Potential of Municipal Solid Waste Fuel in Awka for Energy Generation.

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ABSTRACT-- Municipal solid waste (MSW) in an area is significant in the production of "eco-friendly fuels and as substitutes for renewable sources of energy," depending on appropriate materials selection to achieve desirable invention. The selection of a specific area's MSW for energy/industrial drives depends on the chemical constituents. This research focused on the physical and elemental evaluation of MSW in Awka, Anambra State, Nigeria. The Chemical make-up of the waste samples was established following the American Standard Test Method procedure, while the physical characteristics were ascertained through direct measurements with the official report. The following were the obtained average elemental evaluation results: 74.88 % Volatile solid, 5.10% ash, 15.40 % Moisture content, 4.65% Fixed carbon, 46.03% carbon, 2.13% nitrogen and 0.22% sulphur. The average calorific value was gotten as 26.675MJ/kg using the XRY-1A model bomb calorimeter. The attained outcome implied that MSW generated in Awka would yield good renewable fuels due to its high percentage of volatile matter and its minimal inert gasses with high calorific value. On the basis of about 63,786 ton/annum capacity incineration plant of about 105 MWh of electricity energy could be generated from the wastes and with 26,152 ton/annum capacity gasification plant of about 50 MWh could be generated.

Keywords: Municipal solid waste, calorific value, elemental analysis, moisture content, volatile solids, potential energy.

1. INTRODUCTION

Anambra State is situated in the south-eastern part of Nigeria. In 2011, its population was estimated at 4,805,600 with a population density of 992.1 p/km^2. Its capital city, Awka, has a population 2.5 million people. Anambra state economic resources are concentrated in Awka because most of its business transactions (services, industries and commerce) take place in the city. Presently, most MSW generated in Nigerian cities, including Awka, are dumped into borough pits while some are disposed along road sides, causing threat to health of the citizens. Efforts have been made by researchers to develop techniques to manage municipal solid waste in Nigeria and other developing countries with a view to reducing health hazards associated with poor management of solid wastes.

Municipal solid waste (MSW) consists of a combination of household, commercial and manufacturing waste arising in a given locality (Fobil et al., 2005; Kothari et al., 2010). The rate at which wastes can be generated is greatly influenced by socio-economic development, level of industrial development, and atmospheric condition of the area under consideration. The hidden energy available in the ganic fraction of MSW can be converted to more useful rms of energy by implementing appropriate waste-to-ergy technologies. According to Gary (2010), obtaining ergy from wastes also presents some extra advantages, hich included:

(i) Reduction of the total waste quantity by almost (60 – 90) %, based on the waste components and the implemented technology;
(ii) Land availability as a result of minimized land filling process;
(iii) Reduction in the cost of waste transportation.
(iv) Significant decrease in environmental pollution.

Municipal solid waste includes: municipal sludge, automobile bodies. Incinerated ashes at municipal waste landfills are not included in MSW (Young, 2006). Different kinds of farm and agricultural wastes have their unique application (completely distinct from that of MSW), like the production of diverse animal feeds (Paul et al., 2019). Although MSW has significant heterogeneity of constituents, the average hydrocarbon structure is approximated as $C_6H_{10}O_4$ (Gary, 2010), and the final breakdown of constituents involved with industrial waste and domestic waste depends on the particular site (Young, 2006). Generally, each source of MSW has distinctive characteristic constituents. The MSW which was collected at each source point is presumed to have the same component characters (Wendy et al., 2014).

The selection of the MSW from a particular area as fit for renewable energy has to be prepared based on analyzing its proximate and ultimate constituents which vary from one place to another. This will facilitate the prudent use of these wastes. It was shown that MSW with quality features could be used to generate electricity in the municipality through thermal technology, like incineration and gasification (Paul et al., 2020). The findings of this study are expected to indicate if MSW generated in Awka would be an excellent renewable fuel that can be to establish a miniature power plant.

1. METHODOLOGY

2.1 Generation of Wastes in Awka

Data on waste disposal/collection in Awka Municipality and evacuation rates at the Ring Road final dumpsite, Agu-Awka, were collected from the Anambra State Waste Management Agency (ASWAMA). Several visits were also made to the dumpsite at Agu-Awka in order to ascertain the waste management operations there. Waste collection and generation at the dumpsite involved three major categories of ASWAMA vehicles: compactor, chain-up and Truck. Wastes generated in various parts of Awka were collected daily by waste disposal vehicles and sent to the dumpsite. The mass of the generated waste is on a wet basis at the point of depositing at Ring-road dumpsite, Agu-Awka. The category of vehicles and the number of delivery trips made in a day were recorded by ASWAMA personnel stationed at the site.

