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Full Length Research Paper

Renewable energy potentials of the municipal solid waste generated in Gombe-Metropolis

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ABSTRACT: An investigation to determine the renewable energy generating potentials of the municipal solid waste in the Gombe metropolis was conducted in an effort to harness the growing quantity of solid waste generated in the metropolis. The American Society for Testing and Materials (ASTM D3172 and ASTM D3176) were used to determine the potential energy stored in the municipal solid waste samples collected from INEX cleaners and GOSEPA dumpsites using physical, proximate, and ultimate analysis model equations, (2.0-2.4). While the percentage of carbon and hydrogen contents of the sampled solid waste was determined using Artificial Neural Networks (ANN) model equations 1 and 2 using proximate analysis results. The energy recovery potentials of the two dumpsites that were studied show that a total of 439,577 kWh/day of electricity can be generated from both INEX (361,963.2kWh/day) and GOSEPA (77,613.8kWh/day) by burning 909.13kWh/tones of solid waste with INEX having (509.88kWh/tones) and GOSEPA (399.25kWh/tones) which translate into generating 18,315.7kW of energy, with INEX producing (15,081.8kW) and GOSEPA (3,233.9kW), and based on the average household electricity consumption of 1,095kWh/year in Gombe metropolis, and assuming no energy loss, the total electricity generated could supply about 33,045.28 households with electricity daily. The investigation recommends that incineration of the municipal solid waste to generate energy should be considered as an alternative to landfilling in open dumpsites/open burning at our dumpsites, so as to mitigate the effect of climate change, and also address the missing link for sustainable solid waste management in Gombe-metropolis. The investigation also recommends that the Gombe State government should try and establish Gombe Power Holdings Company that would utilize the quantum of municipal solid waste that is generated in Gombe-metropolis to provide more electrical energy in the State for the growth of small and medium scale enterprises/companies.

Keywords: Gombe metropolis, municipal solid waste generated, renewable energy potentials

