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Evaluation of the heating (Calorific) value of municipal wet solid waste from Kabagarame Dumping site in Bushenyi District, Uganda.

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ABSTRACT

Modern management of waste around the world has moved from waste disposal to energy recovery through WtE. Technologies that can be utilized to recover energy from MSW via thermal conversion processes such as incineration, gasification, pyrolysis, biochemical conversion processes and chemical conversion. The aim of this research was to evaluate the heating (calorific) value of municipal wet solid waste from Kabagarame dumping site in Bushenyi District, Uganda. Wet solid waste samples were analyzed, the heating value of the wastes were evaluated. The results showed that other organics had the highest calorific value of 26.22 MJ/kg, followed by paper 16.60 MJ/kg, followed by food waste 16.51MJ/kg and then wood 16.14 MJ/kg on dry matter basis. The results on the heating value on wet basis showed that other organics had the highest calorific value of 12.82 MJ/kg, followed by paper 14.04 MJ/kg, followed by food waste 13.66 MJ/kg and then wood 9.89 MJ/kg. The heating value of plastics was not obtained since they are recovered from the dumping site and recycled. This energy can be harnessed by different production facilities particularly Tea factories in the region through incineration process so as to generate heat necessary for their production processes. In conclusion, results from this research also suggest that understanding the composition of municipal solid waste is essential for creating the best disposal strategy, so that recovering resources trapped in the wastes can be optimized. It is therefore necessary that energy derived from municipal solid wastes can be taken into account in the national energy budget.
Keywords: Heating value, solid waste, Kabagarame and dumping site.

INTRODUCTION

The sustainable development goal seven aims at ensuring that energy that is reliable and affordable is delivered as a means of eradicating poverty [1].Management of waste sustainably should be taken into account for the generations in the future so as to ensure that the health of human, resource scarcity on earth as well as the environment are protected. It is thus important to ensure that there is minimal extraction and consumption of natural resources through recycling of waste, and efficient management of waste of avoid the impact of disposal of waste to the environment [2]. More so, modern management of waste around the world has moved from waste disposal to energy recovery and recycling and this has led to a high interest in WtE [3].The recovery of energy practice has advantages that are competitive and these include; occupation of land that is small, reduction of volume of waste, minor pollution, and more so it is regarded of a means for disposal of waste that is very effective in the current era and in the future [4]. There are several technologies that can be utilized to recover energy locked in MSW and these include; biochemical conversion, thermochemical conversion and chemical conversion [5]. Waste characteristics are considered in the selection of technology of WtE that can be utilized [6]. More so, the energy potential of waste is a very critical component that is used to identify the amount of energy that can be extracted from the waste [7].

A WtE plant that was established recently in Ethiopia in Africa has attracted interest from several governments in Africa towards application of technologies that can extract energy from waste [8].Incineration is considered to be the more efficient towards handling of variable characteristics in municipal solid waste in comparison to other technologies of WtE [9]. Incineration of municipal solid waste is currently the WtE option that is mature technologically and widely used. It has the ability of reducing the volume of waste by about 90 percent and mass by a percentage of 70 [10]. In addition to that, slag that comes from incineration in grate plant fired by biomass is fit for use directly to improve the soil due to the lower concentration of elements that are hazardous [11]. Also, the ash can be utilized as a material for construction in applications of concrete and asphalt [12]. The heat that is generated through the process of incineration can be used in operations of turbines that are vapor based and more so in the operations of heat exchangers [13]. There is rapid urbanization; 5.1%/annum, and rise in population; 3.3%/annum, in Uganda and this has led to new economic and social opportunities and also more advanced challenges which include management of waste which is not tallying with the growth in population, slums development, overcrowding, settlements that are informal that have solid waste management (SWM) practices that are poor. Anticipations say that urbanization in Uganda will hit 50 % by 2040 [14]. A lot of interventions to tackle poor WM have been undertaken by the country for example a credit of US$150 million for International Development Association (IDA) was approved by the World Bank Board of Executive Directors to fund the infrastructure in urban areas and develop delivery of service in 14 municipalities in Uganda [15]. There has not been any visible change despite all the support financially offered towards SWM [16].

