Combustion and energy content comparison of loose biomass briquettes produced from cow dung and cactus binders

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Abstract

This paper compares combustion behaviour and energy content of cow dung and cactus bonded briquettes. Briquettes were produced using yellow thatching grass, groundnut shells, sugarcane leaves, Mopani leaves and combination recipe (composed of all loose samples) collected from a location in the north eastern part of the Limpopo province. The aim was to identify loose biomass feedstock available in that location to sustainably produce good quality briquettes with the highest energy content and good combustion behaviour. Cow dung and cactus were selected as binders during the briquetting process. Briquettes produced with cow dung binder exhibited good performance with regards to improved energy content. The briquettes were produced for varying compaction pressures of 6, 12 and 19 MPa. Cow dung bonded briquettes were found to have the highest energy content across all pressures. At 6 MPa, Mopani leaves briquettes had 21.53 MJ/kg, groundnut shells 16.85 MJ/kg at 12 MPa and sugarcane 19.11 MJ/kg at 19MPa. The lowest energy content for cow dung was reported with yellow thatching grass at minimum average of 14.84 MJ/kg across all pressures. Cow dung bonded briquettes were found to have the highest combustion rates across all pressures with groundnut shells recording 209.67 g/min at 19 MPa, 104.71 g/min at 12 MPa and 83.16 g/min at 6 MPa. The lowest performance was recorded for sugarcane leaves at 38.13 g/min. Cactus bonded briquettes were found be very low on both energy content and combustion rates due to its pressure insensitivity and higher moisture content. The highest energy content for cactus bound briquettes was found to be at 16.49 MJ/kg for Mopani leaves followed by groundnut at 15.5 MJ/kg with the lowest at 12.6 MJ.kg for yellow thatching grass. The highest combustion rate was found at combination recipe with 59.48 g/min followed by Mopani leaves at 53.91 g/min. The lowest was 3.36 g/min for yellow thatching grass. Overall, cow dung bound briquettes performed better than cactus briquettes for all compaction pressures.

Key words: **Loose biomass, Briquettes, Energy content, Combustion, Compaction pressure**

1. INTRODUCTION

Main energy sources worldwide are mainly fossil fuels such as coal. This energy is required for basic human needs such as cooking, space heating and industrial activities. Given the negative impacts of fossil fuels on the environment, there is a need to minimise reliance on coal and biomass offers the best possible substitute for clean energy production [1]. Use of biomass resources requires understanding of their conversion methods to improve energy and bulk density. The most widely used biomass is round wood because does not require any conversion process. Harnessing loose agricultural and forestry residues will improve biomass usage as an energy source. This requires understanding of available feedstocks and harvest periods for selected location [2].

Even pre-processing handling affects performance. Krzy-zaniak at al [3] analysed the effect of loose biomass storage methods on quality using four storage methods for a period of twelve months before conversion into biomass briquettes. Willow wood chips were stored under 1.) controlled (no cover), 2.) permeable covers, 3.) vapour permeable foils and 4.) wooden shed. Results showed improved energy content by 10-20 % of briquettes produced from the raw material kept under permeable covers. Longer storage period improves bulk density especially samples of biomass materials with good lignin and it also reduces amount of volatiles by 3 % [4]. Agricultural residues such as groundnut shells retain nitrogen due to the use of fertilizers. Research conducted in Brazil using biomass-controlled plantation and fertilizers showed no negative effect on bulk density and final briquette quality [5]. Research on possibility of briquetting loose biomass was investigated using 12 loose biomass samples from agricultural and forestry residues. The aim was to analyse their combustion behaviour focusing on understanding their burn rate before briquetting. Results showed good performance on Eucalyptus saw dust that burned slowly at 0.4 g/sec with other 10 samples at the average combustion rate of 1.9 g/sec and maize cob was found to combust faster at 3.19 g/sec [6]. Performance of sawdust, rice husk and groundnut shell briquettes were compared through water boiling test. Results showed groundnut shell briquettes to combust slowly at improved combustion rate of 0.000213 kg/s. This could be due to the high percentage of lignin that promotes compaction and bonding for better bulk density [7]. Pelusa, at al [8] used eco-fuel briquettes to analyse the combustion behaviour for domestic application. The burn rate results were reported to be at 2 g/min. The achieved burn rate might be due to the highest energy content reported to be 18.9 MJ/kg. Besides energy content, good humidity resistance and influences the quality of the final briquettes produced [9].