INTRODUCTION

The world in the 21st century is facing challenges of increasing energy demand, waste management and global climate change, as such substituting fossil fuel with municipal solid waste derived energy would be a promising strategy to simultaneously meet part of our energy needs, manage municipal solid waste (MSW) and mitigate greenhouse gas (GHG) emission. The severe impacts of climate change may still be avoided if efforts are made to transform current energy systems from fossil energy based to renewable energy base through energy recovery from MSW. Glover and Mattingly (2009) acknowledged that the growing climate, energy and environmental concerns coupled with technological developments and regulatory changes, have ignited new interest in municipal solid waste as an energy source with the potential to provide renewable energy while reducing greenhouse gas emissions. African cities are faced with the challenges of sustainable energy supply (Tanko, 2015). Secured energy production, waste disposal, and the minimization of pollution are some of the key problems that must be addressed for sustainable cities of the future. Waste management has become one of the major issues of concern worldwide, and MSW incineration for energy recovery is now being used increasingly to treat MSW that cannot be recycled economically (Swithenbank *et al*. 2012). Energy recovery from waste entails the conversion of mostly non-recyclable wastes into usable heat, electricity, or fuel through a variety of processes which include; combustion/incineration, gasification, pyrolysis, anaerobic digestion, and briquetting and landfill gas (LFG) recovery. These techniques help to reduce carbon emissions by offsetting the need for energy from fossil fuel as well as reduce methane generation from landfills (Bajracharya *et al*., 2016). There have been rigorous efforts to meet the increasing energy demand but relying on the traditional fossil fuels alone is synonymous to taking a great risk of backward trend in modern developmental strategies. The main reason behind this assertion is that fossil fuels and other conventional energy resources are not only limited but their global reserves is declining as each day closes. The global potential of municipal solid waste (MSW) as an energy source is as yet un-quantified (Allen *et al*., 2009). Action to reduce the impact of climate change is critical, and limiting the increase in average global temperatures to less than 2°C requires concerted global action both locally, nationally and internationally. Renewable energy has been growing rapidly in the last decade, becoming an important component of energy supply (OECD/IEA 2010); it plays a key role in mitigating global greenhouse gas emissions by radically lowering the emissions profile of the global energy system (IRENA 2015). To properly analyze and plan the use of renewable energy in African countries, there is need for accurate and documented estimates of their renewable energy potentials, as well as to identify the most suitable locations for investment and deployment in renewable energy technologies. The accuracy of this information correlates directly with the risk taken in the decision-making process. Accurate data strengthens each country's national strategy to deploy renewable energy technologies (IRENA-DBFZ 2013). This means solid waste now contains an increasingly complex mix of materials, including plastics, precious metals and hazardous materials that are difficult to deal with safely (EU, 2010). It was against this background that the present study was conceptualized to determine the energy content of solid waste in Gombe metropolis for possible electricity generation by incineration process. Hamzeh *et al*. (2011) acknowledged that about 10% of global energy supply is generated from biomass with the remaining 90% obtainable from fossil and other conventional energy resources, this development is a clear indication that the entire world is vulnerable to serious environmental hazard if the trend is allowed to persist for a longer period of time. Converting the huge quantities of municipal solid waste generated in Gombe to electricity will increase the energy supply, energy mix and balance of Gombe metropolis. Rapid urbanization and industrialization coupled with the increasing growth in population has led to a sharp rise in the quantity of municipal solid waste (MSW) generation in most of cities of the developing nations (Arugula *et al*., (2015). Amber *et al*.(2012) maintained that at a population growth rate of 2.03%, energy consumption and waste generation in Nigeria is expected to soar over the next few years, so also in Gombe metropolis, which is one of the most populous metropolitan city in the northeastern part of Nigeria, with population growth rate of 3.2% and urbanization rate of 3.5% per annum (NPoP'C, 2009) leading to higher MSW generation of 21,297 tons and 5,832 tons per month for INEX and GOSEPA dumpsites respectively (INEX, 2018, and GOSEPA, 2018), causing a lot of problems to man and the general environment.

Literature review

Energy recovery from MSW is defined as a waste treatment process that allows for the generation of energy in the form of electricity or heat from the wastes that would have otherwise been disposed in the landfills/dumpsites (UNEP, 2009; Amoo and Fagbenle, 2013). It is an economical and environmentally friendly approach for addressing the issues of waste management as well as the ongoing energy and climate change crisis. Among the MSW, food waste, textile, rubber, leather, wood can be the source of elevated energy value and plastic bags can have the energy equivalent to that of kerosene (Shrestha, 2011). Moreover, Amoo and Fagbenle, (2013) further pointed out that the interest in the practical applications of Waste to Energy dates back to several decades; it is hardly a new or novel idea. What is however new is the confluence of factors that have increased the attractiveness of Waste to Energy. These factors include rising oil prices, urban air pollution, and energy supply security, reduction in foreign oil imports, carbon dioxide (CO_2) emissions and climate change. These considerations are not confined to a single nation or part of the world and thus render the concept of Waste to Energy as abundantly and equitably available to humanity. Renewable energy sources replenish themselves naturally without being depleted in the earth; they include hydropower, biomass energy, geothermal energy, solar energy, wind energy and ocean (tide and wave) energy. The world's growing energy need, alongside increasing population led to the continual use of fossil fuel-based energy sources (coal, oil and gas) which become problematic by creating several challenges such as: depletion of fossil fuel reserves, greenhouse gas emissions and other environmental concerns, geopolitical and military conflicts, and the continual fuel price fluctuations. These problems will create unsustainable situations which will eventually result in potentially irreversible threat to human societies (UNFCC, 2015). Notwithstanding, renewable energy sources are the most outstanding alternative and the only solution to the growing challenges (Tiwari and Mishra, 2011). In 2012, renewable energy sources supplied 22% of the total world energy generation (U.S. Energy Information Administration, 2012) which was not possible a decade ago.

