Original Research Article

DESIGN OF MEDICAL WASTES INCINERATOR FOR HEALTH CARE FACILITIES IN AKURE

ABSTRACT

Health Care Facilities (HCFs) are primarily saddled with the responsibilities of providing medical care, thus ensuring sound health of individuals. Tremendous efforts have been made by the government to ensure her availability in nooks and crannies of every community, which have resulted into improved medical services. However, among other environmental challenges confronting health care facilities in developing countries is Medical Waste generated in the course of carrying out their duties which is often ignored and in most instances treated as municipal or domestic solid waste. Effective management of medical waste requires keen planning, training and tracking throughout the waste generation, segregation, storage, collection, transportation, treatment and disposal processes. The fundamental information for selecting and designing the most efficient treatment method of medical waste is obtained by means of Waste Composition Analysis. Results from this study revealed that the daily waste generation rate of Ondo State Specialist Hospital Akure (OSSHA) and Mother and Child Hospital Akure (MCHA) was 124.5 kg/day. The hospitals' waste consists of 81.6% combustible wastes and 18.4% non-combustible wastes by mass. The combustible wastes are paper (6.50%), textiles (14.34%), cardboard (3.88%), plastics (6.04%) and food waste (19.08%). Since the ratio of combustible medical waste is higher than non-combustible medical waste, incineration (thermal destruction) at elevated temperature under controlled operational condition is considered the best disposal option to detoxify the medical waste. In other to prevent the release of harmful gases from burnt medical waste through incinerator, a counter-current packed bed wet scrubber is designed which operates by impaction and absorption.

Keywords: Health Care Facilities, Medical waste, incinerator, waste composition analysis

1.0 INTRODUCTION

Health-care facilities generate medical waste which is capable of creating unsafe environment for both man and animals, as well as alter the properties of soil and local groundwater. Management of a medical waste thus becomes a matter of concern to public health administrator, environmentalist, infection control specialists, as well as the populace due to its potential environmental hazards and public health risks as it contains highly toxic chemicals, bacteria and pathogenic viruses [1, 2]. It is undoubted that health-care activities generate various types of hazardous and infectious materials. However, the consequences of indiscriminate disposal of medical waste have been highlighted by various regional and global studies, but the methods to manage this waste in a scientific manner putting into consideration safety of the ecosystem have not been fully introduced [3, 4, 5]. As a result, majority of the health institutions disposed combustible and non-combustible medical waste by open burning together with domestic waste, a practice considered inimical to the health of nearby dwellers [6, 7]. In Nigeria, biomedical wastes are characterized as infectious wastes which are further categorized as pathological waste, culture and stock of infectious agents, sharps (hypodermic needles, syringes and scalpel blades), waste from human blood, waste from surgery or autopsy that were in contact with infectious agents and products of blood and laboratory waste [8, 9]. Other wastes in these category includes waste from diverse therapeutic operations such as dialysis, autopsy, chemotherapy and biopsypara clinical test which generates chemical, radioactive and toxic materials that affect the environment and her occupants [2]. Every health-care facility is expected to effectively manage their waste following the right processes from the point of generation to final disposal [6]. Incineration of

Medical Waste has many benefits such as significant volume reduction (about 90%) and mass reduction (about 70%), thorough disinfection and energy recovery. Thus, incineration ensures detoxification, decrement and resource recovery, and it has been technically proven as an reliable waste treatment method [5, 10, 11].

1.1 Incineration Technology

Disposal of medical waste through incineration process has been widely accepted in the field of infectious and hazardous waste management with regards to its advantages, which includes reduction in the quality (infectious state) and quantity (weight and volume) of the waste, reduction in toxic emission, suitability for all types of waste apart from sharps, exclusion of the risk of contamination of soil and local groundwater and low construction cost [2]. Waste obtained from hospitals is heterogeneous in nature because they consist of various degrees of elements in major and minor quantities, some of which are toxic and extremely infectious if not properly managed [4, 9, 12]. Hence, the need for incineration to decontaminate the medical waste by subjecting it to thermal destruction process at high temperature ($1100^{o}C$ - $1600^{o}C$) under controlled operational conditions. The products of combustion are ash residue, water and carbon-dioxide. Incinerator is the unit in which the process occur. A well-designed incinerator does not only consider reduction of waste volume as priority but the environment as well must be put into consideration, hence, the need for incorporation of a gas cleaning device to the incineration process to ensure the release of clean and safe air to the atmosphere. A complete combustion of the medical waste and reduction in potential pollutants contained in the emission lends the process well to waste disposal in areas where population density is relatively high and availability of sites for landfill is low [13, 14]. Incinerators reduce the solid mass of the initial waste by 80–85% and compresses the volume by 95–96%, based on the composition and extent of recovery of the material. Thus, as incineration does not replace landfilling completely, it reduces the required volume for disposal definitely [15, 16, 17].

