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Design of Biomedical Waste Incinerator

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***Abstract:** Medical centres including hospitals, clinics and places where diagnosis and treatment are conducted generate wastes that are highly hazardous and put people under risk of fatal diseases. Although the understanding of medical waste management and control techniques is very important, but during undergraduate and postgraduate programmes offered by the different branches like Mechanical, civil, Chemical Engineering give less emphasis on this area. In the present work, the meaning of medical waste, the risks of exposure, medical waste management regulatory acts, medical waste management procedures and control techniques are presented. The contents presented in this work can be served as a supplementary material in an under-graduate elective course on waste management and as an educational guide for medical staff training on waste handling. Biomedical waste has become a serious health hazard in many countries including India. Careless disposal of waste can contribute to spread of serious disease, environmental pollution among health care providers, patients and common people.*
The present work refers to make available treatment & disposal of Bio-Medical Waste in Most scientific manner at a reasonable cost and to comply all the guidelines of the Bio-Medical Waste Management & Handling Rules, 2016.

I. INTRODUCTION

Most of the hazardous waste obtained from various sources consists of carbon, hydrogen, oxygen with halogens like sulphur, nitrogen, heavy metals and other toxic substances in trace quantities. The hazardous waste so obtained is detoxified by subjecting to the incineration process which is gaining popularity as a disposal technology in the field of hazardous waste management. Incineration may be defined as the thermal destruction of the waste at elevated temperature say 1200˚C to 1600˚C under controlled operational condition. The products of combustion are carbon-dioxide, water, and ash as a residue. The unit in which the process takes place is termed as Incinerator. Properly controlled incineration is an effective means of reducing waste volume. It ensures cleaner and more complete combustion of waste and lends itself well to waste disposal in areas where population density is relatively high and availability of sites for landfill is low. Potential pollutants can be contained within the resulting residue which, if disposed of carefully, reduces the risk of contamination of local groundwater. Landfill will always be required for the residue, which typically amounts to about one-third of the initial mass of waste. There are however, a number of technical, social and environmental problems associated with incineration. These arise from the potential pollutants contained in the emissions and residual solids remaining after from the combustion process.

II. INCINERATORS TO TREAT BIO-MEDICAL WASTE

There are basically three types of incinerators that are available for the incineration of bio-medical waste, namely:
Multiple-chamber (retort and in-line), Controlled-air and Rotary kiln

Table 1: Type Of Incinerator

Waste Type	Technology
Solid industrial or hazardous	Rotary Kiln
Municipal Solid	Moving Grate
Liquid or Gaseous	Static Hearth
Homogenous e.g. sludge	Fluidized Bed

III.DESIGN OF PRIMARY CHAMBER

For designing the primary chamber, initially volume of the chamber is to be found out. For finding out the volume 50 kg of waste is dumped as a heap and the volume of the volume of the heap is considered. Volume of the heap = $2.5m^3$ Assuming a L/D = 2, we can find out the area of the chamber

$(\pi/4)D^2 L = 2.5m^3$ and L/D = 2 ref [2]

Dimensions of the primary chamber = L*D L = 2.33 m D= 1.17 m

Fig 1 Heat and Material Balance Sample Calculation [ref 1]

A heat and material balance is an important part of designing and/or evaluating incinerators. The procedure entails a mathematical evaluation of the input and output conditions of the incinerator. It can be used to determine the combustion air and auxiliary fuel requirements for incinerating a given waste and/or to determine the limitations of an existing incinerator when charged with a known waste.

A. Assumptions of waste

An incinerator is to be designed to incinerate a mixture of 40% red bag and 60% yellow bag (with a PVC contented 4%) biomedical waste. Throughput is to be 50 kg/h of Waste. The auxiliary fuel is natural gas; the waste has been ignited; and the secondary burner is modulated. Design requirements are summarized as follows:

1) Secondary chamber temperature: 1100°C
2) Flue gas residence time at 1000°C: 1 second
3) Residual oxygen in flue gas: 6% minimum.

B. Assumptions for combustion

Calculations involving incineration of biomedical waste are usually based on a number of assumptions. In our design, the chemical empirical formula, the molecular weight and the higher heating values of each of the main components of biomedical waste have been taken as below.

