APPENDIK A

PERHITUNGAN NERACA MASSA

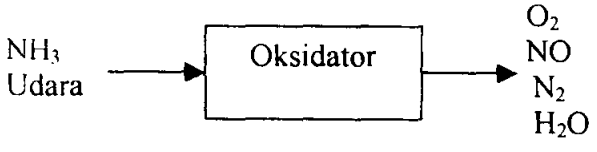
Kapasitas = 1)000 ton / tahun

Basis : fasa = NH_3 gas

Udara gas

vaktu = ! jam

1. Oksidator 1 (R – 210)



NH_3 masuk = 712,1415 kg

Udara masuk = 10417,8510 kg = 361,2292 kmol

O_2 = 0,21*361,2292 = 75,8581 kmol

N_2 = 0,79*361,2292 = 285,3711 kmol = 7990,3906 kg

Ammonia yang digunakan mempunyai kemurnian 99,5 %

NH_3 = 0,995*712,1415 = 708,5808 kg

H_2O = 0,005*712,1415 = 3,5607 kg

Dari Ullman vol. 17 :

Reaksi : $NH_{3\,(g)} + \frac{5}{4} O_{2\,(g)} \longrightarrow NO_{(g)} + \frac{3}{2} H_2O_{(g)}$ (1)

$NH_{3\,(g)} + \frac{3}{4} O_{2\,(g)} \longrightarrow \frac{1}{2} N_{2\,(g)} + \frac{3}{2} H_2O_{(g)}$ (2)

Reaksi 1:

NH_3 yang bereaksi pada reaksi 1 sebesar 96 %

NH_3 yang bereaksi = 0.96*708,5808 = 680,2376 kg = 40,0140 kmol

NH_3 sisa = 708,5808 – 680,5808 = 28,3432 kg

O_2 mula = 75,8581 kmol

O_2 yang bereaksi = $\frac{5}{4} * 40,0140 = 50,0175$ kmol

O_2 sisa = 75,8581 – 50,0175 = 25,8406 kmol

NO hasil = 40,0140 kmol = 1200,4193 kg

H_2O hasil = $\frac{3}{2} * 40,0140 = 60,0210$ kmol

Reaksi 2 :

NH_3 mula = 28,3432 kg = 1,6672 kmol

NH_3 yang bereaksi = 1,6672 kmol

O_2 mula = 25,8406 kmol

O_2 yang bereaksi = $\frac{3}{4} * 1,6672 = 1,2504$ kmol

O_2 sisa = 25,8406 – 1,2504 = 24,5902 kmol = 786,8874 kg

N_2 mula = 7990,3906+3,5607 = 7993,9514 kg

N_2 yang bereaksi = $\frac{1}{2} * 1,6672 = 0,8336$ kmol = 23,3408 kg

N_2 hasil = 7993,9514+23,3408 = 8017,2928 kg

H_2O mula = 60,0210 kmol

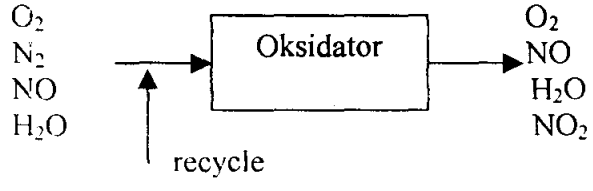
H_2O yang bereaksi = $\frac{3}{2} * 1,6672 = 2,5009$ kmol

H_2O hasil = 60,0210+2,5009 = 62,5218 kmol = 1125,3931 kg

Neraca massa :

Masuk	kg	Keluar	kg
NH_3	712,1415	N_2	8017,2928
Udara	10417,8510	O_2	786,8874
		NO	1200,4193
		H_2O	1125,3931
Total	11129,9926		11129,9926

2. Oksidator 2 (R – 230)



Reaksi : $NO_{(g)} + \frac{1}{2} O_{2(g)} \longrightarrow NO_{2(g)}$ (95 %)

Recycle : O_2 = 46,3998 kg

N_2 = 8017,2928 kg

NO = 262,9430 kg

NO_2 = 54,5872 kg

NO masuk total = NO masuk oksidator 2 + NO recycle

= 1200,4193+262,9430 = 1463,3624 kg = 48,7787 kmol

NO yang bereaksi = 0,95*48,7787 = 46,2805 kmol

NO sisa = 48,7787-46,2805 = 2,4983 kmol = 74,9481 kg

O_2 masuk total = 786,8874+46,3998 = 833,2872 kg = 26,0402 kmol

O_2 yang bereaksi = $\frac{1}{2} * 46{,}2805 = 23{,}1402$ kmol

O_2 sisa = 26,0402- 23,1402 = 2,9000 kmol = 92,7996 kg

NO_2 mula = 54,5872 kg = 1,1867 kmol

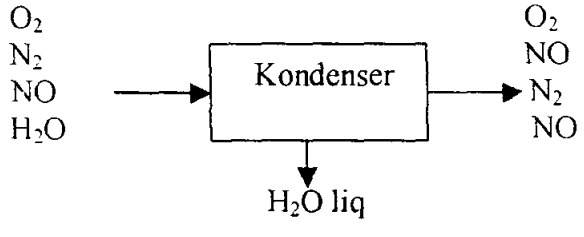
NO_2 yang bereaksi = 46,2805 kmol

NO_2 hasil = 46,2805+1,1867 = 47,4672 kmol = 2183,4890 kg

Neraca massa :

Masuk	kg	Keluar	Kg
O_2	833,2872	O_2	92,7996
N_2	16034,5857	N_2	16034,5857
NO	1463,3624	NO	74,9481
NO_2	54,5872	NO_2	2183,4890
H_2O	1125,3931	H_2O	1125,3931
	19511,2156		19511,2156

3. Kondenser (E – 232)

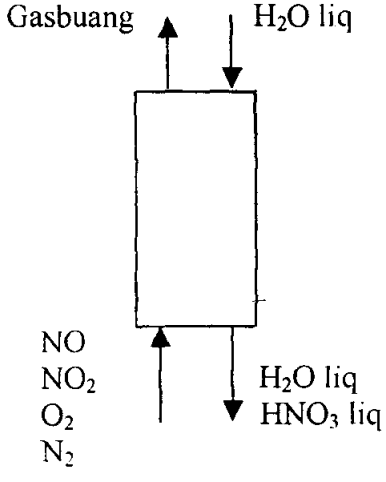


H_2O gas diasumsi mengembun semua

Neraca massa :

Masuk	kg	Keluar	kg
O_2	92,7996	O_2	92,7996
N_2	16034,5857	N_2	16034,5857
NO	74,9481	NO	74,9481
NO_2	2183,4890	NO_2	2183,4890
H_2O	1125,3931	bawah	
		H_2O cair	1125,3931
Total	19511,2156		19511,2156

4. Absorber (D – 240)



Reaksi : $3\ NO_2 + H_2O \longrightarrow 2\ HNO_3 + NO$ (95 %)

NO_2 mula = 47,4672 kmol

NO_2 yang bereaksi = 0,95*47,4672 = 45,0938 kmol

NO_2 sisa = 47,4672- 45,0938 = 2,3734 kmol = 109,1745 kg

H_2O yang bereaksi = $\frac{1}{3} * 45{,}0938 = 15{,}0313$ kmol = 270,5628 kg

HNO_3 hasil = $\frac{2}{3} * 45{,}0938 = 30{,}0625$ kmol = 1136,3636 kg

NO mula = 74,9481 kg = 2,4983 kmol

NO yang bereaksi = $\frac{1}{3} * 45{,}0938 = 15{,}0313$ kmol

NO hasil = 15,0313+2,4983 = 17,5295 kmol = 525,8861 kg

Untuk menghasilkan HNO_3 60 %, H_2O yang ditambahkan = 1028,1386 kg

H_2O sisa = 1028,1386 - 270,5628 = 757,5758 kg

Neraca massa :

Masuk	kg	Keluar	kg
Bawah		Bawah	
O_2	92,7996	HNO_3	1136,3636
N_2	16034,5857	H_2O	757,5758
NO	74,9481	Atas	
NO_2	2183,4890	O_2	92,7996
Atas		N_2	16034,5857
H_2O	1028,1386	NO	525,8861
		NO_2	109,1745
	19413,9610		19413,9610

Gas yang keluar sebagian dibuang dan sebagian direcycle.

Gas yang direcycle = 50 % dari gas yang keluar dari absorber

Gas yang direcycle :

O_2 = 46,3998 kg

N_2 = 8017,2928 kg

NO = 262,9430 kg

NO_2 = 54,5872 kg

APPENDIKS B

PERHITUNGAN NERACA PANAS

APPENDIK B

PERHITUNGAN NERACA PANAS

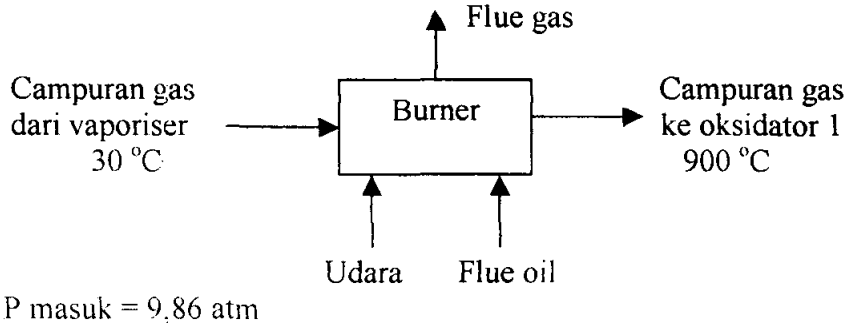
Kapasitas = 15000 ton / tahun

Basis : fasa = NH_3 gas

Udara gas

waktu = 1 jam

1. Burner (Q-211)



P masuk = 9,86 atm

P keluar = 9,66 atm

T masuk = 30 °C = 303 K

T keluar = 900 °C = 1173 K

Masuk	kmol	keluar	Kmol
NH_3 99,5 %	41,6812	NH_3	41,6812
H_2O 0,5 %	0,1272	N_2	285,4983
Udara		O_2	75,8581
O_2	75,8581		
N_2	285,3711		

Perhitungan entalpi masuk :

Dari table B.1 Smith Van Ness diperoleh :

	ω	Tc, K	Pc, Pa
NH_3	0,253	405,7	$11,3.10^6$
N_2	0,038	126,2	$3,39.10^6$
O_2	0,022	154,6	$5,02.10^6$

Untuk NH_3 99,5 %:

$$Pr = \frac{P}{Pc} = \frac{9,86\ atm}{11,3.10^6\ Pa} * \frac{101325,0247\ Pa}{atm} = 0,0884$$

$$Tr = \frac{T}{Tc} = \frac{303}{405,7} = 0,7469$$

Dari Smith Van Ness :

$$\frac{H^R}{R.Tc} = Pr.\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right] \qquad (6.62)$$

$$B° = 0,083 - \frac{0,422}{Tr^{1.6}} \qquad (3.50)$$

$$B° = 0,083 - \frac{0,422}{0,7469^{1.6}} = -0,5902$$

$$\frac{dB°}{dTr} = \frac{0,675}{Tr^{2.6}} \qquad (6.64)$$

$$\frac{dB°}{dTr} = \frac{0,675}{0,7469^{2.6}} = 1,4417$$

$$B' = 0,139 - \frac{0,172}{Tr^{4.2}} \qquad (3.51)$$

$$B' = 0,139 - \frac{0,172}{0,7469^{4.2}} = -0,4470$$

$$\frac{dB'}{dTr} = \frac{0,722}{Tr^{5.2}} \qquad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0,722}{0,7469^{5.2}} = 3,2938$$

$$\frac{H^R}{R.Tc} = 0,0884.[-0,5902 - 0,7469 * 1,4417 + 0,253(-0,4470 - 0,7469 * 3,2938)]$$

$$\frac{H^R}{R.Tc} = -0,2124$$

$$H^R = 8314,51 \ \frac{J}{kmol.K} * 405,7 \text{ K} * -0,2124 = -716489,018 \text{ J/kmol}$$

$$H^R = 41,6812 \text{ kmol} * -716489,018 \text{ J/kmol} = -29864122,06 \text{ J}$$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

Dari Smith & Van Ness, tab. C.1 untuk NH_3 :

$A = 3,578$; $B = 3,02.10^{-3}$; $D = 0,186.10^5$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}\left(T^2 - To^2\right) + \frac{C}{3}\left(T^3 - To^3\right) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{303}^{298} \frac{Cp}{R} dT = 3,578(298 - 303) + \frac{3,02.10^{-3}}{2}(298^2 - 303^2)$$

$$+ 0,186.10^5\left(\frac{1}{298} - \frac{1}{303}\right)$$

$$\int_{303}^{298} \frac{Cp}{R} dT = -25,9351$$

$$H^{id} = 41,6812 * 8314,51 * -25,9351 = -8987657,607 \text{ J}$$

Hin NH_3 $= -H^R + H^{id}$

$= 29864122,06 - 8987657,607 = 21176464,45$ J

untuk H_2O 0,5 % :

$$Pr = \frac{P}{Pc} = \frac{9,86\ atm}{3,39.10^6\ Pa} * \frac{101325,0247\ Pa}{atm} = 0,2947$$

$$Tr = \frac{T}{Tc} = \frac{303}{126,2} = 2,4010$$

Karena Pr >= 0,2 maka dipakai persamaan compressible

Dari Smith Van Ness pers.6.60 :

$$\frac{H^R}{R.Tc} = \frac{(H^R)^\circ}{R.Tc} + \omega.\frac{(H^R)'}{R.Tc}$$

dari Smiyh Van Ness table E.5 dan E.6 diperoleh :

$$\frac{(H^R)^\circ}{R.Tc} = -0,05599$$

$$\frac{(H^R)'}{R.Tc} = 0,03721$$

$$\frac{H^R}{R.Tc} = -0,05599 + 0,038.0,03721 = -0,05458$$

$H^R = 126,2 * 8314,51 * -0,05458 = -57266,1354$ J/kmol

$H^R = 0,1272 * -57266,1354 = 7284,2525$ J

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}\left(T^2 - To^2\right) + \frac{C}{3}\left(T^3 - To^3\right) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{303}^{298} \frac{Cp}{R} dT = 3{,}28(298-303) + \frac{0{,}593.10^{-3}}{2}(298^2 - 303^2)$$

$$-0{,}04.10^{5}\left(\frac{1}{298} - \frac{1}{303}\right) = -17{,}4313$$

$H^{id} = 0{,}1272 * 8314{,}51 * -17{,}4313 = -18435{,}4906$ J

Hin H_2O 0,5 % = $-H^R + H^{id}$

$= 7284{,}2524 - 18435{,}4906 = 11151{,}2382$ J

Dengan cara yang sama dapat memperoleh entalpi masuk untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hin, joule
NH_3 99,5 %	-29.864.122,06	-8.987.657,607	21.176.464,45
H_2O 0,5 %	-7.284,2524	-18.435,4906	-11.151,2382
N_2	-16.342.100,06	-41.359.609,21	-25.017.509,15
O_2	-5.981.764,625	-11.162.698,48	-5.180.933,859
Total			-9.033.129,797

Perhitungan entalpi keluar :

Untuk NH_3 :

$$Pr = \frac{P}{Pc} = \frac{9{,}66\ atm}{11{,}3.10^{6}\ Pa} * \frac{101325{,}0247\ Pa}{atm} = 0{,}08662$$

$$Tr = \frac{T}{Tc} = \frac{1173}{405{,}7} = 2{,}8913$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{R.Tc} = \Pr\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$B° = 0,083 - \frac{0,422}{Tr^{1,6}} \qquad (3.50)$$

$$B° = 0,083 - \frac{0,422}{2,8913^{1,6}} = 0,00581$$

$$\frac{dB°}{dTr} = \frac{0,675}{Tr^{2,6}} \qquad (6.64)$$

$$\frac{dB°}{dTr} = \frac{0,675}{2,8913^{2,6}} = 0,0427$$

$$B' = 0,139 - \frac{0,172}{Tr^{4,2}} \qquad (3.51)$$

$$B' = 0,139 - \frac{0,172}{2,8913^{4,2}} = 0,137$$

$$\frac{dB'}{dTr} = \frac{0,722}{Tr^{5,2}} \qquad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0,722}{2,8913^{5,2}} = 3,2938$$

$$\frac{H^R}{R.Tc} = 0,08662.[0,00581 - 2,8913 * 0,0427 + 0,253(0,137 - 8,8913 * 0,00289)]$$

$$\frac{H^R}{R.Tc} = -0,0073715$$

$$H^R = 8314,51 \ \frac{J}{kmol.K} * 405,7 \text{ K} * -0,0073715 = -24865,5045 \text{ J/kmol}$$

$$H^R = 41,6812 \text{ kmol} * -24865,5045 \text{ J/kmol} = -1036424,067 \text{ J}$$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}(T^2 - To^2) + \frac{C}{3}(T^3 - To^3) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{298}^{1173} \frac{Cp}{R} dT = 3{,}578(1173 - 298) + \frac{3{,}02.10^{-3}}{2}(1173^2 - 298^2)$$

$$+ 0{,}186.10^5\left(\frac{1}{1173} - \frac{1}{298}\right)$$

$$\int_{298}^{1173} \frac{Cp}{R} dT = 5027{,}7494 \text{ K}$$

H^{id} = 41,6812 * 8314,51 * 5027,7494 = 1742410575 J

Hout $NH_3 = H^R + H^{id}$

= -1036424,067 + 1742410575 = 1741374151 J

Dengan cara yang sama dapat memperoleh entalpi keluar untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hin, joule
NH_3	-1036424,0667	1742410575	1741374151
O_2	-129893,303	2177851728	2177721835
N_2	-178487,4556	7742423391	11661340890
Total			11661340890

Menghitung kebutuhan bahan bakar :

Bahan bakar yang digunakan LNG dengan komposisi :

Metana = 87,1 %

Etana = 3,41 %

Propana = 1,73 %

N_2 = 7,1 %

CO_2 = 0,31 %

Helium = 0,35 % (Ullman's)

Basis kebutuhan bahan bakar = x kg

Metana = 87,1 % = 0,8710 x kg = 0,0544 x kmol

Etana = 3,41 % = 0,0341 x kg = $1,1367.\ 10^{-3}$ x kmol

Propana = 1,73 % = 0,0173 x kg = $3,9318.\ 10^{-4}$ x kmol

N_2 = 7,1 % = 0,0710 x kg = $2,5357.\ 10^{-3}$ x kmol

CO_2 = 0,31 % = 0,0031 x kg = $7,0455.\ 10^{-5}$ x kmol

Helium = 0,35 % = 0,0035 x kg = $8,75.10^{-4}$ x kmol

Reaksi yang terjadi : $CH_4 + 2\ O_2 \longrightarrow CO_2 + 2\ H_2O$ (1)

$C_2H_6 + \frac{7}{2}\ O_2 \longrightarrow 2\ CO_2 + 3\ H_2O$ (2)

$C_3H_8 + 5\ O2 \longrightarrow 3\ CO_2 + 4\ H_2O$ (3)

Kebutuhan O_2 :

Reaksi 1 :

O_2 yang bereaksi = 2 * 0,0544 x = 0,1088 x kmol

CO_2 hasil = 0,0544 x kmol

H_2O hasil = 0,1088 x kmol

Reaksi 2 :

O_2 yang beraksi = $\frac{7}{2} * 1{,}1367.10^{-3} = 3{,}9785.10^{-3}\ x$ kmol

CO_2 hasil = $2 * 1{,}1367.10^{-3}\ x = 2{,}2734.10^{-3}\ x$ kmol

H_2O hasil = $3 * 1{,}1367.10^{-3}\ x = 3{,}4101.10^{-3}\ x$ kmol

Reaksi 3 :

O_2 yang bereaksi = $5 * 3{,}9318.10^{-4}\ x = 1{,}9659.10^{-3}\ x$ kmol

CO_2 hasil = $3 * 3{,}9318.10^{-4}\ x = 1{,}1795.10^{-3}\ x$ kmol

H_2O hasil = $4 * 3{,}9318.10^{-4}\ x = 1{,}3567.10^{-3}\ x$ kmol

Kebutuhan O_2 = $0{,}1088 + 3{,}9785.10^{-3} + 1{,}9659.10^{-3} = 0{,}1147\ x$ kmol

O_2 yang ditambahkan 15 % berlebih = $1{,}15 * 0{,}1147\ x = 0{,}1319\ x$ kmol

= $4{,}2226\ x$ kg / jam

N_2 yang masuk = $\frac{79}{21} * 0{,}1319\ x = 0{,}4962\ x$ kmol = $13{,}8935\ x$ kg / jam

O_2 sisa = $0{,}1319\ x - 0{,}1147\ x = 0{,}0172\ x$ kmol

CO_2 hasil = $0{,}0544\ x + 2{,}2734.10^{-3}\ x + 1{,}1795.10^{-2}\ x + 7{,}0455.10^{-5}\ x$

= $0{,}0685\ x$ kmol

H_2O hasil = $0{,}1088\ x + 3{,}4101.10^{-3}\ x + 1{,}3567.10^{-3}\ x = 0{,}1136\ x$ kmol

Entalpi bahan bakar masuk :

$$H_{CH4} = n . R \int_{303}^{298} \frac{Cp}{R} dT$$

H_{CH4} = 0,0544 x . 8314,51.

$$\left[1{,}702(298-303)+\frac{9{,}081.10^{-3}}{2}\left(298^2-303^2\right)-\frac{2{,}164.10^{-6}}{3}\left(298^3-303^3\right)\right]$$

= -9578,6143 x J

Dengan cara yang sama didapatkan entalpi bahan bakar masuk:

Komponen	Entalpi, Joule
CH_4	-9578,6143x
C_2H_6	-302,7161x
C_3H_8	-148,1893x
N_2	-369,2174x
CO_2	-13,150x
He	-90,9759x

Entalpi total bahan bakar masuk = -10502,8632x J

Entalpi udara masuk :

$$H = n \,.\, R \int_{303}^{298} \frac{Cp}{R} dT$$

Komponen	Entalpi, Joule
O_2	-19409,3964x
N_2	-72250,5406x

Entalpi total udara masuk = -91659,937x J

Entalpi pembakaran :

HHv = 86000 Btu/gal

ρ = 3,4469 lb/gal

$$Hv = \frac{86000}{3,4469} = 24949,95503 \text{ Btu/lb} = 26323699,55 \text{ J/lb}$$

$H = m \cdot Hv = x \cdot 26323699,55 \cdot 2,2046 = 58033228,03x$ J

Entalpi fuel gas keluar :

CO_2 = 0,0685 x kmol

H_2O = 0,1136 x kmol

He = $8,75 \cdot 10^{-4}$ x kmol

O_2 = 0,0172 x kmol

N_2 = $0,4962 x + 2,5357.10^{-5}x = 0,4962x$ kmol

$$H = n \cdot R \int_{298}^{1473} \frac{Cp}{R} dT$$

Komponen	Entalpi, Joule
CO_2	4091801,915x
H_2O	5306653,113x
He	21379,324x
O_2	678084,9274x
N_2	18489976,14x

Entalpi fuel gas total = 28587895,42x J

Panas yang hilang = 20% dari panas pembakaran

= 0,2 . 58033228,03x

= 11606645,61x J

Entalpi masuk :

Entalpi bahan = 9033129,8

Entalpi bahan bakar = 10502,8632 x

Entalpi udara = 11606645,61 x

Entalpi pembakaran = 58033228,03 x +

(9033129,8 + 58135390,83 x) Joule

Entalpi keluar :

Entalpi bahan = 11661340890

Entalpi fuel gas = 28587895,42 x

Panas yang hilang = 11606645,61 x +

(11661340890 + 40194541,03 x) Joule

Entalpi masuk = Entalpi keluar

9033129,8 + 58135390,83 x = 11661340890 + 40194541,03 x

17940849,8 x = 116523047760

x = 649,4847 kg

Entalpi bahan bakar = 10502,8632 . 6494847 = 6821448,955 J

Entalpi udara = 91659,937 . 6494847 = 59531726,68 J

Entalpi pembakaran = 58033228,03 . 6494847 = 37691693700 J

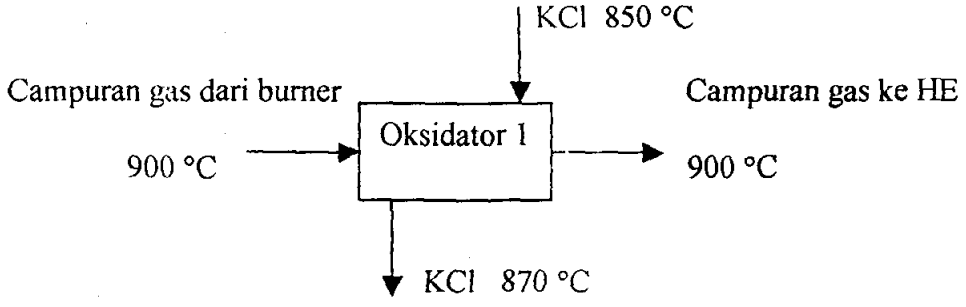
Entalpi fuel gas = 28587895,42 . 6494847 = 18567400680 J

Panas yang hilang = 11606645,61 . 6494847 = 7538338742 J

Neraca panas :