2.2 Composition of Awka MSW

The percentage composition of MSW generated in the case study area for the period of 12 months (January to December, 2020) was estimated through the researcher's field observation and interactions with the dumpsite agents and some scavengers. Five days were randomly selected for sorting and weighing of the waste components according to the delivery equipment. The selected days were: Wednesday 15th January, Wednesday, 22nd March; Wednesday, 25th May; Wednesday, 22nd July; Wednesday, 23rd September and Wednesday, 25th November, all in 2020. The selection was made to cover the beginning, middle and end of the parts of the months of the year and various seasons of the year.

The delivered wastes were separated according to the nature of materials as they were received from waste-collecting centers. The separated wastes were weighed and recorded according to the various categories. The obtained value was then used to calculate the percentage of each component of the waste delivered per day. The obtained percentage values were used to compute the average quantity of each component of MSW. The result was taken as the sample for Awka city.

2.3 Analysis of Awka MSW

Some samples of the waste were collected from the dumpsite and analyzed with a bomb calorimetric experiment at the National Centre for Energy Research & Development (NCERD) Laboratory of the University of Nigeria Nsukka to obtain the heating/calorific values and elemental analysis of the wastes. The standard test method (ASTME) was applied for evaluations.

This analysis which gives an idea of the bulk constituents that make up a fuel, was done to ascertain the percentage volatile matter constituent, ash constituent, moisture constituent and percentage constituent of fixed carbon of the MSW samples.

2.3.1 Percentage volatile matter, ash and moisture content

Meynell (1982) methods was used. The dried residue was exposed to heat in a muffle furnace at 600°C for two (2) hours. A desiccator was used to cool the residue which was heated and the weight was taken.

$$\text{Volatile solid (VS)} = \frac{B - C_r}{g} x \frac{100}{1} \quad (1)$$

$$\%\ \text{Ash} = \frac{D - G}{g} \times \frac{100}{1} \quad (2)$$

$$\%\ \text{MC} = \frac{g - A}{g} \times \frac{100}{1} \quad (3)$$

2.3.2. Percentage ash content

This is the residue after the complete removal of moisture, fats, proteins, carbohydrates, vitamins and organic acids at about 600°C; typically regarded as a gauge of the number of minerals available in the raw waste. Using the A.O.A.C. (1990) method, 1g of the well-grounded samples was weighed into porcelain crucible. The crucible saw washed, dried in an oven at 100°C, cooled in a desiccator and weighed. The mixture was then put in a muffle furnace and heated at 600°C for four hours, after which they were removed, cooled in a desiccator and then weighed.

$$\% \text{ Ash} = \frac{D-G}{g} \times \frac{100}{1} \quad (4)$$

2.3.3 Percentage moisture content
Washed porcelain crucibles were dried in an oven at 100°C for 30 minutes and allowed to cool in a desiccator. A known weight of the crucibles had 1g of the sample deposited in it and then put inside the oven set at 105°C for 4 hours. At the end of the set time, the samples were brought out from the oven, allowed to cool and then weighed. The process was repeated until a stable weight was obtained. The A.O.A.C method (1990) was used.

$$\% \text{ MC} = \frac{g-A}{g} \times \frac{100}{1} \quad (5)$$

2.3.4 Percentage fixed carbon
The percentage moisture content (%MC), percentage volatile solids (%VS) and percentage ash content (%AC) were added together and the result subtracted from 100, to get the percentage fixed carbon (% FC) as shown in the Equation (9).

$$\% \text{ FC} = 100 - (\% \text{ MC} + \% \text{ VS} + \% \text{ AC}) \quad (6)$$

2.4 Chemical analysis of the Awka MSW
The percentage chemical elements that make up the Awka MSW, which included: carbon, nitrogen and sulphur were determined. Some samples of the wastes were collected from the dumpsite and analyzed with bomb calorimetric experiment at the National Centre for Energy Research & Development (NCERD) Laboratory, University of Nigeria Nsukka to obtain the heating/calorific values and elemental analysis of the wastes, thus:

2.4.1 Determination of Carbon Content
Walkey-Black (1934) method was used for the evaluation of carbon content. 0.05gram of the well-grounded sample was measured into a 500ml conical flask. 10ml of 1M potassium dichromate was added to the flask, and the mixture was stirred. 20ml of concentrated H_2SO_4 was added, and the flask was again stirred for a minute in a fume cupboard. The mixture was allowed to cool for 30 minutes, after which 200ml of distilled water, 1gram of Sodium Fluoride (NaF), and 1ml of diphenylamine indicator were added. It was then shaken and titrated with ferrous ammonium sulphate. thus:

$$\% \text{ Carbon} = \frac{V_b - V_s \times M \times 1.33 \times 0.003 \times 100}{g} \quad (7)$$

2.4.2 Nitrogen/Crude Protein Determination
A micro Kjeldahl distillation unit (make: Barloworld, UK model 734205) 100 ml conical flask (Receiver flask) apparatus, 0% NaOH and Boric acid indicator solution as a reagent were used to determine the nitrogen and crude protein content of the MSW.

$$\% \text{ Nitrogen} = \frac{V_s \times 0.014 \times M \times 100}{g} \frac{}{10} \quad (8)$$

Percentage crude protein = % N x 6.25.

The Reaction Equation is stated below;

$$\text{N (waste)} + \text{Conc. } H_2SO_4 \longrightarrow (NH_4)_2SO_4 \quad (9)$$

$$(NH_4)_2SO_4 + 2NaOH \xrightarrow{Catalyst} Na_2SO_4 + 2NH_3 \quad (10)$$

The ammonia yielded was retrieved in excess boric acid.

$$NH_3 + H_3BO_3 \longrightarrow NH_4BO_2 + H_20 \quad (11)$$

After total ammonia distillation, standard HCl was used to titrate the ammonium borate solution because strong acid (HCl) displaces weak boric acid from its salt

$$NH_4BO_2 + HCl \longrightarrow NH_4Cl + HBO_2 \quad (12)$$

One mole of ammonia is equivalent to 1 mole of ammonium borate, which is equivalent to 1 mole of HCl. Knowing the amount of 0.01 M HCl used for the titration, the amount of ammonia bound to borate can be calculated. From this amount, the quantity of nitrogen in the sample was calculated.

2.4.3 Determination of Sulphur Content

Three grams of a mixture of magnesium oxide and anhydrous sodium carbonate (2:1) was mixed up with a gram of the pulverized sample using the Eschka method. The heat was applied to the mixture up to 400 °C for the period of two hours in a muffle furnace and was later digested and cooled in water. The sulphate was precipitated as barium sulphate through the addition of Barium chloride. The precipitate was then filtered and the quantity of sulphur was determined (ASTM 1992).

$$\% \text{ Sulphur} = \frac{\text{Ppt } (BaSO_4) \text{ x } 0.1373 \text{ x } 100}{g} \quad (13)$$

2.5 Determination of Calorific value

The Calorific value was determined using the bomb calorimeter (model XRY-1A, make: Shanghai Changji, China). The combustion heat was computed as the gross energy using A.O.A.C (1975) method.

$$\text{Energy content} = \frac{E\Delta T - 2.3L - V}{g} \text{ (KJ/kg)} \quad (14)$$

2.6 Energy Recovery Potential of Awka MSW

The method presented by Ityona et al, (2012) was used for the evaluation of the potential energy from incineration technology.

Available energy = Total calorific value × Total tons = NCV × W (15)

Total available energy = Available e × efficiency = NCV × W × η (16)

Units produced = total available energy × conversion factor = NCV × W × η × 0.278 (17)

The conversion factor (0.278) is the constant for converting energy from Joules to KWh.

The model for calculating the amount of electricity that can be obtained by means of gasification as presented by Santiago et al., (2019) was used for the evaluation of the potential energy from gasification, thus:

$$ERP_G = 0.278\, x\, W\, x\, R_f\, x\, \eta\, x\, NCV \quad (18)$$

Where ERP_G = energy recovery potential in gasification,

W = total quantity of wastes, R_f = percentage of rejection after the mechanical treatment.

$$R_f = \frac{(W-p)}{W}\, x\, 100\% \quad (19)$$

Efficiency was assumed to be 23% of all energy produced for each electricity calculation. This was the average of the stated 18% to 27% efficiency range of the incineration plants by Catarina, (2014), as well as the recommended efficiency for a gasification plant by Santiago et al., (2019).

2. RESULTS AND DISCUSSIONS

3.1 Generation of Wastes in Awka

The result of the quantity of wastes generated in Awka in 2020, as recorded by ASWAMA, is displayed in Table 1. The table revealed the categories of the equipment used their capacities and the number of trips made to the dumpsite to deposit wastes.