1) Input Temperature of waste, fuel and air is 15.5˚C.
2) Air contains 23% by weight O_2 and 77% by weight N_2.
3) Air contains 0.0132kg H_2O/kg dry air at 60% relative humidity and 26.7˚C dry bulb temperature.
4) For any ideal gas 1kg mole is equal to 22.4m^3 at 0˚C and 101.3kpa.
5) Latent heat of vaporization of water at 15.5˚C is 2460.3 KJ/Kg

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Table 2: Calculation Of Material Input

Components	Empirical formula	Molecular weight	Higher heating value
Tissue	$C_6H_{10}O_3$	118.1	20471
Cellulose, swabs, bedding	$C_6H_{10}O_5$	162.1	18568
Plastic polyethylene	$(C_2H_4)_X$	28.1	46304
PVC	$(C_2H_3Cl)_X$	62.5	22630
Sharps	Fe	55.8	0
Moisture disinfectants	H_2O	18	0
Alcohol	C_2H_5OH	46.1	30547
Glass	SiO_2	60.1	0

The above table provides a range of characteristics for various types of biomedical waste. Sound judgment should be exercised when making use of this table to assign the component weight percent required performing heat and material balance calculations. The yellow bag waste is typically composed of mainly human tissue. Based on an input of 40% of 50 kg/h (i.e., 20 kg/h), the yellow bag was assumed to have the following composition.

Tissue (dry) $C_5H_{10}O_3$ 0.15 × 20 = 3 kg/h
Water H_2O 0.8 × 20 = 16.0 kg/h
Ash - 0.05 × 20 =4 kg/h
Total Red Bag = 20.0 kg/h

The red bag waste input is 60% of 50 kg/h (i.e. 30 kg/h) and was assumed to have the following composition:

Polyethylene $(C_2H_4)_X$ 0.35 × 30 = 105 kg/h
Polyvinylchloride(C_2H_3Cl)0.04×30=12kg/h
Cellulose $C_6H_{10}O_5$ 0.51 × 30 = 15.3 kg/h
Ash 0.1 × 30 = 3.0 kg/h
Total Yellow Bag = 30.00 kg/h

TABLE 3: CALCULATION OF HEAT INPUT OF WASTES (KJ/H)

Component	HHV KJ/Kg	Input Kg/h	Total Heat in KJ/h
$C_5H_{10}O_3$	20,471	3	61413
H_2O	0	16	0
$(C_2H_4)_X$	46,304	10.5	486192
$(C_2H_3Cl)_X$	22,630	1.2	27156
$C_6H_{10}O_5$	18,568	15.3	284090.4
Ash	0	4	0.0
TOTAL		50.0	858851.4 KJ/h

C. Determination of stoichiometric oxygen for wastes

The total stoichiometric (theoretical) amount of oxygen required to burn (oxidize) the waste is determined by the chemical equilibrium equations of the individual components of the biomedical waste and are provided in the following:

1) $C_5H_{10}O_3 + 6O_2 = 5CO_2 + 5H_2O$
118.1 6(32) 5(44) 5(18)
1.0 1.63 1.86 0.76
Tissue (as fired)
2) 4.89 5.58 2.28
3) $(C_2H_4)_X + 3\,O_2 = 2CO_2 + 2H_2O$
28.1 3(32) 2(44) 2(18)
1.0 3.43 3.14 1.29
Poly 10.5 36.015 32.97 13.545
Ethylene (as fired)
4) $2(C_2H_3Cl)_X + 5O_2 = 4CO_2 + 2H_2O + 2HCl$
2(62.5) 5(32) 4(44) 2(18) 2(36.5)
PVC 1.0 1.28 1.41 0.29 0.58
(as fired) 1.2 1.536 1.692 .348
5) $C_6H_{10}O_5 + 6O_2 = 6CO_2 + 5H_2O$
162.1 6(32) 6(44) 5(18)
Cellulose 1.0 1.19 1.63 0.56
(as fired) 15.3 18.207 24.939 8.568

The stoichiometric oxygen required to burn the combustible component of the biomedical waste (30 kg/h) is 60.648 kg/h oxygen (sum of 4.89, 36.015, 1.536 and 18.207).

D. Determination of air for waste based on 150% excess

From step 4, stoichiometric oxygen is 60.648kg/h. Therefore, stoichiometric air =60.648×100/23 =263.6869kg/h air

Total air required for waste (at 150% excess) = (1.5 ×263.6869) + 26.6869=659.22kg/h

1) Material balance

a) Total Mass in Waste = 50 kg/h

b) Dry air = 659.22 kg/h

c) Moisture in air = 8.70 kg/h (659.22× 0.0132) [step1]

d) Total Mass In = 667.92 kg/h

e) Total Mass output (assuming complete combustion)

2) Dry products from waste.

