International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-11, Issue-11, November 2024

Effects of Mix Ratio on physical and combustion properties of a Novel Briquette of Sawdust and Banana Agro-Waste

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Abstract - **Currently, there is a high demand for clean energy from renewable sources owing to their minimal environmental impacts. In Kenya, biomasses such as sawdust from sawmill industries and agro-wastes, such as banana leaves and pseudo stem, are potential sources of renewable energy. However, these biomasses are normally discarded in the fields and little information exists on their use as fuel in blended briquettes. Consequently, the current study investigates the use of carbonized sawdust and banana waste as raw materials for briquettes production. Specifically, the study aims at characterizing physical and combustion properties of blended briquettes produced from the two raw materials. In the study, pseudo-stem and banana leaves from Musa acuminata AAA species and sawdust from Eucalyptus tree species were collected, dried to 8 % moisture content, hammer milled, sieved and carbonized in muffle furnace at 400 ℃ for 5 minutes. Blended briquettes were produced at constant compaction pressure of 5 MPa at varying blend ratios (0:1 to 1:0) using molasses as a binder. The manufactured briquettes were then characterized in terms of mass density, durability index, ash content, moisture content, volatile matter and calorific value. From the characterization study of the raw materials: sawdust, banana waste and molasses had moisture contents of 12.52 %, 14.63 % and 22.23 %; volatile matter of 25.32 %, 31.45 % and 43.25 %; calorific value of 15.92 MJ/kg, 12.35 MJ/kg and 11.24 MJ/kg; ash content of 5.79 %, 6.89 % and 8.00 %, respectively. The determined mass density, calorific value and durability index of the blended briquettes increased with increase in ratios of sawdust while ash content, moisture content and carbon monoxide emission decreased. The density ranged from 392.54 kg/m^3 to 681.21 kg/m^3, calorific value from 23.40 MJ/kg to 25.92 kg/m^3, ash content from 6.89 % to 5.79 %, moisture content from 11.10 % to 7.45 %, durability index from 95.35 % to 99.70 % and carbon monoxide emission from 5.64 ppm to 1.74 ppm. The moisture content ranged from 6.65 % to 8.76 %, ash content from 5.82 % to 5.83 %, carbon monoxide emission from 4.58 ppm to 5.66 ppm, calorific value from 25.54 MJ/kg to 22.03 MJ/kg, density from 763.33 kg/m^3 to 557.68 kg/m^3 and durability index from 99.01 % to 96.52 %. From determined properties, the blended briquettes from carbonized sawdust and banana waste can be used as alternative source of fuel.**

Index Terms— Agricultural waste, briquettes, combustion, Mechanical, Physical.

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I. INTRODUCTION

Biomass is being highly promoted as an alternative energy resource for the fossil fuel, especially during the past three decades, the effect of escalating prices is attributed to factors such as world economic growth, declining value of the dollar and unrest in Middle East coupled with declining domestic oil supply (Banpast *et al.*, 1997). A study by Kituyi *et al.* (2001) showed that about 15.4 million tons of fuel wood were consumed in 1997 and this was supplied by farm land trees, indigenous forests, woodlands and timber off-cuts from plants. Various researchers have reported this shortage in Kenya (Kituyi, Marfa, Huber, *et al.*, 2001). As a result, there is an increase in the utilization of crop residues by farmers to fulfill their energy requirements. Replacing traditional forms of biomass energy use with modern ones is expected to have a number of benefits such as a decrease in the emission of greenhouse gases and forest destruction; reduced health hazards; and an increase in available energy (Janssen & Rutz, 2012).

The uncertainty of prices and supply of crude oil has prompted the search for alternative sources of energy to meet the ever growing energy demand. By compacting these biomass, high density and energy concentrated solid material called briquettes are produced which can supplement existing energy sources. Biomass from forestry has been the main source of fuel wood in Kenya. A study by Kituyi *et al.* (2001) showed that about 15.4 million tonnes of fuel wood were consumed in 1997 and this was supplied by farm land trees, indigenous forests, woodlands and timber off-cuts from plants. Furthermore, this study revealed very minimal utilization of crop residues as domestic fuel (about 1.4 million tonnes). However, fuel wood supply has been declining in rural Africa (Jama *et al.*, 2008). Various researchers have reported this shortage in Kenya (Kituyi, Marufu, Huber, *et al.*, 2001). As a result, there is an increase in the utilization of crop residues by farmers to fulfill their energy requirements. For example, Mugo (1999) reported that a shortage of fuel wood supplies resulted in approximately 40% of the farmers in western Kenya utilizing crop residues and cow dung as domestic energy sources. In other parts of western Kenya, rural households have resorted to buying crop residues in order to cater for their fuel needs (Mahri, 2004).

