DESIGN AND EVALUATION OF A DOUBLE CHAMBER INCINERATOR FOR LOW EMISSIONS

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Abstract: *This work on design and evaluation of a double chamber incinerator is part of a project on engineering design and production of a smokeless and non-pollutant emitting incineration system. The incinerator is designed to have double chambers each equipped with a burner and auxiliary air supply system. This incinerator is double walled and filled with insulating and lagging material. The primary chamber is designed to have between 750-980^oC temperature, while the secondary is designed to operate in a temperature of at least 1100^oC. The operating principles of the designed inconeration system in order to achieve the goal of reduction of emissions is based on the 3T's of combustion. This was possible the temperatures of operations in primary and secondary chambers, increasing gas residence time and design to encourage turbulence. The performance parameters of the incinerator were evaluated using classical emperical models as applicable to incineration systems.*

Keywords: *Incineration, Double Chamber, Emissions, Non-pollutant*

1. INTRODUCTION

Solid waste management is an important part of the urban infrastructure that ensures the protection of environment and human health (Sandna, 1982). In most cities in the developing world, several tons of municipal solid waste (MSW) are left uncollected on the streets each day, interfering with the free flow of drainage, creating feeding ground for pests that spread diseases, thus, creating and enormous health and infrastructural problems (Olisa, Amos, and Kotingo, 2016). The degradation of the environment caused by inefficient disposal of waste can be expressed by the contamination of soil, surface and ground water through leaching; the spreading of diseases by different vectors like birds, insects and rodents. There is also uncontrolled release of methane by anaerobic decomposition of waste and air pollution by open burning of waste. The sustainability of the land filling system has become a global challenge due to increased environmental concern. Therefore, there is need to practice integrated solid waste management approach such as, incorporation or more environmental and economic friendly concepts of source separation, recovery of waste, legitimization of the informal systems, partial privatization and public participation (Kreith, 1994).

Open burning of waste can be defined as the combustion of unwanted combustible materials such as paper, wood, plastics, textiles, rubber, waste oils and other debris in nature (open air) or in open dumps, where smoke and other emissions are released directly into the air without passing through chimney or stack. Open burning can also include incineration devices that do not control the combustion air to maintain an adequate temperature and do not provide sufficient time for complete combustion. This waste management practice is used in many developing countries while in developed countries open burning of waste may either be strictly regulated, or otherwise occur more frequently in rural areas than in urban areas.

While waste incineration is defined as the combustion of solid and liquid waste in controlled incineration facilities. Modern refuse combustors have tall stacks and specially designed combustion chambers, which provide high combustion temperatures, long residence times, and efficient waste agitation while introducing air for more complete combustion (IPCC, 2006). Types of wastes incinerated include, municipal waste (MSW), industrial waste, hazardous waste, clinical or hospital waste, and sewage sludge. The practice of MSW incineration is currently more common in developed countries, while it is common for both developed and developing countries to incinerate clinical waste. Incineration of waste converts the 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 particulates 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 electric power and steam for process industries.

As part of integrated waste management, the challenges of urban solid waste management can be addressed by building an incinerator to thermally treat the solid waste. Incinerators reduce the solid mass of the original waste by 85-90% and the volume (already compressed somewhat in garbage trucks) by 95-96%, depending on composition and degree of recovery of materials such as metals from ash for recycling (Knox, 2005; Ramboll, 2006). In the process of incineration, many harmful substances contained in the waste are destroyed. The process of incineration involves taking into consideration the temperature that the combusting gases reached, the length of time the gases remain at elevated temperatures, how well the air and gases are mixed and whether is adequate oxygen to permit complete combustion (Niessen, 2014).

Incineration has a particular strong benefits for the treatment of certain types of wastes in niche areas such as clinical wastes and certain hazardous wastes where pathogens and toxins can be destroyed by high temperatures. Waste combustion is particularly popular in countries like, Japan where land is a scarce resource. Denmark and Sweden have been leaders by using the energy generated from more than a century, in localized combined heat and power facilities supporting district heating scheme (Kleis, and Dalager, 2004). 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 MSW, in particular, Luxembourg, Netherlands, Germany and France.

Due to the increasing use of high-tech products, not only the amount of waste produced is increasing, but also the nature of waste produced is changing (European Commission, 2010). Some waste streams indeed contain a complex mix of materials, such as plastics, precious metals and hazardous compounds that are difficult to deal with safely (Block, Van Caneghem, Van Brecht, Wauters, and Vandecasteele, 2015). Incinerators are used to control open air burning basically to reduce air pollution, and sometimes where it is possible and convenient, energy recovery is the practice (Annunziato, 2006). Inspite of the control burning that is supposed to take place with use of incinerator, air pollution still takes place. The most publicized concerns from environmentalists about the incineration of solid wastes, be it, MSW, clinical or hazardous wastes, involved the fear that it produces significant amount of dioxins and furan emissions (Beychok, 1987). Dioxins and furans are considered by many to be serious health hazards (EPA, 2012). Other gaseous emissions in the flue gas from incinerator furnaces include, nitrogen oxides, sulfur oxides, hydrochloric acid, heavy metals, and fine particles (Chang, Jen, Wu, and Lin, 2003).

