value as well the strength of the briquette (Zakari et al., 2013). Binders such as starch, molasses and coal tar have been used for enhancing the characteristics of the briquettes (Zakari et al., 2013; Sen et al., 2016). Introduction of biomass and binders in the coal fines during briquetting have also resulted in a briquette with a lower attrition index and increase the compressive strength (Tosun, 2007). The addition of additives like Ca $(OH)_2$ and $CaCO_3$ have been proposed by several studies so as to remove sulphur contaminants the biomass briquettes (Singh et al., 2009). This study therefore proposed to use coal fines with a combination of saw dust and molasses as a binder especially with the addition of Ca $(OH)_2$ as a desulphurizing additive so as to come up with a high quality briquette for application as a solid fuel at domestic and industrial level.

2. Materials and methods

2.1. Materials

Coal fines with particle size of ≤ 2 mm were used for briquetting and this particle size was achieved through sieving. A manual briquetting machine with a hydraulic pressure of 5 MPa was used to make

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rectangular briquettes with briquettes size of 30 mm × 25 mm X 15 mm. Briquetting was done at standard pressure and hot temperature of 250 °C. Pulverized coal fines were mixed with saw dust for ratios ranging from 5 to 25 wt %. Molasses, which is a waste product in the sugar manufacturing industry was used as a binder in the ratios ranging from 0 to 8 wt %. A desulphirizing agent, Ca (OH) $_2$ with 99% purity was added at 5 wt % of the coal-saw dust briquettes so as to minimize environmental pollution. A bomb calorimeter model XRIA was used for determination of the briquette calorific value. An AND moisture analyser was used for the briquette moisture content analysis. Experiments were repeated 3 times and the average values were used to plot the graphs. The obtained data had standard deviations within 5%.

2.2. Methods

A sample containing 2 kg of the mixture of coal fines saw dust and molasses was used during briquetting. The proximate analysis of the coal-saw dust-molasses briquette was analysed according to the ASTM D3172 standard methodology. The moisture content (MC) was determined by heating the briquette at 105 °C for 3 min. The briquettes volatile matter (VM) was determined at 925 °C for 7 min in a furnace. The fixed carbon (FC) was determined by heating the briquette at 800 °C for 3 h. The ash content (AC) was then calculated as the difference in the total MC, VC and FC as indicated in Equation (1).

$$AC\ (\%) = MC\ (\%) - VC\ (\%) - FC\ (\%) \tag{1}$$

The shatter index of the briquettes was determined by dropping them thrice at metal base at a height of 2m. The amount of briquette that remained was used to measure the index of the briquette breakability. The weight loss as a percentage of the briquette was expressed as a percentage of the initial mass of the briquette remaining. The shatter resistance was therefore calculated by subtracting the percentage weight loss from 100%. The percentage weight loss is calculated in accordance to Equation (2):

$$\%\ Weight\ loss = \frac{W_1 - W_2}{W_1} \tag{2}$$

Where W_1 is the weight of the briquette before shattering and W_2 is the weight of the briquette after shattering in grams.

The calorific value of the briquettes was determined using the bomb calorimeter. The coal-saw dust-molasses briquette was analysed for the sulphur content using the Eschka methodology (ASTM, 1992). The relative density of the briquette was calculated in accordance to Equation (3).

$$Relative\ density\left(\frac{kg}{m^3}\right) = \left(\frac{M_b(kg)}{V_b(m^3)}\right) \tag{3}$$

Where M_b is the mass of the dried briquette and V_b is the volume of the briquettes.

The saw dust, coal fines and molasses binder were mixed in the desired ratio to come up with a mixture which was fed into the hot pressing briquetting machine. A schematic representation of the coal-saw dust-molasses briquetting process is shown in Fig. 1.

Response surfaces graphs in Excel were used to schematically represent the effect of changing the saw dust and molasses composition on the coal-saw dust-molasses briquette's physicochemical parameters.

