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Design of an incinerator to treat combined biomedical wastes generated from four major hospitals in Chandigarh and Shimla City, India.

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ABSTRACT

It is of prime importance to provide adequate healthcare facilities for a developing country. In this context, the India Government has been successful in implementing these objectives. However, with the increase in healthcare provisions has also lead to massive increase in generation of biomedical wastes. Inefficient handling of Health Care Wastes (HCW) in a hospital environment poses a severe threat to workers, patients, waste handlers and the general human community due to possibility of transmission of pathogens. Hence, a sound biomedical waste management practice is needed to avoid any potential issues. In general, a sound waste management technique involves appropriate planning including collection, segregation, storage, treatment and disposal procedures and adequate training of the workers involved in the process. In general, incineration is one of the most widely used techniques for disposal of biomedical wastes. The process involves burning of the waste at very high elevated temperatures (1500°C) under controlled operating conditions in a chamber known as incinerator. The end products generated are carbon dioxide and water with ash as residual material. The paper presents in an in-depth analysis of design aspects of the incineration chamber.

Keywords: Biomedical Waste, Hazardous substances, Incineration process, Heat generation, Chandigarh, Shimla.

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INTRODUCTION

Proper management techniques are very important for biomedical waste management as any deficiencies in the system can cause severe problems. Proper management of biomedical waste includes proper procedures for collection, segregation, storage, transportation and disposal of solid waste [3]. Majority of biomedical wastes generated in hospitals are organic in nature and primarily consists of carbon, hydrogen, halogens, nitrogen, heavy metals and other certain chemicals (traces). Due to the nature of the wastes generated in a healthcare facility, incineration is considered to be one of the best methods for detoxification and safe disposal of biomedical waste [6].

Incineration is generally defined as the destruction of wastes at relatively high temperatures of 1200°C to 1600°C under controlled conditions for destruction and detoxification of biomedical wastes. The high temperature is required to be maintained in the incinerator chamber to ensure complete combustion of the toxins and pathogens, elimination of odors without damaging any internal components of the system [4]. The final end products after incineration process are primarily CO$_2$, water and residual ash [4]. The CO$_2$ generated from the incineration process will be have considerably less effect as a greenhouse gas in comparison to CH$_4$ that will be generated due to anaerobic process if the waste was dumped in open landfill (CH$_4$ has 1.38 times more potent as greenhouse gas than CO$_2$). The equipment in which the process is done is called an Incinerator. In practice, there are primarily three types of incinerators available including Multiple Chamber (retort and in-line), Controlled Air and Rotary Kiln type of incinerators [12].

Multiple Chamber Incinerator is one of the most widely used incinerators for disposal of biomedical waste. In this incinerator, the combustion of waste is a two-stage process. The first stage involves application of the biomedical waste in the primary chamber wherein it is operated on a limited supply of air (less than the stoichiometric requirement) for the combustion process whereas the second stage involves addition of excess air to oxidize the volatile gases generated from the first stage reactions. It is important to note that since air rates in the primary chamber is low, entrained particulates in the volatile gases generated and leaving the primary chamber is low due to which gas cleaning devices are absent for controlled air incinerators. Figure 1 shows the line diagram to explain the incineration process inside a Multiple Chamber Incinerator [5].

![Figure 1: Schematic diagram of incineration system. [12]](image)

Incineration process is an effective means of reducing the biomedical waste volume particularly for high population density areas and consequently with less availability of land area for landfill sites. It is a clean and efficient waste disposal technology as it reduces the amount of residue to be dumped in the landfill site by about 30-35% [8]. Proper disposal of residual ash will also reduce risk of groundwater contamination.
However, there remain environmental and technical issues in the incineration primarily due to emissions and nature of residual solids in ash after burning process [8].