In 2005, the Ministry of Environment of Germany, where there were 66 incinerators at that time, estimated that "…whereas in 1990 one third of all dioxins emissions in Germany came from incineration plants, but for the 2000 the figure was less than 1%. Chimneys and tiled stoves in private households alone discharge approximately 20times more dioxins into the environment than incineration plants (Ministry of Environment, 2005). Therefore, to monitor and limit the formation of hazardous gases associated with the use incinerators, various techniques have been employed through different designs.

As stated earlier, MSW incineration process is a common practice in developing countries like Nigeria, hence this work focused on the design and development of a double chamber incinerating system for solid waste management and pollution control. The principle behind the double chamber incinerator is based on enhancing complete combustion of waste and flue gases through increased thermal combustion temperature and resident time of the gaseous products.

2. LITERATURES AND THEORETICAL BACKGROUND OF INCINERATION

Incineration may be defined as the thermal destruction of the waste at elevated temperatures say 900^oC to 1600^oC under controlled operational condition (John and Swamy, 2011). Properly controlled incineration is an effective means of reducing waste volume. It ensures cleaner and more complete combustion of wastes and lends itself well to waste disposal in areas where population density is relatively high and sites for ladnfill is low. Incineration uses combustion to make infectious medical waste harmless and reduce the waste mass and volume by more than 90%. Proper incineration can convert certain wastes into gases and incombustible solid residues (e.g., ash) that are relatively harmless. Incinerators are usually designed to retain a suitable temperature of the combustion chamber. To this end, suitable materials are used for the inside wall of the incinerator (Picken, Russell, and Nwadukwe, 2014). The material should have high heat flow resistance and should be ableto withstand high temperatures.

The application of combustion principle is either external or internal. External combustion application is found in incinerators and other areas such as burner furnace, and boiler heaters, while internal combustion application is found in car engines, jet plane engines, power generators, etc. Over the years, even in the 20th century, in most waste management process, combustion (incineration) remains an attractive or necessary element of waste management. Occasionally, as for the incineration of fumes or essentially ash-free liquids or solids, combustion processes may properly be called ‘disposal’. For most solid and many liquids, incineration is the only a processing step, whereas liquid and solid residues there produced remain for subsequent disposal (Niessen, 2002).

However, incineration of wastes offers the following potential advantages: (1) Volume reduction; important for bulky solids or wastes with high combustible and/or moisture content. (2) Detoxication; for combustible carcinogens, pathological contaminated materials, toxic organic compounds, or biologically active materials. (3) Environmental impact mitigation; the impact of the CO_2 ‘greenhouse gas’ generated in incinerating solid waste is less than that of the methane (CH_4) and CO_2 generated in landfilling operations. The pollutant air emissions per kilowatt of power are significantly less than that generated by coal and oil burning utility plants (Rigo, Ferraro, and Wilson, 1994). (4) Regulatory compliance. (5) Energy recovery; important when large quantities of waste are available and reliable markets for by-product fuel, steam, or electricity are nearby. (6) Stabilization in landfills; incineration forms oxides or glassy, sintered residues that are insoluble (nonleaching). (7) Sanitation; prevention of public health hazard through destruction of pathogenic organism.

These advantages have justified development of a variety of incineration systems, of widely different complexity and function to meet the needs of municipalities, commercial, industrial firms, and institutions. Going contrary to these advantages are the following disadvantages: (1) Cost; incinerators are usually costly waste processing step. (2) Operating problems; high maintenance requirement and equipment unreliability (3) Staffing problem; the low status often associated or accorded to waste disposal job can make it difficult to obtain and retain qualified supervisory and operating staff. (4) Secondary environmental impacts; air emissions (odour, gases, fly ash, carcinogenic hydrocarbons), waterborne emissions–water used in wet scrubber-type air pollution control often becomes highly acidic, residue impacts – residue disposal presents a variety of aesthetic, and worker health-related issues that require attention in system design. (5) Public sector reaction (6) Technical risk; process analysis of combustors is very difficult (Niessen, 2002).

Nevertheless, with all these disadvantages, incineration has persisted as an important concept of waste management because of its advantages in control of pollution to the environment.

