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Assessment of the energy recovery potentials of solid waste generated in Akosombo, Ghana

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The main attributes of waste as a fuel are water content, calorific value, and burnable content. The study was conducted to evaluate the energy recovery potential of solid waste generated in Akosombo. A total of twelve (12) samples were collected from the township in December, 2012 (dry month) and May, 2013 (Wet month). Samples were weighed and segregated into organic and inorganic components. The organic component was thoroughly mixed, shredded and sieved for analysis at Ghana Atomic Energy Commission Laboratory, Accra. Proximate analysis was conducted to obtain the chemical characteristics of the solid waste. Dulong's Equation was used to determine the heating values with the data obtained from the ultimate analysis. The study obtained moisture contents of 58 and 36% for the wet and dry months respectively that shows the prospects of bio-chemical conversion for the wet month and thermo-chemical conversion for the dry month. The study obtained high percentage organic matter (70%) that can support both conversions. The calorific values ranged between 1.39×10^4 to 2.99×10^4 kJ/kg making it suitable for thermo-chemical conversions. The study reveals that the types of solid waste generated in Akosombo have substantial organic matter, moisture content and calorific value or energy content, making them suitable for energy generation. It is therefore recommended that thermal plants that can convert solid waste into fuel should be provided to harness the potentials of waste in the country.

Key words: Municipal solid waste, waste, energy, heating values, calorific value.

INTRODUCTION

Municipal solid waste generation rates are influenced by economic development, the degree of industrialisation, public habits, and local climate. As a general trend, the higher the economic development, the higher the amount of municipal solid waste (MSW) generated. Nowadays more than 50% of the entire world's population lives in urban areas. The high rate of population growth, the rapid pace of the global urbanisation and the economic

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expansion of developing countries are leading to increased and accelerating rates of municipal solid waste production (World Bank, 2012).

With proper MSW management and the right control of its polluting effects on the environment and climate change, municipal solid waste has the opportunity to become a precious resource and fuel for the urban sustainable energy mix of tomorrow: only between 2011 and 2012, the increase of venture capital and private equity business investment in the sector of waste-to-energy - together with biomass has registered an increase of 186%, summing up to a total investment of USD 1 billion (UNEP/Bloomberg NEF, 2012). Moreover, waste could represent an attractive investment since MSW is a fuel received at a gate fee, contrary to other fuels used for energy generation, thus representing a negative price for the waste to energy plant operators (Energy Styrelsen, 2012).

Globally, so much effort is being channelled towards developing processing technologies to release the resource and economic value of residual wastes as population grows and the demand for the best sustainable management of waste is needed. The effectiveness of solid waste management is of great importance for human health and for environmental protection (Wikner, 2009). Growing population, increased urbanization rates and economic growth are dramatically changing the landscape of domestic solid waste in terms of generation rates, waste composition and treatment technologies. The global MSW generation is approximately 1.3 billion tonnes per year or an average of 1.2 kg/capita/day. It is to be noted however that the per capita waste generation rates would differ across countries and cities depending on the level of urbanization and economic wealth. The amount of municipal solid waste generated is expected to grow faster than urbanization rates in the coming decades, reaching 2.2 billion tons/year by 2025 and 4.2 billion by 2050 (World Bank, 2012). Municipal solid waste is generated by households, commercial and industrial sectors as a result of the concentration of population and activities in urban areas. It is estimated that approximately 760,000 tonnes of MSW annually or approximately 2,000 tonnes per day is generated in Accra, but only 1,200 to 1,300 tons are properly collected (AMA, 2009).

Biomass referred to organic materials that have become residues and they are mainly from plants and animals. Biomass from fossil energy carriers begins with peat; biomass has been grouped into two categories namely primary and secondary products. The primary products come from direct photosynthetic exploitation of solar energy which includes the entire phytoplankton, such as agricultural and forestry products such as fast-growing trees, energy grass, vegetable residues, waste from agricultural including straw and residual wood from forest and industry. The secondary products of biomass are formed by decomposition of organic matter other organisms like animals, such as manure, solid waste, kitchen waste and garbage (Kaltschmitt et al., 2007). Bioenergy is currently the primary energy resource for about 2.7 billion people worldwide (Wicke et al., 2011), playing a traditional role in Africa. The total primary energy demand (TPED) for Africa is predominantly determined by biomass demand, with almost half of the energy demand (47.9%) being covered by biomass and waste. The International Energy Agency (IEA) projects a decline in the total energy share of biomass and wastes by 2035, but biomass will still continue to remain an important energy resource for Africa in the future (IEA, 2010).

