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Original article

Physico-chemical characteristics of solid waste for treatment options: a case study of Kumasi, Ghana

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A B S T R A C T

The study aimed at determining the physical and chemical characteristics of solid waste generated in Kumasi for treatment and disposal options. Ninety households were conveniently selected comprising all the three categories of income levels in the metropolis. Solid wastes generated from these households were separated into its components with the weight and volume of each component measured. Subsequently sub-samples from the composite samples were then taken to the laboratory for the chemical analysis. An estimated amount of 1227 tons of domestic solid waste is generated daily based on the city's current population. The study revealed that about 61% and 15% of the daily waste generated could be treated using composting or anaerobic digestion method and reuse or recycling method respectively, thus diverting a chunk of the waste from going to the landfill and subsequently increasing the lifespan of the only landfill in the city.

1. Introduction

The concept of waste management in the world is one of the most actual targets of humanity. In recent years, management of solid waste has become an issue of increasing concern, becoming one of the primary environmental concerns of public debate (Rahman and Yousof, 2007). Open dumps were the means of solid waste disposal in the three major cities of Ghana (Accra, Kumasi, and Takoradi) (Johannessen and Boyer, 1999). In an attempt to address the escalating problems of solid waste management due to urbanization and rapid economic growth, Ghana under the World Bank's Urban Environmental Sanitation Project developed plans to build its first sanitary landfills in these three major cities (Government of Ghana, 2003).

The waste management system so far in Ghana has not properly integrated other solutions as collection, treatment, and supply for re-use, reprocessing and final disposal. There are different kinds of waste based on their origin, compositions and characteristics: physical, chemical and biological. Based on their origin, characteristics and compositions, household wastes should be sorted and handle in different ways to achieve the development of ecologically and healthy management of solid waste (Anomanyo, 2004).

In past years, land filling has often been seen to solve the escalating problems of waste management. However, the built landfill may be crammed even before its estimated lifetime and may revert to open dump if proper management system is not put in place resulting in greater difficulty for solid waste disposal. In Kumasi, Ghana, only one sanitary landfill exists to accommodate the increasing volumes of solid waste generated. There is no form of waste treatment to reduce the increasing volume of waste that ends up at the landfill. Over the years, individuals and communities have rejected landfill sitting and have encroached on land designated for land filling.

It is time therefore to establish a paradigm shift of waste management with a necessity of an integrated waste management system whereby collection/sorting, composting, anaerobic digestion, incineration, recycling of the municipal solid waste are incorporated. In integrating the appropriate waste treatment and disposal options into the management of waste to divert waste from going to landfill, the physical and chemical characteristics of solid waste are imperative to achieving this. It is against this background that the relevance of the study cannot be underestimated.

2. Materials and methods

2.1. Study area

The Kumasi metropolis is the second largest city in Ghana. It is the capital of the Ashanti Region and commercial capital of Ghana. Most of the people in Kumasi are traders, artisans, and office and factory workers. The Kumasi metropolis is divided into ten (10) sub-metropolitan areas. The metropolis is located at a vantage point that makes it accessible to every part of the country. The city has a concentric road system of structure and a centrally located commercial area from which radiates its major arterial roads, some of which serve as a trunk road linking it to other parts of the country. The minimum and maximum temperatures are 21°C and 30 °C, respectively, with only little variability throughout the year. Mean minimum and maximum annual humidity are 59% and 94% respectively. The city is generally less humid in the dry season and its population has doubled twice since 1970. The last population census in 2000 counted 1.17 million inhabitants. Currently Kumasi population according to the Kumasi Metropolitan Assembly projections is approximately 2.1million inhabitants (KMA, 2009). Kumasi has been categorized into four housing units. These are tenement housing, indigenous housing, New Government housing and the high cost housing. The necessity for the housing units is strictly for planning purposes.

