International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 4, April 2017)

Effect of Mix Ratios and Binders on Physical and Combustion Characteristics of Faecal Matter–Sawdust Briquettes

Mbuba, M. Jesca[1], Nyaanga, D. M.[2], Kabok, P. A.[3], Reinilde, Eppinga[4]

[1,2]Egerton University, 536-20115, Egerton
[3] Bondo University, 210-40601, Bondo
[4]SNV/NCSP, Kenyatta Highway, Nakuru

***Abstract*— Faecal matter is globally viewed as an expensive liability with its potential value as a resource neglected. This arises majorly due to the associated large infrastructure capital costs, operation, maintenance, rehabilitation and expansion of the sewage treatment plants. However, there is need to find sustainable ways to utilize this resource as sludge is expected to rise as the population increases. In Kenya, firewood and charcoal have been and will still be the major source of energy in households in rural and peri-urban households. This consumption has led to the decline of the forest cover in Kenya. Hence, there is an urgent need to find alternative fuels to replace the traditional ones. It suffices to say that biomass such as agricultural residues, sludge, wood and animal waste can be agglomerated to form briquettes which can be used as an alternative sources of energy. Also there are growing concerns in the economical disposal of the sawdust at the country wide dotted timber workshops and saw mills. The research was therefore conducted on this background to establish whether faecal matter and sawdust can be densified and used as a source of energy. The research focused on selected physical and combustion characteristics of faecal matter and sawdust briquettes using different ratios and binders. The briquettes were sun dried for two weeks and subjected to various tests to determine their moisture content, density, volatile matter, fixed carbon, ash content and calorific value. The activities carried out included pre-treatment of drying, carbonization, size reduction, binding and agglomeration of faecal matter and sawdust. Molasses and boiled faecal matter formed the binders and a rotating drum with the technique of non – pressure agglomeration was used to form fireball briquettes. Carbonized faecal matter and sawdust were mixed at the ratios (3:1, 1:1 and 1:3) and bonded with a binder at 10%. It was found that moisture content and density ranged between 6.9% - 8.6% and 499 kg/m3 – 745 kg/m3. The volatile matter, ash content/caloric value of the bonded briquettes depended on the type of binder and raw material used. Molasses had the highest volatile matter at 56.3%. Faecal matter had the highest ash content of 52.4% and calorific value of 23.246 MJ/kg. The results suggest that the faecal matter and sawdust could be developed as a source of energy for domestic purpose.**

Keywords — **Binders, faecal-sawdust-briquettes, physical-combustion characteristics and ratios.**

I. INTRODUCTION

Fuel wood is a biomass which is widely used in households for cooking, heating and lighting. In Kenya, the annual energy consumption is 70% fuel wood, 21% petroleum and 9% electricity (Matiru, 2007). Fuel wood supplied 89% and 7% rural and urban household energy respectively in the year 2000 (IIED, 2010). Today it is known that charcoal provides domestic energy for 82% of urban and 34% of rural households (GoK, 2013). Due to deforestation, Kenya's closed forest canopy was 6.99% in 2010 (Republic of Kenya, 2016) and in 1963 the forested area in Kenya was estimated at 10% (Gachuri, 2015). The situation is expected to decline further as the charcoal demand is projected to double from the year 2000 to 2030 because of the expected high rates of urbanization in Sub-Saharan Africa (SSA) (Arnold *et al*., 2006).

