41^{st} WEDC International Conference, Egerton University, Nakuru, Kenya, 2018

TRANSFORMATION TOWARDS SUSTAINABLE
AND RESILIENT WASH SERVICES

Faecal matter-saw dust composite briquette and pellet fuels: production and characteristics

D. M. Nyaanga, P. A. Kabok, J. Mbuba, S. O. Abich., R. Eppinga & J. Irungu (Kenya)

PAPER 2891

This work relates to the sustainable development goal (SDG) 6.2 which relates to access to adequate sanitation and hygiene. Raw sludge emptied on to drying beds inside greenhouses was carbonized from milled materials (faecal matter, saw dust, banana stalks and market waste) and a binder (molasses and faecal matter). Four percentages (25, 50, 75 and 100) were variedly used. The average calorific value of faecal matter was found to be 13.1MJ/kg with average moisture content of 9.1%, volatile matter of 2.2%, ash content of 48.3% and fixed carbon of 40.4%. Caloric values of market waste, sawdust, banana talk and human waste were respectively found to be 2.5, 2.7, 3.2 and 4.0. The briquettes and pellets showed no pathogens, concentration of heavy metals were insignificant. Mixture of sawdust and faecal matter took shorter duration to boil water compared to faecal matter mixed with other biomass materials.

Introduction

The potential to supplement charcoal and firewood as heating and cooking energy sources has been explored by Nakuru County Sanitation Programme (NCSP) through SNV in selected estates of Nakuru town (capital of Nakuru County). It is the 4th largest town by population (307,990, by 2009 census) in Kenya with an estimated 75,216 households (CBS, 2010). In the less developed estates, pit latrines are used for human waste disposal which often need emptying as an option for abandonment/replacement due to land unavailability. Biomass such as human waste has properties (Jenkins et al.; 2008, Sivasanga et al., 2013; Paulrud, 2004; and López-González et al.,2013)) that can allow their densification into fuel briquettes and pellets but after preliminary treatment.

The need for development of biomass resources as an alternative energy source (Nunes et al., 2014) in Kenya is enhanced by diminishing fossil reserves, increasing cost of fuel and rising environmental air pollution concerns. This arises as Fuel wood is also widely used in households (Kenya) for cooking, heating and lighting and respectively. In the year 2000, it supplied 89% and 7% rural and urban household energy (IIED, 2010). Matiru (2007) reported the annual energy consumption in Kenya as 70% fuel wood while respectively petroleum and electricity constituted a lower percentage (21% and 9%). About 1.6 million metric tonnes of charcoal is produced annually (Gachuri, 2015) thus creating a huge effect on deforestation and provided domestic energy for 82% of urban and 34% of rural households (GoK, 2013).

Nevertheless, densification do minimize the disadvantages of non homogeneous properties and size when using biomass as an energy source. The restrictive factors (Arranz, 2011) are also compensated by its localized nature and availability that provides substantial socio-economic and environmental benefits. The factors include low bulk densities and heterogeneity in moisture and granulometry, among others. Pelletizing and briquetting are currently the most commonly used techniques among those available (Grover and Mishra, 1996).

The availability of saw dust and sludge though can be a nuisance on the onset, they would make economic sense when used as components of briquettes. According to Wairire (1994), the economical disposal of sawdust is a concern to the wood industries as amounts of sludge are expected to increase as the Kenya's urban population rises, estimated at 22% in 2009 and to increase to 41% in 2050 (UNDESA, 2008). Burnt sawdust pollutes the environment. Therefore, such loose biomass can be upgraded by technologies such as carbonization and agglomeration to be used efficiently as a source of energy.

Material and methods

Project sites

The project and research site was at the NAWASSCO's Domestic Treatment Plant at Kaloleni in Nakuru Town (Latitude *0° 18′ 11.156″ S Longitude 36° 4′ 48.094″ E*)) faecal matter was collected from Low income pilot areas of the town namely Kaloleni, Kivumbini and Manyani estates. Laboratory analysis was done at the University of Nairobi, Chemistry Department.

