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Combustion Characteristics and Energy Potential of Municipal Solid Waste in Arusha City, Tanzania

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Abstract: Municipal Solid Waste (MSW) generation has been increasing due to population growth, changing life style, technology development and increased consumption of goods. The increase of waste generation combined with the use of waste dumps may lead to environmental and social problems such as water contamination, land and atmospheric pollutions, resulting to breeding grounds for vermin, cause risk of fire, bad smell and potentially are the cause of illness. Energy recovery from municipal solid waste can alleviate these problems while providing a source of energy. The objective of this study is to evaluate the combustion properties and energy potential from municipal solid waste of Arusha, Tanzania. Incineration is among the methods for MSW treatments, and therefore, the data and information provided shows that energy can be recovered from Arusha MSW during incineration process. Energy flow (exothermic and endothermic) and thermal degradation analysis were carried out using Differential Scanning Calorimetry (DSC) and thermo – gravimetric analysis (TGA) respectively. The sample of composition of municipal solid waste examined included paper, cardboard, wood, textile, rubber, polyethylene Teraphthalate (PETE), low density polyethylene (LDPE) and food waste. These materials were heated in a combined DSC and TGA analyser and experiments were performed at heating rate of 10°C/min, in a pure nitrogen atmosphere at temperatures between room temperature and 1100 °C. The results observed from TGA and DTG show that the highest reactivity was the samples from Central Market, followed by those from Sakina and Ngarenaro market. It was observed that municipal solid waste is less reactive to combustion compared to dry biomass, thus its reactivity can be improved by removing non- combustible materials such as metals and food scraps or by pre-treating the MSW so as to reduce the amount of oxygen present in it. The final analysis of the municipal solid waste showed that, the average percentage of nitrogen, sulfur, chlorine and phosphorus in the waste were 2.36%, 0.37%, 0.04% and 0.11% respectively, which is low and therefore, emissions released by this MSW during combustion are also low. The energy content of the solid waste tested was about 12MJ/kg on dry basis. The elemental composition shows that municipal solid waste contains 50% and 5% of carbon and hydrogen respectively.

Keywords: Municipal Solid Waste, Thermal Behavior, Thermo Gravimetric Analysis

1. Introduction

The generation of municipal solid wastes (MSW) in Tanzania has grown steadily in recent years. It has been estimated by Dar es Salaam Local Authority (DLA), that approximately 4200 tons per day of solid waste were generated in Dar es salaam, Tanzania in 2011, which represent a generating rate of 0.93kg/cap/day basing on a population of 4.5 million [1].The increasing waste generation among others is due to the increase of population in urban areas which is caused by migration of people from rural areas seeking employment for poverty alleviation. Mundi [2], points out that over past 51 years, urban population in Tanzania has increased from 528,508 in 1960 to 12,359,930 in 2011. Globally, 1.2 billion people live on less than $1.25 a day, where a large number of them live in southern Asia and sub Sahara Africa, Tanzania inclusive [3].The lack of both awareness and technologies for the utilization of MSW into valuable assets such as energy conversion, recycling, incineration and composting is still a problem to society [4]. Due to that reason, Arthur et al [5] reports that the disposed solid waste at Murieti dumpsite in Arusha, Tanzania amounted to 120 tons per day in 2012, and according to Breeze [1], about 63% of the solid waste was found disposed in unplanned areas in the city of Dar es Salaam in 2011.

The utilization of fossil fuels has been in practice for many years now as a source of energy, however this utilization produces greenhouse gases such as CO_2, and generate other pollutants such as SO_2, and NO_x which increase generation of acid rain [5]. Globally, fossil fuel resources are depleting while the consumption is increasing. Terra Symbiosis [6], explain that, discoveries of oil peaked around 1960 and have since slowed significantly. In fact, the time will come when the costs of extraction will increase whilst production will start to decline. World energy consumption doubled between 1970 and 2000, and it is expected to double again between now and 2050. Global consumption of coal increased by 5.4 percent in 2011, to 3.72 billion tons of oil equivalent, while natural gas use grew by 2.2 percent, to 2.91 billion tons of oil equivalent [7].

