ENERGY CONVERSION FROM MUNICIPAL SOLID WASTE IN NIGERIA

'Awajiogak A. Ujile[1] and B. T. Lebele - Alawa[2]

[1]Department of Chemical / Petrochemical Engineeering, Faculty of Engineering, Rivers State University of Science & Technology, PMB 508 Port Harcourt, Nigeria.

[1]Department of Mechanical Engineering, Faculty of Engineering, Rivers State University of Science & Technology, PMB 5080, Port Harcourt, Nigeria.

ABSTRACT

This paper investigates a source of energy generation which has not been well harnessed in Nigeria: trash (Municipal Solid Waste) to energy. Wastes from nine major cities in Nigeria were considered. First and Second Laws of Thermodynamics were used to determine the power developed from the combustion of the municipal solid wastes. The analysis and evaluation from the work has shown that about 2.26MW of electrical energy could be generated daily from wastes per city. This is quite significant in the quest for alternative/complimentary energy source in Nigeria.

Keywords: Energy generation, solid wastes, combustion.

INTRODUCTION

Presently, most municipal solid waste (MSW) generated in Nigerian cities are dumped into borough pits. Some are disposed along road sides, causing threat to health of the citizens. The waste management system has not attained acceptable standards. 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. One of the ways to manage MSW is its conversion to energy in the form of heat and electricity (Ujile, 2008). Romania is making attempt to establish waste to energy concept in one of the cities, Bucharest (Alexie and Dimitru, 2008). Some of the benefits of the technique adopted by Ujile's work include: energy loss reduction, reduction of landfill size and cost reduction. During the process of incineration, waste material is converted to gases, particles and heat. These products are later used for the generation of electricity (Troschinetz and Mihelcic 2009; Eze, 2010). In the recent time municipal solid waste (MSW) has also been given a good attention as to the gasification and combustion of same in a fluidized bed (Choi et al., 2008) to eliminate the environmental menace and gainfully generate energy in the form of process heat, electricity etc. On the other hand the problem of power generation in Nigeria has affected the national economy adversely. As at December 2009 the Federal Government promised to generate 6000 MW of electricity to the citizenry of about 140 million people. However, the actual amount generated was only 3500 MW. The installed and available capacities are shown in table 1.

TABLE 1: POWER GENERATING STATIONS AND THEIR INSTALLED CAPACITY

SITE	TYPE	INSTALLED CAPACITY [MW]	AVAILABLE CAPACITY [MW]	NO. OF UNITS
Afam	Thermal	700	488	18
Delta	Thermal	812	540	20
Egbin	Thermal	1320	1100	6
Ijora	Thermal	66.7	40	3
Sapele	Thermal	1020	790	10
Jebba	Thermal	540	450	6
Kainji	Hydro	760	560	12
Shiroro	Hydro	600	600	6
Orji River	Thermal	60	-	4
Others	Diesel	46	18	-

(Source: National Electric Power Authority profile, 2004)

The inability of the Federal Government to meet up the expected target was as a result of several extraneous factors. The energy sector is expected to witness an injection of over eight billion U.S dollars for the complete rectification of the nation's moribund power sector between 2010 and 2020, while another ₦301.3 billion will be required to develop gas infrastructure to power the various power plants that are expected to come on stream within the period. Olajide and Hamisu, (2008) stated that this was required for attaining short term power generation level of 6000 MW, medium term of 10000 MW and long term of 20000 MW within 18 months, 3 years and 12 years respectively. In order to satisfy the demand, new power stations are being planned for construction at Geregu, Omotosho and Oronshogbo. The short term planned to be achieved in December 2009 could not be realized for obvious reasons. In order to achieve the set targets of 10000 and 20000 MW another source should be integrated.

This presentation therefore is to introduce another source of energy generation which has been overlooked in Nigeria: trash (municipal solid waste (MSW)) to energy. Table 2 shows the MSW generation in some towns in Nigeria. Typical densities and moisture contents of domestic, industrial and municipal wastes vary with geographical locations, seasons of the year, activities in place and length of time of storage. Details of these parameters could be obtained from (Perry and Green, 1997).

