GLOBAL JOURNAL OF ENGINEERING, DESIGN & TECHNOLOGY
(Published By: Global Institute for Research & Education)
www.gifre.org

MUNICIPAL SOLID WASTE COMPOSITION AND CHARACTERISTICS RELEVANT TO THE WASTE –TO-ENERGY DISPOSAL METHOD FOR NAIROBI CITY

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Abstract

The composition and thermo-physicochemical analysis of residential solid waste of Nairobi city are presented. Waste sampling in three city zones (residential) selected on the basis of population density and the city centre was done according to the ASTM D 5231-92 with 90% confidence level. The results showed high percentage of organic matter, followed by plastics, paper and others. The high density zones had the highest percentage of organic matter while low density zones had high content of plastics. The moisture content averaged a high value of 68.9% and was fairly uniform over the sampled zones. The Bulk density, determined using a 1m cubed box showed small variations and averaged 296 kg/m^3. The Calorific value, determined according to British Standard 1016; part 5: 1967 had an average value of 12.48 MJ/kg excluding plastics. These characteristics are important in the feasibility and development of a waste - to - energy disposal method.

***Key Words*:** Waste, Calorific value, Moisture content.

1. Introduction

The common methods employed for municipal solid waste (MSW) disposal in urban cities are composting, landfilling, recycling, and incineration (or waste – to – energy, (WTE)) (Kumar 2000, Fobil 2001, Yousuf 2007, Allison 2009). The feasibility and implementation of any disposal method or a combination requires knowledge concerning waste composition and characteristics. The advantage of WTE is that there is a considerable reduction of between 60 to 80% of the original weight in addition to power generation (Fobil 2002, Salvato et al, 2003). Also, whereas other fuels have to be purchased for power production, MSW is considered free.. However, WTE feasibility assessment requires data on waste composition, density, moisture content and calorific value. The bulk density is critical for estimation of collection, storage and tipping costs. The later two are crucial for combustion and may determine effectiveness of the disposal procedure (Fobil et al, 2005). This procedure is suitable for Nairobi that experiences shortage of both land and power.

Combustion of solid waste depends on moisture content. High moisture content results in low net energy from the waste i.e. low calorific value. With very low calorific value, there might be need for auxiliary fuel to support combustion. According to JICA 2005 (cited in Yousuf, 2007), combustion of waste requires 5024 kJ/kg to facilitate self combustion and at least 6280kJ/kg for power production.

Previous studies (Farid Industries et al. 1985, JICA 1998, Allison 2009) on municipal solid waste in Nairobi have reported mainly on solid waste production and composition – that is the quantities and percent composition. In view of lack of data on physical and chemical characteristics of solid waste, the work reported here is useful in regard to WTE disposal method for the city. Further, due to changes in population and lifestyles, it is important to establish the current composition of the MSW.

Municipal solid waste studies in other developing countries, (Fobil et al 2005, Sivapalan et al 2002, Yousuf et al 2007) found the wastes to consist of a high proportion of organic matter with high moisture content. However, bulk densities varied from as high as 540 kg/m^3 (Accra, Ghana) to a low of 120 kg/m^3 (Kuala Lumpur). The calorific values also showed differences, with 1.578 MJ/kg, for Dhaka, 14 – 20 MJ/kg for Accra and 7.96MJ/kg for Kuala Lumpur. These variations indicate the dependence of the characteristics upon source of waste.

The population of Nairobi has been increasing rapidly at 4% per annum since 2000 and is now estimated at 3.14 million (UNEP & UN-Habitat, 2007, Ministry of Planning, 2009). The increase in the number of residents in the city coupled with economic growth has led to increased municipal solid waste (MSW) generation. The generation rose from 1500 tonnes in 1998 to 2400 tonnes per day in 2004. About 85% of the waste generated was residential (JICA 1998, Bahri 2005).

For a long time, solid waste collection and disposal in Nairobi has been characterised by general inefficient, unfavourable and inadequate organisational set-up. For a while now, less than 40% of the city receives waste collection services. The remaining 60% is either dumped in open spaces and burnt, or scavenged (Mwaura 1991, UNCHS 1998). Urgent considerations for establishment of a proper solid waste disposal and management plan for the city are therefore required.

It is hoped that the data presented here is a contribution to overall task of designing waste management program particularly for a WTE plant.

The objectives of this study were (1) to determine the residential municipal solid waste composition in Nairobi by sampling selected areas in the city, (2) to determine the characteristics;– moisture content, calorific value and density of the waste through laboratory measurements and (3) to theoretically estimate the specific energy potential of the waste.

