Calorific Value and Moisture Content Of Selected Solid Wastes at Chuka University

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Abstract- Solid waste, which typically consists of metals, plastics, glasses, paper, wood, and organics, is generated and accumulated due to human day to day activities. The waste often leads to ecological pollution unless an appropriate solid waste management system is applied. Remarkably, solid waste can be channeled into a very useful form to generate energy leading to the reduction of the use of fossils fuels which are rapidly becoming limited, reduction of wastes in dumping sites and also be an additional source of energy. For such ventures though, the amount of energy that can be recovered from burning solid waste needs to be determined. In this work, solid waste samples were collected, classified, sundried, powdered and sieved using a sieve of size 500µm. The percentage moisture content of fruits waste, animal dung, and yard trimming & vegetables were found to be 33, 48, and 55 % respectively. The fruits waste had the highest calorific value of 104,130.91J/g, followed by the animal dung with 95,804.13 J/g and the least was yard trimming and vegetables with 95,100.39 J/g. The average specific energy content is 98345.14 J/g.

Keywords: Solid Waste (SW), calorific value, Moisture content (MC), Digital bomb calorimetry

1 Introduction

Solid waste production increases with increase in population and human activities, and this is increasing at Chuka university as the student population increases. This may result to pollution of the environment if not well handled. Since World War II food packaging was gradually introduced for hygienic food preparation[1]. This increases the amount of garbage and ashes accumulation. The packaging led to introduction of paper, metal, glass, and even plastic where food were packed. It have been noted that solid waste generation is directly proportional to the personal income[2]

World Bank survey provided the following data; low income countries generated waste per capita in the range of 0.4-0.5kg/day, middle income countries generated waste in the range of 0.5-0.6kg/day and high income countries generated waste in the range of 0.7-1.8kg/day[3]. It's recently thought that if solid waste was collected continuously it would be a very important renewable resource and the environment would be much clean.

Since national power supplies are approximately wholly depending on fossils fuel and firewood which are becoming limited gradually throughout the year, there is need to look for an alternative ways for generating power. A 550KW/hr can be generated from burning one ton of solid waste which can compensate mining of a ¼ of a ton of coal[4].

The access of electricity in Kenya is low despite the government effort to increase electricity connection which is currently at 15%. The government have a target of connecting 65% of citizens to electricity by the year

2022[5]. In Kenya, national energy analysis show that citizens relies on wood fuel and Biomass that account for 68% of the total consumption where petroleum is 22%, electricity is 9% others account for 1%. Currently Kenya have effectively installed 1429 MW of electricity. Electricity supply is highly depending on hydro-power and fossil fuel with 52.1% and 32.5% respectively. Currently the electricity demand is at 1600 MW and is predicted to grow up to a range of 2600-3600 by 2020[6,7].

In Kenya separation of SW is not commonly done and scavengers of reusable waste like organic, plastic, metal, paper and glass is practiced in open dumpsites. Organic waste has the biggest percentage in Nairobi city, although it's deviating toward more papers, plastics and glasses. The MSW stream in Nairobi was seen to consist 51% food waste, 17% papers, 12% plastics, 7% grasses and wood, 3% metals, 3% textile, 2% glasses and 5%. [8,9]. In 2004 ITDG research gave a slightly different MSW composition with organic consisting 61%, 21% plastics and 12% papers[10].

In Chuka University a lot of SW generated is collected from the compound and buildings by sanitation service providers. These waste consists of plastic, metal, glass, paper, food scrap and yard trimming. The majority of collected waste is not reused. The waste are separated according to their composition and sent to their respective pits e.g. composite and burning pit and metal yard.

Figure 1: One of the dumping sites at Chuka University (Photo taken by the researcher)

Figure 2: Chuka University burning open ground (photo taken by the researcher)

It's not documented on the amount, type and the calorific value of SW generated in Chuka University. This is what encouraged the need to carry out this study.

