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DESIGN OF INCINERATOR FOR THE TREATMENT OF BIO-MEDICAL SOLID WASTE IN CHIKMAGALUR CITY

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ABSTRACT

Healthcare is one of the most essential services in any growing society. The government has made major efforts to ensure its services and outreach to reach remote rural area. This effort has resulted in both improved services and positive impact on the health of the people. Competing with all of the other environmental problems faced by developing countries, medical waste is often overlooked or simply viewed as solid waste issue. However, sound medical waste management is kept to protecting health in the country and requires dedicated planning, training and tracking throughout the medical waste collection, storage, treatment and disposal process. Incineration is one of the best methods among various disposal facilities to detoxify medical waste. Incineration may be defined as the thermal destruction of the waste at elevated temperature say 1200^{0}C to 1600^{0}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.

INTRODUCTION

The management of a bio-medical waste is a subject of considerable concern to public health administrator, infection control specialists, as well as the general public. It is well known fact that healthcare activities generate various types of hazardous and infectious material. Even though the consequences of discharging such wastes carelessly have been recognized earlier, it is only recently that methods to manage this waste in a scientific manner have been initiated in India.

Hospital hazardous waste is unique in several ways there is a large variety of wastes but the volume are small relative to industrial facilities. Hospital employs toxic chemicals and hazardous materials include chemotherapy and antineoplastic chemicals, formaldehyde, photographic materials, radio nuclides, solvents, mercury, waste anesthetic gases, other toxic, corrosive and chemicals.

Every heath care facility should evolve a bio-medical waste management plans as per the BMW rules. (Biomedical Waste Management and Handling Rules, 1998- MOEF- India)

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INCINERATION TECHNOLOGY

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 ^{o}C to 1600^{o}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.

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
- Rotary kiln

Quantification of waste

From the study it can be concluded that average wastes quantification in Chickmagalur city covering 1 Government hospital, 10 private hospitals and Nursing homes and 27 clinics and laboratories is as mentioned in the Table.

DESIGN OF INCINERATOR

Design of Primary Chamber

For designing the primary chamber, initially volume of the chamber is to be found out. For finding out the volume 100kg of waste is dumped as a heap and the volume of the volume of the heap is considered.

Volume of the heap = 5m^3

Assuming a suitable depth of 2.2m, we can find out the area of the chamber

$$\text{Area} = v/\text{depth} = 5/2.2 = 2.3\text{m}^2$$

Assume length and breadth as 1.5:1

Therefore L/B =1.5/1

L =1.5B

Dimensions of the primary chamber = L*B*H

Therefore A = L*B

2.3 = 1.5B*B

2.3 = 1.5B2

B = 1.238m

L = 1.857m

H = 2.2m

Heat and Material Balance Sample Calculation

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.

Assumptions : An incinerator is to be designed to incinerate a mixture of 30% red bag and 70% yellow bag (with a PVC contented 4%) biomedical waste.

Sr. No.	Types of health care establishment	Quantity of waste generation /month	Quantity of waste generation/ day
1.	Government General Hospital	2029.6 kg/month	67.64 kg/day
2.	10 Hospitals & Nursing home	383 kg/month	12.91 kg/day
3.	27 Clinics & laboratories	115.33 kg/month	3.84 kg/day

Total wastes generated per month = 2527.9kg/month

Total wastes generated per day = 84.39kg/day

Characterization of biomedical waste (in units)

