Mehdi Imanian Najafabadi

"موازنه انرژی و مواد"

Dr Kharat

- Dimension and units:

$5m + 6kg = X \longrightarrow$ Dimension is different

$5lb + 6kg = \checkmark \longrightarrow$ Dimension is same but unit is different

- Dimension: is a property that can be measured, such as length, time, mass or temprature, or calculated by multyplying or dividing other dimension, such as: $\frac{length}{time}$ = Velocity , $(length)^3$ = Volume.

- example: The position of an entity moving in a straight line along the X-axis depends on time (t) according to the following equation: $X_{(ft)} = at^2 - bt^3$ $t_{(sec)}$.

what are the dimension of $\underline{a}$ and $\underline{b}$?

$a\left(\frac{ft}{sec^2}\right)$ & $b\left(\frac{ft}{sec^3}\right)$

Reynolds Number: $Re = \frac{\rho V D}{\mu}$

$\rho \rightarrow$ density, $V \rightarrow$ Velocity, $D \rightarrow$ diameter, $\mu \rightarrow$ Viscocity $\rightarrow$? واحد

if $\begin{cases} \rho\left(\frac{gr}{cm^3}\right) \\ V\left(\frac{cm}{sec}\right) \\ D\,(cm) \end{cases}$ $\quad \frac{gr}{cm^3} \Big| \frac{cm}{sec} \Big| cm \equiv \frac{gr}{cm.sec} = C.P$ (centi Poise)

Note: Reynolds Number is Dimensionless

system	SI	CGS	AES
Length	meter (m)	centimeter (cm)	foot (ft)
mass	kilogram (kg)	gram (gr)	pound mass (lb_m) or (lb)
time	second (s)	second (s)	hour (hr)
Force	Newton (N)	dyne	pound force (lb_f)

Field unit:

SCF : standard cubic foot — برای گاز

bbl : barellel (بشکه) — برای نفت

} حجم

دونوع بشکه : 1. reservior   2. Stock tank

بستگی به نوع چاه

رابطه دو بشکه : $B_o \searrow_{oil} = 1.30 \frac{bbl \to reservior}{STB \to \text{stock tank barellel}}$

$B_g \searrow_{gas} = 0.0001 \frac{ft^3}{SCF}$

Note: $1 bbl = 5.61 ft^3$

Note: B_o : oil formation volume factor

---

unit conversion:

Note: $\overline{MW} \equiv x \left(\frac{lb_m}{lb_m mol}\right) \equiv x \left(\frac{gr}{grmol}\right) \equiv x \left(\frac{kgr}{kgrmol}\right)$

example:

$1000 \frac{bbl}{day}$ (BPD) of oil flows through a 4 inch internal pipe. what is velocity in $\frac{m}{s}$?

$Q\left(\frac{volume}{time}\right) = \vec{V}\left(\frac{length}{time}\right) A (length)^2 \Rightarrow \vec{V} = \frac{Q}{A} = \frac{\text{volumetric flow rate}}{\text{cross sectional}}$

$1000 \frac{bbl}{day} \left| \frac{42\ gal}{bbl} \right| \frac{m^3}{264.17 gal} \left| \frac{1 day}{24\ hr} \right| \frac{1\ hr}{3600\ s} = 0.001840 \frac{m^3}{s}$

$A = \pi r^2 = \pi\ (2\ inch)^2 \left|\left(\frac{1\ m}{39.37\ inch}\right)^2\right. = 0.00810\ m^2$

$\Rightarrow \vec{V} = 0.001840 \frac{m^3}{s} \left| \frac{1}{0.00180\ m^2} \right. = \boxed{0.227 \frac{m}{s}}$

Dimensional Homogenty:

1. All Additive terms on both side of the equation must have the same unit. $Y = a + bX$

2. Exponent, trancendental functions, the arguments are dimensionless. In X^Z, Z is dimensionless, $Exp(X)$, $\sin(X)$ too.

example: $t_{(sec)} = t_0 (?)_{sec} + \frac{3.52 (?)_{m^2} \, h_{(m)}}{V (\frac{m^3}{sec})}$

H-W

example: Darcy's Law: if $V(\frac{cm}{s})$ & $\mu_{(cp)}$ & $\frac{dP}{dX}(\frac{atm}{cm})$

then $\Rightarrow K_{(darcy)}$ $\Longrightarrow V = \frac{q}{A} = \frac{-K}{\mu} \frac{dP}{dX}$ → permibility, → viscosity

1. if $V(\frac{bbl}{day \cdot ft^2})$ & $\frac{dP}{dX}(\frac{psi}{ft})$ $\Longrightarrow V = \frac{q}{A} = (-1.128) \frac{K}{\mu} \frac{dP}{dX}$

prove ?

2. if $V(\frac{ft}{day})$ & $\frac{dp}{dX}(\frac{psi}{ft})$ $\Longrightarrow V = \frac{q}{A} = (6.33) \frac{-K}{\mu} \frac{dP}{dX}$

$K = -\mu V \frac{dX}{dP}$

evaluate ?

$\Longrightarrow (cP)(\frac{cm}{s})(\frac{cm}{atm}) \left| \frac{(1 \, m)^2}{(100 \, cm)^2} \right| \frac{(3.2808 \, ft)^2}{(1 \, m)^2} \left| \frac{60 \, s}{1 \, min} \right| \frac{60 \, min}{1 \, hr} \left| \frac{24 \, hr}{1 \, day} \right| \frac{1 \, atm}{14.696 \, psi}$

$g_c \equiv$ conversion factor $= \boxed{6.33 \frac{(cP) \, ft^2}{psi \cdot day}}$

$F = ma \longrightarrow 1 \, lb_f = (?) \, lb_m \cdot \frac{ft}{sec^2}$

evaluate

$lb_f = (1 \, lb_m) \, 32.174 \frac{ft}{sec^2}$

$32.174 \frac{lb_m \cdot ft}{lb_f \cdot sec^2} \longrightarrow g_c$

$F = \frac{ma}{g_c}$

- in SI system:

$F(N)$ & $m(kg)$ & $a(\frac{m}{sec^2})$ $\Longrightarrow g_c = 1 \frac{kg \cdot m}{N \cdot sec^2}$

- in CGS system:

$F(dyne)$ & $m(gr)$ & $a(\frac{m}{sec^2})$ $\Longrightarrow g_c = 1 \frac{kg \cdot m}{dyne \cdot sec^2}$

✓ - in AES system:

$F(lb_f)$ & $m(ft)$ & $a(\frac{lb_m}{sec^2})$ $\Longrightarrow g_c = \boxed{32.174 \frac{lb_m \cdot ft}{lb_f \cdot sec^2}}$

example: find the kinetic Energy if $(ft.lb_f)$ of 200 lb_m moving at $5 \frac{ft}{sec}$. $K_E = \frac{1}{2} m V^2$.

$$K_E (ft.lb_f) = \frac{\frac{1}{2}(200 lb_m)(5 \frac{ft}{sec^2})}{\underbrace{32.174 \frac{lb_m . ft}{lb_f . sec^2}}_{g_c}} = 77.7 \ ft.lb_f$$

example: what is the potential Energy in $(ft.lb_f)$ of 45.4 kg drives hanging 20 ft have the surface of the earth?

$$P_E (ft.lb_f) = \frac{Mgh}{g_c}$$

$$P_E = \frac{45.4 \ kg \left| \frac{lb_m}{0.454 \ kg} \right| 32.178 \frac{ft}{sec^2} \left| 20 \ ft \right.}{\underbrace{32.174 \frac{lb_m . ft}{lb_f . sec^2}}_{g_c}} = 2000 \ ft.lb_f$$

---

significan figure:

$65000 = 6.5 \times 10^4$

$0.00065 = 6.5 \times 10^{-4}$

65000 2

65000. 5

6.50×10^4 3

$(4.82)(2.653) = \underbrace{12.78746}_{12.8 \ (3)}$

(3) (4)

Note: در ضرب و تقسیم کمترین مقدار را در نظر می‌گیریم.

110.3 (4)

0.038 (4)

$\underbrace{110.338}_{110.3 \ (4)}$

Note: در جمع و تفریق بیشترین مقدار را در نظر می‌گیریم.

$$Density = \frac{Mass}{Volume} \Rightarrow \rho = \frac{m}{V} \quad \begin{cases} \rho(T,P) & \text{for gas} \\ \rho(T) & \text{for liquid} \end{cases}$$

$$\text{specific volume} = \frac{Volume}{Mass} \Rightarrow \boxed{\hat{V} = \frac{1}{\rho}} \quad \begin{cases} \hat{V}(T,P) & \text{for gas} \\ \rho(T) & \text{for liquid} \end{cases}$$

$$\text{specific gravity} = S.G = \frac{\rho \rightarrow \text{substance}}{\rho_{ref} \rightarrow \text{Refrence}}$$

$\rho_{substance} = S.G \times \rho_{ref}$

$$\boxed{S.G = \frac{141.5}{131.5 + {}^{\circ}API}} \qquad \text{or} \quad {}^{\circ}API = \frac{141.5}{S.G} - 131.5$$

Example: $\rho_{water}(4^{\circ}C) = 1.00 \ \frac{gr}{cm^3} = 1000 \ \frac{Kgr}{m^3} = 62.43 \ \frac{lb_m}{ft^3}$

Example: Benzene:

$$S.G = 0.879 \left(\frac{20^{\circ}C}{4^{\circ}C}\right) \Longrightarrow \rho_{(20^{\circ}C)} = S.G \times \rho^{4^{\circ}C}_{water}$$

$$= (0.879)(62.43) = 54.9 \ \frac{lb_m}{ft^3}$$

$$= (0.879)\left(1.00 \ \frac{gr}{cm^3}\right) = 0.879 \ \frac{gr}{cm^3}$$

Note: $\rho \rightleftarrows V \rightleftarrows s.gr \rightleftarrows API$, $\rho \leftrightarrow m \leftrightarrow API$

S.G	°API
0.9	25.7
0.85	35
0.80	45.32

نفت سبک‌تر می‌شود

Note: نفت با کمتر از 20°API را نفت سنگین است و بیشتر از 20° API سبک است.

Example: The density of a crude oil is 25°API. what is the specific gravity at 60°F refrenced to water at 4°C ?

$$S.gr = \frac{141.5}{131.5 + {}^{\circ}API} \Rightarrow S.gr = 0.904$$

$$\Longrightarrow \rho(60^{\circ}F) = (0.904)\left(0.999 \ \frac{gr}{cm^3}\right) = 0.903 \ \frac{gr}{cm^3}$$

Example: $S.gr = 0.903 \left(\frac{60^{\circ}F}{4^{\circ}C}\right)$ & $\dot{V} = 400 \, (bPd) \left(\frac{bbl}{day}\right)$

& $\rho^{(4^{\circ}C)}_{water} = 62.43 \ \frac{lb_m}{ft^3}$

$$\dot{m}\left(\frac{lb_m}{min}\right) = ? = 400 \frac{bbl}{day} \Big| 0.903 \Big| 62.43 \frac{lb_m}{ft^3} \Big| \frac{5.615 \ ft^3}{1 \ bbl} \Big| \frac{1 \ day}{24 \ hr} \Big| \frac{1 \ hr}{60 \ min}$$

$$= 87.9 \ \frac{lb_m}{min}$$

Mass fraction, Mole fraction, $\overline{MW}$, Basis

$$X_i = \text{mass (weight) fraction} = \frac{\text{mass (weight) of component}}{\text{mass (weight) of mixture}} = \frac{\text{mass of component } i}{\text{total mass}} \quad \& \quad \sum_{i=1}^{N} X_i = 1$$

$$Y_i = \text{mole fraction} = \frac{\#\text{mole of component}}{\text{Mole of mixture}} = \frac{\text{mole of compont } i}{\text{total mole}} \quad \& \quad \sum_{i=1}^{N} Y_i = 1$$

1. $\overline{MW}$ = Molecular weight $= \frac{\text{total mass}}{\text{total mole}}$
2. $\overline{MW} = Y_1 MW_1 + Y_2 MW_2 + \cdots + Y_n MW_n = \sum_{i=1}^{n} Y_i MW_i$
3. $\frac{1}{\overline{MW}} = \frac{X_1}{MW_1} + \frac{X_2}{MW_2} + \frac{X_3}{MW_3} + \cdots + \frac{X_N}{MW_N} = \sum_{i=1}^{n} \frac{X_i}{MW_i}$

