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Engineering Design of a Smokeless and Non-Pollutant Emitting Incineration System

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Original Research Article

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Abstract: This research project is embarked on to achieve an engineering and technological innovation of designing and construction of a smokeless and non-pollutant emitting incineration system (prototype at this point) for environmental sustainability. The incinerator is designed with two-chambers (primary and secondary) each equipped with burner, with an overfire air jet system added to the secondary chamber to increase residence time. Due to intended movability of the system at this stage of the design, the incinerator is double walled and lagged with fibre glass. The temperature in the primary chamber was designed at 800^0C, while that of secondary chamber is designed for 1000^0C. An air pollution control system in the form of a wet scrubber is designed to be retrofitted to the incinerator to completely remove the remaining flue gases and particulate matters released from the incinerator through a wash down and absorption mechanism. This system therefore, will improve our incineration system in municipal, hospital and industrial solid waste removal. The water for the spray tower is designed to be mixed slake lime to help in absorption of some acidic gases in the smokes from the incinerator.
Keywords: Double chamber, Incinerator, Wet scrubber, Flue gas, Solid waste.

INTRODUCTION

Solid waste disposal by combustion (incineration) is now and will continue to be an important part of our national solid waste management programme. Treatment of solid wastes (municipal, hospital, industrial etc.) has become one of the main concerns of many urban and rural communities.

Adequate management of the wastes through reduction of the waste production from household by recycling and reuse should be given the highest priority. However, some portions of these wastes are buried underground, i.e. landfill. In order to meet the worldwide demand for clean environment, various national, regional, state, or local regulations or guidelines have been proposed and enforced. Incineration of solid wastes is usually considered to be the most effective in volume reduction of the solid waste, thereby reducing the burden of landfill. Incineration can remain a viable option when it ensures pollution minimization.

The need for a quick, reliable, and environmentally friendly method of waste disposal generated from households, hospitals, markets, industries etc., has brought attention to the design and construction of a specialty incinerator to suit both rural and urban purposes. Incineration is a method of waste destruction in a furnace by controlled burning at high temperatures [1]. Incineration of waste materials converts the waste into ash, flue gases and heat. The ash is mostly formed by inorganic constituents of the waste, and may take the form of solid lumps or particulate matters carried by the flue gas. Incineration has frequently been preferred to other waste treatment or disposal alternatives due to advantages such as; the volume and mass of the solid waste is reduced to a fraction of its original size by 85-90% volume, the waste reduction is immediate and not dependent on long biological break down reaction times.

The public health impact associated with emissions from solid wastes (municipal, hospital etc,) has become and continue to be a major subject of concern because of the following points: (i) some materials are not supposed to be incinerated as they are more valuable if recycled, they are non-combustible or their by-product may give rise to harmful emissions (ii) poor operating practice and the presence of chlorine in the waste may lead to emissions containing highly toxic dioxins and furans (iii) the control of metal emissions may be difficult for inorganic wastes containing heavy metals, such as arsenic, cadmium, chromium, copper, lead, mercury, nickel, etc. (iv) incinerators require high capital costs and trained operators leading to moderately high operating costs (v) supplementary fuels are sometimes required to achieve the necessary high temperatures (vi) residual disposal (fly ash and bottom ash) presents a variety of aesthetic, water pollution, and worker health related problems that require attention in system design and operation (vii) process analysis of combustors is very difficult, changes in waste character are common due to seasonal variations in municipal waste or product changes in industrial waste.

Nevertheless, incineration of wastes offers the following potential advantages:

- Volume reduction is very important for bulky solids or wastes with a high combustible and/or moisture content.
- Detoxification especially for combustible carcinogens, pathologically contaminated material, toxic organic compounds, or biologically active materials that would affect sewage treatment plants.
- Environmental impact mitigation especially for organic materials that would leach from landfills or create odour nuisances. In addition, the impact of the CO_2 "green house gas" generated in incinerating solid wastes is less than that of the methane (CH_4) and CO_2 generated in landfilling operations.
- Biodegradation of organic material in landfill leads to subsidence and gas formation that disrupts cell capping structures, but destruction of waste organic matters eliminates this problem.
- Incineration also forms oxides or gassy, sintered residues that are insoluble (non-leaching).
- Energy recovery which is an important factor is made possible when large quantities of waste are available and reliable markets for by-product fuel, steam, or electricity is created.
- Destruction of pathogenic organisms presenting hazards to public health is achieved.