Incineration/Combustion

In this process, solid waste is directly burned in combustion chambers at high temperature of usually (about 800^{o}C and above) to avoid the deficiencies of conventional incinerators, some modern incinerators utilize higher temperatures of up to 1650^{o}C using supplementary fuel. These reduce waste volume by 97% and convert metal and glass to ash and are the most suitable in treating healthcare wastes (MoUD_GOI, 2000). Heat from combustion can be used as energy source for generation of steam as well as electricity. Incineration has been widely applied in many developed countries, especially those with limited space for landfilling such as Japan and many European countries. Globally, about 130 million tons of waste is annually combusted in more than 600 plants in 35 countries. (MoUD_GOI, 2000) further stated that incineration reduces the mass of waste and can offset fossil-fuel use; in addition, GHG emissions are avoided, except for the small contribution from fossil carbon. Incineration is perhaps the oldest method for recovering the energy stored in MSW (MoUD_GOI, 2000).

MATERIALS AND METHODS

Study area

Location of the study area

Gombe city the capital of Gombe State is located in the northeastern part of Nigeria on coordinates 10017'N 11010'E. It has a total area of 52Km^{2} (20sq mi) with a population of 377,341 people (2006 census), and the projected population of 534,314.856 people (Adamu *et al.*, 2017). Gombe metropolis, which is one of the most populous metropolitan city in the northeastern part of Nigeria, has an annual population growth rate of 3.2%, and high rate of urbanization at 3.5% per annum (NPoP'C, 2009). The state has eleven local Governments areas which include Akko, Balanga, Billiri, Dukku, Funakaye, Gombe, Kaltungo, Kwami, Nafada, Shongom and Yamaltu-Deba.Gombe was carved out of the old Bauchi State on 1st October, 1996 by the Military Regime of General Sani Abacha (Misbahu, 2015).

INEX Cleaners dumpsite

This is a sanitary landfill located opposite Federal College of Education (Tech) Gombe along Ashaka road in Gombe metropolis (Plate 1). It is located on coordinate 11^{o}8'36.757"E 10^{o} 20'45.095"N and 11^{o}8'42.73"E 10^{o} 21'6.575"N respectively, and covers an area of 89,177.16m^{2}.

GOSEPA dumpsite

This is a burrow pit located adjacent to Grave yard along Ashaka road in Gombe metropolis (Plate 2). It is located on coordinate 11^{o}8'50.898"E 10^{o} 19'15.474"N and 11^{o}8'50.522"E 10^{o}19'13.164"N respectively. It covers an area of 28,832.19m^{2}.

Statistical tools

Data generated from this investigation was analyzed using Pearson Correlation to check the relationship between heating value and solid waste composition, and the relationship between quantity, heating value and the type of dumpsite. While Proximate and Ultimate analysis (ASTM D3172 and ASTM D3176) were used to determined solid waste moisture content, volatile matter, ash content and fixed carbon, and total nitrogen, sulphur, carbon, hydrogen and oxygen of solid waste samples from the two dumpsites respectively.

Solid waste samples collection at INEX cleaners' dumpsite

The 89,177.16m^{2} area of the INEX dumpsite was segmented into two (2) sampling points at 120m intervals during the months of February and June, 2019. Coordinates of the sampling points were recorded. Waste samples were randomly collected from the sampling points and a composite was formed. The composite obtained were segregated and sorted into agriculture/vegetables waste, paper, spoiled organic food, plastics/polyethene, soil, metals, glass and textiles.

