

Classification and Characterization of Solid Waste – Case Study of Egerton University and its Environs, Kenya

Nyoti Stephen G. Mugo¹, Nyaanga D.M.², Owido S. F. O³, Owino George O.⁴ and Muniu John M.⁵

¹ Department of Industrial and Energy Engineering, Egerton University, P.O.BOX 536-20115, Egerton. Kenya. Email smnyoti35@gmail.com

²Professor, Department of Agricultural Engineering, Egerton University e-mail dmnyaanga@gmail.com

³Professor, Department of Crops, Horticulture and Soil, Egerton University e-mail sfoowido@yahoo.com

⁴Doctor, (Ph.D) Industrial and Energy Engineering, Egerton University e-mail george_opar_o@hotmail.com

⁵Department of Electrical and Control Engineering, Egerton University e-mail muniu@egerton.ac.ke

Abstract - The classification and characterization of solid waste is important in order to plan for long term and design solid waste management of efficient and economical systems. Such systems includes the selection and operation of equipment for treatment and handling of waste, types of disposal facilities that will allow energy generation and resource recovery. The major waste management problems identified from Egerton University and its environs were poorly designed collection bins, inappropriate bin locations, inadequate labour for collection and transportation of waste lack of appropriate waste treatment and disposal facilities. Wastes were classified into four different categories as per their sources which were domestic/ residential, agricultural, institutional/industrial and commercial. Wastes were characterized based on Moisture Content (MC), ash content, Volatile Matter (VM), fixed carbon, density and calorific value. The MC was obtained by weighing a container when empty and with waste sample, placing it in a drier for 12 hours at 102°C and reweighing it when cold. The VM was determined by putting a sample into weighed crucible, placing it into a furnace at 950°C for 10 minutes and recording the weight when cold. The mean values of various parameters were: moisture content 37%, ash content 12%, volatile matter 42%, fixed carbon 9%, density 232kg/m³, and calorific values 10MJ/kg. Since the waste had high calorific values and volatile matter, then it could be used for waste to energy methods.

Key Words: Ash content, Calorific value, Characterization, Classification, Density, Moisture content, Solid waste and Volatile matter.

1. INTRODUCTION

Solid waste include but not limited to polythene papers, use plastics, rubber, old automobile tyres, old dresses, cotton pieces, skin pieces, leather, charcoal, old newspapers, junk mail, duplicating papers, charts, today's meal scraps, rotten fish, vegetable peelings, rice husk, wheat husk, maize cobs, sawdust, animal manure, grass clippings, street sweepings,

rotten seeds grains, dust, broken furniture, sewage sludge and abandoned materials. The composition of waste is influenced by external factors such as geographical location, the population's lifestyle, energy sources and weather as reported by Katiyar *et al.* 2013 [1], Arsad *et al.* 2006 [2] and Zekkos *et al.* 2010 [3]. Solid waste management activities include; waste segregation, collection, transportation, treatment and disposal. Waste management standards is still poor and outdated in many developing countries, with poor waste generation rates documentation and its composition, inefficient storage and collection systems, disposal of wastes with toxic and hazardous (Ayub *et al.*, 2013 [4]). The various waste disposal methods used are open dumping, recycling, landfilling, composting, and incinerating. Waste recycling which includes photocopying papers, plastics, can, glass, aluminum and other metals is cheap and saves resources, money, energy and reduces emissions (Omari, 2015 [5], Henry *et al.*, 2006 [6]). Some of the medical wastes find their way into open dump sites which may results to scavengers retrieving items and reusing, leading to serious health implications due to the transmission of infectious disease. However, if waste contains large fraction of plastics, polythene papers which are non-decomposable and medical waste which are hazardous then, incineration is better disposal method as reported by Chang *et al.* 2008 [7] and Ansah, (2014) [8].

Manohara and Belagali, (2014) [9] reported that, the system required careful segregation, physical description, size measurement, and testing of all waste constituents which was not done as required by law. The testing of all waste constituents were challenging tasks and time consuming. Paolo (2010) [10] investigated the effect of waste separation at the source on low calorific value of municipal solid waste where he emphasized that separate collection plays an irreplaceable role in waste management. Dixon and Langer (2006) [11] presented a framework for classifying waste constituents based on their material type, shape, size and degradation potential which considered broad range of waste physical constituent and mechanical properties that appear to affect the engineering properties.

Waste characterization is a major factor in the waste management system. It is considered as a basis for the design of efficient, cost effective and environmentally compatible waste equipment. The percentage components in waste to be combusted must be determined on the basis of waste characterization analysis (Beck, 2005 [12]; Chang *et al.*, 2008 [7]; Alhassan and Tanko, 2012 [13]). The primary purposes for waste characterization are: data becoming basis for planning economic analysis, design and subsequent management and operation of a disposal system or material energy resource recovery facilities; rehabilitation or retrofit of facilities; plant optimization and emission monitoring as noted by Oumarou *et al.* (2012) [14]. The waste composition must be known in order to select the most economical collection means, plan for suitable sanitary landfill sites, design and operate an efficient incineration plant, design compositing plant or grinding plant, forecast accurately the cost and efficiency of operation when choosing a particular method of disposal and finally forecast future demand (Aguilar-Virgen *et al.*, 2010 [15]).