TABLE 2: URBAN MUNICIPAL SOLID WASTE GENERATION RATE IN NIGERIA

City	Population	Agencies	Tonnage /month	Density (kg/m^3)	Kg/capita/ day
Lagos	8,029,200	Lagos waste managem ent authority	255,556	294	1.06
Kano	3,248,700	Kano State Environmental Protection Agency	98,440	245	1.01
Ibadan	1,835,307	Oyo State Environmental Protection Commission	53,960	286	0.98
Kaduna	1,458,900	Kaduna State Environmental Protection Agency	44,640	303	1.02
Port Harcourt	5,700,000	Rivers State Environmental Protection Agency	179,600	325	1.05
Makurdi	259,500	Urban Development Board	7,863	270	1.01
Onitsha	509,500	Anambra State Environmental Protection Agency	15,440	234	1.01
Nsukka	100,700	Enugu State Environmental Protection Agency	3,051	257	1.01
Abuja	778,567	Abuja Environmental Protection Agency	24,290	298	1.04

Nigeria as a developing country with high rate of influx of investments (oil companies, textile companies, the breweries and bottling companies etc) now generates sewage sludge in large quantities which are neither treated nor converted to any form of energy. Also the Northern region of Nigeria produces cereals and legumes (sorghum, maize, millet, wheat, cowpea and groundnuts) as well as fruits and vegetables (oranges, mangoes, tomatoes, onions, spinach and water-melon) which take the largest percentage of the nations cereals and legumes in supply. Cereals and legumes are known to come with lots of straws, chaffs and shells as wastes when processed for storage and/or supply.

Another unnoticed waste is the sugarcane bagasse. Though there is no data on it as to the quantity being generated in Nigeria, but literature reveals that it has a good amount of energy in the family of biomass (Adio, et al 2009). The basic methods of handling waste stream are source reduction, reuse, recycling, composting, trash to energy and land filling. The advantage of the process is that it will also establish clean environment for the country and reduce/eliminate health hazards presently associated with environmental pollution.

In other parts of the world municipal waste is being converted into energy. The total number of municipal waste combustion facilities in United States is 62 and the wastes burned in these facilities totaled 8.44% of the total municipal waste managed in landfills, incinerators and transfer stations. These amounts to 88470 tons per day combusted municipal waste (Solid Waste Digest, 1994). The report stated that the cost per ton averages $77 in New Jersey and New York compared to $57 for the nation. The generation of municipal solid wastes in Nigeria as shown in Table 2 can be utilized to obtain energy for the country.

PROCESS DESCRIPTION

Although there are several potential methods to recover energy from MSW (e.g., conversion to ethanol, anaerobic digestion, gasification, pyrolysis, etc.), combustion is the most-advanced and the most-applied conversion technology.

Combustion: Direct combustion is the most prevalent technology used to reclaim the energy value in MSW. In 1993, there were 125 municipal waste-to-energy facilities in the United States with a rated MSW capacity of approximately 2500 MW of energy. The most common options are mass burn and Refused-derived fuel (RDF) facilities, with mass burn being the most prevalent. In a typical mass burn facility, waste is received into a pit where an overhead crane mixes the waste and removes oversize materials. The waste is fed onto a grate of the furnace, which agitates and moves the waste across the combustion chamber. Air for combustion is introduced from under the grate (underfire air) and from nozzles located above the grate (overfire air). The formation and emission of pollutants (e.g., CO, NOx, SOx, hydrocarbons, dioxins, etc.) are affected significantly by the design and operation of the combustor. Energy is recovered from the hot flue gases in a water wall boiler and is recovered as hot water and steam. The cooled flue gases then pass through air pollution control (APC) equipment which normally includes combinations of scrubbers to remove acid gases (e.g., HCl) electrostatic precipitators (particulate removal), and/or fabric filters (fine particulates).

