**A TETFUND Sponsored Project On:**

# Design and Construction of Modular Solid Waste Incinerator for Auchi Polytechnic Auchi

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## Abstract

An incinerator is a valuable technology for combusting campus, household, medical and carnage waste as an alternative to discharging it in a landfill. Heat energy may be recovered and it helps avoid open burning of municipal waste which otherwise creates much more harmful emissions and endanger human health and environment. In this research, a small scale modular solid waste incinerator was designed from hybridization of the dominant incinerator (control and excess air). Refractory requirement for the contact refractory like alumina and special insulating materials was selected for high thermal efficiency. For economic reasons, the bricks were made locally. Raw materials included, kaolin and shale. The precise composition was Silica 58%, alumina 27%, lime 4%, Iron oxide 5% Magnesia 0.8%. The raw materials were mixed while water was added gradually till the suitable consistency was reached. Moulds were used to compact and form the bricks. A week long open air drying was applied for solidification. An enclosure-like arrangements of bricks were made and wood was used as fuel to fire the bricks. The maximum temperature reached was 600ºC while firing the bricks. The bricks were set in the metallic mainframe of the incinerator using refractory mortar as the binder. The frame measures 1.6m by 1.0m by 0.9m and a brick, 0.2m by 0.3m by 0.15m. Thereafter, ten test firing on typical campus waste were done. The waste incinerator digest was examined by percentage combustion analysis. The average combustion efficiency of campus waste was 96.7%. The derived thermodynamic validity indicating the combustion efficiency was measured from the firing based data.

## 1.0 Introduction

### 1.1 Introduction

A crucial environmental challenge of modern times is the generation of humongous waste with poor or none disposal strategies in Africa and other developing nations. Ayuba, AbdMaf, Sabrina and NurAzim (2013) reported that mankind's livelihood is tied to the environment and that solid waste, desertification and flooding are the three major environmental problems in Nigeria and many other developing and even developed countries. Global municipal waste generation for every man, woman and child is currently at one tonne per year, its safe disposal has become a critical environmental crisis (Swithenbank, Nassezadeh, Goh and Siddall, 1999). In Nigeria, the rate of waste generation is estimated at

0.65-0.95 kg/capita/day which cumulatively averages about 42 million tonnes of wastes generated every year. This is approximately 68 % of the tonal of waste generated in sub-Sahara Africa per annum and wherewithal to systematically curb these wastes presents an enormous problem for the nation (Chinedu, Ezeibe and Anijiofor, 2018). When the re-use and recycling options have been exhausted, there still remains a bulk portion of municipal, clinical and hazardous wastes which must be disposed of in accordance to global standard. It has been reported that landfill creates the problems of methane leakage, groundwater contamination, and land usage, and is now perceived as environmentally unfriendly. Government across developed countries are imposing landfill tax to discourage burying waste and recognizing incinerators as the most environmentally friendly means of disposing of various forms of waste. Therefore, efficient solid waste disposal system will largely depend on the design of optimised incinerators (Swithenbank et al., 1999).

Incineration is an engineered process using controlled flame combustion to thermally degrade waste materials while producing heat, dry inorganic ash, and gaseous emissions (James and Welp, 2009). Also, incineration is the method of direct controlled burning of waste in the presence of oxygen at temperatures of about 800$^{o}$C and above, liberating heat energy, gases and inert ash. Net energy yield depends upon the density and composition of the waste. Relative percentage of moisture and inert materials, which add to the heat loss; ignition temperature; size and shape of the constituents; design of the combustion system, etc. Interest in incineration as a reliable and cost-effective method of solids handling has grown for several reasons. In this process about 95% reduction in volume and 70% reduction in weight of solids are feasible, which greatly reduces transportation requirements. Its offers complete destruction of pathogens, viruses and organic compounds in solids. Incineration has potential for heat energy recovery for autogenous combustion and process use, building heating, or power generation. Moreover, this method of waste disposal decreasing public acceptance of bio-solids land application in some locations (U. S. Environmental Protection Agency, 2001).

In the face of the numerous merits of incinerator in municipal solid and medical waste disposal, this best practice is absent across the campuses, health centres, towns and cities in Nigeria. The data from waste generation in Nigeria shows a direct correlation between population and waste accumulation (Table 1). Major cities such as Lagos, Benin, Abuja, Port Harcourt, Kaduna etc. with certain forms of waste management authorities struggle with efficient waste reception, storage let alone incorporating incinerator systems. At best, most cities waste disposal strategies focus mainly on open dump, open burning and landfills which are all regression to the stride achieved in 21st century waste disposal systems. The vagueness in Federal Environmental Protection Agency (FEPA) Degree No. 58 of 1988 policy on the collection, treatment and disposal of solid waste, shows a lack of innovation. Therefore, the aim of this paper is to design and construct small scale or modular waste incinerator with design model that can be scalable to medium or large scale application. The thermodynamic validity of the incinerator will be measured by computing higher heating value (HHV) from the ultimate analysis of the digested solid waste using the Mott-Spooner model. The value of the F-Factor ($F_{\mathrm{d}}$) will be determine as stipulated by United States Environmental Protection Agency (U.S EPA).