This study focused on the classification and characterization of solid waste in Egerton University and its environs within 2015-2016 period, for the purpose of choosing the best and appropriate waste treatment and disposal options. The solid waste is classified into two major groups which are the sources-based and types. The waste were classified into four different groups according to the waste sources-based which included domestic/residential, agriculture, institution/industrial and commercial. The waste type-based classification consider the physical, chemical, and biological characteristics of wastes. This included garbage, ashes/residues, combustible/non-combustible, bulky wastes, street wastes and biodegradable/non-biodegradable wastes. The parameters considered for waste characterization included moisture content, ash content, volatile matter, fixed carbon, density and calorific values determine in order to understand the elemental components of sample.

2. MATERIALS AND METHODS

2.1 Study Area and Materials Preparations

The waste sampling and experiments were carried out from the month of May to August, 2015 at Egerton University and its environs. The average ambient temperatures ranged between 19-24°C. The research was done at Egerton University in the Department of Agricultural Soils and Animal Science Nutritional Laboratories. Solid waste samples were collected from the University dumping site (student cafeterias, departments of crops, Horticulture and Soil, Animal Health, Human Anatomy, Medical) and neighbouring residential estates (Njokerio, Ngundu, and Green Valley). The solid waste samples were obtained from collection bins. Waste samples were prepared by drying for three days, chopped into small pieces and packed separately as per their types. The samples were reduced further to less than 1mm size to form a homogenous material in order to increase surface area which would allow easier heat penetration. They

were then packed, labelled and stored in sealable polythene bags to prevent any changes in their physical and chemical properties.

2.2 Classification of solid waste

Solid wastes are the organic and inorganic waste materials which includes both heterogeneous wastes from the urban and rural community as well as a more homogeneous accumulation. Wastes are classified on the basis of source of generation and type. The solid wastes sources and types as well as composition and the rate at which they are generated/disposed is essential for the design and operation of the functional elements associated with waste management system.

The study used the source-based classification which included the domestic/residential, agricultural, institutional and commercial wastes. Domestic/residential wastes are from household, dwellings, apartments and consists of leftover food, vegetable peels, old clothes and ashes. Agricultural waste consists of spoiled food grains and vegetables, agricultural remains and litters generated from fields, orchards, vineyards and farms. Institutional wastes mainly consists of photocopying papers, polythene papers, and plastic generated from administrative and public buildings such as research institutes, hospitals, offices, schools, colleges, universities and other educational centers. Commercial wastes consisting of leftover food, glasses, metals, ashes, polythene papers and plastics generated from stores, restaurants, markets, hotels, motels, shops and supermarkets stores, offices, hotels, shops, lodges, restaurants, business centers, warehouses, markets, slaughter houses and other commercial establishments. The wastes were manually separated out and placed into polythene bag corresponding to their categories or types. The weight of each of these sorted wastes was obtained and their average taken. These waste had the potential for recycling if they were sorted out from source as done in developed nations.

2.3 Characterization of solid waste

The percentage of the components in the wastes were determined on the basis of characterization. The wastes were characterized into two major groups which were physical and combustion characterization. The results of waste characterization were represented in the Table 3.1.

2.3.1 Physical characterization of solid waste

The physical waste characterization included moisture content and the waste density. The moisture content of wastes usually expressed as percentage per unit weight of wet or dry material while the density is expressed as mass per unit volume. The MC and the density was also used as part of the waste classification methods.

a) Moisture contents

In the wet-weight method of measurement, the MC in a sample was expressed as a percentage of the weight of the material when wet whereas in the dry-weight method, it was expressed as a percentage of the weight of the material when dry. The study used the dry-weight method. The moisture content was determined according to ASTM E871-82 [16] standard. An empty container was preheated for twenty minutes and then fifty grams of waste sample was quickly put into the container. The sample was placed in an oven at temperature 102°C for twelve hours and then cooled to room temperature and reweighed. The difference in weight represents the moisture content of the sample expressed in percentage. These MC in the samples were calculated using equation 3.1

$$M = \left\{ \frac{S - B}{S} \right\} \times 100\% \quad (3.1)$$

Where, M = moisture content in percentage (%),
S = weight of sampled waste in grams,
B = weight of sampled waste after heating in grams.

b) Density

The density of a sample was carried out as follows: the weight of an empty container of known volume V_1 was taken and recorded as W_1 . The waste sample was placed into the container until it overflowed. The contents in the container was settled by dropping it three times from a height of 20cm and the volume topped up with the remainder of the sample. If insufficient material which could not fill-up the container then, the unoccupied container volume V_2 would be measured. The weight of the container and its contents was taken and recorded as W_2 . For the filled-up container, the density in kg/m^3 , was calculated using equation 3.2

$$\text{Density} = \frac{W_2 - W_1}{V_1} \quad (3.2)$$

For a partially-filled container, the density in kg/m^3 , was calculated using equation 3.3

$$\text{Density} = \frac{W_2 - W_1}{V_1 - V_2} \quad (3.3)$$

2.3.2 Combustion solid waste characterization

The combustion characterization was done in order to estimate the heating value of solid waste. It was done to determine parameters like volatile matter, ash content, fixed carbon and calorific value as shown in the Table 3.1.

