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Research article

Physico-Chemical Composition and Energy Content Analysis of Solid Waste: A Case Study of Castlereagh District, Northern Ireland.

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Abstract

The physico-chemical characterization of municipal solid waste generated in Castlereagh district in Northern Ireland was carried out. The solid waste type were observed to comprise of glass (9.59%), metal (2.74%), paper (25.83%), plastics (3.87%), compostable (organic matter) (57.48%), WEEE(0.22%) and other waste(0.27%). Both WEEE and other waste were lumped and referred to as uncompact municipal waste (UMW). The moisture content as-discarded, density and solid waste generation rate were obtained to be 16.3692%, 150.489kg/m^3 and 25.94tonne/day respectively. Its chemical formula with and without sulphur were also determined and obtained to be $C_{510.909}H_{1136.545}O_{476.891}N_{13.255}S$ and $C_{38.546}H_{85.748}O_{35.979}N$ respectively. The suitability of the municipal solid waste as a possible source of energy was also put into consideration; an energy content of the solid waste was determined and observed to be 14.74MJ/kg which is significant. Hence, it can be used to generate energy in Castlereagh district.

Keywords: chemical; characterization; component; energy content; solid waste.

1.0 Introduction

Solid wastes are all the wastes arising from human and animal activities that are normally solid and that are discarded as useless or unwanted (Peavy et al., 1985). It encompasses the heterogeneous mass of throwaways from residences and commercial activities as well as the more homogeneous accumulations of a single industrial activity. They are generated by almost every activities and the amount varies by source, season, geography and time (Robert 1999). These wastes must be properly handled stored, collected, processed, and disposed of to reduce the risk they will pose to the general public. The rate of solid waste generation has been on the increase due to increase in human population (Cunninghams et al., 2005; Zurbrugg 2003; Sridhar and Ojediran, 1983).Many techniques including solid waste management using landfill techniques are used in environmental waste in some part of the world, there still exist a need for effective waste control to provide a platform for sustainable development (Susu et al., 2003). In developed countries such as Ireland, proper waste management practices have led to reduce environmental and health implication associated with solid wastes, due to formation and implementation of sustainable policies designed to protect human life's and the environment in general (Momoh et al., 2010).

The solid waste that transported to landfill has a certain composition and characteristics depends on the source, climate and volume of the solid waste generated. Social economic household conditions, lifestyle, and behavioral characteristics will reflect the amount of and the composition of the solid waste produced (Burnley et al., 2007) chemical compound of solid waste which consists of water, organic and inorganic, and their percentage depends on the type and climate. Domestic solid waste are usually very diverse, but generally consists of a minimum of 75% organic matter, while the rest is inorganic (Titien et al., 2013).

The implementation of proper solid waste management program has the potential to support the principles of sustainable development [Momoh et al., 2010]. The practice of reuse and recycling of solid waste in form of compost, biogas and recovery, if properly utilized by developing countries can help to alleviate poverty and reduce problems of joblessness (World Bank 2001; Cunninghams et al., 2001). Characterization of solid waste are very important variables used to identify potential waste management as well as prevention of degradation by the authorities.

A lot of research work have been done on characterization of municipal solid waste. 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 waste. They neglected the energy content of the solid waste. Momoh et al (2010) had also worked on solid waste characterization. They considered the physical composition and energy content of solid waste, but neglected its chemical composition.

This study was carried out to evaluate the compositions (physical and chemical), energy content and characteristics of municipal solid waste in Castlereagh landfill, Northern Ireland.

2.0 Material and Method

2.1 Study Area

Castlereagh is a local government district with the status of borough in Northern Ireland. A mainly urban borough to the south of Belfast city, it is governed by Castlereagh Borough Council. It occupies an area of about 85km^2 with a population of about 67, 000. According to Northern Ireland Municipal Statistics, Annual Report 2010/11, solid waste material collected for recycling in Castlereagh are categorized into glass, metal, paper & card, plastics, compostable, WEEE and other waste. Other wastes comprise of textiles, wood, rubble, batteries, paints, oils and other unclassified materials. Among these waste materials, paper & card, plastics, compostable (Organic matters) and few components of other waste are organic in nature, while glass, metal and WEEE (Waste Electrical and Electronic Equipment) are inorganic in nature.