Apart from fuel wood, there are other biomass which can be utilized to provide energy such as agricultural residues, sludge, wood chips, poultry waste and sawdust (Dhughana, 2011). There is also a growing need for renewable and sustainable energy sources to serve as alternative to traditional household sources of energy. According to Wairire (1994), the economical disposal of sawdust and wood shavings is a growing concern to the wood industries. This is because sawdust is burnt releasing a lot of smoke which pollutes the environment or it is disposed in no-man's land such as railway reserves. In Kenya, the amounts of sludge is expected to increase as the urban population is projected to rise from 22% in the year 2009 to 41% in the year 2050 (UNDESA, 2008). Oladeji (2010) also affirms that biomass can be upgraded and used as fuel by determining parameters such as calorific value, ash content, density and moisture content.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 4, April 2017)

Grover and Mishra (2006) found out that loose biomass can be upgraded by agglomeration in order to improve their physical and combustion properties. According Li and Liu (2000), a moisture content of 15% and above results into less dense briquettes. In addition, briquettes below 4% moisture content crumble and absorb moisture from atmosphere. The findings of Chirchir *et al*. (2013) showed that the density of the original materials have a direct impact on the briquettes densities. The carbonized material is less dense but after agglomeration its volumetric energy density increases (Dhughana, 2011).

The calorific value of carbonized material is influenced by the type, chemical composition and moisture content of the biomass (Jenkins *et al*, 2008). According to Ndiema *et al*. (2002), Dermirbas and Sahin (2001), the ash content depends on the elemental composition of the biomass. Little information exists on the physical and combustion properties of spherical faecal matter-sawdust briquettes. The aim of this study was to find suitable ratio and binder of faecal matter-sawdust briquettes which can be utilized as energy by determining selected physical and combustion characteristics.

II. Material And Methods

Raw Materials Preparation

Domestic sludge was obtained from the exhausters trucks using buckets and poured into the drying beds in a greenhouse to dry for a period of two weeks. Once the sludge dried to 10 % moisture content, it was carbonized in a drum kiln. The sawdust was collected from the saw mills in Nakuru town, dried in the greenhouse drying beds for two days to a moisture content of 10% and carbonized. Later on, the carbonized faecal matter and sawdust were reduced into small particle sizes of about 1 mm using a hammer mill. Milled faecal matter and sawdust were mixed in the mix ratios of 1:3, 1:1 and 3:1. To form a binder solution, 1kg of dried and milled uncarbonized faecal matter was boiled in 20 litres of water for 3 hours. The boiling of the uncarbonized faecal matter was necessary to eliminate harmful bacteria such as E.coli, Strep. faecalis and Salm. typhimurium which do not survive at temperatures above 62^0 C (Jorgensen.A.J *et al*. 1998).The binder amount was 10% of each mix ratio by weight.

Briquetting

The rotating drum was used in making the fireball briquettes. In each session of briquetting, 18 kg of the mix ratio was poured on the bed of the rotating drum. As the briquetting machine rotated 2kg of the binder (boiled faecal matter or molasses) was sprinkled.

The briquettes formed by nucleation, coalescence and consolidation to a diameter of 40mm. After briquetting process the briquettes were spread on the beds to dry for four days and selected to determine the following physical and combustion characteristics.

A. Moisture Content

Three briquettes were taken from each set of the ratios. The briquettes were weighed using an electronic balance. The oven was pre-heated to an internal temperature of $(105\pm5)^0$C, samples were then be put in it and logging of the weight was done after every one hour. The sample was considered oven dry when the weight remained unchanged to within (1g) for two consecutive measurements. The moisture content was determined as per ASTM D-3173-87(39) (2004a) Specification and equation 1.

$$M_{wb} = \frac{M_w}{M_w + M_{dm}} \qquad (1)$$

Where (M_{wb}) is moisture content in wet basis, (M_w) amount of the moisture content (kg), (M_{dm}) amount of dry matter (kg)

B. Density

Three samples were be collected from each ratio for determination of the density. The diameter of each briquette was measured using the vernier caliber and mass using an electronic balance. The density was determined as per equation (2).

$$\rho = \frac{m}{v} \qquad (2)$$

Where (ρ) is density (kg/m^3), (m) briquette mass (kg) and (v) volume (m^3).