Satisfying the energy demands through the use of renewable energy sources is on the main agenda now days because of the fossil fuel depletion and environmental issues. Municipal solid waste is the result of human activities which if an appropriate management system is not used, it may lead to environmental pollution and endanger mankind's health. However, the MSW generations increases can be taken as an opportunity for the source of energy for power generation in domestic or industrial use. The European Commission's Environmental Data Center [8], clearly states that the principal definition of municipal waste is "Municipal waste include households and similar wastes". The bulk of the waste stream originating from households and other similar wastes from various sources such as commerce, private, and public service are also included. Imed [9], argues that in low income countries Tanzania inclusive, the solid wastes originated from home, commerce and other areas such as public sectors are more than 50% of the collected solid waste. It is opposite in high income countries where life style favors fewer home cooking by generating only about 30% of solid waste from these areas. Generally, these MSW can be grouped into organic and inorganic materials [10, 11].

Combustible materials from municipal solid waste can be used for energy recovery as they can reduce the utilization of fossil fuels, thus assisting in minimizing global warming [12].The emission of CO_2 coming from biogenic combustion of municipal solid waste is renewable, hence reducing the global warming as it completes the carbon cycle as it does in biomass [13, 14]. Many studies also show that, energy recovery from municipal solid waste can be a better way of managing environment from pollution [15, 16, 17].

There has been much research conducted on the utilization of MSW for the energy recovery. Sushmita [18], for example conducted a research on Technological Options for treatment of MSW of Delhi which finally found out that the landfills used have a lot of potential for energy recovery that can be used for commercial applications such as power generation, whereby the methane gas from this landfills could be transported as pipeline gas. Amin and Yang [19], did a research and concluded that MSW is a domestic energy resource with a potential to provide a significant amount of energy and suggested to have a plan of incineration in Tanjung Langsat landfill area which could use the high average amount of heating value about 23000KJ/Kg of collected MSW. Suroop and Juggurnath [20], investigated the energy potential from co- firing coal with municipal solid waste by comparing the electricity units generated and the amount of Greenhouse Gas emission when using MSW alone as a fuel and when it is co-fired with coal. Sveta Angelova et al [21], carried out a research on municipal solid waste utilization and disposal through gasification. The syngas from this process has a calorific value of 7.5 – 17.5 MJ/m^3 which can be used to generate electricity and heat or for chemical conversion into various products. The study concluded that, converting MSW to energy has the environmental advantages of reducing the number of landfills, preventing water/air contamination, and lessening the dependence on oil and other fossil fuels for power generation. JD Nixon et al [22], conducted a study and compared five technologies to evaluate options of energy recovery from MSW in India. In the study, Anaerobic Digestion (AD) was identified as the preferred technology for generating electricity from MSW. Both Analytical hierarchy process (AHP) and hierarchical analytical network process (HANP) models gave priority to Anaerobic Digestion and Gasification processes for the energy recovery from MSW.

The scope of this paper is thus to evaluate and analyze the combustion characteristics and energy potential of Arusha City. The use of WTE technologies in Tanzania for converting MSW into energy are still not yet employed. The information provided in this paper is useful for energy recovery during MSW disposal through incineration process. In Tanzania, solid wastes are thrown away in landfills and in various damps instead of utilizing them and convert what would otherwise be a waste product into a high value product. Energy in the form of heat can be recovered from these solid wastes and used in various applications such as warming or steam production for electricity generation. In order to achieve this, the study focused on determining the characteristics of municipal solid waste from three different areas in Arusha; Ngarenaro, Sakina and the Central market.

The paper is structured as follows. Section 2 provides methodology and materials applied in the study, section 3 describes results obtained and discussion of the proximate analysis, ultimate analysis and the calorific value of the solid waste materials. Section 4 provides detailed information on the Thermo Gravimetric Analysis (TGA) curves and Derivative Thermal Gravimetric (DTG) analysis curves of the solid waste materials. A short conclusion is provided in section 5.

2. Material and Methods

2.1. Methodology

This section presents the methodology applied to undertake a study. The methodology consisted of sampling and selection, sorting and laboratory analysis to determine the chemical and physical properties of municipal solid waste of Arusha city. The method of sampling based on ASTM D5231 namely random truck sampling and quartering [10]. Figure 1 shows one of the trucks used to carry the waste to the dumping site, where sorting and sampling was conducted. Wastes were randomly collected from different collecting sources of Central market, Sakina and Ngarenaro markets within Arusha as shown in Figure 2. The random track sampling is shown in the flow chart of Figure 3.

