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LAMPIRAN A

REAKTOR FIXED BED MULTITUBE

LAMPIRAN A

PERHITUNGAN SPESIFIKASI ALAT

A. REAKTOR HIGH TEMPERATUR SHIFT CONVERTION

Kode : R–01

Fungsi : Tempat berlangsungnya reaksi Shift convertion antara ethylene (C_2H_4), hidrogen chlorida (HCl), dan udara membentuk ethylene dichloride ($C_2H_4Cl_2$), dan air (H_2O).

Jenis : *Fixed bed multitubular* reaktor dilengkapi dengan pendingin

Fase : Gas

Kondisi Operasi : T = 280 °C

P = 11 atm

Sifat Reaksi Eksotermis

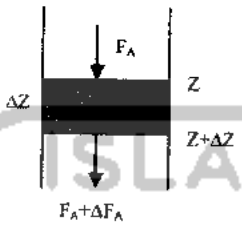
Konversi = 99 % terhadap C_2H_4

PENYUSUNAN MODEL MATEMATIS

1. Neraca Massa pada Reaktor

Komponen	BM	Input (kg/jam)	Output (kg/jam)
N_2	28	63.274,7459	63.274,7459
O_2	32	16.819,8692	8.494,0339
C_2H_4	28	14.717,3855	147,1739
HCl	36,5	38.370,3265	383,7033
C_2H_3Cl	62,5	396,6970	396,6970
$C_2H_4Cl_2$	99	2,6150	51.518,5646
H_2O	18	0,0000	9.366,5646
Total		**133.581,6390**	**133.581,6390**

Penyusunan neraca massa dibuat pada elemen volume di sebuah pipa dalam reaktor. Dalam hal ini diasumsikan tidak ada distribusi komposisi arah radial, sehingga arah axial saja yang ditinjau (karena L/D >>)



Gambar 2. Neraca Massa pada Elemen Volume

Reaksi yang terjadi adalah sebagai berikut :

$$C_2H_4 + 1/2\,O_2 + 2\,HCl \longrightarrow C_2H_4Cl_2 + H_2O \quad \text{.....(1)}$$

Neraca massa C_2H_4 di elemen volume pada steady state

$$F_{Ainput} - F_{Aoutput} - F_{Areaction} = 0$$

$$F_A\big|_Z - F_A\big|_{Z+\Delta Z} - (-r_A).\rho_b.\pi D_i^{\,2}/4.Nt.\Delta Z = 0$$

bila persamaan di atas dibagi dengan ΔZ menjadi :

$$\frac{F_A\big|_Z - F_A\big|_{Z+\Delta Z} - (-r_A).\rho_b.\pi D_i^{\,2}/4.Nt.\Delta Z = 0}{\Delta Z}$$

$$\frac{F_A\big|_{Z+\Delta Z} - F_A\big|_Z}{\Delta Z} = -(-r_A).\rho_b.\pi D_i^{\,2}/4.Nt$$

$$\text{limit}\ \frac{F_A\big|_{Z+\Delta Z} - F_A\big|_Z}{\Delta Z} = -(-r_A).\rho_b.\pi D_i^{\,2}/4.Nt$$

$\Delta Z \rightarrow 0$

diperoleh :

$$\frac{dF_A}{dZ} = \frac{-(-r_A).\rho_b.\pi D_i^{\,2}.Nt}{4}$$

$$F_A = F_{A0}(1 - x_A)$$

maka :

$$\frac{dx_A}{dZ} = (-r_A).\rho_b.\pi D_i^{\,2}.\frac{Nt}{4.F_{A0}} \quad \text{.....(2)}$$

dengan :

Nt : jumlah tube

D_t : diameter dalam tube, m

F_A : Flowrate C_2H_4, kmol/j

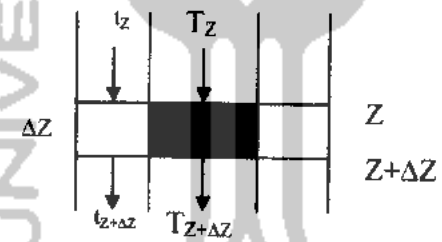
x_A : konversi

ρ_b : bulk density katalisator, kg/m^3

$(-r_A)$: kecepatan reaksi (1)

2. Neraca Panas pada Reaktor

Perbedaan suhu arah radial dalam tube dianggap tidak ada sehingga dapat disusun persamaan steady state sebagai berikut :



Gambar 3. Neraca Panas pada Elemen Volume

Neraca panas dalam pipa steady state:

R.O.H in – R.O.H out + R.O.H generated – R.O.H transferred =0

$$\sum F_i.Cp_i(T-298)\Big|_Z - \sum F_i.Cp_i(T-298)\Big|_{Z+\Delta Z} + F_{A0}.\Delta x_A.\Delta H_R - UD.\pi.D_0.\Delta Z.Nt.(T-t) = 0$$

bila persamaan di atas dibagi dengan ΔZ menjadi :

$$\frac{\sum F_i.Cp_i(T-298)\Big|_Z - \sum F_i.Cp_i(T-298)\Big|_{Z+\Delta Z} - F_{A0}.\Delta x_A.\Delta H_R - UD.\pi.D_0.\Delta Z.Nt.(T-t) = 0}{\Delta Z}$$

$$\text{limit}\ \frac{\sum F_i.Cp_i(T-298)\Big|_{Z+\Delta Z} - \sum F_i.Cp_i(T-298)\Big|_Z}{\Delta Z} = F_{A0}.\frac{\Delta x_A}{\Delta Z}.\Delta H_R - UD.\pi.D_0.Nt.(T-t)$$

$\Delta Z \rightarrow 0$

$$\sum F_i.Cp_i\frac{dT}{dZ} = F_{A0}.\frac{\Delta x_A}{\Delta Z}.\Delta H_R - UD.\pi.D_0.Nt.(T-t)$$

$$\frac{dT}{dZ} = \frac{F_{A0}.\frac{dx_A}{dZ}.\Delta H_R - UD.\pi.D_0.Nt.(T-t)}{\sum F_i.CP_i} \qquad \text{.....(3)}$$

dengan :

D_0 = diameter luar tube, m

Cp = kapasitas panas gas, kJ/kmol.K

T = suhu gas, K

t = suhu pendingin, K

ΔHR = panas reaksi, kJ/k.mol

Neraca panas pendingin pada steady state:

R.O.H in – R.O H out + R.O.H Transferred =0

$$Mc.Cpc.(t-298)\Big|_Z - Mc.Cpc.(t-298)\Big|_{Z+\Delta Z} + UD.\pi.D_0.\Delta Z.Nt.(T-t) = 0$$

bila dibagi dengan ΔZ diperoleh :

$$\frac{Mc.Cpc.(t-298)\Big|_Z - Mc.Cpc.(t-298)\Big|_{Z+\Delta Z} + UD.\pi.D_0.\Delta Z.Nt.(T-t) = 0}{\Delta Z}$$

$$\text{limit}\ \frac{Mc.Cpc.(t-298)\Big|_{Z+\Delta Z} - Mc.Cpc.(t-298)\Big|_Z}{\Delta Z} = UD.\pi.D_0.Nt.(T-t)$$

$$Mc.Cpc.\frac{dt}{dZ} = UD.\pi.D_0.Nt.(T-t)$$

$$\frac{dt}{dZ} = \frac{UD.\pi.D_0..Nt.(T-t)}{Mc.Cpc} \quad \text{.....(4)}$$

dengan :

Mc = kecepatan alir pendingin, kg/j

Cpc = kapasitas panas pendingin, kJ/kg.K

3. Penurunan Tekanan dalam Bed Katalisator

Penurunan tekanan dalam pipa yang berisi butir-butir katalisator dapat dipakai persamaan *Ergum* (*Perry and Green, 6th hal 4-37 1984*).

$$\frac{-dP}{dZ} = \left[\frac{150(1-\varepsilon)\mu}{Dp} + 1.756\right]\frac{(1-\varepsilon)G}{\varepsilon^3 Dp.\rho.gc}$$

Keterangan ;

P = Tekanan, N/m^2

G = *Fluks massa* gas ($kg/s.m^2$)

μ = Viskositas fluida, kg/m.dtk

D_P = Diameter katalisator, m

gc = Faktor konfersi satuan = 1 pd sistem SI

4. Data dan Estimasi sifat-sifat Fisis

a) BM rata-rata Gas (BM_G)

$$BM_G = \sum_{i=1}^{N} Y_i.BM_i$$

Dimana :

Yi = fraksi mol komponen i

Bmi= BM komponen i

b) Densitas Gas

$$\rho_G = \frac{P.BM_G}{RT}$$

Dimana :

ρ_G = densitas gas campuran

P = tekanan, atm

Bm_G = BM rata-rata, kg/kmol

R = tetapan gas, 82,06 dm^3atm/kmol K

T = suhu operasi, K

A. Langkah Perancangan

1. Menentukan Jenis Reaktor

Dipilih reaktor jenis *fixed bed multitubes* dengan pertimbangan :

- Reaksi berada dalam fasa gas dengan katalis padat
- Reaksi eksotermis sehingga diperlukan luas perpindahan panas yang besar agar kontak dengan pendingin berlangsung optimal
- *Pressure drop* lebih kecil daripada *fluidized bed reactor*
- Umur katalis panjang
- Tidak diperlukan pemisahan katalis dari gas keluaran reaktor
- Pengendalian suhu relatif mudah karena dipakai tipe *shell* dan *tube*
- Mencegah terjadinya *partial melting*, akibat dari naiknya temperatur (profil suhu reaktor vs panjang tube), bila memakai single tube, dikhawatirkan suhu makin naik secara konstan.

2. Menentukan Bahan Konstruksi

Dalam perancangan digunakan bahan konstruksi *low-alloy steel SA – 212 grade B* dengan pertimbangan sebagai berikut :

- Memiliki *allowable stress* cukup besar
- Mampu bertahan pada tekanan tinggi
- Harga relatif murah
- Bahan tahan korosi

3. Menentukan kondisi umpan

Menghitung Density Umpan (ρ)

Untuk menghitung density umpan maka digunakan persamaan virial, sebagai berikut :

$$B^{\circ} = 0{,}083 - \frac{0.422}{Tr^{1.6}}$$

$$B^{I} = 0{,}139 - \frac{0.172}{Tr^{4.2}}$$

$$\frac{B.Pc}{R.Tc} = B^{\circ} + \omega B^{I}$$

$$Z = 1 + \left[\frac{BPc}{RTc}\right]\left[\frac{Pr}{Tr}\right]$$

Umpan masuk pada kondisi ;

T = 553 K

P = 11 atm

Komponen	BM	Mol	Massa	yi
		(kmol/jam)	(kg/jam)	
N_2	28	2.259,8124	63.274,7459	0,517277
O_2	32	525,6209	16.819,8692	0,120316
C_2H_4	28	525,6209	14.717,3855	0,120316
HCl	36,5	1.051,2418	38.370,3265	0,240632
C_2H_3Cl	62,5	6,3472	396,6970	0,001453
$C_2H_4Cl_2$	99	0,0264	2,6150	0,000006
H_2O	18	0	0	0
Total		**4.368,6696**	**133.581,6390**	**1,0000**

ωi	Tci	Pci	Tri	Pri
	(K)	(bar)		
0,04	126,2	33,9000	4,382	0,329
0,022	154,6	50,5000	3,577	0,221
0,085	282,4	50,4000	1,958	0,221
0,132	324,6	83,1000	1,704	0,134
0,101	429,7	56,0000	1,287	0,199
0,288	561	53,7	0,986	0,208
0,345	647,3	220,5	0,854	0,051
			14,748	**1,362**

B^0	B^1	BPc/RTc	Z	V
				(m3)
0,043	0,139	0,049	1,004	9355,621
0,028	0,138	0,031	1,002	2172,286
-0,061	0,129	-0,050	0,994	2155,868
-0,097	0,121	-0,081	0,994	4308,589
-0,199	0,079	-0,191	0,970	25,409
-0,349	-0,044	-0,361	0,924	0,101

yi.V
4839,4476
261,3608
259,3855
1036,7844
0,0369
0,0000
6397,0152

Dari perhitungan diperoleh : $\rho_{umpan} = \frac{m}{V}, kg/m^3$

Density campuran = 20,8819 kg/m^3 = 0.0209 g/cm^3

Menghitung Viskositas Umpan (μ)

Menentukan viskositas campran gas digunakan persamaan :

$\mu_{gas} = A+BT+CT^2$, (Carl L. Yaws)

Komponen	A	B	C
N_2	42,606	4,7500E-01	-9,8800E-05
O_2	44,224	5,6200E-01	-1,1300E-04
C_2H_4	-3,985	3,8726E-01	-1,1227E-04
HCl	-9,118	5,5500E-01	-1,1100E-04
C_2H_3Cl	-6,067	3,9013E-01	-8,3970E-05
$C_2H_4Cl_2$	1,025	3,1792E-01	-4,1853E-05
H_2O	-36,826	4,2900E-01	-1,6200E-05

(Sumber : Yaws, Chemical Properties Handbook)

$\mu_{gas} = A+BT+CT^2$, micropoise

Sehingga diperoleh μ_{gas} = 265,7571 micropoise

Menghitung Konduktivitas Umpan (k)

Menentukan konduktivitas campran gas digunakan persamaan :

$k_{gas} = A+BT+CT^2$, (Carl L. Yaws)

Dengan nilai konstanta A, B, C

Komponen	A	B	C
N_2	3,0900E-03	7,5930E-05	-1,1014E-08
O_2	1,2100E-03	8,6157E-05	-1,3345E-08
C_2H_4	-1,2300E-03	3,6219E-05	1,2459E-07
HCl	1,1900E-03	4,4775E-05	2,0997E-10
C_2H_3Cl	-7,6400E-03	5,8427E-05	2,4051E-08
$C_2H_4Cl_2$	-6,8200E-03	4,0081E-05	3,1925E-08
H_2O	5,3000E-04	4,7093E-05	4,9551E-08

(Sumber : Yaws, Chemical Properties Handbook)

Sehingga diperoleh (k) = 0,0401 W/m.K

Menghitung Kapasitas Panas Umpan (Cp)

Untuk menghitung kapasitas panas gas campuran pada suhu 280 °C, maka digunakan persamaan

$Cp_{gas} = A+BT+CT^2+DT^3+ET^4$, (Carl L. Yaws)

Komponen	A	B	C	D	E
N_2	29,342	-3,53E-03	1,00E-05	-4,31E-09	2,59E-13
O_2	29,526	-8,89E-03	3,80E-05	-3,26E-08	8,86E-12
C_2H_4	32,083	-1,48E-02	2,47E-04	-2,37E-07	6,82E-11
HCl	29,244	-1,26E-03	1,12E-06	4,96E-09	-2,49E-12
C_2H_3Cl	17,193	1,45E-01	-6,42E-05	-3,23E-09	6,78E-12
$C_2H_4Cl_2$	37,275	1,43E-01	1,03E-05	-7,83E-08	2,88E-11
H_2O	33,933	-8,41E-03	2,99E-05	-1,78E-08	3,69E-12

(Sumber : Yaws, Chemical Properties Handbook)

Sehingga diperoleh Cp gas campuran = 1,1477 kjoule/kg K.