Material collection, drying, carbonization and milling

Sludge was collected from septic tanks and pit latrines in Nakuru municipality and delivered to the site using bowsers. It was mixed with sawdust, banana stocks and market wastes in order to enhance its combustion characteristics and production capacity. Figure 1 gives the flow chart for the fuel production stages.

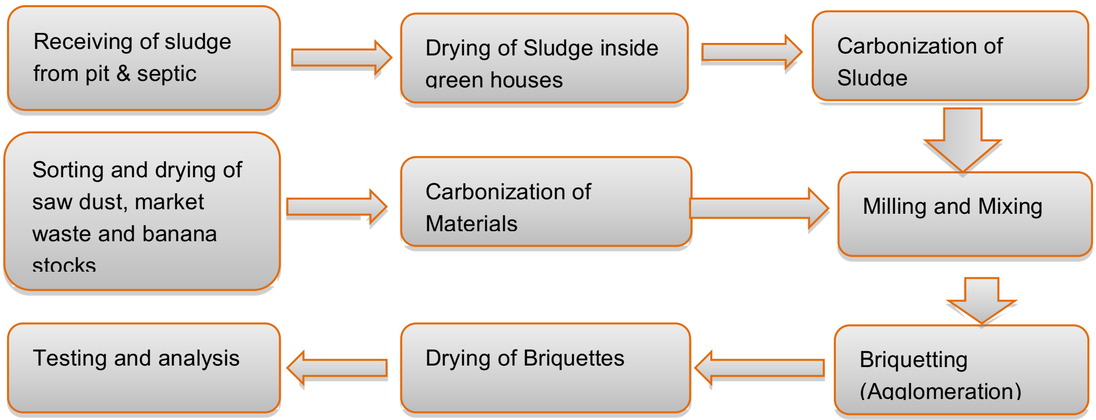


Figure 1. Briquette production process flow chart

Sludge, in its raw form, contains excess moisture that must be removed ahead of carbonization and briquetting/palletising processes. The raw sludge was foremost emptied onto drying beds inside green houses at the Nakuru NAWASSCO Sewage Treatment. Carbonisation process followed by conversion of organic substances (sludge, banana stalks and market waste) into carbon or a carbon-containing residue through pyrolysis or burning under limited oxygen supply, done using locally fabricated drum kilns. The methods involved use of drums which were either open at the top or fitted with chimneys and were effective for sludge, banana stalks and market waste. The methods were not effective in carbonizing sawdust because of the size of grain. A modification of cutting the drum into two halves along the length specifically to carbonise saw dust was effective compared to other methods, save for volume handled. The different carbonized materials were reduced (hammer and roller technology/mill) in sizes and then passed through a 2mm sieve to get powder for mixing. The small particles enable adequate distribution of binding material which permits higher compactness of the briquette or pellet.

Briquetting and pelletizing

This involved compacting carbonized materials (faecal matter, saw dust, banana stalks and market waste) and a binder (molasses, faecal matter) in specific moulds by mechanical machines that enhanced coagulation of the fine particles into dense products. Mix ratios of raw material in various proportions were adopted from Chirchir et al. (2011); four percentages of 25, 50, 75 and 100) were used for faecal matter, sawdust, banana stalk. One litre of a selected a binder was diluted in 20 litres of water for making 50 kg of the mixed carbonised materials for briquette production as recommended by Mbuba et al. (2016) to enable bonding to a given shape.

The twenty-two (22) different samples of composite briquettes (based on different ratios of feedstocks with faecal matter as a constant) were made using the different binding materials. The briquettes were then allowed to dry for 3 days on the drying racks in the open air/sun or in the greenhouse. Similarly, different proportions of raw materials faecal matter, saw dust, banana stalks and market waste) were mixed with a cassava starch binder then fed into a pelletizing machine where pressure was applied mechanically to form fuel pellets. A total of thirteen (13) samples were prepared and characterized for performance as a fuel.

