# Chemical Process Calculations CL204
# Module-4
# Material Balance With Chemical Reaction

## Tutorials

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## Module - 4

## Material balance with chemical reaction

First consider a single reaction in a reactor block.

inert gas Argon in the Feed.

$$3H_2 + N_2 \rightleftharpoons 2NH_3 + \text{heat}$$

$\nu_i$    $-3$    $-1$    $+2$    Exothermic reversible reaction.

& $\nu_{Argon} = 0$

$F_{in} \longrightarrow$ [Reactor] $\longrightarrow F_{out}$ ?

Conversion $x = 50\%$

$F_{in}^{N_2} = 6$ kmol/hr

$F_{in}^{H_2} = 9$ kmol/hr

$\underline{F_{in}} = 6 + 9 = 15$ kmol/hr

$F_{out}^{N_2} = 4.5$ kmol/hr

$F_{out}^{H_2} = 4.5$ "  & $F_{out}^{NH_3} = 3$ kmol/hr

For 100% conversion

1 mol of $N_2$ reacted with 3 mol of $H_2$

6 " " " " " $\frac{3}{1} \times 6 = 18$ mol of $H_2$

6 kmol/hr " " " 18 kmol/hr of $H_2$

but $H_2$ inlet flowrate is 9 kmol/hr

So, $H_2$ is limiting reactant.

3 kmol/hr $H_2$ ---- 1 kmol/hr $N_2$.

9 " " ---- $\frac{1}{3} \times 9 = 3$ kmol/hr $N_2$

↓ Limiting — excess.

excess $N_2 = 6-3 = 3$ kmol/hr $N_2$.

% excess $= \frac{6-3}{3} \times 100$

$= 100\%$ excess $N_2$

So 50% conversion will be based on Limiting reactant $H_2$.

$F_{in}^{H_2} = 6$ kmol/hr.

50% conversion, $9 \times 0.5 = 4.5$ kmol/hr $H_2$ will be reacted.

So outlet flowrate of $H_2$, $F_{out}^{H_2} = 9 - 4.5 = 4.5$ kmol/hr

For $N_2$. reacted $= 4.5/3 = 1.5$ kmol/hr

So $F_{out}^{N_2} = 6 - 1.5 = 4.5$ kmol/hr

$NH_3$ Formed $=$ $N_2$ reacted $\times 2$

$= 1.5 \times 2 = 3$ kmol/hr

$=$ $H_2$ reacted $\frac{2}{3}$

$= 4.5 \times \frac{2}{3} = 3$ kmol/hr

## Generalized material balance for a reactor

$$F_i^{out} = F_i^{in} + \underline{\underline{\upsilon_i \xi}}$$

$\upsilon_i \xi$ = molar flow change due to chemical reaction of species i

$\xi$ = extent of reaction

$$\xi = \frac{F_{N_2}^{out} - F_{N_2}^{in}}{\upsilon_{N_2}} = \frac{4.5-6}{-1} = 1.5 \qquad \left[ \xi = \frac{F_i^{out} - F_i^{in}}{\upsilon_i} \right]$$

$$\xi = \frac{F_{H_2}^{out} - F_{H_2}^{in}}{\upsilon_{H_2}} = \frac{4.5-9}{-3} = 1.5$$

$$\xi = \frac{F_{NH_3}^{out} - F_{NH_3}^{in}}{\upsilon_{NH_3}} = \frac{3-0}{2} = 1.5$$

$$\therefore \quad F_i^{out} = F_i^{in} + \nu_i \xi .$$

$$\left.\begin{aligned} N_2: \quad & F_{N_2}^{out} = 6 + (-1) \times 1.5 = 4.5 \\ H_2: \quad & F_{H_2}^{out} = 9 + (-3) \times 1.5 = 4.5 \\ N_2: \quad & F_{N_2}^{out} = 0 + (2) \times 1.5 = 3 \end{aligned}\right\}$$

$$\xi = \frac{F_i^{out} - F_i^{in}}{\nu_i}$$

$$= -\left[\left(\frac{F_i^{in} - F_i^{out}}{F_i^{in}}\right)\right] \frac{F_i^{in}}{\nu_i}$$

