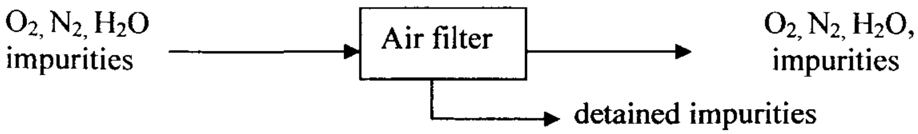
APPENDIX A
MASS BALANCE

Air filter (FG-212)



Feed air = 8816.9136

Assumed impurities = 0.0036%

Impurities = 8816.9136 × 0.0036% = 0.3178 kg/h

$$\text{Humidity} = 0.02 \frac{\text{kg } H_2O}{\text{kg dry air}}$$

$$N_2 = \frac{0.79}{1.02} \times \text{total air} = 6631.1530$$

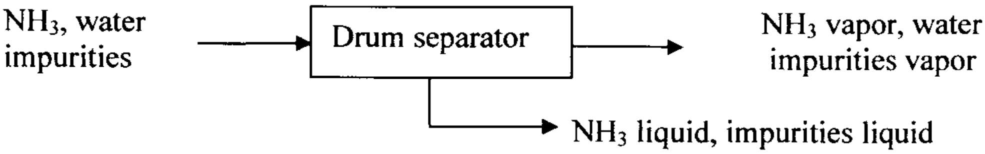
$$O_2 = \frac{0.21}{1.02} \times \text{total air} = 2013.2390$$

$$H_2O = \frac{0.02}{1.02} \times \text{ total air} = 172.2038$$

Air Filter (FG-212)

input	kg/hour	output	kg/hour
N_2	6631.1530	N_2	6631.1530
O_2	2013.2390	O_2	2013.2390
H_2O	172.2038	H_2O	172.2038
Impurities	0.3178	Impurities	0.2802
		Detained impurities	0.0376
	8816.9136		8816.9136

Drum Separator (D-113)



Pure ammonia (NH_3) = 489.6652 kg/h

Assumption 98% NH_3 vaporize

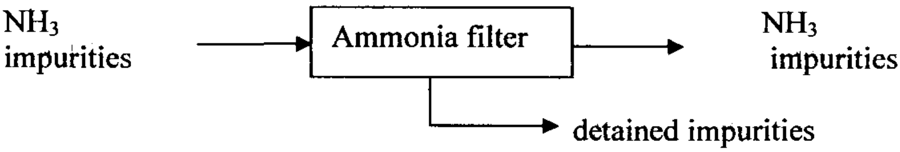
NH_3 vapor = 98% × 489.6652 kg/h = 480.0639

NH_3 liquid = 489.6652 – 480.0639 = 9.6013 kg/h (recycle)

Drum Separator (D-113)

input	kg/hour	output	kg/hour
NH_3 feed	489.6652	NH_3 liquid	9.6013
		NH_3 vapor	480.0639
Impurities	0.0856	Impurities vapor	0.0486
		Impurities liquid	0.0370
Water	2.4006	Water	2.4006
	492.1514		492.1514

Ammonia Filter (FG-115)



Feed: NH_3 vapor = 480.0639 kg/h

Assumption 10 % detained as impurities

Detained impurities = 0.0048 kg/h

NH_3 for tail gas = 7.4864 kg/h

NH_3 into reactor = 480.0639 – 7.4864 = 472.5775 kg/h = 27.7497 kmol/h

Ammonia Gas Filter (FG-115)

input	kg/hour	output	kg/hour
NH_3	480.0639	NH_3	480.0639
Impurities	0.0486	Impurities	0.0438
		Detained impurities	0.0048
	480.1125		480.1125

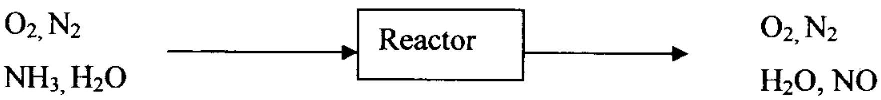
Ammonia + Air filter (FG-312)

Assumption all the impurities are detained.

Ammonia+air filter (FG-312)

input	kg/hour	output	kg/hour
NH_3	472.5297	NH_3	472.5297
Water	154.9756	Water	154.9756
Impurities	0.2470		
N_2	5949.1279	N_2	5949.1279
O_2	1806.0416	O_2	1806.0416
		Detained impurities	0.247
	8382.9218		8382.6748

Tubular Membrane Reactor



Component loading to the reactor :

NH_3 = 27.1920 kmol/h = 472.5297 kg/h

Air = 277.3562 kmol/h :

- H_2O in air $= \frac{0.032}{1.032} \times 277.3562 = 8.6002$ kmol/h = 154.9756 kg/h
- N_2 in air $= \frac{0.79}{1.032} \times 277.3562 = 212.3172$ kmol/h = 5949.1279 kg/h
- O_2 in air $= \frac{0.21}{1.032} \times 277.3562 = 56.4388$ kmol/h = 1806.0416 kg/h +

Total = 8382.6748 kg/h

There are 2 reactions occur:

NH_3 +	$\frac{5}{4}O_2$ →	NO +	$\frac{3}{2}H_2O$		Conversion = 98%
27.1920	33.99	27.1920	40.788		

NH_3 +	$\frac{3}{4}O_2$ →	$\frac{1}{2}N_2$ +	$\frac{3}{2}H_2O$		Conversion = 2%
0.5549	0.4162	0.2775	0.8324		

The rest of O_2 = 56.4388 – (33.99 + 0.416)
= 22.0326 kmol/h
= 705.0432 kg/h

Component that is formed:

NO = 27.1920 kmol/h
= 815.7529 kg/h

H_2O = (40.788 + 0.8324) kmol/h
= 749.9996 kg/h

N_2 = 0.2775 kmol/h
= 7.7756 kg/h

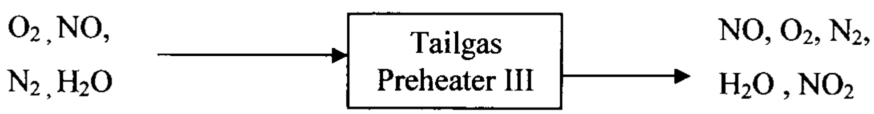
Product from the reactor:

NO = 27.1920 kmol/h	= 815.7529 kg/h
H_2O = 749.9996 kg/h + 154.9756 kg/h	= 904.9752 kg/h
N_2 = 7.7756 kg/h + 5949.1279 kg/h	= 5956.9035 kg/h
O_2 = 22.0326 kmol/h	= 705.0432 kg/h +
Total	= 8382.6748 kg/h

Tubular Membranes Reactor (R-310)

input	kg/hour	output	kg/hour
NH_3	472.5297	NH_3	
O_2	1806.0416	O_2	705.0432
NO		NO	815.7529
N_2	5949.1279	N_2	5956.9035
H_2O	154.9756	H_2O	904.9752
	8382.6748		8382.6748

Tailgas Preheater III (E-513)



The reaction is:

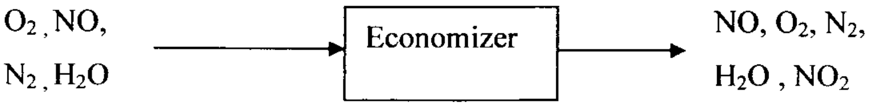
	2 NO +	O_2	→ 2 NO_2
M	27.1920	22.0326	
R	6.7980	3.3990	6.7980
S	20.3940	18.6336	6.7980

Conversion = 25%

Tail gas Preheater III (E-513)

input	kg/hour	output	kg/hour
NO	815.7529	NO	611.8200
O_2	705.0432	O_2	596.2693
N_2	5956.9035	N_2	5956.9035
H_2O	904.9752	H_2O	904.9752
NO_2		NO_2	312.7068
	8382.6748		8382.6748

Economizer (E-413)



The reaction is:

	$2\,NO$	+	O_2	→ $2\,NO_2$
M	20.3940		18.6336	6.7980
R	6.7980		3.3990	6.7980
S	13.596		15.2346	13.5960

Conversion = 25%

Economizer (E-413)

input	kg/hour	output	kg/hour
NO	611.8200	NO	407.8800
O_2	596.2693	O_2	487.5024
N_2	5956.9035	N_2	5956.9035
H_2O	904.9752	H_2O	904.9752
NO_2	312.7068	NO_2	625.4137
	8382.6748		8382.6748

Tailgas Preheater II (E-512)

The reaction is:

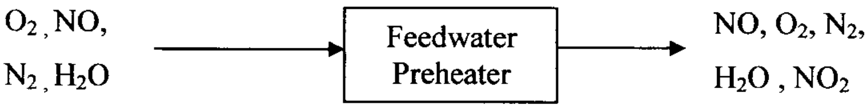
	$2\,NO$	+	O_2	→ $2\,NO_2$
M	13.5960		15.2346	13.5960
R	6.7980		3.3990	6.7980
S	6.7980		11.8356	20.3940

Conversion = 25%

Tail gas Preheater II (E-512)

input	kg/hour	output	kg/hour
NO	407.8800	NO	203.9400
O_2	487.5024	O_2	378.7356
N_2	5956.9035	N_2	5956.9035
H_2O	904.9752	H_2O	904.9752
NO_2	625.4137	NO_2	938.1205
	8382.6748		8382.6748

Feedwater Preheater (E-411)



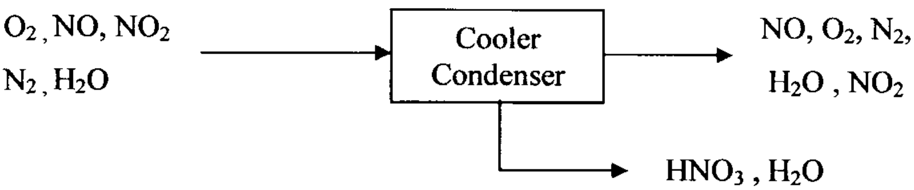
The reaction is:

	2 NO	+ O_2	→ 2 NO_2	Conversion = 24%
M	6.7980	11.8356	20.3940	
R	6.5261	3.3990	6.7980	
S	0.2719	8.5725	26.9201	

Feedwater Preheater (E-411)

input	kg/hour	output	kg/hour
NO	203.9400	NO	8.1570
O_2	378.7356	O_2	274.3200
N_2	5956.9035	N_2	5956.9035
H_2O	904.9752	H_2O	904.9752
NO_2	938.1205	NO_2	1238.3191
	8382.6748		8382.6748

Cooler Condenser (E-611)



The reaction is:

	$3\ NO_2$ +	H_2O	→ $2\ HNO_3$ +	NO
M	26.9201	50.2206		
R	13.1100	4.3700	8.7400	4.3700
S	13.8105	45.8506	8.7400	4.3700

	NO +	$\frac{1}{2} O_2$	→ NO_2	95 %
M	4.3700	8.5725		
R	4.1515	2.0757	4.1515	
S	0.2185	6.4968	4.1515	

Component out from cooler condenser

NO = 0.2185 kmol/h = 6.5550 kg/h

NO_2 = 4.1515 + 13.8101 = 17.9616 kmol/h = 828

O_2 = 6.4967 kmol/h

N_2 = 212.5947 kmol/h

H_2O = 45.8506 kmol/h

Cooler Condenser (E-611)

input	kg/hour	output	kg/hour
NO	8.1570	NO	6.5550
O_2	274.3200	O_2	208.8944
NO_2	1238.3191	NO_2	828.4132
N_2	5956.9035	N_2	5956.9035
H_2O	904.9752	H_2O	828.2278
HNO_3		HNO_3	553.6809
	8382.6748		8382.6748

Absorption Tower (T-610)

From the *Chemical and Catalytic Reaction Engineering* by Carbery, 1976 page 289 for absorption with reaction process:

The equilibrium absorption reaction in the absorber is

$3NO_2 + H_2O_{(l)} \leftrightarrow 2HNO_{3(l)} + NO$ (a)

$2NO_2 \leftrightarrow N_2O_4$ (b)

Reaction (a) is equilibrated slowly; (b) instantaneously

The irreversible rate of gas-phase oxidation of NO in terms of partial pressure is

$$-\frac{d(NO)}{d\theta} = k_1 (NO)^2 (O_2) \qquad \text{(c)}$$

where k_1 is,

$$\log k_1 = \frac{635}{T} - 1.026 \quad \text{T in Kelvin} \qquad \text{(d)}$$

HNO_3 to be produced in this preliminary plant is 60 wt%, with 1.6 ID and 30 cm plate spacing.

Component loading to the absorber

species	Feed rate (lbmol /h)
NO	0.4817
NO_2	39.5979
O_2	14.3225
N_2	468.6832

Secondary air loading to the absorber

O_2 = 28.597 lb mol

N_2 = 522.3826 lb mol

Total component loading to the absorber with secondary air:

species	Feed rate (lbmol /h)	Feed rate (kg/h)
NO	0.4817	6.555
NO_2	39.5979	828.4132
O_2	28.597	415.0912
N_2	522.3826	6639.4147

Process water needed = 446.3547 kg/h

Water from cooler condenser = 828.2278 kg/h

Nitric acid from cooler condenser = 553.6809 kg/h

By simulating with Matlab (M-file program attached):

Amount of tray needed: 22

Product from the reactor:

Species	Rate (kg/h))
NO	17.9314
O_2	281.7852
NO_2	0.8249
N_2	6639.4147
H_2O	1111.1111
HNO_3	1666.6667
N_2O_4	0.0035

Absorption Tower (T-610)

input	kg/hour	output	kg/hour
NO	6.555	NO	17.9314
O_2	415.0912	O_2	281.7852
NO_2	828.4132	NO_2	0.8249
N_2	6639.4147	N_2	6639.4147
H_2O	828.2278	H_2O	1111.1111
H_2O process	446.3547	H_2O process	
HNO_3	553.6809	HNO_3	1666.6667
N_2O_4		N_2O_4	0.0035
	9717.7375		9717.7375

SCR Reactor (R-510)

Component loading to the SCR-reactor (tail gas from the absorber + ammonia):

Species	Rate (kg/h)	Rate (kmol/h)
NO	17.9314	0.5977
NO_2	0.8249	0.0179
NH_3	7.4864	0.4396
N_2	6639.4147	236.9527
O_2	281.7852	8.8058

Reaction in the SCR-reaction

$6\ NO + 4\ NH_3 \rightarrow 5\ N_2 + 6\ H_2O$

$6\ NO_2 + 8\ NH_3 \rightarrow 7\ N_2 + 12\ H_2O$

Assumption: conversion of both reactions is 90%

	$6\ NO$	+	$4\ NH_3$	→	$5\ N_2$	+	$6\ H_2O$	Conversion = 90%
M	0.5977		0.4279					
R	0.5777		0.3851		0.4814		0.5777	
S	0.02		0.0428		0.4814		0.5777	

	$6\ NO_2$	+	$8\ NH_3$	→	$7\ N_2$	+	$12\ H_2O$	Conversion = 90%
M	0.0179		0.0117					
R	0.0079		0.0105		0.0092		0.0158	
S	0.01		0.0012		0.0092		0.0158	

From the reaction :

Species	Rate (kmol/h)
NO	0.02
NO_2	0.01
NH_3	0.044
N_2	0.4906
H_2O	0.5935

Product from the reactor:

NO = 0.02 kmol/h = 0.6 kg/h

NO_2 = 0.01 kmol/h = 0.4601 kg/h

NH_3 = 0.044 kmol/h = 0.7493 kg/h

N_2 = 0.4906 kmol/h + 6639.4137 kg/h = 6653.1531 kg/h

H_2O = 0.5935 kmol/h = 10.6949 kg/h

O_2 = 8.8058 kmol/h = 281.7852 kg/h +

Total = 6947.4426 kg/h

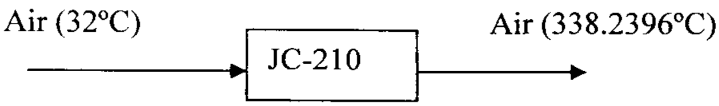
SCR Reactor (S-510)

input	kg/hour	output	kg/hour
NO	17.9314	NO	0.6
NO_2	0.8249	NO_2	0.4601
NH_3	7.4864	NH_3	0.7493
N_2	6639.4147	N_2	6653.1531
H_2O		H_2O	10.6949
O_2	281.7852	O_2	281.7852
	6947.4426		6947.4426

APPENDIX B

HEAT BALANCE

Air Compressor (JC-210)



T_{ref} = 25°C

T_{input} of air = 32°C

$T_{av} = (T_{input} + T_{ref})/2$

T_{av} = (32+25)/2 = 28.5°C

Entering N_2 = 6807.0420 kg/h

Entering O_2 = 1809.5299 kg/h

Entering H_2O = 172.2824 kg/h

From Kern, at 32°C:

Cp N_2 = 0.23 kcal/kg.°C

Cp O_2 = 0.21 kcal/kg.°C

Cp H_2O = 0.44 kcal/kg.°C

The entering enthalpy:

H N_2 = m.Cp.ΔT = 6807.0420x0.23x(32-25) = 10959.3376 kcal/h

H O_2 = m.Cp.ΔT = 1809.5299x0.21x(32-25) = 2660.0090 kcal/h

H H_2O = m.Cp.ΔT = 172.2824x0.44x(32-25) = 530.6298 kcal/h +

Total 14149.9764 kcal/h

T_{ref} = 25°C

T_{output} of air = 338.2396°C

$T_{av} = (T_{input} + T_{ref})/2$

T_{av} = 181.6198 °C

From Kern, at 181.6198 °C:

Cp N_2 = 0.2488 kcal/kg.°C

Cp O_2 = 0.2197 kcal/kg.°C

Cp H_2O = 0.5004 kcal/kg.°C

The exiting enthalpy:

$H\ N_2 = m.Cp.\Delta T = 6807.0420 x 0.2488 x (338.23962-25)$ =530580.1906 kcal/h

$H\ O_2 = m.Cp.\Delta T = 1809.5299 x 0.2197 x (338.2396-25)$ =124418.5118 kcal/h

$H\ H_2O = m.Cp.\Delta T = 172.2824 x 0.5004 x (338.2396-25)$ = 26783.6456 kcal/h +

Total 681782.3480 kcal/h

$H_{in} = H_{out} + Q$

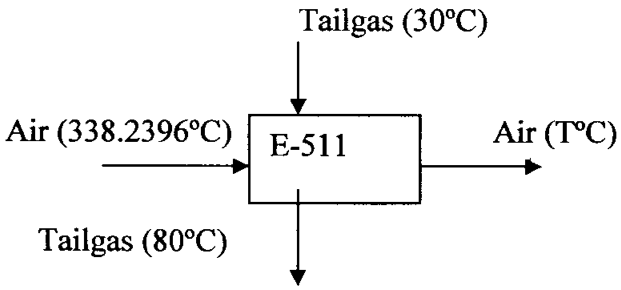
$14149.9764 = 681782.348 + Q$

$Q = 667632.3716$ kcal/h

Air Compressor (JC-210)

input	kkal/hour	output	kkal/hour
heat of material	14149.9764	heat of material	681782.3480
heat of compression	667632.3716		
	681782.3480		681782.3480

Tail gas Preheater I (E-511)



ΔH_{in} for entering air is taken from the output of air compressor's heat balance;

ΔH_{in} of air = 681782.3480 kcal/h

Enthalpy of tail-gas at 30°C; it is the total of each component's

$m_{component}.cP_{component}.\Delta T$

Cp at $T_{av} = (30+25)/2 = 27.5$°C; simulated by ChemCAD; $m_{component}$ is taken from mass balance. $\sum m_{component}.cP_{component}.\Delta T$ is calculated by MATLAB.

