CHAPTER ONE

INTRODUCTION

1.1 Introduction

Nitric acid (HNO_3), also known as aqua fortis and spirit of niter, is a highly corrosive and toxic strong mineral acid which is normally colorless but tends to acquire a yellow cast due to the accumulation of oxides of nitrogen if long-stored. Ordinary nitric acid has a concentration of 68%. When the solution contains more than 86% HNO_3, it is referred to as fuming nitric acid. Depending on the amount of nitrogen dioxide present, fuming nitric acid is further characterized as white fuming nitric acid or red fuming nitric acid, at concentrations above 95%. Nitric acid is also commonly used as a strong oxidizing agent. The earliest known written description of the method of synthesizing nitric acid is credited to the alchemist jabiribnhayyan (Geber).later a dutch chemist,johannrudolfglauber, was the first to make nitric by distillation of saltpeter with sulfuric acid , or oil of vitriol as he calld it . the product (sodium sulfate decahydrate)is named "Glauber,s salt " to commemorate him. Aqua regia (latin for royal water) is one of the chemical the ancient scientists concocted.It is a highly corrosive, fuming yellow or red solution. The mixture is formed by mixing concentrated nitric and hydrochloric acid, usually in a volumetric ratio of one to three. It is one of the few reagents that can dissolve gold and platinum, the so-called royal, or noble metals- hence the name "royal water". The effectiveness of aquaregia is partly because of the presence of both chlorine and nitrosylchloride.The main method for the manufacture of nitric acid based on the oxidation of ammonia in a way that the chemical developed by the German William Ostwald in 1901 is oxidation of ammonia to nitric oxide and carbon dioxide nitric air or oxygen the existence of a network of platinum as a catalyst, and then absorbs

nitrogen dioxide in the water component of nitric acid, smoked and then is distilled to remove water using sulfuric acid[1].Decomposes nitric acid giving the water and nitrogen dioxide and oxygen component liquid yellow brown. And nitric acid and, as noted previously fully ionized strong acid in aqueous solutions to ions and hydrogen ions and nitrate is also considered a strong oxidizing agent. Among the most important are the reactions of nitric acid neutralization reaction with ammonia to form ammonium nitrate and is an important compound enters the agricultural fertilizer industry.It called nitric acid salts as the nitrates .nitrate potassium known as rock salt and sodium nitrate for two large importance in the chemical industry, and almost all nitrate insoluble in water except under $BiONO_3.H_2O$ bismuth nitrate used in medicine to detect intestinal disorders. And betrick acid interaction with organic compounds produced many nitrate like Natroyjlasrin and Netrosslauluz. And the use of sodium nitrate and calcium and ammonium and potassium in the fertilizer industry to be a source of nitrogen for the germination of plant[1].

1.2 Uses of nitric acid[1]

1. As a starting material in the manufacture of nitrogen fertilizers such as ammonium nitrate, ammonium phosphate and nitro phosphate. A large amounts are reacted with ammonia to yield ammonium nitrate.

2. Weak acid are used to digest crude phosphates.

3. As a nitrating agent in the preparation of explosives such as TNT, nitroglycerine, cellulose polynitrate.

4. In manufacture of organic intermediates such as nitroalkanes and nitroaromatics.

5.Used in the production of adipic acid.

6. Used in fibers, plastics and dyestuffs industries

7.Used in metallurgy and in rocket fuel production

8.As the replacement of sulfuric acid in acidulation of phosphate rock.

1.3 Physical properties[1]

Dissociation constant (pKa) of -1.4.In aqueous solution, it almost completely (93% at 0.1 mol/L).Will decompose at higher temperatures to form nitrogen oxides. Nitric acid is both a strong acid and a strong oxidant, particularly when hot and Concentrate.

Table (1.1): physical properties of nitric acid

Properties	Value
Chemical formula	HNO_3
Molar mass g/mol	63.01
Density g/cm^3	1.5129
Melting point	-42 $^\circ$C
Boiling point	83°C
Flash point	Non – flammable
Heat of formation Kj/mol	-174.100
Heat of fusion Kj/mol	2.50

Chemical properties[1]

Nitric acid is normally considered to be a strong acid at ambient temperatures. There is some disagreement over the value of the acid dissociation constant , though the pk_a value is usually reported as less than (-1) .This means that the nitric acid in diluted solution is fully dissociated except in extremely acidic solutions the pk_a value rises to 1 at a temperature of 250 $^\circ$C [3].

CHAPTER TWO

MATERAIL BALANCE
AND
ENERGY BALANCE

2.1 Material Balance

2.1.1 Introduction

Material balances are important first step when designing a new process or analyzing an existing one. They are almost always prerequisite to all other calculations in the solution of process engineering problems. Material balances are nothing more than the application of the law of conservation of mass, which states that mass can neither be created nor destroyed. Thus, you cannot, for example, specify an input to a reactor of one ton of naphtha and an output of two tons of gasoline or gases or anything else. One ton of total material input will only give one ton of total output, i.e. total mass of input = total mass of output. A material balance is an accounting for material. Thus, material balances are often compared to the balancing of current accounts. They are used in industry to calculate mass flow rates of different streams entering or leaving chemical or physical processes.

Production capacity P=14644 tan/year[1]

Year=300 day

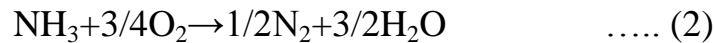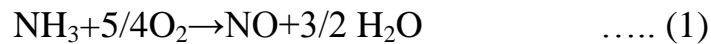P=14644 tan /yr * 1000 kg/tan * yr/300day * day/24hr.

P=2034Kg/hr   58%HNO_3

42%H_2O

Reactions:

In the reactor (oxidizer)

$$NH_3 + 5/4 O_2 \rightarrow NO + 3/2 \ H_2O \qquad \ldots (1)$$

$$NH_3 + 3/4 O_2 \rightarrow 1/2 N_2 + 3/2 H_2O \qquad \ldots (2)$$

In the cooler

$$NO + 1/2 O_2 \rightarrow NO_2 \qquad \ldots (3)$$

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO \qquad \ldots (4)$$

In the absorber

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO \qquad \ldots (5)$$

NH_3 F_1 ⟶ ⟶ Tail gases

Air F_2 ⟶ ⟶ P=2034Kg/hr 58wt% HNO_3

42 wt% H_2O

Reactions:

$$NH_3 + 5/4 O_2 \rightarrow NO + 3/2 \ H_2O \qquad \ldots (6)$$

$$NH_3 + 3/4 O_2 \rightarrow 1/2 N_2 + 3/2 H_2O \qquad \ldots (7)$$

$$NO + 1/2 O_2 \rightarrow NO_2 \qquad \ldots (8)$$

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO \qquad \ldots (9)$$

$$2NH_3 + 5/2 O_2 + 2NO_2 \rightarrow 2NHO_3 + NO + 2H_2O + 1/2 N_2 \ldots (10)$$
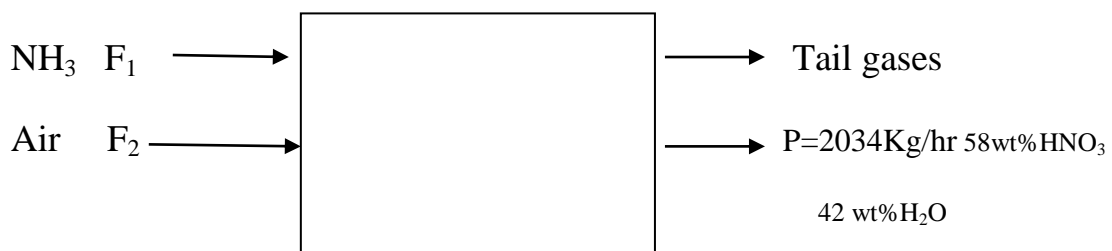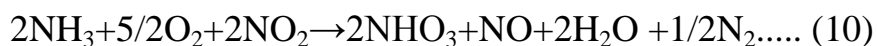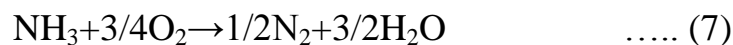
Over all yield of HNO_3 based on NH_3 = 94% [3]

$$Yield = \frac{\text{kmole } HNO_3 \text{ producte} * S}{\text{kmole } NH_3 \text{ fed to the process}}$$

S = stoichiometric factor

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$$S = \frac{\text{mole NH}_3}{\text{mole HNO}_3} \qquad \Longrightarrow \quad S = \frac{2}{2} = 1$$

HNO_3 product $= 0.58*P$

$= 0.58*2034$

$= 1179.72 Kg/hr$

mole product of $HNO_3 = 1179.72/63$

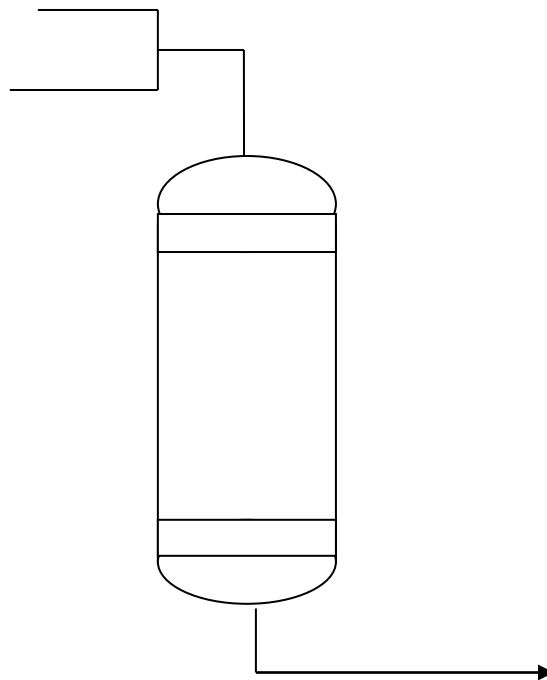$= 18.7257 Kmole/hr$

NH_3 fed to the process $= \frac{F_1}{17}$

$$0.94 = \frac{18.7257}{\frac{F_1}{17}}$$

$F_1 = 338.66$ k g/hr NH_3

2.1.2 Material Balances in Reactor(Oxidizer)(R-O1)

$338.66 Kg/hr F_1$

Kg/hr Air F_2

O_2 Kg/hr

N_2Kg/hr

NO Kg/hr

H_2O Kg/hr

Reactions :

Reaction 1= $NH_3 + 5/4 O_2 \rightarrow NO + 3/2\ H_2O$

Reaction 2= $NH_3 + 3/4 O_2 \rightarrow 1/2 N_2 + 3/2 H_2O$
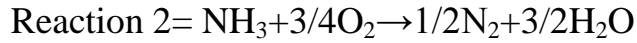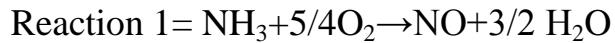
Excess air is supplied to the oxidizer to keep the ammonia concentration below the explosive limit reperted to be 13% by volume NH_3.
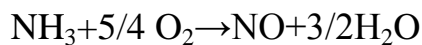
The inlet concentration of ammonia with be taken is 10% by volume [3]

Air supplied $= (\frac{F1}{17})(\frac{0.90}{0.15})$

$$= (\frac{338.66}{17})(\frac{0.90}{0.10})$$

$$= 179.2906\ Kmol/hr$$

Inlet O_2 $= 0.21(179.2906)$

$= 37.6510$ k mole/ hr

$= 1204.83$ k g/ hr

Inlet $N_2 = 0.79(179.2906)$

$= 141.6396$ k mole/ hr

$= 3965.91$ Kg/hr

Reaction (1)

$NH_3 + 5/4\ O_2 \rightarrow NO + 3/2 H_2O$

For reaction F1= 96% of NH_3 [3]

NH_3 reacted $= 0.96 * 338.66$

$$= 325.11\ k\ g\ /hr$$

$$= \frac{325.11}{17}$$

$$= 19.1241 \text{ k mole/ hr}$$

$$\text{O}_2 \text{ reacted} = \frac{5}{4}(19.1241)$$

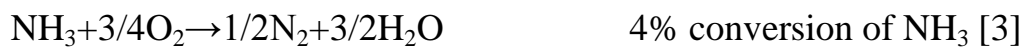$$= 764.96 \text{ Kg/hr}$$

NO produced $= 19.1241$ K mole/ hr

$$= 573.72 \text{ Kg/hr}$$

$$\text{H}_2\text{O produced} = \frac{3}{2}(19.1241)$$

$$= 28.6862 \text{Kmole/ hr}$$

$$= 516.35 \text{Kg/hr}$$

Reaction (2)

$$\text{NH}_3 + 3/4\text{O}_2 \rightarrow 1/2\text{N}_2 + 3/2\text{H}_2\text{O} \qquad \qquad 4\% \text{ conversion of NH}_3 \text{ [3]}$$

17   32   28   18

$$\text{NH}_3 \text{ reacted} = 0.04 \, F_1 = 0.04 \, (338.66)$$

$$= 13.55 \text{Kg/hr}$$

$$= \frac{13.55}{17} = 0.7971 \text{Kmole/hr}$$

$$\text{O}_2 \text{ reacted} = \frac{3}{4}(0.7971)$$

$$= 0.5978 \text{ Kmole/hr}$$

$$= 19.13 \text{ Kg/hr}$$

$$\text{N}_2 \text{ produced} = \frac{1}{2}(0.7971)$$

$$= 0.3986 \text{ Kmole/hr}$$

$$= 11.16 \text{Kg/hr}$$

H_2O produced $= \dfrac{3}{2}$ (0.7971)

$\qquad\qquad$ = 1.1957 k mole /hr

$\qquad\qquad$ = 21.52 Kg/hr

Exit products

O_2 = inlet − reacted

$\quad$ = 1204.83 − 764.96 − 19.13 $\implies$ 420.74Kg/hr

N_2= inlet + produced

$\quad$ = 3965. 91 + 11.16

$\quad$ = 3977.07Kg/hr

NO = inlet + produce

$\quad$ = 0 + 573.72 $\implies$ 573.72 Kg/hr

H_2O = inlet + produced

$\quad$ = 0 + 516.35 + 21.52

$\quad$ = 537.87 Kg/hr

Compound	In put / Kg/hr	Out put / Kg/hr
NH_3	338.6	-
O_2	1204.83	420.74
N_2	3965.91	3977.07
NO	-	573.72
H_2O	-	537.87
Total	5509.40	5509.40

2.1.3 Material Balance On Cooler Condenser

In the cooler – condenser the gases are cooled from 234 ∘c to 40 ∘c (at 8 atm). The composition of the acid leaving the unit is taken as 45 wt % HNO_3 .

420.74 Kg/hr O_2

3977.07 Kg/hr N_2 C-O3

573.72 Kg/hr NO

537 .87 Kg/hr H_2O

O_2= e Kg/hr

N_2 =b Kg/hr

NO =r Kg/hr

NO_2 =m Kg/hr

T= 40 ∘C

55wt% H_2O

45wt% HNO_3

$NO + 1/2\ O_2 \rightarrow NO_2(g)$

$3NO + H_2O \rightarrow 2HNO_3 + NO$
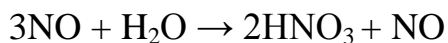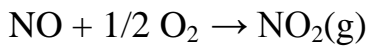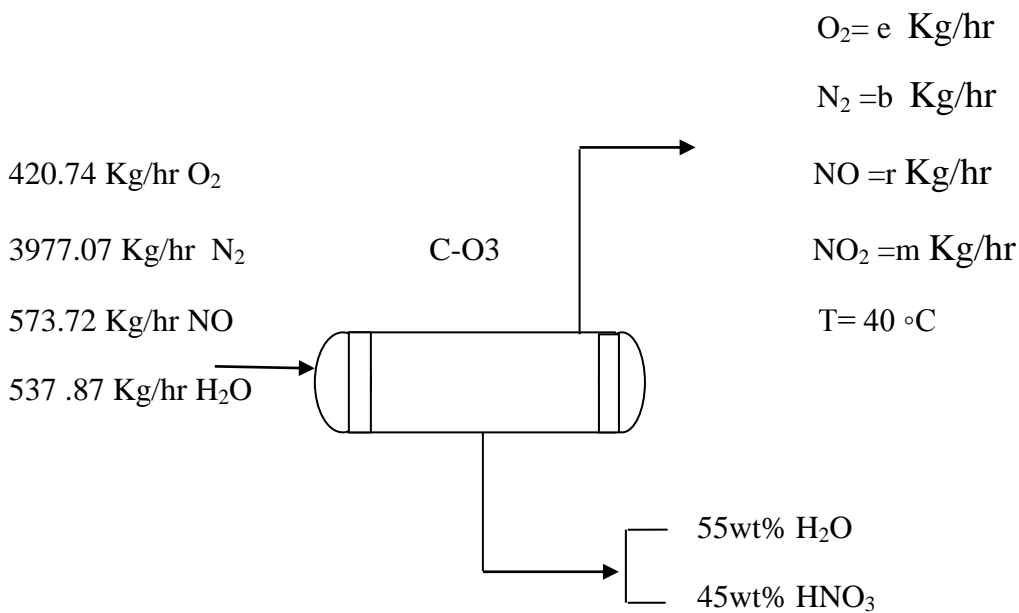
For simplicity in this preliminary balance the quantity of (NO) in the outlet gases, will be take as equal to the quantity from reaction (4)

H_2O balance :

In – reacted = out

$(\frac{537.87}{18}) - (\frac{0.45B}{63})(\frac{1}{2}) = (\frac{0.55B}{18})$

29.88= 0.03413 B

B = 875.60 Kg/hr

Stream B

$H_2O = 0.55B = 0.55(875.60)$

$\quad = 481.58$ Kg/hr

$HNO_3 = 0.45B = 0.45(875.60) \Longrightarrow 394.02$ Kg/hr

O_2 balance

In – reacted = out

$(\dfrac{420.74}{32}) - (\dfrac{573.72}{30})(\dfrac{1}{2}) = \dfrac{e}{32}$

$e = 114.76$ kg/ hr O_2

N_2 in $= N_2$ out

$b = 3977.07$ Kg/hr

NO balance

NO out = NO produced from reaction (4)