A tremendous venture confronting engineers and scientists in growing nations is the search for suitable answer for the treatment, collection and disposal or re-use of home waste to produce power [17-24]. Even though the energy desires have been met by the invention of the deposits of fossil fuel, the deposits are restricted in quantity, exploration and manufacturing [25-27]. Centers that convert waste to energy are part of answer of the global solid waste disposal hassle. These centers, while blended with recycling of crucial material, landfilling and composting, might be a long-time period financial answer since they are developed and operated in a manner that suits the environment [26]. Generation of energy is pivotal for the development of a nation economically, socially and intellectually. Waste to energy (WtE) is one of the ways for generation of energy sustainably [27]. The generation of energy from waste in liquid, gas or solid form has the ability of minimizing over dependency on fossil fuels, thereby enhancing a feasible optional technique to manage most MSW. 64% of world's WtE is obtained via incineration of waste with other renewable energy forms from waste obtained from anaerobic digestion of organic waste and landfill gas [17]. The Third National Development Programme (NDP III) aim is to increase consumption and accessibility to clean energy. Access to services of sustainable energy is very crucial for growth of the economy, reduction in the poverty rates, and more so transformation of the society both socially and culturally. The development of energy is very critical for utilizing of the key opportunities for growth through facilitation of the agenda of industrialization by developing sustainability, business cost reduction, allowing production, thereby leading to an increase in the competitiveness, growth of the economy that is sustainable and an improvement in the quality of life. More so, The Uganda Vision 2040 aims to have access to energy that is clean, affordable and reliable so as to facilitate industrialization, among others.

According to The Third National Development Programme (NDP III), the country's energy mix is dominated by biomass which contributes 88% (charcoal, firewood, crop residues). 120, 000 hectares of forest cover is lost annually with 72,000 hectares (60%) lost through firewood and charcoal. Currently, the country suffers a $2.3 billion biodegradation loss with wood fuel contributing 25%. Similarly, [18] asserts that the policy of renewable energy in Uganda encourages the utilization of municipal solid waste as a resource of renewable energy. Technologies that extract energy from waste are able to minimize the quantity by a percentage of 90, and this depends on the composition, by extracting the energy locked in the Municipal Solid Waste thereby providing means of utilizing alternative renewable energy resources and thus reduce the use of precarious energy and ensure both environmental protection and energy security [19].

In Uganda waste generation is between 0.3 kg/capita/day for low income earners and 0.66 kg/capita/day for high income earners in urban areas [20]. In 2008 a memorandum of understanding (MOU) on SWM was signed by Bushenyi–Ishaka Town Council and the Gemert-Bakel Municipality with an aim to promote the segregation of non-biodegradable and biodegradable waste at the level of households. Over Shs. 150 million was invested in the project, and two centers that are separate for treatment of waste were put up in the municipality; Nyaruzinga center which was to be utilized for waste that is biodegradable waste and Kabagarame site which was to be utilized for non-biodegradable waste [20]. In accordance to the designs that are in place for both the compost plant and site for landfill that were acquired from the physical planner of the municipal that were approved in 2009, both the sites fulfilled the guidelines as per the national and international guidelines. However, most of the infrastructure that were specified in the design have not been implemented. Currently, a private operator only recovers the plastics and exports them to processing plants in Kampala. For the rest of the municipal solid waste, land filling that is uncontrolled and unsanitary has been mainly adopted and this subsequently can cause health, environmental and aesthetic hazards. The fraction of the waste that is organic is responsible for the pollution by leachate, and methane generation, and therefore the removal of this biodegradable waste from the waste stream would reduce the emissions at the dumpsite. This can be achieved through the conversion of this waste into energy. This can be a powerful means that can ensure the reliability and stability of energy systems in the region particularly for several tea factories as this energy can be harnessed for its production processes. However, this can be achieved after a thorough study to ascertain feasibility of the Municipal waste for generation of energy and this justifies the need for this study.