Masuk	Joule / jam	Keluar	Joule /jam
Entalpi bahan	9033129,8	Entalpi bahan	11661340890
Entalpi bahan baker	6821448,955	Entalpi fuel gas	18567400680
Entalpi pembakaran	18567400680	Panas yang hilang	7538338742
Entalpi udara	59531726,68		
Total	37767080010		37767080010

2. Oksidator I (R-210)



Suhu masuk = 900 °C = 1173 K

Masuk	kmol	Keluar	Kmol
NH_3	41,6812	O_2	24,5902
O_2	75,8581	N_2	286,3319
N_2	285,4983	NO	40,0140
		H_2O	62,5218

Dari Perry 7th ed., table 2-164 diperoleh :

Zat	ω	Tc , K	Pc , Pa
NH_3	0,253	405,7	$11,3 . 10^6$
O_2	0,022	154,6	$5,02 . 10^6$
N_2	0,038	126,2	$3,39 .10^6$
NO	0,583	180,2	$6,52 . 10^6$
H_2O	0,345	647,1	$21,994 . 10^6$

Menghitung entalpi masuk :

Untuk NH_3 :

$$Pr = \frac{P}{Pc} = \frac{9,66\ atm}{11,3.10^6\ Pa} * \frac{101325,0247\ Pa}{atm} = 0,08662$$

$$Tr = \frac{T}{Tc} = \frac{1.73}{405,7} = 2,8913$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{R.Tc} = Pr.\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$B° = 0,083 - \frac{0,422}{Tr^{1,6}} \qquad (3.50)$$

$$B° = 0,083 - \frac{0,422}{2,8913^{1,6}} = 0,00581$$

$$\frac{dB°}{dTr} = \frac{0,675}{Tr^{2,6}} \qquad (6.64)$$

$$\frac{dB^{\circ}}{dTr} = \frac{0,675}{2,8913^{2,6}} = 0,0427$$

$$B^{'} = 0,139 - \frac{0,172}{Tr^{4,2}} \qquad (3.51)$$

$$B^{'} = 0,139 - \frac{0,172}{2,8913^{4,2}} = 0,137$$

$$\frac{dB^{'}}{dTr} = \frac{0,722}{Tr^{5,2}} \qquad (6.65)$$

$$\frac{dB^{'}}{dTr} = \frac{0,722}{2,8913^{5,2}} = 3,2938$$

$$\frac{H^{R}}{R.Tc} = 0,08662.[0,00581 - 2,8913 * 0,0427 + 0,253(0,137 - 8,8913 * 0,00289)]$$

$$\frac{H^{R}}{R.Tc} = -0,0073715$$

$$H^{R} = 8314,51 \ \frac{J}{kmol.K} * 405,7 \text{ K} * -0,0073715 = -24865,5045 \text{ J/kmol}$$

$$H^{R} = 41,6812 \text{ kmol} * -24865,5045 \text{ J/kmol} = -1036424,067 \text{ J}$$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}(T^2 - To^2) + \frac{C}{3}(T^3 - To^3) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{1173}^{298} \frac{Cp}{R} dT = 3,578(298 - 1173) + \frac{3,02.10^{-3}}{2}(298^2 - 1173^2)$$

$$+ 0,186.10^{5}\left(\frac{1}{298} - \frac{1}{1173}\right)$$

$$\int_{1173}^{298} \frac{Cp}{R} dT = -5027,7494 \text{ K}$$

H^{id} = 41,6812 * 8314,51 * -5027,7494 = -1742410575 J

Hin NH_3 = $-H^R + H^{id}$

= 1036424,067 – 1742410575 = -1741374151 J

Dengan cara yang sama dapat memperoleh entalpi masuk untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hin, joule
NH_3	-1036424,0667	-1742410575	-1741374151
O_2	-129893,303	-2177851728	-2177721835
N_2	-178487,4556	-7742423391	-11661340890
Total			-11661340890

Menghitung panas reaksi :

1. $NH_3 + \frac{5}{4} O_2 \longrightarrow NO + \frac{3}{2} H_2O$

2. $NH_3 + \frac{3}{2} O_2 \longrightarrow \frac{1}{2} N_2 + \frac{3}{2} H_2O$

Zat	ΔH_{298}, J/kmol	Kmol reaksi 1	Kmol reaksi 2
NH_3	-46110000	40,014	1,6672
NO	90250000	40,014	-
H_2O	-241818000	60,021	2,5009

Reaksi 1 :

$\Delta H°_{298} = (n.\ \Delta H_{298})_{produk} - (n.\ \Delta H_{298})_{reaktan}$

= (40,014 . 90250000 + 60,021 . –241818000) – (40,014 . –46110000)

= -9057849140 J

Reaksi 2 :

$\Delta H°_{298} = (n.\ \Delta H_{298})_{produk} - (n.\ \Delta H_{298})_{reaktan}$

$= (2,5009\ .\ -241818000) - (1,6672\ .\ -46110000)$

$= -527888044,2$ J

$\Delta H°_{298}$ total $= (n.\ \Delta H_{298})_{reaksi\ 1} - (n.\ \Delta H_{298})_{reaksi\ 2}$

$= -9057849140 - 527888044,2$

$= -9585737184$ J

Menghitug entalpi keluar :

Untuk O_2 :

$$Pr = \frac{P}{Pc} = \frac{9,46\ atm}{5,02.10^6\ Pa} * \frac{101325,0247\ Pa}{atm} = 0,1909$$

$$Tr = \frac{T}{Tc} = \frac{1173}{154,6} = 7,5873$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{R.Tc} = Pr.\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$B° = 0,083 - \frac{0,422}{Tr^{1,6}} \qquad (3.50)$$

$$B° = 0,083 - \frac{0,422}{7,5873^{1,6}} = 0,016488$$

$$\frac{dB°}{dTr} = \frac{0,675}{Tr^{2,6}} \qquad (6.64)$$

$$\frac{dB°}{dTr} = \frac{0,675}{7,5873^{2,6}} = 0,003476$$

$$B = 0,139 - \frac{0,172}{Tr^{4.2}} \qquad (3.51)$$

$$B = 0,139 - \frac{0,172}{7,5873^{4.2}} = 0,13897$$

$$\frac{dB'}{dTr} = \frac{0,722}{Tr^{5,2}} \qquad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0,722}{7,5873^{5.2}} = 0,000019146$$

$$\frac{H^R}{R.Tc} = 0,1909.[0,016488 - 2,8913 * 0,003476 + 0,022(0,13897 - 7,5873 * 0,000019146)]$$

$$\frac{H^R}{R.Tc} = -0,0013041$$

$$H^R = 8314,51 \ \frac{J}{kmol.K} * 154,6 \text{ K} * -0,0013041 = -1676,3169 \text{ J/kmol}$$

$$H^R = 24,5902 \text{ kmol} * -1676,3169 \text{ J/kmol} = -41220,9669 \text{ J}$$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}(T^2 - To^2) + \frac{C}{3}(T^3 - To^3) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{298}^{1173} \frac{Cp}{R} dT = 3,639(1173 - 298) + \frac{0,506.10^{-3}}{2}(1173^2 - 298^2)$$

$$+ 0,227.10^5\left(\frac{1}{1173} - \frac{1}{298}\right)$$

$$\int_{298}^{1173} \frac{Cp}{R} dT = 3452,9452 \text{ K}$$

$$H^{id} = 24,5902 * 8314,51 * 3452,9452 = 705973515,8 \text{ J}$$

Hout O_2 $= H^R + H^{id}$

$= -41220,9669 + 705973515,8 = 705932294,8$ J

Dengan cara yang sama dapat memperoleh entalpi keluar untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hout, joule
O_2	-41220,9669	705973515,8	705932294,8
N_2	-175350,3063	7765029775	7764854425
NO	714652,491	1125362953	1126077605
H_2O	-4042222,37	2079198768	2075156546
Total			11672020870

Entalpi masuk = Entalpi keluar + panas reaksi + Q

11661340890 = 11672020870 – 9585737184 + Q

Q = 9575057203 J = 2288493,595 kkal

Menghitung kebutuhan KCl :

$Q = m \cdot Cp \cdot \Delta T$

$$m = \frac{Q}{Cp \cdot \Delta T}$$

Dari Perry 6th ed. : Cp KCl = 10,93 + 0,00376 T

T = 1133 K

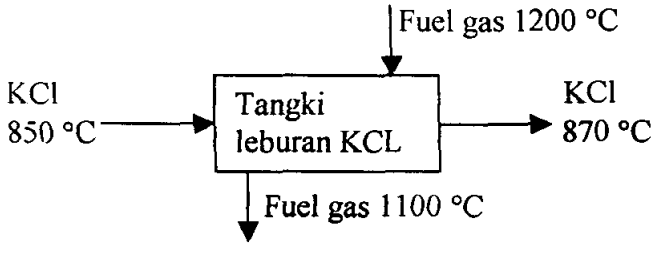
Cp KCl = 10,93 + 0,00376 . 1133 = 15,1901 kkal/kg K

$$m = \frac{2288493,595}{15,1901 \cdot (1143 - 1123)} = 7532,8457 \text{ kg}$$

Neraca panas :

Masuk	Joule / jam	Keluar	joule /jam
Entalpi masuk	11661340890	Entalpi keluar	11672020870
Panas reaksi	9585737184	Panas yang diserap	9575057203
Total	21247078070		21247078070

3. Tangki Leburan KCL (F-212)



KCl masuk = 7532,8457 kg

Menghitung entalpi masuk :

Suhu masuk = 850 °C = 1123 K

Cp KCl = 10,93 + 0,00376 * T

= 13,6015 kkal/kg K

H = m * Cp * ΔT = 7532,8457 * 13,6015 * (298 – 1123)

= -84527726,36 kkal = -353664007100 J

Menghitung entalpi keluar :

Suhu keluar = 870 °C = 1123 K

Cp KCl = 13,6391 kkal/kg K

H = m * Cp * ΔT = 7532,8457 * 13,6391 * (1143 – 298)

= 86816216,91 kkal = 363239051600 J

Panas yang hilang = 20 % dari panas masuk

= 0,2 * (-353664007100 J+ Q)

= 70732801420 + 0,2 Q

Entalpi masuk + Q yang disuplai = Entalpi keluar + panas yang hilang

353664007100 + Q = 363239051600 + 70732801420 + 0,2 Q

Q = 10038480740 J = 2399254479 kal

Menghitung kebutuhan fuel gas :

Q = m . Cp . ΔT

$$m = \frac{Q}{Cp \ . \ \Delta T}$$

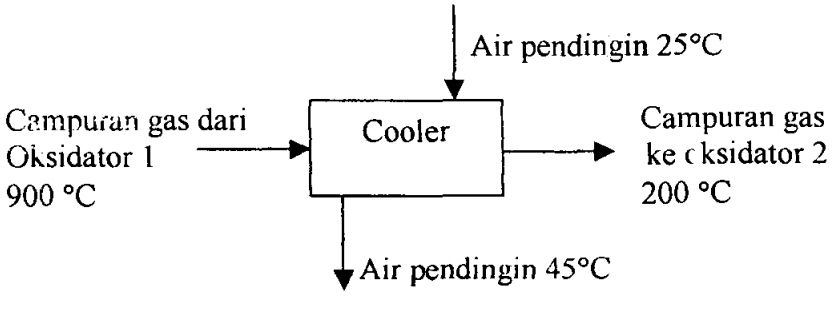
Cp = 8,3327 kal/mol K

BM = 28,0108 g/gmol

$$m = \frac{2399254479}{8{,}3327 \ .(1200-1100)} = 287752{,}8862 \ mol = 8060188{,}545 \text{ g}$$

= 8060,1885 kg

4. Cooler (E-214)



Masuk	kmol	Keluar	Kmol
N_2	286,3319	O_2	286,3319
O_2	24,5902	N_2	24,5902
NO	40,0140	NO	40,0140
H_2O	62,5218	H_2O	62,5218

Menghitug entalpi masuk :

Suhu masuk = 900 °C = 1173 K

Untuk O_2 :

$$\text{Pr} = \frac{P}{Pc} = \frac{9,46\ atm}{5,02.10^6\ Pa} * \frac{101325,0247\ Pa}{atm} = 0,1909$$

$$\text{Tr} = \frac{T}{Tc} = \frac{1173}{154,6} = 7,5873$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{R.Tc} = \text{Pr}\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$\text{B°} = 0,083 - \frac{0,422}{Tr^{1,6}} \qquad (3.50)$$

$$\text{B°} = 0,083 - \frac{0,422}{7,5873^{1,6}} = 0,016488$$

$$\frac{dB°}{dTr} = \frac{0,675}{Tr^{2,6}} \qquad (6.64)$$

$$\frac{dB°}{dTr} = \frac{0,675}{7,5873^{2,6}} = 0,003476$$

$$B' = 0,139 - \frac{0,172}{Tr^{4,2}} \qquad (3.51)$$

$$B' = 0,139 - \frac{0,172}{7,5873^{4,2}} = 0,13897$$

$$\frac{dB'}{dTr} = \frac{0,722}{Tr^{5,2}} \qquad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0,722}{7,5873^{5,2}} = 0,000019146$$

$$\frac{H^R}{R.Tc} = 0,1909.[0,016488 - 2,8913 * 0,003476 + 0,022(0,13897 - 7,5873 * 0,000019146)]$$

$$\frac{H^R}{R.Tc} = -0,0013041$$

$$H^R = 8314,51 \ \frac{J}{kmol.K} * 154,6 \text{ K} * -0,0013041 = -1676,3169 \text{ J/kmol}$$

$$H^R = 24,5902 \text{ kmol} * -1676,3169 \text{ J/kmol} = -41220,9669 \text{ J}$$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}(T^2 - To^2) + \frac{C}{3}(T^3 - To^3) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{1173}^{298} \frac{Cp}{R} dT = 3,639(298 - 1173) + \frac{0,506.10^{-3}}{2}(298^2 - 1173^2) + 0,227.10^5\left(\frac{1}{298} - \frac{1}{1173}\right)$$

$$\int_{1173}^{298} \frac{Cp}{R} dT = -3452,9452 \text{ K}$$

$$H^{id} = 24,5902 * 8314,51 * -3452,9452 = -705973515,8 \text{ J}$$

$$H \text{ in } O_2 = -H^R + H^{id}$$

$$= 41220,9669 - 705973515,8 = -705932294,8 \text{ J}$$

Dengan cara yang sama dapat memperoleh entalpi masuk untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hin, joule
O_2	-41220,9669	-705973515,8	-705932294,8
N_2	-175350,3063	-7765029775	-7764854425
NO	714652,491	-1125362953	-1126077605
H_2O	-4042222,37	-2079198768	-2075156546
Total			-11672020870

Menghitug entalpi keluar :

Untuk N_2 :

$$Pr = \frac{P}{Pc} = \frac{9{,}37\ atm}{3{,}39.10^6\ Pa} * \frac{101325{,}0247\ Pa}{atm} = 0{,}28$$

$$Tr = \frac{T}{Tc} = \frac{473}{154{,}6} = 3{,}748$$

Karena Pr > 0,2 digunakan persamaan compressible :

Dari Smith Van Ness pers.6.60 :

$$\frac{H^R}{R.Tc} = \frac{(H^R)^0}{R.Tc} + \omega \frac{(H^R)^1}{R.Tc}$$

Dari Smith Van Ness tabel E.5 dan E.6 diperoleh :

$$\frac{(H^R)^0}{R.Tc} = -0{,}01679$$

$$\frac{(H^R)^1}{R.Tc} = 0{,}04409$$

$$\frac{H^R}{R.Tc} = -0{,}01679 + 0{,}038 \,.\, 0{,}04409 = -0{,}015114$$

$H^R = 8314{,}51 \ \frac{J}{kmol.K} * 126{,}2 \text{ K} * -0{,}015114 = -15859{,}4198 \text{ J/kmol}$

$H^R = 286{,}3319 \text{ kmol} * -15859{,}4198 \text{ J/kmol} = -4541057{,}796 \text{ J}$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}\left(T^2 - To^2\right) + \frac{C}{3}\left(T^3 - To^3\right) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{298}^{473} \frac{Cp}{R} dT = 3{,}28(473 - 298) + \frac{0{,}593.10^{-3}}{2}(473^2 - 298^2)$$

$$+ 0{,}04.10^5\left(\frac{1}{473} - \frac{1}{298}\right)$$

$$\int_{298}^{473} \frac{Cp}{R} dT = 618{,}9714 \text{ K}$$

$H^{id} = 286{,}3319 * 8314{,}51 * 618{,}9714 = 1473591110 \text{ J}$

Hout $N_2 = H^R + H^{id}$

$= -4541057{,}796 + 1473591110 = 1469050052 \text{ J}$

Untuk O_2 :

$$Pr = \frac{P}{Pc} = \frac{0{,}37 \ atm}{5{,}02.10^6 \ Pa} * \frac{101325{,}0247 \ Pa}{atm} = 0{,}1891$$

$$Tr = \frac{T}{Tc} = \frac{473}{154{,}6} = 3{,}0595$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{RTc} = Pr\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$B° = 0,083 - \frac{0,422}{Tr^{1,6}} \quad (3.50)$$

$$B° = 0,083 - \frac{0,422}{3,0595^{1,6}} = 0,012487$$

$$\frac{dB°}{dTr} = \frac{0,675}{Tr^{2,6}} \quad (6.64)$$

$$\frac{dB°}{dTr} = \frac{0,675}{3,0595^{2,6}} = 0,036865$$

$$B' = 0,139 - \frac{0,172}{Tr^{4,2}} \quad (3.51)$$

$$B' = 0,139 - \frac{0,172}{3,0595^{4,2}} = 0,13751$$

$$\frac{dB'}{dTr} = \frac{0,722}{Tr^{5,2}} \quad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0,722}{3,0595^{5,2}} = 0,0021535$$

$$\frac{H^R}{R.Tc} = 0,1891.[0,012487 - 3,0595 * 0,036865 + 0,022(0,13751 - 3,0595 * 0,0021535)]$$

$$\frac{H^R}{R.Tc} = -0,018598$$

$$H^R = 8314,51 \ \frac{J}{kmol.K} * 154,6 \text{ K} * -0,018598 = -23905,9252 \text{ J/kmol}$$

$$H^R = 24,5902 \text{ kmol} * -23905,9252 \text{ J/kmol} = -587851,4814 \text{ J}$$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}(T^2 - To^2) + \frac{C}{3}(T^3 - To^3) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{298}^{473} \frac{Cp}{R} dT = 3{,}639(473-298) + \frac{0{,}506.10^{-3}}{2}(473^2 - 298^2)$$

$$+ 0{,}227.10^{5}\left(\frac{1}{473} - \frac{1}{298}\right)$$

$$\int_{298}^{473} \frac{Cp}{R} dT = 642{,}7781 \text{ K}$$

H^{id} = 24,5902 * 8314,51 * 642,7781 = 131419488,8 J

Hout O_2 = $H^R + H^{id}$

= -587851,4814 + 131419488,8 = 130831637,3 J

Dengan cara yang sama dapat memperoleh entalpi keluar untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hout, joule
O_2	-587851,4814	131419488,8	130831637,3
N_2	-4541057,796	1473591110	1469050052
NO	-729670,3573	211893618,5	211163948,1
H_2O	-41594202,34	374331932,8	332737730,5
Total			2143783368

Panas yang hilang = 5 % dari panas masuk

= 0,05 * 11672020870

= 583601043,5 J

Entalpi masuk = Entalpi keluar + Q yang diserap + panas yang hilang

11672020870 = 2143783368 + Q + 583601043,5

Q = 8944636459 J

Menghitung kebutuhan air pendingin :

Cp = 4,181 Kj/kg K = 4181 J/kg K

Q = m . Cp . ΔT

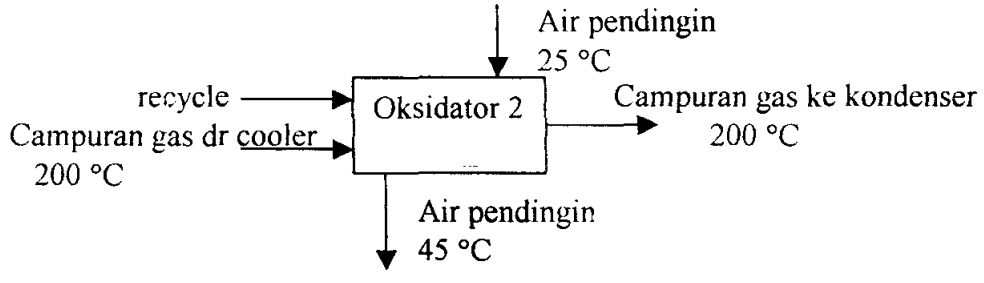
$$m = \frac{Q}{Cp \ . \ \Delta T}$$

$$m = \frac{8944636459}{4181 \ . \ (318 - 298)} = 106967{,}6687 \text{ kg}$$

Neraca panas :

Masuk	joule / jam	Keluar	joule /jam
Entalpi masuk	11672020870	Entalpi keluar	2143783368
		Panas yang diserap	8944636459
		Panas yang hilang	583601043,5
Total	11672020870		11672020870

5. Oksidator 2 (R-230)



Masuk	Kmol	Keluar	Kmol
O_2	24,5902	O_2	2,900
N_2	286,3319	N_2	572,6638
NO	40,0140	NO	2,4983
H_2O	62,5218	NO_2	47,4672
Recycle		H_2O	62,5218
O_2	1,4500		
N_2	286,3319		
NO	8,7648		
NO_2	1,1867		

Menghitug entalpi masuk :

Untuk O_2 :

$$\text{Pr} = \frac{P}{Pc} = \frac{9{,}46\ atm}{5{,}02.10^6\ Pa} * \frac{101325{,}0247\ Pa}{atm} = 0{,}1909$$

$$\text{Tr} = \frac{T}{Tc} = \frac{473}{154{,}6} = 3{,}0595$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{R.Tc} = \text{Pr}.\left[B^{\circ} - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$B° = 0{,}083 - \frac{0{,}422}{Tr^{1.6}} \qquad (3.50)$$

$$B° = 0{,}083 - \frac{0{,}422}{3{,}0595^{1.6}} = 0{,}012487$$

$$\frac{dB^{\circ}}{dTr} = \frac{0,675}{Tr^{2,6}} \qquad (6.64)$$

$$\frac{dB^{\circ}}{dTr} = \frac{0,675}{3,0595^{2,6}} = 0,036865$$

$$B' = 0,139 - \frac{0,172}{Tr^{4,2}} \qquad (3.51)$$

$$B' = 0,139 - \frac{0,172}{3,0595^{4,2}} = 0,13751$$

$$\frac{dB'}{dTr} = \frac{0,722}{Tr^{5,2}} \qquad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0,722}{3,0595^{5,2}} = 0,0021535$$

$$\frac{H^R}{R.Tc} = 0,1909.[0,012487 - 3,0595 * 0,036865 + 0,022(0,13751 - 3,0595 * 0,0021535)]$$

$$\frac{H^R}{R.Tc} = -0,018602$$

$$H^R = 8314,51 \ \frac{J}{kmol.K} * 154,6 \text{ K} * -0,018602 = -23911,3663 \text{ J/kmol}$$

$$H^R = 24,5902 \text{ kmol} * -23911,3663 \text{ J/kmol} = -587985,2786 \text{ J}$$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}(T^2 - To^2) + \frac{C}{3}(T^3 - To^3) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{473}^{298} \frac{Cp}{R} dT = 3,639(298 - 473) + \frac{0,506.10^{-3}}{2}(298^2 - 473^2)$$

$$+ 0,227.10^{5}\left(\frac{1}{298} - \frac{1}{473}\right)$$

$$\int_{473}^{298} \frac{Cp}{R} dT = -642{,}7781 \text{ K}$$

$H^{id} = 24{,}5902 * 8314{,}51 * -642{,}7781 = -131419488{,}8$ J

Hin O_2 $= -H^R + H^{id}$

$= 587985{,}2786 - 131419488{,}8 = -130831637{,}3$ J

Untuk O_2 recycle :

$$Pr = \frac{P}{Pc} = \frac{9{,}46\ atm}{5{,}02.10^6\ Pa} * \frac{101325{,}0247\ Pa}{atm} = 0{,}1909$$

$$Tr = \frac{T}{Tc} = \frac{473}{154{,}6} = 3{,}0595$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{RTc} = Pr\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$B° = 0{,}083 - \frac{0{,}422}{Tr^{1.6}} \qquad (3.50)$$

$$B° = 0{,}083 - \frac{0{,}422}{3{,}0595^{1.6}} = 0{,}012487$$

$$\frac{dB°}{dTr} = \frac{0{,}675}{Tr^{2{,}6}} \qquad (6.64)$$

$$\frac{dB°}{dTr} = \frac{0{,}675}{3{,}0595^{2.6}} = 0{,}036865$$

$$B' = 0{,}139 - \frac{0{,}172}{Tr^{4.2}} \qquad (3.51)$$

$$B' = 0{,}139 - \frac{0{,}172}{3{,}0595^{4.2}} = 0{,}13751$$

$$\frac{dB'}{dTr} = \frac{0,722}{Tr^{5,2}} \qquad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0,722}{3,0595^{5,2}} = 0,0021535$$

$$\frac{H^R}{R.Tc} = 0,1909.[0,012487 - 3,0595 * 0,036865 + 0,022(0,13751 - 3,0595 * 0,0021535)]$$

$$\frac{H^R}{R.Tc} = -0,018602$$

$H^R = 8314,51 \ \frac{J}{kmol.K} * 154,6\ K * -0,018602 = -23911,3663\ J/kmol$

$H^R = 1,45\ kmol * -23911,3663\ J/kmol = -34671,4811\ J$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}(T^2 - To^2) + \frac{C}{3}(T^3 - To^3) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{473}^{298} \frac{Cp}{R} dT = 3,639(298 - 473) + \frac{0,506.10^{-3}}{2}(298^2 - 473^2)$$

$$+ 0,227.10^5\left(\frac{1}{298} - \frac{1}{473}\right)$$

$$\int_{473}^{298} \frac{Cp}{R} dT = -642,7781\ K$$

$H^{id} = 1,45 * 8314,51 * -642,7781 = -7749358,163\ J$

Hin O_2 recycle $= -H^R + H^{id}$

$= 34671,4811 - 7749358,163 = -7714686,682\ J$

Hin O_2 total = Hin O_2 + Hin O_2 recycle

$= -130831637,3 - 7714686,682 = -138546324\ J$

Dengan cara yang sama dapat memperoleh entalpi masuk untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hin, joule
O_2	-622656,7597	-139168847	-138546324
N_2	-9865899,718	-2777045909	-2767180009
NO	-924181,005	-252936963,1	-25202782,1
NO_2	-211431,7715	-7794251,766	-7582819,995
H_2O	-41594202,34	-374331932,8	-332737730,5
Total			-3271249666