The government of Ghana faces the challenge to increase renewable energy in the national energy mix in a sustainable manner. Its goal is to increase the proportion of renewable energy, particularly solar, wind, mini hydro and waste-to-energy in the national energy supply mix and to contribute to them mitigation of climate change (Ghana Renewable Energy Bill, 2011). Non-conventional energy exploitation through useful harnessing of biomass energy locked up in urban solid waste stream into grid energy seems to be a more probable option that has gained both political and public discussions on alternative energy sources (Akuffo, 1998).

Electricity is a basic input for the development of human beings, since it contributes to improving the quality of life and the social and economic growth of the people. However, the rampant use of natural resources cause harmful effects on the global climate, increasing the search for alternative sources of clean energy generation and less impact on the environment. In this sense, the use of municipal solid waste (MSW) emerges as a promising and advantageous alternative from the standpoint of environmental and financial. The proper reuse of the "trash" improved sanitation in urban centers, decreases emissions of greenhouse gases due to its decomposition and helps reduce the consumption of fossil fuels (Possoli et al., 2013).

The process of utilization of biogas generated in landfills is the simplest to explore the energy potential of MSW for energy generation. This is an alternative that can be applied to manage and solve the problems related to greenhouse gas emissions. The transformation of the energy potential of biogas into electricity is made from a process central station, where is the equipment of biogas capture and power generation (Alves, 2000). People, having become conscious of environmental impacts and the cost of fossil fuels and of landfill increases, the incinerators of the past were progressively transformed to the modern waste-to-energy (WTE) power plants that are fuelled by solid waste (Themelis, 2006).

According to Johannessen and Boyer (1999), the design and optimisation of solid waste management technologies and practices that aim at maximising the yield of valuable products from waste, as well as minimising the environmental effects have had little consideration in the Africa Region.

The MSW matter is a structural problem that requires great investments based on efficiency and in the environmental impacts. The MSW consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food, scraps, newspapers, appliances, paint and batteries. The dump is an inappropriate way to dispose municipal solid waste. The indiscrimate disposal of waste promotes the proliferation of infectious diseases, soil pollution and the emission of greenhouse gases.

Many alternatives for dealing with municipal solid waste to provide a sustainable solution that reduces greenhouse gas emissions lower the risk of ground water contamination and conserves land are now becoming more significant. The importance of energy to economic development as almost every single activity is more or less dependent on energy. The possibility of power crisis in the country is inevitable once our water levels go down or supply of gas from the West Africa Gas company is cut. Shortage of power has reoccurred so many times in Ghana. The main objective of the study was to evaluate the energy potential of solid waste streams in the Akosombo Township.

MATERIALS AND METHODS

Study area

The study was conducted at Akosombo in the Asuogyaman District of the Eastern region, Ghana. Where the country's largest hydropower station is found. It is mainly made up of Volta River Authority (VRA) estates with a population of about 0.22 million. It is situated at the south west of the Volta basin, the township lies on latitude 6°16'0.47"N and longitude 0°2'40.75"E (Google Map Data, 2013). The Eastern Region harbours the two major hydropower plants in the country, found in Akosombo and Akuse.

Sample collection and analysis

Solid waste characterisation methods used was in accordance with USEPA (1999) and Shukla et al. (2000). Random sampling was used to collect samples directly from six waste temporal and final disposal sites; dumping site, dustbins, trucks, market, slaughter house and the drains for the characterisation of solid waste. Seasonal conditions were considered as Akosombo has two main seasons: wet and dry seasons. A total of twelve (12) samples were collected from the township within the months of December, 2012 (dry month) and May, 2013 (Wet month) (Figures 1, 2 and 3).

