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Calorific Value of Wastes and Their Constituents in an Institution in South West Nigeria and Development of a Waste to Energy Model

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Abstract

Environmental degradation due to pollution by solid wastes and the erratic power supply characterizing many urban areas in developing countries are the driving force of this study. The study explored possible energy bonus availability in various solid wastes based on their calorific values. Eight categories of solid waste, either heterogeneous or homogeneous in composition, were identified from University of Ibadan, an institution in South West Nigeria, with a population of over 30,000. These wastes were collected through purposive sampling and the moisture content and calorific values of the samples were determined using standard methods. Results of the study indicate that construction waste is the most beneficial heterogeneous waste with 18.58 MJ/Kg; the wooden component of the waste showed 15.73 MJ/Kg. Animal wastes, cassava peels from small scale community-based cassava processing mill and plant waste from lawns and gardens showed substantial energy, 18.12 MJ/Kg, 14.36 MJ/Kg and 14.19 MJ/Kg respectively. From heterogeneous municipal wastes, low density plastics or nylons, wood and paper showed calorific values of 25.20 MJ/Kg, 15.73 MJ/Kg and 13.14 MJ/Kg respectively. Plastics showed 10.91 MJ/Kg whereas concrete, metals and non-combustible materials showed no calorific value. Recommendations proffered by the study include a need to educate communities on the importance of waste separation before disposing and the adoption of waste-to-energy strategies as a sustainable source of energy bonus in institutions and a replicable model with example from a University community is proposed.

Keywords

Solid Waste, Calorific Value, Energy Bonus, Waste-to-Energy Model, Municipal Waste, Construction Waste

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1. Introduction

1.1. Background of Study

The environment is an integral part of human existence. Over time, man has interacted with and influenced his immediate environment, and both share a symbiotic relationship that has been studied under various conditions and thematic disciplines. While the natural environment provides basic amenities and a vast supply of natural resources for man, man in return is supposed to care for and protect the environment from degradation [1].

Furthermore, environmental degradation has been a major source of concern, most especially in developing countries such as China, India and Nigeria. Pollution undoubtedly is one of the main contributors to this phenomenon. Bulte and Soest [2] suggested that production and consumption patterns of households are the main causes of environmental damage

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leading to pollution in developing countries, irrespective of urban or rural areas. In Nigeria, solid waste has contributed greatly to land and water pollution. In Ibadan region the environmental degradation is more pronounced as it is the third most populous city in Nigeria and one of the foremost cities in Africa.

Okeniyi et al. [3] reported that Nigeria generates a meager 4000MW of energy mostly from hydroelectric power projects which is not adequate even for urban needs as the growing Nigerian cities suffer from unending erratic power supply. This trend in turn has played a significant role in low development and declining economic activities [4]. Nigeria therefore needs to look for sustainable alternative sources of energy. In recent years, many Nigerian States are embracing the idea of 'Waste to Energy' approach as a strategy to overcome the energy deficit. While Lagos State has made some strides, many others are still at an infant stage due to lack of data on the waste quantity, composition and derivable energy. Hence, this study attempts to collect baseline data on moisture content and calorific values of solid waste generated in an institution with a view of proffering solution to waste management and also augmenting energy demand through an institutional approach as a model.

The study will also aid in creating more awareness on the importance of proper waste segregation and disposal as well as educating the public on the most useful components or resources untapped from solid wastes which are thrown away carelessly.

1.2. Energy Demand and Reclaimable Energy in Solid Waste

Power generation has been a constant challenge in several tropical countries due to lack of sustainability in the sources of energy being harnessed, the methods used for power generation and supply as well as poor maintenance of facilities utilized for power generation. Waste-to-Energy (WtE), as an alternative means of energy generation can be effectively exploited in institutions of developing countries because of the stable nature of wastes available with low toxic and hazardous components. Mehrzad et al. [5] in Okeniyi et al. [3] states that the provision of sufficient amount of energy is a global challenge faced both by developed and developing countries. Developing countries in particular have borne the heavy detrimental effects of poor power generation and supply as this has led to a disruption in economic activities and an overall decline in the standard of living [6, 3].