1	2	3	4	5	6	7	8
Waste class	Component description	Typical component weight percent	HHVdry basis (kj/kg)	Bulk density as fired (kg/m3)	Moisture content of component	Weighted heat value range of waste component (k/kg)	Typical component heat value of waste as fired (kj/kg)
A1 (Red bag)	Human anatomical	95-100	18600-27900	800-1200	70-90	1770-8370	2800
	Plastics swabs,	0-5	32500-46400	32500-46400	0-1	0-2300	400
	absorbents Alcohol,	0-5	18600-27900	18600-27900	0-32	0-1400	200
	Disinfectant	0-0.2	25500-32500	25500-32500	0-0.2	0-70	50
							3450
A2 (Orange bag)	Animal anatomical	80-100	20900-37100	500-1300	60-90	1670-14840	3500
	Plastic	0-15	32500-46400	80-2300	0-1	0-6960	1000
	Glass	0-5	0	2800-3600	0	0	0
	Beddings, Shavings	0-10	18600-20900	320-730	0-1880	0-1880	1400
							5900
A3 (a) (yellow bag)	Paper, swabs, cellulose	60-90	18600-27900	80-1000	0-30	7810-25110	15000
	Plastic, PVC	15-30	22500-46400	80-2300	0-1	3340-13920	7540
	Sharps,	4-8	140	7200-8000	0-1	-10	10
	Needles, Alcohol,	0-0.2	16200-32500	800-1000	0-50	0-70	30
	Disinfectants	2-5	0-23200	1000-1020	80-100	0-230	70
	Fluids, residual						
							22650
A3(b) (yellow bag) lab waste	Plastic	50-60	32500-46400	80-2300	0-1	16090-27840	21000
	Sharps	0-5	140	7200-8000	0-1	0-10	0
	Cellulosic material	5-10	18600-27900	80-1000	0-15	790-27900	1500
	Fluids, residuals	1-20	0-23200	1000-1020	95-100	0-230	70
	Alcohol,	0-0.2	25500-32500	800-1000	0-50	0-70	50
	Disinfectants Glass	15-25	0	2800-3600	0	0	0
							22620
A3 (c) (yellow bag)	Swabs, Pads	5-30	18600-27900	80-1000	0-30	630-8370	2300
	Plastics	50-60	32500-46400	80-2300	0-1	16090-27840	21000
	Sharps, Glass	0-10	140	7200-8000	0-1	0-10	0
	Fluids	0-10	0-23200	1000-1020	80-100	0-460	230
							23530
B1(blue bag)	Non infected animal	90-100	20900-37100	500-1300	60-90	1880-14840	3000
	Anatomical	0-10	3250-4640	80-2300	0-1	0-4640	2300
	Plastic Glass	0-3	0	2800-3600	0	0	0
	Beddings, Shavings	0-10	018600-20900	320-730	10-50	00-1880	1400
							6700

Chemical Characteristics

Components	Emphirical Formula	Molecular Weight	Higher Heating Value (kj / Kg)
Tissue	$C_5H_{10}O_3$	118.1	20,471
Cellulose, swabs, bedding	$C_6H_{10}O_5$	162.1	18,568
Plastics-Poly- Ethylene 96%-	$(C_2H_4)_x$	28.1*	46,304
PVC4 %	$(C_2H_3Cl)_x$	62.5*	22,630
Sharps	Fe	55.8	0
Moisture	H_2O	18.0	0
Disinfectants, Alcohol	C_2H_5OH	46.1	30,547
Glass	SiO_2	60.1	0

*: Represents monomer

Throughput is to be 100 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:
Secondary chamber temperature: 1100°C
Flue gas residence time at 1000°C: 1 second
Residual oxygen in flue gas: 6% minimum.

STEP 1: Assumptions

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 above.

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

Step 2: Calculation of Material Input

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 red bag waste is typically composed of mainly human t issue as indicated in table 3A. Based on an input of 30% of 100 kg/h (i.e., 30 kg/h), the red bag was assumed to have the following composition.

Tissue (dry)	$C_6H_{10}O_3$	0.15 x 30 = 4.5 kg/h
Water	H_2O	0.8 x 30 = 24.0 kg/h
Ash	-	0.05 x 30 = 1.5 kg/h

Total Red Bag = 30.0 kg/h

The yellow bag waste input is 70% of 100 kg/h (i.e. 70 kg/h) and was assumed to have the following composition:

Polyethylene	$(C_2H_4)_x$	0.35 x 70 = 24.50 kg/h
Polyvinylchloride	$(C_2H_3Cl)_x$	0.04 x 70 = 2.80 kg/h
Cellulose	$C_6H_{10}O_S$	0.51 x 70 = 35.70 kg/h
Ash	_	0.1 x 70 = 7.0 kg/h

Total Yellow Bag = 70.00 kg/h

Component	HHV kj/kg	Input kg/h	Total Heat in kj/h
$C_5H_{10}O_3$	20,471	4.5	92,119.5
H_2O	0	24.0	0.0
$(C_2H_4)_x$	46,304	24.5	1,134,448.0
$(C_2H_3Cl)_x$	22,630	2.8	63,364.0
$C_6H_{10}O_5$	18,568	35.7	662,877.6
Ash	0	8.5	0.0
		100.0	1,952,809.1kj/h

Step 3: Calculation of Heat Input of Wastes (Kj/H)

The HHV and heat input of each component are tabulated below.

