Determination of Energy Content of the Municipal Solid Waste of Ado – Ekiti Metropolis, Southwest, Nigeria

ABSTRACT

Municipal Solid Waste (MSW) is a: material discarded as worthless to the city and this has been a serious threat to the eco-system. Thiscan be channeled into a very useful form to generate energy and thereby converting it to wealth. The waste samples were harvested, sorted, sundried, pulverized and sieved using a sieve size of 500μ.The moisture content of the constituents of the waste sample was determined. The digital bomb calorimeter (Cal – 2k Eco Calorimeter)was used to test the calorific value of the prepared waste samples. The results indicated that the polythene products waste has the specific energy content of 35,959 kJ/kg while the bones component of the waste sample has 6,994.39 kJ/kg. The mean specific energy content is 17.57MJ/kg. The total energy content of the MSW generated within the urban metropolis is 4,449,426.14MJ/day.This implies that when used per day for steam production 51.5MW of electricity could be generated in Ado-Ekiti.

Keywords: Municipal Solid Waste (MSW), Eco-system, Generate Energy, Wealth, Electricity

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1 INTRODUCTION

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In the early part of the 20th century, most refuse came from kitchen and consisted mainly of food scraps and local ashes. Only about fifteen percent of it is now composed of what most people think of as real garbage, which is likely to decompose and decay. Since World War (II)and at an accelerated rate convenience packaging has become the hallmark of rapid sanitary food preparation. Packaging has reduced the quantity of garbage and ashes as paper, metal, glass and plastics have become the new components [16].The nature of urban waste understandably varies with country, city, suburb and season and can be determined precisely only by analysis in each particular case [20].It also varies with time as living patterns alter. However, the personal income has been found to have the most significant effect onwaste generation. According to the world Bank data, per capita waste generation ranges between 0.4 and 0.6 kg/day for low income countries between 0.5 and 0.9 kg/day for middle income countries and between 0.7 and 1.8 kg/day for industrialized countries[16].Based on a comprehensive study encompassing nationwide survey and analysis of the solid waste sector in Nigeria, the above waste is also applicable to be observed in Nigeria cities. It is also observed that high income household generated higher quantities of waste than the lower income group [16].

In developing countries where waste management systems are insufficient, coupled with the expanding urban population [5] ;[8],the problem of refuse disposal is reaching proportions that are called for concern. Also, the operation and management of Municipal Solid Waste (MSW) Collection services are fairly rudimentary. South-Western part of the country (Nigeria) is being faced with the problem of lack of information about the quantities and types of MSW collected, the amount recovered or revived and the siting of MSW disposal sites [2].Added to this problem is the erratic power supply from the national grid. Wastes are important source of energy presently used in the generation of electricity and at the same time making the environment clean. The National energy supplies are at present almost entirely dependent on fossil fuels and firewood which are depleting fast [12].
[7]characterized the refuse in Kano and found out that 13 Megawatts of electricity could be produced from wastes in 1995 covering at least the entire Kano metropolitan area. The main problem facing policy makers in the waste management sector is how to predict the amount of solid waste, generated in the near future in order to devise the appropriate treatment or disposal mechanism[14]. [1],investigated the impact of waste scavengers - case study of Ilorin in Kwara State, Nigeria. [13],considered ten agricultural wastes in Nigeria to determine their energy content using the method of Association of Official Analytical Chemists.The results of their