a) Volatile matter

The volatile matter was determined according to ASTM E872-82 Standard [17]. A twenty grams of sampled waste

was weighed and recorded before placing it in a weighed crucible. The crucible was covered to avoid contact with air during devolatilization. The crucible and sample was then placed in the muffle furnace chamber, power switched on and its temperature maintained at 950°C for ten minutes. The crucible was then removed and cooled to a room temperature. The crucible weight was recorded without disturbing the cover. Volatile matter calculation was determined using equation 3.4.

$$V = \left\{ \frac{A - B}{A} \times 100 \right\} - M \quad (3.4)$$

Where, V = volatile matter in percentage,
A = weight of sampled wastes before heating in grams,
B = weight of waste after heating in grams,
M = moisture contents determined from equation 3.1.

b) Ash content

Ash content of solid waste is the non-combustible residue left after waste is burnt. The ash content was determine using E1534-93 standard [18]. A twenty grams of sampled waste was placed into a weighed and uncovered crucible, then placed into the muffle furnace. The power was switched on and the temperature maintained at 725°C for one hour. The crucible and its content was removed from the furnace and weight recorded after it cooled. Ash content was determined using equation 3.5.

$$A_s = \left\{ \frac{A - B}{C} \right\} \times 100\% \quad (3.5)$$

Where, AS = ash content percentage,
A = weight of container and ash residue grams.
B = weight of empty container grams,
C = weight of sampled waste used (with moisture content)

c) Fixed carbon

The fixed carbon of a fuel is the percentage of carbon available for char combustion. Fixed carbon gives an indication of the proportion of char that remains after the devitalization phase. The fixed carbon was calculated by subtracting the sum of moisture, ash and volatile matter from 100 percent. It contains the errors and scatter of the other three measurements and is regarded as an approximate figure. Fixed carbon content was calculated using equation 3.6.

$$F_c = 100 - (M + V + A_s) \quad (3.6)$$

Where F_c = fixed carbon %, M = total moisture %
V = volatile matter %, A_s = ash content %.

d) Calorific value

The calorific value (CV) technique was based upon the principles of calorimetric. The CV of the sample was

determined using standard Auto bomb calorimeter type E2K Combustion Calorimeter System. The waste samples were dried and ground into small particles which were later sieved and compressed to form pallets. A reaction vessel containing the samples and excess pure pressurized oxygen at 30bars was immersed in a water bath at ambient conditions of 22°C. The firing circuit was tested and the calorimeter was adjusted by weighing sufficient water into the calorimeter vessel to submerge the bomb completely. The energy released by the complete combustion of the reactants within the vessel was absorbed by water bath, and caused the water jacket temperature to rise. A pure compound of a known heating value like benzoic acid was burned in order to obtain a thermal response, or water equivalence, of the apparatus to a particular heat release. In this experiment, the water equivalence W was determined using the tablet of benzoic acid. The CV of the waste were calculated according to ASTM D240-02 Standard [19] and the value of W was determined from the equation 3.7.

$$W = \frac{(P_{OC} \times M_C) + R_Y + R_Z}{\Delta T} \quad (3.7)$$

Where; P_{OC} = Calorific value of reference substance;
 M_C = weight of the reference substance
 R_Y = correction of formation of sulphuric acid;
 R_Z = sum of all the extraneous quantities of heat.
 Using a constant-volume oxygen bomb calorimeter, heating value of solid sample was calculated using equation 3.8.

$$HV = \frac{W \Delta T - D_1 - D_2 - D_3 - D_4}{m} \quad (3.8)$$

Where W = water equivalent, kJ/°C; ΔT = temperature rise °C
 D_1 = correction heat of formation of nitric acid;
 D_2 = correction heat of formation of sulfuric acid
 D_3 = combustion of gelatin capsule used with liquid testing
 D_4 = heat combustion of firing wire; m = weight of sample, g
 HV = heating value of fuel in kJ/kg

3. RESULTS AND DISCUSSION

This section includes the results of waste classification, characterization which included moisture contents, density, volatile matters, ash contents, fixed carbon and calorific value. The graphs were generated from summary results of the statistical data. Waste characterization experiments were repeated three times and graphs were discussed from the means, standard deviation and the Least Significantly Different (LSD).

