LAMPIRAN

REAKTOR

Fungsi : Mereaksikan ethyl chloride dengan sodium lead menjadi tetra ethyl lead, lead dan sodium chloride pada suhu 70°C dan tekanan 3,5 atm.

Jenis : Reaktor Alir Tangki Berpengaduk (RATB)

Reaksi yang terjadi :

$$4\ C_2H5Cl + 4\ NaPb \longrightarrow Pb(C2H5)4 + 3\ Pb + 4\ NaCl$$

Kondisi operasi :

Tekanan : 3,5 atm

Temperatur : 70°C

- Menentukan Harga Konstanta Kecepatan Reaksi

Rumus: $k = \dfrac{1}{C_{A0}\,t.(M-1)} Ln\left[\dfrac{M - X_A}{M(1 - X_A}\right]$

Dimana: X_A = 0,90

t = 1 jam (*Sumber: Groggins, 1985*)

Tabel A.1.Data Kecepatan Volumetrik Umpan Total

Komposisi	Berat Umpan (kg/jam)	Berat Molekul (kg/kmol)	Mol Umpan (kmol/jam)	ρ (kg/lt)
NaPb	3955,9684	230	17,1999	0,8960
C_2H_5Cl	1885,9649	64.5	29,2398	0,9170
$Pb(C_2H_5)_4$	12,6263	323	0,0610	1,6590
H_2O	20,2424	18	1,1246	1
H_2SO_4	58,4193	98	0,5961	1,7958
Total	5933,2212			

$$FV = \frac{3955,9684}{0,8960} + \frac{1885,9649}{0,9170} + \frac{12,6263}{1,6590} + \frac{20,2424}{1} + \frac{58,4193}{1,7958} \quad \frac{kg/jam}{kg/m^3}$$

= (4415,1433+2056,6684+7,6108+20,2424+32,5311)

= 6532,1959 liter / jam

$C_{AO} = C_{NaPb}$; $C_{BO} = C_{C2H5Cl}$

$$C_{AO} = \frac{\text{mol umpan NaPb}}{\text{Kec. Volumetrik umpan total}}$$

$$= \frac{17,1999 \text{ kmol/jam}}{6532,1959 \text{ liter/jam}}$$

= 0,0026 kmol/liter = 2,6331 mol/liter

- Menentukan volume reaktor dan waktu tinggal
  - Untuk 1 RATB

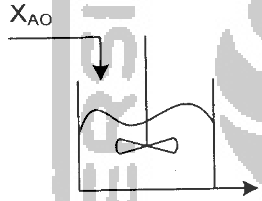
Diketahui   k   = 0,8403 liter/mol jam

X_{A1} = 0,90

M = 1,7

C_{AO} = 2,6331 mol/liter

FV = 6532,1959 liter / jam



Neraca Massa Komponen:

Input – Output – yang bereaksi = Acc

$$Fv.C_{A0} - Fv.C_{A0} - (-r_A).V = 0$$

$$Fv.(C_{A0} - C_A) = (-r_A).V$$

$$\frac{(C_{A0} - C_A)}{(-r_A)} = \frac{V}{Fv}$$

Dimana

$$C_{A1} = [C_{A0}(1 - (X_{A1} - X_{A0}))]$$

$$(-r_A) = k.C_{A1}.C_{B1} \qquad \rightarrow \text{orde 2}$$

$$= k.C_{A0}(1 - X_{A1}).(C_{B0} - C_{A0}.X_{A1})$$

$$= k.C_{A0}^2(1 - X_{A1}).(M - X_{A1})$$

$$M = \frac{C_{B0}}{C_{A0}}$$

$$\left[\frac{V}{Fv}\right] = \frac{C_{A0} - (1 - X_{A0}) - C_{A0}(1 - X_{A1})}{k.C_{A0}{}^{2}(1 - X_{A1})(M - X_{A1})}$$

$$\left[\frac{V}{Fv}\right] = \frac{C_{A0}(X_{A1} - X_{A0})}{k.C_{A0}{}^{2}(1 - X_{A1})(M - X_{A1})}$$

$$\left[\frac{V}{Fv}\right] = \frac{(X_{A1} - X_{A0})}{k.C_{A0}(1 - X_{A1})(M - X_{A1})}$$

