Design and Fabrication of a Low Capacity Incinerator

Emmanuel M. Adigio, Alexander N. Okpala, Ezenwa A. Ogbonnaya

***Abstract*— Incineration may not be the best method for the treatment of waste. Nevertheless, it is better than burning the waste in the open air as it is being done in most developing countries. The incineration process as a complementary Municipal Waste Management Program is innovative for the Nembe City. This will reduce the quantity of waste dumped into the rivers, by also using enlightenment program. This paper presents the design, fabrication and test running of a 50 kg hr-1 incinerator for waste management in a riverine community in Bayelsa State, Nigeria. The design of the incinerator includes a gas treatment unit, where the particulate matter is reduced using baffles and smoke filter. Investigation showed that the community with a population of 150,000 produces over 500 tonnes of waste per week, for which most of it is dumped into the river. Experimental results show that the designed capacity is 62 kg hr-1 with a bulk loading capacity of 260 kg. The waste reduction was 75% where the ash can be accumulated for land reclamation or road reconstruction. The combustion efficiency was determined to be 81.5%. Investigation on the effect of the heat exchanger on the incinerator efficiency and the quality of heat produced is ongoing, though visual inspection of the flue gas showed low content of particulate matter. The experiment also shows that the heat from the thermal treatment can be recovered for steam production.**

***Index Terms*— garbage, incinerator, thermal treatment, waste management.**

I. INTRODUCTION

The best practice for waste management is the reduction of waste production, thus, decreasing incinerator use, emissions and the resulting health and environmental risks. Waste management has defied many strategies in both developing and developed countries, aborting most efforts made by international, federal governments, and state city authorities [1] – [3].

Other regions, like the Pacific Island Countries and Territories adopt the vision of "A healthy and a socially, economically and environmentally sustainable Pacific for future generations", involving Sustainable Financing, Integrated solid waste Management, covering the 4Rs (refuse, reduce, reuse, recycle), collection and disposal, Legislation, Awareness, Communication and Education [4].

Common practice in waste management is the provision of dump site for landfill where all manner of waste is dumped. When the authorities cannot properly manage the dump site, scavengers are allowed to recover recyclables [5] and indiscriminately set the fields on fire causing dangerous infernos. Investigation shows that effluent from landfills caused by rainwater, known as leachate, peculates through the waste contain heavy metals and other hazardous compounds [6] – [7]. It was reported that analysis of deep boreholes and sited around landfills did not indicate strongly polluted water, though, requiring treatment before use while soil around the landfills was found to be unsuitable for crop production [8].

However, investigation of shallow boreholes and wells sited near the dump site showed high level of pollution [9]. Gas emitted from landfill contains compounds that can lead to the development of specific organism, with also its attendant odour from rotting organic materials, dust and concentration of rodent and birds [10]. Investigators [11] has reported that beside these inconveniences, like the odour and the noise from rodents and birds, there is no adequate evidence in the increase in risk of cancer or birth defects for communities in the proximity of dumpsites.

In order to properly manage waste, there is need for the characterization of the waste to determine the treatment process required to reduce them. It was reported that most municipal solid waste in developing countries contains about 50% of organic waste [12] – [13] where composting or the production of biogas can be encouraged. Assessment of clinical waste showed a high percentage of sharp objects [14], which require careful handling, suggesting the safest method of processing as thermal destruction. Clinical waste includes infectious, pathogenic, genotoxic, radioactive, and pharmaceutical materials, plus sharps.

In Malaysia, like most developed country, healthcare wastes are treated by incineration technology and the incinerated ash is disposed of in landfills [15]. In addition to various types of waste that is hazardous, the annual production of waste is increasing leading to increase in landfills [16], thus, following regulation in designs to minimize dioxins production, incineration will provide for now the fastest method of treating the waste. Similarly, in order to reduce landfill, some countries have successfully implemented new strategies, focusing in waste to energy, using incineration and advanced thermal treatment [17] where these researchers are providing treatment unit for the flue gas to reduce dioxins released to the environment.

