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Mass And Energy Balance For Fixed Bed Incinerators

A case of a locally designed incinerator in Tanzania

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***Abstract*—An estimation of mass and energy balance of an incinerator is an important consideration toward the design and operation of the incineration process. This paper is aimed to study the mass and energy balance of a locally made fixed bed incinerator. The results shows that the total mass rate of 49 kg/h of municipal solid waste and 9.75 kg/h of diesel consumed 458.9 kg/h of air. The incineration process generates 379,287.14 kJ/h with ash and flue gases emissions at a total mass rate of 528.51 kg/h.**

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I. INTRODUCTION

Energy access is a key factor to social economic development. It is a known fact that energy generation depletes natural resource and contaminates the environment [1]. However, energy can also be generated from sources that do not necessarily deplete the natural resources. It is also a fact that waste management and disposal in most of urban centers in developing countries is a major challenge. Urban centers are growing at a rate that do not match the economic growth of the countries, making it difficult to allocate resources for proper management of urban waste. For municipal solid waste crude dumping in open pits and open burning are among most practiced methods of municipal solid waste disposal in most developing countries. Open burning is known to have a potential to pollute the environment due to incomplete combustion of the municipal solid waste. Incineration on the other hand is known method of waste disposal which reduces the volume of the waste with less time consuming compared to other methods of waste disposal [2, 3]. Incineration offers the possibility to control the ash and the flue gas emission so as to meet the environmental regulations. Under normal conditions the incineration can dispose more than 99% of organic waste [4]. The incineration process involves conversion of elemental constituents in organic wastes to toxic gases and non-toxic gases [5]. The incineration process can be used to recover energy from waste. The amount of energy recovered depends on the contents of the waste and the degree of pre-treatment of wastes, activities of waste generating centers and season of the year [6]. Auxiliary fuel is required at the beginning of the process and during the process to maintain the desired temperature [7].

Understanding the energy value of fuel is important in energy calculations of energy systems. The gross calorific value of municipal solid waste varies from 6 to 12MJ/kg [6, 8]. The heat released due to combustion of municipal solid waste must be controlled so as to maintain the desired temperature [9].

Incineration of municipal solid waste results into secondary products some which can cause serious environmental and health impacts. Control of combustion conditions alters the composition of the various secondary substances resulting from the incineration process. The primary toxic pollutants gases from incinerator are such as NOx, SOx, CO, HCl, dioxins and furans, their composition is influenced by combustion conditions [10]. The designers of the incinerator must know the amount of air needed for complete combustion, anticipated flue gas composition, air flow rate and exit temperature in order to control the emissions and toxic gases formed [11].

Conditions such as oxygen concentration, residence time, temperature and mixing turbulence have big influence in the formation of these pollutants [12]. High combustion temperature combined with high oxygen concentration, residence time, and mixing turbulence reduces the quantity of CO produced but increase the possibility of the formation of NO_x [13]. The formation of furans and dioxins is favored by low oxygen concentration, high temperature and high residence time [14]. The oxygen, carbon monoxide and carbon dioxide concentration in the effluent gas are a useful indicators of the combustion performance [15].

The mass and energy balances information enables the designer to predict the amount of auxiliary fuel needed, the size and capacity of the incinerator [16].

The combustion reaction of municipal solid waste are as follows;

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)} \qquad \Delta H^{o} = -393.5\,kJ\,mol^{-1}$$

$$C_{(s)} + CO_{2(g)} \rightarrow 2CO_{(g)} \qquad \Delta H^{o} = -221.06\,kJ\,mol^{-1}$$

$$H^{+}_{(aq)} + Cl^{-}_{(aq)} \rightarrow HCl_{(aq)} \qquad \Delta H^{o} = -167.2\ kJ\ mol^{-1}$$

$$H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow H_{2}O_{(l)} \qquad \Delta H^{o} = 285.83\,kJ\,mol^{-1}$$

$$S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)} \qquad \Delta H^{o} = -297\ kJ\ mol^{-1}$$

These reaction equations are the major input for consideration in energy and mass balances.

Mass and energy balance of the incinerator can be described by mass and energy balances laws. The law of conservation of mass and law of conservation of energy [17].