Minimization of the impacts of medical waste in HCFs is pre-requisitely a function of appropriate and practicable waste management system. Ethically, it is the responsibility of HCFs management to ensure proper medical waste management, which involves the determination of sources, waste characterization, frequency of generation, safe handling practices, segregation, storage, transportation, treatment and final disposal [1, 2, 15]. Most dominant approach to medical waste treatment and disposal in Africa, Asia and some parts in Europe are landfill, open burning and incineration. However, most of the HCFs often neglect the harmful side of these practices when it is not duly followed according to the World Health Organisation standard [3, 5, 8]. The use of incinerator without flue gas emission control device is as good as burning the waste in open space while unengineered landfill is synonymous to direct contamination of groundwater. Therefore, this study is geared towards design and the development of a medical waste incinerator equipped with a counter-current packed bed wet scrubber.

2.0 MATERIAL AND METHODS

The medical waste incinerating system equipped with air pollution control device for the health care facilities in Akure, Ondo state, Nigeria was designed and developed using appropriate and essential principles. The fabrication of the system is in progress. The major component of the incineration system includes the combustion system, connecting ducts, filtration system and the air pollution control system.

2.1 Design of a Controlled-Air-Batch-Feed Incineration Technology

2.1.1 Determination of the Incinerator Capacity

The incinerator capacity and burning time (residence time) was determined from the quantity of waste load generated by the HCFs using the equations developed by Walter [18]:

$$Y = 1.72 \text{ x } W^{0.76} \tag{1.}$$

$$N = \frac{W}{0.9Y} \tag{2.}$$

Where W is the waste load (lbs/day or kg/day), Y is the optimum incinerator capacity (lbs/hr or kg/hr) and N is the Optimum burning time (hrs/day). From the survey and measurement, the average wastes quantification from the two public hospitals is shown in Table 1 below.

Table 1: Quantity of medical wastes generated daily and monthly in the HCFs

S/N	Type of health care facility	Quantity of waste generation (Kg/day)	Quantity of waste generation (Kg/month)
1	Ondo State Specialist Hospital, Akure	81.2	2,436
2	Mother and Child Hospital, Akure	43.3	1,299
	Total Wasste Generated	124.5	3,735

For unknown future of higher generation of medical waste, the waste load (W) from the HCFs is estimated as 269 kg/day. Hence the optimum incinerator capacity (Y) is 100 kg/hr.

2.1.2 Design assumptions

For the air-starved batch-feed type of incinerator designed to treat a mixture of 70% ‘black bag’ and 30% ‘red bag’ medical wastes at a optimum throughput capacity of 100 kg/hr, the following assumptions were made with regards to United States Environmental Protection Agency [19].

- Ignition/Primary chamber temperature is 760°C (1400°F)
- Secondary chamber temperature is 1100°C (2010°F)
- Flue gas residence time at 1000°C (1830°F) is 1 second
- Residual oxygen in flue gas is 6% minimum
- 30% of air required for stoichiometric combustion is supplied into the primary chamber

- Excess air at 150% of the theoretically required air is supplied in the secondary chamber of the incinerator during the peak burning rate.
- Detailed monitoring of the temperatures of gases and water and at critical points of the system with the use of appropriate devices.
- The use of thick standard materials for adequate protection of the combustion chamber from fire.
- A little opening (sealed glass covered by blast-gates) as view point is installed on the primary chamber to enhance easy view of the flame pattern and the waste bed.
- The use of adequate refractory and insulation materials for combustion chambers outside surfaces to maintain operating temperature.
- The burners are rightly positioned in the primary chamber to provides maximum impingement of the flame onto the wastes achieving a minimum supply of 80% of the total heat input of the incinerator design capacity.

2.1.3 Design of primary chamber

In design of the primary chamber of the starved-air-batch-feed incinerator, the initial volume of the chamber is determined. The optimum incinerator capacity per hour (100kg/hr) was dumped as a heap and the volume is calculated as slightly rounded parabolic shape measured as 5 m^3 value of which is used in the design of the chamber using equation [20].

$$V = L \text{ x } B \text{ x } H \qquad (3.)$$

Assuming a suitable chamber depth, H of 2 m, with the ratio of length to breadth as 1.5:1, Hence, the width of incinerator, B is1.29 m and the length of incinerator, L is1.93 m.

Chamber sizing is based on heat release, which is the amount of heat generated when combustible material burns. [7, 17]. Biomedical waste contains varieties of low density, high heating value wastes (e.g. plastics), as well as high density, low heating value wastes (e.g. tissue, bones). Therefore, the primary chamber was sized to accommodate the variation in the waste composition. The volume of the primary chamber was designed to allow for a total heat release rate of 41,020.73 kJ/h and with an operating temperature range between 400-760°C (750-1400°F).