$r = (\dfrac{0.45B}{63})(\dfrac{1}{2})(30)$

$\quad = (\dfrac{0.45*835.60}{63})(\dfrac{1}{2})(30)$

$\quad = 93.81$ Kg/hr NO

NO_2 balance

In + generation = out + consumption

$0 + (\dfrac{573.72}{30}) = (\dfrac{m}{46}) + (\dfrac{0.45*875.6}{63})(\dfrac{3}{2})$

$m = 448.16$ Kg/hr NO_2

Compound	In put / Kg/hr	Out put / Kg/hr
O_2	420.74	114.76
N_2	3977.07	3977.07
NO	573.72	93.81
NO_2	-	448.16
H_2O	537.87	481.58
HNO_3	-	394.02
Total	5509.4	5509.4

2.1.4 Material Balance In Absorber

W

Kg/hr H_2O

$O_2 = n_1$ kg/ hr

$N_2 = n_2$ Kg/hr

NO $= n_3$ Kg/hr

$NO_2 = n_4$ Kg/hr

A Kg/hr

42 wt% H_2O [3]

114.76K /hr O_2

3977.07 Kg/hr N_2

93.81 Kg/hr NO

448.161 Kg/hr NO_2

P = 2034Kg/hr

58 wt% HNO_3

481.58 B

Kg/hr H_2O
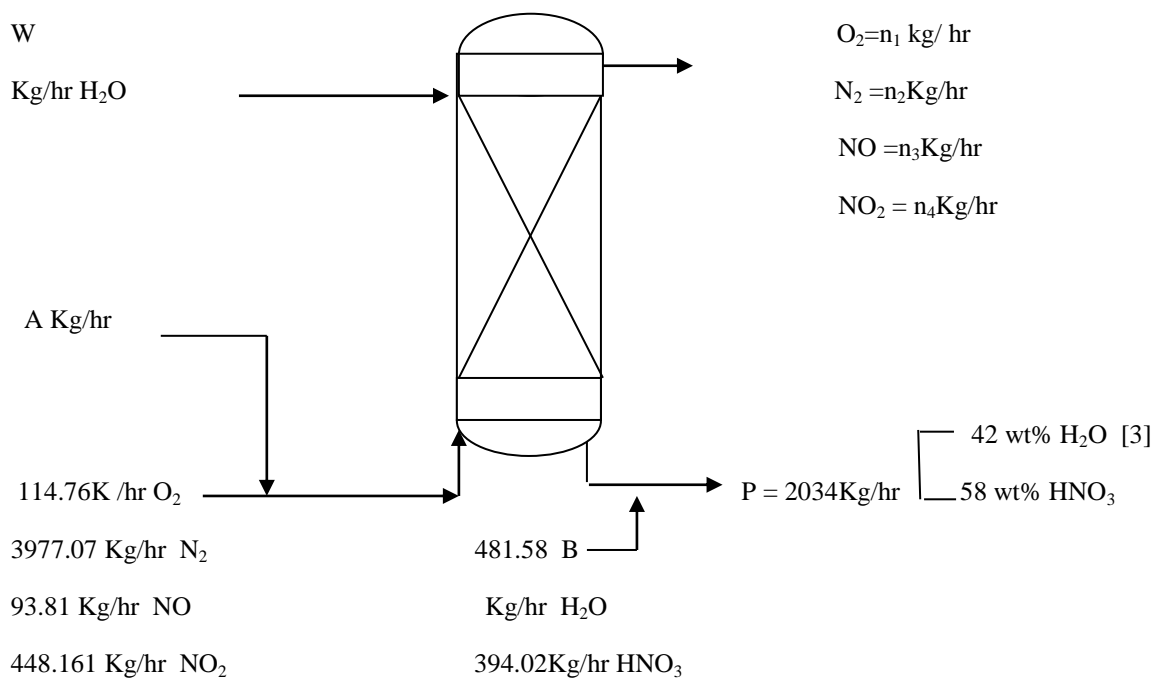
394.02Kg/hr HNO_3

The air consist of 21 % O_2 and 79 % by volume

$$O_2 wt\% = \frac{0.21*32}{(0.21*32)+(0.79*28)}$$

O_2= 23.30 wt%

N_2 = 76.7 wt %

Stream L

$H_2O = 0.42P - 481.58$

$\quad = 0.42\,(2034) - 481.58$

$\quad = 372.70$ Kg/hr

$HNO_3 = 0.58\,P - 394.02$

$\quad = 0.58\,(2034) - 394.02$

$\quad = 785.70$ Kg/hr

H_2O balance

$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$
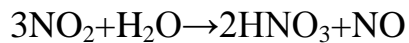
In − reacted = out

$(\frac{w}{18}) - (\frac{785.7}{63})\,(\frac{1}{2}) = (\frac{372.70}{18})$

W= 484.94 Kg/hr

N_2 balance

In = out $\implies$ $3977.07 + 0.767A = 0.9629\,G$

$A = 1.2554G - 5185.23$ $\qquad$ …..(1)

Reactions :

$NO + 1/2\,O_2 \rightarrow NO_2(g)$

$3NO + H_2O \rightarrow 2HNO_3 + NO$
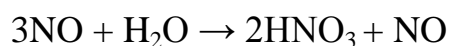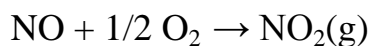
Tail gases containing 3% O_2 and 0.2 % NO

Assume = 0.05% NO

Percent of N_2 in the tail gases

$= 1 - 0.03 - 0.002 - 0.0005$

$= 0.9672 = 96.75 \%$

The percentage must be contacted to weight percent .

$$O_2 \text{wt} \% = \frac{(0.03*32)}{(0.03*32)+(0.002*30)+(0.9675*28)+(0.0005*46)}$$

$O_2 = 3.41 \text{ wt}\%$

$N_2 = 96.29 \text{ wt } \%$

$NO = 0.21 \text{ wt}\%$

$NO_2 = 0.08 \text{ wt}\%$

<u>Over all material balance</u>

$w + A + (114.70 + 3977.07 + 93.81 + 448.16) + B = G + P$

$484.94 + A + 4633.74 + (481.58 + 394.02) = G + 2034$

$A = G - 3960.28 \ldots\ldots (2)$

Substitution equation (2) in (1) we get

$G - 3960.28 = 1.2554 \, G - 5185.23$

$1224.95 = 0.2554 G$

$G = 4796.20 \text{ Kg/hr}$

$A = 4796.20 - 3960.28$

$= 835.92 \text{ Kg/hr air (secondary air)}$

Stream G

$O_2 = 0.0341\ G = 0.0341\ (4796.201)$

$= 163.55$ Kg/hr

$N_2 = 0.9629\ G = 0.9629\ (4796.201)$

$= 4618.26$ Kg/hr

$NO = 0.0021\ G = 0.0021\ (4796.201)$

$= 10.07$ Kg/hr

$NO_2 = 0.00086G = 0.00086\ (4796.201)$

$= 3.84$ Kg/hr

over all material balance

484.94 Kg/hr H_2O	W	G 4796.20Kg/hr gase
338.66 Kg/hr HN_3	F_1	
1204.83 Kg/hr O_2	F_2	P 2034 kg/ hr
835.92 Kg/hr Air	A	
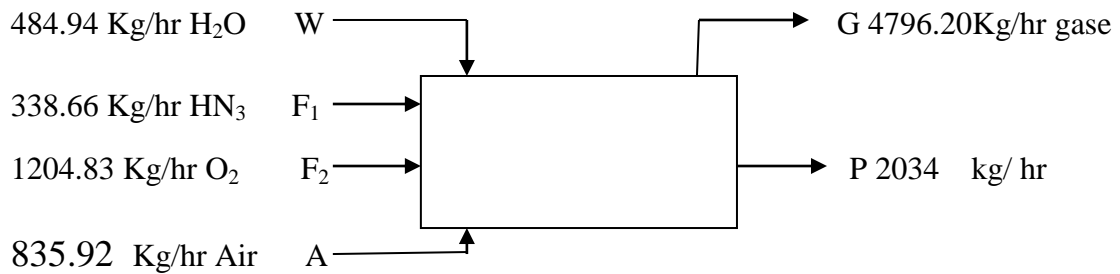
Total in $= w + F_1 + F_2 + A$

$= 484.94 + 338.66 + 1204.83 + 3965.91 + 835.92$

$=\ 6830.26$Kg/hr

Total out $= G + P$

$= 4796.20 + 2034$

$= 6830.20$ Kg/hr

2.2 Energy Balance

Gas Heat capacity

$$C_P = a + b\,T + C\,T^2 + d\,T^3 \text{ [3]}$$

C_P = gas heat capacity J/ mol .k

 T = temperature   k

2.2 .1 energy balance on compressor

O_2 1204.83Kg/hr O_2 1204.83 Kg/hr
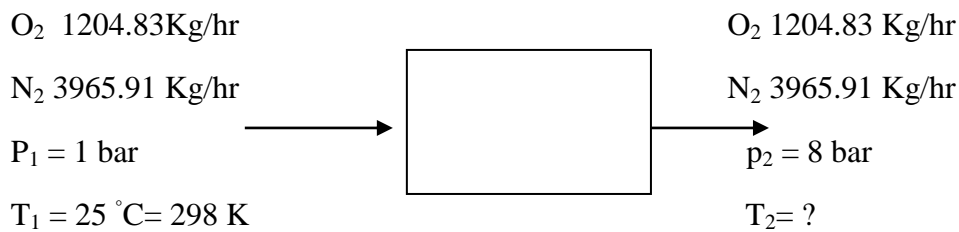
N_2 3965.91 Kg/hr N_2 3965.91 Kg/hr

$P_1 = 1$ bar $p_2 = 8$ bar

$T_1 = 25\ °C = 298$ K $T_2 = ?$

$$\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^m \qquad \text{[3]}$$

$$m = \frac{\gamma - 1}{\gamma E_P}$$

$$\gamma = \frac{C_P}{C_V}$$

= 1.4 for air   [3]

E_P = compressor efficiency

For inlet conditions

$$P_1\,V_1 = n_1 R T_1$$

$P_1 = 1$bar $= 100$ k pa

$T_1 = 25\ °C = 298$ K

$$n_1 = \frac{1204.83}{32} + \frac{3965.91}{28} = 179.291 \ \text{k mol/hr}$$

$$100 \ V_1 = 179.291 * 8.314 * 298$$

$$V_1 = 4442.06 \ \text{m}^3/\text{hr}$$

$$= 1.23 \ \text{m}^3/\text{s}$$

For $V_1 = 1.23 \ \text{m}^3/\text{s}$ and centrifugal compressor $E_P = 68\%$ Fig (3.6) [3]

$$m = \frac{1.4-1}{1.4*0.68} = 0.420$$

$$(\frac{T_2}{298}) = (\frac{8}{1})^{0.42}$$

$$T_2 = 714 \ k = 441 \ C^{\circ}$$

$$W = Z_1 \ T_1 \ R \ (\frac{n}{n-1}) \ [(\frac{P_2}{P_1})^{\frac{(n-1)}{n}} - 1] \qquad\qquad [3]$$

Where

W= work k j/k mol

$Z_1 = 1$ $P_1 = 1\text{bar}$

$$n = (\frac{1}{1-m})$$

$$n = (\frac{1}{1-0.42}) = 1.724$$

$$w = 298*8.314 \ (\frac{1.724}{1.724-1}) \ [(\frac{8}{1})^{\frac{(0.724)}{1.724}} \ -1 \ ]$$

$$w = 8228 \ \text{k j/k mol}$$

$$w = 8228(\frac{k \ j}{k \ mol}) * 179.291 \ (\frac{k \ mol}{hr})$$

$$= 1475206 \ \text{k j /hr}$$

$$\text{Power} = \left(\frac{w}{E_P}\right) = \left(\frac{1475206}{0.68}\right)$$

$$= 2169421 \text{ k j/hr}$$

$$= 603 \text{ k w}$$

2.2.2 Energy Balance on Cooler (CO-3)

The air is cooled from $441^\circ C$ to $230^\circ C$ [3]

O_2 1204.83 Kg/hr

N_2 3965.91 Kg/hr

$T = 441^\circ C$ (714 K)

O_2 1204.83 Kg/hr

N_2 3965.91 Kg/hr

$T = 230^\circ C$ (503K)
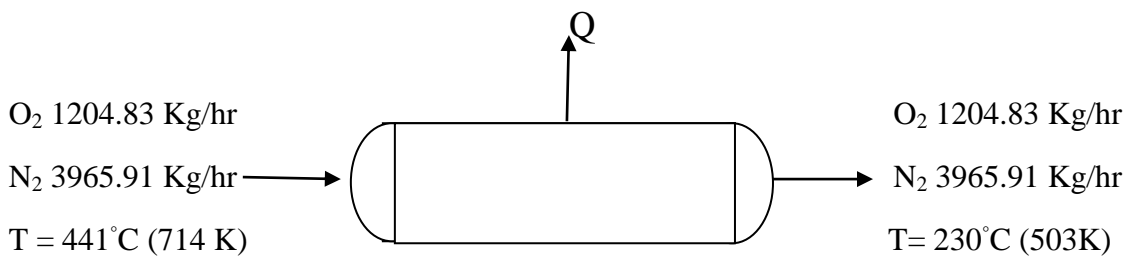
Energy balance

$m \Delta H_{in} = m \Delta H_{out} + Q$

$T_{ref} = 25^\circ C = 298 \text{ k}$

$m\Delta H_{in} = \Sigma mi \int_{298}^{714} cpi \, dT$

$m\Delta H_{in} = \dfrac{1204.83}{32} [\, 28.106(714\text{-}298) - \dfrac{3.68*10^{-6}}{2}(714^2\text{-}298^2)$

$+\dfrac{1.745*10^{-5}}{3}(714^3\text{-}298^3) - (\dfrac{1.065*10^{-8}}{4}) \, (714^4\text{-}298^4) + \dfrac{3965.91}{28}$

$[31.15(714\text{-}298)-\dfrac{1.356*10^{-2}}{2} (714^2\text{-}298^2) +\dfrac{2.679*10^{-5}}{3}(714^3\text{-}298^3)- \dfrac{1.168*10^{-8}}{4}$

$(714^4\text{-}298^4)]$

$m\Delta H_{in} = 2194048 \text{ k j/hr}$

$M \Delta H_{out} = \Sigma mi \int_{298}^{503} cpi \, dT$

$$m\Delta H_{out} = \frac{1204.83}{32} [\ 28.106(503\text{-}298) - \frac{3.68*10^{-6}}{2}(503^2\text{-}298^2) + \frac{1.745*10^{-5}}{3}$$

$$(503^3\text{-}298^3)\ -(\frac{1.065*10^{-8}}{4})\ (503^4\text{-}298^4) + \frac{3965.91}{28}[31.15(503\text{-}298)\text{-}\ \frac{1.356*10^{-2}}{2}$$

$$(503^2\text{-}298^2)\ +\frac{2.679*10^{-5}}{3}(503^3\text{-}298^3)\text{-}\ \frac{1.168*10^{-8}}{4}\ 503^4\text{-}298^4)]$$

$m\Delta H_{out} = 1079082$ k j/hr

$2194048 = 1079082 + Q$

$Q = 1114966$ k j /hr

$Q = mC_P\Delta T_{H2O}$ $\quad\quad \Delta T_{H2O} = 40\text{-}25 = 15\ °C$ $\quad$ [3]

$m = (\frac{Q}{CP\Delta T_{H2O}}) = \frac{1114966}{4.2*15} = 17698$ Kg/hr $\quad H_2O$

2.2.3 Energy Balance On Ammonia Vaporizer

The ammonia will be stored under 8 bar as liquid at $15°C$ .the saturated of ammonia at 8 bar is $20\ °C$ $\quad\quad$ [3]

NH_3 338.66Kg/hr $\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad$ NH_3 338.66 kg/ hr

Liquid at 15 °C = 288 K $\quad\quad\quad\quad\quad\quad\quad\quad$ sat . vapour at 20 °C =293 K[3]

Q
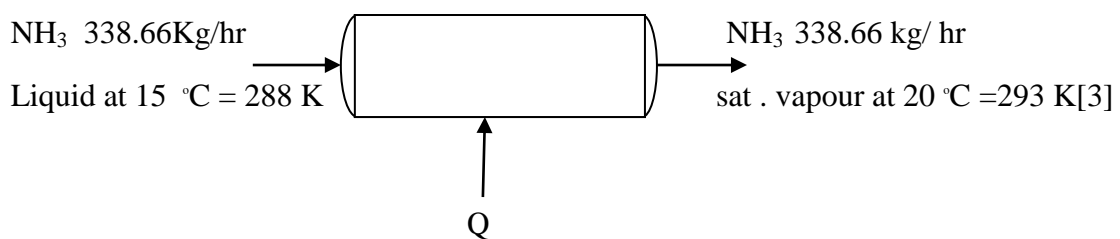
Energy balance

$m\Delta H_{in} +\ Q = m\Delta H_{out}$

T_{ref} 25°C = 298 K

$m\Delta H_{in} = mC_P\Delta T$

$$= (338.66*4.54)(293-298)$$

$$= -15375 \text{ k j/hr}$$

$$m\Delta H_{out} = mC_P\Delta T + m\lambda$$

$$= (338.66*4.54)(293-298) + (338.66*1374)$$

$$= 457631 \text{ k j/hr } -15375 + Q = 457631$$

$$Q = 473006 \text{ k j/hr}$$
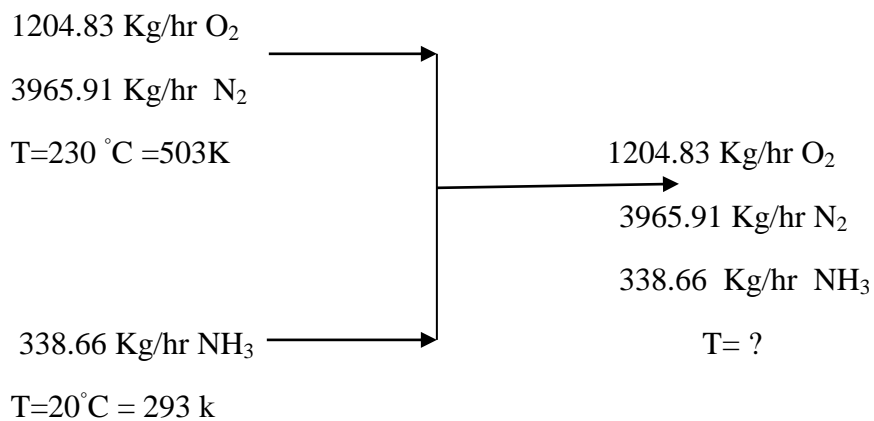
Q is supplied by saturated steam at 100 C° and 101.3 k pa

