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Determination of Electric Energy from Municipal Solid Wastes: A Case Study of Auchi Metropolis, Nigeria

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Abstract

The electric energy problem and environmental degradation are currently two vital issues affecting the development of Auchi metropolis. Rapid industrialization and high population growth in Auchi has led to the migration of people from neighboring villages to the metropolis which in turns increases the generation rate of municipal solid waste in the area. This is one of the important contributing factors for environmental degradation at national level. Municipal solid waste management is one of the major environmental problems of Auchi metropolis. Consequently, the Auchi metropolis has serious problem of electricity, load shedding is now impractical as living standards are become a great barrier in socio-economic growth. This study was carried out in Auchi metropolis to make municipal solid waste management more effective and efficient, in-site specific study was carried out which help to established 100 waste collection points in the metropolis under investigation. The waste generated was collected daily in each zone, sorted, and individual component were weighed and recorded. This help to determined how much net weight, percentage of weight and total weight of waste generated in the metropolis. The waste components are food waste of 92.8%, plastics waste of 48.1%, paper waste of 47.4%, garden trimming waste of 37.1%, textile waste of 28.8%, wood waste of 16.5%, and tin cans waste of 28.0%. From the results, it was discovered that food waste has the highest waste of 92.8% which has adverse effect on the lives of the people in the metropolis. Using standard table of ultimate analysis for chemical composition of waste component, chemical composition of each waste element and the amount of carbon, hydrogen, oxygen, nitrogen, sulfur, and ash content for each type of waste was determined. Dulong's formula was used to determined Heat Energy and Net Electrical Energy from the waste components generated from the Auchi metropolis solid waste that resulted to be 48MW or 1146MWh per day which fulfills 8% of the energy demand (580MW) of the metropolis. It was found that energy generation from Municipal Solid Waste is an alternative way of solving electricity problem as well as waste management in the metropolis.

1. Introduction

The energy problem and environmental degradation are currently two vital issues for global sustainable development. Rapid industrialization and population explosion in Nigeria has led to the migration of people from villages to cities, which generate thousands of tons of municipal solid waste daily, which is one of the important contributors for environmental degradation particularly at Auchi metropolis and the national level. Consequently, the Auchi metropolis has serious problem of electricity, load shedding is now impractical as living standards are becoming a great barrier in socio-economic growth. Municipal solid waste management is one of the major environmental problems of Nigeria cities including Auchi metropolis. Improper management of municipal solid waste causes hazards to inhabitants. Massive volume of solid waste is generated every day in the Municipal areas and unfortunately solid waste management is being deteriorated day by day. Municipal solid waste (MSW) can be defined as the aggregate of the discarded unwanted materials, generated from the daily activities of man as they interact with their environment [1]. Municipal Solid Waste generation rate has increased globally over the years due to population growth, changes in lifestyle, technology development and increasing consumerism [2]. This increase in waste generation rate could lead to a rise in environmental challenges if not adequately managed [3]. A Study was conducted in Ilorin to estimate the quantity of municipal solid waste generated per annum as well as the quantity and the fractions of the waste streams available for energy production [1]. A study also carried out In Columbia was to evaluate the techno-economic prefeasibility of waste to energy projects using four different conversion technologies of incineration, gasification, anaerobic digestion and landfill gas [4]. Biological conversion technologies enable the exploitation of biogas produced from the mass fraction of solid waste [5-7] and several studies have evaluated the potentials of landfill biogas for producing electricity [8-11]. Some researchers have also assessed the energy recovery potential of biogas from anaerobic digestion for generating electricity in Brazil, Spain, China and Tanzania. Gasification is a thermal conversion technology process for recovery energy from MSW [12] which reduces the waste volume in 95% and produces less emissions compared to incineration [13] After critical reviewed of the relevant literatures, it was observed that generating electrical energy from municipal waste in Auchi metropolis has not been established to the best of our knowledge; that formed the basis of our research work. The aim of this work is to determine electrical energy from municipal waste generated in Auchi metropolis.

2. Methodology

2.1. Research Design

The study was carried out in Auchi metropolis. To make solid waste management more efficient, a site specific study was carried out to determine the components of municipal waste generated in the metropolis, creation of waste collection points as well division of the metropolis into 5 zones for easy collections. The management of the municipal waste (collection and transportation) include; the local government council, the private firm, and the community environmental management group. There are 100 waste collection points in the metropolis which keeps on increasing each year as new collection points are needed to satisfy the increasing generation rate of solid waste. All the waste from collection points is dumped at the borrowed-pits were laterite was collected for road construction and in the bush. In this study the waste generated was collected daily in each zone, sorted and individual components were weighed and recorded.