4. Menentukan spesifikasi Shell and Tube

- Pemilihan tempat katalisator (tube)
- Katalisator

Jenis : CuCl2 (Cupric Chloride)

Bentuk : Hijau gelap (Bulat)

ρ katalis : 1,6400 g/cm^3

$$Vs = \frac{\pi}{4} D^2 L$$

$$= 0{,}2 \text{ cm}^3$$

$$Vs = \pi / 6(Dp)^3$$

Dp = 0,3175 cm

Bulk Density, ρbulk

$$\rho b = \rho s\,(1-\varepsilon) + \rho ud\,\varepsilon \longrightarrow \rho ud = \frac{P * BM}{R * T}$$

$$=1{,}0500 \text{ g/cm}^3 \qquad = 0{,}0011 \text{ g/cm}^3$$

Diameter reaktor dipilih berdasarkan pertimbangan agar perpindahan panas berjalan dengan baik. Pengaruh ratio Dp/DT terhadap koeffisien perpindahan panas dalam pipa yang berisi katalisator dibanding dengan pipa kosong yaitu hw/hi, telah diteliti oleh Colburns (Smith, 511)

Dp/DT	0,05	0,1	0,15	0,2	0,25	0,3
hw/hi	5,50	7,0	7,80	7,5	7,0	6,6

Dipilih:

Dp/DT = 0,15

Dimana:

Dp : Diameter katalisator, cm

DT : diameter tube, inchi

hw = koeffisien perpindahan panas dalam pipa berisi katalis

hi = koeffisien perpindahan panas dalam pipa berisi kosong, cal/j cm^2K

Sehingga:

Dp/DT = 0,15

Dp = 0,3175 cm

$$DT = \left[\frac{0,3175}{0,15}\right] cm = \frac{2,1167 cm}{2,54} = 0.8333 \text{ inchi}$$

Menentukan jenis dan ukuran tube

Dari hasil perhitungan, diambil ukuran pipa standart, (Kern Q. D, 1950)

Ukuran pipa IPS = 1 in

OD = 1,32 in

ID = 1,049 in

Flow area perpipa = 0,864 in^2

Schedule number = 40

Pipa tersusun secara triangular pitch

Menghitung mass velocity umpan (Gt)

Asumsi Re = 2100

$$G_t = \frac{Re \times \mu}{D_t} = 63279,4948 \text{ kg/m}^2 \text{ jam}$$

Menentukan jumlah tube (Nt)

G (jumlah massa umpan gas) = 133581,6390 kg/jam

$a_t = \frac{G}{G_t} = 2{,}1110\ m^2$

Luas penampang pipa ;

$$Ao = \eta . di^2 \frac{\varepsilon}{4}$$

$$= 2{,}0063\ cm^2 = 0{,}000201\ m^2$$

Jumlah pipa maksimal ;

$$Nt_{max} = \frac{At}{Ao}$$

$$= 10522 \text{ tube}$$

Kecepatan volumetrik ;

$$Qv = \frac{G}{\rho_g}$$

$$= 1776948{,}6715\ cm^3/\text{detik}$$

$$V_{max} = \sqrt{\frac{4.(\rho_B - \rho_g).g.Dp}{3.\rho_g.F_o}}$$

$$= 143{,}0618\ cm/\text{detik}$$

$$At = \frac{Qv}{V_{max}}$$

$$= 12420{,}8473\ cm^2 \quad \text{, maka}$$

Jumlah pipa minimum :

$$Nt_{min} = \frac{At}{Ao}$$

$$= 6191 \text{ tube} \quad \text{,sehingga}$$

Diambil jumlah tube sebanyak 8187 tube

Lay Out pipa dalam reaktor

Susunan tube = Triangular

Pitch tube (Pt) = 1,25 ODt = 1,65 in = 4,1910 cm

Clearance (C') = Pt – ODt = 0,33 in

Luas penampang *shell* = luas pipa total

$\frac{\pi}{4}.IDs^2 = 2 \text{ x } Nt \text{ x luas segitiga sama sisi}$

$= Nt.2.(0,5.Pt^2.\sin 60) = 0,866.Pt^2.Nt$

Menghitung diameter *Equivalen* (De)

Diameter *equivalen* dapat diartikan sebagai diameter dari area dalam shell, bila dipandang sebagai pipa. (*Kren*, 1965)

Diameter *equivalen* (D_e) $Des = \frac{4.\left(0,5.Pt^2.0,866 - 0,5.\pi.\frac{OD^2}{4}\right)}{0,5.\pi.OD}$

= 1,9453 inch

Menghitung diameter dalam shell (IDs)

Diameter shell yang dipakai untuk Nt pipa.

diameter shell ;

$$IDs = \sqrt{\frac{4.0{,}866.Nt.Pt^2}{\pi}}$$

= 156,8088 in = 3,9829 m

Menghitung baffle space (B)

Baffle space (B) = 0,25 × ID_S = 39,2022 in

Menghitung flow area shell

$$a_s = \frac{ID \times C' \times B}{P_t} = 1229{,}450134 \text{ in}^2 = 7931{,}920481 \text{ cm}^2$$

Menghitung mass velocity sisi shell (air pendingin)

w_s (laju air pendingin) = 413350,43 kg/jam

$$G_s = \frac{w}{a_s} = 5{,}21 \times 10^5 \text{ kg/m}^2\text{.jam}$$

Menghitung bilangan reynold sisi shell (downtherm A)

Media pendingin dalam reaktor digunakan Downterm A

- T = 200 – 750 F (366,3 – 671,89 ^{0}K)
- BM = 165
- Cp = 0,11152 + 0,0003402 T (cal/g K)
- Densitas, ρ = 1,3644 – 9,7073*10^{-4} T (g/cm^3)
- Konduktifitas termal, K = 1,512 – 0,0010387 T (cal/g cm K)
- Viskositas, μ = 35,5898 – 6,04212 T (g/cm J)

Suhu downtherm A = 97 °C = 370 K

$$Re_s = \frac{De \times G_s}{\mu} = 6{,}20 \times 10^4 \text{ (aliran turbulen)}$$

dari Fig. 24. Kern didapat data friksi (f) = 0,0009 ft^2 / in^2

Menghitung koefisien perpindahan panas

Shell, Downtherm A	Tube, Reaktan
▪ ***Menghitung Bilangan Prandtl (Pr)*** Cp = 0,2373 cal/g.K k = 1,1276 cal/cm.jam.K $Pr = \frac{Cp \times \mu}{k} = 4,21$ $Re_s = \frac{De \times G_s}{\mu} = 6,20 \times 10^4$	▪ ***Menghitung Bilangan Prandtl (Pr)*** $Pr = \frac{Cp \times \mu}{k} = 0,7602$
▪ ***Menghitung koefisien perpindahan panas (h_o)*** $De = \frac{4.Pt^2 - \mu.OD^2}{4.\mu.OD} = 23,8033$ $h_o = 0,36\left(\frac{k}{D_e}\right).(Re).(Pr)^{1/3}$ $= 1 \times 10^3$ kJ/jam.m^2.K	▪ ***Menentukan jH*** Dari figure 28 Kern diperoleh nilai jH = 25
	▪ ***Menghitung koefisien perpindahan panas (h_i)*** $h_i = jH\left(\frac{k}{D}\right)(Pr)^{1/3}$ = 123,6733 kJ/jam.m^2.K
	▪ ***Koreksi h_i ke permukaan pada diameter luar tube*** $h_{io} = h_i\left(\frac{ID}{OD}\right) = 98,2828$ kJ/jam.m^2.K

▪ ***Menghitung koefisien perpindahan panas bersih (U_C)***

$$U_c = \frac{h_{io} \times h_o}{h_{io} + h_o} = 9,09 \times 10^1 \text{ kJ/jam.ft}^2\text{.K}$$

- ***Menghitung Dirt Overall Coefficient (U_d)***

$$UD = \frac{Uc}{Uc\,(Rd+1)} \qquad = 90{,}3374 \text{ kJ/jam.m}^2\text{.K}$$

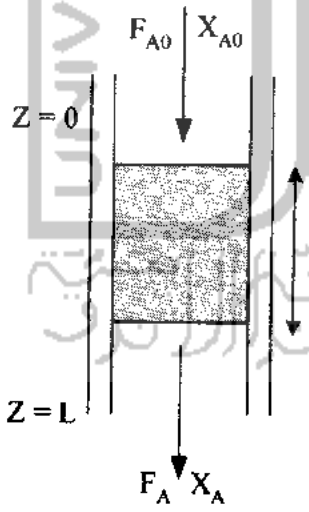
$$= 21{,}2112 \text{ kcal/jam.m}^2\text{.K}$$

5. Menghitung Panjang Tube (Lt)

Untuk menghitung tube, maka perlu memperhatikan perubahan konversi tiap panjang tube. Panjang tube yang diinginkan adalah saat reaksi mencapai konversi maksimal.

Perubahan Konversi Tiap Satuan Panjang Tube

Elemen volume dalam satu tube= $\frac{\pi}{4} \times ID_t^{\,2} \times \Delta Z$



Neraca massa komponen pada elemen volum untuk semua tube:

Laju input – laju output + laju reaksi = laju akumulasi

Pada keadaan *steady state* laju akumulasi = 0

$$F_A|_z - F_A|_{z+dz} - (-r_A)\Delta W = 0$$

dimana

$$\Delta W = \Delta V_t \times \rho_B$$

$$\rho_B = \rho \times (1-\varepsilon)$$

$$\Delta V_t = N_t \times A \times \Delta Z$$

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

sehingga persamaan diatas menjadi

$$F_A|_Z - F_A|_{Z+\Delta Z} - (-r_A).N_t.\frac{\pi}{4}.ID_t^2.\Delta Z.\rho(1-\varepsilon) = 0$$

$$F_A|_Z - F_A|_{Z+\Delta Z} = (-r_A).N_t.\frac{\pi}{4}.ID_t^2.\Delta Z.\rho(1-\varepsilon)$$

$$\frac{F_A|_Z - F_A|_{Z+\Delta Z}}{\Delta Z} = (-r_A).N_t.\frac{\pi}{4}.ID_t^2.\rho(1-\varepsilon)$$

limit $\Delta Z \rightarrow 0$, maka

$$\frac{-dF_A}{dZ} = (-r_A).N_t.\frac{\pi}{4}.ID_t^2.\rho(1-\varepsilon)$$

karena $F_A = F_{Ao}(1 - X_A)$

$$dF_A = d(F_{Ao}(1 - X_A))$$

$$dF_A = -F_{Ao}.dX_A$$

$$\frac{F_{Ao}.dX_A}{dZ} = (-r_A).N_t.\frac{\pi}{4}.ID_t^2.\rho(1-\varepsilon)$$

$$\frac{dX_A}{dZ} = \frac{(-r_A).N_t.\frac{\pi}{4}.ID_t^2.\rho(1-\varepsilon)}{F_{Ao}}$$

Keterangan :

ε = porositas katalis

A = luas perpindahan panas

$F_A|_z$ = laju alir masuk elemen volume

$F_A|_{z+\Delta z}$ = laju alir keluar elemen volume

ID_t = diameter dalam tube

N_t = jumlah tube

-ra = kecepatan reaksi, mol A yang bereaksi /gr katalis.detik

V_t = volume tube

W = berat katalis

Z = panjang tube

ρ_B = *bulk density* katalis

➢ ***Reaksi***

Reaksi yang terjadi di dalam reaktor adalah :

Reaksi utama :

$$C_2H_4 + 1/2\,O_2 + 2\,HCl \longrightarrow C_2H_4Cl_2 + H_2O$$

➢ ***Persamaan Kecepatan Reaksi***

Konstanta kesetimbangan juga tergantung pada temperatur, sesuai dengan rumus :

$$k = e^x$$

dimana $x = \frac{1}{RT}\left(11.321 - 31{,}08T + 3T\ln T - 2{,}8.10^{-4}T^2 - \frac{91.500}{T}\right)$

T = Suhu, K

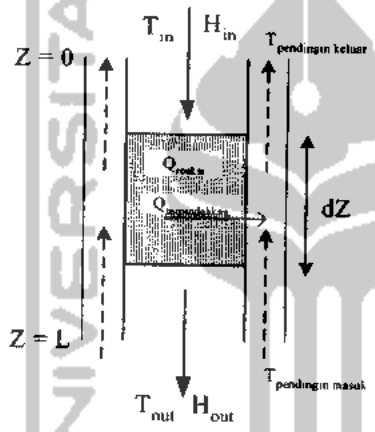
R = konstanta gas, cal/gmol K

Perubahan Suhu Tiap Satuan Panjang Tube

Reaktor *fixed bed multitube* menyerupai alat penukar kalor, dimana gas mengalir di dalam pipa – pipa yang berisi katalis dan media pendingin mengalir diluarnya (*shell*) secara lawan arah.