$\lambda = 2257 \text{ k j/kg}$ [5]

$Q = m \lambda \rightarrow m = \frac{Q}{\lambda}$

$m = \dfrac{473006}{2257} = 210 \text{ Kg/hr steam}$

2.2.4 Energy Balance on Mix Point

1204.83 Kg/hr O_2

3965.91 Kg/hr N_2

T=230 °C =503K   1204.83 Kg/hr O_2

                                                3965.91 Kg/hr N_2

                                                338.66 Kg/hr NH_3

 338.66 Kg/hr NH_3 T= ?

T=20°C = 293 k

Energy balance

$$M \Delta H_{in} = m \Delta H_{out}$$

$$T_{ref} = 25^{\circ}C = 298 \text{ k}$$

$$M \Delta H_{in} = \Sigma \, mi \int_{298}^{503} cpi \, dT + m \int_{298}^{293} cpdT$$

$$m\Delta H_{in} = \frac{1204.83}{32} [\, 28.106(503\text{-}298) - \frac{3.68*10^{-6}}{2}(503^2\text{-}298^2)$$

$$+\frac{1.745*10^{-5}}{3}(503^3\text{-}298^3) -(\frac{1.065*10^{-8}}{4}) \, (503^4\text{-}298^4)+\frac{3965.91}{28}$$

$$[31.15(503\text{-}298)-\frac{1.356*10^{-2}}{2}\,(503^2\text{-}298^2) +\frac{2.679*10^{-5}}{3}(503^3\text{-}298^3)- \frac{1.168*10^{-8}}{4}$$

$$(503^4\text{-}298^4)] + \frac{338.66}{17}[\, 27.315(293\text{-}298) + \frac{2.383*10^{-2}}{2}(293^2\text{-}298^2)$$

$$+\frac{1.705*10^{-5}}{3}(293^3\text{-}298^3) -(\frac{1.184*10^{-8}}{4}) \, (293^4\text{-}298^4)$$

$$m\Delta H_{in} =233372+ 851069\text{-} 3540$$

$$= 1080901\text{k j/hr}$$

$$M \Delta H_{out} = \Sigma \, mi \int_{298}^{T} cpi \, dT$$

$$m\Delta H_{in} = 1204.83 [\, 28.106(T\text{-}298) - \frac{3.68*10^{-6}}{2}(T^2\text{-}298^2) +\frac{1.745*10^{-5}}{3}$$

$$(T^3\text{-}298^3) -(\frac{1.065*10^{-8}}{4}) \, (T^4\text{-}298^4)+\frac{3965.91}{28} [31.15(T\text{-}298) - \frac{1.356*10^{-2}}{2} \, (T^2\text{-}$$

$$298^2) +\frac{2.679*10^{-5}}{3}(T^3\text{-}298^3)- \frac{1.168*10^{-8}}{4} \, (T^4\text{-}298^4)] + \frac{338.66}{17} [\, 27.315(T\text{-}298)$$

$$+ \frac{2.383*10^{-2}}{2}(T^2\text{-}298^2) +\frac{1.707*10^{-5}}{3}(T^3\text{-}298^3) -(\frac{1.184*10^{-8}}{4}) \, (T^4\text{-}298^4)$$

$$m\Delta H_{out}= 6014.439(T\text{-}298)\text{-} 0.723(T^2\text{-}298)+ 1.597*10^{-3}(T^3\text{-}298)\text{-} 5.728*10^{-8}(T^4\text{-}298)$$
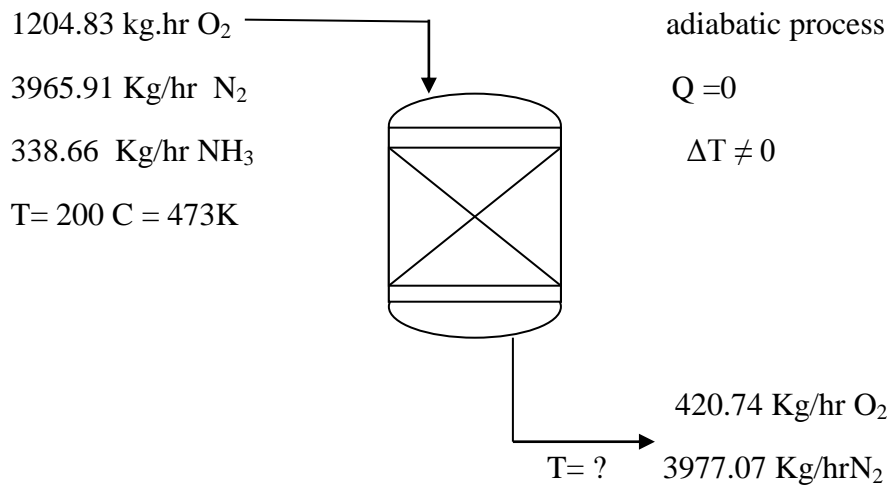
$1080901 = 6014.439(T-298) - 0.723(T^2-298^2) + 1.597*10^{-3}(T^3-298^3) - 5.728*10^{-8}(T^4-298^4)$

By trial and error

T K	Left side	Right side
470	1080901	1060178
475	1080901	1092061
473.25	1080901	1080894

Exit mixture temp. = 473.25 k= 200 °C

2.2.5 Energy Balance on Reactor

1204.83 kg.hr O_2 adiabatic process

3965.91 Kg/hr N_2 Q =0

338.66 Kg/hr NH_3 $\Delta T \neq 0$

T= 200 C = 473K

420.74 Kg/hr O_2

T= ?   3977.07 Kg/hrN$_2$

573.72 Kg/hr   NO

537.87 Kg/hr H_2O

Reactions

$NH_3+5/4O_2 \rightarrow NO+3/2\ H_2O$

$NH_3+3/4O_2 \rightarrow 1/2N_2+3/2H_2O$
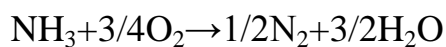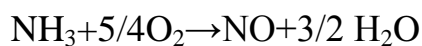
Energy balance

$$M \Delta H_{in} = m \Delta H_{out} + n_1 \Delta H_{r1} + n_2 \Delta H_{r2}$$

$$T_{ref} = 25°C = 298 \text{ k}$$

$$M \Delta H_{in} = \Sigma \, m_i \int_{298}^{473} c_{pi} \, dT$$

$$= 1080901 \text{ k j/hr}$$

$$M \Delta H_{out} = \Sigma \, m_i \int_{298}^{T} c_{pi} \, dT$$

$$= \frac{1204.83}{32} [\, 28.106(T-298) - \frac{3.68*10^{-6}}{2}(T^2-298^2) + \frac{1.745*10^{-5}}{3}(T^3-298^3) -$$

$$(\frac{1.065*10^{-8}}{4}) \, (T^4-298^4) + \frac{3977.07}{28} [31.15(T-298) - \frac{1.356*10^{-8}}{2} \, (T^2-298^2)$$

$$+ \frac{2.679*10^{-5}}{3}(T^3-298^3) - \frac{1.168*10^{-8}}{2} \, (T^2-298^2) + \frac{2.679*10^{-5}}{3}(T^3-298^3) -$$

$$\frac{1.168*10^{-8}}{4} + (T^4-298^4) + \frac{375.72}{30}[\, 29.345 \, (T-298) - \frac{9.378*10^{-6}}{2}(T^2-298^2)$$

$$+ \frac{9.746*10^{-6}}{3}(T^3-298^3) - (\frac{4.186*10^{-6}}{4}) \, (T^4-298^4) + \frac{537.87}{18} [32.243 \, (T-$$

$$298) + \frac{1.923*10^{-3}}{2} \, (T^2-298^2) + \frac{1.055*10^{-5}}{3}(T^3-298^3) - \frac{3.596*10^{-9}}{2}$$

$$m\Delta H_{out} = 6318.70 \, (T-298) - 0.9433(T^2 - 298^2) + 1.5121*10^{-3}$$

$$(T^3 - 298^3) - 4.966*10^{-7}(T^4 - 298^4)$$

$$\Delta H_r = \Sigma \Delta H_{298P} - \Sigma \Delta H_{298R}$$

Reaction (1)

$$\Delta H_{r1} = \frac{3}{2} \Delta H_{F298H2O} + \Delta H_{F298NO} - \frac{5}{2} \Delta H_{F298O2} - \Delta H_{F298NH3}$$

$$= \frac{3}{2} \, (-242) + (90.43) - 0 - (45.72)$$

$$n_1 \, \Delta H_{r1} = -227.22 \text{ kj/hr}$$

Reaction (2)

$$\Delta H_{r1} = \frac{3}{2} \Delta H_{F298H2O} + \frac{1}{2} \Delta H_{F298N2} - \frac{3}{4} \Delta H_{F298O2} - \Delta H_{F298NH3}$$

$$= \frac{3}{2} (-242) + (0) - 0 - (45.72)$$

$$= -317.82 \text{ k j/hr}$$

NH_3 reacted $= 0.7971$ k mol/hr
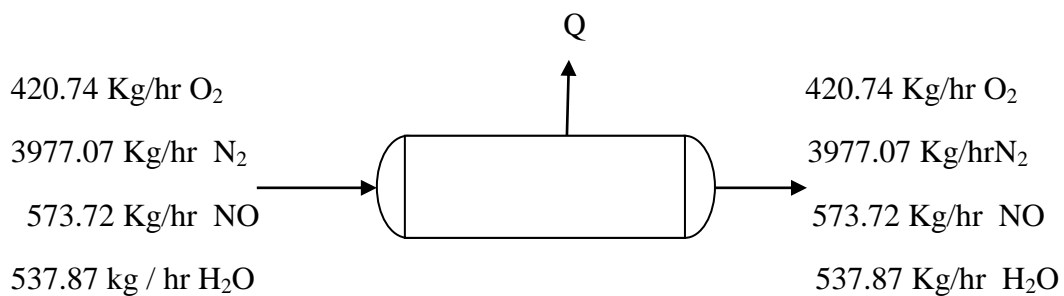
$$= 797.1 \text{ mol /hr}$$

$n_2 \Delta H_{r2} = (797.1)(-317.82)$

$$= -253334 \text{ k j/hr}$$

Exit temperature from reactor $= 900 \,^{\circ}C$

2.2.6 Energy balance on wast heat boiler

The gases are cooled from 900 to 234 $^{\circ}C$

420.74 Kg/hr O_2 420.74 Kg/hr O_2

3977.07 Kg/hr N_2 3977.07 Kg/hrN_2

573.72 Kg/hr NO   573.72 Kg/hr NO

537.87 kg / hr H_2O 537.87 Kg/hr H_2O

$M \Delta H_{in} = m \Delta H_{out} + Q$

$m \Delta H_{in} = \Sigma mi \int_{298}^{1173} cpi \, dT$

$m\Delta H_{in} = 5685201$ k j/hr

$$m \, \Delta H_{out} = \Sigma \, mi \int_{298}^{507} cpi \, dT$$

$$m\Delta H_{out} = 6318.70(507\text{-}298)\text{-}0.9433(507^2\text{-}298^2)+1.5121*10^{-3}(507^3\text{-}298^3)\text{-}$$

$$4.966*10^{-7}(507^4\text{-}298^4)$$

$$m\Delta H_{out} = 1290054 \text{ k j/hr}$$

$$5685201 = 1290054 + Q \implies Q = 4395147 \text{ k j /hr}$$

Water inlet at 25 °C and 10 bar and exit saturated vapour at 10 bar T sat = 180°C   [5]

$\lambda = 2013$ k j /kg   [5]
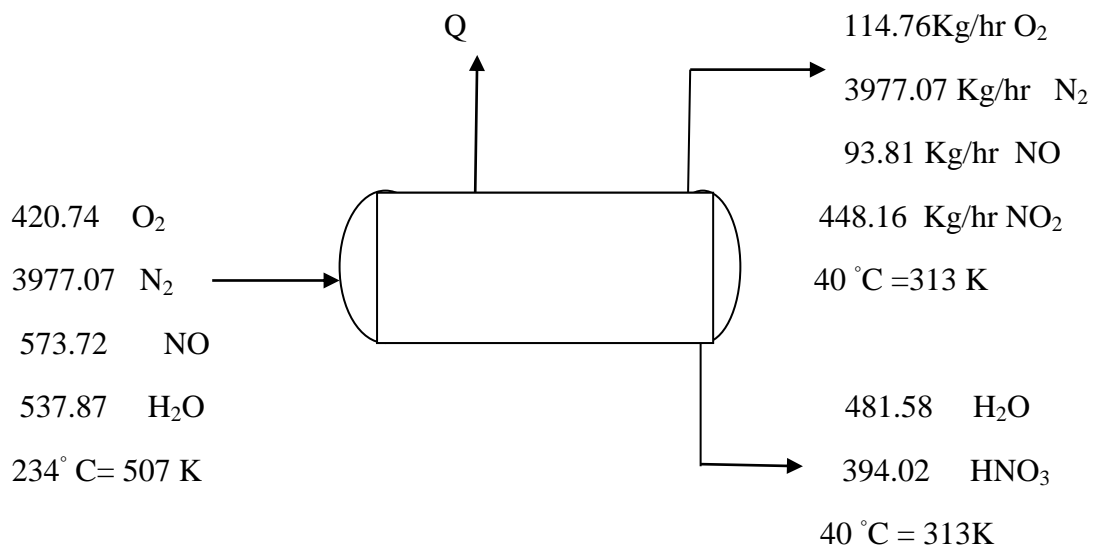
$$Q = m \, C_p \, \Delta T + m\lambda$$

$$m = \frac{Q}{cp\Delta T + \lambda} = \frac{4395147}{4.2(180-25)+2013}$$

m = 1650 Kg/hr steam

2.2.7 Energy Balance on Cooler Condenser

The gases are cooled from 234 to 40 °C

Q

114.76Kg/hr O_2

3977.07 Kg/hr N_2

93.81 Kg/hr NO

448.16 Kg/hr NO_2

40 °C = 313 K

420.74 O_2

3977.07 N_2

573.72   NO

537.87 H_2O

234° C = 507 K

481.58 H_2O

394.02 HNO_3

40 °C = 313K

Reactions:

$$NO + 1/2 O_2 \rightarrow NO_2$$

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$
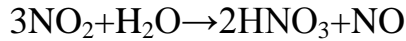
Energy balance

$$M \Delta H_{in} = m \Delta H_{out} + n_1 \Delta H_{r1} + n_2 \Delta H_{r2} + Q$$

$$m\Delta H_{in} = \Sigma \, mi \int_{298}^{507} CPidT_{gases} + m\lambda_{H2O} + m\lambda_{HNO3}$$

$$\Sigma mi = \int_{298}^{507} cpidT = 1290054 \, k\frac{j}{hr}$$

$$M\lambda_{H2O} + m\lambda_{HNO3} = (481.58*2260) + (3940.02*627)$$

$$= 3558763 \, k \, j/hr$$

$$m\Delta H_{in} = 1290054 + 3558763 = 4848817 k \, j/hr$$

$$m\Delta H_{out} = \Sigma \, mi \int_{298}^{313} CPdT_{gases} + \Sigma \, miC_{Pi}\Delta T_{\,liquid}$$

gas heat between $25 - 40 \, ^{\circ}C$ (298- 313k)

Component	CP KJ /Kg .k [3]
O_2	0.92
N_2	1.04
NO	1.0
NO_2	0.81

$$m\Delta H_{out} = [(114.76*0.92) + (3977.07*1.04) + (93.81*1.0) + (448.16*0.81)][313-298] + [(481.58*4.20) + (394.02*1.94)][313-298]$$

$$= 112284 \, k \, j/hr$$

$$\Delta H_{r298} = \Sigma\Delta H_{f298p} - \Sigma\Delta H_{f298R}$$

Reaction (1)

$\Delta H_{r1} = (33.87) - 0 - (90.43)$

$\quad = -56.56 \text{ k j/mol}$

$\Delta H_{r1} = \Delta H_{r2} + \int_{298}^{313} \Delta CPdT$

$\int_{298}^{313} \Delta CPdT = \int_{298}^{313} CPdT_{NO2} - \frac{1}{2}\int_{298}^{313} CPdT_{O2} - \int_{298}^{313} CPdT_{NO}$

$\quad = [(0.81*46) - (\frac{1}{2})(0.92*32) - (1*30)][313-298]$

$\quad = -112 \text{ J /mol}$

$\quad = 0.11 \text{ k j/mol}$

$\Delta Hr_1 = -56.56 - 0.11$

$313 = -56.67 \text{ kg/mol}$

No reacted $n_1 = (\frac{573.72}{30})(1000) = 19124 \text{ mol/hr}$

$n_1 \Delta H_{r1} = (19124)(-56.67)$

$\quad = -1083757 \text{ k j/hr}$

Reaction (2)

$\Delta H_{r2} = (90.43) + 2(-173.67) - (-242) - 3(33.87)$

$\quad = -116.52 \text{k j/mol}$

$\Delta H_{r2} = \Delta H_{r2} + \int_{298}^{313} \Delta CPdT$

313   298

$\int_{298}^{313} \Delta CPdT = \int_{298}^{313} CPdT_{NO} - 2\int_{298}^{313} CPdT_{HNO3} - \int_{298}^{313} CPdT_{H2O}$