2.2. Method of data collection

Table 1: Solid Waste Collection Points in each Zone

Zones	Number of Collection Points
1	26
2	20
3	14
4	18
5	22
TOTAL	100

From the collected waste components net weight of food wastes, paper wastes, plastics wastes, textiles wastes, garden trimmings wastes, wood wastes and tin cans wastes from all 26 collection point in zone one is determined. Then total weight and percentage of each type of waste is determined using Equation 1 and Equation 2. The total weight of solid waste in zone one is represented in Table 1.

$$\% \text{ of Weight} = \frac{\text{Net weight}}{500} X\ 100 \quad (1)$$

$$\text{Total Weight or Wet Mass } = \frac{\text{Net weight}}{500} X\ 1200000 \text{ kg} \quad (2)$$

2.3. Model Employed

Standard table of ultimate analysis of combustible waste was used to determine the amount of carbon, hydrogen, oxygen, nitrogen, sulphur, and ash content for each type of wastes generated in the metropolis. The application of Dulong's formula helps to determined heat energy on wastes through open air incineration technique. Incineration technique is chosen because it has many advantages over other techniques like the majority of wastes will burn without giving rise to noxious products of combustion in significant quantities, the volume and mass occupied by the waste is greatly reduced, it produces an effectively sterile ash residue. Though the study does not involve analysis of gases emitted from waste to energy process and its impact on environment.

Solid waste of Auchi metropolis is generally have paper, plastics, food wastes, garden trimming/yard waste, textiles, wood and tin cans. The waste generated was collected daily; sorted and individual components were weighed and recorded as shown in Table 2. From the collected data net weight of food wastes, paper, plastics, textiles, garden trimmings, wood and tin cans from all 100 collection point is determined and total weight of each type of waste is determine taking solid waste collected per day from the metropolis, total weight is determined using Equation 1 and % weight is determined by using Equation 3.

$$\% \text{ weight} = \frac{Net\ weight}{500} X \frac{100}{1} \quad (3)$$

$$-\text{Total weight or wet mass} = \frac{Net\ weight}{500} X \frac{120000\ kg}{1} \quad (4)$$

Many important observations have been raised on how to determined net weight of food wastes, plastics, paper, garden trimmings, textiles, wood and tin cans sampled from 100 collection points. Once percentage weight composition is determined, total weight of whole collection points of Auchi metropolis can be easily determine using Equation 2. Taken the total average of municipal waste collected in Auchi metropolis as 1200 – 1250 tons/day (Etsako West Local Government Council Waste Management Report, 2014).Now using typical moisture content data, dry mass of each type of waste is determined. Tin cans dry mass is not considered as it has got vey less moisture and also tin cans give zero energy in incinerators. Once dry mass is determined, the amount of carbon, hydrogen, oxygen, nitrogen, sulfur and ash content could be determined for each type of waste using standard table of ultimate analysis of combustible waste and Equation 5.

Element content = Dry mass/100 x Standard ultimate analysis mass percent kg (5)

Now revised mass is determined for solid waste, as moisture in solid waste converts into hydrogen and oxygen due to heat in incinerators.

2.4. Heat Energy (Dulong's Formula)

To determine heat energy generated by whole Kanpur city's solid waste Dulong's formula needs to be applied. Dulong's formula described in Equation (6).

$$\text{Heat Energy} \frac{\text{kJ}}{\text{kg}} = 337\text{C} + 1428\ (\text{H} - \frac{O}{8}) + 9s \quad (6)$$

Where C = carbon percentage
H = hydrogen percentage
O = oxygen percentage
S = sulfur percentage

3. Results and Discussion

Table 2: Net Weight, % Weight and Total Weight of each Waste Type for all The Zones in the Auchi Metropolis

Type of Waste	Net weight (kg)	% Weight	Total Weight (kg)
Food wastes	464.11	92.82	111,386.40
Plastic wastes	240.44	48.09	57,705.60
Paper wastes	236.90	47.38	56,856.00
Garden Trimmings	185.90	37.05	44,445.20
Textiles wastes	143.94	28.79	34,545.60
Wood wastes	82.46	16.49	19,790.40
Tin Cans wastes	139.99	28.00	33,597.60

From Table 2; It is observed that food waste has highest weight composition percentage of (92.82%) followed by plastics wastes (48.097%), paper wastes (47.38%), garden trimmings wastes (37.05%), textile wastes (28.79%), tin cans wastes (28.00%) and wood wastes (16.49%).Once percentage weight composition is determined from the collated data, total weight of whole 100 collection points of Auchi metropolis can be easily found out using Equation 2.Total weight of solid waste of the entire Auchi metropolis is shown in Figure1.