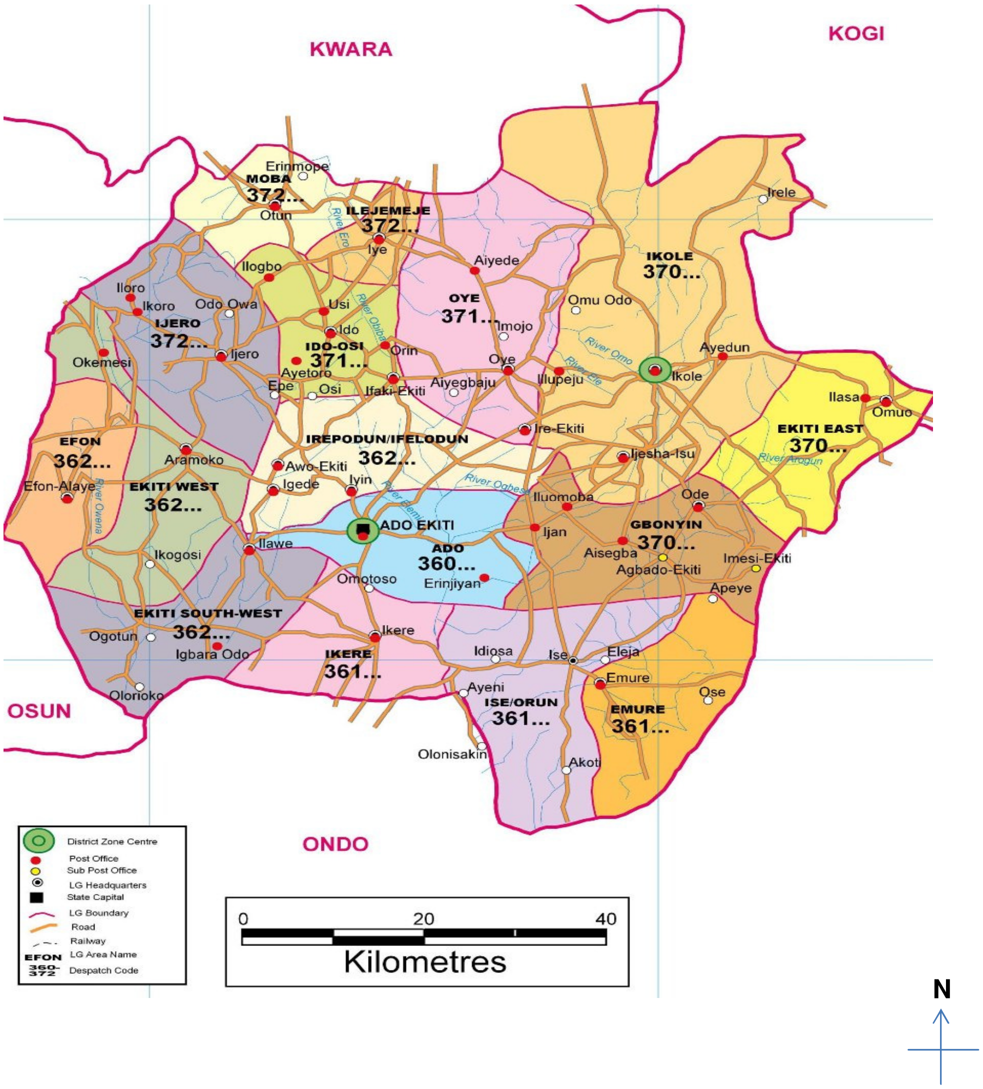
analysis revealed the mean Higher Heating Values in kJ/kg of the wastes samples and were presented in the Table 1.

1.1 The Development of Ado – EkitiLocal Government.

Ado – Ekiti local government was carved out of the defunct Ekiti Central Local Government by the Ibrahim Badamosi Babangida administration in May 1989. Ado – Ekitigovernment could be regarded as a one town local government with many farm settlements such as Igirigiri, Idege, Ilamuo, Ago- Aso, Emirin, Temidire, Esunmo, Ureje etc. Since the Lord Lugard reforms of 1916, Ado – Ekiti has been enjoying a unique political position as a linchpin of administration when it was Ekiti Divisional Council. It maintained this position until 1952 when Ado - Ekiti District Council was created and started operating in this capacity in 1955. In 1996 when Ekiti State was created, Ado-Ekiti was made the State Headquarters. Ado – Ekiti local government was confirmed as the most populous local government in Ekiti State going by the 2006 population census which put the population to 308,621. As at now the local government is presumed to have a population density of 4.3986 people per square kilometer and spreads over an area of $16km^2$ [10].

