An Optimal Design of the Bio-Medical Waste Incinerator for Three Hospitals of Agra City

Sandeep Kumar Verma[a], Vipin Kumar[b*]

[a] Department of Chemical Engineering, Hindustan College of Science & Technology Farah Mathura, U.P., India
[b] Department of Biotechnology, Hindustan College of Science & Technology Farah Mathura Mathura

Abstract: ***This paper describes an improved design of biomedical waste incinerator which may meet the national as well as international standards. Incineration Technology have now become the fast-developing technology, due to stringent regulations, imposed by the Govt. and Environment Protection agencies. The manufacturers of incinerators, all round the world are now bound to improve the design of incinerators to meet the international standards in all parameters including the emission limits. Central Pollution Control Board (India) has prescribed "Guidelines for Biomedical waste incinerators (Revised Draft)" issued in March 2017. The CPCB has recommended for several modifications in the design of biomedical waste incinerators. An optimal design of Biomedical Waste incinerator in the perspective of the recent guidelines of CPCB, India (2017) is being presented.***

Keywords: Biomedical Waste, Incinerator, Design, High Heating Value, Energy Balance, Mass Balance

1.Introduction

Proper design of biomedical waste incinerators plays the most important role for better performance of incineration system. Biomedical waste incinerators differ from the majority of other incinerators like MSW incinerators etc. The biomedical waste consists of human tissues animal carcasses, organs etc. which requires very high temperature for complete destruction.

J. Bujak (2010) [1] has presented his investigation paper on characteristics of biomedical wastes using an input output method. According to the author medical waste is heterogeneous consisting of organic waste, medicines, plastics and contaminated cellulose and tissues etc. due to which the properties of fuel (wastes) undergo significant changes in terms of heating value. Due to the lower heating value, the velocity of combustion also changes which in turn leads to the temperature and pressure variations in the combustion chamber.

John S.E. Swamy et.al (2011) [2] has presented his paper on designing a biomedical waste incinerator for Chikmanaglur City. In this paper the authors have described the whole process of designing in a systematic way.

Rajiv Ganguly et al. (2017) [3] has observed that the design of an incinerator is highly influenced by the heat and material balance, which evaluates the input and output contents of the incinerator. This determines the auxiliary fuel and combustion air requirements.

S.S Wahid et al, (2013)[4] has presented an efficient and optimal design of hazardous waste incineration plant for hospital with a capacity of 100kg/h. The author designed the incinerator according to the standard specifications and guidelines of Egyptian environmental affairs agency. Through the experimental work the author concluded that the incineration plant operated efficiently at the designed parameter level and has a full compliance with the standards and rules of Egyptian environmental affairs agency.
For proper designing and for calculation for determining the appropriate volume of the secondary chamber, the formula and other specific parameters have been developed and the draft report had been approved in 1986 by the Environmental Approval Branch, Ontario Ministry of Environment, Ontario Canada. The draft report was entitled as "the Incinerator design and operating criteria" [5].

As per instructions of the MoEF & CC (government of India), issued on 28 March 2016[6], the constituents of red category are not permitted for incineration. Only yellow category wastes are permitted to be incinerated. Due to this notification the quantities of wastes for incineration have been reduced. The table given below is based on the survey conducted in March 2018 by the author.

The total quantity of waste (yellow bag) generated for incineration in Agra (from three major hospitals) city on a monthly and daily basis was quantified to obtain a sample size of waste to be used for designing purpose as shown in Table 1.

Table 1

S. No	Name of health care units	Quantity of waste (yellow category only) generated/ month	Quantity of waste (yellow category only) generated/ day
a	S.N.M.C Hospital	1650 kg	55
b	Lady Loyal Hospital	300 kg	10
c	District Hospital	750 kg	25

As it is clear from the table 1 that the total average waste generated per day is 90 kg/day and hence the design waste is assumed to be 100kg/day.