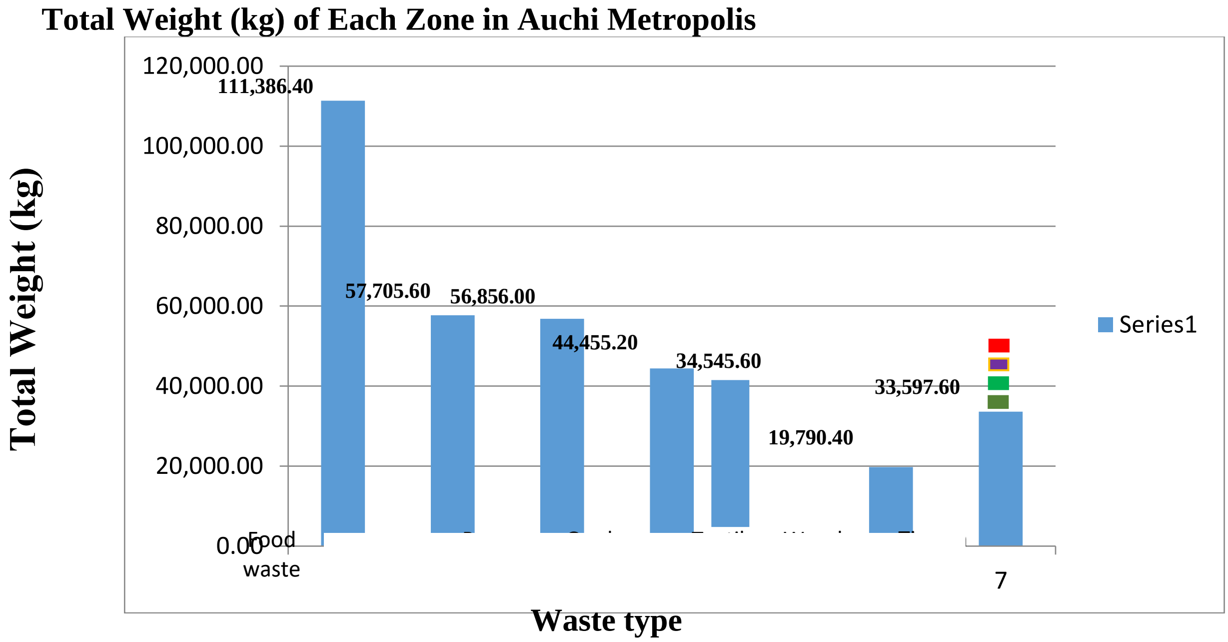

Fig. 1: Total weight of bifurcated solid waste from all the collection zones in Auchi Metropolis

In previous section all the Auchi metropolis wet mass or total weight of food wastes, plastics, paper, garden trimmings, textiles, wood and tin cans are determined (see Figure 2). Now using typical moisture content data, dry mass of each type of waste is determined. Tin cans dry mass is not considered as it has got very less moisture and also tin cans give zero energy in incinerators. Once dry mass is determined then the amount of carbon, hydrogen, oxygen, nitrogen, sulfur and ash content is determined for each type of waste using standard table of chemical composition of waste components as shown in Table 3, and Equation 3.

$$\text{Element content} = \frac{\text{Dry weight}}{100}\ X\ Standard\ Ultimate\ analysis\ mass\ percent\ kg \quad (3)$$

Table 3: Chemical Composition of Waste Components (typical data on the ultimate analysis of the combustible components in municipal waste) Percentage by Weight (Dry Mass)

Component	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Food	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	5.0
Plastics	60.0	7.2	22.8	-	-	10.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	-	2.0	-	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Yard	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.5
Glass	0.5	0.1	0.4	<0.1	-	98.9
Metals	4.5	0.6	4.3	<0.1	-	90.5
Dirt and ash	26.3	3.0	2.0	0.5	0.2	68.0

*Adapted in part from Ref. 6.

Table 3 was used to determine the percentage of the reversed mass as shown in Table 4.

Table 4: Percent by weight (Dry Mass)

Element	Reversed mass	Percent by mass
Carbon	292.60	41.61
Hydrogen	37.38	5.34
Oxygen	214.52	30.51
Nitrogen	11.09	1.57
Sulphur	1.37	0.18
Ash	146.17	20.79
Total	703.13	100

Now revised mass is determine for solid waste, as moisture in solid waste converts into hydrogen and oxygen due to heat in incinerators. The final revised mass of element content of whole Auchi metropolis solid waste can be seen in Table 5. From Equation 3; the following elements were determined.