Laju Panas Masuk – Laju Panas Keluar + Laju Panas Reaksi = Laju Akumulasi

Pada *steady state* → laju akumulasi = 0



$H_{input} - H_{output} + Q_{reaksi} + Q_{terpindahkan} = 0$

$H_{input} = \sum_{i=1}^{n} H_i|_Z$

$H_{output} = \sum_{i=1}^{n} H_i|_{Z+\Delta Z}$

$Q_{reaksi} = (-\Delta H_r).F_A$

$Q_{terpindahkan} = U_D.N_t.\Delta A(T - T_s) = U_D.N_t.\pi.ID_t.\Delta Z(T - T_s)$

$$\sum_{i=1}^{n} H_i|_Z - \sum_{i=1}^{n} H_i|_{Z+\Delta Z} + ((-\Delta H_r).F_A) + (U_D.N_t.\pi.ID_t.\Delta Z.(T - T_s)) = 0$$

$$\sum_{i=1}^{n} H_i|_Z - \sum_{i=1}^{n} H_i|_{Z+\Delta Z} + \left((-\Delta H_r).F_{Ao}.\left(X_A|_Z - X_A|_{Z+\Delta Z}\right)\right) + \left(U_D.N_t.\pi.ID_t.\Delta Z(T-T_s)\right) = 0$$

$$\sum_{i=1}^{n} H_i|_Z - \sum_{i=1}^{n} H_i|_{Z+\Delta Z} = \left((-\Delta H_r).F_{Ao}.\left(X_A|_Z - X_A|_{Z+\Delta Z}\right)\right) - \left(U_D.N_t.\pi.ID_t.\Delta Z(T-T_s)\right)$$

Ruas kanan dan ruas kiri dibagi ΔZ

$$\frac{\sum_{i=1}^{n} H_i|_Z - \sum_{i=1}^{n} H_i|_{Z+\Delta Z}}{\Delta Z} = \frac{\left((-\Delta H_r).F_{Ao}.\left(X_A|_Z - X_A|_{Z+\Delta Z}\right)\right) - \left(U_D.N_t.\pi.ID_t.\Delta Z(T-T_s)\right)}{\Delta Z}$$

$$\frac{\sum_{i=1}^{n} H_i|_Z - \sum_{i=1}^{n} H_i|_{Z+\Delta Z}}{\Delta Z} = \left((-\Delta H_r).F_{Ao}.\frac{\left(X_A|_Z - X_A|_{Z+\Delta Z}\right)}{\Delta Z}\right) - \left(U_D.N_t.\pi.ID_t.(T-T_s)\right)$$

limit $\Delta Z \rightarrow 0$

$$\frac{\sum_{i=1}^{n} dH_i}{dZ} = \left((-\Delta H_r).F_{Ao}.\frac{dX_A}{dZ}\right) - \left(U_D.Nt.\pi.ID_t(T-T_s)\right)$$

karena $dH_i = (F_i.Cp_i)\,dT$; maka

$$\sum_{i=1}^{n}(F_i.Cp_i)\frac{dT}{dZ} = \left((-\Delta H_r).F_{Ao}.\frac{dX_A}{dZ}\right) - \left(U_D.N_t.\pi.ID_t(T-T_s)\right)$$

$$\frac{dT}{dZ} = \frac{\left((-\Delta H_r).F_{Ao}.\frac{dX_A}{dZ}\right) - \left(U_D.N_t.\pi.ID_t(T-T_s)\right)}{\sum_{i=1}^{n}(F_i.Cp_i)}$$

Keterangan :

Cp_i = kapasitas panas bahan i

F_{Ao} = laju alir massa mula-mula

F_i = laju lair bahan i

Hi = enthalpi bahan i

ID_t = diameter dalam tube

N_t = jumlah tube

T = suhu aliran massa dalam tube pada Z tertentu

T_s = suhu pendingin dalam shell pada Z tertentu

U_D = koefisien perpindahan panas menyeluruh

X_A = konversi bahan A

Z = panjang reaktor

$-\Delta H_r$ = panas reaksi

➢ ***Entalpi Reaksi***

Panas reaksi pada suhu T dapat dihitung dengan persamaan

$$\Delta H_r = \Delta H_{r298} + \int_{298}^{T}\left(\sum_{i=1}^{n} Cp_i\right)dT$$

$$\Delta H_r = \Delta H_{r298} + \int_{298}^{T}\left(\sum_{i=1}^{n} \Delta Cp_i.dT\right)$$

$$\Delta H_r = \Delta H_{r298} + \int_{298}^{T}\left(\sum_{i=1}^{n} \Delta A + \Delta B.T + \Delta C.T^2 + \Delta D.T^3 + \Delta E.T^4\right)$$

$$\Delta H_r = \Delta H_{r298} + \sum_{i=1}^{n}\left(\Delta A(T-298) + \frac{\Delta B}{2}\left(T^2-298^2\right) + \frac{\Delta C}{3}\left(T^3-298^3\right)\right)$$

$$+\frac{\Delta D}{4}\left(T^4-298^4\right) + \frac{\Delta E}{5}\left(T^5-298^5\right)$$

➢ ***Kapasitas Panas***

$Cpi = A + BT + CT^2 + DT^3 + ET^4$ (kj/kmol.K)

Komponen	A	B	C	D	E
N_2	29,342	-3,5395E-03	1,0076E-05	-4,3116E-09	2,5935E-13
O_2	29,526	-8,8999E-03	3,8083E-05	-3,2629E-08	8,8607E-12
C_2H_4	32,083	-1,4831E-02	2,4774E-04	-2,3766E-07	6,8274E-11
HCl	29,244	-1,2615E-03	1,1210E-06	4,9676E-09	-2,4963E-12

C_2H_3Cl	17,193	1,4564E-01	-6,4281E-05	-3,2385E-09	6,7882E-12
$C_2H_4Cl_2$	37,275	1,4362E-01	1,0378E-05	-7,8305E-08	2,8872E-11
H_2O	33,933	-8,4186E-03	2,9906E-05	-1,7825E-08	3,6934E-12

Komponen	ΔHf (kj/mol)
C_2H_4	52300
HCl	-92300
O_2	0
$C_2H_4Cl_2$	-129700
H_2O	-241800

- ***Panas Reaksi (ΔHr)***

  Reaksi di reaktor :

  Reaksi ; $C_2H_4 + 1/2\,O_2 + 2\,HCl \longrightarrow C_2H_4Cl_2 + H_2O$

Perubahan Tekanan Tiap Satuan Panjang Tube

Pressure drop dalam tube pada reaktor *fixed bed multitube* dapat diturunkan dari persamaan berikut :

$$\frac{dP}{dZ} = \frac{\left(1{,}75 + 150\left(\frac{\mu(1-\varepsilon)}{D_p \times G_t}\right)\right) \times G_t^{\,2}}{D_p \times \rho_f \times g_c}\left(\frac{1-\varepsilon}{\varepsilon^3}\right)$$

(Sumber : Rase, Chemical Reactor Design for Process Plant, hal. 492)

Keterangan :

P = tekanan dalam tube

μ = viskositas gas

ε = porositas bed

D_p = diameter partikel katalis

G_t = kecepatan alir gas dalam tube

ρ_f = density gas masuk dalam tube

g_c = gravitasi

Menghitung Panjang Tube (Z)

Panjang tube dihitung menggunakan tiga persamaan diferensial diatas dan ditentukan saat konversi reaksi mencapai batas maksimalnya. Perhitungan panjang tube menggunakan persamaan *Range-Kutta* dengan memasukkan empat persamaan berikut :

1. $$\frac{dX_A}{dZ} = \frac{(-r_A).N_t.\frac{\pi}{4}.ID_t^2.\rho(1-\varepsilon)}{F_{Ao}}$$

2. $$\frac{dT}{dZ} = \frac{\left(\left(-\Delta H_r\right)F_{Ao}\frac{dX_A}{dZ}\right) - \left(U_D.N_t.\pi.ID_t\left(T-T_s\right)\right)}{\sum_{i=1}^{n}\left(F_i.Cp_i\right)}$$

3. $$\frac{dt}{dZ} = \frac{UD.\pi.D_0..Nt.(T-t)}{Mc.Cpc}$$

4. $$\frac{dP}{dZ} = \frac{\left(1{,}75+150\left(\frac{\mu(1-\varepsilon)}{D_p\times G_t}\right)\right)\times G_t^2}{D_p\times\rho_f\times g_c}\left(\frac{1-\varepsilon}{\varepsilon^2}\right)$$

Hasil running program menggunakan metode Runge Kutta adalah sebagai berikut:

KOMPOSISI HASIL REAKSI, kgmol/jam

z	X	TG	TC	P		Konversi X	C_2H_4	HCl	O_2	$C_2H_4Cl_2$	H_2O	Total
0.00	0.0000	553	370	11		0.0000	0.0642	0.1284	0.0642	0.00000	0.0000	0.2568
	0.1096	552.9392	370.0174	11.0000		0.1096	0.0572	0.1214	0.0286	0.00704	0.0070	0.2212
	0.3960	552.8156	370.0746	11.0000		0.3960	0.0388	0.1030	0.0194	0.02543	0.0254	0.2120
	0.5275	552.8164	370.1318	11.0000		0.5275	0.0303	0.0945	0.0152	0.03387	0.0339	0.2078
0.10	0.3420	552.9076	370.1011	11.0000		0.3420	0.0422	0.1064	0.0211	0.02196	0.0220	0.2137
	0.4983	552.8920	370.1583	11.0000		0.4983	0.0322	0.0964	0.0161	0.03199	0.0320	0.2087
	0.5891	552.9160	370.2155	11.0000		0.5891	0.0264	0.0906	0.0132	0.03783	0.0378	0.2058
	0.6501	552.9539	370.2726	11.0000		0.6501	0.0225	0.0867	0.0112	0.04174	0.0417	0.2038
0.20	0.5100	552.9583	370.2154	11.0000		0.5100	0.0315	0.0957	0.0157	0.03275	0.0327	0.2083
	0.5968	552.9844	370.2726	11.0000		0.5968	0.0259	0.0901	0.0129	0.03832	0.0383	0.2056
	0.6556	553.0232	370.3298	11.0000		0.6556	0.0221	0.0863	0.0111	0.04209	0.0421	0.2037
	0.6985	553.0678	370.3869	11.0000		0.6985	0.0194	0.0836	0.0097	0.04485	0.0448	0.2023
0.30	0.6177	553.0385	370.3297	11.0000		0.6177	0.0245	0.0887	0.0123	0.03966	0.0397	0.2049
	0.6706	553.0796	370.3869	11.0000		0.6706	0.0211	0.0853	0.0106	0.04306	0.0431	0.2032
	0.7099	553.1254	370.4440	11.0000		0.7099	0.0186	0.0828	0.0093	0.04558	0.0456	0.2019
	0.7404	553.1738	370.5011	11.0000		0.7404	0.0167	0.0809	0.0083	0.04754	0.0475	0.2009
0.40	0.6900	553.1317	370.4440	11.0000		0.6900	0.0199	0.0841	0.0100	0.04430	0.0443	0.2026
	0.7249	553.1789	370.5011	11.0000		0.7249	0.0177	0.0819	0.0088	0.04654	0.0465	0.2014
	0.7523	553.2282	370.5583	11.0000		0.7523	0.0159	0.0801	0.0080	0.04830	0.0483	0.2006
	0.7746	553.2787	370.6154	11.0000		0.7746	0.0145	0.0787	0.0072	0.04973	0.0497	0.1998
0.50	0.7410	553.2311	370.5582	11.0000		0.7410	0.0166	0.0808	0.0083	0.04757	0.0476	0.2009
	0.7653	553.2811	370.6154	11.0000		0.7653	0.0151	0.0793	0.0075	0.04914	0.0491	0.2001
	0.7853	553.3321	370.6725	11.0000		0.7853	0.0138	0.0780	0.0069	0.05042	0.0504	0.1995
	0.8021	553.3838	370.7296	11.0000		0.8021	0.0127	0.0769	0.0064	0.05150	0.0515	0.1990

12.00	0.9896	565.4354	383.5443	10.9997		0.9896	0.0007	0.0649	0.0003	0.06354	0.0635	0.1929
	0.9896	565.4883	383.6001	10.9997		0.9896	0.0007	0.0649	0.0003	0.06354	0.0635	0.1929
	0.9897	565.5411	383.6559	10.9997		0.9897	0.0007	0.0649	0.0003	0.06354	0.0635	0.1929
	0.9897	565.5939	383.7118	10.9997		0.9897	0.0007	0.0649	0.0003	0.06355	0.0635	0.1929
12.10	0.9897	565.5411	383.6559	10.9997		0.9897	0.0007	0.0649	0.0003	0.06354	0.0635	0.1929
	0.9897	565.5939	383.7117	10.9997		0.9897	0.0007	0.0649	0.0003	0.06355	0.0635	0.1929
	0.9898	565.6467	383.7676	10.9997		0.9898	0.0007	0.0649	0.0003	0.06355	0.0635	0.1929
	0.9898	565.6995	383.8234	10.9997		0.9898	0.0007	0.0649	0.0003	0.06355	0.0635	0.1929
12.20	0.9898	565.6467	383.7675	10.9997		0.9898	0.0007	0.0649	0.0003	0.06355	0.0635	0.1929
	0.9898	565.6995	383.8234	10.9997		0.9898	0.0007	0.0649	0.0003	0.06355	0.0635	0.1929
	0.9899	565.7523	383.8792	10.9997		0.9899	0.0007	0.0649	0.0003	0.06355	0.0636	0.1929
	0.9899	565.8051	383.9350	10.9997		0.9899	0.0006	0.0648	0.0003	0.06356	0.0636	0.1929
12.30	0.9899	565.7523	383.8792	10.9997		0.9899	0.0007	0.0649	0.0003	0.06355	0.0636	0.1929
	0.9899	565.8051	383.9350	10.9997		0.9899	0.0006	0.0648	0.0003	0.06356	0.0636	0.1929
	0.9900	565.8579	383.9908	10.9997		0.9900	0.0006	0.0648	0.0003	0.06356	0.0636	0.1929
	0.9900	565.9107	384.0465	10.9997		0.9900	0.0006	0.0648	0.0003	0.06356	0.0636	0.1929
12.40	0.9900	565.8579	383.9907	10.9997		0.9900	0.0006	0.0648	0.0003	0.06356	0.0636	0.1929
	0.9900	565.9107	384.0465	10.9997		0.9900	0.0006	0.0648	0.0003	0.06356	0.0636	0.1929
	0.9901	565.9635	384.1023	10.9997		0.9901	0.0006	0.0648	0.0003	0.06357	0.0636	0.1929
	0.9901	566.0163	384.1581	10.9997		0.9901	0.0006	0.0648	0.0003	0.06357	0.0636	0.1929
12.50	0.9901	565.9635	384.1023	10.9997		0.9901	0.0006	0.0648	0.0003	0.06357	0.0636	0.1929
	0.9901	566.0163	384.1581	10.9997		0.9901	0.0006	0.0648	0.0003	0.06357	0.0636	0.1929
	0.9901	566.0691	384.2139	10.9997		0.9901	0.0006	0.0648	0.0003	0.06357	0.0636	0.1929
	0.9902	566.1219	384.2696	10.9997		0.9902	0.0006	0.0648	0.0003	0.06358	0.0636	0.1929
12.60	0.9901	566.0691	384.2139	10.9997		0.9901	0.0006	0.0648	0.0003	0.06357	0.0636	0.1929
	0.9902	566.1219	384.2696	10.9997		0.9902	0.0006	0.0648	0.0003	0.06358	0.0636	0.1929
	0.9902	566.1747	384.3254	10.9997		0.9902	0.0006	0.0648	0.0003	0.06358	0.0636	0.1929
	0.9903	566.2275	384.3812	10.9997		0.9903	0.0006	0.0648	0.0003	0.06358	0.0636	0.1929