Volume cairan dalam reaktor:

$$V = \frac{Fv.X_{A}}{k.C_{A0}(1 - X_{A1})(M - X_{A1})}$$

$$= \frac{6532{,}1959 \times 0{,}90\,liter/jam}{0{,}8403\,liter/jam \times 2{,}6331\,mol/liter \times (1 - 0{,}90)(1{,}7 - 0{,}90)}$$

$$= \frac{5878{,}9763\,liter/jam}{0{,}1770\ \ /jam}$$

= 33213,1453 liter x 0,2642 galon/lt

= 8774,9130 galon

$$\theta = \frac{V}{Fv}$$

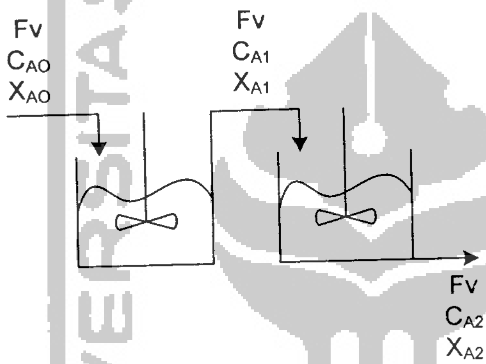
$$= \frac{33213{,}1453\,liter}{6532{,}9130\,liter/jam}$$

= 5,084 jam

Jadi, untuk 1RATB didapat volume reaktor sebesar 33213,1453 liter dan waktu tinggal sebesar 5,084 jam.

- Untuk 2 RATB $V_2 = \dfrac{Fv.(0{,}90 - X_{A1})}{k.C_{A0}(1-0{,}90)(M-0{,}90)}$

Dengan $X_{A0} = 0$; $X_{A1} = \ldots.?$; $X_{A2} = 0{,}90$



$$V_1 = \frac{Fv.(X_{A1} - 0)}{k.C_{A0}(1 - X_{A1})(M - X_{A1})}$$

$$V_2 = \frac{Fv.(0{,}90 - X_{A1})}{k.C_{A0}(1-0{,}90)(M-0{,}90)}$$

Berdasarkan trial diperoleh $X_{A1} = 0{,}7063$

$V_1 = V_2$ = 7146,5274 liter x 0,2642 galon/lt

= 1888,1125 galon

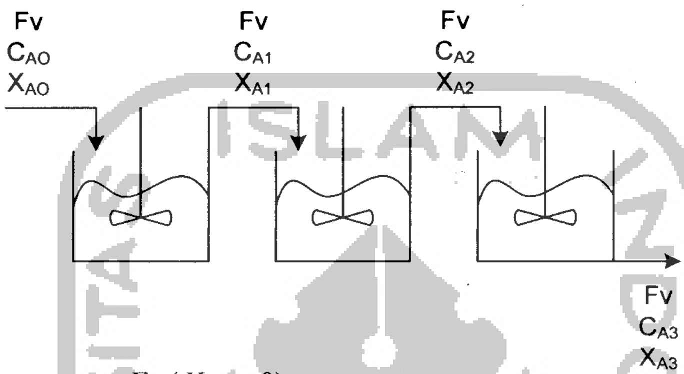
$$\theta = \frac{V}{Fv}$$

$= \dfrac{7146{,}5274 \text{ liter}}{6532{,}1959 \text{ liter / jam}}$

= 1.0940 jam

- Untuk 3 RATB

Dengan X_{A0} = 0; X_{A1} =….?; X_{A2}=….?; X_{A3} = 0,90



$$V_1 = \frac{Fv.(X_{A1} - 0)}{k.C_{A0}(1 - X_{A1})(M - X_{A1})}$$

$$V_2 = \frac{Fv.(0{,}90 - X_{A1})}{k.C_{A0}(1 - 0{,}90)(M - 0{,}90)}$$

$$V_3 = \frac{Fv.(0{,}90 - X_{A2})}{k.C_{A0}(1 - 0{,}90)(M - 0{,}90)}$$

Berdasarkan trial diperoleh :

X_{A1} = 0,5804

X_{A2} = 0,8012

V_1 = V_2 = V_3 = 3647.1417 liter x 0,2642 galon/lt

= 963.5748 galon

$$\theta = \frac{V}{Fv}$$

$$= \frac{3647.1417\ \text{liter}}{6532{,}1959\ \text{liter / jam}}$$

= 0,5583 jam

b. Menghitung Harga Reaktor

$$CostB = CostA\left(\frac{sizeB}{sizeA}\right)^{0,6}$$ (Timmerhaus, P-731)