Figure 1. *One of the trucks carrying MSW from the city to the site.*

Figure 2. *Two different collecting points at Ngarenaro market.*

The wastes were sorted and weighted by using weighing balance and then separated according to defined classification such as food waste, plastics, mixed papers, frozen fruits, diapers, local news papers, cardboards, yard wastes, leathers, glass and metal as shown in Figure 4.The non-combustible wastes were removed from the rest of the wastes. The combustible waste was availed for analysis in accordance to the method developed by [10]. In order to accurately determine the waste composition, an average weight of about 200kg of municipal solid waste was taken. This was assumed to be a good representative of the total municipal solid waste composition at each collecting point under this study. The samples were subjected to standards test methods of proximate and ultimate analysis in accordance to ASTM D3172 and ASTM D3176 respectively.

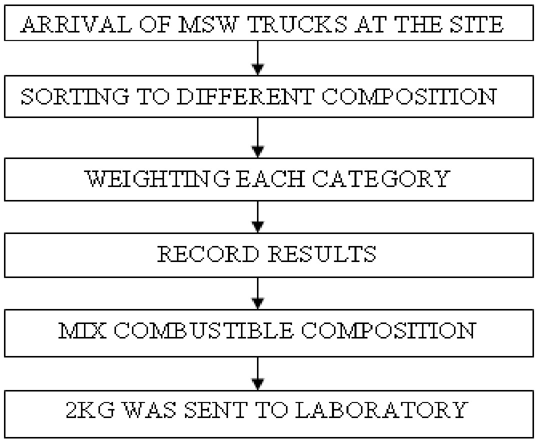

Figure 3. *Flow of random truck sampling.*

The thermal degradation analysis was studied under Nitrogen condition using a thermo gravimetric analyzer type NETZSCH STA 409 PC Luxx connected to power unit 230V, 16A. High purity nitrogen of 99.95% used as carrier gas controlled by gas flow meter was fed into the thermo gravimetric analyzer with flow rate of 60ml/min and a pressure of 0.5 bars. In the STA 409 PC Luxx, proteus software was used to acquire, store and analyze the data.

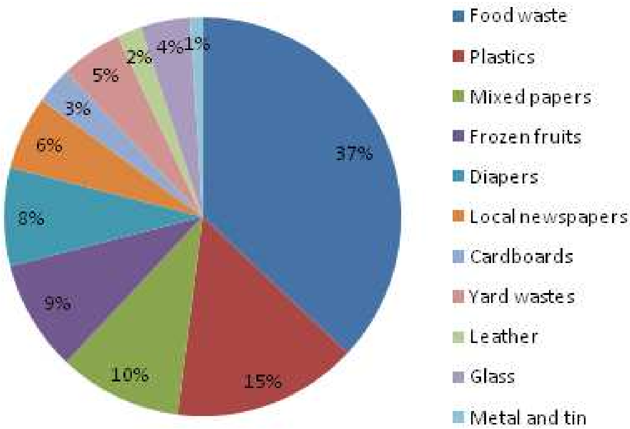

Figure 4. *MSW composition.*

2.2. Sample Preparation

The samples were shredded into smaller pieces of approximately 30mm size, mixed up and grounded in a grinding machine of less than 1mm size, for the purpose of increasing surface area of the sample that will allow easy penetration of heat [23, 24].

Then a sample of 30±0.1 mg with average particle size less than 1mm was loaded to crucible, dried in the oven at 100^oC

for 1hr in a VECSTAR 174799 FURNACE, Model-F/L in accordance to standard (ASTM D3176), and then analyzed in the TG equipment in the temperature ranging from room temperature to 1100°C, at heating rate of 10°C/min.

The heating rate variations change the peak temperature of the decomposition. The more the heat rate, the more increase of temperature [24]. The calculated thermo-gravimetric output from proteus software was obtained as thermal decomposition profile, thermo-gravimetric (TG), Derivative Thermo-gravimetric (DTG) and Differential Scanning Calorimetry (DSC) curves.