2.2. Methods

The research used multiple approaches and techniques to collect the data that is relevant for achieving the research objectives. These included desk study, interviews, reconnaissance survey, physical characterization and the laboratory analysis to investigate the chemical composition of the waste. In the physical characterization of the waste 90 households, that cuts across the 10 sub-metropolitan areas representing the High, Middle and Low income groups was used for the study. In the identification of these households, the criteria used by the Waste Department of the Kumasi Metropolitan Assembly for the classification of income groups were adopted. The waste generated was collected from the selected households every day at a fixed time for 30 consecutive days to allow for variation in waste generation over the month. In the chemical analysis of the waste, refuse was pooled together from the selected households to produce a huge composite waste sample. Triplicate subsamples of the composite were then used for chemical characterization. Proximate analysis was carried out to determine the moisture content, ash content and the organic matter content of the waste. The Calorific and Total Nitrogen values were determined using the Oxygen Bomb Calorimetric and Kjeldhal Procedure respectively.

3. Results and Discussion

3.1. Physical characteristics of the solid waste

The physical characteristics of solid waste considered are the per capita generation rate, waste composition, moisture content and bulk density.

3.1.1. Per capita generation rate for the three income groups

The study revealed significant variations in the per capita generation rates for the three income groups [Figure 1]. This is in agreement with the common understanding that waste quantities generated are directly proportional to the household income levels (Diaz et al, 1993; Abu-Qudais et al, 1997).

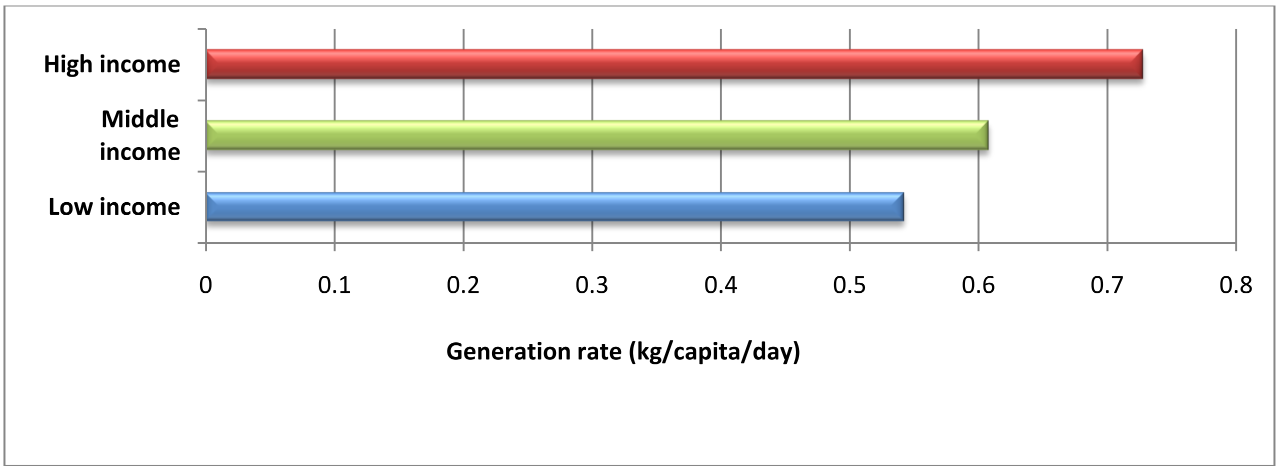

Fig. 1. The per capita generation rate at the three income groups.

The trend observed could be attributed to the differences in the purchasing power at the three income groups. The World Health Organization (WHO) expert committee report (1982) establishes generation rate of 0.2kg/capita/day to 3kg/capita/day for developing countries. The results of the study for the three income groups is in agreement with the WHO expert committee report (1982) and is necessary in making an informed decision on the proper management of waste. Kotoka (2001) established a generation rate of 0.94kg/capita/day for high income communities in Kumasi. The 0.728kg/capita/day obtained for the high income communities in this study is slightly lower than that obtained by Kotoka (2001) and this may be due to the fact that residents lately spend much more time outside and as a result consume less food from the homes leaving little to be collected from the households.

3.1.2. Waste composition and variation

Figure 2 depicts the percentages of the nine (9) waste compositions by household income levels.

