Determination of Calorific Value of Some Selected Waste Materials in Rivers State of Nigeria

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ABSTRACT

Energy generation has been a major challenge in developing countries due to increasing demand on the fuel source which calls for alternative resources. This study presents a systematic approach in utilizing some waste materials and bomb calorimeter to determine the calorific value of the waste materials. The percentage of moisture content, the change in temperature, the volume of trioxocarbonate (iv) acid used and the calorific value of the waste were studied. The process of determining temperature change, carbonic acid and the heat of combustion were carried out using bomb calorimeter in the National Centre for Energy Research and Development (NCERD) Laboratory, University of Nigeria Nsukka. The direct measurements of the initial and final temperature requirement of each specific waste were recorded with the volume of the carbonic acid produced. The calorific value of the waste obtained from this study were 17611.62kJ/kg, 14140.38 kJ/kg, 10555.92 kJ/kg, 11754.62 kJ/kg, 11309.33 kJ/kg and 15015.50 kJ/kg for oil palm fibre, sachet water bag, elephant grass, waste paper, sawdust (soft wood), and sawdust (hard wood) respectively. The results obtained from the analysis indicate that oil palm fibre has the highest calorific value followed by saw dust (hard wood), sachet water bag, waste paper, saw dust (soft wood) and elephant grass respectively. In view of the above result, the heat of combustion or calorific value of this waste is sufficient to be used as fuel for domestic and for medium size industrial plants as a renewable energy source with slight moderation.
Keywords: *Bomb calorimeter, Briquetting, Calorific value, Energy, Incineration, Solid waste.*

INTRODUCTION

Waste generated throughout the world poses crucial question of how to effectively and efficiently manage it in the phase of prevailing health challenges, non-degradable nature of plastic, global warming among others. As industrial development increases worldwide, environmental protection, material recycling and generation of energy from waste are contemporary for sustainability. As a result, renewable energy resources from briquetting technology are used worldwide. Waste-based fuels are utilized in

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many countries in the form of briquette (Islam R. F., Islam R. M. and Beg, 2008) briquettes are produced not only from biomass, but also from different type of wastes like milled paper, plastic and other combustible wastes (Yaman, Sahan, Haykiri-acma and Kucukbayrek, 2000). Preconditioning of the waste materials before briquetting is necessary, for instance, the processing of municipal waste by disintegrator milling for size reduction enables better properties of the product to be obtained by drying, mixing before briquetting. Mixing of milled plastic waste with biological materials (wood sawdust, paper and so on) of low moisture content leads to better briquette pressing as well as to greater calorific value (Krizan, 2009). Briquetting is the process of compressing coal dust into fuel. It is the most widely accepted technology for waste material compacting. The technology uses mechanical and chemical properties of materials to compress waste into compact shape without usage of additives or binders in the high pressure and temperature compacting process of the biomass such as sawdust, paper and so on and compounded plastic waste (Krizan, 2009). With the fast depletion of conventional resources and the growing awareness and concern regarding the environmental effects of their utilization, there should be a plan to identify and develop alternate energy sources in developing countries like Nigeria. This study is aimed at determining the calorific value of some waste materials in Rivers State, Nigeria. The specific objectives include:

i To facilitate greater energy recovery from waste using briquetting process.

ii To reduce the emission of green house gases from consolidated fossil fuel by the use of biomass in the waste.

iii To determine the value of the energy to improve marketability.

Briquette: This is a block of compressed coal dust sawdust and wood chips used for fuel. Briquetting involves turning waste into a source of energy using thermodynamics principle (Singh, Bhoi and Patel, 2007). Thermodynamic relates heat and work and the conversion of one into the other. Chemical energy in green plant which is derived from solar energy during photosynthesis is converted into thermal energy during combustion. This principle obeyed the first law of thermodynamics which is the law of conservation of energy. Mathematically, change in internal energy of a system is equal to the heat flow into the system plus the work done on the system (Salzaman, 2001). This implies that:

$$\Delta U = Q + W \qquad \text{.................................1}$$

where

U = change in internal energy,

Q = heat flow,

W = work done

If no work is done, $\Delta U = Q$ (constant volume) 2

Combustion is the reaction between combustible material and an oxidizer to form an oxidized product with the release of heat energy.