- RATB, V1 = 8774.9130 galon

$$CostB = \$3200\left(\frac{8774{,}9130gal}{30gal}\right)^{0,6}$$

= \$ 96.565,7054

- RATB, V_2 = 1888,1125 galon

$$CostB = \$3200\left(\frac{1888{,}1125gal}{30gal}\right)^{0,6}$$

= \$ 38.414,3908

untuk 2 reaktor = 2 x \$ 38.414,3908 = \$ 76.828,7816

- RATB, V_3 = 963,5748 galon

$$CostB = \$3200\left(\frac{963{,}5748gal}{30gal}\right)^{0,6}$$

= \$ 25.657,1548

untuk 3 reaktor = 3 x \$ 25.657,1548 = \$ 76.971,4644

❖ RATB, V_4 = 633,9664 galon

$$CostB = \$3200\left(\frac{633{,}9664\,gal}{30\,gal}\right)^{0,6}$$

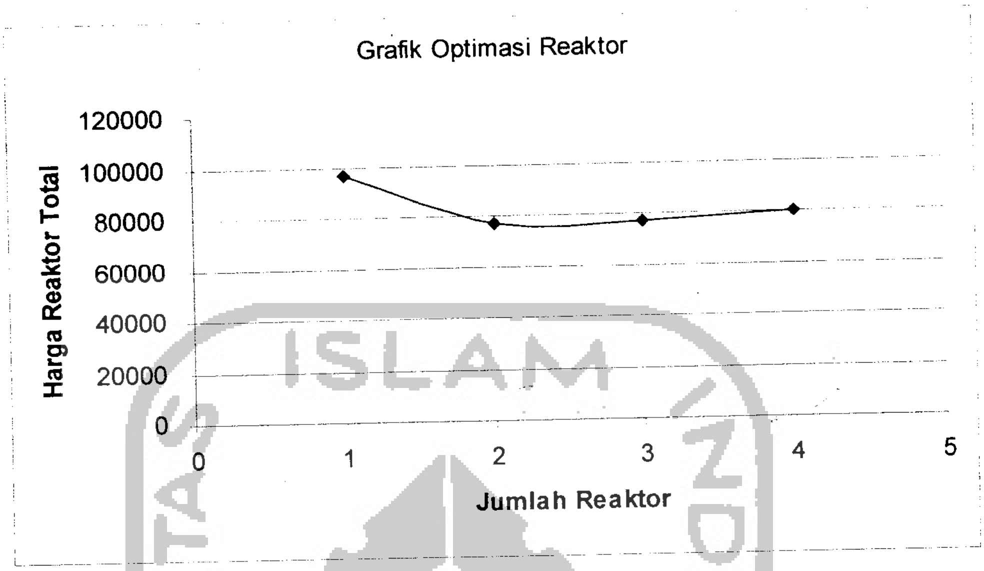
= \$ 19.957,1548

untuk 4 reaktor = 4 x \$ 19.957,9977 = \$ 79.831,9910

(Data harga total tiap reaktor ditampilkan pada tabel optimasi reaktor)

Tabel A.2. Hasil Perhitungan Optimasi Reaktor

Jumlah reaktor (n)	Konversi (X)	Vol. tiap reaktor (Lt)	Harga Total (\$)	Waktu tinggal (jam)
1	X_1 = 0,90	33213,1454	96.565,7054	5,0845
2	X_1 = 0,7063 X_2 = 0,90	7146,5274	76.828,7816	1,0940
3	X_1 = 0,5804 X_2 = 0,8012 X_3 = 0,90	3647,1417	76.971,4644	0,5583
4	X_1 = 0,4949 X_2 = 0,7190 X_3 = 0,8350 X_4 = 0,90	2399,5700	79.831,9910	0,3673



PERANCANGAN REAKTOR

- Menentukan Ukuran Reaktor (Untuk 2 Reaktor)

Asumsi :

- Volume cairan selama reaksi tetap
- Bisa dianggap isotermal karena cairan dalam tangki mixed flow
- Reaksi sederhana orde dua terhadap butanol dan asam asetat

Dari data perhitungan diperoleh :

K = 0,8403 liter/mol jam

C_{AO} = 2,6331 mol/liter

M = 1,7

X_{A1} = 0,7066

FV = 6532,1959 liter / jam

Perancangan yang dibuat ini memiliki over design 20 % sehungga volume reaktor menjadi :

Volume design = 1,2 x V_L

= 1,2 x 7146,5274 lt
= 8575,832851 lt

Dipilih tangki silinder tegak, dengan H:D = 1,5 : 1

Jenis head : Flanged and Dished Head Torisperical

Volume head : 0,000049 di^3 (Brownell and Young, p.88, 5-11)

Dimana : D = Diameter, inchi

VH = Volume head, ft^3

Volume reactor dihitung berdasarkan persamaan :

$$VR = \frac{\pi D^2 H}{4} + 2\ VH$$

$$= \frac{\pi D^2 H}{4} + 2 \times 0{,}000049\ ft^3 \times \frac{D^3 in^3}{12 ft^3}$$