Replacing traditional forms of biomass energy use with modern ones would have a number of benefits such as a decrease in the emission of greenhouse gases and forest destruction; reduced health hazards; and an increase in available energy. In addition, the utilization of biomass for energy production can contribute considerably to job creation, hence improving the rural economies and reducing rural urban migration (Thornley *et al.,* 2008). Elsewhere in the USA, America and Duncan (2001) reported that over 66,000 rural jobs have also been created in biomass power generation and an additional 40,000 in biofuels.

This study aimed at producing blended briquettes at varying mixture ratios of sawdust and banana waste and determines their physical and combustion properties. It is anticipated that produced briquettes would supplement traditional fuels and save environmental degradation both by deforestation and pollutants emission from combusting fossil fuels.

II. EXPERIMENTAL METHODS

A. MATERIAL

The material used in this study consisted of sun dried sawdust and banana waste which were ground, sieved, carbonized and compacted to produce briquettes. Materials were carbonized to increase the carbon content hence the heating value.

1) Sawdust

Sawdust collected had a moisture content of about 28 %. It was sun dried to approximately 5 % moisture content and hammer milled before carbonizing at 400°C for 5 minutes in the muffle furnace according to Gimba and Turoti (2008). The carbonized sawdust was then cooled to room temperature in the desiccator.

2) Banana waste

Samples of dried banana leaves were obtained directly from harvested banana trees and only the leaves that were already dry were collected. The pseudo stem was obtained from harvested banana plants. By having high humidity, pseudo stem was pressed in a hydraulic press to remove the largest liquid fraction, and after that process, it was dried in a forced ventilation muffle at 60 ºC to a moisture content of 8%. The dried pseudo stem and banana leaves were hammer milled and sieved using a 2.5 mm sieve, to obtain fines with an average particle size of 2.5 mm. The milled pseudo stem and leaves were blended at the same ratios before mixing with carbonized sawdust as indicated in section 3.3.2.

3) Molasses

A commercial molasses was used in this study. 10 litres were bought from a hardware supplier and stored in a cold and dry place in the work shop. It was black in colour with a viscosity of 0.076 poise. In the current study, it was used as a binder during briquette manufacturing and its proportion was maintained at 20 % by mass in all briquettes made.

DETERMINATION OF PHYSICAL AND COMBUSTION PROPERTIES OF SAWDUST AND BANANA WASTE

Density

Density of sawdust and banana waste was determined according to ASAE S269.4 standards. Since density is property of mass against volume, the process of determining density was accomplished as follows. Both the mass and volume were measured and the measurements were computed and treated as the mass (m) and volume (v) in each case. Mass was measured using electronic balance and volume was determined after 5 MPa compaction in a mould measuring 50mm and 100 mm. The density was determined using the Equation 3.1:

$$\rho = \frac{m}{v} \qquad \text{Equation 3.1}$$

Where ρ – is density (g/cm^3)

m - is the mass (g)

v - is the volume of the briquette (cm^3)

4) Calorific value

Calorific (heating) value of biomass is indicative of the energy content of the fuel. A Parr 6200 oxygen bomb calorimeter (Parr Instrument Company, Moline, IL) was used to determine the calorific value of sawdust. One gram was placed in a stainless steel crucible, and the material in the vessel (bomb) ignited by a 2223 cotton fuse. The vessel was filled with oxygen and surrounded by a water jacket. Upon ignition, the released heat was transferred to the water jacket. The temperature rise in the water jacket was used by the calorimeter to calculate the heating value of the sample.

Ash content

The amount of ash-forming material present in fuel is an indication of suitability of sawdust as fuel. ASTM 03174-97 (39) was used as by Nopporn (2013). In this case an empty crucible was heated to a temperature 500°C for 30 minutes in muffle furnace before the cover was placed over it and cooled over desiccant for one hour. Thereafter, one gram of the sample was put on the weighed crucible, covered and heated gradually to temperature of 725°C within 2 hours. The crucible was then cooled in desiccators before weighing. Difference in mass gives the ash content.