C. Volatile Matter (%Vm)

The percentage volatile matter was determined by using the standard method, ASTM 872-82 whereby a given mass of the briquette sample was pulverized in a crucible and placed in an oven until a constant weight was obtained. The briquettes were then kept in a furnace at a temperature of 550°C for 10 min and weighed after cooling in a desiccator. The percentage volatile matter was calculated as equation 3.

$$\%\,V_m = \frac{ODW - Ws}{ODW} \times 100 \qquad (3)$$

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 4, April 2017)

Where ODW - Oven Dry Weigh, Ws - Weight of sample after 10 min in the furnace.

D. Ash Content

Ash content was determined by weighing one gram of the sample and putting it in a crucible and covering it with a lid. The crucible was placed in a muffle furnace and heated gradually to temperature of 750^0 C within two hours. It was then allowed to cool and weighed. The ash content was determined according to ASTM Standards D 3174 - 97 (1998) Specifications and equation 4.

$$PAC = \frac{A}{B} * 100\% \quad (4)$$

Where (PAC) is percentage ash content, (A) and (B) weight of ash and briquette respectively.

E. Fixed Carbon

Fixed carbon was calculated by subtracting the sum of (%) volatile matter and (%) ash content from 100 % as shown in equation 5.

$$\% f_c = 100\% - (\% V_m + \% Ash) \quad (5)$$

Where f_c is fixed carbon, V_m volatile matter

F. Calorific Value

Calorific value is an indication of the amount of heat generated when one kilogram of fuel is burnt. The experiment was carried out using an adiabatic bomb calorimeter in accordance to standard procedures outlined in ASTM E 711-87 (2004b). A reaction vessel containing one gram of the sample and excess pure oxygen was immersed in the water bath at ambient conditions. The current was passed through an ignition wire leading to combustion of the reactants and release of energy which was absorbed by water bath causing the water jacket temperatures to rise. The calorific value was then read on the digital screen of the bomb calorimeter.

III. RESULTS

A. Moisture Content

The average moisture content of the faecal matter - sawdust briquettes at selected mix ratios ranged between 6% and 9% as shown in figure (1). The percentages depended on the type of binder as faecal matter bonded briquettes at the mix ratio of 1:3 had the lowest moisture content at 6.9% wb as compared with molasses bonded briquettes that had the highest moisture content of 8.6% wb.

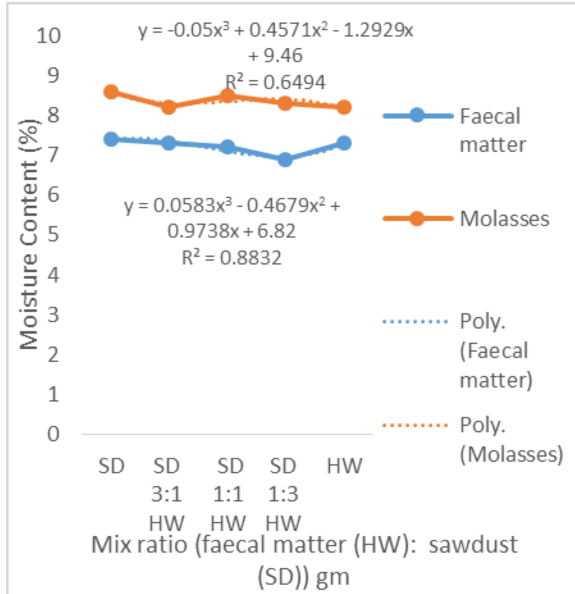

Figure (1)

B. Density

The determined density of briquettes ranged between 499 kg/m^3 – 745 kg/m^3 and 487 kg/m^3 – 734 kg/m^3 for faecal matter and molasses bonded briquettes respectively. Faecal matter bonded briquettes were higher in density than molasses bonded briquettes. Thus the density of the composite briquettes had a relationship on the type of the biomass and binder as shown in figure (2).