The principal components observed were organics (45%, 69%, 71%), miscellaneous (36%, 12%, 0%), plastics (8%, 10%, 10%), for low, middle and high income groups respectively. From the analysis of results the organic waste dominates the bulk of household waste sampled. The percentage of organic waste obtained at the high income level in the study agrees with that obtained by Ketibuah et al, (2004). The low income group recorded the least percentage of organic waste in comparison with the other two income groups. This could be due to the dependence of livestock in such homes on the organic waste generated.

The miscellaneous composition of the waste recorded 36% for the low income group. This could be due to the reason that most residents in the low income group use the locally manufactured clay stove and coal pots for cooking purposes and as a result generate some amount of ash. In their quest to keep their kitchen clean coupled with their unpaved nature of their surroundings, they end up adding a substantial amount of sand, silt and ashes to the waste which consequently mixes up with the organics. This limits the extent of separation of organic fraction, thus giving rise to a significant miscellaneous waste fraction which constitutes remains of food, sand and ashes at the low and middle income levels. The 36% obtained in this study compared to the 34% obtained by Ketibuah et al, (2004) at the low income communities in the city indicates an appreciable amount of miscellaneous in the waste generated at the low income households.

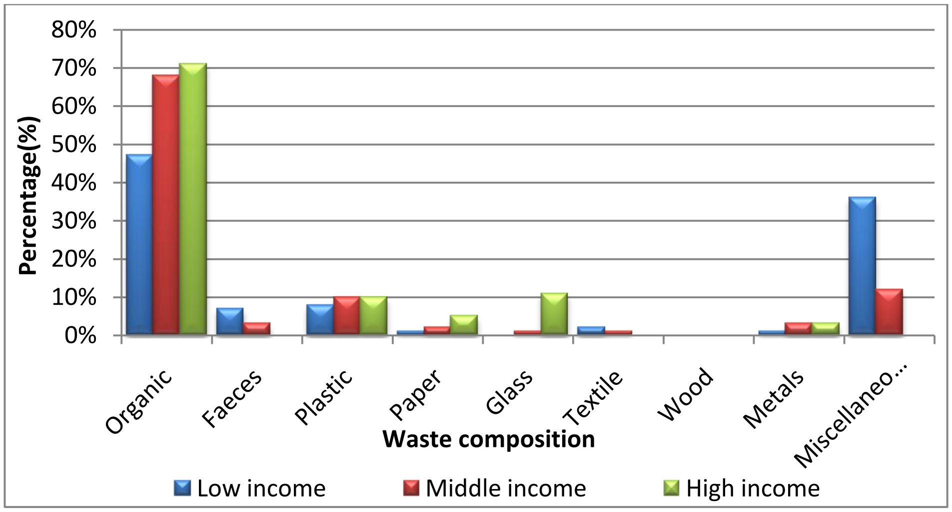

Fig. 2. Average waste composition in the three income groups.

The study further revealed an increase in plastic generation of about 10% compared to results obtained by Kotoka (2001), indicating a growing trend in plastics generation. Glasses generation were very similar for both the low and middle income levels with a significant increase of approximately 10% at the high income level. The increase of glasses generation could be as a result that household in the high income group have greater purchasing power to buy a greater variety of products packaged in glass containers.

Also feaces was observed as a composition of the waste generated in the low and middle income groups. The trend observed could be due to the absence of in-house toilet facility at some households, resulting in children and aged adults who are unable to visit the public places of convenience provided by the Kumasi Metropolitan Assembly in the communities to defecate into plastic bags which consequently end up in the refuse generated at these households. The 3% faeces recorded at the middle income level is mainly pampers and this was observed to have come from babies from such households. The inclusion of faeces in the waste may pose health hazards for those directly involved in the manual sorting. Plates 1: A, B are pictures showing children defeating into plastic bags. These situations were captured during the field work at the low income level.