Geographically, the local government is located on latitude $7^{0}35^{1}$and $7^{0}47^{1}$North of the equator, longitude $5^{0}11^{1}$ and $5^{0}16^{1}$ east of the Greenwich meridian. The fig.1.1 shows that Ado-Ekiti is bounded on the North and West by IfelodunIrepodun Local Government and East and South by Gbonyin, Ikere and Ekiti Southwest local government. Its longest North-South extent is 16km and the longest East-West stretch is about 20km. Ado-Ekiti local government is a one town local government that doubles as local government and state headquarter which is about 200m above the sea level. The landscape is dotted with rounded inselbergs and steep sided hills of volcanic origin such as Ayoba hills central to the region are gently undulating slopes which form the source of streams like Amu, AwedeleAjilosun, Adere etc.[9]

Ado – Ekiti area lies within the tropical climate with two distinct seasons of wet and dry. The dry weather is brought by the tropical continental (CT) air-mass, blowing in from the Sahara desert between the months of November and March and the wet season comes either the tropical Maritime (MT) air-mass originating from the Atlantic Ocean between the month of April and October. The total rainfall in the area is 1452mm giving a mean monthly rainfall of 121mm. There is a sharp fall in rainfall at a period between July and August (August Break). Temperature in the region is high throughout the year with a mean temperature of 27^0C and a range of 3.7^0C between the month of highest temperature (February) and the month of lowest temperature (August) [10].



Source: Ekiti State Ministry of Urban and Regional Planning (2014)

Fig. 1.1: Map of Ekiti State, Nigeria Showing the Geographical Location of Ado-Ekiti.

Table 1 : The Calorific Value of Waste Samples in kJ/kg

Waste Samples	Energy Content (Mean Higher Heating Values) (kJ/kg)
Groundnut Shell	16,505
Yam Peels	19,597
Coconut Shell	20,647
Mango Peels	15,891
Palm Oil mill affluent	17,303
Corn Cob	19,458
Cherry	28,203
Orange Peels	19,299v
Melon Shell	21,392
Black Walnut Hull	21,143

Source :Jekayinfa and Omisakin, (2005)

All the waste samples considered have heat values greater than some well-known biomass-fuel and fall within the limit for the production of steam in the electricity generation. [17]investigated the effect of separate collection of municipal solid waste on the calorific value of the residual waste. He emphasized that, separate collection plays an irreplaceable role in solid waste management and incineration. Considering the average Italian Municipal Solid Waste Composition, he proposed separate collection scenarios different from those tested; the regression modeling was also proposed. He calibrated it and it was partiallytested. [15]investigated the municipal solid waste generated in Port Harcourt. They found it in large quantities but remains as litter in parts of the municipality. It has been known that in some parts of the country, the refuse were open – burned which often constitutes environmental hazards. Consequent of the heterogeneous nature of the MSW, it is very difficult if not impossible to make projections. The biogenic combustible of the municipal solid wasteundergo a biological decomposition until a stable material is formed and this is the consequence of the emanating odour from the dumpsite, sewers and landfill where organic materials are present [18].A comprehensive and holistic characterization of the Municipal Solid Waste is crucial to the long – term efficient and economic planning for solid waste management. In this research work, the energy content of the Municipal Solid Waste of the people living in Ado-Ekiti metropolis, Ekiti State, Nigeria was determined.

Table1.1: The Gravimetric Composition (kg/day) of the MSW in Ado-Ekiti, Ekiti State, 2014

S/N	Combustible Components	% Composition	Quantity MSW generated (kg/day)	Deviation (kg/day)
1	Bones	3.73	11,190	7,560
2	Food waste	9.76	29,280	10,530
3	Rubber and Leather	3.71	11,130	-7,620
4	Polythene Products waste	12.62	37,860	19,110
5	Paper and Cardboards	8.14	24,420	5,670
6	Textiles waste	4.36	13,080	-5,670
7	Leaves and Vegetables	8.39	25,170	6,420
8	Animal dungs and Excreta	5.83	17,490	-1,260
9	Wood waste	5.20	15,600	-3,150
10	Charcoal	1.35	4,050	-14,700
11	Fruit waste	12.53	37,590	18,840
12	Coconut and Palm kernel waste	1.13	3,390	-15,360
13	Tuberous peels waste	7.66	22,980	-4,230
14	Metal and Cans	3.90	11,700	-7,050
15	Glass and Ceramics	9.71	29,130	10,380
16	Miscellaneous/ Unclassified waste (dirt, sand, stones, egg shells and ashes)	1.98	5,940	-12,810
Total		**100**	**300,000**	

Source :Rominiyi, (2015)