Example:

	Mass %	mass (lb_m)	MW ($\frac{lb_m}{lb_m\,mol}$)	mole	% mole
C_1	62.6	62.6	16.04	3.903	78.4
C_2	21.42	21.42	30.07	0.7123	14.31
C_3	15.98	15.98	44.09	0.3624	7.28
	100 %	100 lb_m		4.978 mole	100%

Basis = 100 lb_m

1. $\frac{\text{total mass}}{\text{total mole}} = \overline{MW} = 20.09 \frac{lb_m}{lb_m\,mol}$
2. $\sum_{i=1}^{n} Y_i MW_i = \overline{MW}$ 3. $\sum_{i=1}^{n} \frac{X_i}{MW_i} = \overline{MW}$

Temprature: principle temprature scale:

Relative:
- °F fahrenheit
- °C celsius

Absolute:
- °R Rankin
- °K kelvin (SI)

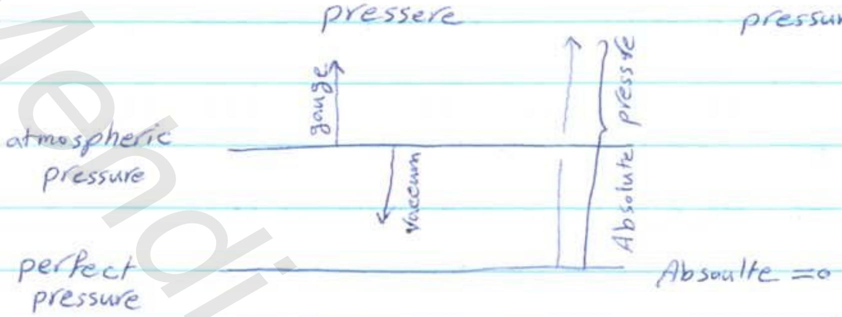
$°R = °F + 459.67$ $°K = °C + 273.15$

$$\frac{\Delta °F}{\Delta °C} = \frac{212°F - 32°F}{100°C - °C} = 1.8 \frac{\Delta °F}{\Delta °C} = 1.8 \frac{°R}{°K} \qquad 0°R = 0°K$$

$$T(°R) = T(°K)\, 1.8 \frac{°R}{°K}$$

Pressere :

Relative gauge	Relative vaccum	absolute
above atmospheric pressere	bellow atmospheric pressure	above vaccum pressure



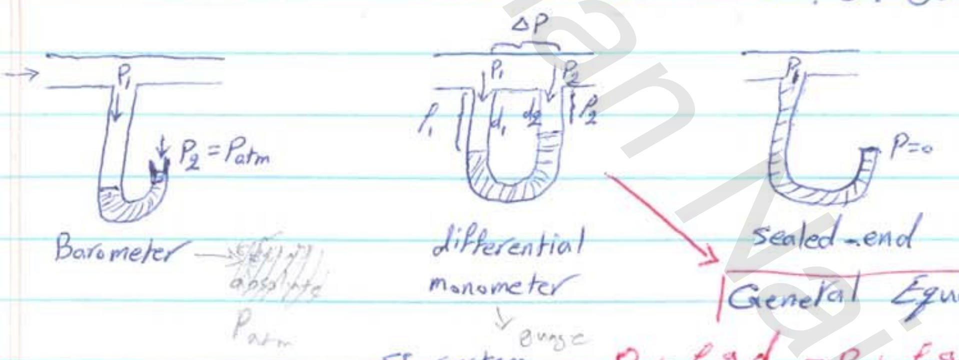
$P_{abs} = P_{gauge} + P_{atm}$

$P_{abs} = P_{atm} - P_{vacum}$

psia → absolute

psig → gauge

Manometr که درآن باز باشد Barometer است.



General Equation :

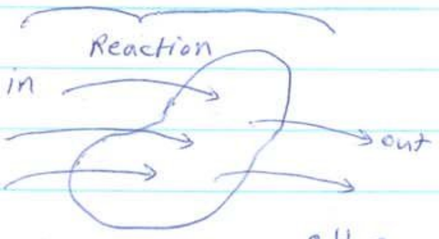
SI system $\quad P_1 + \rho_1 g d_1 = P_2 + \rho_2 g d_2 + \rho_p (d_1 - d_2) g$

CGS system $\quad P_1 + \frac{\rho_1 g d_1}{g_c} = P_2 + \frac{\rho_2 g d_2}{g_c} + \frac{\rho_p (d_1 - d_2) g}{g_c}$

"Material Balance" Hw: 6.4 - 6.6 - 7.1 - 7.13

is a computation method which accounts the material that enters, leaves is Generated, consumed, or accumulated within a system.

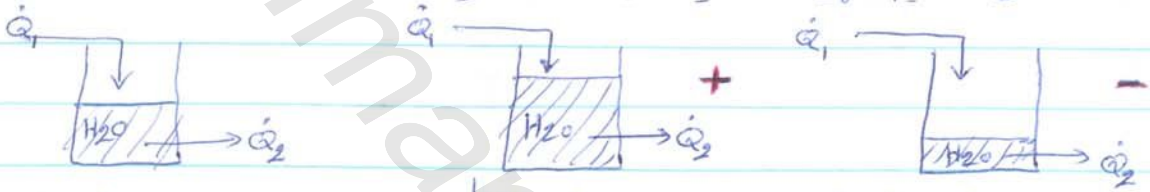
Component
CH_4
A
B



$CH_4 + O_2 \longrightarrow CO_2 + 2H_2O$

انباشته شدن
accumulation

در حالتی که سیستم ناپایدار است یعنی سیستم با زمان تغییر کند.



$\dot{Q}_1 = \dot{Q}_2 \Longrightarrow$ Accumulation $= 0$ | $\dot{Q}_1 > \dot{Q}_2$ Accumulation > 0 | $\dot{Q}_1 < \dot{Q}_2$ Accumulation < 0

steady state : No variation with time پایدار
unsteady state : variation with time ناپایدار

Accumulation تجمع : = Input − output + Generation − Consumption

steady state: $Acc = 0$

$\Rightarrow In - out + Gen - Con = 0$

if No Reaction $\Rightarrow In - out = 0 \Rightarrow \boxed{In = out}$

system
- open system : ورودی و خروجی دارد.
- closed system: نه ورودی و نه خروجی
- semi. batch: یا ورودی دارد و خروجی ندارد و یا بالعکس

system کامل‌ترین :
- unsteady state
- Reaction
- open

step in Material Balance:

1. understanding problem 

2. Development of solution

3. Mathematical solution

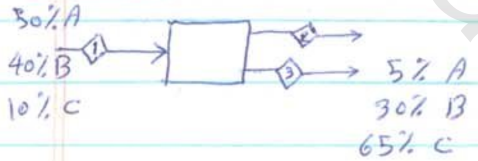
solution of Material Balance problems:

1. Sketch the process. Make sure you understand the process and what questions are asked.

2. lable all streams: This is an accounting step which assists in organizing a solution.
علامت گذاری فرآیندها

3. Include a material balance table with the sketch. Put all known compositions and flows in table. put all specifications on the sketch. This will clearly show what is unknowns.

Example



component	1	2	3
1-A	X(1,1) 50%	X(1,2)	X(1,3) 5%
2-B	X(2,1) 40%	X(2,2)	X(2,3) 30%
3-C	X(3,1) 10%	X(3,2)	X(3,3) 65%
total	S_1	S_2	S_3

$\underbrace{\text{bottom product stream = 6\% stream Feed}}_{\text{specification}}$

X(I, J) : Amount of componet I in stream J

I → component Number

J → stream Number

S_J = Stream J

M = Total number of unknown = (Total number of stream) x (Total number of component + 1)

مثال (در جدول فوق) : 3 x (3+1) = 12

(حداکثر unknown در جدول فوق)

N = Known ⟹ M − N = # Actual unknown

4. write the General Material balance equation.

5. Decide which terms apply in the specific case Address each of

the five terms. (Acc = In - out + Gen - Con)

6. write specific Material balance. تا اینجا تعیین مسئله بود.

حل مسئله

7. Determine Maximum Number of unknown. #stream(#comp+1)
From this number substract (تفریق) the known. that apear in the table to determine the actual unknown.

8. write independ equations equal in number to the number of unknowns. These equations include Material balance, specification, Defination (1) and Basis. ارتباط بین stream ها

9. solve the system of equation for all unknown.

Countinue of Example:

Actual unknown = 6

(1) MB (Material Balance) = 3

(2) specification = 1

$$\boxed{\begin{aligned} S_1 &= 50\% S_1 + 40\% S_2 + 10\% S_3 \\ S_2 &= X(1,2) + X(2,2) + X(3,2) \end{aligned}}$$

(3) Df = 1

(4) Basis = 1

Total = 6

(1) Definition: $S_J = \sum_{I=1}^{n} X(I,J)$

check the solution : In = out ?

(برای مثال فوق) $S_1 = S_2 + S_3$

نمونه ی یک جدول کامل برای تست سوم حل مسئله.

Stream	1	2	3	4
Component	lbm/hr			
A				
B				
C				
D				
Total	S_1	S_2	S_3	S_4
T	T_1	T_2	T_3	T_4
P	P_1	P_2	P_3	P_4

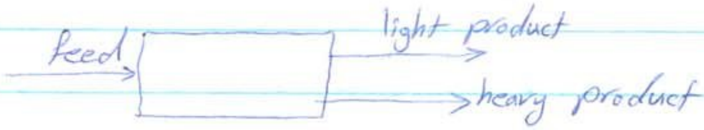
در این قسمت واحدها را می نویسیم.

10. check ⟹ Total stream out = IN برای وقتی که معادله ای شیمیایی نباشد

Hw# 7.14 & 8.3 & 8.23

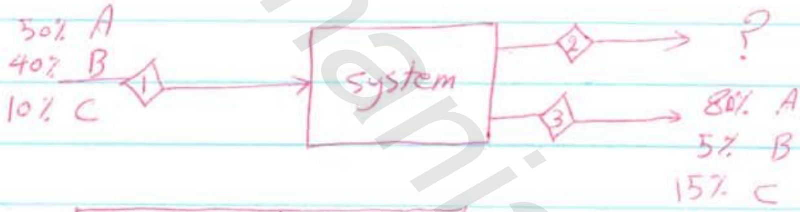
Eg: A sepration process is shown below. A feed with 50% A, 40% B and 10% C enters, the seprator. Two streams, namely Light & Heavy products leaves the separator. The composition of the heavy stream is as follows:

80% A
5% B
15% C



Find the composition of light product stream if the ratio of the heavy to feed stream is 60%.

sol:



comp	1	2	3
A	50%	$X(1,2)$	80%
B	40%	$X(2,2)$	5%
C	10%	$X(3,2)$	15%
total	S_1	S_2	S_3

$N = 3 \times (3+1) = 12$

$M = 6$

Actual # of unknown = 6

MB = 3
DF = 1
SP = 1
Basis = 1

6

$\cancel{Acc} = IN - out + \cancel{GEN} - \cancel{Con}$

Note: Steady State $\rightarrow$ Acc = 0

$\Rightarrow \boxed{IN = out}$

continue:

1- Component A	$X(1,2) + 0.8\, S_3 = 0.5\, S_1$	①
2- 〃 B	$X(2,2) + 0.05\, S_3 = 0.4\, S_1$	②
3- 〃 C	$X(3,2) + 0.15\, S_3 = 0.1\, S_1$	③
4- Definition	$S_2 = X(1,2) + X(2,2) + X(3,2)$	④
5- Specification	$S_3 = 0.6\, S_1$	⑤
6- Basis	$S_1 = 100\ \frac{kg}{hr}$	⑥

⑥	S_1
⑤	S_3
①	$X(1,2)$
②	$X(2,2)$
③	$X(3,2)$
④	S_2

Comp	①	②	③
A	50%	2 5%	80%
B	40%	32 97.5%	5%
C	10%	1 2.5%	15%
total	100	40	60

$\Longrightarrow$

$X(1,2) = 2$

$X(2,2) = 32$

$X(3,2) = 1$

$S_2 = 40$

check

out = IN

$40 + 60 = 100$ ✓

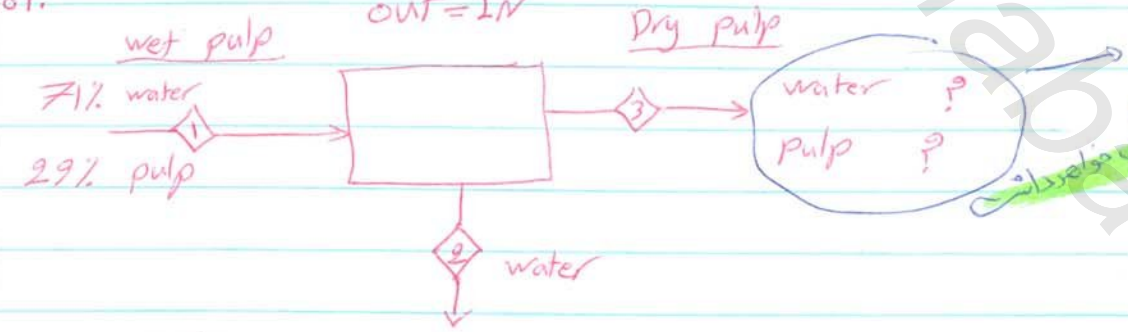
Eg: A wet paper pulp is found to contain 71% water. After drying it is found that 60% of the original water has removed. calculate the following:

a) composition of the dried plup.

b) the mass of water removed per Kilogram of wet pulp.