With these afore-mentioned points, incineration has persisted as an important concept in waste management. However, the flue gases must be cleaned of gaseous and particulate pollutants before they emitted into the atmosphere or environment. The quantity of pollutants in the flue gas from incineration plants may or may not be reduced by several processes, depending upon the plant design. Particulates can be collected by particle filtration, most often by electrostatic precipitators, and/or baghouse filters [2]. Acid gas scrubbers were used in removing hydrochloric acid, nitric acid, hydrofluoric acid, mercury, lead and other heavy metals [3]. Sulphur-dioxide may also be removed by dry desulphurization by injection of limestone slurry into the flue gas before the particle filtration [4, 5].

Several processes of treatment and energy valorization of waste incineration effluents have been proposed by different researchers such as: Mezerette, Girard, and Vergnet [6]; Briane, Doat, and Redacker [7]; Girard [8]; Halouani and Farhat [9]. However, the incineration technique remains at present the most promising technique of de-pollution, but its efficiency of removal of pollutants and hazardous emissions depends on the chemical compositions of waste, the design of equipment, the chemistry of reagents, and the ability of engineers to optimize these conditions.

METHODS AND MATERIALS

Double chamber incineration system

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^{o}C up to 980^{o}C. 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 and 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.

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 (1);

$$C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5H_2O + heat \qquad (1)$$

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.

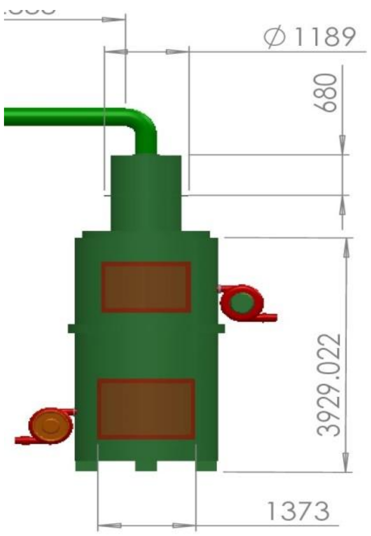

Fig-1: A Two-dimensional view of the double chamber Incinerator design [10]

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 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 [10].

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 [17];

$$P_{fc} = \frac{moles\ of\ fixed\ carbon}{moles\ of\ oxygen} \qquad (2)$$

When there is enough primary air for the overall reaction as in (3), then $P_{fc} = 1$, and the air is oxidizing the carbon at maximum rate.

$$C + {}^{1}/_{2}\,(O_2) \rightarrow CO \qquad (3)$$

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

$$C + O_2 = CO_2 \tag{4}$$

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

$$P_{fc} = 5.72\frac{M_c}{M_a} = \frac{5.72M_w(1 - F_m)F_c}{M_a} \tag{5}$$

Where; F_m = moisture fraction, F_c = char fraction. P_{fc} can also be expressed in terms of volumetric gas (6) fractions so that performance can be checked by a gas analysis;

$$P_{fc} = \frac{F_{CO} + F_{CO_2}}{F_{CO} + 2F_{CO_2} + 2F_{O_2}} \tag{6}$$

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,

$$Q_{pc} = Q_{loss} + Q_p + Q_a + Q_v \tag{7}$$

Where; Q_{pc} = the exothermic heat of the combustion occurring in the primary chamber. Other terms on the right hand side of (7) can be obtained from the following expressions;

$$Q_{loss} = A(h_c + h_r)(T_{ex} - T_o) \tag{8}$$

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,

$$Q_p = M_w(1 - F_m)(F_p)H_p + (C_p)_p(T_s - T_o) \tag{9}$$

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.

$$Q_a = M_p(C_{pair})(T_s - T_o) \tag{10}$$

And,

$$Q_v = M_w(F_m)[C_{p1}(212 - T_o) + H_m + C_{p2}(T_s - 212)] \tag{11}$$

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,

$$(Q_{aux})_{min} = Q_{pc} - Q_t \tag{12}$$

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 [17], can be expressed as;

$$V_{pc} = V_a + V_c + V_p + V_o \tag{13}$$

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.