To generate energy from these solid waste, energy generation processes are used. For example combustion, pyrolysis and gasification. The Calorific value is the amount of energy present in solid waste and is determined by complete combustion of specified amount at constant pressure and normal condition. Here the determination of calorific value of SW sample collected from Chuka University dumpsites will be done by digital bomb calorimeter.

The rapid increase in population lead to increase in solid waste generation. The biogenic combustible of the solid waste undergoes a biological decomposition until a stable material is formed and this results to bad odor from the dumpsites, sewers and dumpsite where organic waste are present. In addition, most of these solid waste are combusted in an open burning pit thus polluting the environment. In this study, the calorific value of the solid waste generated by the people living in Chuka University was determined.

Solid waste are all non-liquid waste and they come from non-municipal where they are generated from industries, agriculture, mining etc. These solid waste are disposed in the dumping site as shown in figure 3. About 99% of waste

2 Overview of Solid Waste Production

Some Solid waste are hazardous and creates significant health problem and unpleasant living environment if not disposed safely and appropriately [11].

Figure 3: A landfill in Danbury, CT in 1991 (United Nations Photo)

In 2012 Hoornweg and Bhade-Tata gave a file of global SW situation and report show that 1.3 billon tons of SW was generated annually at the rate of 1.2kg/capita/day globally. Countries with high income generated SW at the rate of 2.13kg/capita/day while countries with low level of income generated SW at lower rate. A class of society of people of lower and lower middle income were combined their average in SW generation was 0.8kg/capita/day. Generation rate of waste in upper middle and high income countries were increased at 1.37 and 2.53 times consecutively. These research gave an evidence that once a country gain a higher economic activities, the rate of SW generation also increases. United State have the highest rate of waste generation per capita per day of 2.08, followed by EU with 1.51, China with 1.08, India had 0.46, Brazil with 0.85, Philippines with 0.38 and Kenya with 0.53 [12]. Taking SW composition from countries without the same level of income, it's clear that the level of income is inversely proportional to the percentage of organic wastes in the SW while other component of SW tend to correlate directly with the level of income. It shows that low, middle and upper middle income society generate organic waste of (64%, 59%, 54% consecutively) while high income society generate 31% of papers and 28% of organic waste. The percentage of plastic, metal and glass waste does not differ much among the strata.

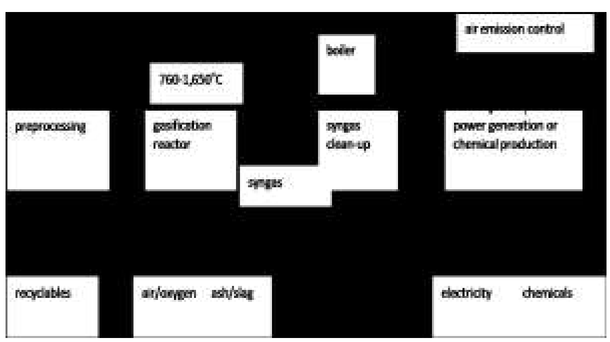
Agamuthu [13] research show that landfilling is the most commonly method used in the management of waste in the developing countries. The cost of construction of the open dumping and landfilling is lower compared to other method of waste disposal like gasification and pyrolysis.

3 Dealing with Solid Waste Pollution

3.1 Advanced Thermal Treatment (Gasification)

The flow diagram is shown in figure 4. The combustion does not fully occur since the fuel is not allowed to oxidize completely. In gasification temperature of 650℃ is involved and the process is usually exothermic but some heat is required to initialize and maintain the process. Gasification is not applicable in raw waste and therefore the raw waste require mechanical preparation and separation of materials like metal and glass, inert material such as rubble come first to process the remaining waste. The main output is a syngas which consist of CO, H_2, CO_2 and CH_4. Gasification plant use less water compared to traditional coal based plants, using commercially proven technology CO_2 can be captured for storage, sold for enhanced oil recovery (EOR) or for enhanced coal bed methane (ECBM) [14]. Typically, the gas generated from this process will have a net calorific value (NCV) of 4-10MJ/Nm^3. The calorific value from gasification is very low compared to natural gas which has a NCV of around 38MJ/Nm^3[15]. Tarring is the biggest problem in energy recovery from syngas at ATT facilities. The deposition of tar causes blockage and also has been associated with plant failure.