$$CH_{4(g)} + 20_{2(g)} \rightarrow C0_{2(g)} + 2H_2 0_{(g)} + Heat$$

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Solid Waste Generation and Management: Waste generation encompasses activities in which materials are identified as no longer being of value (in their present form) and are either thrown away or gathered together for disposal. Waste generation at present is not controllable, however, reduction at source is included in a systemic method of limiting the quantity of waste generation (Tchnobanoglous, 2002). Solid waste management is associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid waste in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations (Tchobanoglous, 2002). In its scope, it includes all administrative, financial, legal, planning and engineering functions involved in the whole spectrum of solutions to problem of solid wastes thrust upon the community by its inhabitants. It involves the principle of integrated solid waste management (ISWM) which involves the application of suitable techniques, technologies and management programmes covering all types of solid waste from all sources to achieve the twin objectives of waste reduction and effective management with the aim of militating against potential hazards to the environment and human life.

Waste Processing and Energy Recovery Processes: Recent studies of solid waste processing have been with the intent of producing clean renewable energy where waste becomes energy for electricity. Thermochemical conversion through incineration of briquette as a processing technique is discussed below:

Thermochemical Conversion: Incineration is one of the most effective means of dealing with many wastes, which reduces their harmful potential, and often to convert them into energy form (Tchobanoglous, 2002). Incineration is the process of burning waste in the presence of excess air at the temperatures of about 800^{o}C and above. In practice about 65-80% of the energy content of the organic matter can be recovered as heat energy which can be utilized either for thermal application or for producing power (Srinivas, 2003). Incineration reduces the amount of waste by 95-96 percent depending upon composition, other thermochemical conversion methods include: Gasification and Pyrolysis. Other conversion method include biochemical conversion, a process where enzymatic decomposition of organic matter by microbial action produces biomass energy (methane gas or alcohol).

Table 1: Desirable range of important waste parameters for technical viability of energy recovering

Waste treatment method	Basic principle	Important waste parameters	Desirable range
Thermo-chemical		Moisture content	< 45%
Conversion	Decomposition	Organic/volatile matter	> 40%
* Incineration	of organic	Filed carbon	< 15 %
* Pyrolysis	Matter by	Total inert	< 35 %
* Gasification	Action of heat	Calorific value (Net CV)	> 1200 k-cal/kg

After: (The Expert Committee, 2000)

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Calorific value is the amount of heat generated from combustion of a unit weight of a substance, expressed as kcal/kg. The calorific value is determined experimentally using bomb calorimeter in which the heat generated at a constant temperature of 25^{o}C from the combustion of a dry sample is measured. Since the test temperature is below the boiling point of water, the combustion water remains in the liquid state. However, during combustion, gases remains above 100^{o}C so that the water resulting from combustion is in the vapour state shows typical values of the residue and calorific value for the component of solid waste while evaluating incineration as a means of disposal or energy generation. The calorific value (CV) of the waste depends on the composition of the waste. Waste with a lot of polyvinyl chloride (PVC) has a higher calorific value than waste with less PVC and more paper.

MATERIALS AND METHOD

Rivers State is in the South-South Nigeria with twenty-three Local Government Areas. The collection points of the selected wastes are located within the two local government areas of Rivers State (Ikwerre and Obio/Akpor) as shown in figure 1.