Step 4: 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)	4.5		7.32	8.38	3.43	
2.	$(C_2H_4)_x$	+	$3O_2$	= $2CO_2$	+ $2H_2O$	
	28.1		3(32)	2(44)	2(18)	
	1.0		3.43	3.14	1.29	
Poly Ethylene (as fired)	24.5		83.7	76.7	31.4	
3.	$2(C_2H_3Cl)_x$	+	$5O_2$	= $4CO_2$	+ $2H_2O$	+ 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)	2.8		3.58	3.94	0.81	1.64
4.	$C_6H_{10}O_5$	+	$6O_2$	= $6CO_2$	+ $5H_2O$	
	162.1		6(32)	6(44)	5(18)	
Cellulose	1.0		1.19	1.63	0.56	
(as fired)	35.7		42.3	58.1	19.8	

The stoichiometric oxygen required to burn the combustible components of the biomedical waste (67.5kg/h) is 136.9kg/h oxygen (sum of 7.32, 83.7, 3.58 and 42.3).

Step 5: Determination of Air for Waste Based on 150% Excess

From step 4, stoichiometric oxygen is 136.9 kg/h.

Therefore, stoichiometric air =136.98*100/23 =595.2kg/h air

Total air required for waste (at 150% excess) = (1.5*595.2) + 595.2=1488kg/h

Step 6: Material Balance

Total Mass in Waste	= 100.0 kg/h
Dry air	= 1488.0 kg/h
Moisture in air	= 19.6 kg/h (1488 x 0.0132) [step1]
Total Mass In	= 1607.6 kg/h

Total Mass output (assuming complete combustion)

A. Dry Products from waste

Air supplied for waste = 1488.0 kg/h	
Less stoichiometric air for waste	= 595.2 kg/h
Total excess air	= 892.8 kg/h or 150%
Add nitrogen from stoichiometric air 0.77 X 595.2	= 458.3 kg/h
Sub-Total	= 1351.1 kg/h
Add total $C0_2$ from combustion:	
$C0_2$ formed from $C_5H_{10}O_3$	= 8.38 kg/h
$C0_2$ formed from $(C_2H_4)_x$	= 76.70 kg/h
$C0_2$ formed from $(C_2H_3Cl)_x$	= 3.94 kg/h
$C0_2$ formed from $C_6H_{10}O_5$	= 58. 10 kg/h
Total Waste Dry products	= 1498.22 kg/h

B. Moisture

H_2O in the waste	= 24.0 kg/h
H_2O from combustion reactions	= 55.44 kg/h
H_2O in combustion air	= 19 .6 kg/h [step 6]
Total Moisture	= 99.04 kg/h

C. Ash Output = 8. 5 kg/h

D. HC1 formed from Wastes

HC1 formed from $(C_2H_3Cl)_x$	= 1.64 kg/h
Total Mass Out	= Sum of (A, B, C, D) = 1607.4 kg/h

Step 7: Heat Balance

A. Total Heat in From Waste (Qi)

Qi = 1,952,809.1 kJ/h [see Step 3]

B. Total Heat out Based on Equilibrium Temperature of 1100°C (Qo)

i) Radiation loss = 5% of total heat available
= 0.05 x 1,952,809.1
= 97,640.0 kJ/h

ii) Heat to ash = mCpdT
= (8.5) (0.831) (1084.5)
= 7660.4 kJ/h

Where m = weight of ash
= 8.5 kg/h

Cp = mean heat capacity of ash
= 0.831 kJ/kg. °C (assumed average value)

dT = Temperature difference

= (1100-15. 5) °C
= 1084. 5°C

iii) Heat to dry combustion
Products = mCpdT
= (1498.22) (1.086) (1084.5)
= 1,764,554.1 kJ/h

Where m = weight of combustion products
= 1498.22 kg/h
Cp = mean heat capacity of dry products
= 1.086 kJ/kg°C (assumed average value)
dT = (1100-15.5) °C = 1084. 5°C

iv) Heat to moisture = (mCpdT) + (mHv)
(mCpdT)+ (mHv) = (99.04 x 2.347 x 1084. 5) + (99. 04 x 2460.3)
= 252,088.6 + 243,668.1
= 495,756.7 kJ/h

Where m = weight of water = 99.04 kg/h
Cp = mean heat capacity of water
= 2.347 kJ/kg. °C
dT = (1100-15. 5) °C = 1084. 5°C
Hv = latent heat of vaporizations of water
= 2460.3 kJ/kg

Total Heat Out (Qo) = sum of (i, ii, iii, iv) = 2,365,611.2 kJ/h
Net Balance = Qi - Qo
= 1,952,809.1 - 2,365,611.2
= -412,802.1 kJ/h (deficiency)

Auxiliary fuel must be supplied to achieve Design temperature of 1100°C.