Results and discussions

Sludge characteristics

Raw sludge from different sanitation systems (pit latrines, septic tanks and school sanitation) were characterised in terms of pathogen and chemical loads; and physical and combustion properties. The sludge was found to contain high amounts of pathogens including bacteria and other disease causing microorganisms including *Salmonella, Shigealla*, *Escherichia coli* (E. coli), *Ascaris Lumbricoides* and *Sclustosoma mansonic* eggs and heavy metals such as zinc (93.5ppm) and copper (45.8 ppm) and lead (10.4 ppm) (Wilkister et al; 2018).

The levels of heavy metals were lower than recommendations by WHO (WHO, 1993). However, for safety of working with the sludge, pathogens were eliminated by intense temperatures through heating to boiling point at 930 C for a period of 3 hours for it to be tested as a binder. Similarly, carbonization of dry sludge involved heating it in a drum kiln (200l drum cut into 2, lower half with air inlets and upper half with chimney) to temperatures as high as 4500 C and 6000 C depending on the kiln management.

The physical and combustion characteristics of faecal matter from different areas are as in Table 1 below. Note that the volatile matter and calorific matter of any organic matter have bearing on the suitability of the material as an energy recovery resource.

Table 1. Physical and combustion characteristics of faecal matter

Sample	Moisture content (%)	Volatile matter content (%)	Ash content (%)	Density (kg/m^3)	Fixed carbon (%)
Pit latrine 1	7.8	2.2	46.7	487.4	43.4
Pit latrine 2	10.2	2.3	51.2	494.3	36.4
Septic tank 1	10.9	2.9	50.6	436.8	35.6
Septic yank 2	9.2	2.3	48.1	453.2	40.4
School sanitation blocks	7.3	1.2	45.1	578.4	46.4
Average	**9.1**	**2.2**	**48.3**	**490.0**	**40.4**

The calorific value of faecal matter was high at 13.1 MJ/kg. The averages of physical properties of faecal matter namely moisture content, volatile matter, ash content and fixed carbon were 9.1%, 2.2% 48.3%, 40.4% respectively, while density was 490 kg/m3. These properties compare well with what is reported in literature (Muspprattet et al., 2014).

Briquette and pellet characteristics

The fuel briquettes and pellets were tested for a number of parameters to ensure safety and fuel viability. The briquettes and pellets showed no presence of pathogens. Concentration of heavy metals such as zinc (93.5ppm), copper (45.8 ppm) and lead (10.4 ppm) may be attributed to carbonisation, though (Wilkister et al, 2018) indicate that these levels are within limits. Cadmium was not detected in the raw and treated faecal matter. This implies that the pre-treatment for faecal matter was effective in elimination of pathogens but heavy metals increased by densification of the biomass fuel products. The different briquettes and pellets were evaluated for performance in three types of cook stoves commonly used in Kenyan households namely Gasifier cookstove-Terry model; Jikokoa and Kenya ceramic jiko (KCJ). This mainly tested the burning characteristics of the fuel products on the time required to ignite, boiling time (boil 1 litre of water), and the rate of burning, smell of the product when burning among others.

Round shaped briquettes were identified to have better combustion characteristics compared to triangular and cylindrical briquettes. Charcoal briquettes were found to have the highest calorific value of 4.5 kcal/g. The caloric values of market waste, sawdust, banana talk and human waste were found as 2.5, 2.7, 3.2 and 4.0 respectively. Fig 1 presents the effect of various mix ratios on calorific value of faecal matter saw dust briquettes.