Menghitung panas reaksi :

$NO + ½ O_2 \longrightarrow NO_2$ (ΔH_r = -1127 kj/mol)

NO yang bereaksi = 46,2805 kmol = 46280,5 mol

ΔH_r = -1127 kj/mol * 46280,5 mol = -52158123,5 kj = -52158123500 j

Menghitung entalpi keluar :

Untuk O_2 :

$$Pr = \frac{P}{Pc} = \frac{9,25\ atm}{5,02.10^6\ Pa} * \frac{101325,0247\ Pa}{atm} = 0,1867$$

$$Tr = \frac{T}{Tc} = \frac{473}{154,6} = 3,0595$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{R.Tc} = Pr.\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$B^\circ = 0{,}083 - \frac{0{,}422}{Tr^{1{,}6}} \qquad (3.50)$$

$$B^\circ = 0{,}083 - \frac{0{,}422}{3{,}0595^{1{,}6}} = 0{,}012487$$

$$\frac{dB^\circ}{dTr} = \frac{0{,}675}{Tr^{2{,}6}} \qquad (6.64)$$

$$\frac{dB^\circ}{dTr} = \frac{0{,}675}{3{,}0595^{2{,}6}} = 0{,}036865$$

$$B' = 0{,}139 - \frac{0{,}172}{Tr^{4{,}2}} \qquad (3.51)$$

$$B' = 0{,}139 - \frac{0{,}172}{3{,}0595^{4{,}2}} = 0{,}13751$$

$$\frac{dB'}{dTr} = \frac{0{,}722}{Tr^{5{,}2}} \qquad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0{,}722}{3{,}0595^{5{,}2}} = 0{,}0021535$$

$$\frac{H^R}{RTc} = 0{,}1867.[0{,}012487 - 3{,}0595 * 0{,}036865 + 0{,}022(0{,}13751 - 3{,}0595 * 0{,}0021535)]$$

$$\frac{H^R}{R.Tc} = -0{,}018189$$

$$H^R = 8314{,}51 \ \frac{J}{kmol.K} * 154{,}6 \text{ K} * -0{,}018189 = -23380{,}3914 \text{ J/kmol}$$

$$H^R = 2{,}900 \text{ kmol} * -23380{,}3914 \text{ J/kmol} = -67803{,}1350 \text{ J}$$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}\left(T^2 - To^2\right) + \frac{C}{3}\left(T^3 - To^3\right) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{298}^{473} \frac{Cp}{R} dT = 3{,}639(473-298) + \frac{0{,}506.10^{-3}}{2}(473^2 - 298^2)$$

$$+ 0{,}227.10^{5}\left(\frac{1}{473} - \frac{1}{298}\right)$$

$$\int_{298}^{473} \frac{Cp}{R} dT = 642{,}7781 \text{ K}$$

$H^{id} = 2{,}900 * 8314{,}51 * 642{,}7781 = 15498715{,}64$ J

Hout O_2 $= H^R + H^{id}$

$= -67803{,}1350 + 15498715{,}64 = 15430912{,}51$ J

Dengan cara yang sama dapat memperoleh entalpi keluar untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hout, joule
O_2	-67803,1350	15498715,64	15430912,51
N_2	-8764182,305	2947182221	2938418039
NO	-42650,9908	13229715,94	13187064,95
NO_2	-7479212,269	354838573,4	347359361,1
H_2O	-40670732,98	374331932,8	333661199,8
Total			3648056578

Entalpi masuk = Entalpi keluar + panas reaksi + Q

3271249666 = 3648056578 - 52158123500 + Q

Q = 51781316590 J = 51781316,59 kJ

Menghitung kebutuhan air pendingin :

Cp H_2O = 4,181 kj/kg °K

Q = m * Cp * ΔT

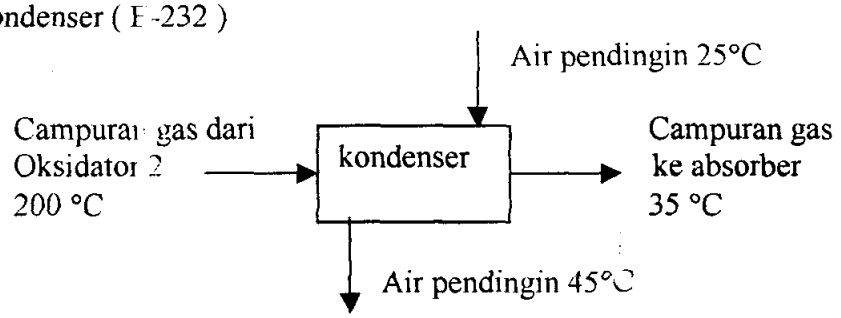
$$m = \frac{Q}{Cp * \Delta T}$$

$$m = \frac{51781316,59}{4,181 * (45 - 25)} = 617289,5732 \text{ kg}$$

Neraca panas :

Masuk	joule / jam	Keluar	joule /jam
Entalpi masuk	3271249666	Entalpi keluar	3648056578
		Panas reaksi	-52158123500
		Panas yang diserap	51781316590
Total	3271249666		3271249666

6. Kondenser (E-232)



Masuk	Kmol	Keluar	Kmol
O_2	2,900	O_2	2,900
N_2	572,6638	N_2	572,6638
NO	2,4983	NO	2,4983
NO_2	47,4672	NO_2	47,4672
H_2O uap	62,5218	H_2O liquid	62,5218

Menghitung entalpi masuk :

Untuk O_2 :

$$\text{Pr} = \frac{P}{Pc} = \frac{9,25\ atm}{5,02.10^6\ Pa} * \frac{101325,0247\ Pa}{atm} = 0,1867$$

$$\text{Tr} = \frac{T}{Tc} = \frac{473}{154,6} = 3,0595$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{R.Tc} = \text{Pr}.\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$\text{B°} = 0,083 - \frac{0,422}{Tr^{1.6}} \qquad (3.50)$$

$$\text{B°} = 0,083 - \frac{0,422}{3,0595^{1.6}} = 0,012487$$

$$\frac{dB°}{dTr} = \frac{0,675}{Tr^{2,6}} \qquad (6.64)$$

$$\frac{dB°}{dTr} = \frac{0,675}{3,0595^{2,6}} = 0,036865$$

$$B' = 0,139 - \frac{0,172}{Tr^{4,2}} \qquad (3.51)$$

$$B' = 0,139 - \frac{0,172}{3,0595^{4,2}} = 0,13751$$

$$\frac{dB'}{dTr} = \frac{0,722}{Tr^{5,2}} \qquad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0,722}{3,0595^{5,2}} = 0,0021535$$

$$\frac{H^R}{R.Tc} = 0,1867.[0,012487 - 3,0595 * 0,036865 + 0,022(0,13751 - 3,0595 * 0,0021535)]$$

$$\frac{H^R}{R.Tc} = -0,018189$$

$$H^R = 8314,51 \ \frac{J}{kmol.K} * 154,6 \text{ K} * -0,018189 = -23380,3914 \text{ J/kmol}$$

$$H^R = 2,9000 \text{ kmol} * -23380,3914 \text{ J/kmol} = -67803,1350 \text{ J}$$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}\left(T^2 - To^2\right) + \frac{C}{3}\left(T^3 - To^3\right) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{473}^{298} \frac{Cp}{R} dT = 3,639(298 - 473) + \frac{0,506.10^{-3}}{2}(298^2 - 473^2)$$

$$+ 0,227.10^5\left(\frac{1}{298} - \frac{1}{473}\right)$$

$$\int_{473}^{298} \frac{Cp}{R} dT = -642,7781 \text{ K}$$

H^{id} = 2,900 * 8314,51 * -642,7781 = -15498715,64 J

Hin O_2 = $-H^R + H^{id}$

= 67803,1350 – 15498715,64 = -15430912,51 J

Dengan cara yang sama dapat memperoleh entalpi masuk untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hin, joule
O_2	-67803,1350	-15498715,64	-15430912,51
N_2	-8764182,305	-2947182221	-2938418039
NO	-42650,9908	-13229715,94	-13187064,95
NO_2	-7479212,269	-354838573,4	-347359361,1
H_2O	-40670732,98	-43037173,1	-2366441,12
Total			-3316761818

Menghitung entalpi keluar :

Untuk O_2 :

$$Pr = \frac{P}{Pc} = \frac{9\ atm}{5{,}02.10^6\ Pa} * \frac{101325{,}0247\ Pa}{atm} = 0{,}1817$$

$$Tr = \frac{T}{Tc} = \frac{308}{154{,}6} = 1{,}9222$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{R.Tc} = Pr.\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$B° = 0{,}083 - \frac{0{,}422}{Tr^{1.6}} \qquad (3.50)$$

$$B° = 0,083 - \frac{0,422}{1,9222^{1,6}} = -0,05708$$

$$\frac{dB°}{dTr} = \frac{0,675}{Tr^{2,6}} \qquad (6.64)$$

$$\frac{dB°}{dTr} = \frac{0,675}{1,9222^{2.6}} = 0,11247$$

$$B' = 0,139 - \frac{0,172}{Tr^{4,2}} \qquad (3.51)$$

$$B' = 0,139 - \frac{0,172}{1,9222^{4,2}} = 0,12949$$

$$\frac{dB'}{dTr} = \frac{0,722}{Tr^{5,2}} \qquad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0,722}{1,9222^{5,2}} = 0,020044$$

$$\frac{H^R}{R.Tc} = 0,1817\left[-0,05708 - 1,9222 * 0,11247 + 0,022\left(0,12949 - 1,9222 * 0,020044\right)\right]$$

$$\frac{H^R}{R.Tc} = -0,05073$$

$H^R = 8314,51 \ \frac{J}{kmol.K} * 154,6 \text{ K} * -0,05073 = -65207,9631 \text{ J/kmol}$

$H^R = 2,9000 \text{ kmol} * -65207,9631 \text{ J/kmol} = -189103,0931 \text{ J}$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}\left(T^2 - To^2\right) + \frac{C}{3}\left(T^3 - To^3\right) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{298}^{308} \frac{Cp}{R} dT = 3{,}639(308-298) + \frac{0{,}506.10^{-3}}{2}(308^2 - 298^2)$$

$$+ 0{,}227.10^5\left(\frac{1}{308} - \frac{1}{298}\right)$$

$$\int_{298}^{308} \frac{Cp}{R} dT = 35{,}4499 \text{ K}$$

$H^{id} = 2{,}900 * 8314{,}51 * 35{,}4499 = 854772{,}768$ J

Hout O_2 $= H^R + H^{id}$

$= -189103{,}0931 + 854772{,}768 = 665669{,}6749$ J

Panas pengembunan H_2O :

λ pengembunan pada suhu 180 °C = 2014,98 kJ/kg

$H = m \cdot \lambda = 1125{,}3924 \cdot 2014{,}98 \cdot 1000 = 2267643178$ J

Hout $H_2O = H^{id}$ + H pengembunan

Dengan cara yang sama dapat memperoleh entalpi keluar untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hout, joule
O_2	-189103,0931	854772,768	665669,6749
N_2	-3594683,855	166804863,5	160210179,6
NO	-186491,4082	746309,8089	559817,4007
NO_2	-17337271,19	18134028,36	796757,17
H_2O	-	692426158,4	2960069336
Total			3112301760

Entalpi masuk = Entalpi keluar + Q yang diserap

3316761818 = 3112301760 + Q

Q = 194460058,2 J = 194460,0582 kJ

Menghitung kebutuhan air pendingin :

Cp = 4,181 Kj/kg K

Q = m . Cp . ΔT

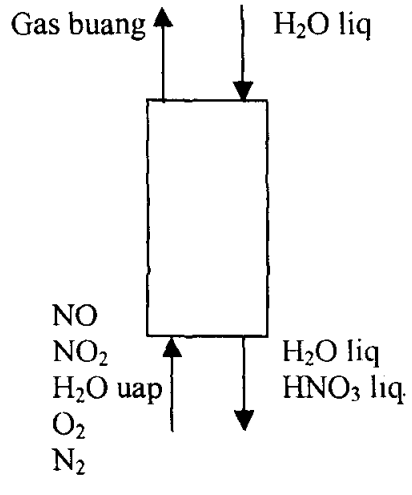
$$m = \frac{Q}{Cp \ . \ \Delta T}$$

$$m = \frac{194460,0582}{4,181 \ . \ (318-298)} = 2325,5209 \ kg$$

Neraca panas :

Masuk	joule / jam	Keluar	joule /jam
Entalpi masuk	3316761818	Entalpi keluar	3122301760
		Panas yang diserap	*194460058*
Total	3316761818		3316761818

7. Absorber (D-240)



Masuk	Kmol	Keluar	Kmol
Bawah		Atas	
O_2	2,900	O_2	2,9000
N_2	572,6638	N_2	572,6638
NO	2,4983	NO	17,5295
NO_2	47,4672	NO_2	2,3734
Atas		Bawah	
H_2O (l)	57,1188	H_2O (l)	42,0875
		HNO_3 (l)	30,0625

Menghitung entalpi masuk :

Untuk O_2 :

$$\text{Pr} = \frac{P}{Pc} = \frac{9{,}86\ atm}{5{,}02.10^6\ Pa} * \frac{101325{,}0247\ Pa}{atm} = 0{,}2947$$

$$\text{Tr} = \frac{T}{Tc} = \frac{308}{154{,}6} = 2{,}4406$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{RTc} = \text{Pr}\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$B° = 0{,}083 - \frac{0{,}422}{Tr^{1{,}6}} \qquad (3.50)$$

$$B° = 0{,}083 - \frac{0{,}422}{2{,}4406^{1{,}6}} = -0{,}05696$$

$$\frac{dB°}{dTr} = \frac{0{,}675}{Tr^{2{,}6}} \qquad (6.64)$$

$$\frac{dB^{\circ}}{dTr} = \frac{0,675}{2,4406^{2,6}} = 0,1125$$

$$B' = 0,139 - \frac{0,172}{Tr^{4,2}} \qquad (3.51)$$

$$B' = 0,139 - \frac{0,172}{2,4406^{4,2}} = 0,1295$$

$$\frac{dB'}{dTr} = \frac{0,722}{Tr^{5,2}} \qquad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0,722}{2,4406^{5,2}} = 0,02004$$

$$\frac{H^R}{R.Tc} = 0,19902.[-0,05696 - 1,9922 * 0,1125 + 0,022(0,1295 - 1,9922 * 0,02004)]$$

$$\frac{H^R}{R.Tc} = -0,05555$$

$$H^R = 8314,51 \ \frac{J}{kmol.K} * 154,6 \text{ K} * -0,05555 = -71403,8193 \text{ J/kmol}$$

$$H^R = 2,9000 \text{ kmol} * -71403,8193 \text{ J/kmol} = -207071,0761 \text{ J}$$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}(T^2 - To^2) + \frac{C}{3}(T^3 - To^3) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{308}^{298} \frac{Cp}{R} dT = 3,639(298 - 308) + \frac{0,506.10^{-3}}{2}(298^2 - 308^2)$$

$$+ 0,227.10^5\left(\frac{1}{298} - \frac{1}{308}\right)$$

$$\int_{308}^{298} \frac{Cp}{R} dT = -35,4499 \text{ K}$$

H^{id} = 2,900 * 8314,51 * -35,4499 = -854772,768 J

Hin O_2 = $-H^R + H^{id}$

= 207071,0761 – 854772,768 = -647701,6919 J

Dengan cara yang sama dapat memperoleh entalpi masuk untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hin, joule
O_2	-207071,0761	-854772,768	-647701,6919
N_2	-31765414,9	-166804863,5	-135039448,6
NO	-204200,6819	-746309,7667	-542109,0848
NO_2	-18983690,26	-18134018,36	-849671,9
H_2O	-	-32122026,26	-32122026,26
Total			-167501613,7

Menghitung panas reaksi :

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

Zat	ΔH_{298}, J/kmol	Kmol yang bereaksi
NO_2	33180000	45,0938
H_2O	-285830000	15,0313
HNO_3	-174100000	30,0625
NO	90250000	15,0313

$\Delta H°_{298} = (n.\ \Delta H_{298})_{produk} - (n.\ \Delta H_{298})_{reaktan}$

= (30,0625 . –174100000 + 15,0313 . 90250000) –

(45,0938 . 33180000 + 15,0313 . -285830000)

= -1077122230 J

Menghitung entalpi keluar :

Untuk O_2 :

$$Pr = \frac{P}{Pc} = \frac{9{,}66\ atm}{5{,}02.10^6\ Pa} * \frac{101325{,}0247\ Pa}{atm} = 0{,}1950$$

$$Tr = \frac{T}{Tc} = \frac{303}{154{,}6} = 1{,}9599$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{R.Tc} = Pr.\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$B° = 0{,}083 - \frac{0{,}422}{Tr^{1.6}} \qquad (3.50)$$

$$B° = 0{,}083 - \frac{0{,}422}{1{,}9599^{1.6}} = -0{,}06079$$

$$\frac{dB°}{dTr} = \frac{0{,}675}{Tr^{2.6}} \qquad (6.64)$$

$$\frac{dB°}{dTr} = \frac{0{,}675}{1{,}9599^{2.6}} = 0{,}11798$$

$$B' = 0{,}139 - \frac{0{,}172}{Tr^{4.2}} \qquad (3.51)$$

$$B' = 0{,}139 - \frac{0{,}172}{1{,}9599^{4.2}} = 0{,}1288$$

$$\frac{dB'}{dTr} = \frac{0{,}722}{Tr^{5.2}} \qquad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0{,}722}{1{,}9599^{5.2}} = 0{,}02182$$

$$\frac{H^R}{R.Tc} = 0{,}195.[-0{,}06079 - 1{,}9599 * 0{,}11798 + 0{,}022(0{,}1288 - 1{,}9599 * 0{,}02182)]$$

$$\frac{H^R}{R.Tc} = -0{,}05657$$

$H^R = 8314{,}51 \ \frac{J}{kmol.K} * 154{,}6 \text{ K} * -0{,}05657 = -72722{,}3257 \text{ J/kmol}$

$H^R = 2{,}9000 \text{ kmol} * -72722{,}3257 \text{ J/kmol} = -210894{,}7444 \text{ J}$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}(T^2 - To^2) + \frac{C}{3}(T^3 - To^3) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{298}^{303} \frac{Cp}{R} dT = 3{,}639(303 - 298) + \frac{0{,}506.10^{-3}}{2}(303^2 - 298^2)$$

$$+ 0{,}227.10^5\left(\frac{1}{303} - \frac{1}{298}\right)$$

$$\int_{298}^{303} \frac{Cp}{R} dT = 17{,}6983 \text{ K}$$

$H^{id} = 2{,}900 * 8314{,}51 * 17{,}6983 = 426741{,}8457 \text{ J}$

Hout $O_2 = H^R + H^{id}$

$= -210894{,}7444 + 426741{,}8457 = 665669{,}6749 \text{ J}$

Dengan cara yang sama dapat memperoleh entalpi keluar untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hout, joule
O_2	-210894,7444	426741,8457	665669,6749
N_2	-32203710,77	83384258,64	51180547,87
NO	-1476187,632	2617305,456	1141117,824
NO_2	-962146,6522	460292,8246	52035658,97
H_2O	-	26453422,3	26453422,3
HNO_3	-	22980280,05	22980280,05
Total			101469361,3

Entalpi masuk = Entalpi keluar + panas reaksi + Q yang diserap

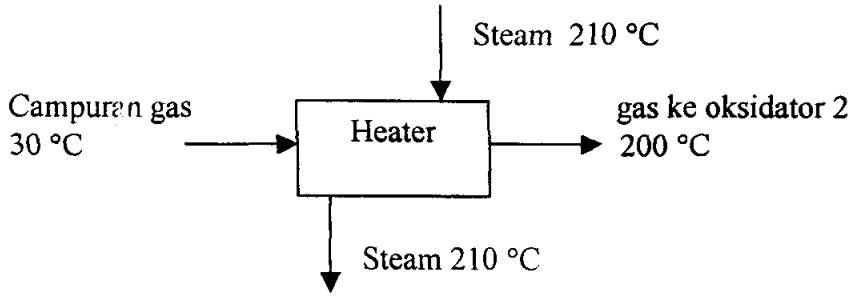
167501613,7 = 101469361,3 – 1077122230 + Q

Q = 1143154483 J

Neraca panas :

Masuk	joule / jam	Keluar	joule /jam
Panas masuk	167501613,7	Panas keluar	101469361,3
		Panas reaksi	-1077122230
		Panas yang diserap	1143154483
Total	167501613,7		167501613,7

8. Heater (E-233)



Masuk	Kmol	Keluar	Kmol
O_2	1,4500	O_2	1,4500
N_2	286,3319	N_2	286,3319
NO	8,7648	NO	8,7648
NO_2	1,1876	NO_2	1,1876

Menghitung entalpi masuk :

Untuk N_2 :

$$Pr = \frac{P}{Pc} = \frac{9{,}66\ atm}{5{,}02.10^6\ Pa} * \frac{101325{,}0247\ Pa}{atm} = 0{,}2887$$

$$Tr = \frac{T}{Tc} = \frac{303}{126{,}2} = 2{,}4009$$

Karena Pr > 0,2 digunakan persamaan compressible :

Dari Smith Van Ness pers.6.60 :

$$\frac{H^R}{R.Tc} = \frac{\left(H^R\right)^0}{R.Tc} + \omega \frac{\left(H^R\right)^1}{R.Tc}$$

Dari Smith Van Ness tabel E.5 dan E.6 diperoleh :

$$\frac{\left(H^R\right)^0}{R.Tc} = -0{,}05481$$

$$\frac{(H^R)^1}{R.Tc} = 0{,}03202$$

$$\frac{H^R}{R.Tc} = -0{,}05481 + 0{,}038 \,.\, 0{,}03202 = -0{,}05359$$

$$H^R = 8314{,}51 \ \frac{J}{kmol.K} * 126{,}2 \text{ K} * -0{,}05359 = -56234{,}9336 \text{ J/kmol}$$

$$H^R = 286{,}3319 \text{ kmol} * -56234{,}9336 \text{ J/kmol} = -16101855{,}38 \text{ J}$$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}(T^2 - To^2) + \frac{C}{3}(T^3 - To^3) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{303}^{298} \frac{Cp}{R} dT = 3{,}28(298 - 303) + \frac{0{,}593.10^{-3}}{2}(298^2 - 303^2)$$

$$+ 0{,}04.10^5\left(\frac{1}{298} - \frac{1}{303}\right)$$

$$\int_{303}^{298} \frac{Cp}{R} dT = -17{,}5125 \text{ K}$$

$$H^{id} = 286{,}3319 * 8314{,}51 * -17{,}5125 = -41692174{,}17 \text{ J}$$

$$\text{Hout } N_2 = -H^R + H^{id}$$

$$= 16101855{,}38 - 41692174{,}17 = -25590318{,}79 \text{ J}$$

Dengan cara yang sama dapat memperoleh entalpi masuk untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hin, joule
O_2	-105447,3723	-213371,4039	-107924,0316
N_2	-16101855,38	-41692174,17	-25590318,79
NO	-738098,0271	-1308660,41	-570562,3829
NO_2	-481073,3261	-230146,7469	250926,5792
Total			-26017878,63

Menghitung entalpi keluar :

Untuk O_2 :

$$\text{Pr} = \frac{P}{Pc} = \frac{9{,}46\ atm}{5{,}02.10^6\ Pa} * \frac{101325{,}0247\ Pa}{atm} = 0{,}1909$$

$$\text{Tr} = \frac{T}{Tc} = \frac{473}{154{,}6} = 3{,}0595$$

Karena Pr < 0,2 digunakan persamaan Virial :