Step 8: Required Auxiliary Fuel to Achieve 1100°C

i) Total heat required from fuel = 412,802.1 + 5% radiation loss = 433,442.2 kJ/h
ii) Available heat (net) from natural gas at 1100°C and 20%
excess air = 15,805.2 kJ/m^3 (assumption)
Natural gas required = 433,442 .2/15,805.2 m^3/h = 27.42 m^3/h

Step 9: Products of Combustion from Auxiliary Fuel

i) Dry Products from Fuel
at 20% Excess Air = 16.0 kg [8] x 27.42 m^3 /h m^3 fuel = 438.7 kg/h
ii) Moisture From Fuel = (1.59 kg (8)/m^3fuel) x 27.42 m^3/h = 43.59kg/h

Step10: Secondary Chamber Volume Required to Achieve One Second Residence Time at 1000 °C

i) Total Dry Products
From waste + fuel = 1498.22 kg/h + 438.7 kg/h = 1936.9 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 (Vp) can be calculated as follows:
Vp = 1936.9 kg dp/h x (22.4 m^3)/29kg dp) x (1273K / 273k)* x (1 h/3600s)
= 1.94 m3 /s

ii) Total Moisture
From waste + fuel = 99.04 kg/h +43.6 kg/h = 142.6 kg/h
Using the ideal gas law, the volumetric flow rate of Moisture at 1000°C (Vm) can be calculated as follows:

Vm = (142. 6 kg H_2O/h) x (22.4 m^3/18kg H_2O) x (1273K/ 273k) x (lh/3600s)
= 0.23 m^3/s

Total Volumetric Flow Rate = sum of (i, ii)
= 1.94 + 0.23
= 2.17 m^3/s

Therefore, the active chamber volume required to achieve one second retention is 2.17 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

Step 11: Residual Oxygen in the Flue Gas

The residual oxygen (%02) can be determined using the following equation:

EA (excess air) = % O_2/ (21%-%0_2)
Therefore, (150 /100) = % O_2/ (21%-%O_2)
%02 = 12.6%

CONCLUSION

1. Waste generation rate in government hospital varies from 65-75kg/day and in case of private hospital the waste generation varies from 11-13 kg/day
2. An incinerator has been designed to treat the biomedical waste which is being generated in chikmagalur city with a capacity of 100kg/hr.
3. From material balance analysis by assuming complete combustion total mass input (1607.6kg/hr) is found to be equal to total mass output (1607.4kg/hr).
4. From the heat balance analysis, total heat input is found to be 1952809.1kj/hr and total heat output

is found to be 2365611.2kj/hr and therefore a deficiency of 412802.1kj/hr incurred and hence this deficiency should nullified by supplying an auxiliary fuel to achieve the design temperature of 1100^{0}C.

5. From the analysis it is found out that an additional amount of 27.42m3/hr natural, gas is required to nullify the deficit and to achieve a design temperature of 1100^{o}C.
6. From the design the volume of secondary chamber is found to be 2.17m^{3}with a detention time of 1sec.
7. The design dimension of primary chamber obtained is 1.8*1.2*2.2 (L*B*H)

REFERENCES

Aarne Vesiland, P., Jeffrey Peirce, J. and Ruth Weiner, 1994. *Environmental Engineering*, 2nd Edition, Butterworth Heinemann.

Bio-medical Waste Management, June 2004. Environmental Management and Policy Research Institute (EMPRI)

Bio-medical Waste Management systems in Chickmagalur city', BE project report Sowmya.M.S, Sunil Kumar.K, Suneeth kumar, Blessy Merlin K.E. Easaw

Chandorkar, A.G. and Nagoba, B.S. 2004. *Hospital Waste Management.* Paras Medical Publishers, 2nd Edition.

Coker, A.O. *et al*. 1999. *Characterization and Management of solid Hospital Waste', 25th WEDC Conference*, Addis Ababa, Ethopia, Page No.331-334.

Central Pollution Control Board 2000. *Manual on Hospital Waste Management'*, March, 2000.

Estimation of Bio-medical Waste Generation Rates, 2003. State of Environment Report (SOER), KSPCB, Page No. 146-148

Gopinath, D. and Prithbish, S. 2003. *Journal of the Indian Society of Hospital Waste Management.* Volume-1 and 2, Issue-1.

Handbook of Operation and Maintenance of Hospital Medical Waste Incinerators,1990. USEPA,EPA..No. 625-6-89-024.

Incinerator design and operating criteria volume II Bio-medical waste incineRators' Ontario Ministry Of The Environment 135 St. Clair Avenue West Toronto, Ontario October 1986.

Trivedy, R.K. 2010. *Handbook of Environmental Laws, Rules, Acts, Guidelines, Compliances and Standards.* B.S. Publications, Hyderabad, India