2.2 Machine Conception

The main concept behind this machine is to design a movable and well-regulated incineration system equipped with air pollution control device that will be economically feasible and environmental friendly. The machine is expected to be used basically for burning solid combustible medical wastes at 400^{o}C – 760^{o}C and 1100^{o}C in the primary and secondary combustion chambers respectively. The material selected for the designed are locally available which makes the cost of production low. The incinerator uses basic principle of conduction to achieve burning while flue gas emission control device utilises the principle of absorption and impaction with the aid of counter-current randomly-packed bed and water (wet scrubber) to remove hazardous/infectious substances from emitted gases. It is expected that the machine reduces the quantity and quality of the medical waste after burning to produce ash and harmless gases. A conceptual drawing of the machine is shown in figure 1.

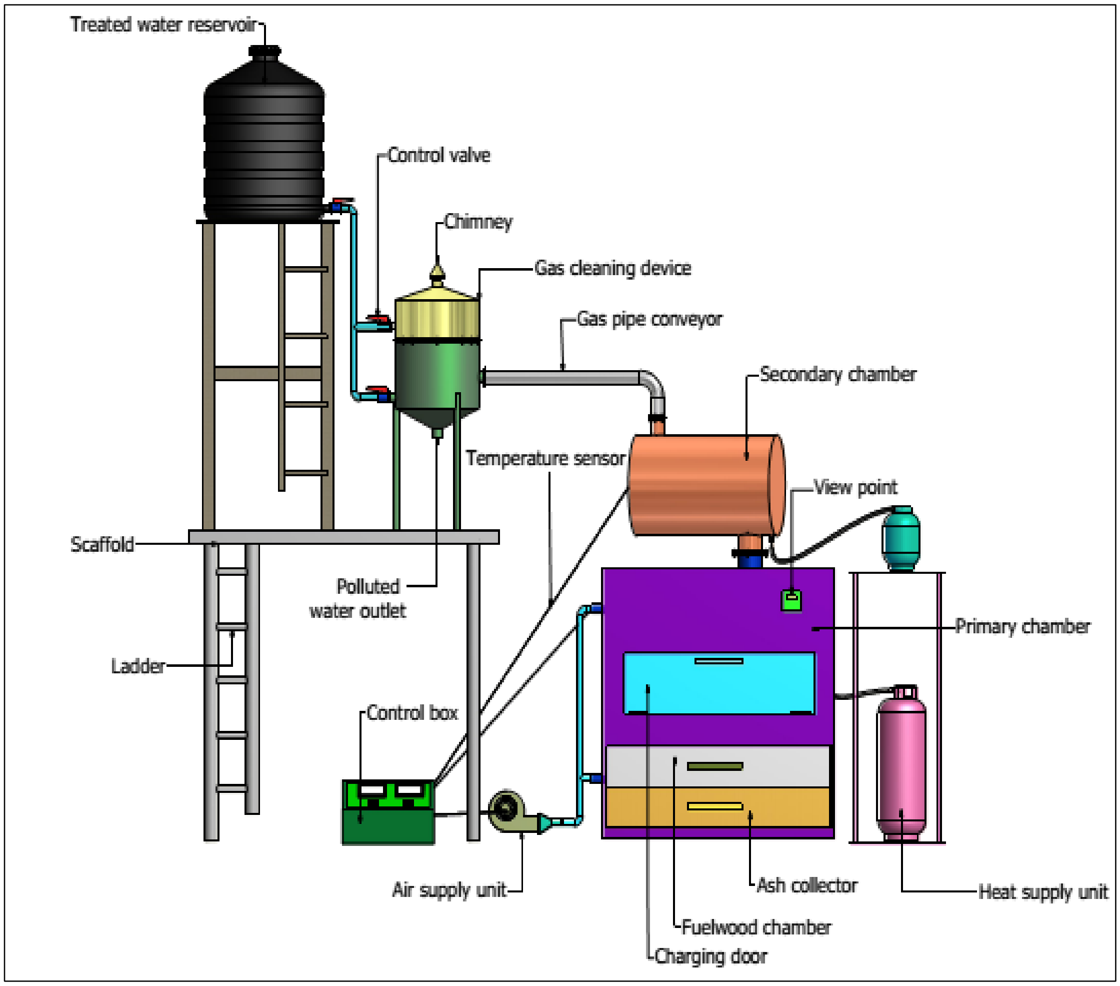

Figure 1: Conceptual drawing of a batch feed incinerator incorporated with packed bed wet scrubber

2.3 Heat and Material Balance

Heat and material balance calculation is an integral part of designing and evaluating incinerators. The technique involves a detailed estimation of the input and output conditions of the incinerator. It was used to determine the combustion air and auxiliary fuel requirements for incinerating a given medical waste and/or to determine the limitations of an existing incinerator when charged with a known waste [4, 20]. The following steps were taken to calculate the heat and material balance sample.