A. Mass balance of the system

The mass balance of the system show the relation between the mass input to the mass output and the mass of remaining or generated in the system

For the given mass change at time Δt say $t_2 - t_1$

$$\int_{t_1}^{t_2} m_{in}dt - \int_{t_1}^{t_2} m_{out}dt = \int_{t_1}^{t_2} \frac{d(m)}{dt}dt$$

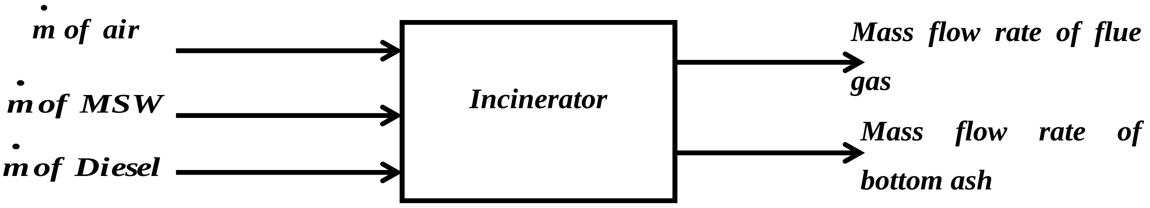

Figure 1: Mass balance of the system

Figure 1 shows the mass balance of the system, the inlet stream is composed of municipal solid waste, diesel and air. The outlet stream is composed of flue gases and bottom ash.

B. Energy balance of the system

The energy balance of a system is done in accordance with the thermodynamics laws. The law of conservation of energy which states that the total energy of an isolated system is constant. The energy cannot be created but can be transform from one form to another.

For the time

$$\Delta t = t_1 - t_2$$

$$\int_{t_1}^{t_2} E_{in}dt + \int_{t_1}^{t_2} E_{g}dt - \int_{t_1}^{t_2} E_{out}dt = \int_{t_1}^{t_2} \frac{d(E)}{dt}dt$$

$$E_{in} + E_{g} - E_{out} = \Delta E$$

According to first law of thermodynamics the sum of all energies is constant.

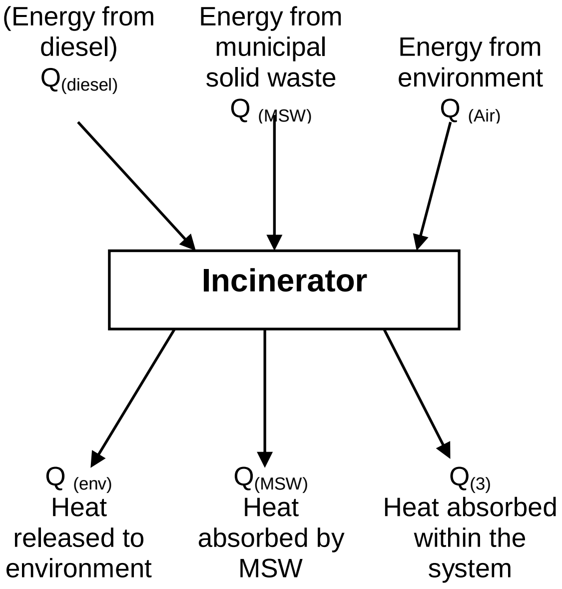

Figure 2: Energy balance of the incinerator

C. *Stoichiometric combustion*

- Theoretical oxygen requirement for the waste to be burned is the minimum amount of oxygen (O_2) which is required for complete combustion. As air is composed of 21 moles % of oxygen and 79 moles % of nitrogen by mass, when assuming the composition of other gases negligible [18]. In practice the actual amount of oxygen supplied is normally greater than theoretical oxygen, this is due to imperfect mixing of combustion, the extra oxygen will fulfil the requirements at material time to ensure sufficient oxygen for combustion [19, 20], in most cases the fraction of excess oxygen (*f*) for incineration combustion is set to 20-50% [21].

II. MATERIALS AND METHODS.

A. *Equipment use*

The mass and energy balance calculation for the locally made fixed bed incinerator located at Bagamoyo hospital, Tanzania was conducted. This incinerator is used by the Bagamoyo district hospital for incineration of hospital waste. In our case it is used as a pilot example for this study. The incineration layout is shown in Figure 3.