Site Location

Shimla is located in the south-western districts of Himachal Pradesh and lies between the UTM coordinates of (699211.48, 3499122.47) located in the UTM zone of 43R at a height of 2000 m above MSL in ‘middle Himalayas’. As per the latest population census carried out in India in the year 2011, the population of Shimla district is 14,101 with a population density of 159 inhabitants per km² covering an area of 5131 km². Chandigarh lies within the UTM coordinates of (670358.11, 3401399.32) in the zone 43R covering an area of 114 Km² and has a population of 1.05 million as per 2011 census with a decadal growth rate of 17%.

MATERIAL AND METHODS

The following sub-sections explain the methodology carried out for complete design of the incinerator.

Quantification of Waste

The total quantity of waste generated in Shimla and Chandigarh (from four major hospitals) on a monthly and daily basis was quantified to obtain a sample size of waste to be used for designing purpose [3]. This is much greater than earlier reported literature [7]. This has been shown in Table 1. It is observed from Table 1 that the total waste generated per day is 449.36 kg/day and hence the design waste is assumed to be 500 kg/day.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name of Health Establishment</th>
<th>Quantity of Waste generated/month</th>
<th>Quantity of Waste generated/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>IGMC Hospital, Shimla</td>
<td>3,012 kg/month</td>
<td>100.4 kg/day</td>
</tr>
<tr>
<td>2.</td>
<td>INDUS Hospital, Shimla</td>
<td>97.8 kg/month</td>
<td>3.26 kg/day</td>
</tr>
<tr>
<td>3.</td>
<td>MAX Hospital, Mohali</td>
<td>6,498 kg/month</td>
<td>216.3 kg/day</td>
</tr>
<tr>
<td>4.</td>
<td>IVY Hospital, Mohali</td>
<td>3,882 kg/month</td>
<td>129.4 kg/day</td>
</tr>
</tbody>
</table>

Table 1: Waste generation from four major hospitals in Shimla and Chandigarh city used for incinerator design

Design of an Incinerator

The following steps were used to design the incinerator. Each step of the design procedure has been discussed in great details including the assumptions involved in the design process.

Design of Primary Chamber

For designing of Primary chamber of Multiple Chamber Incinerator under controlled air conditions initially volume of primary chamber is to be determined so as 500 kg of waste is dumped and the volume of heap is considered [1].

\[
\text{Volume of heap (for 500 kg of waste)} = 8 \text{ m}^3
\]

Assuming suitable depth of 3 m we can find the area of chamber as

\[
\text{Area} = \frac{\text{Volume}}{\text{Depth}} = \frac{8}{3} = 2.66 \text{ m}^2
\]

Assume the ratio of length and breadth as 1.75:1

Therefore \( L/B = 1.75/1 \)

\( L = 1.75B \)

Dimensions of Primary Chamber = \( L \times B \times H \)
Area = L*B
2.66 = 1.75 B*B
2.66 = 1.75 B²
B = 1.23 m
L = 2.16 m
H = 3 m
Hence, the dimensions of the primary chamber are 2.16 m x 1.23 m x 3 m

Heat and Material Balance Sample Calculations

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 requirements and combustion air requirements or to determine the limitations for Incinerator when charged with known quantity of waste.

The general assumption is that an incinerator is designed for incineration of 30% of red bags and 70% of yellow bags (PVC contented 5%) of the biomedical waste [9]. In general, the waste input rate is 100 kg/hr, the auxiliary fuel used in the incinerator is natural gas, and the when ignited the secondary burner is modulated.

Design requirements can be summarized as (a) Temperature to be maintained in the Secondary Chamber is 1100°C (b) the flue gas residence time for this temperature is about 1 second and (c) the oxygen content in flue gas should be a minimum of 6% [11].

Assumptions in the Design.