2.2 Theory

The moisture content of solid waste as percentage wet weight (X_w) and dry weight (Xd) is determined as follows:

$$X_W = \frac{W}{W_W} \text{ X } 100\% \quad (1)$$

$$X_d = \frac{W}{W_d} \text{ X } 100\% \quad (2)$$

The density of solid waste as discarded is determined with equation (3)

$$\rho = \frac{M}{V} \quad (3)$$

Where:

$$M = \sum m_i$$

$$V = \sum v_i$$

In order to access the heating value (energy content) of the solid waste generated, the equation (4) as developed by Dulong is employed:

$$\text{Energy content } (E), \text{ KJ/Kg} = 337C + 1428 \left(H - \frac{O}{8} \right) + 9S \quad (4)$$

The overall efficiency of a mass- fired combustor plant is obtained by equation [5] (Edward, 2001)

$$\eta = \frac{E_o}{E_i} \quad (5)$$

$$E_i = M_f * E \quad (6) \text{ (Edward, 2001).}$$

Combining equations 5 and 6 to yield equation 7,

$$E_o = \eta * M_f * E \quad (7)$$

2.2 Characterization of solid waste sample

Table 1: Castlereagh Solid Waste Component & Percentage

Component	Weight (Tonne)	Percentage by mass (%)
Glass	908	9.59
Metal	259	2.74
Paper	2,446	25.83
Plastic	366	3.87
Compostable(Organic)	5,442	57.48
WEEE	21	0.22
Other waste	26	0.27
Total	9,468	100

Source: NIEA/NISRA (2010/11).

To characterize 9,468 Tonnes of Castlereagh solid waste sample collected, the following typical data on ultimate analysis of the combustible components in solid are used (Tchobanologhous et al., 1972) as shown in table 2.

Table 2: Typical component values and composition of solid waste

Component	Moisture (%) Typical	Density kg/m^3 Typical	C	H	O	N	S	Ash
Glass	2	195	-	-	-	-	-	-
Metal	3	320	-	-	-	-	-	-
Paper	6	85	43.5	6.0	44.0	0.3	0.2	6.0
Plastics	2	65	60.0	7.2	22.8	-	-	10.0
Compostable(Organic)	25	240	48.5	6.5	37.5	2.2	0.3	5.0
UMW								
a) Textile	10	65	55.0	6.6	31.2	4.6	0.15	2.5
b) Wood	20	240	49.5	6.0	42.7	0.2	0.1	1.5
c) Rubble	8	480	26.3	3.0	2.0	0.5	0.2	68.0

Source: Tchobanoglous et al (1977).

Assumptions:

1) For simplicity, both WEEE and other waste materials are lumped and referred to as uncompacted municipal waste.
2) a , b, and c are combustible components of lumped WEEE and other waste materials (UMW).
3) Typical composition of textiles, wood and rubble in municipal solid waste are 2%, 2% and 4% by mass respectively (Tchobanoglous 1977).

Table 3: Component table for the determination of dry mass and volume of solid

Component	Percent by mass	Moisture content, %	Dry mass Kg	Typical Density Kg/m^3	Volume M^3
Glass	9.59	2	9.3982	195	0.0492
Metal	2.94	3	2.6578	320	0.0086
Paper	25.83	6	24.2802	85	0.3039
Plastics	3.87	2	3.7926	65	0.0595
Compostable	57.48	25	43.11	240	0.2395
UMW	0.49	20	0.392	130	0.0038
Total	100kg		83.6308kg		0.6645