A **B**

Plate.1. A, B: Faeces being packaged in plastic bags

3.1.3. Bulk density of solid waste

Bulk density is an important parameter used to define the number and capacity of waste storage and collection facilities required. According to Ketibuah et al (2004) bulk density of solid waste varies from 250 to 600 Kg/m3 for low income countries like Ghana. The WHO expert committee report (1982) quotes density of (100-500) Kg/m3 for all income levels in developing countries. The mean value obtained from the high income community of Kwame Nkrumah University of Science and Technology by Kotoka, (2001) was 235 Kg/m3. The densities obtained in this study for the three income groups (low, middle and high) in Kumasi are 381, 237, 306 Kg/m3 respectively and agree with the WHO expert committee report. The density of 306 Kg/m3 obtained for the high income communities in Kumasi in the study is quite comparable to that obtained by Kotoka, (2001) except that the value obtained is on the high side. The trend observed could be due to the high amount of wet waste (71%) and glasses (12%) in the waste collected as at the time of sampling.

3.1.4. Moisture content

Moisture content is one of the physical characteristics of solid waste that could give room for the consideration of certain solid waste treatment options. The moisture content of the waste sampled for the three income groups increased from the low through to the middle and to the high income group level (Figure 3).

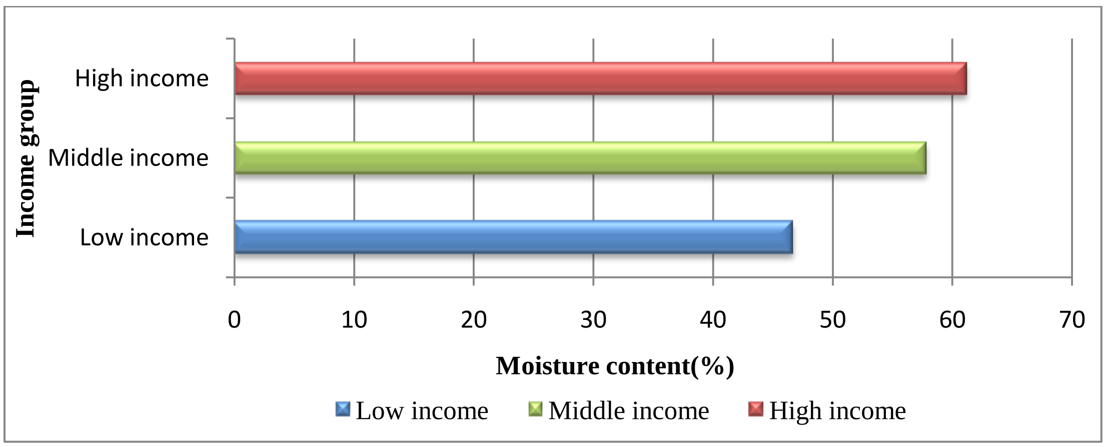

Fig.3. Moisture content of the waste in the three income groups.

The trend observed could be attributed to the fact that significant proportion of the waste from the low and middle income groups constituted the miscellaneous waste fraction. The low income group had 36% of the waste to be the miscellaneous with a corresponding lower organic waste fraction (45%) whiles the middle income group had 12% of the miscellaneous with a higher organic waste fraction (69%). Since the organic waste fraction contributes greatly to the moisture content of the waste, this in a blend with the miscellaneous waste fraction accounted for the trend in Figure 3. The miscellaneous fraction of the waste is the inseparable mixture of food, sand, ash, and silt in the waste. The trend of moisture content observed agrees with that of Cointreau's (1982) estimation of moisture content for developing countries, 40-80% by weight of waste. The higher the level of moisture, the longer it takes for the material to burn. High moisture content may affect the useful calorific value obtainable from waste. The trend of moisture content observed indicates that, the wastes in Kumasi is wet and suggest a possible difficulty in waste handling and may inhibit waste incineration as an option for treatment.

3.2. Chemical characteristics of solid waste

The chemical characteristics of solid waste considered are the total organic carbon, total organic nitrogen, its subsequent C and N ratio and the waste calorific values.

3.2.1. Carbon and nitrogen ratio

The composting and anaerobic digestion potential of organic waste fraction depends on the chemical characteristics of the waste. These include the concentration of Organic Carbon (C), Total Nitrogen (N) and the consequent Carbon/Nitrogen (C/N) ratio. The relationship between the amount of carbon and nitrogen present in organic fraction is expressed in terms of the C/N ratio.