302.8527 = 1,1775 D^3 + 0,1693 D^3

D^3 = 224,8610 ft^3

D = 6,0809 ft = 72,9714 in = 1,8535 m

H = 1,5 D

f = Tekanan maksimal yang diijinkan,psi = 12650 psi

C = Korosi yang diijinkan,in = 0,125

r = Jari-jari reaktor = 0,5 x 72.9714 in = 36,4857in

Bahan konstruksi reaktor = Carbon Steel SA 283 Grade C

(Brownell and Young, table 13-1 ; p.251)

Jenis sambungan = "Single Welded Butt Joint with Backing Strip"

(Brownell and Young, p.254 Table 13-2)

Tekanan Perancangan

P = 1,2 x Poperasi

P operasi = P design + P hirostatis

P design = 1 atm = 14,7 psi

P hidrostatis = ρ cairan kg/m^3 x Tinggi cairan m

ρ cairan = M / Fv

= 5933. kg/jam / 6532,1959 L/jam

= 0,9083 kg/L x 0,0361

= 0,0386 lb/in^3

P hidrostatis = 0,0386 lb/in^3 x 92,1703 in

= 3,0248 lb/in^2

= 3,0248 psi

P operasi = 14,7 psi + 3,0248 psi

= 17,7248 psi

P = 1,2 (14,7 psi + 3,0248 psi)

= 21,2697 psi

$$ts = \frac{21,2697 \text{ psi} \times 36,4857 \text{ in}}{(12650 \text{ psi} \times 0,85) - (0,6 \times 21,2697 \text{ psi})} + 0,125$$

= 0,1973 in

Jadi tebal yang dipilih tebal shell standar = 1/4 in

❖ **Menghitung Ukuran Head dan Bottom Reaktor**

ID shell = 1,8535 m = 72,9714 in = 6,0809 ft

OD shell = 72,9714 in + 2 x (1/4 in) = 73,4714 in = 1,8662 m

Dari table (*5.7 Brownell, LE & Young EH*) untuk OD, maka

➢ **Menentukan Tebal *Head***

Konstruksi *head* : *Stainless steel* SA. 167 Grade 3

Bentuk *Head* : *Flanged and Dished Head (Torispherical)*

Tebal *head* dihitung dengan persamaan berikut :

$$t = \frac{0,885 \cdot P \cdot rc}{f \cdot E - 0,1P} + C \qquad (Eq.13\text{-}12,\ P\text{-}258,\ Brownell\&Young)$$

Dimana : rc *(inside spherical or crown radius,* in)

Dari tabel 5.7 Brownell and Young ; p.90

icr = 4 3/8 in untuk OD = 72

r = 72 in

$$th = \frac{0{,}885.21{,}2697\,psi.72in}{12650.0{,}85 - 0{,}1.21{,}2697\,psi} + 0{,}125in$$

= 0,2511 in

t head standar = 1/4"

- **Menentukan Ukuran *Head***

Bentuk : *Flanged and Standart Dished Head*

Bahan : Carbon steel SA. 283 Grade C

Pertimbangan yang dilakukan dalam pemilihan jenis *head* meliputi :

1. *Flanged & Standard Dished Head*

   Umumnya digunakan untuk tekanan operasi rendah, harganya murah dan digunakan untuk tangki dengan diameter kecil.

2. *Torispherical Flanged & Dished Head*

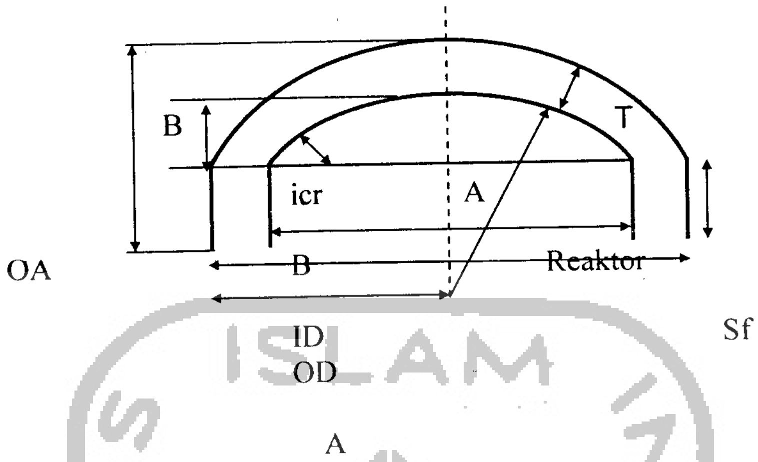
   Digunakan untuk tekanan operasi hingga 15 bar dan harganya cukup ekonomis.