The major assumptions involved in the design process are as follows

- The design of Incinerator involves number of assumptions, the chemical empirical formula, the molecular weight and higher heating values of the components have been taken from specific tables given in design books of Incinerator. This has been summarized and shown in Table 2.
- The Input Temperature of the Waste, Fuel and Air is assumed as 15.5°C depending on our site-specific conditions [2].
- Air in general contains approximately 23% oxygen and 77% Nitrogen by weight.
- Air contains 0.0132 Kg H₂O/Kg dry air at 60% relative humidity and 26.7°C dry bulb temperatures.
- For any ideal gas 1Kg/mole is equal to 22.4 m³ at 0 °C and 101.3 KPa.
- Latent heat of vaporization of water at 15.5°C is 2460.3 Kj/Kg.

Calculation of Material Input

The different range of values for different types of biomedical waste characteristics have been summarized in Table 2. Robust judgment is required to make use of the table for assigning weight percentage for performing heat and material balance calculations [8].

The A1 (red bag waste) primarily consists of human tissue as observed from Table 2. Assuming that total input component of A1 is 30% of 100 kg/h (i.e., 30 kg/h), the red bag was calculated to have the following constituents as shown in Table 3.

In a similar fashion, the yellow bag primarily consists of higher fraction of polyethelene and cellulose, followed by PVC as observed from Table 2. The total input constituents of yellow bag is 70% of 100 kg/h (i.e., 70 kg/h), and the different constituents were summarized as shown in Table 4.
## Table 2: Characterization of biomedical wastes [10]