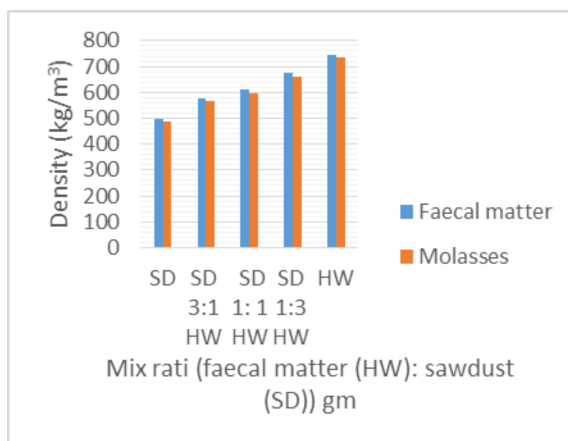

Figure (2)

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 4, April 2017)

C. Volatile matter

The volatile matter for the composite briquettes increased with increase in the mix ratio of sawdust and molasses as a binder and decreased with increase in the faecal matter. Pure sawdust briquettes had volatile matter of 56.3% and 54.7% when bonded with molasses and faecal matter respectively. The volatile matter was contributed to by the elemental composition of the materials used figure (3).

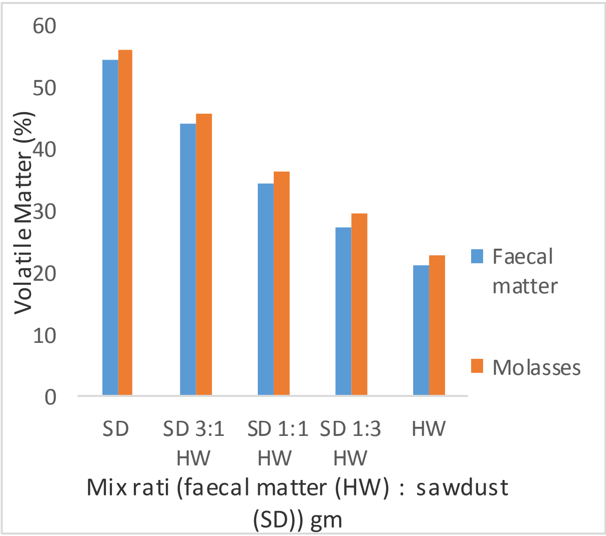

Figure (3)

D. Ash content

Pure faecal matter briquettes had ash content of 52.4% which declined with increase in sawdust in the mix ratios. The mean ash content of the sampled briquettes ranged between 12.4% - 52.4% and it depended on the type of binder and biomass used. Faecal matter bonded briquettes had higher ash content than those briquettes bonded with molasses. There was significant effect of the ash content as the mix ratio of faecal matter changed as shown in figure (4).

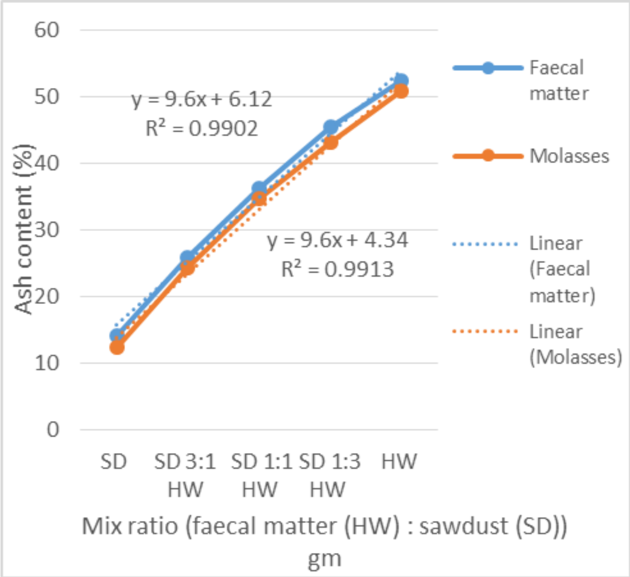

Figure (4)

E. Fixed carbon

The average fixed carbon of the composite briquettes decreased from 23.4% - 19.1% and 22.6% - 18.3% for faecal matter and molasses bonded briquettes respectively. The type of biomass influenced the fixed carbon content as in figure (5) as feacal matter briquettes had higher amount of the fixed carbon.