2. Materials and Methods

This work commenced in the month of June 2010 with the selection of the sampling zones in Nairobi. The waste sampling was then undertaken in the period 4th - 29th July, 2010. During the sampling period, it was noted that no rainfall was recorded in the sampling areas. The average ambient temperatures ranged between 20 - 25° C and relative humidity (RH) 44 – 64% (Ministry of Environment, 2010). Waste characteristics are known to change with the weather seasons, especially the moisture content and density (Allison, 2009).

2.1 Sampling Areas

The waste sampling was based on the assumption that there is a positive correlation between per capita waste generation and income levels of residents (Kreith, 1994). This allowed the classification of the city into areas depending on population density.

Nairobi is divided into four administrative districts. According to Kenya's ministry of planning census report (2009), the percent population in each of the districts is as shown in Table 1.

Table 1: Nairobi Districts.

District	Percent population (%)
Nairobi East	36.5
Nairobi North	33.8
Nairobi West	22
Westlands	7.7

Each of the districts consists of residential estates (zones) of different population density. For example Nairobi west has estates with population density as low as 135/ sq km and others as high as 76,000/sq. km. Only Westlands has most of the estates with comparatively low population density. The estates in which sampling was made were chosen from among those within the districts and classified into high population density zones, medium population density zones and low population density zones. High density zones were identified as those with density of 30,000/sq. km and above, medium density zone 5000 – 29,000/sq. km and low density zone below 5,000/sq.km. Zones were selected from the districts to represent this classification. In this respect, the sampling areas were identified as Dandora (43,918/sq.km, Nairobi East), and Kibera (65,197/sq.km, Nairobi West) as representative of the high density zones, Kariobangi South (23,480/sq.km, Nairobi East) and BuruBuru (11,994/sq.km, Nairobi East) as medium density zones, and Loresho (1,937/sq.km, Westlands) represented the low density zones. The City centre was also sampled in anticipation of the difference in the type of waste generated therein.

The number of samples (households) from each zone was determined by utilizing the generic estimates as per the American Society of Testing and Materials (ASTM) method for unprocessed municipal solid waste (D 5231-92) tables and as suggested by Cascadia Consulting Group inc., (2003). Typically, the confidence level is set at 80% or 90% and based on this procedure, the number of samples required were 58. In the six selected zones, 10 samples or more per zone could be used.

2.2 Waste Composition

Waste in polythene bags was collected from residential houses, one bag from each house early morning on each sampling day. In every zone, except Kibera, refuse was pooled together from 15 randomly selected households to produce one waste composite sample. The combined weight of 15 samples to make the composite sample from each zone ranged between 100kg and 200kg. In Kibera, where it was difficult to use polythene bags (waste from houses is normally dumped on an open site), the waste was collected from a dump site heap close to a busy road to make the same weight. In other estates, sampling of the waste in the bags was then done at the source before any scavenging or recycling occurred.

Empty clean Polythene bags of known weight were marked with five classes of solid waste - Plastics, Papers, Organic or food waste (Putrescibles), Inorganics (bottles, metals and others) and Leather & Textiles (LT). The solid waste in each composite sample was then hand picked and separated out into a polythene bag corresponding to its class. The polythene bags containing waste of each class were then weighed. The percentage representation of each class of waste was determined to give the composition of the waste.

As stated earlier, this sampling procedure was done early each day before refuse collectors in trucks picked it for transfer to the Dandora dump site. Since the waste was mainly found in polythene bags in the morning, the effect of the weather was considered small and the waste fillings were negligible. This may not be true for the case of Kibera where the sample was obtained on the road dump site. However, as stated earlier, during the sampling period of this study, 4th - 29th July 2010, no rain fall was recorded in Nairobi and mean temperatures ranged between 20 - 25° C and RH 44 – 64% (Ministry of Environment, 2010).

2.3 Moisture Content, Calorific Value and Bulk Density

To determine the moisture content, two samples of waste with weight varying between 16 kg and 20 kg was randomly selected from each composite sample in each zone. It was then sealed and placed in another waterproof sealed bag and taken to a laboratory. In the laboratory, the weight of the sample was measured and then placed in an electrically heated oven (Elsklo type JN 200R) that had been preheated and set at 105°C. The sample waste was left to dry at this temperature for 24 hours It was reweighed again to obtain the dry weight. To ensure that the drying process is complete, the sample was returned to the oven for another 2 hours and reweighed. This was repeated until the change in weight was less than 0.1%.

