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Characterization of Physical Properties of Biomass Waste Materials in Kenya for Gasification: Rice Husks and Coffee Husks

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ABSTRACT— This work presents characterization of coffee husks and rice husks based on their calorific value, percentage moisture content, volatile matter, ash content, fixed carbon, bulk density and porosity for gasification. Calorific value of rice husks and coffee husks was 15.9kJ/g and 18.1kJ/g respectively. Bulk density of sampled rice husks and coffee husks was 127.4kg/m^3 and 218.0kg/m^3 respectively. Porosity of sampled rice husks and coffee husks was 87.4% and 71.9% respectively. A moisture content of sampled rice husks and coffee husks was 8.0% and 8.8% respectively. The percentage volatile matter of sampled rice husks and coffee husks was 62.8% and 78.4% respectively. The percentage ash content of sampled rice husks and coffee husks was 20.2% and 3.9% respectively. The percentage fixed carbon of sampled rice husks and coffee husks was 17.0% and 17.7% respectively.

Keywords— biomass gasification; rice husks; coffee husks; biofuels

1.0 INTRODUCTION

About 45.2% of Kenya's population lives below the poverty line. Low income has forced most of the Kenyans to opt for the cheapest available sources of energy. Biomass fuels are the most important source of energy in Kenya with wood-fuel (firewood and charcoal) accounting for over 68% of the total primary energy consumption (MOE, 2014). In spite of past efforts to promote substitutes for wood-fuel, the number of people relying on them is not decreasing. Consequently, it is projected that biomass will continue to be the main source of energy for the majority of the rural population and urban poor. As a result of deforestation, biomass resources (fire wood and charcoal) are getting scarce. Waste products from agro-processing industries such as coffee husks and rice husks have been a major challenge in disposal. Biomass gasification is one of the few technologies that can potentially generate carbon negative energy with pollution-free power and also turn these wastes into energy through gasification. Unlike other countries in the developed world, gasification technology is still new in Kenya and Africa in general so its adoption can help in recycling bio waste materials and reduce deforestation (Practical Action, 2012). According to Rajvanshi (1986), the choice and design of a gasifier is dependent on fuel properties. Yang *et al.* (2005) also reports that the properties of biofuels affects their combustion in a gasifier reactor. The findings of this study can therefore be used to inform the design of gasifiers in the country and help in utilization of these bio-waste materials in gasification. This study used Arabica coffee husks and long grain rice husks obtained from Thika Coffee Mills Ltd and Nice Rice Millers Ltd respectively, all located in Central Kenya.

2.0 METHODOLOGY

2.1 Determination of Bulk Density

A graduated glass cylinder of volume V, 0.005m^3 was completely filled with the sample and the material was slightly compacted to ensure there are no large void spaces. The glass cylinder and the sample were then weighed to obtain the combined weight, W_2. (Zhang *et al.*, 2012). Three replicates were carried out and the mean obtained. The bulk density of the sample was calculated using equation (1).

$$\rho_b(\mathrm{kg/m^3}) = (W_2 - W_1) \,/\, V \qquad (1)$$

Where:

ρ_b = bulk density of fuel sample

W_2 = weight of the glass cylinder container +sample

W_1 = weight of the glass cylinder container

V = volume of the glass cylinder container

(Zhang *et al.*, 2012)

2.2 Determination of Porosity

The porosity of biomass was determined by using a sample of Volume V_s 0.0030 m^3 in a 0.005m^3 graduated cylinder. A wire mesh screen was placed on the top of the sample to prevent material getting suspended when water is added. Water was gently added over the sample until the water level went above the level of the sample. The cylinder was gently rocked from the sides to remove any air bubbles and then the final water level was recorded. Then the amount of added water to the cylinder and the water level were recorded (Zhang *et al*., 2012). The cylinder was emptied and cleaned thoroughly after each test. The test was done in triplicates and the porosity of biomass fuel was calculated using equation (2).