3.1 Solid Waste Classification and Characterization

The waste were classified into four different groups which were domestic/ residential, agricultural, institutional/ industrial and commercial. Wastes characterization are

important in evaluating alternative equipment needs, systems, management program and plans especially with respect to the implementation of waste disposal, energy and resource recovery options. Table 4.1 shows the classification and characterization of solid waste. If waste sorting was done at the source and recycling carried out, then some of the incineration problems would be solved. Karak *et al.* (2011) [20] reported that recycling paper, plastics, glass and metal could reduce the cost of incineration and emission control. The study also revealed that scavengers hamper the collection process from the waste bins by salvaging for recyclables and scattering the waste creating unaesthetic environment. The scavengers include human being and the animals like dogs, donkeys and vultures. It was also observed that some residents poured waste water into collection bins making it hard for the incineration processes.



Fig 3.1: Mixed wastes deposited in the collection bins

Table 3.1: Classification and characterization properties

Waste Types	MC %	AC %	VM %	FC %	Density kg/m ³	CV MJ/kg
Domestic / Residential waste	55.69	12.33	26.66	5.32	307.64	4.26
Agricultural waste	39.44	15.59	36.46	8.51	251.83	7.67
Institutional / industrial waste	9.02	7.88	68.16	14.94	85.52	16.87
Mixed solid waste	34.72	11.94	43.76	9.58	228.58	10.27
Commercial waste	46.51	14.37	32.75	6.37	284.34	12.65
Average Value	37.08	12.42	41.56	8.94	231.58	10.34

3.1.1 Moisture Content

Figure 3.2 shows the effect of Moisture Content (MC) for different types of solid wastes. The MC is used to determine the quality for different types of waste as a fuel. Domestic/residential waste yielded the highest MC of 55.69% by weight followed by commercial which gave 46.51%, agricultural gave 39.44% and mixed waste gave 34.72%. Institutional waste, since they contained high percentage of polythene papers and plastics and do not absorb water from atmosphere making it to dry faster under the sun, yielded the lowest MC of 9.02%. The result of MC for commercial waste agreed with the findings by Das and Bhattacharyya, (2013) [21] who reported that municipal solid waste at Kolkata, India in 2010 gave MC of 46% by weight. The results also agreed with the findings by Chang *et al.* (2008) [7] who reported that MC for solid waste from Taiwan ranged from 37.6 to 65.9%. The results fulfilled the required values for fuel incineration without auxiliary, which should not exceed MC of 50% as reported by Medina *et al.*, (2013) [22]. The results differed slightly with the findings by Katiyar *et al.* (2013) [1] who noted that MC of municipal waste varied from 24.3 to 42.2% in Bhopal, India. The results also differed slightly with the findings by Yildiz *et al.* (2012) [23] who noted that the urban waste for developed countries gave MC values ranging from 15 to 40%. The results differed with the findings of Omari, (2015) [5] who noted that the MC for Arusha municipal waste ranges from 55.7 to 64.03% by weight. The results also differed with the findings by Alhassan and Tanko, (2012) [13] where they reported that the MC for municipal waste from Nigeria gave 10.25%. Therefore, to produce fuel with good properties and to ensure the sustainability of combustion, the waste had to be dried in oven as reported by Chen *et al.* (2014) [24]. The moisture content was calculated using equation 3.1

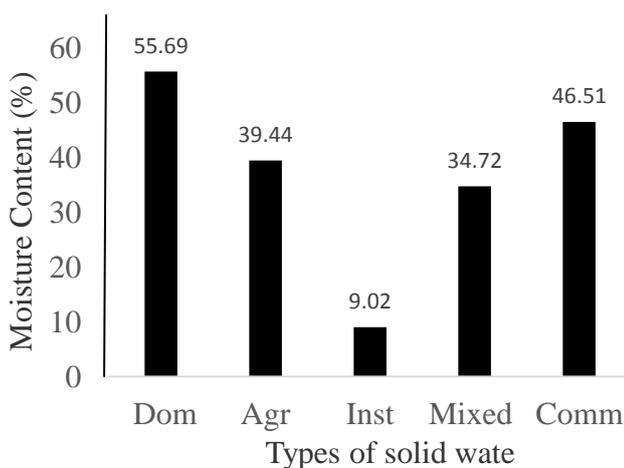


Fig 3.2: Moisture content for different types of wastes

3.1.2 Density of wastes

Figure 3.3 shows the density of different types of solid waste. Density is necessary for proper waste management

practices such as collection, storage, transportation and for designing the disposal facilities. Density varies with waste compaction, composition and decomposition. The domestic/residential waste yielded the highest density of 307.64kg/m³, since it contained ash residues from jikos, cooked food and vegetable peelings, agricultural waste gave 238.49kg/m³ and mixed waste (228.58kg/m³). The institutional waste yielded the lowest density of 85.52kg/m³ while the commercial yielded a density of 284.38kg/m³. The commercial waste results agreed with findings by Sivapalan *et al.* (2002) [25] who noted that the municipal solid waste in Kuala Lumpur gave the density ranging from 120 to 330 kg/m³. The results also agreed with the findings by Ogwueleka, (2009) [26] who reported that the density for municipal waste generated in some cities in Nigeria ranged from 280 to 340kg/m³. The results differed with the findings by Katiyar *et al.* (2013) [1] who reported that municipal solid waste of Bhopal gave an average density of 314.9 kg/m³. The result also differed with the findings done by Fobil *et al.* (2005) [27] who noted that municipal solid waste in the city of Accra gave the density ranging from 410 to 540 kg/m³. The waste density was calculated using equation 3.2 and 3.3.