ΔH_{in} of tail-gas = 8443.50369 kcal/h

Enthalpy of tail-gas at 80°C; it is the total of each component's

$m_{component}.cP_{component}.\Delta T$

Cp at T_{av} = (80+25)/2 = 52.5°C, simulated by ChemCAD, $m_{component}$ is taken from mass balance. $\sum m_{component}.cP_{component}.\Delta T$ is calculated by MATLAB.

ΔH_{out} of tail-gas = 95066.7380 kcal/h

Total ΔH_{in} = ΔH_{in} of air + ΔH_{in} of tail-gas

= 681782.3480 kcal/h + 8443.50369 kcal/h

= 690225.8517 kcal/h

Qloss = 8736.5485 kcal/h

Total ΔH_{in} = Qloss + ΔH_{out} of tail-gas + ΔH_{out} of air

690225.8517 kcal/h = 8736.5485 kcal/h + 95066.7380 kcal/h + ΔH_{out} of air

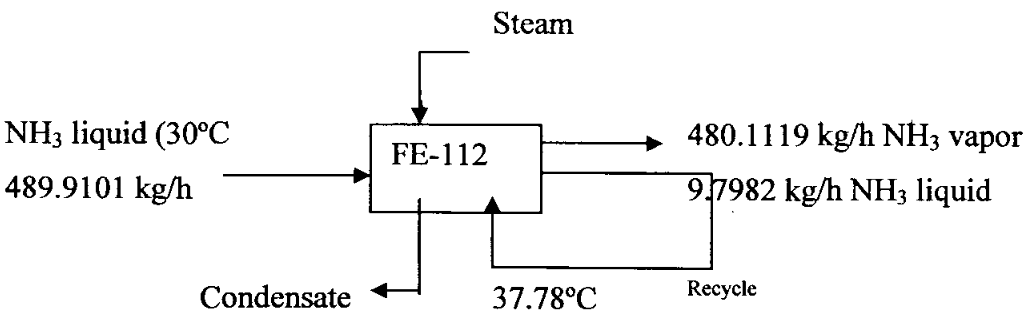
ΔH_{out} of air = 586422.5654 kcal/h

By trial and error of $\sum m_{component}.cP_{component}.\Delta T$ formula, it can be found that the temperature of exiting air is 255 °C

Tail gas Preheater I (E-511)

input	kkal/hour	output	kkal/hour
enthalpy of compression air	681782.348	enthalpy of compression air	586422.5654
Enthalpy of tail gas	8443.50369	enthalpy of tail gas	95066.738
		Q loss	8736.5485
	690225.8519		690225.8519

AmmoniaVaporizer (FE-112)



The enthalpy entering vaporizer

489.9101 kg/h liquid ammonia 99.5% enters vaporizer at 30°C and 170 psi

Percentage of exiting ammonia recycled is 5 %

F = FF+R

489.9101 = 480.1119 + 9.7982

H_{in} = 480.1119 kg/h x 81.721 kcal/kg + 9.7982 kg/h x 86.28 kcal/kg

= 40,080.6133 kcal/h

The enthalpy exiting vaporizer:

Q NH_3 out = 480.1119 x 351.9 + 9.7982 x 86.28

(vapor) (liquid)

=169,796.7663 kcal

40,080.6133 + Q = 169,796.7663

Q = 129,716.153 kcal/h

Considering the amount of 10 % of Q loss

Q supply = (40,080.6133 + 129,716.1530).100%/90% = 188,663.0737 kcal/h

Q loss = 18,866.3074 kcal/h

Superheated steam wanted at 200°C and 700 kPa, from Geankoplis' Appendix;

h_V = 2844.8 kJ/kg and h_L = 419.04 kJ/kg

For steam, $\lambda = h_V - h_L$ =2465.76 kJ/kg.°C x 1 kcal/4.184 kJ = 589.3308 kcal/kg.°C

So the amount of steam needed = Q supply/ λ

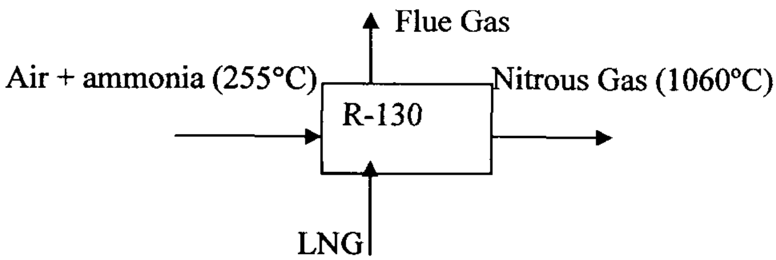
= 188,663.0737 $^{kcal}/_{h}$ / 589.3308 $^{kcal}/_{kg.°C}$

= 320.131 kg/h

AmmoniaVaporizer (FE-112)

input	kkal/hour	output	kkal/hour
heat of material	40080.6133	heat of material	169796.7633
steam	148582.4574	Q loss	18866.3074
	188663.0707		188663.0707

Tubular membrane Reactor (R-310)



Entering enthalpy:

$Tav = (T_{input} + T_{ref})/2$

$= (255 + 25)/2 = 140°C$

$\Delta H_{in} = 538{,}749.3484$ kcal/h

$Q_{loss} = 10\% \times \Delta H_{in}$

$= 53{,}874.9348$ kcal/h

Reaction in the reactor:

$NH_3 + 5/4\ O_2 \rightarrow NO + 3/2\ H_2O$ 98%.......(1)

$NH_3 + ¾\ O_2 \rightarrow ½\ N_2 + 3/2\ H_2O$ 2%.........(2)

$$\Delta H_1 = -\frac{904.10^3}{4}\frac{kJ}{kmol} \times 0.239\frac{kcal}{kj} \times 27.1920\frac{kmol}{h} = -1{,}468{,}748.688\frac{kcal}{h}$$

$$\Delta H_1 = -\frac{1268.10^3}{2}\frac{kJ}{kmol} \times 0.239\frac{kJ}{kmol} \times 0.559\frac{kmol}{h} = -84{,}081.7774\frac{kcal}{h}$$

Total entering enthalpy = (1,552,830.465 + 538,749.3484) kcal/h

= 2,087,555.198 kcal/h

temperature exiting reactor is maintained at 1060°C

$T_{av2} = 542.5°C$

$\Delta H_{out} = 2{,}549{,}260.657$ kcal/h

Total exiting enthalpy = 2,549,260.657 kcal/h + Q_{loss}

= 2,549,260.657 kcal/h + 53,874.9348 kcal/h

= 2,603,135.582 kcal/h

$0.9\ Q_{LNG} = 545{,}177.275$ kcal $\rightarrow Q_{LNG} = 572{,}419.1944$ kcal

LNG fuel, consist of:

Species	Composition
CH_4	87.1%
C_2H_6	3.41%
C_3H_8	1.73%
N_2	7.1%
CO_2	0.31%
He	0.35%

From Perry 6th-ed,

- heating value (HV) = 86000 btu/gal
- ρ 3.4469 lb/gall

HV = 13870.365 kcal/kg

Heat needed = 572,419.1944 kcal

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

$C_2H_6 + 7/2\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$

$C_3H_8 + 2\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$

Fuel needed = a kg

CH_4 = 87.1% x a/16 = 0.0544a

C_2H_6 = 3.41% x a/30 = 0.0011367a

C_3H_8 = 1.73% x a/44 = 0.0003932a

N_2 = 7.1% x a/28 = 0.002536a

CO_2 = 0.31% x a/44 = 0.00004076a

He = 0.35% x a/4 = 0.000875a

From reaction 1,2,3

O_2 needed = 0.1147a

O_2 added is 15% excess = 1.15 x 0.1147a kmol = 0.1319a kmol = 4.2226a kg/J

N_2 flow in = 79/21 x 4.2226a = 0.4392a kmol = 13.8935a kg/J

O_2 remaining = 0.1319a – 0.1147a = 0.0172a kmol

CO_2 product = 0.0685 a

H_2O product = 0.1136a kmol

Heat produced:

1. Fuel flow in = 2.7962a kcal
2. Heat flow in = 21.0077a kcal
3. Combustion heat = 86000 btu/gal

ρ = 3.4469 lb/gal

HV = 86000/3.4469 = 24949.96 btu/lb x 2.326/1 x 1/4.184 = 13870.3654 kcal/kg

Heat of flue gas flow out:

CO_2 = 0.0685a kmol = 3.014a kg

H_2O = 0.1136a kmol = 2.0448a kg

He = 8.75×10^{-4}a kmol

O_2 = 0.0172a kmol

N_2 = 0.4962a kmol = 13.8936a kg

Temperature flue fas flow out = 1200°C = 1473 K

Heat flue fas (CO_2, H_2O, O_2, N_2, He) = 6721.2493a kcal

Q loss = 20% x 13870.365 = 2774.073a

Heat flow in

Material	=	528749.3484
NH_3 reaction	=	1552830.465
Fuel	=	2.7962a
Air	=	21.0077a
Combustion	=	13870.365a +

Heat flow out

Heat material	=	2519260.657
Material Q loss	=	52874.9348
Heat flue gas	=	6721.2493a
Fuel Q loss	=	2774.073a +
		2602135.592 + 9495.3223a

2081579.513 + 13894.1689 a = 2602135.592 + 9495.3223a

4398.8466a = 520556.079

a = 118.3392

Heat flow in:

H material	=	538749.3484 kcal/J
H NH_3 reaction	=	1552830.465 kcal/J
H air	=	2486.0344 kcal/J
H fuel	=	330.9 kcal/J
H combustion	=	1641407.898 kcal/J +
		3735804.646 kcal/J

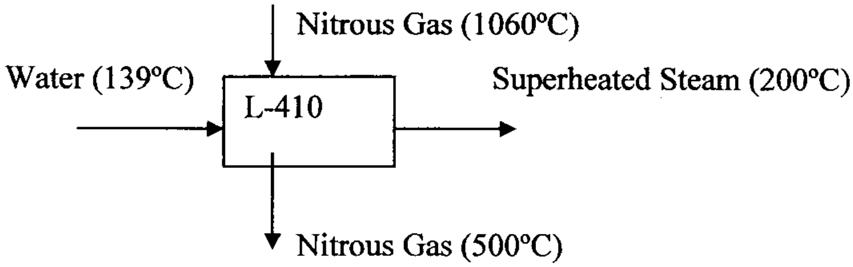
Heat flow out:

H material	=	2549260.657 kcal/J
Q loss	=	391156.584 kcal/J
H flue gas	=	795387.405 kcal/J +
		3735804.646 kcal/J

Tubular Membranes Reactor (R-310)

input	kkal/hour	output	kkal/hour
heat of material	538749.3484	heat of material	2549260.6570
heat of NH3 reaction	1552830.4650	Q loss	391156.5840
heat of air	2486.0344	heat of flue gas	795387.4050
heat of fuel	330.9000		
heat of combustion	1641407.8980		
	3735804.6460		3735804.6460

Waste Heat Boiler (L-410)



Tr=25°C

The enthalpy of entering nitrous gas from reactor R-310 = 2,549,260.6570 kcal/h

T_{av} output of nitrous gas = (500+25)/2 = 262.5 °C

Cp of each component of nitrous gas at T_{av} 262.5 °C is taken using ChemCAD

The exiting enthalpy of nitrous gas:

H O_2 = m.Cp.ΔT = 705.0432x0.2354x(500-25) = 78834.4054 kcal/h

H NO = m.Cp.ΔT = 815.7529x0.2459x(500-25) = 95281.9781 kcal/h

H N_2 = m.Cp.ΔT = 5956.9035x0.2543x(500-25) = 719549.2660 kcal/h

H H_2O = m.Cp.ΔT = 904.9752x0.5047x(500-25) = 216951.9671 kcal/h +

Total 1110617.6170 kcal/h

ΔH of nitrous gas = 1,110,617.6170 kcal/h – 2,549,260.6570 kcal/h

= -1,438,643.0400 kcal/h

Therefore, the amount of heat of 1,438,643.0400 kcal/h has to be removed from the nitrous gas by water. This heat is also used to make the water to be steam.

Then, at the T_{av} =139°C;

1,438,643.0400 kcal/h = m_{water} x (h_V – h_L)

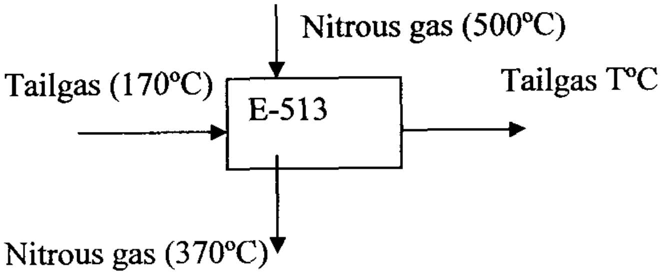
= m_{water} x (22818.3639 – 589) kJ/kg x 1/4.184 kcal/kJ

m_{water} = 2700 kg/h

Waste Heat Boiler (L-410)

input	kkal/hour	output	kkal/hour
enthalpy of nitrous gas	2549260.6570	enthalpy of nitrous gas	1110617.6170
enthalpy of air	277407.6000	enthalpy of superheated steam	1383249.0550
		Q loss	272631.4380
	2926668.2570		2926668.2570

Tail Gas Preheater III (E-513)



For nitrous gas;

T_{in} = 500 °C; T_{out} = 370 °C

Cp for components at T_{av} , simulated by ChemCAD as follow,

Components \ T	262.5°C	197.5°C
NO	0.2459	0.2521
O_2	0.2354	0.2305
N_2	0.2543	0.2521
H_2O	0.5047	0.5428
NO_2	0.2436	0.2380

$m_{component}$ is taken from mass balance. $\sum m_{component}.cP_{component}.\Delta T$ is calculated by MATLAB.

ΔH_{in} of nitrous gas = 1110617.6177 kcal/h

ΔH_{out} of nitrous gas = 813875.709 kcal/h

ΔH_{in} of tail gas is taken from Tail Gas Preheater II heat balance= 390035.9594 kcal/h

Qloss = 10%.(ΔH_{in} of nitrous gas + ΔH_{in} of tail gas)

= 150065.3576 kcal/h

The NO gas has its 25% reaction here

$$NO + \frac{1}{2} O_2 \rightarrow NO_2 , \Delta H_{rx} = -13651 \text{ kcal/kmole}$$

6.7980 kmoles/h NO x 13651 kcal/kmole = 92799.498 kcal/h

ΔH_{in} of nitrous gas + ΔH_{in} of tailgas + ΔH^{o}_{rx} = Qloss + ΔH_{out} of nitrous gas + ΔH_{out} of tail gas

1110617.6177 + 390035.9594 + 92799.498 = 150065.3576 + 813875.709 + ΔH_{out} of tail gas

ΔH_{out} of tail gas = 537365.4320 kcal/h

By trial and error of this equations;

$\Delta H_{out} = \sum m_{component}.cP_{component}.\Delta T$

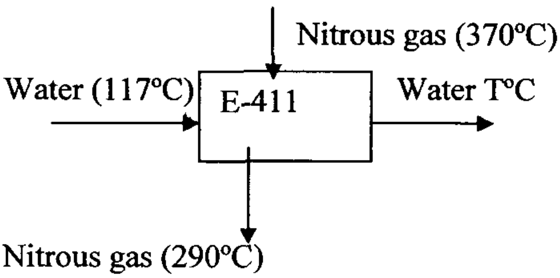
It can be found that the ΔT= 310°C

Therefore, T_{out} of tail gas = 310 °C

Tail Gas Preheater III (E-513)

Input	**kkal/hour**	**output**	**kkal/hour**
enthalpy of nitrous gas	1110617.6177	enthalpy of nitrous gas	813875.7090
heat of reaction	92799.4980	Q loss	149412.4354
enthalpy of tail gas	297236.4610	enthalpy of tail gas	537365.4320
	1500653.3760		1500653.5760

Economizer (E-413)



For nitrous gas;

T_{in} = 370 °C; T_{out} = 290 °C

ΔH_{in} of nitrous gas is taken from output of Tail gas Preheater III = 813875.709 kcal/h

ΔH_{out} of nitrous gas is taken from input of Tail gas Preheater II = 740910.38 kcal/h

Qloss = 10%.(ΔH_{in} of nitrous gas + ΔH_{in} of water)

The NO gas has its 25% reaction here

$NO + \frac{1}{2} O_2 \rightarrow NO_2$, ΔH_{rx} = -13651 kcal/kmole

6.7980 kmoles/h NO x 13651 kcal/kmole = 92799.4980 kcal/h

ΔH_{in} of nitrous gas + ΔH_{in} of water + ΔH^{o}_{rx} = Qloss + ΔH_{out} of nitrous gas + ΔH_{out} of water

ΔH_{in} of nitrous gas + ΔH_{in} of water + ΔH^{o}_{rx} = (0.1x ΔH_{in} of nitrous gas + 0.1x ΔH_{in} of water)+ ΔH_{out} of nitrous gas + ΔH_{out} of water

0.9x813875.709 + 0.9x 2700x(117-25) +92799.4980=740910.38 + ΔH_{out} of water

2700. Cp_{Tout} (T_{out}-25) = 307937.2561

ΔT= 114°C

Therefore, T_{out} of water = 139°C

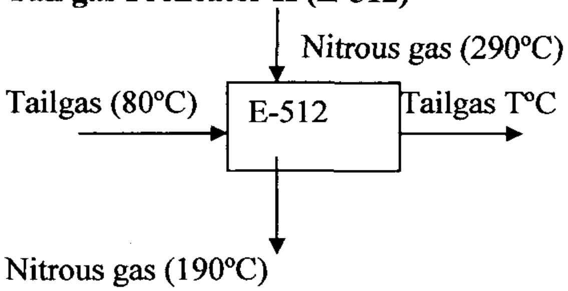
By trial and error and by the mass of 2700 kg/h of superheated steam wanted to be produced in waste heat boiler; ΔT= 92°C

T_{out} = 117 °C

Economizer (E-413)

input	kkal/hour	output	kkal/hour
enthalpy of nitrous gas	813875.7090	enthalpy of nitrous gas	740910.3800
enthalpy of air	260820	enthalpy of air	329346
heat of reaction	92799.4980	Q loss	97238.8270
	1167495.2070		1167495.2070

Tail gas Preheater II (E-512)



For nitrous gas;

T_{in} = 290 °C; T_{out} = 190 °C

Cp for components at T_{av} , simulated by ChemCAD as follow,

Components \ T	(T_{in}=290°C) T_{av}= 157.5°C	(T_{out}=190°C) T_{av}= 107.5°C
NO	0.2422	0.2416
O_2	0.2277	0.2246
N_2	0.2511	0.2505
H_2O	1.0415	1.0117
NO_2	0.2363	0.2390

$m_{component}$ is taken from mass balance. $\sum m_{component}.cP_{component}.\Delta T$ is calculated by MATLAB.