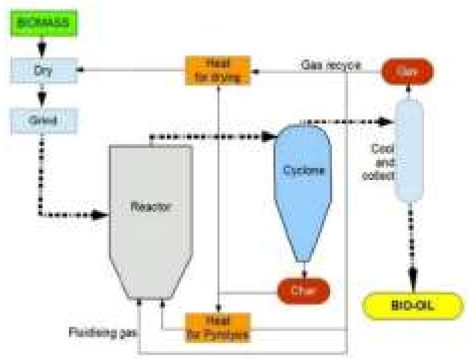
Application of higher temperature (700-1,700℃) in gasification i.e. secondary processing phase may be used to crack tar and clean up the syngas for energy recovery. This lead to higher efficiency energy recovery than applicable through other waste thermal treatment processes. NB most commercial gasification facilities processing SW feedstock use a secondary combustion chamber to burn syngas and recover energy through a steam circuit. The other main product produced by gasification is a solid residue of non-combustible material (ash) which contain relatively low level of carbon[16].



3.1.1.1 ***Figure 4: Gasification processes [17]***

3.2 Pyrolysis

Pyrolysis is a waste to energy technology used to convert biomass and plastics waste into liquid. The process is as shown in figure 5.



3.2.1.1 ***Figure 5: Pyrolysis process diagram [18]***

The solid waste is heat in pyrolysis reactor at 650-1000°C in absence of oxygen. By this process, the chemical constituents and chemical energy of some organic waste is recovered. The organic constituent's splits up into gaseous liquid and gaseous fractions like CO_2, CO, CH_4, tar and charred carbon [19].

The high demand of liquid fuel is predicted to increase in the next 30 years. The transportation sectors relies heavily on petroleum (liquid fuel), which emits a lot of greenhouse gases. Pyrolysis present an opportunity to manufacture low-carbon liquid fuel and decrease the emission of the pollutants gas. In fact, pyrolysis can be carbon negative if the bio char produced is buried into the soil to increase soil fertility instead of burning. The fuel generated is considered is second generation fuel since the feedstock is from renewable sources like waste and biomass. As a result, they are less carbon-intensive than fossils fuel [20].

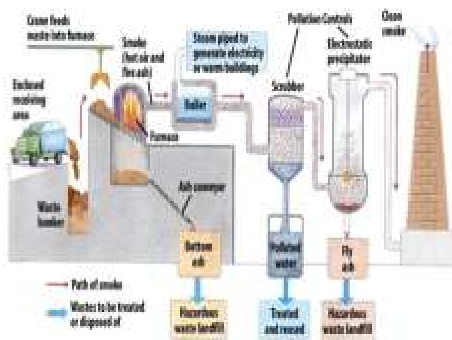
3.3 Incineration

Waste incineration is addition of oxygen to the combustible components contained in the SW. Incineration reduces the solid waste by (80-85) % and reduce the volume by approximately 95% [21]. Burning is one of the most complex waste treatment system that altogether provide for the overall management of the wide range of waste in the society. Over the last 10-15 year the incineration sector has rapidly upgraded due to technological development [10]. The cause of this change is due to legislation of specific industries resulting to reduction of emission of hazardous gases to the environment from individual facilities.

All waste incineration plant must comply with the Waste Incineration Directive (WID) 2000 in the UK. This directive sets the most restrictive emission controls in any thermal processes regulated in the EU. The Industrials Emission Directive (IED) is a new form of the WID together with six other European [10]. The main aim of IED is to reduce pollution in air, water and land from generated of wastes. Operator's combusting waste would need to comply with Annex VI of the IED. They are required to ensure that complete burnout of waste is achieved. The carbon content in the residue indicate reduction of combustible material and destruction of the waste. The common objective of waste incineration is to treat waste so as to reduce their quantity and hazard. Waste is usually a heterogeneous material comprising of organic substances, water, metal and mineral. Fuel gases that contain the majority of the available fuel energy as heat are created during waste incineration. The organic substance in the SW burns after the ignition temperature is reached and it's in contact with oxygen. The actual combustion process take place in the gas phase in few seconds thus releasing the energy continuously. If the calorific value of the waste and oxygen supply is enough, then there will be thermal chain reaction and self-supporting combustion i.e. no need of adding fuel [22]. Most important thing is that incineration process can be used in energy, mineral and chemical content recovery from solid waste.