For each zone, the calorific value of each of the classes: Putrescibles, Paper and LT were determined separately and then averaged according to their percentage composition in the waste to give the overall value for the sampled MSW. The procedure adopted during the determination of the calorific values was based on the British standard, B.S. 1016: Part 5: 1967. The Putrescibles were put in a conical metallic mortar, pounded, broken down into smaller particle dust and thoroughly mixed. Samples were then taken from this and made into pellets. The pellets were combusted in oxygen charged Bomb calorimeter (Chadwell Heath Essex) at 25 atmospheres. The calorific value was then obtained. Similarly, waste paper and LT were also made into pellets and combusted in the calorimeter and their calorific values determined.

The bulk density of the waste in each zone was determined using a 1m cube wooden box. A 1m internal dimensions cube box was constructed that could hold $1m^3$ of waste. The box was weighed while empty and when filled with MSW. The total weight less the weight of the empty box gave the density of the waste.

3. Results and Discussions

The waste composition of the sampled zones is shown in Table 2. When all the zones were considered, the organic waste concentration was highest, being high in high density zones and decreasing with population density. In Kibera (high density zone), the waste was sampled from a heap close to a busy road. In such a case, the waste is usually scavenged by humans and dogs. The percent composition may not reflect the similar values as those obtained straight from the houses. However this did not seem to affect the trend in percentage composition of the various waste categories.

Table 2**:** Waste composition in the sampled zones

Waste category	High population density zone (Dandora & Kibera**)**	Medium population density zone (Kariobangi south & Buruburu	Low population density zone (Loresho**)**	City centre
Plastics	14.4%	12.9%	15.8%	13.5%
Papers	6.4%	9.3%	12.3%	22.6%
Putrescibles	64.2%	63.8%	56.5%	52.8%
LT	12.4%	5.7%	4.2%	7.8%
In-organics	7.9%	8.3%	11.4%	3.3%

The waste from the low population density zone had the highest percentage plastics followed by the high population density zone. It was observed that the nature of plastics differed such that the latter zone waste contained heavier plastic containers and the former being characterised by thin plastic bags. In the high density zones packaging is increasingly of small quantity goods in thin plastic bags.

The city centre had a predictably high percentage papers due to high generation by offices. In a number of cases, paper waste is picked directly by recyclers and is not available as part of the MSW. The actual paper content may require investigating the recycling aspect which was not considered in this work. Nevertheless, the percentage composition of papers showed that the high population density zone had the lowest and the low population density zone the highest. Again this may be attributed to the difference in packaging between the zones.

The waste composition showed a reducing trend in LT concentration with population density. This may be attributed to the high use of used textiles and shoes ('Mitumba') within the high population density zones which have a short life.

The averaged moisture contents and density of the MSW from the sampled zones are shown in Table 3.

Table 3: Moisture content and bulk density of waste in the zones.

Zone	Moisture Content %	Mass Density kg/m^3
High density	69.0	296
Medium density	69.5	290
Low density	63.75	282

When all the samples were considered, the minimum moisture content was found to be 63.2% and a maximum of 75.0%. The average for medium and high density zones was found to be nearly the same while that of the low density zone had slightly a lower value of 63.7%. Since the low density zone consisted of only about 8% of the city population, the moisture content for the waste may be taken as fairly uniform at the average value of 68.9%. The moisture content in Nairobi is therefore high, consistent with studies from other developing countries (Yousuf, 2007, Fobil et al, 2005). This is of course a drawback to the waste-to energy process. However, it may be noted that the samples came directly from the houses in polythene bags with little chance for natural drying. The food waste as expected was fairly wet.

The averaged bulk densities of the MSW in the sampled zones are also shown in Table 3. There is a gentle decrease trend from the high population density zone to the low population density zone. However this is considered small and may be taken as constant at an average value of 289 kg/m^3. This small difference may be due to more or less similar types of food waste from the majority of the sampled population (High & Medium zones) and the fact that the moisture content (water) is high and nearly the same in most of the waste. The densities are significantly lower than those reported by Fobil et al (2005) for the city of Accra that ranged between 410 and 540 kg/m^3 and with less variations as compared to that of Kuala Lumpur, 120 – 330 kg/m^3 (Sivapalan k. et al, 2002). The density, together with the distance from the source to the disposal site, is important in consideration of the tipping costs. Shown in Table 4 are the average calorific values of the various classes in the sampled zones.