$i$ = Limiting reactant ; $H_2$ $\Rightarrow$ $\frac{9-4.5}{9} = 0.5 = 50\%$

$$\frac{F_{LR}^{in} - F_{LR}^{out}}{F_{LR}^{in}} = x = \text{Fractional conversion.}$$

$$\boxed{\begin{aligned} \xi &= -x \frac{F_{LR}^{in}}{\nu_{LR}} \\ x &= -\frac{\xi \nu_{LR}}{F_{LR}^{in}} \end{aligned}}$$

LR = Limiting reactant

$$\xi = -0.5 \frac{9}{(-3)}$$

$$\xi = 1.5$$

# Material balance for multiple reaction

$$C_6H_6 + Cl_2 \longrightarrow C_6H_5Cl + HCl \quad \text{— (i)}$$

$\nu_i$: −1 −1 +1 +1

$$C_6H_6 + 2Cl_2 \longrightarrow C_6H_4Cl_2 + 2HCl \quad \text{— (ii)}$$

$\nu_i$: −1 −2 +1 +2

1st reaction extentent of reaction $\xi_1$.

2nd " " " " $\xi_2$

Flowrate of benzene $C_6H_6$ in the inelet (Reactor) (Fresh feed + Recycle) = 100 kmol/hr.

Flowrate of chlorine in the inlet (Reactor) (Fresh feed + Recycle) = 111.11 kmol/hr.

in overall 2 mol $C_6H_6$ reacted with 3 mol $Cl_2$

100 " " " " $\frac{3}{2} \times 100$

$= 150$ mol $Cl_2$

but feed flowrate $Cl_2$ is 111.11 kmol/hr

so, $Cl_2$ is limiting reactant

so, Benzene is excess reactant.

so, 111.11 kmol/hr $Cl_2$ will be reacted with.

$= 111.11 \times \frac{2}{3}$ kmol/hr Benzene

(100% conversion)

$= 74.07$ kmol/hr Bz.

But overall conversion of benzene is 55.3% (given)

$\therefore$ converted benzene flowrate $= 100 \times \frac{55.3}{100}$

$= 55.3$ kmol/hr.

Product stream having Bz flowrate

unreacted Bz = 100 − 55.3 = 44.7 kmol/hr.

∴ Overall $Cl_2$ conversion = $55.3 \times \frac{3}{2}$.

= 82.95 kmol/hr.

∴ Product stream having $Cl_2$ = 111.11 − 82.95

unreacted $Cl_2$ = 28.16 kmol/hr.

Monochlorobenzene $C_6H_5Cl$ in outlet.

= $55.3 \times \frac{1}{2}$ . = $82.95 \times \frac{1}{3}$.

= 27.65 kmol/hr

Dichlorobenzene, $C_6H_4Cl_2$ in reactor

outlet = $55.3 \times \frac{1}{2} = 82.95 \times \frac{1}{3}$

= 27.65 kmol/hr.

111.11 $Cl_2$

100 $Bz$

$\therefore\ x_{Bz}^{in} = \frac{100}{111.11+100}$

$\therefore\ x_{Cl_2}^{in} = \frac{111.11}{111.11+100}$

$F_{Cl_2}^{out} = 28.16$ kmol/hr

$F_{Bz}^{out} = 44.7$ "

$F_{MCl}^{out} = 27.65$ "

$F_{DCl}^{out} = 27.65$ "

$x_{Cl_2}^{out} = \frac{F_{Cl_2}^{out}}{\Sigma F_i^{out}}$

$x_{Bz}^{out} = \frac{F_{Bz}^{out}}{\Sigma F_i^{out}}$

$x_{MCl}^{out} =$

$x_{DCl}^{out} =$

$F_{HCl}^{out} = \underset{(i)}{27.65} + \underset{(ii)}{2 \times 27.65}$

$= 82.95$ kmol/hr.

