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Experimental study of biomedical waste incinerator using input-output method: A case study of biomedical waste incinerator at Etmadpur, Agra, India

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ABSTRACT

Proper calculation of the in-put and out-put balance of mass and energy plays the most important role in evaluating the performance of incinerator. This paper describes an experimental study of the biomedical waste incinerator located in Agra (India). The experimental study continued for a period of one month (1/06/2019 to 30/06/2019).This incinerator incinerated 200 kg of medical waste per cycle. The cycle time varies between 1 hrs.to 1.20 hrs. Our study was done in the first batch of about one hour in the morning from 8 am to about 9 am (with some variation in cycle time). The results describe that 200 kg/h of medical waste with 15 kg/h of LPG, consumed 1534.01 kg/h of air. The analysis exhibited that the incineration process generates 2833645 kJ/h with ash and flue gases emissions at a total mass rate of 1794.60 kg/h. The further study showed that the energy in-put was 3985684 kg/h and the out-put was 3985614.41 kg/h. The difference is too small. Due to the small difference it is concluded that the efficiency of performance may be said to be satisfactory but the plant is of old design. The operator of CBMWTF has been advised to install a new plant of improved design.

***Key words**: Biomedical waste, Incinerator, Flue gas, Ash, Mass and energy balance*

Introduction

The in-put and out-put balancing method is based on the principle of the first law of Thermodynamics which is the statement of the conservation of mass as well as the conservation of energy. The principle states that whatever mass goes into a processing system, it must come out fully if there is no accumulation inside the system of processing.

Similarly the conservation of energy states that whatever energy enters into a processing system, it must come out fully if there is no leakage in any of the pipes or in the processing chamber. The same principles apply in the biomedical wastes incineration system. Campbell, (1989) has compared the biomedical waste and the municipal solid wastes and has observed that although the characteristics of both types of wastes are similar, yet there are three differences eg. The medical wastes has comparatively higher amounts of wet cellulosic solids and plastic wastes secondly it has higher heating value and thirdly it has low percentage of incombustibles.

There are many unit operations in a complete process of biomedical wastes incineration systems. In such systems the output of the preceding unit turns to be the input of the subsequent unit opera-

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tion. In such case any leakage in any of the units may cause imbalances in the mass or energy balance calculations. Thus equality in mass balance as well as the energy balance shows the efficiency of the performance.

Literature Review

There are sufficient literatures available on the in-put and out-put balances in municipal solid waste incinerators but only a few research papers can be found in the field of the biomedical waste incinerators. The gist of some of the research papers are presented as follows:

Bujak (2010) has his presented their research paper on the lower thermal value of the medical waste. The authors observed that the medical waste was heterogeneous consisting of plastic, organic waste, body parts, animal anatomical parts. For this reason the properties of the fuel waste undergo significant changes in terms of fuel heating value. It also causes the variation in combustion velocity, temperature and pressure (Bujak *et al*., 2010).

Arthur (2015), has his presented their study on the in-put and the out-put balances used for evaluation of performance of a M.S.W. incinerator in Tanzania. The authors concluded that the excess air ratios for incineration process should be optimizedfor reducing the rate of emission of flue gases and increase the incinerator's performance (Bujak *et al*., 2010)

Lee *et al* presented studies on "energy and mass balance calculation for incinerators". The authors observed that the calculation of material and heat balance in an incinerator plays the most important role for evaluating the incinerators performance (Lee *et al.,* 2007)

Manyele *et al* presented study on performance evaluation based on the consumption of the auxiliary fuel and the cycle type (Manyele *et al*., 2017)

Bogale and Federice reported on the calculation of mass and energy balance for evaluation of highly efficient waste to energy incineration plant. The authors reported that the performance evaluation of the plants was of great importance in order to increase the efficiency of the plants (Bogale and Federice, 2014)

Torreta *et al.* (2014) carried on researches on the in-put and the out-put balance of a M.S.W. incinerator in Italy for evaluation of the performance (Torreta *et al.,* 2014).