5) Volatile matter

Volatile matter was determined using the standard method, ASTM E872-82 (2006) as used by Sotannde *et al.*, (2010). This process was carried out by heating empty crucible to temperature of 500°C for 30 minutes in muffle furnace. The cover was then placed and cooled in desiccators for one hour. Thereafter, one gram of the sample was put in the weighed crucible and closed with tightly fitting cover so that carbon deposit did not burn away. The sample was then transferred into the muffle furnace, ignited and temperature allowed to rise to 950°C and was maintained for 7 minutes. The crucible was then removed from the furnace, cooled in desiccators, weighed and difference in mass was volatile matter.

6) *Moisture content*

Moisture content was determined as per ASTM E1871-82 (2006) standard. Empty crucibles were heated to 105°C for duration of 1 hr. They were then removed from the oven, covered and cooled immediately in a desiccant for 30 minutes. One gram of each of the samples was then weighed, put in the crucibles then dried in an oven at 105°C for 24 hrs. The crucibles were cooled in desiccators to room temperature then weighed again. Difference in mass is the moisture content.

FABRICATION OF BRIQUETTES

7) Preparation of moulds and dies

Cylindrical moulds of 50 mm by 100 mm were produced from the mild steel. The cylindrical mould of 75 mm in diameter by 100 mm in length was clamped in lathe machine drill at the centre to produce an internal hole of 50 mm. The surface finishing of the internal hole was smoothened to reduce friction during briquetting process.

8) Briquetting Procedure

Briquettes were produced by mixing carbonized sawdust, milled banana waste and binder. The weight of binder was kept at 20 % of sample mix weight. This was in accordance with findings of Davies and Davies (2013) for best binder ratio. 50 g of the materials-binder mixtures were hand-fed into the mould and compacted at 5 MPa using a hydraulic press shown in Figure 3.1.The compaction time was 5 minutes as recommended by Onaji and Siemons (2003) while compaction pressure was in accordance with (Oladeji and Lucas (2011). The pressure gauge was calibrated before the experiment was conducted. Once the mixture ratio was loaded into the mould, a flat cover was inserted into the base of the mould. The mould with the content was then loaded on the table of the press. Using flexible arm, the die was mounted manually on the mould till the required pressure was attained. The mould was then unloaded from the hydraulic pressure before the briquetted was removed from the mould for drying.

Figure 3.1 Hydraulic press used for production of blended briquettes.

To study the effect of mix ratios on the physical and combustion properties, the briquettes were fabricated at constant compaction pressure of 5 MPa using milled particle sizes of 2.5 mm. The pressure and particle size used in the study were based on the work of (Oladeji and Lucas, 2011). Table 3.1 show the experimental design adopted for this study.

Table 3.1: Mix ratio of blended briquettes made at constant pressure of 5 MPa and 2.5 mm particle sizes

S/No.	Sample ID	Mix Ratio
1	SD:BW	1:0
2	SD:BW	4:1
3	SD:BW	3:2
4	SD:BW	1:1
5	SD:BW	2:3
6	SD:BW	1:4
7	SD:BW	0:1

Sawdust (SD), banana waste (BW)

To study the effect of particle size on the physical and combustion properties, the briquettes were fabricated at constant compaction pressure of 5 MPa and using a mix ratio of 1:0. The particle sizes were varied from 2.5 mm, 5 mm, 7 mm, 9 mm and 11 mm. For each particle size five replications were carried out and average values recorded.

B. STATISTICAL ANALYSIS

The study involved seven mixture ratios and five particle sizes of blended briquettes. Five samples were analyzed for each condition and mean value reported. Graphical representation of the data was based on mean values and error bars on standard deviation. The data was analyzed using the T test to obtain the P values by comparing consecutive two mix ratios at a time. The P values output shows the significance difference of the different mix ratios. Sample T-test input and output files are given in Appendix C. In addition, data analysis was carried out using SAS statistical software. Significance studies were based on Least Significant Difference method LSD at $\alpha = 0.05$.