3. Results and discussion

The effects of the saw dust and molasses binder concentration on the coal-saw dust-molasses briquette various properties are discussed in detail below. The initial coal-saw dust-molasses mixture had a sulphur content of around 500 ppm before the briquetting with Ca $(OH)_2$ as a desulphurizing agent. After the hot pressing briquetting at 250 °C, the sulphur content significantly reduced to 0.1–0.2 ppm. The $Ca(OH)_2$ reacted with the sulphur to produce calcium hydroxide and water

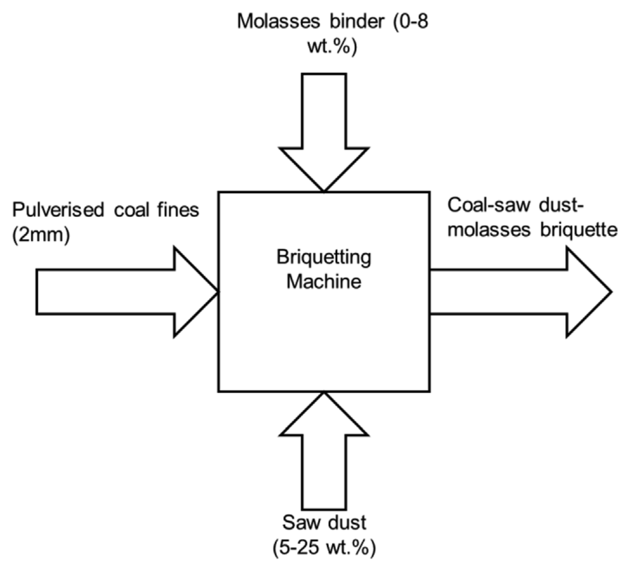

Fig. 1. Briquetting process for the coal fines-saw dust-molasses briquette.

which formed part of the fillers for the briquettes. The reaction is indicated in Equation (4).

$$Ca(OH)2 + SO_2 \rightarrow CaSO_3 + H_2O \tag{4}$$

3.1. Effect of saw dust and binder concentration on calorific value

The calorific value of the briquette gives the indication of the intensity of the heating value. High calorific values are required in high quality briquettes so as to harness as much energy as possible from the briquettes. In this study, as the molasses binder concentration increased to 8 %wt., the briquettes calorific value increased and on the other hand, as the saw dust compost increased from 5 wt % to 25 wt %, the caloric value also significantly increased (Fig. 2). Highest calorific values of 25–26 MJ/kg were observed when the molasses binder concentration was 8 wt % and the saw dust concentration was 25 wt %. High binder and saw dust concentration resulted in increased interlocking bonds with the coal fines resulting in a briquettes that has a high heating value due to the additional strength provided by the combined effect of the high saw dust and binder concentration (Blesa et al., 2003; Sen et al., 2016). The calorific values obtained for the briquettes were in the same range as lumpy coal, which is 23–25 MJ/kg, therefore making them have the same application as lumpy coal such as application in boilers.

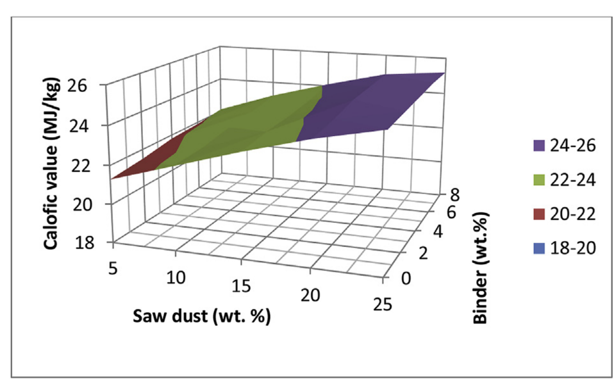

Fig. 2. Effect of saw dust and molasses concentration on the briquette calorific value.

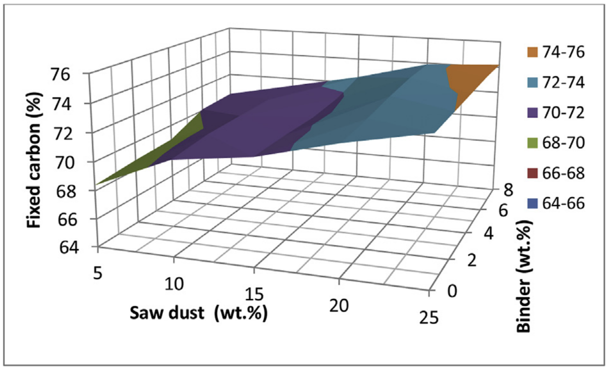

Fig. 3. Effect of saw dust and molasses concentration on the briquette fixed carbon.