For example, in Nigeria, it is observed that there is hardly a family unit without a generator to serve as an alternate source of power supply - it has become an indispensable asset to the average Nigerian home. Also, it is impossible for factories and industries to operate in this nation by relying solely on power from the national grids [7]. Okeniyi et al. [3] expose the fact that 'the generated energy supply, of about 4000 MW for the whole nation has not been sufficient for the urban areas connected to the national grid and has not made the expansion of energy provision for rural communities possible. This is such that, communities could remain unconnected to sustainable source of energy provision for economic growth except drastic approach of energy sourcing is employed'. This is a discouraging reality. It is no wonder that industries and factories are being established outside the country, in regions where cost of power is well reduced [3]. It is thus needful for developing countries like Nigeria to uncover alternative means of fighting this menace of inadequate power generation.

Furthermore, in a study on generation, characteristics and energy potential of municipal solid waste for power generation in Nigeria, it was noted that the direct burning of solid wastes as a waste management option in the open air at elevated temperatures liberates heat energy, inert gases and ash which can be conveniently used for power generation where the net energy yield depends upon the density and composition of the waste; relative percentage of moisture and inert materials, size and shape of the constituents and design of the combustion system [8]. Reclaimable energy generated from waste is a major source of environmentally sustainable energy that is not yet fully explored in Nigeria [3]. According to Amber et al. [8], lack of proper existing policies, legislation, waste handling and lack of awareness are obstacles to the adoption of waste to energy technology in Nigeria. With the availability of relevant waste to energy facilities, it is envisaged that there would be sufficient energy supplied to cities in developing countries. Much more, it is expected that an energy bonus could be obtained from densely populated areas due to a corresponding high waste generation which in turn could be used to supplement areas with high energy consumption requirements [3].

In addition, waste to energy provides an avenue for both the government and the members of the community to be involved in the process of energy generation. Communities can be actively involved in the processes of waste collection, sorting and conveyance to sites that have been demarcated and set up by the government for waste to energy production. Hence, it is an all-encompassing strategy for energy generation. This study attempts to shed more light on the possibility and advantages of waste to energy strategies being implemented in a developing country such as Nigeria which is catching up at a fast rate.

2. Materials and Methods

2.1. Study Area

Ibadan in South West Nigeria is one of the foremost cities in Africa in respect of population, trading activities and natural resources. The city of Ibadan is also the third most populous city in Nigeria with the population put at 2.6 million [9]. The city is located approximately on longitudes 3°45ˈ E and 4°00ˈ E and latitudes 7°15ˈN and 7°30ˈN [10]. Residents of Ibadan are engaged in various trades, covering primary, secondary and tertiary sectors and ranging from agriculture (practiced by a section of the populace) to white collar jobs. The city is also gearing towards industrialization characterized by high waste generation and energy demand.

University of Ibadan and surroundings were purposively selected for this study. The University of Ibadan occupies an area of 1,185.04 Ha [10]. There are two sources of electricity supply to the university presently. These are: The Ibadan Electricity Distribution Company (IBEDC) and Alternative Source of Power – Generators. When in session, the University pays an average of ₦40 million per month as electricity bills to IBEDC and an average of ₦20 million when there is an industrial action or the school is out of session. Just 3 out of the 6 diesel generators are presently working and these require a running cost of ₦4.92 million per month (Source: Electrical Unit and Power Unit of the Maintenance Department, University of Ibadan). The varied land use types on the campus ensured different categories of wastes.

2.2. Methodology

The study explored the possibility of energy bonus availability contained in various categories of solid waste based on analysis of their calorific values. To achieve this, eight categories of solid waste, were identified (Table 1).