Generalized material balance equations.

$Bz: \quad F_{Bz}^{out} = F_{Bz}^{in} + \xi_1 \nu_{Bz}^{1} + \xi_2 \nu_{Bz}^{2} \quad \text{—(i)}$

$\nu_{Bz}^{1} = -1; \quad \nu_{Bz}^{2} = -1$

$Cl_2: \quad F_{Cl_2}^{out} = F_{Cl_2}^{in} + \xi_1 \nu_{Cl_2}^{1} + \xi_2 \nu_{Cl_2}^{2} \quad \text{—(ii)}$

$\nu_{Cl_2}^{1} = -1; \quad \nu_{Cl_2}^{2} = -2$

MCBZ: $F_{MCBZ}^{out} = F_{MCBZ}^{in} + \xi_1 \nu_{MCBZ}^{1}$ — (iii)

$\nu_{MCBZ}^{2} = 0$ ; $\nu_{MCBZ}^{1} = +1$

DCBZ: $F_{DCBZ}^{out} = F_{DCBZ}^{in} + \xi_2 \nu_{DCBZ}^{2}$ — (iv)

$\nu_{DCBZ}^{1} = 0$ ; $\nu_{DCBZ}^{2} = +1$

HCl: $F_{HCl}^{out} = F_{HCl}^{in} + \xi_1 \nu_{HCl}^{1} + \xi_2 \nu_{HCl}^{2}$ — (v)

$\nu_{HCl}^{1} = +1$ ; $\nu_{HCl}^{2} = +2$

f (conversion) = f ( $\xi_1, \xi_2$ ).

If overall conversion of Bz is $x_{Bz}$

" " " " $Cl_2$ " $x_{Cl_2}$

$$\Rightarrow \quad \frac{-\nu_{Bz}^{1}\xi_1 - \nu_{Bz}^{2}\xi_2}{F_{Bz}^{in}} = x_{Bz} \quad \text{— (vi)}$$

$$\Rightarrow \quad \frac{-\nu_{Cl_2}^{1}\xi_1 - \nu_{Cl_2}^{2}\xi_2}{F_{Cl_2}^{in}} = x_{Cl_2} \quad \text{— (vii)}$$

Say yield of MCBz is 27.65 % } ⇒ given
yield of DCBz " 27.65 % } or kmol

yield is in the form of kmol/hr of a product formed per kmol/hr of Benzene in the feed.
or kmol.

$$\text{Yield of MCBz} = \frac{27.65 \text{ kmol/hr}}{100 \text{ kmol/hr}}$$

$$= 0.2765$$

$$= 27.65\%$$

yield of DCBz = 27.65 %

**MCBz:**

$$\xi_1 = \frac{F^{out}_{MCBz} - F^{in}_{MCBz}}{\vartheta'_{MCBz}}$$

$$= \frac{27.65 - 0}{+1} = 27.65$$

DCBz:

$$\xi_2 = \frac{27.65 - 0}{+1} = 27.65$$

$$\Rightarrow \xi_1 = \xi_2 = 27.65$$

Put in the (i)

BZ:

$$F^{out}_{Bz} = 100 + 27.65 \times (-1) + 27.65 \times (-1)$$

$$F^{out}_{Bz} = 44.7 \text{ kmol/hr} \text{ (checked)}$$

$Cl_2$ : $F_{Cl_2}^{out} = 111.11 + 27.65 \times (-1) + 27.65 \times (-2)$

$F_{Cl_2}^{out} = 28.16$ kmol/hr (checked) ✓

MCBZ : $F_{MCMZ}^{out} = 0 + 27.65 \times (+1)$

$= 27.65$ kmol/hr (checked) ✓

DCBZ : $F_{DCBZ}^{out} = 0 + 27.65 \times (+1)$

$= 27.65$ kmol/hr (checked) ✓

$Cl_2$ : $F_{HCl}^{out} = 0 + 27.65 \times (+1) + 27.65 \times (+2)$

$= 82.95$ kmol/hr (checked) ✓

If conversion of products are given.
Find (calculate) $\xi_1$ & $\xi_2$ from.
equantion (vi) & (vii) [solve $\xi_1$ & $\xi_2$]

And calculate outlet concentration from material balance equations.