Gehrmann *et al.* (2017) presented the research which elucidate the performance evaluation methods for treatment processes of wastes. The authors have observed that, if the mass balance is not equalized, it exhibits that the resultant enthalpy flows and some other related aspects would be erroneous.

Methodology

In the present papers, the methodology used for calculation of mass and energy balance in biomedical waste incineration in Agra, (India) is broadly based on the method adopted by Omari *et al.* (2015) for calculating the input and out-put balance in MSW incinerator in Tanzania. Some essential modifications have been made to suit the combustion of medical waste which requires high temperature of about 1050 ^{o}C for the complete combustion. The ultimate analysis of the medical waste has also been used as and when required. In order to elucidate the whole procedure, the processes have been described in several ste

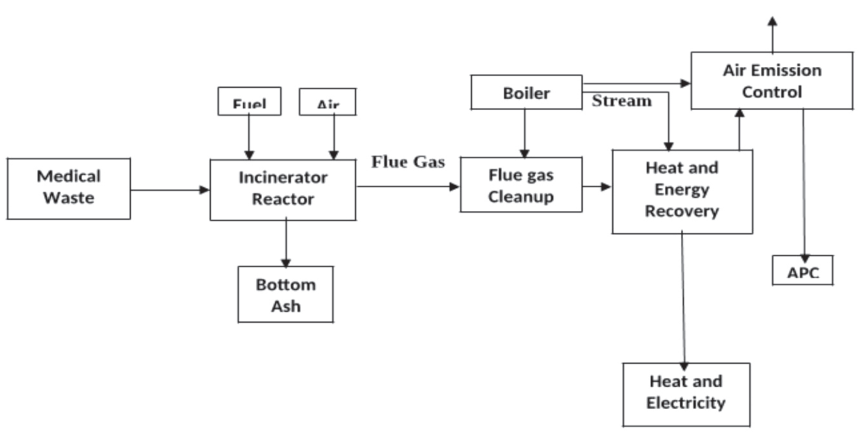

Fig. 1. The Flow Chart of the Process

The Chemical Analysis of the biomedical waste

The biomedical waste may be analyzed in two ways:
(1) Proximate Analysis
(2) Ultimate Analysis

Proximate Analysis

The fractions of Proximate Analysis are as follows:
(i) The contents of moisture: It increases the weight of the waste but does not increase the heating value.
(ii) Volatile Matters: Such matters are converted to gases during the process of combustion.
(iii) Fixed carbon: Such carbon remains on the surface of the grates as charcoal.
(iv) Ash: It adds to the weight but does not generate heat.

Ultimate Analysis

The objective of the ultimate analysis is to find the proportion of O_2, N_2, H_2, C and S in the waste.

The ultimate analysis is also used in mass balance calculation in the waste incineration process.

Liberty *et al* has presented the research papers on the process of the measurement of the percentages of C, H_2, O_2, N_2, S and Chlorine in the medical waste using the combustion process followed by using Chromatography Technology (Seeker, --).

Seeker has also presented the ultimate analysis using the emission data tests that he performed for estimating the chemical composition (Torretta and Lonescn, 2014).

The following results can be obtained from the aforesaid table
1. The total mass combusted = 158 kg/h
2. Stoichiometric oxygen = 232.04 kg/h

From above chemical reaction the total oxygen is 232.04 kg/h

Total air= 232.04x100/23=1008.86 kg/h

Table 1. Chemical Characteristics of biomedical waste

Sr. No	Component	Empirical formula	Molecular weight	Input Kg/h	Higher heating value (kJ/kg)	Total heating kJ/hr
1	Tissue	$C_5H_{10}O_3$	118.1	60	20471	1228260
2	Cellulose, swabs, bedding	$C_6H_{10}O_5$	162.1	84	18568	1559712
3	Polyethylene	$(C_2H_4)_x$	28.1	8	46304	370432
4	PVC	$(C_2H_3Cl)_x$	62.5	6	22630	135780
5	Water	H_2O	18	42	0	0
				200		3294184