2.1 Methods and Estimation of Combustion Emissions

For waste incineration, the most accurate emission estimates can be developed by determining the emissions on a plant-by-plant basis and/or differentiated for each waste category (e.g., MSW, sewage sludge, industrial, clinical, hazardous wastes). The methods for estimating CO_2, CH_4, and N_2O emissions from incineration and open burning of waste vary because of the different factors that influence emission levels. Estimation of the amount of fossil carbon in the waste burned is the most important factor determining the CO_2 emissions. The non-CO_2 emissions are more dependent on the technology and conditions during incineration process (IPCC, 2006). The general approach to calculate greenhouse gas emissions from incineration and open burning waste, is to obtain the amount of dry weight of waste incinerated (preferably differentiated by waste type) and to investigate the related greenhouse emission factors (preferably from country-specific information on the carbon content and the fossil carbon fraction).

There are three methods or tiers according to IPCC (2006) applicable in estimating emissions, these tiers or methods differ in what extent the total amount of waste, the emission factors, and parameters used are default (Tier 1), country-specification (Tier 2a, Tier 2b) or plant specification (Tier 3). In the research we adopted Tier 1 for our analysis.

2.1.1 Estimating CO_2 Emissions

The common method (Tier 1) 11for estimating CO_2 emissions from incineration and open burning of waste is based on an estimate of the fossil carbon content in the waste combusted, multiplied by the oxidation factor, and converting the product (amount of fossil carbon oxidized) to CO_2. Data on the amount of waste incinerated/open-burned are necessary (Anderl, Halper, Kurzweil, Poupa,…, and Weiser, 2004). Default data on characteristic parameters (such as dry matter content, carbon content, and fossil carbon fraction) for different types of waste are provided in Table 1. The method based on the total amount of waste combusted is given by equation (1), and that of MSW composition is given in equation (2). It is preferable to apply (2) for MSW, but if the required MSW data are not available (1) should be used.

$$CO_2\ Emissions = \sum_i (SW_i \times dm_i \times CF_i \times FCF_i \times OF_i).44/12 \qquad (1)$$

Where; CO_2 = Carbon(iv)oxide emissions in inventory year, Gg/yr; SW_i = total amount of solid waste type *i* (wet weight) incinerated or open burned, Gb/yr; dm_i = dry matter content in the waste (wet weight) incinerated or open-burned, (fraction); CF_i = fraction of carbon in the dry matter (total carbon content), (fraction); FCF_i = fraction of fossil carbon in the total carbon, (fraction); OF_i = oxidation factor (fraction); 44/12 = conversion factor from C to CO_2; i = type of waste incinerated/open-burned (MSW: municipal solid waste (if not estimated using equation (2)), ISW: industrial solid waste, SS: sewage sludge, HW: hazardous waste, CW: clinical waste, and others that must be specified)

$$CO_2\ Emissions = MSW.\sum_j (WF_j \times dm_j \times CF_j \times FCF_j \times OF_j).44/12 \qquad (2)$$

Where: WF_i = fraction of waste type/material of component *j*in the MSW. With $\sum_j WF_j = 1\ as\ j =$ components of the MSW incinerated/open-burned such as paper/cardboard, textiles, food waste, wood, nappies, plastics, glass, etc.

Table 1: Default Data for CO_2 Emission Factors for Incineration and Open Burning of Waste (IPCC, 2006)

Parameters	Management Practice	MSW	Industrial Waste (%)	Clinical Waste (%)	Sewage Sludge (%)	Fossil Liquid Waste (%)
Dry matter content in % of wet weight		40-90	NA	NA	NA	NA
Total carbon content in % of dry weight		38-70	50	60	40-50	80
Fossil carbon fraction in % of total carbon content		16-80	90	40	0	100
Oxidation factor in % of carbon input	Incineration	100	100	100	100	100
	Open-burning	58	NO	NO	NO	NO

NA: Not Available, NO: Not Occurring

2.1.2 Estimating CH_4 Emissions

Methane emissions from incineration and open burning of waste are as a result of incomplete combustion. Important factors affecting the emissions are temperature, residence time, air ratio (i.e., air volume in relation to amount of waste). Methane emissions are particularly relevant for open burning, where a large fraction of carbon in the waste is not oxidized. In large and well-functioning incinerators, CH_4 emissions are usually very small. It is good practice to apply the CH_4 emission factor (Table 2). If the storage area gases are fed into the air supply of the incinerator chamber, they will be incinerated and emissions will be reduced to insignificant levels (BREF, 2005). The calculation of CH_4 emissions is based on the amount of waste incinerated/open-burned and on the related emission factor as given by equation (3);

$$CH_4\ Emissions = \sum_i (IW_i \times EF_i) \times 10^{-6} \qquad (3)$$

Where: CH_4 Emissions = methane emissions in inventory year, Gg/yr; IW_i = amount of solid waste of type *i* incinerated or open-burned, Gg/yr; EF_i = aggregate CH_4 emission factor, kg CH_4/Gg of waste; 10^{-6} = conversion factor from kilogram to gigagram; *i* = category or type of waste incinerated/open-burned, specified as in CO_2.