Samples were labelled independently as dumping site, dustbin, garbage track, slaughter house, drains and market bin after collection. The mass of solid waste sample collected during each sampling was about 10 kg throughout the study period. The samples were transported to the Ghana Atomic Energy Commission laboratory and stored in a fridge at 4°C. Determination of waste material composition was done by way of physical segregation (manual sorting) and observation of collected wastes components. Each bag of waste was weighed, and then its contents emptied, sorted and weighed again. The percentage (%) composition was categorised into ten major categories as organic material. The organic components was thoroughly mixed, shredded and sieved to a quality size of < 2 mm which can be handled in the laboratory for further analysis.

Chemical composition of the solid waste sample

This was done in accordance with Bank (2009) who conducted proximate analysis by looking at moisture, volatile matter, ash and carbon. Dulong's formula as adopted by Nithikul (2007) was used to determine the heating values with the data obtained from the ultimate analysis.

This volatile matter is measured by igniting waste at 950°C (additional loss of weight on ignition at 950°C in the covered crucible). Moisture content was determined by the loss of moisture when heated to 105°C for 1 h. The ash was determined by the weight of residue after burning in the crucible, this time around opened. Compositions were experimentally determined using head space analysis and colorimetric method.

Moisture content determination

The various component of waste was weighed and placed in the oven and heated to 105°C for 1 h. Samples were cooled in desiccators and then reweighed. The percentage moisture was determined using the formula below:

$$M = \frac{(w - d) \times 100}{W} \tag{1}$$

Where: M = wet-mass moisture content, %
w = initial mass of sample as delivered, kg
d = mass of sample after drying, kg

Determination of volatile matter and ash

The dried sample and crucible was placed into a muffle furnace and ignited at 950°C for 30 min, till the ash was charred to a clear white colour. The crucible plus ash was removed from the muffle furnace, cooled for at least 30 min and carefully weighed on an analytical balance. The weight of volatile matter (on a dry basis) was computed as the difference between the dry weight of solid waste and the weight of the residue after ignition. Therefore:

$$\%\ \text{volatile matter (dry basis)} = \frac{\text{Weight of dry solid waste - Weight of residue after ignition} \times 100}{\text{Weight of dry solid waste}} \tag{2}$$

Ash content is the amount of residue obtained after ignition of solid waste. Therefore:

$$\%\ \text{ash (dry basis)} = \frac{\text{Weight of residue after ignition} \times 100}{\text{Weight of dry solid waste}} \tag{3}$$

Determination of calorific value

The calorific values (higher heating values) were determined using the modified Dulong equation.
The formula is as follows:

$$HHV\ (KJ/kg) = 337°C + 1428\ (H_2 – O_2/8) + 9S \tag{4}$$

The calorific values were again calculated by using the Dulong equation, considering Nitrogen in the formula below:

$$HHV\ (KJ/kg) = 337°C + 1419\ (H_2 - O.125\ O_2) + 93\ S + 23\ N \tag{5}$$

Where, C = Carbon (%), H = Hydrogen (%), O = Oxygen (%), S = Sulphur (%), N = Nitrogen (%).

Figure 1. Map of Ghana.

Lower Heat Value (kJ/g) (LHV) is the net energy released on combustion.

$$\text{LHV (kJ/kg)} = \text{HHV} - (2.766 \times W) \quad (6)$$

Where, W = moisture content, 2.766 kg/g = coefficient of heat requirement for evaporation (Enthalpy of vaporisation) (Banks, 2009).

Determination of energy content

The energy content of the solid waste sample on both dry basis and ash-free dry basis was estimated by using the data on typical energy values of various components.

$$\text{Energy values converted to dry basis: kJ/kg (dry basis)} = \frac{\text{kJ/kg (as discarded)} \times 100}{100\% - \%\text{moisture}} \quad (7)$$

RESULTS AND DISCUSSION

Proximate analysis

Percentage composition of solid waste generated in Akosombo Township

The study obtained organic matter content that ranged between 60 to 100% with the highest value recorded from slaughter house in both seasons while the least was recorded from truck samples in dry season (Table 1). The study recorded organic matter in percentages that was higher than that of Wikner (2009), who conducted three consecutive tests and recorded the organic material (biodegradable, plastics etc) ranging between 40 and 60% of the total solid waste of the unsorted municipal solid waste (UMSW) used for experiment at Kumasi.