Mean Gravimetric Composition of the Components of MSW = 18,750 kg/day

Standard Deviation = 10,109.97 kg/day

Table1.2:The Heating Value of Individual Components for Electronic Plastic Waste Resins

Resin	Heating value (HV) (kJ/kg)
PMMA	24053.83
ABS	35158.97
PA	26494.67
PC	26713.82
PC/ABS	29719.53
PE	34799.27
PC/PBT	23511.30
PBT	15723.35
PP	45358.28
HIPS	37758.68
PVC	14116.27
ABS/PVC	22364.59

Source: American Plastic Council, (2000)

1.2Electro-Plastic Waste

Study conducted by Daren et al, (1999) shown that 49% of the electronic waste materials consist of metal and about 33% consist of plastic. Basically, the unique electrical insulating properties of plastics are their strength, heat and corrosion resistance, flexibility, lightweight, durability and it is very cost-effective. These characteristics made plastics important materials for use in the electronics equipment (American Plastic Council, 2000).

Fig.1.2 is a huge amount of solid waste dumped at the King's Market in Ado-Ekiti Metropolis which creates an eyesore to the people with its characteristic foul odour that pollute the environment.

Fig. 1.2 :Refuse Dumped on the Road side at King's Market Ado-Ekiti, Ekiti State.

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1.3Energy Conversion Processes

Biomass wastes can be easily converted into other forms of energy at high temperatures, They break down to form smaller and less complex molecules both liquid and gaseous including some solid products. Combustion represents a complete oxidation to carbon dioxide (CO_2) and water (H_2O). By controlling the process using a combination of temperature, pressures and various catalysts and through limiting the oxygen supply, partial breakdown can be achieved to yield a variety of useful fuels. The main thermo-chemical conversion approaches are as follows: pyrolysis/charcoal production, gasificationand combustion. The advantages of thermo-chemical conversion processes include the following: rapid completion of reactions , large volume reduction of biomass, range of liquid, solid and gaseous products are produced and some processes do not require additional heat to complete the process.

1.1.2 Chemical Composition

The information on the chemical composition of solid wastes is important in evaluating alternative processing and recovery options. For example, consider the incineration process. Typically, MSW can be a combination of semi moist combustible and non-combustible materials. If solid wastes are to be used as fuel, the four most important properties to be known are:

(i) Proximate analysis

(ii) Fusing point of ash

(iii) Ultimate analysis

(iv) Heating value. [11]

1.4 Heating Value of Fuels

The heating of a fuel is the quantity of heat produced by its combustion at constant pressure under "normal" conditions ($25^0$and 1 atmosphere). The combustion process products generate water. The following are the various Heating Values :

i. The Higher Heating Values (HHV) consists of the combustion products of water condensed and that the heat of vapourization condensed in the water vapour is recovered . The water produced in the combustion is in the liquid state.

ii. The Lower Heating Value (LHV) assumes that water product of combustion at vapour state and that the heat of vapourization is not recovered.

iii. The Net Heating Value (NHV) is the same as Lower Heating Value and it is obtained by subtracting the latent heat of vapourization of water vapour formed by the combustion from the Gross Heating Value (GHV) or Higher Heating Value.

iv. The Gross Heating Value (GHV) is the total heat obtained by complete combustion at constant pressure including the heat releasing by condensing the water vapour in the combustion products. It account for liquid water in the fuel prior to the combustion of valuable fuels such as wood and coal . If a fuel has no water prior to the combustion then the gross heating value is equal to the higher heating value [6].

HHV $= LHV + \Delta Hvap \{MWH2O^{n}H2O^{out}/MW\ fuel\ nFuel.in\}$(1)

$\Delta Hvap =$ Heat of vapourization per mole of water (kJ/kg or Btu/lb)

H_2O .out = mole of water vapourized.

Nfuel = number of moles of fuel combusted and MW is the molecular weight

1.5Determination of Energy Content of Municipal Solid Waste

The energy content of the organic components in MSW can be determined by:

(i) Using a full scale boiler as a calorimeter.

(ii) Using a laboratory bomb calorimeter of any type.

(iii) Calculation if the elemental composition is known.

In this research work due to the difficulty in using a full scale boiler, most of the data on the energy content of the organic components of the municipal solid waste was based on the results of electronic bomb calorimeter tests.