Aim of the study

The aim of this research was to examine the heating value of wet solid waste samples in Kabagarame Dumping site in Bushenyi District, Uganda.

Research Question

(i) What is the Heating Value of the solid waste?

Figure 1: Kabagarame dumping site

MATERIALS AND METHODS

Research Design

The study utilized quantitative research design.This was characterized by collecting data which was expressed numerically. Such data was solved by statistical tools such as bar graphs, pie charts.

Sampling Design

This involved taking samples of solid waste that are representative from the dumping site having the composition and properties of the mass of waste from where it was collected. The method of spot sampling was used in the process of sampling. Wet solid waste samples were taken from dump site from five spots where an amount of waste (1500g) was taken per spot and the total amount collected formed a sample size of about 7500g per week. The waste samples were filled in polyethene bags so that they could be weighed and then stored. The polyethene bags were labelled with identification numbers for indicating the spot from which the sample was collected and the period of sampling. Five samples of 1500g each of the raw solid waste were taken from five spots from the dump site per week and this was done during a 13-week period.

Project Implementation flow chart

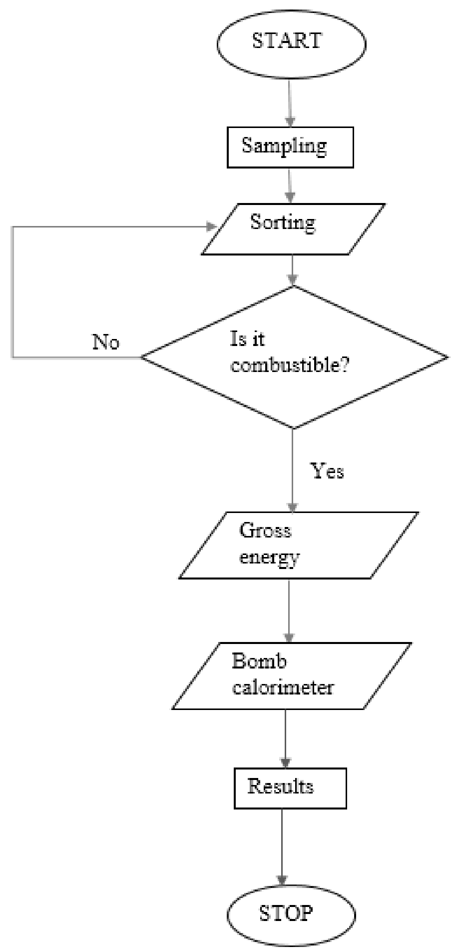

Figure 2: Project Implementation flow chart

The number of samples to be sorted were estimated on the basis of ASTM D5231 method of calculation;

$$n_0 = \left(\frac{t \times s}{e \times x}\right)^2 \qquad (1)$$

Governing component; other organics.
At 95% confidence interval;

$$for: n = \infty, t = 1.960,\ s = 0.06,\ e = 0.3,\ x = 0.05$$

$$n_0 = \left(\frac{1.960 \times 0.06}{0.3 \times 0.05}\right)^2$$

$$or \quad n_0 = 61$$

At 95% confidence interval the value of t statistic corresponding to $n = 61$ is 2.000. Hence n' is obtained by;