ΔH_{in} of nitrous gas = 740910.38 kcal/h

ΔH_{out} of nitrous gas = 456441.885 kcal/h

The NO gas has its 25% reaction here

$NO + ½ O_2 \rightarrow NO_2$, ΔH_{rx} = -13651 kcal/kmole

6.7980 kmoles/h NO x 13651 kcal/kmole = 92799.498 kcal/h

ΔH_{in} of tail gas at 80°C is taken from output of tailgas preheater I heat balance

ΔH_{in} of tailgas = 95066.738 kcal/h

ΔH_{in} of nitrous gas + ΔH_{in} of tailgas + ΔH^{o}_{rx} = Qloss + ΔH_{out} of nitrous gas + ΔH_{out} of tail gas

740910.38 + 95066.738 + 92799.498 = 82298.7716 + 456441.885 + ΔH_{out} of tail gas

ΔH_{out} of tail gas = 390035.9594 kcal/h

By trial and error of this equations;

$\Delta H_{out} = \sum m_{component}.cP_{component}.\Delta T$

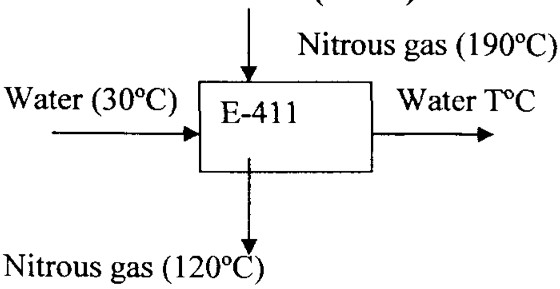
It can be found that the ΔT=145°C

Therefore, T_{out} of tail gas = 170 °C

Tail Gas Preheater II (E-512)

input	kkal/hour	output	kkal/hour
enthalpy of nitrous gas	740910.3800	enthalpy of nitrous gas	456441.8850
enthalpy of tail gas	95066.7380	Q loss	82298.7716
heat of reaction	92799.4980	enthalpy of tail gas	390035.9594
	928776.6160		928776.6160

Feed water Preheater (E-411)



For nitrous gas;

T_{in} = 190 °C; T_{out} = 120 °C

ΔH_{in} of nitrous gas is taken from output of Tail gas Preheater II = 740910.38 kcal/h

Cp for components at T_{av} , simulated by ChemCAD as follow,

Components \ T	(Tout=120°C) T_{av}= 72.5°C
NO	0.2419
O_2	0.2230
N_2	0.2505
H_2O	1.0029
NO_2	0.2479

$m_{component}$ is taken from mass balance. $\sum m_{component}.cP_{component}.\Delta T$ is calculated by MATLAB.

ΔH_{out} of nitrous gas = 263143.331 kcal/h

Qloss = 10%.(ΔH_{in} of nitrous gas + ΔH_{in} of water)

The NO gas has some of its reaction here

$NO + \frac{1}{2} O_2 \rightarrow NO_2$, ΔH_{rx} = -13651 kcal/kmole

6.5261 kmoles/h NO x 13651 kcal/kmole = 89087.7911 kcal/h

ΔH_{in} of nitrous gas + ΔH_{in} of water + ΔH^{o}_{rx} = Qloss + ΔH_{out} of nitrous gas + ΔH_{out} of water

ΔH_{in} of nitrous gas + ΔH_{in} of water + ΔH^{o}_{rx} = (0.1x ΔH_{in} of nitrous gas + 0.1x ΔH_{in} of water)+ ΔH_{out} of nitrous gas + ΔH_{out} of water

$0.9x45644.1885 + 0.9x\ m\ x\ 0.9999x\ (30-25) + 89087.7911 = 26314.3331 + \Delta H_{out}$ of water

$m.\ Cp_{Tout}\ (T_{out}-25) = 103853.2277 + 4.49955.m$

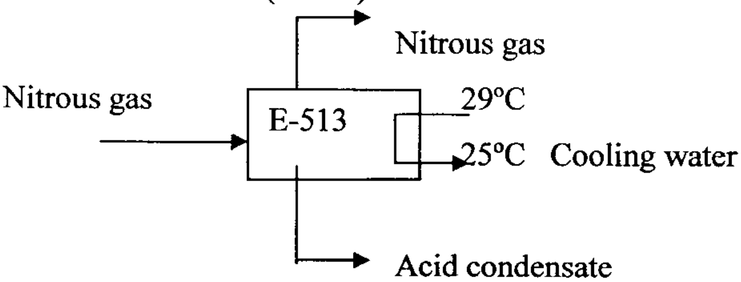
By trial and error and by the mass of 2700 kg/h of superheated steam wanted to be produced in waste heat boiler; $\Delta T = 92°C$

$T_{out} = 117\ °C$

Feed water Preheater (E-411)

input	kkal/hour	output	kkal/hour
enthalpy of nitrous gas	456441.8850	enthalpy of nitrous gas	263143.3310
water	13482.4500	water	- 253368
heat of reaction	89087.7911	heat of reaction	42500.7451
	559012.0761		559012.0761

Cooler Condenser (E-611)



$NO_2 + 1/3\ H_2O \rightarrow 2/3\ HNO_3 + 1/3\ NO$

$\Delta H_{rx} = -138.476x10^3 /3\ \ kJ/kmoles\ x\ 1\ kcal / 4.184\ kJ$

$= -11032.1861\ kcal/kmole$

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

$\Delta H_{rx} = -113.048x10^3 /2\ \ kJ/kmoles\ x\ 1\ kcal / 4.184\ kJ$

$= -13509.5602\ kcal/kmole$

$\Delta H_{rx}1 = -11032.1861$ kcal/kmole x 13.11 kmoles (reacted NO_2) = 144631.9598 kcal/h

$\Delta H_{rx}2 = -13509.5602$ kcal/kmole x 4.1515 kmoles (reacted NO) = 56084.9392 kcal/h

+

Total 200716.8990 kcal/h

Enthalpy nitrous gas enters is taken from output of Feed water Preheater (E-411)

ΔH_{in} of nitrous gas = 263143.331 kcal/h

ΔH_{in} of nitrous gas + ΔH_{rx} total = 463860.23 kcal/h

T / Components	(T_{out}=30°C) T_{av}= 27.5°C
NO	0.2459
O_2	0.2354
N_2	0.2543
H_2O	0.5047
NO_2	0.2436

From mass balance of each component and its Cp, using equation

$\Delta H = m.Cp.\Delta T$

ΔH_{out} of nitrous gas = 16650.0306 kcal/h

Therefore, to find the flow rate of cooling water

463860.23 = 16650.0306 + 46386.023 (Qloss) + Q absorbed by cooling water

Q = 400824.1764 kcal/h

Cooling water at 27°C; λ = 2552.63 – 117.43 = 2435.2 kJ/kg = 582.0268 kcal/kg

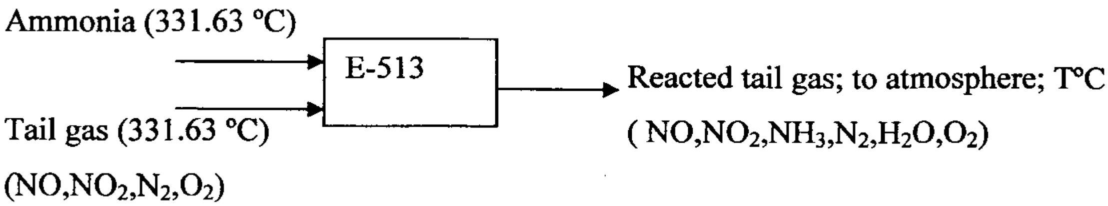
400824.1764 = m.582.0268 + m. 1. (29-25)

m= 683.969 kg/h

Cooler Condenser (E-611)

input	kkal/hour	output	kkal/hour
heat of material	263143.331	heat of material	16650.0306
heat of reaction	200716.899	Q loss	51820.6742
water	19066.4389	water vapour	414455.9641
	482926.6689		482926.6689

SCR Reactor (R-510)



$T_{in} = 331.63$ °C

Cp for components at $T_{av} = (331.63$ °C $+25$ °C$)/2 = 178.315$°C, simulated by ChemCAD as follow,

T / Components	(T_{in}=331.63°C) T_{av}= 178.315°C
O_2	0.2404
N_2	0.2574
NO_2	0.2511
NO	0.2494
NH_3	0.6417

$m_{component}$ is taken from mass balance. $\sum m_{component}.cP_{component}.\Delta T$ is calculated by MATLAB.

$\Delta H_{in} = 547661.2680$ kcal/h

$6NO + 4NH_3 \rightarrow 5N_2 + 6H_2O$ $\Delta H^o_{rx} = -108007$ kcal/kmole

$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$ $\Delta H^o_{rx} = -81602.2$ kcal/kmole

0.5777 kmole NO x -108007/6 = -10399.274 kcal/h

0.0179 kmole NO_2 x -81602.2/6 = -243.4465 kcal/h

Qloss = 10 %. 547661.2680 kcal/h

= 54766.1268 kcal/h

$\Delta H_{in} + \Delta H^o_{rx} = Qloss + \Delta H_{out}$

547661.268 + 10642.7206 = 54766.1268 + H out

$\Delta H_{out} = 503537.8618$ kcal/h

By trial and error of this equations;

$\Delta H_{out} = \sum m_{component}.cP_{component}.\Delta T$

It can be found that the T out = 307 °C

H NO = m.Cp.ΔT = 0.6000x0.2459x(307-25) = 42.1985 kcal/h

H NO_2 = m.Cp.ΔT = 0.4601x0.2511x(307-25) = 32.5798 kcal/h

H NH_3 = m.Cp.ΔT = 0.7493x0.6417x(307-25) = 135.5929 kcal/h

H N_2 = m.Cp.ΔT = 6653.1531x0.2574x(307-25) = 482931.0934 kcal/h

$H\ H_2O = m.Cp.\Delta T = 16.6949x0.5008x(307\text{-}25)$ = 1510.3937 kcal/h

$H\ O_2 = m.Cp.\Delta T = 281.7852x0.2404x(307\text{-}25)$ = 19103.0077 kcal/h +

Total ΔH_{out} 503754.8659 kcal/h

So, it needs correction of Q loss by this value of ΔH_{out} for T_{out} = 307 °C

Qloss = 54549.1227 kcal/h

SCR Reactor (R-510)

input	kkal/hour	output	kkal/hour
enthalpy of material	547661.268	enthalpy of material	503754.8659
heat of reaction	10642.7206	Q loss	54549.1227
	558303.9886		558303.9886

APPENDIX C

EQUIPMENT SPECIFICATION

Ammonia Storage Tank (TT-611)

Function: to storage liquid ammonia

Type: horizontal with elliptical dished head

Consideration: suitable to storage high pressure liquid

Operation condition: T = 30°C, P =11 atm

(Perry 7^{ed}, p 2-88)

Ammonia needed = 492.3720 kg/hr

At 1 atmosphere:

S_v ammonia liquid = 1.648×10^{-3} (Perry 7^{ed}, p 2-214)

$$\rho \text{ ammonia} = \frac{1}{S_v} = \frac{1}{1.648 \times 10^{-3}} = 606.7961 \text{ kg/m}^3$$

ρ H_2O = 995.6470 kg/m^3 = 62.1181 lb/ft^3 (Perry 7^{ed}, p 2-91)

$$\frac{1}{\rho NH_3} = \frac{0.995}{6067.961} + \frac{0.005}{995.6470} = 1.6448 \times 10^{-3}$$

$$\rho NH_3 = 607.9833 \, {kg}/{m^3} = 37.9319 \, {lb}/{ft^3}$$

For 7 days (108 hours)

$$V_{liquid} = \frac{492.3720}{607.9833} \times 168 = 136.0539 \, {m^3}/{\tan k}$$

V_{liquid} = 80% V_{tank}

$$V_{tank} = \frac{100}{80} \times 136.0539 = 170.0674 \, m^3 = 103{,}78087.23 \, in^3 = 6005.6545 \, ft^3$$

Assumption: $\frac{L}{D} = 1.5$

$$V = L\left(\frac{\pi D^2}{4}\right)$$

$$170.0674 = \frac{1.5}{4}\pi D^3$$

$D^3 = 144.3577$ m

D = 5.2458 m = 206.5271 in = 17.2014 ft

L = 1.5 × 5.2458 = 7.8687 m

V dished head = $0.000049\ D^3$

= $0.00049\ (206.5271)^3$

= $431.6455\ ft^3$

V tank = V shell + 2 V dished head

6005.6545 = V shell + 2 × 437.6455

V shell = $5142.3635\ ft^3$

$$V\ shell = \frac{\pi}{4} D^2 h$$

$$5142.3635\ ft^3 = \frac{\pi}{4}(17.2104)^2 \times h$$

h = 22.1050 ft

$$\frac{h}{D} = \frac{22.1050}{17.2104} = 1.3 \text{ (range < 2, acceptable)}$$

$$P_{hidrostatik} = \rho \times \frac{(h-1)}{144} = 62.1181 \times \left(\frac{22.1050-1}{144}\right) = 9.1042 \text{ psia}$$

Shell thickness

P design = 1.2 (161.7+9.1042) = 204.965 psia

Construction material: stainless steel AISI-304L with elliptical dished head

F allowable = 18750 lb/in^2 (Brownell & Young, 1959)

ε = 85% (double welded)

c = 1/8 in

$$ts = \frac{P D_i}{2(F\varepsilon - 0.6P))} + c$$

$$= \frac{204.965 \times 206.5271}{2 \times (18750 \times 0.85 - 0.6 \times 204.965)} + \frac{1}{8} = 1.4634 \text{ in} = 1\frac{1}{2} \text{ in}$$

Head thickness

k = 2 (Brownell & Young, p 133)

$$V = \frac{1}{6}\left(2 + k^2\right)$$

$$= \frac{1}{6}(2+4) = 1$$

$$t_h = \frac{P \times D \times V}{2f\varepsilon - 0.2P}$$

$$= \frac{204.965 \times 206.5271 \times 1}{2 \times 18750 \times 0.85 - 0.2 \times 204.965} + \frac{1}{8} = 1.4547 = 1.5 \text{ in}$$

From table 5.11

sf = 3 in

$$\text{Head height } = \left(\frac{ID}{4}\right) + sf + t$$

$$= \left(\frac{206.5271}{4}\right) + 3 + 1.4547$$

$$= 56.0865 = 4.6739 \text{ ft}$$

Specification

Material	: stainless steel AISI-304L
Capacity	: 6005.6545 ft^3
Diameter	: 17.2104 ft
Height of the top	: 4.6739 ft
Height of the bottom	: 4.6739 ft
Shell thickness	: 1,5 in
Top thickness	: 1.5 in
Bottom thickness	: 1.5 in
Total height	: 31.4528 ft
Amount	: 1

Ammonia Solution Pump (J-110)

Function: to pump 99.5% ammonia

Type: centrifugal

Operation condition: T = 30°C, P= 11 atm = 161.7 psia

Length pipe planned = 27 ft = 8.2296 m

Piping planned is completed with:

- 2 standard elbow 90°
- 2 gate valve, wide open
- 1 sudden enlargement
- 1 sudden contraction

At P = 11 atm

Sv NH_3 liq = 1.648×10^{-3} m^3/kg (Perry 7th ed, p 2-214)

$$\rho\, NH_3 = \frac{1}{sv} = \frac{1}{1.648 \times 10^{-3}} = 606.7961 \text{ kg/m}^3$$

ρ H_2O = 995.68 kg/m^3 (Geankoplis 3rd ed, App A2-3, p 855)

$$\frac{1}{\rho NH_3\, solution} = \frac{X\, NH_3}{\rho NH_3} + \frac{X\, H_2O}{\rho H_2O} = \frac{0.995}{606.7961} + \frac{0.005}{995.68} = 1.6448 \times 10^{-3} \text{ m}^3\text{/kg}$$

ρ NH_3 solution = 607.9834 kg/m^3 = 37.9567 lb/ft^3

μ NH_3 solution = 0.1 Cp = 0.1 x 2.42 = 0.242 lb ft/hr = 6.7222×10^{-5} lb ft/s (kern, fig 14)

Rate NH_3 solution = 492.3720 kg.hr = 1085.5 lb/hr (X) → 1.02 X = 1107.21 lb/hr

$$\text{Volumetric rate} = \frac{1107.21}{37.9567} = 29.1703 \text{ ft}^3\text{/hr} = 8.1029 \times 10^{-3}$$

Safety factor 20%

Q_F = feed = 1.2 v = 1.2 x (8.1029×10^{-3}) = 9.7235×10^{-3} ft^3/s = 2.7534×10^{-4} m^3/s

Calculating optimum diameter

Trial = turbulen

Optimum diameter for turbulen pipe can be found from Peter & Timmerhaus, 1991, p 525, eq 15