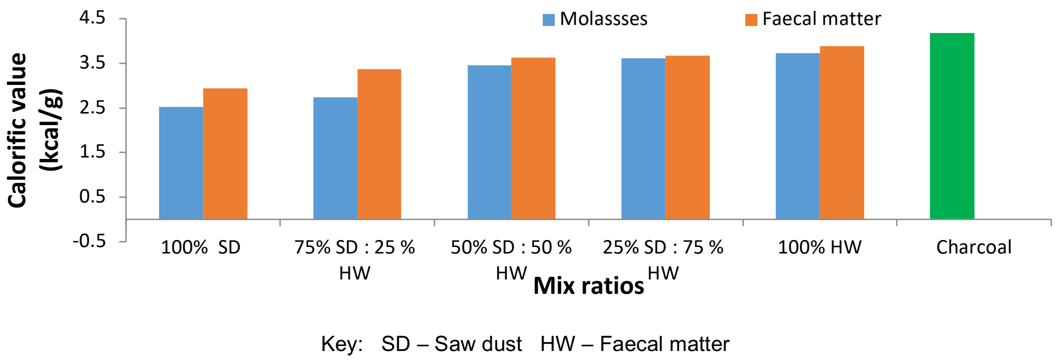


Figure 1. Calorific value for faecal matter briquettes with two binders and charcoal

Though, it was observed that there was significant difference in calorific value when different raw materials mixing ratios were used, there was no significant effect on calorific value when molasses and faecal matter were introduced as binding agent. The average calorific value of faecal matter and sawdust was 18.8 MJ/kg. This value is above 17.5 MJ/kg the minimum required for briquettes to perform satisfactory (DIN, 1996).

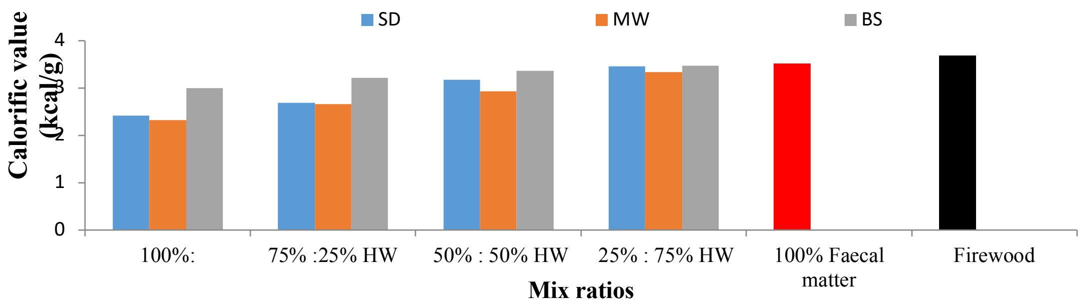
The carbon monoxide emitted after burning of fuel products with different mix ratios of biomass, showed that; charcoal dust briquettes produced the highest amount of CO (39%) and sawdust emitted the least amount (20%). CO emitted were respectively 35%, 32%, 25% and 22 % for 100%, 75%, 50% and 25% of human waste mix ratios. There was no significant difference in amount of carbon monoxide from the different ratios used, but the difference was significant when materials were carbonised separately. Sawdust and faecal matter had low carbon monoxide emissions compared to mixture of faecal matter with other types of biomass.

Performance of fuel pellets

There was a difference in calorific value of the pellets made from different the mix ratios and different raw materials (Figure 2).

In all the mix ratios, banana stalk had the highest calorific value followed by saw dust with human waste briquettes having the least calorific value. The calorific values obtained in this study of 10 MJ/kg to 16.7 MJ/kg are consistent with those obtained by Denibras (1999) based on waste paper and wheat straw mixtures. There was significant difference in percentage of ash content and mix ratios with different materials used for the briquettes. The market wastes had the highest ash content and saw dust showed the least ash content for all mix ratios. The ash content values were however higher than the tolerance level for fuel which should be below 4% (Grover, 1995). Njenga et al. (2013) and Demirbas and Sahin (2001) concluded 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 faecal matter used in this study therefore had a lot of incombustible elements.

There was a significant difference in time required to boil 1 litre of water considering mix ratios and different materials. A mixture of sawdust and faecal matter took relatively shorter duration to boil compared to faecal matter mixed with other biomass materials.