Table 2: CH_4 Emission Factor for Incineration of MSW (GIO, 2004)

TYPE OF INCINERATOR/TECHNOLOGY		CH_4 Emission Factors (kg/Gg waste incinerated on a wet weight basis)
Continuous incineration	Stoker	0.2
	Fluidized bed	0
Semi-continuous incinerator	Stoker	6
	Fluidized bed	188
Batch type incinerator	Stoker	60
	Fluidized bed	237

2.1.3 Estimating N_2O Emissions

Nitrogen oxide is emitted in combustion process at relatively low combustion temperatures between 500 and 950°C. Other important factors affecting the emissions are the type of air pollution control device, type and nitrogen content of the waste and the fraction of excess air (BREF, 2005; Korhonen *et al.*, 2001; Loffler *et al.*, 2002; Kilpinen, 2002; Tsupari *et al.*, 2005). The calculation of N_2O emissions is based on the waste input to the incinerator or the amount of waste open-burned and a default emission factor (Tables 3 and 4). This relationship is given by equation (4);

$$N_2O\ Emissions = \sum_i (IW_i \times EF_i) \times 10^{-6} \quad (4)$$

N_2O emissions can also be calculated based on the influencing factors as follows;

$$N_2O\ Emissions = \sum_i (IW_i \times EC_i \times FGV_i) \times 10^{-9} \quad (5)$$

Where: N_2O Emissions = N_2O emissions in inventory year, Gg/yr; EC_i = N_2O emission concentration in flue gas from the incineration of waste type *i*, mg N_2O/m^3; FGV_i = flue gas volume by amount of incinerated waste type *i*, m^3/Mg; 10^{-9} = conversion from milligram to gigagram.

Table 3: N_2O Emission Factors for Incineration of MSW (GIO, 2005; Johnke, 2003; Spakman, 2003; Anderl, 2004)

Country	Type of Incineration/Technology		Emission factor for MSW (g N_2O/t MSW incinerated)	Weight basis
Japan	Continuous incineration	Stoker	47	Wet weight
		Fluidized bed	67	Wet weight
	Semi-continuous incinerator	Stoker	42	Wet weight
		Fluidized bed	68	Wet weight
	Batch type incinerator	Stoker	56	Wet weight
		Fluidized bed	221	Wet weight
Germany			8	Wet weght
Netherlands			20	Wet weight
Austria			12	Wet weight

Table 4: N_2O Emission Factors for Incineration of Sludge and Industrial Wastes (GIO, 2005; Johnke, 2003)

Country	Type of Waste	Type of Incinerator/Technology	Emission Factor for Industrial Waste (g N2O/t waste)	Weight Basis
Japan	Waste paper, waste wood		10	Wet weight
	Waste oil		9.8	Wet weight
	Waste plastics		170	Wet weight
	Sludge (except sewage sludge)		450	Wet weight
	Dehydrated sewage sludge		900	Wet weight
	High molecular weight flocculant	Fluidized bed incinerator at normal temperature	1508	Wet weight
	High molecular weight flocculant	Fluidized bed incinerator at high temperature	645	Wet weight
	High molecular weight flocculant	Multiple hearth	882	Wet weight
	Other flocculant		882	Wet weight
	Lime sludge		294	Wet weight
Germany	Sewage sludge		990	Dry weight
	Industrial waste		420	Wet weight

2.2 Emissions Reduction Process by The Three T's

All the emissions and others mentioned above occur due to incomplete combustion of waste at low combustion temperatures. The disadvantages of incineration are majorly cause by the environmental and hazardous pollutions resulting from these emissions, which must be tackled in order to obtain clean and health friendly incineration. These products of incomplete emissions can be reduced by design inclusion of the phenomenon known as 3T's of combustion which are, Temperature, Time, and Turbulence.

2.2.1 Temperature

Among the three T's of combustion, temperature is probably the most critical with respect to incineration combustion. Essenhigh (1968) theorized that a small change in flame temperature can significantly change the efficiency of combustion. Moisture and too much excess air are the major causes of reduced incinerator flame temperatures for a given fuel. More understanding of the incineration process through quantitative measurement and analysis, coupled with experience factors and valid assumptions, combustion and heat calculations are invaluable in designing an incinerator and in evaluating its performance

(Kaiser, 1965). The importance of high combustion temperatures and chamber heating cannot be over emphasized in reduction of incineration emissions through complete combustion.

