Nigerian Research Journal of Engineering and Environmental Sciences 3(1) 2018 pp. 273-279

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

EXERGY CONTENT ANALYSIS OF SOLID WASTE GENERATED IN UNIVERSITY OF LAGOS, NIGERIA

***[1]Salami, L., [2]Odunlami, M.O. and [3]Koleola, O.**

[1]Environmental Engineering Research Unit, Department of Chemical and Polymer Engineering, Faculty of Engineering, Lagos State University, Epe, Lagos State, Nigeria
[2]Department of Chemical Engineering, School of Engineering, Lagos State Polytechnic, Ikorodu, Lagos State, Nigeria.
[3]Department of Energy and Environmental Engineering, Faculty of Engineering, Edinburgh Napier University, Edinburgh, Scotland, United Kingdom.
*lukumon.salami@lasu.edu.ng

ARTICLE INFORMATION

Article history:
Received 03 April, 2018
Revised 30 April, 2018
Accepted 02 May, 2018
Available online 30 June, 2018

Keywords:
Energy
Exergy
Simulation
Solid wastes
University

ABSTRACT

There is a possibility of energy recovery from heat released during solid waste incineration. Exergy is the portion of total energy embedded in solid waste that is available for conversion to useful work. This study was carried out to analyse the exergy content and simulate the power output of solid wastes generation in University of Lagos, Nigeria. The combustion heat balance of the solid wastes was determined and the exergy analysis of the heat released during combustion was done. Simulation of power output from fluidized bed incinerator was carried out at different operating efficiency values ranging between 15% and 95% with the aid of Microsoft excel version 2007. The results showed that the 18.65 tons/day of solid wastes generation in University of Lagos has a moisture content of 11.86 % and a caloric value of 15,215.53 kJ/kg. The heat released during incineration of the solid wastes and the thermal exergy transferred were 2.67 x 10^8 and 1.99 x10^8 kJ/day respectively. The energy and exergy efficiencies were found to be 94.35 % and 70.32 % respectively. The simulated power output at 15% and 95% efficiency values were 0.43 x 10^8 and 2.69 x 10^8 kJ/day respectively. The energy value of the waste can be used for power generation in University of Lagos for its sustainable development which reduces the dependence on the national grid for electricity consumption.

1. INTRODUCTION

Solid wastes are all the waste arising from human and animal activities that are normally solid and are discarded as useless or unwanted (Salami et al., 2011). They are generated by almost every activity and the amount varies by source, season, geography and time (Robert, 1999). Solid wastes encompass the heterogeneous mass of throwaways from residences and commercial as well as the heterogeneous accumulation of a single industrial activity (Olafadehan and Salami, 2011).

Humans have a tremendous impact on the environment through simple use of resources and this results in solid waste either as a by-product or as an end result. Solid wastes create a significant environmental problem on many levels. It often signifies inefficient use of resources such as excessive packaging (Olafadehan and Salami, 2011). Traditionally, disposal of waste and making it a problem is most commonly deployed for many businesses. It remained a problem until the disposal of waste became linked with ecological degradation (Pitt et al., 2002) Most developed countries have advanced from an ethos of removing waste from point of depositing in the most expedient and economic alternative locations to control waste production, provision of appropriate treatment options and engineering of final land disposal so as to maximize resource recovery (Alexander, 2003). Many techniques including solid waste management using land filling techniques are used in environmental waste management in Nigeria, however, there still exist a need for effective waste control to provide a plat form for sustainable development (Susu *et al*., 2003).

Many researchers have worked on solid wastes. Olafadehan and Salami (2011) worked on proactive solid waste management and control. They presented steps for effective solid waste management and control in Nigeria. They neglected the analysis of energy content of solid wastes. Salami *et al.* (2011) characterized tonnage of solid waste in Lagos State, Nigeria. They determined the physical and chemical composition of the waste and the mass of biodegradable material in the municipal solid waste as well as the actual volume of methane gas expected from the solid wastes but the energy content of the solid waste was not analysed. Okeniyi and Anwan (2012) researched on solid waste generation in Covenant University, Ota, Nigeria. The research provided the percentage composition of average waste generation per day in the institution. The energy content of the wastes was not considered. Adeyinka *et al.* (2014) worked on physico-chemical composition and energy content analysis of solid waste using Castlereagh district, Northern Ireland as a case study. They evaluated the physical and chemical composition and the energy content of the solid waste. Adeniran *et al.* (2017) studied the solid waste generation and characterization in the University of Lagos for a sustainable waste management. They provided the composition of the daily waste generation but neglected the energy and exergy content analysis of the solid waste.