Figure 2. A Layout of Akosombo Township. Source of maps (Google Map Data, 2013).

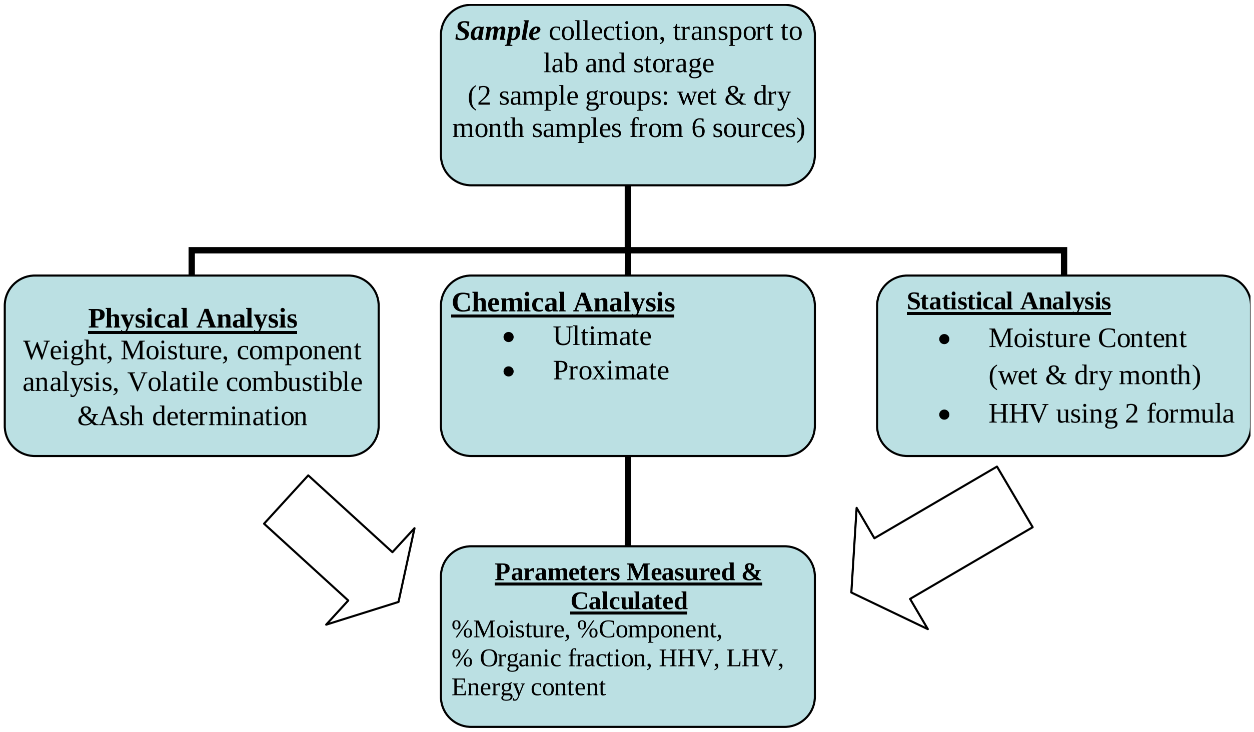

Figure 3. Work plan for precision measures.

Table 1. Percentages of the various components of solid waste generated from the study area.

Sample source	Season	% Organic component	% Inorganic component	% Moisture	% Volatile matter	% Ash
Dumping site	Wet	70.6	29.4	53.32	74.1	17.02
	Dry	65	35	26.72	75.9	19
Dustbin	Wet	75	25	26.2	85.8	1.07
	Dry	68	38	52.4	87.5	1.2
Truck	Wet	60	40	73.71	86	1.04
	Dry	67	33	43.11	68.5	1.05
Slaughter House	Wet	100	-	24.63	75.4	4.87
	Dry	100	-	28.7	70.5	4.52
Market	Wet	75	25	66.49	52.0	11.12
	Dry	62	38	60.35	70.6	10.85
Drains	Wet	64	36	71.74	30.5	2.34
	Dry	65	32	75.6	42.5	2.21