2.3.1 Heating Values of Material Input

The material flow per hr into the incinerator is 100kg/hr. Based on an input of 30% of 100 kg/h (i.e 30 kg/h), the ‘red bag’ is assumed to have the following composition, according to Oumarou *et al.* [17] and John and Swamy [20]: dry tissue, water and ash represents 6.0, 21.0 and 3.0 kg/h respectively.

The black bag waste input is 70% of 100.02 kg/h (i.e 70 kg/h) is assumed to consist of polyethylene, polyvinylchloride, cellulose, ash in the proportion of 21.0 kg/h, 2.1 kg/h, 36.4 kg/h, 10.5 kg/h respectively as shown in Table 2.

Table 2: Higher heating values and total heat of the combustible medical waste

Component	Calorific value kcal/g	HHV kJ/kg	Input kg/h	Total Heat in kJ/h
$C_5H_{10}O_3$	6.028	25,220	6.0	151,320.0
H_2O	0.0	0.0	21.0	0.0
$(C_2H_4)x$	9.039	37,820	21.0	794,220.0
$(C_2H_3Cl)x$	9.119	38,154	2.1	80,123.4
$C_6H_{10}O_5$	5.703	23,860	36.4	868,504.0
Ash	0.0	0.0	13.5	0.0
Total			**100.0**	**1,894,167.4**

2.3.2 Determination of Stoichiometric Oxygen for combustible medical Wastes and Combustion air rates

The total stoichiometric (theoretical) amount of oxygen required to oxidize (burn) the waste is determined by the chemical equilibrium equations of the individual components of the biomedical waste froom laboratory analysis, the stoichiometric oxygen required to burn the combustible component of the biomedical waste (100 kg/h) is shown in Table 3.

Table 3: The combustion equation and the stoichiometric air requirement

Waste	**Combustion Equation**	**Stoichiometric air requirement (per kg waste) (kg/hr)**
Tissue (dry)	$C_5H_{10}O_3 + 6O_2 \rightarrow 5CO_2 + 5H_2O$	9.34
Poly Ethylene	$(C_2H_4)x + 3O_2 \rightarrow 2CO_2 + 2H_2O$	79.5
PVC	$2(C_2H_3Cl)x + 5O_2 \rightarrow 4CO_2 + 2H_2O + 2HCl$	4.27
Cellulose	$C_6H_{10}O_5 + 6O_2 \rightarrow 6CO_2 + 5H_2O$	41.6
		134.8

The stoichiometric air is calculated thus:

$$\text{Stoichiometric air} = \text{Stoichiometric } O_2 \text{ x} \frac{\text{Total Input (kg/h)}}{\text{Molecular weight of } O_2} \qquad (4.)$$

$$= 134.8 \text{ x} \frac{100}{23} = 586.1 \text{ kg/h of air}$$

Primary chamber was supplied at 30 % of that required for stoichiometric combustion total air required for waste at primary chamber = (0.3 x 586.1) + 586.1 = 761.9 kg/h. The air supply in the secondary chamber was designed to provide excess air 150 % of that theoretically required during the peak burning rate [3, 11, 20]. Hence, Total air required for waste at secondary chamber (150% excess) = (1.5 x 586.1) + 586.1= 1465.3 kg/h.

2.3.3 Material Balance for Combustion Chambers.

A. Total Mass Input

Total air required for waste at secondary chamber (Dry air) = 1465.3 kg/h

Total mass of waste per hour = 100 kg/h

Moisture in air = mass of oxygen in air x dry air (5.)

= 0.0132 x 1465.3 = 19.3 kg/h

Total Mass input = mass of waste + Dry air + moisture in air (6.)

= 100 kg/h + 1465.3 kg/h + 19.3 kg/h = **1584.6 kg/h**

B. Total Mass Output (Assuming Complete Combustion)

Dry Products from waste

Less stoichiometric air for waste = 586.1kg/h

Total excess air = 586.1 x 1.5 = 879.2 kg/h

Adding nitrogen from stoichiometric air 0.77 x 586.1= 451.3 kg/h

Sub-total air = (879.2 + 451.3) = 1330.5 kg/h

Add total $C0_2$ from combustion:

$C0_2$ formed from $C_5H_{10}O_3$ = 10.47 kg/h

$C0_2$ formed from $(C_2H_4)x$ = 72.4 kg/h

$C0_2$ formed from $(C_2H_3Cl)x$ = 3.92 kg/h

$C0_2$ formed from $C_6H_{10}O_5$ = 56.2 kg/h

142.9 kg/h

Total waste dry products = Sub-total air + total $C0_2$ from combustion (7.)