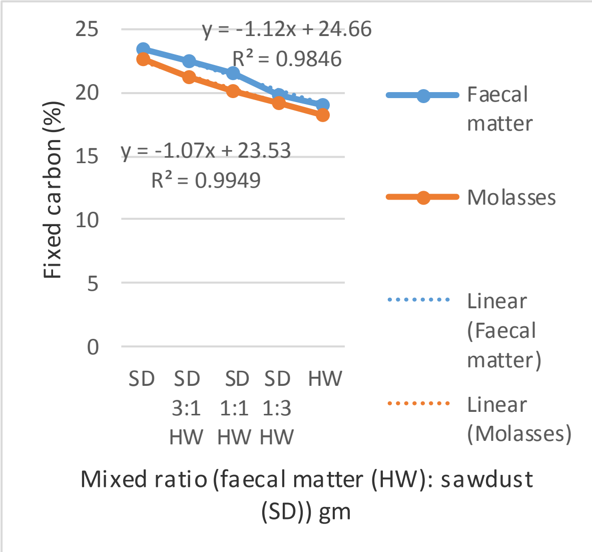

Figure (5)

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 7, Issue 4, April 2017)

F. Calorific value

The calorific value of faecal matter-sawdust briquettes inclined to the type of biomass and the binder as in figure (6). The average calorific values ranged from 20.385 MJ/kg – 23.083 MJ/kg and 20.527 MJ/kg - 23.246 MJ/kg for molasses and faecal matter bonded briquettes respectively. Faecal matter bonded briquettes had the highest calorific value of 23.246 MJ/kg. The calorific value was above 17.5 MJ/kg which is the DIN 51731 minimum value for briquettes to be considered as having satisfactory calorific value (Deutsches Institut fur Normung (DIN), 1996).

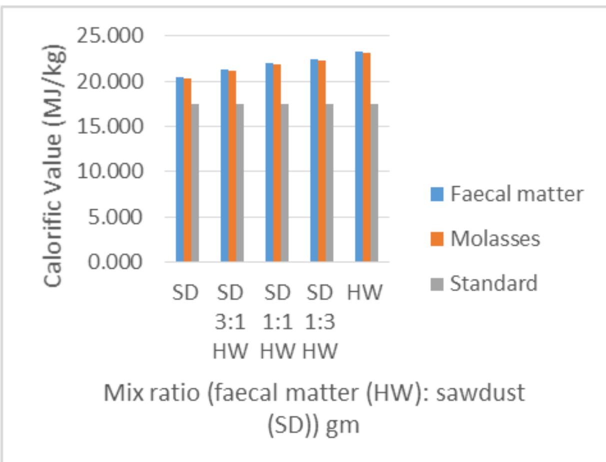

Figure (6)

IV. Discussions

Singh (2004) and Li and Liu (2000) found that briquettes with moisture content between (5-10)% are strong, durable and burn with little smoke as compared to briquettes with moisture content of 15% and above. Briquettes with moisture content below 5% tend to absorb the moisture from the atmosphere leading to decrease in the quality of the fuel (Fasina, 2008). In this study, the moisture content was between 6%-9% which was within the acceptable limit of less than 12% according to the German standards (Deutsches Institut fur Normung (DIN), 1996).

Density is directly proportional to the energy density and it depends with the original density of the biomass and the method of agglomeration. The densities of the raw materials were 0.4663 g/cm^3 and 0.1969 g/cm^3 for faecal matter and sawdust respectively. This explains why briquettes with a high percentage of faecal matter had higher densities as compared to those with high sawdust content.