Yield is given 30% ($\frac{\text{kmol of product produced}}{\text{kmol of Bz reacted}} \times 100$)

$$0.3 = \frac{F_{MCBZ}^{produced}}{55.3}$$

$$\Rightarrow F_{MCBZ}^{produced} = 0.3 \times 55.3 \text{ kmol/hr}$$

$$= 16.59 \text{ kmol/hr}$$

$$F_{MCBZ}^{out} = \underline{\underline{16.59 \text{ kmol/hr}}}$$

Material balance of system with reactor, separator mixer, and with recycle and purging streams.

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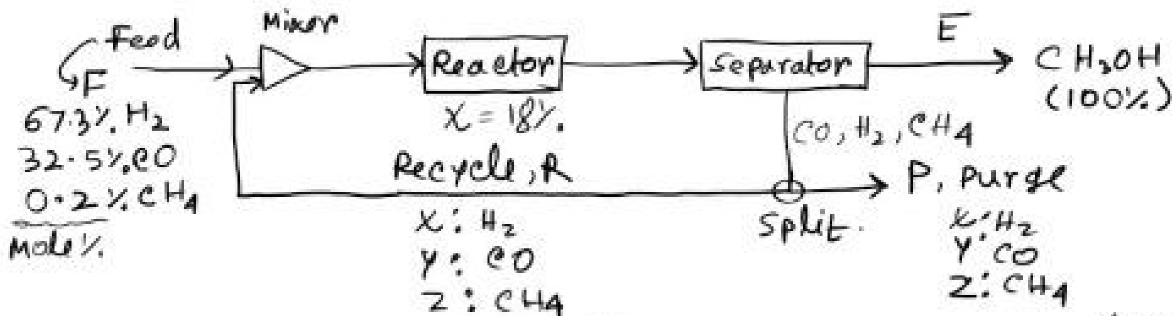
→ Material balance with chemical reaction in a chemical process.
like, production of $NH_3$, $C_2H_4Cl_2$, MCBz, DCBz, etc.

Consider a steady state open process where the following reaction takes place:

$$CO + 2H_2 \longrightarrow CH_3OH$$




x, y, z are mole fraction $z = 0.032$ ($CH_4$) (3.2 %).

$$\nu_{CO} = -1 \; ; \quad \nu_{H_2} = -2 \; ; \quad \nu_{CH_3OH} = +1, \quad \nu_{CH_4} = 0$$

$x$ = fractional conversion of limiting reactant = 0.18

if 100% conversion is carried out

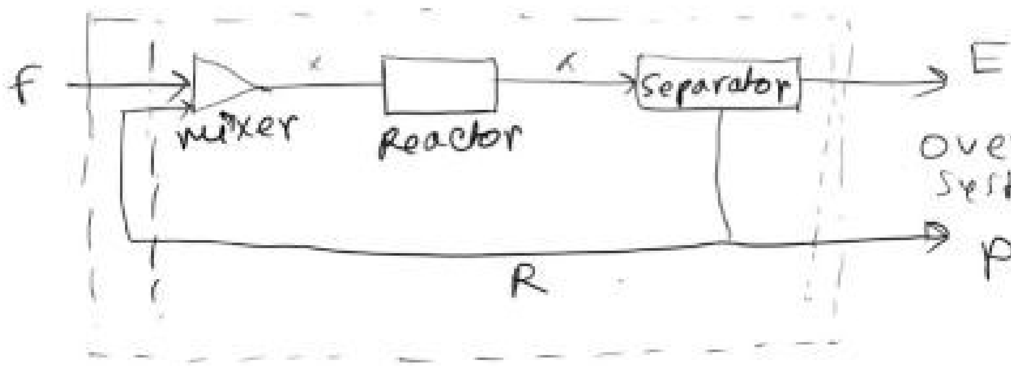
then 32.5% CO will be reacted with 65% $H_2$

but $H_2$ is in the feed is 67.3% (excess).

$$= \frac{67.3 - 65}{67.3} \times 100\%$$

and CO is limiting reactant.