Solid waste samples collection at GOSEPA dumpsite

The 28,832.19m^{2} area of the GOSEPA dumpsite was segmented into two (2) sampling points at 120m intervals during the months of February and June, 2019. Coordinates of the sampling points was recorded. Waste

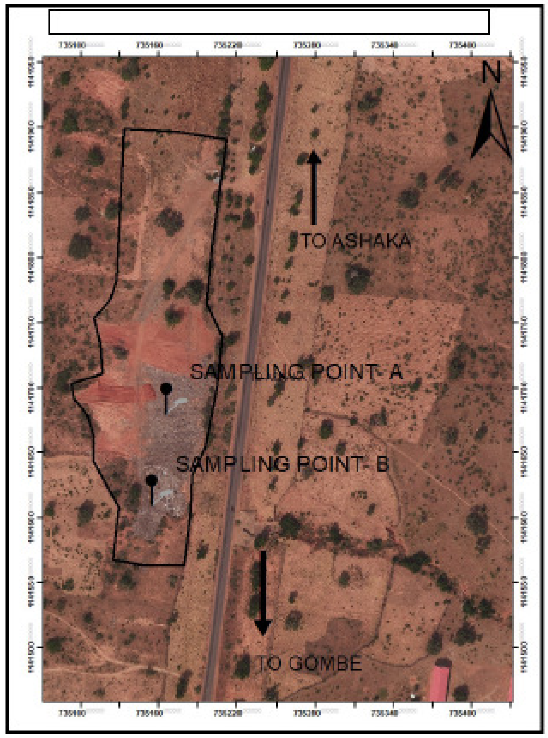

Plate 1: Sampling Points at INEX Cleaners Dumpsite in Gombe Metropolis (in black color).

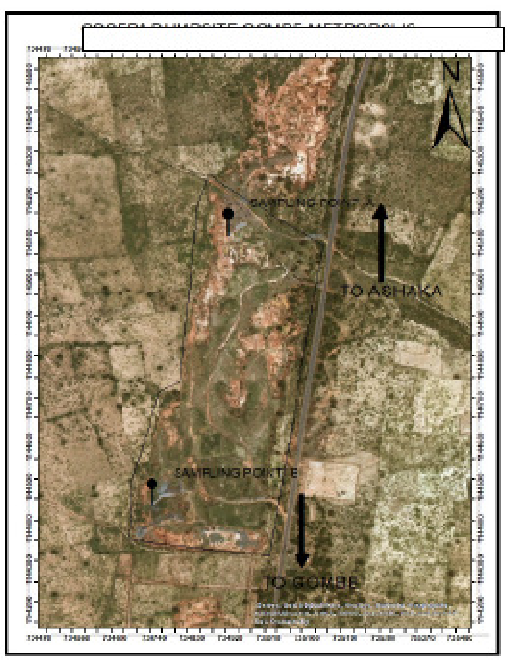

Plate 2: Sampling points at Gombe State Environmental Sanitation and Protection Agency (GOSEPA) Dumpsite in Gombe Metropolis (in black colors).

samples were randomly collected from the sampling points and a composite was formed. The composite obtained were segregated and sorted into agriculture/vegetables waste, paper, spoiled organic food, plastics/polyethene, soil, metals, glass and textiles.

RESULTS

Calculation for % of carbon in waste from INEX dumpsite using ANN model equation

%Carbon (C) = 0.97*(%FC) + 0.7*(%VM – 0.1*(%ash) – ((%M)*(0.6 – 0.01*(%M)….(1)
%Carbon (C) = 0.97*(7.20) + 0.7*(49.4 – 0.1*(34.29) – (38.37)*(0.6 – 0.01*(38.37)
%Carbon (C) = 6.984 + 0.7*(49.4 – 3.429) – ((38.37)*(0.6 – 0.3837)
%Carbon (C) = 6.984 + 0.7*(45.971) – (38.37)*(0.2163)
%Carbon (C) = 6.984 + 0.7*(45.971) – (38.37)*(0.2163)
%Carbon (C) = 6.984 + 32.1797 – 8.2994
%Carbon (C) = 30.8643

Calculation for % of hydrogen in waste from INEX dumpsite using ANN model equation

%Hydrogen (H) = 0.036*(%FC) + 0.086*((%VM) – 0.1*(%Ash) – 0.0035*(1 – 0.02*(%M)*(%M)^2 ……………………. .(2)