The moisture content of samples were determined after drying at 105°C in an electric oven until the samples reached a constant weight. The dried material was then used to obtain the calorific value using a bomb calorimeter (Model 6100, Parr Instrument Company). Furthermore, the most energy rich components of solid wastes based on the calorific values were identified. Theoretical calculations of calorific value were also carried out using the Bento's Model of Proximate Analysis to assess any variation.

Table 1. Waste categories examined in the study.

S/N	Component of Solid Waste	Nature in terms of Constituents	Constituents contained in Waste Sample
1	Food Waste	Homogeneous	Leftover food (cooked rice, beans, fried plantain, assorted soups, meat and fish scraps, including bones, spices and pounded yam.)
2	Animal Waste	Homogeneous	Animal droppings (poultry and piggery droppings)
3	Plant Waste	Homogeneous	Plant waste materials (weeds, cut grass, broken off branches, fallen leaves and unripe fallen fruits)
4	Domestic Waste	Heterogeneous	Paper, food scraps, nylons and drink cans.
5	Industrial Waste	Homogeneous	Cassava peels
6	Market Waste	Heterogeneous	Spoilt / rotten fruits (mangoes in particular), onion peels, moin-moin leaves (moin-moin is beans cake and is cooked wrapped with leaves), nylons and newspapers.
7	Construction Waste	Heterogeneous	Rusted nails, broken pieces of wooden formwork, chipped blocks, leftover concrete mix chippings, steel reinforcement bars and links.
8	Institutional Waste	Heterogeneous	Waste papers, tissue paper and cardboards, low density plastics or nylons, PET bottles and assorted drink cans.

Note: In this study, 8 types of solid waste and 7 identifiable constituents were used; heterogeneous wastes were obtained from markets, institution, households and construction sites. Such constituents include; HDPE plastics, LDPE nylons, paper and cardboard, metal cans (aluminum metal), scrap iron (rusted or broken nails, scraps etc.), wood and concrete.

3. Results

3.1. Moisture Content

Table 2 summarizes the moisture content of various samples of solid waste collected in the study. Construction waste showed the least amount of moisture, 7.6% as compared with others. Food waste by nature, contains the largest amount of moisture 82.9%. The categories of waste were ranked according to their moisture level.

Table 2. Moisture content of solid wastes and their components with their ranking.

Waste or its Component	Fresh Weight (g)	Dry Weight (g)	Moisture Content (%)	Rank in respect of Moisture
Food waste	2311.4	396.5	82.9	1
Animal waste	3134.2	747.6	76.2	4
Plant waste	1008.8	319.5	68.3	5
Household waste	951.4	335.5	64.7	6
Cassava processing waste	1605.7	343.8	78.6	2

Waste or its Component	Fresh Weight (g)	Dry Weight (g)	Moisture Content (%)	Rank in respect of Moisture
Market waste	2669.4	610.1	77.1	3
Construction waste	1202.7	1111.1	7.6	8
Institutional waste	936.1	836.4	10.7	7

Index: 1 shows the highest and moisture level decreases with higher number.

3.2. Calorific Value

The results (Table 3) indicate that construction waste is the most beneficial waste in terms of energy generated 18.58 MJ/Kg, with its varied components; specifically the wood component of the waste showed the highest, 15.73 MJ/Kg. However, animal wastes, cassava processing waste (small scale industry) and plant waste also showed a substantial amount of recoverable energy (MJ/Kg) 18.12, 14.36 and 14.19, respectively. Furthermore, when considered based on individual constituents in heterogeneous waste, LDPE/nylon, wood and paper showed calorific values (MJ/Kg): 25.20, 15.73 and 13.14, respectively showing their high energy potential compared to HDPE plastics which showed 10.91, and little or no energy in concrete, metals and other non-biodegradable and non-combustible materials.

Table 3. Calorific Values of solid wastes (experimental values).