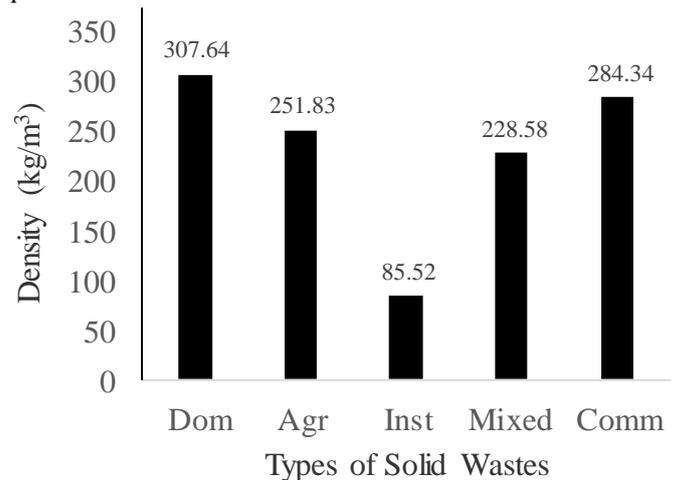


Fig 3.3: Density for different types of solid waste

3.1.3 Volatile Matters

Volatile matter of a solid waste fuel is vapor released when heated. Figure 3.4 shows the volatile matters (VM) of different categories of solid wastes. The institutional/industrial waste yielded the highest VM of 68.12% followed by mixed waste (43.73%), agriculture (36.46%), while domestic had the lowest VM of 26.66%. The commercial waste yielded VM of 32.75% which agreed with findings by Omari (2015) [5] who noted that the VM for municipal waste in Arusha ranges from 30.02 to 34.69 % by weight. The results differed with the findings by Katiyar *et al.*, (2013) [1] who noted that the municipal waste at Bhopal in India gave the VM of 46.6%. Since plastic, rubber, mattress and cotton wool wastes have high VM, they should be distributed and mixed with other wastes and not be concentrated in one

charge. Loading an incinerator with high VM wastes, meant that the heating values would exceed the designed thermal capacity of the plant. Also, high combustion temperatures due to high VM would damage the refractory lining, resulting into excessive emissions. Manyele and Kagonji, (2012) [28] noted that wastes with high VM would release more volatile gases at the primary chamber than wastes with low VM. The volatile matter was calculated using equation 3.5.

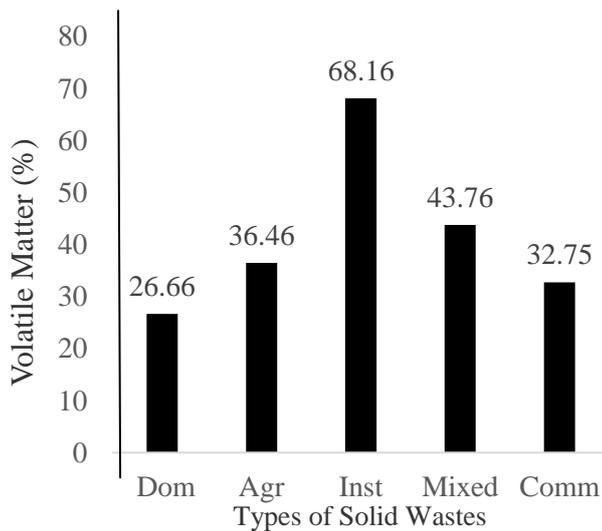


Fig 3.4: Volatile matters for different types waste

3.1.4 Ash Content

Figure 3.5 shows the Ash Contents (AC) of different types of waste. Agricultural yielded the highest AC of 15.59% by weight due cow dung followed by the domestic/residential which gave 12.33% and the mixed waste gave 11.94%. However, the institutional waste yielded the lowest AC of 7.88%. The commercial waste gave AC of 14.37% which agreed with the findings by Chang *et al.*, (2008) [7] who reported that the AC from municipal solid waste in Taiwan ranged from 4.4% to 15.7%. The results also agreed with the findings by Katiyar *et al.*, [1] who reported that the AC from municipal waste in Bhopal, India ranged from 9.7% to 22.93% by weight. Since the AC values were lower than 50%, which was considered optimal, then it would be possible to use incineration techniques without auxiliary fuels as waste final treatment as reported by De-Medina *et al.*, (2013) [29]. The ash content was calculated using equation 3.5.