KOMPOSISI HASIL REAKSI, kg/jam

Komponen — dlm kg

C_2H_4	HCl	O_2	$C_2H_4Cl_2$	H_2O	Total
1.7977	4.6867	2.0545	0.0003	0.0000	8.5392
1.6006	4.4299	0.9147	0.6969	0.1266	7.7688
1.0858	3.7588	0.6205	2.5173	0.4576	8.4399
0.8494	3.4506	0.4854	3.3530	0.6096	8.7480
1.1829	3.8854	0.6760	2.1738	0.3952	8.3133
0.9019	3.5191	0.5154	3.1674	0.5758	8.6796
0.7386	3.3062	0.4220	3.7449	0.6808	8.8925
0.6290	3.1633	0.3594	4.1323	0.7513	9.0354
0.8808	3.4916	0.5033	3.2420	0.5894	8.7071
0.7249	3.2883	0.4142	3.7934	0.6897	8.9104
0.6192	3.1505	0.3538	4.1670	0.7576	9.0482
0.5420	3.0499	0.3097	4.4399	0.8072	9.1487
0.6872	3.2392	0.3927	3.9265	0.7138	8.9595
0.5921	3.1153	0.3384	4.2627	0.7750	9.0834
0.5215	3.0232	0.2980	4.5124	0.8204	9.1755
0.4667	2.9517	0.2667	4.7063	0.8556	9.2470
0.5572	3.0697	0.3184	4.3861	0.7974	9.1289
0.4946	2.9881	0.2826	4.6075	0.8377	9.2106
0.4452	2.9238	0.2544	4.7821	0.8694	9.2749
0.4052	2.8716	0.2315	4.9237	0.8952	9.3271
0.4657	2.9504	0.2661	4.7098	0.8563	9.2483
0.4219	2.8933	0.2411	4.8647	0.8844	9.3054
0.3859	2.8464	0.2205	4.9920	0.9076	9.3523
0.3557	2.8071	0.2033	5.0985	0.9269	9.3916

FRAKSI MOL

Komponen — fraksi mol — KG/KMOL

C_2H_4	HCl	O_2	$C_2H_4Cl_2$	H_2O	Total	BM campuran
0.2500	0.5000	0.2500	0.0000	0.0000	1.0000	97.5012
0.2584	0.5487	0.1292	0.0318	0.0318	1.0000	101.1595
0.1829	0.4858	0.0915	0.1199	0.1199	1.0000	111.2927
0.1460	0.4550	0.0730	0.1630	0.1630	1.0000	116.2453
0.1977	0.4981	0.0988	0.1027	0.1027	1.0000	109.3139
0.1543	0.4619	0.0772	0.1533	0.1533	1.0000	115.1283
0.1282	0.4401	0.0641	0.1838	0.1838	1.0000	118.6375
0.1102	0.4252	0.0551	0.2048	0.2048	1.0000	121.0482
0.1510	0.4592	0.0755	0.1572	0.1572	1.0000	115.5757
0.1259	0.4383	0.0630	0.1864	0.1864	1.0000	118.9370
0.1086	0.4238	0.0543	0.2067	0.2067	1.0000	121.2666
0.0957	0.4131	0.0478	0.2217	0.2217	1.0000	122.9952
0.1198	0.4332	0.0599	0.1936	0.1936	1.0000	119.7618
0.1041	0.4201	0.0520	0.2119	0.2119	1.0000	121.8698
0.0922	0.4102	0.0461	0.2257	0.2257	1.0000	123.4589
0.0829	0.4024	0.0415	0.2366	0.2366	1.0000	124.7063
0.0982	0.4152	0.0491	0.2187	0.2187	1.0000	122.6528
0.0877	0.4064	0.0438	0.2310	0.2310	1.0000	124.0691
0.0793	0.3994	0.0396	0.2408	0.2408	1.0000	125.1971
0.0724	0.3937	0.0362	0.2489	0.2488	1.0000	126.1193
0.0828	0.4023	0.0414	0.2368	0.2368	1.0000	124.7290
0.0753	0.3961	0.0376	0.2455	0.2455	1.0000	125.7345
0.0691	0.3909	0.0345	0.2528	0.2527	1.0000	126.5663
0.0639	0.3865	0.0319	0.2588	0.2588	1.0000	127.2671

0.0187	2.3678	0.0107	6.2901	1.1436	9.8309		0.0035	0.3362	0.0017	0.3293	0.3293	1.0000	135.3694
0.0186	2.3677	0.0106	6.2904	1.1437	9.8310		0.0034	0.3362	0.0017	0.3293	0.3293	1.0000	135.3716
0.0185	2.3675	0.0106	6.2907	1.1437	9.8311		0.0034	0.3362	0.0017	0.3293	0.3293	1.0000	135.3738
0.0185	2.3674	0.0105	6.2910	1.1438	9.8313		0.0034	0.3362	0.0017	0.3294	0.3293	1.0000	135.3759
0.0185	2.3675	0.0106	6.2907	1.1437	9.8311		0.0034	0.3362	0.0017	0.3293	0.3293	1.0000	135.3738
0.0185	2.3674	0.0105	6.2910	1.1438	9.8312		0.0034	0.3362	0.0017	0.3294	0.3293	1.0000	135.3759
0.0184	2.3673	0.0105	6.2913	1.1438	9.8314		0.0034	0.3362	0.0017	0.3294	0.3294	1.0000	135.3780
0.0183	2.3672	0.0104	6.2916	1.1439	9.8315		0.0034	0.3361	0.0017	0.3294	0.3294	1.0000	135.3802
0.0184	2.3673	0.0105	6.2913	1.1438	9.8314		0.0034	0.3362	0.0017	0.3294	0.3294	1.0000	135.3780
0.0183	2.3672	0.0105	6.2916	1.1439	9.8315		0.0034	0.3361	0.0017	0.3294	0.3294	1.0000	135.3801
0.0182	2.3671	0.0104	6.2919	1.1439	9.8316		0.0034	0.3361	0.0017	0.3294	0.3294	1.0000	135.3822
0.0181	2.3670	0.0104	6.2922	1.1440	9.8317		0.0034	0.3361	0.0017	0.3294	0.3294	1.0000	135.3843
0.0182	2.3671	0.0104	6.2919	1.1439	9.8316		0.0034	0.3361	0.0017	0.3294	0.3294	1.0000	135.3822
0.0181	2.3670	0.0104	6.2922	1.1440	9.8317		0.0034	0.3361	0.0017	0.3294	0.3294	1.0000	135.3843
0.0180	2.3669	0.0103	6.2925	1.1440	9.8318		0.0033	0.3361	0.0017	0.3294	0.3294	1.0000	135.3863
0.0180	2.3668	0.0103	6.2928	1.1441	9.8319		0.0033	0.3361	0.0017	0.3295	0.3294	1.0000	135.3884
0.0180	2.3669	0.0103	6.2925	1.1440	9.8318		0.0033	0.3361	0.0017	0.3294	0.3294	1.0000	135.3863
0.0180	2.3668	0.0103	6.2928	1.1441	9.8319		0.0033	0.3361	0.0017	0.3295	0.3294	1.0000	135.3883
0.0179	2.3667	0.0102	6.2931	1.1441	9.8320		0.0033	0.3361	0.0017	0.3295	0.3295	1.0000	135.3904
0.0178	2.3666	0.0102	6.2934	1.1442	9.8321		0.0033	0.3361	0.0016	0.3295	0.3295	1.0000	135.3924
0.0179	2.3667	0.0102	6.2931	1.1441	9.8320		0.0033	0.3361	0.0017	0.3295	0.3295	1.0000	135.3903
0.0178	2.3666	0.0102	6.2934	1.1442	9.8321		0.0033	0.3361	0.0016	0.3295	0.3295	1.0000	135.3923
0.0177	2.3665	0.0101	6.2937	1.1442	9.8322		0.0033	0.3361	0.0016	0.3295	0.3295	1.0000	135.3943
0.0176	2.3664	0.0101	6.2940	1.1443	9.8323		0.0033	0.3360	0.0016	0.3295	0.3295	1.0000	135.3963
0.0177	2.3665	0.0101	6.2937	1.1442	9.8322		0.0033	0.3361	0.0016	0.3295	0.3295	1.0000	135.3943
0.0176	2.3664	0.0101	6.2939	1.1443	9.8323		0.0033	0.3360	0.0016	0.3295	0.3295	1.0000	135.3963
0.0176	2.3663	0.0100	6.2942	1.1443	9.8324		0.0033	0.3360	0.0016	0.3296	0.3295	1.0000	135.3983
0.0175	2.3662	0.0100	6.2945	1.1444	9.8325		0.0032	0.3360	0.0016	0.3296	0.3296	1.0000	135.4002

FRAKSI BERAT

Komponen — fraksi berat

C_2H_4	HCl	O_2	$C_2H_4Cl_2$	H_2O	Total
0.2105	0.5489	0.2406	0.00004	0.0000	1.0000
0.2060	0.5702	0.1177	0.08970	0.0163	1.0000
0.1286	0.4454	0.0735	0.29826	0.0542	1.0000
0.0971	0.3944	0.0555	0.38329	0.0697	1.0000
0.1423	0.4674	0.0813	0.26148	0.0475	1.0000
0.1039	0.4054	0.0594	0.36493	0.0663	1.0000
0.0831	0.3718	0.0475	0.42113	0.0766	1.0000
0.0696	0.3501	0.0398	0.45735	0.0831	1.0000
0.1012	0.4010	0.0578	0.37234	0.0677	1.0000
0.0813	0.3690	0.0465	0.42573	0.0774	1.0000
0.0684	0.3482	0.0391	0.46054	0.0837	1.0000
0.0592	0.3334	0.0339	0.48530	0.0882	1.0000
0.0767	0.3615	0.0438	0.43825	0.0797	1.0000
0.0652	0.3430	0.0373	0.46928	0.0853	1.0000
0.0568	0.3295	0.0325	0.49179	0.0894	1.0000
0.0505	0.3192	0.0288	0.50896	0.0925	1.0000
0.0610	0.3363	0.0349	0.48046	0.0874	1.0000
0.0537	0.3244	0.0307	0.50024	0.0909	1.0000
0.0480	0.3152	0.0274	0.51560	0.0937	1.0000
0.0434	0.3079	0.0248	0.52789	0.0960	1.0000
0.0504	0.3190	0.0288	0.50927	0.0926	1.0000
0.0453	0.3109	0.0259	0.52279	0.0950	1.0000
0.0413	0.3044	0.0236	0.53377	0.0970	1.0000
0.0379	0.2989	0.0216	0.54288	0.0987	1.0000

TEKANAN PARSIAL

Komponen

C_2H_4	HCl	O_2	$C_2H_4Cl_2$	H_2O	Total
2.7500	5.4999	2.7500	0.0001	0.0000	11.0000
2.8429	6.0357	1.4214	0.3501	0.3499	11.0000
2.0121	5.3434	1.0061	1.3193	1.3192	11.0000
1.6060	5.0050	0.8030	1.7931	1.7929	11.0000
2.1743	5.4786	1.0872	1.1300	1.1299	11.0000
1.6976	5.0813	0.8488	1.6862	1.6860	11.0000
1.4099	4.8415	0.7050	2.0219	2.0217	11.0000
1.2123	4.6768	0.6061	2.2525	2.2523	11.0000
1.6609	5.0507	0.8305	1.7290	1.7288	11.0000
1.3854	4.8211	0.6927	2.0505	2.0503	11.0000
1.1944	4.6619	0.5972	2.2733	2.2732	11.0000
1.0526	4.5438	0.5263	2.4387	2.4385	11.0000
1.3177	4.7647	0.6589	2.1294	2.1292	11.0000
1.1449	4.6207	0.5725	2.3310	2.3309	11.0000
1.0146	4.5121	0.5073	2.4830	2.4829	11.0000
0.9124	4.4269	0.4562	2.6024	2.6022	11.0000
1.0807	4.5672	0.5404	2.4059	2.4058	11.0000
0.9646	4.4704	0.4823	2.5414	2.5412	11.0000
0.8721	4.3934	0.4361	2.6493	2.6491	11.0000
0.7965	4.3304	0.3983	2.7375	2.7373	11.0000
0.9105	4.4254	0.4552	2.6045	2.6044	11.0000
0.8281	4.3567	0.4140	2.7007	2.7005	11.0000
0.7599	4.2998	0.3799	2.7803	2.7801	11.0000
0.7024	4.2519	0.3512	2.8473	2.8471	11.0000

0.0019	0.2408	0.0011	0.63983	0.1163	1.0000		0.0381	3.6983	0.0191	3.6222	3.6220	10.9997
0.0019	0.2408	0.0011	0.63986	0.1163	1.0000		0.0379	3.6981	0.0190	3.6224	3.6223	10.9997
0.0019	0.2408	0.0011	0.63988	0.1163	1.0000		0.0378	3.6980	0.0189	3.6226	3.6225	10.9997
0.0019	0.2408	0.0011	0.63990	0.1163	1.0000		0.0376	3.6978	0.0188	3.6229	3.6227	10.9997
0.0019	0.2408	0.0011	0.63988	0.1163	1.0000		0.0378	3.6980	0.0189	3.6226	3.6225	10.9997
0.0019	0.2408	0.0011	0.63990	0.1163	1.0000		0.0376	3.6978	0.0188	3.6228	3.6227	10.9997
0.0019	0.2408	0.0011	0.63993	0.1163	1.0000		0.0374	3.6977	0.0187	3.6231	3.6229	10.9997
0.0019	0.2408	0.0011	0.63995	0.1163	1.0000		0.0372	3.6975	0.0186	3.6233	3.6231	10.9997
0.0019	0.2408	0.0011	0.63993	0.1163	1.0000		0.0374	3.6977	0.0187	3.6230	3.6229	10.9997
0.0019	0.2408	0.0011	0.63995	0.1163	1.0000		0.0372	3.6975	0.0186	3.6232	3.6231	10.9997
0.0019	0.2408	0.0011	0.63997	0.1164	1.0000		0.0371	3.6974	0.0185	3.6235	3.6233	10.9997
0.0018	0.2408	0.0011	0.64000	0.1164	1.0000		0.0369	3.6973	0.0184	3.6236	3.6235	10.9997
0.0019	0.2408	0.0011	0.63997	0.1164	1.0000		0.0371	3.6974	0.0185	3.6234	3.6233	10.9997
0.0018	0.2408	0.0011	0.64000	0.1164	1.0000		0.0369	3.6973	0.0184	3.6236	3.6235	10.9997
0.0018	0.2407	0.0010	0.64002	0.1164	1.0000		0.0367	3.6971	0.0184	3.6238	3.6237	10.9997
0.0018	0.2407	0.0010	0.64004	0.1164	1.0000		0.0366	3.6970	0.0183	3.6240	3.6239	10.9997
0.0018	0.2407	0.0010	0.64002	0.1164	1.0000		0.0367	3.6971	0.0184	3.6238	3.6237	10.9997
0.0018	0.2407	0.0010	0.64004	0.1164	1.0000		0.0366	3.6970	0.0183	3.6240	3.6239	10.9997
0.0018	0.2407	0.0010	0.64006	0.1164	1.0000		0.0364	3.6968	0.0182	3.6242	3.6240	10.9997
0.0018	0.2407	0.0010	0.64009	0.1164	1.0000		0.0362	3.6967	0.0181	3.6244	3.6242	10.9997
0.0018	0.2407	0.0010	0.64006	0.1164	1.0000		0.0364	3.6968	0.0182	3.6242	3.6240	10.9997
0.0018	0.2407	0.0010	0.64008	0.1164	1.0000		0.0362	3.6967	0.0181	3.6244	3.6242	10.9997
0.0018	0.2407	0.0010	0.64011	0.1164	1.0000		0.0361	3.6966	0.0180	3.6246	3.6244	10.9997
0.0018	0.2407	0.0010	0.64013	0.1164	1.0000		0.0359	3.6964	0.0180	3.6248	3.6246	10.9997
0.0018	0.2407	0.0010	0.64011	0.1164	1.0000		0.0361	3.6966	0.0180	3.6246	3.6244	10.9997
0.0018	0.2407	0.0010	0.64013	0.1164	1.0000		0.0359	3.6964	0.0180	3.6248	3.6246	10.9997
0.0018	0.2407	0.0010	0.64015	0.1164	1.0000		0.0358	3.6963	0.0179	3.6250	3.6248	10.9997
0.0018	0.2406	0.0010	0.64017	0.1164	1.0000		0.0356	3.6962	0.0178	3.6252	3.6250	10.9997