<table>
<thead>
<tr>
<th>Waste class</th>
<th>Component description</th>
<th>Typical component weight percentage</th>
<th>HHVdry basis (kJ/kg)</th>
<th>Bulk density as fired (kg/m³)</th>
<th>Moisture content of component</th>
<th>Weighted heat value range of waste component (kJ/kg)</th>
<th>Typical component heat value of waste as fired (kJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 (Red bag)</td>
<td>Human anatomical</td>
<td>95-100</td>
<td>18600-27900</td>
<td>800-1200</td>
<td>70-90</td>
<td>1770-8370</td>
<td>2800</td>
</tr>
<tr>
<td></td>
<td>Plastics swabs,</td>
<td>0-5</td>
<td>32500-46400</td>
<td>32500-46400</td>
<td>0-1</td>
<td>0-2300</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>Absorbents Alcohol,</td>
<td>0-5</td>
<td>18600-27900</td>
<td>18600-27900</td>
<td>0-32</td>
<td>0-1400</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>Disinfectant</td>
<td>0-0.2</td>
<td>25500-32500</td>
<td>25500-32500</td>
<td>0-0.2</td>
<td>0-70</td>
<td>50</td>
</tr>
<tr>
<td>A2</td>
<td>Animal anatomical</td>
<td>80-100</td>
<td>20900-37100</td>
<td>500-1300</td>
<td>60-90</td>
<td>1670-14840</td>
<td>3500</td>
</tr>
<tr>
<td>(Orange bag)</td>
<td>Plastic</td>
<td>0-15</td>
<td>32500-46400</td>
<td>80-2300</td>
<td>0-1</td>
<td>0-6960</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>Glass</td>
<td>0-5</td>
<td>0</td>
<td>2800-3600</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Beddings, Shavings</td>
<td>0-10</td>
<td>18600-20900</td>
<td>320-730</td>
<td>0-1880</td>
<td>0-1880</td>
<td>1400</td>
</tr>
<tr>
<td>A3(a)</td>
<td>Paper, swabs, cellulose</td>
<td>60-90</td>
<td>18600-27900</td>
<td>80-1000</td>
<td>0-30</td>
<td>7810-25110</td>
<td>15000</td>
</tr>
<tr>
<td>(yellow bag)</td>
<td>Plastic, PVC</td>
<td>15-30</td>
<td>22500-46400</td>
<td>80-2300</td>
<td>0-1</td>
<td>3340-13920</td>
<td>7540</td>
</tr>
<tr>
<td></td>
<td>Sharps</td>
<td>4-8</td>
<td>140</td>
<td>7200-8000</td>
<td>0-1</td>
<td>-10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Needles, Alcohol,</td>
<td>0-0.2</td>
<td>16200-32500</td>
<td>800-1000</td>
<td>0-50</td>
<td>0-70</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Disinfectant</td>
<td>2-5</td>
<td>0-23200</td>
<td>1000-1020</td>
<td>80-100</td>
<td>0-230</td>
<td>70</td>
</tr>
<tr>
<td>Item</td>
<td>Type</td>
<td>Quantity</td>
<td>Weight (g)</td>
<td>Volume (ml)</td>
<td>Concentration (%)</td>
<td>Weight (g)</td>
<td>Volume (ml)</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>------------</td>
<td>----------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>A3(b)</td>
<td>Plastic</td>
<td>50-60</td>
<td>32500-46400</td>
<td>80-2300</td>
<td>0-1</td>
<td>16090-27840</td>
<td>21000</td>
</tr>
<tr>
<td>(yellow bag)</td>
<td>Sharps</td>
<td>0-5</td>
<td>140</td>
<td>7200-8000</td>
<td>0-1</td>
<td>0-10</td>
<td>0</td>
</tr>
<tr>
<td>Lab waste</td>
<td>Cellulosic material</td>
<td>5-10</td>
<td>18600-27900</td>
<td>80-1000</td>
<td>0-15</td>
<td>790-27900</td>
<td>1500</td>
</tr>
<tr>
<td>Fluids, residuals</td>
<td></td>
<td>1-20</td>
<td>0-23200</td>
<td>1000-1020</td>
<td>95-100</td>
<td>0-230</td>
<td>70</td>
</tr>
<tr>
<td>Alcohol</td>
<td></td>
<td>0-0.2</td>
<td>25500-32500</td>
<td>800-1000</td>
<td>0-50</td>
<td>0-70</td>
<td>50</td>
</tr>
<tr>
<td>Disinfectants Glass</td>
<td>Glass</td>
<td>15-25</td>
<td>0</td>
<td>2800-3600</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A3(c)</td>
<td>Swabs, Pads</td>
<td>5-30</td>
<td>18600-27900</td>
<td>80-1000</td>
<td>0-30</td>
<td>630-8370</td>
<td>2300</td>
</tr>
<tr>
<td>(yellow bag)</td>
<td>Plastics</td>
<td>50-60</td>
<td>32500-46400</td>
<td>80-2300</td>
<td>0-1</td>
<td>16090-27840</td>
<td>21000</td>
</tr>
<tr>
<td>Sharps, Glass</td>
<td></td>
<td>0-10</td>
<td>140</td>
<td>7200-8000</td>
<td>0-1</td>
<td>0-10</td>
<td>0</td>
</tr>
<tr>
<td>Fluids</td>
<td></td>
<td>0-10</td>
<td>0-23200</td>
<td>1000-1020</td>
<td>80-100</td>
<td>0-460</td>
<td>230</td>
</tr>
<tr>
<td>B1 (bluebag)</td>
<td>Non-infected animal</td>
<td>90-100</td>
<td>20900-37100</td>
<td>500-1300</td>
<td>60-90</td>
<td>1880-14840</td>
<td>3000</td>
</tr>
<tr>
<td>Anatomical</td>
<td></td>
<td>0-10</td>
<td>3250-4640</td>
<td>80-2300</td>
<td>0-1</td>
<td>0-4640</td>
<td>2300</td>
</tr>
<tr>
<td>Plastic Glass</td>
<td></td>
<td>0-3</td>
<td>0</td>
<td>2800-3600</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Beddings, Shavings</td>
<td></td>
<td>0-10</td>
<td>018600-20900</td>
<td>320-730</td>
<td>10-50</td>
<td>00-1880</td>
<td>1400</td>
</tr>
</tbody>
</table>