Process parameters such as conversion temperature could improve final briquetting quality. Good briquettes must have high extractable energy content that can be comparably matched with the current energy content of fossil fuels. Bio-char (Gmelina arborea) was used to investigate the effect of processing temperature towards improving energy content [10]. Results showed positive contribution at the highest temperature of 900^{0}C. Energy content improved to 32.82 MJ/kg from the average range of 15-21 MJ/kg. Other process parameters of interest is the binding substance. Tabakav et al [11] used chips from Siberian wood and peat of Kandinsky deposits to produce briquettes bonded with pyrolysis liquids and dextrin. Siberian briquettes showed the highest energy content of 29.1 MJ/kg against the peat briquettes with 20.9 MJ/kg. Briquettes were also produced from rice ban and palm kernel were produced at varying binder ratio of 10, 20, 30, 40 and 50% by weight [12]. It was found that briquettes produced with binder ratio of 50% burns slower at 1.6 g/min followed by 40% binder ratio at 1.7 g/min.

Further research on briquette quality production was conducted using grouped municipal wastes to compare the amount of energy content available. Municipal solid waste (MSW) and urban wood biomass (UWB) were used to produce briquettes. As expected, it was found that urban wood biomass has the highest energy content of 16.96-21.59 MJ/kg followed by municipal solid waste at 7.10-19.90 MJ/kg. [13]. Solid briquettes performance was also measured using Tannery solid briquettes and sub-bituminous coal briquettes [14].

The aim was to compare the amount of extractable energy content available. Results showed similar amount of energy content between the two briquettes with sub-bituminous coal briquettes slight higher at 20-24.74 MJ/kg against 18.62- 42.10 MJ/kg for Tannery solid briquettes.

This research on biomass briquetting performance present an opportunity to replace fossil fuels. As a result, the use of biomass has an annual increase of 7.4 % on existing biomass usage percentage of 12 % from 2013 to 2014 [15]. This trend can be sustained through further research work especially in the use of binders. Binders improve the quality of the briquettes, but little is known about their impact on combustion and emissions. This paper will focus on investigation the performance of cow dung and cactus as briquetting binders.

2. EXPERIMENTAL PROGRAMME

2.1 Aim of the investigation

The aim of this investigation was to compare the combustion behaviour and energy content of loose biomass briquettes produced with cow dung and cactus binders respectively.

2.2 Materials

Five loose biomass materials were used in the investigation. These were yellow thatching grass, sugar cane leaves, groundnut shells, Mopani leaves and combine recipe (mixture of the four in equal proportion). The materials were collected from the Maphophe Village in the northern part of the Limpopo province. The binders were freshly collected cow dung and green cactus leaves.

2.3 Sample preparation

Prior to briquetting, the loose biomass was cut down to 20 mm sizes and mixed in various proportions with the binder i.e. cow dung or crushed cactus. The various briquette samples were produced at compaction pressures of 6 MPa, 12 MPa and 19 MPa using a hydraulic pressing machine.

2.4 Descriptions of equipment

2.4.1 Briquettes production

Briquettes were produced using a standard 30-ton workshop hydraulic press for compaction (Figure1 (a)). Briquettes mould set consisting of three components (base plate, compaction shaft and moulding cylinder) was used for briquettes moulding as shown in Figure 1 (b).

(a) (b)

Figure 1: Loose biomass briquetting equipment (a) 30 Ton hydraulic press (b) briquettes molding set

2.4.2 Energy content

A CAL2k full system bomb calorimeter was used for energy measurement. The system has specification of 50/60 Hz 5W power rating and 90-264 VAC with temperature resolution of 0.000001 ^{0}C, operating temperature range of 0-60 ^{0}C, relative standard deviation of 0.1 (%RSD) and resolution of 0.001 (MJ/kg). The complete combustion station is shown in Figure 2.

Figure 2: CAL2k bomb calorimeter for measuring energy content

2.4.3 Combustion behaviour

Combustion analysis set up consisted of data management station shown in Figure 2 (a), programmed (Richter scale) mass decay monitoring, Imbawula Entsha ceramic lined stove and a fume hood shown in Figure 2 (b). Data logging was done using National Instrument software (Signal Express). The scale was connected to the data logging computer via a USB connector to monitor mass change during combustion.

(a)

(b)

Figure 2: Complete combustion test station (a) Data management station, (b) combustion station

2.5 Experimental procedure

2.5.1 Energy content

Briquettes were selected according to their production pressures. Each briquette sample was crashed to course particles and a small portion weighing 0.5 grams was laced in a crucible and used for calorific value measurement. The calorific values were measured in MJ/kg using a CAL2K Bomb calorific meter.

2.5.2 Combustion behaviour

Briquettes produced at various pressures were combusted using Imbawula Entsha ceramic lined stove while the combustion rate was monitored using a programmed mass decay monitoring RICHTER Scale through Labview Signal Express software (National Instruments). Yellow thatching grass, groundnut shell, sugarcane leaves, Mopani leaves and combination recipe burn rates were then reported in grams per minute and equation 1 was used to compute burn rate for all briquettes samples.