Opt Diameter = 3.9 $(Q_F)^{0.45}$ (ρ NH_3 solution)$^{0.13}$

= 3.9 $(Q_F)^{0.45}$ $(37.9567)^{0.13}$ = 0.7778 in

Pipe 1 in schedule 80

From Geankoplis App A.5-1

OD = 1.315 in

ID = 0.957 in = 0.07975 ft = 0.0798 ft = 0.0243 m

Inside cross section area = 0.00499 ft^2 (A) v = linear velocity = $\frac{Q_F}{A} = \frac{9.7235\times10^{-3}}{0.00499} = 1.9486$ ft/s = 0.5939 m/s

$$N_{Re} = \frac{ID\, v\, \rho\, NH_3\ solution}{\mu\, NH_3\ solution} = \frac{0.0798\times1.9486\times37.9567}{6.7222\times10^{-5}} = 87801.6358 \rightarrow \text{turbulan}$$

From Geankoplis p 88 for commercial steel

ε = equivalent roughness for new pipes = 4.6 x 10^{-5} m

ID = 0.957 in = 0.0243 m

$$\frac{\varepsilon}{ID} = \frac{4.6\times10^{-5}}{0.0243} = 1.893\times10^{-3} = 0.0019 \approx 0.002$$

For N_{Re} = 87801.6358; from Geankoplis p 88, fig 2.10-3, f = 0.0064

From Geankoplis p 93, table 2.10-1

Elbow 90° → k_f = 0.75, $\frac{Le}{D} = 35$

Gate valve, wide open → k_f = 0.17, $\frac{Le}{D} = 9$

Pipe friction

Sudden contraction (h_c)

$$h_c = 0.55\left(1-\frac{A_2}{A_1}\right)^2 \frac{v_2^{\,2}}{2\alpha}$$

$$= 0.55(1-0)^2\left(\frac{0.5939^2}{2\times1}\right)$$

= 0.097 J/kg

Sudden enlargement (h_{ex})

$$h_{ex} = \left(1-\frac{A_1}{A_2}\right)^2 \frac{v_1^{\,2}}{2\alpha}$$

$$= (1-0)^2\ \frac{0.5939^2}{2\times1} = 0.1764\ \text{J/kg}$$

Straight pipe (F_f)

$$F_f = 4f\frac{\Delta L}{D}\frac{v^2}{2} = 4\times0.0064\frac{8.2296}{0.0243}\frac{0.5939^2}{2} = 1.529\ \text{J/kg}$$

Fitting (h_f)

2 elbow 90°

$h_f = k_f \frac{v_1^2}{2}$

$= 0.75 \frac{0.5939^2}{2} 2\,(\text{amount}) = 0.2645$ J/kg

2 gate valve, wide open

$h_f = k_f \frac{v_1^2}{2}$

$= 0.17 \frac{0.5939^2}{2} 2 = 0.0599$ J/kg

Total friction

$\Sigma F = h_c + h_{ex} + F_f + h_f$

$= 0.097 + 0.1764 + 1.529 + (0.2645 + 0.0599)$

$= 2.1268$ J/kg $= 0.7115$ ft lbf / lbm

Power pump

Bernoulli equation

$$\frac{\Delta v^2}{2g_c} + \frac{g}{g_c}\Delta z + \frac{\Delta P}{\rho} + \sum F = -Ws$$

$$\frac{1.9486^2}{2 \times 32.174} + \frac{32.174}{32.174} + 0 + \left(\frac{(170 - 161.7)144}{37.9567}\right) + 0.7115 = -Ws$$

-Ws $= 0.059 + 0 + 31.4885 + 0.7115$

$= 32.259$ lbf ft / lb

Power pump $= Ws \times Q_F \times \rho$ NH_3 solution

$= 32.2590 \times (9.7235 \times 10^{-3}) \times 37.9567$

$= 11.9059$ lbf ft / s

$= 0.0216$ HP

Capacity $= 9.7235 \times 10^{-3}$ ft^3/s $= 0.7274$ US gal/s $= 43.6449$ US gal /min

Pump efficiency 50% (Peter & Timmerhaus, 4th ed, fig 14-38)

BHP (Brake Horse Power) $= \frac{0.0216}{0.5} = 0.0433$ HP

Motor efficiency 81% (Peter & Timmerhaus, 4th ed, fig 14-38)

$$\text{Power pump} = \frac{0.0433}{0.81} = 0.0534\,\text{HP}$$

Specification

Construction material : Carbon Steel SA-240 Grade C

Quantity : 2 (1 for reserve)

Ammonia Vaporizer (FE-112)

Function: to vaporize ammonia liquid to ammonia vapor

Assumption: ammonia solution non vaporized = 2% (Ullman)

Calculation:

Rate of ammonia vapor = 1085.5 lb/hr

Ammonia will vaporize isothermally at 100 °F and vapor pressure is 209.4 psia, steam is used as heater at 85 psig with

H_{fg} = 888.8 Btu/lb

Ts = 327.8 °F

T_{ref} = 25 °C = 298 K

T_1 = 30 °C = 303 K

T_2 = 100 °F = 37.78 °C = 310.78 K

$$\int_{T_{ref}}^{T_1} Cp_1\,dT = a\left(T_1 - T_{ref}\right) + \frac{b}{2}\left(T_1^{\,2} - T_{ref}^{\,2}\right) + \frac{c}{3}\left(T_1^{\,3} - T_{ref}^{\,3}\right) + \frac{d}{4}\left(T_1^{\,4} - T_{ref}^{\,4}\right)$$

$$= 2.01494\times 10(303 - 298) + \frac{8.45765\times 10^{-1}}{2}\left(303^2 - 298^2\right) +$$

$$\frac{-4.06741\times 10^{-3}}{3}\left(303^3 - 298^3\right) + \frac{6.60687\times 10^{-6}}{4}\left(303^4 - 298^4\right)$$

= 431.4869 J/mol K

$$\int_{T_{ref}}^{T_2} Cp_2\,dT = a\left(T_2 - T_{ref}\right) + \frac{b}{2}\left(T_2^{\,2} - T_{ref}^{\,2}\right) + \frac{c}{3}\left(T_2^{\,3} - T_{ref}^{\,3}\right) + \frac{d}{4}\left(T_2^{\,4} - T_{ref}^{\,4}\right)$$

$$= 2.01494\times 10(310.78 - 298) + \frac{8.45765\times 10^{-1}}{2}\left(310.78^2 - 298^2\right) +$$

$$\frac{-4.06745\times 10^{-3}}{3}\left(310.78^3 - 298^3\right) + \frac{6.60687\times 10^{-6}}{4}\left(310.78^4 - 298^4\right)$$

= 1112.9818 J/mol K

$Q_{in} = Q_{out}$

$$m_1 \int_{T_{ref}}^{T_1} Cp_1\, dT + m_2 \int_{T_{ref}}^{T_2} Cp_2\, dT = m_3 \int_{T_{ref}}^{T_3} Cp_3\, dT$$

$$492.3828 \times 431.4869 + 9.8477 \times 1112.9818 = 502.2305 \int_{T_{ref}}^{T_3} Cp_3\, dT$$

$$\int_{T_{ref}}^{T_3} Cp_3\, dT = 444.8496$$

$$444.8496 = 2.01494 \times 10(T_3 - 298) + \frac{8.45765 \times 10^{-1}}{2}\left(T_3^2 - 298^2\right) + \frac{-4.06745 \times 10^{-3}}{3}\left(T_3^3 - 298^3\right) + \frac{6.60687 \times 10^{-6}}{4}\left(T_3^4 - 298^4\right)$$

T_3 = 303.1542 K = 30.1542 °C = 86.2776 °F

Mass Balance

(Hl_3) enthalpy solution at 86.2776 °F; 209.4 psia = 150 Btu/lb

(Hl_2) enthalpy solution at 100 °F; 209.4 psia = 160 Btu/lb

(Hv) enthalpy vapor at 100 °F; 209.4 psia = 630 Btu/lb

Preheat

$q_p = m_3$ x ($Hl_2 - Hl_3$) = 11072.1 lb/hr (160-150) = 11072.1 Btu/hr

Vaporization

$q_v = m_1$ ($H_v - Hl_2$) = 1085.5 x (630-160) = 5101820 Btu/hr

Ammonia, Q = $q_p + q_v$ = (11072.1 + 5101850) = 5112922.1 Btu/hr

Steam, Q = H_{fg} x m_{steam}

$$m_{steam} = \frac{Q}{h_{fg}} = \frac{5112922.1}{888.8} = 5752.6126 \text{ lb/hr}$$

Δt weighted (subscripts p and v indicate preheating and vaporizing)

$$(\Delta t)_p = \text{LMTD} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}}$$

$$= \frac{(327.8 - 86.2776) - (327.8 - 86)}{\ln \frac{(327.8 - 86.2776)}{(327.8 - 86)}}$$

$$= 241.6611\ °F$$

$$(\Delta t)_v = LMTD = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}}$$

$$= \frac{(327.8 - 100) - (327.8 - 86.2776)}{\ln \frac{327.8 - 100}{327.8 - 86.2776}}$$

$$= 234.5943\ °F$$

$$\frac{q_p}{(\Delta t)_p} = \frac{11072.1}{241.6611} = 45.8166\ Btu/hr\ °F$$

$$\frac{q_v}{(\Delta t)_v} = \frac{5101850}{234.5943} = 21747.57\ Btu/hr\ °F$$

$$\Sigma \frac{q}{\Delta t} = 21793.3868\ Btu/hr\ °F$$

$$\text{Weighted } \Delta t = \frac{Q}{\Sigma \frac{q}{\Delta t}} = \frac{5112922.1}{21793.3868} = 234.609\ °F$$

T_c and t_c = average values of temperature will be satisfactory for preheat zone

$$t_c = t_a = \frac{1}{2}(100 + 86.2776) = 93.1386°F$$

$T_c = T_s = 327.8$ °F

Trial

Assume $U_D = 400$ Btu/hr ft^2 °F

Assigned OD = ¾ in, 10 BWG, $P_T = 1$ in square

$$A = \frac{Q}{U_D \times \Delta t} = \frac{5112922.1}{400 \times 234.609} = 54.4834\ ft^2$$

a'' = 0.1963

A = Nt x Lt x a''

$$Nt = \frac{A}{Lt \times a''} = \frac{54.4834}{10 \times 0.1963} = 27.7552$$

Assumption 2 tube passes

Standardization = 32 tube, 2 passes, ¾ in OD, 1 in sq pitch

Nearest count = 26 tubes in a 8 in ID shell

Corrected U_D

A = Nt x L x a'' = 26 x 10 x 0.1963 = 51.038 ft^2

$$U_D = \frac{Q}{A \times \Delta t} = \frac{5112922.1}{51.038 \times 234.609} = 427.003 \text{ Btu/hr ft}^2 \text{ °F}$$

<table>
<tr><th>Hot Fluid = tube side, steam</th><th>Cold Fluid = shell side, ammonia</th></tr>
<tr><td>

Flow area, a't = 0.182 in^2 Kern, table 10

$$a_t = \frac{Nt \times a't}{144n} = \frac{26 \times 0.182}{144 \times 2} = 0.0164 \text{ ft}^2$$

Mass velocity

$$Gt = \frac{m_s}{a_t} = \frac{5752.6126}{0.0164} = 350769.061$$

At Ts = 327.8 °F

μ = 0.015 cp = 0.0363 lb/ft hr fig 15

D = 0.482 in = 0.0402 ft table 10

$$Re_t = \frac{D \times Gt}{\mu}$$

$$Re_t = 0.0402 \frac{350769.061}{0.0363} = 388454.9932$$

h_{io} for condensing steam

= 1500 Btu/hr ft^2 °F

$$U_D = \frac{h_{io} \times h_o}{h_{io} + h_o}$$

$$= \frac{1500 \times 252.7778}{1500 + 252.7778}$$

= 216.3233 Btu/hr ft^2 °F

$$Ap = \frac{q_D}{U_D (\Delta t)_p}$$

$$= \frac{45.8166}{216.3233} = 0.2118 \text{ ft}^2$$

h_{io} for condensing steam

</td><td>

$$B = \frac{ID}{5} = \frac{8}{5} = 1.6 \text{in}$$

c' = P_T – OD = 1 – ¾ = 0.25

$$a_s = \frac{ID \times c'B}{144 P_T} = \frac{8 \times 0.25 \times 1.6}{144 \times 1} = 0.0222 \text{ft}^2$$

mass velocity

$$Gs = \frac{m_1}{a_s} = \frac{1085.5}{0.0222} = 48896.3964$$

At t_c = 93.1386 °F

μ = 0.1 cp = 0.24191 lb/ft hr

$$De = \frac{0.95}{12} = 0.0792 \text{ft}$$ fig 28

$$Re_s = \frac{De\ Gs}{\mu}$$

$$Re_s = \frac{0.0792 \times 48896.3964}{0.24191} = 16008.41054$$

jH = 70 fig 28

At t_c, k = 0.29 table 4

cp = 1.15 Btu/lb °F fig 2

$$k\left(\frac{cp\ \mu}{k}\right)^{\frac{1}{3}} = 0.2860$$

$$h_o = jH \frac{k}{De}\left(\frac{cp\ \mu}{k}\right)^{\frac{1}{3}}$$

$$= 70 \frac{0.286}{0.0792} = 252.7778 \text{Btu/hr ft}^2 \text{ °F}$$

</td></tr>
</table>

= 1500 Btu/hr ft^2 °F $Uv = \frac{h_{io} \times h_o}{h_{io} + h_o}$ $= \frac{1500 \times 894.9495}{1500 + 894.9495}$ $= 560.523$ $Av = \frac{q_v}{U_v(\Delta t)_v}$ $= \frac{21747.57}{560.523} = 38.7987 ft^2$ Ac = Ap + Av $= 0.2118 + 38.7987$ $= 39.0105$ ft^2 $U_C = \frac{\Sigma UA}{AC}$ $= \frac{21793.3868}{39.0105}$ = 558.6544 Btu/hr ft °F $Rd = \frac{U_C - U_D}{U_C \times U_D}$ $Rd = \frac{558.6544 - 216.3233}{558.6544 \times 216.3233}$ = 0.003 hr ft^2 °F/Btu	Vaporization At 100 °F μ 0.019 cp = 0.0460 lb/ft hr $Re_s = \frac{De\,Gs}{\mu}$ $Re_s = \frac{0.0792 \times 48896.3964}{0.0460} = 84186.84$ jH = 200 fig 28 At 100 °F k = 0.0185 table 5 cp = 1.151 Btu/lb °F fig 2 $k\left(\frac{cp\,\mu}{k}\right)^{\frac{1}{3}} = 0.3544$ $h_o = jH\frac{k}{De}\left(\frac{cp\,\mu}{k}\right)^{\frac{1}{3}}$ = 894.9495 Btu/hr ft^2 °F

Pressure Drop

For Re_t = 388454.9932 f = 0.000119 fig 26 from table 7, specific vol of stream at 85 psig =1360 psia v = 0.3124 ft^3/lb $s = \frac{1}{0.3124 \times 62.5} = 0.051$	Preheat Re_s = 16008.41054 f = 0.0019 Length of preheat zone $Lp = \frac{L\,Ap}{A\,c}$

$$\Delta Pt = \frac{1}{2}\frac{f\,Gt^2\,Ln}{5.22\times10^{10}\times De\times s\times\phi t}$$

$$\Delta Pt = \frac{1}{2}\frac{0.000119\times(350769.061)^2\times10\times2}{5.22\times10^{10}\times0.0402\times0.0512\times1}$$

$= 1.3628$ psi

$$Lp = \frac{10\times0.2118}{30.0105} = 0.054\ \text{ft}$$

No of crosses

$$N+1 = \frac{12\,Lp}{B} = \frac{12\times0.054}{1.6} = 0.405 \approx 1$$

s = 0.61 table 6

$$Ds = \frac{8}{12} = 0.6667\ \text{ft}$$

$$\Delta Ps = \frac{f\,Gs^2\,Ds\,(N+1)}{5.22\times10^{10}\times De\times s\times\phi s}$$

$$\Delta Ps = \frac{0.0019\times(48896.3964)^2\times0.6667\times1}{5.22\times10^{10}\times0.0792\times0.61\times1}$$

$= 0.0012$

Vaporization

$Re_s = 84186.84$

f = 0.0014

Length of vaporization zone

Lv = L – Lp = 10 – 0.054 = 9.946 ft

No of crosses

$$N+1 = \frac{12\,Lv}{B} = \frac{12\times9.946}{1.6} = 74.595 \approx 75$$

Mol wt = 17

Density

$$\rho = \frac{17}{359\frac{(100+460)}{492}\frac{14.7}{209.4}} = 0.5926\ \text{lb/ft}^3$$

$S_{outlet\ liq} = 0.61$ table 6

$\rho_{outlet\ liq} = 0.61 \times 62.5 = 38.125\ \text{lb/ft}^3$

$$S_{outlet\ mix} = \frac{\frac{m_3}{62.5}}{\frac{m_1}{\rho}+\frac{m_2}{\rho_{outlet\ liq}}}$$

	$= \dfrac{\dfrac{502.2305}{62.5}}{\dfrac{492.3828}{0.5926} + \dfrac{9.8477}{38.125}}$ $= 0.0097$ $S_{inlet} = 0.61$ $S_{mean} = \dfrac{(0.61 + 0.0097)}{2} = 0.3099$ $\Delta Ps = \dfrac{f\ Gs^2\ Ds\ (N+1)}{5.22 \times 10^{10} \times De \times s \times \phi s}$ $= \dfrac{0.0014 \times (48896.3964)^2 \times 0.6667 \times 75}{5.22 \times 10^{10} \times 0.079^2 \times 0.61 \times 1}$ $= 0.8422$ ΔPs tot = 0.0012 + 0.8422 = 0.8434

Specification

$U_C = 558.6544$

$U_D = 216.3233$

Rd calculated = 0.003

ΔP tube = 1.3628 psi

ΔP shell = 0.8434 psi

Separator Drum (D-113)