$-3\int_{298}^{313} cpdT_{NO2}$

$= [(1*30) + 2(1.94*63) - (4.20*18) - 3(0.81*46)]*[(0.81*46)]*[313-298]$

$$= 1306 \text{ J /mol}$$

$$= 1.31\text{k j/mol}$$

$\Delta Hr_2 = -116.5 + 1.31 \implies = -115.21\text{kJ/mol } H_2O \text{ reacted}$

H_2O reacted $n_1 = (\dfrac{537.87-481.58}{17})(1000) = 3127$ mol/hr

$n_2\Delta H_{r2} = (3127)(-115.21)$

$$= -360262 \text{ k j/hr}$$
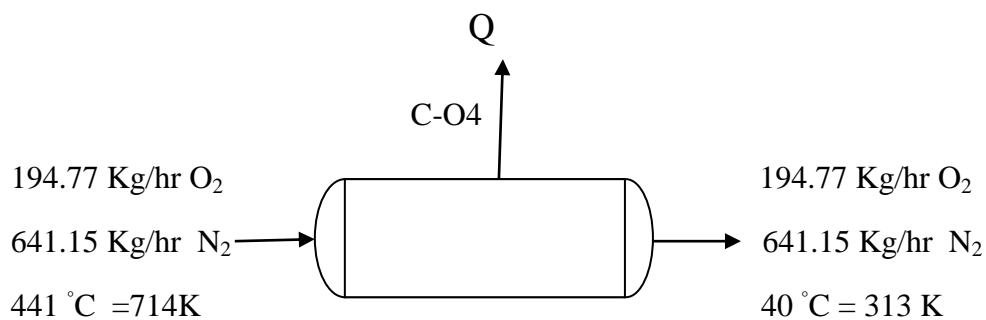
$4848817 = 112284 - 1083757 - 360262 + Q$

$Q = 6180552$ K j /hr

$Q = m\ c_p\ \Delta T_{H2O}$ $\qquad\qquad \Delta T_{H2O} = 40 - 25 = 15\ ^\circ C$

$m = (\dfrac{Q}{CP\Delta T}) = (\dfrac{6180552}{4.2*15}) = 98104$ Kg/hr

2.2.8 Energy Balance On Cooler

Air is cooled 441to 40 $^\circ$C $\qquad$ [3]

194.77 Kg/hr O_2 $\qquad\qquad\qquad\qquad\qquad$ 194.77 Kg/hr O_2

641.15 Kg/hr N_2 $\qquad\qquad\qquad\qquad\quad$ 641.15 Kg/hr N_2

441 $^\circ$C = 714K $\qquad\qquad\qquad\qquad\qquad$ 40 $^\circ$C = 313 K

Energy balance

$m\ \Delta H_{in} = m\ \Delta H_{out} + Q$

$T_{ref} = 25^\circ C = 298$ k

$m\ \Delta H_{in} = \Sigma\ mi \int_{298}^{714} cpi\ dT$

39

$$m\Delta H_{in} = \frac{194.77}{32} \left[28.106(714-298) - \frac{3.68*10^{-6}}{2}(714^2-298^2) + \frac{1.745*10^{-5}}{3}(714^3-298^3) - \left(\frac{1.065*10^{-8}}{4}\right)(714^4-298^4) + \frac{641.15}{28} \left[31.15(714-298) - \frac{1.356*10^{-2}}{2}(714^4-298^4)\right] \right]$$

$$m\Delta H_{in} = 354685 \text{ k j/hr}$$

$$m\ \Delta H_{out} = \Sigma mi \int_{298}^{313} cpi\ dT$$

$$m\Delta H_{out} = \frac{194.77}{32} \left[28.106(313-298) - \frac{3.68*10^{-6}}{2}(313^2-298^2) \frac{1.745*10^{-5}}{3}(313^3-298^3) - \left(\frac{1.065*10^{-8}}{4}\right)(313^4-298^4) + \frac{641.15}{28} \left[31.15(313-298) - \frac{1.356*10^{-2}}{2}(313^2-298^2) + \frac{2.679*10^{-5}}{3}(313^3-298^3) - \frac{1.168*10^{-8}}{4} 313^4-298^4)\right] \right]$$

$$m\Delta H_{out} = 12664 \text{ k j/hr}$$

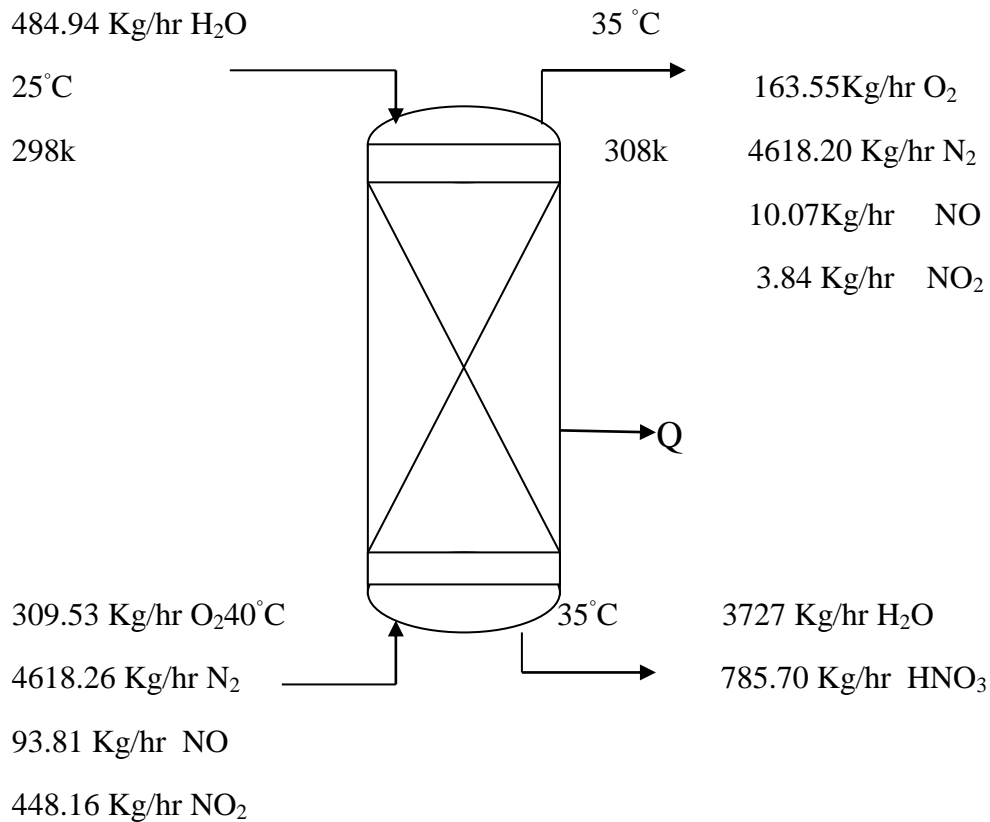$$354685 = 12664 + Q$$

$$Q = 342021 \text{ k j /hr}$$

$$Q = mC_P\Delta T_{H2O} \qquad \Delta T_{H2O} = 40\text{-}25 = 15\ ^\circ C \quad [3]$$
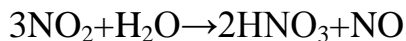
$$m = \left(\frac{Q}{CP\Delta T_{H2O}}\right)$$

$$= \frac{342021}{4.2*15}$$

$$= 5429 \text{ Kg/hr}$$

2.2.8 Energy Balance on Absorber

484.94 Kg/hr H_2O 35 $^{\circ}$C

25°C   163.55Kg/hr O_2

298k   308k   4618.20 Kg/hr N_2

                                   10.07Kg/hr   NO

                                   3.84 Kg/hr NO_2

                                     →Q

309.53 Kg/hr $O_2$40°C   35°C   3727 Kg/hr H_2O

4618.26 Kg/hr N_2 785.70 Kg/hr HNO_3

93.81 Kg/hr NO

448.16 Kg/hr NO_2

Reactions:

$NO+1/2O_2 \rightarrow NO_2$

$3NO_2+H_2O \rightarrow 2HNO_3+NO$

Energy balance

$m \Delta H_{in} = m \Delta H_{out} + n_1 \Delta H_{r1} + n_2 \Delta H_{r2}$

$T_{ref} = 25^{\circ}C = 298\ k$

$m = \Delta Hin = m\ C_P\ \Delta T_{H2O} + \Sigma\ mi \int_{298}^{313} CPidT_{gases}$

$m\Delta Hin = (484.94*4.20)(298-298)+ [(309.53*0.92)+(4618.26*1.04)+$

$(93.81*1)+(448.16*0.81)][313-298]$

$m\Delta H_{in} = 83169\ k\ j/hr$

$$m\Delta H_{out} = \Sigma \ mi \int_{298}^{308} CPdT_{gases} + \Sigma mi \ CP\Delta T_{liquid}$$

$$= [(163.55*0.92)+ (4618.26*1.04) +$$

$$(10.07*1)+(3.84*0.81)][308-298]+[(372.70*4.20)+(785.70*1.94)][308-298]$$

$$m\Delta H_{out} = 80563 \ k \ j/hr$$

$$\Delta H_{r1} = -56.67 \ k \ j/mol$$

$$O_2 \ reacted \ n_1 = (\frac{309.53-163.55}{32})(2)(1000)$$

$$= 9124 \ mol/hr$$

$$n_1 \ \Delta H_{r1} = (9124)(-56.67)$$

$$= -517057 \ k \ j/hr$$

$$\Delta H_{r2} = -115.21 \ k \ j/mol$$

$$H_2O reacted = (\frac{484.94-372.70}{18})(1000)$$

$$= 6236 \ mol/hr$$

$$n_2 \ \Delta H_{r2} = (6236)(-115.21)$$

$$= -718450 \ k \ j/hr$$

$$83169 = 80563- 517057- 718450+ Q$$

$$Q = 1071775$$

$$Q = m \ C_P \ \Delta T_{\ H2O} \qquad \Delta T_{H2O} = 30\text{-}25 \ ^{\circ}C$$

$$m = (\frac{Q}{CP\Delta T}) = (\frac{1071775}{4.2*5}) = 51037 \ Kg/hr$$

CHAPTER THREE
EQUIPMENT DESIGN

3.1 Introduction of Equipment Design

Design is a creative activity, and as such can be one of the most rewarding and satisfying activities undertaken by an engineer. It is the synthesis, the putting together, of ideas to achieve a desired purpose. The design does not exist at the commencement of the project. The designer starts with a specific objective in mind, a need, and by developing and evaluating possible designs, arrives at what he considers the best way of achieving that objective; be it a better chair, a new bridge, or for the chemical engineer, a new chemical product or a stage in the design of a production process. When considering possible ways of achieving the objective the designer will be constrained by many factors, which will narrow down the number of possible designs; but, there will rarely be just one possible solution to the problem, just one design. Several alternative ways of meeting the objective will normally be possible, even several best designs, depending on the nature of the constraints. These constraints on the possible solutions to a problem in design arise in many ways. Some constraints will be fixed, invariable, such as those that arise from physical laws, government regulations, and standards. Others will be less rigid, and will be capable of relaxation by the designer as part of his general strategy in seeking the best design. The constraints that are outside the designer's influence can be termed the external constraints. These set the outer boundary of possible designs; as shown in Figure (3.1). Within this boundary there will be a number of plausible designs bounded by the other constraints, the internal constraints, over which the designer has some control; such as, choice of process, choice of process

conditions, materials, equipment. Economic considerations are obviously a major constraint on any engineering design: plants must make a profit. Time will also be a constraint. The time available for completion of a design will usually limit the number of alternative designs that can be considered[3].
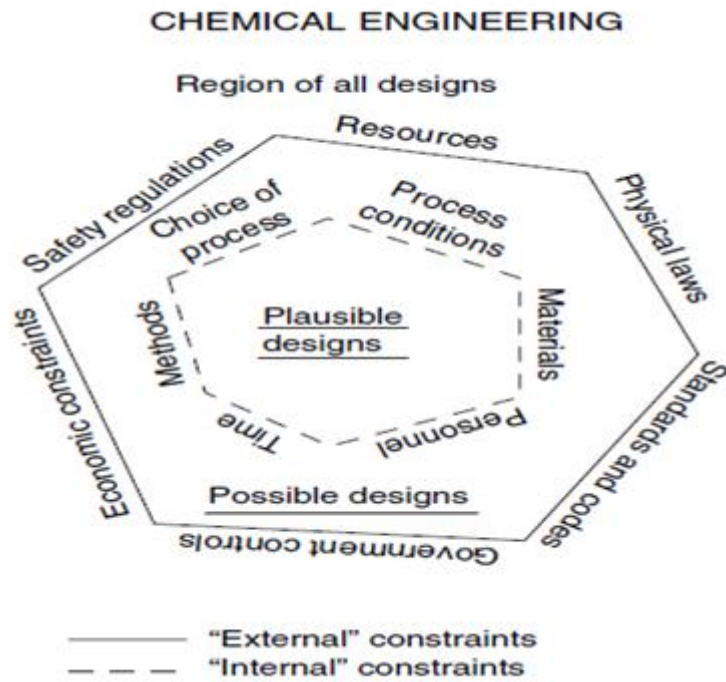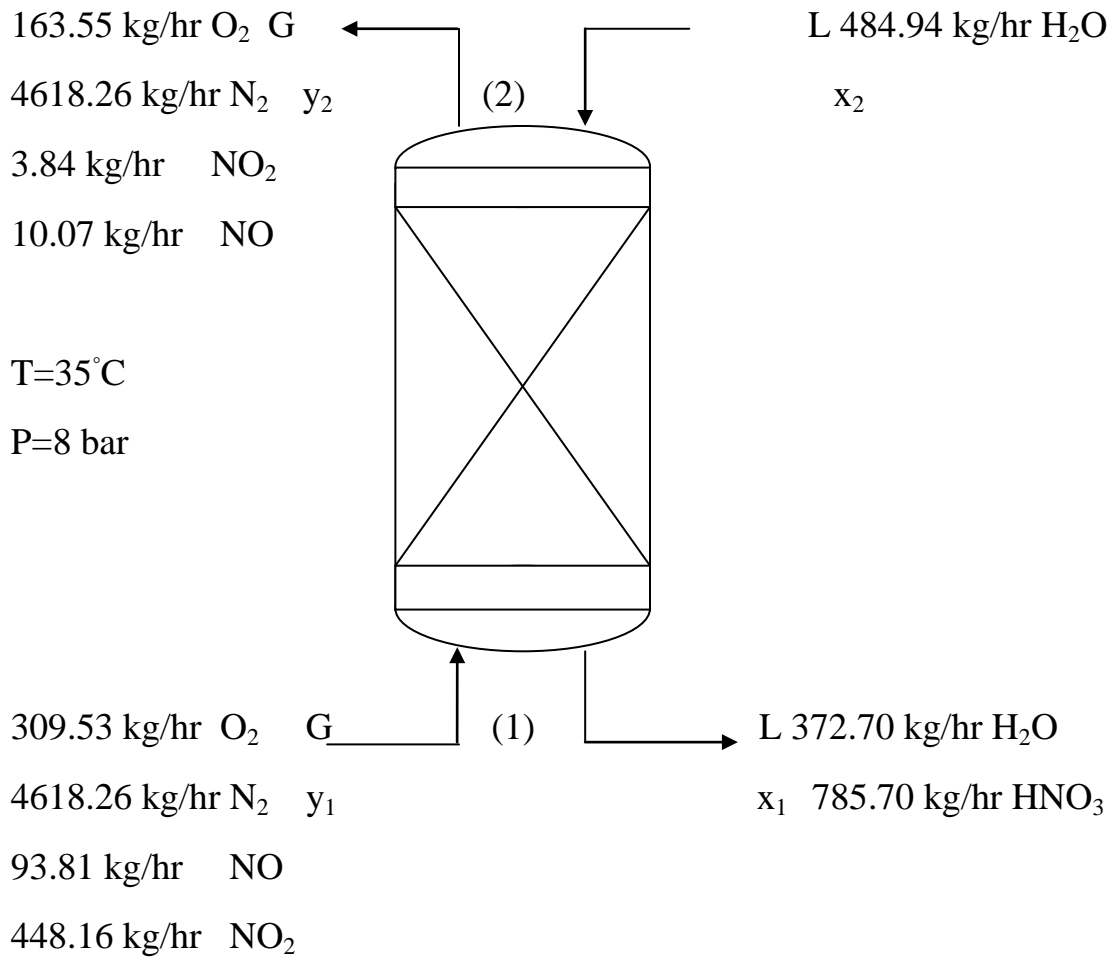

Figure (3.1): Design constrain

3.2 Design of Absorber

163.55 kg/hr O_2 G ←   L 484.94 kg/hr H_2O

4618.26 kg/hr N_2 y_2 (2) x_2

3.84 kg/hr NO_2

10.07 kg/hr NO

T=35°C

P=8 bar

309.53 kg/hr O_2 G_____ (1) ⌐_____→ L 372.70 kg/hr H_2O

4618.26 kg/hr N_2 y_1 x_1 785.70 kg/hr HNO_3

93.81 kg/hr NO

448.16 kg/hr NO_2

Inlet gas

Component	Kg/hr	M .wt	K mol /hr	Mol% y
O_2	309.53	32	9.673	5.16
N_2	4618.26	28	164.938	87.98
NO	93.81	30	3.127	1.66
NO_2	448.81	46	9.743	5.20
Total	5469.76		187.481	

Column diameter

$$F_{L.V} = (\frac{L}{G})(\frac{\rho_V}{\rho_L})^{0.5} \qquad [3]$$

Where :

$F_{L.V}$ = liquid vapour flow factor .

L   = liquid mass flow rate kg/s .

G   = gas mass flow rate kg/s .

P_v = vapourdensity kg/m^3 .