It is evident from the available literature that the exergy content analysis of solid waste generation in University of Lagos has not been carried out. Therefore, the aim of this study is to analyse the exergy content and simulate the power output of the solid waste generation in University of Lagos. Exergy is the portion of the total energy embedded in a system that is available for conversion to useful work (olafadehan *et al*., 2012). If the exergy content of the solid waste generation in University of Lagos is known, it can provide the amount of energy that can be converted to useful work for power generation to sustain the university.

2. THEORY

The moisture content of solid wastes is expressed as the mass of moisture per unit mass of wet or dry material. The wet – mass moisture content, M, is given by:

$$M = \left(\frac{a-b}{a}\right)\times 100 \tag{1}$$

Where a is the in initial mass of solid waste sample as delivered and b is the mass of sample after drying.

To obtain the dry mass, the solid waste material was dried in an oven at 77°C for 24 hours in order to dehydrate the material completely and to limit the vaporization of volatile materials. The heat released from the combustion of solid wastes is partly stored in the combustion products (gases and ash) and partly transferred by convection, conduction and radiation to the combustor wall and to the incoming waste. The energy content of the waste can be estimated using the modified Dulong equation (Olafadehan et al., 2012) given by:

$$E = 337C + 1428\left(H - \frac{O}{8}\right) + 95S \tag{2}$$

Where C, H, O and S are percentages of carbon, hydrogen, oxygen and sulphur in the solid waste respectively.

For the exergy analysis and evaluation of energy and exergy efficiencies, the following assumptions are made:

1. The reference environment temperature, T_o, is 25^0C.
2. The thermal product is delivered at an effective temperature, T, of 900°C
3. The energy and exergy of combustible waste are identical.

The flow of exergy associated with the heat transfer, Q, is given by (Dincer and Rosen, 2007):

$$E_{XQ} = \int_{Qi}^{Qf}\left(1 - \frac{T_0}{T}\right)\delta Q \tag{3}$$

This is the minimum work required by the system of the control mass and environment in bringing the control mass from an initial state (i) to final state (f), δQ is an increment heat transfer. If the temperature, T, of the control mass is constant, the thermal exergy transfer associated with a heat transfer is:

$$E_{XQ} = \int_{Qi}^{Qf}\left(1 - \frac{T_0}{T}\right)Q = \tau Q \tag{4}$$

Where $\tau = \left(1 - \frac{T_0}{T}\right)$

The energy and exergy efficiencies can be calculated as follows:

Energy efficiency (η) = energy output / energy input (5)

Exergy efficiency (Ψ) = thermal exergy output/ energy input (6)

3. ENERGY AND EXERGY ANALYSIS

3.1. Determination of Combustion Heat Balance

A fluidized bed incinerator was considered in this study which is a water wall incinerator. The incinerator is useful for the recovery of steam and also in controlling furnance temperature without introducing excess air. The fluidized bed incinerator burns solid waste at high pressure thereby producing hot gases (Olafadehan *et al.*, 2012). The combustible components of wastes generation on daily basis in University of Lagos, obtained from the work of Adeniran *et al.* (2017) is presented in Table 1.

Table 1: Combustible component of waste generation on daily basis in University of Lagos

Component	Mass (tons)
Paper	4.83
Plastics	2.90
Textile	2.25
Organic matter	4.83
Leather	1.29
Total	16.10

Table 2 provides the typical values of moisture content and ultimate analysis of the combustible components in solid waste generation in University of Lagos while Table 3 shows the composition of combustible component of solid waste generation in University of Lagos.

Table 2: Typical values on moisture content and ultimate analysis of combustible components of solid waste generation in University of Lagos (Tchobanoglous et al., 1972 and Salami et al., 2011).

Component	Typical moisture (%)	% by mass (dry basis)					
		C	H	O	N	S	Ash
Paper	6.00	43.50	6.00	44.00	0.30	0.20	6.00
Plastics	2.00	60.00	7.20	22.80	-	-	10.00
Textile	10.00	55.00	6.60	31.20	4.60	0.15	2.00
Organic matter	25.00	48.50	6.50	37.50	2.20	0.30	5.00
Leather	10.00	60.00	8.00	11.60	10.00	0.40	10.00

Table 3: Composition of combustible components of solid waste generation in University of Lagos (Adeniran *et al.*, 2017).

