LAMPIRAN A

LAMPIRAN

PERHITUNGAN REAKTOR

Kode : R – 01

Fungsi : Mereaksikan Aluminium Klorida ($AlCl_3$) 92709.3916 kg/jam dan Oksigen (O_2) 16681.0859 kg/jam menghasilkan produk akhir Aluminium Oksida (Al_2O_3) 34722.2222 kg/jam dengan produk samping Klorin (Cl_2) 72445.7330 kg/jam

Jenis : Reaktor Alir Pipa (RAP)

Bahan Konstruksi : *Stainless Steel SA 167 Grade 3 Type 304*

Kondisi Operasi : (US 6,521,203 B1 dan US 9,382,600 B2)

Temperatur, T : 500^0C

Tekanan, P : 24,67 atm

Konversi, X : 98%

Residence Time, (τ) : 1 jam = 60 menit

1) Perhitungan Neraca Massa Reaktor

Reaksi di Reaktor adalah sebagai berikut :

$$2AlCl_{3\,(g)} + \frac{3}{2} O_{2\,(g)} \longrightarrow Al_2O_{3\,(s)} + 3\,Cl_{2\,(g)}$$

Tabel A.1. Neraca Massa *Reaktor* (R – 01)

KOMPONEN	INPUT		OUTPUT
	ARUS 3	ARUS 4	ARUS 5
AlCl3	92709.3916		1887.2851
O2		16681.0859	335.2372
Al2O3			34722.2222
Cl2			72445.7330
N2	62752.6909		62752,6909
SUB TOTAL	155462.0825	16681.0859	**172143.1684**
TOTAL	**172143.1684**		**172143.1684**

2) Perhitungan Neraca Panas

Panas umpan : Tref = 25^0C = 298 K

Tin = 500^0C = 773 K

- Panas feed masuk R – 01 dari F – 02

Komponen	Fi	BM	ni	$\int$Cp.dT	$\Delta H = ni\int Cp.dT$
	(kg/jam)		(kmol/jam)	(kJ/kmol.K)	(kJ/jam)
N2	62752.6909	28.0000	2241.1675	13844.4867	31027814.1877
AlCl3	92709.3916	133.3400	695.2857	30162.9296	20971852.7811
Total					51999666.9688

- Panas feed masuk R – 01 dari F – 03

Komponen	Fi	BM	ni	∫Cp.dT	ΔH = ni∫Cp.dT
	(kg/jam)		(kmol/jam)	(kJ/kmol.K)	(kJ/jam)
O2	33362.2630	32.0000	1042.5707	14008.8988	14605267.7570
Total					14605267.7570

- Panas reaksi pembentukan terdiri dari :

$$2AlCl_{3\,(g)} + \frac{3}{2} O_{2\,(g)} \longrightarrow Al_2O_{3\,(s)} + 3\,Cl_{2\,(g)}$$

$\Delta Hof = \Delta H^0_f P - \Delta H^0_f R$

Data Heat of formation (ΔHof) pada 25^0C Data Entalpi :

$\Delta H^0 f\ AlCl_3$ = - 584,5048 kJ/mol

$\Delta Ho^0 f\ O_2$ = 0

$\Delta H^0 f\ Al_2O_3$ = -2506,5926 kJ/mol

$\Delta H^0 f\ Cl_2$ = 0

Pada T = 298 K

Panas umpan masuk (reaktan) :

Komponen	n	ΔHof	n . ΔHof
	(kmol/jam)	(kJ/mol)	(kJ/jam)
AlCl3	695.2857	-584.5048	-406397.8130
O2	1042.5707	0.00	0.0000
Total			-406397.8130

Panas umpan keluar (produk) :

Komponen	n	ΔHof	n . ΔHof
	(kmol/jam)	(kJ/mol)	(kJ/jam)
Al2O3	681.2286	-2506.5926	-1707562.5913
Cl2	884.9625	0.00	0.0000
Total			-1707562.5913

ΔH^0_f = ΔH^0_f Produk - ΔH^0_f Reaktan

= -1.707.562,5913 – (-40.6397,8130)

= -1.301.164,7782 kJ/jam

Panas pembentukan reaktan T = 773 K

Komponen	n	∫Cp dt	ΔH = ni∫Cp.dT
	(kmol/jam)	(kJ/kmol.k)	(kJ/jam)
AlCl3	695.2857	30162.9296	20971852.7811
O2	1042.5707	14008.8988	14605267.7570
Total			35577120.5381

Panas pembentukan produk T = 773 k

Komponen	n	∫Cp dt	ΔH = ni∫Cp.dT
	(kmol/jam)	(kJ/kmol.k)	(kJ/jam)
Al2O3	681.2286	28489.3095	19407732.7154
Cl2	884.9625	15357.1695	13590519.0804
Total			32998251.7957

Qreaksi = ΔH_{Reaksi}

ΔH_{Reaksi} = -3.880.033,5206 kJ/jam

Qci (Panas yang harus dibuang) = 3.880.033,5206 kJ/jam

Tanda (-) menunjukan bahwa reaksi yang terjadi adalah reaksi Eksotermis, karena panas yang terbentuk sangat besar maka diperlukan sebuah jaket.