III. RESULTS AND DISCUSSIONS

A. EFFECTS OF MIX RATIO ON PHYSICAL AND COMBUSTION PROPERTIES OF BLENDED BRIQUETTE

1) Effects of mix ratios on the density of blended briquettes

The density of blended briquette manufactured at different mix ratios of saw dust to banana waste (SD: BW) is summarized in Figures 4.1. It is clear from the results that the density increases as the proportion of sawdust was increased. This may be attributed to the fact that the determined density of sawdust was higher than that of banana waste. Varying ratios of briquetting materials have direct impact on densities as found by Chirchir *et al* (2013). This is in agreement with the current findings. Increasing sawdust proportion in the mix seems to have significant effect for all ratios. The determined densities of briquettes ranged from 392.54 kg/m^3 to 681.21 kg/m^3 which fits well with typical values of 100 to 2000 kg/m^3 (Martin, J. and Mae, R. and Manaay, A. (2008). Notably, density is important property of fuel since it affect the rate of burning. Ideally, highly dense fuel burns longer than less dense one.

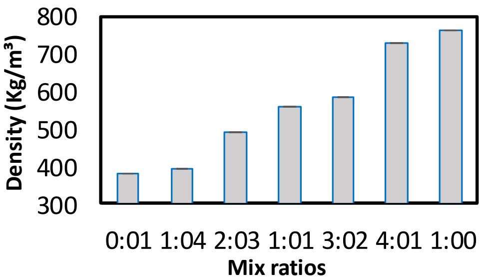

Figure 4.1: Variations of blended briquettes densities as a function of sawdust to banana waste mix ratio. The error bars are based on standard deviation of the means.

Comparing the P values of the blended briquettes density at all mix ratios shows significant difference at 95% confident level ($p < 0.05$). This is also confirmed by the non-overlapping error bars between the means. Therefore the density of the blended briquettes is significantly different at different mix ratios.

2) Effects of mixture ratios on the durability of blended briquettes

Durability of briquettes signifies the hardness. Hard fuel burn slowly as compared to a soft fuel. Figure 4.2 shows durability index at different mix ratios of sawdust and banana waste in the blended briquettes. Generally, the durability index reduces as the amount of banana waste in the blended briquettes decreases. The difference in durability indexes between the mean values of 0:1, 1:4 and 2:3 blended briquettes were significant at 95% confident level ($p < 0.05$). However, durability index was not significantly different between 1:1, 3:2 and 4:1 mix ratios. Apparently, any mix ratio between 1:1 and 1:0 produces blended briquettes with similar durability indexes. The 1:1 mix ratio is the optimal blend above which no significant difference is noted in the durability indexes. This is also confirmed by the overlapping error bars between the means in this range. Fuel with higher durability is preferred since it hardly breaks during handing and also burning duration is longer. Briquette strength has impact on the briquette durability, because when the strength increases the absorption of atmospheric humidity decreases.

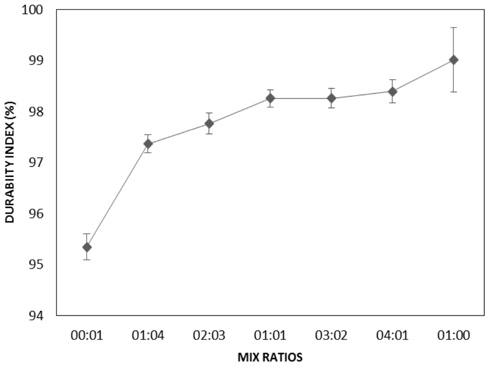

Figure 4.2 Variations of blended briquettes durability as a function of sawdust to banana waste mix ratio. The error bars are based on standard deviation of the means

3) Effects of mixture ratios on the moisture content of blended briquettes

Figure 4.3 shows the results of the mean moisture content of blended briquettes produced at different mix ratios. Generally, moisture content decreased with decreasing content of the banana waste in the briquettes. This could be attributed to hygroscopic nature of the banana waste content which was not carbonized in this study. However, the decrease was not significant between 4:1 and 1:0 mix ratios ($p > 0.05$). Apparently, no gain is achieved in moisture content reduction by increasing sawdust content in the blended briquette above 50%. Consequently, 1:1 mix ratio may be considered the optimal blend ratio. Moisture of briquettes depends mainly on the initial moisture of raw material and it changes during the briquetting process, when the temperature increases by compression, some amount of moisture evaporates. High moisture content of briquettes leads to their bed consistency, increased number of crumbles, low energy value and consequently low price (Li and Liu, 2000).