Burn rate (g/min) = $M_{inital} – M_{Final} / T_{total}$ ……………………………………………………………. (1)

where M_{inital} is the mass before combustion, M_{Final} is the mass after combustion and T_{total} is the total time taken during combustion.

3. DISCUSION OF RESULTS

3.1 Energy content

Calorific values were measured for the five loose biomass samples. Results show a direct relationship between compaction pressure for cow dung and bulk density. This influences the amount of energy available in each briquette. Cactus bonded briquettes were found to be insensitive to compaction pressure. Detailed results are shown in Table 3.

Cow dung binder

6 MPa

Mopani leaves exhibited the highest energy content of 21.53 MJ/kg followed by groundnut shell at 17.1 MJ/kg. Combination recipe had the lowest energy content at 14.84 MJ/kg. Energy content of yellow thatching grass and sugarcane leaves was similar at an average of 15 MJ/kg.

12 MPa

It was found that some biomass loose samples are partially insensitive to the compaction pressure. results showed Mopani leaves as one such sample. Mopani leaves energy content reduced by 5.15 MJ/kg when compacted at a pressure of 12 MPa. The highest energy content was found for groundnut shell at 16.85 MJ/kg followed by Mopani leaves at 16.38 MJ/kg. The lowest energy content was found to be for sugarcane leaves for 13.53 MJ/kg.

19 MPa

At 19 MPa, sugarcane leaves responded positively to compaction pressure with the highest energy content of 19.11 MJ/kg followed by groundnut shell at 18.08 MJ/kg. Mopani leaves and combination recipe were found to have average of 16 MJ/kg while yellow thatching grass reported the lowest energy content at 14.35 MJ/kg.

Cactus binder

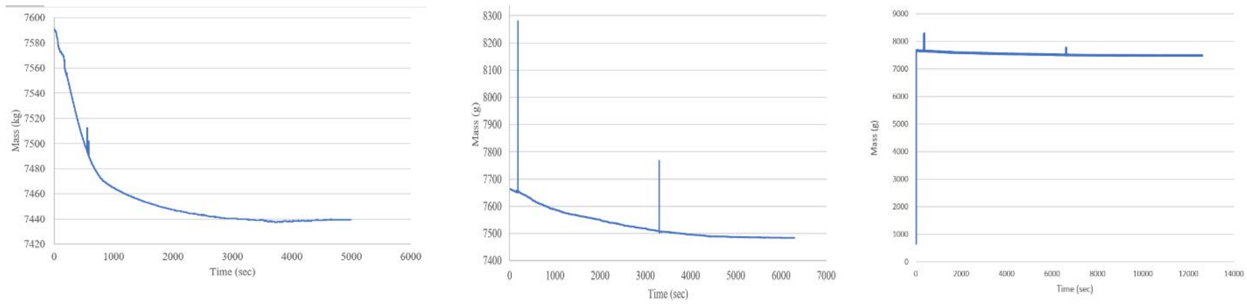
Loose biomass briquettes with cactus binders were analysed for their energy content. Virtual inspection showed cactus briquette having most briquettes samples with lower energy content, thus their dry honeycomb shape resulted in final lower bulk density. The highest energy content was found for Mopani leaves at 16.49 MJ/kg followed by groundnut shell at 15.5 MJ/kg. Sugarcane leaves, combination recipe and yellow thatching grass were found to be relatively low at an average of 13 MJ/kg.

Table 1: Loose biomass briquettes calorific values for varying pressures with cow dung binds and 19 MPa for cactus binds

Biomass samples Calorific values	Cow dung 6Mpa -CV (MJ/kg)	Cow dung 12MPa-CV (MJ/kg)	Cow dung 19MPa- CV (MJ/kg)	Cactus 19 MPa- CV (MJ/kg)
yellow thatching grass	15.57	15.79	14.35	12.60
Ground nut shells	17.10	16.85	18.08	15.50
Sugarcane leaves	15.47	13.53	19.11	13.35
mopani leaves	21.53	16.38	16.36	16.49
combination recipe	14.84	15.07	16.44	13.97