Dari Smith Van Ness pers.6.62 :

$$\frac{H^R}{R.Tc} = \text{Pr}.\left[B^o - Tr * \frac{dB^o}{dTr} + \omega\left(B' - Tr * \frac{dB'}{dTr}\right)\right]$$

$$B° = 0{,}083 - \frac{0{,}422}{Tr^{1{,}6}} \qquad (3.50)$$

$$B° = 0{,}083 - \frac{0{,}422}{3{,}0595^{1{,}6}} = 0{,}012487$$

$$\frac{dB°}{dTr} = \frac{0{,}675}{Tr^{2{,}6}} \qquad (6.64)$$

$$\frac{dB^{\circ}}{dTr} = \frac{0,675}{3,0595^{2,6}} = 0,036865$$

$$B' = 0,139 - \frac{0,172}{Tr^{4,2}} \qquad (3.51)$$

$$B' = 0,139 - \frac{0,172}{3,0595^{4,2}} = 0,13751$$

$$\frac{dB'}{dTr} = \frac{0,722}{Tr^{5,2}} \qquad (6.65)$$

$$\frac{dB'}{dTr} = \frac{0,722}{3,0595^{5,2}} = 0,0021535$$

$$\frac{H^R}{R.Tc} = 0,1867.[0,012487 - 3,0595 * 0,036865 + 0,022(0,13751 - 3,0595 * 0,0021535)]$$

$$\frac{H^R}{R.Tc} = -0,018189$$

$$H^R = 8314,51 \ \frac{J}{kmol.K} * 154,6 \text{ K} * -0,018189 = -23380,3914 \text{ J/kmol}$$

$$H^R = 1,4500 \text{ kmol} * -23380,3914 \text{ J/kmol} = -34657,9421 \text{ J}$$

$$H^{id} = n.R \int_{To}^{T} \frac{Cp}{R} dT$$

$$\int_{To}^{T} \frac{Cp}{R} dT = A(T - To) + \frac{B}{2}(T^2 - To^2) + \frac{C}{3}(T^3 - To^3) - D\left(\frac{1}{T} - \frac{1}{To}\right)$$

$$\int_{298}^{473} \frac{Cp}{R} dT = 3,639(473 - 298) + \frac{0,506.10^{-3}}{2}(473^2 - 298^2)$$

$$+ 0,227.10^5\left(\frac{1}{473} - \frac{1}{298}\right)$$

$$\int_{298}^{473} \frac{Cp}{R} dT = 642,7781 \text{ K}$$

H^{id} = 1,4500 * 8314,51 * 642,7781 = 7749357,822 J

Hout O_2 = $H^R + H^{id}$

= -34657,9421 + 7749357,822 = 7714699,88 J

Dengan cara yang sama dapat memperoleh entalpi keluar untuk zat lain :

Zat	H^R, Joule	H^{id}, Joule	Hout, joule
O_2	-34657,9421	7749357,822	7714699,88
N_2	-4475946,154	1473591110	1469115164
NO	-563934,4791	46413884,83	45849950,35
NO_2	-191255,8866	8871113,844	8679857,957
Total			1531359672

Panas yang hilang = 5% dari panas masuk

= 0,05 (Q + 26017878,63)

= 0,05Q + 1300893,932

Entalpi masuk + Q = Entalpi keluar + panas yang hilang

26017878,63 + Q = 1531359672 + 0,05Q + 1300893,932

Q = 1585939671 J = 1585939,671 kJ

Menghitung kebutuhan steam :

λ pada 210 °C = 1899,058 kJ/kg

Q = m . λ

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

$$m = \frac{1585939,671}{1899,058} = 835,1191 \text{ kg}$$

Neraca panas :

Masuk	joule / jam	Keluar	joule /jam
Panas masuk	260178789	Panas keluar	1531359672
Panas yang disuplai	1585939671	Panas yang hilang	315758788
Total	1846118460		1846118460

APPENDIKS C

PERHITUNGAN SPESIFIKASI PERALATAN

APPENDIK C

PERHITUNGAN SPESIFIKASI ALAT

1. Filter Udara (H-120)

   Fungsi : untuk menghilangkan debu dalam udara masuk

   Tipe : bag filter

   Kapasitas filter = 400 – 1800 lb/ft^{2}hari (Perry 3^{ed}, hal 990)

   Diambil kapasitas 1800 lb/ft^2 hari

   Rate udara masuk = 10.417,8510 kg/jam = 551.212,6634 lb/hari

   $$\text{Flow area} = \frac{rate\ udara}{kapasitas\ filter} = \frac{551212{,}6634\ lb/hari}{1800\ lb/ft^2 hari} = 306{,}2293\ ft^2$$

   Spesifikasi :

   Tipe : bag filter

   Kapasitas : 1800 lb/ft^{2}hari

   Flow area : 306,2293 ft^2

   Jumlah : 2

2. Tangki NH_3 (F-110)

   Fungsi : Menyimpan NH_3 dalam bentuk cair selama 1 minggu

   Tipe : Tanki silinder horisontal dengan tutup elliptical dished head

   Kondisi operasi :

   Tekanan, P = 15,8607 atm = 233,0882 psia (Perry 6th ed, pp 3-46)

   Temperature, T = 30 °C

   Dari perry 7th ed pp.2-214 :

Pada P = 15,8607 atm, sv NH_3 cair = $1,678.10^{-3}$ m^3/kg

$$\rho\ NH_3 = \frac{1}{Sv} = \frac{1}{1,678.10^{-3}} = 595,9476\ kg/m^3$$

$$\rho\ H_2O = 995.647\ kg/m^3$$

$$\rho \text{ lar } NH_3 = \frac{1}{\frac{xNH_3}{\rho NH_3} + \frac{xH_2O}{\rho H_2O}} = \frac{1}{\frac{0,995}{595,9476} + \frac{0,005}{995,647}} = 597,1462\ kg/m^3$$

$$= 37,2785\ lb/ft^3$$

Direncanakan :

- Untuk persediaan selama 7 hari = 168 jam
- 2 tangki

Kebutuhan NH_3 = 712,1415 kg/jam = 1569,9872 lb/jam = 42,1151 ft^3/jam

$$\text{Volume larutan total} = \frac{42,1151\ ft^3/jam * 168\ jam}{2} = 3537,6670\ ft^3$$

Volume larutan = 80 % volume tangki

$$\text{Volume tangki} = \frac{3537,6670\ ft^3}{0,8} = 4422,0838\ ft^3$$

Diambil L = 2 D

$$V = 0,000076.D^3 + \frac{\pi.D^2.L}{4} + 0,000076.D^3$$

$$4422,0838 = \frac{\pi.D^3}{2} + 0,000152.D^3$$

D = 14,1196 ft = 169,4352 in

L = 21,1794 ft = 338,8704 in

Menghitung tebal shell :

P design = 1,2 * P operasi

P design = 1,2 * 233,0882 = 279,7058 psia

Bahan konstruksi ferritic stainless steel type 430

Dari Perry ed.6 tabel. 23-11, f allow = 75.200 lb/in^2

E = 80 % (Double welded butt joint)

$$ts = \frac{P.r}{f.E - 0,6.P} + c \qquad \text{(Brownell \& Young, pers.13.1)}$$

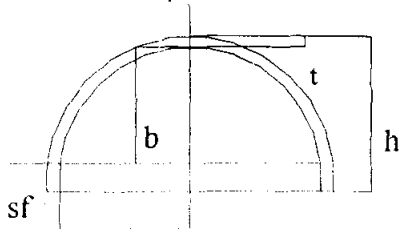
$$ts = \frac{279,7058.\frac{169,4352}{2}}{75200.0,8 - 0,6.279,7058} + 0 = 0,3950 \text{ in} \approx \frac{7}{16} \text{in}$$

Menghitung tebal tutup :

Dari Brownell & Young pers.7.57 :

$$t = \frac{P.d.V}{2.f.E - 0,2.P} + c$$

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



a

$$k = \frac{a}{b}$$

$$a = \frac{D}{2}$$

$$a = \frac{169{,}4352\ in}{2} = 84{,}7176\ in$$

$$b = \frac{D}{4}$$

$$b = \frac{169{,}4352}{4} = 42{,}3588\ in$$

$$k = \frac{84{,}7176\ in}{42{,}3588\ in} = 2$$

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

$$t = \frac{P.d}{2.f.E - 0{,}2.P} + c$$

$$t = \frac{279{,}7058 * 169{,}4352}{2 * 75200 * 0{,}8 - 0{,}2 * 279{,}7058} + 0 = 0{,}3941 \text{ in} \approx \frac{7}{16}\ in$$

Menghitung kedalaman tutup :

ID = 169,4352 in

$$OD = ID + 2.t = 169{,}4352 + 2.\frac{7}{16} = 170{,}3102 \text{ in}$$

Dari Brownell & Young table 5.11 :

sf = 3 in

$$h = t + b + sf = \frac{7}{16} + 42{,}3588 + 3 = 45{,}7963\ in$$

Menghitung panjang tangki keseluruhan :

Panjang tangki = panjang shell + 2 * tinggi tutup

= 338,8704 + 2 * 45,7963

= 430,4630 in

Spesifikasi alat :

Tipe : tangki horizontal dengan tutup elliptical dished head

Kapasitas : 3537,6670 ft^3/minggu

Bahan konstruksi : ferritic stainless steel

Jumlah : 2

Dimensi tangki : Diameter tangki (OD) = 170,3102 in

Panjang shell = 338,8704 in

Tebal shell = tebal tutup = $\frac{7}{16}$ *in*

Tinggi tutup = 45,7963 in

3. Kompresor (G-121)

Fungsi : Menaikkan tekanan udara dari 1 atm menjadi 9,86 atm

Tipe : Rotary-screw compressor

Perhitungan Power Kompresor :

Udara masuk kompressor pada suhu 30 °C

O_2 = 75,8581 kmol = 2427,4592 kg

N_2 = 285,3711 kmol = 7990,3906 kg

Jumlah gas masuk = 10.417,8510 kg = 22967,1943 lb

Dari Smith & Van Ness, pers. 3.46 :

$Z = Z^0 + \omega.Z'$

$Tr = \frac{T}{Tc}$

$Pr = \frac{P}{Pc}$

Harga Z^0 dan Z' diperoleh dari Smith & Van Ness tabel E.1 dan E.2 :

Komponen	Tr	Pr	Z^0	Z'	ω
O_2	1,96	0,1981	0,9952	0,0342	0,02
N_2	2,4	0,2938	0,9956	0,0203	0,038

$Z_{O2} = 0,9959$

$Z_{N2} = 0,9964$

Karena harga Z mendekati 1, maka diasumsi sebagai gas ideal :

BM gas = (0,21 * 32) + (0,79 * 28) = 28,84

$$\rho_{gas} = \frac{BM}{V} * \frac{P_1}{P_0} * \frac{T_0}{T_1}$$

$$= \frac{28,84}{359} * \frac{9,86}{1} * \frac{273}{273+30} = 0,7137 \text{ lb/ft}^3$$

$$qfm = \frac{22967,1943 \ lb/jam}{0,7137 \ lb/ft^3} = 32181,7905 \text{ ft}^3\text{/jam} = 536,3632 \text{ ft}^3\text{/menit}$$

Dari Smith Van Ness pers.3.21 :

$$\frac{R}{Cp} = \frac{\gamma - 1}{\gamma}$$

$Cp = \sum Y_i.Cp_i$

$= 0,79 * 28463,752 + 0,21 * 26374,7315$

Cp = 28025,0577 J/Kmol.K

$$\frac{8314,15}{28025,0577} = \frac{\gamma - 1}{\gamma}$$

$\gamma = 1,4218$

Jumlah stage yang dibutuhkan :

Dari Ulrich, pers. 4-49 :

$(Tp,i)^q = Tp,T$

dimana : q = jumlah stage

Tp,i = rasio tekanan = 3,14

Tp,T = rasio dari tekanan masuk dan keluar

$$q = \frac{\ln(Tp,T)}{\ln(Tp,i)} = \frac{\ln(9,86/1)}{\ln 3,14} = 2$$

Dari Peters and Timmrhaus pers.24, hal. 524 :

$$Hp = \frac{3,03*10^{-5}.\gamma.q}{\gamma-1} * P_1 * q_{fm} * \left(\left(\frac{p_2}{P_1}\right)^{(\gamma-1)/\gamma} - 1\right)$$

Dimana :

γ = Cp/Cv udara = 1,4218

P_1 = tekanan udara masuk, lbf/ft^2

P_2 = tekanan udara keluar , lbf/ft^2

q_{fm} = kecepatan volume gas pada kondisi masuk, ft^3/min

$$Hp = \frac{3,03.10^{-5}*1,4218*2}{1,4218-1} * 2116,228 * 533,6538 * \left(\left(\frac{9,86}{1}\right)^{(1,4218-1)/1,4218} - 1\right)$$

Hp = 454,86

Efisiensi motor = 80 % (Peters 4^{ed}, hal 524)

$$\text{Hp motor} = \frac{454,86}{0,8} = 568,575 \text{ hp} \approx 570 \text{ hp}$$

Spesifikasi :

Tipe : Sentrifugal compressor

Daya motor : 570 hp

Bahan : Stainless steel

Jumlah : 1

4. Ekspander (G-111)

Fungsi : untuk menurunkan tekanan NH_3 dari 15,8607 atm menjadi 9,86 atm

P_1 = 15,8607 atm = 16,0709 bar

P_2 = 9,86 atm = 9,9906 bar

Massa NH_3 = 712,1415 kg/jam = 0,1978 kg/s

ρ_{NH3} = 597,1462 kg/m^3

asumsi efisiensi = 50 %

Dari Ulrich, pers. 4-19 :

$$Ws = \frac{\varepsilon * m * (P_1 - P_2)}{\rho}$$

$$Ws = \frac{0{,}5 * 0{,}1978\ kg/s * (16{,}0709 - 9{,}9906)\ bar * 100000\ j/bar.m^3)}{597{,}1462\ kg/m^3}$$

= 100,7026 watt = 0,135 hp ≈ 0,5 hp

Spesifikasi :

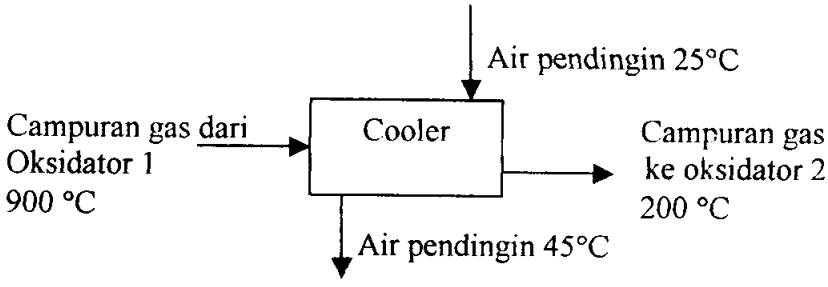
Tipe : Ekspander

Daya motor : 0,5 hp

Bahan : stainless steel

Jumlah : 1

5. Cooler (E-214)



Fungsi : untuk mendinginkan gas dari suhu 900 °C sampai 200 °C.

Tipe : shell and tube

Perhitungan berdasarkan Kern :

1. Neraca panas

   W gas = 11129,9926 kg/jam = 24537,1817 lb/jam

   w air = 106967,6687 kg/jam = 235820,9224 lb/jam

   Q = 8944636459 J/jam = 8477846,245 btu/jam

2. Δt

   T_1 = 900 °C = 1652 °F

   T_2 = 200 °C = 392 °F

   t_1 = 25 °C = 77 °F

   t_2 = 45 °C = 113 °F

   $\Delta t_1 = (T_2 - t_1) = 392 - 77 = 315$ °F

   $\Delta t_2 = (T_1 - t_2) = 1652 - 113 = 1539$ °F

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{1652 - 392}{113 - 77} = 35$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{113 - 77}{1652 - 77} = 0{,}02286$$

$$\Delta t_{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}} \qquad (5.14)$$

$$= \frac{1539 - 315}{\ln \frac{1539}{315}} = 771{,}60\ ^\circ F$$

3. Tc dan tc

$$Tc = Tav = \frac{T_1 + T_2}{2} = \frac{1652 + 392}{2} = 1008{,}5\ ^\circ F$$

$$tc = tav = \frac{t_1 + t_2}{2} = \frac{113 + 77}{2} = 95\ ^\circ F$$

$U_D = 2 - 50$ btu/jam.ft^2.°F (Tabel 8)

Dipilih $U_D = 25$

$$A = \frac{Q}{U_D * \Delta t} = \frac{8477846{,}245}{25 * 771{,}60} = 439{,}4945\ ft^2$$

Digunakan :

OD tube = 1 in, 10 BWG

ID tube = 0,732 in

L = 12 ft

a'' = 0,2618 ft^2/ft

Jumlah tube = $Nt = \frac{A}{a'' * L} = \frac{439{,}4945}{0{,}2618 * 12} = 139{,}8951$

Dari table 9 untuk square pitch :

Passes = 4

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

Nt = 158 tube

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

U_D terkoreksi $= \frac{Nt}{Nt_{std}} * U_D = \frac{139,8951}{158} * 25 = 22,1353$ btu/jam.ft^2.°F

Fluida panas : bagian shell, gas	Fluida dingin : bagian tube, air
4'. $B = \frac{1}{5} * 21,25 = 4,25$ in $C' = P_T - OD = 1\frac{1}{4} - 1 = \frac{1}{4}$ in $as = \frac{ID * C' * B}{144 * P_T}$ $as = \frac{21,25 * 0,25 * 4,25}{144 * 1,25}$ $= 0,1254$ ft^2	4. a't = 0,421 in^2 (table 10) $at = \frac{Nt * a't}{144 * n} = \frac{158 * 0,421}{144 * 4}$ $= 0,1155$ ft^2
5'. $Gs = \frac{W}{as} = \frac{24537,1817}{0,1254}$ $= 195671,3054$ lb/jam.ft^2	5. $Gt = \frac{w}{at} = \frac{235820,9224}{0,1155}$ $= 2041739,588$ lb/jam.ft^2 $V = \frac{Gt}{3600.\rho} = \frac{2041739,588}{3600 * 62,5}$ $= 9,0744$ ft/s
6'. Pada Tc = 1008,5 °F $\mu = 0,035 * 2,42$ (fig.15) $= 0,0847$ lb/ft.jam $De = \frac{0,99}{12} = 0,0825$ ft (fig. 28) $Res = \frac{De * Gs}{\mu}$	6. Pada tc = 95 °F $\mu = 0,75 * 2,42$ (fig.14) $= 1,815$ lb/ft.jam

$$= \frac{0,0825 * 195671,3054}{0,0847}$$

$$= 190588,9339$$

7'. $j_H = 90$ (Fig. 28)

8'. Pada Tc = 1008,5 °F

k = 0,0369 btu/jam.ft^2(°F/ft)

c = 0,2878 btu/lb.°F

$$\left[\frac{c * \mu}{k}\right]^{\frac{1}{3}} = \left[\frac{0,2878 * 0,0847}{0,0369}\right]^{\frac{1}{3}}$$

$$= 0,8709$$

9'. $\frac{ho}{os} = j_H . \frac{k}{De}\left[\frac{c.\mu}{k}\right]^{\frac{1}{3}}$

$$= 90.\frac{0,0369}{0,0825}.0,8709$$

$$= 35,0577 \text{ btu/jam.ft}^2.°F$$

10'. $tw = tc + \frac{\frac{ho}{os}}{\frac{hio}{ot} + \frac{ho}{os}}.(Tc - tc)$

$$= 95 + \frac{35,0577}{168,36 + 35,0577}$$

$$(1008,5 - 95)$$

$$= 252,44 \text{ °F}$$

11'. Pada tw = 252,44 °F

$D = \frac{0,732}{12} = 0,061$ ft (table 10)

$Ret = \frac{D * Gt}{\mu}$

$Ret = \frac{0,061 * 2041739,588}{1,815}$

Ret = 68620,4490

6. $\frac{hi}{ot} = 230$ btu/jam.ft^2.°F (Fig.25)

$\frac{hio}{ot} = hi * \frac{ID}{OD} = 230 * \frac{0,732}{1}$

$= 168,36$ btu/jam.ft^2.°F

11. Pada tw = 252,44 °F

$\mu_w = 0,42 * 2,42$ (Fig. 14)

$\mu_w = 0,019 * 2,42$ (Fig.15)	= 1,0164 lb/ft.jam
= 0,04598 lb/ft.jam	$ot = \left[\frac{\mu}{\mu w}\right]^{0.14} = \left[\frac{1,815}{1,0164}\right]^{0.14}$
$os = \left[\frac{\mu}{\mu w}\right]^{0.14} = \left[\frac{0,0847}{0,04598}\right]^{0.14}$	= 1,0846
= 1,0893	
12'. ho = 35,0577 * 1,0893	12. hio = 168,36 * 1,0846
= 38,1883 btu/jam.ft^2.°F	= 182,6033 btu/jam.ft^2.°F

13. $Uc = \frac{hio * ho}{hio + ho} = \frac{182,6033 * 38,1883}{182,6033 + 38,1883} = 25,5832$ btu/jam.ft^2.°F

14. $Rd = \frac{U_C - U_D}{U_C * U_D} = \frac{25,5832 - 22,1353}{25,5832 * 22,1353} = 0,00589$ ft^2.jam.°F/btu

Perhitungan pressure drop :

1'. Untuk Res = 190588,9339	1. Untuk Ret = 68620,4490
f = 0,00012 ft^2/in^2 (Fig. 29)	f = 0,00001 (Fig. 26)
s = 0,73 (tabel 6)	s = 1 (table. 6)
2'. $N + 1 = 12 * \frac{L}{B} = 12 * \frac{12}{4,25}$	2. $\Delta Pt = \frac{f.Gt^2.L.n}{5,22.10^{10}.D.s.ot}$
= 33,88	$= \frac{0,00001.2041739,588^2.12.4}{5,22.10^{10}.0,061.1.1,0846}$
$Ds = \frac{21,25}{12} = 1,7708$ *ft*	= 4,92 psi
3'. $\Delta Ps = \frac{f.Gs^2.Ds.(N+1)}{5,22.10^{10}.De.s.os} =$	3. Gt = 2041739,588
$\frac{0,00012.195671,3054^2.1,7708.33,88}{5,22.10^{10}.0,0825.0,73.1,0893}$	$\frac{V^2}{2 * g'} = 0,054$ (Fig. 27)

= 2,15 psi Allowable ΔPs = ΔPt 10 psi	$\Delta Pr = \frac{4*n}{s} * \frac{V^2}{2g'} = \frac{4*4}{1} * 0{,}054$ = 0,864 psi $\Delta P_T = \Delta Pt + \Delta Pr$ = 4,92 + 0,864 = 5,784 psi

Spesifikasi :

Tipe : 2 – 4 Shell and Tube

Jumlah tube: 158

U_D : 22,1353 btu/jam.ft^2.°F

U_C : 25,5832 btu/jam.ft^2.°F

ΔPs : 2,15 psi

ΔP_T : 5,784 psi

Jumlah : 1

6. Burner (Q-211)

Fungsi : untuk menaikkan suhu gas dari 30 °C menjadi 900 °C

Tipe : Thermal direct fired heater

Tekanan = 1 atm

Udara masuk = 6417,1323 kg/jam

BM udara = 28,84 kg/kmol

$$\rho_{udara} = \frac{P*BM}{R*T}$$

$$= \frac{1\ atm*28{,}84\ kg/kmol}{0{,}0821\ \frac{m^3.atm}{kmol.K}*303\ K} = 1{,}1593\ kg/m^3$$

Rate udara masuk = $\frac{6417{,}1323\ kg/jam}{1{,}1593\ kg/m^3}$ = 5535,1771 m^3/jam

= 195471,8764 ft^3/jam = 3257,8646 ft^3/menit

Dari Perry 5th ed, hal. 9-33 diperoleh :

A = 30 in

B = 27 in

C = 72 in

D = 30 in

Spesifikasi :

Tipe : Thermal Direct Fired Heater

Bahan : Stainless Steel

Jumlah : 1

7. Tangki leburan KCl (F-212)

Fungsi : untuk menjaga suhu leburan KCl.

Tipe : silinder vertical dengan tutup berbentuk elliptical dished head dilengkapi dengan coil pemanas dan pengaduk.