∴ 18% of CO (LR) will be converted to $CH_3OH$.




overall system → $F = E + P$

For no chemical reaction

Overall material balance for overall system

Composition balance for → overall system = mixer + reactor + separator

CO: $F_{CO}^{out/overall} = F_{CO}^{in/overall} + \upsilon_{CO}\xi$

$$[E+R+P]_{CO}^{out} = [R+F]_{CO}^{in} + \upsilon_{CO}\xi$$

$$\Rightarrow \quad E\times 0 + \cancel{R}y + Py = R\cancel{y} + F\times 0.325 + (-1)\xi$$

$$\Rightarrow \quad Py = 0.325F - \xi \quad \text{— (i)}$$

$H_2$: $E \times 0 + R\cancel{x} + Px = R\cancel{x} + F \times 0.673 + (-2)\xi$

$\Rightarrow \quad Px = 0.673F - 2\xi$ — (ii)

$CH_3OH$: $E \times 1 + R \times 0 + P \times 0 = R \times 0 + F \times 0 + (+1)\xi$

$\Rightarrow \quad E = \xi$ — (iii)

$CH_4$: $E \times 0 + R \times \cancel{0.032} + P \times 0.032 = R \times \cancel{0.032} + F \times 0.002$

$\Rightarrow \quad 0.032P = 0.002F$ — (iv)

Summation of compositions

$x + y + z = 1$ — (v)

$z \to \underline{\underline{0.032}}$

$f(\xi) = x$

$$\Rightarrow \quad \frac{-\nu_{LR}\,\xi}{F_{LR}^{\text{reactor feed}}} = 0.18 \quad \text{— (vi)}$$

$LR = CO$

$$\Rightarrow \quad \frac{-(-1)\,\xi}{RY + 0.325F} = 0.18$$

$$\Rightarrow \quad 0.18\,RY + 0.18 \times 0.325F = \xi \quad \text{— (vi)}$$

$N_U = F, E, R, P, x, Y, \xi \quad (7)$.

and $N_E = 6$ (independent equations).

$\therefore N_D = 7 - 6 = (1)$

take $F = 100$ kmol/hr

from (iv) eqn. $0.032P = 0.002F$ [$CH_4$ balance]

$$\Rightarrow \quad P = 6.25 \text{ kmol/hr.}$$

So, number of equation will be = 6-1=5

" " variables " " = 6-1=5.

∴ Solve eqns. (i), (ii), (iii), (v), (vi)

to find $E, \xi, R, x, y$.

$F = 100$ kmol/hr

$P = 6.25$ "

$N_D = 0$

$E = 31.25$ kmol/hr

$R = 705.55$ "

$\xi = 31.25$ "

$x = 0.768$ (mol fraction) : $H_2$

$y = 0.2$ " ; CO

$z = 0.032$ : $CH_4$

$x+y+z = 0.768+0.2+0.032 = 1$ (checked)

$\frac{R}{P} = C$ will be provided

or 99% R and 1% P

or 90% R and 10% P $\frac{R}{P} = \frac{9}{1} \Rightarrow$

$\therefore R = \underline{9 \times P} = 6.25 \times 9$

here $\frac{R}{P} = \frac{705.55}{6.25}$ <u>fixed</u>

various reactions can be there.

$N_2 + 3H_2 \rightarrow NH_3$.

$F = N_2; H_2;$ <u>Ar</u> (inert).

$\therefore 2C_6H_5 + Cl_2 \rightarrow 2C_6H_5Cl$ MCBZ ...

$C_6H_6 + 3H_2 \rightarrow C_6H_{12}$ (cyclohexane)

<u>Example 12.2</u>.