ρ_L = liquid density kg/m^3 .

vapour density

$$\rho_V = \frac{P M_{av}}{RT} \qquad [3]$$

$$M_{av} = \Sigma\, M_i\, y_i \qquad [3]$$

Where :

M_{av} = average molecular weight kg/k mol.

M_i = molecular weight of component i kg/k mol .

y_i = mol fraction of component i .

M_{av} = (32* 0.0516) + (28*0.8798) + (30*0.01660) + (46*0.052)

   = 29.18 Kg/Kmol

P = 8 bar = 800 kpa   [3]

T = 35 $^\circ$C = 308 K   [3]

$$\rho_V = \frac{810.4 * 29.18}{8.314 * 308} \;\; = 9.12 \text{kg/m}^3$$

Liquid density

Density of H_2O at 35 $^\circ$C   [6]

ρ_L = 994 kg/m^3

L = 484.94 kg/hr

L = 0.135 kg/s

G = 5469.76 kg/hr

G= 1.519 kg/s

$$F_{L.V} = \left(\frac{0.135}{1.519}\right)\left(\frac{9.12}{994}\right)^{0.5} = 0.01$$

$$V_W^{*} = \left[\frac{K_4 \rho_V (\rho_L - \rho_V)}{13.1 F_P \left(\frac{\mu_L}{\rho_L}\right)^{0.1}}\right]^{0.5} [3]$$

Where:

V_W^* = gas mass flow rate per unit cross – sectional area kg/m^2.s

K_4 = constant

μ_L = liquid viscosity kg/m.s

F_p= packing factor .

Design pressure drop for absorber from from15 to50 mmH$_2$O /m packing

Select Δp = 42 mmH$_2$O /Packing   [3]

For $F_{L.V}$ =0.01   and ΔP = 42 mmH$_2$O /m packing

K_4 = 3   fig 11.44 [6]

K_4 at flooding = 7   [6]

Percent flooding = $(\dfrac{K_4}{K_4\ at\ flooding})^{0.5}* 100\%$

$$= (\frac{3}{7})^{0.5}*100\% = 65\%$$

Select 1 1/2 inch in talox saddle

F_P = 170 m^{-1} table 11.2   [3]

Viscosity of H$_2$O at 35°C

μ_L= 0.722 μ_L = 0.722*10^{-3} kg/m.s

$V_W^* = [\dfrac{3*9.12(994-9.12)}{13.1*170\ (\frac{0.722*10^{-3}}{994})^{0.1}}]^{0.5}$ [3]

$$= 7.052\ \text{kg/m}^2.\text{s}$$

$A = \dfrac{G}{V_W^*}$

Where :

A= cross-sectional area of column m^2.

$A = (\frac{1.519}{7.052}) = 0.215 \text{ m}^2$

$A = \frac{\pi}{4} D^2$

$0.215 = \frac{\pi}{4} D^2 \quad D = 0.52 \text{ M}$

Height of column

$Z = HOG \cdot NOG \quad [3]$

Where :

Z = height of packing m.

HOG = over all height of gas phase transfer unit m.

NOG = number of transfer unit .

$HOG = Hg + \frac{mG}{L} H_L \quad [3]$

Where :

Hg = individual height of gas film transfer unit m.

H_L = individual height of of liquid film transfer unit m.

m = slop of equilibrium line .

G = gas molar flow rate kmol/hr

L = liquid molar flow rate k mol/hr

Absorption with chemical reaction ,vapour pressure of NO_2 over the solution can be negligible .

$P_A^\circ = 0$

$P_A^* = P_A^\circ X_A$

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$$\frac{P_A^*}{P_T} = \frac{P_A^\circ}{P_T} \, X_A$$

$$y^*{}_A = m \, x_A \quad m = \left(\frac{P_A^\circ}{P_T}\right) = 0$$

$$m = \rho_V u \, A$$

$$u = \frac{m}{A \rho_V}$$

$$u = \frac{1.519}{9.12 * 0.215}$$

$$= 0.77 \text{ m/s}$$

For u = 0.77 m/s , 1.5 inch intalox saddle 8 bar and 35 °C

Hg = 0.65m   [7]

HOG = Hg = 0.65 fig 12.21   [7]

$$NOG = \int_{y_2}^{y_1} \frac{dy}{y - y^*} \qquad [3]$$

For absorption with chemical reaction y*=0

$$NOG = \int_{y_2}^{y_1} \frac{dy}{y} = Ln \frac{y_1}{y_2}$$

$$y_1 = 0.052$$

$$y_2 = \frac{\frac{3.84}{46}}{\frac{163.55}{32} + \frac{4618.26}{28} + \frac{10.07}{30} + \frac{3.84}{46}} = 0.0005$$

$$NOG = Ln \frac{0.052}{0.0005} = 4.64$$

Z= (0.65) (4.64)

$$= 3.02 \text{ m}$$

Pipe sizing

$$d = 293 \ G^{0.53} \ \rho^{-0.37} \qquad [3]$$

where:

d = optimum pipe diameter mm .

G = fluid mass flow rate kg/s .

ρ = fluid density kg/m^3 .

inlet gases

G =5469.76 kg/hr = 1.519 kg/s

ρ = 9.12 kg/m^3

$d = 293 \ (1.519)^{0.53} \ (9.12)^{-0.37} = 162\text{mm} = 6\frac{1}{2} \text{ inch}$

outlet gases

G = 4795.72 kg/hr = 1.332 kg/s

ρ = 8.79 kg/m^3

$d = 293 \ (1.332)^{0.53} \ (8.79)^{-0.37} = 153\text{mm} = 6 \text{ inch}$

inlet liquid

G =484.94 kg/hr = 0.135 kg/s

ρ = 994 kg/m^3

$d = 293 \ (0.135)^{0.53} \ (994)^{-0.37} = 8\text{mm} = \frac{1}{2} \text{ inch}$

outlet liquid

G = 1158.4kg/hr =0.322kg/s

$\rho = 1390 \text{ kg/m}^3$

$d = 293 \ (0.322)^{0.53} \ (1390)^{-0.37} = 11\text{mm} = \frac{1}{2} \text{ inch}$

Mechanical design

Shell

$e = \dfrac{Pi \, Di}{2F - Pi} + c$ [3]

where

e = thickness of shell mm.

Pi = Design pressure N/ mm^2 .

Di = shell inside diameter mm .

f = design stress N/ mm^2 .

C = corrosion constant mm.

d = 0.52 m = 520 mm

operating pressure = 8 bar

design pressure pi = 1.1 *8 = 8.8 atm N/mm^2

C = 2 mm   [3]

At T= 35 °C design stress of high silicon iron

f = 135 N/mm^2 Table 13.2   [3]

$e = \dfrac{0.88 * 520}{2 * 135 - 0.88} + 2 = 3 \text{ mm}$

Ellipsoidal head

$$e = \frac{Pi*Di}{2Jf - 0.2Pi} + c \quad [3]$$

where

e = thickness of ellipsoidal head mm .

J = joint factor = 0.8   [3]

$$e = \frac{0.88*520}{2*0.8*135 - 0.2*0.88} + 2 \; = 3mm$$

supports

weight loads

weight of vessel (shell)

$W_V = C_V \, \pi \, \rho_m D_m g \; (H_V + 0.8D_m) \, t*10^{-3} \quad [3]$

where

W_V = total weight of shell exchuding internal fitting N .

C_V = constant.

ρ_m = density of vessel material kg/m^3.

H_V = height (length)of shell m .

D_m = mean diameter of shell m.

t = wall thickness mm

t = e = 3mm

C_V = 1.15 [3]

ρ_m = 7100 kg/m^3 [4]

$D_m = (Di + t*10^{-3})$ [3]

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$D_m = (0.52 + 3*10^{-3}) \quad = 0.523m$

$H_V = 3.02 \text{ m}$

$W_V = 1.15\pi *7100*0.523 *9.81 (3.02 +0.8 *0.523)(3*10^{-3})$

$Wv = 1358 \text{ N}$

Weight of fluid

$W_f = v \rho g \quad$ [3]

Where

W_f = Weight of fluid N .

V = volume of fluid m^3 .

ρ = density of fluid kg /m^3 .

$W_f = \frac{\pi}{4} (0.52)^2 (3.02) (1390) (9.81) = 8746 \text{ kg/m}^3$

$W = w_v + w_f \quad$ total weight

$W = 1358 + 8746 = 10104 \text{ N}$

Added 10% above total weight

$W = 1.1 (10104) = 11114 \text{ N}$

design of bracket   support

$F_{bs} = 60 L_c t_c \quad$ [3]

Where

F_{bs} = design load per bracket N .

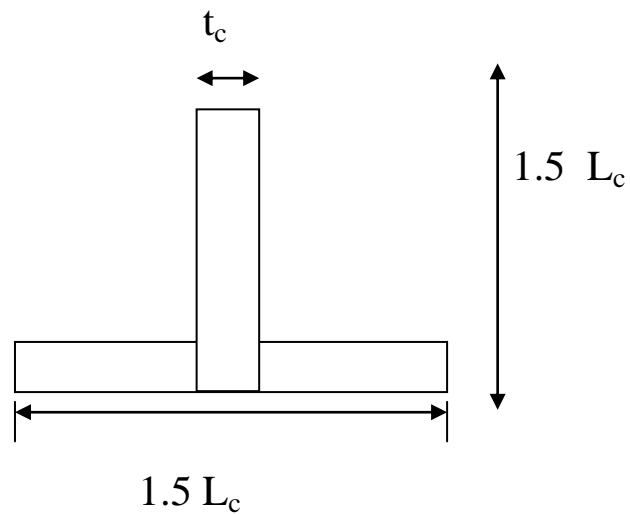L_c = depth of bracket   mm.

t_c = thickness of plate mm.
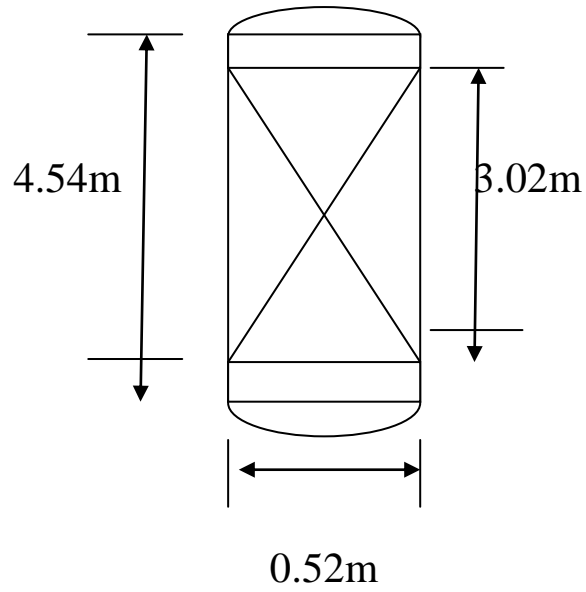
use four brackets

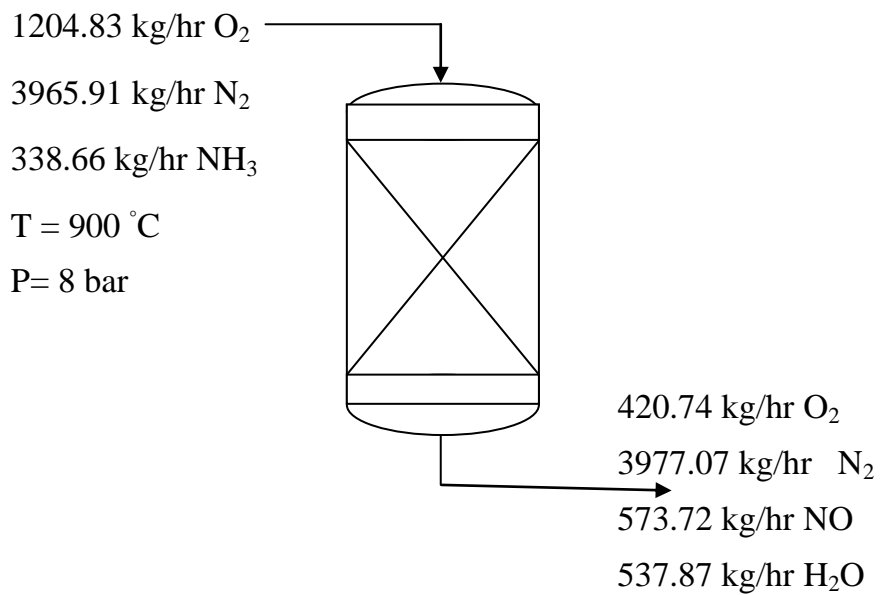$F_{bs} = \dfrac{11114}{4} = 2779$ N

Take t_c = 3 mm

2779= 60 *3 L_c

Lc = 16mm

t_c

1.5 L_c

1.5 L_c

Type	Packed
Length packed	3.02 m
Diameter	0.52m
Volum =$\dfrac{\pi}{4} D^2 L$	0.614
Temp. $^\circ$C	35 $^\circ$C
Pressure bar	8 bar
Material of count	High silicon iron

4.54m   3.02m

0.52m

3.3 Design of fixed bed reactor

1204.83 kg/hr O_2

3965.91 kg/hr N_2

338.66 kg/hr NH_3

T = 900 $^\circ$C

P= 8 bar

420.74 kg/hr O_2

3977.07 kg/hr N_2

573.72 kg/hr NO

537.87 kg/hr H_2O

Reaction

$NH_3 + 5/4\ O_2 \rightarrow\ NO + 3/2\ H_2O$

$NH_3 + ¾\ O_2 \rightarrow 1/2\ N2 + 3/2\ H_2$
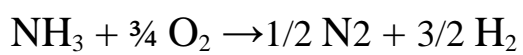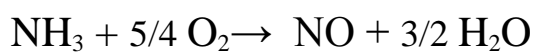
Kinetic

On the basis of mass transfer control the rate of ammonia oxidation may be written in term of mass transfer coefficient with the ammonia partial pressure at the catalyst surfer assumed to be zero for this rapid reaction

$$-rA = kg\, awR.PA \quad \dots\dots\dots (1)$$

$-rA$ = rate of reaction $gmol\,(NH_3)/\,(cm.s)$.

Kg_A = mass transfer coefficient.

A_{wR} = interfacial surface per unit volume cm^2/cm^3.

P_A = the partial pressure of NH_3 in the bulk fluid (atm).

$$P_A = y_A\, P$$

Where:

y_A= initial mole fraction of NH_3.

P = total pressure (atm).

$$-rA = kg.a_{wR}.yAP \quad \dots\dots\dots (1) \quad [10]$$

For plug flow

$$\left(\frac{-G}{M_F}\right) dyA = (-rA)\, dz \quad \dots\dots\dots (2) \quad [10]$$

$$(-rA)dz = Kg.a_{wR}.y_A\, P\, dz \quad [10]$$

D z = height of bed =fw.dns/a_{wR}

f w = wire area per gauze cross section area.

Ns = number of gauze

$$(-rA)dz = Kg. a_{wR} \cdot yAP \frac{f_w d_{ns}}{a_{wR}}$$

$$(-rA)dz = Kg. y_A P\ fw\ dns \ldots \ldots \ldots (5) \qquad [10]$$

Substitution (3) in (2) we get

$$-\frac{G}{MF} d_{yA} = Kg. yA\ P\ fw\ dns.$$

G = mass flow rate per unit cross section area $gm/cm^2.s$

M_f = molecular weight of feed gm/mol

$$-\int_{yA1}^{yA2} \frac{d_{yA}}{y_A} = \frac{M_f}{G} kg\ pf_w \int_0^{ns} d_{ns}$$

$$\ln \frac{y_{A1}}{y_{A2}} = \frac{M_f}{G} kg.P.fw.ns$$

$$y_{A2} = y_{A1}(1 - x_A)$$

x_A = conversion

$$\ln \frac{y_{A1}}{y_{A1}(1 - x_A)} = \frac{Mf}{G} kg.P.fw.ns$$

$$\ln \frac{1}{(1 - x_A)} = \frac{Mf}{G} kg.P.fw.ns$$

$$\ln(1 - X_A) = -\frac{Mf}{G} kg.p.fw.ns \ldots \ldots (4)$$

$$kg = \frac{0.865\ NRe^{-0.648}.G}{PN^{\frac{2}{3}}\ MmE}\ [10]$$

Where:

N_{Re} = Reynolds number = $\left(G\frac{dw}{\mu E}\right)$ [10]

N_{sc} = Schmidt number = $\frac{\mu}{\rho D}$ [10]

G= mass flow rate per unit cross-section area gm/cm^2 .s

dw = diameter of wire cm.

μ = fluid viscosity (gm/cm.s).

ρ = fluid density (gm/cm^3)

D = diffusivity of NH_3 in air (cm^2 /s).

Mm= molecular weight of mixture gm/gmol .