Subsequently, studies have shown that the ashes from the incineration of waste has been actively recycled in the areas of roadbed, asphalt paving, and concrete products in many of European and Asian countries [18] – [20].

This study is to design an incinerator for a community in Bayelsa State, Nigeria, with a population of 140,000. The population is similar in status to that of Yenagoa, thus**,** it is assumed that waste **production** is 0.51 kg per person per day [13], i.e. weekly waste production is 500 Tonnes.

Emmanuel M. Adigio, Mechanical Engineering Department, Niger Delta University, Wilberforce Island, Nigeria, Mobile No. 002348064118064

Alexander N. Okpala, Mechanical Engineering Department, Niger Delta University, Wilberforce Island, Nigeria, Mobile No. 002348030854206

Ezenwa A. Ogbonnaya, Mechanical Engineering Department, Niger Delta University, Wilberforce Island, Nigeria, Mobile No. 002348037778406

II. DESIGN AND FABRICATION

A. Materials

The incinerator was designed using computer assisted design software "Solidedge". The materials for the fabrication include 4 mm plates, 2 mm plates, H-beams, refractory cements, rook-wools, blower fan and burners. Stainless steel angle irons (1.5" x1.5") were used for the grates to withstand the high temperature of the incineration. The choices of materials were made from availability, after effective costing. The chimney was produced from a 6" mild steel pipe. The heat exchanger was made of 2" mild steel pipe without fins. The incinerator rest on a concrete slap

B. Dimensioning

The incinerator was designed to treat a bulk waste of 250 kg. Using the bulk density of municipal solid waste of 261 kg m^{-3} [12], the volume for the solid waste in the incinerator for batch treatment is 0.96 m^3.

Consequently, the total volume for the thermal treatment is 5 times the batch volume (treatment chamber}, thus, 4.8 m^3. . Heat recovery unit was also included in the design via a heat exchanger to recycle the energy using a blower fan. In order to reduce the effect of lost heat on operators of the incinerator, the unit is encased with the 2 mm plates forming a dimension of 2.7 m (Height) x 2.1 m (Width) x 3.4 m (length). On the flue gas treatment unit is mounted a 6 m exhaust pipe.

Detailed drawing showing parts of right half view and left half view is shown in the Figures, 1 and 2 while Figure 3 shows a pictorial view of the equipment.