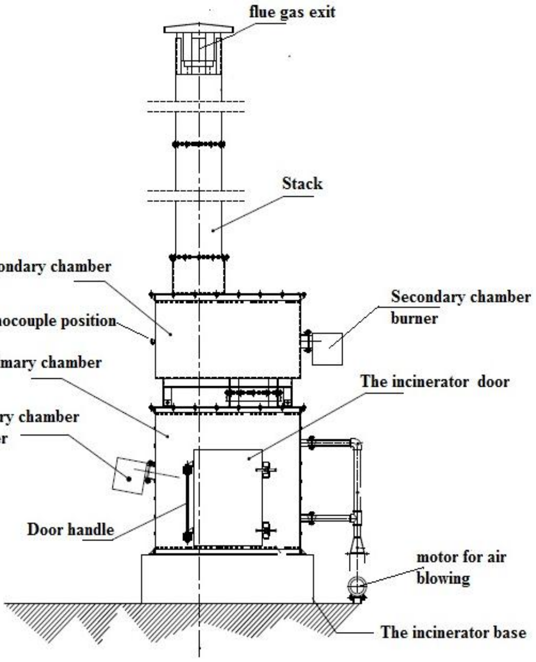

Figure 3: The fixed bed incinerator layout (Source: [22]

Table 1: Auxiliary equipment of the incinerator

S/N	Equipment	Qty.	Type	Specification	Source
1	Burner	2	LO 20 Alpha Thermal	Fuel consumption 10-20*l/h*, thermal power 425,000 - 435,000 *kJ/h,* Motor power =240W, pump pressure =10-12 bar	[23]
2	Thermal couples	2	K Nickel-Chromium	Grade wire -270 to 1260^{o}C Extension grade wire 0 to 200^{o}C Melting point 1400^{o}C	[24]
3	Motor for air blowing	2	Induction motor	Single phase induction motor	Type: PME 0438-035 No: 04408278 kW 0.22, V=230, Hz=50 A=1.15 Year 2011

A. *Materials used*

1) *Municipal solid waste*

The municipal solid waste composition for this experiment, the waste composition analysis and values of proximate analysis and ultimate analysis was studied earlier by Omari and others [25].

Table 2: Proximate, ultimate analysis and HHV studied of municipal solid waste.

	Proximate analysis				
Location	Moisture as received (wt. %)	Volatile (wt.%) dry basis	Ash (wt. %) dry basis	FC (wt. %) dry basis	HHV (MJ/kg)
Kaloleni	59.67	84.43	8.16	7.41	11.90
Sakina	63.99	84.00	10.00	6.00	11.37
Central market	55.70	78.30	13.48	8.22	12.76

	Ultimate analysis						
Location	C (wt. %)	H (wt. %)	O (wt. %)	N (wt. %)	S (wt. %)	Cl (wt. %)	P (wt. %)
Kaloleni	55.57	5.34	34.88	2.09	0.31	0.04	0.10
Sakina	55.70	5.29	34.27	2.13	0.22	0.07	0.13
Central Market	53.20	5.24	34.71	2.86	0.37	0.04	0.11

Source: [25]

The empirical formula calculated for municipal solid waste was found to be

$$CH_{1.158}O_{0.474}N_{0.037}S_{0.002}Cl_{0.000}P_{0.001}$$

By assuming negligible value of Cl and P the empirical formula for municipal solid waste will be

$CH_{1.158}O_{0.474}N_{0.037}S_{0.002}$ [22]

This formula corresponds with other municipal solid waste formulas studied by [26] and earlier studied in Klein theses work in 2002 [27]. In their study, they show that the municipal solid waste has the mean hydrocarbon formula of $C_6H_{10}O_4$, mixed food waste $C_6H_{9.6}O_{3.5}N_{0.28}S_{0.2}$, mixed papers waste $C_6H_{9.6}O_{4.6}N_{0.036}S_{0.01}$ and Yard waste $C_6H_{9.2}O_{3.8}N_{0.01}S_{0.04}$. By using the results observed, the chemical formula for Bagamoyo municipal solid waste was found to be $C_6H_{9.948}O_{2.844}N_{0.222}S_{0.012}$.

2) *The diesel consumed*

The diesel used in this experiment is a general purpose diesel fuel grade No. 1-D S500 for use in diesel engine application with maximum sulphur content of 500 ppm [28]. The density of the diesel is 852 kg/m^3 at 21^{o}C with general formula of $C_{12}H_{23}$ and HHV of 45,013 kJ/kg, sulphur and moisture contents of 170 ppm and 0.055 wt. % respectively.

3) *The air supply.*

The air is supplied to the incinerator by using blowers connected to two motors sideways of the incinerator. The one connected at right hand side is supplying the staved air to the primary chamber, above and below the grate in the primary chamber. The excess air is supplied to the secondary chamber by the right hand side blower through the pipe closer to the exit of the chamber.