Kondisi operasi :

Tekanan, P = 1 atm

Temperatur, T = 850 °C

Leburan KCl yang dibutuhkan = 7532,8457 kg/jam = 16607,1688 lb/jam

ρ_{KCl} = 1,1354 gr/cm^3 = 70,8815 lb/ft^3

$$\text{Volume KCl} = \frac{16607{,}1688 \ \frac{lb}{jam}}{70{,}8815 \ \frac{lb}{ft^3}} * 1 \ jam = 234{,}2948 \ ft^3$$

Volume KCl = 80 % volume tangki

$$\text{Volume tangki} = \frac{234{,}2948}{0{,}8} = 292{,}8685 \ ft^3$$

H = 1,5 D

$$V = 0{,}000076.D^3 + \frac{\pi.D^2.H}{4} + 0{,}000076.D^3$$

$$292{,}8685 = \frac{\pi.1{,}5.D^3}{4} + 0{,}000152.D^3$$

D = 6,2875 ft = 75,4509 in

H = 9,4313 ft = 113,1763 in

Menentukan tekanan hidrostatik :

$$P_{hidrostatik} = \frac{\rho.h}{144}$$

$$\text{h = tinggi liguid} = \frac{Vol.leburan \ KCl - 0{,}000076.D^3}{\frac{\pi.D^2}{4}}$$

$$= \frac{234{,}2948 \ ft^3 - 0{,}000076 * 6{,}2875^3 \ ft^3}{\frac{\pi * 6{,}2875^2 \ ft^2}{4}} = 7{,}5454 \text{ ft}$$

$$P_{hidrostatik} = \frac{70{,}8815 \ lb/ft^3 * 7{,}5454 \ ft}{144} = 3{,}7141 \ lb/in^2$$

$P = 14{,}696 + 3{,}7141 = 18{,}4101 \text{ lb/in}^2$

$P_{design} = 1{,}2 * 18{,}4101 = 22{,}0921 \text{ lb/in}^2$

Menghitung tebal shell :

Bahan konstruksi ferritic stainless steel type 430

Dari Perry ed.6 tabel. 23-11, f allow = 75.200 lb/in^2

E = 80 % (Double Welded Butt Joint)

$$ts = \frac{P.D}{2.f.E} + c \qquad \text{(Brownell \& Young, pers.3.16)}$$

$$= \frac{22{,}0921\ lb/in^2 * 75{,}4509\ in}{2 * 75200\ lb/in^2 * 0{,}8} + 0$$

$$= 0{,}01385\ in \approx \frac{3}{16}\ in$$

Menghitung tebal tutup :

Dari Brownell & Young pers.7.57 :

$$t = \frac{P.d.V}{2.f.E - 0{,}2.P} + c$$

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

$$k = \frac{a}{b}$$

$$a = \frac{D}{2}$$

$$b = \frac{D}{4}$$

$$k = \frac{D}{2} * \frac{4}{D} = 2$$

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

$$t = \frac{P.d}{2.f.E - 0{,}2.P} + c$$

$$t = \frac{22{,}0921 * 75{,}4509}{2 * 75200 * 0{,}8 - 0{,}2 * 22{,}0921} + 0 = 0{,}01385 \text{ in} \approx \frac{3}{16} \text{ in}$$

Menghitung kedalaman tutup :

ID = 75,4509 in

$$OD = ID + 2.t = 75{,}4509 + 2.\frac{3}{16} = 75{,}8259 \text{ in}$$

Dari Brownell & Young table 5.11, hal. 94 :

sf = 3 in

$$b = \frac{75{,}4509}{4} = 18{,}8627 \text{ in}$$

$$h = t + b + sf = \frac{3}{16} + 18{,}8627 + 3 = 22{,}0502 \text{ in}$$

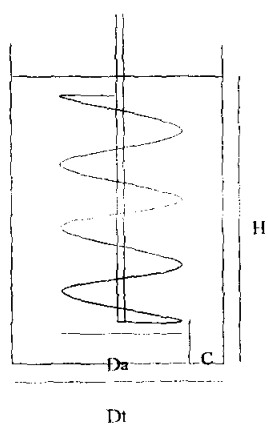
Menghitung tinggi tangki keseluruhan :

Tinggi tangki = tinggi sheil + 2.tinggi tutup

= 113,1763 + 2 * 22,0502 = 157,2767 in

Menghitung pengaduk :

Tipe : helical-ribbon agitator



Dari Geankoplis, tab. 3.4-1, hal. 144 :

$\frac{D_a}{D_t} = 0{,}3 - 0{,}5$, diambil : 0,4

$\frac{H}{D_t} = 1$

$\frac{W}{D_a} = \frac{1}{5}$

$\frac{C}{D_t} = \frac{1}{3}$

Dengan D_t = 6,2875 ft maka didapat :

Da = 0,4 * 6,2875 = 2,515 ft = 0,7666 m

H = 6,2875 ft

$W = \frac{1}{5} * 2{,}515 = 0{,}503$ ft

$C = \frac{1}{3} * 6{,}2875 = 2{,}0958$ ft

Dari Geankoplis, hal. 141 kecepatan agitator 20 - 200 rpm, diambil 100 rpm =1,67 rps.

μ = 0,0168 lb/ft.s

$Nre = \frac{Da^2 * N * \rho}{\mu} = \frac{2{,}515^2 * 1{,}67 * 70{,}8815}{0{,}0168} = 44567{,}2737$

Dari Geankoplis, fig. 3.4-4, hal. 145, diperoleh Np = 4

$P = Np * \rho * N^3 * Da^5$

$P = 4 * 1135{,}4\ kg/m^3 * 1{,}67^3\ rps^3 * 0{,}7666^5\ m^5 = 5600{,}1849$ J/s = 7,5099 hp

effisiensi pengaduk = 90 %

Power yang dibutuhkan = $\frac{7,5099}{0,9}$ = 8,3444 ≈ 8,5 hp

Menghitung koil pemanas :

Perhitungan berdasarkan Kern :

1. Neraca panas

   W gas = 8060,1885 kg/jam = 17769,4916 lb/jam

   Q =10038480740 J /jam = 9514606,506 btu/jam

2. Δt

   T_1 = 1200 °C = 2192 °F

   T_2 = 1100 °C = 2012 °F

   t_1 = 850 °C = 1562 °F

   t_2 = 870 °C = 1598 °F

   $\Delta t_1 = (T_2 - t_1) = 2012 - 1562 = 450$ °F

   $\Delta t_2 = (T_1 - t_2) = 2192 - 1598 = 594$ °F

   $$\Delta t_{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}} \qquad (5.14)$$

   $$= \frac{594 - 450}{\ln \frac{594}{450}} = 518,6727 \text{ °F}$$

3. suhu kalorik

   Tc = 2102 °F

   tc = 522 °F

4. asumsi ukuran pipa 1,25 in sch. 40 :

   OD = 1,66 in

   ID = 1,38 in = 0,115 ft

   $a' = 1,5\ in^2 = 0,01042\ ft^2$, $a'' = 0,435\ ft^2/ft$

Vessel side	Coil side
5. $Nre = \frac{Da^2.N.\rho}{\mu}$ $= \frac{2,515^2.1,67.70,8815}{0,0168}$ $= 44567,2737$	5 .$a' = 0,01042\ ft^2$ $G = \frac{W}{a'} = \frac{17769,4916}{0,01042}$ $= 1705325,487\ lb/hr.ft^2$ $c = 0,28$ Btu/lb.°F $\mu = 0,046.2,42 = 0.1113$ lb/ft.hr $k = 0,018$ Btu/hr.ft^2.(°F/ft) $Nre = \frac{D.G}{\mu} = \frac{0,115.1705325,487}{0,1113}$ $= 176201,451$
6. jc = 1100 Btu/hr.ft^2.°F (fig.20.2) k = 0,154 Btu/hr.ft^2.(°F/ft) cp = 1,124 Btu/lb.°F 6,2875 ft	6. j_H = 1250 Btu/hr.ft^2.°F (fig28) $hi = j_H.k.\left(\frac{c.\mu}{k}\right)^{\frac{1}{3}} / D$ $= 1250.0,018.1,2008/0,115$ $= 234,9391$ Btu/hr.ft^2.°F
7. $ho = jc.\frac{k}{D_s}.\left(\frac{cp.\mu}{k}\right)^{\frac{1}{3}}.\left(\frac{\mu}{\mu_w}\right)^{0.14}$ $= 1100.0,02449.7,6141.1$ $= 205,1162$ Btu/hr.ft^2.°F	7. $hio = hi.\frac{ID}{OD} = 234,9391.\frac{1,38}{1,66}$ $hio = 195,3103$ Btu/hr.ft^2.°F

8. $Uc = \frac{ho.hio}{ho + hio} = \frac{195,3108.205,1162}{195,3108 + 205,1162} = 100,0467$ Btu/hr.ft^2.°F

9. $Rd = \frac{U_C - U_D}{U_C.U_D}$

$0,004 = \frac{100,0467 - U_D}{100,0467.U_D}$

$U_D = 71,4619$ Btu/hr.ft^2.°F

10. Luas permukaan koil

$A = \frac{Q}{U_D.\Delta t} = \frac{9514606,506}{38,9208.518,6727} = 198,6981\ ft^2$

11. Panjang pipa

$Lc = \frac{A}{a''} = \frac{198,6981\ ft^2}{0,435\ ft^2/ft} = 456,7772$ ft

12. Diameter koil

Dc, diambil 0,7 * Ds = 0,7 * 6,2875 ft = 4,4013 ft

$Nc = \frac{Lc}{Dc.\pi} = \frac{456,7772}{4,4013.\pi} = 33,0349 \approx 34$ buah

hc = [(nc – 1) * (OD + 0,7)] + OD

= [(34 – 1) * (1,66 + 0,7)] +1,66

= 77,2625 in

$H_{liquid} = 7,5454$ ft = 90,5448 in

Rancangan memadai karena $H_{lig} > hc$

Spesifikasi :

Fungsi : untuk menjaga suhu leburan KCl.

Tipe : silinder vertical dengan tutup berbentuk elliptical dished head dilengkapi dengan coil pemanas dan pengaduk.

Dimensi tangki : D = 6,2875 ft

H = 7,5454 ft

t tutup = t shell = $\frac{3}{16}$ *in*

Tipe pengaduk : helical ribbon

Diameter pengaduk : 2,515 ft

Power : 8,5 hp

Dimensin koil : Dc = 4,4013 ft

Lc = 456,7772 ft

hc = 77,2625 in

8. Oksidator 1 (R-210)

Fungsi : untuk mereaksikan NH_3 dan O_2 dengan bantuan katalis platinum-rhodium.

Tipe : tangki silinder tegak dengan tutup berbentuk elliptical dished head dilengakapi dengan jaket pendingin.

Kondisi operai :

Tekanan = 9,66 atm = 141,9634 psia

Suhu = 900 °C = 1173 K

Komposisi gas masuk :

Gas	kg/jam	kmol/jam	fraksi mol
O_2	2427,4592	75,8581	0,1882
N_2	7990,3906	285,3711	0,7079
NH_3	705,0201	41,6812	0,1034
H_2O	3,5607	0,1978	0,000491
Total	11129,9926	403,1082	

Massa gas = 11129,9926 kg/jam = 408,9530 lb/jam

Dari Smith & Van Ness, pers. 3.46 :

$Z = Z^0 + \omega.Z'$

$Tr = \frac{T}{Tc}$

$Pr = \frac{P}{Pc}$

Harga Z^0 dan Z' diperoleh dari Smith & Van Ness tabel E.1 dan E.2 :

Komponen	Tr	Pr	Z^0	Z'	ω
O_2	1,96	0,1981	0,9952	0,0342	0,02
N_2	2,4	0,2938	0,9956	0,0203	0,038
NH_3	2,89	0,0839	1,0003	0,0049	0,253
H_2O	1,81	0,0429	0,9980	0,0034	0,345

Z_{O2} = 0,9959

Z_{N2} = 0,9964

Z_{NH3} = 1,0015

Z_{H2O} = 0,9992

Reaksi :

$$NH_3 + \frac{5}{4}O_2 \longrightarrow NO + \frac{3}{2}H_2O$$

Diketahui kecepatan reaksi orde 2 :

$-r_A = k.C_{NH3}.C_{O2}$

$$k = 5{,}152.10^{11} \exp \frac{-32150}{RT}$$

R = konstanta gas, cal/mol. K

T = suhu, K

ε_A = 0,11

Digunakan D_{shell} = 2 m = 78,7392 in

$$-r_A = k.\left[\frac{(C_{NH3})_o(1-X_A)}{1+\varepsilon_A.X_A}\right]\left[\frac{(C_{O2})_o - \frac{5}{4}(C_{NH3})_o.X_A}{1+\varepsilon_A.X_A}\right]$$

$$\int_0^Z \frac{dZ}{FAo} = \int_0^{X_A} \frac{dX_A}{-r_A.A}$$

$$Z = \frac{FAo}{A}\int_0^{X_A} \frac{dX_A}{-r_A}$$

$(C_{NH3})_o = 1{,}0361.10^{-5}$ kmol/lt = 10,36 mol/m^3

$(C_{O2})_o = 1{,}8966.10^{-5}$ kmol/lt = 18,96 mol/m^3

$(F_{NH3})_o$ = 705,0201 kg/jam = 11,5199 mol/s

$(F_{O2})_o$ = 2427,4604 kg/jam = 21,0717 mol/s

$(F_{N2})_o$ = 7993,9514 kg/jam = 79,3051 mol/s

$(F_{H2O})_o$ = 3,5607 kg/jam = 0,05495 mol/s

$(F_{NO}) = (F_{NH3})_o.X_A = 11,5199.X_A$

$$(F_{O2}) = (F_{O2})_o - \frac{5}{4}.(F_{NH3})_o.X_A = 21,0717 - 14,3999.X_A$$

(F_{N2}) = 8017,2928 kg/jam = 79,5366 mol/s

$$(F_{H2O}) = (F_{H2O})_o + \frac{3}{2}.(F_{NH3})_o.X_A = 0,05495 + 17,2799.X_A$$

Cp_{NH3} = 7,1025 kal/mol.K

Cp_{O2} = 8,4362 kal/mol.K

Cp_{N2} = 7,673 kal/mol.K

Cp_{NO} = 8,2071 kal/mol.K

Cp_{H2O} = 6,947 kal/mol.K

$$Z = 3,6669.\int_0^{X_A} \frac{dX_A}{5,152.10^{11} \exp^{\frac{-41670}{RT}}.\left[\frac{10,36.(1-X_A)}{1+0,11.X_A}\right]\left[\frac{18,96-12,95.X_A}{1+0,11.X_A}\right]}$$

$\sum Fi.Cpi.(Ti - Tb) = \sum Fo.Cpo.(To - Tb) + \Delta Hr.\ F_{Ao}.X_A$

[11,5199 . 7,1025 + 21,0717 . 8,4362 + 79,3051.7,673+0,05495.6,947].(735,5-298) =

[11,5199 . X_A . 8,2071 + (21,0717 - 14,3999.X_A) . 8,4362 + 79,5366 . 7,673+

(0,05495+17,2799.X_A).6,947].(T-298)-25205,0669.11,5199.X_A

379957,7842 = (788,4311+93,1081.X_A).(T-298)-290359,8502.X_A

$$T = \frac{379957,7842 + 290359,8502.X_A}{788,4311 + 93,1081.X_A} + 298$$

X_A	T, K	Z
0	779,92	17,2542
0,333	879,68	7,8855
0,666	972,16	0,5356
0,999	1058,15	0,0892

$$Z = \frac{0,333}{2} * (17,2542 + 2 * (7,8855 + 0,5356) + 0,0892)$$

$Z = 5,6919 \text{ m} \approx 6 \text{ m}$

Tinggi shell = 1,2 * 6 = 7,2 m = 283,4611 in

$$V_{katalis} = \frac{1}{4}.\pi.D^2.Z = \frac{1}{4}.\pi.2^2.6 = 18,8496 \text{ m}^3$$

$\rho_{bulk\ katalis} = 0,385 \text{ kg/m}^3$

$m_{katalis} = 18,8496 \text{ m}^3 * 0,385 \text{ kg/m}^3 = 7,2571 \text{ kg}$

BM gas = 27,61

$$\rho \text{ gas} = \frac{27,61}{359} * \frac{9,66}{1} * \frac{273}{273+900} = 0,1729 \text{ lb/ft}^3$$

$P_{design} = 1,2 * 141,9634 = 170,3561 \text{ lb/in}^2$

<u>Menghitung tebal shell :</u>

Bahan konstruksi ferritic stainless steel type 430

Dari Perry ed.6 tabel. 23-11, f allow = 75.200 lb/in^2

E = 80 % (Double Welded Butt Joint)

$$ts = \frac{P.D}{2.f.E} + c$$ (Brownell & Young, pers.3.16)

$$ts = \frac{170{,}3561\ lb/in^2 * 78{,}7392\ in}{2 * 75200\ lb/in^2 * 0{,}8} + 0$$

$$= 0{,}1115\ \text{in} \approx \frac{3}{16} in$$

Menghitung tebal tutup :

Dari Brownell & Young pers.7.57 :

$$t = \frac{P.d.V}{2.f.E - 0{,}2.P} + c$$

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

$$k = \frac{a}{b}$$

$$a = \frac{D}{2}$$

$$b = \frac{D}{4}$$

$$k = \frac{D}{2} * \frac{4}{D} = 2$$

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

$$t = \frac{P.d}{2.f.E - 0{,}2.P} + c$$

$$t = \frac{170{,}3561 * 78{,}7392}{2 * 75200 * 0{,}8 - 0{,}2 * 170{,}3561} + 0 = 0{,}1115\ \text{in} \approx \frac{3}{16}\ in$$

Menghitung kedalaman tutup :

ID = 78,7392 in

$OD = ID + 2.r = 78,7392 + 2.\frac{3}{16} = 79,1142$ in

Dari Brownell & Young table 5.11, hal. 94 :

sf = 3 in

$b = \frac{78,7392}{4} = 19,6848\ in$

$h = t + b + sf = \frac{3}{16} + 19,6848 + 3 = 22,8723\ in$

Menghitung tinggi tangki keseluruhan :

Tinggi tangki = tinggi shell + 2.tinggi tutup

= 283,4611 + 2 * 22,8723 = 329,2057 in

Menghitung jaket pemanas :

Perhitungan berdasarkan Kern :

1. Neraca panas

   W_{KCl} = 7532,8457 kg/jam = 16606,9116 lb/jam

   Q = 9575057203 J = 9075367,47 btu/jam

1. Δt

   t_1 = 850 °C = 1562 °F

   t_2 = 870 °C = 1598 °F

   T_1 = 900 °C = 1652 °F

   T_2 = 900 °C = 1652 °F

$\Delta t_1 = (T_2 - t_1) = 1652 - 1562 = 90\ °F$

$\Delta t_2 = (T_1 - t_2) = 1652 - 1598 = 54\ °F$

$$\Delta t_{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}} \qquad (5.14)$$

$$= \frac{54 - 90}{\ln \frac{54}{90}} = 70,4741\ °F$$

$\rho = \rho_{KCl} = 1,1354\ gr/cm^3 = 70,8815\ lb/ft^3$

$\mu = 0,045.10^{-3}\ kg/m.s = 3,0239.10^{-5}\ lb/ft.s$

$k = 0,0043\ Btu/jam.ft^2.(°F/ft)$

$c = 0,52\ Btu/lb.°F$

Diambil spasi jaket = 1,5 in 16606,9116 lb/jam

ID jaket = ODshell + 2.1,5 = 79,1142 + 3 = 82,1142 in = 6,8429 ft

$$De = \frac{4.flow\ area}{wetted\ parameter} = \frac{4.\pi\left(IDj^2 - OD_s{}^2\right)}{4.\pi.OD_s} = \frac{\left(82.1142^2 - 79,1142^2\right)}{79,1142}$$

De = 6,1138 in = 0,5099 ft

$$\text{Rate air pendingin} = \frac{16606,9116}{70,8815} = 234,2912\ ft^3/jam = 0,06508\ ft^3/s$$

$$\text{Flow area} = \frac{1}{4} * \pi * (ID_j{}^2 - ODs) = \frac{1}{4} * \pi * (82,1142^2 - 79,1142^2)$$

$$= 379,8855\ in^2 = 2,6381\ ft^2$$

$$G = \frac{16606,9116\ lb/jam}{2,6381\ ft^2} = 6295,0428\ lb/jam.ft^2 = 1,7486\ lb/s.ft^2$$

$$Nre = \frac{De.G}{\mu}$$

$$Nre = \frac{0,5099 * 1,7486}{3,0239.10^{-5}} = 29485,8581$$

$$j = \frac{hi.Di}{k}\left(\frac{c.\mu}{k}\right)^{-\frac{1}{3}}\left(\frac{\mu}{\mu_w}\right)^{-0,14}$$

Dari Kern, fig. 20.2, hal 718 : j = 1250

$$\left(\frac{c.\mu}{k}\right)^{-\frac{1}{3}} = \left(\frac{0,52 * 3,0239.10^{-5}}{0,0043}\right)^{-\frac{1}{3}} = 0,003657$$

$$1250 = \frac{hj.6,8429}{0,0043}.0,003657.1$$

hj = 214,7896 Btu/jam.ft^2.°F

$$hio = \frac{hj.ID}{OD} = \frac{214,7896.78,7392}{79,1142} = 213,7715 \text{ Btu/jam.ft}^2.°F$$

$$Uc = \frac{h_j.h_{io}}{h_j + h_{io}} = \frac{214,7896 * 213,7715}{214,7896 + 213,7715} = 107,1397 \text{ Btu/jam.ft}^2.°F$$

Rd = 0,005

$$hd = \frac{1}{Rd} = \frac{1}{0,005} = 200$$

$$U_D = \frac{Uc * hd}{Uc + hd} = \frac{107,1397 * 200}{107,1397 + 200} = 69,7661$$

Q = 9575057203 J = 9075367,47 btu/jam

$$A = \frac{Q}{U_D * \Delta t_{LMTD}} = \frac{9075367,47}{69,7661 * 70,4741} = 1845,8238 \text{ ft}^2$$

Spesifikasi :

Fungsi : untuk mereaksikan NH_3 dan O_2 dengan bantuan katalis platinum-rhodium.

Dimensi : D_{shell} = 6,5616 ft

H_{shell} = 23,6218 ft

Tebal tutup = tebal shell = $\frac{3}{16}$ in

Tinggi katalis = 19,6848 ft

Bahan : Ferritic Stainless Steel

Jumlah : 1

9. Bag filter (H-220)

Fungsi : untuk mengambil katalis platinum yang terikut gas keluar dari oksidator 1.

Tipe : bag filter

Kapasitas filter = 400 – 1800 lb/ft^{2}hari (Perry 3^{ed}, hal 990)

Diambil kapasitas 1800 lb/ft^2 hari

Rate gas masuk = 11129,9926 kg/jam = 588892,3606 lb/hari

$$\text{Flow area} = \frac{rate\ udara}{kapasitas\ filter} = \frac{588892{,}3606\ lb/hari}{1800\ lb/ft^2 hari} = 327{,}1624\ ft^2$$

Spesifikasi :

Tipe : bag filter

Kapasitas : 1800 lb/ft^{2}hari

Flow area : 327,1624 ft^2

Jumlah : 2

10. Blower (G-231)

Fungsi : untuk mengalirkan gas dari oksidator 1 ke oksidator 2

Tipe : centrifugal bower

Kondisi operasi :

Gas masuk blower pada suhu = 200 °C

N_2 = 8017,2928 kg = 286,3319 kmol

O_2 = 786,8874 kg = 24,5902 kmol

NO = 1200,4193 kg = 40,0140 kmol

H_2O = 1125,3931 kg = 62,5218 kmol

Jumlah gas masuk = 11129,9926 kg/jam = 24537,1817 lb/jam

Dari Smith & Van Ness, pers. 3.46 :

$Z = Z^0 + \omega.Z'$

$$Tr = \frac{T}{Tc}$$

$$Pr = \frac{P}{Pc}$$

Harga Z^0 dan Z' diperoleh dari Smith & Van Ness tabel E.1 dan E.2 :

Komponen	Tr	Pr	Z^0	Z'	ω
O_2	3,06	0,19	1,0008	0,0109	0,02
N_2	3,75	0,28	1,0027	0,0659	0,038
NO	2,62	0,15	0,9996	0,0098	0,583
H_2O	0,73	0,04	0,9649	-0,0324	0,345

Z_{O2} = 1,0102

Z_{N2} = 1,0052

Z_{NO} = 1,0053

Z_{H2O} = 0,9537

BM gas = 19,994

$$\rho \text{ gas} = \frac{19,994}{359} * \frac{9,37}{1} * \frac{273}{273+200} = 0,3012 \text{ lb/ft}^3$$

$$\text{qfm} = \frac{24537,1817 \ lb/jam}{0,3012 \ lb/ft^3} = 81466,7735 \text{ ft}^3\text{/jam} = 1357,7735 \text{ ft}^3\text{/menit}$$

Dari Perry 5th ed, hal 6-20 :

$$\text{Hp} = \frac{144 * qfm * (P_2 - P_1)}{33000} = \frac{144 * 1357,7735 * (9,46 - 9,37)}{33000} = 0,6223 \ hp$$

Efisiensi = 80 %

$$\text{Hp motor} = \frac{0,6223}{0,8} = 0,7778 \ hp \approx 1 \text{ hp}$$

Spesifikasi :

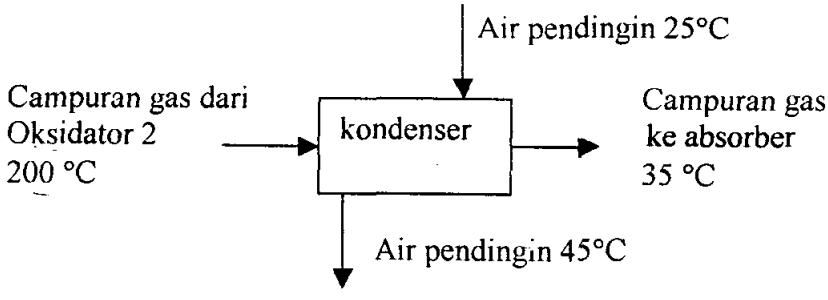
Tipe : Centrifugal blower

Daya motor : 1 hp

Bahan : Stainless steel

Jumlah : 1

11. Kondenser (E-232)



Fungsi : untuk mendinginkan gas dari suhu 200 °C ke 35 °C

Tipe : shell and tube

Perhitungan berdasarkan Kern :