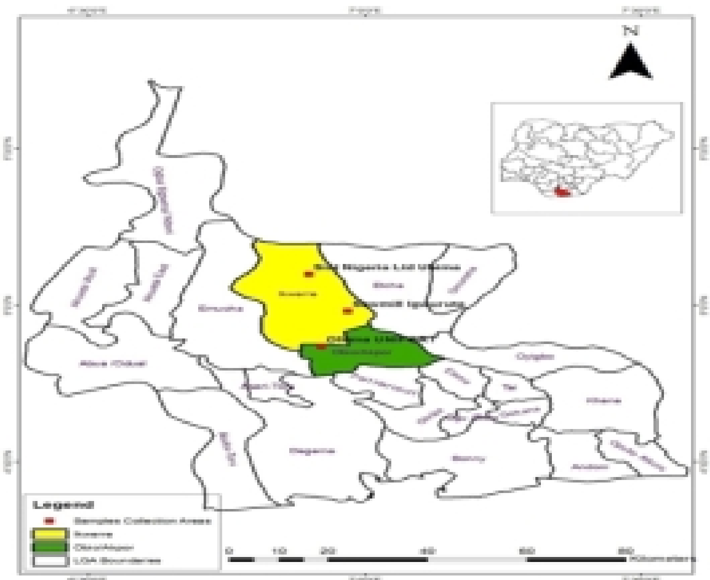

Figure 1: Map showing Rivers State, Nigeria and sample collection areas

The materials and methods include the laboratory apparatus, waste samples; and the experimental procedures employed. Bomb calorimeter (model XRY-1A) is a type of constant-volume calorimeter used in measuring the heat of combustion of a particular reaction. This bomb calorimeter has a capacity of weighing mass of sample 0.900g to 1.200g. Electronic weighing balance (model: scout pro spu 401) was used in measuring the weight of samples, it has a maximum weighing capacity of 400g. Materials used are Combustible wire (Nickel fuse wire), Methyl orange indicator, Distilled water among other waste samples used; Oil palm fibre, Sachet water bag, Elephant grass, Waste paper, and Saw dust from wood. The process of determining

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the calorific values of waste include: Preparation of samples (shredding and drying) and the determination of the calorific value of the waste. Samples were pre-treated by removing foreign and undesired material; all samples with the exception of sawdust were initially shredded with scissors before they were oven dried to reduce the moisture content. In this process, (Determination of Calorific Value) known dried weight of waste sample ranging from 0.900g to 1.200g were fed into stainless steel bomb cup with a spatula. A 10cm length of a combustible wire was measured and connected to the positive and negative terminals of the bomb passing through the sample. Also, 10ml of distilled water was added to the bomb chamber to saturate the internal atmosphere. The bomb was then closed and about 25atm of pure oxygen were injected into the bomb. The whole bomb was immediately immersed in a bomb calorimeter (model XRY-1A adiabatic) before electrically igniting the samples.

Energy is released by the combustion process and heat flows from these crosses, the stainless steel walls thus raises the temperature of the steel bomb, its content and surrounding water jacket. The initial and final temperature was accurately recorded. The length of unburned wire after thorough rinsing of the wire was measured. The acid was then titrated against 25cm^3 of sodium trioxocarbonate(iv)acid (Na_2CO_3). The colour change indicates the end point or the volume of acid used. The carbonic acid (trioxocarbonate(iv) acid H_2CO_3) produced is a function of the calorific value of the combusted waste materials. The volumes of acid used is shown on table 3. The samples were shredded, dried, weighed and burning in a bomb calorimeter at the National Centre for Energy Research and Development (NCERD) Laboratory, University of Nigeria Nsukka. In the laboratory, bomb calorimeter is used to determine the calorific value; theoretically it is calculated using the equation;

$$W = \frac{\sum \Delta T - \Phi - V}{M}$$

....4

where:

W	=	energy value (calorific value),
ÄT	=	change in temperature,
Φ	=	constant (heat of combustion of wire) = 2.30 J/g,
V	=	Volume of acid used,
M	=	Mass of sample,
∑	=	standard energy value of the bomb,
Calorimeter	=	13039.308 J.

RESULTS AND DISCUSSION

Table 2 and 3 show the results of the moisture content for the six different solid waste samples, the acid/base titrations and calorific value of the waste using bomb calorimeter respectively. Also, figure 2 shows the bar charts of moisture content, volume of acid used, change in temperature and calorific value of waste. The moisture content determination processes are shown on table 2. Results of the combustion process to determine calorific value of waste samples are shown on table 3.

Moisture Content: Wastes with different moisture contents have different drying characteristics. Those with high moisture content require a longer drying time and more heat energy. The result of the analysis as shown on table 2 and figure 2 indicates the moisture content of the waste ranging from 20.61% (Soft wood Sawdust) to 31.10 % (Oil palm fiber), respectively. The high or low percentage of the waste moisture content is attributed to the nature of material, or exposure to wet or dry environment. Also, the volume of carbonic acid used range from 2.50cm^3 (sachet water bag) to 6.50cm^3 (oil palm fiber) respectively. It is a function of the calorific value and carbon composition of the waste samples (Demirbas, 2001). The volume of acid used are as shown on table 3 and figure 2.

Calorific value of the waste: Table 4 and figure 2 show the calorific value of the waste obtained from this analysis as 17611.62kJ/kg, 14140.38 kJ/kg, 10555.92 kJ/kg, 11754.62 kJ/kg, 11309.33 kJ/kg and 15015.33 kJ/kg for oil palm fiber, sachet water bag, elephant grass, waste paper, saw dust (softwood) and sawdust (hard wood) respectively. The highest value of 17611.62kJ/kg obtained from oil palm fiber agrees with Syamsiro, Saptoadi and Tambunan (2011), the wax (oily) components in the oil palm fiber sample is the reason for the increase in the burning rate and high calorific value.