Sol:

out = IN



نکته: بطور کلی خشک نمی شود و مقداری آب خواهد داشت

comp	①	②	③
pulp	29%	0	$X(1,3)$
water	71%	100%	$X(2,3)$
total	S_1	S_2	S_3

$N = 3(2+1) = 9$

$M = 4$

Actual unknown $= 5$

MB	2
Df	1
SP	1
Basis	1
	5

$$\underset{S.S}{\cancel{Acc}} = IN - out + \underset{N.R}{\cancel{GEN}} - \underset{N.R}{\cancel{Con}} \implies out = IN$$

pulp: $X(1,3) = 0.29 S_1$ ①

water: $X(2,3) + S_2 = 0.71 S_1$ ②

Def: $S_3 = X(1,3) + X(2,3)$ ③

spi: $S_2 = 0.6(0.71 S_1)$ ④

Bas: $S_1 = 100$ ⑤

⑤ S_1 → ④ S_2 → ① $X(1,3)$ → ② $X(2,3)$ → ③ S_3

$\implies S_1 = 100$ kg/hr

$S_2 = 42.6$

$X(1,3) = 29$

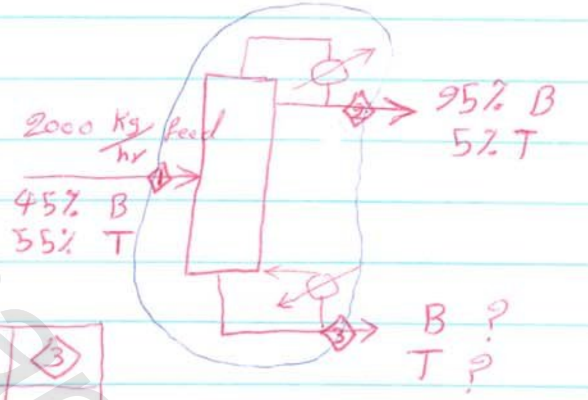
$X(2,3) = 28.4$

$S_3 = 57.4$

comp	①	②	③	part (a)
pulp	29	0	29	50.5%
water	71	42.6	28.4	49.5%
total	100	42.6	57.4	

part (b) $\frac{42.6}{100}$

Eg: A mixture containing 45% benzene (B) and 55% Toluene (T) by mass is feed to a distillation culmn. An overhead stream of 95% benzene is produced, and 8% of the benzene fed to the column leaves in the bottom stream. The feed rate is 2000 $\frac{kg}{hr}$. Determine the composition of the bottom stream.



$\Longrightarrow$

Comp	1	2	3
B	45%	95%	X(1,3)
T	55%	5%	X(2,3)
total	2000	S_2	S_3

$\Longrightarrow \begin{cases} N = 3(2+1) = 9 \\ M = \quad 5 \\ \text{Actual unknown} = 4 \end{cases}$

$$\underbrace{\cancel{Acc}^{\,0}}_{\text{Steat state}} = IN - out + \underbrace{\cancel{Gen}^{\,0} - \cancel{Con}^{\,0}}_{\text{No reaction}} \Longrightarrow IN = out$$

B: $X(1,3) + 0.95\,S_2 = 900$ (1)

T: $X(2,3) + 0.05\,S_2 = 1100$ (2)

Def: $S_3 = X(1,3) + X(2,3)$ (3)

Spe: $X(1,3) = 0.8\,(900)$ (4)

(4) → (1) → (2) → (3)

$\Longrightarrow X(1,3) = 72$ & $X(2,3) = 1056.42$

$S_2 = 871.58$ & $S_3 = 1128.42$

check: $IN = out \Longrightarrow S_3 + S_2 = S_1$

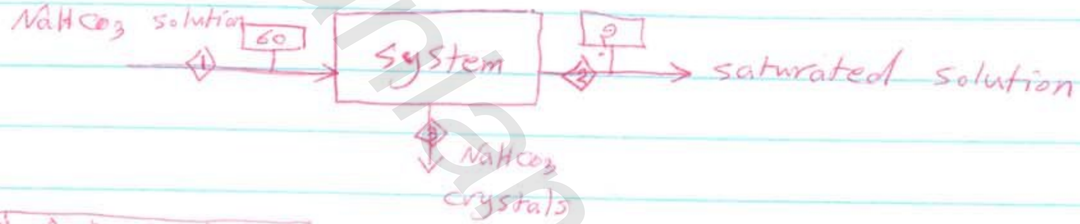
$1128.42 + 871.58 = 2000$ ✓

Eg: A tanks hold: 10,000 kg of saturated solution of $NaHCO_3$ at 60°c. we want to crystallize 500 kg of $NaHCO_3$ from the solution. To what Temperature must the solution be cooled?

$\boxed{\text{Solubility}}$

T, °c	$\frac{\text{kg } NaHCO_3}{100 \text{ kg } H_2O}$
60	16.4
50	14.45
40	12.7
30	11.1
20	9.6
10	8.14

sol:



Comp	①	②	③
$NaHCO_3$	$X(1,1)$ 1408.9	$X(1,2)$ 908.9	500
H_2O	$X(2,1)$ 8591.1	$X(2,2)$ 8591.9	0
total	10000	S_2	500

N = 9
M = 4
Actual unknown = 5

MB: 2
Def: 2
Spc: 1
5

$$X(1,1) = 10{,}000^{\text{total}} \left| \frac{16.4 \text{ kg } NaHCO_3}{116.4 \text{ Total}} \right.$$

$X(2,1) = 10.000 - X(1,1)$

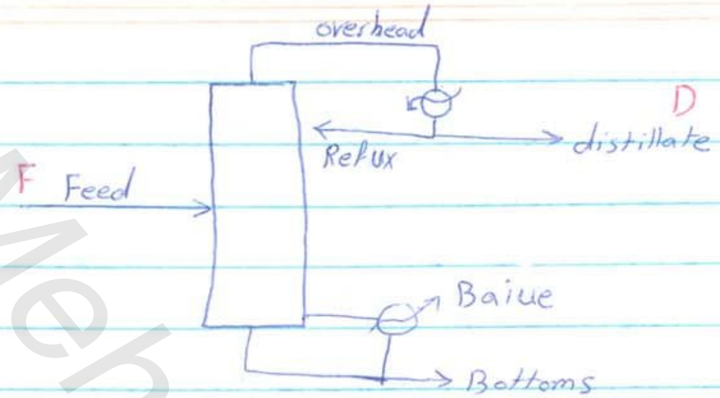
$X(2,2) = X(2,1)$

$500 + X(1,2) = X(1,1)$

$S_2 = X(1,2) + X(2,2)$

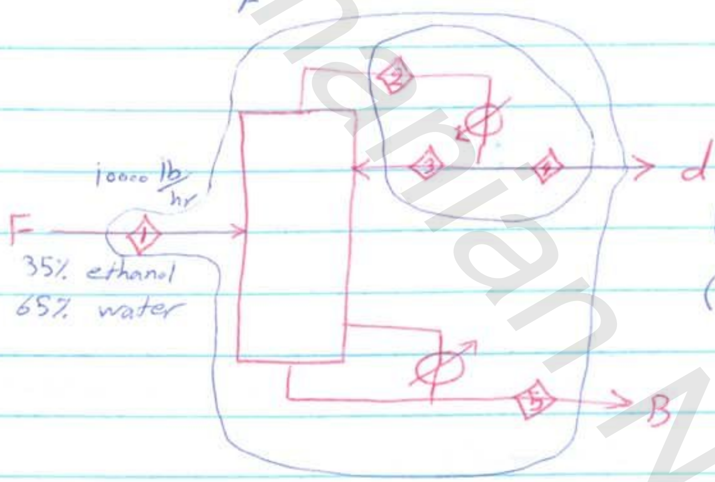
$$\Longrightarrow \frac{\text{kg } NaHCO_3}{100 \text{ kg } H_2O} = \frac{908.9}{8591.9} \times 100 = 10.6 \ \frac{\text{kg } NaHCO_3}{100 \text{ kg } H_2O}$$

$$\Longrightarrow \boxed{27\,°c}$$



$$\text{Reflux Ratio} = \frac{\text{Reflux}}{\text{Distillate}}$$

Distillation column Example: 10,000 $\frac{lb}{hr}$ of an ethanol-water solution containing 35% ethanol are feed to a distillation tower. The Reflux Ratio is 10 to 1. The $\frac{d}{F}$ for ethanol is 0.91 and $\frac{d}{F}$ for water is 0.1. Determine material balan



Reflex Ratio = $\frac{10}{1}$

$\left(\frac{d}{F}\right)_E = 0.91$

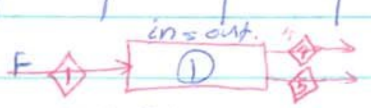
$\left(\frac{d}{F}\right)_w = 0.1$

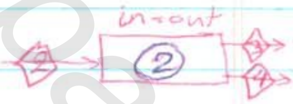
Comp	1	2	3	4	5
E	3500	$x(1,2)$	$x(1,3)$	$x(1,4)$	$x(1,5)$
W	6500	$x(2,2)$	$x(2,3)$	$x(2,4)$	$x(2,5)$
total	10000	S_2	S_3	S_4	S_5

$M = 5(2+1) = 15$

$N = \quad 3$

Actual unknown = 12

system 1 

system 2 

Ethanol ① $x(1,4) + x(1,5) = 3500$

water ② $x(2,4) + x(2,5) = 6500$

③ $x(1,4) + x(1,3) = x(1,2)$

④ $x(2,3) + x(2,4) = x(2,2)$

⑤ $S_2 = x(1,2) + x(2,2)$

⑥ $S_3 = x(1,3) + x(2,2)$

⑦ $S_4 = x(1,4) + x(2,4)$

⑧ $S_5 = x(1,5) + x(2,5)$

⑨ $x(1,4) = 0.91(3500)$ ⑩ $x(1,3) = 10\,x(1,4)$

⑪ $x(2,4) = 0.10(6500)$ ⑫ $x(2,3) = 10\,x(2,4)$

$\longrightarrow x(1,2) = 35035$ $\quad x(2,2) = 7150$ $\quad S_2 = 42185$

$x(1,3) = 31850$ $\quad x(2,3) = 6500$ $\quad S_3 = 38350$

$x(1,4) = 3185$ $\quad x(2,4) = 650$ $\quad S_4 = 3835$

$x(1,5) = 315$ $\quad x(2,5) = 5850$ $\quad S_5 = 6165$

$$Acc = IN - out + Gen - Con \Rightarrow \underbrace{out = IN + GeN - Con}_{\text{برای موازنه‌هایی که واکنش دارند}}$$

$$aA + bB \longrightarrow cC + dD$$

$$\underset{1\,mol}{C} + \underset{1.2\,mol}{O_2} \longrightarrow CO_2 \Rightarrow \begin{cases} C: \text{Limiting reactant.} \\ O_2: \text{Excess Reactant.} \end{cases}$$

% Reaction $\qquad$ Yield $= \dfrac{\text{خروجی}}{\text{ورودی}} \times 100$ $\qquad$ selectivity

eg: Reaction 50% $\longrightarrow$ CO_2 produced: ?

sol: $1^{mol}\,C$ Limiting reactant in feed $\left| \dfrac{50 \text{ mol C consumed}}{100 \text{ mol C Feed}} \right| \dfrac{1 \text{ mol } CO_2 \text{ Generated}}{1 \text{ mol C consumed}} = 0.5$ mol CO_2 GeN

1 mol C in feed $\left| \dfrac{50 \text{ mol C consumed}}{100 \text{ mol C feed}} \right| \dfrac{1 \text{ mol } O_2 \text{ consumed}}{1 \text{ mol C consumed}} = 0.5$ mol O_2 consumed.