3. *Eliptical Dished Head*

   Digunakan untuk tekanan operasi tinggi dan harganya cukup mahal.

4. *Hemispherical Head*

   Digunakan untuk tekanan operasi sangat tinggi, kuat dan ukuran yang tersedia terbatas. (*P-87 Brownell, 1959*)



Gambar. Dimensi tutup reaktor

Keterangan Gambar :

ID	=	Diameter dalam *head*
OD	=	Diameter luar *head*
t	=	Tebal *head*
r	=	Jari-jari *disk*
icr	=	Jari-jari dalam sudut *disk*
b	=	Tinggi *head*
sf	=	*Straight Flange*

Ukuran *Head* :

ID = ID shell = 72.9714 in = 6.0809 ft

Dari tabel 5.7 Brownell and Young ; p.90

icr = 4 3/8 in untuk OD = 72

r = 72 in

OD = ID + (2x tshell)

= 72.9714 + (2 x 1/4)

= 73,4714

a = ID/2 = 36.4857 in

AB = a – icr

= (36,4857– 4 3/8) in

= 32,1107 in

BC = rc – icr

= (72 – 4 3/8) in

= 67,6250 in

$AC = \sqrt{BC^2 - AB^2}$

$= \sqrt{(67{,}6250)^2 - (32{,}1107)^2}$

= 59,5151

b (*Deep of dish*) = rc – AC

b = (72 – 59.5151) in

= 12,4849 in

Sf (*Straight of Flange*) = 3 in (*Tabel 5.8, P-93, Brownell&Young*)

OA (Tinggi *head* bagian dalam) = Sf + b + t*head*

= (3 + 12,4849 + 1/4) in

= 15,7349 in = 1,3112 ft

Volume sebuah *head* untuk *Torispherical dished head* adalah :

$$V = 0{,}000049 \times ID^3$$ (*Eq.5-11, P-88, Brownell%Young*)

Jadi , Volume *head* total adalah :

$$Vhead(V_{HT}) = 0{,}000049 \cdot ID^3 + \left(\pi/4\right) \cdot ID^2 \cdot Sf$$

$$= \left[0{,}000049 \times (6{,}0809\,ft)^3\right] + \left[\pi/4 \times (6{,}0809\,ft)^2 \times (0{,}25)\,ft\right]$$

$$= 7{,}2679\,ft^3$$

$$= 0{,}2058\ m^3$$

Tinggi *head* = OA = 15,7349 in =1,3112 ft = 0,3997 m

Volume shell, V_S $= Vr - (2.V_{HT})$

$$= 7{,}1465\ m^3 - (2 \times 0{,}2058\ m^3)$$

$$= 6{,}7309\ m^3$$

Tinggi shell, Hs $= \dfrac{4.\ Vs}{\pi.\ ID^2}$

$$= \frac{4 \times 6{,}7309\ m^3}{3{,}14 \times (1{,}8535m)^2}$$

$$= 2.4974\ m$$

Tinggi cairan dalam shell, ZC $= \dfrac{4.(V_S - V_{HT})}{\pi \times ID^2}$

$$= \frac{4.(\ 6{,}7309\ m^3 - 0{,}2058\ m^3)}{3{,}14 \times (1{,}8535m)^2}$$

$$= 2.5737\ m$$

Tinggi total reaktor = Hs + 2.OA

= 2,4974 m + 2 x (0,3997 m)

= 3,2967 m

❖ **Menghitung Ukuran dan Power Pengaduk**

Dipilih pengaduk turbin dengan 6 flate blades (Foust, P.573)

Jumlah buffle = 4

Data pengaduk

$$\frac{D_t}{Di} = 3 \; ; \; \frac{Z_L}{Di} = 2{,}7 - 3{,}9 \; ; \; \frac{Zi}{Di} = 0{,}75 - 1{,}3$$

Dimana : Di = diameter Pengaduk

Dt = diameter tangki

Zl = tinggi cairan

Zi = jarak pengaduk dari dasar reactor

W = lebar baffle

Tugas pengaduk : untuk mencampur

$$Dt/Di = 3 - 6 \longrightarrow dipilih = 3$$

$$ZL/Di = 2{,}7 - 3{,}9 \longrightarrow dipilih = 3{,}9$$ (*Brown, P-507*)

$$Zi/Di = 0{,}75 - 1{,}3 \longrightarrow dipilih = 1$$

Diketahui :