Solid waste generated in the study area has organic material of about 70% on the average. According to Shukla et al. (2000), the desirable range of organic component of the solid waste as a parameter for technical viability of energy recovery methods should be greater than 40%. The present study revealed that solid waste generated from Akosombo have sufficient amount of organic matter for bio-chemical conversion energy plants. Hence, a microbial fuel cell will able to produce electricity by converting the chemical energy content of organic matter of the solid waste generated. This is done through catalytic reaction of microorganisms and bacteria that are present in nature. This technology could be used for power generation in combination with a waste water treatment facility (Min et al., 2005). Inorganic matter of the waste ranged from 0 to 40% with the highest recorded from track samples in wet season while the least was recorded in slaughter house samples in both seasons (Table 1). Moisture content of the waste ranged between 24.63 to 75.6% with the highest recorded from

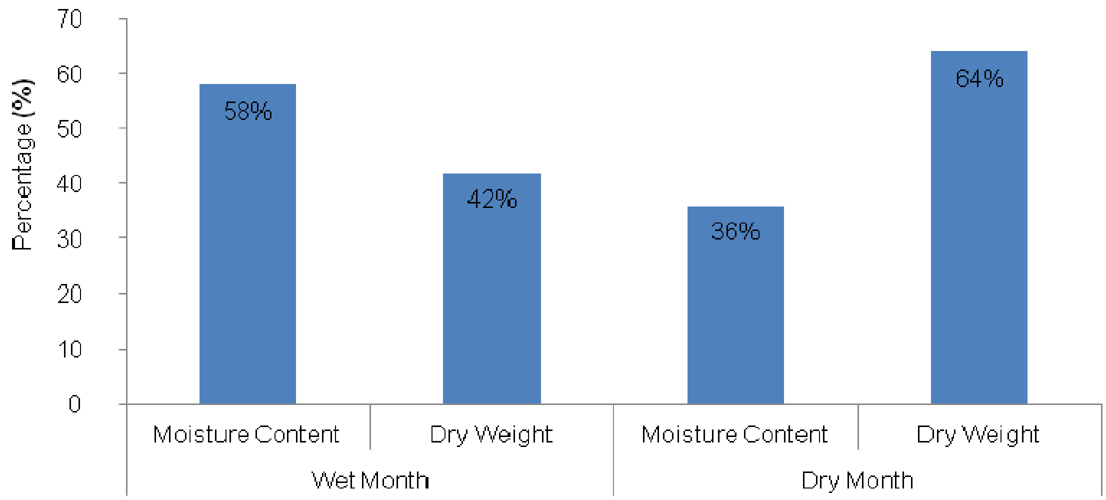

Figure 4. Wet and dry month moisture content and dry weigh of the soild waste.

Table 2. Heating values of the solid waste generated in Akosombo

HHV (kg/kJ)	Dumping site	Dustbin	Truck	Slaughter house	Drain	Market
HHV (Dulong's modified equation)	22906.2	21545.77	13882.95	29859.05	15428.12	18419.09
HHV (Dulong's equation)	22854.2	21521.47	13784.13	29808.83	15419.39	18404.87

drains in dry season while the least was recorded from slaughter house samples in wet season (Table 1). Volatile matter ranged between 30.5 to 87.5% with the highest recorded from dustbin in dry season while the least was recorded in drains samples in wet season (Table 1). According to Shukla et al. (2000), the volatile and the organic component should be greater than 40 % of the total mass of the solid waste to qualify the waste as fuel. Hence, solid waste generated from the study area can be used as fuel. The percentage ash content of the waste ranged between 1.04 to 19% with the highest recorded from dumping site in dry season while the least was recorded in track samples in wet season (Table 1).

Moisture content and dry weight of the solid waste generated in Akosombo Township

The study obtained moisture content of about 58% for wet month and 36% for the dry month (Figure 4). This implies that the moisture contents for the wet month can support a bio-chemical conversion system (plant), as it has been reported by Shukla et al. (2000) that the moisture content for such a convention should be greater than 50% while the moisture content for a thermo-chemical conversion plant should be less than 45%. This means that the waste generated during the dry month can be used as fuel to feed a thermo-chemical plant (incineration, pyrolysis or gasification) since both values recorded by this study fall within the specified range. Cheremisinoff (2003) also reported that water content for municipal solid waste should be under 60% to be able to sustain an incineration without additional fuel. This indicates the possibility of using co-generation system for the utilisation of water as fuel in the dry and wet seasons.