For an optimum design of combustion temperature, the area of heat balance calculation should be properly evaluated. The heat losses due to radiation, heating of the refractory materials, and air leakage are very significant for batch operated incinerators. It can be shown that most of the heat from refractory incinerators goes up the chimney. Some researchers assumed that 2 to 5% of heat is lost by radiation and heating of furnace areas, but generally this is during continuous operation. Therefore a two stage incineration is highly recommended to increase the combustion of flue gases through an additional burner in a secondary chamber. Such arrangement facilitates a preheat cycle and better temperature control in the secondary chamber over the entire burning cycle. Feuss and Flower (1969) recommended the installation of automatically controlled auxiliary burners and indicating pyrometers. The indicating pyrometer facilitates air adjustments and alerts for excessive air leakage, as well as defective or dirty thermocouples or burners. However, temperature should be maintained between 700^{o}C (1200^{o}F) and 920^{o}C (1800^{o}F) at least in the secondary chamber.

2.2.2 Time

It is now axiomatic that the time required for complete combustion of solid waste is a function of temperature and turbulence and the burning characteristics of the waste. With good mixing achieved by proper use of overfire air systems, combustion time can be significantly reduced. It has been found that a minimum of 0.5 seconds at about 1400^{o}F is apparently required for the complete combustion of most obnoxious gases (Feuss and Flower, 1969). It is possible to calculate roughly the average residence time in the primary or ignition chamber if one assumes that the temperatures specified in the standards are actually reached, that the excess air admitted to the chamber is controlled in accordance with the criteria, and that the approximate combustion air calculations supplied or implied are satisfactory.

The retention or residence time in the secondary combustion chamber is as or more significant, because of possible short circuiting, inadequate mixing, and low initial temperatures in the primary chamber. Therefore, it is imperative to create a system that will increase the residence time of the gases in the secondary chamber such as overfire air jets with a burner providing higher combustion temperatures than that in the primary chamber.

2.2.3 Turbulence

It has been generally accepted that by increasing turbulence without decreasing temperature, the time required for complete combustion is reduced. The common methods of creating turbulence in incinerators are increased velocities, directional changes, and forced overfire air systems. The former two are cheaper, but the latter is believed by researchers to be more effective. The different mixing chamber velocities called for in the existing codes are interesting but of questionable significance. The velocities in the mixing chamber are subject to wide variation with temperature, burning rate, etc. the forced overfire air systems have the advantage of creating turbulence over the burning waste and reducing the potential of prolonged smoldering.

3. METHODS AND MATERIALS

Two stage starved air incinerator was conceived in the mid 50's and it proved an effective means of incineration. Compact size, low emission levels without scrubbers or settling chambers, and overall simplicity are advantages inherent in the concept. The present double chamber design follows some of the concepts, therefore, it is not revolutionary but an evolution of this old design with additional application of the fundamental theories of fluid mechanics, thermodynamics and combustion.

Combustion processes are complicated. An analytical description of combustion system behaviour requires consideration of the following; (a) chemical reaction kinetics and equilibrium under non-isothermal, non-homogeneous, unsteady conditions. (b) fluid mechanics in non-isothermal, non-homogeneous, reacting mixtures with heat release which can involve laminar, transition, and turbulent, plug, recirculating, and swirling flows within geometrically complex enclosures. (c) heat transfer by conduction, convection, and radiation between gas volumes, liquids, and solids with high heat release rates and (with boiler system) high heat withdrawal rates.

In incineration applications, this complexity is often increased by frequent, unpredictable shifts in fuel composition that result in changes in heat release rate and combustion characteristics (ignition temperature, air requirements, etc.). Compounding these process-related facets of waste combustion are the practical design and operating problems in material handling, corrosion, odor, vector, and vermin control, residue disposal, associated air and water pollution control, and myriad social, political, and regulatory pressures and constraints. These constraints include the problem of designing an incinerator to cope with virtually any type of waste without any human intervention, low emissions, high cost effectiveness, and operational reliability.

3.1 Operational Principle of the Double Chamber Incinerator

The fundamental operational principle of this double chamber incinerating system can be stated in the following sequence:

The raw wastes are fed into the primary chamber, which is a refractory lined or double-walled lagged shell. The amount of loading (waste to be charged) into the primary chamber is related to the burning rate for this particular incinerator design. A fraction of the waste, generally the fixed carbon, is oxidized releasing heat.This heat causes the endothermic pyrolysis of the volatile fraction of the waste, and results in a dense combustible smoke. The air (oxygen) flow rate into the primary chamber is carefully increased through an air pump system as the system is designed not to be air starved. This additional air helps in increasing the combustion temperature of the primary chamber hence leading to an almost complete combustion. The combustion temperature in the primary chamber is maintained at about 750^oC up to 980^oC. In the primary chamber, the air to fuel ratio is made to be low to reduce the entrainment of fly ash and particles, as well as fuel required to heat the excess air.