Objectives to be achieved

a. A biomedical waste incinerator of the capacity of 100 kg/h is intended to be designed for incineration of waste of yellow category which contains the human anatomical wastes, animal anatomical waste and discarded medicines along with plastic ampoules etc. These are the items prescribed for incineration by the CBCB India as per instructions issued in 2016. All these items may be categorized into cellulose, Tissue, Polyethylene, PVC and water etc. for the calculation.

b. To achieve the temperature of 1200 ^{0}C in the secondary chamber

c. To achieve the residence time of 1 second at 1100 ^{0}C

The whole process of the design of Biomedical waste may conveniently be explained stepwise because for every forward step is interconnected with the previous steps

Step one-***Designing of Biomedical waste Incinerator***

Some assumptions are basic requirement for designing of an incinerator these are;

a. The air contains .0143 kg H_20/kg dry air at 65% relative humidity

b. The ratio of oxygen in air is 23% by weigh and the Nitrogen is 77% by weight

c. The ambient temperature of air and the fuel may be assumed to be 18 ^{0}C

d. The water temperature 18 ^{0}C and the latent heat of vaporization is 2460.3kj/kg

e. 1 kg mole of any ideal gas = 22.4m^{3}at 0^{0}C and 101.3 kpa.

Step two- ***Dimensions of primary chamber***

For designing the primary chamber the dimensions of the chamber is to be found out. For finding out the volume 100 kg of waste is dumped and the volume of the heap is 6m^3 and the depth of the heap is 3m.

The area of chamber = volume/depth = 6/3 = 2m^2

Assume length and breadth as 2:1

Therefore L/B = 2/1 = 2

L= 2B

Area = L*B or 2 = 2B*B or B = 1m and L = 2B =2*1 = 2m^2

Dimension of primary chamber = L*B*H = 6

or 2*1*H = 6 or H = 3m.
The dimension of the primary chamber is, L=2, B=1 and H=3.

Step three: Characteristics of biomedical waste:

Table 2: Chemical empirical formula

Component	Chemical formula	HHV kJ/kg	Input kg/h	Total heat in kJ
Tissue	$C_5H_{10}O_3$	20471	24	491304
Water	H_2O	0	25	0
Polyethylene	$(C_2H_4)x$	46304	3	138912
PVC	C_2H_3Cl	22630	2	45260
Cellulose	$C_6H_{10}O_3$	18568	37	687016
Ash		0	9	0
Total			100	1362492

Step four-***Determination of the stoichiometric oxygen***

During the process of burning of the fuel, a chemical reaction takes place in between the oxygen and the fuel. When the fuel is completely burned and the quantity of oxygen has also been fully consumed, this point is termed as stoichiometric point and the quantity of oxygen exactly consumed up to this point is termed as stoichiometric oxygen.

The stoichiometric oxygen can be found out by the following table -3s which shows the chemical equilibrium equations of the components.

Table 3: Chemical equilibrium equations and chemical characteristics of biomedical waste.

Components	Input Kg/h	HHV (Kj/kg)	Total heat in (kj/kg)	Chemical Empirical Formula			
Cellulose				$C_6H_{10}O_5$	+ $6O_2$	= $6CO_2$	+$5H_2O$
				162.1	6(32)	6(44)	5(18)
				1.0	1.19	1.63	0.56
H_2O	25	0	0.0				
Cellulose (as	37	18568	687016	37 (1x37)	44.03 (1.19x	60.31	20.72 (0.56x37)

fired)	Kg/h				37)	(1.63x37)		
Tissue				$C_5H_{10}O_3$	+ $6O_2$	= $5CO_2$	+$5H_2O$	
				118.1	6(32)	5(44)	5(18)	
				1.0	1.63	1.86	0.76	
Tissue as fired	24 Kg/h	20471	491304	24 (1x24)	39.12 (1.63x224)	44.64 (1.86x 24)	18.24 (0.76x24)	
Polyethylene				$(C_2H_4)x$	+ $3O_2$	= $2CO_2$	+ $2H_2O$	
				28.1	3(32)	2(44)	2(18)	
				1.0	3.43	3.14	1.29	
Polyethylene as fired	3 Kg/h	46304	138912	3 (1x3)	10.29 (3.43x 3)	9.24 (3.14X3)	3.87 (1.29X3)	
PVC				$2(C_2H_3Cl)x$	+ $5O_2$	= $4CO_2$	$2H_2O$	+ 2HCl
				2(62.5)	5(32)	4(44)	2(18)	2(36.5)
				1.0	1.28	1.41	0.29	0.58
PVC as fired	2 Kg/h	22630	45260	2 (1X2)	2.56 (1.28X 2)	2.82 (1.41X2)	0.8 (0.29x2)	1.16(0.58x2)
Ash	9	0	0.0					
	100.0		1362492 kj/h					