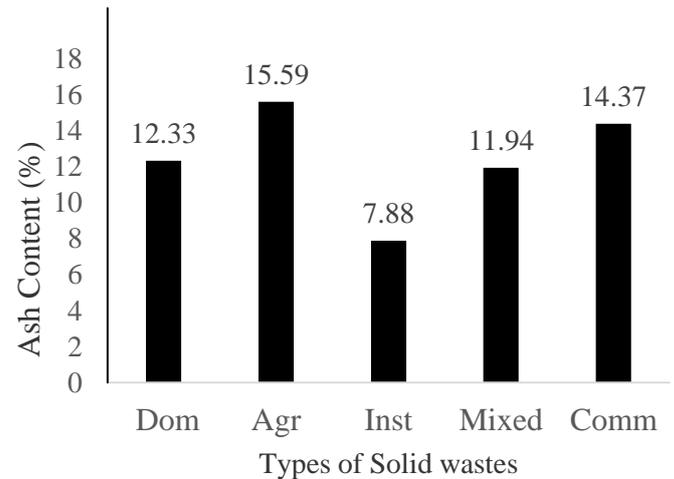


Fig 3.5: Ash content for different types of waste

3.1.5 Fixed Carbon

Figure 3.6 show Fixed Carbon (FC) from different types of waste. The institution/ industrial waste yielded the highest FC of 14.94%, followed by mixed waste which gave 9.58%, agricultural waste 8.51%, and the domestic/ residential waste 5.32% by weight. The commercial waste yielded the FC of 6.37% which agreed with the findings of Omari, (2015) [5] who reported that the FC from municipal waste in Arusha, Tanzania ranged from 1.72% to 7.02% by weight. The institutional waste results agreed with the findings by Oumarou *et al.*, (2012) [14] where they reported that the municipal wastes in Northern cities of Nigeria had an average FC ranging from 10 to 16.62% by weight. The results differed with the findings of Katiyar *et al.*, (2013) [1] who noted that the municipal wastes in Bhopal, India had an average FC of 9.5 % by weight. The fixed carbon was calculated using equation 3.6.

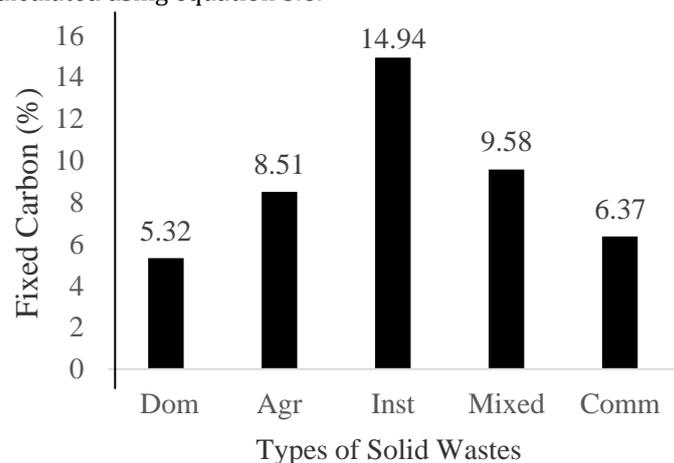


Fig 3.6: Fixed carbon of different types of solid waste

3.1.6 Calorific value

Figure 3.7 shows the average calorific values of different categories of waste. The calorific value depends upon

moisture, carbon and hydrogen contents in the waste and represents the amount of chemical energy in a given waste components as reported by Bujak, (2010) [30] and Kathiravale *et al.*, (2003) [31]. The institutional waste yielded the highest Calorific Value (CV) of 16.87MJ/kg followed by mixed waste giving 10.27MJ/kg and agricultural waste gave 7.67MJ/kg. However, the domestic/residential waste yielded the lowest CV of 4.26MJ/kg. The commercial waste yielded CV of 12.65 MJ/kg which agreed with the findings by Khamala and Alex, (2013) [32] who reported that the CV for municipal solid waste from Nairobi, Kenya gave 12.48 MJ/kg. The result also agreed with the findings by Omari, (2015) [5] who reported that the CV for municipal wastes from Arusha, Tanzania gave 12.42MJ/kg. The results differed with the findings by Das and Bhattacharyya, (2013) [19] where they reported that the CV for municipal waste at Kolkata, India gave 5.03MJ/kg in the year 2010. The results also differed with the findings by Omari *et al.*, (2014) [33] who reported that the CV for municipal wastes of Arusha, Tanzania yielded 12MJ/kg. Oumarou *et al.*, (2012) [14] recommended that the energy recovery would be possible with an addition supplementary fuel to the waste where CV had fallen below 9.5MJ/kg. The CV was calculated using equation 3.7 and 3.8.