%Hydrogen (H) = 0.036*(7.20) + 0.086*(49.4 – 0.1*(34.29) – 0.0035*(1 – 0.02*(38.37)*(38.37)^2

%Hydrogen (H) = 0.2592 + 0.086*(49.4 – 3.429) – 0.0035*(1– 0.7674)*(1,472.25)
%Hydrogen (H) = 0.2592 + 0.086*(45.971) – 0.0035*(1– 0.7674)*(1,472.25)
%Hydrogen (H) = 0.2592 + 0.086*(45.971) – 0.0035*(1– 0.7674)*(1,472.25)
%Hydrogen (H) = 0.2592 + 3.9535 – 0.0035*(0.2326)*(1,472.25)
%Hydrogen (H) = 0.2592 + 3.9535 – 1.1985
%Hydrogen (H) = 0.2592 + 3.9535 – 1.1985
%Hydrogen (H) = 3.142

Calculation for % of carbon in waste from GOSEPA dumpsite using ANN model equation

%Carbon (C) = 0.97*(%FC) + 0.7*(%VM – 0.1*(%ash) – (%M)*(0.6 – 0.01*(%M)……(1)
%Carbon (C) = 0.97*(8.44) + 0.7*(42.01 – 0.1*(37.3) – (55.01)*(0.6 – 0.01*(55.01)
%Carbon (C) = 8.1868 + 0.7*(42.01 – 3.73) – (55.01)*(0.6 – 0.5501)
%Carbon (C) = 8.1868 + 0.7*(38.28) – (55.01)*(0.0499)
%Carbon (C) = 8.1868 + 26.796 – (55.01)*(0.0499)
%Carbon (C) = 8.1868 + 26.796 – 2.7449
%Carbon (C) = 8.1868 + 26.796 – 2.7449
%Carbon (C) = 32.2379

Calculation for % of hydrogen in waste from GOSEPA dumpsite using ANN model equation

%Hydrogen (H) = 0.036*(%FC) + 0.086*(%VM) – 0.1*(%Ash)–0.0035*(1-0.02*(%M))*(%M)^2 …………………………………(1)

%Hydrogen (H) = 0.036*(8.44) + 0.086*(42.01) – 0.1*(37.3) – 0.0035*(1- 0.02*(55.01)*(55.01)^2
%Hydrogen (H) = 0.30384 + 0.086*(42.01 – 3.73) – 0.0035*(1 – 1.1002)*(3,026.10)
%Hydrogen (H) = 0.30384 + 0.086*(38.28) – 0.0035*(1 – 1.1002)*(3,026.10)
%Hydrogen (H) = 0.30384 + 3.2920 – 0.0035*(–0.1002)*(3,026.10)
%Hydrogen (H) = 0.30384 + 3.2920 + 1.0612
%Hydrogen (H) = 4.65704

Calculation for % of oxygen in waste from INEX dumpsite

%Oxygen= 100 - %Ash + %S + %N + %C + %H
%Oxygen =100 – 34.29 + 0.092 + 4.76 + 30.8643 + 3.142
%Oxygen =100 – 73.1483
%Oxygen =26.8517

Calculation for % of oxygen in waste from GOSEPA dumpsite

%Oxygen= 100 - %Ash + %S + %N + %C + %H
%Oxygen=100 –37.30 + 0.089 + 6.52 + 32.2379 + 4.65704
%Oxygen=100 – 80.80394
%Oxygen =19.1961

Lower heating value (LHV) calculation using physical analysis model equations:

INEX Physical Analysis Calculation using
LHV= [88.2 P_{pl} + 40.5 (P_{ga} + P_{pa})] – 6W ……………………… (2)
= [88.2 x 18.40 + 40.5 (76.32 + 20.5)] – 6 x 38.37
= 1,622.88 + 40.5 (96.82) – 230.22
= 1,622.88 + 3,921.2 – 230.22 = 5,313.86
LHV= 5,313.9.
INEX Physical Analysis Calculation using (2.1)
LHV= 2229.91+ 7.90P_{pa} + 28.16P_{pl} + 4.87P_{ga} – 37.28W (3)