- Media pendingin

Panas keluar : Tref = 25^0C = 298 K

Tin = 500^0C = 773 K

Komponen	Fi	BM	ni	∫Cp.dT	ΔH = ni∫Cp.dT
	(kg/jam)		(kmol/jam)	(kJ/kmol.K)	(kJ/jam)
AlCl3	3774.5702	133.3400	28.3079	35238.1679	997517.1549
O2	670.5656	32.0000	20.9552	14008.8988	293558.9356
Al2O3	69444.4444	101.9400	681.2286	28489.3095	19407732.7154
Cl2	62752.6909	70.9100	884.9625	15357.1695	13590519.0804
N2	185418.7832	28.0000	6622.0994	13844.4867	91679567.3469
Total					125968895.2332

Panas dowtherm A (Qdowtherm A)

Qdowtherm A = (Qsensible out + Qreaksi total) - (Qsensible in)

Qdowtherm A = 125968895,2332 + (-3880033,5206)

Qdowtherm A = 55483926,9868 kJ/jam

Panas dowtherm A (Q dowtherm A)

Q dowtherm A = (Qsensible out + Qreaksi total) - (Qsensible in)

Q dowtherm A = 125968895.2332 + -3880033.5206

Q dowtherm A = 55483926.9868 kJ/jam

Data temperatur dowtherm A yang dibutuhkan:

T dowtherm A input =	30	oC =	303	K
T dowtherm A output =	200	oC =	473	K
ΔT =	170	oC =	170	K

Q dowtherm A = m dowtherm A . Cp . ΔT

m dowtherm A = Q dowtherm A / Cp . ΔT

m dowtherm A = (11127102.9529 kJ/jam) / (4.1855 kJ/kg.K) . (341 K)

m dowtherm A = 191873.0400 kg/jam

Panas dowtherm A masuk :

Tair input =	30	oC =	303	K
Treferensi =	25	oC =	298	K
ΔT =	5	oC =	5	K

Q dowtherm A in = m . Cp . ΔT

= -1631880.2055 kJ/jam

Panas dowtherm A pendingin keluar :

T dowtherm A output =	200	oC =	473	K
Treferensi =	25	oC =	298	K
ΔT =	175	oC =	175	K

Q dowtherm A out = m . Cp . ΔT

= -57115807.1923 kJ/jam

Neraca Panas Reaktor

	Input	Output
Qsensible	66604934.7257	125968895.2332
QR		-3880033.5206
Qair	-1631880.2055	-57115807.1923
Total	**64973054.5202**	**64973054.5202**

3) Menghitung Kecepatan Volumetrik (Fv,L/jam)

Tabel A.2. Densitas Gas

Komponen	massa (kg/jam)	massa (kmol/jam)	xi	ρL (g/cm3)	ρ (kg/m3)	ρL campuran (kg/m3)
$AlCl_3$	92709.3916	695.2857	0.2011	51.8647	51864.6583	7966.4115
N_2	62752.6909	2240.0955	0.6480	10.8962	10896.2458	7061.2838
O_2	16681.0859	521.3035	0.1508	12.4464	12446.4289	1877.0491
TOTAL	172143.1684	3456.6846	1.0000	75.2073	75207.3330	16904.7443

$$= \frac{m\,gas}{\rho\,gas}$$

$$= \frac{172143{,}1684\ \text{kg/jam}}{16904{,}7443\ \text{kg/m}^3} = 10{,}1831\ \text{m}^3\text{/jam} = 10{,}1831\ \text{L/jam}$$

Sehingga di dapatkan kecepatan volumetric sebesar 10,1831 L/jam

4) Menghitung Nilai Konstanta Kecepatan Reaksi, k

Komponen	ρ (kg/m^3)	Fw (kg/jam)	Fw (kmol/jam)	Fv (m^3/jam)	Cn (kmol/m^3)
$AlCl_3$	7966.412	92709.3916	695.2857	0.0859	0.0001
O_2	1433.559	16681.0859	521.3035	0.0859	0.0002
N_2	7967.370	92709.3916	3309.4659	0.0859	0.00003
TOTAL	17367.340	202099.8691	4526.0550	0.2578	0.0003

Diketahui :