Key: SD – Saw dust, MW-Market waste, BS – Banana stalk, HW – Faecal matter

Figure 1. Calorific value of composite faecal matter pellets

Marketing of faecal biomass fuel

A market study was conducted to establish customer views and attitudes on faecal briquettes and pellets. (362 households and 238 businesses/institutions). The households were more receptive to briquettes than pellets due its compatibility with the fuel equipment and cost efficiency. Majority of the household's cook in confined places that are without defined kitchen space thus making them prone to indoor pollution. Controlled Cooking Tests showed that faecal matter briquettes burnt longer than charcoal and had less emissions. Consumers proposed pricing of briquettes less than half a dollar per 1kg and packaging in small quantities of 2kg or 5kg packets (Kimaru et al., 2017). The purchasing power is informed by household's income and therefore households indicated a preference to purchase the fuel. While perception towards the product is commonly overstated, households were found to be positive about faecal matter briquettes. This was mainly influenced by households understanding the production process and assurance on safety of the product. It is however recommended that, consumer education should be considered when introducing the products. In addition, research should be carried out on stoves to optimise performance of briquettes and marketing (Kimaru et al., 2017).

Conclusion and recommendations

The research findings do indicate that: Sludge has a relatively higher calorific value compared to sawdust, market waste and banana stocks. Sawdust was identified as the most appropriate biomass material to mix with faecal matter at a ratio of 50:50 in making fuel products for its availability, high calorific value and low ash content. The raw sludge had a high concentration of pathogens and adequate measures must be in place to ensure elimination before using sludge in making briquette and pellet fuel. Molasses was selected as the most appropriate binding agent for its properties and availability. The ratio of mixing binding agent and feedstock at 1:9 was found to be effective and appropriate. The round shaped briquettes produced by a rotating drum/ agglomeration technique was identified as the most effective for briquette making. The round shaped briquettes had better features and properties.

Acknowledgements

The authors would like to extend thanks to individuals and partner organisations involved. This research is part of the research partnership between Nakuru County Sanitation Programme (NCSP)/Nakuru Water and Sanitation Services Company (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 research benefitted from the Aqua for All managed VIA Water fund and Egerton University and University of Nairobi laboratories. The authors gratefully acknowledge use of the services and facilities of the aforementioned institutions. We also appreciate K. Wanjala and K. Nyandeje for their technical support in the briquetting process.

References

Africa Turnaround Limited 2017 *Biomass Fuel Market Study.* Study Commissioned by EU-Nakuru County Sanitation Programme.

Arranz, J. I. 2011 *Analysis of Densified of the Combination from Different Biomass Waste*. Doctoral Thesis, University of Extremadura, Badajoz, Spain.

Chirchir D., Nyaanga D and Githeko J. 2013 *Effect of binder types and amount on physical and combustion characteristics Int. J. Eng. Res. & Sci. & Tech,*2(1):13-20.

Demirbas, A. 1999 *Physical properties of briquettes from waste paper and wheat straw mixtures*. Energy Conversion and Management (40):437–445.

Demirbas A, Sahin A 1998 *Evaluation of biomass residue 1: briquetting waste paper and wheat straw mixtures*. Fuel Processing Technology, (55): 175-183.

Food and Agriculture Organization (FAO). (1987). *Simple technologies for charcoal making*, FAO, Rome, Italy.

Gachuri, W. G. 2015 *Optimising the utilisation of sawdust of eucalyptus tree species; a fuel for tea industry*. Unpublished MSc Thesis University of Nairobi.

GoK 2013 *Analysis of the charcoal value chain in Kenya*. Ministry of Environment, Water and Natural Resources.

Grover, P.D. And Mishra, S.K. 1996 *Biomass Briquetting, Technology, and Practices. Regional Wood Energy Development Programme in Asia*: Bangkok, Thailand; FAO. Field Document No. 46.

IIED 2010 *Biomass energy in Kenya*. Nairobi, Kenya. International Institute for Environment and Development.