Table 1: Quantity of waste generated at Ring-road dumpsite, Awka in 2020 (ton/yr)

S/N	Equipment	Waste Capacity (kg)	Total Number of Trips	Total Waste Quantity (kg)	Total Wastes Quantity (Ton)
1	Innoson Compactor	10,330	3585.75	37,040,797.5	37,040.6
2	Iveco Compactor	13,500	771	10,408,500	10,408.5
3	Benz Compactor	13,000	740.5	9,626,500	9,626.5
4	MAN Compactor	12,300	41	504,300	504.3
5	Innoson Chain up	1,476	1,855	2,737,980	2,738.0
6	911 Truck	8,000	433.5	3,468,000	3,468.0
	TOTAL			**63,786,077.5**	**63,785.9**

[Source: ASWAMA report]

The amount of Waste generated in Awka per inhabitant per year was estimated using the population of the city (2.5 million people) and the total quantity of wastes by ASWAMA (63,786,077.5 kg). Therefore, the amount/inhabitant/year was 25.51 kg per person which is equivalent to 0.071 kg per person per day.

3.2 Waste Composition of Awka MSW

The quantity of waste delivered by each ASWAMA equipment at the dumpsite on each of the selected days was sorted by the scavengers. The sorted waste categories showed that Awka municipal solid waste components include: Food and Organic Wastes, Plastic and Nylon, Textiles, Leather and Rubber, Wood, Paper, and Metals Glass.

The percentage summary of the MSW compositions is shown in Table 2.

Table 2: Summary of Percentage composition of Wastes [Source: Field study]

Day/Month	**Average Percentage Composition**							
	Food and Organic Wastes	**Plastic and Nylon**	**Textiles**	**Leather and Rubber**	**Wood**	**Paper**	**Metal**	**Glass**
15th Jan	47.9	11	5.1	2.8	10.7	13.2	7.3	0.9
22ndMar.	47.7	9.5	5.7	3.2	12	14	7	1
25th May	50.5	8.8	5.2	3	13.3	12.9	5.3	1.2
22nd July	48.3	10	5.8	3.4	11.7	13.6	6.4	0.9
23rd Sept	48.0	10.5	5.7	2.6	12.3	13.6	6.5	1
25th Nov	52.5	9.8	6.2	3	14.3	13.9	6.3	2.2
Total	294.9	59.6	34.0	18	74.3	81.2	38.8	7.2
Average	**49.2**	**10**	**5.6**	**3**	**12.4**	**13.5**	**6.5**	**1.2**

The result of the average percentage composition of MSW generated at the dumpsite, Awka in 2020 was shown in a pie-chart of Figure 1. The figure clearly showed that the more significant portion of the MSW deposited at Awka was food and organic wastes. This could be due to the standard of living of the people of the area and the level of industrialization or lack of proper/sufficient storage facilities. The study showed that insufficient storage facilities were mainly due to inadequate electrical power supply.

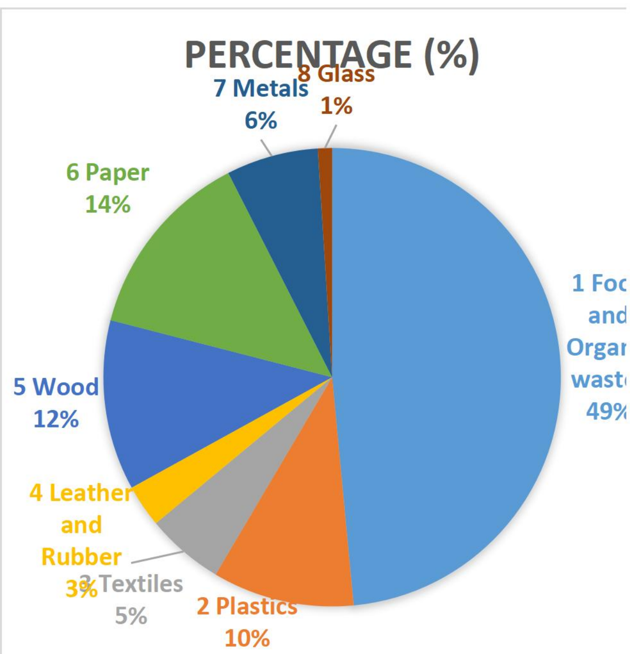

Fig 1: Percentage waste composition of Awka [source: Author].