Table 2. Chemical reaction in incinerator Chemical equilibrium equations of the components

Sr. No.	Component	In Put in Kg/h	Empirical formula			
1	Tissue	60	$C_5H_{10}O_3$	$+ 6O_2$	$=5CO_2$	$+ 5H_2O$
			118.1	6(32)	5(44)	5(18)
			1.0	1.63	1.86	0.76
	Tissue	(as fired)	60	97.54	111.76	45.72
2	Polyethylene	8	$(C_2H_4)_x$	$+ 3O_2$	$=2CO_2$	$+2H_2O$
			28.1	3(32)	2(44)	2(18)
			1.0	3.43	3.14	1.29
	Polyethylene (as fired)		8	27.33	25.05	10.24
3	PVC	6	$2(C_2H_3Cl)_x$	$+5O_2$	$=4CO_2$	$+2H_2O$
			2(62.5)	5(32)	4(44)	2(18)
			1.0	1.28	1.41	0.29
	PVC (as fired)		6	7.68	8.44	1.728
4	Cellulose	84	$C_6H_{10}O_5$	$+6O_2$	$=6CO_2$	$+5H_2O$
			162.1	6(32)	6(44)	5(18)
			1	1.19	1.63	0.56
	Cellulose (asfired)		84	99.49	136.80	46.63
		158	158	232.04	282.05	104.318

Total nitrogen = 1008.86 X 0.77 = 776 + 176.85 (from step 1-b) = 953.67 kg/h.

Mass balance system

The balance of input and output of mass has been represented through the following figure

Fig. 2. Input and output balance of Incinerator

The input consists of the following:

1. Amount of medical waste
2. Amount of LPG
3. Amount of air

The out let stream is composed of

1. Rate of mass of flue gas
2. Rate of mass of ash

The Process of calculation of mass in-put and out-put Material used for mass input

(i) Before starting the incineration process, yellow bags where opened for sorting and weighing the components of the medical waste with hand held spring balance. The weight was found to be 200kg.

(ii) The contents of H_2O in the waste were estimated to be 21% which is at par with various researchers on the basis of proximate analysis. Thus the total moistures content in the waste was found to be 42 kg/h and the total mass of dry waste would be 158 kg/h.

(iii) After completion of incineration cycle time the ash was measured and found to be 15 kg/h. This shows that the mass of waste consumed in forming flue gases is 185 kg/h which gives the equivalent of mass reduction by 92.5%. The value of unreacted material found to be 7.5%

The amount of LPG consumed

(i) The chemical formula of liquefied petroleum gas is $C_4 H_{10}$

(ii) The density of LPG is 495 kg/m^3 at 25^{0}C

(iii) The volumetric flow rate of LPG measured found to be 0.0303 m^3/h.

(iv) The HHV of LPG is 46100 kJ/kg.

(v) At the end of the incineration cycle time the consumption of LPG was measured and found to be = 0.0303X495= 15 kg/h

The Mass of Air Supplied

Step-1 a

The Calculation of mass of air supplied for consumption in Combustion Chamber.

There are three pipes P1, P2 and P3 fitted in the incinerator. The velocities of the air in the pipes measured are 7.3, 7.4 and 10.9 m/s and the diameters are 110, 110 and 120 mm.

The air density of Agra is 1.2922 kg/m^3 at temperature of 26.7 ^{0}C at relative humidity of 60%.

For pipe 1 mass flowrate of air = (J/4D12)X (V_1)X(p) (3.14/4)X(0.11X0.11) X(7.3)X (1.2922)X (3600)=322.55Kg/h

For pipe 2 mass flow rate of air =(Ë/4D22)X(V_2)X(p) = (3.14/4) X (0.11X0.11) X (7.4) X (1.2922) X (3600) = 326.97 Kg/h

For pipe 3 mass flow rate of air = (Ë/4D32) X (V_3) X (p) = (3.14/4) X (0.12X0.12) X (10.9) X (1.2922) X (3600) = 573.17 kg/h.