The above table shows that the total weight of biomedical waste is 66 Kg/h (sum of 37+24+3+2) and the stoichiometric oxygen is 96 Kg/h (sum of 44.03+39.12+10.29+2.56)

<u>Step five</u>- *Determining the quantity of Stoichiometric and excess air, (Nitrogen etc.)*

From the above calculation it is found that the stoichiometric oxygen is 96 kg/h it is assumed here that the air contains only 23% oxygen and 77% Nitrogen etc.

Thus, the stoichiometric air (containing nitrogen etc.) can be calculated as

96x 100/23 = 417.39

As for criteria of incineration design propounded and approved by the Ontario ministry of environment (1986), the requirement of total air at 150% excess air may be worked out as follows.

Total air required for waste at (150% excess) = 1.5 x 417.39 + 417.39

= 1043.47 kg/h.

<u>Step six</u>- *Calculation of Mass balance*

The constituents of the mass are (1) The mass of wastes (2) the mass of air without $H_2$0 contents (3) H_2O contents in the air

The aggregate of mass input

a. Total mass of biomedical waste for incineration = 100kg/h
b. Total Mass of air without $H_2$0 contents = 1043.47 kg/h
(As calculated in step five)
c. H_2O contents in the air = 14.92 (1043.47x0.0143) [step1]

Total of Mass Input = 1158.39 Kg/h

The aggregate of mass output

a. <u>Dry products from waste</u>

Total amount of air required for waste = 1043.547 kg/h

Stoichiometric air for waste = 417.39 kg/h

The amount of air remaining after subtracting the stoichiometric air (total excess air)
= (1043.47-417.39)
= 626.08 kg/h

The remaining excess air = 626.08kg/h

The amount of Nitrogen in stoichiometric air = 0.77x 417.39= 321.39 kg/h

Adding the amount of Nitrogen n the remaining = 947.47 kg/h (626.28 +321.39 from step four)

Addition of Total carbon di oxide from combustion

CO_2 formed from $C_6H_{10}O_5$ = 60.31
CO_2 formed from $C_5H_{10}O_3$ = 44.64
CO_2 formed from (C_2H_4) = 9.42
CO_2 formed from (C_2H_3Cl) = 2.82

Sub Total = 117.19

Total = 1064.66 (947.47+117.19)

b. <u>H_20 contents in the waste</u>

Amount of H_20 contents in the waste = 25 kg/h
The amount of H_2O contents in burning reaction 43.41 kg/h
(20.72+ 18.24 +3.87 + 0.58) from table 2

The amount of moisture during combustion process = 14.92 kg/h [step 6]
Total moisture = 83.33 kg/h

c. <u>The quantity of ash output</u> = 9kg/h

d. <u>HCl due to chemical reaction</u>

HCl produced due to chemical reaction ($C_2H_3C_6$) = 1.16
Total mass output = 1158.15 (sum of a, b,c and d)

(1064.66+ 83.33 + 9+ 1.16)

<u>Step seven</u> -*The balance of Energy*

Energy generated from the waste component (Q-1) = 1362492 kJ/h (from table-2)
Energy output at the desired temperature of 1200 ^{0}C (Q-2)

a. Loss of energy due to radiations= loss of 5% of total energy available
= 0.05x1362492 = 68124.6Kj/h

b. Energy to ash= the formula for determining energy to ash is (m) (C_P) (dT)

Where m - stands for quantity of ash = 9 kg/h

C_P -stands for thermal capacity of ash = 0.965 kj/kg (based on assumption)
dT – stands for change in temperature between the following:

Assumed requirement of Secondary chamber =1200 ^{0}C and assumed input temperature of waste, fuel and air= 18 ^{0}C thus it is calculated as: 9x 0.965x 1182= 10265.67 kj/h

c. Energy to dry combustion products the formula is (m)(C_P)(dT)

Where m stands for combustion products= 1064.66 (from step 6A)

C_P stands for thermal capacity of products without any moisture = 1.156 kJ/kg (based on assumption)

dT – stands for difference in desired temperature and the ambient temperature= 1200 ^{0}C – 18 ^{O}C = 1182 ^{0}C

thus, the calculation is 1064.66x 1.156x 1182= 1454742.9 kJ/kg

d. Heat to moisture

The formula is (mC_PdT) + (mH_V) where m= total moisture= 83.33(from step 6B)

C_P means heat capacity of water= 2.347
dT means difference in temperature= 1200 ^{0}C-18^{0}C=1182 ^{0}C
H_V= Absorbed heat for change of phase from water to vapor (Latent heat)= 2395.3 KJ/kg

Calculation- 83.33x 2.347x 1182 + 83.33x83.33x 2395.3= 199600.34
=231170.25 + 199600.34 = 430770.59

Total energy out(Q2) = sum of (a + b +c+d)
68124.6 + 10265.67 + 1454742.9 + 430770.59= 1963903.76Kj/h

Net balance= Q 1 – Q 2
1362492 from table 1- 1963903.76

Deficiency = 601411.76kj/h

There is a need of auxiliary fuel to need the deficiency of601411.76 kJ/h

<u>Step eight -</u>*Finding out the quantity for auxiliary fuel*

a. The quantity of energy needed = 601411.76 KJ/kg
5 % radiation loss = .05x 601411.76=30070.58
Total = (601411.76+ 30070.58)=631482.34kj/h

b. The quantity of energy expected to be available from natural gas at the temperature of 1200 ^{0}C =17242.03 kJ/m^3

The natural gas needed = (631482.34/17242.03) =36.62 m^3/h

<u>Step nine</u> -*Types of waste (fuel) produced by using the auxiliary fuel*

There are two types of wastes (fuel) produced by using the auxiliary fuel

a. Waste (fuel without moisture) = 16.00kg [9] x 36.62m^3/h=585.92 kg/h

b. H_2O Contents from waste (fuel) = 1.59 kg/m^{3}fuel 36.62 m^3/h= 58.22kg/h

<u>Step ten</u> -To determine the volume of secondary chamber with the objective of achieving the temperature of 1100 ^{0}C with 1 sec residence time (The calculations are based on the formula developed and approved by Ontario ministry of the environment, Toronto, Ontario Canada

a. Total waste and fuel (without any moisture contents

The sum of waste and fuel: 1064.66kg/h (From Step. 6A) +Fuel = 585.92 (From Step 9) Total 1650.58 kg/h

Paper ID: SR251216111339 DOI: https://dx.doi.org/10.21275/SR251216111339

The Products without moisture have the properties of air and thus, the volumetric flow rate of dry products (dp) at 1100 ^{0}C (VP) can be worked out as presented below

The formula is as follows:

VP =1650.58 dp/h x 22.4 m^3(Ideal Gas Law) / 29 kgdpx (1373 k / 273 k) x (1h /3600s)
= 1.83 m^3/s

b. Waste and fuel with moisture
= 83.33 (From Step 6B) +58.22 (From step 9) = 141.55 kg/h
VM can be worked out as presented below

(Calculated on basic of formula approved by Ontario Ministry of the Environment)

The Formula:

V_m = 141.55 kg H_2O/h x 22.4 m^3 ÷ 18 kg H_2O x (1373 k ÷ 273 k) x(1h/3600s)

Calculation made on the basic of the above Formula= 0.24m^3/s

Total Volumetric Flow Rate = Sum of (a+b) 1.83+ 0.24 = 2.07 m^3/s

By observation of the design it has been found the volume of 2.07 m^3 with one Second retention time is sufficient for the active chamber of the incinerator.