Total: 6700
Table 3: Waste generation from Red bags considering four major hospitals in Shimla and Chandigarh city used for incinerator design

<table>
<thead>
<tr>
<th>Compound</th>
<th>Chemical Composition</th>
<th>Fraction assumed</th>
<th>Generation (kg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tissue (dry)</td>
<td>C₅H₁₀O₃</td>
<td>0.25</td>
<td>0.25 * 30 = 7.5</td>
</tr>
<tr>
<td>Water</td>
<td>H₂O</td>
<td>0.10</td>
<td>0.10 * 30 = 3.0</td>
</tr>
<tr>
<td>Ash</td>
<td>-</td>
<td>0.05</td>
<td>0.05 * 30 = 1.5</td>
</tr>
<tr>
<td>Swabs</td>
<td>C₆H₁₀O₅</td>
<td>0.25</td>
<td>0.25 * 30 = 7.5</td>
</tr>
<tr>
<td>Plastics</td>
<td>(C₂H₄)x</td>
<td>0.35</td>
<td>0.35 * 30 = 10.5</td>
</tr>
<tr>
<td>Total Red bag</td>
<td></td>
<td>1.00</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 4: Waste generation from yellow bags considering four major hospitals in Shimla and Chandigarh city used for incinerator design

<table>
<thead>
<tr>
<th>Compound</th>
<th>Chemical Composition</th>
<th>Fraction assumed</th>
<th>Generation (kg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tissue (organs)</td>
<td>C₅H₁₀O₃</td>
<td>0.15</td>
<td>0.15 * 70 = 10.5</td>
</tr>
<tr>
<td>Polyethelene</td>
<td>(C₂H₄)x</td>
<td>0.30</td>
<td>0.30 * 70 = 21.0</td>
</tr>
<tr>
<td>PVC</td>
<td>(C₂H₃Cl)x</td>
<td>0.20</td>
<td>0.20 * 70 = 14.0</td>
</tr>
<tr>
<td>Cellulose</td>
<td>C₆H₁₀O₅</td>
<td>0.35</td>
<td>0.35 * 70 = 24.5</td>
</tr>
<tr>
<td>Total Yellow bag</td>
<td></td>
<td>1.00</td>
<td>70</td>
</tr>
</tbody>
</table>

Table 5: Summary of total heat generation from waste input (considering both yellow and red bag)

<table>
<thead>
<tr>
<th>Compound</th>
<th>Chemical Composition</th>
<th>Calorific Value (Kj/Kg)</th>
<th>Total Input (kg/hr)</th>
<th>Total Heat in Kj/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tissue</td>
<td>C₅H₁₀O₃</td>
<td>20,471</td>
<td>7.5+10.5 = 18</td>
<td>3,68,478</td>
</tr>
<tr>
<td>Cellulose, Swabs</td>
<td>C₆H₁₀O₅</td>
<td>18,568</td>
<td>7.5+24.5 = 32</td>
<td>5,94,176</td>
</tr>
<tr>
<td>Plastic</td>
<td>(C₂H₄)x</td>
<td>46,304</td>
<td>10.5+21 = 31.5</td>
<td>14,58,576</td>
</tr>
<tr>
<td>PVC 4%</td>
<td>(C₂H₃Cl)x</td>
<td>22,630</td>
<td>0+14 = 14</td>
<td>3,16,820</td>
</tr>
<tr>
<td>Ash</td>
<td>0</td>
<td>0</td>
<td>0+1.5 = 1.5</td>
<td>0</td>
</tr>
<tr>
<td>Moisture</td>
<td>H₂O</td>
<td>0</td>
<td>0+3.0 = 3.0</td>
<td>0</td>
</tr>
<tr>
<td>Total heat generation</td>
<td></td>
<td>100</td>
<td>27,38,050</td>
<td></td>
</tr>
</tbody>
</table>

Calculation of Heat Input of waste.