---

stoichiometry: $\qquad aA + bB \longrightarrow cC + dD$

Limiting Reactant:

ex: suppose x mole of A and y mole of B are mixed.

Feed Ratio: $\dfrac{x}{y} < \dfrac{a}{b}$ stochiometry Ratio, limiting reactant is A and B is excess

F . R

$\dfrac{x}{y} > \dfrac{a}{b}$ " " " " B " A " "

$$\underset{1}{C} + \underset{1.2}{O_2} \longrightarrow CO_2$$

$a = 1$ mol of C $\qquad b = 1$ mol of O_2 $\qquad x = 1$ mol of C in feed

$y = 1.2$ mol of O_2 in feed $\Rightarrow \dfrac{a}{b} = 1 \qquad \dfrac{x}{y} = \dfrac{1}{1.2}$

50% Excess of O_2

excess → Required

$$\frac{150 \text{ mole } O_2 \text{ feed}}{100 \text{ mole } O_2 \text{ Required}}$$

$$\% \text{ conversion} = \frac{\text{Amount Reactant}}{\text{Amount feed}} \times 100\%$$

limiting Reactant

$$\% \text{ excess} = \frac{\text{Feed} - \text{Required}}{\text{Required}} \times 100$$

مطلوب

$$\text{selectivity} = \frac{\text{Amount of desired product}}{\text{Amount of undesired product}}$$

$$\text{yield} = \frac{\text{Amount of specific product formed}}{\text{Amount of limiting reactant consumed}} \times 100$$

Ex: $C + O_2 \longrightarrow CO_2$

1 mole of C and 1.2 mole of O_2 are mixed. 0.5 mole of O_2 burn.

(a) what is the convesatio of C? $(\% \text{ conversion})_C = \frac{0.5}{1} \times 100 = 50\%$

(b) 〃 〃 〃 〃 〃 O_2? $(\% \text{ conversion})_{O_2} = \frac{0.5}{1.2} \times 100 = 42\%$

(c) 〃 〃 〃 〃 〃 total feed? $(\% \text{ conversion})_T = \frac{0.5 + 0.5}{2.2} =$

Ex: $C + O_2 \longrightarrow CO_2$

$C + \frac{1}{2} O_2 \longrightarrow CO$

suppose that 1 mole C & 1.2 mole O_2 are mixed and burned.

The product is as follows: $\begin{cases} 0.6 \text{ mol } CO_2 \\ 0.4 \text{ mol } CO \\ 0.4 \text{ mol } O_2 \end{cases}$

$$\text{selectivity of } CO_2 = \frac{\text{Amount of } CO_2}{\text{Amount of } CO} = \frac{0.6}{0.4} = 1.5$$

$$\text{selectivity of } CO = \frac{\text{Amount of } CO}{\text{Amount of } CO_2} = \frac{0.4}{0.6} = 0.67$$

– orsat gas (dry gas): یعنی از مجموع درصد مولی آب را حذف کنیم.

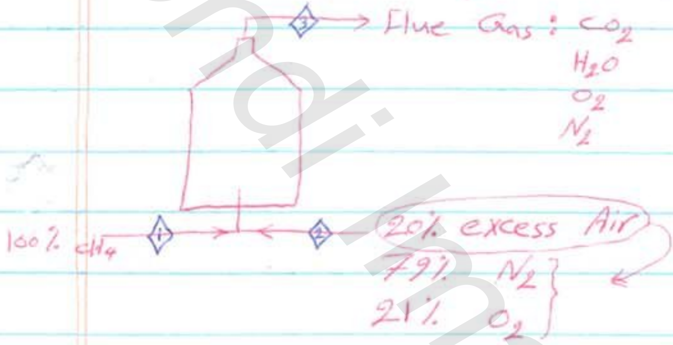
– Tie component: رابطه بین یک واکنش است بدون دخالت کردن در خود واکنش.

Material Balance with chemical Reaction:

Combustion:

Ex: ① methane is burned in a Furnace (کوره) in the presence of 20% exeess of Air. The reaction is complete. Find the composition of the Flue Gas on wet and dry basis.

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



comp	①	②	③
CH_4	100%	0	0
N_2	0	79%	$X(2,3)$
O_2	0	21%	$X(3,3)$
H_2O	0	0	$X(4,3)$
CO_2	0	0	$X(5,3)$
total	S_1	S_2	S_3

$M = 3(5+1) = 18$

$N \quad = 11$

$\boxed{\text{Actual unknown} = 7}$

$Out = IN - CON + GEN$

MB	4
DF	1
B	1
SP	1
Equation	7 ✓

① $N_2: X(2,3) = 0.79\, S_2$ Tie Component نقشی در مصرف شدن ندارد

② $O_2: X(3,3) = 0.21\, S_2 - S_1 \text{ mole } CH_4 \left| \dfrac{2\ O_2 \text{ consumed}}{1\ CH_4 \text{ consumed}} \right|$

③ $H_2O: X(4,3) = S_1 \text{ mol } CH_4 \text{ consumed} \left| \dfrac{2\ H_2O \text{ produce}}{1\ CH_4 \text{ consum}} \right|$

④ $CO_2: X(5,3) = S_1 \text{ mol } CH_4 \text{ consumed} \left| \dfrac{1\ CO_2 \text{ produce}}{1\ CH_4 \text{ consum}} \right|$

⑤ $S_3 = X(2,3) + X(3,3) + X(4,3) + X(5,3)$

- این قسمت ⑥ برای امتحان خیلی مهم است، نکته دارد.

sp:

(6) $S_2 = S_1$ mole of CH_4 in ~~Feed~~ $\left|\dfrac{2\ O_2\ \text{Required}}{1\ CH_4\ \text{in Feed}}\right|\left|\dfrac{120\ \text{mol}\ O_2\ \text{Feed}}{100\ \text{mol}\ O_2\ \text{Required}}\right|\left|\dfrac{1\ \text{mol Air}}{0.21\ \text{mol}\ O_2}\right|$

(Note: 20% excess O_2 $\longrightarrow$ $\dfrac{120\ \text{mole feed}}{100\ \text{mole Required}}$)

{O_2 Required} {% excess} {21% O_2 in Air}

Basis:

(7) $S_1 = 100$ Mole

$\Longrightarrow$ $S_2 = 1142.8$ $\quad X(2,3) = 902.8$ $\quad X(3,3) = 39.98$

$X(4,3) = 200$ $\quad X(5,3) = 100$ $\quad S_3 = 1242.78$

comp	1	2	3	wet Analysis	orsat / Dry Analysis آب را صفر می‌کنیم
CH_4	100%	0	0	0	0 $\longrightarrow$ 0
N_2	0	79%	902.8	72.6%	86.6% $\longrightarrow$ 902.8
O_2	0	21%	39.98	3.2%	3.8% $\longrightarrow$ 39.98
H_2O	0	0	200	16.1%	0 $\longrightarrow$ 0
CO_2	0	0	100	8.1%	9.6% $\longrightarrow$ 100
total	100	1142.8	1242.78	100%	100% $\longrightarrow$ 1042.78

EX(2): pervious example with 50% conversion (مصرف شدن):

comp	1	2	3
CH_4	100%	0	$X(1,3)$
N_2	0	79%	$X(2,3)$
O_2	0	21%	$X(3,3)$
H_2O	0	0	$X(4,3)$
CO_2	0	0	$X(5,3)$
total	S_1	S_2	S_3

MB = 5

Df = 1

Sp = 1

Bar = 1

8

unknown = 8

Out = IN - CoN + GeN

CH_4: $X(1,3) = S_1 - S_1 \text{ mol } CH_4 \text{ feed} \left| \frac{50 \text{ mole } CH_4 \text{ consu}}{100 \text{ mole } CH_4 \text{ feed}} \right|$

N_2: $X(2,3) = 0.79\, S_2$

O_2: $X(3,3) = 0.21\, S_2 - S_1 \text{ mol } CH_4\, f \left| \frac{50 \text{ mol } CH_4 \text{ con}}{100 \text{ mol } CH_4\, f} \right| \left| \frac{2 \text{ mol } O_2 \text{ con}}{1 \text{ mol } CH_4 \text{ con}} \right|$

H_2O: $X(4,3) = S_1 \text{ mole } CH_4\, f \left| \frac{50 \text{ mol } CH_4 \text{ con}}{100 \text{ mol } CH_4\, F} \right| \left| \frac{2 \text{ mol } H_2O \text{ Gen}}{1\ CH_4 \text{ coN}} \right|$

CO_2: $X(5,3) = S_1 \text{ mole } CH_4^{f} \left| \frac{50 \text{ mol } CH_4 \text{ con}}{100 \text{ mol } CH_4\, f} \right| \left| \frac{1 \text{ mol } CO_2 \text{ GeN}}{1 \text{ mol } CH_4 \text{ con}} \right|$

$S_3 = X(1,3) + X(2,3) + X(3,3) + X(4,3) + X(5,3)$

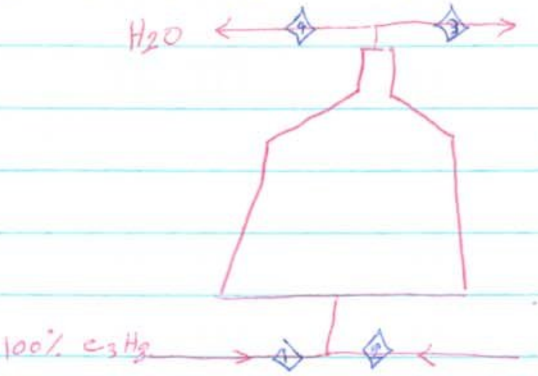
نکته حائز مهم → $S_2 = S_1 \text{ mole } CH_4 \text{ feed} \left| \frac{2 \text{ mol } O_2 \text{ Required}}{1 \text{ mol } CH_4 \text{ Feed}} \right| \left| \frac{120 \text{ mol } O_2\, F}{100 \text{ mol } O_2 \text{ Required}} \right| \left| \frac{1 \text{ mol Air}}{0.21 \text{ mol } O_2} \right|$

$S_1 = 100$

comp	1	2	3	wet analysis
⟹ CH_4	100%	0	50	4 %
N_2	0	79%	902.8	72.6%
O_2	0	21%	140	11.3 %
H_2O	0	0	100	8 %
CO_2	0	0	50	4 %
total	100		1242.8	100 %

حل شود

Ex 3: A Furnace burns C_3H_8. The orsat analysis of the combustion Gases is N_2: 83.8% , O_2: 5.5%, CO_2: 8.6%, and CO: 2.1%. what was the percentage excess Air?



N_2 83.8%
O_2 5.5%
CO_2 8.6%
CO 2.1%

نکته: در آنالیز orsat ـــ ولی اتفاقی نیفتاده و باید بدانیم که بخار آب در خروجی وجود دارد.

(*) - ممکن است در $\boxed{Ex 3}$ سؤال شود که orsat را به wet analy تبدیل کنیم.