Total quantity of air for incinerator combustion chamber= 322.55+ 326.97 + 573.17=1222.69 kg/h.

Step-1b: Air supplied to the burner

The burner is set to operate with150% excess air

$2C_4H_{10}+13 (O_2+ 3.76 N_2) \rightarrow 8CO_2+ 10 H_2O + 48.88N_2$

The aforesaid table shows that oxygen is =53.79 kg/h and the excess quantity = 53.79 X 1.50 + 53.79 = 134.47

Then air supplied to the burner =134.47 + 176.85 =311.32kg/h

Total air = mass of air for combustion in incinerator is 1222.69 (from step-1a) + mass of air for burner is 311.32 (from step-1b) =1534.01 kg/h

Table 3. LPG and air consumption of burners

	C_4H_{10}	O_2	N_2	CO_2	H_2O	N_2	O_2
Total mass	116	416	1368.64	352	180	1368.64	0
NormalizeLPG	1	3.58	11.79	3.03	1.55	11.79	0
LPGfired (kg/h)	15	53.79	176.85	45.45	23.25	176.85	80.68

Total mass flow rate of air=1534.01 kg/h

Step-2 Calculation of specific humidity of the air

The specific humidity of air at 26.7 °C can be found by the following formula.

X=means humidity in air (kg water/kg air)

P_a– pressure of the atmospheric in Pascal

P_w- the partial pressure due to water content in air

X= (18*3502.36)/29 (101325-3502.36) =0.02206

Specific humidity of air = 0.02206kg (H_2O)/kg air)

Step-3 (a) Calculation of mass of moisture in the air

Mass of moisture in the combustion air = [specific humidity (0.02206 kg water/kg dry air) from step-3] X [total mass of air 1534.01 kg/h from step-1a and step 1b)]=

.02206x1534.01=33.85 kg water/kg air

Step-3 (b) Calculation of mass of moisture in the medical waste

Mass of moisture in the medical waste = 21% of the mass flow rate of medical waste (200kg/h) =200x21%=42 kg/h

Total moisture =mass of moisture in air from step- 3a (33.85 kg/h) +mass of moisture in medical waste from step- 3b (42kg/h)=75.85kg/h

Total moisture =75.85kg/h

Step-4a Calculation of total quantity of fuel

(Quantity of dry medical waste

Mass flow rate of dry medical waste used =Mass flow rate of medical waste (200kg/h) – mass flow rate of moisture in medical waste (42kg/h) = 158 kg/h

Step-4b: Mass of LPG consumed of =15kg/h (from observation)

Total quantity of fuel= [quantity of dry medical waste (158 kg/h from step 4a)] + [quantity of LPG 15 kg/h from step 4b] = 173 kg/h

Step-5: Quantity of un-reacted materials

Total mass of un-reacted materials **=** 7.5% of dry medical waste (158 kg/h) =11.85 kg/h

Step-6: Total mass flow rate in put

Sum of step 1a and 1b + step3a and 3b + step4a and 4b + step 5

=1534.01 +75.85kg/h+173 kg/h+ 11.85 kg/h =1793.75kg/h

Calculation of Mass flow rate out due to effluent gases

The effluent gases consist of CO_2, H_2O, O_2, N_2 and HCl. These gases are measured by the emission meter using combustion gas analyzer. The concentration of flue gases inpercentages are 12.6%, 11.2%, 15.2%, 58.3%, 0.21%, . The densities are 1.842, 0.804, 1.331, 1.165 and 1.18 kg/m^3. The velocity of the flue gas is measured to be 6 m/s and the area of the stack is 0.0653 m^2 .The formula for calculating the mass flow rate of flue gas is $m_{flue\ gas} = (A_{stack})\ X\ (V_{flue\ gas})\ X\ (p_{flue\ gas})$.