= (1330.5 + 142.9) kg/h = 1473.4 kg/h

Moisture present in waste

H_2O in the waste = 21.0 kg/h

H_2O from combustion reactions = 55.5 kg/h

H_2O in combustion air = 19.3 kg/h

Total Moisture = 95.8 kg/h

Ash Output

Ash Output = 13.5 kg/h

HC1 formed from Wastes

HC1 formed from $(C_2H_3Cl)x$ = 1.65 kg/h

Total Mass Out

Total Mass Out = Total waste dry products + Total moisture + Total CO_2 from combustion + HCl formed from waste + Ash Output (8.)

$$= (1330.5 + 95.8 + 142.9 + 1.65 + 13.5)\ \text{kg/h} = \mathbf{1584.4\ kg/h}$$

2.3.4 Energy balance of the incinerator

Analysis of energy balance for an incinerator prototype entails the use of first law of thermodynamics and energy conservation [21] i.e.;

$$\Sigma E_{\text{input}} = \Sigma E_{\text{output}} \qquad (9.)$$

A. Total energy input to the incinerator

$$\text{Energy}_{\text{input}} = Q_{\text{bmw}} + Q_{\text{Natural gas}} + Q_{\text{air}} \qquad (10.)$$

Assuming energy from air $Q_{(\text{air})}$ is negligible we have the energy input to be:

$$\text{Energy}_{\text{input}} = Q_{\text{bmw}} + Q_{\text{Natural gas}} \qquad (11.)$$

Total heat in from combustible medical waste Q_{bmw} is the summation of all combustible materials:

Total heat required to burn cellulose = 868,504 kJ/h

Total heat required to burn Rubber = 794,220 kJ/h

Total heat required to burn Plastic = 80,123.4 kJ/h

Total heat required to burn Tissue = 151,320 kJ/h

Q_{bmw} = Total heat required input = 1,894,167.4 kJ/h

Total heat in from natural gas $Q_{\text{Natural gas}}$ is calculated as:

$Q_{\text{Natural gas}}$ = Energy from natural gas

Mass flow rate of natural gas = 20.6 kg/h (assumed)

= mass flow rate of natural gas x higher heating value of natural gas

= 20.6 kg/h x 43,000 kJ/kg = 885,800 kJ/h

Hence, the total energy supplied to the system = (1,894,167.4 + 885,800) kJ/h

$$\text{Energy}_{\text{in}} = 2{,}779{,}967.4\ \text{kJ/h}$$

B. Total energy output from the incinerator

$$\text{Energy}_{\text{output}} = Q_{\text{et}} + H_{\text{flue gases}} \qquad (12.)$$

Total heat out based on equilibrium temperature of 1100°C (Q_{et})

Radiation loss (R_{loss}) = 5% of total heat available (13.)

= 0.05 x 1,894,167kJ/h = 94,708.35 kJ/h

Heat to ash, Heat to dry combustion products and Heat out due to flue gases release is calculated using equation 14 as used by Patel and Kumar [4], Ganguly *et al.* [12] and Walter [18];

$$\Delta H = mC_p\Delta T \qquad (14.)$$

Heat to ash (H_{ash}) is calculated as 12,166.5 kJ/h using equation 14, Where weight of ash, m = 13.5 kg/h, mean heat capacity of ash, Cp = 0.831 kJ/kg^{o}C ([20] and Temperature difference, ΔT = 1084.5^{o}C.

Heat to dry combustion products (H_{dcp}) is then calculated as 1,735,321.9 kJ/h using equation 14, where weight of combustion products, m = 1473.4 kg/h, mean heat capacity of dry (medical wastes) products, Cp = 1.086 kJ/kg^{o}C and Temperature difference, ΔT = 1084.5^{o}C.

Heat to moisture ($H_{moisture}$) is then calculated as 479,538.5 Kj/h using equation 15,

$$\Delta H_{moisture} = mC_p\Delta T + mH_v \qquad (15.)$$

Where weight of water, m_3 = 95.80 kg/h, mean heat capacity of water, Cp_3 = 2.347 kJ/kg^{o}C, Temperature difference, ΔT = 1084.5^{o}C, Hv = latent heat of vaporizations of water = 2460.3 kJ/kg.

Heat out due to flue gases release ($H_{flue\ gases}$) is then calculated as 266,570.7 kJ/h using equation 4, which involves the addition of the Heat out due to release of CO_2, O_2, HCl respectively, where the mass, m are 142.9 kg/h, 134.8 kg/h and 1.65 kg/h; specific heat capacity, Cp are 0.844 kJ/kg°C, 0.919 kJ/kg°C and 0.795 kJ/kg°C for CO_2, O_2 and HCl respectively; and Temperature difference, ΔT is 1084.5°C.