The waste comprises of combustible (Food and organic matter, wood, paper, plastic, textiles) and non-combustible (Metal, glass) materials. The composition for combustible wastes totaled 92.5%, while the non-combustible waste composition was 7.5%. The combustible waste fraction had 77% biodegradable (Food and organic material, wood, paper) and 15.5% non-biodegradable (plastic, textile) waste. This implied that the waste of Awka could be recovering its energy by either thermo or non-thermo degradation technology. The recovery technology improves materials and energy from waste, and the energy would otherwise be disposed-off to the dumpsite. By recovering these wastes, the release of greenhouse gases to the atmosphere would be minimized.

3.3 Analyzing Awka MSW

The analysis of municipal solid waste was determination based on the Volatile Solids, Ash Content, Moisture Content, Fixed Carbon, Calorific Values. Samples of paper, Leather and rubber, wood, plastic and nylon, textile, food and organic materials collected after separation. The summary of values obtained is shown in table 3.

Table 3, Analysis of Awka MSW

Sample	**MC (%)**	**VS (%)**	**AC (%)**	**FC (%)**	**CV (MJ/Kg)**
MMSW	6.22	82.77	6.67	4.31	29.213
Paper	5.80	80.11	10.43	3.66	28.089
L & R	1.10	79.00	7.30	12.60	30.786
Wood	5.80	86.93	4.19	3.08	30.174
Plastic & Nylon	0.40	93.06	3.05	3.49	32.368
Textile	2.70	90.47	2.54	4.29	31.775
F & O	85.6	11.79	1.52	1.09	4.323
Average Value	**15.4**	**74.88**	**5.10**	**4.65**	**26.675**

3.5 Chemical Composition of Awka MSW

Table 4 shows a summary of chemical composition of municipal solid waste in Awka: Carbon Content of Awka MSW.

Table 4, Summary of chemical composition of MSW in Awka

Sample	Carbon content (%)	Nitrogen Content (%)	Sulphur Content (%)
Mixed MSW	51.41	3.66	0.37
Paper	42.29	0.77	0.08
Leather & Rubber	50.85	2.38	0.25
Wood	55.25	2.06	0.21
Plastic & Nylon	43.74	0.49	0.06
Textile	47.54	1.65	0.16
Food & Organic material	31.12		0.40
Average	**46.03**	**2.13**	**0.22**

The results show considerably satisfactory carbon content for all the samples analyzed, signifying their potential to contribute immensely to the samples' combustibility.

Low Nitrogen content was obtained throughout the sample, which is a positive result because it indicates a minimal release of Nitrogen oxides to the atmosphere.

The low sulphur content for all the analysed samples suggests an insignificant discharge of Sulphur oxides to the environment, thereby making it environmentally acceptable for the area.

3.6 Potential Energy Recovery from Awka MSW

The average value of energy released as shown in Table 3 showed that the value obtained was about 26.675 MJ/kg. This was the energy contained in MSW in dry basis. In this case, the energy of 1kg MSW is equivalent to energy of 1.15 kg of net MSW. This is because an average moisture content of 15.4% was taken out during bomb calorimetric experiment and the moisture of 0.15 kg required 1.0142 MJ/kg to dry MSW. This energy was obtained from 26.675MJ/kg, which was the average calorific value obtained from all MSW. The balance of 25.66 MJ/kg of the CV is the energy that one would recover per kg of dry MSW from the MSW energy conversion. For the case study, the total waste generated was about 63,786 tons of waste per year. This is equivalent to energy of 105 MWh, using (18-20), thus:

Equivalent Energy = Balance Energy (CV) × Total Waste Quantity (W) × η × Conv. Factor

= 104, 654 kWh

= **105 MWh**

4 CONCLUSIONS

An overview of the characteristics of MSW in Awka: physical properties, analysis, chemical composition and the calorific value was performed from which the following deductions were reached:

I. Awka generates a substantial quantity of MSW with thermally good quality composition which can be used to develop the energy system in the area.

II. The MSW sample with an elevated average volatile content of 74.88% can be kindled for combustion purposes.

III. The average calorific value of 26.675 MJ/kg obtained for the sample indicates that Awka MSW can produce the heat required for thermal/industrialized purposes.

IV. Awka MSW would not pose a threat to the environment due to the average low nitrogen (2.13%) and sulphur (0.22%) contents.

V. Awka MSW possesses potential of energy recovery through thermal technology.

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