The heat released and absorbed by the municipal solid waste degradation was determined from the differential scanning calorimetry curves. The DSC monitors heat effect associated with phase changes transitions and chemical reactions as a function of temperature [24]. The heat was determined by calculating the area between the baseline and the curve. The heat can be positive or negative. When the heat is positive the process is endothermic and when the heat is negative the process is exothermic [24].

3. Results and Discussion

3.1. Proximate and Ultimate Analysis

This section presents the results obtained from the analysis. The results of proximate and ultimate analysis are shown in Table 1 & 2. The moisture content of the municipal solid waste as received ranged between 55.70 and 63.99 wt. %, which is more than 50 wt. % of the total weight of the sample. This high moisture content hinders the combustion process as it rises the ignition temperature [5]. The volatile matter released from MSW samples for Ngarenaro, Sakina and Central market were 74.43, 84.00 and 78.31wt %, respectively.

This can be compared with the volatile matter contained in pure biomass such as forest residue, oak wood, and pine which are 79.9%, 78.1% and 83.0 wt. % respectively [20]. Generally, solid wastes which contain high volatile, have low fixed carbon, the same case for the Arusha municipal solid waste from Sakina which has volatile matter of 84.00% and fixed carbon of about 6.00 wt. %, compared to that of Ngarenaro and Central market. The advantage of high volatile and low fixed carbon is rapid burning of fuel, while fuel with low volatile and high fixed carbon like coal need to be burned on a grate as it takes long time to burn out, unless it is pulverized to a very small size [25].

Basing on proximate analysis of Table 1 and values of volatile matter and fixed carbon obtained, the study shows that, the Arusha municipal solid waste is combustible. The ash content ranged between 3.29 to 5.97 wt. %, which is relatively low, and advantageous for waste management and environment preservation due to possibility of having small quantity of heavy metals, salts, chlorine and organic pollutant [24]. The ultimate analysis of the municipal solid waste in Table 2 shows that, the average percentage amount of nitrogen, sulfur, chlorine and phosphorus in the waste were 2.36, 0.37, 0.04 and 0.11 respectively which is low, therefore, emissions released by these MSW during combustion are also low. The carbon and hydrogen content are above 50% and 5% respectively which may contribute to high calorific value of Arusha municipal solid waste. The oxygen content is more than 34%. Sulfur content is about 0.29%, which is low compared to those of bituminous coal which is 1.1 wt. % [5].

Table 1. *Proximate analysis of municipal solid waste from different areas of Arusha City.*

Location	Moisture of received MSW (wt %)	Volatile (wt %) Dry basis	Ash (wt %) Dry basis	Fixed Carbon (wt %)	HHV (MJ/kg)
Ngarenaro	59.67	74.43	8.16	17.41	11.00
Sakina	63.99	84.00	10.00	6.00	11.37
Central Market	55.70	78.30	13.48	8.22	12.7

Table 2. *Ultimate analysis of municipal solid waste from different areas of Arusha City.*

Location	C (wt %) Dry basis	H (wt %) Dry basis	O (wt %) Dry basis	N (wt %) Dry basis	S (wt %) Dry basis	Cl (wt %) Dry basis	P (wt %) Dry basis
Ngarenaro	55.57	5.38	34.88	2.09	0.31	0.04	0.10
Sakina	55.70	5.29	34.27	2.13	0.22	0.07	0.13
Central Market	53.20	5.24	34.71	2.86	0.37	0.04	0.11

3.2. Calorific Value

The average energy content of municipal solid waste from Arusha city as measured by using a bomb calorimeter was 12MJ/kg on dry basis. This is about 40% of energy contained in coal which is 27MJ/kg and 30% less than energy contained in other biomasses which is about 17MJ/kg [5, 20].This means energy release during combustion of MSW is lower than that of coal and biomass combustion, and therefore, one needs to burn larger amount of MSW to get the same amount of energy. The energy content of MSW can be improved by pre-treating the MSW so as to reduce the amount of oxygen, since oxygen reduces the energy content of fuel [24]. The MSW can also be co-fired with coal for improving energy content of the feedstock to the combustion plant [20]. Other efficiency processes which convert MSW to energy are pyrolysis, gasification and torrefaction, which are used to produce bio-oil, syngas and char.