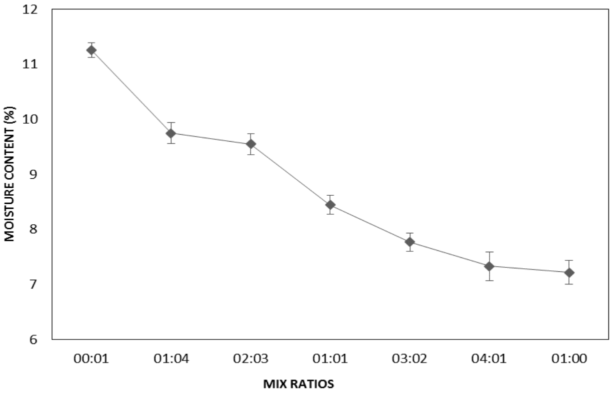

Figure 4.3: Variations of blended briquettes moisture content as a function of sawdust to banana waste mix ratio. The error bars are based on standard deviation of the means.

4) Effects of mixture ratios on the calorific value of blended briquettes

Caloric value of the fuel is the heat produced when 1 kg of fuel is burnt. It varies based on other combustion of the fuel. Figure 4.4 shows the calorific values obtained from different mix ratio of sawdust and banana waste in the blended briquettes. In general, the caloric value of blended briquettes decreased as the banana waste content was increased. At the ratio of 1:0, the calorific value was 25.92 MJ/kg but reduced significantly to 23.40 MJ/ kg at ratio of 0:1. This reduction was significant at 95% confident level for all mix ratio ($p < 0.05$). This could be attributed to lower calorific values of non-carbonized banana waste, its increased moisture content and volatile matter.

Based on the previous studies on the calorific value, the results obtained for the rice husk was 13,389 kJ/kg while that of corncob briquette was 20,890 kJ/kg. These energy values are sufficient enough to produce heat required for household cooking and small scale industrial cottage applications. They also compare well with the value obtained in this research, for examples, groundnut shell briquette gives 12,600 kJ/kg (Musa, 2007), cowpea 14,372.93 kJ/kg, and soybeans gives 12,953 kJ/kg (Enweremadu, *et al.,* 2004).

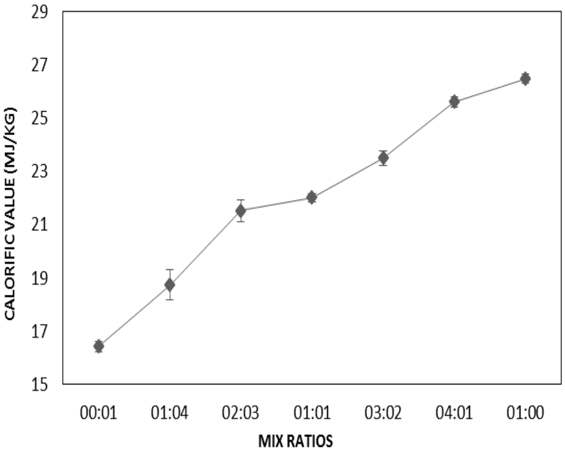

Figure 4.4: Variations of blended briquettes calorific values as a function of sawdust to banana waste mix

ratio. The error bars are based on standard deviation of the means.

5) Effects of mixture ratios on the ash content of blended briquettes

Results obtained for ash content of blended briquettes are as shown in Figure 4.5. At mixture ratios of 1:0, the ash content was 5.79 % but increased significantly to 6.89 % at ratio of 0:1. In general, the decrease was almost linear but there was no significant different between 1:4 and 2:3 and also between 1:1 and 3:2 mix ratios ($p < 0.05$). This suggests that, the amount of ash content in fuel is contributed significantly by the characteristics of the original materials, such as, banana waste. Higher ash content is not desirable in the fuel because it lowers calorific value of the fuel.