The briquette densities obtained from this study were between (487 - 745) kg/m^3 which does not meet the requirements of the DIN 51731 German standard of (1000 – 1400) kg m^{-3}. The low briquette densities were due to the non-pressure agglomeration method used. In addition, there was a significant difference ($p \leq 0.05$) between the densities of all briquettes due to the binders used.

The ignitability of the fuel and the release of smoke is directly proportional to the amount of the volatile matter which depends on the raw material (Chirchir, 2011). The amount of volatile matter decreases during the carbonization process due to the reduction of oxygen leading to increase in the carbon content (Dhughana, 2011). Volatile matter of composite briquettes increased with increase in the mix ratios of sawdust and use of molasses as a binder. The results were supported by Sotannde *et al*. (2010) findings in which the volatile matter depended on the type of the binder and composition of original biomass.

According to DIN (1996), the minimum ash content recommended by DIN 51731 is 0.7% which is lesser than the range of (12.4 – 52.4) % obtained in this study. Ndiema *et al*. (2002), Demirbas and Sahin (2001) found out that the ash content depends on the elemental composition of the briquette feedstock. The mean ash content of faecal matter-sawdust briquettes increased with ratios of faecal matter as a feedstock and binder.

The calorific value of the briquettes in this study was higher than the minimum required calorific value of 17.5 MJ/kg for commercial briquettes DIN, (1996) and Sotannde *et al*. (2010). It is evident that at high proportion of faecal matter there was high calorific value obtained. However, the calorific values obtained in this study of (20.385 – 23.246) MJ/kg were lower than that of charcoal dust (28.7 MJ/kg) (Chirchir, 2011). This could be ascribed to the high ash content of the briquettes.

V. Conclusion And Recommendation

This study examined the physical and combustion characteristics of carbonized faecal matter-sawdust briquettes using selected binding agents. It was observed that the physical and combustion characteristics were significantly affected by the type of biomass and binder. It showed further that the faecal matter-sawdust briquettes at 50%/50% bonded with faecal matter exhibited the positive attributes for moisture content (7.3%), volatile matter (34.5%), ash content (36.4%) and calorific value (22.001 MJ/kg). Molasses bonded briquettes had lower calorific value as compared to faecal matter bonded briquettes.

The study revealed that faecal matter and sawdust are suitable for production of domestic solid fuel that can be used as a source of energy since the calorific value was above 17.5 MJ/kg (DIN, 1996) for all mix ratios. However, the results suggests that more study should be conducted on the emissions from the faecal matter bonded briquettes because of health purposes.

Acknowledgements

This research is part of the research partnership between Nakuru County Sanitation Programme (NCSP)/Nakuru Water and Sanitation Services Company Ltd. (NAWASSCO) and Egerton University. NCSP is a European Union co-funded programme implemented by NAWASSCO with the support of the Nakuru County government, Umande Trust, SNV Netherlands Development Organisation and Vitens Evides International. The authors gratefully acknowledge use of the services and facilities of the aforementioned institutions. We also appreciate John Irungu, Kelly Wanjala and Kevin Nyandeje for their support and assistance in the briquetting process.

REFERENCES

[1] Arnold, J., Köhlin, G., and Persson, R. (2006). Woodfuels, livelihoods, and policy interventions: changing perspectives. World Development, 34(3); 596–611.

[2] ASTM (American Society for Testing and Materials, (2004a). Annual Books of ASTM Standards Parts Gaseous Fuel; Coal and Coke, Atmosphere Analysis, Easton Maryland, USA.

[3] ASTM (American Society for Testing and Materials, (2004b). Standard Test Methods for Gross Calorific Value of Refuse – Derived Fuel by Bomb Calorimeter Annual Books of ASTM Standards.