Function: to separate ammonia vapor and liquid from vaporizer

Type: horizontal cylindrical drum with hemispherical head ends

Operation condition: T = 100 °F

P = 209.4 psia

Calculation

From mass balance: ammonia vapor = 1085.5 lb/hr

ammonia solution = 27.71 lb/hr +

1113.21 lb/hr

At 100 °F and pressure 209.4 psia from Hougen p 629

ρ = 1.2 ft^3/lb

holding time = 10 mins

$$\frac{L}{D} = \frac{3}{1}$$

Drum vol = 1113.21 lb/hr x 10 mins x $\frac{1}{60}$ hr/mins x 1.2 ft^3/lb

= 222.642 ft^3

Drum vol = shell vol + head vol

$$222.642 = \frac{\pi}{4} ID^2 L + 2 \times \left(\frac{1}{2}\frac{1}{6}\pi\ ID^3\right)$$

$$222.642 = \frac{\pi}{4} ID^2\ 3ID + 2 \times \frac{1}{2} \times \frac{1}{6} \pi\ ID^3$$

$$= \frac{3}{4}\pi\ ID^3 + \frac{\pi}{6} ID^3$$

222.642 = 0.9167 π ID^3

ID^3 = 77.3089

ID = 4.26 ft = 1.2984 m

L = 3 ID = 3 x 1.2984 = 3.8952

Drum diameter = 1.2984 m = 51.1193 in

Drum length = 3.8952 m = 153.3580 in

Calculating shell thickness

P = 209.4 psia = 194.7 psig

P design = 1.2 x 194.7 = 233.64 psig

Planned

Construction material = stainless steel SS

From table 13.1 Brownell and Young

f allowable = 18750 lb/in^2

ε = 85%

$$c = \frac{1}{8}$$

$$t_s = \frac{P ri}{f\ \varepsilon - 0.6P} + \frac{1}{8}$$

$$= \frac{233.64 \frac{51.1193}{2}}{18750 \times 0.85 - 0.6 \times 233.04} + \frac{1}{8}$$

$$= 0.5030 \text{ in} \approx \frac{5}{8} \text{ in}$$

Calculating head thickness

Planned: construction material: stainless steel SS

elliptical dished head

k = 2 (Brownell and Young p 133)

$$V = \frac{1}{6}(2 + k^2)$$

$$= \frac{1}{6}(2 + 2^2)$$

$$= 1$$

$$t_h = \frac{P\,dV}{2f\varepsilon - 0.2P} + \frac{1}{8}$$

$$= \frac{233.64 \times 51.1193 \times 1}{2 \times 18750 \times 0.85 - 0.2 \times 233.64} + \frac{1}{8}$$

$$= 0.5002 \approx \frac{5}{8} \text{ in}$$

$$OD = ID + 2\,t_s = 51.1193 + (2 \times \frac{5}{8}) \text{ in} = 52.3693 \text{ in}$$

From table 5.7; Brownell and Young p 90; OD standard = 54 in, icr = $3\frac{1}{4}$ in, r = 48 in

$$a = \frac{ID}{2} = \frac{51.1193}{2} = 25.5597 \text{ in}$$

$$AB = \frac{ID}{2} - icr = 25.5597 - 3\frac{1}{4} = 22.3097 \text{ in}$$

$$BC = r - icr = 48 - 3\frac{1}{4} = 44.75 \text{ in}$$

$$b = r - \sqrt{(BC)^2 - (AB)^2}$$

$$= 48 - \sqrt{(44.75)^2 - (22.3097)^2}$$

$$= 9.2077 \text{ in}$$

Assigned sf = 2 in

Height of head= OA $= t + b + sf$

$$= \frac{5}{8} + 9.2077 + 2$$

$$= 11.8327 \text{ in}$$

Total length = shell length + 2 height of head + 2 head thickness

$$= 153.3580 + 2 \times 11.8327 + 2 \times \frac{5}{8}$$

$$= 178.2734 \text{ in}$$

Air Filter (FG-212)

Function: to remove dust from inlet air

Type: bag filter

Consideration: suitable for dry dust with minimum size < 1 μm.

Capacity: $1800 \dfrac{lb}{ft\,day}$

Inlet air from material balance: 8788.7913 kg/hr = 19375.7693 lb/hr

Flow area: $\dfrac{inlet\,air \times 24hr}{filter\,capacity} = \dfrac{19375.7693 \times 24}{1800} = 250.3436 ft^2$

Ammonia Gas Filter (FG-115)

Capacity = 400 – 1800 lb/ft^2 day

Taken = 1800 lb/ft^2 day

Inlet ammonia = 480.1119 kg/hr = 1058.4547 lb/hr

$$\text{Flow area} = \frac{\text{inlet ammonia} \times 24 \text{ hour}}{\text{filter capacity}} = \frac{1058.4547 \times 24}{1800} = 14.1127 \text{ft}^2$$

Ammonia + Air Filter (FG-312)

Capacity = 400 – 1800 lb/ft^2 day

Taken = 1800 lb/ft^2 day

Inlet ammonia + air = 9261.3514 kg/hr = 20417.5753 lb/hr

$$\text{Flow area} = \frac{20417.5753 \times 24}{1800} = 272.2343 \text{ ft}^2$$

Blower (JS-211)

Type: centrifugal

Operation condition: T = 32 °C

P = 1 atm

air mol wt = 27.17 g/mol

$$\rho_{air} = \frac{P\ mol\,wt}{RT} = \frac{1 \times 28.84}{0.082 \times 305} = 1.1531\,\text{kg/m}^3$$

Inlet air = 8788.7913 kg/hr = 19375.7693 lb/hr

$$\text{Volumetric rate} = \frac{8788.7913}{1.1531} = 7621.8813\ \text{m}^3/\text{hr} = 4485.9063\ \text{ft}^3/\text{min}$$

From Perry 6th ed p 6-2

$$\text{Compression ratio (r)} = \frac{P_2}{P_1} = 1.4$$

P_1 = 1 atm

P_2 = 1.4 atm

$$\text{Compression power} = HP = \frac{0.00436 \times k \times Q \times P_1 \times \left(r^{\frac{k-1}{k}} - 1 \right)}{k - 1}$$

Assigned k = 1.41

HP = 6.9136 ≈ 7 HP

Specification

Function	: to compress air which flows to air filter
Type	: centrifugal blower
Air volumetric rate	: 4485.9063 ft^3/min
Power	: 7 HP
Quantity	: 1

Air Compressor (JC-210)

Function: to compress air pressure from 1 atm to 7 atm

Type: centrifugal compressor

Consideration: suitable to handle large volumes of gas and can increase gas pressure up to several hundred kPa.

Inlet pressure: 1 atm = 2116.228 lbf/ft^2

Outlet pressure: 7 atm = 14813.596 lbf/ft^2

Pressure ratio: 7/1 = 7

Compressor multistage is used because pressure ratio > 4 (Ulrich, 1984)

$(r_p,I)^q = r_p,T$

$(r_p,I)^q = 7$ atm

$(r_p,I) = 2.65$ atm

Compression ratio per stage: = 3.14

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}$$

T_2 = outlet temperature stage 1

$$T_2 = 305 \left(\frac{2.65}{1}\right)^{(1.395-1)/1.395}$$

T_1 = inlet temperature stage 1

$= 401.9237$ K = 128.9237 °C

Compressor stage 1

$$H_p = \frac{3.03\times10^{-5}\times k}{k-1}\times P_1\times q_{fm}\times\left[\left(\frac{P_2}{P_1}\right)^{(k-1)/k}-1\right]$$

(Peters & Timmerhause 4^{ed}, eq 14-27)

$$k = \frac{C_p}{C_v} air = 1.395$$

q_{fm} = gas volumetric velocity at inlet condition

ρ at 32 °C = 0.0724 lb/ft^3 (Perry 6^{ed}, table 3-30)

inlet air = 8788.7739 kg/hour = 4460.3432 ft^3/min

$$H_p = \frac{3.03\times10^{-5}\times1.395}{1.395-1}\times2116.228\times4460.3432\times\left[\left(\frac{2.65}{1}\right)^{(1.395-1)/1.395}-1\right] = 320.9821$$

Motor efficiency = 50% (Peters & Timmerhasuse 4^{ed}, p 524)

$$\text{Motor } H_p = \frac{320.9821}{0.5} = 641.9642 h_p$$

Specification:

Pressure ratio = 2.65

Motor power = 641.9642 h_p

Material = carbon steel

Compressor stage 2

Inlet air pressure stage 2 = 2.65 atm = 5608.0042 lbf/ft^2

$$T_2 = T_1 \times \left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma}$$

$$= 401.9237 \times \left(\frac{7}{2.65}\right)^{(1.395-1)/1.395} = 611.2396 K = 338.2396 °C$$

P air at 256.1671 °C = 2.0952 kg/m^3 = 0.1308 lb/ft^3

Inlet air = 8788.7739 kg/hour = 19375.7309 lb/hour

$$q_{fm} = \frac{19375.7309}{0.1308} = 148132.4992\ ft^3/hour = 2468.875\ ft^3/min$$

$$H_p = \frac{3.03 \times 10^{-5} \times 1.395}{1.395 - 1} \times 5608.0042 \times 2468.875 \times \left[\left(\frac{7}{2.65}\right)^{(1.395-1)/1.395} - 1\right] = 469.0495$$

Motor efficiency = 70% (Peters & Timmerhause, p 524)

$$H_p\ motor = \frac{469.0495}{0.5} = 938.0989 h_p$$

Specification

Pressure ratio = 2.6415

Motor power = 938.0989 h_p

Material = carbon steel

Ammonia Preheater (E-114)

Heat balance

M ammonia vapor = 480.1119 kg/hr = 1058.4547 lb/hr

Q = m Cp Δt

= 1058.4547 x 0.55 x (491-100)

= 227620.6832 Btu/hr

λ steam at 572 °F = 1329.1

M steam = 171.2593 lb/hr

$$\Delta t_{LMTD} = \frac{(572-491)-(572-100)}{\ln\left(\frac{572-491}{572-100}\right)} = 221.84°F$$

Inner pipe, steam	Cold fluid: annulus, ammonia
$D = \frac{1.38}{12} = 0.115$ ft	$D_2 = \frac{2.067}{12} = 0.1725$ ft
Flow area	$D_1 = \frac{1.66}{12} = 0.138$ ft
$a_p = \frac{\pi D^2}{4}$	$a_e = \frac{\pi\left(D_2^{\ 2} - D_1^{\ 2}\right)}{4} = 0.00826$ ft^2
$= \frac{\pi 0.115^2}{4}$	$De = \frac{\left(D_2^{\ 2} - D_1^{\ 2}\right)}{D_1} = 0.0762$ ft
$= 0.0104$ ft^2	
$Gp = \frac{w}{a_p} = \frac{171.2593}{0.0104} = 16467.24$	$Ga = \frac{W}{a_a} = \frac{1058.4547}{0.00826} = 128142.2157$
At 572 °F	At 295.5 °F
$\mu = 0.02$ cp x 2.422 = 0.0484 lb/ft hr	$\mu = 0.015$ cp
$\mathrm{Re}_p = \frac{D\,Gp}{\mu}$	$= 0.015$ x 2.42
$= \frac{0.115 \times 16467.24}{0.0484} = 39126.71$	$= 0.0363$
jH = 20	$\mathrm{Re}_a = \frac{De\,Ga}{\mu}$
At 572 °F, c = 0.48, k = 0.0248	$= \frac{0.0762 \times 128142.2155}{0.0363}$
$\left(\frac{c\mu}{k}\right)^{\frac{1}{3}} = \left(\frac{0.48 \times 0.0484}{0.0248}\right)^{\frac{1}{3}} = 0.97853$	$= 268992.75$
$h_i = jH \frac{k}{D}\left(\frac{c\mu}{k}\right)^{\frac{1}{3}} 1$	jH = 556
$= 120 \frac{0.0248}{0.115} 0.9785 = 25.3219$	At 295.5 °F
$h_{io} = h_i \frac{ID}{OD} = 25.3219 \frac{1.38}{1.66} = 21.0507$	c = 0.55
	k = 0.0195
	$\left(\frac{c\mu}{k}\right)^{\frac{1}{3}} = 1.008$
	$h_o = jH\left(\frac{k}{De}\right)\left(\frac{c\mu}{k}\right)^{\frac{1}{3}} 1$

$U_C = \frac{h_{io} h_o}{h_{io} + h_o} = 18.33$ Rd = 0.002 $\frac{1}{U_D} = \frac{1}{18.33} + 0.002$ $U_D = 17.682$ $A = \frac{Q}{U_D \Delta t}$ $= \frac{227620.6832}{17.682 \times 221.84} = 58.0284\,ft^2$	$= 550\frac{0.0195}{0.0762}1.008 \times 1$ $= 141.874$

Required length = $\frac{58.0284}{0.435} = 133.4$ lin ft

Hairpin length = 12 ft

12 ft hairpin is used in series of 6

The surface actually = 144 x 0.435 = 62.64 ft^2

$$U_D = \frac{227620.6832}{62.64 \times 221.84} = 16.38$$

$$R_D = \frac{U_C - U_D}{U_C U_D} = \frac{18.33 - 16.38}{18.33 \times 16.38} = 0.007$$

Pressure Drop

Inner pipe, steam	Cold fluid: annulus, ammonia
$Re_p = 39126.71$ $f = 0.0035 + \frac{0.264}{\left(\frac{DG}{\mu}\right)^{0.42}}$ $= 0.0035 + \frac{0.264}{39126.71^{0.42}}$ $= 0.0066$ s = 1 ρ = 62.5 x 1 = 62.5	$De' = (D_2 - D_1)$ $= (0.1725 - 0.138)$ $= 0.0345$ $Re' = \frac{D'eGa}{\mu}$ $= \frac{0.0345 \times 128142.2155}{0.0363}$ $= 121788.0561$ $f = 0.0035 + \frac{0.264}{121788.0561^{0.42}}$

$\Delta F_p = \frac{4fG_p^2 L}{2g\rho^2 D} = 0.003$ ft $\Delta P_p = \frac{0.003 \times 62.5}{144} = 0.001$ psi	$= 0.00543$ s = 0.61 ρ = 62.5 x 0.61 = 38.125 $\Delta Fa = \frac{4f\,Ga^2 L}{2g\,\rho^2 De'} = 1.225$ ft $V = \frac{G}{3600\rho}$ $= \frac{128142.2155}{3600 \times 38.125}$ $= 0.934$ fps $Ft = 3\left(\frac{V^2}{2g'}\right) = 3\left(\frac{0.934^2}{2 \times 32.2}\right) = 0.04$ ft $\Delta Pa = \frac{(1.225 + 0.04)38.125}{144} = 0.335$ psi

Tail gas preheater I (E-511)

Function: to heat tail gas from absorber (T-610)

Type: shell and tube heat exchanger

Consideration: suitable to heat transfer with large capacity

From material balance:

Mass of tail gas = 6939.9597 kg/hr = 15299.7348 lb/hr

Mass of air = 8788.87739 kg/hr = 19375.6038 lb/hr

Q = 86623.2341 kkal/hr = 343524.8814 btu/hr

$$\Delta t_{LMTD} = \frac{(491-86)-(640.8313-176)}{\ln\left(\frac{491-86}{640.8313-176}\right)} = 434.2289\ °F$$

$$R = \frac{640.8313 - 572.0261}{1756 - 86} = 0.7645$$

$$S = \frac{176 - 86}{640.8313 - 86}$$

$F_T = 0.8$ (Kern, fig. 18)

$\Delta t = 0.8 \times 434.2289 = 347.3831$ °F

$T_c = \dfrac{640.8313 + 491}{2} = 565.9157$ °F

$t_c = \dfrac{176 + 86}{2} = 131$ °F

Trial $U_D = 10$

$A = \dfrac{Q}{U_D \Delta t} = \dfrac{343524.8814}{10 \times 347.3831} = 98.8893\ ft^2$

Assigned:

OD tube = 1 in, 10 BWG (Kern, table 10)

ID tube = 0.732 in

L = 12 ft

$a'' = 0.2618\ ft^2$

amount of tube = $\dfrac{A}{a'' L} = \dfrac{98.8893}{0.2618 \times 12} = 31.4774 \approx 32$

From Kern table 9 for square pitch:

$P_T = 1\frac{1}{4}$ in

N_t standar = 32 buah

Passes = 2

ID shell = 10 in

$A = 32 \times 12 \times 0.2618 = 100.5312\ ft^2$

$UD = \dfrac{Q}{A \times \Delta t} = \dfrac{343524.8814}{100.5312 \times 347.3831} = 9.8367$

Shell, air	Tube, gas
$c' = P_T - OD = 1\frac{1}{4} - 1 = \frac{1}{4}$	$a't = 0.421$
$B = ID\ shell = 10$	$at = \dfrac{N_t \times a't}{144 \times n} = \dfrac{32 \times 0.421}{144 \times 2} = 0.0468\ ft^2$
$a_s = \dfrac{ID \times c' \times B}{144 \times P_T} = \dfrac{10 \times \frac{1}{4} \times 10}{144 \times 1\frac{1}{4}} = 0.1389\ ft^2$	$G_t = \dfrac{w}{at} = \dfrac{15299.7348}{0.0468}$ $= 326917.1403$ lb/hr ft

$G_s =$ $\frac{W}{a_s} = \frac{19375.6038}{0.1389} = 139504.3474\ lb/hr\ ft$	$t_c = 131$ °F
At $T_c = 565.9157$ °F	$\mu = 0.034 \times 2.42 = 0.0823$ lb/hr ft
$\mu = 0.029 \times 242 = 0.0702$ lb/hr ft (fig.15)	c = 0.2878
$D_e = 0.99/12 = 0.0825$ (fig.28)	k = 0.0369
c = 0.26	$D = \frac{0.732}{12} = 0.061$ ft
k = 0.0265 (fig. 3)	$Re_t = \frac{DG_t}{\mu} = \frac{0.061 \times 326917.4103}{0.0823}$
$Re_s = \frac{D_e G_s}{\mu} = \frac{0.0825 \times 139504.3474}{0.0702}$	$= 242300.1656$
$= 163947.4168$	$\frac{L}{D} = \frac{12}{0.061} = 196.7213$
$J_H = 250$ (fig 28)	$J_H = 490$
$\left(\frac{c\mu}{k}\right)^{\frac{1}{3}} = \left(\frac{0.26 \times 0.0702}{0.0265}\right)^{\frac{1}{3}} = 0.8831$	$\left(\frac{c\mu}{k}\right)^{\frac{1}{3}} = \left(\frac{0.2878 \times 0.0823}{0.0369}\right)^{\frac{1}{3}} = 0.8626$
$\frac{h_o}{\phi_s} = J_H \left(\frac{k}{D_s}\right)\left(\frac{c\mu}{k}\right)^{\frac{1}{3}}$	$\frac{h_i}{\phi_t} = J_H \left(\frac{k}{D}\right)\left(\frac{c\mu}{k}\right)^{\frac{1}{3}}$
$= 250\left(\frac{0.0265}{0.0825}\right)0.8831 = 70.9156$	$= 490\left(\frac{0.0369}{0.061}\right)(0.8626)$
	$= 255.6831$
$U_c = \frac{h_{io} h_o}{h_{io} + h_o} = \frac{187.16 \times 70.9156}{187.16 + 70.9156}$	$\frac{h_{io}}{\phi_t} = \frac{h_i}{\phi_t}\frac{ID}{OD} = 255.6831\frac{0.732}{1} = 187.16$
$= 51.4290$	
$R_d = \frac{U_c - U_D}{U_c U_D} = \frac{51.4290 - 9.8367}{51.4290 \times 9.8367} = 0.0822$	
(Acceptable, because > 0.003)	