B. *Mass balance of the system*

1) *Mass flow rate of municipal solid waste used*

This is done by taking the mass of municipal solid waste at the beginning and the time taken to complete the incineration process. By measuring the mass of waste consumed and time taken, assumed constant flow rate, the mass flow rate of combustible waste was calculated.

2) *Mass flow rate of diesel used*

The mass flow rate of diesel consumed was calculated by measuring the volume of diesel consumed, duration of the operation and the density, the value of mass flow rate was obtained.

3) *Mass flow rate of the oxygen and air used*

The mass flow rate of oxygen used was determined by taking 21% of mass flow rate of air used. The mass of air used was determined by measuring the velocity of air used, knowing the standard air density of Bagamoyo, the cross section area of pipe used to supply air to the incinerator, the mass flow rate of air was obtained.

4) *Mass out due to bottom ash left*

The mass of bottom ash left was measured. The total time consumed was about 0.9264h and the mass flow rate of ash was found to be 5.87 kg/h

5) *Mass rate out due to effluent gases*

The mass of flue gases such as CO, CO_2, NO_X, O_2 and H_2Ovapor are measured by using Kane 900 plus emission meter. Kane 900 plus emission meter hand held combustion analyzer can measure combustion efficiency, composition of O_2, CO_2, NO_X, SO_X and excess air in the flue gas emission. Since each gas has the ability to conduct heat at a specific rate, thermal conductivity principle is used in operating this instrument. The operation principle using Wheatstone bridge configuration is shown in Figure 4.

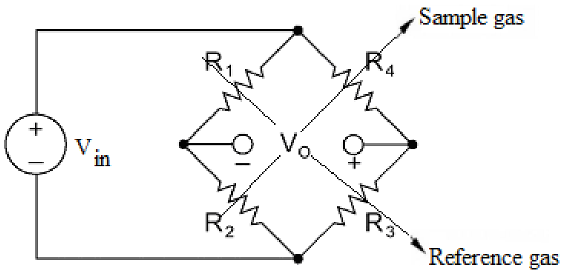

Figure 4: Wheatstone bridge configuration

When all the resistors are balanced, the voltage output is zero and the current passed through is balanced. Then, the electric current is passed through the resistance bridge to heat the element. The sample gas is passing through one side differs with other side of the heated bridge. The temperature of the resistors of the side where sample gas is passed will change according to thermodynamics laws. This change in temperature cause imbalance and therefore cause the potential difference. The current flow due to this potential difference caused by resistance change will be interpreted in the output signal [29, 30]. The output signal strength is set in such a way that when sample gas is passed over one side of the bridge, the voltage value is compared to a reference value voltage which correlates to content of the sample gas and therefore the gas composition content can be identified.

6) *Energy balance equations*

a) Energy in = Q (Diesel1) + Q (msw1) +Q (air)

Q (diesel$_1$) = Energy from auxiliary fuel (diesel)

= $\dot{m}_{(diesel)}$ *HHV of diesel

Q (msw$_1$) dry = energy from municipal solid waste

= $\dot{m}_{(MSW)_{dry}}$ *HHV value of municipal solid waste

b) Energy out = Q (Effluent.) + Q (msw2) + Q (3)

Q (Effluent.) = Heat released to the environment (Heat released by flue gases)

$$\sum(m_{gases} * C_{p(gases)} * \Delta T_1)$$

Where:

m $_{(gases)}$ is the mass of gases (kg),

cp $_{(gases)}$ = specific heat capacity of gases (kJkg^{-1}K^{-1}),

Δt_1 is the change in temperature between ambient and flue gases exit temperature (K),

Q $_{(msw2)}$ is the heat absorbed by municipal solid waste during pyrolysis.