2 METHODOLOGY

2.1 Sample Harvesting and Preparations

Waste samples were randomly collected throughout the city of Ado-Ekiti in the local dumpsites and dinobins located at some strategic locations in Ekiti state capital (Ado – Ekiti),The solid waste samples categorized into combustible components and non-combustible components were sun-dried, pulverized (the organic part of the constituents) and sieved with a mesh size of 500 micron.

2.1 Procedure to Determine the Percentage Moisture Content (MC) in theMunicipal Waste Samples

The mass of silica crucible was measured using the digital weighing balance and recorded w_1(g), the spatula was used to fetch 1.00g of pulverized solid waste samples inside the crucible. The content kept inside the silica crucible and the crucible was measured and recorded as w_2(g). It was then heated in a muffle furnace at a temperature of 105^0C for 1 hour. The crucible is taken out, cooled in a desiccator and weighed. The process of heating , cooling and weighing wasrepeated until a constant mass of the Municipal solid waste sample (anhydrous) was obtained w_3(g) .The equation 2 was used to determine the percentage moisture content of the combustible components of the municipal solid waste.

$$\%\ \text{MC in the solid waste} = \frac{w_2 - w_3}{w_2 - w_1} \times \frac{100}{1} \quad [11](2)$$

Where :$w_2 - w_3$ is the loss in mass of the solid waste sample.

$w_2 - w_1$ is the initial mass of the solid waste. The procedures to determine the moisture content of the combustible components of municipal solid waste were replicated three times and the percentage average values were presented in the Table 3.3

2.2 Evaluation of the Energy Content of the Municipal Solid Waste Using Bomb Calorimeter(The Cal 2k-Eco Calorimeter)

0.5g of already dried pulverized waste sample was measured. The pre-cut of firing cotton was looped over the firing wire. The weighed crucible and the sample in a crucible holder were inserted and it was ensured that the firing cotton touches the samples. The lid assembly was inserted into the vessel body and the cap-down was screwed until it touches the top of the lid. The vessel was placed onto the vessel holder under the filling station uprightly positioned and filled with oxygen to 3000kPa.The vessel was inserted into the measuring chamber and then closed the lid.

The temperature stabilization phase was carried out for the duration of 10 minutes and when the initial conditions are met at a voltage of 220V the vessel was **automatically** fired .The **calorific value** figure was calculated **automatically** every 6 seconds taking into account the calibration curve, calorific value corrections and sample mass. The duration of this phase is 10 minutes.The vessel and defiling cap are defilled to release the pressure inside the vessel. The vessel cap was unscrewed and the lid assembly was removed. It was also ensured that the vessel and the residue between each sample was cleaned with soft cloth and cooled in fresh air in the open. The procedure was repeated three times and the mean values obtained were presented under results and discussion..

3.0 RESULTS AND DISCUSSIONS

This study was designed toevaluate the energy content of the municipal solid waste in the city of Ado-Ekiti ,Ekiti State. The results of the moisture content and the energy content of the municipal solid waste were also presented.

Table 3.3 : Moisture Content Analysis of Municipal Solid Waste in Ado –Ekiti, Ekit State

S/N	Components	% Moisture Content	% Deviation Moisture Content
1	Bones	3.58	-0.41
2	Food waste	5.90	-1.68
3	Rubber and Leather	0.86	-5.82
4	Polythene products waste	0.82	--5.86
5	Paper and Cardboards	5.57	-1.11
6	Textiles waste	1.80	-4.88
7	Leaves and Vegetables	12.79	6.11
8	Animals' dungs and Excreta	11.33	4.65
9	Wood waste	9.40	2.72
10	Charcoal	6.73	0.05
11	Fruit waste	9.55	2.87
12	Coconut and palm kernel waste	8.91	2.23
13	Tuberous peels waste	9.55	2.87

Mean Moisture Content = 6.68%

Standard Deviation of the Moisture Content = 3.92%

Table; 3.4 The Experimental Higher Heating Values (HHV) (kJ/kg) of the Combustible components of MSW in Ado – Ekiti, Ekiti State.