3.2. Effect of saw dust and binder concentration on fixed carbon content

The fixed carbon content refers to the combustible solid residue that you get after heating the briquette and the volatile matter is released (Taulbee et al., 2009). The higher the fixed carbon content, the higher the quality of the briquette. The fixed carbon content increased with increase in both the saw dust and molasses binder concentration (Fig. 3). The highest fixed carbon content of 74–76% was observed at saw dust composition of 25 wt % and molasses binder concentration of 8 wt %. The increase in the fixed carbon content can be attributed to the increased interlock of the coal-sawdust-molasses particles as the briquetting process occurred (Venter and Naude, 2015). The high fixed carbon content can also be related to the high calorific value of the coal-saw dust-molasses briquette (Kwong et al., 2007). The fixed carbon of the briquettes was 7% higher in comparison to the lumpy coal which was an indication that the values obtained where acceptable especially for the application of the briquette as a solid fuel.

3.3. Effect of saw dust and binder concentration on the shatter index

The shatter index refers to the percentage of the briquette that remains or does not pass through a sieve after the briquettes have been subjected to a drop procedure (Borowski and Hycnar, 2013). In this study, as the saw dust concentration and the molasses binder concentration increased in relation to coal fines ratio, the shatter index significantly decreased (Fig. 4). The shatter index decreased by almost 150% as the saw dust concentration was increased to 25 wt % as well as when the molasses binder was increased to 8 wt %. The combination of the saw dust and the molasses binder enhanced the agglomeration effect of the coal fines resulting in a strong and less brittle briquette (Kim et al., 2016).

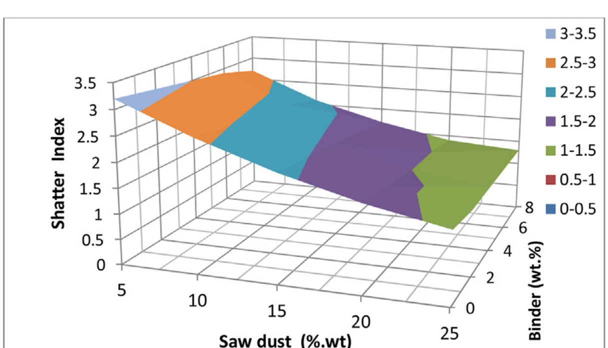

Fig. 4. Effect of saw dust and molasses concentration on the briquette shatter index.

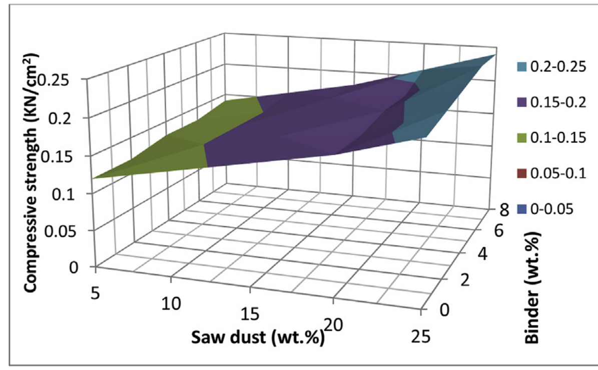

Fig. 5. Effect of saw dust and molasses concentration on the briquette compressive strength.

3.4. Effect of saw dust and binder concentration on the compressive strength

The compressive strength refers to the resistance of the briquette from breaking when subjected to compression (Ibeto et al., 2016). In this study, as the saw dust concentration increased to 25 wt % and the molasses binder concentration increased to 8 wt %. The compressive strength increased to between 0.20 and 0.25 kN/cm^2 (Fig. 5). The 80% increase in the compressive strength was attributed to the increased interlocking of the coal fines-saw dust-molasses binder especially at high concentration of the latter (Venter and Naude, 2015) resulting in a stronger briquette. The briquettes compressive strength was in comparable to the lumpy coal ones which are 0.29–0.48 kN/cm^2. This was an indication that the briquettes can also withstand and pressure from attrition during transportation and storage like the lumpy coal.

3.5. Coal-saw dust-molasses briquette characteristics

A summary of the coal-saw dust-molasses briquette is shown in Table 1. Addition of the $Ca\ (OH)_2$ also resulted in a low sulphur content coal-saw dust-molasses briquette (Kwong et al., 2007). High composition of sulphur in the briquette will result in the emission of sulphur dioxide in the environment which has a potential to cause acid rain in the long term. The characteristics of the briquettes allows them to be used as a solid fuel for heating and cooking at domestic level as well as industrial applications in boilers. In reference to the lumpy coal that is predominant in Southern Africa, the coal-saw dust-molasses briquette had properties that allowed it to be used as an alternative (Table 1).

Table 1
Physicochemical characteristics of the sawdust, coal-saw dust-molasses and lumpy coal.