=2229.91 + 7.90 x 2.05 + 28.16 x 18.40 + 4.87 x 76.32 – 37.28 x 38.37
=2229.91 + 16.195 + 518.144 + 371.6784 – 1,430.4336
=2,246.105 + 889.8224 – 1,430.4336 =3,135.9274 – 1,430.4336=1,705.49
LHV= 1,705.5

GOSEPA Physical Analysis Calculation using
LHV= [88.2 P_{pl} + 40.5 (P_{ga} + P_{pa})] – 6W ……………………… (4)
= [88.2 x 11.40 + 40.5 (85.9 + 0.71)] – 6 x 55.01 = 1,005.48 + 40.5 (86.61) – 330.06 = 1,005.48 + 3,507.705 – 330.06 = 4,513.185 – 330.06 = 4,183.125
LHV= 4,183.1.

GOSEPA Physical Analysis Calculation using

LHV= 2229.91+ 7.90P_{pa} + 28.16P_{pl} + 4.87P_{ga} – 37.28W (5)
= 2229.91 + 7.90 x 0.71 + 28.16 x 11.40 + 4.87 x 85.9 – 37.28 x 55.01
= 2229.91 + 5.609 + 321.024 + 418.333 – 2,050.7728
=2,235.519 + 739.357 – 2,050.7728
= 2,974.876 – 2,050.7728
= 924.1032
LHV= 924.1

Lower heating value (LHV) calculation using proximate analysis model equations:

INEX Proximate Analysis Calculation using

LHV= 45V – 6W ………………………………….. (6) Traditional model)

Where LHV= lower heating value
V= Physical combustible component content (%)
W= Moisture content (%)
= 45 x 49.40 – 6 x 38.37
= 2,223 – 230.22
= 1,992.78
LHV= 1,992.8

INEX Proximate Analysis Calculation using

LHV= 44.75V – 5.85w + 21.5 ………………………(7) Bento's model)
=44.75 x 49.40 – 5.85 x 38.37 + 21.2
= 2,210.65 – 224.4645 + 21.2
= 2,210.65 – 245.6645
= 1,964.98
LHV = 1,964.9

GOSEPA Proximate Analysis Calculation using
LHV= 45V – 6W ………………………………….. (8) Traditional model)
= 45 x 42.01 – 6 x 55.01= 1,890.45 – 330.06= 1,560.39
LHV= 1,560.4.

GOSEPA Proximate Analysis Calculation using

LHV= 44.75V – 5.85w + 21.5 ……………………… (9) Bento's model)
=44.75 x 42.01 – 5.85 x 55.01 + 21.2 = 1,879.9475 – 321.8085 + 21.2 = 1,879.9475 – 321.8085 + 21.2 =1,879.9475 – 343.0085 =1,536.939
LHV=1,536.9

Lower heating value (LHV) calculation using ultimate analysis model EQUATION:

INEX Ultimate Analysis Calculation
LHV = 81C + 342.5(H – O/8) + 22.5S – 6(W + 9H) (10) Dulong's model)
= 81 x 30.8643 + 342.5(3.142 – 26.8517/8) + 22.5 x 0.092 – 6(38.37 + 9 x 3.142)
= 2,500.0083 + 342.5 (3.142 – 3.3565) + 2.07 – 6(47.37 x 3.142)
= 2,500.0083+ 342.5 x 3.142 – 3.3565 + 2.07 – 6 x 148.8365
= 2,500.0083+ 1,076.135 – 5.4265 – 893.019
=3,576.1433 – 5.4265 – 893.019
=3,570.7168 – 893.019
=2,677.6978
LHV= 2,677.7 kcal/kg