Table 1
Carbon to Nitrogen ratios of waste for the three income groups considered.

Component	Low income group	Middle income group	High income group
Total solids (TS, %)	54.41 ± 3.06	42.46 ± 6.66	39.33± 2.39
Fixed solids (%, TS)	40.55 ± 5.85	31.98 ± 3.86	20.14 ± 3.98
Organic matter(%,TS)	59.45 ± 5.85	68.02 ± 3.86	79.86± 3.98
Organic Carbon (%)	33.29 ± 3.28	38.09 ± 2.16	44.72 ± 2.23
Total nitrogen (%)	1.25 ± 0.100	1.54 ± 0.07	1.79 ± 0.07
C/N ratio	26.60	24.70	25.00

The study revealed a C/N ratio of 26.6:1, 24.7:1 and 25.0:1 for low, middle and high income groups respectively. Even though there were differences between the C/N ratio obtained for the three income groups that for the middle and high income groups were quite similar with that for the low income group being slightly higher than those obtained for the middle and high income group's levels. According to Mamo et al (2002), the ideal C/N ratio lies between 25:1 and 30:1, a range considered favorable for composting without further balancing of the carbon to nitrogen ratio before the execution of the composting itself. However in the event when the C/N of the compost material exceeds 30:1, the bacteria present to enhance degradation become deficient in nitrogen and the process of decomposition is slowed. The result of C/N ratio present a viable option where the organic waste generated in Kumasi could be treated using composting.

The C/N ratio could also be used in determining the potential viability of anaerobic digestion of the organic waste. A C/N ratio ranging from 20:1-30:1 is considered optimum for anaerobic digestion (Anomanyo, 2004). If the C/N ratio is very high, then nitrogen will be consumed rapidly by the methane forming bacteria (methanogens) before meeting their protein requirement and will no longer react on the left over carbon content of the material. As a result, gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of Ammonia (NH4). Ammonia will increase the pH value of the contents in the digester. At a pH higher than 8.5, ammonia will start showing toxic effect on methanogen population. And this will subsequently give rise to a high amount of gas been produced. The C/N ratios obtained in relation to what is considered the optimum for anaerobic digestion makes this option of handling organic waste fraction a viable one. Materials with high C/N ratio could be mixed with those of low C/N ratio to bring the average ratio of the composite sample to a desirable level.

3.2.2. Calorific value

The study revealed some differences in the gross calorific values per mass of waste from the three income groups and among the various sample types both within and between the three income levels investigated [Table 2]. This however suggests a close association of gross calorific values and material composition in waste streams. Generally it was noted that the calorific values decreased from the very high income group through the middle to the low income group. This trend could be attributed to the reason that solid waste from a high income group is rich in compounds containing high energy bonds than those of the middle and low income groups.

Plastic recorded the highest calorific value in all the three income groups. This was followed by the simulate sample which is the natural waste as it was collected using the percentages for the various waste fractions obtained during the characterization stage. Interestingly, the organic waste had reasonably good calorific values in all the three income groups. However since the organics contributes greatly to the high moisture content in the waste, part of the calorific values obtained for the organic waste will have to be used as an additional fuel in order to offset the energy required to evaporate the moisture in the waste, which will leave a net less calorific value. According to Abu-Qudais et al (2000) the minimum calorific value of a sample for power generation is 6280kJ/kg.

Table 2
Calorific values of waste from urban waste zones in Kumasi, Ghana

	Calorific values (KJ/kg)		
Component	**Low income group**	**Middle income group**	**High income group**
Organic	12680.8 ± 1129.78	14986.4± 1129.78	16715.6 ± 1129.78
Paper	14410 ± 1129.78	14986.4 ± 1129.78	14986 ± 1129.78
Plastic	37466 ± 2259.54	40348± 1129.78	40348 ± 1129.78
Cloth	13833 ± 0.00	17292 ± 0.00	-
Simulate	16139 ± 1129.78	23056± 1956.80	27667. 2 ± 2989.11

3.3. Material balances and quantities of solid waste

To determine the generation and movement of solid wastes with any degree of reliability, a detailed materials balance analysis for each income generating source is required. There exist several treatment and disposal options for solid waste. However for a waste treatment option to achieve its long term objective of sustainability the study performed the material balances of the various waste streams that are generated in order to ascertain the availability of inflow of materials for whatever treatment option under consideration.