Pressure drop	
$Nre_s = 97729.5487$	$Nre_t = 242300.1656$
f = 0.0014	f = 0.00013
$N+1 = \frac{L}{B} \times 12 = \frac{12}{10} \times 12 = 14.4$	ρ gas $= \frac{P\,mol\,wt}{RT} = \frac{7 \times 26.9112}{0.0821 \times 328} = 6.9954$

ρ air = 0.2696 lb/ft^3 $s = \frac{0.2696}{62.5} = 0.0043$ ID_s = 10 in = 0.8333 ft $\Delta p_s = \frac{fG_s^2 ID_s(N+1)}{5.22\times10^{10} De\, s\phi_s}$ $= \frac{0.0014\times139504.3474^2\times0.8333\times14.4}{5.22\times10^{10}\times0.0825\times0.0043\times1}$ = 1.7655 (acceptable, because < 10 psi)	= 0.4368 lb/ft^3 $s = \frac{0.4368}{62.5} = 0.007$ $\Delta p_t = \frac{fG_t^2 Ln}{5.22\times10^{10} D_s\phi_t}$ $= \frac{0.00013\times(326917.4103)^2\times12\times2}{5.22\times10^{10}\times0.061\times1}$ = 0.1047 psi $\frac{v}{2g'} = 0.0014$ $\Delta p_r = \frac{4n}{s}\frac{v}{2g'} = \frac{4\times2}{0.007}\times0.0014 = 1.6$ Δp_t = 0.1047+1.6 = 1.7047 (acceptable, because < 2 psi)

Specification:

Shell ID: 10 in, baffle space = 10 in, passes = 1

Tube OD: 1 in, 10 BWG, L=12 ft, passes = 2, $P_T = 1\frac{1}{4}$ in square pitch

Tube amount = 32

U_d = 9.8367

U_c = 51.4290

R_d = 0.0822

Δp shell = 1.7655 psi

Δp tube = 1.7047 psi

Tail Gas Preheater II (E-512)

Function: to preheat the tail gas

From mass balance:

Mass of tail gas = 15299.7348 lb/hr

Mass of nitrous gas = 8382.6748 lb/hr

Q = 294969.2214 kcal/hr = 1169770.072 btu/hr

$$\Delta t_{LMTD} = \frac{(554-482)-(374-176)}{\ln\frac{554-482}{374-176}} = 124.5550$$

$$R = \frac{554-374}{482-176} = 0.5882$$

$$S = \frac{482-176}{554-176} = 0.8095$$

$F_T = 0.99$

$\Delta t = 0.99 \times 124.555 = 123.3095$

$$T_c = \frac{554+374}{2} = 464\ °F$$

$$t_c = \frac{482+176}{2} = 329\ °F$$

trial $U_D = 20$

$$A = \frac{Q}{U_D \Delta t} = \frac{1169770.072}{20 \times 123.3095} = 474.3228\ ft^2$$

Assigned:

OD tube: 1 in, 10 BWG

ID tube: 0.732 in

L: 12 ft

a" = 0.2618 ft^2

$$\text{Amount of tube}: \frac{A}{a''L} = \frac{474.3228}{0.2618 \times 12} = 150.9845$$

From Kern table 9, for square pitch

$$P_T = 1\frac{1}{4}\ in$$

N_T standar = 152, passes = 6

$$\text{Shell ID} = 21\frac{1}{4}\ in$$

$A = 152 \times 12 \times 0.2618 = 477.5232\ ft^2$

$$U_D = \frac{Q}{A\Delta t} = \frac{1169770.072}{477.5232 \times 123.3095} = 19.866$$

Shell, nitrous gas	Tube, tail gas
$c' = P_T - OD = 1\frac{1}{4} - 1 = \frac{1}{4}$	$a't = 0.421$ (table 10)
$B = \frac{ID\ shell}{5} = \frac{21\frac{1}{4}}{5} = 4.25$	$a_t = \frac{N_t a't}{144n} = \frac{152 \times 0.421}{144 \times 6} = 0.0741\ ft^2$
$a_s = \frac{IDc'B}{144P_T} = \frac{21\frac{1}{4} \times \frac{1}{4} \times 4.25}{144 \times 1\frac{1}{4}} = 0.1254\ ft^2$	$G_t = \frac{15299.7348}{0.0741} = 206474.1538$ lb/hrft
$G_s = \frac{W}{a_s} = \frac{8382.6748}{0.154} = 66847.4864$ lb/hr ft	At $t_c = 329$ °F
At $T_c = 464$ °F	$\mu = 0.0239 \times 2.42 = 0.0578$ lb/hr ft
$\mu = 0.026 \times 2.42 = 0.0629$	$c = 0.26$
$D_e = \frac{0.99}{12} = 0.0825$	$k = 0.0265$
$c = 0.26$	$D = \frac{0.732}{12} = 0.061$ ft
$k = 0.0265$	$Re_t = \frac{DG_t}{\mu} = \frac{0.061 \times 206474.1538}{0.0578}$
$Re_s = \frac{D_e G_s}{\mu} = \frac{0.0825 \times 66847.4864}{0.0629}$	$= 217905.1433$
$= 87677.5458$	$\frac{L}{D} = \frac{12}{0.061} = 196.7213$
$j_H = 170$	$j_H = 480$
$\left(\frac{c\mu}{k}\right)^{\frac{1}{3}} = \left(\frac{0.26 \times 0.0629}{0.0265}\right)^{\frac{1}{3}} = 0.8514$	$\left(\frac{c\mu}{k}\right)^{\frac{1}{3}} = \left(\frac{0.26 \times 0.0578}{0.0578}\right) = 0.8277$
$h_o = j_H\left(\frac{k}{D_s}\right)\left(\frac{c\mu}{k}\right)^{\frac{1}{3}}$	$h_i = j_H\left(\frac{k}{D_s}\right)\left(\frac{c\mu}{k}\right)^{\frac{1}{3}}$
$= 170\left(\frac{0.0265}{0.0825}\right)0.8517$	$= 480 \times \left(\frac{0.0265}{0.061}\right) \times 0.8277 = 172.5958$
$= 46.4914$	$h_{io} = hi \times \frac{ID}{OD} = 172.5958 \times \frac{0.732}{1} =$ 126.3401
$U_c = \frac{h_{io} \times h_o}{h_{io} + h_o} = \frac{126.3401 \times 46.4914}{126.3401 + 46.4914}$	
$= 33.9853$	

$R_d = \frac{U_c - U_D}{U_c U_D}$ =0.0209 (acceptable, because > 0.003)	

Pressure Drop	
$Nre_s = 87677.5458$ f = 0.0014 (fig 29) $N+1 = \frac{L}{B} \times 12 = \frac{12}{4.25} \times 12 = 33.8824$ $\rho_{nitrous\ gas} = P \times \frac{BM}{RT}$ $= \frac{7 \times 26.89}{0.082 \times 513} = 4.4746\ kg/m^3$ $= 0.2793\ lb/ft^3$ $s = \frac{0.2793}{62.5} = 4.4688 \times 10^{-3}$ $ID_s = 21\frac{1}{4}$ in = 1.7708 ft $\Delta p_s = \frac{f G_s^2 ID_s (N+1)}{5.22 \times 10^{10} De\ s \phi_s} = 1.9504$	$Nre_t = 217905.1433$ f = 0.00011 $\rho_{gas} = P \times \frac{BM}{RT} = \frac{7 \times 26.9112}{0.0821 \times 438}$ $= 5.2386\ kg/m^3 = 0.3271\ lb/ft^3$ $s = \frac{0.3271}{62.5} = 5.2336 \times 10^{-3}$ $\Delta p_t = \frac{f G_t^2 Ln}{5.22 \times 10^{10} D_s \phi_t}$ $= 0.106$ psi $\frac{v}{2g'} = 0.009$ $\Delta p_r = \frac{4n}{s}\frac{v}{2g'} = \frac{4 \times 6}{5.2336 \times 10^{-3}} \times 0.009$ $= 1.13757$ $\Delta p_T = 0.106 + 1.3757 = 1.4817$ (acceptable, because < 2psi)

Specification:

Type: shell and tube heat exchanger

Shell ID = $1\frac{1}{4}$, baffle space = 4.25 in, passes = 1

Tube OD = 1 in 10 BWG, L = 12 ft, passes = 6, $P_T = 1\frac{1}{4}$ in (square pitch)

Amount of tube = 152

$U_D = 19.866$

$U_C = 33.9853$

$R_d = 0.0209$

Δp shell = 1.9504

Δp tube = 1.4817

Tail Gas Preheater III (E-513)

Function: to preheat tail gas

Type: shell and tube heat exchanger

Consideration: suitable to heat transfer with large capacity

From material balance:

Mass of tail gas = 15299.7348 lb/hr

Mass of nitrous gas = 8382.6748 lb/hr

Q = 146676.5504 kcal/hr

$$\Delta t_{LMTD} = \frac{(932-635)-(698-482)}{\ln\frac{932-635}{698-482}} = 254.3501$$

$$R = \frac{532-698}{635-482} = 1.53$$

$$S = \frac{635-482}{932-482} = 0.437$$

$F_T = 0.675$ (kern, fig 18)

$\Delta t = 0.675 \times 254.3501 = 171.6863$

$$T_c = \frac{932+698}{2} = 815 \text{ °F}$$

$$t_c = \frac{635+482}{2} = 558.5 \text{ °F}$$

Trial $U_D = 20$

$$A = \frac{Q}{U_D \times \Delta t} = \frac{518680.4822}{20 \times 171.6863} = 169.4021 \text{ ft}^2$$

Assigned:

OD tube = 1 in, 10 BWG (kern, table10)

ID tube = 0.732 in

L = 12 ft

a" = 0.2618 ft^2

Amount of tube = $\frac{A}{a''L} = \frac{169.4021}{0.2618 \times 12}$ =53.9222

From Kern, table 9, for square pitch

$P_T = 1\frac{1}{4}$ in

N_T standard = 56, passes = 2

Shell ID = $13\frac{1}{4}$ in

$A = 56 \times 12 \times 0.2618 = 175.9296\ ft^2$

$U_D = \frac{Q}{A\Delta t} = \frac{581680.4822}{175.9296 \times 171.6863} = 19.2579$

Shell, nitrous gas	Tube, tail gas
$c' = P_T - OD = 1\frac{1}{4} - 1 = \frac{1}{4}$	$a't = 0.421$ (table 10)
B = ID shell	$a_t = \frac{N_t \times a't}{144n} = \frac{56 \times 0.421}{144 \times 2} = 0.0819\ ft^2$
$a_s = \frac{ID \times c' \times s}{144P_T} = \frac{13\frac{1}{4} \times \frac{1}{4} \times 13\frac{1}{4}}{144 \times 1\frac{1}{4}} = 0.2438\ ft^2$	$G_t = \frac{W}{a_t} = \frac{15299.7348}{0.0819} = 186809.9487$ lb/hrft
$G_s = \frac{W}{a_s} = \frac{8382.6748}{0.2438} = 34383.4077$ lb/hr ft	At t_c = 558.5 °F
At T_c = 815 °F	$\mu = 0.028 \times 2.42 = 0.0678$ lb/hr ft
$\mu = 0.03 \times 2.42 = 0.0726$ lb/hr ft (fig 15)	c = 0.26
$D_e = 0.99/12 = 0.0825$ (fig 28)	k = 0.0265
c = 0.23 (fig 3)	$D = \frac{0.732}{12} = 0.061$ ft
k = 0.0265 (table 5)	$Re_t = \frac{DG_t}{\mu} = \frac{0.061 \times 186809.9487}{0.0678}$ = 168073.8477
$Re_s = \frac{D_e G_s}{\mu} = \frac{0.0825 \times 34383.4077}{0.0726}$ = 39072.0542	$\frac{L}{D} = \frac{12}{0.061} = 196.7213$
$j_H = 115$ (fig 28)	$j_H = 390$
$\left(\frac{c\mu}{k}\right)^{\frac{1}{3}} = \left(\frac{0.23 \times 0.0726}{0.0265}\right)^{\frac{1}{3}} = 0.8573$	$\left(\frac{c\mu}{k}\right)^{\frac{1}{3}} = \left(\frac{0.26 \times 0.0678}{0.0265}\right)^{\frac{1}{3}} = 0.8729$

$$h_o = j_H\left(\frac{k}{D_s}\right)\left(\frac{c\mu}{k}\right)^{\frac{1}{3}}$$

$$= 115\times\left(\frac{0.0265}{0.0825}\right)\times 0.8573 = 36.9394$$

$$U_c = \frac{hio\times ho}{hio + ho} = 27.5417$$

$$R_d = \frac{U_c - U_D}{U_c U_D} = \frac{27.5417 - 19.2579}{27.5417\times 19.2579}$$

$= 0.0156$ (acceptable, because > 0.003)

$$h_i = j_H\left(\frac{k}{D_s}\right)\left(\frac{c\mu}{k}\right)^{\frac{1}{3}}$$

$$= 390\times\left(\frac{0.0265}{0.061}\right)\times 0.8729 = 147.8922$$

$$h_{io} = hi\times\frac{ID}{OD} = 147.8922\times\frac{0.732}{1} = 108.257$$

Pressure Drop

$Nre_s = 39072.0542$

$f = 0.0017$ (fig 29)

$$N+1 = \frac{L}{B}\times 12 = \frac{12}{13\frac{1}{4}}\times 12 = 10.8679$$

$$\rho_{nitrous\ gas} = P\times\frac{BM}{RT}$$

$$= \frac{7\times 26.89}{0.082\times 708} = 3.2422\ \text{kg/m}^3$$

$$= 0.2024\ \text{lb/ft}^3$$

$$s = \frac{0.2024}{62.5} = 0.00324$$

$$ID_s = 13\frac{1}{4}\ \text{in} = 1.1042\ \text{ft}$$

$$\Delta p_s = \frac{fG_s^2 ID_s(N+1)}{5.22\times 10^{10} De\ s\phi_s} = 1.7285$$

$Nre_t = 168073.8477$

$f = 0.00013$

$$\rho_{gas} = P\times\frac{BM}{RT} = \frac{7\times 26.9112}{0.0821\times 565.5}$$

$$= 4.0574\ \text{kg/m}^3 = 0.2533\ \text{lb/ft}^3$$

$$s = \frac{0.2533}{62.5} = 4.0528$$

$$\Delta p_t = \frac{fG_t^2 Ln}{5.22\times 10^{10} D_s\phi_t}$$

$$= \frac{0.00013\times(186809.9487)^2\times 12\times 2}{5.22\times 10^{10}\times 0.061\times 1}$$

$$= 0.0342\ \text{psi}$$

$$\frac{v}{2g'} = 0.0045$$

$$\Delta p_r = \frac{4n}{s}\frac{v}{2g'} = \frac{4\times 2}{4.0528\times 10^{-3}}\times 0.8883$$

$$\Delta p_t = 0.0342 + 0.8883 = 0.9225$$

(acceptable, because < 2psi)

Specification:

Type = shell and tube heat exchanger

Shell ID = 10 in, baffle space = 20 in, passes = 2

Tube: OD = 1 in, 10 BWG, L = 12 ft, passes = 2, $P_T = 1\frac{1}{4}$ in (sq pitch)

Tube amount = 56

$U_D = 19.2579$

$U_c = 27.5417$

$R_d = 0.0156$

Δp shell = 1.17285 psi

Δp tube = 0.9225 psi

Economizer (E-413)

Function: to cool nitrous gas from tail gas pre heater 3

Type: shell and tube

Calculation

m nitrous = 8382.6478 lb/hr

m water = 5952.3810 lb/hr

Q = 72965.3290 c cal/hr = 289361.2349 Btu/hr

$$\Delta t_{LMTD} = \frac{(698-554)-(282.2-242.6)}{\ln\left(\frac{698-554}{282.2-242.6}\right)} = 80.8685$$

$$R = \frac{698-554}{282.2-242.6} = 3.4091$$

$$S = \frac{282.2-242.6}{698-242.6} = 0.087$$

$F_T = 0.99$

$\Delta t = 0.99 \times 80.8685 = 80.0598$

$$T_c = \frac{698+554}{2} = 626$$

$$t_c = \frac{282.2+242.6}{2} = 262.4$$

trial $U_D = 15$

$$A = \frac{Q}{U_D\,\Delta t} = \frac{289361.2349}{15 \times 80.0598} = 240.9542$$

Assigned

OD tube = 1 in, 10 BWG

ID tube = 0.7320 in

L = 12 ft

a'' = 0.2618 ft^2

$$\text{tube amount} = \frac{A}{a''\,L} = \frac{240.9542}{0.2618 \times 12} = 76.6979$$

from Kern, table 9, for sq pitch

$P_T = 1\frac{1}{4}$ in

N_T = 76, passes = 2

ID shell = $15\frac{1}{4}$

A = 76 x 12 x 0.2618 = 238.7616

$$U_D = \frac{Q}{A\,\Delta t} = \frac{289361.2349}{238.7616 \times 80.0598} = 15.1378$$