Heat used to raise MSW (ash) from ambient temperature to maximum temperature + heat used to dry MSW (Heat to raise moisture from ambient temperature to 100°C and the enthalpy of vaporization) + heat to raise vapor from boiling point to exit temperature

$$(m_{ash} * C_{p(ash)} * \Delta T_2) + (m_{H_2O} * C_{p_{H_2O(l)}} * \Delta T_3 +$$

$$m_{H_2O} * h_{v(H_2O)} + m_{H_2O} * C_{p_{w(g)}} * \Delta T_4$$

Where: m (ash) = mass of ash (kg), Cp (ash) = specific heat capacity of ashes (kJkg^{-1}k^{-1}), ΔT_2 = Change in temperature between ambient and maximum temperature of incinerator (K), $m_{(H2O)}$ = mass of moisture present in waste (kg), Cp (H_2O) = specific heat capacity of water (kJkg^{-1}K^{-1}), ΔT_3 = Change in temperature between ambient and boiling point of water (K), $h_{v(H_2O)}$ = enthalpy of vaporization of water (Jkg^{-1}), $C_{pw(g)}$ = specific heat capacity of water vapor (kJkg^{-1}K^{-1}), ΔT_4 = Change in temperature between boiling point of water and exit temp of incinerator (K), Q $_{(3)}$ = Heat loss due to radiation which is taken as 3-5% of the total heat available

III. RESULTS AND DISCUSSION

A. *Mass balance of the system*

The mass of the materials used during incineration are changing as the chemical reactions occur between municipal solid waste, auxiliary fuel and air.

1) *Mass input by municipal solid waste and diesel*

From the experiment the mass of waste incinerated was 49 kg/h. The total mass of ash remaining after the combustion was 5.87 kg/h this shows that the mass of waste consumed in forming flue gases is 43.13 kg/h which give the equivalent of mass reduction by 88.02 %. The value of unreacted material found to be 11.98 %. This value is closer to the value obtained in proximate analysis from various researches. Since the waste has 55% moisture it implies that the total mass of dry waste will be 19.4 kg/h, and the total moisture will be 23.72 kg/h. Volume flow rate of diesel consumed was measured and was found to be 0.011439 *m*^{3}*/h*. Since the density (ρ) of diesel = 852 (kg/m^3), the mass flow rate of the diesel = 0.011439*852 = 9.75 kg/h

2) *Mass of air supplied and moisture contents from air*

To the incinerator for municipal solid waste were measured and calculated

Mass of air supplied to the incinerator were measured by using an anemometer. The air supplied velocity to the incinerator was measured to be 6.2 m/s for pipe P1 which is located at the bottom of the grate bed. The air velocity for pipe P2 which is located at the exit of primary chamber is 6.3 m/s while the air velocity of pipe P3 located at the exit of the secondary chamber was found to be 9.2 m/s. Their respective diameters are 0.05 m, 0.05m and 0.0625 m. Density of air ρ (air) and humidity of Bagamoyo at 22.75 are 1.2922 kg/m3 and 77.2% respectively [31] From the value of humidity the specific humidity was calculated.

The relative humidity 77% at 22.75°C, the specific humidity at corresponding vapor pressure of 2701.275 is found by formula

$$x = \frac{0.62198\, x\, Pw}{(Pa - Pw)} \;,$$

Where:
x – Specific humidity at saturation (kg water /kg air),
Pa - the atmospheric pressure (Pa),
Pw - partial pressure of water in moist air

The value of specific humidity found to be 0.0174042 kg (water)/kg (air)

The burner is set to operate with 50% excess air

$$C_{12}H_{23} + 17.75(O_2 + 3.76N_2) \rightarrow 12CO_2 + 11.5H_2O + 66.74N_2$$

Table 3: Diesel and air consumption of burners

	$C_{12}H_{23}$	O_2	N_2	CO_2	H_2O	N_2	O_2
Total mass	167	568	1868.72	528	207	1868.72	0
Normalize diesel	1	3.4	11.19	3.16	1.24	11.19	0
Diesel fired *Kg/h*	9.75	49.74	163.65	30.83	12.09	163.65	16.58

According to the balance equation in equation above, the total mass of air with 50% excess will be 213.395 kg/h and the calculated value of specific humidity of 0.0174042 kg $_{(water)}$/kg $_{(air)}$ the total mass of humidity was found to be 7.984872918 *kg* $_{(water)}$/*kg* $_{(air)}$