[4] ASTM Standards D 3174-97, (1998). Standard test method for ash in the analysis sample of coal and coke. Annual Book of ASTM Standards, 5:05.05, West Conshohocken, PA: American Society for Testing and Materials, 303-302

[5] ASTM Standards E 872-82, (2013). Standard test method for volatile matter in the analysis of particulate wood fuels, ASTM Standards, International, West Conshohocken.

[6] Chirchir, D.K. (2011). Evaluation of Physical and Combustion Characteristics of Biomass Composite Briquettes. Master of Science Degree in Engineering Systems and Management. Egerton University, Nakuru.

[7] Chirchir, D., Nyaanga, D., and Kitheko, J. (2013). Effects of binder types and amount on Physical and Combustion Characteristics of Biomass Composite Briquettes. International Journal of Engineering Research, Science and Technology, 2(1).

[8] Demirbas, A., and Sahin, A. (2001). Evaluation of Biomass Residue; Briquetting Waste Papers and Wheat Straw Mixtures. Journal on Fuel Processing Technology, 55: 175 – 183.

[9] Deutsches Institut fur Normung (DIN). (1996). Testing of solid fuels - Compressed untreated wood - Requirements and testing. German National Standard, 4p.

[10] Dhughana,A. (2011). Torrefaction of Biomass. Master of degree in Applied Science. Dalhousie University, Halifax, Nova Scotia.

[11] Fasina, O. O. (2008). Physical properties of peanut hull pellets. Bioresource Technology. 99(5):1259-1266.

[12] Gachuri, W. G. (2015). Optimising the utilisation of sawdust of eucalyptus tree species. A fuel tea industry.Master of Science Degree in Environmental and Biosystems Engineering. University of Nairobi, Nairobi.

[13] GoK, (2013).Analysis of the charcoal value chain in Kenya. Ministry of Environment, Water and Natural Resources.

[14] Grover, P., and Mishra, K. (2006). Biomass Briquetting Technology and Practices.

[15] International Institute for Environment and Development (IIED). (2010). Biomass energy in Kenya. Nairobi, Kenya.

[16] Jenkins, P., Baxter, C., and Miles, T. (2008). Combustion Properties of Biomass Fuel Processing Technology. Journal on Fuel Processing Technology, 54: 17 – 46

[17] Jorgensen et al. (1998). Decontamination of water by direct heating in solar panels. Journal of Applied Microbiology, 85: 441 – 447.

[18] Li Y., and Liu H. (2000). High pressure densification of wood residues to form an upgraded fuel. Biomass and Bioenergy 19(3):177 – 186.

[19] Matiru,V. (2007). Forest Cover and Forest Reserve Cover in Kenya Policy and Practices. Oxford Press. Nairobi, Kenya.

[20] Ndiema, C., Manga, P., and Ruttoh, C. (2002). Cashew Nut Shell Liquid: An agricultural by product with potential for commercial exploitation in Kenya, 2013 vol.15 no.1. Journal of Agriculture, Science and Technology.

[21] Oladeji, M. (2010). Fuel characterization of briquettes produced from corncob and rice husk resides. The Pacific Journal of Science and Technology, 11: 101–106.

[22] Republic of Kenya, (2016). National Forest Programme 2016–2030. Ministry of Environment and Natural Resources, Nairobi, Kenya.

[23] Singh,R. (2004). Equilibrium Moisture Content of Biomass. Journal of Bio Energy and Biomass, 26:251 – 253.

[24] Sotannde, O., Oluyege, G., and Abah, B. (2010). Physical and combustion properties of Briquettes from sawdust of Azadirachta indica. Journal of Forestry Research, 21: 63 – 67.

[25] UNDESA. (2008). World Urbanization Prospects. New York: United Nations Department of Economic and Social Affairs.

[26] Wairire, S.M. (1994). Sustainable Urban Development and Resources Base Sustenance. Master of Arts in planning, development of urban and region planning. University of Nairobi, Nairobi.