GOSEPA Ultimate Analysis Calculation

LHV = 81C + 342.5(H – O/8) + 22.5S – 6(W + 9H) (11) Dulong's model)
= 81 x 32.2379 + 342.5 (4.65704 – 19.1961/8) + 22.5 x 0.089 – 6(55.01 + 9 x 4.65704)
=2,611.2699+ 342.5 x 4.65704 – 2.3995 + 2.0025 – 6(64.01 x 4.65704)
=2,611.2699 + 1,595.0362 – 4.402 – 6(298.0971)
=4,206.3061 – 4.402 – 1,788.5826
=4,201.9041 – 1,788.5826
=2,413.3215
LHV =2,413.3 kcal/kg

Potential power generation (electricity)

Potential Power Generation (electricity) calculation using INEX Dumpsite Potential Power Generation

E= LHV x W_t x 1000/859.845 x *n* ……………………………………………….. (12)
Where LHV= lower heating value of the solid waste (kcal/kg)
W_t = daily waste disposal (tonnes/day)
n = conversion efficiency which is given as 0.22 (IEA, 2007)

E= LHV x W_t x 1000/859.845 x *n* (13)
= 1992.8 x 709.9/24 x 1000/859.845 x 0.22 =1992.8 x 29.5792 x 1.1630 x 0.22 = 58, 945.4298 x 0.25586 =15,018.777
E= 15,081.8

Potential electricity generation per day from INEX dumpsite:

=15,081.8 x 24
=361,963.2 kWh/day

According to Jos Electricity Distribution Company (JEDCO, 2019) average household energy consumption in Gombe is 1,095 kWh/year (3kW × 365 days). Therefore, the electricity generation from incineration of metropolis solid waste could generate electricity to the following households:
361,963.2/1,095 x 365 = 120,654.4

The potential electricity generation per ton of metropolis solid waste (kW/ton):

361,963.2/709.9 = 509.879 = 509.88 kWh/ton

GOSEPA Dumpsite Potential Power Generation

E= LHV x W_t x 1000/859.845 x *n* ………………………………………………………. (14)
= 1,560.4 x 194.4/24 x 1000/859.845 x 0.22 =1,560.4 x 8.1 x 1.1630 x 0.22 =12,639.24 x 0.25586 = 3,233.88
E=3,233.9

The potential energy generation per day from GOSEPA dumpsite:

=3,233.9 x 24
=77,613.8 kWh/day

According to Jos Electricity Distribution Company (JEDCO, 2019) average household energy consumption in Gombe is 1,095 kWh/year (3kW x 365 days). Therefore, the electricity generation from incineration of metropolis solid waste could generate electricity to the following households:
77,613.8/1,095 x 365 = 25,871.27
While the potential electricity generation per ton of metropolis solid waste (kWh/ton):
77,613.8/194.4 = 399.248 = 399.25 kWh/ton.

DISCUSSION

The potentials for energy generation from the municipal solid waste in Gombe metropolis was determined in terms of solid waste incineration from their two officially designated solid waste disposal sites, using ASTM standard (ASTM D3172 and ASTM D3176), and ANN Model Equations.
The result of the proximate analysis of the INEX and GOSEPA dumpsites indicated that INEX had 38.37% moisture content; 34.29% Ash content; 49.40% Volatile matter; 7.20% Fixed carbon. While that of GOSEPA had 55.01% Moisture Content; 37.30% Ash Content; 42.01 Volatile matter; 8.44% Fixed Carbon. While the result of the ultimate analysis of the INEX and GOSEPA dumpsite had indicated that INEX had 4.76% Total Nitrogen; 0.092% Sulphate; 30.8643% Carbon; 3.142% Hydrogen; 26.8517% Oxygen. The result further indicated that GOSEPA had 6.52% Total Nitrogen; 0.089% Sulphate; 32.2379% Carbon; 4.6570% Hydrogen; 19.1961% Oxygen (Plate 3 and 4). Therefore, the result above shows that waste from GOSEPA dumpsite are having higher concentration of hydrogen (4.6570%) than that of INEX (3.142%), and the higher the amount of hydrogen in a waste sample, the higher the quantity of energy it will generate, and these corroborate the findings of (Hamzeh *et al*., 2011), and that of (Singh *et al*., 2016) which also discovered that, the higher the quantity of oxygen in a waste sample, the lower it energy potentials.