Table 5: Reverse of Element Content

Component	Wet Weight	Dry Weight	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food waste	464.11	196.40	94.32	12.57	73.70	5.10	0.78	9.80
Plastics	240.44	84.22	50.40	6.05	19.15	0.00	0.50	8.40
Paper	236.90	108.35	46.98	6.48	47.52	0.3	0.2	6.5
Garden Trimming	185.90	71.52	34.42	4.32	27.36	2.45	0.22	3.24
Textile	143.94	68.40	37.40	4.49	21.22	3.13	1.10	1.70
Wood	82.46	46.55	23.27	2.82	20.07	0.09	0.05	0.71
Tin cans	139.99	128.20	2.76	0.77	5.50	0.00	0.00	115.84
Total		703.64	292.60	37.38	214.52	11.09	1.37	141.17

From Table 5, the chemical composition of the various waste components was determined using the table of typical data on the ultimate analysis of the combustible components in municipal waste;
Heat Energy (Dulong's Formula)
To determine heat energy generated by whole Auchi metropolis solid waste Dulong's formula needs to be applied.
Dulong's formula described in Equation 4.

$$\text{Heat Energy (kJ/kj} = 337\,C + 1428\,(H - \frac{O}{8} + 9S) \quad (4)$$

Where C = carbon percent
H = hydrogen percent
O = oxygen percent
S = sulfur percent
Putting percent by mass value from Table 5 into Dulog's formula, net heat generated by Auchi metropolis is obtained below;

$$\text{Heat Energy Generated(kJ/kj} = (337 + 41.61) + 1428\,(5.34 - \frac{30.51}{8} + 9\,X\,0.18)$$

14022.57 + 1428 (5.34 – 3.81) + 1.62
14022.57 + 1428 (1.53) + 1.62 = 16,194.75
Heat Energy Generated = 16194.75 kJ/kg (5)

Various steps are carried out to determine electricity. First, heat energy generated is used to determine steam energy which is 70% of heat energy. Finally, after determined steam energy, net electric power generated by solid waste is determined after heat losses. All this is shown:

Steam energy available = 70% of heat energy (6)

Now putting heat energy value from Equation 5.
Steam energy available = (0.70 × 16194.75) kJ/kg = 11,336.325 kJ/kg
The above results for steam energy is used to run the turbines, these turbines are coupled with generators which produces electricity. Heat rate is the heat input required to produce one unit of electricity (kWh).

1kW = 3,600 kJ/h (7)

From Eq. 7, it is interpreted that if the energy conversion is 100 % efficient then to produce ounit of electricity, 3600kJ energy is required. But in practical no energy conversion is 100% efficient, considering the conversion efficiency of 31.6% in a power plant heat input of 3600 ÷ 31.6% = 11395 kJ/kWh is required.
So, to produce 1kWh electrical energy 11395 kJ of steam energy is required.
Therefore, Electric power generation = Steam- energy ÷ 11395kJ/kWh
Electric power generation = (11336.325 ÷ 11395) kWh/kg
= 0.994850811 kWh/kg
Total weight of solid waste collected from Kanpur city = 1200 tons/day
Total electric power generation = (0.994850811 ×1200000) kWh/day
= 1193820.973 kWh/day
Now, Station service allowance = 6% of total electric power generation
Station service allowance = (0.06 × 1193820.973) kWh/day
= 71629.25838 kWh/day
Unaccounted heat loss = 5% of electric power generation
Unaccounted heat loss = (0.05 × 1193820.973) kWh/day = 59691.04865 kWh/day

Net electric power generation = Electric power generation – (station service allowance + unaccounted heat loss).

Net electric power generation = 1193820.973 – (71629.25838 + 59691.04865)
= 1062499.693 kWh/day = 1062.499693 MWh/day

The above generated electricity is for one day and one day has 24 hours, so using this, net electric power is determined on per hour basis.

Net electric power generated = 1062.499693 MWh / 24h = 44.3 MW ≈ 44 MW

Hence, if Waste-to-Energy incineration method is applied on all the 1200 tons/day solid waste of Auchi metropolis then total of 1063MWh/day units can be generated which is equal to 44MW. Auchi metropolis electricity demand is 580MW, which will likely to increase to 976MW by 2021 – 2022. Electrical energy generated from solid waste can fulfill 8% of this demand. Besides electrical energy generation from solid waste also help to reduce the waste volume greatly due to conversion of solid waste into ash which solves solid waste management problem particularly in Auchi metropolis.

4. Conclusion

It is expected that the experience on the development of Waste to Energy in Auchi can offer some helpful lessons to other developing Areas. In addition, power produced from the Waste to Energy activity can reduce the costly natural resources "fossil fuel" utilization in power generation. Fossil fuel are depleting day by day while on the other hand solid waste is increasing day by day, Waste to Energy solves both these problem by managing solid waste and producing electricity.

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