



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

WASTE TO ENERGY CONVERSION

TUTORIAL ON INCINERATION

PRASENJIT MONDAL
CHEMICAL ENGINEERING



Problem 1

A dry MSW has the following composition on mass basis:

C: 40 (%), H: 5 %, O: 30 % and Ash:25 %. Determine the stoichiometric oxygen requirement for the combustion of the MSW. Assume the ash as inert and average molecular weight of ash is 56. If the ratio of nitrogen to oxygen in air is 4:1 (v/v), determine the stoichiometric requirement of air.

Basis : 100 g dry MSW

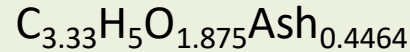
C = 40 g = $40/12 = 3.33$ moles

H = 5 g = $5/1 = 5$ moles

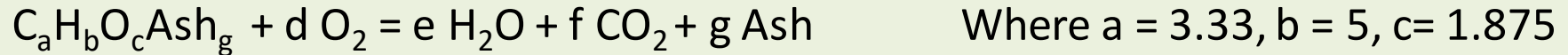
O = 30 g = $30/16 = 1.875$ moles

Ash = 25 g = $25/56 = 0.4464$ moles

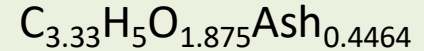
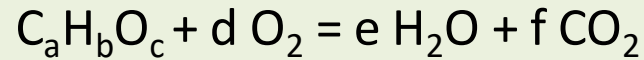
Average Molecular formula of the MSW



Since the ash is inert the combustion reaction will be as follows:



By mass balance of the components



$a=f$ (C balance)

$b = 2e$ (H balance)

$c + 2d = e + 2f$ (O balance)

Therefore

$$a = f = 3.33,$$

$$b = 5$$

$$e = b/2 = 5/2 = 2.5$$

$$c = 1.875$$

$$1.875 + 2d = 2.5 + 2 \times 3.33$$

$$\begin{aligned} \text{Or } 2d &= 2.5 + 6.66 - 1.875 \\ &= 7.285 \end{aligned}$$

$$d = 3.6425$$

Therefore for 100 g of MSW O_2 requirement =

$$3.6425 \times 32 = 116.56 \text{ g}$$

Stoichiometric requirement of O_2 is 116.56 g per

100 g of MSW

Or 1.1656 g O_2 per g of MSW

N_2 in the air containing 3.6425 mole $O_2 = 4 \times 3.6425 =$

14.57 mole; Mass of $N_2 = 14.57 \times 28 = 407.96 \text{ g}$

Therefore mass of air = $407.96 + 116.56 = 524.52 \text{ g}$

Stoichiometric requirement of air = 524.52 g per 100 g of MSW



Problem 2.

A MSW has the following composition on mass basis:

C: 35.5 (%), H: 4.8 %, O: 25 %, N:0.40 %, S:0.15%, Cl:0.55%, Moisture: 26% and Ash:7.6%. Assume average molecular weight of ash is 56.

Determine the molecular formula and heating value on dry basis and as received basis of the MSW using the following

$$\text{HHV in MJ/Kg} = 0.3516 \cdot \text{C} + 1.16225 \cdot \text{H} - 0.1109 \cdot \text{O} + 0.0628 \cdot \text{N} + 0.10465 \cdot \text{S}$$

If this waste is incinerated in fixed bed inclinator what will be the composition of the flue gas if 20 % excess air is supplied ?

If the ash of the above sample contains 0.3 % K_2O and 0.2 % Na_2O respectively. Determine whether the waste will form slag in the furnace.