1. Neraca panas

   W gas = 19511,2156 kg/jam = 43014,4259 lb/jam

   w air = 2325,5209 kg/jam = 5126,8434 lb/jam

   Q = 194460058,2 J/jam = 184311,8479 btu/jam

2. Δt

   T_1 = 200 °C = 392 °F

   T_2 = 35 °C = 95 °F

   t_1 = 25 °C = 77 °F

   t_2 = 45 °C = 113 °F

   $\Delta t_1 = (T_2 - t_1) = 95 - 77 = 18$ °F

   $\Delta t_2 = (T_1 - t_2) = 392 - 113 = 279$ °F

   $$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{392 - 95}{113 - 77} = 8,25$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{113 - 77}{392 - 77} = 0{,}1143$$

$$\Delta t_{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}} \qquad (5.14)$$

$$= \frac{279 - 18}{\ln \frac{279}{18}} = 95{,}23\ ^\circ F$$

3. Tc dan tc

$$Tc = Tav = \frac{T_1 + T_2}{2} = \frac{392 + 95}{2} = 243{,}5\ ^\circ F$$

$$tc = tav = \frac{t_1 + t_2}{2} = \frac{113 + 77}{2} = 95\ ^\circ F$$

$U_D = 2 - 50$ btu/jam.ft^2.°F (Tabel 8)

Dipilih $U_D = 20$

$$A = \frac{Q}{U_D * \Delta t} = \frac{184311{,}8479}{20 * 95{,}23} = 99{,}7682\ ft^2$$

Digunakan :

OD tube = 1 in, 10 BWG

ID tube = 0,732 in

L = 12 ft

a'' = 0,2618 ft^2/ft

$$\text{Jumlah tube} = Nt = \frac{A}{a'' * L} = \frac{99{,}7682}{0{,}2618 * 12} = 31{,}7571$$

Dari table 9 untuk square pitch :

Passes = 2

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

Nt = 32 tube

ID shell = 10 in

U_D terkoreksi = $\frac{Nt}{Nt_{std}} * U_D = \frac{31,7571}{32} * 20 = 19,8481$ btu/jam.ft^2.°F

Fluida panas : bagian shell, gas	Fluida dingin : bagian tube, air
4'. B = $\frac{1}{5} * 10 = 2$ in C' = P_T -- OD = $1\frac{1}{4} - 1 = \frac{1}{4}$ in as = $\frac{ID * C' * B}{144 * P_T}$ as = $\frac{10 * 0,25 * 2}{144 * 1,25}$ = 0,028 ft^2 5'. Gs = $\frac{W}{as} = \frac{43014,4259}{0,028}$ = 1536229,496 lb/jam.ft^2 6'. Pada Tc = 243,5 °F μ = 0,02 * 2,42 (fig.15) = 0,0508 lb/ft.jam De = $\frac{0,99}{12}$ = 0,0825 ft (fig. 28)	4. a't = 0,421 in^2 (table 10) at = $\frac{Nt * a't}{144 * n} = \frac{32 * 0,421}{144 * 2}$ = 0,0468 ft^2 5. Gt = $\frac{w}{at} = \frac{5126,8434}{0,0468}$ = 109547,9359 lb/jam.ft^2 V = $\frac{Gt}{3600.\rho} = \frac{109547,9359}{3600 * 62,5}$ = 0,4869 ft/s 6. Pada tc = 95 °F μ = 0,75 * 2,42 (fig.14) = 1,815 lb/ft.jam

$$Res = \frac{De * Gs}{\mu}$$

$$= \frac{0,0825 * 1536229,496}{0,0508}$$

$$= 2494860,894$$

7'. $j_H = 400$ (Fig. 28)

8'. Pada Tc = 243,5 °F

k = 0,018 btu/jam.ft^2(°F/ft)

c = 0,255 btu/lb.°F

$$\left[\frac{c * \mu}{k}\right]^{\frac{1}{3}} = \left[\frac{0,255 * 0,0508}{0,018}\right]^{\frac{1}{3}}$$

$$= 0,8961$$

9'. $$\frac{ho}{\alpha s} = j_H . \frac{k}{De}\left[\frac{c.\mu}{k}\right]^{\frac{1}{3}}$$

$$= 400 . \frac{0,018}{0,0825} . 0,8961$$

$$= 78,2051 \text{ btu/jam.ft}^2.°F$$

10'. $$tw = tc + \frac{\frac{ho}{\alpha s}}{\frac{hio}{\alpha t} + \frac{ho}{\alpha s}} (Tc - tc)$$

$$= 95 + \frac{78,2051}{109,8 + 78,2051}$$

$$(243,5 - 95)$$

$$= 156,77 °F$$

$$D = \frac{0,732}{12} = 0,061 \text{ ft} \quad \text{(table 10)}$$

$$Ret = \frac{D * Gt}{\mu}$$

$$Ret = \frac{0,061 * 109547,9359}{1,815}$$

$$Ret = 3681,7764$$

9. $\frac{hi}{\alpha t} = 150$ btu/jam.ft^2.°F (Fig.25)

$$\frac{hio}{\alpha t} = hi * \frac{ID}{OD} = 150 * \frac{0,732}{1}$$

$$= 109,8 \text{ btu/jam.ft}^2.°F$$

11'. Pada tw = 156,77 °F μ_w = 0,0575 * 2,42 (Fig.15) = 0,1392 lb/ft.jam $\phi s = \left[\frac{\mu}{\mu w}\right]^{0,14} = \left[\frac{0,0508}{0,1392}\right]^{0,14}$ = 0,8684 12'. ho = 78,2051 * 0,8684 = 67,9133 btu/jam.ft^2.°F	11. Pada tw = 156,77 °F μ_w = 0,6 * 2,42 (Fig. 14) = 1,452 lb/ft.jam $\phi t = \left[\frac{\mu}{\mu w}\right]^{0,14} = \left[\frac{1,815}{1,452}\right]^{0,14}$ = 1,0317 12. hio = 109,8 * 1,0317 = 113,2807 btu/jam.ft^2.°F

$$Uc = \frac{hio * ho}{hio + ho} = \frac{113,2807 * 67,9133}{113,2807 + 67,9133} = 42,4587 \text{ btu/jam.ft}^2\text{.°F}$$

$$14.\ Rd = \frac{U_C - U_D}{U_C * U_D} = \frac{42,4587 - 19,8481}{42,4587 * 19,8481} = 0,02683 \text{ ft}^2\text{.jam.°F/btu}$$

Perhitungan pressure drop :

1'. Untuk Res = 2494860,894 f = 0,0001 ft^2/in^2 (Fig. 29) s = 0,73 (tabel 6) 2'. $N + 1 = 12 * \frac{L}{B} = 12 * \frac{12}{2}$ = 72 $Ds = \frac{10}{12} = 0,8333$ *ft* 3'. $\Delta Ps = \frac{f.Gs^2.Ds.(N+1)}{5,22.10^{10}.De.s.\phi s} =$	1. Untuk Ret = 3681,7764 f = 0,00035 (Fig. 26) s = 1 (table. 6) 2. $\Delta Pt = \frac{f.Gt^2.L.n}{5,22.10^{10}.D.s.\phi t}$ $= \frac{0,00035.109547,9359^2.12.2}{5,22.10^{10}.0,061.1.1,0317}$ = 0,0307 psi 3. Gt = 109547,9359

$\frac{0,0001.1536229,496^2.0,8333.72}{5,22.10^{10}.0,0825.0,73.0,8684}$ = 5,18 psi Allowable ΔPs = 10 psi	$\frac{V^2}{2*g'} = 0,0016$ (Fig. 27) $\Delta Pr = \frac{4*n}{s} * \frac{V^2}{2g'} = \frac{4*2}{1} * 0,0016$ = 0,0128 psi $\Delta P_T = \Delta Pt + \Delta Pr$ = 0,0307 + 0,00128 = 0,0435 psi Allowable ΔPs = 10 psi

Spesifikasi :

Tipe : 1 – 2 Shell and Tube

Jumlah tube : 32

U_D : 19,8481 btu/jam.ft^2.°F

U_C : 42,4587 btu/jam.ft^2.°F

ΔPs : 5,18 psi

ΔP_T : 0,0435 psi

Jumlah : 1

12. Blower (G-241)

Fungsi : untuk mengalirkan gas ke menara absorber

Tipe : centrifugal bower

Kondisi operasi :

Gas masuk blower pada suhu = 35 °C

N_2 = 16034,5857 kg = 572,6638 kmol

O_2 = 92,7996 kg = 2,9000 kmol

NO = 74,9481 kg = 2,4983 kmol

NO_2 = 2183,4890 kg = 47,4672 kmol

Jumlah gas masuk = 18385,8225 kg/jam = 40533,3843 lb/jam

Dari Smith & Van Ness, pers. 3.46 :

$Z = Z^0 + \omega.Z'$

$Tr = \frac{T}{Tc}$

$Pr = \frac{P}{Pc}$

Harga Z^0 dan Z' diperoleh dari Smith & Van Ness tabel E.1 dan E.2 :

Komponen	Tr	Pr	Z^0	Z'	ω
O_2	2	0,2	0,9944	0,0155	0,02
N_2	2,44	0,29	0,9979	0,0198	0,038
NO	1,70	0,15	0,9915	0,0122	0,583
NO_2	0,99	0,14	0,9499	-0,0112	0,141

Z_{O2} = 0,9947

Z_{N2} = 0,9987

Z_{NO} = 0,9986

Z_{NO2} = 0,9482

Karena harga Z mendekati 1, maka diasumsi sebagai gas ideal

BM gas = 29,392

$$\rho \text{ gas} = \frac{29,392}{359} * \frac{9,86}{1} * \frac{273}{273+35} = 0,7226 \text{ lb/ft}^3$$

$$\text{qfm} = \frac{40533,3843 \ lb/jam}{0,7226 \ lb/ft^3} = 56096,9219 \text{ ft}^3\text{/jam} = 934,9486 \text{ ft}^3\text{/menit}$$

Dari Perry 5th ed, hal 6-20 :

$$\text{Hp} = \frac{144 * qfm * (P_2 - P_1)}{33000} = \frac{144 * 934,9486 * (9,86 - 9,46)}{33000} = 1,6387 \ hp$$

Efisiensi = 80 %

$$\text{Hp motor} = \frac{1,6387}{0,8} = 2,0484 \ hp \approx 2,5 \text{ hp}$$

Spesifikasi :

Tipe : Centrifugal blower

Daya motor : 2,5 hp

Bahan : Stainless steel

Jumlah : 1

13. Oksidator 2 (R-230)

Fungsi : mereaksikan NO dan O_2 menjadi NO_2

Tipe : Tangki silinder tegak dengan tutup berbentuk elliptical dished head dan dilengkapi dengan jaket pendingin.

Kondisi operasi :

Tekanan = 9,46 atm

Suhu = 200 °C = 473 K

Massa gas = 19511,2156 kg/jam = 43014,4259 lb/jam

Reaksi : $NO + \frac{1}{2}O_2 \longrightarrow NO_2$

$$A + \frac{1}{2}B \longrightarrow C$$

ΔH_{298} = -1127 kj/mol = -1068,1857 Btu/mol

F_{Ao} = 1463,3624 kg/jam = 13,5497 mol/s

F_{Bo} = 833,2872 kg/jam = 7,2334 mol/s

F_{Co} = 54,5872 kg/jam = 0,3296 mol/s

$F_A = F_{AO}(1 - X_A) = 13,5497.(1 - X_A)$

$F_B = F_{BO} - \frac{1}{2}F_{AO}.X_A = 7,2334 - 6,7749.X_A$

$F_C = F_{CO} + F_{AO}.X_A = 0,3296 + 13,5497.X_A$

Diketahui kecepatan reaksi orde 3 :

$$-r_A = \frac{k_p}{R.T} P^2_{NO} * P_{O2}$$

$$\log k_p = \frac{652,1}{T} - 1,0366$$

dimana : r = kecepatan reaksi, kmol/m^3.s

k_p = konstanta kecepatan reaksi, 1/atm^2.s

R = konstanta gas, atm.m^3/kmol.K

T = suhu, K

P = tekanan parsial, atm

$$\tau = CAo \int_0^{XA} \frac{dX}{-r_A}$$

$$= CAo \int_0^{XA} \frac{dX}{\frac{k_p}{RT} P^2{}_A * P_B}$$

$$= \frac{PA_o}{R.T} \int_0^{XA} \frac{dX}{\frac{k_p}{RT} P^2{}_A * P_B}$$

$$\tau = PAo \int_0^{XA} \frac{dX}{k_p \left[\left(P^2{}_{A0}(1 - X_A)^2 \right) * \left(P_{B0} - \left(\frac{1}{2} * P_{A0} X_A \right) \right) \right]}$$

Zat	n, kmol	fraksi mol
NO	48,7787	0,0686
O_2	26,0402	0,0367
NO_2	1,1867	0,0017
N_2	572,6638	0,8052
H_2O	62,5218	0,0879
Total	711,1912	

PAo = 0,6490 atm

PBo = 0,3472 atm

Cp_A = 7,1064 Btu/mol.°C

Cp_B = 7,0881 Btu/mol.°C

Cpc = 10,9812 Btu/mol.°C

$$\tau = 0{,}649 \int_0^{X_A} \frac{dX}{k_p\left[\left(0{,}4212.(1-X_A)^2\right)*\left(0{,}3472-0{,}3245.X_A\right)\right]} \quad (1)$$

$[FAo.Cp_A + FBo.Cp_B + FCo.Cp_C].(Ti-Tb) = [FA.Cp_A + FB.Cp_B + FC.Cp_C].(T-Tb) + \Delta H_r.FAo.X_A$

$(13{,}5497 . 7{,}1064 + 7{,}2334 . 7{,}0881 + 0{,}3296 . 10{,}9812) . (385{,}5-298) = [13{,}5497.(1-X_A).7{,}1064 + (7{,}2334 - 6{,}7749.X_A).7{,}0881 + (0{,}3296 + 13{,}5497.X_A).10{,}9812].(T-298) - 1068{,}1857.13{,}5497.X_A$

$13228{,}1555 = (151{,}1801 + 4{,}4812.X_A).(T-298) - 14473{,}5958.X_A$

$$T = \frac{13228{,}1555 + 14473{,}5958.X_A}{151{,}1801 + 4{,}4812.X_A} + 298$$

X_A	T	k_p	$\tau = 0{,}649.f(X)$
0	385,5	4,5183	0,9822
0,19	403,1	3,8117	2,1577
0,38	420,5	3,2672	5,4798
0,57	437,71	2,8392	18,0914
0,76	454,73	2,4971	106,5090
0,95	471,56	2,2195	7134,0803

$$\tau = \frac{0{,}19}{2}.\left(0{,}9822 + 2.\left(2{,}1577 + 5{,}4798 + 18{,}0914 + 106{,}5090\right) + 7134{,}0803\right)$$

$\tau = 702{,}9558$ s $= 0{,}1953$ jam $\approx 0{,}2$ jam

Dari Smith & Van Ness, pers. 3.46 :

$Z = Z^0 + \omega.Z'$

$Tr = \frac{T}{Tc}$

$Pr = \frac{P}{Pc}$

Harga Z^0 dan Z' diperoleh dari Smith & Van Ness tabel E.1 dan E.2 :

Komponen	Pr	Tr	Z^0	Z'	ω
O_2	0,19	3,06	1,0007	0,0011	0,022
N_2	0,28	3,75	1,0027	0,0135	0,038
NO	0,14	2,62	0,9996	0,0092	0,583
NO_2	0,13	1,53	0,9882	0,0102	0,141
H_2O	0,04	0,73	0,9642	-0,0337	0,345

Z_{O2} = 1,0010

Z_{N2} = 1,0032

Z_{NO} = 1,0049

Z_{NO2} = 0,9896

Z_{H2O} = 0,9526

Karena harga Z mendekati 1, maka diasumsi sebagai gas ideal

BM gas = 19,3864

$$\rho \text{ gas} = \frac{19,3864}{359} * \frac{9,46}{1} * \frac{273}{273+200} = 0,2948 \text{ lb/ft}^3$$

$$\text{Volume} = \frac{m}{\rho} = \frac{43014,4259}{0,2948} = 145910,5356 \text{ ft}^3\text{/jam}$$

Untuk waktu tinggal 0,2 jam, maka V = 29182,1071 ft^3

H = 1,5 D

$$V = 0{,}000076.D^3 + \frac{\pi.D^2.H}{4} + 0{,}000076.D^3$$

$29182{,}1071 = 1{,}1782.D^3$

D = 26,0302 ft = 312,3656 in

H = 39,0454 ft = 468,5448 in

Menghitung tebal shell :

$P_{design} = 1{,}2 * P_{operasi}$

P_{design} = 1,2 * 9,46 = 11,34 atm = 166,6526 psia

Bahan konstruksi ferritic stainless steel type 430

Dari Perry ed.6 tabel. 23-11, f allow = 75.200 lb/in^2

E = 80 % (Double Welded Butt Joint)

$$ts = \frac{P.D}{2.f.E} + c$$ (Brownell & Young, pers.3.16)

$$= \frac{166{,}6526\ lb/in^2 * 312{,}3656\ in}{2 * 75200\ lb/in^2 * 0{,}8} + 0$$

$$= 0{,}4327 \text{ in} \approx \frac{7}{16} in$$

Menghitung tebal tutup :

Dari Brownell & Young pers.7.57 :

$$t = \frac{P.d.V}{2.f.E - 0{,}2.P} + c$$

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

$$k = \frac{a}{b}$$

$$a = \frac{D}{2}$$

$$b = \frac{D}{4}$$

$$k = \frac{D}{2} * \frac{4}{D} = 2$$

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

$$t = \frac{P.d}{2.f.E - 0{,}2.P} + c$$

$$t = \frac{166{,}6526 * 312{,}3656}{2 * 75200 * 0{,}8 - 0{,}2 * 166{,}6526} + 0 = 0{,}4328 \text{ in} \approx \frac{7}{16} \ in$$

Menghitung kedalaman tutup :

ID = 312,3656 in

$$OD = ID + 2.t = 312{,}3656 + 2.\frac{7}{16} = 313{,}2406 \text{ in}$$

Dari Brownell & Young table 5.11, hal. 94 :

sf = 3 in

$$b = \frac{312{,}3656}{4} = 78{,}0914 \ in$$

$$h = t + b + sf = \frac{7}{16} + 78{,}0914 + 3 = 81{,}5289 \ in$$

Menghitung tinggi tangki keseluruhan :

Tinggi tangki = tinggi shell + 2.tinggi tutup

= 468,5448 + 2 * 81,5289 = 631,6026 in

Menghitung jaket pendingin :

T_1 = 200 °C = 392 °F

T_2 = 200 °C = 392 °F

t_1 = 25 °C = 77 °F

t_2 = 45 °C = 113 °F

$$\Delta t_{LMTD} = \frac{(392-113)-(392-77)}{\ln\left(\frac{392-113}{392-77}\right)} = 296{,}64\ °F$$

Massa air pendingin = 617289,5732 kg/jam = 1360876,593 lb/jam

ρ_{air} = 997,08 kg/m^3 = 62,2454 lb/ft^3

μ_{air} = 0,8937.10^{-3} kg/m.s = 6,0054.10^{-4} lb/ft.s = 2,1619 lb/ft.jam

k = 0,38 Btu/jam.ft^2.(°F/ft)

c = 1 Btu/lb.°F

Diambil spasi jaket = 1,5 in

ID jaket = ODshell + 2.1,5 = 313,2406 + 3 = 316,2406 in = 26,3534 ft

$$De = \frac{4.flow\ area}{wetted\ parameter} = \frac{4.\left(IDj^2 - OD_s^{\ 2}\right)}{4.\pi.OD_s} = \frac{\left(316{,}2406^2 - 313{,}2406^2\right)}{313{,}2406}$$

De = 6,0287 in = 0,5024 ft

$$\text{Rate air pendingin} = \frac{1360876{,}593}{62{,}2454} = 21863{,}0977\ ft^3/jam = 6{,}0731\ ft^3/s$$

$$\text{Flow area} = \frac{1}{4} * \pi * (ID_j^{\ 2} - OD_s^{\ 2} = \frac{1}{4} * \pi * (316{,}2406^2 - 313{,}2406^2)$$

$$= 1483{,}1801\ in^2 = 10{,}2999\ ft^2$$

$$G = \frac{1360876{,}593\ lb/jam}{10{,}2999\ ft^2} = 132125{,}7098\ \text{lb/jam.ft}^2 = 36{,}7016\ \text{lb/s.ft}^2$$

$$Nre = \frac{De.G}{\mu}$$

$$Nre = \frac{0{,}5024 * 36{,}7016}{6{,}0054^{-4}} = 30703{,}8280$$

$$j = \frac{hi.Di}{k}\left(\frac{c.\mu}{k}\right)^{-\frac{1}{3}}\left(\frac{\mu}{\mu_w}\right)^{-0.14}$$

Dari Kern, fig. 20.2, hal 718 : j = 1700

$$\left(\frac{c.\mu}{k}\right)^{-\frac{1}{3}} = \left(\frac{1 * 2{,}1619}{0{,}38}\right)^{-\frac{1}{3}} = 1{,}7852$$

$$\left(\frac{\mu}{\mu_w}\right)^{-0.14} = 1$$

$$1700 = \frac{hj.26{,}3534}{0{,}38}.1{,}7852.1$$

$hj = 158{,}2554\ \text{Btu/jam.ft}^2.°F$

$$hio = \frac{hj.ID}{OD} = \frac{158{,}2554.312{,}3656}{313{,}2406} = 157{,}8133\ \text{Btu/jam.ft}^2.°F$$

$$Uc = \frac{h_j.h_{io}}{h_j + h_{io}} = \frac{158{,}2554 * 157{,}8133}{158{,}2554 + 157{,}8133} = 79{,}017\ \text{Btu/jam.ft}^2.°F$$

$Rd = 0{,}005$

$$hd = \frac{1}{Rd} = \frac{1}{0{,}005} = 200$$

$$U_D = \frac{Uc * hd}{Uc + hd} = \frac{79{,}017 * 200}{79{,}017 + 200} = 56{,}6396$$

Q = 51781316,59 kj = 49079025,45 Btu

$$A = \frac{Q}{U_D * \Delta t_{LMTD}} = \frac{49079025,45}{56,6396 * 296,64} = 2921,1367 \text{ ft}^2$$

Spesifikasi alat :

Fungsi : mereaksikan NO dan O_2 menjadi NO_2

Tipe : silinder tegak dengan tutup elliptical dished head dilengkapi dengan jaket pendingin

Dimensi : D = 313,2406 in

H = 468,5448 in

Tebal shell = $\frac{7}{16}$ in

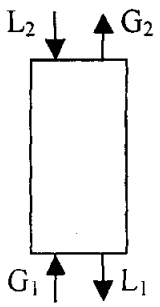
tebal tutup = $\frac{7}{16}$ in

Bahan : ferritic stainless steel

Jumlah : 1

14. Absorber (D-240)

Fungsi : Mengabsorpsi gas NO_2 menjadi HNO_3



Kondisi operasi :

P = 9,86 atm

T = 35 °C

Reaksi : $3\ NO_2 + H_2O \longrightarrow 2\ HNO_3 + NO$

Menghitung diameter kolom :

Gas masuk kolom, G_1

Gas	kg/jam	kmol/jam	Fraksi mol	Fraksi berat
NO_2	2183,4890	47,4672	0,0759	0,1188
N_2	16034,5857	572,6638	0,9155	0,8721
O_2	92,7996	2,9000	0,0046	0,0050
NO	74,9481	2,4983	0,0040	0,0041
Total	18385,8224	625,5292		

G_1 = 18385,8224 kg/jam = 40533,3841 lb/jam

Gas keluar kolom, G_2

Gas	kg/jam	kmol/jam	Fraksi mol	Fraksi berat
NO_2	109,1745	2,3734	0,0040	0,0065
N_2	16034,5857	572,6638	0,9617	0,9566
O_2	92,7996	2,9000	0,0049	0,0055
NO	525,8861	17,5295	0,0294	0,0314
Total	16762,4456	595,4630		

G_2 = 16762,4456 kg/jam = 36954,4876 lb/jam

Liquid masuk (H_2O), L_2 = 1028,1386 kg/jam = 2266,6344 lb/jam

Larutan HNO_3 keluar, L_1 = 1893,9394 kg/jam = 4175,3788 lb/jam

Direncanakan *Packed Column* dengan memakai packing 1,5 in keramik Rasching Ring (RR).