Dt = 1,8535 m

$$Dt/Di = 3$$

$$Di = \frac{Dt}{3} = 0{,}6178m$$

$$\frac{ZL}{Di} = 3{,}9$$

$$ZL = 3{,}9 \times 0{,}6178m = 2{,}4095m$$

$$\frac{Zi}{Di} = 1 \longrightarrow \quad Zi = 1 \times 0{,}6178m = 0{,}6178m$$

$$\frac{W}{Di} = 0{,}17 \longrightarrow W = 0{,}17 \times Di$$

$$= 0{,}17 \times 0{,}6178m = 0{,}1050m$$

$$\frac{H}{Di} = 0{,}2 \longrightarrow \quad H = 0{,}2 \times Di$$

$$= 0{,}2 \times 0{,}6178m = 0{,}1236m$$

$$\frac{L}{Di} = 0{,}25 \longrightarrow \quad L = 0{,}25 \times Di$$

$$= 0{,}25 \times 0{,}6178m = 0{,}1545m$$

Ringkasan Ukuran Reaktor

- Diameter dalam reaktor (Dt) : 1.8535 m = 6.0809 ft
- Tinggi reaktor (ZR) : 3.2967 m = 10,8159 ft
- Tinggi zona pengadukan (ZL) : 2.4095 m = 7.9052 ft
- Jarak pengaduk dari dasar (Zi) : 0.6178 m = 2.0270 ft
- Diameter pengaduk (Di) : 0,6178 m = 2,0270 ft
- Tinggi pengaduk (H) : 0,1236 m = 0,4054 ft
- Lebar pengaduk (L) : 0,1545 m = 0,5067 ft
- Lebar *buffle* (W) : 0,1050 m = 0,3446 ft
- Tinggi cairan dalam silinder (ZC) : 2.5737 m = 8,4439 ft

- **Menghitung Kecepatan Pengaduk dalam Reaktor**

$$\frac{WELH}{2Di} = \left[\frac{H \cdot Di \cdot N}{600}\right]^2$$ (Eq. 8-8, P-345, HF. Rase)

Dimana :

WELH : *Water Equipment Liquid Height*

Di : Diameter pengaduk (ft)

N : Kecepatan putaran pengaduk (rpm)

H : Tinggi pengaduk (ft)

$$WELH = ZL \times \left(\rho_{cairan} / \rho_{air} \right)$$

$$= 8,4440\,ft \times \left(0,9083 / 1 \right)$$

$$= 7,6697\,ft$$

$$N = \frac{600}{\pi \cdot Di} \sqrt{\frac{WELH}{2Di}}$$

$$= \frac{600}{\pi \times 2,0270} \sqrt{\frac{7,6697}{2 \times 2,0270}}$$

$$= 129,6644\,rpm$$

$$= 2,1611\,rps$$

μ campuran = 5.7722 cp = 0.00388 lb/ft.s

1 cp = 6,7179 x 10^{-4} lb/ft.s

➢ **Menghitung Bilangan Reynold**

$$Nre = \frac{N \cdot Di^2 \cdot \rho}{\mu}$$

$$= \frac{2,1611 \times (2,0270)^2 \times 56,8444}{0.00388}$$

$$= 130121.2318$$

karena Nre > 2100 maka alirannya *turbulens*

➢ **Menghitung Power Pengaduk**

$$Pa = \frac{N_p \times \rho \times N^3 \times D_i^5}{g_c} \times \frac{1}{550}$$

$$= \frac{5,5 \times 56,8444 \times (2,1611)^3 \times (2,0270)^5}{32,2 \times 550}$$

= 3353.1560 ft.lbf/s

$= 6,0966 Hp$

Np (konstanta) = 5,5 untuk NRe > 10.000 *(HF. Rase, P-345)*

Jika Effisiensi pengaduk 80 % *(Timmerhause)*

Maka : $Power = \frac{Pa}{Eff}$

$$= \frac{6,0966}{80\%} = 7,6208 Hp$$

Digunakan Hp standar = 10 Hp (standar NEMA)

➢ **Menghitung Jumlah Pengaduk**

Jumlah Pengaduk $= \frac{WELH}{ID}$ (Eq.8.9, P-345, HF.Rase)

$= \frac{2,3377}{1,8535}$

$= 1,2613 \approx 2$ pengaduk

❖ **Menghitung neraca panas**

Data panas pembentukkan dari John A. Dean, 13ed " Lange's handbook of chemistry"