$\in$ = voidage

$$Kg = \frac{(0.865\ \mu^{0.648}\ \in^{0.648}\ \rho^{0.667}\ D^{0.667}\ G)}{(G^{0.648}dw^{0.648}\mu^{0.667}Mm\ \in)}$$

$$Kg = \frac{(0.865\ \rho^{0.667}D^{0.667}\ G)}{(G^{0.648}dw^{0.648}\mu^{0.019}\ PMm\ \in^{0.352})} \ldots\ldots\ldots (5)$$

Substitution(5) in (4)

$$\ln(1 - xA) = \frac{\left(-\frac{MF}{G}\right)(0.865\ \rho^{0.667}D^{0.667}\ \in\ Pfw.ns)}{(G^{0.648}\ dw^{0.648}\mu^{0.019}\ PMm\ \in^{0.352})}$$

$$\frac{Mf}{Mm} \cong 1$$

$$\ln(1 - xA) = \frac{(0.865ns\, fw\, \rho^{0.667} D^{0.667})}{\in^{0.352} G^{0.648} dw^{0.648} \mu^{0.019}}$$

Type of catalyst 90% Pt_10% Rh   [11]

Gauze mesh nw = 80   [10]

Gauze diameter =180mm =18cm   [10]

The gauze wire diameter dw=0.003 inch [10] =0.0076 cm

$$a_{WR} = \pi\, nw^2 \left[\left(\frac{1}{nw}\right)^2 + dw^2 \right]^{0.5} \quad [10]$$

$$a_{WR} = \pi\, 80^2 \left[\left(\frac{1}{80}\right)^2 + 0.003^2 \right]^{0.5} \quad [10]$$

$$a_{wR} = 258\ in^{-1}$$

$$=102\ cm^{-1}$$

$$fw = awR.2dw \quad [10]$$

$$=(258)(2)(0.003) = 1.55\ in$$

$$\in = 1 - \frac{awR\, dw}{4} [10]$$

$$\in = 1 - \frac{(258)(0.003)}{4}$$

$$\in = 0.8065$$

$$\rho mix = \frac{(Mmix)}{(ZRT)}$$

ρmix = density of mixture gm/cm^3

$Mmix$ = average molecular weight

Comp.	Kg/hr	M.W	K mol/hr	Mol% y	T_C K	P_C bar
O_2	1204.83	32	37.651	18.90	154.6	50.5
N_2	3965.91	28	141.640	71.10	126.2	33.3
NH_3	338.66	17	19.921	10.00	405.6	112.8
Total	5509.4		199.212	100		

$$\acute{T}c = \sum Tci\ yi$$

$$\acute{T}c = (154.6*0.1896)+(126.2*0.7110)+(405.6*0.10)$$

$$=159.5\ k$$

$$\acute{P}c = \sum Pci\ yi$$

$$=(50.5*0.1890)+(33.9*0.7110)+(112.8*0.10)$$

$$=44.9\ bar$$

$$Tr = \frac{T}{\acute{T}c}$$

$$Tr = \frac{900+273}{159.5} = 7.35$$

$$Pr = \frac{P}{\acute{P}c}$$

$$= \frac{8}{44.9}$$

$$= 0.18$$

For Tr=7.35   and   Pr= 0.18

Z1 =1   Fig.(3-8)   [3]

$$Mav. = \sum Mi\ yi$$

$$= (32 * 0.1890) + (28 * 0.7110) + (17 * 0.10)$$

$$= 27.66 \, kg/kmol$$

$$= 27.66 \, gm/mol$$

$$T = 900c° = 1173 \, k° \quad \text{[film temperature]}$$

$$P = 8 \, bar = 800 \, kpa$$

$$Pv = \frac{(800 * 27.66)}{(8.314 * 1173)} = 2.27 \, kg/m^3$$

$$= 2.27 * 10^{-3} \, gm/cm^3$$

$$\mu \, mix = (12.5 + 29.20 * 10^{-3}T)*10^{-5}$$

Where:

Viscosity of mixture $gm/cm.s$

$$T = temperature \, k°$$

$$\mu \, mix = (12.5 + 29.20 * 10^{-3} * 117)*10^{-5}$$

$$= 46.8 * 10^{-5} \, gm/cm.s$$

$$D = 0.227(T/293)^{1.5} \, (1/P) \quad \text{[10]}$$

Where:

$$D = diffusivity \, of \, NH3 \, in \, air \, cm^2/s$$

$$T = temprature \, K$$

$$P = pressure \, atm.$$

$$P = 8bar * \left(\frac{atm}{1.013bar}\right) = 7.897 \, atm$$

$$D = 0.227 \left(\frac{1173}{293}\right)^{1.5}\left(\frac{1}{7.897}\right)$$

$$D = 0.230 \, cm^2/s$$

Mass flow $m = 5509.4\dfrac{kg}{h} * \dfrac{1000gm}{kg} * \dfrac{h}{3600s}$

$$m = 1530.4 \, gm/s$$

$$G = \rho u \quad \text{[3]}$$

u = gas velocity cm/s

$u = 28\ Ft/sec$ (given)

$u = 28\ \dfrac{Ft}{sec} * \dfrac{30.48cm}{Ft} = 853.44\dfrac{cm}{s}$

$G = \rho u$

$G = 2.27 * 10^{-3} * 853.44$

$= 1.937\ gm/cm^2.s$

$G = \dfrac{m}{A} \Rightarrow A = \dfrac{m}{G}$

$A = \dfrac{1530.4}{1.937} = 790.1\ cm^2$

$A = \dfrac{\pi}{4} Dr^2$

$790.1 = \dfrac{\pi}{4}\ Dr$

$Dr = 32\ cm$

$\ln(1 - 0.9999) = \dfrac{(-0.865ns)(1.55)(2.27 * 10^{-3})(0.230)}{(0.8065)0.0076)(1.937)(48.6 * 10^{-3})}$
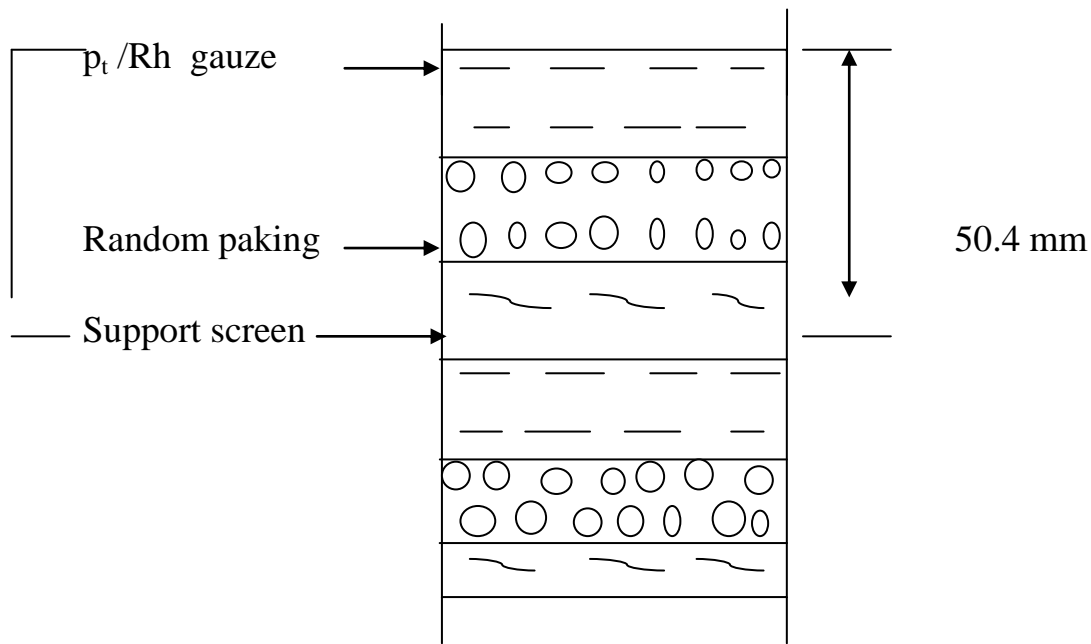
$\ln(1 - 0.9999) = -0.1664\ ns$

$ns = 56\ gauze$

thicness of one layer $= 2inch = 504mm$

Each layer containing two gauzes

No.of layer $= \dfrac{56}{2} = 28$

Total leight of bed=28*50.4 $= 411$ mm=1.411 m

p$_t$ /Rh gauze

Random paking

50.4 mm

Support screen

Pipe sizing

$$d = 260 \ G^{0.52} \rho^{-0.37} [3]$$

Where:

d=optimum pipe diameter.

G=fluid mass flow rate kg/s.

ρ=fluid density kg/m^3

Inlet gases

$$G = 5509.40 \frac{kg}{h} = 1.530 \frac{kg}{s}$$

$$\rho = 5.25 \ kg/m^3$$

$$d = 260(1.530)^{0.52} (5.25)^{-0.37}$$

$$= 176mm \cong 7inch$$

Outlet gases

$$G = 1.530 \frac{kg}{s}$$

$$\rho = 2.21 \frac{kg}{m^3}$$

$$d = 260(1.530)^{0.52}(2.21)^{-0.37}$$

$$= 242mm \cong 9.5\ inch$$

Mechanical design

Shell

$$e = \frac{Pi\ Di}{2F - Pi} + c \qquad [3]$$

Where:

c =thickness of shell mm.

Pi=design pressure N/mm^2.

Di=inside shell diameter .

F=design stress N/mm.

c= corrosion constant.

Di = 0.32m=320mm.

Operating pressure =8 bar.

Design pressure Pi=1.1*8=8.8 bar=0.88 N/mm^2.

c= 1mm

at$T = 900\ C°$design stress of stainless steel

F=55 N/mm^2 Table 13.2   [3]

$$e = \frac{0.88 * 320}{2 * 55 - 0.88} + 1 = 4mm$$

Ellipsoidal head

$$e = \frac{Pi\ Di}{2jf - 0.2Pi} + c \quad [3]$$
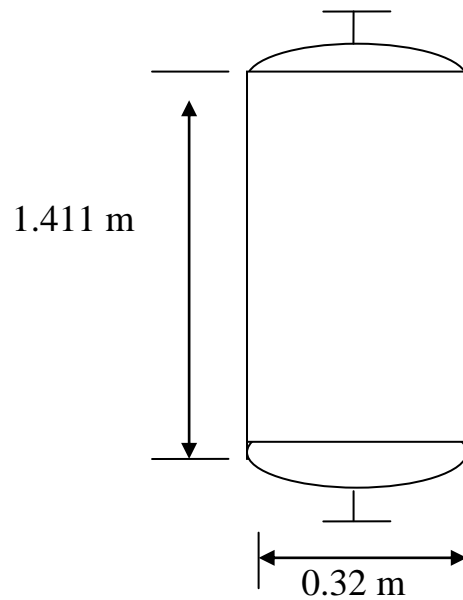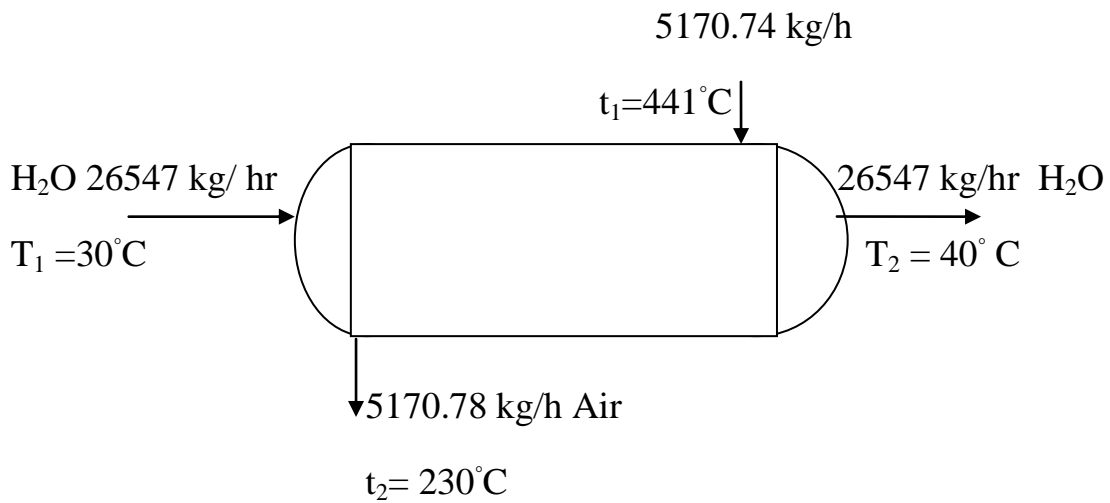
Where:

c=thickness of ellipsoidal head mm.

J=joint factor = 0.8   [3]

$$e = \frac{0.88 * 320}{2 * 0.8 * 5 - 0.2 * 0.88} + 1 = 4mm.$$

Type	Fixed bed
Volume m3	0.11342
Height m	1.411
Diameter m	0.32
Material of const	St.st

1.411 m

0.32 m

3.4 Design of Heat Exchanger

5170.74 kg/h

$t_1 = 441°C$

H_2O 26547 kg/ hr

$T_1 = 30°C$

26547 kg/hr H_2O

$T_2 = 40°$ C

5170.78 kg/h Air

$t_2 = 230°C$

Tube Side (Air)

$t_1 = 441$ C

$t_2 = 230$ C

shell Side (Water)

$T_1 = 30$ C

$T_2 = 40$ C

$Q = UA\ T_{lm}F$

Where

Q = heat transferred per unit time W.

U = Overall   heat transfer Coefficient W/m .C

A = heat transfer area m .

Tm = the mean temperature difference C.

F = Correction factor

From Energy balance   Q = 1114966 KJ/h

$$Q = 1114966 * \frac{KJ}{h} * \frac{1000J}{KJ} * \frac{h}{3600S}$$

Q = 309713 W

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{ln\frac{T_1 - t_2}{T_2 - t_1}}$$ [3]

$$\Delta T_{lm} = \frac{(30 - 230) - (40 - 441)}{ln(\frac{30 - 230}{40 - 441})}$$

ΔT_{lm}= 288.9

Use one shell and two tube passes

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$

$$R = \frac{30 - 40}{230 - 441} = 0.05$$

$$S = \frac{t_2 - t_1}{T_1 - t_1}$$

$$S = \frac{230 - 441}{30 - 441} = 0.51$$

For R = 0.05 and S = 0.51 F=1   From fig.12.19   [3]

For Water gases system

U = 20 – 300   Table 13-1   [3]

By trial and error assume U = 100W/m^2.C

$$A = \frac{Q}{U\Delta T_{lm} \ F} = \frac{309713}{100*288.9*1} = 10.72 \ m^2$$

Select

Tube length L = 1.83 m

Tube out Sid diameter d_o= 50mm   [3]

Tube thickness = 3.2mm

di = d_o -2*3.2

= 50 – 2*3.2 = 43.6 mm =0.0436m

Surface area of one tube = л D L

$$= л *0.05 * 1.83$$

$$= 0.287 \text{ m}^2$$

No. Of tube $= \dfrac{Total\ area}{area\ of\ one\ tube}$

$Nt = \dfrac{10.72}{0.287} = 38$

Tube Side coefficient hi

Mean tube temperater tm $= \dfrac{t_1 + t_2}{2}$

$$= \dfrac{441 + 230}{2} = 336 \text{ }^{\circ}\text{C} \quad =609 \text{ K}$$

$P_v = \dfrac{PM}{RT}$

P = 8 bar = 800 kpa

T = 336 $^{\circ}$C = 609 K

$P_v = \dfrac{800*29}{8.314*609} = 4.58 \text{ Kg/m}^3$

Cp = 1.022 KJ/Kg.C

K = 0.048 w/m.c   [4]

м = 0.03 centipoises $= 3*10^{-5}$ Ns/m^2

No.of tube per pass $= \dfrac{38}{2} = 19$

Mass flow rate per tube m $= \dfrac{5170.74}{19*3600}$

$$m = 0.0756 \text{ Kg/s}$$

m = puA

Where

m = mass flow rate kg/h

P = Fluid *density* kg/m^2

U = Fluid velocity m/s

A = cross section area of tube m^2

$A = \frac{\pi}{4}d^2 = \frac{\pi}{4}(0.0436)^2 = 1.49 \times 10^{-3}$ m^2

$11.08 \text{ m/s} = U = \frac{m}{\rho A} = \frac{0.0756}{4.58 \times 1.49 \times 10^{-3}}$

$Re = \frac{\rho u d_i}{\mu} = \frac{4.58 \times 11.08 \times 0.0436}{3 \times 10^{-5}} = 73751 > 210$

$Nu = 0.021 \, Re^{0.8} Pr^{0.33} \left(\frac{\mu}{\mu w}\right)^{0.14}$ [3]

$Nu = \text{Nusselt number} = \frac{h_i \, d_i}{k}$

$Pr = \text{prondtl number} = \frac{cp \, \mu}{k}$

h$_i$ = inside fluid film coefficient w/m^2.°c

d$_i$ = inside tube diameter

k = fluid thermal conductivity w/m.°c

p = Fluid density kg/m^3

M = fluid viscosity kg/m.s

cp = fluid heat capacity   J/kg.°c

u = fluid velocity m/s

Re = 73751

$Pr = \frac{cp \, \mu}{k} = \frac{1.022 \times 10^3 \times 3 \times 10^{-5}}{0.048} = 0.64$

$\left(\frac{\mu}{\mu w}\right)^{0.14} = 1$ [3]

$Nu = 0.021(73751)^{0.8} (0.64)^{0.33}(1)^{0.14}$

Nu = 142.06

$$Nu = \frac{h_i d_i}{k} = 142.06 = \frac{h_i * 0.0436}{0.048}$$

$h_i = 156$ w/m^2.°c

Shell side coefficient h_o

Mean shell temperature $T_m = \frac{T_1 + T_2}{2}$

$T_m = \frac{30 + 40}{2} = 35$°C

$P = 994$ kg/m^3

$M = 0.72$ c.p

$\quad = 7.2 * 10^{-4}$ Ns/m^2[6]

$Cp = 4.20$ kJ/kg.°C

$K = 147 * 10^{-5}$ cal/cm.°C

$\quad = 0.617$ w/m.°C

$$Nu = J_n Re Pr^{0.33} (\frac{\mu}{\mu w})^{0.14} \text{ [3]}$$

Where

Nu = Nusselt number $= \frac{h_o d_e}{k}$

Re = Reynolds number $= \frac{\rho u_s d_e}{\mu}$

Pr = Prandtl number $= \frac{cp\mu}{k}$

h_o = out side fluid film coefficient w/m^2.c

d_e = equivalent diameter m

k = fluid thermal conductivity w/m.°c

p = Fluid density kg/m^3

M = fluid viscosity kg/m.s

cp = fluid heat capacity   J/kg.°c

u_s = fluid velocity m/s

use square tube pitch $p_t = 1.25$ d_o

$$d_e = \frac{1.27}{d_o}(p_t{}^2 - 0.785\ d_o{}^2) \quad [3]$$

Where

d_o, d_e and pt in mm

$d_o = 50mm$

$P_t = 1.25(50) = 62.5mm$

$$d_e = \frac{1.27}{50}(62.5^2 - 0.785*50^2) = 49.4mm$$

$$= 0.0494m$$

$$D_b = do\left(\frac{Nt}{k_1}\right)^{1/n_1} \quad [3]$$

Where

D_b = bundle diameter mm

Nt = total number of tube

K_1 and n_1 = constant

For squar tube pitch and two tube passes

$K_1 = 0.156$

$N_1 = 2.291$ Table 12.4 [3]

$$D_b = 50\left(\frac{38}{0.156}\right)^{1/2.291} = 551\ mm$$

For bundle diameter $D_o = 551$ mm and split ring flooting head

$D_s - D_b = 60$ mm   Fig 12.10

$D_s - 551 = 60 \implies Ds = 611$ mm $= 0.611m$

$$A_s = \left(\frac{p_t - d_o}{p_t}\right)(DslB) \quad [3]$$

Where

A_s = Cross flow area m^2

l_B = baffle Spacing   m

l_B = (0.20 to l) shell diameter   [3]