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 point representing 1 second retention 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^{o}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, and 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;

$$T_e = \frac{\{M_w H_T + (mC_p)_{air} T_s + (mC_p)_{dw} T_s + M_m[212C_{p1} - H_m - C_{p1}(212 - T_s)]\}}{(mC_p)_{air} + (mC_p)_{dw} + M_m C_{p2}} \quad (14)$$

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.

Concept of Overfire Air Jet

Jets have been utilized for many years as an integral part of furnaces, boilers and other combustion systems. For instance, air jets are used in boilers fired with pulverized coal to convey the fuel into the combustion chamber, to control the heat release patterns and to supply secondary air for complete combustion. In processes employing a burning fuel bed, properly placed air jets supply secondary air where needed above the fuel bed to complete combustion [11]. Also, jets of air and/or steam are used to induce turbulence and control temperature by dilution of furnace gases.

Kaiser, Halitsky, Jacobs, and Mccabe [12] in their research found out that undergrate air is necessary in incinerators to expedite the combustion of refuse below the layer that can be reached by overfire air, particularly during the latter half of the burn, when cans, bottles and ash cover the burning charge. Rose and Crabuagh [13] reported a decrease in contamination of 35-50% where overfire air is the predominant source of combustion air. Overfire air jets have been used effectively for years to reduce smoke in bituminous coal-fired boilers. Specific instructions for sizing and location of the jets have been published by BCR Inc [14].

Kaiser *et al.*, [12] as published online by Taylor and Francis in 2012 studied two separate arrangements of overfire air nozzles which they tested to provide increased turbulence near the top of the burning refuse, so as to promote more complete combustion of suspended particles and gases. Their arrangement A consisted of two standard 4in. mild steel pipe manifolds entering the furnace through holes cut in the front wall immediately below the furnace roof and tangent to the side walls. The second arrangement B was a simple one-pipe manifold, which is a 5.5in. mild steel tube with 18 ports drilled 3/4in. in two rows and directed 60^0 from the horizontal plane. They also added and auxiliary fuel firing burner to arrangement B and recorded (Table 1 & 2) remarkable improvement in reduction of pollutants (particulate matters, and gases). Therefore, the location, sizing and pressurizing of the overfire air nozzles are important design considerations for air pollution control [15].

Table-1: Comparison of emissions of the two overfire air jets arrangements [12]

	Basic Incinerator	Overfire Jet Arrangements	
		A	B
Refuse charge, lb	275	275	275
Duration of burn, mins.	117	105	90
Overfire jets, lb air per hr, avg	0	804	640
Percent of total furnace air	0	10	8.6
Blower output, cfm	-	178	142
Manifold pressure, in.wc	-	0.45	0.74
Furnace draft, in. wc avg	0.4	0.5	0.57
Particulate matter, lb for test	3.62	3.01	2.18
Per 100lb of charge, lb	1.31	1.09	0.79
Noxiuos gases, lb for test	6.83	3.89	4.43
Per 100lb of charge, lb	2.48	1.41	1.61
Q-Ruds (von Brand)	855	460	345
Smoke, % light absorption, avg.	2.81	1.27	1.10
Odour concentration	8	7	-
Furnance temp., max., ^oF	1160	1300	1530
Average, ^oF	488	507	630
Flue gas at Ist floor, max., ^oF	1270	1410	1483
Average, ^oF	450	495	589
Residue weight, in % of charge	38	36	37

Table-2: Comparison of emission with auxiliary gas firing added to B [12]

	Basic Incinerator	Overfire Jet Arrangements	
		One-Pipe Overfire Air Jets	Gas Burner and B
Refuse charge, lb	275	275	275
Duration of burn, mins.	117	90	85
Natural gas for test, Btu input	0	0	743,600
Per 100lb of charge, Btu emissions	0	0	270,000
Particulate matter, lb for test	3.62	2.18	1.40
Per 100lb of charge, lb	1.31	0.79	0.51
Noxiuos gases, lb for test	6.83	4.43	2.00
Per 100lb of charge, lb	2.48	1.61	0.73
Q-Ruds (von Brand)	855	345	100
Smoke, % light absorption, avg.	2.81	1.10	0.18