S/N	Components	Experimental HHV (kJ/kg)	Deviation HHV (kJ/kg)
1	Bones	6,994.39	-9,417.95
2	Food waste	14,176.14	-2,236.20
3	Rubber and Leather	20,946.52	4,534.18
4	Polythene products waste	35,959.00	19,546.66
5	Paper and Cardboards	11,210.00	-5,202.34
6	Textiles waste	17,800.48	1,388.14
7	Leaves and vegetables	14,069.37	-2,342.97
8	Animals' dungs and Excreta	13,848.16	-2,564.18
9	Wood waste	16,795.96	383.62
10	Charcoal	18,711.70	2,299.36
11	Fruit waste	14,328.96	-2,083.38
12	Coconut and palm kernel waste	13,944.80	-2,467.54
13	Tuberous peels waste	14,574.95	-1,837.39

Mean HHV= 16,412.34 kJ/kg

Standard Deviation = 6,783.09 kJ/kg

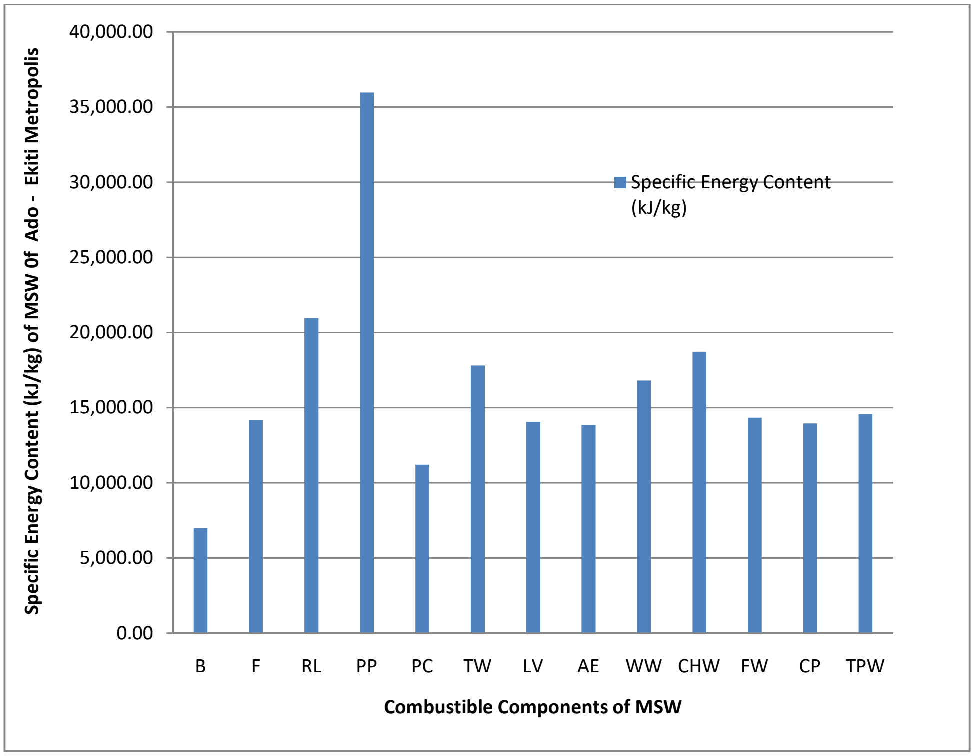

Fig.3.3: Bar Chart of Specific Energy Content of Components of the Municipal Solid Waste (MSW) in Ado- Ekiti, Ekiti State.

It can be easily deduced directly from both table 3.4and fig.3.3 that the polythene products waste have the highest calorific value of 35,959.00 kJ/kg , next to this is rubber and leather of 20,946.52 kJ/kg. Also, charcoal waste have heating value of 18,711.70 kJ/kg and textiles waste have a heating value of 17,800.48 kJ/kg .The wood waste is of specific energy content of 16,795.96 kJ/kg. Tuberous peels waste generated in Ado-Ekiti, is of 14,574.95 kJ/kg. The fruit waste and food waste were of 14,328.96 kJ/kg and 14,176.14 kJ/kg respectively. Leaves and vegetables waste have the specific energy content of 14,069.37 kJ/kg. Also, the other two components of the waste samples found during sorting of the municipal solid waste were Coconut and palm kernel waste ,Animal dungs and Excreta of 13,944.80 kJ/kg and 13,848.16 kJ/kg respectively. The least specific energy content of 6,994.39 kJ/kg was found in bones waste generated in Ado-Ekiti, Ekiti State. The average quantity in Tonnes of the waste generated in Ado-Ekiti is 300 Tonnes/day [9].