Residence Time (τ) = 60 menit

X_A = 98%

Ca0 = Fa0/Fv = 2696,9208 kmol/m3

$$k\,\tau\,C_{AO} = \frac{C_{AO} - C_{AO}}{C_A} = \frac{X_A}{1 - X_A}$$

k = 0,0219 m^3/kmol.jam

5) Menghitung Volume Reaktor, V

V = $Qo \; x \; \tau$

= 10,1831 m^3/jam x 1 jam

= 10,1831 m^3

Faktor keamanan = 20%

Vdesign = 12,2198 m^3

6) Menghitung Panjang Reaktor, L

Reaktor ini berupa tanki horizontal dengan D

$$T = \left(\frac{2V}{\pi} \right)^{(1/3)}$$

$$= \left(\frac{2 \times 12,2198}{3,14} \right)^{(\frac{1}{3})}$$

= 1,9817

m (ID)

Reaktor berbentuk silinder maka :

Volume reaktor = volume silinder

$$V = \pi \times D^2 \times L$$

$12,2198 = 3,14 \text{ x } (1,98)^2 \text{ x L}$

L = 15,2841 m

7) Menghitung Koefisien Perpindahan Panas, hi

$hi.D_T$ = k.0,74 x N_{re}.0,67 x N_{pr}.0,39 x N_{vis}^0,14 (Persamaan Holland)

Dimana :

hi = Koefisien Perpindahan Panas

D_T = Diameter Tanki = 1,9817 m r = 0,9908

K = Konduktivitas Termal

- Menghitung Nilai Nre

A = π x r^2

= 3,14 x 0,9908 x 0,9908

= 3,0830 m^2

v = $\frac{Qo}{A}$

= $\frac{10,1831}{3,0830}$

= 3,3030 m^3/jam

Viskositas Campuran Masuk, µ

µ $AlCl_3$ = 0,25 Cp

µ N_2 = 0,043 Cp

µ O_2 = 0,044 Cp

(Yaws "Chemical Properties Handbook", hal 473)

µ Total = $(\mu\ AlCl3)(X\ AlCl3) + (\mu\ N2)(X\ N2) + (\mu\ O2)(X\ O2)$

= (0,25 x 0,5385) + (0,043 x 0,3645) +(0,044 x 0,0969)

= 0,1528 Cp

Diketahui :

ρ = 7046,3844 kg/m^3 = 439,8914 lb/ft3

v = 3,3030 m/jam = 10,8366 ft/hr

μ	= 0,1528	Cp	=	0,3698	lb/ft.hr
D_T	= 1,9818	m	=	6,5019	ft

Menghitung Nilai, Nre :

$$Nre = \frac{D \times v \times \rho}{\mu}$$

$$= 83815,3292$$

- Menghitung, Npr

Konduktivitas Termal, k

k $AlCl_3$ = 0,0118 Btu/(hr)(ft^2)(^{0}F/ft)

k O_2 = 0,0007 Btu/(hr)(ft^2)(^{0}F/ft)

k N_2 = 0,0018 Btu/(hr)(ft^2)(^{0}F/ft)

(Yaws "Chemical Properties Handbook", hal 526)

$$k = \frac{(0,0118 + 0,0007 + 0,0018)}{3}$$

$$= 0,0048 \text{ Btu/(hr)}(ft^2)(^0\text{F/ft})$$

Spesifikasi Heat, Cp

Cp $AlCl_3$ = 0,6939 Btu/(lb)(^{0}F)

Cp O_2 = 0,2531 Btu/(lb)(^{0}F)

Cp N_2 = 0,2515 Btu/(lb)(^{0}F)

(Yaws "Chemical Properties Handbook", hal 51)

Cp Total = (0,6939 + 0,2531 + 0,2515)

= 1,1984 Btu/(lb)(^{0}F)

Menghitung Nilai, N_{pr} = $\frac{Cp \times \mu}{k}$

= $\frac{(1{,}1984\ Btu/lb.°F)(0{,}3698 lb/ft.hr)}{0{,}0048\ Btu/lb.ft°F/ft}$

= 92,7922

Sehingga :

$hi.D_T$ = k.0,74 x N_{re}.0,67 x N_{pr}.0,39 x N_{vis}^0,14

= (0,048.0,74) x (83815,3292.0,67) x (92,7922.0,39) x (0,1528/0,1528^0,14)

= 20,7583 Btu/(hr)(ft^2)(^{0}F)