The heat generated from the waste (input value) considering both the red and yellow bags is the product of the calorific value of the specific waste type by the total amount of waste generated. The total heat generation from the waste input has been summarized and presented in Table 5. The methodology is used similar to as described in reported literature [8].

Determination of stoichiometric O₂ for wastes.

The overall stoichiometric requirement of oxygen has been determined from chemical reactions for each of the individual components of the biomedical waste and has been represented in each of the following reactions shown below:

1. Tissue  C₅H₁₀O₃+6O₂= 5CO₂+ 5H₂O
   118.1  6(32) 5(44)  5(18)
To summarize,

Total combustible components of biomedical waste generated per hour = 18 + 31.5 + 14 + 32 = 95.5 kg/h

Total amount of oxygen required for stoichiometrically burning the biomedical waste generated per hour = 29.34 + 108 + 17.92 + 38.08 = 193.34 kg/h

Hence total Stoichiometric $O_2$ required = 193.34 kg/h for burning combustible components of the biomedical waste 95.5 kg/h.

**Determination of Air for Waste Based on 150% Excess**

- It is observed from Step 4 that the Stoichiometric $O_2$ requirement to burn the flammable parts of the HCW generated is 193.34 kg/h

- By our assumption (Step 1) air consists of 23% $O_2$, hence total amount of air required is $= 193.34 \times (100/23) = 840.60$ kg/h

- Since Air determination is based on 150% excess, the total Air requirement (150% excess) = $(1.5 \times 840.60) + 840.60 = 2101.5$ kg/h

**Material Balance**

This step basically involves the mass balance of the different products of the biomedical waste and has been shown below:

- Total Mass Input
  - Waste Input Rate = 100.0 kg/h
  - Dry air (Step 5) = 2101.5 kg/h
  - Moisture in air = 0.0132 (Step 1) x 2101.5 = 27.73 kg/h
  - Hence Total Mass Input = 2229.23 kg/h

- Total Mass Output (assuming complete combustion of waste)

**(A) Dry Products from Waste**

Air requirement for Waste = 2101.5 kg/h

Subtracting Stoichiometric air requirement (Step 5) = 840.60 kg/h
Hence, Total excess air = 2101.5 – 840.60 = 1260.9 kg/h

Now, the stoichiometric air also consists of 77% nitrogen (Step 1), hence Add nitrogen from stoichiometric air (77%) = 0.77 * 840.60 = 647.26 kg/h

Total production = 1260.9 + 647.26 = 1908.16 kg/h

Further, combustion of these products will also lead to generation of CO₂ (Step 4)

CO₂ formed from C₅H₁₀O₃ = 33.48 kg/h
CO₂ formed from (C₂H₄)x = 99 kg/h
CO₂ formed from (C₂H₃Cl)x = 19.71 kg/h
CO₂ formed from C₆H₁₀O₅ = 52.16 kg/h

Hence total CO₂ generated = 33.48 + 99 + 19.71 + 52.16 = 204.35 kg/h

Total Waste Dry products = 1908.16 + 204.35 = 2112.51 kg/h

(B) Moisture

Total moisture generated from Waste (Table 4) = 3 kg/h
Moisture in combustion air (Step 6) = 27.73 kg/hr
Moisture generated from Combustion reactions (Step 5) = 13.68 + 40.6 + 8.18 + 17.92 = 80.38 kg/h

Hence, total moisture generation = 3 + 27.73 + 80.38 = 111.11 kg/h

(C) Ash

Total Ash output (Table 3) = 1.5 kg/h

(D) HCl generation from Waste

HCl formed from (C₂H₃Cl)x (Step 4) = 8.18 kg/h

Total Mass Output = Sum (A, B, C, D)

Total Mass Output = 2233.30 kg/h

Heat Balance

(A) Total heat input generated from the Waste (Step 3, Table 4) \( Q_i = 27,38,050 \) KJ/h