The results obtain using model equation 2.0 and model equations 2.1 for INEX waste samples have LHV of 5,313.9kcal/kg, and 1,705.5kcal/kg respectively. It also shows that using model equation 2.0 and 2.1 for GOSEPA waste samples has LHV of 4,183.1kcal/kg, and LHV of 924.1kcal/kg respectively. Furthermore, the Traditional model equation 2.2 and Bento's model equation 2.3 for the INEX waste samples had LHV of 1,992.8kcal/kg, and LHV of 1,964.9kcal/kg respectively. While that of GOSEPA waste samples had LHV of 1,560.4kcal/kg, and LHV of 1,536.9kcal/kg respectively. Using ultimate analysis with Dulong's model equation for waste samples from INEX and GOSEPA dumpsites with LHV of 2,677.7kcal/kg, and 2,413.3kcal/kg respectively. It has been reportedby (Amin *et al*., 2011) that the proximate analysis model equations gives an accurate estimation of the lower heating values of waste samples. Therefore, this study adopted the computed LHV of the model equation 2.2 for the calculation of the energy recovery potentials of the solid waste from the two dumpsites based on its accuracy as stated earlier.

The result of the energy recovery potentials of the two dumpsites under study with the total potential electricity generation of 439,577 kWh/day from both INEX (361,963.2kWh/day) and GOSEPA (77,613.8kWh/day) by burning 909.13kWh/tonnes of solid waste with INEX having (509.88kWh/tonnes) and GOSEPA (399.25kWh/tonnes) which translate into generating 18,315.7kW with INEX producing (15,081.8kW) and GOSEPA (3,233.9kW), based on the average household electricity consumption of 1,095kWh/year for Gombe metropolis, and assuming no energy lost, the total electricity generated could supply about 33,045.28 households with electricity daily which corroborated the

Plate 3: Taking coordinates of the sampling points using GPS at INEX Cleaners Dumpsite.

Plate 4: Drying of waste samples in an Oven at the laboratory as part preparations for samples analysis.

findings of (US Energy Information Administration, 2012) which shows that the average energy generation per tonne of municipal solid waste combusted in United States is about 563kWh/tonne. Consequently this indicates the feasibility of waste to energy plant such as incineration to produce electricity.

Conclusion

The Energy generating potentials of municipal solid waste from the two major dumpsites in Gombe metropolis were determined based on solid waste incineration using empirical models. The energy recovery potentials of the two dumpsites that were studied shows that a total of 439,577 kWh/day of electricity can be generated from both INEX (361,963.2kWh/day) and GOSEPA (77,613.8kWh/day) by burning 909.13kWh/tones of solid waste with INEX having (509.88kWh/tones) and GOSEPA (399.25kWh/tones) which translate into generating 18,315.7kW of energy, with INEX producing (15,081.8kW) and GOSEPA (3,233.9kW), and based on the average household electricity consumption of 1,095k

Wh/year in Gombe metropolis, and assuming no energy loss, the total electricity generated could supply about 33,045.28 households with electricity daily.

Recommendations

This research recommend that incineration of the municipal solid waste to generate energy should be considered as an alternative to land filling in open dumpsites/open burning at our dumpsites, so as to mitigate the effect of climate change, and also address the missing-link for the sustainable solid waste management in Gombe-metropolis. The investigation also recommend that Gombe State government should try and establish Gombe Power Holdings Company that would utilize the quantum of municipal solid waste that is generated in Gombe-metropolis to provide more electrical energy in the State for the growth of small and medium scale enterprises/companies.

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