4 unknown

comp	①	②	③	④
C_3H_8	100%	0	0	0
N_2	0	79%	$X(2,3)$ 83.8%	0
O_2	0	21%	$X(3,3)$ 5.5%	0
CO_2	0	0	$X(4,3)$ 8.6%	0
CO	0	0	$X(5,3)$ 2.1%	0
H_2O	0	0	0	100%
total	S_1	S_2	S_3	S_4

$$out = IN - CON + GEN$$

نکته: در مسائلی که composition خروجی را داشته باشیم می توانیم، خروجی را به عنوان Basis انتخاب کنیم.

$$\checkmark\ C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O \quad \text{واکنش اصلی}$$

$$C_3H_8 + \frac{7}{2}O_2 \longrightarrow 3CO + 4H_2O$$

نکته: در سوختن هیدروکربن ها همیشه وقتی CO تولید شود آن واکنش اصلی و واکنشی که CO تولید می کند فرعی است.

$S_3 = 100$ mole

N_2: $out = IN \quad 83.8 = 0.79 S_2 \Longrightarrow S_2$

C_3H_8: $\underset{0}{out} = IN - CON + \cancel{GEN} \Rightarrow IN = CON$

$$\Longrightarrow S_1 = 8.6\ mol\ CO_2 \left|\frac{1\ C_3H_8}{3\ CO_2}\right| + 2.1\ mole\ CO \left|\frac{1\ mol\ C_3H_8}{3\ mol\ CO}\right.$$

(*) H_2O: $out = GEN \quad S_4 = 8.6\ mol\ CO_2 \left|\frac{4\ H_2O}{3\ CO_2}\right| + 2.1\ mole\ CO \left|\frac{4\ H_2O}{3\ CO}\right|$

$$\Longrightarrow S_1 = 3.57 \qquad S_2 = 106.1 \qquad S_4 = 14.3$$

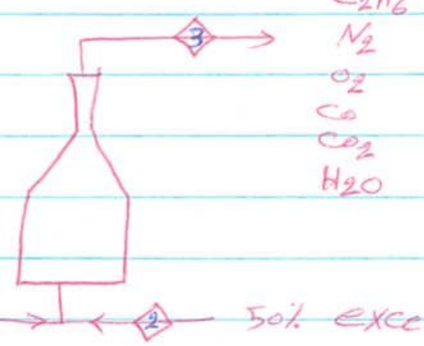
$$\%\ excess\ \underset{Air}{O_2} = \frac{Feed\ \overset{Air}{O_2} - Required\ \overset{Air}{O_2}}{Required\ \underset{Air}{O_2}} \times 100$$

نکته: درصد اضافی فقط برای واکنش اصلی است یعنی دیگر برای واکنش CO نوشته نمی شود.

$$\%\ excess = \frac{(0.21)(106.1) - 3.57\ mol\ C_3H_6 \left|\frac{5\ mol\ O_2}{1\ C_3H_8}\right.}{3.57\ mol\ C_3H_6 \left|\frac{5\ mol\ O_2}{1\ C_3H_6}\right.} \times 100 = 24.6\%$$

Ex(5): combustion C_2H_6 with 50% excess Air

conversion: 90% $\rightarrow$ 25% of that burns goes to CO and the balance to CO_2.



comp	1	2	3
C_2H_6	100%	0	X(1,3)
O_2	0	21%	X(2,3)
N_2	0	79%	X(3,3)
CO_2	0	0	X(4,3)
CO	0	0	X(5,3)
H_2O	0	0	X(6,3)
total	S_1	S_2	S_3

$C_2H_6 + \frac{7}{2} O_2 \longrightarrow 2 CO_2 + 3 H_2O$ principle reaction

$C_2H_6 + \frac{5}{2} O_2 \longrightarrow 2 CO + 3 H_2O$

out = IN − CON + GEN

9 unknown (6 MB, 1 D, 1 sp, 1 B)

C_2H_6 : $X(1,3) = S_1 - S_1 \text{ mol } C_2H_6{}^F \left| \frac{0.9 \, C_2H_6 \text{ con}}{1 \, C_2H_6 \, F} \right.$

O_2 : $X(2,3) = 0.21 S_2 - S_1 \text{ mol } C_2H_6 \times \frac{0.9 \, C_2H_6 \text{ con}}{1 \, C_2H_6 \, F} \left[\underbrace{\frac{0.75 \text{ mol } C_2H_6}{1 \text{ mol } C_2H_6} \left| \frac{\frac{7}{2} O_2}{1 \, C_2H_6} \right.}_{\text{Reaction \# 1}} + \underbrace{\frac{0.25 \text{ mol } C_2H_6}{1 \text{ mol } C_2H_6} \left| \frac{\frac{5}{2} O_2}{1 \, C_2H_6} \right.}_{\text{Reaction \# 2}} \right]$

N_2: $X(3,3) = 0.79\, S_2$

CO_2: $X(4,3) = 0.9\, S_1 (0.75)$ mole C_2H_6 consumed in Reac#1 $\left| \dfrac{2 \text{ mol } CO_2}{1\ C_2H_6} \right|$

CO: $X(5,3) = 0.9\, S_1 (0.25)$ mol C_2H_6 consumed in Reac#2 $\left| \dfrac{2 \text{ mol } CO}{1\ C_2H_6} \right|$

H_2O: $X(6,3) = 0.9\, S_1$ mole C_2H_6 $\left| \dfrac{3 \text{ mole } H_2O}{1\ C_2H_6} \right|$

$$S_3 = X(1,3) + X(2,3) + X(3,3) + X(4,3) + X(5,3) + X(6,3)$$

$$S_2 = \{O_2 \text{ Required}\} \left| \frac{150\ O_2 \text{ Feed}}{100\ O_2 \text{ Required}} \right| \left| \frac{1 \text{ Air}}{0.21\ O_2} \right|$$

Note: $S_2 = \{O_2 \text{ Required}\}\ \{\% \text{ excess}\}\ \{\%\, O_2 \text{ in Air}\}$

$$S_2 = \text{mole } C_2H_6\ S_1 \left| \frac{\frac{7}{2}\ O_2 \text{ Required}}{1\ C_2H_6} \right| \left| \frac{150}{100} \right| \left| \frac{1}{0.21} \right|$$

نکته: در اینجا (O_2) فقط باید واکنش اصلی را در نظر بگیریم.

$S_1 = 100$

$\Rightarrow$ $S_2 = 2500$ $\quad X(1,3) = 10$ $\quad X(2,3) = 232.5$

$X(3,3) = 1975$ $\quad X(4,3) = 135$ $\quad X(5,3) = 45$

$X(6,3) = 270$ $\quad S_3 = 2667.5$

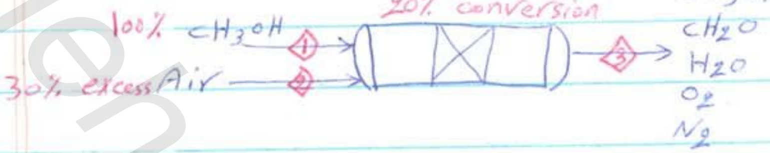
chapter 9 , chapter 10

HW # 7   27, 29   13, 19

Recycle: calculation:

Ex: consider the production of formaldehyde from methanol.

$$CH_3OH + \frac{1}{2}O_2 \longrightarrow CH_2O + H_2O$$



suppose that the percentage conversion is 20% of the methanol at 30% excess Air. Find the composition of the product.

comp	1	2	3
CH_3OH	100 %	0	X(1,3) 80
N_2	0	79%	X(2,3) 244.5
O_2	0	21 %	X(3,3) 55
CH_2O	0	0	X(4,3) 20
H_2O	0	0	X(5,3) 20
total	S_1	S_2	S_3

Acc = IN - out + GEN - CON ⟹ out = IN + GEN - CON

8 unknown
5 MB
1 SP
1 D
1 B

CH_3OH : $X(1,3) = S_1 - \frac{20}{100} S_1$

N_2 : $X(2,3) = 0.79\, S_2$

O_2 : $X(3,3) = 0.21\, S_2 - \frac{20}{100} S_1\, CH_3OH \left| \frac{\frac{1}{2}\, O_2}{1\, CH_3OH} \right|$

CH_2O : $X(4,3) = \frac{20}{100} S_1\, CH_3OH \left| \frac{1\, CH_2O}{1\, CH_3OH} \right|$

H_2O : $X(5,3) = \frac{20}{100} S_1\, CH_3OH \left| \frac{1\, H_2O}{1\, CH_3OH} \right|$

$S_2 = \{O_2 \text{ Required}\} \left\{ \frac{130\, O_2\, F}{100\, O_2 \text{ Required}} \right\} \left| \frac{1 \text{ Air}}{0.21\, O_2\, F} \right| \Rightarrow$

$S_2 = S_1 \text{ Mole } CH_3OH \left| \frac{\frac{1}{2}\, O_2}{1\, CH_3OH} \right| \frac{130}{100} \left| \frac{1}{0.21} \right|$

$S_3 = X(1,3) + X(2,3) + X(3,3) + X(4,3) + X(5,3)$

$\Rightarrow$ $S_1 = 100$ Mole $\qquad S_2 = 309.52$

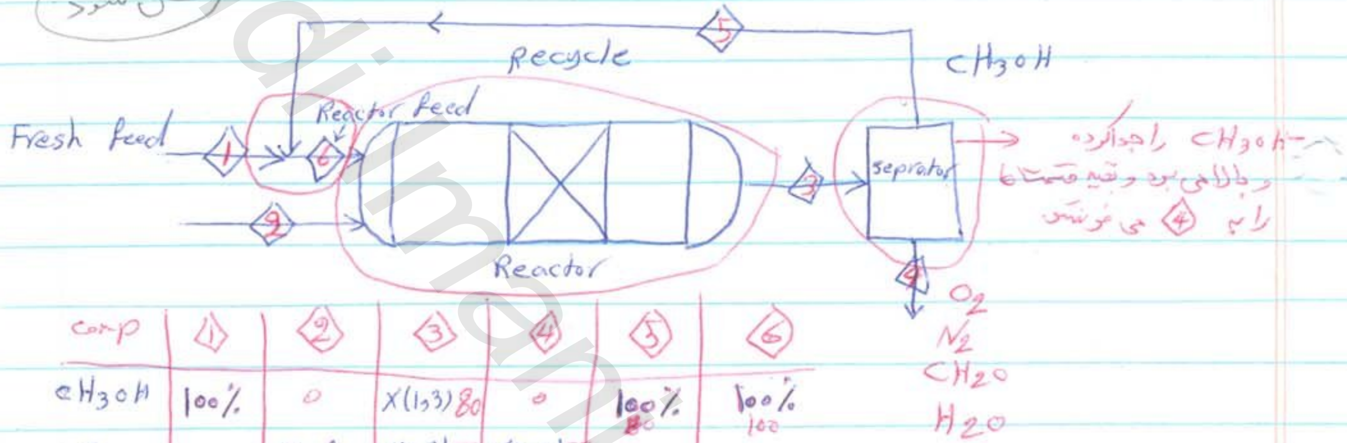
$X(1,3) = 80 \qquad X(2,3) = 244.52$

$X(3,3) = 55 \qquad X(4,3) = 20$

$X(5,3) = 20$

Ex: جدول موازنه را کامل کنید ← ------ + صورت مسئله قبلی

حل شود



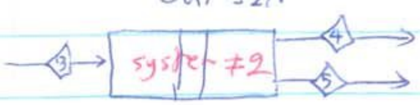
comp	①	②	③	④	⑤	⑥
CH_3OH	100%	0	$X(1,3)$ 80	0	100% 80	100% 100
O_2	0	21% 65	$X(2,3)$ 55	$X(2,4)$ 55	0	0
N_2	0	79% 244.5	$X(3,3)$ 244.5	$X(3,4)$ 244.5	0	0
CH_2O	0	0	$X(4,3)$ 20	$X(4,4)$ 20	0	0
H_2O	0	0	$X(5,3)$ 20	$X(5,4)$ 20	0	0
total	S_1 20	S_2 309.5	S_3 419.5	S_4 334.5	S_5 80	S_6 100

نکته: می توانیم نوشتن معادلات را برحسب system یا component نوشت.