KAPASITAS PANAS

VISKOSITAS GAS, Kg/cm jam

Suhu Gas	Komponen						Komponen				
TG	C_2H_4	HCl	O_2	$C_2H_4Cl_2$	H_2O	CP campuran	C_2H_4	HCl	O_2	$C_2H_4Cl_2$	H_2O
553.000	65.8363	29.4958	31.5612	109.3283	35.7540	39.0982	6.3301E-04	9.4987E-04	1.1536E-03	5.9053E-04	7.0364E-04
552.9392	65.8309	29.4957	31.5606	109.3220	35.7534	41.8926	6.3295E-04	9.4977E-04	1.1535E-03	5.9047E-04	7.0355E-04
552.8156	65.8202	29.4953	31.5594	109.3093	35.7520	46.6517	6.3284E-04	9.4958E-04	1.1533E-03	5.9035E-04	7.0337E-04
552.8164	65.8202	29.4953	31.5595	109.3094	35.7520	48.9795	6.3284E-04	9.4958E-04	1.1533E-03	5.9035E-04	7.0337E-04
552.9076	65.8282	29.4956	31.5603	109.3188	35.7530	45.7245	6.3292E-04	9.4972E-04	1.1535E-03	5.9044E-04	7.0351E-04
552.8920	65.8268	29.4955	31.5602	109.3172	35.7528	48.4570	6.3291E-04	9.4970E-04	1.1535E-03	5.9042E-04	7.0349E-04
552.9160	65.8289	29.4956	31.5604	109.3197	35.7531	50.1072	6.3293E-04	9.4974E-04	1.1535E-03	5.9045E-04	7.0352E-04
552.9539	65.8322	29.4957	31.5607	109.3235	35.7535	51.2416	6.3297E-04	9.4980E-04	1.1536E-03	5.9048E-04	7.0358E-04
552.9583	65.8326	29.4957	31.5608	109.3240	35.7536	48.6695	6.3297E-04	9.4980E-04	1.1536E-03	5.9049E-04	7.0358E-04
552.9844	65.8349	29.4958	31.5610	109.3267	35.7538	50.2503	6.3300E-04	9.4984E-04	1.1536E-03	5.9051E-04	7.0362E-04
553.0232	65.8383	29.4959	31.5614	109.3307	35.7543	51.3467	6.3303E-04	9.4990E-04	1.1537E-03	5.9055E-04	7.0368E-04
553.0678	65.8422	29.4960	31.5618	109.3353	35.7547	52.1608	6.3308E-04	9.4997E-04	1.1537E-03	5.9059E-04	7.0375E-04
553.0385	65.8396	29.4959	31.5615	109.3322	35.7544	50.6399	6.3305E-04	9.4993E-04	1.1537E-03	5.9057E-04	7.0370E-04
553.0796	65.8432	29.4961	31.5619	109.3365	35.7549	51.6322	6.3309E-04	9.4999E-04	1.1538E-03	5.9061E-04	7.0376E-04
553.1254	65.8472	29.4962	31.5623	109.3412	35.7554	52.3808	6.3313E-04	9.5006E-04	1.1538E-03	5.9065E-04	7.0383E-04
553.1738	65.8514	29.4963	31.5628	109.3462	35.7559	52.9689	6.3318E-04	9.5014E-04	1.1539E-03	5.9070E-04	7.0390E-04
553.1317	65.8478	29.4962	31.5624	109.3418	35.7554	52.0021	6.3314E-04	9.5007E-04	1.1538E-03	5.9066E-04	7.0384E-04
553.1789	65.8519	29.4963	31.5628	109.3467	35.7559	52.6696	6.3318E-04	9.5015E-04	1.1539E-03	5.9070E-04	7.0391E-04
553.2282	65.8562	29.4965	31.5633	109.3517	35.7565	53.2016	6.3323E-04	9.5022E-04	1.1540E-03	5.9075E-04	7.0398E-04
553.2787	65.8606	29.4966	31.5637	109.3569	35.7570	53.6370	6.3328E-04	9.5030E-04	1.1541E-03	5.9080E-04	7.0406E-04
553.2311	65.8564	29.4965	31.5633	109.3520	35.7565	52.9816	6.3323E-04	9.5023E-04	1.1540E-03	5.9075E-04	7.0399E-04
553.2811	65.8608	29.4966	31.5638	109.3572	35.7571	53.4561	6.3328E-04	9.5031E-04	1.1541E-03	5.9080E-04	7.0406E-04
553.3321	65.8653	29.4968	31.5642	109.3624	35.7576	53.8491	6.3333E-04	9.5038E-04	1.1542E-03	5.9085E-04	7.0414E-04
553.3838	65.8698	29.4969	31.5647	109.3677	35.7582	54.1804	6.3338E-04	9.5047E-04	1.1542E-03	5.9090E-04	7.0421E-04

565.4354	66.9186	29.5320	31.6766	110.5962	35.8894	58.4533	6.4473E-04	9.6916E-04	1.1731E-03	6.0267E-04	7.2204E-04
565.4883	66.9232	29.5321	31.6770	110.6015	35.8900	58.4563	6.4478E-04	9.6924E-04	1.1732E-03	6.0272E-04	7.2212E-04
565.5411	66.9278	29.5323	31.6775	110.6069	35.8906	58.4594	6.4483E-04	9.6932E-04	1.1733E-03	6.0277E-04	7.2220E-04
565.5939	66.9324	29.5324	31.6780	110.6122	35.8912	58.4624	6.4488E-04	9.6940E-04	1.1734E-03	6.0282E-04	7.2227E-04
565.5411	66.9278	29.5323	31.6775	110.6069	35.8906	58.4593	6.4483E-04	9.6932E-04	1.1733E-03	6.0277E-04	7.2220E-04
565.5939	66.9324	29.5324	31.6780	110.6122	35.8912	58.4624	6.4488E-04	9.6940E-04	1.1734E-03	6.0282E-04	7.2227E-04
565.6467	66.9370	29.5326	31.6785	110.6176	35.8918	58.4654	6.4493E-04	9.6948E-04	1.1735E-03	6.0287E-04	7.2235E-04
565.6995	66.9415	29.5328	31.6790	110.6229	35.8923	58.4684	6.4497E-04	9.6956E-04	1.1735E-03	6.0292E-04	7.2243E-04
565.6467	66.9370	29.5326	31.6785	110.6176	35.8918	58.4654	6.4493E-04	9.6948E-04	1.1735E-03	6.0287E-04	7.2235E-04
565.6995	66.9415	29.5328	31.6790	110.6229	35.8923	58.4684	6.4497E-04	9.6956E-04	1.1735E-03	6.0292E-04	7.2243E-04
565.7523	66.9461	29.5329	31.6795	110.6282	35.8929	58.4714	6.4502E-04	9.6965E-04	1.1736E-03	6.0297E-04	7.2251E-04
565.8051	66.9507	29.5331	31.6800	110.6336	35.8935	58.4744	6.4507E-04	9.6973E-04	1.1737E-03	6.0303E-04	7.2259E-04
565.7523	66.9461	29.5329	31.6795	110.6282	35.8929	58.4714	6.4502E-04	9.6965E-04	1.1736E-03	6.0297E-04	7.2251E-04
565.8051	66.9507	29.5331	31.6800	110.6336	35.8935	58.4744	6.4507E-04	9.6973E-04	1.1737E-03	6.0303E-04	7.2259E-04
565.8579	66.9553	29.5332	31.6805	110.6389	35.8941	58.4774	6.4512E-04	9.6981E-04	1.1738E-03	6.0308E-04	7.2266E-04
565.9107	66.9599	29.5334	31.6810	110.6442	35.8946	58.4804	6.4517E-04	9.6989E-04	1.1739E-03	6.0313E-04	7.2274E-04
565.8579	66.9553	29.5332	31.6805	110.6389	35.8941	58.4774	6.4512E-04	9.6981E-04	1.1738E-03	6.0308E-04	7.2266E-04
565.9107	66.9599	29.5334	31.6810	110.6442	35.8946	58.4804	6.4517E-04	9.6989E-04	1.1739E-03	6.0313E-04	7.2274E-04
565.9635	66.9644	29.5335	31.6815	110.6496	35.8952	58.4834	6.4522E-04	9.6997E-04	1.1740E-03	6.0318E-04	7.2282E-04
566.0163	66.9690	29.5337	31.6819	110.6549	35.8958	58.4863	6.4527E-04	9.7005E-04	1.1740E-03	6.0323E-04	7.2290E-04
565.9635	66.9644	29.5335	31.6815	110.6496	35.8952	58.4833	6.4522E-04	9.6997E-04	1.1740E-03	6.0318E-04	7.2282E-04
566.0163	66.9690	29.5337	31.6819	110.6549	35.8958	58.4863	6.4527E-04	9.7005E-04	1.1740E-03	6.0323E-04	7.2290E-04
566.0691	66.9736	29.5339	31.6824	110.6603	35.8964	58.4893	6.4532E-04	9.7014E-04	1.1741E-03	6.0328E-04	7.2298E-04
566.1219	66.9782	29.5340	31.6829	110.6656	35.8970	58.4922	6.4537E-04	9.7022E-04	1.1742E-03	6.0333E-04	7.2305E-04
566.0691	66.9736	29.5339	31.6824	110.6603	35.8964	58.4893	6.4532E-04	9.7014E-04	1.1741E-03	6.0328E-04	7.2298E-04
566.1219	66.9782	29.5340	31.6829	110.6656	35.8970	58.4922	6.4537E-04	9.7022E-04	1.1742E-03	6.0333E-04	7.2305E-04
566.1747	66.9828	29.5342	31.6834	110.6709	35.8975	58.4952	6.4542E-04	9.7030E-04	1.1743E-03	6.0339E-04	7.2313E-04
566.2275	66.9873	29.5343	31.6839	110.6763	35.8981	58.4981	6.4547E-04	9.7038E-04	1.1744E-03	6.0344E-04	7.2321E-04

	kJ/jam.cm^2.K	ΔH reaktan			del H product		Kj/mol	
μ campuran	UD	C_2H_4	HCl	O_2	$C_2H_4Cl_2$	H_2O	ΔH reaktan	ΔH product
0.0009	0.00903	13938.099794	7455.348331	7763.253574	24190.409959	8816.357699	29156.701700	33006.767658
0.0009	0.00903	13934.094603	7453.553866	7761.333470	24183.758823	8814.182513	29148.981939	32997.941336
0.0008	0.00903	13925.959408	7449.908602	7757.433056	24170.248806	8809.763938	29133.301067	32980.012744
0.0008	0.00903	13926.011128	7449.931779	7757.457855	24170.334698	8809.792031	29133.400762	32980.126729
0.0008	0.00903	13932.014575	7452.621888	7760.336250	24180.304608	8813.052813	29144.972713	32993.357422
0.0008	0.00903	13930.992030	7452.163713	7759.846002	24178.606495	8812.497438	29143.001746	32991.103933
0.0008	0.00903	13932.572661	7452.871948	7760.603814	24181.231401	8813.355923	29146.048422	32994.587324
0.0008	0.00903	13935.064271	7453.988323	7761.798344	24185.369095	8814.709144	29150.850938	33000.078239
0.0008	0.00903	13935.357655	7454.119772	7761.938995	24185.856301	8814.868480	29151.416422	33000.724781
0.0008	0.00903	13937.075261	7454.889318	7762.762420	24188.708604	8815.801296	29154.726999	33004.509901
0.0008	0.00903	13939.625635	7456.031926	7763.985036	24192.943772	8817.186335	29159.642597	33010.130107
0.0008	0.00903	13942.563118	7457.347898	7765.393166	24197.821698	8818.781534	29165.304182	33016.603231
0.0008	0.00903	13940.636653	7456.484863	7764.469691	24194.622658	8817.735376	29161.591208	33012.358034
0.0008	0.00903	13943.339064	7457.695504	7765.765117	24199.110204	8819.202899	29166.799686	33018.313102
0.0008	0.00903	13946.355422	7459.046717	7767.210972	24204.118997	8820.840835	29172.613112	33024.959832
0.0008	0.00903	13949.545134	7460.475503	7768.739848	24209.415556	8822.572822	29178.760485	33031.988378
0.0008	0.00903	13946.772344	7459.233476	7767.410813	24204.811306	8821.067225	29173.416633	33025.878531
0.0008	0.00903	13949.880039	7460.625513	7768.900368	24209.971664	8822.754667	29179.405921	33032.726331
0.0008	0.00903	13953.123696	7462.078367	7770.455014	24215.357687	8824.515849	29185.657077	33039.873535
0.0008	0.00903	13956.451261	7463.568712	7772.049794	24220.882931	8826.322497	29192.069767	33047.205428
0.0008	0.00903	13953.316009	7462.164502	7770.547185	24215.677016	8824.620265	29186.027697	33040.297281
0.0008	0.00903	13956.611080	7463.640289	7772.126388	24221.148300	8826.409266	29192.377757	33047.557565
0.0008	0.00903	13959.971822	7465.145395	7773.736980	24226.728518	8828.233827	29198.854197	33054.962345
0.0008	0.00903	13963.376287	7466.669985	7775.368439	24232.381221	8830.082029	29205.414711	33062.463250
0.0009	0.00903	13938.099794	7455.348331	7763.253574	24190.409959	8816.357699	29156.701700	33006.767658