$$n' = \left(\frac{1.960 \times 0.06}{0.3 \times 0.05}\right)^2$$

$$or \quad n' = 64$$

n_0 And n' do not differ by more than 10% and hence 64 samples were chosen

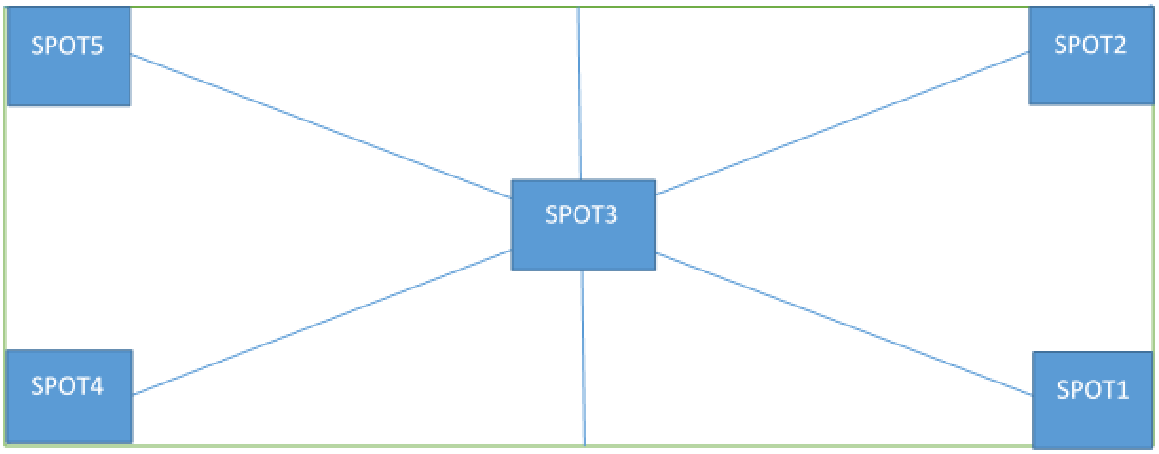

Figure 3: Illustration of sampling spots

Sorting

This involved determining the individual components available in the mass of waste and their distribution by mass. The polyethene bags containing the waste samples were emptied onto a clean flat leveled area with the electronic scale positioned on the same area. Hand Sorting was used for sorting of the Waste into various component categories as described in table below.

Table 1: Condensed Municipal Solid Waste Categories

Category	Description
1. Food waste	Comprised of all the wastes of food that include bones
2. Mixed paper	Office paper, magazines, computer paper, waxed paper and paper that lies in the corrugated and newsprint categories.
3. Wood	Comprises of all kinds of wood
4. Other organics	rubber, textiles, leather, and materials that are burnable primarily, and materials included in the yard waste category
5. Glass	Comprises of all kinds of glass
6. Other inorganics	ceramics ,sand, rock, plaster , dirt, and metals that are in the categories of aluminum and ferrous
7. Plastic	This comprises of all kinds plastic

Source: ASTM D5231-92(2003)

Heating Value (Calorific Value)

The Heating Value of the solid waste is the amount of heat released during combustion of a specific amount of waste and this was measured using a Bomb calorimeter instrument. This was determined on both wet and dry basis. For the dry basis, the Wet solid waste samples were subjected to thorough drying. This was done by subjecting the samples of mass (2.00g-2.40g) in an oven maintained at a temperature of 105°C for a period of 12 hours. The samples were then retrieved and the moisture content as well as percentage of dry matter were obtained as follows;

$$Mass\ of\ Moisture\ Content = (crucible\ mass + sample\ mass) - oven\ mass$$

Similarly,

$$\%\ of\ dry\ matter = \frac{sample\ mass - mass\ of\ moisture\ content}{sample\ mass} \times 100$$

The Heating Value was obtained as follows for both wet and dry matter;

(a) 0.99g-1.00g of solid waste sample was prepared into a fuel cup that was then lowered onto the fuel cup holder of the bomb.

(b) 15 Calories of Fuse wire were cut .The wire was then attached between the leads/arms of the cradle and then pointed into the fuel contained in the fuel cup .This was done while ensuring that the fuse wire does not make any contact with the fuel cup. This is because the fuse cannot ignite if it makes contact with the cup.