S/N	Waste Category	Calorific Value (MJ/Kg)	Rank (In terms of Calorific Value)
Homogenous wastes			
1	Food waste	5.01	8
2	Animal waste	18.12	2
3	Plant waste	14.19	4
4	Household waste	10.09	7
5	Cassava processing waste	14.36	3
6	Market waste	11.49	6
7	Construction waste	18.58	1
8	Institutional waste	13.21	5
Constituents of heterogeneous waste			
9	HDPE / Plastic	10.91	4
10	LDPE / Nylon	25.20	1
11	Paper / Cardboard	13.14	3
12	Scrap Aluminum	0	-
13	Scrap Iron	0	-
14	Wood waste	15.73	2
15	Concrete waste	0	-

Index: 1 shows the highest value which decreases with higher number

3.3. Estimation of the Amount of Solid Waste Required for Energy Demand in the Model Community

An estimate of the amount of waste (in Kg) required to meet energy demand of the model community (University of Ibadan) is calculated by converting the energy unit of calorific value obtained (MJ/Kg) to the unit of electricity consumption (kWh) using the conversion rate of 1 MJ to 0.278 kWh. Table 4 summarizes the conversion of calorific values obtained for each type or component of solid waste examined to the derivable electricity units and the waste required to meet up with the estimated amount of about 3.6 million kWh in the model.

Table 4. Estimated amount of solid waste required to meet energy demand in the model community.

S/N	A	B	C	D
1	Food waste	5.01	1.39	2.59
2	Animal waste	18.12	5.03	0.72
3	Plant waste	14.19	3.94	0.91
4	Household waste	10.09	2.80	1.29
5	Cassava processing waste	14.36	4.00	0.90
6	Market waste	11.49	3.19	1.13
7	Construction waste	18.58	5.16	0.70
8	Institutional waste	13.21	3.67	0.98
9	HDPE / Plastic waste	10.91	3.03	1.19
10	LDPE / Nylon waste	25.20	7.00	0.51

S/N	A	B	C	D
11	Paper waste	13.14	3.65	0.99
12	Scrap aluminum waste	0	0	Not Suitable
13	Scrap iron waste	0	0	Not Suitable
14	Wood waste	15.73	4.37	0.82
15	Concrete waste	0	0	Not Suitable

Key:
A - Component of Waste (per Kg)
B - Calorific Value per Kg (MJ)
C - Corresponding Amount of Electricity per Kg (kWh)
D - Amount of waste required for energy generation (x 10^6 Kg).

It should be noted that the above computation is an estimation based on the assumption that there was a continuous decline in the quantity of electricity available for consumption in the University of Ibadan from the year 2004 till date. However, variables of electricity consumption have been on a constant increase and there have been significant efforts made towards improving the quality and quantity of electricity generated and supplied in the institution. Thus, it is expected that average amount of electricity consumed on campus in the year 2017 exceeded the estimated value of about 3.6 million kWh.

3.4. Model of Waste to Energy (WtE) Facility

The model facility (Figure 1) proposed based on the results of this study would help to greatly reduce pollution resulting from poor solid waste control and management practices in the institution and provide a cost effective means of alternative energy production. This model facility focuses on municipal solid waste as produced in typical communities. The study aims at providing a solution to environmental pollution by municipal solid waste alone and eliminates hazardous waste through encouraging source separation or segregation. The model is replicable and can also be adapted for other smaller and larger communities and institutions. Separate collection vans shall pick up the recyclable versus non-recyclable waste and upon reaching the waste-to-energy facility (WtE), further sorting will be done to confirm that no reusable or recyclable waste, and also hazardous waste is burnt. Incineration, which is one of the most common WtE implementation, shall be used in this model facility. The process of incineration is selected because it is economical and more common in developing countries such as Nigeria compared to other methods such as gasification and pyrolysis. Also, precautions will be put in place to ensure pollution due to harmful gases from combustion is avoided. Direct combustion of solid waste would be employed in this facility during which the waste would be added to the boiler in batches and it is expected that the model facility incinerates 80 to volume. As the solid waste is burnt as fuel, water in the system boils to produce steam that powers steam generators which in turn make electric energy and heat available.