0.0008	0.00903	14763.540392	7822.365420	8156.448195	25557.861075	9261.814629	30742.354007	34819.675704
0.0008	0.00903	14767.075106	7823.925282	8158.121340	25563.702827	9263.710298	30749.121728	34827.413124
0.0008	0.00903	14770.609919	7825.485088	8159.794443	25569.544623	9265.605920	30755.889451	34835.150543
0.0008	0.00903	14774.144831	7827.044840	8161.467505	25575.386464	9267.501497	30762.657175	34842.887961
0.0008	0.00903	14770.609633	7825.484962	8159.794308	25569.544149	9265.605767	30755.888902	34835.149916
0.0008	0.00903	14774.144544	7827.044713	8161.467369	25575.385991	9267.501343	30762.656627	34842.887334
0.0008	0.00903	14777.679555	7828.604410	8163.140389	25581.227879	9269.396873	30769.424354	34850.624752
0.0008	0.00903	14781.214665	7830.164052	8164.813366	25587.069812	9271.292357	30776.192084	34858.362169
0.0008	0.00903	14777.679269	7828.604284	8163.140253	25581.227406	9269.396720	30769.423806	34850.624126
0.0008	0.00903	14781.214379	7830.163926	8164.813231	25587.069339	9271.292204	30776.191536	34858.361544
0.0008	0.00903	14784.749588	7831.723513	8166.486167	25592.911319	9273.187643	30782.959269	34866.098961
0.0008	0.00903	14788.284896	7833.283046	8168.159062	25598.753344	9275.083035	30789.727004	34873.836379
0.0008	0.00903	14784.749303	7831.723388	8166.486032	25592.910847	9273.187490	30782.958723	34866.098337
0.0008	0.00903	14788.284611	7833.282920	8168.158927	25598.752873	9275.082882	30789.726459	34873.835755
0.0008	0.00903	14791.820019	7834.842399	8169.831780	25604.594946	9276.978229	30796.494198	34881.573175
0.0008	0.00903	14795.355526	7836.401822	8171.504592	25610.437065	9278.873530	30803.261940	34889.310595
0.0008	0.00903	14791.819734	7834.842273	8169.831645	25604.594475	9276.978076	30796.493653	34881.572551
0.0008	0.00903	14795.355242	7836.401697	8171.504457	25610.436595	9278.873378	30803.261396	34889.309972
0.0008	0.00903	14798.890849	7837.961066	8173.177228	25616.278761	9280.768633	30810.029143	34897.047394
0.0008	0.00903	14802.426556	7839.520381	8174.849957	25622.120974	9282.663844	30816.796893	34904.784818
0.0008	0.00903	14798.890565	7837.960941	8173.177093	25616.278291	9280.768481	30810.028599	34897.046772
0.0008	0.00903	14802.426272	7839.520256	8174.849822	25622.120505	9282.663691	30816.796350	34904.784196
0.0008	0.00903	14805.962079	7841.079517	8176.522510	25627.962766	9284.558856	30823.564106	34912.521622
0.0008	0.00903	14809.497986	7842.638724	8178.195157	25633.805074	9286.453976	30830.331866	34920.259050
0.0008	0.00903	14805.961795	7841.079392	8176.522376	25627.962297	9284.558704	30823.563563	34912.521002
0.0008	0.00903	14809.497702	7842.638599	8178.195023	25633.804606	9286.453824	30830.331324	34920.258430
0.0008	0.00903	14813.033710	7844.197751	8179.867628	25639.646963	9288.348899	30837.099090	34927.995861

Kj/kmol

$C_A = C_{A0}(1-X_A)$ $rA = kC_AC_B^2 = kC_{A0}^2(1-X_A)(M-2X_A)^2$

ΔH reaktan	ΔH product	Panas Reaksi	Harga k	CA	Kec. Reaksi	Densitas Gas	G	fk	Cpcooler
29156701.7	33006767.7	3610865.9578	7.088725	0.029841223	0.02525	1.475555	8.8138	4.2060	0.99326
29148981.9	32997941.3	3609759.3965	7.080791	0.026570919	0.0178051	1.531086	8.8138	4.0817	0.99328
29133301.1	32980012.7	3607511.6772	7.064697	0.018024272	0.0055451	1.684832	8.8138	3.9823	0.99336
29133400.8	32980126.7	3607525.9676	7.064799	0.014100446	0.0026549	1.759806	8.8138	3.9340	0.99344
29144972.7	32993357.4	3609184.7083	7.076674	0.019637003	0.0071829	1.654600	8.8138	4.0020	0.9934
29143001.7	32991103.9	3608902.1870	7.074650	0.014971695	0.0031824	1.742658	8.8138	3.9452	0.99348
29146048.4	32994587.3	3609338.9020	7.077778	0.012260581	0.0017485	1.795697	8.8138	3.9110	0.99356
29150850.9	33000078.2	3610027.3014	7.082712	0.010441635	0.0010808	1.832060	8.8138	3.8876	0.99364
29151416.4	33000724.8	3610108.3588	7.083293	0.014621797	0.0029681	1.749220	8.8138	3.9410	0.99356
29154727	33004509.9	3610582.9015	7.086695	0.012032764	0.0016549	1.800006	8.8138	3.9083	0.99364
29159642.6	33010130.1	3611287.5100	7.091749	0.010278580	0.0010323	1.835134	8.8138	3.8857	0.99373
29165304.2	33016603.2	3612099.0492	7.097574	0.008997664	0.000693	1.861143	8.8138	3.8690	0.99381
29161591.2	33012358	3611566.8265	7.093754	0.011407933	0.0014117	1.812313	8.8138	3.9005	0.99373
29166799.7	33018313.1	3612313.4166	7.099113	0.009829628	0.0009038	1.844074	8.8138	3.8800	0.99381
29172613.1	33024959.8	3613146.7205	7.105099	0.008656949	0.0006179	1.867965	8.8138	3.8647	0.99389
29178760.5	33031988.4	3614027.8927	7.111433	0.007746616	0.0004431	1.886673	8.8138	3.8527	0.99397
29173416.6	33025878.5	3613261.8983	7.105927	0.009249958	0.0007538	1.855748	8.8138	3.8726	0.99389
29179405.9	33032726.3	3614120.4102	7.112098	0.008210514	0.0005277	1.877016	8.8138	3.8589	0.99397
29185657.1	33039873.5	3615016.4584	7.118544	0.007390844	0.0003852	1.893912	8.8138	3.8481	0.99405
29192069.8	33047205.4	3615935.6607	7.125160	0.006726061	0.0002906	1.907688	8.8138	3.8393	0.99413
29186027.7	33040297.3	3615069.5835	7.118926	0.007730147	0.0004408	1.886821	8.8138	3.8527	0.99405
29192377.8	33047557.6	3615979.8083	7.125478	0.007002885	0.000328	1.901859	8.8138	3.8430	0.99413
29198854.2	33054962.3	3616908.1483	7.132166	0.006405480	0.0002513	1.914265	8.8138	3.8351	0.99421
29205414.7	33062463.2	3617848.5391	7.138945	0.005905186	0.0001971	1.924683	8.8138	3.8284	0.99429

30742354	34819675.7	3838121.6973	8.867066	0.000310744	3.566E-08	2.003536	8.8138	3.7922	1.01254
30749121.7	34827413.1	3839091.3962	8.875314	0.000309280	3.52E-08	2.003381	8.8138	3.7924	1.01261
30755889.5	34835150.5	3840061.0923	8.883568	0.000307828	3.473E-08	2.003225	8.8138	3.7926	1.01269
30762657.2	34842888	3841030.7855	8.891828	0.000306389	3.428E-08	2.003070	8.8138	3.7927	1.01277
30755888.9	34835149.9	3840061.0136	8.883568	0.000307853	3.474E-08	2.003225	8.8138	3.7926	1.01269
30762656.6	34842887.3	3841030.7070	8.891827	0.000306414	3.429E-08	2.003069	8.8138	3.7927	1.01277
30769424.4	34850624.8	3842000.3976	8.900093	0.000304986	3.384E-08	2.002914	8.8138	3.7929	1.01285
30776192.1	34858362.2	3842970.0855	8.908364	0.000303571	3.341E-08	2.002758	8.8138	3.7931	1.01293
30769423.8	34850624.1	3842000.3191	8.900092	0.000305010	3.385E-08	2.002913	8.8138	3.7929	1.01285
30776191.5	34858361.5	3842970.0071	8.908363	0.000303595	3.341E-08	2.002757	8.8138	3.7931	1.01293
30782959.3	34866099	3843939.6925	8.916640	0.000302191	3.298E-08	2.002601	8.8138	3.7932	1.01301
30789727	34873836.4	3844909.3751	8.924923	0.000300799	3.256E-08	2.002445	8.8138	3.7934	1.01309
30782958.7	34866098.3	3843939.6142	8.916639	0.000302214	3.299E-08	2.002601	8.8138	3.7932	1.01301
30789726.5	34873835.8	3844909.2969	8.924922	0.000300822	3.257E-08	2.002444	8.8138	3.7934	1.01309
30796494.2	34881573.2	3845878.9771	8.933211	0.000299441	3.215E-08	2.002288	8.8138	3.7936	1.01317
30803261.9	34889310.6	3846848.6546	8.941505	0.000298072	3.174E-08	2.002131	8.8138	3.7937	1.01325
30796493.7	34881572.6	3845878.8989	8.933210	0.000299464	3.216E-08	2.002287	8.8138	3.7936	1.01317
30803261.4	34889310	3846848.5766	8.941505	0.000298094	3.175E-08	2.002130	8.8138	3.7937	1.01325
30810029.1	34897047.4	3847818.2517	8.949805	0.000296736	3.134E-08	2.001973	8.8138	3.7939	1.01333
30816796.9	34904784.8	3848787.9242	8.958111	0.000295389	3.095E-08	2.001816	8.8138	3.7941	1.01341
30810028.6	34897046.8	3847818.1737	8.949804	0.000296758	3.135E-08	2.001973	8.8138	3.7939	1.01333
30816796.4	34904784.2	3848787.8463	8.958110	0.000295411	3.096E-08	2.001816	8.8138	3.7941	1.01341
30823564.1	34912521.6	3849757.5165	8.966422	0.000294074	3.057E-08	2.001658	8.8138	3.7942	1.01349
30830331.9	34920259.1	3850727.1841	8.974740	0.000292749	3.018E-08	2.001501	8.8138	3.7944	1.01357
30823563.6	34912521	3849757.4387	8.966422	0.000294096	3.057E-08	2.001658	8.8138	3.7942	1.01349
30830331.3	34920258.4	3850727.1064	8.974739	0.000292770	3.019E-08	2.001500	8.8138	3.7944	1.01357
30837099.1	34927995.9	3851696.7717	8.983063	0.000291455	2.981E-08	2.001343	8.8138	3.7946	1.01365
30843866.9	34935733.3	3852666.4346	8.991392	0.000290150	2.944E-08	2.001185	8.8138	3.7947	1.01373

dx/dz	dT/dz	dTc/dz	dP/dz	Runge kutta			
F1	F2	F3	F4	K	L	M	N
2.191803	-1.216762	0.347057	-3.46501E-05	0.219180	-0.121676	0.034706	-0.000003
1.735782	-0.749013	0.346901	-3.24067E-05	0.572808	-0.247174	0.114477	-0.000003
0.796910	0.004762	0.346529	-2.87325E-05	0.262980	0.001572	0.114355	-0.000003
0.487715	0.176577	0.346394	-2.71744E-05	0.160946	0.058270	0.114310	-0.000003
0.947501	-0.094144	0.346640	-2.94019E-05	0.312675	-0.031067	0.114391	-0.000003
0.550614	0.145525	0.346474	-2.75198E-05	0.181703	0.048023	0.114336	-0.000003
0.369419	0.229387	0.346383	-2.64756E-05	0.121908	0.075698	0.114306	-0.000003
0.268125	0.267652	0.346318	-2.57949E-05	0.088481	0.088325	0.114285	-0.000003
0.525820	0.158122	0.346463	-2.73879E-05	0.173521	0.052180	0.114333	-0.000003
0.356266	0.234775	0.346376	-2.63942E-05	0.117568	0.077476	0.114304	-0.000003
0.260148	0.270396	0.346312	-2.57392E-05	0.085849	0.089231	0.114283	-0.000003
0.199512	0.289425	0.346260	-2.52704E-05	0.065839	0.095510	0.114266	-0.000003
0.320546	0.248753	0.346342	-2.61623E-05	0.105780	0.082088	0.114293	-0.000003
0.238165	0.277635	0.346283	-2.5577E-05	0.078595	0.091620	0.114273	-0.000003
0.184884	0.293573	0.346233	-2.51499E-05	0.061012	0.096879	0.114257	-0.000003
0.148177	0.303116	0.346188	-2.48232E-05	0.048898	0.100028	0.114242	-0.000002
0.211106	0.286022	0.346245	-2.53672E-05	0.069665	0.094387	0.114261	-0.000003
0.166471	0.298517	0.346198	-2.49913E-05	0.054935	0.098511	0.114245	-0.000002
0.135014	0.306219	0.346155	-2.46988E-05	0.044555	0.101052	0.114231	-0.000002
0.111922	0.311219	0.346114	-2.44643E-05	0.036934	0.102702	0.114218	-0.000002
0.147703	0.303227	0.346160	-2.48212E-05	0.048742	0.100065	0.114233	-0.000002
0.121330	0.309250	0.346118	-2.45633E-05	0.040039	0.102052	0.114219	-0.000002
0.101607	0.313252	0.346079	-2.43537E-05	0.033530	0.103373	0.114206	-0.000002
2.191803	-1.216762	0.347057	-3.46501E-05	0.219180	-0.121676	0.034706	-0.000003

0.000297	0.320117	0.338387	-2.30085E-05	0.000098	0.105639	0.111668	-0.000002
0.000295	0.320104	0.338354	-2.30113E-05	0.000097	0.105634	0.111657	-0.000002
0.000292	0.320091	0.338322	-2.30141E-05	0.000096	0.105630	0.111646	-0.000002
0.000290	0.320078	0.338290	-2.30169E-05	0.000096	0.105626	0.111636	-0.000002
0.000292	0.320091	0.338322	-2.30141E-05	0.000096	0.105630	0.111646	-0.000002
0.000290	0.320078	0.338290	-2.30169E-05	0.000096	0.105626	0.111636	-0.000002
0.000287	0.320065	0.338258	-2.30197E-05	0.000095	0.105621	0.111625	-0.000002
0.000285	0.320052	0.338226	-2.30225E-05	0.000094	0.105617	0.111615	-0.000002
0.000287	0.320065	0.338258	-2.30197E-05	0.000095	0.105621	0.111625	-0.000002
0.000285	0.320052	0.338226	-2.30225E-05	0.000094	0.105617	0.111615	-0.000002
0.000283	0.320039	0.338194	-2.30253E-05	0.000093	0.105613	0.111604	-0.000002
0.000280	0.320026	0.338162	-2.30281E-05	0.000093	0.105609	0.111593	-0.000002
0.000283	0.320039	0.338194	-2.30253E-05	0.000093	0.105613	0.111604	-0.000002
0.000280	0.320026	0.338162	-2.30281E-05	0.000093	0.105609	0.111593	-0.000002
0.000278	0.320013	0.338130	-2.3031E-05	0.000092	0.105604	0.111583	-0.000002
0.000276	0.320000	0.338098	-2.30338E-05	0.000091	0.105600	0.111572	-0.000002
0.000278	0.320013	0.338130	-2.3031E-05	0.000092	0.105604	0.111583	-0.000002
0.000276	0.320000	0.338098	-2.30338E-05	0.000091	0.105600	0.111572	-0.000002
0.000274	0.319988	0.338066	-2.30366E-05	0.000090	0.105596	0.111562	-0.000002
0.000271	0.319975	0.338034	-2.30394E-05	0.000090	0.105592	0.111551	-0.000002
0.000274	0.319988	0.338066	-2.30366E-05	0.000090	0.105596	0.111562	-0.000002
0.000271	0.319975	0.338034	-2.30395E-05	0.000090	0.105592	0.111551	-0.000002
0.000269	0.319962	0.338002	-2.30423E-05	0.000089	0.105587	0.111541	-0.000002
0.000267	0.319949	0.337970	-2.30451E-05	0.000088	0.105583	0.111530	-0.000002
0.000269	0.319962	0.338002	-2.30423E-05	0.000089	0.105587	0.111541	-0.000002
0.000267	0.319949	0.337970	-2.30451E-05	0.000088	0.105583	0.111530	-0.000002
0.000265	0.319936	0.337938	-2.3048E-05	0.000087	0.105579	0.111519	-0.000002
0.000263	0.319924	0.337906	-2.30508E-05	0.000087	0.105575	0.111509	-0.000002