## 1.2 Aim

The aim of this research is to design and construct modular solid waste incinerators to cater for the waste management of Auchi Polytechnic Auchi with minimal environmental impact.

## 1.3 Objectives

The specific objectives of this research are to;

i. Design an incinerator with minimal emission of environmentally harmful gases.
ii. Construct the incinerator in suitable locations in Auchi Polytechnic, Auchi.
iii. Measure the efficiency of the incinerator by analysing the percentage combustion.

## 1.4 Significance

This incinerator could be replicated in major cities in Nigeria, especially the ones with reoccurring dumps of solid waste heaped at embarrassing locations. The daily turnout of waste should determine whether it is a small, medium or large scale incinerator to be employed to tackle the waste challenge. This has a potential of tackling the global ordeal of tonnes of plastic waste generated on daily basis. Contaminated hospital items are properly disposed by incineration particularly during the COVID 19 pandemic. The heat energy generated is effectively converted to electricity in other climes.

## 1.5 Scope

The research is limited to material selection, design, construction and test running of modular solid waste incinerators for area I of Auchi Polytechnic, Auchi campus. The recipe for bricks was formulated by the researchers and fired locally for specific quality assurance.

# 2.0 Literature Review

## 2.1 Incineration

Incineration is a waste treatment process that involves the combustion of organic substances contained in waste materials. Incineration and other high temperature waste treatment systems are described as thermal treatment. Incineration of waste materials converts waste into ash, flue gas and heat. The ash is mostly formed by the inorganic constituents of the waste and may take the form of solid lumps or particles carried by the flue gas. The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere. In some cases the heat generated by incineration can be used to generate power (Knox, 2006).

Incineration with energy recovery is one of several waste-to-energy technologies such as gasification, pyrolysis and anaerobic digestion. While incineration and gas technologies are similar in principle, the energy produced from incineration is high temperature heat whereas combustible gas is often the main energy product from gasification. Incinerator and gasification may also be implemented without energy and materials recovery (Herbert and Lewis, 2007).

Incinerators reduce the solid mass of the original waste by 80-85% and the volume by 95-96%, depending on composition and degree of recovery of materials such as metals from the ash for recycling.

Incineration has particularly strong benefits for the treatment of certain waste types in niche areas such as clinical wastes and certain hazardous waste where pathogens and toxins can be destroyed by high temperatures. Examples include chemical multi-product plants with diverse toxic or very toxic wastewater streams, which cannot be routed be routed to a conventional wastewater treatment plant (Kleis et al., 2004).

Waste combustion is particularly popular in countries such as Japan, Singapore and the Netherlands, where land is a scarce resource. Denmark and Sweden have been leaders by using the energy generated from incineration for more than a century, in localised combined heat and power facilities supporting district heating schemes. In 2005, waste incineration produced 4.8% of the electricity consumption and 13.7% of the total domestic heat consumption in Denmark. A number of other European countries rely heavily on incineration for handling municipal waste, in particular Luxembourg, the Netherlands, Germany and France (Knox 2005).

## 2.2 Principles of Incinerator Design

Waste management has become a major concern worldwide and incineration is now being increasingly used to treat waste which cannot be economically recycled. The combustion of conventional well specified fossil fuels is a very complex process since it involves two-phase turbulent reacting flow including radiant heat transfer. Incineration is even more complex since the waste is poorly specified and its composition varies from moment to moment. In the past, the design of incinerators has not been based on fundamental understanding and modelling of the process, and empirical rules have had to be used.

Over the years, computational fluid dynamics (CFD) has provided a means to model the freeborn region in a conventional municipal solid waste incinerator but the open literature contains no rigorous fundamentally based model of bed region. The prediction of the flow composition emerging from this region is particularly important since it provides the upstream boundary condition for the flow calculations in the freeboard. For example, the calculation of the subsequent history of heavy metals requires knowledge of their emission rate from the burning bed.