3) Mass balance analysis summary

- Mass input and output of the incinerator

Mass input and output of the incinerator is calculated from measured value of the air flow rate. The value of mass output due to flue gas emission measured and calculated by assuming complete combustion. The concentration of the flue gases in percentage was taken as the average values of O_2, N_2, CO_2, H_2O and SO_2. The flue gases velocity in m/s was recorded, the measured value of gas concentration, and the density of each identified gas O_2, N_2, CO_2, H_2O and SO_2 were used to calculate the mass flow rate using $m_i = A_i\, x\, V_i\, x\, \rho_i$ where m_i = mass flow rate of gas (kg/h), V_i = Velocity of flue gas *(m/s)* and ρ_i = density of the gases *(kg/m³)*. Subsequently the respective masses were 39.21 (kg/h), 334.75(kg/h), 75.28(kg/h), 67.07(kg/h), and 0.127(kg/h) respectively from their corresponding densities of 1.331 (kg/m^3), 1.165 (kg/m^3), 1.842 (kg/m^3), 0.804 (kg/m^3) and 2.279(kg/m^3)respectively. The respective velocity of gases and stack cross-section area are constant with the values of 3.9 (m/s^2) and 0.03142(m^2) respectively. The total mass output due to flue gas is therefore will be 516.439(kg/h).

- Mass of particulate left

The mass of solid ash left measured to be 5.87(kg/h). This value is different with calculated value by proximate analysis which was 2.87(kg/h).The ash is higher than the calculated value, and total mass is lower than expected this may be due to some unreacted waste material left during the sorting exercise prior incineration and unaccounted mass of municipal solid waste burned and escape with flue gases during incineration. The value of the mass balance were summarized in the table 4.

- Energy balance of the incinerator

Energy in = Energy $_{(diesel)}$ + Energy $_{(msw)}$ +Air $_{(Energy)}$ assuming energy from air is negligible we have;

a) Energy diesel = mass of diesel * HHV of diesel
= 9.75 *kg/h x* 45013 *kJ/kg*
= 438,876.75 *kJ/h*

b) Energy from municipal solid waste = mass of dry combustible waste * HHV of waste
(Mass of combustible waste – moisture (55 %) – unreacted) * HHV of waste
= (22.05-2.867) *kg/h x* 12,010 kJ/kg
= 230,387.83 *kJ/h*

Total energy in = 438,876.75 +230,387.83
= 669,264.58 *kJ/h*

Energy out = Q $_{(Out1)}$ + Q $_{(Out2)}$ +Q $_{(out3)}$

a.) Energy out due to flue gas release

$$Q_{(out1)} = \sum (m_{gases} * C_{p(gases)} * \Delta T_i)$$

$$= m_{CO_2} * C_{p(CO_2)} * \Delta T_1 + m_{O_2} * C_{p(O_2)} * \Delta T_2 + m_{N_2} * C_{p(N_2)} * \Delta T_2 + m_{SO_2} * C_{p(SO_2)} * \Delta T_1 + m_{1(H_2O)(g)} * C_{p(H_2O)} * \Delta T_1)$$

Where:

$\boldsymbol{\Delta T_1}$ = Temperature difference between exit temperature and ignition temperature of gases which was estimated to be 450°C. The gases of CO_2, SO_2 and H_2O $_{(g)}$ are formed from combustion reactions at 450°C

ΔT_2 - Temperature difference between exit temperature and ambient temperature at 22.75°C. The gases N_2 and O_2 are found from the combustion air at ambient temperature.

$m_{2(H_2O)(l)}$ - The mass of water from combustion air and moisture contents of the fuels at ambient temperature

$m_{1(H_2O)(g)}$, $m_{CO_{2(g)}}$ and m_{SO_2} - Mass of H_2O, CO_2 and SO_2 formed due to the chemical reaction in the incinerator

Cp_{CO_2}, Cp_{O_2}, Cp_{N_2}, $Cp_{H_2O_{(l)}}$ $Cp_{H_2O_{(g)}}$ are the specific heat capacities of Carbon dioxide, Oxygen, Nitrogen, water, water vapor and Sulphur dioxide respectively with subsequent values of 0.844, 0.919, 1.04, 4.184, 1.185 and 0.64 kJ/kg °C respectively.

Table 4: Mass balances summary analysis of the system

Mass input	Kg/h	Mass output	Kg/h
Mass of air for incinerator combustion chamber	245.509	Mass of CO_2	75.282
Mass of air for burner	213.395	Mass of H_2O	67.065
Subtotal mass of air	**458.904**	Mass of N_2	334.75
Mass of moisture in combustion air	7.98	Mass of O_2	39.213
Mass of moisture in Diesel and MSW	26.95	Mass of SO_2	0.1267
Subtotal mass moisture	**34.93**	**Total mass of flue gases**	**516.44**
Mass of diesel	9.75	Mass of solid ash remain	5.87
Mass of dry municipal solid waste	22.05	mass of unaccounted particulates	variable
Subtotal mass fuel	**31.8**	**Subtotal particulates**	**variable**
Mass of unreacted materials (13%)	2.867		
Total weight in (kg/h)	**528.5**	**Total weight out (kg/h)**	**522.31**