3.4 Mass Burn Process

Mass burn process is a location that processes municipal solid waste through incineration. They are often used in waste-to-energy conversion and require minimal pre-processing before burning commences. The process is as shown in Figure 6.



3.4.1.1 Figure 6: Mass burn process, obtained from National Research Council [23].

This process is used to generate electricity through solid waste in solid waste facilities. Where SW is off loaded from the collection truck and placed in a trash storage bunker. The waste is sorted by an overhead crane and then it lift the waste into a combustion chamber for burning. The water is heated to steam by the heat produced from the combustion chamber. This steam is sent through the metallic pipes to drive the turbine generator to produce electricity and the acidic gases are removed by the chemical scrubbers from the burning wastes. The residue is collected and taken to landfill where the particulate are captured by baghouse filter system. About 99% of particulate matter is removed by electrostatic precipitators as the gas steam passes through the baghouse filter [24]. Light and tiny particles fall into a hopper (funnel shaped receptacle) and are derived by an enclosed conveyor belt system into ash deposit. These tiny particles are added water to prevent dust and then mixed with large particles from the grate. Finally, the facility take the ash residue to an enclosed room where it is loaded into leak-proof, covered trucks ready to be derived to the main sanitary landfill.

4 Materials and Methods

The study was carried out in Chuka University, a public University in Kenya. It's situated approximately 186km from Nairobi along the Nairobi-Meru highway, in a rural setting on the eastern gradient of Mt. Kenya at an altitude of about 2,000m above sea level. It is specifically located in the medium-sized town of Chuka with a population range of (14,000-18,500) inhabitants[25]. The solid waste samples were collected randomly throughout Chuka University dumping sites. These solid waste samples were identified and classified according to their percentage composition. They were collected and prepared by sun drying, powdering and sieving using a sieve size 500µm.

First the digital weighing balance was used to measure the mass of the empty silica crucible and the measurement recorded as w1 g. 1g of powdered solid waste was placed into a silica crucible using a spatula. The mass of the silica crucible together with the solid waste sample were measured and the reading recorded as w2 g. The sample was then heated in a kiln at a temperature of 105℃ in a period of one hour. The silica crucible containing the heated sample was removed from the kiln and then cooled in a closed glass vessel containing silica gel and mass was recorded. The process of heating, cooling and weighing the powdered solid waste was repeated until a constant mass was acquired w3 g. The equation below was used to calculate the % MC of the combustible component of the solid waste.

$$\% \, MC = \left(\frac{w_2 - w_3}{w_2 - w_1}\right) x \; 100 \; \%$$

Where;

$w_2 - w_3$ Is the mass of SW lost

$w_2 - w_1$ Is the initial mass of SW

The digital bomb calorimeter was used to determine the calorific value of solid waste. A 0.508g of powdered solid waste was measured using a weighing balance. A string was attached to the wire between the electrodes (firing wire). Note, the sample should hang in the air to allow uniform distribution of heating the bomb calorimeter. A string was cut and tied around the sample.