Hence, the total $Energy_{out}$ (Q_{out}) = (R_{loss} + H_{ash} + H_{dcp} + $H_{moisture}$ + $H_{flue\ gases}$) kJ/h (16.)

$$\text{Energy}_{\text{out}} = 2{,}588{,}305.9 \text{ kJ/h}$$

2.3.5 Determination of auxiliary fuel required to achieve 1100°C and mass flow rate

Total heat required from natural gas (H_{fuel}) = 2,779,967.4 + 5% radiation loss = 2,918.965.8 kJ/h, Available heat (net) from natural gas at 1100°C and 20% excess air = 89,814.3 kJ/m^3 (Assumed). Therefore, natural gas required is (2,918.965.8 kJ/hr / 98,947.99 kJ/m^3) = 29.5 m^3/h [14, 20].

Mass flow rate of gas, ṁ = density of methane gas, ρ_a x volumetric flow rate of gas = 1.25 kg/m^3 x 29.5 m^3/h = 36.88 kg/h = 0.01 kg/s.

Assuming 10 gas burners, each burner will consume 3.69 kg of methane gas per hour which is equivalent to 0.0011 kg/s. Six burners in primary chamber will deliver at 0.0066 kg/s (22.14 kg/h) and four burners in secondary chamber at 0.0044 kg/s = 14.74 kg/h. Dry Products from fuel at 20% excess air = dry fuel density x Methane gas required = 16.0 kg/m^3 x 29.5 m^3/hr. fuel = 472 kg/h [14] [20].

2.3.6 Secondary chamber volume required to achieve 1 second residence time at 1100 °C

Total dry product which is the summation of the Total Dry Products from waste and Dry Products from fuel = (1,584.4 + 472) kg/h = 2056.4 kg/h, assuming dry products have the properties of air and using the ideal gas law, the volumetric flow rate (V_P) of dry products (d_p) at 1000°C is calculated as 2.1m^3/s using equation 17 [22].

$$PV_p = nR_pT_p \qquad (17.)$$

ii) Total moisture = Total moisture from waste + Moisture from fuel

= 95.8 kg/h + 46.9 kg/h = 142.7 kg/h

Using the ideal gas law, the volumetric flow rate of moisture at 1000°C (V_m) as 0.2 m^3/s using equation 17. Total volumetric flow rate (V_t) which is the summation of volumetric flow rate of dry products at 1000°C and volumetric flow rate of moisture at 1000°C is 2.3 m^3/s. Therefore, the active chamber volume required to achieve one second retention is 2.3m^3.

The observed one second retention time of 2.3m^3 is sufficient for the active chamber. Although, some dead spaces occur in the chamber creating zero or negligible flow in reality. Hence, the length of the secondary chamber is calculated from the flame front to the location os the temperature sensor to achieve the retention time of one second as recommended by Ganguly *et al.* [12] and Walter [18]

2.4 Residual Oxygen in the Flue Gas

The residual oxygen ($\% O_2$) was determined by taking 21% of mass flow rate of air used through the following equation:

$$\text{EA (excess air)} = \frac{\%O_2}{(21\% - \%O_2)} \qquad (18.)$$

$$\frac{150}{100} = \frac{\%O_2}{(21\% - \%O_2)}$$

$150\ (21\% - \%O_2) = 100\ \%O_2$

$\%O_2 = 12.6\%$

2.5 Efficiency of the machine

The efficiency of the machine is calculated using the relation:

$$\eta_{\text{incinerator}} = \frac{\text{Energy output}}{\text{Energy input}} \text{ x } 100\%$$

$$= \frac{2{,}588{,}305.9}{2{,}779{,}967.4} \text{ x } 100 = 93\%$$

2.6 Air Pollution Control System

2.6.1 Design conception of packed bed wet Scrubber

A vertical design concept is considered for the packed beds wet scrubber, the liquor is sprayed from the top and flows downward across the bed. Appropriate distribution of liquor is important for efficient removal of gases [22]. The collection of acid gases in packed-bed scrubbers is achieved by absorption. The effectiveness of absorption in packed beds is related to the uniformity of the gas velocity distribution, the surface area of the packing material, the amount and uniform distribution of scrubber liquid, and the pH and turbidity of the scrubbing liquid. The measure of gas absorption is affected by the extensive liquid surface contacted by the gas stream as the liquid flows downward over the packing material [16, 18]. Variety of available packing materials offer a large exposed surface area to facilitate contact with and absorption these acid gases. The packing materials which ranges in size from 0.5 to 3 inches are randomly oriented in the bed. Typically, sodium hydroxide (NaOH) or occasionally sodium carbonate (Na_2CO_3) is used with water to neutralize the absorbed acid gases in a packed-bed scrubber. These two soluble alkali materials are preferred because they minimize the possibility of scale formation in the nozzles, pump, and piping. For the typical case of using NaOH as the neutralizing agent, the HC1 and SO_2 collected in the scrubber react with NaOH to produce sodium chloride (NaC1) and sodium sulphite (Na_2S0_3) in an aqueous solution. The conceptual design of the countercurrent packed bed wet scrubber is shown in figure 2 below.