(B) The Total heat output is based on Equilibrium temperature of 1100°C and consists of different components as shown below:

1. **Radiation Loss** = This is generally assumed to be 5% of total heat available
   \[ = 0.05 \times 27,38,050 = 1,369,025 \text{ kJ/h} \]

2. **Heat to Ash** = The heat to ash is computed using the formula
   \[ Q = mCp\Delta T \]
   Where, \( m \) = mass of ash (1.5 kg/h); \( Cp \) = mean heat capacity of ash = 0.831 kJ/kg°C (assumed average value); \( \Delta T \) = Temperature difference = (1100-15.5) °C = 1084.5°C
   Substituting these values, \( Q = (1.5) \times (0.831) \times (1084.5) = 1351.83 \text{ kJ/h} \)

3. **Heat to dry combustion Products** = The heat to dry combustion products is computed using the expression
   \[ Q = mCp\Delta T \]
   Where, \( m \) = weight of combustion products (2112.51 kg/h); \( Cp \) = mean heat capacity of dry products = 1.086 kJ/kg°C (assumed average value); \( \Delta T \) = Temperature difference = (1100-15.5) °C = 1084.5°C
   Substituting these values, \( Q = (2112.51) \times (1.086) \times (1084.5) = 24,884.04 \text{ kJ/h} \)

4. **Heat to moisture** = The heat to moisture is computed using the expression
   \[ Q = mCp\Delta T + mHv \]
   Where, \( m \) = weight of water (111.11 kg/h); \( Cp \) = mean heat capacity of water = 2.347 kJ/kg°C; \( \Delta T \) = Temperature difference = (1100-15.5) °C = 1084.5°C; \( Hv \) = latent heat of vaporizations of water = 2460.3 kJ/kg
   Substituting these values, \( Q = (111.11 \times 2.347 \times 1084.5) + (111.11 \times 2460.3) \)
Q = 2, 82,810.67 + 2, 73,363.93 = 5, 6174.60 kJ/h
The Total Heat output = Q₀ = Sum (1, 2, 3, 4) = 31,82,473.5 kJ/h
Net Heat Balance = Q - Q₀ = 27, 38,050 – 31, 82,473.5 = - 444,423.5 kJ/h (Heat insufficiency)
Hence, Auxiliary fuel must be supplied to achieve Design temperature of 1100°C.

**Auxiliary Fuel Requirement to Achieve 1100°C**

(a) Total heat required from auxiliary fuel = Heat deficiency (Step 7) + 5% radiation loss from the required heat
Hence, Total heat required from auxiliary fuel = 444,423.5 (Step 7) + 0.05*(444,423.5) Or, Total heat required from auxiliary fuel = 4, 66,644.68 kJ/h

(b) The Available net heat from natural gas at 1100°C and 20% excess air (assumption) = 15,805.2 kJ/m³.

The flow rate required for Natural gas to maintain the temperature of 1100°C = 4, 66,644.68 /15,805.2 m³/h = 29.52 m³/h

**Products of Combustion from Auxiliary Fuel**

(i) Dry Products from Fuel at 20% Excess Air = 16.0 kg * 29.52 m³/h m³ fuel = 472.32 kg/h
(ii) Moisture From Fuel = (1.59 kg /m³) * 29.52m³/h = 46.94 kg/h

**Secondary Chamber Volume Required to Achieve One Second Residence Time at 1100 °C**

(i) Total Dry Products (waste and fuel) = 2112.51 kg/h (Step 6a) + 472.32 kg/h (Step 9(i)) = 2584.83 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 1100°C (Vp) can be calculated as follows:
Vp = 2584.83 kg dp/h * (22.4 m³/29 kg dp) * (1373K/273k) * (1 h/3600s) = 2.79 m³/s