Table 4: Average calorific values of MSW in sampled zones

Parameter	High population density zone	Medium population density zone	Low population density zone	Average
CV Putrescibles, MJ/kg	13.22	15.26	17.59	15.70
CV Papers, MJ/kg	17.50	17.01	16.71	17.10
CV LT, MJ/kg	16.72	18.14	16.44	16.90

No significant variation of the CV of paper and LT in the three zones were noticed but there were some differences for Putrescibles especially between the low and high population density zones. This was attributed to the different types of food waste from the zones.

When all the samples were considered, the calorific value of Putrescibles varied between 12.36 MJ/kg and 18.36 MJ/kg giving an average of 15.70 MJ/kg. The Putrescible calorific value was lowest in the high population density zone and highest in the zone with the highest income level. No trends were noticed within the zones.

The mean calorific value for Nairobi waste was then estimated at 12.48 MJ/kg. The inorganics and plastics that constituted 8.3% and 13.8% respectively were not included. Lack of equipment for the case of plastics limited the determination of their calorific value. However, due to environmental concerns and the cost thereof for cleaning flue gases when plastics are combusted, there maybe merit in recycling plastics. Compared to other fuels such as Coal (23.25 kJ/kg), the CV is low and hence power production per unit mass is likely to be less. But when used in a waste to energy plant, the waste is considered as a free source.

The averaged MSW composition from all the samples is shown in Figure 1. The organic matter constituted 58.8% of the waste, Plastics at 13.8%, Papers at 11.3%, inorganics at 8.3% and LT (and others) at 7.8%. When compared with previous studies (Table 5), the organic matter has always constituted over 50 % of the waste, its percentage significantly high in 80s' , a percentage reduction in late 90's and a slight increase thereafter. Allison et al, (2009), found the residential waste characterization as Organic/Biodegradable 58.6%, Plastics 15.9%, Paper, 11.9%, Glass 1.9%, metal 2.0% and others 9.7%, fairly consistent with the findings of this work. In all the studies the food waste in the MSW has always been high and the percentage decrease is probably due to increase in percentage plastics and papers other than actual per capita generation.

The percentage concentration of paper was high in 1985 at 10.16% before the use of thin plastics for wrapping goods. This percentage later reduced in 1998 after the thin plastic bags were introduced and were more common in use.

Because of plastic pollution, there has been a sustained campaign to reduce use of plastics especially the small gauge type. This slowed their increase somewhat and does explain the trends observed in the case of paper percentage. The plastics replaced to a large extent paper as a packaging material. The importation of cheap used textile and shoe products could have made an increase in the LT during the same period. Because the used textiles are relatively affordable to many and have a short life makes it possible for their increase in the overall composition of the waste.

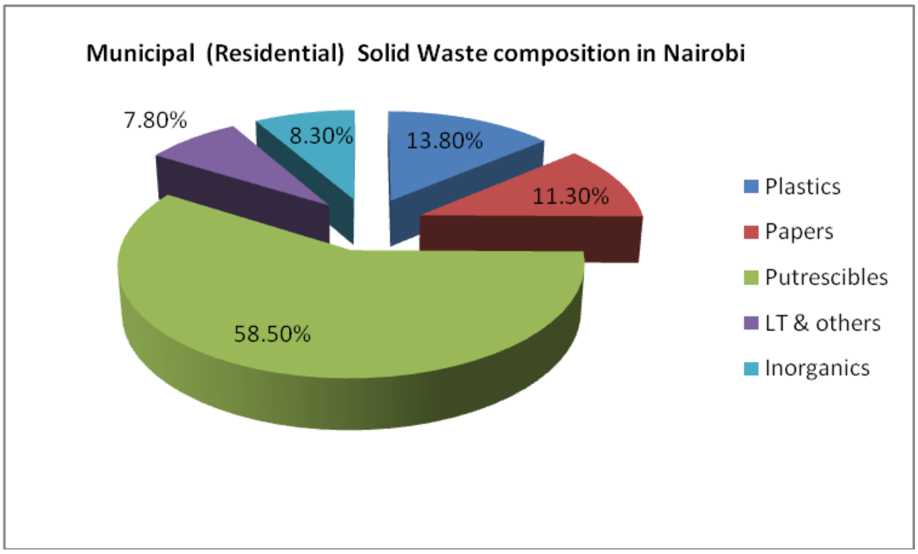

Fig 1 Municipal solid waste composition in Nairobi

Table 5: The Nairobi waste compositions, 1985 – 2010

Waste class	Farid et al., 1985	JICA 1998	This study
Plastics	4.07	11.8	13.8
Papers	10.16	7.3	11.3
Putrescibles	77.97	51.5	58.8
LT	2.07	11.8	7.8
Inorganics	5.73	7.6	8.3

4. Energy Potential from Waste

When waste is combusted, energy is given out as heat. Some of the energy is consumed in drying of the waste (to evaporate the water in the waste) and the rest (net) is available for conversion into useful work or power generation. The water in the waste is represented by the moisture content.