Ans.	Basis = 100 g MSW	Amount of elements
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Composition of the MSW

C: 35.5 (%),
 H: 4.8 %,
 O: 25.0 %,
 N:0.40 %,
 S:0.15%,
 Cl:0.55 %,
 Moisture: 26.0%
 Ash:7.6%
 Total = 100

C: $35.5 \text{ g} = 35.5/12 = 2.958 \text{ moles}$
 H: $4.8 \text{ g} = 4.8/1 = 4.8 \text{ moles}$
 O: $25.0 \text{ g} = 25/16 = 1.5625 \text{ moles}$
 N: $0.40 \text{ g} = 0.4/14 = 0.0286 \text{ moles}$
 S: $0.15 \text{ g} = 0.15/32 = 0.0047 \text{ moles}$
 Cl: $0.55 \text{ g} = 0.55/35.5 = 0.0155 \text{ moles}$
 Moisture: $26.0 \text{ g} = 26/18 = 1.444 \text{ moles}$
 Ash: $7.6 \text{ g} = 7.6/56 = 0.1357 \text{ moles}$
 O from moisture (H_2O) = 1.444 mole
 H from moisture (H_2O) = $2 \times 1.444 = 2.888 \text{ moles}$

Molecular formula $\text{C}_{2.958} \text{H}_{7.688} \text{O}_{3.0065} \text{N}_{0.0286} \text{S}_{0.0047} \text{Cl}_{0.0155} \text{Ash}_{0.1357} (\text{H}_2\text{O})_{1.444}$

Or $\text{C}_{2.958} \text{H}_{7.688} \text{O}_{3.0065} \text{N}_{0.0286} \text{S}_{0.0047} \text{Cl}_{0.0155} \text{Ash}_{0.1357}$

Composition on dry basis

$$\text{C: } 35.5 * 100 / (100 - 26) = 47.97 \%$$

$$\text{H: } 4.8 * 100 / (100 - 26) = 6.49 \%,$$

$$\text{O: } 25.0 * 100 / (100 - 26) = 33.78 \%,$$

$$\text{N: } 0.40 * 100 / (100 - 26) = 0.54 \%,$$

$$\text{S: } 0.15 * 100 / (100 - 26) = 0.203 \%,$$

$$\text{Cl: } 0.55 * 100 / (100 - 26) = 0.74 \%,$$

$$\text{Ash: } 7.6 * 100 / (100 - 26) = 10.27 \%,$$

Now HHV on dry basis can be calculate as follows

$$\text{HHV} = 0.3516 * \text{C} + 1.16225 * \text{H} - 0.1109 * \text{O} + 0.0628 * \text{N} + 0.10465 * \text{S}$$

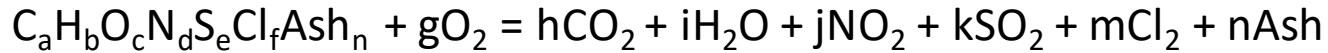
$$\begin{aligned} \text{HHV} &= 0.3516 * 47.97 + 1.16225 * 6.49 - \\ &0.1109 * 33.78 + 0.0628 * 0.54 + \\ &0.10465 * 0.203 \\ &= 20.71 \text{ MJ/Kg} \end{aligned}$$

On as received basis

$$\begin{aligned} \text{HHV} &= 0.3516 * 35.5 + 1.16225 * 4.8 - \\ &0.1109 * 25 + 0.0628 * 0.4 + 0.10465 * 0.15 \\ &= 15.33 \text{ MJ/Kg} \end{aligned}$$



Let us assume the combustion reaction as follows



Molecular formula of the MSW is $C_{2.958}H_{7.688}O_{3.0065}N_{0.0286}S_{0.0047}Cl_{0.0155}Ash_{0.1357}$

By component mass balance

$$a = h = 2.958$$

$$d = j = 0.0286$$

$$e = k = 0.0047$$

$$b = 2i = 7.688 \rightarrow i = 3.844$$

$$f = 2m = 0.0155$$

$$m = 0.00775$$

$$c = 3.0065$$

$$n = 0.1357$$

$$c + 2g = 2h + i + 2j + 2k$$

$$= 2*2.958 + 3.844 + 2*0.0286 + 2*0.0047 = 9.8266$$

$$2g = 9.8266 - 3.0065$$

$$= 6.821$$

$$\text{Or } g = 3.41005$$



O_2 supplied for the combustion = $3.41005 * 1.20 = 4.09206$ moles as 20 % excess air

Assuming 20 % oxygen and 80 % nitrogen in air

N_2 in the air = $4.09206 * 4 = 16.36824$ moles Excess $\text{O}_2 = 3.41005 * 0.2 = 0.68201$ moles