8) Menghitung Hio

hio = $hi \frac{ID}{OD}$

OD = ID + 2t ID = 1,9817 m

t = Tebal tanki silinder

tebal tanki, t

$$t = \frac{P.r}{S.E - 0{,}6P} + C$$ *(Peter, tabel 4, hal 537)*

Pertimbangan : produk dalam reaktor sifatnya korosif. Sehingga, berdasarkan tabel 4 hal 537, *Peter* , dipilih bahan konstruksi yaitu *Stainless Steel SA 167 Grade 3 Type 304.* Pemilihan bahan material untuk reaktor cukup kuat dan terhadap korosi serta mudah di fabrikasi dan harga relatif murah.

dimana :

P = tekanan desain = 24,67 atm

r = jari-jari reaktor = 0,9909 m

S = tekanan desain yang diizinkan = 932,32 atm

E = joint effisiensi = 80%

C = Corrosion allowance = 0,00318 m

Maka :

$$t = \frac{(24{,}67\ atm)(0{,}9909m)}{(932{,}32\ atm)(0{,}80) - 0{,}6(24{,}67\ atm)} + 0{,}00318m$$

= 0,0346 m

OD = ID + 2t

= 2,0510 m

hio = $hi\frac{ID}{OD}$

= 9698.3006 Btu/(hr)(ft^2)(^{0}F) x (1,9817 /2,0510)

= 20,0577 Btu/(hr)(ft^2)(^{0}F)

9) Menghitung Overall Coef, Uc

$$U_c = \frac{h_{io}\ x\ h_i}{h_{io} + h_1}$$

$$U_C = \frac{20{,}0577 \times 20{,}7583}{20{,}0577 + 20{,}7583}$$

= 10,2010 Btu/(hr)(ft^2)(^{0}F)

10) Menghitung Design Coef, U_D

$$\frac{1}{U_D} = \frac{1}{U_c} + Rd$$

Dimana :

Rd = 0,003 (hr)(ft^2)(^{0}F)/Btu

$$\frac{1}{U_D} = \frac{1}{U_c} + Rd$$

$$\frac{1}{U_D} = \frac{1}{10{,}2010} + 0{,}003\ ft^2.hr.{}^\circ F/Btu$$

= 0,1010 (hr)(ft^2)(^{0}F)/Btu

$= 9{,}8981 \text{ Btu/(hr)(ft}^2\text{)(}^0\text{F)}$

Nilai U_D untuk fase gas sekitar 5 – 50 (Kern, Process Heat Transfer, hal 840)

11) Menghitung ΔT (LMTD)

Fluida panas (°F)	Temperatur	Fluida dingin (°F)	Selisih (°F)
932	Tinggi	208,40	723,60
932	Rendah	86,00	846,00
0	Selisih	122,40	-122,40

$$LMTD = \frac{\Delta t_2 - \Delta t_1}{\ln\left(\frac{\Delta t_2}{\Delta t}\right)} = \frac{846{,}00 - 723{,}60}{\ln\left(\frac{846{,}00}{723{,}60}\right)}$$

$= 783{,}2066\ ^0\text{F}$

12) Menghitung Nilai, A

- Luas Selimut (A)

$$\pi \times OD \times L$$

$= 3{,}14 \times 6{,}7290 \times 50{,}1446$

$= 1059{,}5082 \text{ ft}^2$

- Luas Tranfer Panas (A)

$$Q = U_D.A.\Delta t$$

Q = Panas yang diterima oleh air pendingin

= 76.249.988,4697 kkal/jam = 72.271.044,4952 Btu/hr

$$A = \frac{Q}{U_D \cdot \Delta t}$$

$$A = \frac{72271044{,}4952\ Btu/hr}{(9{,}8981\ Btu/ft2.\ hr.\ °\text{F})(783{,}2066°\text{F})}$$

= 9322,5811 ft^2

A luas selimut < A transfer panas (1059,5082 ft^2 < 9322,5811 ft^2)

Sehingga jaket pendingin bias digunakan

13) Menghitung Tebal Jaket

- Jumlah dowtherm A

  m = 191873,0400 kg/jam

  ρ = 61,3266 kg/m^3

- Volume dowtherm A , V

  $V_{dowtherm\ A}$ = m/ρ

  = 3128,70826 m^3/jam

  = 0,8691 m^3/s

  Vreaktor = 12,2198

Vtotal = (0,8691 + 12,2198)

= 13,0888 m^3

D_T (ID) = 1,98177 m

OD = 2,0510 m

H (L) = 15,2842 m

Maka mencari nilai,

Vtotal $= (1{,}4 \times \pi \times D^2 \times H_{total}) - (1{,}4 \times \pi \times ID^2 \times H_{total})$

13,0888 $= (1{,}4 \times \pi \times D^2 \times H_{total}) - (1{,}4 \times \pi \times ID^2 \times H_{total})$

D_{baru} = 1,752

Tebal Jaket = ID + D_{baru}

= 1,9817 + 1,752

= 0,2281 m