Hence,

Net energy (E_{net}) = gross total energy (E_{gross}) – energy required in drying the waste (E_{dry})

$$E_{net} = E_{gross} - E_{dry} \quad (1)$$

The energy required to dry the MSW (E_{dry}) is the sum of the energy required to raise the temperature of the water in waste from its initial temperature (T_i) to vaporization temperature (T_s) 100^0C (= H_s) and the energy required to completely vaporize the water in the waste at T_s – the heat of vaporization (= H_{fg}).

$$E_{dry} = H_s + H_{fg} \quad (2)$$

H_s = Mass (m_w) of moisture in MSW × heat capacity (c_p) of water × change in temperature ($\Delta T = T_s - T_i$)

$$H_s = m_w \times c_p \times (T_s - T_i) \quad (3)$$

H_{fg} = Mass (m_w) of moisture in MSW × latent heat of vaporization (h_{fg})

$$H_{fg} = m_w \times h_{fg} \quad (4)$$

Let m = mass of a sample of MSW. The mass of dry MSW = m – m_w.

Let C_v = Calorific value of dry MSW.

$$E_{gross} = (m - m_w) \times C_v \quad (5)$$

Therefore,

$$E_{net} = (m - m_w)C_v - \lfloor (m_w c_p (T_s - T_i)) + m_w h_{fg} \rfloor \quad (6)$$

For Nairobi, the annual average temperature is typically 24° C.

Hence, the following values may be used to estimate Net energy available.

T_i = 24°C, T_s = 100°C, c_p = 4.2 kJ/kg-K, h_{fg} = 2260 kJ/kg

For 1 kg of MSW, m = 1 kg, m_w = 0.689 kg and the determined average C_v = 12.48 MJ/kg.

E_{net} is evaluated to be 2.1MJ/kg of MSW while E_{gross} is 3.88MJ/kg

The potential energy efficiency may be obtained as;

Energy efficiency = Net energy / Gross total annual energy

$$\eta = \frac{E_{net}}{E_{gross}} \times 100 = 54.1\%$$, that is, 54.1% of the energy in the MSW is potentially recoverable as heat.

Using the solid waste generation rate of 2400 tonnes per day for the year 2004 and at 30% power generation efficiency, the power production is estimated at 177,184 kWh, per day excluding plastics and inorganics.

The estimated power production would be a valuable contribution to the country that is in dire shortage of electricity. This is in addition to being a waste disposal method.

The greatest point in favour of waste-to-energy plants in developing countries is that, a considerable amount of weight reduction, between 70% and 80% of the original weight of raw solids can be achieved (Fobil, 2002). This reduction results into considerable saving in landfill space. Another consideration is that whereas other fuels for a power plant have to purchased, transportation will be the only cost associated with MSW's waste-to-energy plant. This may be recovered from tipping fee paid by residents or the city council.

5. Conclusions

The waste composition in Nairobi consists mostly of organic matter accounting for 58.8% with no significant variation from estate to estate regardless of differences in demographics and socio economic factors. Others were Plastics – 13.8%, Paper – 11.3%, Inorganics – 8.3% and LT 7.8%. Comparing with previous studies, the plastics concentration sharply increased in the 1990's but slowed thereafter.

The average moisture content of MSW in Nairobi was found to be 68.9%, again with slight differences between the estates. The waste was found to have high moisture content. The net energy and efficiency of an incineration plant would be lower as the waste may require initial natural drying before combustion.

The average calorific value of the waste in Nairobi was determined as 12.48 MJ/kg excluding plastics. The calorific value varied from an average of 15.7 MJ/kg for Putrescibles to a high of 17.10 MJ/kg for paper. Due to the high content of Putrescibles in the waste, the average calorific value was controlled by that of the Putrescibles. Also, because of the variations in the composition of the waste, the calorific value may not be fixed as is the case with other fuels such as the fossil fuels.

The bulk density of municipal solid waste in Nairobi had slight variations with a minimum 282 kg/m^3 and a maximum of 296 kg/ m^3 with a mean value of 289 kg/m^3.

The energy contained in a kilogramme of MSW was estimated to be 2.1 MJ and the incineration efficiency was 54.1% .The electric energy potential of waste was estimated at 177,184 kWh per day with an assuming a 30% generation efficiency.

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