3.2 Combustion behaviour

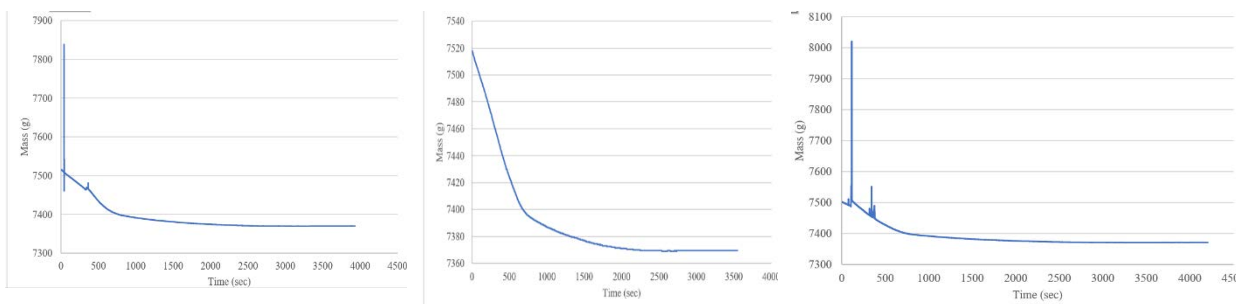
Briquette combustion behaviour was analysed on both cow dung and cactus binders with combustion time and burn rate as main parameters. Cow dung bonded briquettes had the overall longest combustion time compared to cactus bonded briquettes. Groundnut shells were found to have combusted longer at an average of 132.54 seconds followed by combination recipe at an average of 64.84 second cross all compaction pressures. Groundnut shell’s combustion time briquettes produced at 6MPa was found to be 83.16 seconds, 12 MPa recorded 104.71 minutes and 19 MPa was 209.76 minutes. Results are shown in Figure 3 (a), (b) and (c).



(a) (b) (c)

Figure 3: Groundnut shell briquettes with cow dung binds combustion results (a) 6 MPa, (b) 12 MPa and (c) 19 MPa.

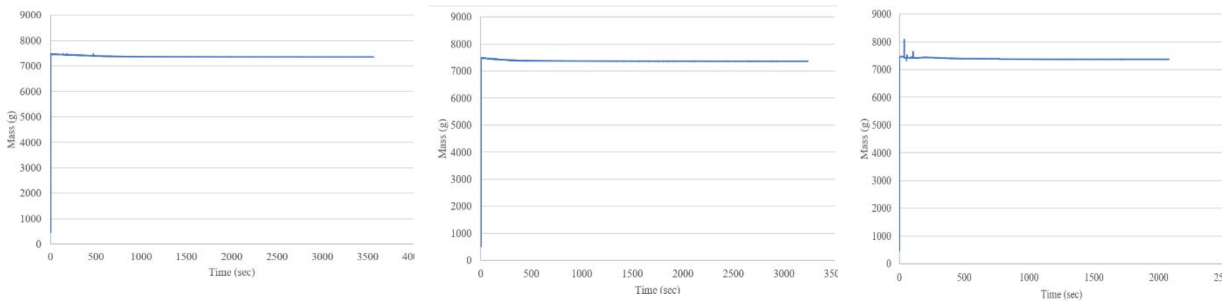
The combination recipe recorded 65.33 at 6MPa, 59.21 minutes at 12 MPa and 69.99 minutes at 19 MPa. These results shown in Figure 4. (a), (b) and (c).



(a) (b) (c)

Figure 4: Combination recipe briquettes with cow dung binds combustion results (a) 6 MPa, (b) 12 MPa and (c) 19 MPa.

Cactus bonded briquettes were found to have the shortest combustion time. This could be due to their low bulk density of the material when dry. The highest combustion time on cactus briquettes was at combination recipe with 59.48 minutes followed by Mopani leaves at 53.91 minutes. These results are shown in Figure 5 (a) and (b). Groundnut shells and sugarcane leaves were found to have an average combustion time of 46.42 minutes. Shortest combustion time was recorded for yellow thatching grass at 34.63 minutes. This result is shown by Figure 5 (c).



(a) (b) (c)

Figure 5: Cactus binds briquettes combustion results (a) Combination recipe, (b) Mopani leaves and (c) Yellow thatching grass.

Burn rate was analysed during combustion. Results of all combusted briquettes showed cow dung bonded briquette to combust much slower with Mopani leaves briquettes burning at a rate of 0.0126 g/min compared to cactus bonded Mopani leaves briquettes which combusted at 0.0288 g/min.

4. CONCLUSION

Briquettes produced using cow dung and cactus binders were compared for their energy content and combustion behaviour. Cow dung bonded Mopani leaves briquettes showed a good performance on both lower and high compaction pressures. For cow dung binder, groundnut shell, Mopani leaves and combination recipe briquettes exhibited good performance and are good candidates for future briquetting with average burn rate of 0.0233 g/min. The highest energy content on cow dung bonded briquettes was at 21 MJ/kg and for cactus was at 16 MJ/kg. Thus, cow dung with 75: 25 mixing ratios performed better with 5 MJ/kg more energy content compared to cactus briquettes. During combustion, cow dung bonded briquettes combusted for the maximum of 209 minutes and cactus bind briquettes lasted for 59 minutes. This is less than half of cow dung briquette performance. Cactus bonded briquettes require blending. Combination recipe briquettes showed improved bulk density with slower burn rate of 0.0288 g/min. Slow burn rate is required for better energy extraction with longer cooking cycles.

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