The smoke, flue gases and some fly ash pass from the primary chamber to the secondary chamber through an opening at one corner of the upper part of the primary chamber. The secondary chamber is equipped with an auxiliary burner system which operates at a temperature higher than what was obtainable in the primary chamber. An overfire air jet system is an additional and/or optional design to the secondary chamber. This overfire airjet system helps in increasing the combustion temperature, the gas residence time amd the turbulence hence incorporating the 3T's of combustion. This design produces a complete combustion of flue gases, fly ashes which are forced back into the primary chamber by the airjet.The secondary chamber involves the oxidation of the volatile compounds and fly ashes making up the smoke from the primary chamber, thereby producing an almost pollutant free emissions.

3.2 Design Specifications of the Incineration Concept

The design concept and specification for this incineration system as earlier stated is a double chambered combustion system (Fig. 1). As the heat energy required for incineration operation entirely depends on the combustion process, the incinerator is designed with an oxygen inlet, which freely allows flow of air into the primary burning chamber. The extra heat source (fire) from the burner is needed to initiate the burning process expressed as in (6);

$$C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5H_2O + heat \qquad (6)$$

In normal circumstance, sufficient oxygen is served by natural induction through air apertures where it meets with fuel and heat so that a complete combustion is experienced. Oxygen starvation often leads to partial combustion of the carbon to CO rather than CO_2.

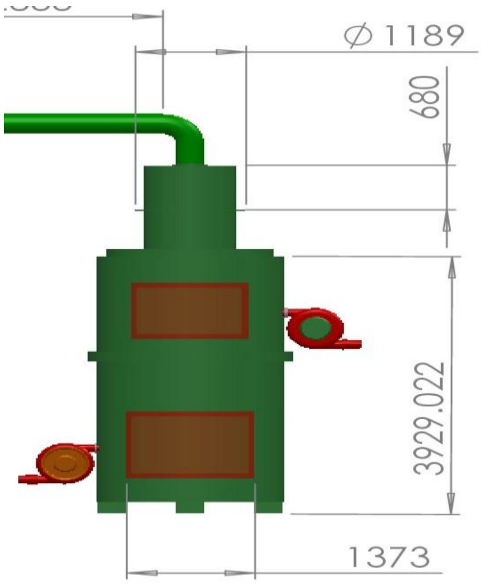

Fig 1: A Two-dimensional view of the double chamber Incinerator design

3.2.1 Primary Chamber Design and Specifications

The design concept of the primary chamber is relative as the shape is not critical, hence can be based on the manufacturers' considerations. The primary chamber of this incinerator is designed as sealed, cylindrical, double walled thick steel shell lined and lagged with fibre glass and/or Calcium silicate insulation system (or can be lined with brick refractory insulators). The chamber receives waste through a the loading port located where the charge of waste will have a minimum disruptive effect on the waste bed.This chamber is equipped with a burner and air (oxygen) supply system, and an opening at the top corner of the chamber smoke and gaseous movement into the secondary chamber.

The specification is that for this given design for a given waste and at a given load rate, there are three quantities that must be specified; primary air supply rate, fuel requirement, and chamber volume. Evaluation of reactions and processes in the primary chamber is achieved as we specify the significant characteristics of the waste, which are evaluated in subsequent empirical formulas for analysis. We make the following assumptions of; waste having a mass of,M_w, is introduced into the primary chamber through the loading port. The primary air having a mass flow rate of,M_a, is introduced through the auxilliary air supply sytem, at an average carbon flow rate of,M_c.

One criterion for the auxiliary air rate is that it must be sufficient for steady state oxidation of the fixed carbon fraction F_c and the realtive carbon saturation factor for the primary chamber,P_{fc}, is given as (English II, 1972);

$$P_{fc} = \frac{moles\ of\ fixed\ carbon}{moles\ of\ oxygen} \quad (7)$$

When there is enough primary air for the overall reaction as in (8), then $P_{fc} = 1$, and the air is oxidizing the carbon at maximum rate.

$$C + {}^{1}/_{2}\,(O_2) \rightarrow CO \quad (8)$$

This is practically an incomplete combustion, therefore, more air is required and in this case some of the carbon undergoes the overall reaction;

$$C + O_2 = CO_2 \quad (9)$$

In terms of waste and air input to the primary chamber,

$$P_{fc} = 5.72\frac{M_c}{M_a} = \frac{5.72M_w(1 - F_m)F_c}{M_a} \quad (10)$$

Where; F_m = moisture fraction, F_c = char fraction. P_{fc} can also be expressed in terms of volumetric gas () fractions so that performance can be checked by a gas analysis;