$$P(\%) = (V_i - V_f)/V_s \qquad (2)$$

Where:

P = porosity of the sample

V_i = combined volume of the sample and water seperately

V_f = final total volume of the sample and added water

V_s = volume of the sample

(Zhang *et al.*, 2012)

2.3 Determination of Particle size distribution

The samples of rice husks and coffee husks were separated into different particle sizes using a sifting column. This was done by placing the 4 sieves with different mesh sizes on a mechanical shaker. The weight of sample residues in each test sieve were determined using a digital weighing balance of model Stanton St01 made in Great Britain with accuracy of 0.1g and recorded in table A.1 and table A.2. Three replicates were carried out and the mean obtained. The individual fractions were then calculated and assigned as a percentage of the sum of all the individual fractions (Zhang *et al.*, 2012).

2.4 Determination of Moisture content

The moisture content was determined in accordance to ASTM Standard D 1762-84(2007). Dishes containing fuel samples were placed in drying oven at 105ºC for duration of 2 hours. The dish was then weighed using a digital weighing balance of model Stanton St01 made in Great Britain to the nearest 0.01g. Three replicates were carried out and the mean obtained.The percentage moisture content was then obtained using equation (3) below.

$$MC(\%) = (W_{ad} - W_{od})/W_{ad} \qquad (3)$$

Where:

MC = moisture content

W_{ad} = weight of sample before drying in oven at 105ºC for duration of 2 hours

W_{od} = weight of sample after drying in oven at 105ºC for duration of 2 hours

(Zhang *et al.*, 2012)

2.5 Determination of Volatile Matter

The volatile matter (VM) determination was done in accordance to ASTM Standard D 1762-84(2007). 5 grams of fuel sample was put in a ceramic crucible and weighed using a digital weighing balance of model Stanton St01 made in Great Britain with accuracy of 0.01g. The samples were first heated at 105°C for 2 hours to drive out moisture. The crucibles were then heated inside a muffle furnace maintained at 950°C for 6 minutes after which they were left to cool and weighed. Three replicates were carried out and the mean obtained. The percent volatile matter was calculated using equation (4) below.

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$$\text{VM}\ (\%) = (W_{od} - F_g) / W_{od} \times 100 \qquad (4)$$

Where:

VM =volatile Matter

F_g = weight of sample after heating in furnace for 6 minutes at 950°C

W_{od} = weight of sample after drying in oven at 105ºC for duration of 2 hours

2.6 Determination of Ash Content

The ash determination was done in accordance with ASTM Standard D 1762-84(2007). 5 grams of fuel sample was weighed using a digital weighing balance of model Stanton St01 made in Great Britain with accuracy of 0.01g and taken in an empty ceramic crucible. The samples were first heated at 105°C for 2 hours to drive out moisture. The crucibles along with the samples was placed in a muffle furnace at 750°C for 6 hours after which the crucibles were left to cool and weighed. Three replicates were carried out and the mean obtained. Calculation of the percent ash content was done as per equation (5) below.

$$\%\ \text{Ash percent} = (W_R / W_{od}) \times 100 \qquad (5)$$

Where:

VM =Volatile Matter

W_R = weight of sample after heating in furnace for 6 hours at 750°C

W_{od} = weight of sample after drying in oven at 105ºC for duration of 2 hours

2.7 Determination of Percentage Fixed Carbon

Fixed carbon (FC) was calculated using the following equation according to Mckendry (2002).

$$\%\ \text{FC} = 100 - (\%\ \text{VM} + \%\ \text{Ash}) \qquad (6)$$

Where:

VM=Volatile Matter

FC =Fixed carbon

2.8 Determination of Energy Content

The calorific value of the briquettes was determined using the P.A. HILTON bomb calorimeter, Model C200 made in United Kingdom. Benzoic acid with a known calorific value of 26.5kJ/g was used as a calibration material. The experiments were conducted at Kenyatta University Mechanical Engineering department from the 6th of October to 13th October, 2017. Three replicates were carried out and the mean obtained. Figure B.1 shows how the equipment was set up for the experiment.