Shell, nitrous gas	Tube, water
$c' = P_T - OD = 1\frac{1}{4} - 1 = \frac{1}{4}$	a't = 0.421
$B = \frac{ID}{5} = \frac{15\frac{1}{4}}{5} = 3.05$	$a_t = \frac{Nt\,a't}{144n} = \frac{76 \times 0.421}{144 \times 2} = 0.1111$
$a_s = \frac{ID\,c'\,B}{144\,P_T} = \frac{15\frac{1}{4} \times \frac{1}{4} \times 3.05}{144 \times 1\frac{1}{4}} = 0.0646$	$Gt = \frac{w}{a_t} = \frac{5952.381}{0.1111} = 53576.7867$
$Gs = \frac{w}{a_s} = \frac{8382.6748}{0.0646} = 129762.7678$	At t_c = 262.4
Tc = 626	μ = 0.17 x 2.42 = 0.4114
μ = 0.0295 x 2.42 = 0.0714	$D = \frac{0.732}{12} = 0.061$
	c = 1.2
	k = 0.398
	$Re_t = \frac{D \times Gt}{\mu}$

$$De = \frac{0.99}{12} = 0.0825$$

c = 0.26

k = 0.0265

$$Re_s = \frac{De\,Gs}{\mu}$$

$$Re_s = \frac{0.0825 \times 129762.7678}{0.0714} = 149935.9712$$

jH = 240

$$\left(\frac{c\,\mu}{k}\right)^{\frac{1}{3}} = \left(\frac{0.26 \times 0.0714}{0.0265}\right)^{\frac{1}{3}} = 0.8881$$

$$h_o = jH\left(\frac{k}{D_s}\right)\left(\frac{c\,\mu}{k}\right)^{\frac{1}{3}}$$

$$= 240\left(\frac{0.0265}{0.0825}\right)0.8881$$

$$= 68.4644$$

$$U_C = \frac{h_{io}\,h_o}{h_{io} + h_o} = 51.6508$$

$$Rd = \frac{U_C - U_D}{U_C \times U_D} = 0.0467$$

$$Re_t = \frac{0.061 \times 53576.7867}{0.4114} = 7944.0544$$

$$\frac{L}{D} = \frac{12}{0.061} = 196.7213$$

jH = 30

$$\left(\frac{c\,\mu}{k}\right)^{\frac{1}{3}} = \left(\frac{1.2 \times 0.4114}{0.398}\right)^{\frac{1}{3}} = 1.0745$$

$$h_i = jH\left(\frac{k}{D}\right)\left(\frac{c\,\mu}{k}\right)^{\frac{1}{3}}$$

$$= 30\left(\frac{0.398}{0.061}\right)1.0745$$

$$= 210.3202$$

$$h_{io} = h_i\,\frac{ID}{OD} = 153.9544$$

Pressure Drop

N Re_s = 149935.9712

F = 0.0013

$$N+1 = \frac{L}{B} - 12 = \frac{12}{3.05} - 12 = 47.2131$$

$$\rho \text{ nitrous gas} = \frac{P\,BM}{RT} = \frac{7 \times 26.89}{0.082 \times 603}$$

$= 3.8068$ kg/m^3

$= 0.2376$ lb/ft^3

N Re_t = 7944.0544

F = 0.00015

ρ water = 6.1609 kg/m^3 = 0.3844 lb/ft^3

$$s = \frac{0.3844}{62.5} = 6.1504 \times 10^{-3}$$

$$\Delta P_t = \frac{f\,Gt^2\,Ln}{5.22 \times 10^{10} \times Ds\,\phi t} = 0.0032$$

$s = \frac{0.2376}{62.5} = 3.8016\times10^{-3}$ $IDs = 15\frac{1}{4}$ in = 1.2708 ft $\Delta Ps = \frac{f\,Gs\,ID_s\,(N+1)}{5.22\times10^{10}\times De\,s\,\phi s}$ $= 5.2079$	$\frac{v}{2g'} = 0.001$ $\Delta \Pr = \frac{4n}{s}\frac{v}{2g'}$ $= \frac{4\times2}{6.1504\times10^{-3}}\times0.001$ $= 1.3007$ ΔPt = 0.0032 + 1.3007 = 1.3039

Feed Water Preheater (E-411)

Function: Cooling nitrous gas exiting tail gas preheater 2

Type: Shell and tube

Calculation

$$m_{nitrous\ gas} = 8382.9748\ \text{lb/hour}$$

$$m_{water} = 5952.381\ \text{lb/hour}$$

Q = 766571.0422 Btu/hour

$$\Delta T_{LMTD} = \frac{(374-248)-(242.6-86)}{\ln\frac{(374-248)}{(242.6-86)}} = 140.746$$

$$R = \frac{374-248}{242.6-86} = 0.8046$$

$$S = \frac{242.6-86}{374-86} = 0.5438$$

$$F_T = 0.83$$

$$\Delta t = 0.83\times140.746 = 116.8192$$

$$T_C = \frac{374+248}{2} = 311\,°F$$

$$t_C = \frac{242.6+86}{2} = 164.3\,°F$$

Trial $U_D = 20$

$$A = \frac{Q}{U_D\Delta t} = \frac{766571.0422}{20\times116.8192} = 328.1015$$

Assigned:

OD tube = 1 in, 10 BWG

ID tube = 0.732 in

L = 12 ft

a" = 0.2618 ft^2

$$\text{tube count} = \frac{A}{a''L} = \frac{328.1015}{0.2618 \times 12} = 104.4377$$

From Table 9 Kern, using square pitch data

P_T = 1¼ in

N_T standard = 112, passes = 2

shell ID = 17¼ in

$$A = 112 \times 12 \times 0.2618 = 351.8592$$

$$U_D = \frac{Q}{A\Delta t} = \frac{766571.0422}{351.8592 \times 116.8192} = 19.6496$$

Shell, nitrous gas	Tube, water
$C' = P_T - OD = 1\frac{1}{4} - 1 = \frac{1}{4}$	$a't = 0.421$
$B = \frac{\text{ID shell}}{5} = \frac{17\frac{1}{4}}{5} = 3.45$	$a_t = \frac{N_t \times a't}{144 \times n} = \frac{112 \times 0.421}{144 \times 2} = 0.1637$
$a_s = \frac{ID \times C' \times B}{144 \times 1\frac{1}{4}} = 0.0827\,ft^2$	$G_t = \frac{W}{a_t} = \frac{59521.381}{0.1637} = 36361.5211$
$G_s = \frac{W}{a_s} = \frac{8382.6748}{0.0827} = 101362.4522\,{}^{lb}/_{hr \cdot ft}$	at t_C = 164.3 °F
at T_C = 311 °F	$\mu = 0.41 \times 2.42 = 0.9922$
$\mu = 0.023 \times 2.42 = 0.0557$	$D = \frac{0.732}{12} = 0.061$
$De = \frac{0.95}{12} = 0.0825$	$c = 1$
$C = 0.25$	$k = 0.392$
$K = 0.0265$	$Re_t = \frac{D \times G_t}{\mu} = \frac{0.061 \times 36361.5211}{0.9922} = 2235.4896$
$Re_s = \frac{De \times G_s}{\mu} = \frac{0.0825 \times 101362.4522}{0.0557} = 150132.896$	$\frac{L}{D} = \frac{12}{0.061} = 196.7213$

$jH = 250$	$jH = 5$
$\left(\frac{C\mu}{k}\right)^{1/3} = \left(\frac{0.25 \times 0.0557}{0.0265}\right)^{1/3} = 0.8069$	$\left(\frac{C\mu}{k}\right)^{1/3} = \left(\frac{1 \times 0.9922}{0.392}\right)^{1/3} = 1.3628$
$h_o = jH\left(\frac{k}{D_s}\right)\left(\frac{C\mu}{k}\right)^{1/3}$	$h_i = jH\left(\frac{k}{D}\right)\left(\frac{C\mu}{k}\right)^{1/3}$
$= 250\left(\frac{0.0265}{0.0825}\right)0.8069 = 64.7965$	$= 5\left(\frac{0.392}{0.061}\right)1.3628 = 43.7883$
$U_C = \frac{h_{io} \times h_o}{h_{io} + h_o} = 21.4448$	$h_{io} = h_i \frac{ID}{OD} = 43.7883 \times \frac{0.732}{1} = 32.053$
$Rd = \frac{U_C - U_D}{U_C \times U_D} = 0.004$	

Pressure Drop

$NRe_s = 150132.896$	$NRe_t = 2235.4896$
$f = 0.0013$	$f = 0.0004$
$N + 1 = \frac{L}{B} - 12 = \frac{12}{3.45} - 12 = 41.7391$	ρ water $= 7.1335\frac{kg}{m^3} = 0.4453\frac{lb}{ft^3}$
ρ nitrous gas $= \frac{P \times BM}{R \times T} = \frac{7 \times 26.89}{0.082 \times 428}$	$s = \frac{0.4453}{62.5} = 7.1248 \times 10^{-3}$
$= 5.3633\frac{kg}{m^3} = 0.3348\frac{lb}{ft^3}$	$\Delta P_t = \frac{f \times G_t^2 \times L \times n}{5.22 \times 10^{10} \times D_s \times \phi_t} = 0.0039$
$s = \frac{0.3348}{62.5} = 5.3568 \times 10^{-3}$	$\frac{V}{2g'} = 0.001$
$ID_s = 17¼$ in $= 1.4375$ ft	
$\Delta P_s = \frac{f \times G_s^2 \times ID_s \times (N+1)}{5.22 \times 10^{10} \times De_s \times \phi_s} = 0.1861$	$\Delta P_r = \frac{4n}{s}\frac{V}{2g'} = \frac{4 \times 2}{7.1248 \times 10^{-3}} 0.001 = 1.1228$
	$\Delta P_t = 1.1228 + 0.0039 = 1.1267$

Specification

Type = shell and tube

shell ID = 17¼ in, baffle space = 3.45 in, passes = 1

tube OD = 1 in 10 BWG, L = 12 ft, passes = 2, P_T = 1¼ in (square pitch)

tube amount = 112

$U_D = 19.6496$

$U_C = 45.1473$

$R_d = 0.0004$

ΔP shell = 0.1861

ΔP tube = 1.1267

Tubular membrane Reactor (R-310)

Type: tubular reactor

From journal catalysis today by Perez-Ramirez, J. and B. Vigeland, 2005:

The membrane that is used is lanthanum ferrite perovskite membrane catalyst

ρ Membrane = 3.8 g/cm^3 (envelope density including pores and cavities in the solid)

Total gas flow of 130 ml/min = 130 ml/min x 60 min/hour x 1 L/1000mL = 7.8 L/hour for diameter = 1 cm and thickness = 30 μm

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

$$A = \frac{\pi}{4}(0.01)^2$$

$$= 7.854 \times 10^{-5}$$

Component loading membrane reactor

NH_3	472.5297
H_2O	154.9756
N_2	5949.1279
O_2	1806.0416
total	8382.6480 kg

From Chemcad (program attached), $\rho_{mixed\ gas} = 1.1254$ kg/m^3

Volume of entering gas = 8382.6748 kg/hour x 1m^3/1.1254 kg = 7519.882 m^3/hour

= 7519882 L/hour

= 2.0899 m^3/s

$$\frac{V_1}{V_2} = \frac{A_1}{A_2}$$

$$\frac{7.8\,L}{7519.882\,L} = \frac{7.854\times10^{-5}\,m^2}{A_2}$$

A_2 = 75.7194 m^2

75.7194 m^2 is used to make 1 membrane tube

Tube assumption

Diameter = 1 in = 2.54 cm = 0.0254 m

Height = 1.5 m

A= Cylinder peripheral area

A= π x 0.0254 x 1.5 = 0.1197 m^2

Amount of tube needed = $\frac{75.7142}{0.11497}$ = 632.6

Assumption: triangular pitch

From Kern table 9 p 842

ID shell = 37 in

Standardized amount of tube = 674

Amount of membrane needed

V= 75.7142 x $30x10^{-6}$ = $2271.426x10^{-6}$ m^3

ρ Membrane = 3.8 gr/cm^3 = 3800 kg/m^3

$2271.426x10^{-6}$ x 3800 = 8.6314 kg

Specification

Tube diameter	=	1 in = 2.54 cm
Amount of tube	=	674
ID shell	=	37 in
Pt	=	$1\frac{1}{4}$ triangular pitch

Cooler Condenser (E-611)

Function: to condensing the nitrous gas

Mass of inlet nitrous gas = 8382.6748 lb/hr

Mass of water = 1497.6459 lb/hr (from heat balance)

Q = 400824.1764 kcal/hr = 1590572.129 lb/hr

$$\Delta t_{LMTD} = \frac{(248-82.4)-(86-68)}{\ln\frac{248-82.4}{86-68}} = 66.5103\ °F$$

$\Delta t = \Delta t_{LMTD} = 66.5013$ °F

Assume, $U_D = 50$

$$A = \frac{Q}{U_D \times \Delta t} = \frac{1590572.129}{50\times 66.5103} = 478.2935\ ft^2$$

Assigned:

Tube OD = 1 in, 10 BWG

Tube ID = 0.732

L = 12 ft

a" = 0.2618 ft^2

$$\text{Amount of tube} = \frac{A}{a"L} = \frac{478.2935}{0.2618\times 12} = 152.2452$$

From Kern table 9, for square pitch

$P_T = 1\frac{1}{4}$ in

N_T standard = 166, passes = 2

Shell ID = $21\frac{1}{4}$ in

Correction A = 166×12×0.2618 = 521.5056

$$\text{Correction } U_D = \frac{Q}{A\Delta t} = \frac{1590572.129}{521.5056\times 66.5103} = 45.857\ Btu/lb\ ft^2\ °F$$

Shell, nitrous gas	Tube, tail gas
$c' = P_T - OD = 1\frac{1}{4} - 1 = \frac{1}{4}$	$a'_t = 0.421$ (table 10)
$B = ID\ shell = 21\frac{1}{4}$ in	$a_t = \frac{N_t a'_t}{144n} = \frac{166\times 0.421}{144\times 2} = 0.2427\ ft^2$
$a_s = \frac{IDc'B}{144P_T} = \frac{21\frac{1}{4}\times\frac{1}{4}\times 21\frac{1}{4}}{144\times 1\frac{1}{4}} = 0.6272\ ft^2$	$G_t = \frac{w}{a_t} = \frac{1497.6459}{0.2427} = 6170.77\ lb/hr\ ft^2$
	$V = \frac{G_t}{3600\rho} = 0.0275$ fps
	At $t_a = 75.2$ °F

$G_s = \frac{W}{a_s} = \frac{8382.6748}{0.6272} = 13365.2341 \text{ lb/hr ft}^2$	$\mu = 0.9 \times 2.42 = 2.178$ lb/hr ft
$G'' = \frac{M}{L \times N_t^{\frac{2}{9}}} = \frac{8382.6748}{12 \times 166^{\frac{2}{9}}}$	$D = \frac{0.732}{12} = 0.061$ ft
$= 224.3076$ lb/hr ft^2	$Re_t = \frac{DG_t}{\mu} = \frac{0.061 \times 6170.77}{2.178}$
Assumption: $h_o = 100$	$= 172.8269$
$t_w = t_a + \frac{h_o}{h_{io} + h_o}(T_v - t_a)$	ID tube correction factor = 0.97
$= 75.2 + \frac{100}{(205.9116 + 100)}(167 - 75.2)$	$h_i = 290 \times 0.97 = 281.3$ (fig 25)
$= 105.2$ °F	$h_{io} = hi \times \frac{ID}{OD} = 281.3 \times \frac{0.732}{1}$
$t_f = \frac{1}{2}(T_v + t_a) = \frac{1}{2}(167 + 105.2) = 136.1$ °F	$= 205.9116$ Btu/hr ft^2 °F
$k_f = 0.398$ (table 4)	
$s_f = 1$ (table 6)	
$\mu_f = 0.30$ cP (table 14)	
From fig 12.9, obtained:	
$h_c = 110$ Btu/hr ft^2 °F	
$U_c = \frac{h_{io} \times h_o}{h_{io} + h_o} = \frac{205.9116 \times 110}{205.9116 + 110} = 71.6981$	
$R_d = \frac{U_c - U_D}{U_c U_D} = 0.008$	

Pressure drop	
$T_v = 167$ °F	$f = 0.003$
$\mu = 0.02 \times 2.42 = 0.0484$ lb/ft hr	$\Delta p_t = \frac{f G_t^2 L n}{5.22 \times 10^{10} D_s \phi_t} = 0.00005$ psi
$D_e = 0.99/12 = 0.0825$	$\Delta p_r = \frac{4n}{s}\frac{v}{2g'} = \left(\frac{4 \times 2}{1}\right)(0.001) = 0.008$
$Nre_s = \frac{DG}{\mu} = \frac{0.0825 \times 13365.2341}{0.0484}$	$\Delta p_T = 0.008 + 0.00005 = 0.0081$
$= 22781.6490$	
$f = 0.0018$ (fig 29)	

$N+1 = \frac{L}{B}\times 12 = \frac{12}{21\frac{1}{4}}\times 12 = 6.7765 \approx 7$ $\rho = 28.97\left(\frac{1}{22.414}\right)\left(\frac{7}{1}\right)\left(\frac{273.2}{348}\right)$=7.1028 $s = \frac{7.1028}{62.5} = 0.1136$ $D_s = \frac{21.25}{12}$=1.7708 $\Delta p_s = \frac{1}{2}\frac{fG_s^2 ID_s(N+1)}{5.22\times 10^{10} De\, s\phi_s}$=0.004 psi	

Absorption Tower (T-610)

From material balance calculation:

Inside diameter of absorber : 1.6 m

Plate spacing : 30 cm

Amount of plate : 22

Calculating thickness of column

Construction material: stainless steel, AISI-304L

P operation = 7 atm = 102.9 psi = 88.2 psig

P design = 1.2 x 88.2 psig = 105.84

From table 13.1 Brownell & Young:

F allowable = 18750 lb/in^2

Corrosion allowance = $\frac{1}{8}$

ε = 85%

$$ts = \frac{P.ri}{f.\varepsilon - 0.6.P} + c$$

$$= \frac{105.84x\frac{62.992}{2}}{18750x0.85 - 0.6x105.84} + \frac{1}{8}$$

$= 0.2099 = 0.3349 = \frac{3}{8}$ in

Calculating thickness of head

Construction material: stainless steel, AISI-304L

Type of head: elliptical dished head

K value = 2 (Brownell & Young, p 133)

$V= \frac{1}{6}(2+k^2)$

$= \frac{1}{6}(2+2^2)$

$= 1$

$$th = \frac{P.d.V}{2.f.\varepsilon - 0.2.P} + c$$

$$= \frac{105.84x62.992x1}{2x18750x0.85 - 0.2x105.84} + \frac{1}{8}$$

$= 0.2093 = 0.3343 = \frac{3}{8}$ in

OD = ID = 2.ts

$= \left(62.992 + 2x\frac{3}{8}\right)$ in

$= 63.742$ in

From table 5.7 Brownell & Young, p 90, OD standard = 84 in, r = 84 in, and icr = 5.125 in

$a = \frac{ID}{2} = \frac{62.992}{2} = 31.496$ in

$AB = \frac{ID}{2} - icr = 31.496 - 5.125 = 26.371$ in

$BC = r - icr = 84 - 5.125 = 78.875$ in

$B = r - \sqrt{(BC)^2 - (AB)^2} = 84 - \sqrt{(78.875)^2 - (26.371)^2} = 9.664$ in