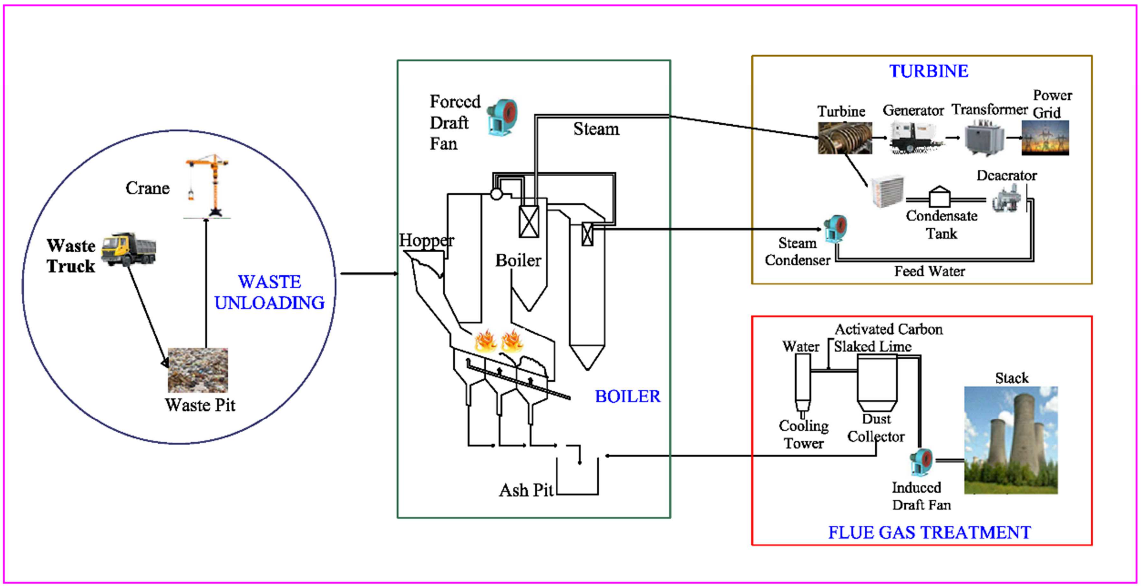

Figure 1. Schematic AutoCAD diagram of a typical waste to energy model facility.

(Adapted from www.sweetcrudereports.com)

3.5. Challenges Likely to Be Posed by Waste to Energy Model

The following are the possible challenges that would be faced by adapting this waste-to-energy model;

(1) Fly ash. Production of fly ash and bottom ash just as is the case when coal is combusted: Sometimes, the residue ash could be clean enough to be used for some ancillary purposes such as raw materials for use in manufacturing cinder blocks or for road construction. However, the fly ash could constitute a potential health hazard because it contains toxic metals such as lead, cadmium, copper, and zinc as well as small amounts of dioxins and furans. In this model facility, measures need to be taken to test the toxicity levels of fly ash. If found toxic, it would be deposited in dedicated landfills with leachate management.

(2) Odour nuisance. This can also be a potential problem if the plant location is not isolated. Some plants store the waste in an enclosed area with a negative pressure, which prevents unpleasant odours from escaping, and the air drawn from the storage area is sent through the boiler or a filter. This process would be adapted in the model waste facility in order to prevent a toxic environment.

(3) Health Hazards. Care should be taken to ensure that the waste handlers and populations in the vicinity are not exposed to unnecessary health risks at the facility and within the vicinity as highlighted by Coker et al. [11] in a study of medical waste management in Ibadan, Nigeria and appropriate PPE use should be encouraged.

3.6. Potential Benefits of WtE Facility Model

This WtE model amongst others shall provide the following benefits;

(1) It would provide an economical, alternative source of energy.

(2) It would solve the problem of waste control and management.

(3) It would lead to more employment opportunities in the society thus reducing social vices and crime.