Calorific value of a material is a function of carbonic acid, the presence and amount of carbon in the waste contributes to the high or low calorific value of the waste. These is typified in the decreasing value range obtained from sawdust (hard wood), sachet water bag, waste paper, sawdust (soft wood), and elephant grass respectively. This agreed with Klanja, Kopitovic and Lovi (2002) findings, which observed that the calorific value of different woods differs due to their difference in hardness, harder woods retains more energy than soft wood. According to Zerb (2004), hard wood generally contains more energy than soft wood on a dry weight basis due to higher lignin content and the presence of more resins in the extraction. The calorific value of the waste depends on the composition of the waste, as waste with a lot of polyvinyl chloride (PVC) (Sachet water bag) has higher calorific value than waste with less PVC and more paper (Demirbas, 2001).

Table 2: Moisture content determination

Samples	Weight of wet sample $(W_{ws})_g$	Weight of dry sample $(W_{ds})_g$	Weight of water $(W_{wt})_g$	Moisture content (MC)%
Oil palm fibre	1.450	1.106	0.3440	31.1031
Sachet water bag	1.100	0.912	0.1880	20.6140
Elephant grass	1.020	0.900	0.1200	13.3333
Waste paper	1.000	0.918	0.0820	8.9325
Sawdust (softwood)	1.200	0.918	0.2820	30.7189
Sawdust (hardwood)	1.200	0.925	0.2750	29.7297

Source: Experimentation, 2013

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Table 3: Calorific value of the waste using bomb calorimeter

Samples	Weight of Sample (g)	Change in temp.	Length of burnt wire (cm)	Volume of Acid (cm^3)	Heat of combustion of wire (J/g)	Energy of machine $(\Sigma)(J)$	Calorific value (CV) (kJ/kg)
Oil palm fibre	1.106	1.496	9.50	6.50	2.30	13039.308	17611.62
Sachet water bag	0.912	0.991	9.00	5.00	2.30	13039.308	14140.38
Elephant grass	0.900	0.730	6.90	2.50	2.30	13039.308	10555.92
Waste paper	0.918	0.829	6.80	3.20	2.30	13039.308	11754.62
Saw dust (soft wood)	0.918	0.798	9.00	2.70	2.30	13039.308	11309.33
Saw dust (hard wood)	0.925	1.067	8.00	5.20	2.30	13039.308	15015.50

Source: Experimentation, 2013

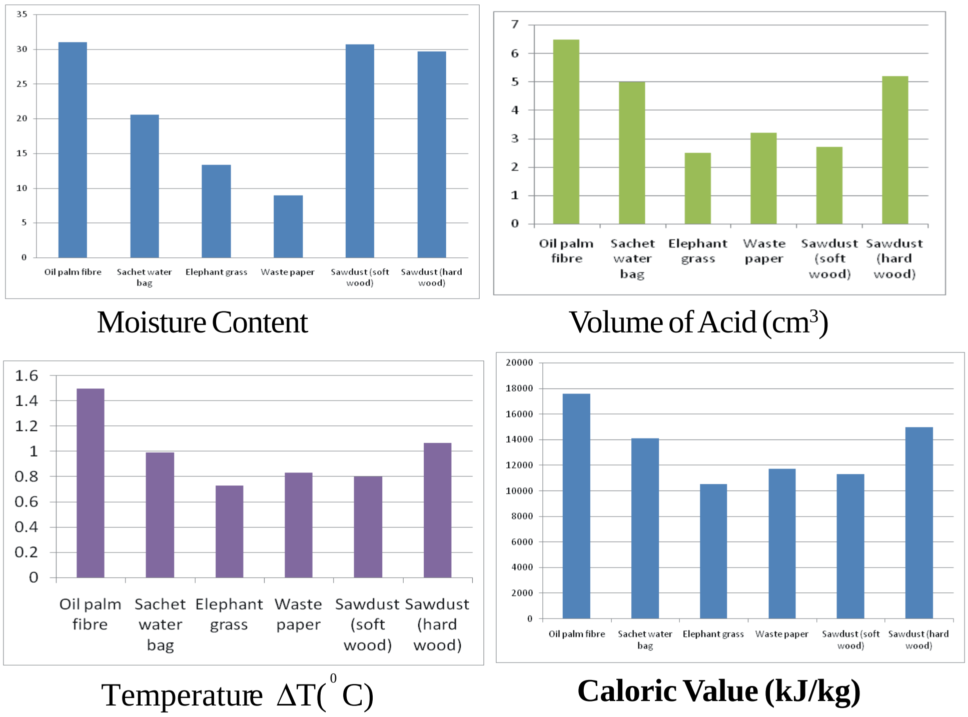

Figure 2: Graphic representation of moisture content, volume of acid, temperature change and caloric value