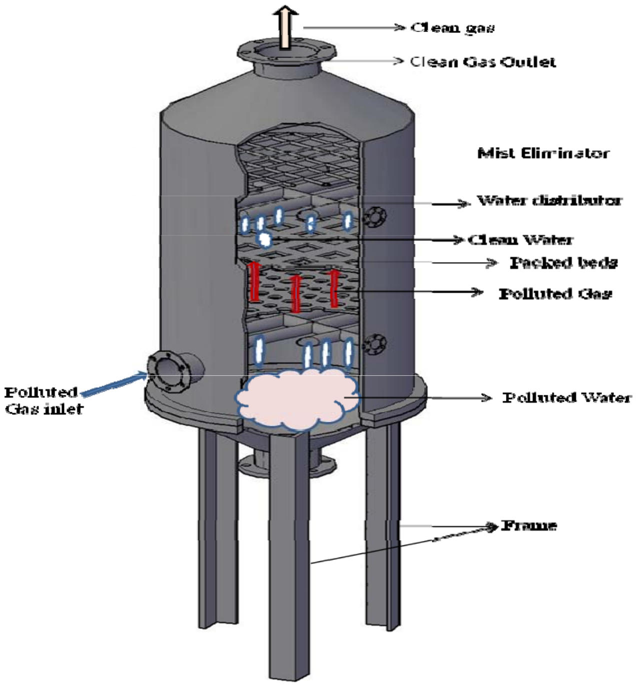

Figure 2: Conceptual drawing of a countercurrent packed bed wet scrubber

2.6.2 Design Analysis of Packed-Bed Scrubber/Absorber

The following assumptions were made in the design of packed tower scrubber:

- Pollutant concentration entering the column in the waste gas Y_1 = 0.07 $(k - mol\ pollutant\ gas/k - mol\ pollutant\ waste\ gas)$
- Pollutant concentration entering the column in the solvent (liquid phase) X_1 = 0.000005 $(k - mol\ pollutant\ gas/k - mol\ pollutant\ solvent)$
- Maximum concentration of the pollutant in the liquid phase if it were allowed to come to equilibrium with the pollutant entering the column in the gas phase X_1^* = 0.55 $(k - mol\ pollutant\ gas/k - mol\ pollutant\ waste\ gas)$
- Waste gas flow rate entering the column G_i = 1.259 m^3/min.
- Liquid flow rate entering the column L_i = 0.078 m^3/min
- Efficiency of the scrubber η = 99%

Pollutant exiting the column in the waste gas can be determined from assumed efficiency of air pollution control device using equation 19 as recommended by Walter [18] and Danzomo *et al.* [23].

$$Y_O = Y_i(1 - {}^{\eta}/_{100}) \tag{19.}$$

Y_O = 0.0007 mol

Minimum liquid to gas phase ratio is calculated as 0.126 using equation 20 as used by

$$\left[\frac{L_S}{G_S}\right]_{min} = \left[\frac{Y_i - Y_O}{X_O{}^* - X_i}\right] \tag{20.}$$

Therefore, the actual liquid to gas phase ratio, which is a product of the minimum liquid to gas ratio and an adjustment factor, Adj_{fac} (usually between 1.2 and 1.5) is calculated as 0.1512 using equation 21.

$$\left[\frac{L_S}{G_S}\right]_{act} = \left[\frac{L_S}{G_S}\right]_{min} \text{ x } Adj_{fac} \tag{21.}$$

The waste flow rate of the gas, G'' through the scrubber is determined as 0.0233 kg/s using equation 22, where ρ_g = density of combustion gases at STP = 1.11 kg/m3 [22]

$$G'' = \frac{\rho_g \text{ x } G_i}{60} \tag{22.}$$

Hence, the gas velocity, V_{GF}, which is determined by dividing the waste gas flow rate by the density of the gas, is calculated as 0.0209 m/s.

The liquid flow rate, L'' through the scrubber is determined as 1.3 kg/s using equation 23, where ρ_L = density of liquid at STP = 1000 kg/m^3 [20, 22].

$$L'' = \frac{\rho_g \text{ x } L_i}{60} \tag{23.}$$

The molar flowrate of the pollutant free solvent, L_s is estimated as 0.000114 kmol/s using equation 24, where the Molecular weight of gas, M_{wg} is 0.029 kg/mol [11, 18]

$$L_S = \left[\frac{L_S}{G_S}\right]_{act} \text{ x } \frac{G''}{M_{wg}(1 + Y_i)} \tag{24.}$$

2.6.3 Assumption of Absorption Factor

The Absorption factor (Abs_{fac}) value is frequently used in describing the relationship between the equilibrium line and the liquid-to-gas ratio [19]. In several pollutant-solvent systems, the most economical value for Abs_{fac} ranges from 1.5 to 2.0 [16, 18]. For this design, the adsorption factor of 1.65 is assumed.