Gas composition of the flue gas

$\text{CO}_2 = 2.958$ moles

$\text{H}_2\text{O} = 3.844$ moles

$\text{NO}_2 = 0.0286$ moles

$\text{SO}_2 = 0.0047$ moles

$\text{Cl}_2 = 0.00774$ moles

$\text{N}_2 = 16.36824$ moles

Excess $\text{O}_2 = 0.68201$ moles

Total moles 23.89329 moles

% composition

$\text{CO}_2 = 100 * 2.958 / 23.89329 = 12.38$

$\text{H}_2\text{O} = 100 * 3.844 / 23.89329 = 16.09$

$\text{NO}_2 = 100 * 0.0286 / 23.89329 = 0.119$

$\text{SO}_2 = 100 * 0.0047 / 23.89329 = 0.019$

$\text{Cl}_2 = 100 * 0.00774 / 23.89329 = 0.032$

$\text{N}_2 = 100 * 16.38824 / 23.89329 = 68.59$

Excess $\text{O}_2 = 0.68201 * 100 / 23.89329 = 2.85$

Slagging index calculation

K_2O in ash = 0.3 %

Na_2O in ash = 0.2 %

$(K_2O + Na_2O)$ in ash = $0.3 + 0.2 = 0.5$ %

$$\begin{aligned}\text{Slagging index} &= 0.1 [\% \text{ ash} * \% \text{ alkali in ash}] \text{ Kg alkali/GJ} \\ &= 0.1 [7.6 * 0.5] = 0.38 \text{ Kg alkali/GJ}\end{aligned}$$

Now we know that an index range of 0 to 0.17 kg/GJ ----- low slagging risk;
0.17 to 0.34 kg/GJ ----- probably slag;
> 0.34 kg/GJ ----- virtual certainty of slagging (Miles *et al.*, 1993).

Thus, it will form slag

Problem 3:

The composition of flue gas (dry basis) from an incinerator is as follows: 12.3% CO₂, 5.1% O₂, and the rest is nitrogen. From these data, calculate:

- a. The weight ratio of hydrogen to carbon in the waste
- b. The percent carbon and hydrogen in the dry waste
- c. The percent excess air used
- d. The moles of exhaust gas discharged from the unit per kilogram dry waste burnt



Basis. 100 mole of dry flue gas

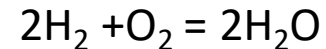
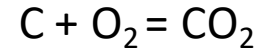
$$\text{CO}_2 = 12.3\%$$

$$\text{O}_2 = 5.1\%$$

$$\text{Inert (N}_2\text{)} = 100 - 12.3 - 5.1 = 82.6\%$$

$$\text{O}_2 \text{ available with supplied air} = 82.6 \times 21/79 = 22 \text{ moles}$$

$$\text{O}_2 \text{ consumed during combustion} = 22 - 5.1 = 16.9 \text{ moles}$$



From the flue gas composition it is evident that the waste does not contain S, Cl and N

Thus 12.3 mole O_2 is consumed by C during combustion

$$\text{O}_2 \text{ consumed by H}_2 \text{ is } 22 - 12.3 - 5.1 = 4.6 \text{ mole}$$



Therefore H_2 present in waste = $4.6 \times 2 = 9.2$ moles

Weight of H in waste = $9.2 \times 2 = 18.4$ g

Weight of C in waste = $12 \times 12.3 = 147.6$ g

Molecular weight of the waste
= $18.4 + 147.6 = 166$ g

H to C ratio in waste = $18.4/147.6 = 0.125$

% C in dry waste = $100 \times 147.6 / (147.6 + 18.4) = 88.92 \%$

% H in dry waste = $100 \times 18.4 / (147.6 + 18.4) = 11.08 \%$

% excess air applied = $5.1 / (22 - 5.1) = 30.18 \%$

H_2O produced during combustion = $2 \times 4.6 = 9.2$ moles

Moles of exhaust gas per kg of waste = $(100 + 9.2) / 166 = 0.658$ moles per g
= 658 moles per kg dry MSW



Thanks...