$l_B = 0.5Ds$

$l_B = 0.5(0.611) = 0.306$ m

$$A_S = \frac{62.5-50}{62.5}(0.611 - 0.306) = 0.0374 \text{ m}^2$$

$$G_s = \frac{w_S}{A_S}$$

Where

G_s = mass velocity kg/m^2 .C

W_s = mass flow rate kg/s

W_s = 26547 kg/h

     = 7.374 kg/s

$$G_s = \frac{7.374}{0.0374} = 197.17 \text{ kg/m}^2.s$$

$G_S = ps\ us \implies us = \dfrac{Gs}{ps} = \dfrac{197.17}{994} = 0.2$ m/s

$$Re = \frac{G_s d_e}{\mu} = \frac{197.17*0.0494}{7.2*10^{-4}} = 13640$$

For Re = 1360 and 25% baffale cut $J_n = 5*10^{-3}$ [3]

$$Pr = \frac{cp\mu}{k} = \frac{4.2*10^3*7.210^{-4}}{0.617} = 4.90$$

Nu $= 5*10^{-3}(13640)(4.90)^{0.33}$ (1)

Nu = 115.23

$$Nu = \frac{h_o d_r}{\mu}$$

$$115.23 = \frac{h_o*0.0494}{0.617}$$

$h_o = 1439$ w/m^2.c

Over all heat transfer Coefficient U

$$\frac{1}{U^\circ} = \frac{1}{h_o} + \frac{1}{h_o d} + \frac{d_o \ln d_o/d_i}{2kw} + \frac{d_o}{d_i} \cdot \frac{1}{h_{id}} + \frac{d_o}{d_i} \cdot \frac{1}{h_i} \qquad [3]$$

Where

U° = over all heat transfer coefficient w/m^{2}c

h_o = out side fluid film coefficient w/ m^2. c

h_{od} = outside dirt coefficient w/m^2.c.

d_o = tube outside diameter m.

Kw = thermarl conductivity of tube wall material w/m.c

$h_{id} = 3000$
$h_{od} = 4000$ ⎤ Table 12.2 [3]

Thermal conductivity of stainless steel

Kw = 16 w/m.c   Table 12.6 [3]

$$\frac{1}{U^\circ} = \frac{1}{1439} + \frac{1}{4000} + \frac{0.05 \ln 0.05/0.0436}{2*16} + \frac{0.05}{0.0436} \cdot \frac{1}{3000} + \frac{0.05}{0.0436} \cdot \frac{1}{4000}$$

U∘ = 112 N/m = 112 N/m^2.c

U°_{ass} = 100 w/m^{2}c

Assume U = 120 W/m^2.$^\circ$c

$$A = \frac{309713}{120*288.9*1} = 8.93 \text{ m}^2$$

$$Nt = \frac{8.93}{0.287} = 32$$

No.of tube per pass $= \frac{34}{2} = 16$

Flow rate per tube $= \dfrac{5170.74}{16*3600}$

$$m = 0.0898 \, kg/s$$

$U = \dfrac{0.0898}{4.58*1.49*10^{-3}} = 13.16 \text{ m/s}$

$Re = \dfrac{4.58*13.16*0.0436}{3*10^{-5}} = 87596$

$Nu = 0.021 \, (87596)^{0.8}(0.64)^{0.33}(1)$

$Nu = 163.02$

$163.02 = \dfrac{h_i*0.0436}{0.048} \implies h_i = 179 \text{ w/m.} \, ^{\circ}\text{C}$

Shell side coefficient h_o

$D_b = 50(\dfrac{32}{0.156})^{1/2.291} = 511 \text{mm}$

For $D_b = 511$ mm and split rong floating head type

$D_s - D_b = 58 \implies D_s = 569 \text{mm}$ [3]

$= 0.569 \text{m}$

$Lb = 0.5(0.569) = 0.285 \text{ m}^2$

$As = (\dfrac{62.5-50}{62.5})(0.569*0.285) = 0.0324 \text{ m}^2$

$Gs = \dfrac{7.374}{0.0324} = 227.59 \text{ kg/m}^2.\text{s}$

$Re = \dfrac{994*0.23*0.0494}{7.2*10^{-4}} = 15686$

For Re = 15686 and 25% baffle cut

$Jn = 5*10^{-3}$ Fig 12.29 [3]

$Nu = 5*10^{-3}(15686)(4.90)^{0.33}(1)$

$Nu = 132.51$

$132.51 = \dfrac{h_o*0.0494}{0.617} \implies h_0 = 1655 \text{ w/m}^2. \, ^{\circ}\text{C}$

$$\frac{1}{U^\circ} = \frac{1}{1655} + \frac{1}{4000} + \frac{0.05 \ln 0.05/0.0436}{2*16} + \frac{0.05}{0.0436} \cdot \frac{1}{3000} + \frac{0.05}{0.0436} \cdot \frac{1}{175}$$

$U^\circ = 127$ w/m$^{2\cdot}$°c

$U_{ass} = 120$ w/m^2.°c

Error $= \frac{127-120}{127} *100\ \% = 5\%$

Tube side pressure drop

$$\Delta p_t = N_P[8\ j_f(\frac{l}{d_i})(\frac{\mu}{\mu_W})^{-0.14} + 2.5][\frac{\rho u_t^2}{2}] \qquad [3]$$

Where

Δp_t = tube side pressure drop N/m^2

N_P = no. of tube passese

j_f = friction factor

u_t = tube side velocity m/s .

for Re = 87596

$j_f = 2.8*10^{-3}$ fig 12.24

$$\Delta p_t = 2[8\ *2.8*10^{-3}\ (\frac{1.83}{0.0436})(1\ )^{-0.14} + 2.5][\frac{4.58*13.16^2}{2}] \qquad [3]$$

$= 2729$ N/m^2

$= 2.73$ kpa $= 0.4$ psi < 10psia ok

Shell side pressure drop

$$\Delta p_t = 8\ j_f(\frac{D_S}{d_e})\ (\frac{l}{l_B})(\frac{\mu}{\mu_W})^{-0.14}\ [\frac{\rho u_t^2}{2}] \qquad [3]$$

Where

Δp_s = shell side pressure drop N/m^2

u_s = shell side velocity m/s .

for Re = 15686 and 25% baffle cut

j_f = $4.7*10^{-2}$ fig 12.30

$$\Delta Ps = 8 * 4.7 * 10^{-2} \left(\frac{0.569}{0.0494}\right)\left(\frac{1.83}{0.285}\right)\left(\frac{994*0.23^2}{2}\right)(1)^{-0.14}$$

$= 731$ N/m^2

$= 0.73$ kpa $= 0.11$ psi < 10psia Ok

Pipe sizing

$d = 260 \, G^{0.52} p^{-0.37}$ [3]

Where

d = optimum pipe diameter mm

G = fluid mass flow rate kg/m^3

P = fluid density kg/m^3

Inlet and out let air

G = 5170.74 kg/h = 1.436 kg/s

P = 4.58 kg/m^3

D = $260(1.436)^{0.52} (4.58)^{-0.37} = 179$mm ≈ 7 inch

Inlet and outlet water

G = 26547 kg/h = 7.374 kg/s

P = 994 kg/m^3

d = $260(7.374)^{0.52}(994)^{-0.37} = 57mm\approx 2\frac{1}{2}$ inch

Mechanical design

Shell

$$e = \frac{Pi\,Di}{2F-Pi} + c \qquad [3]$$

where

e = thickness of shell mm.

Pi = Design pressure N/ mm^2 .

Di = shell inside diameter mm .

f = design stress N/ mm^2 .

C = corrosion constant mm.

D_i = 0.569= 569mm

operating pressure = 8 atm

design pressure pi = 1.1 *8 = 8.8 atm = 0.891 N/mm^2

C = 1 mm   [3]

At T= 441 °C design stress of high stainless steel

f = 100 N/mm^2 Table 13.2   [3]

$$e = \frac{0.891*569}{2*100-0.891} + 1 = 4 \text{ mm}$$

Ellipsoidal head

$$e = \frac{Pi*Di}{2Jf-0.2Pi} + c \quad [3]$$

where

e = thickness of ellipsoidal head mm .

J = joint factor = 0.8   [3]

$$e = \frac{0.891*569}{2*0.8*100-0.2*0.891} +1 \ = 4 \text{ mm}$$

<u>supports</u>

weight loads

weight of vessel (shell)

$$W_V = C_V \ \pi \ \rho_m D_m g \ (H_V +0.8D_m) \ t*10^{-3} \quad [3]$$

<u>where</u>

W_V = total weight of shell exchuding internal fitting N .

C_V = constant .

ρ_m = density of vessel material kg/m^3.

H_V = height (length)of shell m .

D_m = mean diameter of shell m.

t = wall thickness mm

$t = e = 4$mm

$C_V = 1.15$ [3]

$\rho_m = 7800$ kg/m^3 [4]

$D_m = (Di + t*10^{-3})$ \qquad [3]

$D_m= (0.569+2*10^{-3}) \ \ = 0.571$m

$H_V = 1.83$ m

$W_V = 1.15\pi *7800*0.571 *9.81 (1.83 +0.8 *0.571)(4*10^{-3})$

$Wv = 1444$ N

Weight of tubes:

For outside diameter $d_o = 50$mm $= 2$inch

Weight of tube $= 2.41$ Ib/ft table 11-2   [4]

$= 3.593$ kg/m

$W_t = 1.83*3.593*32*9.81$ [3]

   $= 2064$ N

Weight of fluid

$W_f= (\frac{\pi}{4}) D_S^2 L\ p\ g$ [3]

Where

$W_f =$ Weight of fluid N

$\rho =$ density of fluid kg /m^3

$D_S =$ shell diameter m.

$g= 9.81$ m/s^2

$L =$ length of shell m.

$W_f = \frac{\pi}{4} (0.569)^2 (1.83) (994) (9.81) = 4538$ kg/m^3

$W = w_v + w_f + w_t$

Where

W= total weight N

W= 1444+ 2064+4538 =8046 N

Added 10% above total weight

W = 1.1 (8046) = 8851 N = 9 KN

Table	
Length m	1.83
Inside diam. Mm	43.6
Outside diam. Mm	50
Surface area (total) m^2	8.93
No. of tubes	38
No. of passes	2
Inlet temp. ˚C	441
Outlet temp. ˚C	230
Shell	
Diameter m	0.611
Baffle spacing	0.285
Baffle cut %	25
Inlet temp. ˚C	30
Outlet temp .˚C	40
Material of counst.	

0.611

1.83
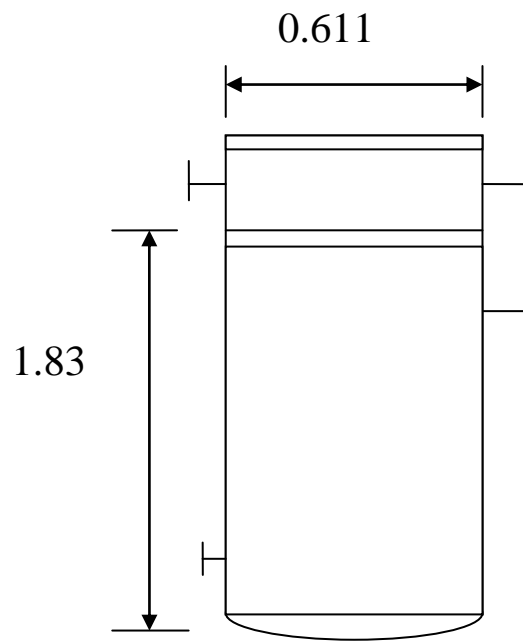
University of Diyala
College of Engineering
Chemical Engineering Department

Production of Nitric Acid

A project report Submitted to the Engineering Department
of Chemical of the University of Diyala in a partial fulfillment
for the Degree of B.Sc in Chemical Engineering

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2015 - 2016

بسم الله الرحمن الرحيم

(...وَأَنزَلَ اللهُ عَلَيكَ الكِتَابَ وَالحِكمَةَ

وَعَلَّمَكَ مَا لَم تَكُن تَعلَمُ وَكَانَ فَضلُ اللهِ

عَلَيكَ عَظِيماً)

صدق الله العظيم

سورة النساء (١١٣)

Nomenclature

symbol	definition	unit
P	Pressure	Psia
T	Temperature	K,$^{\circ}$C
Cp	Heat capacity at constant pressure	j/kmol.k
F	Flow rate	Kg/hr
K	Vapor-Liquid equilibrium	–
A	Vapor to Liquid ratio	–
X	Liquid mole fraction or Conversion	–
Y	Vapor mole fraction	–
Q	Heat rate	J
v	specific volume	m^3/kmol
P_c	Critical pressure	Psia
T_c	Critical temperature	K,$^{\circ}$C
P_r	Reduced pressure	-
T_r	Reduced temperature	–
Z	Compressibility factor	–
N	Molar rate	Kmol/hr
C_v	Heat capacity at constant volume	j/kmol.k
K	Ratio of C_p to C_v	-
R	Gas constant	kj/kmol.K
M_{wt}	Molecular weight	Kg/kmol
W	Work	kj/kmol
ΔH_v	Heat of vaporization	kj/kmol
μ	Viscosity	Pa.s
P	Density or molar density	Kg/m^3
U	Overall heat transfer coefficient	W/m^2 $^{\circ}$C
A	Area	m^2
L	Length	m
D_b	Bundle diameter	m
D_s	Shell diameter	m
Re	Reynolds number	-
Pr	Prandtle number	–
Nu	Nusselt number	–

h_{if}	Inside fouling heat-transfer coefficient	W/m^2 ^{o}C
H_{of}	Outside fouling heat-transfer coefficient	W/m^2 ^{o}C
hi	Inside film heat-transfer coefficient	W/m^2 ^{o}C
hs	Shell film heat-transfer coefficient	W/m^2 ^{o}C
Jh	Heat transfer correction factor	_
de	Equivalent diameter	m
pt	Pitch	m
Np	Number of passes	_