CONCLUDING REMARKS

Incineration is one of the most effective means of managing municipal wastes, reducing their harmful potential, while converting them into energy with 65-80% of the energy content recovered as heat energy and measured as calorific value. The amount of waste is reduced by 95-96% depending on composition. In view of the result of the above analysis, dry bio-waste and high polyvinyl chloride (PVC) containing materials have high calorific value which determines the trading factor of the derived fuel energy. These wastes are observed to be the major component of municipal waste thus, the availability of raw materials for renewable energy generation. With increasing environmental consciousness and the reality of global warming, the need for alternative source of renewable green energy is inevitable thus the need for increased research in

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calorific value of waste materials and the need for more research funding to enhancing the commercial potential of this method as a veritable means of energy in place of depleting fossil fuel reserves. In the future, these wastes could be briquetted for gasification in power stations.

REFERENCES

Demirbas, A. (2001). Biomass resources facilities and biomass conversion processing for fuels and chemicals. *Energy covers Management,* 42, 1357-1378.

EIA (2008). Energy Information Administration. *http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/rentrends.html.*

History of Rivers State of Nigeria. Available online at *www.riversstatenigeria.net.*

IARC (2012). Biological agents. IARC Monogr Eval Carcinog Risks Hum, 100B: PMID: 18335640.

Islam R. F., Islam R. M. and **Beg R. A.** (2008). Renewable energy resources and technologies practice in Bangladesh. Renewable and sustainable energy.

Klanja B., Kopitovic S. and **Lovi S.** (2002). Wood and bark of some poplar and willow clones as fuel wood. *Biomass and Bioenergy,* 23, 427-432.

Krizan, P. (2009). Wood waste compacting process and conception of presses construction. Thesis, FME STU, Bratislava.

NRCS (2006). National Resources Conservation Service. Switchgrass burned for power. Washington, DC: U.S. Department of Agriculture. *http://www.ia.nrcs.usde.ogv/news/newsreleases/2006/switchgrass.html.*

Nimz H. H., Schmitt U. and **Schwab E.** (2002). Wood In: Ulmann's encyclopedia of industrial chemistry (7th ed.). John Wiley and Sons. Inc. pp. 59.

Paist A., Kask U., Vrager A., Muiste P., Padari A. and **Parn L.** (2005). Potential of biomass fuel to substitute for oil shale in energy balance in Estonian energy sector. *Oil shale,* 22, 369-380.

Salzaman W. R. (2001). Chemical thermodynamics, University of Arizona, Retrieved 11-10-2007.

Singh R.N., Bhoi P. R. and **Patel S. R.** (2007). Modification of commercial briquetting machine to produce 35mm diameter briquettes suitable for gasification and combustion. *Renewable energy,* 32, 474-479.

Srinivas, S.V. (2003). Energy from municipal and industrial wastes. Department of Chemical Engineering, Indian Institute of Madras, Chennai.

Sudhir, J. K. (2010). Energy from waste. *International Journal of Environmental Sciences,* 1, 2

Syamsiro M., Saptoadi H. and **Tambunan B. H.** (2011). Experimental Investigation on Combustion of Bio-Pellets from Indonesian Cocoa pod. Husk. *Asian Journal of Applied Science,* 4:712-719.

Technobanoglous G. K. (2002). Handbook of solid waste management (2nd edition). New York: McGraw-Hill Handbooks.

The Expert Committee (2000). Manual on Municipal solid waste management, the ministry of urban development, the government of India, volume 1 and 2.

World Health Organization (2002). Available online at *http:/www.who.int/Countries/ind/en* Accessed on 5th July, 2005.

Yaman S., Sahan M., Haykiri-acma Seven K. and **Kucukbayrek S.** (2000). Production of fuel briqettes from Olive Refuse and Paper Mill Waste. *Fuel Process Technology,* 68, 23-31.

Zerb, J. J. (2004). Energy from wood. Encyclopedia of Forest Science. New York: Elsevier Press.

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