$$P_{fc} = \frac{F_{CO} + F_{CO_2}}{F_{CO} + 2F_{CO_2} + 2F_{O_2}} \quad (11)$$

Based on the energy required to pyrolyze the volatile fraction, F_p, and to vaporize the moisture fraction, F_m, the overall relationship in the primary chamber is,

$$Q_{pc} = Q_{loss} + Q_p + Q_a + Q_v \quad (12)$$

Where; Q_{pc} = the exothermic heat of the combustion occurring in the primary chamber. Other terms on the right hand side of (12) can be obtained from the following expressions;

$$Q_{loss} = A(h_c + h_r)(T_{ex} - T_o) \quad (13)$$

Where; Q_{loss} = the heat loss through the chamber walls, A = the external area of the primary chamber, T_{ex} = temperature of the exterior or outer shell of the chamber, T_o = the ambient temperature, $(h_c + h_r)$ = the total heat transfer coefficient which can be obtained from a basic heat transfer text (). The exterior temperature is very small when the chamber is well insulated, hence, this is generally the least significant term,

$$Q_p = M_w(1 - F_m)(F_p)H_p + (C_p)_p(T_s - T_o) \quad (14)$$

Where; T_s = the smoke or flue gas exit temperature, H_p = the combined latent heat and pyrolytic heat of reaction of the volatile hydrocarbons, and $(C_p)_p$ = the average specific heat of all phases of hydrocarbon.

$$Q_a = M_p(C_{pair})(T_s - T_o) \quad (15)$$

And,

$$Q_v = M_w(F_m)\left[C_{p1}(212 - T_o) + H_m + C_{p2}(T_s - 212)\right] \qquad (16)$$

Where; H_m = the latent heat of steam, C_{p1} = the specific heat of water and C_{p2} = the specific heat of steam.

Typically, when the moisture content exceeds 25%, it is often necessary to supply auxiliary fuel to the primary chamber, or, at least, have the capacity to add extra fuel. If the total heat content of the waste is less than Q_v, it is essential and we have,

$$(Q_{aux})_{min} = Q_{pc} - Q_t \qquad (17)$$

Practically speaking, the system burner in the primary chamber should have a capacity that is at least twice the above value, because poor heat transfer to the waste in the primary chamber can produce low burner efficiency.

However, for a given loading rate and waste toe, the theoretical required volume of the primary chamber, V_{pc}, based on steady state, one-dimensional, homogeneous conditions (English II, 1972), can be expressed as;

$$V_{pc} = V_a + V_c + V_p + V_o \qquad (18)$$

Where; V_a = volume of the ash bed, V_c = volume of char bed, V_p = volume of pyrolytic zone, V_o = volume of overfire zone. Fig. 2, depicts the scheme of the regions in the steady state, one-dimensional, homogeneous condition.

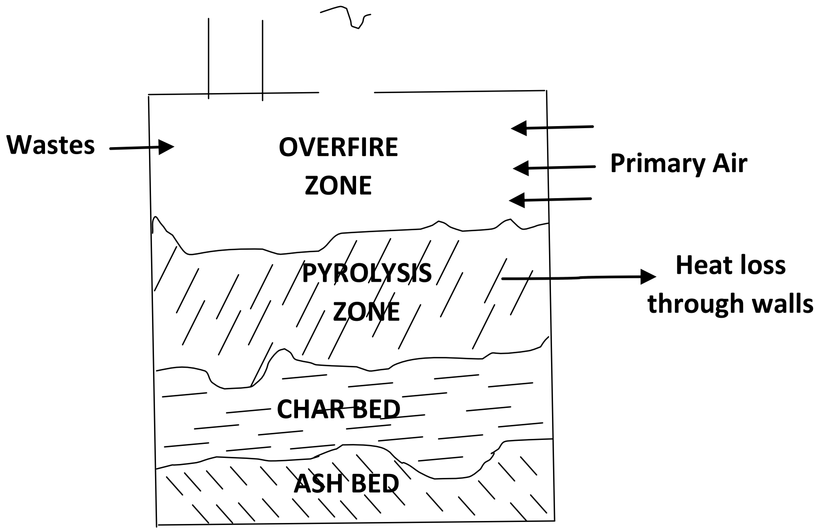

Fig 2: One dimensional schematic of primary chamber

Wastes are generally classified into types (Table 5), based on heat and moisture content, so that the results of incineration system can be generalized. The primary chamber volume required for a given load rate of a waste of known heat and moisture content can be estimated and proper size incinerator can be selected. Heat content, moisture content, and mass breakdown (proximate analysis) are available for wide variety of waste so that reasonable estimates can be made without actual testing (Kaiser, 1965; Kaiser and Friedman, 1968).