برحسب component:

out = ΣIN − CoN + GeN

out = IN



out = IN

CH_3OH: #① $X(1,3) = S_6 - \frac{20}{100} S_6$ ①

#② $\cancel{X(1,5)} = X(1,3)$ (S_5)

#③ $\cancel{X(1,6)} = \cancel{X(1,5)} + S_1$ (S_6, S_5)

O_2: ④ $X(2,3) = 0.21 S_2 - \frac{20}{100} S_6 \left| \frac{\frac{1}{2} O_2}{1\, CH_3OH} \right|$ ②

⑤ $X(2,4) = X(2,3)$

N_2: ⑥ $X(3,3) = 0.79 S_2$

⑦ $X(3,4) = X(3,3)$

CH_2O: ⑧ $X(4,3) = \frac{20}{100} S_6 \; CH_3OH \left| \frac{1\, CH_2O}{1\, CH_3OH} \right.$ ③

⑨ $X(4,4) = X(4,3)$

H_2O: ⑩ $X(5,3) = \frac{20}{100} S_6\, CH_3OH \left| \frac{1\, H_2O}{1\, CH_3OH} \right|$ ④

⑪ $X(5,4) = X(5,3)$

Def: ⑫ $S_3 = X(1,3) + X(2,3) + X(3,3) + X(4,3) + X(5,3)$ ⑦

⑬ $S_4 = X(2,4) + X(3,4) + X(4,4) + X(5,4)$

sp: ⑭ $S_2 = S_6\, CH_3OH \left| \frac{\frac{1}{2}\, O_2}{1\, CH_3OH} \right| \frac{1.3}{1} \left| \frac{1}{0.21} \right.$ ⑤

Bas: ⑮ $S_6 = 100$ Mole ⑥

Ex:

Formaldehyde is manufactureed by catalytic oxidation of methanol using an excess of Air.

$$CH_3OH + \frac{1}{2}O_2 \longrightarrow CH_2O + H_2O$$

A secondary, undesirable reaction occurs if conditions are not properly controlled to form Formic Acid.

$$CH_2O + \frac{1}{2}O_2 \longrightarrow HCOOH$$

The product stream have the following composition.

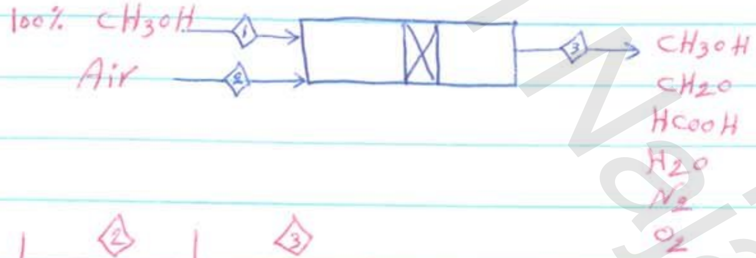
component	mole %
CH_3OH	8.6
CH_2O	3.1
$HCOOH$	0.6
H_2O	3.7
O_2	16
N_2	68

Find:

a) % conversion of CH_3OH to CH_2O.

b) % excess Air.

c) Molar ratio of Methanol to Air.



Comp	1	2	3
CH_3OH	100%	0	8.6
CH_2O	0	0	3.1
$HCOOH$	0	0	0.6
H_2O	0	0	3.7
O_2	0	21%	16
N_2	0	79%	68
total	S_1 12.3	S_2 86.1	100

$S_3 = 100$ Mole

N_2: $0.79 S_2 = 68$

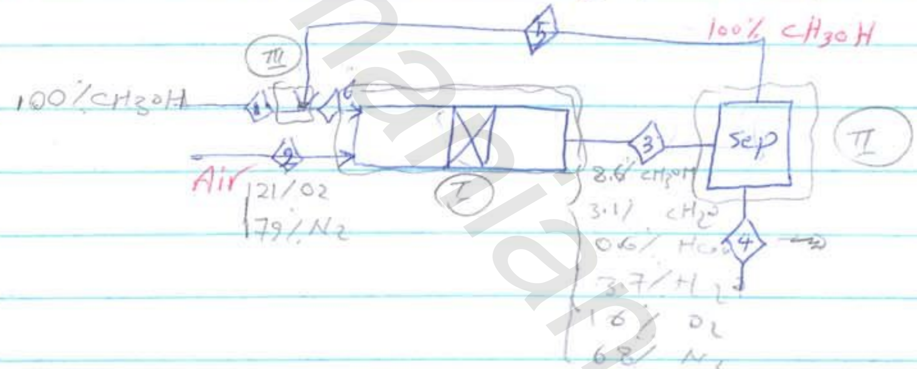
CH_3OH: $\left\{ 8.6 \text{ mol } CH_3OH = S_1 - \left(3.1 \text{ mol } CH_2O \left| \frac{1\ CH_3OH}{1\ CH_2O} \right| + 0.6 \text{ mol } HCOOH \left| \frac{1\ CH_2O}{HCOOH} \right| \frac{1\ CH_3OH}{1\ CH_2O} \right| \right) \right.$

or

$8.6 \text{ mol } CH_3OH = S_1 - 3.7 \text{ mol } H_2O \left| \frac{1\ CH_3OH}{1\ H_2O} \right|$

$\boxed{\%\text{Excess} = 194\%}$

EX: Homework: اگر مثال قبلی را با seprator داشته باشیم.

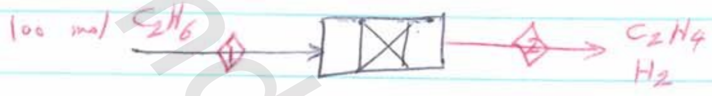


Cn	1	2	3	4	5	6
CH_3OH	100%	0	8.6%	0	100%	10[illegible]%
CH_2O	0	0	3.1%	$x(2,4)$	0	0
HCOOH	0	0	0.6%	$x(3,4)$	0	0
H_2O	0	0	3.7%	$x(4,4)$	0	0
O_2	0	21%	16%	$x(5,4)$	0	0
N_2	0	79%	68%	$x(6,4)$	0	0
Total	S_1	S_2	S_3	S_4	S_5	S_6

unk $- N = 6(7) - 31 = 11$

Element Balance:

Ex: Dehydrogeneration of 100 mole Ethane in a steady state reactor $C_2H_6 \longrightarrow C_2H_4 + H_2$.
The product stream is analyzed for H_2 and it is found that the molar flow rate is 40 mol/min.
Find the composition of the product.



comp	1	2	
C_2H_6	100	$X(1,2)$ 60	42.8%
C_2H_4	0	$X(2,2)$ 40	28.6%
H_2	0	40	28.6%
total	100	S_2 140	

out = IN

$$C: X(1,2)\ \text{mol}\ C_2H_6 \left|\frac{2\ \text{mol}\ C}{1\ \text{mol}\ C_2H_6}\right| + X(2,2)\ \text{mol}\ C_2H_4 \left|\frac{2\ \text{mol}\ C}{1\ \text{mol}\ C_2H_4}\right|$$

$$= 100\ \text{mol}\ C_2H_6 \left|\frac{2\ \text{mol}\ C}{1\ \text{mol}\ C_2H_6}\right| \Rightarrow \boxed{X(1,2) + X(2,2) = 100}$$

$$H: X(1,2)\ \text{mol}\ C_2H_6 \left|\frac{6\ \text{mol}\ H}{1\ \text{mol}\ C_2H_6}\right| + X(2,2)\ \text{mol}\ C_2H_4 \left|\frac{4\ \text{mol}\ H}{1\ \text{mol}\ C_2H_4}\right|$$

$$+ 40\ \text{mol}\ H_2 \left|\frac{2\ \text{mol}\ H}{1\ \text{mol}\ H_2}\right| = 100\ \text{mol}\ C_2H_6 \left|\frac{6\ \text{mol}\ H}{1\ \text{mol}\ C_2H_6}\right|$$

$$\Rightarrow \boxed{1.5X(1,2) + X(2,2) = 130}$$

$$\Rightarrow X(1,2) = 60 \quad , X(2,2) = 40$$

HW: methane is fed to a furnace to burn with 100% excess Air. The outlet O_2 was found to be 220 mole based on 100 mol of methane. Find the composition of product.

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

$$CH_4 + \frac{3}{2}O_2 \longrightarrow CO + 2H_2O$$

ideal $\qquad\qquad$ real

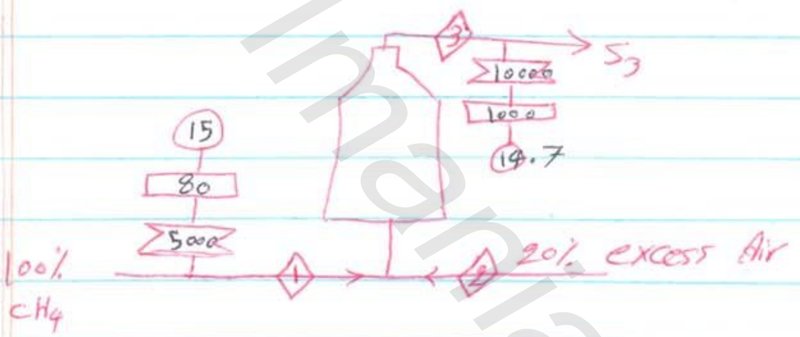
$P\dot{V} = \dot{n}RT$ $\qquad\qquad$ $P\dot{V} = Z\dot{n}RT$

مقدار انحراف از حالت ideal

حل شود

Ex: flue Gas at 1000°F and 14.7 psi leave Furnace at a volumetric rate of 10,000 CFM. The meter on the fuel feed indicates a rate of 5000 CFM at 80°F and 15 psi. If combustion is complete with 20% excess Air, are the two meters consistent?

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



$P\dot{V} = \dot{n}RT$

comp	1	2	3
CH_4	100%	0	0
N_2	0	79%	X(2,3)
O_2	0	21%	X(3,3)
H_2O	0	0	X(4,3)
CO_2	0	0	X(5,3)
	S_1	S_2	S_3

$P_1\dot{V}_1 = S_1 R T_1$ $\quad$ & $P_3\dot{V}_3 = S_3 R T_3$

? = ✓ ← اگر برابر مقدار 10000 باشد

$$S_1 = \frac{P_1\dot{V}_1}{RT_1} = \frac{(15\,psi)(5000\,\frac{ft^3}{min})}{10.731\,\frac{lbf\,ft^3}{in^2\,lbmol\,R}(80+460)R} = 12.95\,\frac{lbmol}{min}$$

$out = \sum IN - Con + GeN$

$X(2,3) = 0.79 S_2 = \boxed{116.92}$

$S_2 = 12.95 \text{ mol } CH_4 \left| \frac{2 \ O_2}{1 \ CH_4} \right| \frac{120 \text{ mol} O_2 F}{100 \text{ mol} O_2 R} \left| \frac{Air}{0.21 \ O_2} \right.$

$X(3,3) = 0.21 S_2 - 12.95 \text{ mol } CH_4 \left| \frac{2 \ O_2}{1 \ CH_4} \right. = \boxed{5.18}$

$X(4,3) = 12.95 \text{ mol } CH_4 \left| \frac{2 \ H_2O}{1 \ CH_4} \right. = \boxed{25.9}$

$X(5,3) = 12.95 \text{ mol } CH_4 \left| \frac{1 \ CO_2}{1 \ CH_4} \right. = \boxed{12.95}$

$S_3 = X(2,3) + X(3,3) + X(4,3) + X(5,3)$

$\boxed{S_3 = 160.95 \ \frac{mol}{Min}}$

$P_3 \dot{V}_3 = S_3 R T_3 \longrightarrow \dot{V}_3 = \frac{S_3 R T_3}{P_3} = \frac{(160.95)(1000+460)(0.73)}{14.7}$

$\longrightarrow \boxed{\dot{V}_3 = 171500 \ \frac{ft^3}{min}} \longrightarrow$ دستگاه خواب است

"Energy Balance"

Acounting for the energy that flows across the system boundaris or accumulates within the system.

یعنی انرژی بر واحد Mass است ← $\hat{E}_1 \equiv$ Energy of the system at time t_1

$\hat{E}_2 \equiv$ 〃 〃 〃 〃 〃 〃 t_2

$\dot{Q} \equiv$ Heat transfer from the surronding to the system.

$\dot{W} \equiv$ work done by the surronding to the system.