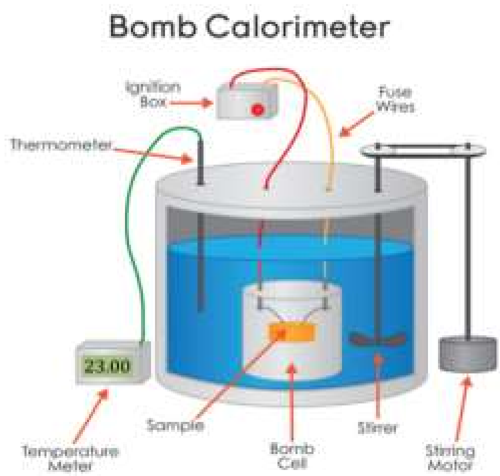


Figure 3. Bomb calorimeter

Then the bomb was sealed by screwing the bottom part of the bomb onto the top part of the bomb holding it still. The bomb was pressurized with 30atm of oxygen. The temperature consistence phase was carried out for a duration of 16 minutes and the vessel was ignited automatically when the initial condition was reached at a voltage of 200V. The calibration curve, calorific value correction and sample mass was taken into consideration and the calorific value was determined automatically for every one minute. The pressurized gas was released slowly from the bomb and then bomb opened fully. The vessel and the residual between each sample was cleaned using a soft cloth and then placed in an open area to cool. The procedure was repeated two times and finally the mean value was calculated and presented under the results and discussion.

5 Results and Discussion

The study sought to first identify and classify solids waste generated at Chuka University. This was done and further the percentage composition of each type of solid waste determined. Figure 4 shows the types of solid waste and their percentage composition. The highest percentage of solids wastes in Chuka university dumpsites and composite pits are polyethylene products at 23%. These products were mainly food wrappers such as bread bags, sugar and rice bags. At second place of the solids waste was animal dung at 16%. Next to this is fruits waste with 14%, Plastic with 9%, yard trimming with 7 % and wood waste, food waste, charcoal, others had

4%, 3%, 2%, 1% respectively. From all the solid waste identified only fruits waste, animal waste and yard trimming were further analyzed, for their moisture content and calorific value is not widely documented.

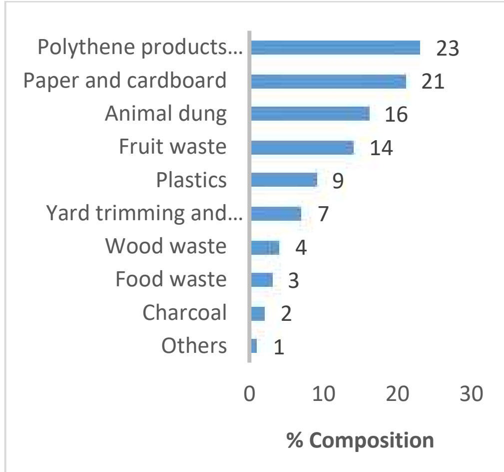


Figure 4: Composition of solid waste generated at Chuka University

The percentage moisture content of the identified solid waste was calculated. The study was only able to do moisture content for only three categories of solid wastes due to inadequate resources where the physical science department allow undergraduate student to analyze only three samples. Time was limited due to the big number of students doing sample analysis using the same instrument. The mean and the standard deviation of the above solid waste was also calculated to help in the determination of the percentage deviation of the percentage moisture content for the solid waste identified. The data was presented in a bar graph shown in the figure 5. Yard trimming and vegetable waste have the highest percentage moisture content of 55.0%. Next to this is animal dung with % MC of 48.0%. Fruits waste have the lowest % MC of 33%.

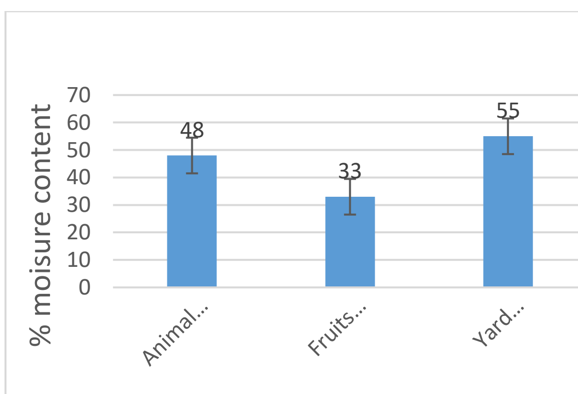


Figure 5: Percentage moisture content of selected SW in Chuka University

Finally, the energy content (J/g) of the selected solid waste in Chuka University was calculated. The study was only able to determine the calorific value for only three categories of solid wastes due to inadequate resources where the physical science department allow undergraduate student to analyze only three samples using digital bomb calorimeter. Also, time limited the analysis for many samples since determination of calorific value is done in duplicates. The results are presented in the bar graph shown in figure 6.