Table 5: Waste Classification (English II, 1972)

Waste	Description	Moisture Content	Heat Content (kJ/kg)
0	Dry paper, cartons, up to 10% plastics	10%	19,771
1	Paper, cartons, up to 20% garbage, no plastic	25%	15,119
3	An average mixture of types 1 and 3	50%	10,002
4	Garbage: animal and vegetable wastes	70%	5,815
5	Pathological waste	85%	2,326

3.2.2 Secondary Chamber Design and Specifications

The purpose of the secondary combustion chamber in an incineration unit is to prevent direct or release of certain chemicals or gases emitted by the incinerator from entering the atmosphere. One of the methods of achieving such is to raise the gases to such a temperature in the pressure of oxygen, as will destroy the chemicals or gases by pyrolysis and/or oxidation and combustion.

The secondary combustion chamber is designed and equipped with burner and an overfire airjet system to increase the efficiency of combustion. The temperature in the secondary chamber is designed for a minimum of 1100^{o}C (2010^{o}F) with an operating temperature of not less than 1000^{o}C (1830^{o}F) at all times. The temperatures in the primary and secondary chambers should be attained within maximum of 45 minutes prior to waste charging or loading.

The volume of the secondary chamber is designed in order to maintain a gas residence time of at least 1 seconds at 1000^{o}C. This chamber volume is made in such a way from the flame front to the location of the temperature sensing device could keep the gas residence time. The secondary chamber is attached with a thermocouple or other temperature sensor located at a pointer presenting 1 second tetention time at the exit of the secondary chamber or at the breeching. This automatic temperature control also regulates the modulating the chamber burner.

The secondary chamber is designed with double-walled shell of steel of not less than 5mm thickness, insulated with lagging material of glass fibre and/or calcium silicate. This insulation through lagging is designed to maintain a maximum temperature of 70 – 90^{o}C (160

– 195°F). the refractory and/or insulated surface of the secondary chamber should be heated over a minimum of 45 minutes prior to feeding or loading of wastes into the incinerator, to ensure optimum conditions for the destruction of micro-organisms.

Turbulence of gases is an important parameter in the design of incinerators and can be achieved in the secondary chamber by high gas combustion velocity, tangential air injection, abrupt changes in flow direction. The design to achieve turbulence was made through the installation of baffles and the location of orifice for smoke and gas flow tangentially at the one corner of the primary chamber roof.

The air supply in the secondary chamber of all incinerators should be able to provide excess air at 40 to 250% of that theoretically required during the peak burning rate. This was achieved by designing an overfire airjet into the secondary chamber. The combustion air supply is designed to be adjustable with temperature control system to maintain the set of temperatures in the primary and secondary chambers of the incinerator.

The burners are designed to maintain a stable flame throughout the range of pressure, input rates, and fuel/air ratios experienced in the primary and secondary chambers. These burners are to supply a minimum of 80% of the total heat input and also capable of modulating down to 15% of total heat input requirement. The burner in the secondary chamber is mounted in a position on the body of the chamber to promote thorough mixing throughout the whole chamber. The positioning also was made in order not to allow the flame to impinge on the refractory walls or on other burners assuming an auxiliary burner is added. Exit temperature of the secondary chamber can be estimated from the overall heat release rate and overall flow rates as;

$$T_e = \frac{\{M_w H_T + (mC_p)_{air} T_s + (mC_p)_{dw} T_s + M_m [212C_{p1} - H_m - C_{p1}(212 - T_s)]\}}{(mC_p)_{air} + (mC_p)_{dw} + M_m C_{p2}} \qquad (19)$$

Where; subscript 'e' refers to chamber or stack exit, subscript 'air' refers to total air, subscript 'dew' refers to dry waste and others are the same as earlier stated.

4. CONCLUSION

The design concept of the primary chamber is relative as the shape is not critical, hence can be based on the manufacturers' considerations. The primary chamber of this incinerator is designed as sealed, cylindrical, double walled thick steel shell lined and lagged with fibre glass and/or Calcium silicate insulation system (or can be lined with brick refractory insulators). The chamber receives waste through a the loading port located where the charge of waste will have a minimum disruptive effect on the waste bed. This chamber is equipped with a burner and air (oxygen) supply system, and an opening at the top corner of the chamber smoke and gaseous movement into the secondary chamber.

The purpose of the secondary combustion chamber in an incineration unit is to prevent direct or release of certain chemicals or gases emitted by the incinerator from entering the atmosphere. The secondary combustion chamber is designed and equipped with burner and an overfire airjet system to increase the efficiency of combustion. The temperature in the secondary chamber is designed for a minimum of 1100^{o}C (2010^{o}F) with an operating temperature of not less than 1000^{o}C (1830^{o}F) at all times. The temperatures in the primary and secondary chambers should be attained within maximum of 45 minutes prior to waste charging or loading. With the implementation of the principle of 3T's of cumbustion an incineration system with little or non emissions was achieved.

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