$C_{12}H_{12}O_{11} \rightarrow C_{12}H_{22}O_{11}$ Example <u>12.3</u>

Bioreactor with recycle Example 12.4

## Elemental material balance

↳ It is different from molar component balance

Example $2CO + O_2 \rightarrow 2CO_2$

∴ molar components are $CO, O_2, CO_2$ (associated with volume change or molar change).

Elements are C, O.

$F_{CO}^{out} \neq F_{CO}^{in}$ (molar balance)

$F_{O_2}^{out} \neq F_{O_2}^{in}$ ,,

$F_{CO_2}^{out} \neq F_{CO_2}^{in}$ ,,

But for elemental balance no volume change or atomic mass change).

Each elements are conserved in a reaction.

C: $F_C^{out} = F_C^{in}$ [atomic mass balance].

O: $F_O^{out} = F_O^{in}$ ,,

↳ It is based on atomic mass balance of an element in a reaction /other process)

# Combustion of coal in a furnace

coal compositions given from coal analysis.

| Component (element) | Percent (wt.) | |
|---|---|---|
| C | 83.05 | coal without ash = 92.64% |
| H | 4.45 | |
| O | 3.36 | |
| N | 1.08 | |
| S | 0.70 | |
| Ash | 7.36 | Ash = 7.36% |
| | Total = 100% | |

Take a basis of 100 lb of coal.

Orsat analysis of gas from the furnace stack is given for 24 hr time.

| Component | Percent (mol %) |
|---|---|
| $CO_2 + SO_2$ | 15.4 |
| $CO$ | 0 |
| $O_2$ | 4.0 |
| $N_2$ | 80.6 |

Moisture in the fuel was 3.9%. (given).
($H_2O$).

So, 100 lb of coal contains 3.9 lb of $H_2O$

Air for burning of coal supplied which contains 0.0048 lb $H_2O$/ lb dry air.

dry air contains $N_2$ : 0.79 (mol fraction)
$O_2$ : 0.21 "

$H_2O$ in coal = 3.9 lb $H_2O$

$H_2O$ — lb-mol
H element - 2 lb mol.

$$= 3.9 \text{ lb } H_2O \left| \frac{1 \text{ lb-mol } H_2O}{18 \text{ lb } H_2O} \right| \frac{2 \text{ lb-mol H}}{1 \text{ lb mol of } H_2O}$$

= 0.433 lb mol H (element).

[ 1 lb mol mo $H_2O$ contains 2 lb mol of → H
and 1 lb mol of → O }

$$= \frac{3.9}{18} \times 1 \text{ lb mol O}$$

= 0.217 lb mol O.

$H_2O$ in air.

$$= \frac{0.0048 \text{ lb } H_2O}{\text{lb of air}}$$

$$= \frac{0.0048 \text{ lb } H_2O}{\text{lb of air}} \left| \frac{29 \text{ lb of air}}{1 \text{ lb mol air}} \right| \frac{1 \text{ lb mol } H_2O}{18 \text{ lb of } H_2O}$$

29 lb = average molecular weight of air.