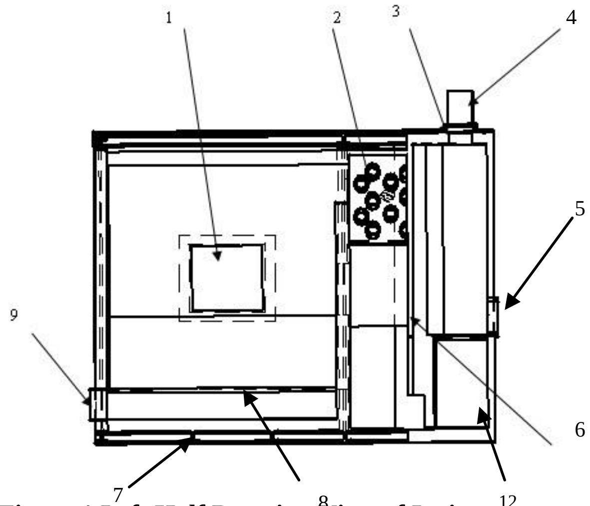

Figure 1 Left Half Drawing View of Incinerator

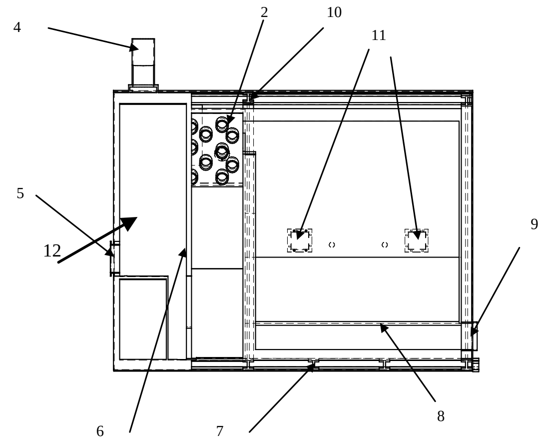

Figure 2 Right Hand Drawing View of Incinerator

1- Waste pot
2- Heat exchanger tubes
3- Smoke filter
4- Flue gas exit pot to chimney
5- Sort extraction pot
6- Flue gas baffle for removing particle matters
7- H-beam for bottom plates
8- Grate made of stainless steel
9- Ash extraction pot
10- Incinerator support beam (top), H- beam
11- Burners pot
12- Space for blower fan installation

Figure 3 Pictorial view of Installed Incinerator

C. Production

The Incinerator was fabricated in a workshop, Ingenieurs Pratiques Company situated at Azikoro inYenagoa, Bayelsa State, Nigeria. The process was started by building a skeleton using H-beams. The 4 mm plates were then formed and inserted in the skeleton. After completing the inner structure, the 2 mm plate was welded over the skeleton. The intricate curves of the inner plate were done using rolling machines and the cut out plates were put together by welding.

The unit was transported to the site of installation at Nembe City, where the finishing, including lagging and refractory work over the inner surface (thermal treatment chamber) were installed to prevent the direct heat on the metal.

The design is such that the flue gas exiting the treatment chamber goes through a gas treatment unit. The gas treatment unit consists of the heat exchanger fabricated from the 2" pipes and a baffle to reduce the quantity of particulate matter (PM) in the flue gas. Finally, filter box was mounted over the exit to the 6 m chimney pipe.

D. Operations

The intention of the operators of the incinerator is to recover the recyclable before the thermal treatment. However, the test carried out after installation was on the waste without sorting. The waste will be feed into the incinerator via the main waste door, no. 1.

The bulk loading for effective operation must not be more than 250 kg. After loading the incinerator the blower will be turned on and simultaneously, the primary burner will be ignited and sustained for 45 minutes to reduce the moisture content of the waste. The secondary burner will then be turned on to complement the burning and also assist in the reduction of the PM. The completion of operation can be checked through the waste door after stopping the burners.

When the thermal treatment is completed, the unit can be allowed to cool down before removing the ash from the ash pot. The un-burnt PM can also be removed from the soot pot after the operation.

The smoke filter will be cleaned from time to time to prevent the blockage of the exhaust.

III. METHODOLOGY

The detailed design of the incinerator was done after determining the operational volume of the unit, following the specification of the client; the Nembe Community and the World Bank. Subsequently, the mass and heat balance was calculated, and figures used to determine the burners and blower dimensions, i.e. the specifications.

Heat balance was done to determine the number of size or number of burners needed for the unit. Studies [13] and [21], have shown that the waste composition can be considered to the same across Bayelsa state. This findings was also reported in Ghana [12], indicating that waste composition is similar in developing countries, particularly, in Africa. Hence, the heat and energy balance was applicable in this analysis as it is in the work of some other researchers [22] by considering the ambient temperature of 25^0C.

The heat balance in the incineration chamber is analyzed from the Tables 1 and 2. Considering the Input and the outputs the Net Heat Balance is 8,787.98kJ/kg (heat required to maintain the incinerator at 600^oC)

Two diesel burners were chosen for the incineration of the waste to sustain the over 600^0C temperature needed for complete combustion. The burners are driven by 7.5 kW motor, a two-stage sliding/modulating working system

Table 1: **Heat Balance Analysis; Input**

Waste Composition	Heat Value (kJ kg^{-1})	Percentage weight (%)	Total Heat value (kJ)
Paper	14,085	9	140,075
Plastic	33,712	4	149,007
Rubber	22,197	3	73,583
Textile	17,476	5	96,555
Wood	16,580	5	91,605
Leather	19,050	4	84,201
Garbage	9,000	49	487,305
Glass	0	8	0
Metal	0	13	0
Heat Input (kJ)			**1,122,331**