Figure B.1 Experimental set up for energy content test

Figure B.2 Photographs of test fuels used in the study

3.0 RESULTS AND DISCUSSION

3.1 Porosity and bulk density

Rice husks presented the highest value of porosity of 87.4% while coffee husks had the lowest porosity of 71.9%. Coffee husks had the highest bulk density of 218.0kg/m^3 while rice husk was the lowest with 127.4% kg/m^3. According to Belonio (2005), the bulk density of both compacted and non-compacted rice husks ranges from 100 to 120 kg/m^3 while Zhang *et al.* (2012), found the porosity of rice husks to be in the range 64%-73%. From table A.1 and table A.2, Rice husks were mainly composed of particles in the range of 2.36-4.75 mm which accounted for 81.0% of the sample while coffee husks were mainly composed of particles in the range 2.36-4.75mm accounting for 67.1% of the sample.

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3.2 Proximate Analysis

The percentage moisture content, volatile matter, carbon content and ash content were obtained for the two fuels. Coffee husks presented the highest moisture content of 8.8% whereas rice husks had the lowest moisture content of 8.0%. Rice husks had the highest percentage ash content of 20.2% whereas coffee husks presented the lowest value of 3.9%. Coffee husks had the highest percentage of volatile matter of 78.4% while rice husk had the lowest value of 62.8%, coffee husks presented the highest percentage of fixed carbon of 17.7% while rice husks gave the lowest value of 17.0%.

3.3 Energy Content

Rice husks showed the lowest heating values of 15.9kJ/g. This could be attributed to the fuel's high ash content. Coffee husks presented the highest calorific value of 18.1kJ/g. This could be attributed to the fuel's high fixed carbon content and low ash content.

Physical properties obtained from other researches in literature are presented in table A.3. Comparing the values obtained from this study and those of previous researches, they are within the same range.

Table A.1 Particle size distribution of rice husks in a 150g sample

Particle size(mm)	Average (g)	Fraction by weight (%)
>4.75	0	0.0
2.36-4.75	121.5	81.0
1.18-2.36	13.8	9.2
0.6-1.18	8.9	5.9
<0.6	5.8	3.9

Table A.2 Particle size distribution of coffee husks in a 150g sample

Particle size(mm)	Average (g)	Fraction by weight (%)
>4.75	23.1	15.4
2.36-4.75	100.6	67.1
1.18-2.36	13.9	9.2
0.6-1.18	7.4	4.9
<0.6	5.2	3.4

Table A.3 Typical properties of coffee husks and rice husks from literature

	Rice husks	Coffee husks
Bulk density (kg/m^3)	96-160	185-300
Porosity (%)	77-89	64-73
Moisture content (%)	6-10	9-12
Ash content (%)	15-24	0.8-6
Fixed carbon (%)	14-19	13-19
Volatile matter (%)	58-68	78-89
Gross calorific value (kJ/g)	15-17	18-20

(Kumar *et al*., 2015; Zhang *et al*.,2014; Quaak *et al*., 1999; Lam *et al*.,2014; Belonio, 2005)

4.0 CONCLUSION

The properties of biomass test fuels had the following physical properties: Calorific value of rice husks and coffee husks was 15.9kJ/g and 18.1kJ/g respectively. Bulk density of sampled rice husks and coffee husks was 127.4kg/m^3 and 218.0kg/m^3 respectively. Porosity of sampled rice husks and coffee husks was 87.4% and 71.9% respectively. The moisture content of sampled rice husks and coffee husks was 8.0% and 8.8% respectively. The volatile matter of sampled rice husks and coffee husks was 62.8% and 78.4% respectively. The ash content of sampled rice husks and coffee husks was 20.2% and 3.9% respectively. The fixed carbon of sampled rice husks and coffee husks was 17.0%and 17.7% respectively.

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