Bagian atas :

G_2 = 16762,4456 kg/jam = 36954,4876 lb/jam

L_2 = 1028,1386 kg/jam = 2266,6344 lb/jam

Dari Smith & Van Ness, pers. 3.46 :

$Z = Z^0 + \omega.Z'$

$$Tr = \frac{T}{Tc}$$

$$Pr = \frac{P}{Pc}$$

Harga Z^0 dan Z' diperoleh dari Smith & Van Ness tabel E.1 dan E.2 :

Komponen	Tr	Pr	Z^0	Z'	ω
NO_2	0,99	0,1379	0,9507	-0,0110	0,141
N_2	2,40	0,2938	0,9976	0,0203	0,038
O_2	1,99	0,1981	0,9945	0,0153	0,022
NO	1,71	0,1542	0,9912	0,0125	0,583

Z_{NO2} = 0,9491

Z_{N2} = 0,9983

Z_{O2} = 0,9948

Z_{NO} = 0,9985

Karena harga Z mendekati 1, maka diasumsi sebagai gas ideal

BM gas = 29,3926

$$\rho \text{ gas} = \frac{29,39}{359} * \frac{9,86}{1} * \frac{273}{273+35} = 0,7155 \text{ lb/ft}^3$$

$\rho_{l,2}$ = 995,68 kg/m^3 = 62,1579 lb/ft^3

$\mu_{l,2}$ = 0,8007.10^{-3} kg/m.s = 1,9369 lb/ft.jam

$$\frac{L_2}{G_2}\left(\frac{\rho_G}{\rho_L - \rho_G}\right)^{\frac{1}{2}} = \frac{2266,6344}{36954,4876}\left(\frac{0,6853}{62,1579 - 0.6853}\right)^{\frac{1}{2}} = 0,0065$$

Dari Treybal fig. 6-34 :

$$\frac{G_f^{\,2}.C_f.\mu_L.^{0,1}.J}{gc.\rho_G.(\rho_L - \rho_G)} = 0,375$$

Jika digunakan keramik rasching ring 1,5 in, C_f=125

$$\frac{G_f^{\,2}.(125)(1,9369)^{0,1}.1,502}{(4,18.10^8)(0,6853)(62,1579 - 0,6853)} = 0,375$$

G_f = 5737,7233 lb/jam.ft^2

$G_{operasi}$ = 50 % * $G_{flooding}$

= 0,5 * 5737,7233 = 2868,8616 lb/jam.ft^2

$$S = \frac{V}{G_{operasi}} = \frac{36954,4876\ lb/jam}{2868,8616\ lb/jam.ft^2} = 12,8812\ ft^2$$

$$Dt = \sqrt{\frac{4*S}{\pi}} = \sqrt{\frac{4*12,8812}{\pi}} = 4,0498\ ft$$

$$\frac{Dt}{30} = \frac{4,0498*12}{30} = 1,6199 > 1,5\ in$$

Bagian bawah :

G_1 = 18385,8224 kg/jam = 40533,3841 lb/jam

L_1 = 1893,9304 kg/jam = 4175,3788 lb/jam

Dari Smith & Van Ness, pers. 3.46 :

$Z = Z^0 + \omega.Z'$

$Tr = \frac{T}{Tc}$

$Pr = \frac{P}{Pc}$

Harga Z^0 dan Z' diperoleh dari Smith & Van Ness tabel E.1 dan E.2 :

Komponen	Tr	Pr	Z^0	Z'	ω
NO_2	0,99	0,1379	0,9507	-0,0110	0,141
N_2	2,40	0,2938	0,9976	0,0203	0,038
O_2	1,99	0,1981	0,9945	0,0153	0,022
NO	1,71	0,1542	0,9912	0,0125	0,583

$Z_{NO2} = 0,9491$

$Z_{N2} = 0,9983$

$Z_{O2} = 0,9948$

$Z_{NO} = 0,9985$

Karena harga Z mendekati 1, maka diasumsi sebagai gas ideal

BM gas = 28,15

$$\rho \text{ gas} = \frac{28,15}{359} * \frac{9,86}{1} * \frac{273}{273+35} = 0,6853 \text{ lb/ft}^3$$

$\rho_{H2O} = 995,68 \text{ kg/m}^3 = 62,1579 \text{ lb/ft}^3$

$\rho_{HNO3} = 1,3533 \text{ gr/cm}^3 = 84,4833 \text{ lb/ft}^3$

$$\rho_L = \frac{1}{\frac{x_1}{\rho_1} + \frac{x_2}{\rho_2}} = \frac{1}{\frac{0,6}{84,4833} + \frac{0,4}{62,1579}} = 73,8704 \text{ lb/ft}^3$$

$\mu_{H2O} = 0,8007.10^{-3}$ kg/m.s = 1,9369 lb/ft.jam

$\mu_{HNO3} = 2,1.10^{-3}$ kg/m.s = 5,0801 lb/ft.jam

$\mu_L = (x_1. \mu_L + x_2. \mu_L) = (0,4. 1,9369) + (0,6. 5,0801)$

$= 3,8228$ lb/jam.ft

$$\frac{L_1}{G_1}\left(\frac{\rho_G}{\rho_L - \rho_G}\right)^{\frac{1}{2}} = \frac{4175,3788}{40533,3841}\left(\frac{0,6853}{73,8704 - 0,6853}\right)^{\frac{1}{2}} = 0,0109$$

Dari Treybal fig. 6-34 :

$$\frac{G_f^{\,2}.C_f.\mu_L^{\,0,1}.J}{gc.\rho_G.(\rho_L - \rho_G)} = 0,375$$

Jika digunakan keramik rasching ring 1,5 in, C_f =125

$$\frac{G_f^{\,2}.(125)(3,8228)^{0,1}.1,502}{(4,18.10^8)(0,6853)(73,8704 - 0,6853)} = 0,32$$

$G_f = 5589,9224$ lb/jam.ft^2

$G_{operasi} = 50\ \% * G_{flooding}$

$= 0,5 * 5589,9224 = 2794,9612$ lb/jam.ft^2

$$S = \frac{V}{G_{operasi}} = \frac{40533,3841\ lb/jam}{2794,9612\ lb/jam.ft^2} = 14,5023 \text{ ft}^2$$

$$Dt = \sqrt{\frac{4*S}{\pi}} = \sqrt{\frac{4*14,5023}{\pi}} = 4,2971 \text{ ft}$$

$$\frac{Dt}{30} = \frac{4,2971*12}{30} = 1,7188 > 1,5 \text{ in}$$

Jadi diameter kolom packed = $\frac{4,0498 + 4,2971}{2}$ = 4,1735 ft = 50,082 in

Luas penampang kolom = $\frac{\pi * D^2}{4} = \frac{\pi * 4,1735^2}{4}$ = 13,6798 ft^2

Menghitung tinggi kolom :

Dari McCabe, pers. 22.50 :

$$H = \left(\frac{G}{K_L a.C_B}\right) \ln \frac{Y_T}{Y_B}$$

Dimana : G = rate massa gas, lb/ft^2.jam

H = tinggi kolom, ft

C_B = rate volumetrik HNO_3, lb/ft^3

$K_L a$ = koefisien perpindahan massa fase liguid, jam^{-1}

Y_B = fraksi mol H_2O pada bagian bawah

Y_T = fraksi mol H_2O pada bagaian atas

$$G = \frac{40533,3841}{13,6798} = 2963,0099 \text{ lb/jam.ft}^2$$

$$K_L a = D_{AB} * \alpha * \left(\frac{L}{\mu_L}\right)^{1-n} * \left(\frac{\mu_L}{\rho * D_{AB}}\right)$$

$$D_{AB} = 1,173.10^{-16} (\varphi.M_B)^{1/2}.\frac{T}{\mu_L.\vartheta_A^{0,6}}$$

Dimana : D_{AB} = difusivitas gas NO_2 dalam air, m^2/s

ϑ_A = volume molar NO_2 pada titik didih, m^3/kmol

φ = association parameter dari air = 2,6

M_B = berat molekul air kg/kmol

L = rate massa air, lb/jam.ft^2

Dari Geankoplis, tab.6.3-2 :

$\vartheta_A = 0,0156 + 2\,(0,0074) = 0,0304$ m^3/kmol

$\mu_L = 0,8007.10^{-3}$ kg/m.s = 1,9369 lb/ft.jam

$$D_{AB} = 1,173.10^{-16}\,(2,6.18)^{1/2}.\frac{35+273}{0,8007.0,0304^{0,6}} = 2,5106.10^{-9}\ \text{m}^2/\text{s}$$

$= 9,7284.10^{-5}$ ft^2/jam

$\rho_L = 995,68$ kg/m^3 = 62,1579 lb/ft^3

$$\text{rate volumetrik} = \frac{2266,6344\ lb/jam}{62,1579\ lb/ft^3} = 36,4657\ \text{ft}^3/\text{jam}$$

$$L = \frac{2266,6344}{13,6798} = 165,6921\ \text{lb/jam.ft}^2$$

Untuk rasching ring 1,5 in harga $\alpha = 100$, n = 0,22

$$K_La = 9,7284.10^{-5} * 100 * \left(\frac{165,6921}{1,9369}\right)^{1-0,22} * \left(\frac{1,9369}{62,1579 * 9,7284.10^{-5}}\right)^{0,5}$$

$= 4,2563$ jam^{-1}

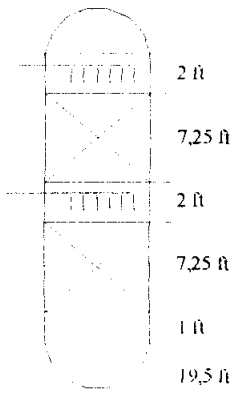
$$\text{Vcamp} = \frac{L_{camp}}{\rho_{camp}} = \frac{4175,3788\ lb/jam}{73,8704\ lb/ft^3} = 56,5230\ \text{ft}^3/\text{jam}$$

$$C_{HNO3} = \frac{2505,2273\ lb/jam}{56,5230\ ft^3/jam} = 44,3223\ \text{lb/ft}^3$$

$Y_B = 0,4$

$Y_T = 1$

$$H = \left(\frac{2963,0099}{2,2598 * 44,3223}\right)\ln\frac{1}{0,4} = 14,3917\ \text{ft} \approx 14,5\ \text{ft}$$



Menghitung pressure drop :

$$\frac{\Delta P}{z} = m.(10^{-8}).(10^{n.L/\rho L}).\frac{G^2}{\rho_G}$$

untuk rascinh ring 1,5 in harga m = 12,08, n = 0,00398

range $\frac{\Delta P}{Z} = 0 - 2{,}6$ lb/ft^2.ft

G = 2963,0099 lb/jam.ft^2

L = 165,6921 lb/jam.ft^2

ρ_G = 0,6853 lb/ft^3

ρ_L = 62,1579 lb/ft^3

$$\frac{\Delta P}{z} = 12{,}08 * (10^{-8}) * (10^{0{,}00398*165{,}6921/62{,}1579}) * \frac{2963{,}0099^2}{0{,}6853} = 1{,}5858 \text{ lb/ft}^2.\text{ft}$$

$\Delta P = 1{,}5858 * 14{,}3917 = 22{,}8231$ lb/ft^2

Menghitung tebal shell :

$P_{design} = 1{,}2 * P_{operasi}$

$P_{design} = 1{,}2 * 9{,}86 = 11{,}832$ atm = 173,8831 psia

Bahan konstruksi ferritic stainless steel type 430

Dari Perry ed.6 tabel. 23-11, f allow = 75.200 lb/in^2

E = 80 % (Double Welded Butt Joint)

$$ts = \frac{P.D}{2.f.E} + c$$ (Brownell & Young, pers.3.16)

$$= \frac{173{,}883\ lb/in^2 * 50{,}082\ in}{2 * 75.200\ lb/in^2 * 0{,}8} + 0$$

$$= 0{,}0724\ \text{in} \approx \frac{3}{16} in$$

Menghitung tebal tutup :

Dari Brownell & Young pers.7.57 :

$$t = \frac{P.d.V}{2.f.E - 0{,}2.P} + c$$

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

$$k = \frac{a}{b}$$

$$a = \frac{D}{2}$$

$$b = \frac{D}{4}$$

$$k = \frac{D}{2} * \frac{4}{D} = 2$$

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

$$t = \frac{P.d}{2.f.E - 0{,}2.P} + c$$

$$t = \frac{173,8831 * 50,082}{2 * 75200 * 0,8 - 0,2 * 173,8831} + 0 = 0,0724 \text{ in} \approx \frac{3}{16} \text{ in}$$

Menghitung kedalaman tutup :

ID = 50,082 in

$$OD = ID + 2.t = 50,082 + 2.\frac{3}{16} = 50,457 \text{ in}$$

Dari Brownell & Young table 5.11, hal. 94 :

sf = 3 in

$$b = \frac{50,082}{4} = 12,5205 \text{ in}$$

$$h = t + b + sf = \frac{3}{16} + 12,5205 + 3 = 15,708 \text{ in} = 1,309 \text{ ft}$$

Menghitung tinggi tangki keseluruhan :

Tinggi tangki = tinggi shell + 2.tinggi tutup

= 19,5 + 2 * 1,309 = 22,118 ft = 265,416

Spesifikasi alat :

Tipe : Packed tower

Dimensi : D = 50,082 in

H = 265,416 in

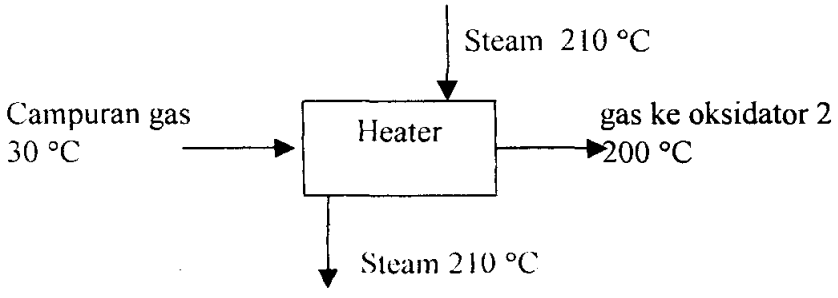
Tebal shell = tebal tutup = $\frac{3}{16}$ in

Tinggi packing : 14,5 ft

Bahan : ferritic stainless steel

Jumlah : 1

15. Heater (E – 233)



Fungsi : untuk memanaskan gas dari suhu 30 °C sampai 200 °C.

Tipe : shell and tube

Perhitungan berdasarkan Kern :

1. Neraca panas

   W steam = 835,1191 kg/jam = 1841,1036lb/jam

   w gas = 8381,2228 kg/jam = 18477,2438 lb/jam

   Q = 1585939671 J/jam = 1503174,863 btu/jam

2. Δt

   T_1 = 210 °C = 410 °F

   T_2 = 210 °C = 410 °F

   t_1 = 30 °C = 86 °F

   t_2 = 200 °C = 392 °F

   $\Delta t_1 = (T_2 - t_1) = 410 - 86 = 324$ °F

   $\Delta t_2 = (T_1 - t_2) = 410 - 392 = 18$ °F

$$\Delta t_{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}} \qquad (5.14)$$

$$\Delta t_{LMTD} = \frac{18-324}{\ln\frac{18}{324}} = 105{,}87\ ^\circ F$$

3. Tc dan tc

$$Tc = Tav = \frac{T_1+T_2}{2} = \frac{410+410}{2} = 410\ ^\circ F$$

$$tc = tav = \frac{t_1+t_2}{2} = \frac{392+86}{2} = 239\ ^\circ F$$

U_D = 2 – 50 btu/jam.ft^2.°F (Tabel 8)

Dipilih U_D = 35

$$A = \frac{Q}{U_D * \Delta t} = \frac{1503174{,}863}{35*105{,}87} = 405{,}6659\ ft^2$$

Digunakan :

OD tube = 1 in, 10 BWG

ID tube = 0,732 in

L = 12 ft

a'' = 0,2618 ft^2/ft

Jumlah tube = Nt = $\frac{A}{a''*L} = \frac{405{,}6659}{0{,}2618*12} = 129{,}1272$

Dari table 9 untuk square pitch :

Passes = 2

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

Nt = 132 tube

ID shell = $19\frac{1}{4}$ in

U_D terkoreksi $= \frac{Nt}{Nt_{std}} * U_D = \frac{129,1272}{132} * 35 = 34,2383$ btu/jam.ft^2.°F

Fluida dingin : bagian shell, gas	Fluida panas : bagian tube, steam
4'. $B = \frac{1}{5} * 19,25 = 3,85$ in $C' = P_T - OD = 1\frac{1}{4} - 1 = \frac{1}{4}$ in as $= \frac{ID * C' * B}{144 * P_T}$ as $= \frac{19,25 * 0,25 * 3,85}{144 * 1,25}$ $= 0,1029$ ft^2 5'. Gs $= \frac{W}{as} = \frac{18477,2438}{0,1029}$ $= 179565,0515$ lb/jam.ft^2 6'. Pada tc = 239 °F $\mu = 0,0235 * 2,42$ (fig.15) $= 0,05687$ lb/ft.jam De $= \frac{0,99}{12} = 0,0825$ ft (fig. 28) Res $= \frac{De * Gs}{\mu}$ $= \frac{0,0825 * 179565,0515}{0,05687}$ $= 260490,8871$	4. a't $= 0,421$ in^2 (table 10) at $= \frac{Nt * a't}{144 * n} = \frac{132 * 0,421}{144 * 2}$ $= 0,1930$ ft^2 5. Gt $= \frac{W}{at} = \frac{1840,1036}{0,1930}$ $= 9534,2155$ lb/jam.ft^2 V $= \frac{Gt}{3600.\rho} = \frac{9534,2155}{3600 * 62,5}$ $= 0,0424$ ft/s 6. Pada Tc = 410 °F $\mu = 0,0165 * 2,42$ (fig.15) $= 0,03993$ lb/ft.jam D $= \frac{0,732}{12} = 0,061$ ft (table 10) Ret $= \frac{D * Gt}{\mu}$

7'. $j_H = 320$ (Fig. 28)

8'. Pada tc = 239 °F

k = 0,0289 btu/jam.ft^2(°F/ft)

c = 0,25 btu/lb.°F

$$\left[\frac{c*\mu}{k}\right]^{\frac{1}{3}} = \left[\frac{0,25*0,05687}{0,0289}\right]^{\frac{1}{3}}$$

$$= 0,7894$$

9'. $$\frac{ho}{\phi s} = j_H \cdot \frac{k}{De}\left[\frac{c.\mu}{k}\right]^{\frac{1}{3}}$$

$$= 320.\frac{0,0289}{0,0825}.0,7894$$

= 88,4917 btu/jam.ft^2.°F

11'. Pada tw = 309,60 °F

μ_w = 0,022 * 2,42 (Fig.15)

μ_w = 0,05324 lb/ft.jam

$$\phi s = \left[\frac{\mu}{\mu w}\right]^{0.14} = \left[\frac{0,05687}{0,05324}\right]^{0,14}$$

= 1,0093

$$Ret = \frac{0,061*9534,2155}{0,03993}$$

Ret = 14565,1677

9. $\frac{hi}{\phi t}$ = 85 btu/jam.ft^2.°F (Fig.25)

$$\frac{hio}{\phi t} = hi*\frac{ID}{OD} = 85*\frac{0,732}{1}$$

= 62,22 btu/jam.ft^2.°

10. $$tw = tc + \frac{\frac{hio}{\phi s}}{\frac{hio}{\phi t}+\frac{ho}{\phi s}}(Tc - tc)$$

$$= 239 + \frac{62.22}{62,22+88,4917}$$

(410 – 239)

= 309,60 °F

11. Pada tw = 309,6 °F

μ_w = 0,014 * 2,42 (Fig. 15)

= 0,03388 lb/ft.jam

	$\phi t = \left[\frac{\mu}{\mu w}\right]^{0,14} = \left[\frac{0,03993}{0,03388}\right]^{0,14}$ = 1,0234
12'. ho = 88,4917 * 1,0093 = 89,3126 btu/jam.ft^2.°F	12. hio = 62,22 * 1,0234 = 63,6759 btu/jam.ft^2.°F

13. $Uc = \frac{hio * ho}{hio + ho} = \frac{63,6759 * 89,3126}{63,6759 + 89,3126} = 37,1732$ btu/jam.ft^2.°F

14. $Rd = \frac{U_C - U_D}{U_C * U_D} = \frac{37,1732 - 34,2383}{37,1732 * 34,2383} = 0,002306$ ft^2.jam.°F/btu

Perhitungan pressure drop :

1'. Untuk Res = 260490,8871 f = 0,00105 ft^2/in^2 (Fig. 29) s = 0,68 (tabel 6)	1. Untuk Ret = 14565,1677 f = 0,00027 (Fig. 26) s = 1 (table. 6)
2'. $N + 1 = 12 * \frac{L}{B} = 12 * \frac{12}{3,85}$ = 37,4026 $Ds = \frac{19,25}{12} = 1,6042$ *ft*	2. $\Delta Pt = \frac{f.Gt^2.L.n}{5,22.10^{10}.D.s.\phi t}$ $= \frac{0,00027.9534,2155^2.12.2}{5,22.10^{10}.0,061.1.1,0234}$ = 1,8076.10^{-4} psi
3'. $\Delta Ps = \frac{f.Gs^2.Ds.(N+1)}{5,22.10^{10}.De.s.\phi s} =$ $\frac{0,00105.179565,0515^2.1,6042.37,4026}{5,22.10^{10}.0,0825.0,68.1,0093}$ = 0,6873 psi	3. Gt = 9534,2155 $\frac{V^2}{2 * g'} = 0,0012$ (Fig. 27)

	$\Delta Pr = \frac{4*n}{s} * \frac{V^2}{2g'} = \frac{4*2}{1} * 0{,}0012$ $= 0{,}0096$ $\Delta P_T = \Delta Pt + \Delta Pr$ $= 1{,}8076.10^{-4} + 0{,}00096$ $= 9{,}7808.10^{-3}$

Spesifikasi :

Tipe : 1 – 2 Shell and Tube

Jumlah tube : 132

U_D : 34,2383 btu/jam.ft^2.°F

U_C : 37,1732 btu/jam.ft^2.°F

ΔPs : 0,6873 psi

ΔP_T : 9,7808.10^{-3} psi

Jumlah : 1

16. Ekspander (G-311)

Fungsi : untuk menurunkan tekanan HNO_3 dari 9,86 atm menjadi 1 atm

Tipe : Ekspander liguid

P_1 = 9,86 atm = 9,9906 bar

P_2 = 1 atm = 1,01325 bar

Massa lar. HNO_3 = 3156,5657 kg/jam = 0,8768 kg/s

Dari Perry 6th ed, tab. 3-66, hal 3-81 :

ρ_{HNO3} = 1,3533 gr/cm^3 = 1353,3 kg/m^3

ρH_2O = 995,647 kg/m^3

$$\rho \text{ lar } NH_3 = \frac{1}{\frac{xHNO_3}{\rho HNO_3} + \frac{xH_2O}{\rho H_2O}} = \frac{1}{\frac{0,6}{1353,3} + \frac{0,4}{995,647}} = 1183,2786 \text{ kg/m}^3$$

asumsi efisiensi = 50 %

Dari Ulrich, pers. 4-19 :

$$Ws = \frac{\varepsilon * m * (P_1 - P_2)}{\rho}$$

$$Ws = \frac{0,5 * 0,8768 \ kg/s * (9,9906 - 1,01325) \ bar * 100000 \ j/bar.m^3)}{1183,2786 \ kg/m^3}$$

= 365,8779 watt = 0,0362 hp ≈ 0,5 hp

Spesifikasi :

Tipe : Ekspander liguid

Daya motor : 0,5 hp

Bahan : stainless steel

Jumlah : 1

17. Tangki HNO_3 (F-310)

Fungsi : untuk menyimpan produk HNO_3

Tipe : tangki silinder tegak dengan tutup atas dan bawah berbentuk elliptical dished head.

Kondisi operasi :

Tekanan, P = 1 atm = 14,696 psia

Temperature, T = 30 °C

ρ HNO_3 = 1,3533 gr/cm^3 = 1353,3 kg/m^3

ρ H_2O = 995,647 kg/m^3

$$\rho \text{ lar } HNO_3 = \frac{1}{\frac{xHNO_3}{\rho HNO_3} + \frac{xH_2O}{\rho H_2O}} = \frac{1}{\frac{0,6}{1353,3} + \frac{0,4}{995,647}} = 1183,2786 \text{ kg/m}^3$$

$$= 73,8693 \text{ lb/ft}^3$$

Direncanakan :

- Untuk persediaan selama 7 hari = 168 jam
- 2 tangki

massa larutan HNO_3 = 1893,9394 kg/jam = 4175,3788 lb/jam

$$\text{rate volumetrik} = \frac{4175,3788}{73,8693} = 56,5239 \ ft^3 / jam$$

$$\text{Volume larutan total} = \frac{56,5239 \ ft^3 / jam * 168 \ jam}{2} = 4748,0052 \text{ ft}^3$$

Volume larutan = 80 % volume tangki

$$\text{Volume tangki} = \frac{4748,0052 \ ft^3}{0,8} = 5935,0065 \ ft^3$$

Diambil H = 2 D

$$V = 0,000075.D^3 + \frac{\pi.D^2.H}{4} + 0,000076.D^3$$

$$5935,0065 = \frac{\pi.D^3}{2} + 0,000152.D^3$$

D = 15,5747 ft = 186,8964 in

H = 31,1494 ft = 373,7929 in

Menentukan tekanan hidrostatik :

$$P_{hidrostatik} = \frac{\rho.h}{144}$$

$$h = \text{tinggi liguid} = \frac{Vol.laru\tan\ HNO_3 - 0{,}000076.D^3}{\frac{\pi.D^2}{4}}$$

$$= \frac{4748{,}0052\ ft^3 - 0{,}000076*15{,}5747^3\ ft^3}{\frac{\pi*15{,}5747^2\ ft^2}{4}} = 25{,}8112 \text{ ft}$$

$$P_{hidrostatik} = \frac{73{,}8693\ lb/ft^3 * 25{,}8112\ ft}{144} = 13{,}2407\ lb/in^2$$

$P = 14{,}696 + 13{,}2407 = 27{,}9367$ lb/in^2

$P_{design} = 1{,}2 * 27{,}9367 = 33{,}5240$ lb/in^2

Menghitung tebal shell :

Bahan konstruksi ferritic stainless steel type 430

Dari Perry ed.6 tabel. 23-11, f allow = 75.200 lb/in^2

E = 80 % (Double welded butt joint)

$$ts = \frac{P.r}{f.E - 0{,}6.P} + c$$ (Brownell & Young, pers.13.1)

$$ts = \frac{33{,}524.\frac{186{,}8964}{2}}{75200.0{,}8 - 0{,}6.33{,}524} + 0 = 0{,}0539 \text{ in} \approx \frac{3}{16} \text{in}$$

Menghitung tebal tutup :

Dari Brownell & Young pers.7.57 :

$$t = \frac{P.d\,V}{2.f.E - 0{,}2.P} + c$$

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

$$k = \frac{a}{b}$$

$$a = \frac{D}{2}$$

$$b = \frac{D}{4}$$

$$k = \frac{D}{2} * \frac{4}{D} = 2$$

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

$$t = \frac{P.r}{2.f.E - 0,2.P} + c$$

$$t = \frac{33,524 * 186,8964}{2 * 75200 * 0,8 - 0,2 * 33,524} + 0 = 0,0539 \text{ in} \approx \frac{3}{16} \text{ in}$$

Menghitung kedalaman tutup :

ID = 186,8964 in

$$OD = ID + 2.t = 186,8964 + 2.\frac{3}{16} = 187,2714 \text{ in}$$

Dari Brownell & Young table 5.11, hal. 94 :

sf = 3 in

$$b = \frac{186,8964}{4} = 48,3942 \text{ in}$$

$$h = t + b + sf = \frac{3}{16} + 48,3942 + 3 = 51,5817 \text{ in}$$

Menghitung tinggi tangki keseluruhan :

Tinggi tangki = tinggi shell + 2.tinggi tutup

= 373,7929 + 2 * 51,5817 = 476,9563 in

Spesifikasi alat :

Tipe : tangki vertikal dengan tutup berbentuk elliptical dished head.