Step-1

Calculation of Mass flow rate out due to effluent gases as Carbon di oxide

Mass flow rate of Carbon di oxide release (m_{CO2}) = =0.0653 X 6 X 1.842 X 3600 X 0.126 = 327.36 kg/h.

Step-2

Mass flow rate of water vapor release (m_{H2O}) =0.0653 X 6 X 0.804 X 3600 X 0.112 = 127.01 kg/h. (Verified experimentally)

Step-3

Mass flow rate of oxygen release (m_{O2}) = 0.0653 X 6 X 1.331 X 3600 X 0.152= 285.35 kg/h.
(Verified experimentally)

Step-4

Mass flow rate of nitrogen release (m_{N2}) = 0.0653 X 6 X 1.165 X 3600 X 0.580 = 953.06kg/h. (Verified experimentally)

Step-5

Mass flow rate HCl release (m_{HCl}) = 0.0653 X 6 X 1.18 X 3600 X 0.0021 =3.49kg/h. (Verified experimentally)

Step-6

Mass flow rate out due to bottom ash left.

The mass flow rate of ash was measured by (i) measuring the mass of bottom ash left (ii) taking the total time consumed. The mass flow rate of ash was measured and found tobe **15 kg/h** (by observation).

Step-7

Mass of unaccounted particulates

Table 4. Summaryof Mass Balances

Mass in put	Kg/h	Mass Out-put	Kg/h
Mass of air for incinerator combustion chamber	1222.69	Mass of CO_2	327.5
Mass of air for burner	311.32	Mass of H_2O	127.56
Total mass of air	1534.01	Mass of N_2	953.67
Mass of moisturein combustion air (.02206 H_2O/kg dry air)	33.85	Mass of O_2	285.74
Mass of moisture in medical waste (200kg)(21% moisture)	42	Mass of HCl	3.5
		Mass rate of flue gas	1698
Subtotal mass of moisture	75.85		
Mass of LPG	15 kg	Mass of solid ash remain from observation	15
Mass of dry medical waste	158 kg	Mass of unaccounted particulate (4.5%)	80.75
Subtotal mass fuel	173	Sub Total particulates	Variable
Mass of unreacted materials (7.5% of 158) kg/h of medical waste)	11.85		
Total weight in(kg/h)	1794.60	Total weight out (kg/h)	1793.75

Mass of unaccounted particulates = 4 to 5 % of total input mass =4.5% of 1794.6 = 80.75 kg/h

Step-8 Total mass flow rate output

Sum of step-1 to step-7 = 327.5 +127.56 + 285.74 + 953.67 + 3.504 + 15 + 80.75= 1793.75 kg/h.

Conclusion: The mass input is 1794.6kg/h and mass output is 1793.75Kg/h. Thus the mass in-put and the out-put are balanced.

Energy balance system

The energy balance of the system has been represented through the following diagram-

The in-put of energy consists of the following:

1. Energy from LPG (kg/h) (Mass of LPG x HHV of LPG)

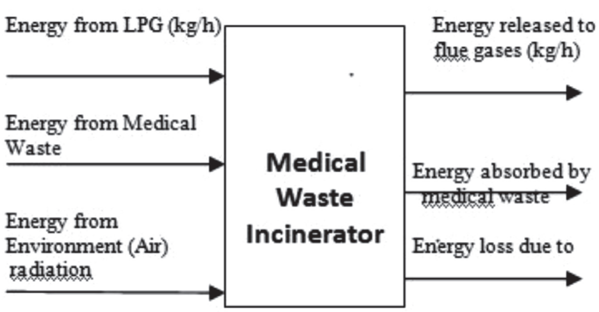

Fig. 3. The Balance of Energy

2. Energy from Medical Waste (Mass of Medical Waste x HHV of Medical Waste)
3. Energy from Environment (Air)

The out-put of energy consists of the following:

1. Energy released to flue gases (kg/h)
2. Energy absorbed by medical waste
3. Energy loss due to radiation

Calculation of Energy Input

Step-1 Energy from auxiliary fuel (LPG)

Q1= Energy from auxiliary fuel (LPG) = (mass flow rate of LPG) x (high heating value of LPG) =15x46100=691500kJ/h

Step-2 Energy from medical waste

Q2= Energy from medical waste = mass flow rate of dry medical waste x high heating value of medical waste=60x20471 + 84x18568 + 8x46304 + 6x22630 =3294184KJ/h.