(ii) Total Moisture (waste and fuel) = 111.11 kg/h (Step 6b) +46.94 kg/h (Step 9(ii)) = 158.05 kg/h
Using the ideal gas law, the volumetric flow rate of Moisture at 1100°C (Vm) can be calculated as follows:
Vm = (158.05 kg H₂O/h) * (22.4 m³/18kg H₂O) *(1373K/273k) * (1 h/3600s) = 0.28 m³/s
Total Volumetric Flow Rate = Sum (Vp,Vm) = 2.79 + 0.28 = 3.07 m³/s

Hence it is observed from the design that a volume of 3.07 m³ with one second retention time is sufficient for the active chamber. In reality, the chamber will have some dead spaces wherein there will be no or negligible flows and these are not accounted for in the design calculation of retention volume. Further, while dimensioning the secondary chamber, the length of chamber should be calculated from the flame front to the location of the temperature sensing device to maintain the retention time of one second [8].

**Residual Oxygen in the Flue Gas**

The residual oxygen in the flue gas can be determined using the following expression
Excess Air = % Residual O₂ / (23% - % Residual O₂)

In our assumption, we have assumed that excess air is 150% and air contains 23% of Oxygen
Substituting these values in above equation, the residual oxygen in flue gas was determined to be 13.8%

**RESULTS AND DISCUSSIONS**

The above section describes the design of an incinerator for a waste of 500kg/day generated from four major hospitals in a 100 km radius of towns Shimla and Chandigarh. Though many reported literature exists regarding assumptions and design considerations for design of incinerator, such detailed design
calculations (particularly detailed mass balance approach and heat requirements) are often not easily available and hence comparisons of such designs are often difficult.

However, in Indian context, a similar such design was reported for Chikmagalur city for eleven hospitals and 27 private clinics with a daily waste generation of about 85kg/day and design waste of 100kg/day [8]. It was observed from the mass balance analysis that for complete combustion a greater mass was generated for our study locations (2229.23kg/hr) in comparison to Chikmagalur city for which the rate of generation was found to be 1607.6 kg/hr [8]. This is primarily because the design waste was significantly higher for our study conditions (500kg/day) than reported for Chikmagalur city (100kg/day). Further, it was observed from both the studies that additional heat requirements were provided using auxiliary fuel, as the design waste was insufficient to generate the required heat to maintain the design temperature. The additional heat requirement for the present study was observed to be slightly higher (444423.5 kJ/hr) in comparison to Chikmagalur (412802. kJ/hr) [8]. It was further observed that volume of the primary and secondary chamber for the incinerator for our study conditions was 8m$^3$ and 3.07m$^3$ respectively while for Chikmagalur they were reported to be 5m$^3$ and 2.17m$^3$ respectively [8].

CONCLUSIONS

The following main conclusions were drawn from the design of the incinerator system

1. The amount of waste generated is about 500kg/day considering the four most important hospitals located in Shimla and Chandigarh within a vicinity of 100km (Distance between Shimla and Chandigarh is 100km).
2. A Multiple Chamber Incinerator has been designed with an operating capacity of 100kg/hr.
3. The dimensions of the Primary Chamber of the incinerator were 2.16 x 1.23 x 3 m.
4. The material balance analysis assuming complete combustion shows that the total mass input (2229.23 kg/hr) is almost equal to the total mass output (2233.30 kg/hr).
5. The heat balance analysis showed that the total amount of heat generated from the input waste was 27,38,050 kJ/hr, whereas the total heat requirement was 31,82,473.5 kJ/hr for complete combustion. Hence, the deficient heat requirement of 444423.5 kJ/hr was required to be supplied by auxiliary fuel to maintain a temperature of 1100°C.
6. From the design analysis it was determine that the flow rate of the natural gas was required to be maintained at 29.52 m$^3$/hr to neutralize the heat deficit and maintain the temperature at 1100°C.
7. The design volume of secondary chamber is found to be 3.07 m$^3$ to maintain a retention time of 1 second.

REFERENCES