(4) It would improve public health in general.

4. Discussion

This study is an attempt to evaluate the calorific value of most predominant wastes and their components generated in an institution. From this data, a 'waste to energy' model was developed which can supplement the energy deficit in the community. The power consumption at the University community from 2004 to date was reviewed. Several companies took over the management of electricity supply and distribution from the government. According to the University of Ibadan Master Plan [10], two sources of electricity supply to the university existed – the Power Holding Company of Nigeria (PHCN) and diesel generators which served as an alternative source of energy. In addition, as at the time, only four out of five generators on ground were functioning but at below the installed capacity of 4MW each. This was due to the fact that the generators were aging for over two decades and needed to be replaced with new ones. A new generator was added and the older ones were serviced. However, presently Ibadan Electricity Distribution Company (IBEDC), a new Company and 3 out of the 6 diesel generators are presently working. The generators require a running cost of ₦4.92 million per month (Source: Electrical Unit and Power Unit of the Maintenance Department, University of Ibadan). This is the plight of a typical institution in Nigeria. It has become glaring that asides power supply from the national grid and generators which are often used as an alternative source of power, more alternative sources of sustainable energy are required. The solution to this plight of the nation is not far-fetched however. There is presently a problem of waste control and management which could be beneficial to society if the nation adopts waste-to-energy strategies and becomes 'waste-wise' as is the proposition of this study.

Waste-to-Energy is a renewable energy source because non-biodegradable waste which is constantly generated in communities such as the University of Ibadan campus can be used over and over again to generate energy. WtE strategies are becoming increasingly popular most especially in countries battling with the problem of waste management and sustainable energy generation. Furthermore, the process helps to reduce carbon emissions by offsetting the need for energy from fossil sources such as coal and petroleum while supplementing the energy generated from other sources such as hydropower and solar energy, thus leading to energy bonus availability [3].

Moreover, the results of the study reveal that energy supply for communities can be supplemented by adapting WtE strategies, thus improving efforts towards better waste control and management. According to Okeniyi et al. [3], such energy sourcing could be initiated by a system of segregated waste collection, from the source of waste generation which would aid the characterization of the waste into their different components. Furthermore, this approach of energy reclamation system, if well developed, is also potent with economic and environmental benefits of job creation and eventual waste volume reduction that could have otherwise been disposed to landfill, along with its waste to energy which portend great advantage towards the attainment of a sustainable environment [3]. In addition, the importance of waste separation, from household units up to community levels cannot be overemphasized. This is because individual constituents of some heterogeneous waste components (such as LDPE/nylon waste as a component of institutional waste, household waste, etc.) give high calorific values and are key players in WtE process. For effective waste to energy operation, as observed from the study, nylon, wood, paper and natural sources of waste, including materials which have not undergone significant processing should be the chief target of WtE processes. Hence, these components should be separated preferably at the point of waste generation for ease and effectiveness. Communities should be provided with color-coded waste bins clearly demarcated for waste segregation e.g. plastics, organic matter (food waste, fruit scraps, vegetable stalk etc.), paper, nylon. In Nigeria, this practice has just started in some locations. Simple systems as initiated in Aleshinloye market in Ibadan adapt two main gradations – wet waste and dry waste however this would result in further waste sorting at the WtE facility [12, 13]. Therefore, to make the WtE system to be more effective, the different waste categories are to be clearly displayed on the bins and communities trained for waste separation.

5. Conclusions

The study reported here proves that developing countries can exploit their vast supply of solid waste to supply an energy bonus by careful consideration and exploitation of the energy potential (calorific value) of waste components produced in the area. By adapting well-monitored systems of waste separation, from household units up to community level, waste-to-energy strategies can prove sustainable and beneficial, even to the economy and industrial sectors of developing countries. In order to ensure sustainability of WtE methods and maximum benefits, it is recommended that communities should embark upon waste segregation at all levels and there should be coordination among the communities, government and all stakeholders who will derive immense benefits.

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