The procedure required to carry out the conversion process includes:

Non- recyclable refuse from trucks would be deposited in an enclosed refuse pit to contain odor and noise.

Over head cranes transfer refuse from the pit to the feed hopper of furnace.

The refuse is moved on reciprocating grate to ensure complete combustion. Air required for combustion is drawn in from the refuse pit to eliminate dust and odor.

A water wall boiler above the grate area recovers the steam producing energy. Steam produced in the water wall boiler drives the turbine generator to generate electricity.

Sophisticated and properly designed computerized equipment in the control room monitors all operations for high efficiency. The electricity is sent to the national grid.

Water from the cooling tower is used to condense steam for recirculation to the boiler.

Air quality control equipment, acid gas scrubber and fabric filter are incorporated for clean emissions.

Treated ash that remains (residue) after the process is sent to engineered landfill.

Figure 1 shows a typical process flow diagram arrangement of waste to energy scheme.

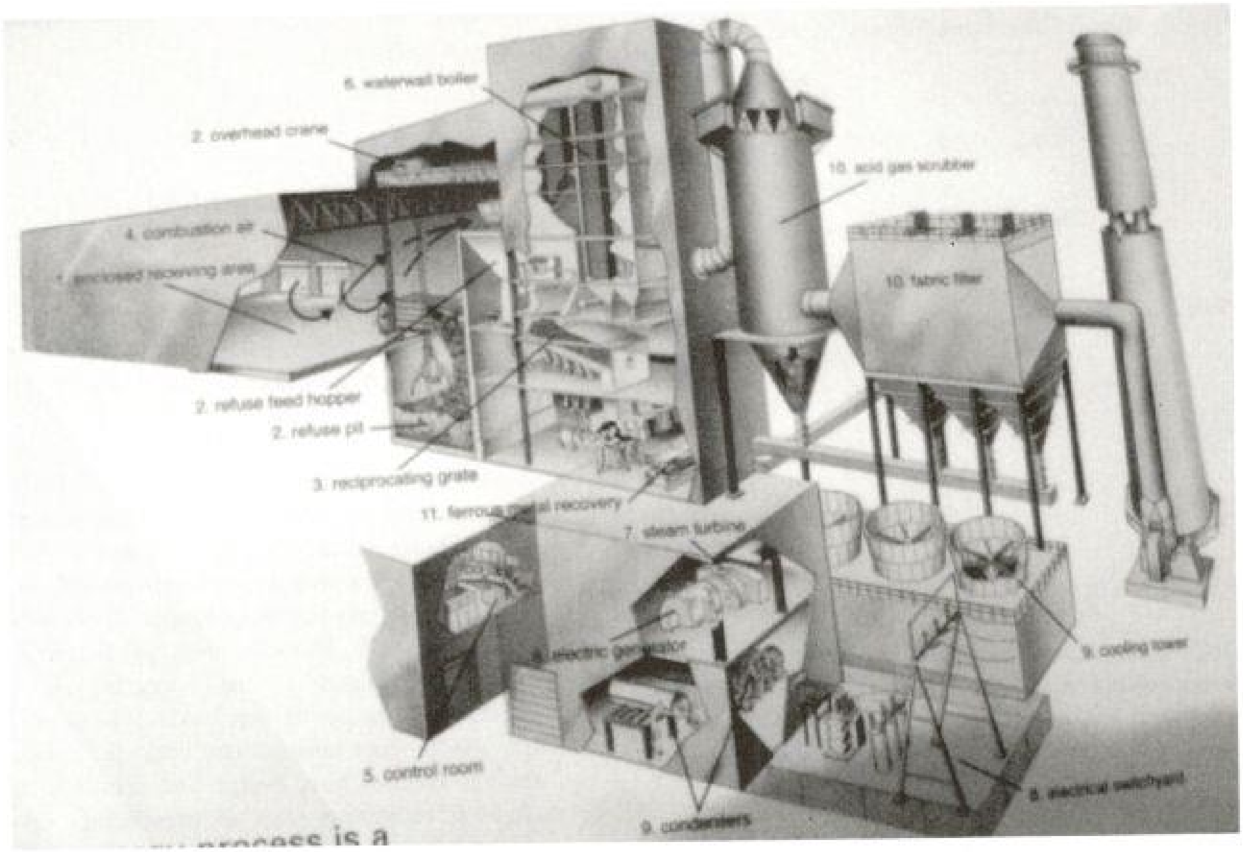


Figure 1: Typical Trash-to-energy Plant (Source: Wheelabrator Manual, 2007)

THERMODYNAMIC EVALUATION OF THE PROCESS

The thermal energy conversion to mechanical energy or work and to electrical energy is by the application of First and Second Laws of thermodynamics. We evaluate the horsepower (watt) developed by the

	Inlet	Outlet
Velocity (m/min)	2000	7500
Temperature (K)	800	440
Pressure (MPa)	3.5	0.15
Flow rate (kg/hr)	10,000	
Heat Loss (KJ/hr)	125,000	

The steady state mass and energy balances on the turbine and its contents (yield) are given as follows:

$(dM/dt) = 0 = M_1 + M_2$; $M_2 = - M_1 = - 10,000$ kg/hr (1)

$$\frac{d}{dt}\left(u + M\left(\frac{v^2}{2} + gh\right)\right) = 0$$