Odour concentration	8	-	10
Furnance temp., max., ^oF	1160	1530	1655
Average, ^oF	488	630	1146
Flue gas at Ist floor, max., ^oF	1270	1483	1500
Average, ^oF	450	589	822
Residue weight, in % of charge	38	37	35 and under

The equation recommended for calculating the flow through an overfire air nozzle is given as;

$$Q = 1096.5C \times A\sqrt{\frac{P_1 - P_2}{w}} \qquad (15)$$

Where, Q is actual air flow, C is 0.90, A is area of nozzle cross section, P_1 - P_2 is difference in pressure head of nozzle and furnace or manifold pressure and furnace draft, w is density of air at nozzle temperature and pressure.

Also, the equation recommended for calculating jet throw (penetration) for a terminal velocity is given as;

$$Throw = 0.75 \times d\sqrt{P_1 - P_2} \qquad (16)$$

Where, throw is measured in metres from the wall, d is nozzle diameter, P_1 - P_2 is difference in pressure across nozzle.

Scrubber Design and Specifications

Scrubber systems are a diverse group of air pollution control devices that can be used to remove some particulates and/or gases from industrial exhaust streams. Traditionally, the term ‘scrubber’ has referred to pollution control devices that use liquid to wash unwanted pollutants from a gas stream. Recently, the term is also used to describe systems that inject a dry reagent or slurry into a dirty exhaust stream to ‘wash out’ acid gases. Scrubbers are one of the primary devices that control gaseous emissions, especially acid gases. Scrubbers can also be used for heat recovery from hot gases by flue gas condensation, which can be useful in waste to energy process.

There are different types of scrubber system generally classified in terms of energy or pressure drop as follows; low-energy scrubbers have pressure drops of less than 12.7cm (5 in.) of water, medium-energy scrubbers have pressure drops between 12.7 and 38.1 cm (5 and 15 in.) of water, and high-energy scrubbers have pressure drops greater than 38.1 cm (15 in.) of water. In this incineration system we are adopting a simple wet (spray) scrubber system for emission reduction for the designed incineration system. Wet scrubbers can also be categorized by the manner in which the gas and liquid phases are brought into contact. Scrubbers are designed to use power, or energy, from the gas stream or the liquid stream, or some other methods to bring the pollutant gas stream in contact with the liquid [16].

Wet scrubbing works via the contact of target compounds or particulate matters with the scrubbing solution. Solutions may simply be water (for dust) or solution of reagents that specifically target certain compounds, in this research study, we used slake lime ($CaCO_3$) as the reagent to be mixed with water. Removal efficiency of pollutants is improved by increasing residence time in the scrubber or by increase or surface area of the scrubber solution by the use of a spray nozzle, packed tower or an aspirator. Wet scrubbers may increase the proportion of water in the gas, resulting in a visible stack plume, if the gas is sent back to a stack.

Determination of Spray Tower Design Parameters

The spray tower or spray absorber is designed for removing particulates not less than 4 microns in size and flue gases containing SO_2 and other pollutants emanating from an incinerator onto which it is retrofitted. This scrubber system (Fig-2) is designed as a circular cross section with no packing in the tower rather it has three layers of sieves in the tower. It is designed as vertical tower though it can be horizontal.

The design concept of the spray tower is that in vertical spray, gas stream is flowing vertically upwards and the liquid is sprayed downwards in a counter current form within the tower, while in horizontal spray, gas stream is flowing horizontally through it and liquid is sprayed vertically downwards perpendicular to the direction of gas flow. Some of the design parameters are calculated as follows;

Tower Diameter or Duct Area

In designing the diameter of the spray tower, it is assumed that maximum permissible gas velocity for the vertical spray tower is 2.3 m/s, but practically, the velocity is less than 2.3 m/s, while that of horizontal spray tower the velocity is usually less than 7 m/s. In order to avoid excessive entrainment of liquid droplets in the exist gas, the diameter of vertical or horizontal spray tower is obtained from the expression;

$$D = \sqrt{\frac{Q_v \times 4}{U_g \times \pi}} \qquad (17)$$

Where; D =; tower diameter Q_v= volumetric flow rate of gas (m^3/s); U_g= gas velocity through tower (for vertical spray tower < 2.3 m/s, for horizontal spray tower < 7 m/s).