CHAPTER FOUR

PROCESS CONTROL

4.1 Introduction to Process Control

4.1 Introduction to Process Control

Control is a science that is used in many engineering disciplines such as chemical, electrical and mechanical engineering and it is applied to a wide range of physical systems from chemical processes to electrical circuits to guided missiles to robots. The field of process control encompasses the basic principles most useful when applied to the physiochemical systems often encountered by chemical engineers such as chemical reactors, heat exchangers, and mass transfer equipment. Control engineering is not a narrow specialty but an essential topic for all chemical engineers. For example, plant designers must consider the dynamic operation of all equipment, because the plant will never operate at steady state. Engineers charged with operating plants must ensure that the proper response is made to the ever-occurring disturbances so the operation is safe and profitable. Process control engineering involves a vast body of material, including mathematical analysis and engineering practice [3]. These major components are shown schematically in Figure (4.1), which can be used to represent many control systems [3].
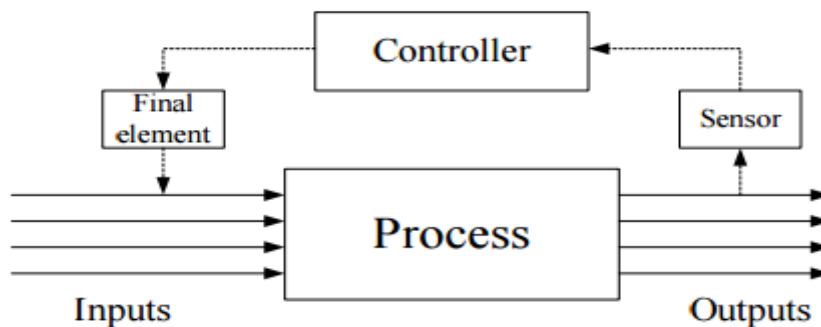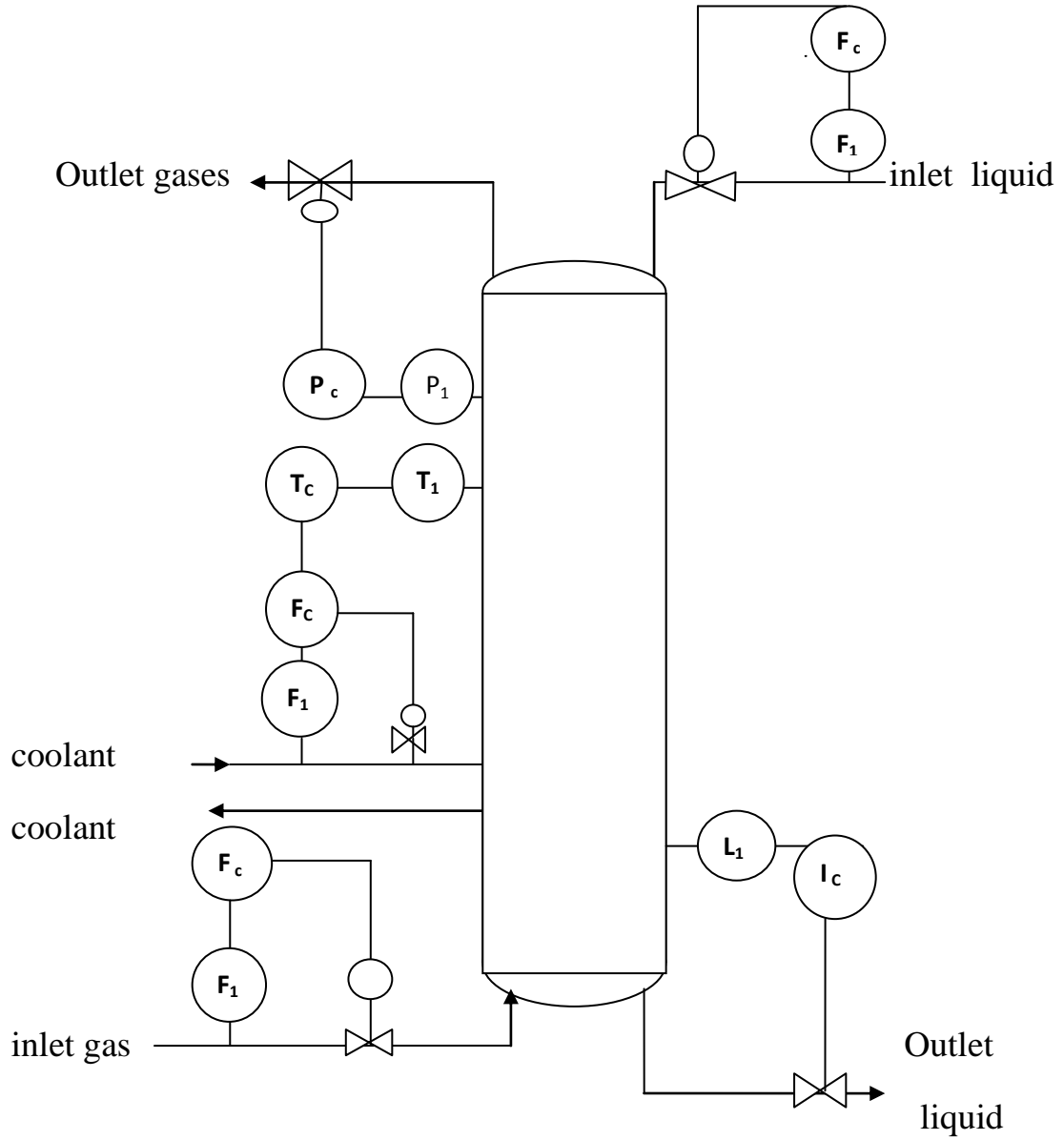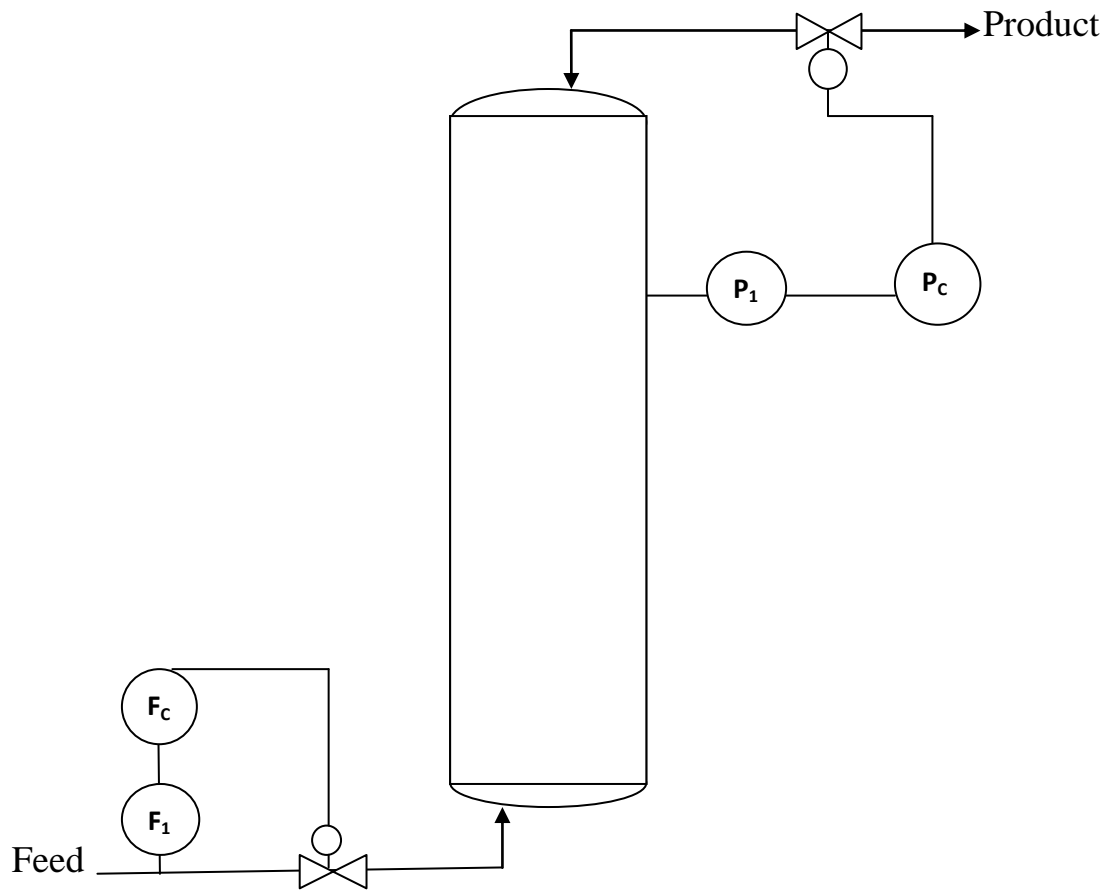

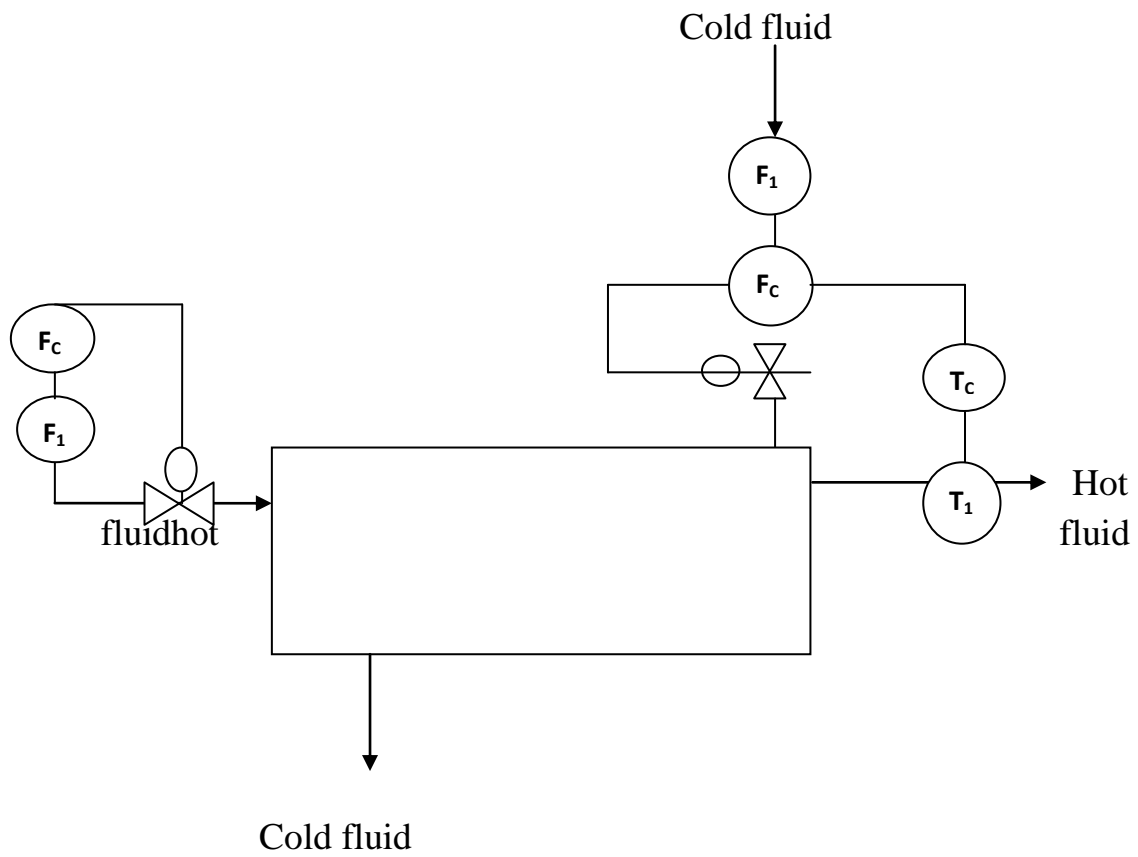Figure (4.1): Schematic diagram of a general feedback control system

4.2 Design of Control System for Absorber[3]

4.3 Design of Control System for Reactor [3]

4.4 Design of Control System for cooler [3]

Cold fluid

F_1

F_c

T_c

F_c

F_1

fluidhot

T_1

Hot fluid

Cold fluid

CHAPTER FIVE

LOCATION, ECONOMIC AND SAEFTY CONSEDRATION

5.1 Plant Location

Considerable care must be exercised in selecting the plant site, and many different factors must be considered. Primarily, the plant should be located where the minimum cost of production and distribution can be obtained, but other factors, such as room for expansion and safe living conditions for plant operation as well as the surrounding community, are also important. The following factors should be considered in selecting a plant site:

1. Raw materials availability

2. Markets

3. Energy availability

4. Climate

5. Transportation facilities

6. Water supply

7. Waste disposal

8. Labor supply

9. Taxation and legal restrictions

10. Site characteristics

11. Flood and fire protection

12. Community factors.

5.1.1 HNO$_3$ Plant Location

Based on these previous factors which are required in HNO3 manufacturing plant, we select Al-Basra city as NH3 can be obtained from NH$_3$ manufacturing plant.

5.2: Site Considerations:

The location of the plant can have a crucial effect on the profitability of a project, and the scope for future expansion. Many factors must be considered when selecting a suitable site, the principle factors to consider are:

1-Marketing area:

For materials that are produced in bulk quantities; such as cement, mineral acids, and fertilizers, where the cost of the product per tone is relatively low and the cost of transport a significant fraction of the sales price, the plant should be located close to the primary market. This consideration will be less important for low volume production, high-priced products; such as pharmaceuticals.

2- Raw materials

The availability and price of suitable raw materials will often determine the site location. Plants producing bulk chemicals are best located close to the source of the major raw material; where this is also close to the marketing area.

3- Transport

The transport of materials and products to and from the plant will be an overriding consideration in site selection.

4- Availability of labor

Labor will be needed for construction of the plant and its operation.Skilled tradesmen will be needed for plant maintenance.

5- Utilities (services)

Chemical processes invariably require large quantities of water for cooling and general process use, and the plant must be located near a source of water of suitable quality. Process water may be drawn from a river, from wells, or purchased from a local authority.

6- Environmental impact and effluent disposal

All industrial processes produce waste products, and full consideration must be given to the difficulties and cost of their disposal. An environmental impact assessment should be made for each new project, or major medication or addition to an existing process.

7- Land (site considerations)

Sufficient suitable land must be available for the proposed plant and for future expansion. The land should ideally be flat, well drained and have suitable load-bearing characteristics.

8- Climate

Adverse climatic conditions at a site will increase costs. Abnormally low temperatures will require the provision of additional insulation and special heating for equipment and pipe runs. Stronger structures will be needed at locations subject to high winds (cyclone/hurricane areas) or earthquakes.

5.3 Health & Safety Information:

Nitric acid is a strong acid and a powerful oxidizing agent. The major hazard posed by it is chemical burns as it carries out acid hydrolysis with proteins (amide) and fats (ester) which consequently decomposes living tissue (e.g. skin and flesh). Concentrated nitric acid stains human skin yellow due to its reaction with the keratin. These yellow stains turn orange when neutralized. Systemic effects are unlikely, however, and the substance is not considered a carcinogen or mutagen. The standard first aid treatment for acid spills on the skin is, as for other corrosive agents, irrigation with large quantities of water. Washing is continued for at least ten to fifteen minutes to cool the tissue surrounding the acid burn and to prevent secondary damage. Contaminated clothing is removed immediately and the underlying skin washed thoroughly. Being a strong oxidizing agent, reactions of nitric acid with compounds such as cyanides, carbides,

metallic powders can be explosive and those with many organic compounds, such as turpentine, are violent and hypergolic (i.e. self-igniting). Hence, it should be stored away from bases and organics .

5.4 Environmental Considerations

Vigilance is required in both the design and operation of process plant to ensure that no harm is done to the environment. Consideration must be given to:

1. All emissions to land, air, water.

2. Waste management.

3. Smells.

4. Noise.

5. The visual impact.

6. Any other nuisances.

7. The environmental friendliness of the products.

Waste management: Waste arises mainly as byproducts or unused reactants from the process, or as off-specification product produced through mis-operation. The designer must consider all possible sources of pollution and, where practicable, select processes that will eliminate or minimize waste generation. Unused reactants can be recycled and off-specification product reprocessed. Integrated processes can be selected: the waste from one process becoming the raw material for another. When waste is produced, processes must be incorporated in the design for its treatment and safe disposal. The following techniques can be considered:

1. Dilution and dispersion.

2. Discharge to foul water sewer (with the agreement of the appropriate authority).

3. Physical treatments: scrubbing, settling, absorption and adsorption.

4. Chemical treatment: precipitation (for example, of heavy metals), neutralization.

5. Biological treatment: activated sludge and other processes.

6. Incineration on land, or at sea.

7. Landfill at controlled sites.

8. Sea dumping (now subject to tight international control).

Noise: Noise can cause a serious nuisance in the neighborhood of a process plant. Care needs to be taken when selecting and specifying equipment such as compressors, air-cooler fans, induced and forced draught fans for furnaces, and other noisy plant. Excessive noise can also be generated when venting through steam and other relief valves, and from flare stacks. Such equipment should be fitted with silencers.

5.5 Cost Estimation

The choice of appropriate equipment often is influenced by considerations of price. A lower efficiency or a shorter life may be compensated for by a lower price. Funds may be low at the time of purchase and expected to be more abundant later, or the economic life of the process is expected to be limited.

5.5.1 Cost estimation on absorber

Height $\quad h = 3.02\ m$

Diameter $\quad D = 0.52m$

Pressure $\quad P = 8bar$

Material of construction high silicon iron

Cost=$5500\ \$$

Pressure factor =1.1

Material factor =1

Fig. 6_5 b   [8]

$$Cost = 5500 * 1.1 * 1 = 6050 \$ \quad in\ (2004)$$

$$Cost\ in\ 2012 = (cost\ in\ 2004)\frac{(cost\ index\ in\ 2012)}{(cost\ index\ in\ 2004)}$$

cost index in 2004 = 444.2

cost index in 2012 = 697.32   [9]

$$Cost\ in\ 2012 = (6050)\left(\frac{697.32}{444.2}\right)$$

$$= 9498 \$$$

5.5.2 Cost Estimation on reactor

Height $h = 1.411m$

Diameter $D = 0.32m$

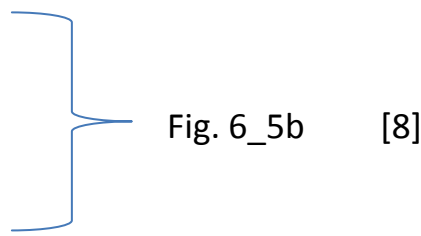Pressure   P= 8 bar

Material of construction : Stainless steel

Cost=2500 $

Pressure factor =1.1   Fig. 6_5b   [8]

Material factor =2

$$Cost = 2500 * 1.1 * 2 = 5500 \$ \quad in\ (2004)$$

$$Cost\ in\ 2012 = (cost\ in\ 2004)\frac{(cost\ index\ in\ 2012)}{(cost\ index\ in\ 2004)}$$

cost index in 2004 = 444.2

cost index in 2012 = 697.32   [9]

$$Cost\ in\ 2012 = (5500)\left(\frac{697.32}{444.2}\right)$$

$$= 8634\ \$$$

5.5.3 Cost Estimation on heat exchanger

Surface area   A= 8.93 m^2

Pressure $P = 8bar$

Material of construction : Stainless steel

Type: floating head

Cost=20000 $

Pressure factor =1   Fig. 6_5b   [8]

Material factor =1

$$Cost = 20000 * 1 * 1 = 20000\ \$ \quad in\ (2004)$$

$$Cost\ in\ 2012 = (cost\ in\ 2004)\frac{(cost\ index\ in 2012)}{(cost\ index\ in\ 2004)}$$

$$cost\ index\ in\ 2004 = 444.2$$

$$cost\ index\ in 2012 = 697.32 \qquad [9]$$

$$Cost\ in\ 2012 = (20000)\left(\frac{697.32}{444.2}\right)$$

$$= 31397\ \$$$

CHAPTER SIX
CONCLUSON AND
RECOMMENDATION

6.1 Conclusions

The case study of the manufacture of nitric acid emphasizes the benefits of a systematic design based on the analysis of the reactor/condenser/absorber. The core of the process is the chemical reactor, whose behavior in recycle depends on the kinetics and selectivity performance of the catalyst, as well as the safety and technological constraints. Moreover, the recycle policy depends on the reaction mechanism of the catalytic reaction. Thus, for Platinum& rodium catalysts the reaction of the ammonia on the active sites is fast and not rate limiting In consequence, the designer should respect the composition of the reaction mixture at the reactor inlet that is compatible with the experimental conditions in which the kinetics of the catalytic process has been studied.

6.2 Recommendation

The recommendations for further work on the production of nitric acid plant are listed below:

1. Other production nitric acid methods can be selected.
2. Other conversion can be selected.
3. Study reaction kinetic of nitric acid in reactor.