2.6.4 Determination of superficial gas flow rate

A Generalised pressure drop correlation chart showing the correlation between the liquid and vapour flow rates, system physical properties and packing characteristics, with the gas mass flow-rate per unit cross-sectional area; with lines of constant pressure drop as a parameter as d used by Coker *et al.* [9]; Doherty and Malone [24], The Abscissa value from the graph is calculated using Equation 25 as 0.06.

$$F_{LV} = \frac{L''}{G''}\sqrt{\frac{\rho_G}{\rho_L}} \qquad (25.)$$

A percentage flooding of 80% is observed, which is satisfactory assuming a pressure drop of 8 mm H_2O/m packing at Ordinate K4 which is 0.4. The superficial gas flow rate/gas mass flow-rate per unit column cross-sectional area, G_{sfr} is then determined using Equation 26 as adopted by John and Swamy [20]; Doherty and Malone [24], where density of combustion gases at STP, ρ_g is 1.11 kg/m3 [22], density of scrubbing, ρ_L and acceleration due to gravitational, g is 9.8 m/s (Gupta and [21]).

$$K_4 = \frac{13.1(\,\mathrm{Gsfr})^2 \text{ x } F_P \left[\frac{\mu_L}{\rho_L}\right]^{0.1}}{\rho_g\left[\rho_L - \rho_g\right]} \qquad (26.)$$

The superficial gas flow rate/gas mass flow-rate per unit column cross-sectional area, G_{sfr} is then calculated as 0.5859 kg/m^{2}s.

2.6.5 Determination of packed-bed area and diameter

The value of the packed bed area and diameter on the actual gas flow rate per unit area is estimated by determining the required column area, S_A. The required column area is calculated by dividing the gas flow rate by the superficial gas flow rate as shown in equation 27 below where Gas flow rate, G" = 0.0233 kg/s, mass flux of gas per cross sectional area of column, G_{sfr} = 0.5265 kg/m^{2}s. The column area required, S_A is 0.039 m^2 while the column diameter, D calculated as 0.223m using equation 28 as adopted by John and Swamy [20], and Danzomo *et al.* [23].

$$\text{SA} = \frac{\text{Gas flow rate (G}'')}{\text{superficial gas mass flow rate }(\text{G}_{\text{sfr}})} \qquad (27.)$$

$$\text{D} = 1.13\sqrt{\text{Tower area}} \qquad (28.)$$

The height of packing, Z is calculated by multiplying the assumed column height, 4m and the height of overall gas phase transfer unit, H_{OG} of 0.25m.

3. CONCLUSION AND RECOMMENDATION

3.1 Conclusion

The estimated quantity of medical waste from surveyed health-care facilities was about 62.25 kg/day, equivalent to 22.41 ton/year. The average generation rates of total medical waste, general waste, hazardous–infectious waste and sharp waste in public hospitals within Akure metropolis were 0.75, 0.50, 0.19 and 0.06 kg/bed/day respectively. Of the total medical waste generated in the facilities, 65.36% consisted of general waste, 26.78% was infectious waste, and 7.86% was sharps waste. The medical waste has higher calorific value, higher heating value and volatile matter, which can realize the sustained combustion of waste. The combustible component accounted for more than 60%, so it is entirely feasible to dispose medical waste by high temperature incineration.

Daily increment of medical waste generation and the quest to safeguard the people and environment from outbreak of diseases, a cost effective and environmental-friendly incinerator was designed in present study to treat biomedical waste generated in surveyed HCFs with a capacity of 100.0 kg/h. From the material balance analysis by assuming complete combustion, total mass input (1584.6 kg/h) is found to be equal to total mass output

(1584.4 kg/h) while the total energy input from the heat balance analysis is found to be 2,779,967.4 kJ/h and total energy output to be 2,588,305.9 kJ/h. From the design analysis, 184.7 m^3/h of natural gas is required to achieve a design temperature of 1100°C. Also, from the design, the volume of secondary chamber is found to be 3.1 m^3 with a detention time of 1 second. A Counter-current packed bed wet scrubber with 99% scrubbing efficiency was designed with the incinerator to adsorb toxic (flue) gases that might be emitted in the course of burning the waste.

3.2 Recommendations

This pilot study in Akure, the state capital territory of Ondo State, Nigeria, shows that very little has been done on medical waste management in the metropolis. It is therefore recommended that the Ministries of Environment and Health put in place a legislation that will regulate medical waste generation and management, and also adopt a multidisciplinary approach to manage medical waste generated within the metropolis and the state at large. Moreover, to improve the existing conditions, extensive research on effective waste management practices and regulation is paramount. However, the unending increment of medical waste generation due to multifaceted activities carried out in hospitals poses enormous environmental and health problems. to pose both environmental and health problems to the residents of the city, it is recommended that an energy recovery incinerator equipped with an air pollution control system is developed, positioned and used in treatment of wastes generated in the health care facilities in Akure, Ondo state, Nigeria.

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