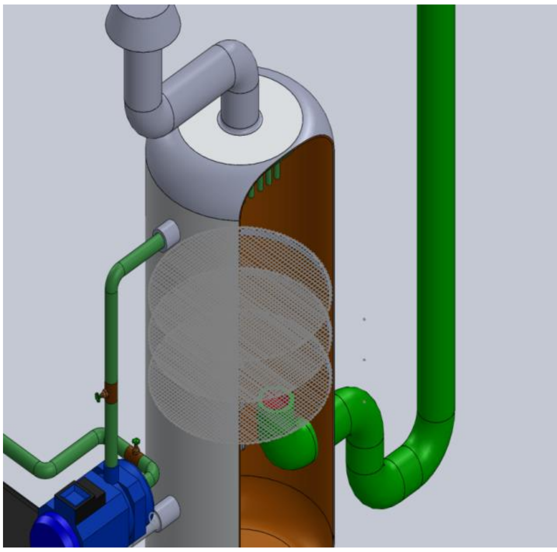

Fig-2: A 3D Design of the Spray Tower Scrubber

Number of Gas Phase Transfer Unit Required for Separation

The following equation is used in the determination of the number of gas phase transfer unit required for separation, which is expressed as;

$$N_G = \frac{Y_1 - Y_2}{Y_2} \qquad \textit{For Vertical Spray Tower} \qquad (18)$$

$$N_G = ln\left[\frac{Y_1}{Y_2}\right] \qquad \textit{For Horinzontal Spray Tower} \qquad (19)$$

Where, N_G= number of gas phase transfer units; Y_1, Y_2= gas phase solute mole fraction at inlet and outlet.

Total Volume of Spray Section

The total volume of the spray section can be computed using the following expression;

$$V = \frac{N_G \times G_m}{K_G} \qquad \textit{For Vertical and Horizontal Spray Tower} \qquad (20)$$

Where, G_m= flow rate of gas phase (kmol/s); K_G= overall volumetric gas phase mass transfer coefficient in kmol/[(s.m^3)(mole fraction of solute in gas).

Chemistry of action of desulphurization in the wet scrubber

Wet scrubber or absorbing tower as already stated is a piece of equipment installed in plants to remove selected gases, and particulates from combustion fumes (flue-gas) in order to meet emission standards. For instance, when one of the gases being removed is SO_2 the chemical reactions can be represented as follows;

The liquid used to 'wash' the flue gas is a water-based calcium solution. Limestone or slake lime ($CaCO_3$) is cheap and creates an alkaline environment in water:

$$CaCO_3 + H_2O \rightleftharpoons Ca^{2+} + HSO_3^- + OH^- \qquad 21)$$

This alkalinity (presence of OH^- radicals) negates the acidity (presence of H^+ protons) formed by the SO_2 in solution;

$$SO_2 + H_2O \rightleftharpoons HSO_3^- + H^+ \qquad (22)$$

The H+ protons combine with the OH^- radicals to form water;

$$H^+ + OH^- \rightleftharpoons H_2O \qquad (23)$$

While the radical HCO_3^- binds with H^+ to create H_2CO_3 (trioxocarbonate acid) which creates an equilibrium with water (H_2O) and carbon(iv)oxide (CO_2).

$$HCO_3^- + H^+ \rightleftharpoons H_2CO_3 \rightleftharpoons H_2O + CO_2 \qquad (24)$$

The net result is the transformation of $CaCO_3$ to calcium ions (Ca^{2+}), the release of carbon (iv) oxide and production of HSO_3^-;

$$CaCO_3 + 2SO_2 + H_2O \rightleftharpoons Ca^{2+} + CO_2 + 2HSO_3^- \qquad (25)$$

The carbon (iv) oxide bubbles up as a gas, while HSO_3^- remains in the water solution.