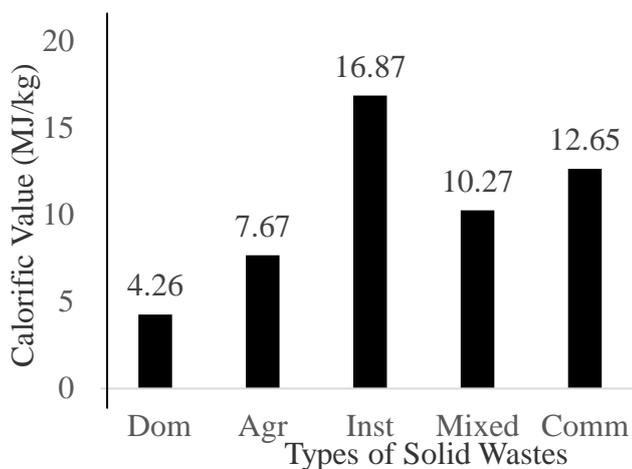


Fig 3.7: Calorific value of different types of waste

4. CONCLUSIONS

The solid waste classification and characterization of are major factors considered in the design of an efficient, cost effective and environmentally compatible waste management system. Inappropriate bin locations and poorly designed small-scale incinerators, lack of waste treatment and disposal facilities were identified as major problems. The wastes were classified into four main types which were domestic/residential, agricultural, institutional/industrial and commercial. The percentages of combusted components in the waste must be determined on basis of characterization analysis. The wastes were characterized into moisture contents, ash contents, volatile matters, fixed carbon, density

and calorific values and yielded mean values of 37.08%, 12.42%, 41.56%, 8.94%, 231.58kg/m³ and 10.34MJ/kg, respectively. Since domestic/residential waste was organic and could retain water it yielded the highest MC of 55.69%, followed by commercial giving 46.51%, agricultural 39.44% and mixed waste gave 34.72%. Institutional/industrial waste yielded the lowest MC of 9.02% since it contained high percentages of polythene papers, plastics and rubbers which could not retain water. Agricultural yielded the highest ash content of 15.59% since it contained animal residues like cow dung, followed commercial (14.37%), domestic/residential (12.33%) mixed (11.94%) and institutional (7.88%). Institutional waste yielded the highest volatile matters of 68.12%, followed by mixed (43.73%), agriculture (36.46%), domestic/residential (26.66%) and commercial (32.75%). Institutional yielded the highest fixed carbon of 14.94%, followed by mixed (9.58%), agricultural (8.51%), commercial (6.37%) and domestic (5.32%). The average density of different types of waste was 231.58 kg/m³. Domestic waste yielded the highest density of 307.64 kg/m³ while the institutional gave the lowest density of 85kg/m³. The average calorific value of the waste in Egerton University and its environs was determined at 10.34 MJ/kg. The calorific value varied from 4.26 MJ/kg for domestic to a maximum of 16.86 MJ/kg for institutional wastes. The calorific value may not be fixed due to the variations in the waste composition, as is the case with the fossil fuels. Since the waste had high calorific values and volatile matter, then it could be used for waste to energy methods though more research needed to be carried out during the wet spell.

REFERENCES

- [1] R. Katiyar, S. Suresh and A. Sharma, "Characterisation of municipal solid waste generated by the city of Bhopal, India," *International Journal of ChemTech Research* vol.5, (2), 2013, pp. 623-628.
- [2] A. Arsad, H. Sulaiman and A. Rahmat, "Combustion behaviour of poultry and plastics waste in as bench scale combustor," *University Technology Malaysia*, 2006.
- [3] D. Zekkos, E. Kavazanjian, J. Bray, N. Matasovic and M. Riemer, "Physical characterization of MSW for geotechnical purposes," *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 136, (9), 2010, pp 1231-1241.
- [4] K. Ayuba, L. Manaf, A. Sabrina and S. Azmin, "Current status of municipal solid waste management practise in FCT Abuja," *Research Journal of Environmental and Earth Sciences* vol. 5, (6), 2013, pp. 295-304.
- [5] A. Omari, "Characterization of Municipal solid waste for energy recovery. A case study of Arusha, Tanzania," *Journal of Multidisciplinary Engineering Science and Technology*. vol. 2 (1), 2015, pp. 230-237.
- [6] R. Henry, Z. Yongsheng, and D. Jun, "Municipal solid waste management challenges in developing countries-Kenyan case study," *Waste Management*, vol. 26, 2006, pp. 92-100.
- [7] C. Chang, C. Wang, D. Mui, M. Cheng and H. Chiang, "Characteristics of elements in waste ashes from a solid