(2)

turbine and the entropy change of the steam obtained from the combustion of municipal solid waste.

Considering a steam turbine operating at the following conditions:

TABLE 3: A TYPICAL STEAM TURBINE CONDITIONS FOR POWER GENERATION

$$M_1\left[h_1 + \frac{(v_1)^2}{2}\right] + M_2\left[h_2 + \frac{(v_2)^2}{2}\right] + W_s + Q = 0$$

Where M is the mass flow rate, h_1 and h_2, the inlet and outlet enthalpies, v is the velocity; W_s and Q are the shaft work and heat flow of the system respectively.

Combining equations 2 and 3 and substituting the proposed data from table 3 we can obtain the power generated by the steam from MSW.

From Mollier diagram; h_1 = 3510 J/g; and S_1 = 7.23J/(g.k) where S is the entropy of the system.

$$\frac{(v_1)^2}{2} = \frac{1}{2}\left[\frac{2000\frac{m}{min}}{60\frac{s}{min}}\right]^2 \cdot 1\frac{\frac{J}{kg}}{\frac{m^2}{s^2}} \cdot 1\frac{kg}{1000\,g}$$

Also =

0.56 J/g

$$h_1 + \frac{(v_1)^2}{2}$$

So that =

3510.6 J/g

$$\frac{dS}{dt} = 0$$

(4)

$= M_1S_1 - M_2S_2 + S_{gen}$

(5)

Since Q = 0, and M_2 = - M_1 and we consider the fact that the turbine would operate reversibly so that S_{gen} = 0 and $S_1 = S_2$ that is the expansion is isentropic we can use entropy- enthalpy plot for steam to determine the Mega watt of power generated by the turbine.

From the initial steam conditions T = 800K, P = 3.5MPa and exiting steam (H_2 = 2690J/g) and final temperature (T=373K).

$$-W = ((3510+0.6) - (2690+7.8))\frac{J}{g}\cdot\left(10000\frac{kg}{hr}\right)\cdot\frac{1000\frac{g}{kg}}{1000\frac{J}{kg}}\cdot\frac{1\,hr}{3600\,s}$$

$= 2258$ KJ/s $= 2.258 \times 10^6$ W = 3028 hp

From the available municipal solid waste generation in Nigeria of 25 million tons annually (Kofoworola, 2007) and proper design thermodynamic considerations energy generation can be obtained.