In the effluent hold tank, at the foot of the scrubber tank (tower) where liquid is collected before the final treatment, another load of limestone is added to the liquid, and a further reaction takes place;

$$CaCO_3 + 2HSO_3^- + CO^{2+} \rightarrow 2CaSO_3 \downarrow + CO_2 \uparrow + H_2O \qquad (26)$$

Calciumtrioxosulphate (iv) is a solid precipitate. It is important to have the precipitation occur in the effluent hold tanks than in the tower itself to avoid clogging.

Outlined Design of the Incineration System

This section incorporates all necessary approach, principle, innovation and criteria for successful attainment of research aim and objectives through the following adopted design criteria.

- The incineration system was designed to a capacity of not less than 50-100kg/hr.
- The design is a two-chamber incinerator i.e., primary and secondary chambers. Each of the chambers operating at a temperature of not less than 800^0C.
- Two gas burners were attached, one to each chamber, with the secondary chamber retrofitted with an air blower system carrying air jets' nozzles and manifold.
- The refractory lining or double wall lagged chambers was designed with enough strength to withstand a minimum temperature of 1000^0C in the primary chamber and minimum of 1200^0C in the secondary chamber.
- A complete and proper calculation of the critical insulation thickness of the incinerator was carried out to minimize to the least, the outside wall temperature of the incinerator and minimize heat losses.
- The incinerator shell is made of mild steel plates of reasonable thickness of not less than 5mm.
- The design calculations and analysis of the piping system was in accordance with ASME piping standards for gaseous and water fluid flow.
- The wet scrubber was designed to connect with the incinerator through the upper part of the incinerator's secondary chamber.
- The scrubber was designed with at least three vents of small mesh sizes between the water solution jet system and the inlet pipe carrying flue gases and particulate matter from the incinerator.

- The scrubbing was equipped with fluid circulation system having a minimum pressure drop of 350mm WC for the water solution used in the scrubber.
- The scrubber is made of stainless steel plates to minimize corrosion or in further design made with a reinforced polymer composite material.

The diagram of Fig-3 shows the complete installation of the designed incineration system after fabrication and test running.

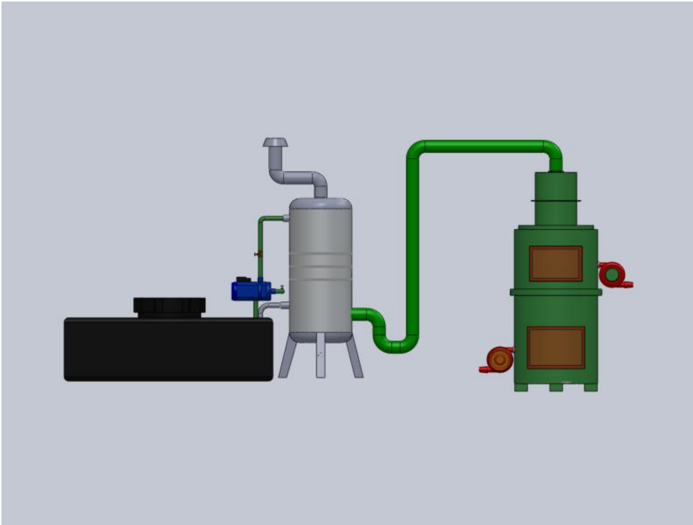

Fig-4: Set-up of the Designed Incineration System

CONCLUSION

The process design of a low pollutant emission incineration system has been completed by this research study. The incinerator is designed as a double chambered system, which because of the intended mobility is designed to be double walled and lagged with a fibre glass system. The incinerator has two burners at each of the primary and secondary chamber, producing a burning temperature of 800^0C at the primary chamber and 1000^0C in the secondary chamber. The critical insulation thickness of the incinerator chambers was carefully and successfully evaluated, and there was reduced heat transfer to the surrounding with double walled and lagged body. The flue gas and particulate matters leaving the incinerator are not allowed into the environment but channeled into a wet scrubbing unit designed as a vertical spay tower with water mixed with slake lime flowing counter currently to the incoming gas and particulate matters. This scrubber system successfully performed the last phase of acid gases and particulate matters removal and allowing for a non-pollutant emission.

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