- waste incinerator in Taiwan," *Journal of Hazardous Materials*, vol. 165, 2008, pp. 766-773.
- [8] B. Ansah, "Characterization of municipal solid waste in three selected communities in the Tarkwa Township of Nsuaem Municipality in Ghana," University of Science and Technology. MSc thesis, 2014.
- [9] B. Manohara and S. Belagali, "Characterization of essential nutrients and heavy metals during municipal solid waste composting," *International Journal of Innovative Research in Science, Engineering and Technology* Vol. 3, (2), 2014, pp. 9664-9672
- [10] S. Paolo, "The effect of separate collection of municipal solid waste on the lower calorific value of the residual waste," *Waste management and Research*, vol. 28, (8), 2010, pp. 754-758.
- [11] N. Dixon and U. Langer, "Development of a MSW classification system for the evaluation of mechanical properties," *Waste Manage*, vol.26, (3), 2006, pp. 220-232.
- [12] R. Beck, "Georgia Statewide waste characterization study," Georgia Department of Community Affairs, U.S.A. 2005.
- [13] H. Alhassan and A. Tanko, "Characterization of solid waste Incinerator bottom ash and the potential for its use," *International Journal of Engineering Research and Applications (IJERA)* vol. 2, (4), 2012, pp. 516-522.
- [14] M. Oumarou, M. Dauda, A. Abdulrahim and A. Abubakar, "Characterization and generation of municipal solid waste in North Central Nigeria," *International Journal of Modern Engineering Research*, Vol. 2, (5), 2012, pp: 3669-3672.
- [15] Q. Aguilar-Virgen, C. Vega, P. Taboada-Gonzalez and S. Ojeda-Benitez, "Municipal solid waste generation and characterization in Ensenada, Mexico," *The Open Waste Management Journal*, vol. 3, 2010, pp. 140-145.
- [16] ASTM, ASTM E871-82 Standard, "ASTM E871-82 Standard Test Method for Moisture Analysis of Particulate Wood Fuels, 2013.
- [17] ASTM, ASTM E872-82 Standard, "ASTM E872-82 Standard test method for volatile matter in the analysis of particulate wood fuels," 2013.
- [18] ASTM, E1534-93 Standard, "ASTM E1534-93 Standard Test Method for Determination of Ash Content of Particulate Wood Fuels," 2013.
- [19] ASTM, D240-02 Standard, "ASTM D240-02 Standard test method for heat of combustion of liquid hydrocarbon fuels by bomb calorimeter," 2012.
- [20] T. Karak, R. Bhagat and P. Bhattacharyya, "Municipal solid waste generation, composition, and management," Taylor & Francis, London, 2011.
- [21] S. Das and B. Bhattacharyya, "Municipal solid waste characteristics and management in Kolkata, India," *International Journal of Emerging Technology and Advanced Engineering*, vol. 3, (2), 2013, pp. 147-152.
- [22] L. Medina, E. Castillo and R. Romero, "Physical and chemical characteristics of municipal solid waste in a rural locality," *International Journal of Business, Humanities & Technology* vol. 3, (8), 2013, pp. 117-122.
- [23] S. Yildiz, C. Yaman, G. Demir, K. Ozcan, A. Coban, K. Sezer and S. Gorene, "Characterization of municipal solid waste in Istanbul, Turkey," *Environmental Progress & Sustainable Energy*, vol.32, (3), 2012, pp. 734-739.
- [24] W. Chen, J. Han, L. Qin, M. Furuuchi and H. Mitsuhiro, "Emission characteristics of PAHs during coal and sewage sludge co-combustion in a drop tube furnace," *Journal of Aerosol and Air Quality Research*, vol.14, 2014, pp. 1160-1167.
- [25] K. Sivapalan, N. Muhd, S. Abd-Halim, S. Kamaruzazaman, and A. Rakmi, "Comprehensive characterization of the municipal solid waste generated in Kuala Lumpur," *Symposium on Environmental & Natural Resources*, 2002.
- [26] T. Ogwueleka, "Municipal solid waste characteristics and management in Nigeria," *Journey of Environment and Health Science Engineering*, vol. 6, (3), 2009, pp. 173-180.
- [27] J. Fobil, D. Carboo and N. Armah, "Evaluation of municipal solid wastes for utilisation in energy production in developing countries," *Environmental technology and management Journal*, vol 5, (1), 2005.
- [28] S. Manyele and I. Kagonji, "Assessment of incineration process performance in a district hospital using statistical analysis," *Scientific Engineering Research Journal* vol. 4, 2012, pp. 421-434.
- [29] L. De Medina, E. Castillo and R. Romero, "Physical and chemical characteristics of municipal solid waste in a rural locality," *International Journal of Business, Humanities and Technology*, vol. 3, (8), 2013, pp. 117-122.
- [30] J. Bujak, "Experimental study of the lower value of medical waste," *Polish J. of Environ. Stud.* vol. 19, (6), 2010, pp. 1151-1158.
- [31] S. Kathiravale, M. Muhd, K. Sopian, A. Samsuddin and R. Rahman, "Modeling the heating value of municipal solid waste," *Fuel*, vol. 82, 2003, pp. 1119-1125.
- [32] E. Khamala and A. Alex "Municipal solid waste composition characteristics relevant to waste to energy disposal method for Nairobi city," *Global Journal of Engineering, Design & Technology*, vol. 2, 2013, pp.1-6.
- [33] A. Omari, M. Said, K. Njau, G. John, and P. Mtui, "Energy recovery routes from municipal solid waste - Case study of Arusha-Tanzania," *Journal of Energy Technologies and Policy*, vol.4, (5), 2014, pp. 1-7.

BIOGRAPHY



Mr. Stephen G. Mugo Nyoti is the corresponding author of this paper and a post graduate in the Department of Industrial and Energy Engineering, Egerton University P.O. Box 536-20115 Egerton, Kenya. He can be reached through phone Number: +254722421189 or e-mail: smnyoti35@gmail.com