$\hat{\eta}_i \equiv$ Energy associated with mass flow in

$\hat{\eta}_o \equiv$ 〃 〃 〃 〃 〃 out

$\dot{m}_i \equiv$ mass flow rate entring the system.

$\dot{m}_o \equiv$ 〃 〃 〃 Leaving 〃 〃.

$M_1 \equiv$ Mass of the system at time t_1

$M_2 \equiv$ 〃 〃 〃 〃 〃 〃 t_2

Energy balance: $M_2 \hat{E}_2 - M_1 \hat{E}_1 = \left[\dot{m}_i \hat{\eta}_i - \dot{m}_o \hat{\eta}_o + \dot{Q} - \dot{W} \right] \Delta t$

$\hat{E}$ $\quad \hat{PE} = \dfrac{gh}{g_c}$ $\quad \hat{KE} = \dfrac{1}{2} \dfrac{V^2}{g_c}$ $\quad \hat{u} = f(T, P)$

$\hat{W}_f = P \hat{V}$ $\quad \hat{H} = \hat{u} + \hat{W}_f$

$\hat{V}$ ← حجم ویژه

$$\hat{M}_2\left[\hat{KE}_2+\hat{PE}_2+\hat{U}_2\right]-\hat{M}_1\left[\hat{KE}_1+\hat{PE}_1+\hat{U}_1\right]=$$
$$\dot{m}_i\left[\hat{KE}_i+\hat{PE}_i+\hat{H}_i\right]-\dot{M}_o\left[\hat{KE}_o+\hat{PE}_o+\hat{H}_o\right]+\dot{Q}-\dot{W}$$

$$\Delta KE+\Delta PE+\Delta U=\dot{m}_i\left[\hat{KE}_i+\hat{PE}_i+H_i\right]-\dot{M}_o\left[\hat{KE}_o+\hat{PE}_o+\hat{H}_o\right]+\dot{Q}-\dot{W}$$

Closed system: $m_i=m_o=0 \Longrightarrow \Delta KE+\Delta PE+\Delta U=Q-W$

chemical process (closed systen) $\longrightarrow \Delta U=Q-W$

if no work $\boxed{\Delta U=Q}$

open system: $(\dot{m}_i=\dot{m}_o)$

$\Delta H+\Delta PE+\Delta KE=Q-W \Longrightarrow Q-W=\Delta H \Longrightarrow \boxed{\Delta H=Q}$ chemical reaction

Mechanical Energy Balance:

1. in compressible flow
2. single flow
3. liquid flow
4. No chemical Reaction
5. steady state (open)

$H=U+PV \longrightarrow \hat{H}=U+\frac{P}{\rho} \Longrightarrow \Delta\hat{H}=\Delta U+\frac{\Delta P}{\rho}$

$$0=\dot{m}_i\left[\hat{KE}_i+\hat{PE}_i+\hat{H}_i\right]-\dot{m}_o\left(\hat{KE}_1+\hat{PE}_o+\hat{H}_o\right)+\dot{Q}-\dot{W}$$

$$\Delta KE+\Delta PE+\Delta U+\frac{\Delta P}{\rho}=Q-W$$

friction $\rightarrow F=\Delta U-Q$

$$\boxed{\frac{\Delta P}{\rho}+\Delta KE+\Delta PE+F=-W}$$

$\frac{\Delta P}{\rho}+\Delta KE+\Delta PE+F=0$ No work

$\frac{\Delta P}{\rho}+\Delta KE+\Delta PE=0$ Bernulli Equation (No friction)

Hw: ch 21 : 31 , 35 , 38
ch 22 : 7, 11, 17, 33
ch 23 : 16, 32, 49

important pages : page 703 enthalpy chart , table E, heat capacity , Apendix F & D

$u = f(T, V)$

$$du = \left(\frac{du}{dT}\right)_V dT + \cancel{\left(\frac{\partial u}{\partial V}\right)_T}^{0} dV \quad , \quad c_V = \left(\frac{\partial u}{\partial T}\right)_V$$

$$\Rightarrow du = c_V \, dT \Longrightarrow \boxed{\Delta u = \int_{T_{ref}}^{T} c_V \, dT}$$ محاسبه U بدون جدول و نمودار

$$H = f(T, P) \quad : \quad dH = \left(\frac{\partial H}{\partial T}\right)_P dT + \cancel{\left(\frac{\partial H}{\partial P}\right)_P}^{0} dP$$

$$c_p = \left(\frac{\partial H}{\partial T}\right)_P \longrightarrow \boxed{\Delta H = \int c_p \, dT}$$

$$c_p = a + bT + cT^2 + dT^3$$

$c_p \approx c_V$ for solid & liquid

$c_p = c_V + R$ (R → gas constant) for ideal gas

mixtures:

open $\quad \Delta H_{totall} = \sum_{i=1}^{n} n_i \Delta H_i$

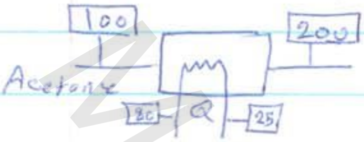
c_1	$X(1,1)$	$\hat{H}(1,1)$	$H(1,1)$	$Q = H_o - H_I$
c_2	$X(2,1)$	$\hat{H}(2,1)$	$H(2,1)$	$\rightarrow Q = H_3 - (H_1 + H_2)$
c_3	$X(3,1$	$\hat{H}(3,1)$	$H(3,1)$	
			H_1	

$$\Delta H_{total} = \sum_{i=1}^{n} n_i \Delta H_i = n_T \sum_{i=1}^{n} y_i \Delta H_i$$

(y_i → mole fraction)

$$\Delta H_{total} = n_T \sum_{i}^{n} y_i \int_{T_1}^{T_2} c_{p_i} \, dT$$

example : چه مقدار آب لازم است تا دمای استون را از 100 به 200 برسانیم؟



state	form	T	a	$b\times10^{-2}$	$c\times10^{-5}$	$d\times10^{-9}$	—
g	1	°C	71.96	20.1	-12.78	34.76	0-1200

$$C_p = 71.96 + 20.1\times10^{-2}T - 12.78\times10^{-5}T^2 + 34.76\times10^{-9}T^3$$

آب $Q_1 = m_1\int_{20}^{25} \underbrace{C_p}_{\text{آب مایع}}\,dT$

Acetone $Q_2 = m_2\int_{100}^{200} \underbrace{C_p}_{\text{Acetone}}\,dT$

$\rightarrow Q_1 = Q_2 \rightarrow m_1 =$

closed system: از لحاظ Material بسته است ولی energy باز است.

$$\cancel{\Delta PE}^{0} + \cancel{\Delta KE}^{0} + \underbrace{\Delta U = Q - W} \longrightarrow \Delta U = Q - W$$

Q: + گرما بگیرد / − گرما بدهد

W: + سیستم به ما کار بدهد. / − ما به سیستم کار دهیم.

- اگر کار مکانیکی نداشته باشیم: No shaft work $\Delta U = Q$

روش‌های بدست آوردن U { جدول / نمودار / رابطه ریاضی } $\longrightarrow$

$$Q = \int_{T_1}^{T_2} C_V \, dT$$

گرمای ویژه در حجم ثابت

$$Q = U_2 - U_1$$

---

open system:

مجموع انرژی درونی و کار انجام شده توسط سیال

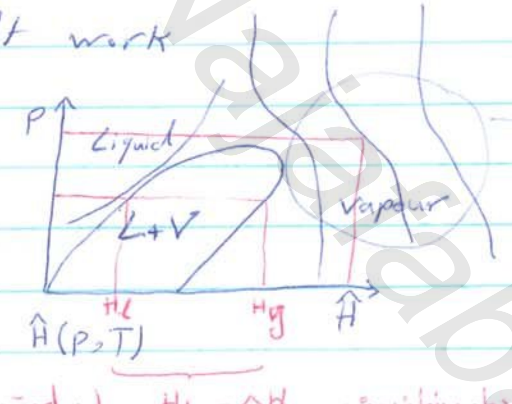
$$\cancel{\Delta PE}^{0} + \cancel{\Delta KE}^{0} + \Delta H = Q - W \longrightarrow \Delta H = Q - W$$

به علت اختلاف ارتفاع انرژی پتانسیل وجود دارد اختلاف ولی ناچیز است (نسبت به ΔH)

به علت اختلاف سرعت وجود دارد ولی ناچیز است (نسبت به ΔH)

$\longrightarrow \Delta H = Q$ No shaft work

ΔH { جدول / نمودار / رابطه ریاضی } $\longrightarrow$



منطقه فوق اشباع

ص ۷۰۳ دمای پنهانی ویژه $H_{Lg} = \Delta H$ (برای تبدیل آب ۱۰۰ به بخار آب ۱۰۰) جدول آخر کتاب

نکته: $\hat{H} = U + PV$ — U: انرژی درونی ویژه، V: حجم ویژه

$$\begin{cases} \hat{H}_l = U_l + PV_l \\ \hat{H}_g = U_g + PV_g \end{cases}$$

$$Q = M\int_{T_1}^{T_2} C_p(T)\, dT = \Delta H$$

نکته: باید توجه کنیم که cp جامد، مایع یا گاز است

(جدول E)

$$\hat{H}(T) = \int_{T_{ref}}^{T} C_p\, dT$$

(جدول D)

مقدارهای $\hat{H}$ در این جدول انتگرالش گرفته شده

و می توانیم به راحتی ΔH را بدست آوریم.

Mechanical Energy Balance:

$$\frac{\Delta P}{\rho} + \frac{\Delta V^2}{2 g_c} + \frac{\Delta Z g}{g_c} + \cancel{F}^{0} = \frac{\cancel{W}^{0}}{M}$$

F → Friction factor

closed system:

Example 1: A vessel contains 100 kg of water at 40 °c, 50 psi. How much heat is required to heat the water to 90 °c

(Note: for Liquid & solid : $C_V \approx C_p$)

روش فرمول:

$$Q = \Delta U \longrightarrow Q = m\int_{T_1}^{T_2} C_V\, dT \approx m\int_{T_1}^{T_2} C_p\, dT$$

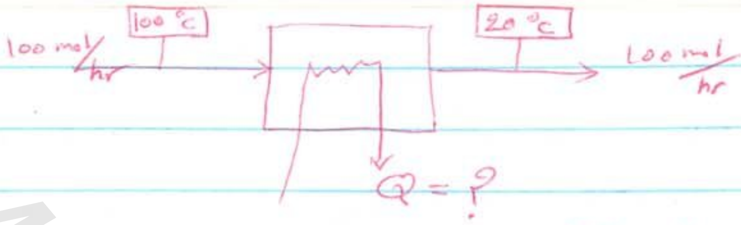
روش جدول:

$$Q = m(\hat{U}_2 - \hat{U}_1) = 100\ \cancel{kg}\,(376.9 - 167.4)\ \frac{kj}{\cancel{kg}}$$

$$\longrightarrow \boxed{Q = 20950\ kj}$$

open system:

Examp 2: 100 mol/hr of N_2 gas entiring a heat exchanger at 100 °c and leaving at 20 °c. calculate the amount of heat that must be removed?