The processes in the bed include drying, pyrolysis, oxidative burning, and gasification of the char. Furthermore, the movement of the grate is designed to mix the waste as it burns. Indeed, the existence of a rigorous bed model would also permit the grate design to be optimised, and, if immediate data on the feed were available, a rational combustion control strategy could be devised. A preliminary model of combustion in the bed is proposed herein based on governing equations for the burning of individual regions of waste in the upward gas flow, their motion, and radiant heat transfer within the bed. The emissions of gases from the surface of the bed is very non-uniform with oxygen emitted from either end of the bed, organic compounds from the one-third region, and carbon monoxide from the centre. The surface layer of this central part of the bed consists of char with gases coming from the oxidising layer below containing NOx derived from the fuel nitrogen. The char region therefore acts as an important reburn zone and it is suggested that this reduces some of the NOx to nitrogen. This is important since the minimization of NOx by optimising the basic combustion process is likely to be environmentally preferable to subsequent control of NOx by the injection of reactants such as ammonia.

The calculation of flow and combustion in the freeboard using CFD can quantify the consequences of design concepts, however guidelines are needed to devise specific design concepts which are worthy of investigation. Thus the computer cannot invent a design but it can quantify the results of ideas.

Incinerator design thus requires a judicious combination of fundamental combustion science, ingenious engineering guided by an understanding of the mixing process, and practical experience of previous failures and successes.

## 3.0 Materials and Methods

### 3.1 Methodology

This section covers materials and incinerator design adopted for the modular solid waste incinerator. The efficiency was calculated from the estimated percentage of waste combusted. A large portion of the typical Auchi Polytechnic campus waste is made up of paper, plastic and organic materials. The incinerator design included the main chamber, the chimney area, the chimney, the bottom outlet and the blower/burner inlets.

### 3.2 Materials

Typically, the materials for the small scale waste incinerator includes fibres, insulating and contact refractories likewise metal. . In this research, a small scale modular solid waste incinerator was designed from hybridization of the dominant incinerator (control and excess air). Refractory requirement for the contact refractory like alumina and special insulating materials was selected for high thermal efficiency. For economic reasons, the bricks were made locally. Raw materials included, kaolin and shale. The precise composition was Silica 58%, alumina 27%, lime 4%, Iron oxide 5% Magnesia 0.8%. The raw materials were mixed while water was added gradually till the suitable consistency and viscosity was reached. Moulds were used to compact and form the bricks. A week long open air drying was applied for solidification. An enclosure-like arrangements of bricks were made and wood was used as fuel to fire the bricks. The maximum temperature reached was 600ºC while firing the bricks. The bricks were set in the metallic mainframe of the incinerator using refractory mortar as the binder. The frame measures 1.6m by 1.0m by 0.9m and a brick 0.2m by0.3m by 0.15m. Asbestos was used as a choice material for insulating the top opening of the incinerator mainly because of its availability. Thereafter, ten test firing on typical campus waste were done. The waste incinerator digest was examined by percentage combustion analysis. The average combustion efficiency of campus waste was 96.7%.

3.3 Design Overview

Our work was predicated on existing incinerator designs that have remarkably high efficiency. Three main types of incinerators design commercially available were considered: controlled air, excess air, and rotary kiln. Of this incinerators, the majority (>95%) are controlled air units. A small percentage (<2%) are excess air. Less than 1% were identified as rotary kiln. The rotary kiln units tend to be larger, and typically are equipped with air pollution control devices. Figure 1 shows the schematics of (a) excess air (b) rotary incinerator (c) controlled air and (d) the adopted design. The design parameter Chamber volume at 1.44 $m^3$ can be scalable to 8 or 10 $m^3$, is suitable for varieties of application like disposal of hospital / urban waste from small clinics, resort or communities and municipal waste.