2.2.1 Determination of physical composition of solid waste.

Using equation (1), the moisture content, X_w , is

$$X_w = \frac{100 - 83.6308}{100} \text{ x } 100\%$$

$$X_w = 16.3692\%$$

The density of the solid waste sample is calculated as:

$$\rho = \frac{\sum m_i}{\sum v_i}$$

$$= \frac{100}{0.6645}$$

ρ = 150.489 kg/m^3

2.2.1 Determination of chemical composition of the solid waste sample

The organic portion of the solid waste sample comprises of paper, compostable (organic matter), plastics and some portion of uncompact municipal solid (textiles, wood, rubble).

Table 4: Computation table for the determination of composition of organic portion of the solid waste

Component	Wet mass (kg)	Dry mass (kg)	C	H	O	N	S	Ash
Paper	25.83	24.2802	10.5619	1.4568	10.6833	0.0728	0.0486	1.4568
Plastic	3.87	3.7926	2.2756	0.2731	0.8647	-	-	0.3793
Compostable	57.48	43.1100	20.9084	2.8021	16.1663	0.9484	0.1293	2.1555
UMS								
a) Textile	0.0098	0.00098	$5.36*10^{-4}$	$6.47*10^{-5}$	$3.06*10^{-4}$	$4.51*10^{-5}$	$1.47*10^{-6}$	$1.47*10^{-5}$
b) Wood	0.0098	0.00196	$9.7*10^{-4}$		$8.37*10^{-4}$			
c) rubble	0.00196	0.001568	$4.12*10^{-4}$	$1.18*10^{-4}$	$3.14*10^{-5}$	$3.92*10^{-6}$	$1.96*10^{-6}$	$2.94*10^{-5}$
				$4.70*10^{-5}$		$7.84*10^{-6}$	$3.14*10^{-6}$	$1.07*10^{-3}$
Total	87.2192	71.1873	33.7478	4.5322	27.7155	1.0213	0.1779	3.9927

The mass of moisture in the organic portion of solid waste sample is:

Wet mass – Dry mass

87.2192 – 71.1873

16.0319kg

Converting moisture content reported in table 4 to hydrogen and oxygen:

Hydrogen = $\frac{2}{18}$ X 16.0319kg

Oxygen = $\frac{16}{18}$ X 16.0319 = 14.2506kg

Total mass hydrogen = 1.7813 + 4.5322 = 6.3135kg

Total mass of 0xygen = 14.2506 + 27.7155 = 41.9661kg

Table 5: Determination of approximate chemical formula with and without sulphur.

Element	Mass (kg)	Molecular mass	Amount (mole)	Normalized Mole ratio Sulphur =1	Normalized Mole ratio Nitrogen=1
Carbon (C)	33.7478	12.01	2.8100	510.909	38.546
Hydrogen (H)	6.3135	1.01	6.2501	1136.545	85.748
Oxygen (O)	41.9661	16.00	2.6229	476.891	35.979
Nitrogen (N)	1.0213	14.01	0.0729	13.255	1.0
Sulphur (S)	0.1779	32.06	0.0055	1.0	-

Hence, the chemical formula of the solid waste sample with sulphur is:

$$C_{510.909}H_{1136.545}O_{476.891}N_{13.255}S$$

And its chemical formula without sulphur is:

$$C_{38.546}H_{85.748}O_{35.979}N$$

2.3.3 Estimation of energy content approximation of the solid waste

Using equation 4 and data obtained in Table 6 below, to obtain the energy content of the solid waste generated in Castlereagh district.

Table 6: Percentage by mass composition of elements and ash

Component	Mass(kg)	Percentage by mass (%)
Carbon	33.7478	38.7
Hydrogen	6.3135	7.2
Oxygen	41.9661	48.1
Nitrogen	1.0213	1.2
Sulphur	0.1779	0.2
Ash	3.9927	4.6
Total	87.2193	100

E, kJ/kg = 337(38.7) + 1428(7.2 – 48.1/8) + 9(0.2)

= 13,041.9 + 1695.75 + 1.8

= 14739.45KJ/kg

≈ 14.74MJ/kg of Castlereagh solid waste.