4. TGA Curves

This section provides detailed information of the Arusha

MSW obtained by using Thermo-gravimetric Analysis (TGA) and Derivative Thermo-gravimetric analysis (DTG). Thermo-gravimetric Analysis (TGA) is a reliable and widely used laboratory technique employed to study the extent of mass changes due to volatilization and combustion of fuel components. In addition to that, it allows great flexibility in controlling the composition of the combustion gases. The municipal solid waste tested degraded from 79 to about 88 wt. % in the thermo gravimetric analyzer as shown in Figure 5. In this case, the MSW has been burned up in their mixed state. Therefore it is important to study the combustion characteristics of the mixed waste. Figure 5 shows the curves that, gives the burning temperature of the mixed MSW, and from the figure it seems that the burning temperature of MSW of Arusha city is around 600 °C.

The MSW from the Central market degraded by 88 wt. %, while those from Ngarenaro degraded by 79 wt. %. The mass change of solid wastes was observed at a range between 31 and 34 wt% and from this, the residues were formed. These residues contain fixed carbon and ash. The high amounts of residues were observed in MSW from Ngarenaro which is 18.54 wt. % whereas those from the Central market and Sakina had lower amount of residues of about 13.95 wt % and 12.89 wt % respectively. The char available in the residues can be used as fuel. However, MSW which has high ash content hinder the combustion of char due to the layer of ash that is formed on the surface and which inhibits the diffusion of oxygen into the char [26].