Waste-to-Energy Systems: The waste generation layout thermodynamic analysis show that steam can be produced. WTE (waste-to-energy) systems take over at this point, using high-pressure/high-temperature steam to drive turbines and produce shaft horsepower for prime movers at industrial plants or to generate electricity. The fuel may be solid waste or gas or oil from a gasifier or pyrolysis system. Typical flow sheets for alternative energy-recovery systems

Similarly, h_2 = 2805 J/g and $h_2 + \frac{(v_1)^2}{2}$ = (2805 + 7.8) J/g = 2812.8 J/g

S_2 = 7.50 J/(g.K)

Therefore, - W_s = (3510.6 – 2812.8) J/g x 1000 kg/hr x 1000g/kg – 12.5 x 10^4 KJ/hr x 1000 J/KJ

= 1903.6 KJ/s = 1.9036 x10^6 W

2553 horse power

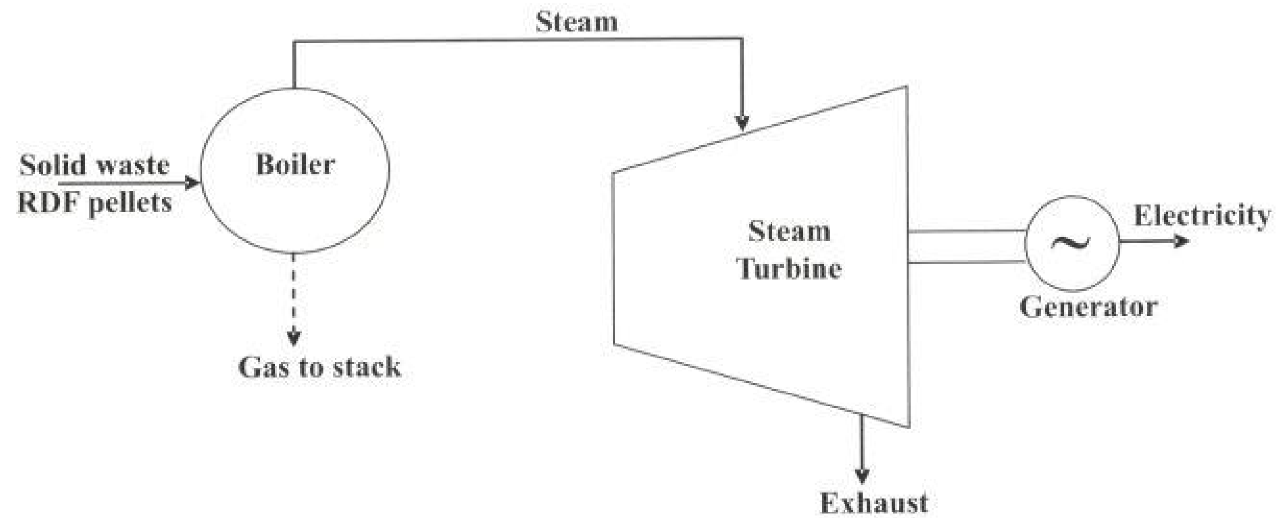
Also, change in entropy of the system, $\Delta S = (S_2 - S_1)$ = 0.27J/g.K

The steady state entropy balance for the turbine and its content required for the conversion of steam may be of the form:

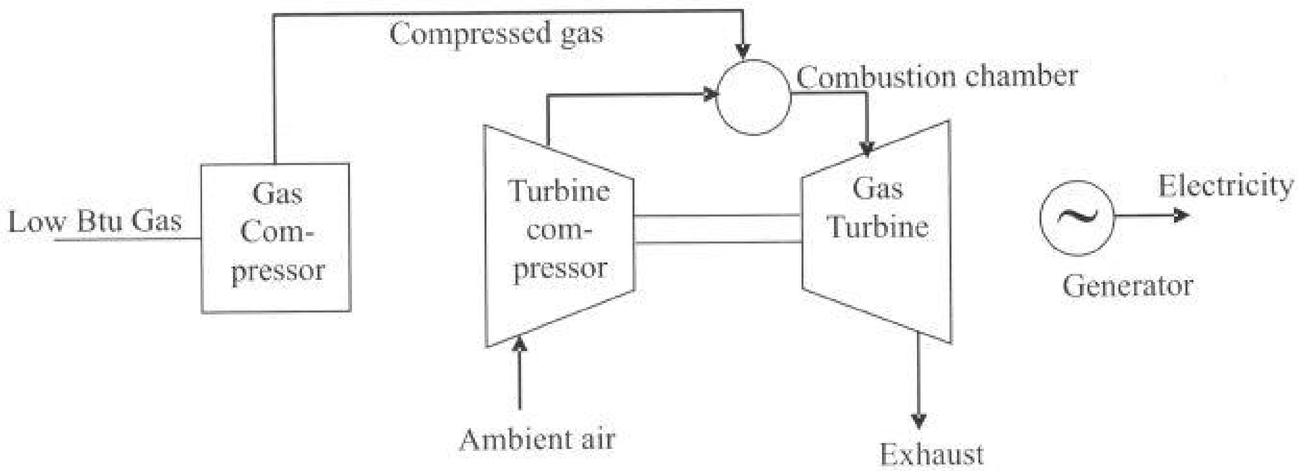
are shown in figure 2. Perhaps the most common flow sheet for the production of electric energy involves the use of a steam turbine generator combination (see Fig. 2a). As shown, when solid wastes are used as the basic fuel source, four operating modes are possible. A flow sheet using a gas-turbine-generator combination is shown in Fig. 2b. The low-energy gas is compressed under high pressure so that it can be used more effectively in the gas turbine. Use of low- or medium-Btu gas for gas turbines has been attempted, and success requires good design and operation of gas cleaning equipment prior to introduction into the combustor of the gas turbine (Perry and Green, 1997)

Wheelabrator entered the new century on solid ground. In 2001, the company reached a significant industry milestone--the conversion of 100 million tons of municipal solid waste into energy by its 16 waste-to-energy facilities. According to a June 2001 Waste Treatment Technology News article, the company's accomplishment stemmed from its "success in developing progressive public/private partnerships; integrating source reduction, recycling, and landfill options; pioneering new energy and environmental technologies; and demonstrating operating procedures that have set high industry standards for efficiency and regulatory compliance." Wheelabrator, (2001). One of the authors visited one of the plants owned by Wheelabrator in Pennsylvania, USA in 2008. It has been a successful venture.

Nigeria requires waste- to- energy technologies to complement the present resource



a)Options with steam-Turbine-Generator Combination



a) Options with Gas- Compressor- Gas Turbine- Generator

Fig. 2: Flow sheet – alternative energy recovery systems

TABLE 4: ENERGY OUTPUT AND EFFICIENCY FOR 1000 METRIC TON OF WASTE/DAY STEAM-BOILER TURBINE-GENERATOR ENERGY RECOVERY PLANT USING UNPROCESSED INDUSTRIAL SOLID WASTES WITH ENERGY CONTENT OF 12,000KJ/Kg

S/NO	ITEM	VALUE
1	Energy available in solid wastes, million KJ/h [1000 metric tons/day x 1000 kg/metric ton x 12,000 KJ/Kg x 10^6 KJ/million KJ]	500
2	Steam energy available, million KJ/h [500 million KJ/h (500 million KJ/h x 0.7)]	350
3	Electric Power generation, KW (350 million KJ/h)/(11,392.41 KWh)*	30715
4	Station service allowance, KW [30715 (0.06)]	- 1843
5	Unaccounted heat losses, KW [30715 (0.05)]	- 1536
6	Net electric power for export, KW	27336
7	Overall efficiency, percent {(27336 KW)/[(500,000,000 KJ/h)/(3600 KJ/KWh)]}(100)	19.7