$Q = m\Delta H$ ① روش

$Q = m\left(\hat{H}(20°C) - \hat{H}(100°C)\right)$ ② روش

$Q = m\int_{100}^{20} c_p\, dT$ ③ روش

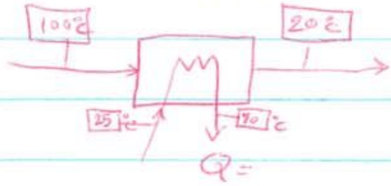
$c_p\left(\frac{J}{mol.°C}\right)$ مهم است

روش ③ $Q = 100\,\frac{mol}{hr}\int_{100}^{20}\left(29 + 0.2199\times10^{-2}T + 0.5723\times10^{-5}T^{2} - 2.876\times10^{-9}T^{3}\right)dT$

$\longrightarrow Q = -23234\ \frac{J}{hr}$

Example 3:

اگر گرمای مثال قبلی برای گرم کردن آب استفاده : مثل قبلی
شود، چه مقدار آب می توان گرم کرد (آب از 25°C به 90°C) ؟



$Q = \Delta H$

$Q = \dot{m}\left(\hat{H}(90°C) - \hat{H}(25°C)\right) = \dot{m}\,(376.9 - 104.8)\,\frac{kJ}{kg}\times\frac{18\ gr}{mol}$

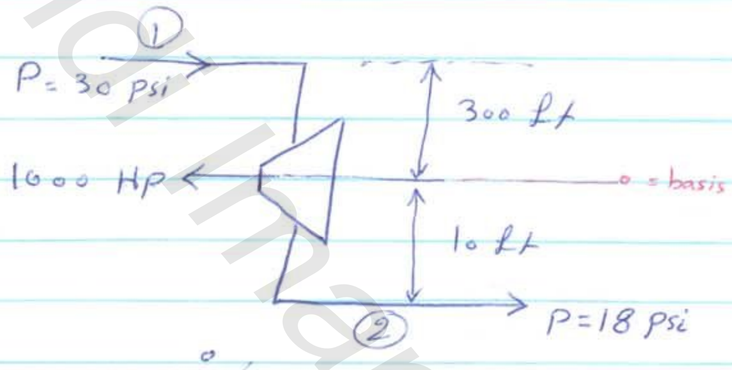
$= 23234\ \frac{J}{hr}$

مقدار Q مثال قبل

Mechanical Energy Balance:

Example 3: consider the following schewater for electric power. Determine the water flow through the turbine. Given the condition at the left. The conducts are of constant cross section and there are no losses.

$\frac{\Delta V^2}{2g_c} = 0$ $\qquad\qquad$ $\rightarrow F = 0$



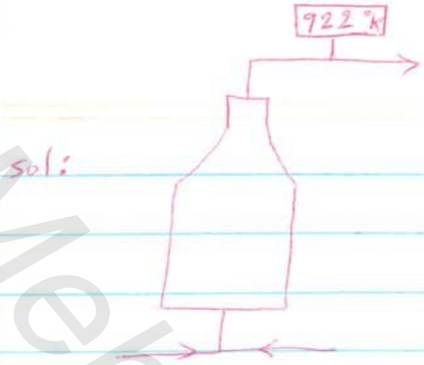
$$\overset{0}{\cancel{F}} + \frac{\Delta P}{\rho} + \overset{0}{\cancel{\frac{\Delta V^2}{2g_c}}} + \frac{g\Delta Z}{g_c} = -\frac{W}{\dot{m}}$$

$$\frac{(18-30)\ \frac{lb_f}{in^2}\ \frac{144\ in^2}{ft^2}}{62.4\ \frac{lb_m}{ft^3}} + \frac{(-10-300)\ ft\ \ 32.2\ \frac{ft}{sec^2}}{32.174\ \frac{lb_m . ft}{lb_f . sec^2}} = \frac{-1000\ Hp\ \frac{550\ \frac{lb_f . ft}{sec}}{1\ Hp}}{\dot{m}\left(\frac{lb_m}{sec}\right)}$$

$$\longrightarrow \dot{m} = 1627\ \frac{lb_m}{sec}$$

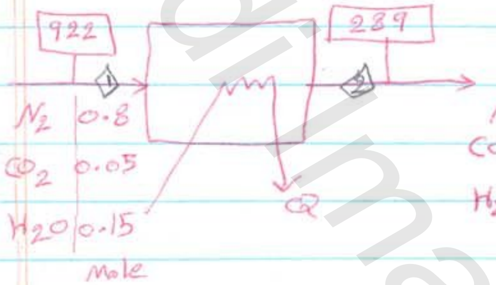
Example 4: A stack gas leaves a furnace at 922 °K and rapidally cools to the ambient temprature of 289 °K. How much heat is given off to the surronding if the composition of the gas is N_2 80% mol, CO_2 5% and H_2O 15%.

sol:



N_2 80% mol
CO_2 5%
H_2O 15%

Basis: 1 Mole



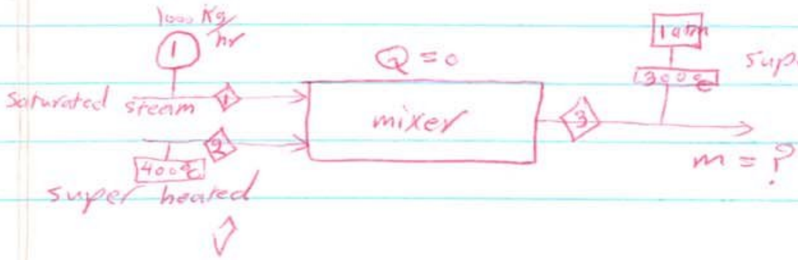
جابجا نوشتم

Comp	x (1)	$\hat{H}$	x (2)	$\hat{H}$
N_2	0.8	493	0.8	19667
CO_2	0.05	616	0.05	29180
H_2O	0.15	588	0.15	22945
		H_1		H_2

$$Q = H_o - H_i = \left[X(1,2)\hat{H}(1,2) + X(2,2)\hat{H}(2,2) + X(3,2)\hat{H}(3,2)\right] - \left[X(1,1)\hat{H}(1,1) + X(2,1)\hat{H}(2,1) + X(3,1)\hat{H}(3,1)\right]$$

$$Q = 510.4 - 20634 = -20123.6 \ J$$

Example 5: Saturated steam at 1 atm is discharged from a turbine at a rate of 1000 $\frac{Kg}{hr}$. super heated steam at 300 °c and 1 atm is needed as a feed to a heat exchanger to produce it, the turbine discharged stream is mixed with super heated steam availible from a second source at 400 °c and 1 atm. The mixing unit operate adiabatically. calculate the amount of steam at 300 °c produced, and the required flow rate of the 400 °c steam.



out = IN
material balance
$\dot{m} = \dot{m}_1 + \dot{m}_2$

$Q = \Delta H = 0$
$\rightarrow H_o = H_i$
Energy balance

$\dot{m}_3 \hat{H}(3) = \dot{m}_2 \hat{H}(2) + \dot{m}_1 \hat{H}(1)$

$\hat{H}(1) = 2676 \frac{Kg}{KJ}$ $\hat{H}(2) = 32788$ $\hat{V} = 3.11 \frac{m^3}{Kg}$ حجم ویژه

$\hat{H}(3) = 3074 \frac{Kg}{KJ} \longrightarrow \dot{m}_3(3074) = 1000(2676) + \dot{m}_2(3278)$

$\longrightarrow \boxed{\dot{m}_3 = 2951 \frac{Kg}{hr}}$, $\dot{m}_2 = 1951 \frac{Kg}{hr}$

$\dot{V}_2 = \dot{m}_2 V_2 = (1951 \frac{Kg}{hr})(3.11 \frac{m^3}{Kg}) = 6067 \frac{m^3}{hr}$

$\boxed{\text{chemical reaction:}}$ $(Q = \Delta H)$

$Q = \Delta H \longrightarrow \Delta H = \int_{T_{ref}}^{T} C_p \, dT \longrightarrow \hat{H}(T) - \hat{H}(T_{ref}) = \int_{T_{ref}}^{T} C_p \, dT$

$\longrightarrow \hat{H}(T) = \hat{H}(T_{ref}) + \int_{T_{ref}}^{T} C_p \, dT \longrightarrow \hat{H}(T) = \Delta\hat{H}_f + \int_{T_{ref}}^{T} C_p \, dT$

$CO + \frac{1}{2} O_2 \longrightarrow CO_2$ واکنش در 25°C انجام می‌شود.

$Q = \Delta H = (1)\hat{H}_{CO_2} - \left((1)\hat{H}_{CO} + (\frac{1}{2})\hat{H}_{O_2}\right)$

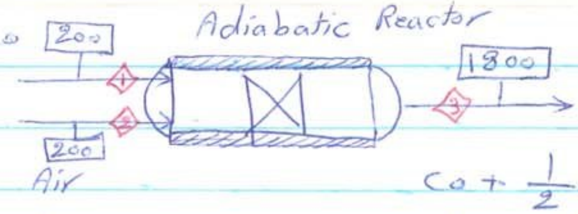
$Q = \left[\Delta\hat{H}_{f CO_2} + \cancel{\int_{25}^{25} C_{p CO_2} \, dT}\right] - \left[\Delta H_{f CO} + \cancel{\int_{25}^{25} C_{p CO} \, dT}\right] - \left[\frac{1}{2}\left(\Delta H_{f O_2} + \cancel{\int_{25}^{25} C_{p O_2} \, dT}\right)\right] \longrightarrow$

$Q = \Delta\hat{H}_{f CO_2} - \left(\Delta\hat{H}_{f CO} + \frac{1}{2}\Delta\hat{H}_{f O_2}\right)$

فرمول کلی : $\hat{H}(I,J) = \Delta\hat{H}_f(I,J) + \underbrace{\int_{T_{ref}}^{T_J} C_p(I,J) \, dT}_{H(I,J)}$

$Q = \Delta H_R + \Delta H$

Example 6:



$CO + \frac{1}{2} O_2 \longrightarrow CO_2$

conversion 100% %execess Air ?

Compo	1	2	3		
Co	100%	0	0	6	unknown
CO_2	0	0	$X(2,3)$	1	Basis
O_2	0	21%	$X(3,3)$	3	MB
N_2	0	79%	$X(4,3)$	1	Def
	S_1	S_2	S_3	5	→ 6
				Energy balance ← 1	

1 unknown from energy balance: $Q = \Delta H = 0 \longrightarrow H_o = H_I$

(*) $\longrightarrow X(2,3)\hat{H}(2,3) + X(3,3)\hat{H}(3,3) + X(4,3)\hat{H}(4,3) = S_1\hat{H}(1,1) + 0.21 S_2 \hat{H}(3,2) + 0.79 S_2 \hat{H}(4,3)$

(1) $S_1 = 1$ Mole

(2) $S_2 = S_1 \text{ mole } CO \left| \frac{\frac{1}{2} O_2}{1 \; S_1} \right| \frac{X \text{ mole Feed}}{1 \text{ mol Required}} \left| \frac{\text{Air}}{0.21 O_2} \right.$

(3) $X(2,3) = S_1 \; CO \left| \frac{1 \; CO_2}{1 \; CO} \right.$

(4) $X(3,3) = 0.21 S_2 - 1 \text{ mol } S_1 \; CO \left| \frac{\frac{1}{2} O_2}{1 \; CO} \right|$

(5) $X(4,3) = 0.79 S_2$

(6) $S_3 = X(2,3) + X(3,3) + X(4,3)$

$$\frac{\int c_p\,dT}{\int dT}$$

	$\Delta \hat{H}_f$ (Btu/gmol)	$\bar{C}_{p_m}$ (200 °F)	$\bar{C}_{p_m}$ (1800 °F)
CO_2	-169,315	9.203	11.880
CO	-47,554	6.981	7.566
O_2	0	7.114	7.946
N_2	0	6.967	7.480

$$\hat{H}(I,J) = \Delta\hat{H}_f(I,J) + \underbrace{\int_{77°F}^{T_J} \bar{C}_p(I,J)\,dT}_{\hat{H}(I,J)}$$

$\rightarrow \hat{H}(1,1) = -46695$ Btu/lbmol

$\hat{H}(3,2) = 879$

$\hat{H}(4,2) = 857$

$\hat{H}(2,3) = -148846$

$\hat{H}(3,3) = 13690$

$\hat{H}(4,3) = 12888$

$\longrightarrow$ (*) $X = 3.77$

$\longrightarrow$ % excess Air $= \frac{X-1}{1} \times 100 = 277\%$

Ideal Gas: $\boxed{PV = nRT}$

Real Gas: $PV = ZnRT$

$\downarrow$

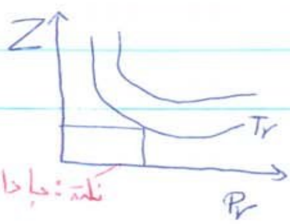
Devintion from ideal Gas

$V_r = \frac{V}{V_c}$

$P_r = \frac{P}{P_c}$

$T_r = \frac{T}{T_c}$

$Z = \frac{V_{actual}}{V_{ideal}}$ وابسته به دما و بالاخص فشار است،



نکته: با داشتن P_r , T_r ← Z بدست می‌آید.