Step-3 Energy from Air

Q3= Assuming energy from air is negligible=0

Step-4 Total in-put of energy

Sum of = step-1 + step-2+ step-3=691500+3294184+0=3985684 kJ/h Total energy in=3985684 kJ/h

Calculation of energy out-put

Energy out= **Q1** (Energy due to flue gas) + **Q2** (Energy absorbed by medical waste) + **Q3** (Heat loss due to radiation)

Q1 (Energy conversion into flue gases)

Formula used for flue gases released $Q1= \Sigma (m_{gases}*C_P (gases)*\Delta T_1) = m_{CO2}* C_{P (CO2)} \Delta T_1+ m_{O2}*C_P (_{O2})*\Delta T_2+ m_{N2}*C_P (_{N2}) \Delta T_2+ m_{HCl}* C_P(_{HCl}) *\Delta T_1+ m_{H2O}* C_P (_{H2O})*''T_3$

Abbreviations used

m_{gases}= Quantity of gases in in kg/h

$C_{P\ gases}$ = Specific heat capacity of gases kJ/kg

ΔT_1 = difference of temperature between ignition temperature (455^{0}C) and exit temperature (1050 ^{0}C)= 1050-455= 595 ^{o}C

ΔT_2 = Difference between ambient temperature (26.7 ^{o}C) and exit temperature (1050 ^{0}C)=1050-26.7= 1023.3^{0}C

ΔT_3 = Difference between ambient (26.7 ^{o}C) and boiling point temperature (100 ^{o}C)= 100-26.7= 73.3^0 C

ΔT_4 **=** Difference between boiling point of water (100 ^{o}C) and exit temperature (1050 ^{0}C)=950 ^{0}C

Step-1 Energy due to CO_2gas released

Formula used $Q_{CO2}= m_{CO2}C_{PCO2}\Delta \mathbf{T_1}$
Q_{CO2}**= (327.5) X (0.846) (595) =164853 kj/h**

Step-2 Energy due to O_2gas released

Formula used $Q_{O2}= m_{O2}C_{PO2}\Delta \mathbf{T_2}$
Calculation Q_{O2}= (285.74) X (0.919) (1023.3) = 268713.52 kJ /h

Step-3 Energy due to N2 gas released

Formula used $Q_{N2}= m_{N2}C_{PN2}\Delta \mathbf{T_2}$

Calculation Q_{N2} = (953.67) X (0.919) (1023.3) = 1014926.13 kJ/h

Step-4 Energy due to water vapor released
Formula used $Q_{H2O}= m_{H2O}C_{PH2O}\Delta \mathbf{T_3}$
Calculation
Q_{H2O} = 127.56 × (1.185×595)= 89939.36kJ/h

Step-5 Energy due to HCl gas released

Formula used $Q_{HCl} = m_{HCl}\ C_{PHCl}\ \Delta T_1$
Calculation Q_{HCl} = (3.504) X (4.184) (595) = 8725.62 kJ /h

Q2 Heat absorbed by the medical waste during pyrolysis

Heat used to raise medical waste (ash) from ambient temperature (26.7 ^{o}C) to maximum temperature (1050 ^{o}C) + heat used to dry medical waste (heat used to raise moisture from ambient temperature (26.7 ^{o}C) to 1050 ^{o}C and the enthalpy of vaporization) + heat used to raise vapor from boiling point (100 ^{o}C) to exit temperature (1050 ^{o}C). The formula used

$(m_{ash}\ C_{P\ (ash)}\ X\ \Delta T_2) + m_{(H2O)}\ C_{P\ H2O}\ (I)\ *\Delta T_3 + m\ (H_2O)*h_{V\ H2O}) + m_{H2O} * C_{PH2O} * \Delta T_4)$
Calculation of energy due to medical waste absorbed Q_2