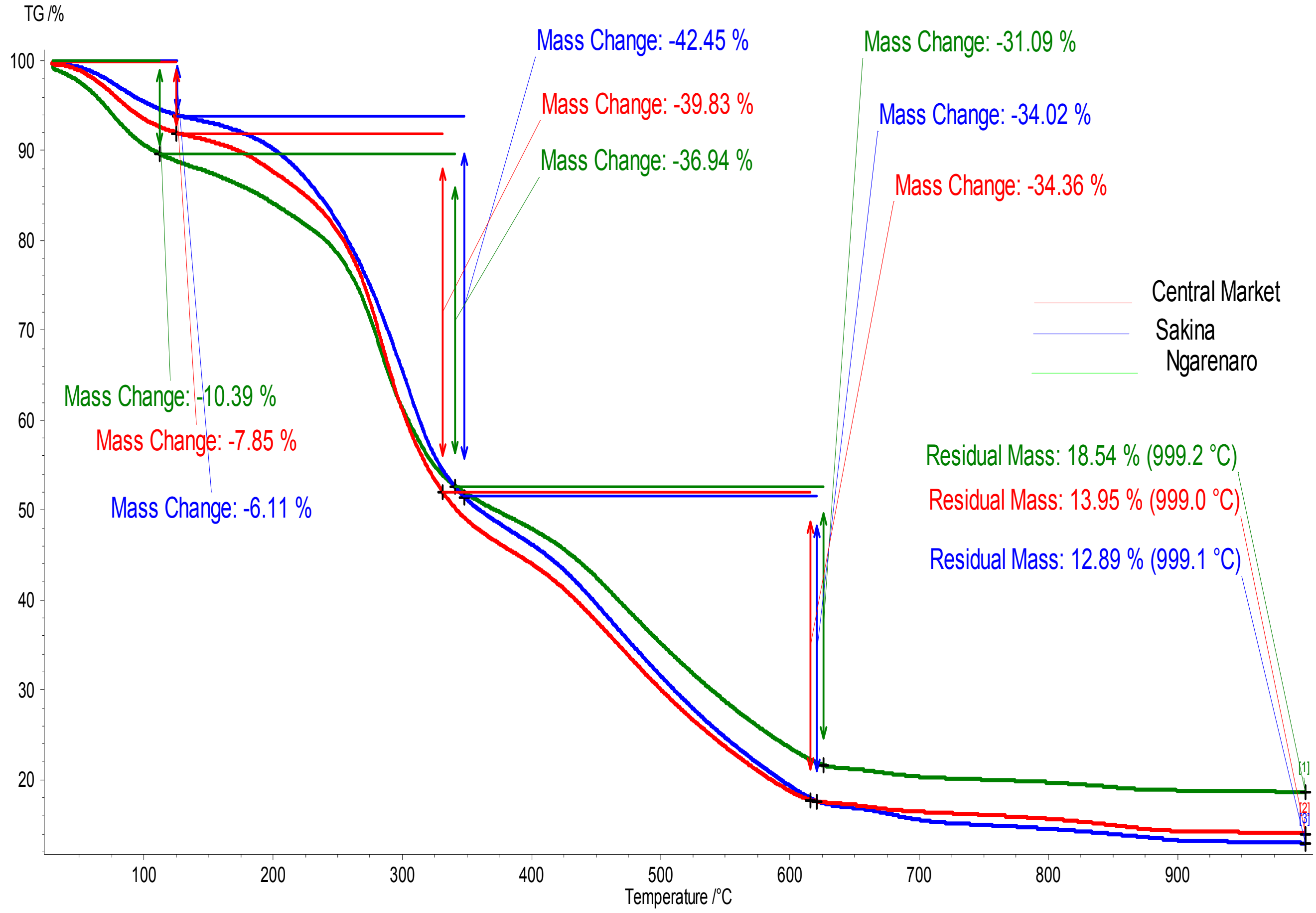

Figure 5. *TGA graphs of Municipal solid waste from three locations in Arusha city.*

4.1. DTG Curves

Derivative Thermo-gravimetric analysis (DTG) is the analysis which gives the trend of reactivity of particles with the increase of temperature in the furnace. The point of the burning profile in which the maximum weight loss comes about to the combustion is called peak temperature. This point is considered as an indicator of the reactivity of the sample. Another purpose of DTG is to assist in understanding of chemical reactions occurring in the furnace, combustor design, temperature profile of the combustion chamber, retention time and giving information on the change of mass and volume of the MSW as it travels down the grate.

4.2. Burning Phases of the MSW

Figure 6 shows the derivative of thermo-gravimetric analysis (DTG), which has four visible zones; these are moisture release zone, lignocellulosic degradation zone, plastic degradation zone and char pyrolysis zone [27]. Lai et al [28], also observed and identified these four zones. In the Figure therefore, thermal destruction of solid waste is accomplished in four phases. The first phase is the drying phase which occurs in the initial heating of the solid materials.

Here moisture is driven off as the materials are heated past the evaporation temperature of water and in this case the temperature is around 150°C. The second phase is the volatilization of vapors and gases which occur as the temperature of the waste continues to rise. Vapors and gases diffuse out as their respective volatilization temperature are attained. Here exothemicity property is shown by the waste materials as they are releasing out energy, and temperature is around 380°C to 640°C. This is the zone where the temperature of the particles is greater than the temperature of the environment and is where the particles release energy. The municipal solid waste shows exothemicity property at the devolatilization zone. The devolatilization is that zone where the temperature of the particles is greater than the temperature of the environment and in this case, it shows that the municipal solid waste can be easily ignited at temperature above 380°C.

The third phase in the burn down of solids is the oxidation of the burnable solids left after the vapors and gases are volatilized where the temperature is between 640°C to 900°C. The fourth phase is the process which involves the final burn down of char and the consolidation and cooling of the inert residues known as ash, the temperature being higher than 900°C. Generally in this case, Figure 6 gives the trend of reactivity of the Arusha municipal solid wastes with temperature.