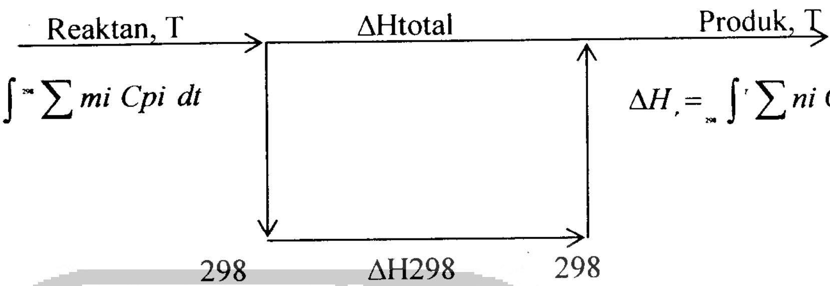
Data panas pembentukan (ΔHf)

Tabel. Data panas pembentukan (ΔHf)

Komponen	ΔHf 298 (kkal/mol)	CP
NaPb	0	0,054
C2H5Cl	-26,83	0,385
Pb(C2H5)4	12,7	0,36
NaCl	-97,34	0,204
Pb	0	0,0297

Entalpi reaksi pada sembarang suhu dapat dituliskan dengan persamaan :

(Smith J.M 1981 P.12 ; Houven O.A 1976 P.348)



$$\Delta H_R = \int_T^{298} \sum mi\ Cpi\ dt \qquad \Delta H_P = \int_{298}^{T} \sum ni\ Cpi\ dt$$

ΔHTotal = ΔHR + ΔHp + ΔH298

$$\int_T^{298} \sum_R mi\ Cpi\ dT + \Delta H_{298} + \int_{298}^{T} \sum_P ni\ Cpi\ dT$$

$$\int_{298}^{T} \sum_P niCpidT - \int_{298}^{T} \sum_R miCpidT + \Delta H_{298}$$

$$\Delta H_{298} + \int_{298}^{T} \left[\sum_P niCpidT - \sum_R miCpidT \right] dT$$

Entalpi reaksi pada suhu standar (ΔH298) dihitung dengan :

$$\Delta H_{298} = \left(\sum_P ai\,\Delta H_{fi} - \sum_R bi\,\Delta H_{fi} \right) \times mol\ yang\ bereaksi$$

dengan :

ΔHtotal	= entalpi reaksi pada sembarang suhu, kcal / jam
ΔH 298	= entalpi reaksi pada suhu standar, kcal / jam
ΔHfi	= entalpi pembentukan komponen i pada suhu standar, kcal / mol
Cpi	= kapasitas panas komponen i, kcal / kg °C
ai	= koefisien reaksi komponen i untuk produk
bi	= koefisien reaksi komponen i untuk reactor
ni	= massa komponen i untuk produk (kg)

mi = massa komponen i untuk reaktan (kg)

Reaksi : $4NaPb + 4C_2H_5Cl \rightarrow Pb(C_2H_5)_4 + 3Pb + 4NaCl$

ΔHR 298 = Σ ΔHf product - Σ ΔHf reaktan

ΔH298 = [ΔHf Pb(C2H5)4 + 3xΔHf Pb + 4xΔHf NaCl] – [4xΔHf NaPb + 4xΔHf C2H5Cl]

= [(1 x 12,7) + (3 x 0) + (4 x (-97,4))] – [(4 x 0) + (4 x (-28,3))]

= -269,3400 kcal/jam

= -269340 kcal/jam

Menghitung ΔHR

Umpan 1

Entalpi masuk Reaktor pada T = 70 °C

Suhu referensi = 25 °C

Tabel. Entalpi masuk reaktor pada T = 70 °C

Komponen	Massa (kg/jam)	CP (kcal/kg °C)	M.CP.ΔT (kcal/jam)
NaPb	3955,9684	0,054	-1068,1115

Umpan 2

Entalpi masuk Reaktor pada T = 70 °C

Suhu referensi = 25 °C

Tabel. Entalpi masuk Reaktor pada T = 70 °C

Komponen	Massa (kg/jam)	CP (kcal/kg °C)	M.CP.ΔT (kcal/jam)
C2H5Cl	1885,9649	0,385	-32674,3421
H2O C2H5Cl	19,0502	1,0005	-857,6854
Jumlah			-33532,0275

Umpan 3

Entalpi masuk Reaktor pada T = 70 °C

Suhu referensi = 25 °C

Tabel. Entalpi masuk Reaktor pada T = 70 °C

Komponen	Massa (kg/jam)	CP (kcal/kg °C)	M.CP.ΔT (kcal/jam)
H2SO4	58,4193	0,339	-891,1869
H2O H2SO4	1,1922	1,0005	-53,6772
Jumlah			-944,8642

Keluar reactor

Entalpi keluar Reaktor pada T = 70 °C

Suhu referensi = 25 °C

dengan media pendingin adalah air. (Faith Keyes, p.563), (Groggins), (us patent 2856419)