Step eleven - The manufacturer of incinerator should be instructed to prepare the incineration machine with the improved design strictly in compliance with the guidelines prescribed by the CPCB India, which has been described below**:**

Guidelines Issued by Central Polution Control Board (April 2017):

Some of the important guidelines prescribed by the Central Pollution Control Board (April 2017) are as follows:

a. Size of the opening to be made large:

The size of the opening should be made larger for facilitating the charging the waste bags.

b. Provision of Pressure gauge and Flow Transmitter in primary chamber:

Incinerator chambers shall also be fitted with a suitable provision of pressure gauges for measuring the air supply or flow rate. Combustion air measurement through flow transmitter should be provided and the display shall be in PLC.

c. A flow meter to be provided on the primary and secondary air ducting:

The provision of flow meter

The device of flow meter should be fitted on the primary & secondary air ducting.

d. Corners should be rounded:

The side corners and the top portion corners of both chambers should be rounded from inside, so that the cold pockets in inactive zones may not be created.

e. The refractory lining of both the chambers should be strong enough to sustain thermal shocks:

The refractory lining of the chamber shall be strong enough to sustain thermal shocks i.e., minimum temperature of 1000^{0}C in the primary chamber and 1050 +/- 50^{0}C in the secondary chamber. The refractory & insulation bricks shall have suitable thickness each& shall conform to IS: 8-1994 & IS: 2042-2006 respectively.

f. Provision of separate burners for Primary and Secondary Chamber:

The Primary and secondary chambers should be equipped with their separate burners. One or more separate burner may be required depending on diameters of the incinerator chamber to maintain the desired temperature in the incinerator chambers.

g. The provision of an automatic switching on/off control:

Device should be provided for the maintenance of proper temperature and automatic switching off/on.

h. Provision of View Port:

Provide projected type of observation or view ports (high-temperature) glass with a metal closure provision) to observe visual condition of the burning process and waste/ash accumulation in the combustion chamber.

i. Provision of Computer Recording Device:

The incinerator should be equipped PLC (Programmable Logical Device) for recording all relevant data e.g. temperature, pressure, date and batch number.

j. Provision of Alarm System to alert in case of emergency:

The incinerator should have alarm system to alert the incinerator in the event of power failure, non-operation of the APCD, not maintaining adequate temperatures in primary and secondary chambers or in case of any emergency.

The manufacturer of incinerator should be instructed to prepare the incineration machine with the improved design strictly in compliance with guidelines prescribed by the Central Pollution Control Board as has been described in the above section.

2.Result and Discussion

An in-depth analysis of the design shows the following features:

a. With the provision of View-Ports the combustion condition inside the chamber can be observed and in case of variation in temperature and pressure may be adjusted for proper functioning of the incineration.
b. Due to the rounded corners, the whole space inside the chamber will become the active zone. The dead zones or cold packets will not be created which will cause the complete combustion of the waste which in turn will avoid the formation of Furans and Dioxins.
c. Due to the exclusion of sharps and plastics from the incineration category now it has become convenient to avoid the fluctuations in temperature, pressure and velocity in the combustion process. The elevated temperature can be maintained constantly which will cause full destruction of pathogens including the endospores.
d. In literatures, some improved designs have been developed during the recent past but these designs have been developed for the biomedical wastes of yellow category and red category both. The sharps e.g. the scalpels blades and needles and plastics were the constituents of the red category. All the wastes of red category are not permitted for disposal by incineration.
e. A similar such design has been developed by John, S.E. Swamy for Chikmangalur city for incinerating 100 kg/day. Through the calculations the authors have found the volume of active chamber 2.17 m^3/s, while in our design the volume has been found to be only 2m $^3/s$. The difference is due to the facts that the authors, John S.E. Swamy et al. have included the red category wastes together with yellow category wastes while in our case the design is only for yellow category wastes. As per notification of MOE&F (Government of India) issued on 25the March 2016, the red category wastes are not permitted to be incinerated but to be treated with Autoclaves and there after sent for recycling.
f. Thus, it may be expected that the design presented, may meet the national as well as international standards.