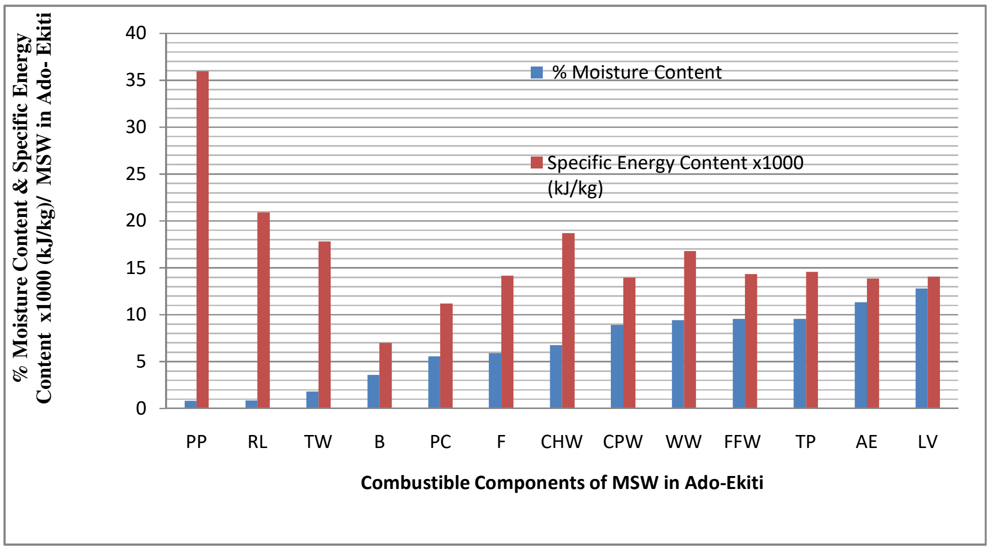

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Fig.3.4 : Variation of % Moisture Content with Specific Energy Content(kJ/kg) of Combustible Components of MSW in Ado -Ekiti ,Ekiti State

It can be inferred from the result of moisture content determination in the fig.3.2 that the lower the moisture content of the municipal solid waste above , the higher the specific energy content. Polytheneproducts waste have the least moisture content of 0.82% hence the higher calorific value of 35,959.00kJ/kg, rubber and leather has a moisture content of 0.86% with the corresponding specific energy content of 20,946.52kJ/kg. The leaves and vegetable waste have the moisture content of 12.79%and specific energy content of 14,069.37kJ/kg.

Table 3.5: The Combustible Components of Municipal Solid Waste Generated (kg/day) and the Energy Content (kJ/day)

S/N	Combustible Components	% Composition	Quantity MSW generated (kg/day)	Specific Energy Content (kJ/kg)	Energy Content (kJ/day)	Electricity Generation Potential (MW)
1	Bones	3.73	11,190	6,994.39	78,267,224.10	0.91
2	Food waste	9.76	29,280	14,176.14	415,077,379.20	4.80
3	Rubber and Leather	3.71	11,130	20,946.52	233,134,767.60	2.70
4	Polythene Products waste	**12.62**	**37,860**	**35,959.00**	**1,361,407,740**	**15.76**
5	Paper and Cardboards	8.14	24,420	11,210.00	273,748,200.00	3.17
6	Textiles waste	4.36	13,080	17,800.48	232,830,278.40	2.69
7	Leaves and Vegetables	8.39	25,170	14,069.37	354,126,042.90	4.10
8	Animal dungs and Excreta	5.83	17,490	13,848.16	242,204,318.40	2.80
9	Wood waste	5.20	15,600	16,795.96	262,016,976. 00	3.03
10	Charcoal	1.35	4,050	18,711.70	75,782,385. 00	0.88
11	Fruit waste	12.53	37,590	14,328.96	538,625,606.40	6.23
12	Coconut and Palm kernel waste	1.13	3,390	13,944.80	47,272,872. 00	0.55
13	Tuberous peels waste	7.66	22,980	14,574.95	334,932,351 .00	3.88
Total		**84.41**	**253,230**	**213,360.43**	**4,449,426,141.00**	**51.5**