Fruits waste have the highest energy content of 104,130.91 J/g, next to this is animal dung with 95,804.13 J/g and yard trimming & vegetables had the least energy content of 95,100.39 J/g. The % moisture content of fruits waste is found to be 33.0%.

The solid waste in Chuka University was identified and their percentage composition determined. The most generated solid waste in Chuka University is polyethylene products with the percentage composition of 23 %. These waste is mainly generated from food wrappers. Next to this waste is papers and cardboards which included used exercise books, newspapers and broken chair cardboard.

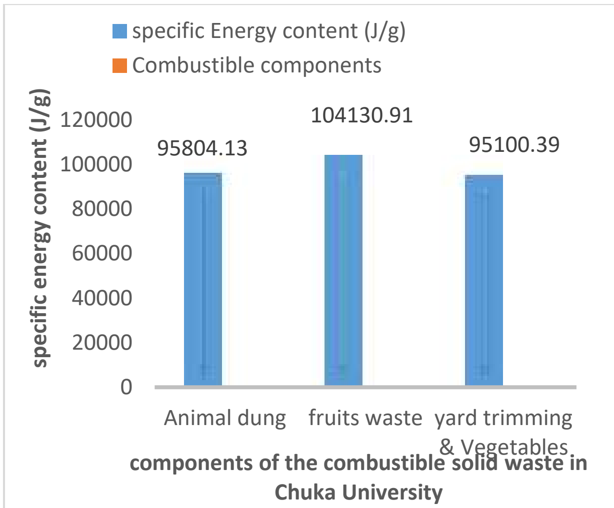


Figure 6: Specific energy content (J/g) of selected SW in Chuka University

The percentage moisture content for animal dung sample is 48%. This value is higher than the value reported by Fapetu which is 11.2%, this deviation might have come due to the nature of the dung and also the type of feed fed to these animals. The percentage moisture content for yard trimming and fruits waste was also seen to have a deviation from the previous research (Pichtel, 2005) which was 60%, 19.4% respectively. This deviation might have arisen due to the nature of the sample and the time the sample had stayed in the composite pit.

The energy content for the identified solid waste was seen to defer from the previous researches where yard trimming, animal dung and fruits waste had 14,069.37 KJ/kg, 13,848.16K J/kg, 37,590 KJ/kg respectively (Fapetu *et. al,* 2017). The analysis shows that the moisture content is inversely proportional to the energy content of solid waste i.e. the higher the calorific value the lower the moisture content. The solid waste with the lowest moisture content should be given the highest priority during the generation of energy this is to reduce the energy needed to evaporate the moisture content of the solid waste during energy recovery. If all these solid waste in Chuka University were burnt completely it would produce electricity which will be used as an alternative source of energy in Chuka University and its Enviros.

6 Conclusion

The aim of the project was achieved. It was noted to be important to classify solid waste according to their composite before discarding them into the main dumping site. This would lead to recovery of useful waste materials thus minimizing the amount of waste sent to the dumping sites. Solid waste with the high moisture content need a lot of time and energy to evaporate the moisture before the energy is recovered from them. This solid waste therefore will increase the cost of energy production leading to low or even negative profits.

The energy content obtained from the three samples shows that there is a huge potential in these solid waste and when combined with appropriate energy recovery technology such as gasification, incineration, pyrolysis etc. will generate energy to address the problem of hydro-power and fossil fuel dependency. Fruits waste has the highest calorific value hence a high potential to generate steam for electricity production.

It is recommended that Universities should introduce waste sorting system to separate different solid waste. This will lead to recovery of useful waste materials thus minimizing the amount of waste sent to the dumping sites.

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