$$= 0.79 \times M.W_{N_2} + 0.21 \times M.W_{O_2}$$

$$= 0.79 \times 28 + 0.21 \times 32$$

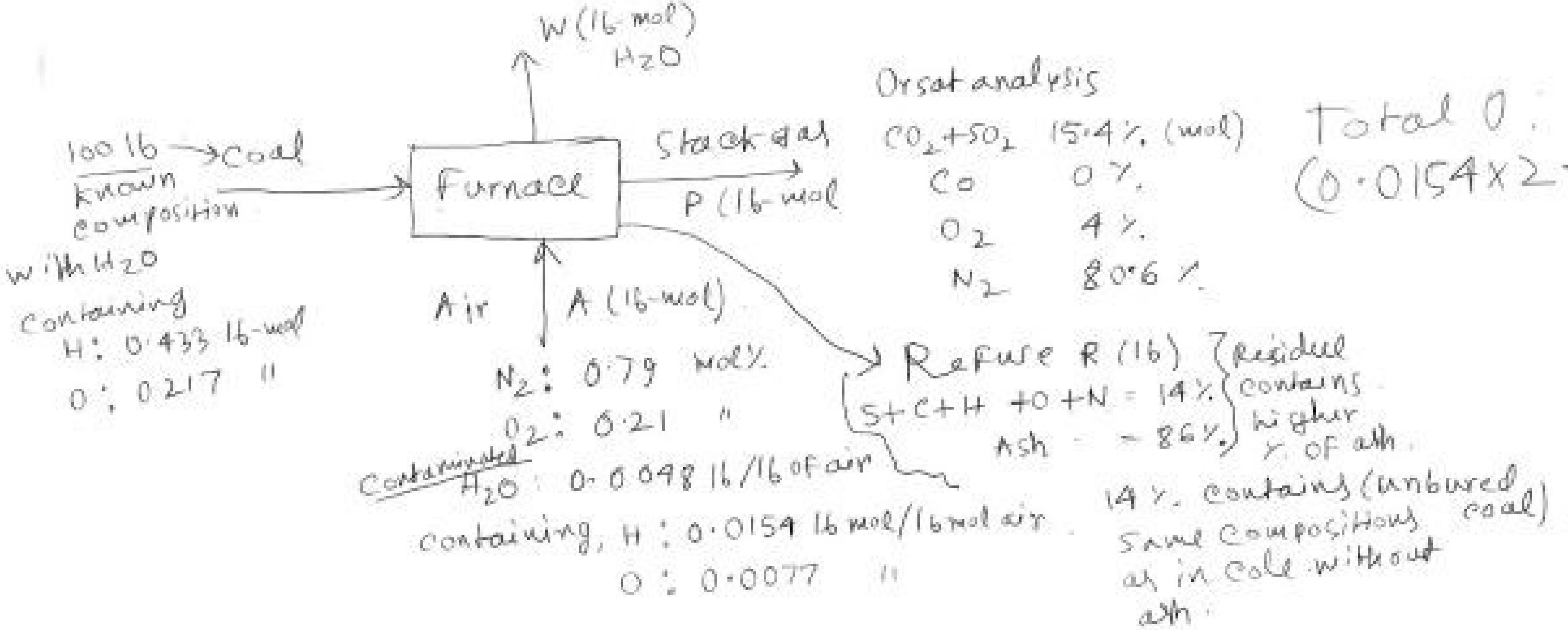
$$= 29$$

$H_2O$ in air $= 0.0077 \frac{\text{lb-mol } H_2O}{\text{lb mol air}}$

$= 2 \times 0.0077$

$= 0.0154$ lb-mol H/lb mol air.

$= 0.0077$ lb-mol O/lb-mol air.




Orsat analysis

| | |
|---|---|
| $CO_2+SO_2$ | 15.4% (mol) |
| CO | 0% |
| $O_2$ | 4% |
| $N_2$ | 80.6% |

Total O:

$(0.0154\times 2 + 0.004\times 2)P$

**Ash balance:**

$\underset{\text{Feed}}{7.36} = \underset{\text{Refuse}}{R \times 0.86}$

$R = \underline{\underline{8.56\ \text{lb}}}$

Unburned coal in refuse = 8.56 X 0.14
= 1.2 lb

1.2 lb coal contains in the refuse will have same composition of pure coal

pure coal

| | | wt% | wt fraction | lb mol |
|---|---|---|---|---|
| C | 83.5 % | 83.5/92.64 | 0.8964 | $\frac{0.8964}{12} \times 1.2$ |
| H | 4.45 % | 4.45/92.64 | 0.048 | $\frac{0.048}{1.008} \times 1.2$ |
| O | 3.36 % | 3.36/92.64 | 0.036 | $\frac{0.036}{16} \times 1.2$ |
| N | 1.02 % | 1.08/92.64 | 0.0116 | $\frac{0.0116}{14} \times 1.2$ |
| S | 0.7 | 0.7/92.64 | 0.00756 | $\frac{0.00756}{32} \times 1.2$ |
| | 92.64 % | | | |

lb mol in 1.2 lb coal in R

| | lb mol |
|---|---|
| C | 0.089648 |
| H | 0.057185 |
| O | 0.00272 |
| N | 0.000999 |
| S | 0.000283 |