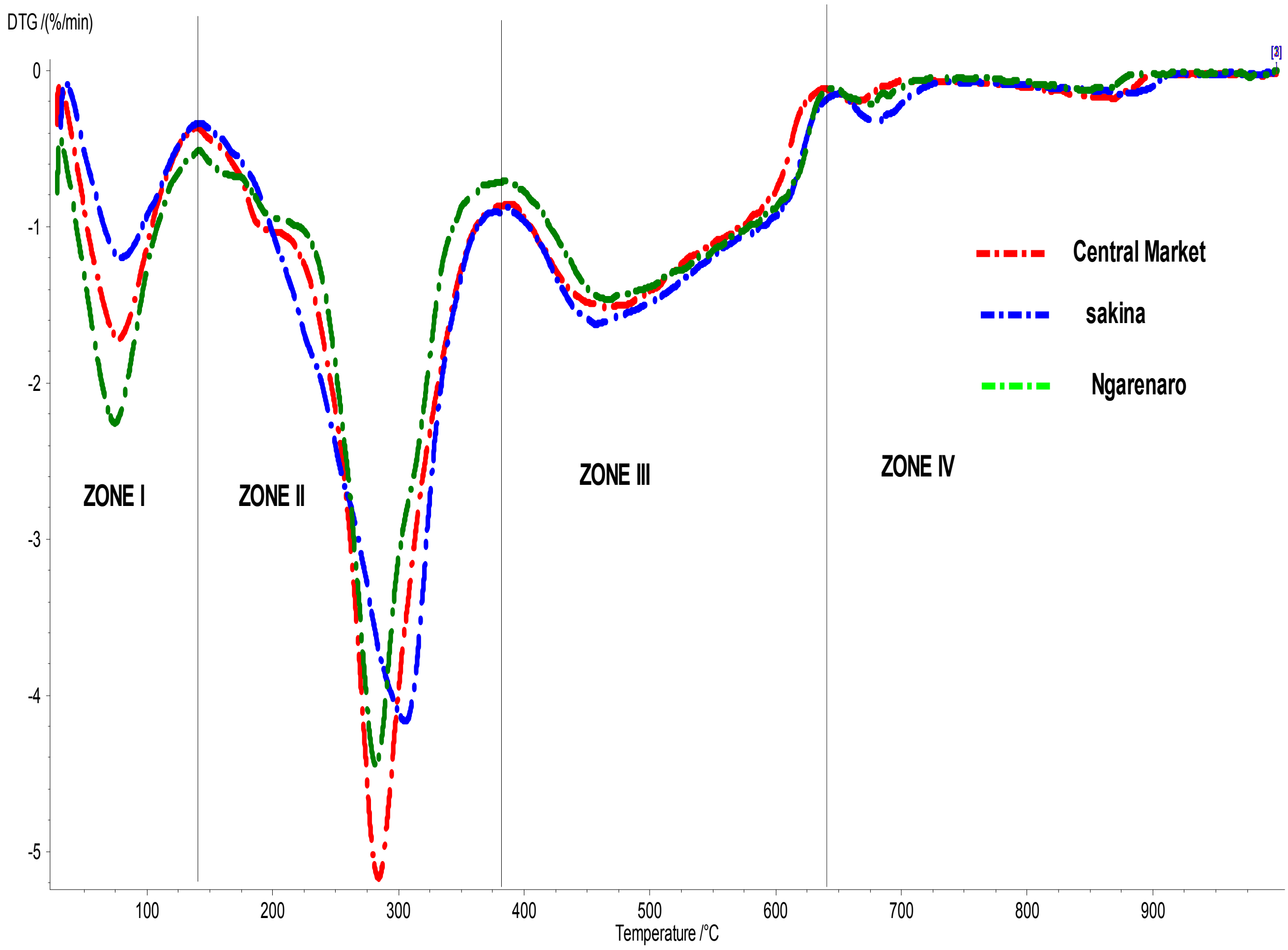

Figure 6. *DTG of municipal solid waste from three locations in Arusha City.*

5. Conclusion

This paper presents the findings of municipal solid waste characterization of Arusha city. The solid waste from three areas within the city was analyzed to determine the potentiality for energy recovery. The ultimate analysis of the waste showed that the waste contains more than 50% and 5% of carbon and hydrogen respectively which may contribute to high calorific value of Arusha municipal solid waste. The average energy content of waste was 12MJ/kg on dry basis, which is equivalent to 40% of energy contained in coal and 30% less than energy contained in other biomasses which exhibit that municipal solid waste can be used for energy recovery. The average percentage amount of nitrogen, sulfur, chlorine and phosphorus in the waste were 2.36%, 0.3%, 0.05% and 0.11% respectively which is relatively low. Therefore emissions released by these MSW during combustion are also low. The results obtained from TGA and DTG showed that the MSW has the burning temperature of around 600°C, which means they are suitable for combustion processes. The most reactivity of solid waste materials was obtained from Central market compared to that of Ngarenaro and Sakina. This indicates that MSW from Sakina has higher energy contents compared to others. Thus based on the results in this paper, this municipal solid waste are suitable for energy conversion.

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