Step-6 Energy absorbed by ash

Formula used $Q_{Ash}= m_{ash}\ C_{PASH}\ \Delta T_2$
Calculation Q_{Ash} = (15) X (0.831) (1023.3) = 12755.43 kJ /h
Step-7 Energy absorbed by medical waste due to moisture
Formula used $Q_{moisture} = m_{moisture}\ C_P \Delta T_3 + m_{\ moisture}\ h_{\ V\ Latent\ heat}$

Calculation $Q_{\ moisture}$ = (75.85) X (4.184) (73.3) + 75.85 X 2460 = 209853.22 kJ /h

Step -8 moisture releases after absorption of energy

Formula used $Q_{moisture} = m_{\ moisture}\ C_{P\ moisture}\ \Delta T_4$

Calculation $Q_{moisture}$= 75.85X1.185X950 ^{o}C = 85388.13 kJ/h

Energy loss due to radiation Q_3

Step-9 Heat loss due to radiation

Energy due to radiation losses 10% of total heat available=10% x 3985684 kJ/h= 398568.4 kJ /h

Step-10 Energy to heat up the incinerator

The energy use to heat up the incinerator before filling the waste, we use the mass flow rate of LPG to 24.99 kg/h and the high heating value of LPG is 46100 kJ/kg thusthe energy to heat up incinerator is 46100 kJ/kg X 24.99 kg/h = 1152039 kJ/h.

Step-11 Energy released due to uncountable energy loss of the system

Energy released due to uncountable for energy loss i.e. 15 % of the total energy input = 15% x 3985684=597852.6 kJ/h

Step-12 Total energy out put

$Q_{\ Total}$ = Total sum of the step-1 to step-11= 3984614.41 kJ/h.

Conclusion

The aforesaid calculations of in-put and out-put of mass have revealed that the mass in-put was 1794.6 Kg/h and the out-put was 1793.75 kg/h. Thus the input and the out-put of mass is nearly equalized.

The calculations of in-put and out-put of energy have revealed that the energy in-put was 3985684 kg/h and the out-put was 3984614.41 kg/h. The difference is too small. It may be concluded that the in-put and out-put of energy is also nearly equalized.

The incineration result generates energy of

Table 9. Summary of energy balance (Energy in-put and out- put balance)

Sl. No.		HHV (kJ/kg)	Total mass input (kg/h)	Total energy input (kJ/h)	Energy consumption	Total energy output (kJ/h)
01	Medical waste (Tissue, cellulose, polyethylene, PVC	20471+18568+ 46304+22630	60+84+8+6= 158 kg	3294184 (step-2 from energy input)	Energy to flue gas release (step-1 to step- 5 from energy output)	1547157.63
02	LPG	46100	15	691500 (step-1 from energy input)	Energy absorbed to medical waste (step-6 to step-8 from energy output)	289996.78
03					Energy due to radiation loss (10% of total heat input of step-9 from energy output)[3]	398568.4
04					Energy to heat up incinerator (step-10 from energy out-put)	1152039
05					Energy released due to un countable for heat loss of the System (variable up to 15% of step 11 from energy output)[3]	597852.6
	Total			3985684kJ/h		3984614.41k J/h

2833645 kJ/h with ash and flue gases emissions at a total mass rate of 1794.6 kg/h. There is energy difference of 2833645 kJ need to recover or optimized.

Although on the basis of the balance of in-put and out-put of mass and energy shows that the incinerator is functioning well, yet there are other parameters, such as, the flue gas emissions on the basis of which the efficiency of performance of the incinerator can be judged.

Recommendation

The existing equipment's of the incinerators are of old design. The equipment's should be replaced with the equipment of improved design.

The monitoring of flue gas emissions should be continuously done by the use of the instruments like the gas analyzer and chromatography techniques for comprehensively testing the efficiency of the incinerators.

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