Table 2: **Heat Balance Analysis; Output**

Activity	**Energy Output (kJ)**
Radiation loss = 5% of total heat available = 5% × 1,122,331	56,117
Heat to ash $= mC_P(T_g - T_C)$ $= 0.35 \times 0.831 \times (600 - 25)$	13,140
Heat to dry combustion product= mC_PdT = $98.6 \times 1.086 \times (600 - 25)$	51,829
Heat to moisture = $(mC_PdT) + (mH_V)$ = $[7.92 \times 2.347 \times (600 - 25)] + [7.92 \times 2460]$ Heat to moisture = $(mC_PdT) + (mH_V)$ = $[7.92 \times 2.347 \times (600 - 25)] + [7.92 \times 2460]$	30,173
Total	**151,259**

The heat balance in the combustion chamber of the incinerator is shown in the schematic diagram of Figure 4.

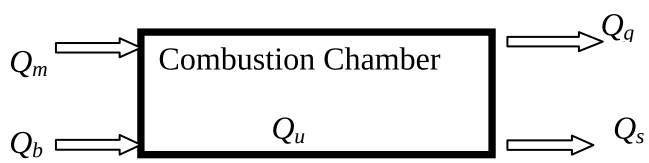

Figure 4: Schematic Diagram of Heat Balance of the Incinerator

Q_m: Heat energy of the waste material
Q_u: Heat energy retained in the unburned waste
Q_g: Heat energy of the flue gas
Q_s: Heat loss to the surrounding
Q_b: Heat supplied by the auxiliary burner

Similarly, a mass balance was calculated to determine and select the size of the blower fan for the introduction of air into the combustion chamber.

Finally, a performance test of the incinerator was performed. The combustion efficiency of the equipment was determined, using Equation 1.

$$\eta = \frac{CO_2}{CO_2 + CO}.100\% \qquad 1.$$

IV. EXPERIMENTATION

Municipal solid waste was gathered using wheel barrows from dump site in the community, including the nearby market landfill. The waste was then weighed, using a simple spring scale. A load of 110.50 kg of the waste was feed into the incinerator and the door was tightly closed. Before running the burners, the time, t, ambient temperature T_a and atmospheric pressure p_a was noted. The primary burner was lit for and the blower turned on for 45 minutes. Then, the secondary burner was lit and the two burners were allowed to run for over 5 hours. The content of the incinerator was examined at interval to ascertain the state of the waste.

Initially, at intervals of 1 hour, then 30 minutes, the primary burner was turned off, for safety, to inspect the burning waste through the waste door. When the waste was observed to have burned down, the incinerator was left to cool down for 1 hours before the grate was drawn open and the ash scraped out and weighed.

V. RESULTS AND DISCUSSIONS

The heat energy transferred into the treatment unit from the incinerator was calculated as shown in Table 1, 61,541kJ kg^{-1}. Part of the heat was recovered with the heat exchanger and returned to the incinerator to sustain the thermal activity.

The ash collected from the ash trough weighed 27.50 kg. The analysis from the input showed that 75.11% of the waste per weight was consumed in the treatment.

The combustion efficiency of the incinerator was analyzed to be 81.5%. This can be improved by the positioning of the burners, increasing the excess air supply and increasing the residence time.

The effect of the heat exchanger on the efficiency of the system will be determined in a future study.

VI. CONCLUSION

A 50 kg/hr incinerator was designed, fabricated and tested for a community in Bayelsa State in Nigeria, where waste is generally dumped into the river causing serious water pollution.

Incineration may not be the best method for the treatment of waste. Nevertheless, it is better than burning the waste in the open air as it is being done in most developing countries. The incineration process as a complementary Municipal Waste Management Program is innovative for the Nembe City. This will reduce the quantity of waste dumped into the rivers, by also using enlightenment program. The bottom ash can also be accumulated for civil works

The mass reduction of waste is 75% which is within the acceptable range of 70 – 80% [23]. The effect of the heat exchanger on the efficiency will be determined in a future study.

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