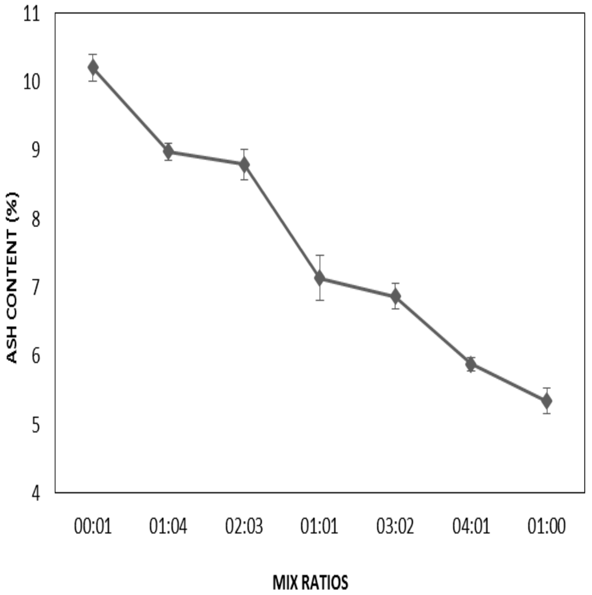

Figure 4.5: Variations of blended briquettes ash content as a function of sawdust to banana waste mix ratio. The error bars are based on standard deviation of the means.

6) Effects of mixture ratios on the carbon monoxide of blended briquettes

Carbon monoxide emission is mainly due to incomplete combustion in fuel. It is a health hazard and brings suffocation if proper ventilation is not provided. From the results obtained in Figure 4.6, the production of carbon monoxide (CO) did not vary significantly from 5 % for mix ratio between 0:1 and 3:2. However, there was a significant reduction in CO production between 3:2, 4:1 and 1:0 mix ratios at 95% confident level ($p < 0.05$). Banana had higher amount of moisture content which could have induced incomplete combustion. This means as BW content reduces then the effect of moisture on combustion reduces. This conforms to emission levels recorded by Banzaert (2013) of 5-7 ppm comparable to other wood biomass levels. Notably, to achieve significant reduction in CO emission from the blended briquettes, the banana waste content has to be less than 40%.

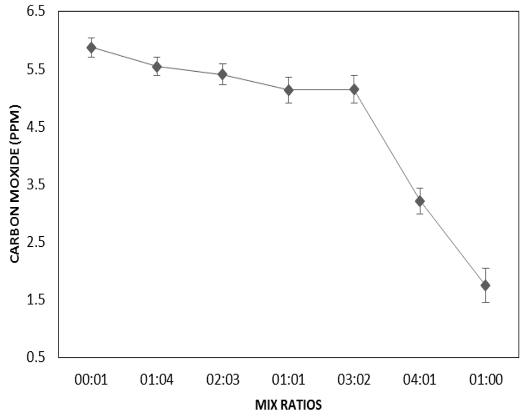

Figure 4.6: Variations of blended briquettes CO emission as a function of sawdust to banana waste mix ratio. The error bars are based on standard deviation of the means.

IV. CONCLUSION

Sawdust has better calorific value (15.92 MJ/kg), lower ash content (5.79 %) and higher density (681.21 Kg/m^3) compared to 12.35 MJ/kg, 6.89 % and 392.54 Kg/m^3, respectively from banana waste under similar condition of measurements. On the other hand, banana waste has higher moisture content (14.63 %) and volatile matter (31.45 %) compared 12.51 % and 25.32 %, respectively from sawdust. Different mix ratio produces blended briquettes with significantly different densities at constant compaction pressure of 5MPa. It is also evident that mix ratio between 1:1 and 1:0 has similar durability indexes while those between 0:1 and 2:3 have significantly different durability indexes. Mix ratio of 1:1 seems to be the optimal blend above which no significant difference is noted in durability index. Moisture content of blended briquettes decreases with the increase in the sawdust content. However, there is no gain in moisture content reduction by increasing sawdust content in the blended briquette above 50%. Consequently, 1:1 mix ratio is considered the optimal blend ratio for this study. Calorific values and ash content of blended briquettes increases significantly with the increase in the sawdust content at all mix ratios studied. However, the carbon monoxide (CO) emission of the blended briquettes decreases as the sawdust content is increased. Notably, to achieve significant reduction in CO emission, the banana waste content in the briquette has to be less than 40%. Consequently, 3:2 mix ratios is considered the optimal blend ratio for this study in terms of CO emission.

ACKNOWLEDGMENT

Ogadis Jepkemei expresses her gratitude to Egerton University and Moi University for the availability of the machines and instruments that were used during the research period and also the technical human resource who were of great help in the accomplishment of the research.

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