6. Mechanical Design Reaktor

1. Pipa

Jenis pipa = *Stainless Steel* SA 213

Susunan pipa = *Triangular Pitch*

Ukuran Pipa (*Kern*, 1983)

Diameter Nominal (IPS) = 1 in

Schedule Number = 40

Diameter luar (OD) = 1,32 in

Diameter dalam (ID) = 1,049 in

Luas penampang pipa = 0,864 in^2

Luas permukaan luar perpanjang pipa = 0,334 ft^2/ft

Luas permukaan dalam perpanjang pipa = 0,274 ft^2/ft

Factor design = 20%

Panjang pipa = 13,50 m

Jarak antara 2 pusat pipa (P_T) = 1,25 OD

= 1,65 in

Clearence ($C = P_T - OD$) = 0,33 in

Jumlah pipa = 8187 buah

2. Isolator

Tebal isolasi dihitung dengan asumsi ;

1. Kondisi adiabatis (Qloss ke lingkungan Kecil)

2. Tg = suhu diameter dalam reaktor

3. Panas radiasi diabaikan

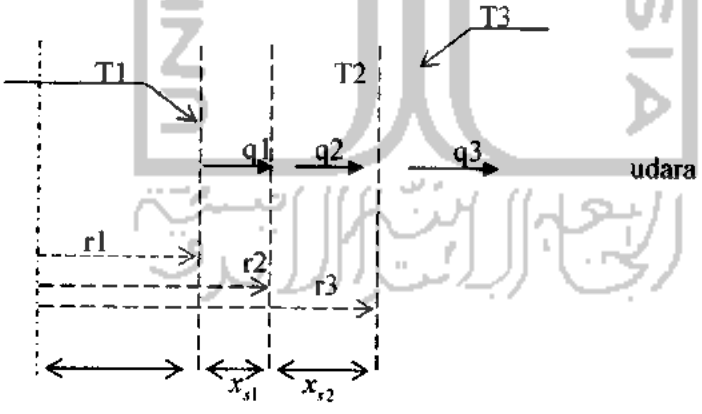
Isolasi reaktor menggunakan *Asbestos* dengan suhu maksimal 932 F dan dinding bagian luar dilapisi *Sainless Stell SA-212 grade B* (*brawnell & young* 1945).

Bahan perancangan

1. Isolator, *Asbestos* berfungsi menahan sampai suhu luar isolator 60 C.
2. Lapisan penahan tekanan karena konduktivitas panas yang tinggi.

Data fisis bahan ;

Bahan	T_{max} (^0F)	ρ Lb/ft^3	k Btu/hr.ft.^0F	Cp kJ/kg. ^0C
Asbestos	932	36	0,195	-
SA-212	-	488	26	-



Keterangan ;

- r_1 = jari-jari dalam shell, 78,4044 in.
- r_2 = jari-jari luar shell, 84,0000 in.
- r_3 = jari-jari penyekat.

- q_1 = transfer panas konveksi dari pendingin ke dalam reaktor.
- q_2 = transfer panas konveksi dari dinding dalam ke luar reaktor
- q_3 = transfer panas konveksi dari dinding luar reaktor ke dinding isolasi.
- T_1 = suhu reaktor.
- T_2 = suhu luar dinding = $97\,^{0}C$
- T_3 = $35\,^{0}C$
- Tu = suhu udara lingkungan = $30\,^{0}C$

T_4 = $97\,^{0}C$ = $206\,^{0}F$ = $666\,^{0}R$ = $370\,^{0}K$

Tu = $30\,^{0}C$ = $86\,^{0}F$ = $546\,^{0}R$ = $303\,^{0}K$

Menentukan Koefisien perpindahan panas konveksi (hc) ke udara dan panas radiasi (hr). (Rase & Barow, 1957)

$hc = 0{,}19 \cdot \Delta T^{1/3}$ = 0,9387 BTU/jam ft^2 °F

$$hr = \frac{\sigma \cdot \varepsilon \cdot \left(\frac{T_4}{100}\right)^4 - \left(\frac{T_U}{100}\right)^4}{(T_4 - T_U)} = 0{,}0202 \text{ BTU/jam ft}^2\,^{\circ}\text{F}$$

Kondisi Stady state

q1 = q2 = q3

Panas yang hilang (Qloss) :

$$\boxed{Qloss = (hc + hr)A(Ts - Tu)}$$

Qloss = 210175,3 Btu/jam

Panas yang hilang direncanakan 5% dari Qloss = 10508,76 Btu/jam

Qisolasi = Qloss – Q hilang 5%

= 199666,5 Btu/jam

Perhitungan isolator

Tebal isolasi ;

$$\frac{2.\pi.L\,(T4-Tu)}{\frac{Ln\,(r2/r1)}{Ks}+\frac{Ln\,(r3/r2)}{Ka}}$$

Dengan menggunakan metode golseak dalam ecxel maka r_3 = 7,0440 ft

Tebal isolasi = $r_3 - r_2$ =0,0440 ft = 0,5278 in.

Menghitung tebal plat lapisan luar

$$ts = \frac{P.r}{(f.E-0,6.P)} + C$$

keterangan ;

- ts = tebal *shell*
- P = tekanan
- r = jari-jari
- E = *effisiensi* pengelasan = 0,8
- C = faktor korosi = 0,125 in
- f = *allow stres* = 17.500 psi

Plate menggunkan ; *SA-212 garde B*

tekanan total reaktor direaktor diambil 1,5 takanan operasi.

P_{op} = Tekanan operasi = 161,7 psi

P design = 242,44 psi

Maka tebal plat lapisan luar = ts 1,4976 in

maka, dipilih tebal standar = 1 1/2 in

= 1,5 in

3.1.1. Perhitungan Qloss ke lingkungan

3.1.2.1. Isolasi

Perpindahan panas dalam reaktor melalui dinding reaktor – isolasi – plate lapisan luar serta udara dapat dijabarkan sebagai berikut ;

$$Qloss = (hc + hr)A(Ts - Tu)$$

$$hc = 0.19(\Delta t)^{1/3}$$

$$hr = \frac{\sigma.E(Ts^4 - Tu^4)}{Ts - Tu}$$

Diketahui : Ts = 206,334 F

Tu = 85,734 F

n = 3

E = 0,81

Maka :

hc = 0,19.(206,334 F-85,734 F)$^{1/3}$

= 0,938719927 BTU/jam.ft^2.F

$$hr = \frac{0,000000001713.0,81(206,334^4 - 85,734^4)}{(206,334 - 85,734)}$$

= 0,0202 BTU/jam.ft^2.°F

sehingga diperoleh ;

$$Qloss = (hc + hr)A(Ts - Tu)$$

= 210.175,2588 btu/jam

3. Tebal *head* (th)

Tebal *head* (th) dihitung dengan persamaan :

$$th = \frac{P.IDS.V}{2.f.E - 0.2P} + C$$

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

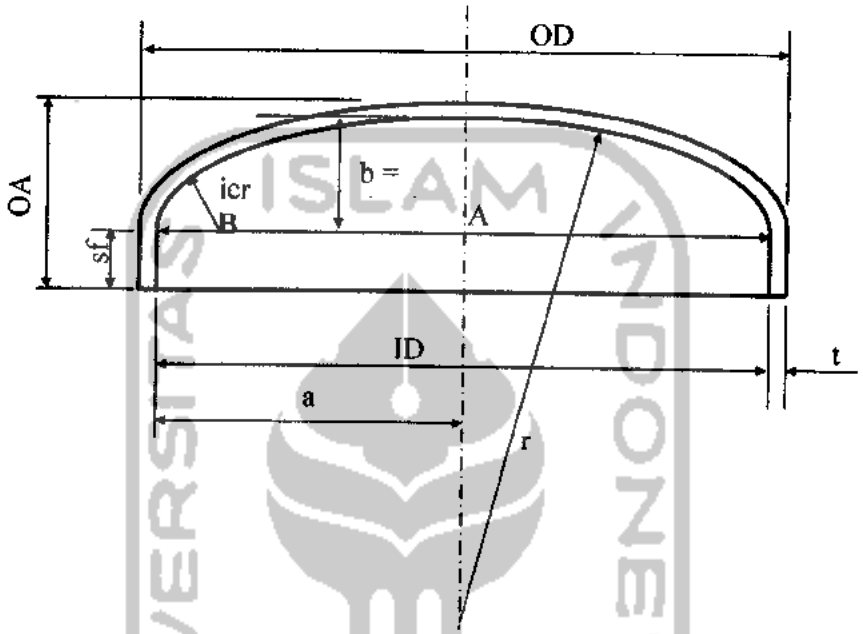
Bahan *head* diambil sama dengan bahan *plat shell*

Th = 2,61964187 in

Dipilih tebal standart = 2,75 in

4. Tinggi head

Dipilih bentuk *Torispherical Dished Head* (tekanan 15–200 psig.



a = ½ IDS = ½ (156,8088) = 78,4044 in

Tabel 5.7 *Brownell and Young* :

→ icr = 10,125 in

r = 144 in

AB = a - (icr)

= 68,2794 in

BC = r - (icr)

= 75,7506 in

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

= 111,2657 in

Dari tabel 5.8 *Brownell dan Young, 1959* diperoleh bahwa untuk tebal *head* 2,75 in maka dipilih *straight flange* (sf) sebesar 4 in.

t = 2¾ → sf = 1 ½ - 4 ½

Diambil sf = 4 in

Tinggi head = b + sf + th

= 111,2657 + 4 + 2,6196

= 117,8854 in

= 2,9942 m

5. Tebal *grid support*

Grid support berfungsi untuk menyangga tumpukan katalis dan memegang pipa. *Grid* support biasanya berbentuk piringan bergelombang atau piringan berlubang dengan tebal antara 4-6 in. *Grid support* terbuat dari bahan tahan korosi seperti *carbon steel, alloy stell, cast iron*, dan keramik (*Rase*, 1977). Karena reaktor harus beroperasi pada suhu 605 K, maka *grid support* dipilih terbuat dari *austenitic steel* (18Cr-8Ni) SA-167 Type 304 grade 3 yang dapat melayani pada suhu operasi ≤ 1300^{0}F dengan tekanan maksimum yang diijinkan (f) 2450 psi. Grid support dipilih berbentuk piringan berlubang (*perforated*).

Asumsi : Ap = N x A_{pipa}

$$= 8187 \times \frac{\eta}{4}(1{,}049)^2 = 7072{,}0516\ in^2$$

Volume pipa reaktor = $\frac{\pi}{4} ID.Z.Nt$

$$= \frac{\pi}{4} x0{,}0266x13{,}5x8718$$

$$= 2.311{,}732\ m^2$$

Volume pipa reaktor ≈ Volume katalis

Volume katalis = 97% x volume pipa reaktor

Volume katalis = $2.242{,}380\ m^3$

Berat katalis $= \frac{V}{\rho b}$

$$= \frac{2.242{,}38 m^3}{1050 kg/m^3}.$$

$$= 2.354.498{,}6936\ kg$$

$$F = m.\frac{g}{gc} = 2.354.489{,}6936 \times \frac{32{,}17}{32{,}17}$$

$$= 2.354.489{,}6936\ kg$$

$$P = \frac{F}{A} = \frac{2.354.489{,}6936}{7072{,}0516} = 332{,}92\ psi$$

$$t = d_{ep}\sqrt{\frac{3}{16}.\frac{P}{f}}$$

$$= 0{,}1161\ in$$

dipilih tebal *grid* yaitu 0,5 in

6. Tinggi Reaktor

Tinggi reaktor total

= Panjang Tube + 2 (tinggi *head*)

= 13,5 + 2 (2,9942)

= 19,4884 m

7. Volume Reaktor

- Volume Head

  $Vh = 0.000049\ IDs^3$ (*Brownell and Young,1959*)

  $= 188{,}9328\ in^3$

Volume ini tidak termasuk *straight flange*

- Volume Shell

  $Vs + Vsf = \pi/4\ (IDs)^2\ (Ls + 2 \times sf)$

  $= 10.259.101{,}18\ in^3$

  $= 168{,}1169 m^3$

- Volume Reaktor

  $V_R = Vs + (2 \times Vh)$

  $= 168{,}1227\ m^3$

8. Pipa Pemasukan Gas

Campuran gas masuk reaktor pada suhu 280 °C dan tekanan 11 atm

Komposisi gas masuk reaktor :

Komponen	BM	Input (kg/jam)
N_2	28	63.274,7459
O_2	32	16.819,8692
C_2H_4	28	14.717,3855
HCl	36,5	38.370,3265
C_2H_3Cl	62,5	396,6970
$C_2H_4Cl_2$	99	2,6150
H_2O	18	0
Total		**133.581,6390**

Jumlah gas masuk = 133.581,6390 kg/jam

= 37,1060 kg/detik

ρ_{mix} = 20,8819 kg/m^3

Dopt = 226 (G)$^{0.50}$ (ρ)$^{-0.35}$ (*Coulson & Richardson*, 1989)

= 226 (37,1060)$^{0.50}$ (20,8819)$^{-0.35}$

= 475,2381 mm = 18,7101 in

Diambil ukuran pipa dengan spesifikasi sebagai berikut :

NPS = 20 in

OD = 20 in

SN = 30

ID = 19,25 in

9. Pipa pengeluaran Gas Hasil Reaksi

Campuran gas hasil reaksi keluar dari reaktor pada suhu 280 °C dan tekanan 10,99 atm.