Calorific values or heating values of the waste generated in Akosombo

The main attributes of waste as a fuel are water content, calorific value and burnable content. The study obtained calorific values or heating values that ranged from 1.39 x 10^4 to 2.99 x 10^4 kJ/kg (Table 2). The Lower Heating Values (LHV) obtained in this study ranged between 1.00 x 10^4 to 3.00 x 10^4 kJ/kg (Table 3). Shukla et al. (2000) reported that the calorific value is a very important parameter in establishing a thermo-chemical conversion technology to generate electricity. The average lower calorific value of the waste must be at least 6,000 kJ/kg throughout all seasons. The annual average lower calorific value must not be less than 7,000 kJ/kg (World Bank, 1999). Some studies reported that calorific value for incinerated waste should not fall lower than 6500 kJ/kg (Rand et al., 2000) otherwise, additional fuel is necessary to maintain efficient combustion. Shukla et al.

Table 3. The lower heating values and energy content of the unsorted solid waste.

Sample source	Season	LHV (kJ/kg)	Energy on dry basis (kJ/kg)	Energy on ash free dry (kJ/kg)
Dumping site	Wet	22912.4	49084	77250.2
	Dry	22985.9	31367.2	42346.8
Dustbin	Wet	21528.5	29171.4	29491.1
	Dry	21555.1	45227.9	46454.9
Truck	Wet	13684.1	52050.5	54194.3
	Dry	13768.7	24202.3	24657.4
Slaughter house	Wet	29012.4	33984.3	41152.4
	Dry	29128.9	40854	43619.2
Market	Wet	29996.3	89514.3	133972
	Dry	10013.2	25254.1	34768.2
Drains	Wet	11611.9	41089.4	44798.8
	Dry	11711.8	47999.3	52779.7

(2000) reported standard value of 286.800 kJ/kg or 1200 k-cal/kg for electricity generation. According to Incineration Mauritius (2007), the minimum LHV required for the waste to combust without the addition of other fuel is 7,000 kJ/kg MSW or 1.94 MWh/ton. The heating values (calorific values) of the solid waste generated from the study area are greater than the standard values for incineration of waste as fuel hence the solid waste can be used as fuel. A higher calorific value will increase the actual investment costs and vice versa (World Bank, 1999).

The study also reveals that the energy content values ranged from 2.4×10^4 to 9.0×10^4 kJ/kg on dry basis and 2.5×10^4 to 13.4×10^4 kJ/kg on ash-free dry basis (Table 3). This study also records energy values that are similar but a bit greater than values obtained from a study conducted at Kitwe in Zambia which were 15,021 to 25,956 kJ/kg on the dry basis and 16,161 to 20,313 kJ/kg on ash-free dry basis (Kazimbaya-Senkwe and Mwale, 2001). The energy values from this study ranged from 1.5×10^4 to 2.6×10^4 kJ/kg on dry basis and 1.6×10^4 to 5.0×10^4 kJ/kg on ash-free dry basis. Hence, the solid waste from the study area can be used as a fuel for a thermo-chemical conversion plant.

Conclusion

The use of renewable energy sources is becoming important to reduce global warming and to provide fuel supply which can contribute to countries' energy mix. The study recorded moisture contents of 58% and 36% for the wet and dry month of the solid waste sampled respectively. The study also recorded high percentage of organic matter (70% on average). The calorific values ranged between 1.39 and 2.99×10^4 kJ/kg, making the waste suitable for thermo-chemical conversion. The energy content values of the waste generated ranged between 2.4×10^4 to 9.0×10^4 kJ/kg on dry basis and 2.5×10^4 to 13.4×10^4 kJ/kg on ash-free dry basis. The study revealed that the types of solid waste generated in the study area have substantial organic matter, moisture content and calorific values or energy content, making them suitable for energy generation. This implies that the solid waste generated have the prospects of bio-chemical conversion and thermo-chemical conversion. Based on the findings of this study it is therefore recommended that thermal plants that can convert solid waste into fuel should be provided to harness the potentials of waste.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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