Table 3
Estimation of the population of three socio-economic groups in Kumasi (KMA, 2009)

Income group	Number of properties	Number of persons/properties	Total number of population	% of total properties
Low	23421	30	702630	43.5
Middle	27238	50	1361900	50.6
High	3164	8	25312	5.9
Total	53823		2089842	100

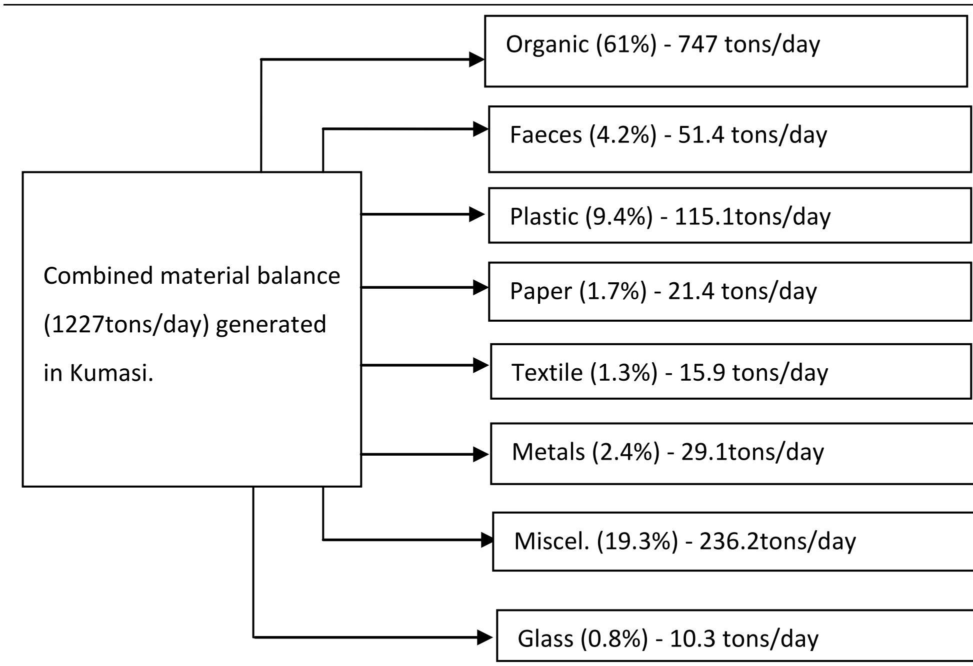

Fig. 4. Combined material balance in waste stream for the various fractions.

The material balances performed went beyond the single waste stream collection system to look at it in terms of the individual components that makes up the solid waste as a whole. The material balances for the various waste streams could contribute immensely to the diversion of waste from the landfill and guarantee that the appropriate waste treatment and disposal options are adopted in the handling of the various waste streams. The material balances for the three income groups using the estimated population as indicated in Table 3 and the percentages obtained in the characterization of the waste gives the quantities of the various fractions readily available.

3.4. Modes of solid waste collection in Kumasi

The two modes of solid waste collection currently in use at the three income levels are the door-to-door collection and the communal collection systems. The door-to-door collection system is extensively adopted by the residents at the high income group level whiles the communal collection system is used mostly by the low income group's residents and some residents of the middle income level. In the door-to-door solid waste collection system the collection crews pick the container containing the waste from either the individual premises or in front of the premise and returns it after the emptying the container whiles in the communal system households discharge their waste at a pre-fixed communal location where temporal storage facilities are available. Currently the two waste collection methods are based on a single waste stream collection system where all the waste irrespective of its heterogeneous composition is lumped together and collected.