Air supplied for waste= 659.22kg/h
Less stoichiometric = 263.68kg/h air for waste
Total excess air = 395.52 kg/h or 150%
Add nitrogen from stoichiometric air = 0.77 × 263.68 = 203.03 kg/h
Sub-Total = 598.55 kg/h
Add total CO_2 from combustion:
CO_2 formed from $C_5H_{10}O_3$ = 5.58 kg/h
CO_2 formed from $(C_2H_4)_x$ = 32.97 kg/h
CO_2formed from $(C_2H_3Cl)_x$ = 1.692 kg/h
CO_2 formed from $C_6H_{10}O_5$ = 24.939 kg/h
Total Waste Dry products = 663.731 kg/h

3) Moisture

1) H_2O in the waste = 16 kg/h
2) H_2O from combustion reactions = 24.741kg/h
3) H_2Oin combustion air = 8.70 kg/h [step 6]
4) Total Moisture = 49.441 kg/h

4) Ash output = 4 kg/h

5) HCl formed from wastes

HC1 formed from $(C_2H_3Cl)_x$ =0.696 kg/h
Total Mass Out = Sum of (A, B, C, D) = 717.868 kg/h

6) Heat balance

1) Total heat in from waste Qi =858851.4 kJ/h [see Step 3]
2) Total heat out based on equilibrium temperature of 1100°C (Q_o)
a . Radiation loss = 5% of total heat available = 0.05 ×858851.4 = 42942.57 kJ/h
b . Heat to ash = m C_p dT = (4) × (0.831)× (1084.5) = 3604.878 kJ/h
Where m = weight of ash = 4kg/h, C_p = mean heat capacity of ash = 0.831 kJ/kg. °C (assumed average value)
dT = Temperature difference = (1100-15. 5) °C = 1084. 5°C
c. Heat to dry combustion Products = m C_p dT = (663.731) × (1.086) × (1084.5) = 781720.47 KJ/h
Where m = weight of combustion products = 663.731 kg/h
C_p = mean heat capacity of dry products = 1.086 kJ/kg° C (assumed average value) dT = (1100-15.5) °C = 1084. 5°C

d. Heat to moisture = (m C_p dT) + (mH_v)
(mC_pdT)+ (mH_v) = (49.441 × 2.347 × 1084. 5) + (49.441 ×2460.3) =247482.94 kJ/h

Where m = weight of water = 49.441 kg/h Cp = mean heat capacity of water = 2.347 kJ/kg. °C
dT = (1100-15. 5) °C = 1084. 5°C
H_v = latent heat of vaporizations of water = 2460.3 kJ/kg
Total Heat Out (Q_o) = sum of (i, ii, iii, iv) = 1075750.858 kJ/h
Net Balance = $Q_i - Q_o$ = 858851.4 – 1075750.858 = -216899.458 kJ/h (difference)
Auxiliary fuel must be supplied to achieve design temperature of 1100°C.

7) Required auxiliary fuel to achieve 1100°C

1) Total heat required from fuel = 216899.458 + 5% radiation loss = 227744.431 kJ/h
2) Available heat (net) from natural gas at 1100°C and 20% excess air = 15,805.2 KJ/m^3 (assumption)
3) Natural gas required = 227744.431/15,805.2 m^3/h = 14.40 m^3/h

8) Products of combustion from auxiliary fuel

1) Dry Products from Fuel at 20% Excess Air = 16.0 kg [8] × 14.40 m^3 /h m^3 fuel =230.4 kg/h
2) Moisture From Fuel = (1.59 kg (8)/m^3fuel) × 14.40 m ^{3}/h = 22.896 kg/h

I. Secondary chamber volume required to achieve one second residence time at 1000 °C

1) Total Dry Products
From waste + fuel = 663.731 kg/h + 230.4 kg/h = 894.131 kg/h
Assuming dry products have the properties of air and using the ideal gas law, the volumetric flow rate of dry products (dp) at 1000°C (V_p) can be calculated as follows:
V_p = 894.131 kg dp/h × (22.4 m^3)/29kg dp) × (1273˚K / 273˚K) × (1 h/3600s) = 0.8945 m^3 /s

2) Total Moisture
From waste + fuel = 49.441 kg/h +22.896 kg/h = 72.337 kg/h
Using the ideal gas law, the volumetric flow rate of Moisture at 1000°C (V_m) can be calculated as follows:
V_m = (142. 6 kg H_2O/h) × (22.4 m^3/18kg H_2O) × (1273K/ 273k) × (l h/3600s) = 0.1182 m^3/s
Total Volumetric Flow Rate = sum of (i, ii) = 0.8945 + 0.1182 = 1.0127 m^3/s

Therefore, the active chamber volume required to achieve one second retention is 1.0127 m^3 ('dead' areas – with little or no flow should not be included in the retention volume). It should be noted that in sizing the secondary chamber to meet the one second retention time required, the length of chamber should be calculated from the flame front to the location of the temperature sensing device. K = °C + 273

9) Residual oxygen in the flue gas

The residual oxygen (%O_2) can be determined using the following equation:
EA (excess air) = % O_2/ (21%-%O_2)
Therefore, (150 /100) = % O_2/ (21%-%O_2)
% O_2 = 12.6%

IV. RESULT

A. Waste generation rate in government hospitals varies from 65-75kg/day and in case of private hospital the waste generation varies from 11-13 kg/day.
B. An incinerator has been designed to treat the biomedical waste with a capacity of 50kg/hr.
C. From material balance analysis by assuming complete combustion total mass input (667.92 Kg/hr) is found to be equal to total mass output (667.92 Kg/ hr).
D. From the heat balance analysis, total heat input is found to be 858851.4 KJ/hr and total heat output is found to be 1075750.858 KJ/hr and therefore a deficiency of 216899.458 KJ/hr incurred and hence this deficiency should nullified by supplying an auxiliary fuel to achieve the design temperature of 1100˚C.