Physicochemical parameter	Saw dust	Coal-saw dust-molasses briquette (this study)	Lumpy coal (predominant in Southern Africa)
Calorific value (MJ/kg)	13–15	25–26	23–35
Fixed carbon (%)	14–17	74–76	51–53
Ash content (%)	8–10	5–6	5–40
Moisture content (%)	12–15	7–8	8–10
Volatile matter (%)	24–28	8–10	20–35
Shatter index (-)		1.0–1.5	–
Compressive strength (KN/cm^2)		0.20–0.25	0.29–0.48
Relative density (kg/m^3)	210–245	750–850	1115–1135
Size (mm)	3–6 mm	30 mm × 25 mm X 15 mm	15–75
Sulphur content (ppm)	2.2–2.7	0.1–0.2	500–800

4. Conclusion

Coal fines can be used as a raw material source to produce high calorific value briquettes. The addition of saw dust as well as molasses as a binder results in a briquette with a calorific value of 26 MJ/kg and fixed carbon of 76%. This coal-saw dust-molasses briquette is of high compressive strength of 0.25 kN/cm^2 and is not easily shattered. The addition of Ca (OH) $_2$ is critical for sulphur removal in the briquette.

Conflicts of interest

The authors declare there is no conflict of interest.

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References

American Society for Testing and Materials, 1992. Annual Book of ASTM Standards, Section 5.50, Petroleum Products, Lubricants and Fossil Fuels.
Blesa, M.J., Miranda, J.L., Izquierdo, M.T., Moliner, R., 2003. Curing time effect on mechanical strength of smokeless fuel briquettes. Fuel Process. Technol. 80 (2), 155–167. https://doi.org/10.1016/S0378-3820(02)00243-6.
Borowski, G., Hycnar, J.J., 2013. Utilization of fine coal waste as a fuel briquettes. Int. J. Coal Prep. Util. 33, 194–204. https://doi.org/10.1080/19392699.2013.787993.
Ibeto, C.N., Ayodele, J.A., Anyanwu, C.N., 2016. Evaluation of pollution potentials and fuel properties of nigerian sub-bituminous coal and its blends with biomass. J. Mater. Environ. Sci. 7 (8), 2929–2937.
Kim, D., Lee, K., dan Park, Ki, 2016. Upgrading the characteristics of biochar from cellulose, lignin, and xylan for solid biofuel production from biomass by hydrothermal carbonization. J. Ind. Eng. Chem. 42, 95–100.
Kim, H., Kazuhiko, S., Masayoshi, S., 2001. Biomass briquette as a technology for desulphurizing and energy saving. Renew. Energy J. 8, 33–75.
Kwong, P.C.W., Wang, J.H., Chao, C.W., Cheung, C.W., Kendall, G., 2007. Effect of Co-combustion of Coal and Rice Husk on the Combustion Performance and Pollutant Emission. Atmospheric Environment, pp. 7462–7472.
Sen, R., Wiwatpanyaporn, S., Annachhatre, A.P., 2016. Influence of binders on physical properties of fuel briquettes produced from cassava rhizome waste. Int. J. Environ. Waste Manag. 17 (2), 158–175. https://doi.org/10.1504/IJEWM.2016.076750.
Singh, R.M., Kim, H.J., Kamide, M., Sharma, T., 2009. Bio briquettes-an alternative fuel for sustainable development. Nepal J. Sci. Technol. 10, 121–127.
Taulbee, D., Patil, D.P., Parekh, B.K., Honaker, R., 2009. Briquetting of coal fines and sawdust Part I: binder and briquetting-parameters evaluations. Int. J. Coal Prep. Util. https://doi.org/10.1080/19392690802628705. February 2009.
Tosun, Y.I., 2007. Clean fuel-magnesia bonded coal briquetting. Fuel Process. Technol. 88, 977–981.
Venter, P., Naude, N., 2015. Evaluation of some optimum moisture and binder conditions for coal fines briquetting. J. S. Afr. Inst. Min. Metall 115, 329–333.
Wang, L., Skreiberg, Ø., Van Wesenbeeck, S., Grønli, M., Antal, M.J., 2016. Experimental study on charcoal production from woody biomass. Energy Fuels 30, 7994–8008.
Wang, L., Lurina, M., Hyytiäinen, J., Mikkonen, E., 2014. Bio-coal market study: macro and micro-environment of the bio-coal business in Finland. Biomass Bioenergy 63, 198–209.
Zakari, I.Y., Ismaila, A., Sadiq, U., Nasiru, R., 2013. Investigation on the effects of addition of binder and particle size on the high calorific value of solid biofuel briquettes. J. Nat. Sci. Res. 3 (12), 30–34.