(c) Two milliliters of distilled water were then added to the bomb.

(d) The assembly of the bomb was then lowered into the bomb carefully after which it was screwed to a fit that is comfortable.

(e) The bomb was then positioned at the bench and 30 bars of oxygen were pumped into the bomb from the oxygen tank.

(f) The bucket was filled with two liters of distilled water after which the bomb vessel was gently placed into the bucket. This was done while ensuring that the bomb was not tipped and the feet of the bomb were aligned with the notches at the bucket.

(g) The initial temperature of the water in the bucket was read from a thermometer

(h) The power cable of the bomb calorimeter was then plugged into the power supply and switched on.

(i) The Fire button was then pushed until a temperature rise was recognized from the thermometer.

(j) The temperature was closely observed till the change in temperature decreased and reached a constant state. This temperature was read and noted as the final temperature.

(k) The power supply to the bomb calorimeter was then switched off.

(l) The bomb was then lifted from the water bucket, depressurized, unscrewed, disassembled and the bomb head carried to the stand.

(m) The Heating Value of the remaining fuse wire was then noted

(n) The above steps were done for all the solid waste samples

(o) The Calorific Value of the solid waste sample on Wet basis was then obtained from;

$$Gross\ energy\ (kcalg^{-1}) = \frac{(\Delta T \times e) - W}{(m \times 1000)} \quad (2)$$

Where; ΔT, Temperature rise (℃), e, Energy equivalent of the Bomb $(2465J)$, W, Fuse wire used (Cal), m, sample mass (g)

The Calorific value of the solid waste sample on dry basis was obtained from;

$$Gross\ energy\ on\ dry\ basis = \frac{Gross\ energy\ on\ wet\ basis\ \times 100}{percentage\ of\ dry\ matter}$$

Figure 4: The researcher collecting solid waste samples from the dumping site, packing and quantifying the samples.

Waste is divided into dry and wet waste for separation at the source. Materials that cannot be recycled are part of the dry refuse. They consist of things like containers, flasks, garments, plastic, timber, glassware, metals, and newspapers among others. The opposite is true for wet samples, which include organic materials like food leftovers, dirty grocery bags, sanitary items, yard debris, tissues, and paper towels. The reports are indicated in Table 2.

$$GE_{wet}(kcalg^{-1}) = \frac{(\Delta T \times e) - W}{(m \times 1000)} \tag{3}$$

Where $e = 2465\,J$, is the enegy equivalent of the bomb calorimeter and $W\ (cal)$ is the fuse wire used and m is the sample mass in grams.

Table 2: Gross energy on Wet basis

Category	Sample mass	T_i (℃)	T_f (℃)	ΔT(℃)	Fuse wire used (cal)	GE (kcal/)	GE_{wet} (MJ/kg)
1. Other organics	0.99	27.92	29.16	1.24	15.00	3.07	12.82
2. Food waste	0.99	25.89	26.84	0.95	7.00	2.36	9.89
3. Wood	1.00	28.92	30.25	1.33	15.00	3.26	13.66
4. Paper	0.99	26.70	28.05	1.35	15.00	3.35	14.04

From Table 2, T_i (℃) refers to the initial temperature, T_f (℃), the final temperature and $\Delta T(℃) = T_f - T_i$, is the change in temperature and GE_{wet} is the gross energy content.