2.2.4 Simulation of Electrical Output for the mass-fired combustor power plant

With energy content of 14739.45kJ/kg and total solid waste generation rate of 9468 tonnes/annum (or 0.3002kg/s) from Castlereagh district. Simulation can be carried out by assuming different operating efficiencies for the mass-fired combustor power plant (Momoh et al., 2010). Its overall efficiency is obtained by using equation (5).

Hence, the potential for electrical energy generation for a fuel mass flow rate of 0.3002kg/s, heating value of 14739.45kJ/kg and assumed overall efficiency values that range between 15% to 95% can be projected as shown in table 7 and figure 1.

Table 7: Electrical energy out generated with corresponding assumed efficiency (ɳ).

Efficiency (%)	Electrical Output generated (kW)
0.15	663.72
0.25	1106.20
0.35	1548.67
0.45	1991.15
0.55	2433.63
0.65	2876.11
0.75	3318.59
0.85	3761.07
0.95	4203.54

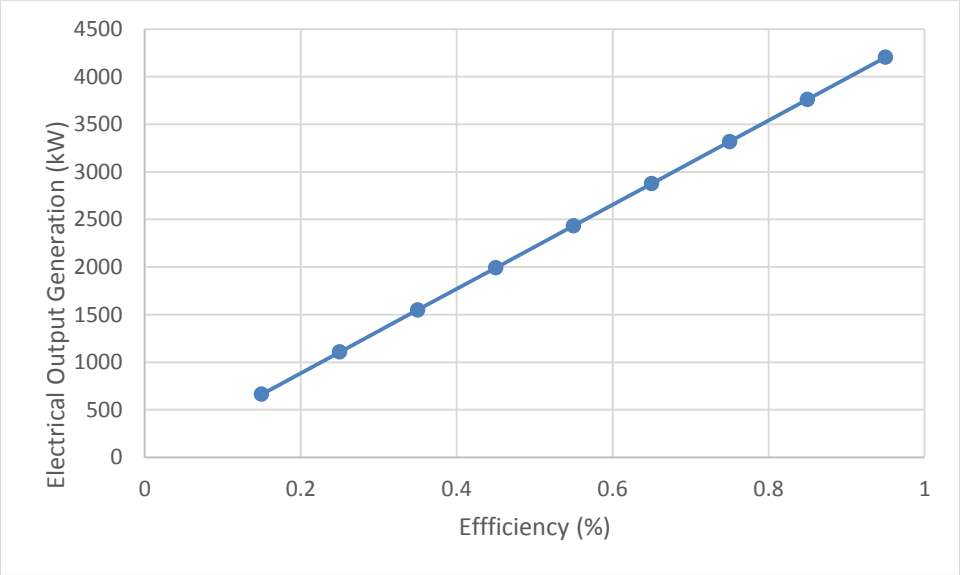

Figure 1: Relationship between simulated electrical energy outputs against power plant assumed efficiencies.

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List of Abbreviations

NIEA	Northern Ireland Environment Agency
NISRA	Northern Ireland Statistics & Research Agency
WEEE	Waste Electrical and Electronic Equipment
UMW	Uncompact Municipal Waste.

Nomenclature

C	Carbon
E	Energy content in kJ/kg
E_i	Energy input in kJ/kg
E_o	Energy output in kJ/kg
H	Hydrogen

M	Mass of solid waste in kg
m_i	Mass of individual component of solid waste
M_f	Mass flow rate of waste generated in kg/s
N	Nitrogen
O	Oxygen
S	Sulphur
V	Volume of solid waste in m^3
v_i	Volume of individual component of solid waste in m^3
ρ	Density of solid waste in kg/m^3
η	Efficiency in %