Komposisi gas keluar reaktor :

komponen	BM	kg/jam
N_2	28	63274,7459
O_2	32	8494,0339
C_2H_4	28	147,1739
HCl	36,5	383,7033
C_2H_3Cl	62,5	396,6970
$C_2H_4Cl_2$	99	51518,7205
H_2O	18	9366,564634
Total		**133.581,6390**

Jumlah gas keluar = 133.581,6390 kg/jam = 37,1060 kg/detik

BM_{mix} = 37,2288 kg/kgmol

$$\rho = \frac{(37,2288).(10,99)}{0.08206.(553)} = 9,0248 kg/m^3$$

Dopt = 226 $(G)^{0.50}$ $(\rho)^{-0.35}$ (*Coulson & Richardson*, 1989)

= 226 $(37,1060)^{0.50}$ $(9,0248)^{-0.35}$

= 637,4230 mm = 25,0953 in

Diambil ukuran pipa dengan spesifikasi sebagai berikut :

NPS = 26

OD = 26 in

SN = 20

ID = 25,25 in

10. Pipa Pemasukan dan pengeluaran *Dowtherm-A*

Dowtherm-A cair masuk *shell* reaktor pada suhu 280 °C dan tekanan 11 atm

ρs = 1007,229 kg/m^3

Jumlah Dowtherm-A masuk = 413.350,4301 kg/jam = 114,8196 kg/detik

Dopt = 226 $(G)^{0.50}$ $(\rho)^{-0.35}$ (*Coulson & Richardson*, 1989)

= 226 $(114,8196)^{0.50}$ $(1007,229)^{-0.35}$

= 215,2888 mm = 6,7536 in

Diambil ukuran pipa dengan spesifikasi sebagai berikut :

NPS = 8

OD = 8,625 in

SN = 40

ID = 7,981 in

11. Man hole

Man hole digunakan untuk membersihkan bagian-bagian reaktor yang tidak terjangkau oleh alat pembersih. Diameter man hole 14 - 24 in (*Backhurst*). Dipilih diameter *man hole* 24 in dan letaknya di sebelah lubang pemasukan umpan dan pengeluaran hasil.

12. Baffle

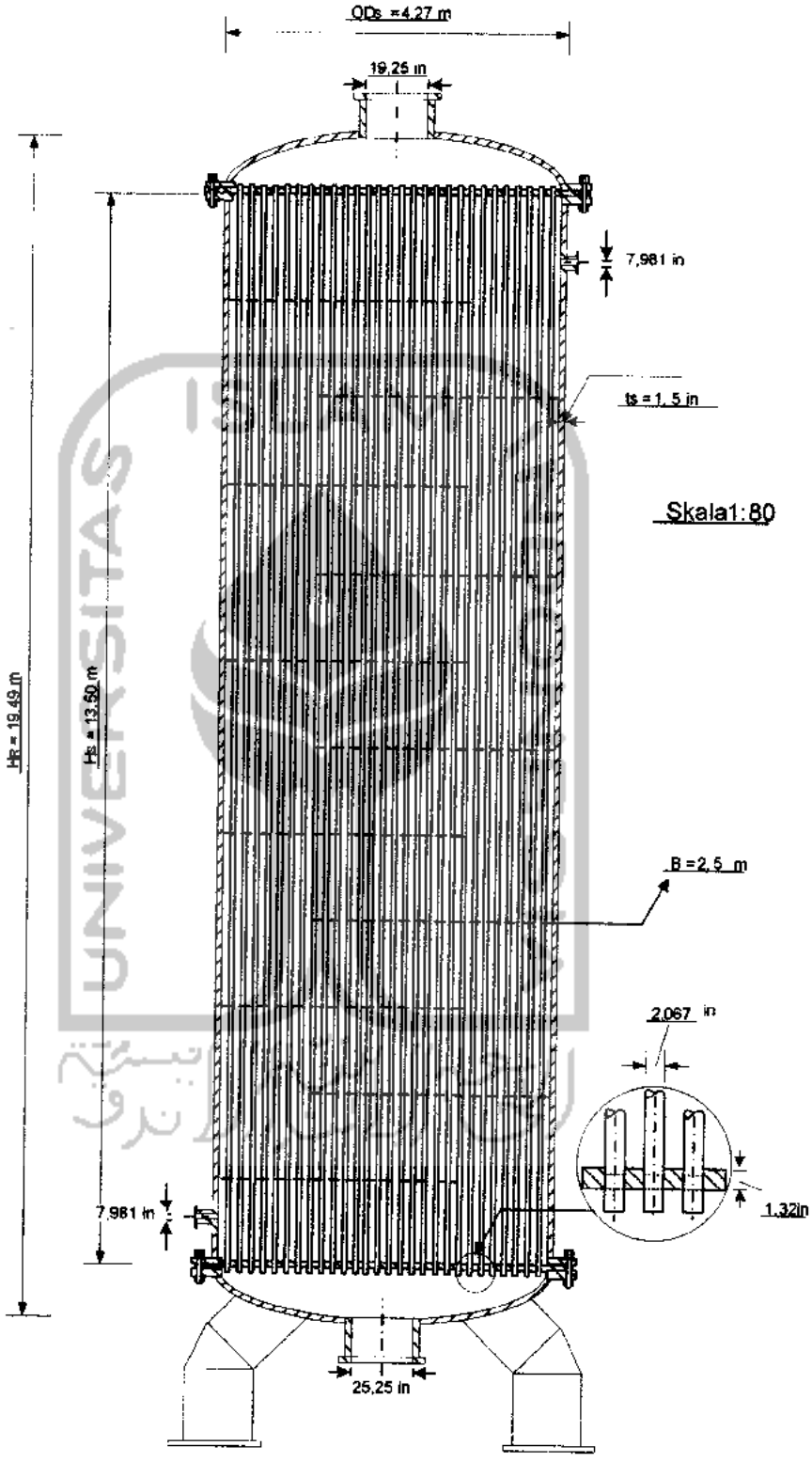
Baffle spacing diambil 0,25 IDS = 39,2022 in

13. Inert Ballast

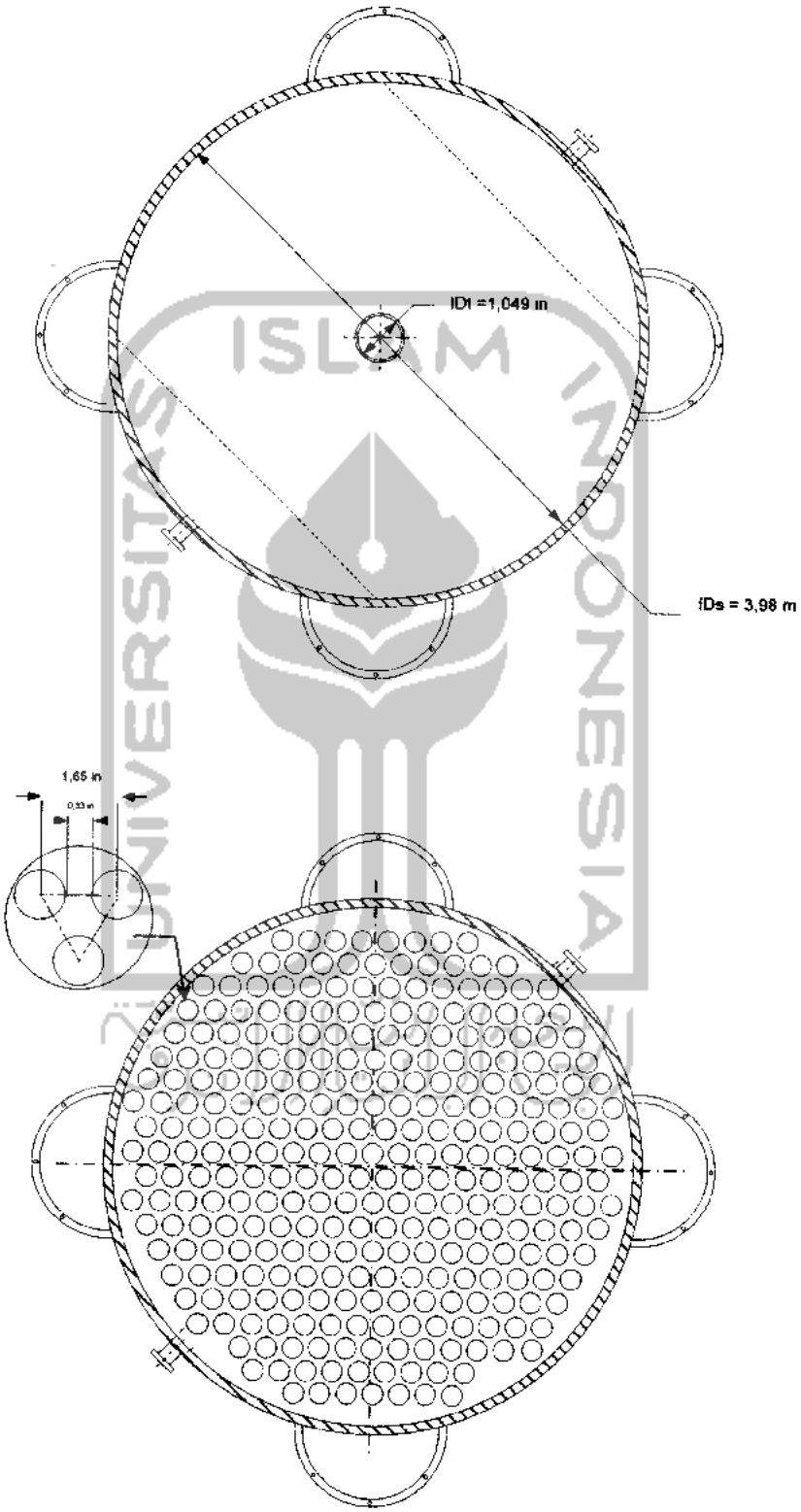
Inert ballast digunakan untuk melindungi permukaan katalisator terhadap pengaruh aliran reaktan yang melaju secara langsung (*Rase*, 1957). *Inert ballast* berbentuk bola-bola keramik. *Inert ballast* terletak pada bagian atas dan bawah tumpukan katalisator. Tebal tumpukan *inert ballast* berkisar antara 0 – 6 in. Diambil *inert ballast* setebal 3 in.

14. Ballast separator screen

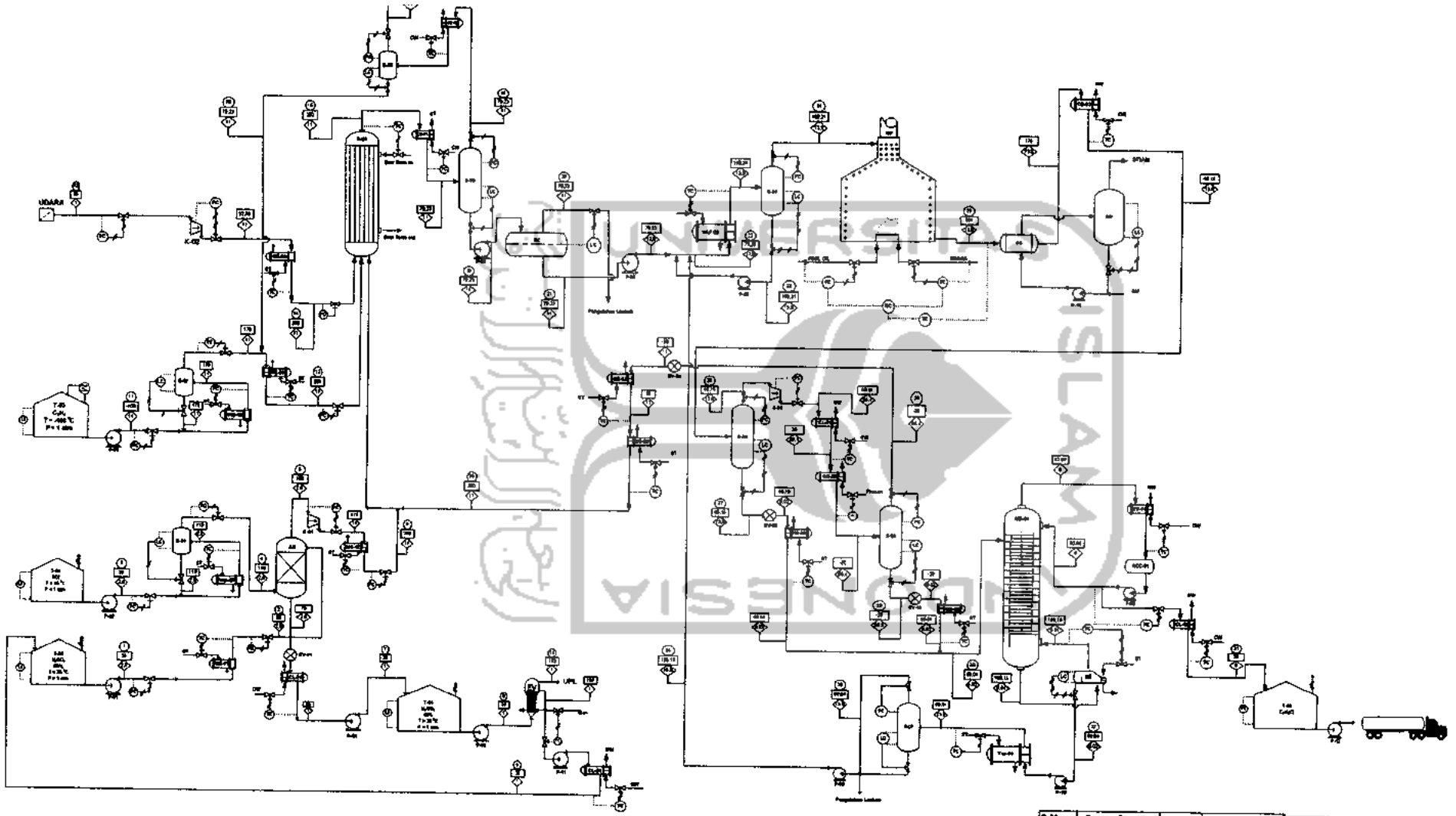
Ballast separator screen berfungsi untuk menyangga *inert ballast*. B*allast separator screen* berupa anyaman kawat yang memiliki ukuran antara 5 ~ 10 *mesh* (*Rase*, 1957). Diambil ukuran *ballast separator screen* 10 *mesh*.



Penampang Depan Reaktor*Fixed bed Multitube*



Penampang atas Reaktor*Fixed bed Multitube*



R-01	Reaktor Fixed Bed
FD	Flash Drum
DC	Decanter
VAP	Vaporizer
RF	Reaktor Furnace
SB	Steam Boiler
SD	Steam Drum
MD	Menara Distilasi
CD	Condenser
AC	Accumulator
RB	Reboiler
HE	Heater
CW	Cool Water
HW	Hot Water
LC	Level Control

Simbol	Nama Alat
CL	Cooler
K	Kompresor
EV	Ekspansi Valve
LI	Level Indikator
FC	Flow Control
TC	Temperatur Control
PC	Pressure Control
RC	Ratio Control
N	Nomor Aliran, Kolom
	Suhu, C
	Tekanan, atm
	Electric
	Pneumatic
	Aliran Bahan