E. From the analysis it is found out that an additional amount of 14.40 m^3/hr natural, gas is required to nullify the deficit and to achieve a design temperature of 1100˚C.

F. From the design the volume of secondary chamber is found to be 1.0127 m^3 with a detention time of 1sec.

G. The design dimension of primary chamber obtained is L =1.26 m, D =0.630 m.

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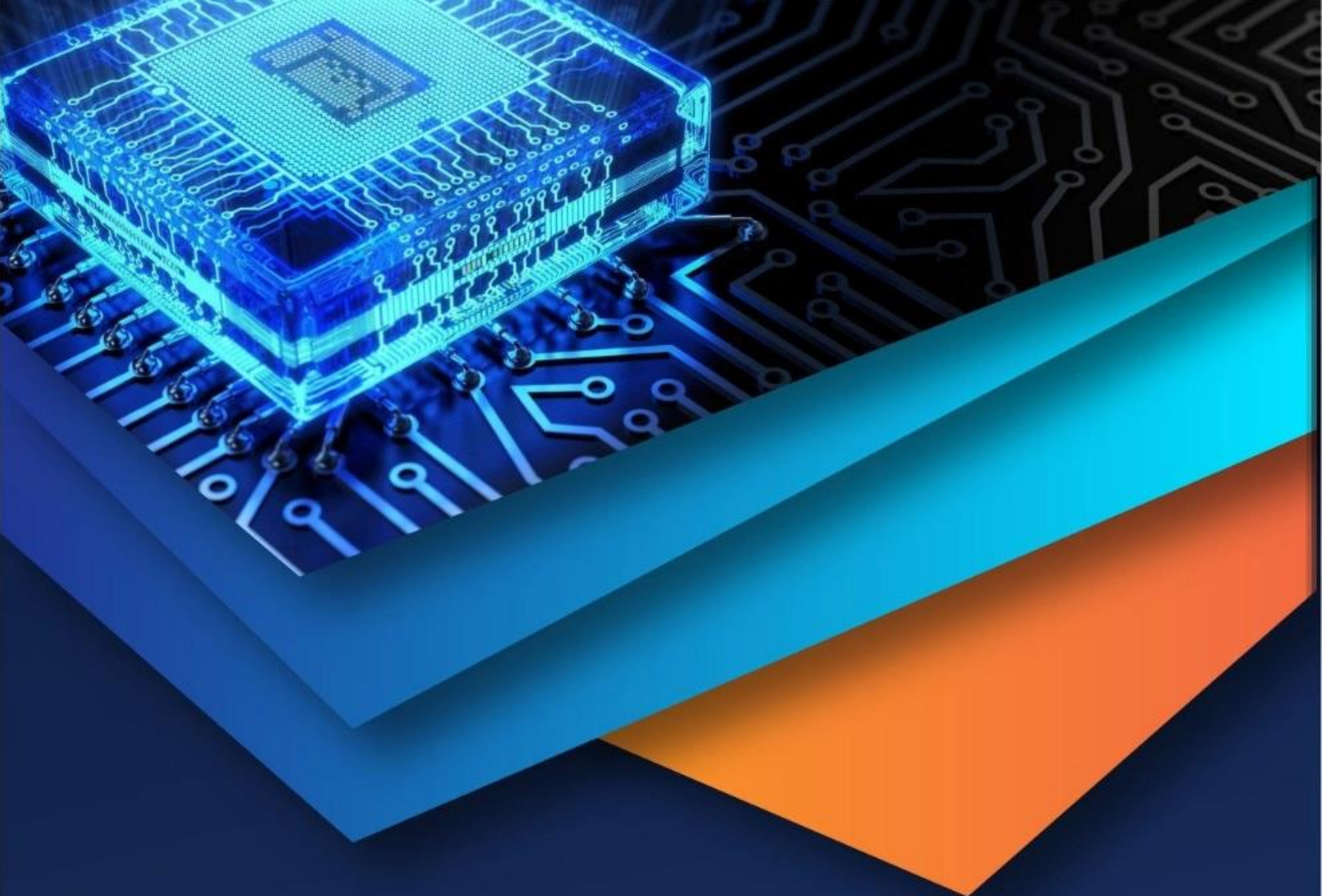

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