Table 3: Gross energy on dry basis

Category	m_s	m_c	$m_s + m_c$	m_o	MC	% Dry matter	Average % Dry matter	GE_{dry} (MJ/kg)
Other organics	2.15	27.27	29.42	28.32	1.10	48.84	49.06	26.22
	2.09	17.52	19.61	18.55	1.06	49.28		
Food waste	2.39	26.36	28.75	27.68	1.07	55.23	59.81	16.51
	2.05	20.73	22.78	22.05	0.73	64.39		
Wood	2.19	26.64	28.83	28.48	0.35	84.05	84.68	16.14
	2.11	28.34	30.45	30.14	0.31	85.31		
Paper	2.22	18.57	20.79	20.47	0.32	85.59	84.42	16.60
	2.03	17.58	19.61	19.27	0.34	83.25		

Where; m_s (g) is the sample mass in grams, m_c (g) is the crucible mass, MC is the water or moisture content in the sample (g) determined using Equation 4 and GE_d is the gross energy content.

$$MC = (m_s + m_c) - m_o \quad (4)$$

The percentage dry matter is determined using Equation 4 expressed in percentage.

$$\%\ dry\ matter = ((m_s - MC) \div m_s) \times 100\% \quad (5)$$

Substituting Equation 4 to Equation 5 yields Equation 6.

$$\%\ dry\ matter = \frac{m_s - \left((m_s + m_c) - m_o\right)}{m_s} \times 100\% \quad (6)$$

From Equation above, $m_s = 2.15\ g$, $m_c = 27.27\ g$ and $m_o = 28.32\ g$, the % dry matter is 48.84%. For the different material categories (other organics, food waste, wood, paper), the % dry matter is summarized in Table 3

The gross energy on dry basis is given by Equation 7.

$$GE_{dry} = \frac{GE_{wet}}{\%\ dry\ matter} \times 100\% \quad (7)$$

when $GE_{wet} = 3072.32 \frac{Kcal}{kg}$,

$\%\ dry\ matter = 49.06$ for other organics, the GE_{dry} will be 6262.37 Kcal/kg (26.22 MJ/kg).

DISCUSSION OF FINDINGS

This research evaluated the heating value of municipal solid waste from Kabagarame dumping site in Bushenyi district, Uganda. The aim of this research was to examine the wet solid waste samples so as to evaluate the heating value of the waste on both wet and dry basis. Experimental work revealed that; other organics have the highest calorific value of 26.22 MJ/kg, followed by paper 16.60 MJ/kg, followed by food waste 16.51MJ/kg and then wood 16.14 MJ/kg on dry matter basis. The results on the heating value on wet basis showed that other organics have the highest calorific value of 12.82 MJ/kg, followed by paper 14.04 MJ/kg, followed by food waste 13.66 MJ/kg and then wood 9.89 MJ/kg. The heating value of plastics was not obtained since they are recovered from the dumping site and recycled. Moreover the heating value of glass and other inorganics was not obtained since they are non-combustible.

CONCLUSION

In conclusion, calorific value of the waste samples from Kabagarame dumping site in Bushenyi District, Uganda is ranked as follows: organics recorded the highest calorific value of 26.22 MJ/kg > paper 16.60 MJ/kg > food waste 16.51MJ/kg and then wood with 16.14 MJ/kg recorded the least calorific value.

RECOMMENDATIONS

Incineration of municipal solid waste being the WtE option that is currently mature technologically and widely used, can be utilized to recover energy locked in this waste. The heat that is generated through the process of incineration can be harnessed by several production facilities particularly the tea factories in the region for their production processes.

LIST OF ACRONYMS

CV	Calorific Value
CC	Correlation Coefficient
IDA	International Development Association
WtE	Waste to Energy
SWM	Solid Waste Management
MOU	Memorandum of Understanding
MSW	Municipal Solid Waste
ASTM	American Society for Testing and Material
HHV	Higher Heating Value
SWMS	Solid Waste Management System
RCRA	Resource Conservation and Recovery Act
C	Carbon
H	Hydrogen
O	Oxygen
N	Nitrogen
S	Sulphur
VM	Volatile Matter
FC	Fixed Carbon
TGA	Thermogravimetric Analysis
MC	Moisture Content
RDF	Refuse-Derived Fuel
GPM	Geometric Programming Model
RMSE	Root Mean Square Error
SPSS	Statistical Package for the Social Sciences
GPS	Global Positioning System

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