Kapasitas : 4748,0052 ft^3/minggu

Bahan konstruksi : ferritic stainless steel

Jumlah : 1

Dimensi tangki : Diameter tangki (OD) = 187,2714 in

Tinggi shell = 3737929, in

Tebal shell = tebal tutup = $\frac{3}{16}$ *in*

Tinggi tutup atas = tutup bawah = 51,5817 in

18. Pompa (L-213)

Fungsi : mengalirkan leburan garam ke oksidator 1

Tipe : screw – pump

ρ_{KCl} = 1,1354 gr/cm^3 = 70,8815 lb/ft^3

μ = 1,2514.10^{-3} cp = 0,00085 lb/ft . s

Massa KCL = 7532,8457 kg/jam = 16606,9116 lb/jam = 4,6030 lb/dt

Rate KCl = $\frac{4,6030\ lb/dt}{70,8815\ lb/ft^3}$ = 0,06508 ft^3/dt

Asumsi aliran turbulen

Dari Peters & Timmerhaus ed. 4, hal. 496 :

Di optimum = 3,9 * (qt) ^{0,45} * (ρ) ^{0,13}

Di optimum = 3,9 * (0,06508) ^{0,45} * (70,8815) ^{0,13} = 1,9847 in

Dari Kern tab. 11 :

Dipilih steel pipe (IPS) berukuran 2 in sch. 40 :

ID = 2,067 in = 0,1723 ft

OD = 2,38 in

A = 3,35 in^2 = 0,02326 ft^2

$$\text{Kecepatan linear} = \frac{0{,}06508\ ft^3/dt}{0{,}02326\ ft^2} = 2{,}7975 \text{ ft/dt}$$

$$N_{Re} = \frac{\rho * v * ID}{\mu} = \frac{70{,}8815\ lb/ft^3 * 2{,}7975\ ft/dt * 0{,}1723\ ft}{0{,}00085\ lb/ft.dt}$$

= 186479,4207 (memenuhi syarat)

Aliran turbuien, maka $\alpha = 1$

Dengan mempergunakan persamaan Bernoulli :

Dari Geankoplis pers. 2.7 - 28:

$$\frac{1}{2*\alpha*gc}*(v_2^2 - v_1^2) + \frac{g}{gc}*(Z_2 - Z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0$$

Perhitungan ΣF :

1. Losses karena kontraksi , hc

$$Kc = 0{,}55 * (1 - \frac{A_2}{A_1})$$

Dimana : A_1 = luas penampang tangki

A_2 = luas penampang pipa

Karena $A_1 >>> A_2$ maka (A_2/A_1) diabaikan

Kc = 0,55 x (1 – 0) = 0,55

$$hc = Kc * \frac{v^2}{2*\alpha*gc} = 0{,}55 * \frac{2{,}7975^2}{2*1*,32{,}174} = 0{,}0669$$

2. Losses karena friksi pada pipa lurus, Ft

Digunakan pipa commersial steel ε = 0,00015 ft

$$\frac{\varepsilon}{D} = \frac{0,00015}{0,1723} = 0,00087$$

Dari Geankoplis ed. 3 fig. 2.10-3 diperoleh f = 0,0045

Penafsiran panjang pipa lurus (ΔL) = 20 m = 65,616 ft

$$Ft = 4 * f * \frac{\Delta L}{D} * \frac{v^2}{2 * g_c}$$

$$= 4 * 0,0045 * \frac{65,616}{0,1723} * \frac{2,7975^2}{2 * 32,174} = 0,8339$$

3. Losses karena friksi pada elbow dan valve, hf

Terdapat 3 buah elbow 90°, 1 gate valve dan 1 globe valve

Dari Geankoplis ed. 3 tabel 2.10 – 1 :

$K_f = 3 * 0,75 + 0,17 + 6 = 8,42$

$$h_f = K_f * \left(\frac{v^2}{2 * \alpha * g_c} \right)$$

$$= 8,42 * \left(\frac{2,7975^2}{2 * 1 * 32,174} \right) = 1,024$$

ΔP = 0

ΣF = 1,9246 ft lbf/lbm

$$-W_s = \frac{1}{2 \cdot \alpha \cdot gc} * (\Delta v^2) + \frac{g}{gc} * (\Delta z) + \frac{\Delta P}{\rho} + \sum F$$

$\Delta v^2 = (2,7975^2 - 0) = 7,8260 \text{ ft}^2 / \text{dt}^2$

ΔZ = 5 m = 16,404 ft

$$-Ws = \frac{1}{2*1*32,174} * 7,826 + \frac{32,174}{32,174} * 16,404 + 0 + 1,9246$$

$$= 18,4502 \text{ lbf/lbm}$$

Dari Peter's & Timmerhaus ed. 4 fig. 14 – 37 :

Efisiensi pompa (η) = 70 %

Dari Geankoplis ed. 3 pers. 3.3 – 2 :

$$\text{Brake hp} = \frac{-w_s \cdot m}{\eta \cdot 550}$$

$$\text{Brake hp} = \frac{18,4502 \ \ ft.lbf/lbm * 4,6030 \ \ lbm/dt}{0,70 * 550 \ \ ft.lbf/s.hp} = 0,2206 \text{ hp}$$

Dari Peters & Timmerhaus ed. 4 fig. 14 – 38 :

Efisiensi motor = 80 %

$$\text{Sehingga dipakai pompa dengan motor} = \frac{0,2206}{0,8} = 0,2757 \approx 0,5 \text{ hp}$$

Spesifikasi :

Fungsi : mengalirkan air dari sand filter ke bak penampungan air bersih

Tipe : centrifugal pump

Rate aliran pompa : 0,8137 ft^3/dt

Power motor : 6,5 hp

Bahan konstruksi : carbon steel

Jumlah : 1 buah

19. Ekspander (G-250)

Fungsi : untuk menurunkan tekanan gas buang dari 9,86 atm menjadi 1 atm

P_1 = 9,86 atm = 9,9906 bar

P_2 = 1 atm = 1,01325 bar

N_2 = 8017,2928 kg = 286,3319 kmol

O_2 = 46,3998 kg = 1,4500 kmol

NO = 262,9430 kg = 8,7648 kmol

NO_2 = 54,5872 kg = 1,1867 kmol

Jumlah gas masuk = 8381,2228 kg/jam = 2,2381 kg/s

Dari Smith & Van Ness, pers. 3.46 :

$Z = Z^0 + \omega.Z'$

$$Tr = \frac{T}{Tc}$$

$$Pr = \frac{P}{Pc}$$

Harga Z^0 dan Z' diperoleh dari Smith & Van Ness tabel E.1 dan E.2 :

Komponen	Tr	Pr	Z^0	Z'	ω
O_2	2	0,2	0,9944	0,0155	0,02
N_2	2,4	0,29	0,9979	0,0198	0,038
NO	1,70	0,15	0,9915	0,0122	0,583
NO_2	0,99	0,14	0,9499	-0,0112	0,141

Z_{O2} = 0,9947

Z_{N2} = 0,9987

Z_{NO} = 0,9986

Z_{NO2} = 0,9482

BM gas = 28,15

$$\rho_{gas} = \frac{BM}{V} * \frac{P_1}{P_0} * \frac{T_0}{T_1}$$

$$= \frac{28,15}{359} * \frac{9,86}{1} * \frac{273}{273+30} = 0,6966 \text{ lb/ft}^3 = 11,1584 \text{ kg/m}^3$$

asumsi efisiensi = 50 %

Dari Ulrich, pers. 4-19 :

$$Ws = \frac{\varepsilon * m * (P_1 - P_2)}{\rho}$$

$$Ws = \frac{0,5 * 2,3281 \ kg/s * (9,9906 - 1,01325) \ bar * 100000 \ j/bar.m^3)}{11,1584 \ kg/m^3}$$

= 93651,7619 watt = 125,5891 hp ≈ 126 hp

Spesifikasi :

Tipe : Ekspander

Daya motor : 126 hp

Bahan : stainless steel

Jumlah : 1

APPENDIKS D

PERHITUNGAN ANALISA EKONOMI

APPENDIK D

PERHITUNGAN ANALISA EKONOMI

Harga alat akan berubah setiap saat tergantung pada kondisi ekonomi dan politik, untuk itu dibutuhkan suatu metode yang dapat dipakai untuk mengkonversi harga alat pada beberapa tahun yang lalu agar dapat diperoleh harga alat yang ekivalen pada saat ini.

Ekivalensi itu dapat dihitung dengan menggunakan persamaan :

$$\text{Harga alat tahun ini} = \frac{\textit{indeks harga saat ini}}{\textit{indeks harga tahun A}} \text{ x harga alat tahun A}$$

Harga alat pada tahun A diperoleh dari literatur Peters & Timmerhaus.

Sedangkan indeks harga tersebut adalah :

Chemical Engineering Plant cost index

- Tahun A (Januari 1990) = 356 (tabel 3, hal 163, Peters & Timmerhaus)
- Saat ini (Januari 2002) = 394,3 (Chemical Engineering, Januari 2002)

D.1. Perhitungan Harga Peralatan

Contoh perhitungan :

Tanki penampung NH_3 (F-110)

Kapasitas = 2617,9574 ft^3 = 19582,3214 gal

Harga Januari 1990 = $ 110.000 (fig 14-56, hal 539, Peters & Timerhaus)

$$\text{Harga alat saat ini} = \frac{394,3}{356} x110000 = \$\ 121.834,27$$

Jumlah = 2 buah

Total harga = $ 121.834,27 x 2 = $ 243.668,54

Dengan cara yang sama didapatkan harga alat yang lain seperti pada tabel I.1.1.

Tabel D.1.1 Harga Peralatan Proses

No.	Nama alat	Kode	Jumlah	Harga, $
1	Tangki penampung NH_3	F-110	2	243.668,54
2	Pompa 1	L-213	1	1.107,58
3	Filter udara	H-120	2	42.075,84
4	Kompresor	G-121	1	126.265,63
5	Ekspander	G-111		28.262,51
6	Furnace	Q-211		221.516,85
7	Oksidator 1	R-210	1	332.275,28
8	Bag filter	H-220	2	96.733,72
9	Cooler	E-214	1	73.844,80
10	Tangki leburan KCl	F-212	1	238.256,63
11	Blower	G-231	1	32.125,54
12	Oksidator 2	E-230	1	115.659,23
13	Condensor	E-232	1	67.850,98
14	Blower	G-241	1	32.125,54
15	Absorber	D-240	1	649.111,72
16	Heater	E-233	1	136.254,22
17	Ekspander	G-250	1	45.265,66
18	Tanki penampung HNO3	F-310	3	275.592,70
19	Ekspander	G-311	1	54.254,54
	Total harga alat			2.738.402,793

Tabel D.1.2. Harga Peralatan Utilitas

No.	Nama Alat	Kode	Jumlah	Harga, $
1	Tangki sand filter	H – 315	2	20.522,56
2	Tangki demineralisasi	D – 320	2	42.088,20
3	Tangki koagulator dan flokulator	H – 313	1	26.718,75
4	Pompa air sumur	L – 310	1	1.100,05
5	Pompa air ke bak koagulator	L – 312	1	1.100,05
6	Pompa air ke bak air bersih	L – 316	1	1.210,24
7	Pompa	L – 318	1	1.250,66
9	Pompa air pendingin	L – 322	1	1.210,24
10	Pompa air proses	L – 330	1	1.210,24
11	Pompa air sanitasi	L – 328	1	1.120,13
12	Pompa umpan air boiler	L – 329	1	1.120,13
13	Cooling tower	E – 363	1	37.520,53
14	Generator		1	41.200,57
15	Boiler		1	15.482,81
16	Tangki bahan bakar		1	10.900,55
	Total harga alat			204.396,44

Tabel D.1.3. Bak Utilitas

No.	Nama Peralatan	Kode	Jumlah	Luas, m^2
1	Bak air sumur	F – 311	1	392
2	Bak air bersih	F – 317	1	392
3	Bak penampung air demineralisasi	F – 324	1	32
4	Bak air pendingin	F – 323	1	162
5	Bak air proses	F – 326	1	18
6	Bak air sanitasi	F – 319	1	15,75
7	Bak air umpan boiler	F – 327	1	15,75
	Total			1027,5

Harga bak = Rp. 300.000,-/m^2

Total harga bak utilitas = (Rp. 300.000,- / m^2) * 1027,5 m^2 = Rp. 361.950.000,-

Total harga peralatan = $ 2.738.402,793 + $ 204.396,44 + Rp. 361.950.000,-

= ($ 2.942.799,233 x Rp. 9000,-/$) + Rp. 361.950.000,-

= Rp. 26.847.143.100,-

D.2. Perhitungan Harga Tanah dan Bangunan

Luas tanah = 10.000 m^2

Harga tanah = Rp. 500.000 / m^2

Harga total tanah = 10.000 x Rp. 500.000

= Rp. 5.000.000.000,-

Luas bangunan kantor = 350 m^2

Harga bangunan = Rp.1.000.000,-

Harga total bangunan = Rp. 350.000.000,-

Luas bangunan lain – lain = 3254 m^2

Harga bangunan lain – lain = Rp. 500.000,-

Harga total bangunan lain – lain = Rp. 1.627.000.000,-

Luas Pabrik dan gudang = 950 m^2

Harga bangunan pabrik = Rp. 800.000,-

Harga total bangunan pabrik = Rp. 760.000.000,-

Harga total tanah dan bangunan = Rp. 5.000.000.000 + Rp. 350.000.000 +
Rp. 1.627.000.000 + Rp. 760.000.000
= Rp. 7.737.000.000,-

D.3. Perhitungan Harga Bahan Baku dan Produk

1. Harga Bahan baku

- NH_3

  Harga = Rp. 4.250,- / kg

  Kebutuhan = 17.091,396 kg / hari

  Total = Rp. 72.638.433 / hari = Rp. 23.970.682.890,- / tahun

- Katalis Pt

  Harga = Rp. 50.000.000,- / kg

  Kebutuhan = 7,2571 kg / 7 hari

  Total = Rp. 362.855.000 / 7 hari = Rp. 17.106.021.430,- / tahun

- KCl

  Harga = Rp. 1750 ,- / kg

  Kebutuhan = 376,6423 kg/tahun

  Total = Rp. 659.124,025,- / tahun

Total harga bahan baku per tahun = Rp. 23.970.682.890 + Rp. 17.106.021.430 +

Rp. 659.124,025

= Rp. 41.077.363.440,-

2. Harga jual produk :

   HNO_3

   Harga = Rp. 9.250,- / kg

   Produksi = 1893,9394 kg / jam = 45454,5456 kg / hari

   Total = Rp. 420.454.546,- / hari

   = Rp. 138.750.000.000,- / tahun

D.4. Perhitungan Gaji Karyawan

No	Jabatan	Jumlah	Upah./bulan, Rp	Total, Rp
1	Direktur Utama	1	10.000.000	10.000.000
2	Direktur Teknik dan Produksi	1	7.500.000	7.500.000
3	Direktur Administrasi & Keuangan	1	7.500.000	7.500.000
4	Sekretaris	3	1.750.000	5.250.000
5	Kabag Produksi	1	5.000.000	5.000.000
6	Kabag Teknik	1	5.000.000	5.000.000
7	Kabag Umum	1	5.000.000	5.000.000
8	Kabag Pemasaran	1	5.000.000	5.000.000

9	Kabag Administrasi & Keuangan	1	5.000.000	5.000.000
10	Kasie Proses	1	3.000.000	3.000.000
11	Kasie Utilitas	1	3.000.000	3.000.000
12	Kasi Laboratorium	1	3.000.000	3.000.000
13	Kasi Maintenance	1	3.000.000	3.000.000
14	Kasi Personalia	1	3.000.000	3.000.000
15	Kasi Keamanan	1	3.000.000	3.000.000
16	Kasi Pemasaran	1	3.000.000	3.000.000
17	Kasi Gudang	1	3.000.000	3.000.000
18	Kasi Keuangan	1	3.000.000	3.000.000
19	Karyawan Proses	36	1.000.000	36.000.000
20	Karyawan Utilitas	16	1.000.000	16.000.000
21	Karyawan Laboratorium	8	1.000.000	8.000.000
22	Karyawan Maintenance	12	1.000.000	12.000.000
23	Karyawan Personalia	4	1.000.000	4.000.000
24	Karyawan Keamanan	16	1.000.000	16.000.000
25	Karyawan Pemasaran	6	1.000.000	6.000.000
26	Karyawan Gudang	12	800.000	9.600.000
27	Karyawan Keuangan	3	1.000.000	3.000.000
28	Karyawan Litbang	1	1.000.000	1.000.000
29	Sopir	4	1.000.000	4.000.000
30	Tukang kebun	2	600.000	1.200.000
	Total =	140		199.050.000

Gaji karyawan per bulan = Rp. 199.050.000,-

Ditetapkan satu tahun produksi adalah 12 bulan ditambah 1 bulan tunjangan untuk hari raya. Jadi gaji karyawan per tahun adalah = Rp. 199.050.000 * 13 bulan

= Rp. 2.587.650.000,-

D.5. Perhitungan Biaya Utilitas

1. Kebutuhan resin

   Kebutuhan Zeolit = 73,7678 * 2 = 147,5356 kg/tahun

   Harga Zeolit = Rp. 2500,-

   Biaya Zeolit per tahun = Rp. 368.839,-

2. Kebutuhan tawas

   Kebutuhan tawas per hari = $0{,}7873\ kg * \frac{60\ menit}{jam} * \frac{1}{25\ menit} * 24\ jam$

   = 45,3485 kg

   Harga tawas = Rp. 3000 / kg

   Biaya alum per tahun = Rp. 3000 * 45,3485 * 330

   = Rp. 44.894.995,2,-

3. Kebutuhan listrik

   Kebutuhan listrik total = 684,9143 KW

   Biaya beban per bulan = Rp. 150.000,-

   Biaya beban per tahun = 12 bulan * Rp. 150.000,- / bulan

   = Rp. 1.800.000,-

   Biaya listrik · WBP = Rp. 950,- / KW (pk. 18.00 – 22.00)

   LWBP = Rp. 775,- / KW (pk. 22.00 – 18.00)

Biaya listrik terpakai per tahun :

= [((4 jam * 666,0383 KW * Rp. 950,- / KW) + (20 jam * 666,0383 KW * Rp. 775,- / KW)) * 330 hari / tahun] + [((4 jam * 15,73 KW * Rp.950,- / KW + (20 jam * 15,73 KW * Rp.775,- / KW)) * 365 hari / tahun]

= Rp. 4.352.807.918,-

Biaya listrik total per tahun = biaya beban + biaya listrik terpakai

= Rp. 1.800.000,- + Rp. 4.352.807.918,-

= Rp. 4.354.607.918,-

4. Kebutuhan bahan bakar

Kebutuhan bahan bakar IDO per bulan = 44.537,4058 lt

Harga bahan bakar per liter = Rp. 1.860,-

Biaya bahan bakar per tahun = 44.537.4058 lt / bln * 12 bln / th x Rp.1.860/lt

= Rp. 994.074.897,5,-

Kebutuhan bahan bakar LNG per bulan = 467.628,984 kg

= 1135,0218 m^3 = 1.135.021,806 lt

Harga bahan bakar per liter = Rp. 650,-

Biaya bahan bakar per tahun = 1.135.021,806 lt / bln * 12 bln / th x Rp.650,

= Rp. 8.853.170.087,-

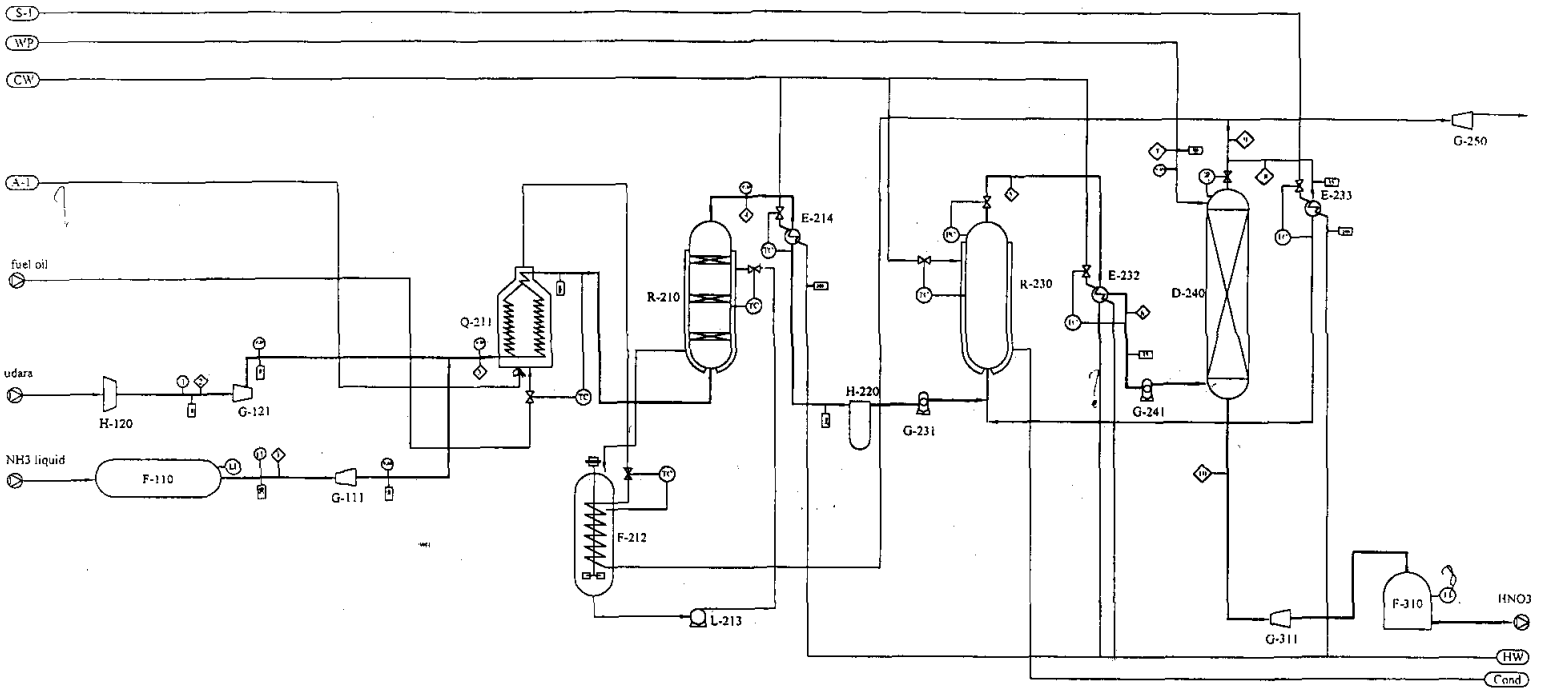
Biaya total bahan bakar = Rp. 994.074.897,5 + Rp. 8.853.170.087

= Rp. 9.847.244.985,-

Total biaya utilitas per tahun :

= Rp. 368.839 + Rp. 44.894.995,2 + Rp. 4.354.607.918 + Rp. 9.847.244.985

= Rp. 14.248.182.270,-



	1	2	3	4	5	6	7	8	9	10
N2	3.3607	7990.3906	7993.9514	8017.2928	16034.5857	16034.5857		8017.2938	8017.2928	
O2		2427.4604	2427.4604	786.8874	92.7996	92.7996		46.3998	46.3998	
H2O uap				1125.3931	1125.3931			262.9430	262.9430	
NO					74.9481	74.9481				
NO2					2183.4890	2183.4890		54.5872	54.5872	
HNO3										1893.9194
NH3	708.3808		708.3808							
H2O cair						1125.3931	1533.1890			1261.6263

Lambang	Keterangan
◇	Nomor Aliran
⬭	Tekanan, atm
▭	Suhu, C