Component	Wet mass (tons)	Dry mass (tons)	Composition					
			C	H	O	N	S	Ash
Paper	4.83	4.54	1.97	0.27	2.0	0.01	0.01	0.27
Plastics	2.90	2.84	1.70	0.20	0.65	-	-	0.284
Textile	2.25	2.03	1.12	0.13	0.63	0.09	0.00	0.04
Organic matter	4.83	3.62	1.76	0.24	1.36	0.08	0.01	0.18
Leather	1.29	1.16	0.70	0.09	0.13	0.12	0.00	0.12
Total	16.10	14.19	7.25	0.93	4.77	0.30	0.02	0.89

The waste has 2.58 tons/day inert (Adeniran *et al.*, 2017).

From Table 3, the moisture content of the solid waste is 16.10 – 14.19 = 1.91 tons which was converted to hydrogen and oxygen tonnages thus:

L. Salami et al. / Nigerian Research Journal of Engineering and Environmental Sciences
3(1) 2018 pp. 273-279

Mass of hydrogen = (2 x 1.91/ 18 x 1) = 0.21 ton

Mass of oxygen = (16 x 1.91/ 18 x 1) = 1.70 ton

Total mass of hydrogen = 0.93 + 0.21 = 1.14 ton

Total mass of oxygen = 4.77 + 1.70 = 6.47 ton

Table 4: The revised composition of the solid waste

Element	Mass (tons)	% by mass
Carbon	7.25	45.11
Hydrogen	1.14	7.09
Oxygen	6.47	40.26
Nitrogen	0.30	1.87
Sulphur	0.02	0.12
Ash	0.89	5.54
Total	16.07	100

The revised composition of the solid waste is presented in Table 4.

The calorific value of the waste was calculated from Equation (2) using the composition in Table 4 as 15,215.53 kJ/kg.

The following assumptions were adapted from the literature (Howard and Odum, 2008):

1) The heating value of carbon = 32789 kJ/kg.
2) Heat lost through the reactor walls and other appurtenances to the surroundings = 0.004 J/kg of furnace input.
3) Latent heat of vaporization of water, l_v = 2420 kJ/kg.
4) Specific heat of residue = 1.0475 J/kg.
5) Unburned carbon in residue = 8% of input carbon.
6) Temperature of entering air (base temperature) = 25 ^oC
7) Temperature of residue from the grate = 750 ^oC.

Heat losses from reactor (i.e unburned carbon, radiation), from latent heat (i.e inherent moisture, moisture in bound water, moisture from oxidation of net hydrogen) and from sensible heat (i.e sensible heat in residue, stack gases) are all put into consideration in this work.

The non-combustible component of the solid waste (Inert) = 2.58 tons/day

Since the incinerator residue is assumed to contain 8% carbon, total residue = 2.58/0.92 = 2.80 tons/day.

Hence carbon in residue = 2.80 – 2.58 = 0.22 ton/day

The net value of hydrogen was computed by subtracting one – eight of the percent oxygen from the total percentage of hydrogen present initially.

The net available hydrogen = (0.0709 – 0.4026/8) x 100 = 2.06%

Hydrogen inbound water = 7.09 – 2.06 = 5.05%

Bound water = 40.26 + 5.03 = 45.29%

Amount of water produced from combustion of hydrogen is:

18 kg water/2kg hydrogen (0.0206/1) ((16.07 + 2.58) tons/day) = 3.46 tons/day

Therefore, the heat balance for the combustion process is calculated thus:

Gross heat input = (16.07 + 2.58) x 10^3 kg/day (15,215.53 kJ/kg) = 2.83 x 10^8 kJ/day

Heat lost in unburned carbon = 0.22 x 103 kg/day (32789 kJ/kg) = 7.21 x 10^3 kJ/day

Heat content of the inherent moisture = ml_v = 1.91 x 10^3 x 2420 = 4.62 x 10^6 kJ/ day

Moisture from the oxidation of hydrogen = 3.46 x 10^3 x 2420 = 8.37 x 10^6 kJ/day

Radiation loss = 0.004 x (16.07 + 2.58) x 10^3 = 0.0746 kJ/day

Sensible heat in residue = $mc\theta$ = 2.80 x 10^3 x 1.047 x (750 - 25) = 2.125 x 10^6 kJ/day