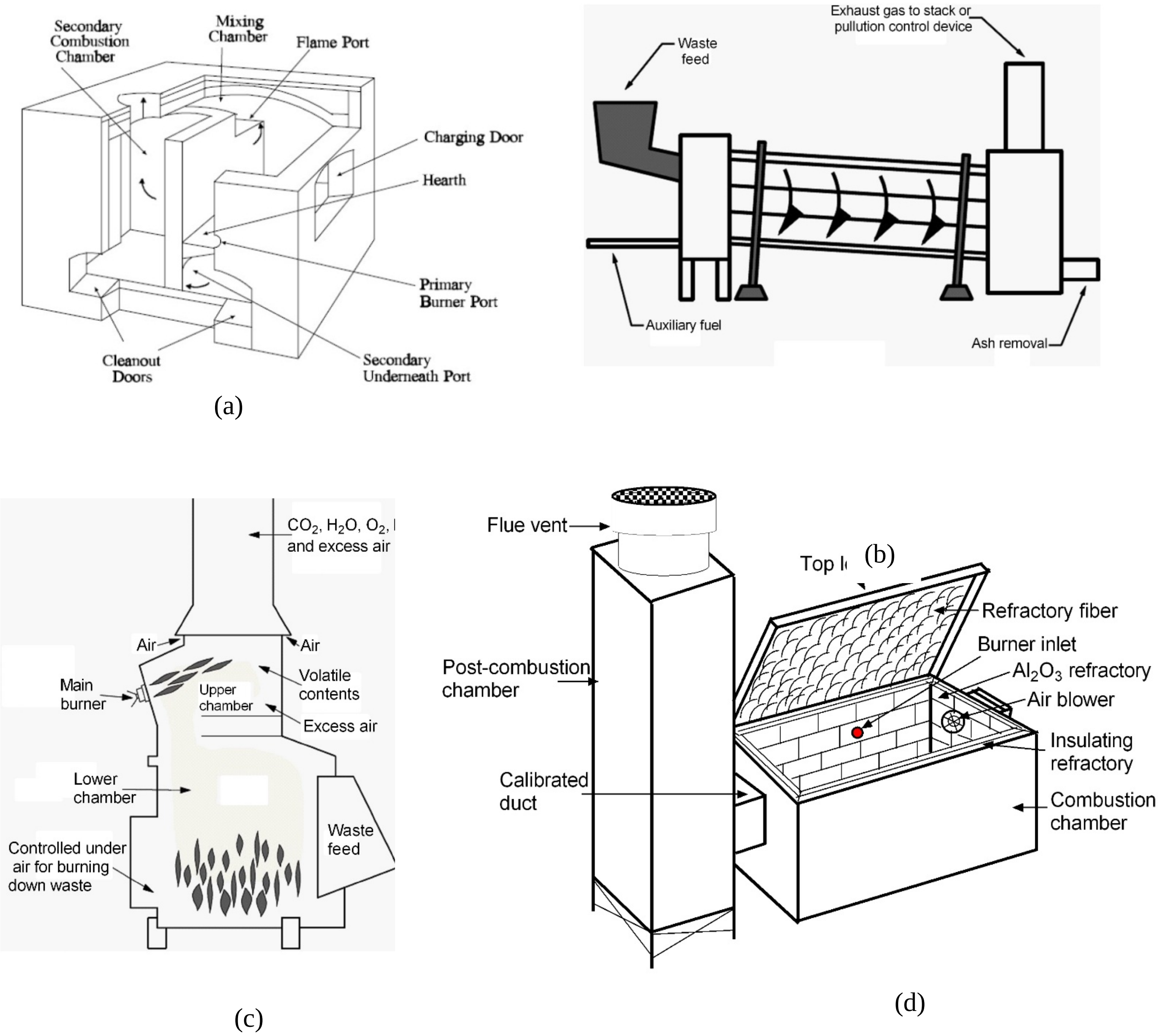


Figure 1. General schematics of solid waste incinerator (a) excess air (b) rotary incinerator (c) controlled air (d) our design, modelled using Graphpad™ software.

The top loading system ensures easy charging of the waste material to be treated into the incineration chamber. In Table1, the design parameters show the chamber volume and capacity adopted.  The design possess a hybrid design merit of regulated and excess incinerator systems coupled with the ideal refractory property requirements.

Table 1. Incinerator chamber volume and capacity

| Parameter | Unit | Chamber | |
|---|---|---|---|
| | | **Combustion** | **Post-combustion** |
| Volume | $m^3$ | 1.44 | 0.05 |
| Maximum burner capacity | *Kg/h* | 40 | - |
| Loading capacity | *Kg* | 120 | - |

## 4.0 Results and Discussion

4.1 Results and Discussion

After the firing of the bricks, the incinerator was built with provision for two burners and a blower. The blower has a power output of 1200W, 1300r/min blow rate and 230v rated voltage. In the incinerator design, the burners were placed almost directly opposite each other and the blower, adjacent to both of them. The burners were locally fabricated from steel pipes. The snout to the end length is 0.4m and a diameter of 0.02m.

A 15kg refuse was loaded in the main chamber for each firing. There were ten of such firings.

**Plate 1:** The wood fired bricks.    **Plate 2**: Wood ash after brick firing

 

**Plate 3:** The enclosure arrangement **Plate 4:** The construction of the incinerator

**Plate 5:** Waste loaded incinerator

**Plate 6:** Ready for firing

**Plate 7:** Firing initiated

**Plate 8**: The blower

## 5.0 Conclusion and Recommendation

### 5.1 Conclusion

The design and construction of a functional incinerator from locally sourced materials in Auchi, Edo state is feasible. The design was scaled down before construction in the Department of Ceramic Technology workshop in Area I. Evidently, the design is scalable in every respect. The average efficiency is 96.7% on typical campus waste (paper, plastic and organic waste).

### 5.2 Recommendation

1. The in-cooperation of the blower and a burner as a single piece will reduce operational combustion time and constrains.
2. The heat generated by combustion of waste in this incinerator could be channelled to preheating or electric generating purposes.
3. The design could be scaled up and applied as a major part of waste management of cities across the country.

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