*11,392.41 KJ/KWh = 3600 KJ/KWh/0,316

Determination of Energy Output and Efficiency for Energy-Recovery Systems An analysis of the amount of energy produced from a solid-waste energy conversion system using an incinerator boiler-steam-turbine-electric-generator combination with a capacity of 1000 metric tons per day of waste is presented in Table 4. If it is assumed that 10 percent of the power generated is used for the front-end processing system (typical values vary from 8 to 14 percent), then the net power for export is 24,604 kW and the overall efficiency is 17.5 percent.
Table 1 shows the generation rate of municipal wastes in some towns in Nigeria. It is time we started to utilize these wastes as to boost our energy resource.

CONCLUSION

The conversion of MSW into energy for power generation has so far not been successful in Nigeria. However, with the persistent power problem affecting all sectors of the economy, there are urgent needs for complimentary energy sources. This work has therefore considered municipal solid waste generation potentials conversion to energy. In developed countries, MSW has been established as one of the sources of energy generation. For example, in United States of America, Wheelabrator has the capability to convert over 100 million tons of MSW to energy from the 16 facilities. Nigeria generates over 250 million tons annually. Table 2 only shows few cities and estimated generation capacities based on the population obtained from available statistics. Our work has revealed the importance of developing appropriate means of harnessing municipal solid waste instead of dumping them along road sides and in borough pits. In addition to the energy advantage, trash to energy will also establish clean environment for Nigeria and reduce health hazards associated with environmental pollution. We recommend that certain cities could start this process with the technology provided in this paper.

REFERENCES

Adio, S. A; Odejobio, O. J; Popoola, A and Asere, A. (2009): The Potentials of Application of Fluidized Bed Combustion in Waste to Energy generation in

Nigeria. Proceedings of 2009 Nigerian Society of Engineers Conference.

Alexei, A and Dumitru, E. (2008): Waste-to-Energy in Romania. Case study – City of Bucharest. Proceedings of 23rd International Conference on Solid Waste Technology and Management. Philadelphia, P.A., U.S.A. March-April, 2008. pp 66- 72.

Choi, K., Lee, K., Lee, D., Osako, M. (2008), Fundamental characteristics of input waste of mall MSW incinerators in Korea, Waste Management, 28, 2293–2300.

Eze, C. L. (2010): Sustainable Municipal Solid Waste Management in Port Harcourt Metropolis, Nigeria. Paper presented at the Symposium of the Nigerian Society of Engineers, Port Harcourt Branch, March 2010

Kofoworola, O. F. (2007), Recovery and recycling practices in municipal solid waste management in Lagos, Nigeria; Waste Management Jour., 27, pp. 1139–114.

Levin, M. A. and M. A. Gealt, Biotreatment of Industrial and Hazardous Waste, McGraw-Hill Inc., 1993.

Olajide, A., & Hamisu, M.(2008, June): Nigeria:$85 Billion Naira Needed for Stable Power Supply won't Improve till December. Abuja, Nigeria.

Perry, H. and Green, D.(1997): 'Chemical Engineers Handbook' 7th Edition

Solid Waste Digest vol.4, no. 9 September 1994 (a publication of Chartwell Information Publishers of Alexandria, VA).

Troschinetz, A. M and Mihelcic, J. R. (2009): Sustainable recycling of municipal solid waste in developing countries, Waste Management, 515- 523

Ujile, A. A. (2008): Technique of Municipal Waste Management in Port Harcourt, Rivers State, Nigeria. Proceedings of 23rd International Conference on Solid Waste Technology and Management. Philadelphia, P.A., U.S.A. March-April, 2008.pp 473-481

http://www.wheelabratortechnologies.com "Wheelabrator Marks Milestone, Waste Treatment Technology News,"June 2001

Wheelabrator Manual 2007. Wheelabrator Falls Inc. Otter Recycling 1201 New Ford Mill Road, Morrisville, Pennsylvania 19067.