Sensible heat in hot gases = (283 – 0.000721 – 0.02 – 4.62 – 8.37 – 0.0000746 – 2.125) x 10^6 = 2.67 x 108 kJ/day

Hence the heat released during incineration of 18.65 ton/day of solid waste was found to be 2.67 x 10^8 kJ/day

3.2. Exergy Analysis

From Equation (4), $\tau = \left(1 - \frac{25+273}{900+273}\right) = 0.7460$

The thermal exergy transfer = 0.7460 x 2.67 x 10^8 = 1.99 x 10^8 kJ/day. This is the exergy associated with energy of 2.67 x 10^8 kJ/day, which is also a quantitative assessment of its usefulness or quality.

The energy efficiency is calculated using Equation (5) to be 94.35%.

The exergy efficiency is found using Equation (6) to be 70.32%.

4. CONCLUSION

This study shows that 18.65 tons/day of solid wastes generation in University of Lagos, have a moisture content of 11.86% and a calorific value of 15,215.53 kg/kJ. The heat released during incineration of solid waste was 2.67 x 10^8 kJ/day. The exergy analysis of the heat released from the incinerator was carried out and the thermal exergy transferred was 1.99 x 108 kJ/day. The energy and exergy efficiencies were found to be 94.35 and 70.32 % respectively. The simulation power output at 15% and 95% efficiency values were 0.43 x 10^8 and 2.69 x 10^8

kJ/day respectively. The lower efficiency value of exergy compared to energy provides a true measure of energy quality. The energy value of the wastes can be used for power generation in University of Lagos for its sustainable development which will reduce the dependence on the national grid for electricity consumption.

5. ACKNOWLEDGEMENT

One of the authors, Dr. L. Salami is grateful to members of the Environmental Engineering Research Unit of Department of Chemical and Polymer Engineering, Lagos State University for their encouragement and support for the success of this study.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Adeniran, A. E., Nubi, A. I. and Adelopo, A. O. (2017). Solid waste generation and characterization in the University of Lagos for a sustainable waste management. *Waste managemen*t, In press.

Adeyinka, S. Y., Wasiu, J., Oluwashola, O. and Adebayo, A. (2014). Physico-chemical composition and energy content analysis of solid waste: A case study of Castlereagh district, Northern Ireland. *American Journal of Engineering Science and Technology Research*, 2(1), pp. 1 – 9.

Alexander, E. (2003). Solid waste management: Lagos State as a case study. B.Sc Thesis, Lagos State University, Lagos, Nigeria.

Dincer, I. and Rosen, M. (2007). Exergy, enviroment and sustainable development. Khiwer, Academic.

Howard, T. and Odum, B. (2008). Concept and methods of ecological engineering. Enviromental Science, University of Florida, Gainessville.

Okeniyi, J. O. and Anwan, E. U. (2012). Solid wastes generation in Covenant University, Ota, Nigeria: Characterisation and implication for sustainable waste management. *Journal of Material and Environmental Science*, 3(2), pp. 419 – 424.

Olafadehan, A. O. and Salami, L. (2011). Proactive solid waste management and control: A way of environmental sustainable in Nigeria. *Nigerian Journal of Engineering Management*, 12(1), pp. 26 – 31.

Olafadehan, A. O., Salami, L., Babatunde, K. A. and Toluwalase, O. A. (2012). Achieving sustainable development in small communities via combined heat and power system. *Engineering*, 4, pp. 160 – 169.

Pitt, M., Brown, A. and Smith, A. (2002). Waste management at Airport. *Facilities*, 20(5): 198 – 205.

Robert, A. C. (1999). Standard handbook of environmental Engineering. McGraw-Hill Company, U.S.A.

Salami, L., Susu, A. A., Patinvoh, R. J. and Olafadehan, O. A. (2011). Characterization study of solid wastes: A case of Lagos State. *International Journal of applied science and technology,* 1(3), pp. 47 – 52.

Susu, A. A., Abhulimen, K. E. and Stephen, O. F. (2003). Proactive management of environmental waste in the Nigeria Petroleum industry. *Engineering and Technology Research journal,* 1(1), pp. 35 – 40.

Tchobanoglous, G., Theisen, H. and Eliassen, R. (1972). Engineering principles and management issues. McGraw-Hill, New York.