Table 5: Energy due to flue gas released

Energy due to flue gas release				
Type of gas	Cp kJ/kg°C	dT (°C)	Mass (kg)	Energy Total (kJ)
CO_2	0.844	550	78.54	36,455.95
O_2	0.919	977.25	32.95	29,591.26
N_2	1.04	977.25	352.70	358,465.15
SO_2	0.64	550	0.14	48.87
H_20 (l)	4.184	77.25	34.93	11,289.87
H_20 (l)	2460 (kJ/kg)	Enthalpy of vaporization	34.93	85,927.80
H_20 (g)	1.185	900	34.93	37,252.85
H_2O(g)	1.185	550	32.14	20,947.25
				579,978.98

b.) Energy released due to chemical reaction. There is formation of CO_2, SO_2 and H_2O

Formation of CO_2

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$$

$$\Delta H^o = -393.5\, kJ\, mol^{-1}$$

Total number of moles of CO_2 =

$$\frac{75.282}{44} = 1.710954545\, \boldsymbol{kmol}$$

ΔH^o = -393.5 *kJ/mol* x 1.710954545 mol = -673,260,613.64J

Formation of H_2O

$$H_{2(g)} + \frac{1}{2} O_{2(g)} \rightarrow H_2O_{(l)}$$

$$\Delta H^o = 241.8\, kJ\, mol^{-1}$$

Total number of moles of H_2O =

$$\frac{32731.527}{18} = 1{,}818.418\, \boldsymbol{mol}$$

$$\boldsymbol{\Delta H^o} = 1.818418\, \boldsymbol{x} 10^3\, \boldsymbol{mol}\ \boldsymbol{x}\, 241.8\, \boldsymbol{kJ\ mol}^{-1}$$

$$= 439.693{,}512.70\, \boldsymbol{J}$$

Formation of SO_2

$$S_{(s)}+O_{2(g)}\rightarrow SO_{2(g)}$$

$$\Delta H^{o} = -297\ kJ\ mol^{-1}$$

Total number of moles of SO_2 =

$$\frac{0.1267}{64}=1.9796875\,\boldsymbol{kmol}$$

$$\boldsymbol{\Delta H^{o}} = 1.9796875\,\boldsymbol{x}\,-297{,}000\boldsymbol{J}\ \boldsymbol{mol}^{-1}$$

$$=-587{,}967.19\boldsymbol{J}$$

Therefore the total energy released during the chemical reaction will be -234,155,068***J***

= 234.16 MJ

c.) Energy due to radiation and losses it varies between 1 – 5 % of total heat available

$$=5\%\,\boldsymbol{x}\ 669{,}264.58\ \boldsymbol{kJ/h}$$

$$=33{,}463.23\ \boldsymbol{kJ/h}$$

d.) The energy use to heat up the incinerator before fill in the waste. The primary chamber was heated up to 400°C and the secondary chamber to 800°C the total diesel of about 5 liters were used

Table 6: Energy Balance summary

Total energy input				Total energy output	
Material	HHV kJ/kg	Mass kJ/h	*Total (kJ/h)*	Energy consumption	*(kJ/h)*
MSW	12010	19.18	230,351.80	Energy due to flue gas releases	579,978.98
Diesel	45013	9.75	438,876.75	Energy due to chemical reaction	-234,155.07
				Heat released due to uncountable for heat loss of the system	Variable (13-15%)
				Energy to heat up incinerator Primary chamber 400°C and Secondary chamber 800°C	289,941.41
		Total *(kJ/h)*	**669,228.55**	**Total *(kJ/h)***	**635,765.32**

IV. CONCLUSION AND RECOMMENDATIONS:

- The excess air ration to the incinerator during incineration must be optimized to minimize emissions and increase the performance of incinerator.
- To acquire more energy from incinerator, the municipal solid waste must be dried to reduce moisture contents improve their physical structure.
- The incineration result generate energy of 379,287.14 kJ/h with ash and flue gases emissions of total mass of 579,978.98 kg/h. there is energy difference of 379,287.14 kJ need to recover or optimized. There is also energy which used to heat up the incinerator before putting waste which was not considered.

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