3.Conclusion

a. The design of dimension of primary chamber is 2*1*3(L*B*H)

b. It has been found through calculations that the volume of the secondary chamber should be 2.07 m^3/s with retention of one second at the temperature of 1100 ^0C

c. Through calculation an analysis of the mass balance, it is found that the mass input and mass output are fully balanced the mass input is 1158.39 kg/h and the mass output is 1158.15 kg/h. The difference of 0.24 is negligible.

d. Through calculations of the energy balance it is found that the energy input is 1362492kJ/h but the energy output is 1963903.76kJ/h. Thus, there is deficiency of 601411.76 kJ/h which requires the auxiliary fuel to achieve the temperature of 1100 ^0C at 1 second retention time.

e. Finally it has been concluded that the amount of natural gas required is 36.62m^3/h to meet the deficiency.

References

[1] J. Bujak (2010) Experimental study of the lower heating value of medical waste – Polish Journal of environmental study 19 No 6(2010) 1151-1158
[2] John S.E. Swamy (2011) Design of incinerator for the treatment of biomedical solid wastes in Chickmangalur City, Journal of Industrial Pollution Control **27(2)**, 173-179.
[3] Rajiv Ganguly (2017)- Design of an incinerator to treat combined biomedical wastes generated from four major hospitals in Chandigarh and Shimla city, India- Research Journal of pharmaceuticals, biological and chemical sciences ISSN -0975-8585.
[4] SS Wahid (2013) - An optimal design of hazardous (biomedical waste incineration plant, international journal of industrial engineering & technologies (IJIET) ISSN 2277, VOL-3 ISSUE-1 March 2013.
[5] Incinerator design and operating criteria, Volume II, Biomedical wastes incinerator, Ontario Ministry of the Environment 135 St. Clair Avenue Waste Toronto Ontario, Oct. 1986.
[6] Published in the Gazette of India, Extraordinary, Part-II Section-3, Sub-section (1) Ministry of Environment, Forest and Climate Change Notification, New Delhi, the 28th March, 2016.
[7] Guidelines for Biomedical Waste Incinerator (Revised Drafts) Central Pollution Control Board (April 2017) (Ministry of Environment, Forest and Climate Change) Parivesh Bhawan, East Arjun Nagar, Delhi, Website: www.cpcb.nic.in.
[8] Y. M. D. A. Balushi, M. M. Ullah, A. A. A. Makhamri, F. S. A. Alawi, M. Khalid, and H. M. A. Ghafri, "Knowledge, Attitude and Practice of biomedical waste management among Health Care Personnel in a secondary care hospital of Al Buraimi Governorate, Sultanate of Oman," *Global Journal of Health Science*, **10**: 3-70, 2018.
[9] O. O. Olanrewaju1* and R. J. Fasinmirin1 Design of Medical Wastes Incinerator for Health Care Facilities in Akure, *"Journal of Engineering Research and Reports* **5(2):** 1-13, 2019.
[10] Robert Ohene Adu, Samuel Fosu Gyasi, David Kofi Essumang, and Kenneth Bentum Otabil, Medical Waste-Sorting and Management Practices in Five Hospitals in Ghanna,"*Journal of Environmental and public health,* Research Article | Open Access Volume 2020 |Article ID 2934296 | March,2020 https://doi.org/10.1155/2020/2934296
[11] Jena, B., Patraik, S., and Patraik, N., 2021. Impact of improper biomedical waste disposal on human health and environment during Covid-19 pandemic. European journal of molecular and clinical medicine. **8(3):** 4137-4143.
[12] Kaushol, R., Rohit, and Dhaka, A.K., 2022. A comprehensive review of the application of plasma

gasification technology in circumventing the medical waste in a post-COVID-19 scenario. Biomass Conversion and Biorefinery, pp. 1-16. https://doi.org/10.1007/s13399-022-02434-z.

[13] Jie, Z., Liu, C., Xia, D., and Zhang, G., 2023. An atmospheric microwave plasma-based distributed system for medical waste treatment. Environmental Science and Pollution Research, 30, pp. 51314-51326. https://doi.org/10.1007/s11356-023-25793-0.

[14] Hadi, A.H., Hussain, B.A., Khalaf, A.A., and Abdurazak, A.F., 2024. A theoretical calculation of electrical energy production from the incineration of Baghdad municipal solid wastes. Journal of Engineering, **30(5):** 86-97.