Height of head:

$OA = t + b + sf = \frac{3}{8} + 9.664 + 2 = 12.039$ in

Taken sf = 2 in

Height of total tray = 23 x 30 cm = 690 cm = 6.9 m = 22.6375 ft

Total height of absorber = 22.6375 + $\frac{12.039x2}{12}$ = 24.644 ft

Type of tray: crossflow

Height of weir = 2 in

Hole size = $\frac{3}{16}$ in

Specification:

Inside diameter of absorber	=	62.922 in = 1.6 m
Place spacing	=	30 cm
Amount of plate	=	22
P design	=	105.84 psia
Thickness of shell	=	$\frac{3}{8}$ in
Thickness of head	=	$\frac{3}{8}$ in
Total height of absorber	=	24.644 ft
Type of tray	=	crossflow
Height of weir	=	2 in
Hole size	=	$\frac{3}{16}$ in

HNO_3 Storage Tank (TT-612)

Function: to storage corrosive ammonia

Type: horizontal tank with elliptical dished head

Consideration: suitable to storage corrosive nitric acid

Operation condition: T = 30 °C, P = 1 atm

Rate in: 2777.7778 kg/hr = 6123.8889 lb/hr

At 1 atm and 30 °C

Sg = 1.504 (Perry 7ed, p 2-214)

ρ $HNO_3 = \left(\left(\frac{1.504}{1}\right) \times 62.43 = 93.8947$ lb/ft^3

ρ H_2O = 995.6470 kg/m^3 = 62.1582 lb/ft^3 (Perry 7[ed], p 2-214)

$$\frac{1}{\rho HNO_3 solution} = \frac{0.6}{93.8947} + \frac{0.4}{62.1582} = 0.0218$$

ρ HNO_3 solution 60% = 77.9707 lb/ft^3

planed: storage the product for 1 day

V liq = $\frac{6123.8889}{77.9707} \times 24hr = 1884.9816 ft^3$

V liq = 80% Vol tank

V tank = $\frac{100}{80} \times 1884.9816 ft^3$

Assumption : $\frac{L}{D} = 1.5$

$$V = L \times \left(\frac{\pi D^2}{4}\right)$$

$$2356.227 = \frac{1.5}{4}\pi D^3$$

D^3 = 2000.0276 → D = 12.5993 ft = 151.1916 in

L = 1.5 ×151.1916 = 226.7874 in

V dished head = 0.000049 D^3

= 0.000049 × $(151.1916)^3$

= 169.3476 ft^3

V tank = V shell + V dished head

2356.227 = V shell + 169.3476 → V shell = 2186.8794 ft^3

V shell = $\frac{\pi}{4} D^2 h$

$$2186.8794 = \frac{\pi}{4}(12.5993)^2 h$$

h = 17.5405 ft

$$\frac{h}{D} = \frac{17.5405}{12.5993} = 1.4 \text{ (range < 2, acceptable)}$$

P hidrostatik $= \rho \frac{(H-1)}{144}$

$= 62.1582 \frac{(17.5405-1)}{144}$

$= 7.1398$ psia

Shell's thickness

P design = 1.2 × (14.7 + 7.1398) = 26.2078 psia

F allowable = 18750 lb/in^2

E = 85% (double welded)

c = 1/8 in

$t_s = \frac{\rho \times D_i}{2(F \times \varepsilon - 0.6P)} + c$

$= \frac{26.2078 \times 151.1916}{2(18750 \times 0.85 - 0.6 \times 26.2078)} + \frac{1}{8}$

$= 0.2494$ in $= 0.25$ in

Head thickness

k = 2 (Brownell & Young, p 133)

$V = \frac{1}{6}(2+4) = 1$

$t_h = \frac{\rho D V}{2 f \varepsilon - 0.2 p} + c$

$= \frac{26.2078 \times 151.1916 \times 1}{2 \times 18750 \times 0.85 - 0.2 \times 26.2078} + \frac{1}{8}$

$= 0.2493$ in $= 0.25$ in

Head depth and tank length (Brownell & Young, table 5.11)

Sf = 3 in

Head height $= \left(\frac{ID}{4}\right) + sf + t$

$= \left(\frac{151.1916}{4}\right) + 3 + 0.2493$

$= 41.0472 \text{ in} = 3.4206 \text{ ft}$

Bottom thickness

$$t = cD\left(\frac{P}{f}\right)^{\frac{1}{2}}$$

$$= 1 \times 151.1916 \times \left(\frac{26.2078}{18750}\right)^{\frac{1}{2}}$$

$= 5.6525 \text{ in}$

Specification:

Material : stainless steel AISI-304L

Capacity : 2536.227 ft^3

Tank length : 12.5993 ft

Total height of tank : 21.4611 ft

Height of top : 3.4206 ft

Shell thickness : 0.25 in

Top thickness : 0.25 in

Bottom thickness : 6 in

Amount : 1

SCR-Reactor (R-510)

Pressure = 7 atm = 102.9 psi

T av operation = 319.315 °C

Gas input composition:

Gas	kg/hour	kmol/hour	mol fraction
NH3	7.4864	0.4404	0.0018
NO	17.9314	0.5977	0.0024
O2	281.7852	8.8058	0.0357
NO2	0.8249	0.0179	0.00007
N2	6639.4147	236.9527	0.96
N2O4	0.0035	3.8035x10-5	0.0000001

Total		246.8145	

Reaction

6 NO + 4 NH3 (5 N2 + 6 H2O — conversion of reaction = 90%

6 NO2 + 8 NH3 (7 N2 + 12 H2O — conversion of reaction = 90%

conversion of reaction 90%

$x = 1 - \exp(-k.9.a.\theta)$ (Carberry, eq. 10-128)

$0.9 = 1 - \exp(-k.9.a.\theta)$

$0.1 = \exp(-k.9.a.\theta)$

$\ln 0.1 = -k.9.a.\theta)$

$-k.g.a.\theta = 2.3026$

$$-k.g.a.\theta = \frac{4.n}{10^{0.7}}$$ (Carberry, p. 586)

$n = 2.9 = 3$

From fig. 15 Kern:

$\mu\ NH_3 = 0.02 \times 2.42 = 0.0484$ lb/hour.ft

$\mu\ NO = 0.021 \times 2.42 = 0.0508$ lb/hour.ft

$\mu\ O_2 = 0.026 \times 2.42 = 0.0629$ lb/hour.ft

$\mu\ NO_2 = 0.025 \times 2.42 = 0.0605$ lb/hour.ft

$\mu\ N_2 = 0.0235 \times 2.42 = 0.0569$ lb/hour.ft

$\mu\ N_2O_4 = 0.023 \times 2.42 = 0.0557$ lb/hour.ft

$$\mu \text{ mixed gas} = \left(0.0484^{\frac{1}{3}} x0.0018\right) + \left(0.0508^{\frac{1}{3}} x0.0024\right) + \left(0.0629^{\frac{1}{3}} x0.0357\right) +$$

$$\left(0.0605^{\frac{1}{3}} x0.00007\right) + \left(0.0569^{\frac{1}{3}} x0.96\right) + \left(0.0557^{\frac{1}{3}} x0.0000001\right)$$

$$= 0.1114 \text{ lb/hour.ft}$$

From table 3-30, Perry 6^{ed}:

$\rho\ NH_3 = 0.0402$ lb/ft^3

$\rho\ NO = 0.0837$ lb/ft^3

$\rho\ O_2 = 0.0892$ lb/ft^3

$\rho\ NO_2$ = 0.1235 lb/ft^3

$\rho\ N_2$ = 0.0782 lb/ft^3

$$\frac{1}{\rho\ mixed} = \frac{0.0018}{0.0482} + \frac{0.0024}{0.0837} + \frac{0.0357}{0.0892} + \frac{0.00007}{0.1235} + \frac{0.9600}{0.0782} = 12.7430$$

ρ mixed = 0.0785 lb/ft^3 (at STP)

ρ mixed at 102.9 psi and 319.315 °C

$$= \frac{0.0785(32+460)}{14.7} x \frac{102.9}{(606.767+460)}$$

$$= 0.2534 \text{ lb/ft}^2$$

$$V = \frac{\mu}{\rho} = \frac{0.1114}{0.0785} = 1.4191 \text{ ft}^3\text{/hour}$$

$$Re = dw \times \frac{u}{V}$$ (Carberry, p.586)

$$10 = 2.5x10^{-4} x \frac{u}{1.4191}$$

u = 56764 ft/hour = 946.0667 ft/min

Total gas flow rate = 246.8145 kmol/hour = 9.0687 lbmol/min

Volume of 1 lbmol at 102.9 psi and 606.767 °F $= Vo\left(\frac{Po}{P}\right)\left(\frac{T}{To}\right)$

$$= 359x\left(\frac{14.7}{102.9}\right)x\left(\frac{606.767+460}{32+460}\right)$$

=11.199 ft^3/lbmol

Gas flow rate (Q) = 9.0687 lbmol/min x 111.199 ft^3/lbmol

= 1008.43 ft^3/min = 60505.8218 ft^3/hour

$$S = \frac{Q}{u} = \frac{1008.43}{946.0667} = 1.0659 \text{ ft}^2$$

S = 0.25 x π x D^2

1.0659 = 0.25 x 3.14 x D^2

D = 1.1653 ft = 13.9836 in

Contact time inside the wire gauss

$\theta = dw.\varepsilon.\frac{n}{V}$; where ε = void fraction average, taken = 0.5

$\theta = 2.5x10^{-4}x0.5x\frac{3}{1.4191}$ = $2.6425x10^{-4}$ hour $^{-1}$ = 0.9513 s $^{-1}$

Calculating the thickness of shell

P = 102.9 psi = 8.2 psig

Pdesign = 1.2 x 88.2 = 105.84 psig

Construction material: stainless steel 55

Type of head: elliptical dished head

k value = 2 (Brownell & Young p 133)

$$V = \frac{1}{6}\left(2+k^2\right)$$

$$= \frac{1}{6}\left(2+2^2\right)$$

$$= 1$$

$$th = \frac{P.d.V}{2.f.\varepsilon - 0.2P} + \frac{1}{8}$$

$$= \frac{105.84x13.9836}{2x18750x0.85 - 0.2x105.84} + \frac{1}{8}$$

$$= 0.1715 \text{ in} \approx \frac{1}{4} \text{ in}$$

$$OD = ID + 2.ts = \left(13.9836 + 2x\frac{1}{4}\right) \text{in} = 14.4836 \text{ in}$$

From table 5.7 Brownell & Young, p 90 taken OD standard =16 in, r = 15 in, and icr = 1 in

$$a = \frac{ID}{2} = \frac{13.9836}{2} = 6.9918 \text{ in}$$

$AB = \frac{ID}{2} - icr = 6.9918 - 1 = 5.9918$ in

BC = r – icr = 15 – 1 = 14 in

$b = r - \sqrt{(BC)^2 - (AB)^2}$

$= r - \sqrt{(14)^2 - (5.9918)^2}$

= 2.35 in

Taken sf = 2 in

Height of head

OA = t + b + sf

$= \frac{1}{4} + 2.35 + 2$

= 4.6 in

Calculating height of shell

Wire space = 1 in

Wire space from top to bottom = (3 – 1) x 1 = 2 in = 0.1667 ft

Height of empty space taken (top + bottom) = 1.5 + 1.5 = 3 ft

Height of shell = 3 + 0.1667 = 3.1667 ft

Total height = height of shell + 2 x height of head + 2 x thickness of head

$= 3.1667 + 2x\frac{4.6}{12} + 2x\frac{1}{12x4}$

= 3.975 ft

Specification:

Construction material	=	stainless steel AISI
Capacity	=	60505.8218 ft^2/hour
Diameter	=	1.1653 ft
Total height of tank	=	3.975 ft
Height of top head	=	0.3833 ft

Height of bottom head	=	0.3833 ft
Thickness of shell	=	$\frac{1}{4}$ in
Thickness of top head	=	$\frac{1}{4}$ in
Thickness of bottom head	=	$\frac{1}{4}$ in
Amount	=	1

Tail Gas Expansion Turbine (JC-515)

Function: to reduce tail gas pressure

P input = 7 atm

P output = 1 atm

Mass = 6947.4426 kg/hour = 1.9298 kg/s

Efficiency assume = 55%

$$P\ gas = \frac{P\ mol\,wt}{R\,T} = \frac{7 \times 28.1371}{0.0821 \times (215.5 + 273)} = 4.911\ \text{kg/m}^3$$

$$Ws = \frac{\varepsilon\, m(p_1 - p_2)}{\rho} = \frac{0.55 \times 1.9298 \times (7-1)10^5}{4.911} = 129675.0153\ \text{J/s} = 129.675\ \text{kW}$$

Specification

P in	:	7 atm
P out	:	1 atm
Gas rate	:	1.9298 kg/s
Ws	:	129.675 kW
Quantity	:	1

Steam Turbine (JC-415)

Function: to convert high pressure steam becomes low pressure steam so the energy produced can be used for compression

P input = 7 atm

P output = 1 atm

T input = 200 °C

Mass = 2700 kg/hr = 0.75 kg/s

From steam table

Inlet enthalpy = 2844.2 kJ/kg = 682.608 kcal/kg = 1222.79 Btu/lbm

Inlet entropy = 6.8859 kJ/kg K

From mollier diagram

Process occurring is assumed expansion isentropic process for ideal gas

Outlet ebthalpy = 1304.5 kJ/kg K

Inlet entropy = 6.8859 kJ/kg K

From fig 4-2, Ullrich 1984, the efficiency is estimated to be 63%. Shaft power is consequently 1200kW

$$Ws = m\,\varepsilon\,(h_1 - h_{2.5}) = m\,(h_1 - h_2)$$

$$h_1 - h_2 = \frac{Ws}{m}$$

$$h_2 = h_1 - \frac{Ws}{m} = 1244.2 \text{ kJ/kg}$$

From steam table, at 1 atm, temperature outlet steam = 100 °C

APPENDIX D

REFERENCES

Ant/OL-1, *Industri Pertahanan Diharapkan Mulai 2007*, in *Media Indonesia.* 2005: Jakarta.

Austin, G. T. (1984). *Shreve's Chemical Process Industries.* New York, McGraw-Hill, Inc.

Brownell, F. E. and E. H. Young (1950). *Process Equipment Design.* New York, John Wiley & Sons.

Carbery, J. J. (1976). *Chemical and Catalytic Reaction Engineering.* New York, Mc Graw Hill.

Garret, D. E. (1989). *Chemical Engineering Economics.* New York, Van Nostrand Reibhold.

Geankoplis, C. J. (1997). *Transport Processes and Unit Operations.* New Delhi, Prentice Hall of India.

Himmeblau, D. M. (1962). *Basic Principles and Calculation in Chemical Engineering.* New York, Prentice Hall.

Kern, D. Q. (1988). *Process Heat Transfer.* Singapore, Mc Graw Hill.

Lowenheim, F. A. and M. K. Moran (1975). *Industrial Chemicals.* New Jersey, John Wiley & Sons, Inc.

McCabe, W. L. e. a. (2005). *Unit Operations of Chemical Engineering.* New York, McGraw-Hill, Inc.

McKetta, J., Ed. (1990). *Encyclopedia of Chemical Processing and Design.* Nitric Acid. New York, Marcel Dekker, Inc.

Meyers, R.A., *Handbook of Chemicals Production Processes.* 1986, New York: Mc Graw-Hill, Inc. 3.6-17 - 3.6-33.

Microsoft Encarta, in *Global Warming*, J. Hart, Editor. 2004.

Nieuwenhuyse, E. v. (2000). *Best Available Techniques for Pollution Prevention and Control in the European Fertilizer Industry, Booklet No. 2 of 8: PRODUCTION OF NITRIC ACID*, EFMA.

Othmer, K., Ed. (1981). *Encyclopedia of Chemical Technology*. Nitric Acid. New York, John Wiley & Sons, Inc.

Perez-Ramirez, J. and B. Vigeland, *Lanthanum Ferrite Membranes in Ammonia Oxidation Opportunities for Nitric Acid Plants.* Elsevier, 2005.

Perry, R. H. and D. Green (1984). *Chemical Engineer's Handbook.* New York, McGraw-Hill Inc.

Perry, R. H. and D. Green (1984). *Chemical Engineer's Handbook.* New York, McGraw-Hill Inc.

Peters and Timmerhaus (1991). *Plant Design and Economic for Chemical Engineering.* Singapore, Mc Graw Hill.

Ullman, ed. *Ullman's Encyclopedia of Industrial Chemistry.* Nitric Acid, Nitrous Acid, and Nitrogen Oxides. Vol. A17. 1991: New York.

Ulrich, G. D. (1984). *A Guide to Chemical Engineering Process Design and Economics.* New York, John Wiley & Sons.

http://203.241.220.200/caddet/ee/R166.pdf

http://64.233.167.104/search?q=cache:Db5IV7FgMi0J:www.hampapua.org/skp/hukum/uu3-2002i.pdf+%22industri+pertahanan%22&hl=id&ie=UTF-8

http://en.wikipedia.org/wiki/Ammonium_nitrate

http://ifcln1.ifc.org/ifcext/enviro.nsf/AttachmentsByTitle/gui_nitrofert_WB/$FILE/nitrofert_PPAH.pdf

http://minerals.usgs.gov/minerals/pubs/commodity/boron/120494.pdf

http://p2pays.org/ref/02/01245/3017111.pdf

http://www.efma.org/publications/BAT%202000/bat02/booklet2.pdf

http://www.fertilizer.org/ifa/publicat/pdf/tech0012.pdf

http://www.greenpeace.to/publications_pdf/Novaky%20technical%20note.pdf

http://www.krupp-uhde.com/cgi-bin/ download.cgi/pdf/TP-nitric_acid.pdf

http://www.mpri.lsu.edu/Clean%20Technologies%20Paper.pdf

http://www.naaic.org/Meetings/National/2002meeting/2002Abstracts/SamacAl.pdf

http://www.specchemonline.com/shownews.asp?secid=7&nav=1&newstype=&key=&page=&newsid=10014

http://www.umweltbundesamt.at/fileadmin/site/publikationen/M150.pdf

http://www.wiley-vch.de/publish/en/books/bySubjectCH00/bySubSubjectCH30/3-527-31318-4/?sID=d05b

http://www.yara.com/en/products/gas_chemicals/chemica