Make elemental balance in lb-mol.

overall $F + A = W + P + R$.

feed Air water Product Refuse.

don't do overall but.

unknown unknown unkn

C+S : ~~$F + A = W + P + R$~~

H :

O :

N :

$$C+S: \frac{83.05}{12} + \frac{0.7}{32} + 0 = 0 + 0.154 \times P + 0.0897 + 0.0003$$

$P = 44.54$ lb-mol.

coal moisture H moisture of air Water P Residue

$$H: \frac{4.45}{1.008} + 0.433 + 0.0154A = 2W + 0 + 0.057$$

A =

**O :** $\frac{3.36}{16}$ + 0.217 (coal moisture) + 0.21 × 2 × A (air) + 0.007A (air moisture) = W (**Water**) + 2P(0.0154 + 0.04) (P (Orsat analysis)) + 0.0027

→ solve H & O

A = 45.4 lb-mol

W = 2.747 lb-mol

≈ 2.75 lb-mol

**N :** $\frac{1.08}{14}$ + 2 × 0.79A (Air) = 0 (W) + P × 0.806 × 2 (P, Orsat analysis) + 0.001 × 2 (Residue, R)

⇒ 19.8 = 20.3 (mostly satisfied).

1% error due to rounding off

% excess air = 100 x $\frac{O_2 \text{ entering} - O_2 \text{ required}}{O_2 \text{ require}}$

Reaction

| | | lb | lbmol | Required $O_2$ |
|---|---|---|---|---|
| C : | $C + O_2 \rightarrow CO_2$ | 83.05 | C 6.92 | 6.92 |
| H : | $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ | 4.45 | H 4.415 | 1.104 |
| | $1H \rightarrow \frac{1}{4}O$ | | | |
| S : | $S + O_2 \rightarrow SO_2$ | 0.7 | 0.022 | 0.022 |

Total $O_2$ = 8.047 lbmol

O. in coal $= \frac{3.36}{16}$ lb mol

$= 0.21$ lb mol O

$\therefore$ $O_2$ in coal $= \frac{0.21}{2}$ lb mol $O_2$

$= 0.105$

Required $O_2 = 8.047 -$ $O_2$ in coal

$= 7.942$ lb-mol

$O_2$ in air $= \overset{A}{45.35} \times 0.21$

$= 9.524$ lb mol

% excess $O_2 = 100 \times \frac{9.524 - 7.942}{7.942}$

$= \underline{19.9\ \%}$

Example 1:

Pure carbon is burned in $O_2$
The flue gas analysis is:

$CO_2$ : 75 % assume it mol %
× $CO$ : 14 %
$O_2$ : 11 %

calculate % excess $O_2$.

$$C + O_2 \rightarrow CO_2$$

✓× $$2C + O_2 \rightarrow CO$$

**Class problem** Assignment

A gas of following compositions burned with 50% excess air.
calculate compositions of flue gas: product gas.

Feed gas

| | | | | |
|---|---|---|---|---|
| $CH_4$ | 60% | | | $H_2O$ |
| $C_2H_6$ | 20% | $+ O_2$ | $\rightarrow$ | $CO_2$ |
| $CO$ | 5% | | | $O_2$ |
| $O_2$ | 5% | | | $N_2$ |
| $N_2$ | 10% | | | |

$$2CO + O_2 \rightarrow 2CO_2$$

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

**Assume 100% conversions methane, ethane, and carbon monoxide.**

# References


- Himmelblau, D.M., Riggs, J.B., Basic Principles and Calculation in chemical engineering, Prentice Hall.