3.5 Solid waste treatment and disposal options

The composition of solid waste dictates the treatment options or technology needed for waste processing prior to final disposal. The single waste stream collection currently practiced in the city employs land filling as the means of wastes management where the various fractions irrespective of their composition are sent to the sanitary landfill. Since solid waste is made up of different materials that do not necessarily share the same disposal characteristics, the research made the following findings.

3.5.1. Composting or anaerobic digestion option

The composting potential aside the high percentage by weight of organic waste is however supported by the favorable C/N ratios as well as the moisture contents obtained in the study. The C/N ratios for the three income groups falls within the optimum range for composting which suggest that the organic waste does need C/N ratio balancing before the execution of the composting process. Similarly the C/N ratio is also an important determining factor for biogas generation using anaerobic digesters. The C/N ratios obtained for the three income groups were within the optimum range for biogas generation. Hence it is noted that the appropriate solid waste treatment option for handling of the organic waste is either composting or anaerobic digestion. If all the organic waste from the three income groups could be source separated, then an estimated amount of 747 tonnes/day (Figure 4) representing 61% of the waste of the total waste generated in Kumasi could be diverted for either composting or anaerobic digestion hence reducing the overall amount of waste going to the landfill and subsequently increasing the lifespan of the landfill.

3.5.2. Incineration option

The calorific values measured for the combustible fraction of the solid waste ranged from 12 - 41 MJ/kg indicating a possible option for incineration. Composting or anaerobic digestion of the organic waste may be considered because the net calorific value after some has been used to dry the organic material may be small in relation to the other combustible samples of the waste. However due to the complexity of the process, municipal solid waste incineration could only be applied on a large scale and for only sorted waste. According to Fobilet al (2005) the minimum preferred capacity is at least 500 tons/day of combustible waste to offset the high capital cost of incineration. The daily volume of the combustible waste readily available for incineration with the organic waste inclusive is about 899 tons representing 73% of the daily waste generated. This meets the least preferred capacity of 500 tons of daily waste to offset the high investment cost. However incineration of the organic waste would not be a suitable option due to the high moisture content. Hence exempting the organics from the combustible materials will leave only 152.3tonnes (12.4%), a value far less than the least preferred capacity of 500 tons a day. The burning of plastics is associated with air pollution due to additives such as heavy metals for coloring. Also the burning of plastic produces dioxins; unless efficient and effective mechanisms are put in place to deal with the pollution, incineration could be detrimental to human health.

3.5.3. Reuse and recycling option

The option for recycling could be considered if the fraction can be sorted at source and kept clean. On the average plastics constitute about 10% by weight of household waste, its presence in household waste is significant due to its bulky volume. Taking this fraction to the landfill could shorten the lifespan of the landfill. The plastics could however be used to make sturdy products such as chairs, buckets and products which could replace hardwood products. The paper/cardboard fraction if collected dry and clean could also be used for manufacturing toilet-roll and egg crates. The plastics, paper, glass and the metals and cans are the waste fractions that can be reused or recycled. In all, a total of 15.6% of the waste generated each day could be reused/ recycled.

3.5.4. Land filling option

The miscellaneous is the waste streams whose ultimate destination ends up at the landfill site. The volume of this fraction that resultantly ends up at the landfill is 236.2 tons representing 19.3% of the daily household waste.

4. Conclusion

The study showed a trend that correlates higher income to higher generation rates. The largest proportion of household waste in Kumasi consists of easily degradable components termed organic waste and the materials typically found in the waste streams are the organic, paper/cardboards, plastics, glass, metals/cans, textile, miscellaneous and faeces. The solid waste in the municipality is wet. The C/N ratios obtained were satisfactory in relation to what is considered the optimum for composting and anaerobic digestion of the organic waste. In comparison to the minimum amount of energy (kJ/kg) for a waste burn without auxiliary fuel, the study envisaged a rather higher energy (kJ/kg) values. The physical and chemical characteristics of solid waste in the municipality by nature are heterogeneous and may not be handled easily by disposal technologies alone but also with treatment technologies. The study's identification of composting and anaerobic digestion as the appropriate treatment option for the organic waste and the potential for generating energy using the waste indicate that greater fraction of the waste could be diverted from going to the sanitary landfill site.

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