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

Kimaru, L. Eppinga R. and Irungu J. 2017 *Consumer Pilot Study: Briquettes, Nakuru County Sanitation Programme.*

López-González, D., Fernandez-Lopez, M., Valverde, J. L. and Sanchez-Silva L. 2013 *Thermogravimetric- mass spectrometric analysis on combustion of lignocellulosic biomass.* Bioresource Technol. 143: 562-574.

Matiru, V. 2007 *Forest Cover and Forest Reserve Cover in Kenya Policy and Practices*. Oxford Press. Nairobi, Kenya.

Mbuba, M. Jesca, Nyaanga, D. M., Kabok, P. A., Reinilde, Eppinga *2017 Binders on Physical and Combustion Characteristics of Faecal Matter–Sawdust Briquettes.*

Mbuba, M. Jesca, Nyaanga, D. M., Kabok, P. A., Reinilde, Eppinga 2017 *Effect of Mix Ratios and Binders on Physical and Combustion Characteristics of Faecal Matter–Sawdust Briquettes.*

Muspratt A. M., T. Nakato, C. Niwagaba, H. Dione, J. Kang, L. Stupin, J. Regulinski, M. Mbéguéré And L. Strande 2014 *Fuel potential of faecal sludge: calorific value results from Uganda, Ghana and Senegal.* Journal of Water, Sanitation and Hygiene for Development 4(2)223-230.

NAWASCCO 2016 *From Pit to Product: Biomass-fuels and Bio-fertilisers from Faecal Matter and Urine in Nakuru, Kenya.* VIA Water Progress Report. Nakuru Water and Sanitation Services Company.

Njenga, M. 2013 *Evaluating Fuel Briquette Technologies and their Implications on Greenhouse Gases and Livelihoods in Kenya*. PhD. Thesis, Faculty of Agriculture, University of Nairobi, Kenya.

Nunes, L.J.R.; Matias, J.C.O.; Catalao, J.P.S. 2014 *Mixed biomass pellets for thermal energy production: A review of combustion models*. *Appl. Energy 127*, 135–140.

UNDESA 2008 *World Urbanization Prospects* United Nations Department of Economic and Social Affairs. United Nations Department of Economic and Social Affairs Report New York.

Ward , B. J. 2009 *Human Fecal Biochar Briquettes from the Sol-Char Toilet for Use as a Solid Fuel in the Developing World*. Thesis submitted to B.S., North Carolina State University.

WHO and UNICEF 2017 *Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines* [online] [viewed 15 June 2015]. Geneva: World Health *Organization (WHO) and the United Nations Children's Fund (UNICEF), 2017. Licence: CC BY-NC-SA 3.0 IGO*. Available from www.who.int/.../news/.../2017/launch-version-report-jmp-water-sanitation-hygiene

WHO 1993 *Guidelines for drinking-water quality*, Vol. 1. Geneva, World Health Organization.

Wilkister, N., Nakitare, K., Kimaru, L. and Eppinga, R 2018 *Microbial Safety of Faecal Sludge for Biomass Fuels and Bio-Fertilizer Production: Case Study of Nakuru County Sanitation Programme.*

Contact details

Prof. Daudi Nyaanga is an Associate Professor in Agricultural Engineering at Egerton University with particular interests in energy and nutrient recovery from organic waste among others. Dr Peter Kabok is a Senior Lecturer at Jaramogi Oginga Odinga University with interests in energy while Jesca Mbuba and Abich Otieno are graduate students at Egerton University. Reinilde Eppinga works for NSCP as an SNV WASH Advisor and John Irungu as the site manager for NAWASSCO where the research was done.

Daudi M. Nyaanga
Egerton University, Kenya.
Tel: +254 721 285 231
Email: dmnyaanga@egerton.ac.ke
www: www.egerton.ac.ke

Kabok P Aguko
Address: Jaramogi Oginga Odinga University.
Tel: +254 728621446
Email: kabpaguko@jooust.ac.ke
www.jooust.ac.ke