Total Energy Content(MJ/day)

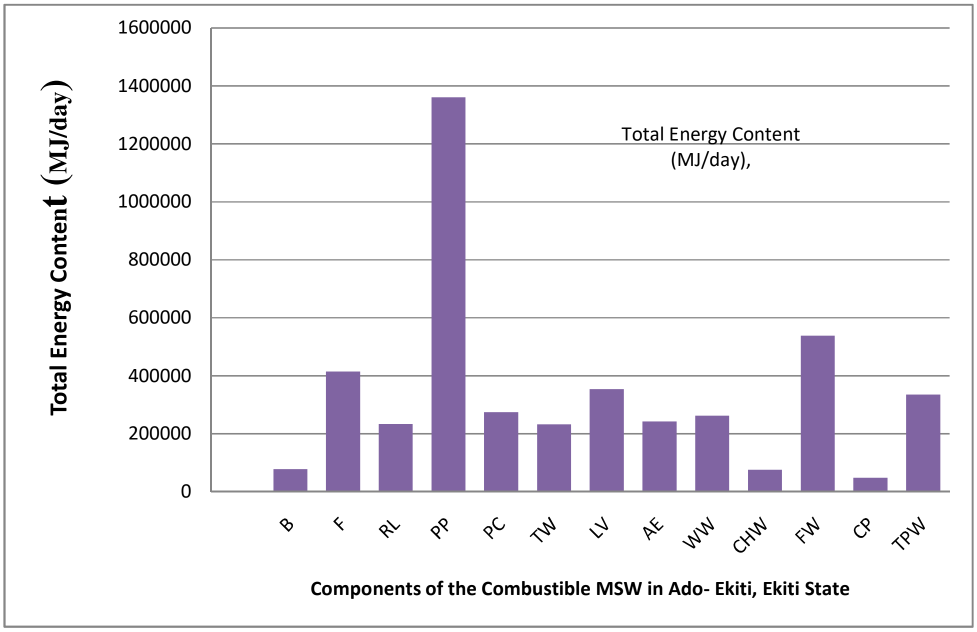

Fig. 3.5: Total Energy Content of the Municipal Solid Waste (MSW) Components in Components of the Combustible MSW in Ado- Ekiti, Ekiti State

$$\overline{E} = \frac{\sum q_i h_i}{\sum C} \qquad (3)$$

Where : $\overline{E}$ is the Mean Energy Content of the Combustible Components of MSW

q_i is the Quantity of each combustible components of MSW in (kg/day)

h_i is the Specific Energy Content (kJ/kg) of the Combustible Components of MSW

C is the Quantity of Biogenic and Non Biogenic Combustible MSW generated per day (kg/day)

$$\overline{E} = \frac{4,449,426.141}{253,230} \text{ (MJ/day)}$$

$\overline{E}$ = 17.57 MJ/day

$$\text{Electricity Generation Potential} = \frac{H}{24 \times 3600 \times 1000}(MW) \qquad (4)$$

Where H is the Total Energy Content (kJ/day) of the Combustible Components of Municipal Solid Waste (MSW).

$$\text{Electricity Generation Potential} = \frac{4{,}449{,}426{,}141.00}{24 \times 3600 \times 1000}(MW)$$

Electricity Generation Potential = 51.50 MW.

When the municipal solid waste stream in Ado-Ekiti is completely burnt per day to produce steam51.50 MW of electricity can be generated

4.0 CONCLUSION

1. The values of the energy content obtained indicated that, there is prospect in the huge potential energy that exist in the MSW and this when combined with appropriate energy recovery technology will make the thermal treatment plants to become net producers of renewable energy to address the problems of acute shortage of the conventional non-renewable energy crisis currently being witnessed in the country and also resource recovery is possible to a great economic advantage.
2. Polythene products waste has the highest calorific value hence a high potential to produce steam to generate electricity.

4.1 RECOMMENDATION

Polythene products waste which has the highest calorific value is a potential source of generating electricity which can woo the investors to the state due to cheap and reliable source of electrical supply to power their machines which can go in a long way to fast-track the industrial development in the young state capital and its environs.

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