Suhu air pendingin masuk = 30 °C

Suhu air pendingin keluar = 50 °C

$\Delta T = (50-30)\ °C$

$= 20\ °C$

$$T\ \text{rata-rata} = \frac{(30+50)°C}{2} = 40°C = 104°F$$

Sifat fisis air pada suhu 104°F :

Cp = 0,9988 kcal/kg °C (Mc Cabe appendix 15, p.1085)

ρ = 993,116 kg/m³ (Mc Cabe appendix 5, p.1071)

wt : jumlah air pendingin yang dibutuhkan

$$wt = \frac{Q(BebanPanas)}{Cp.\Delta T}$$

$$= \frac{254765,3443 kcal / jam}{0,9988 kcal / kg°C.20°C}$$

= 12753,5715

= 3,5427 kg/s

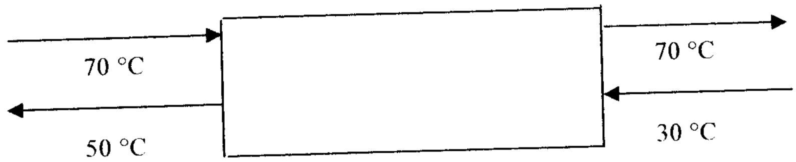
Kecepatan volumetrik air pendingin (Qv)

$$Qv = \frac{wt}{\rho air}$$

$$= \frac{3,6615 kg / dtk}{993,116 kg / m^3}$$

= 0,0036 m³/dtk

Luas perpindahan panas (A)



Suhu masuk reactor (T1) = 70 °C = 158 °F

Suhu keluar reactor (T2) = 70 °C = 158 °F

Suhu pendingin masuk (t1) = 30 °C = 86 °F

Suhu pendingin keluar (t2) = 50 °C = 122 °F

$$LMTD = \frac{(T2-t1)-(T1-t2)}{\ln\frac{(T2-t1)}{(T1-t2)}}$$

$$= \frac{(158-86)-(158-122)}{\ln\frac{(158-86)}{(158-122)}}$$

= 51.9370 °F

A (luas transfer panas) = $\frac{Q}{UDLMTD}$ (Kern, tabel 8, p.840)

Untuk *system medium organic – water* UD = 50 – 125

Dipilih harga UD = 125 btu/j.ft².°F

Q = 254765,3443 kcal/jam

$$A = \frac{(254765{,}3443 kcal/jam).\left(\frac{1 btu}{0{,}252 kcal}\right)}{(125 btu/jam.ft^2.°F)(51{,}9370°F)}$$

= 155,7230

Luas penampang jacket (Aj)

V : kecepatan linear pendingin

V yang diijinkan 1 – 3m/s

diambil V = 3 m/s

$$Aj = \frac{Qv}{V}$$

$= 0{,}0012\ m^2$

Menentukan Diameter Jacket Cooler (DJ)

OD/DR = diameter luar reactor, m

DJ = diameter jacket cooler, m

$$DJ = \left(\frac{4.AJ}{\eta}\right)^{1/2} + OD$$

$$= \left(\frac{4.0{,}0012m^2}{3{,}14}\right)^{1/2} + 1{,}8662m$$

$= 1{,}9051\ m$

Jarak antara DJ dengan DR (X)

X = DJ – DR = 0,0389 m

Dimensi Jacket Cooler

Diketahui :

Diameter jacket = 1.9051 m = 75.0037 in

Diameter jacket = ID jacket cooler

r jacket (ri) = 0.9525 m = 37.5018 in

Over design 20% untuk volume jacket (VJ)

$$VJ = \frac{\eta}{4}.(DJ)^2.H$$

$$= \frac{3{,}14}{4}.(1{,}9052m)^2.1$$

$= 2.8491\ m^3$

karena over design 20%, maka

VJ = 1,2 x 2.8491 = 3.4189 m^3

karena ratio D : H = 1 : 1.5 , maka

Tinggi shell jaket = Diameter jaket

H = 2.8576 m^3

Tebal dinding jacket cooler

$$t = \frac{P.ri}{f.E - 0{,}6.P}$$ (Brownell and Young, p.254)

P perancangan → over design 20 %

Poperasi = 1 atm = 14,7 psia

P = 1,2 x 14,7 = 17.64 psia

Bahan untuk jacket cooler = carbon stell SA-283 Grade C

(Brownell and Young, p.234)

f = 12650

E = 0.85

C = 0.125

Jenis sambungan = Single Welded Butt Joint with Backing Stripp

Tebal jacket cooler (tj) = tebal shell pada jacket

$$t = \frac{P.ri}{f.E - 0{,}6.P} + C$$

$$= \frac{17{,}64\,psia.37{,}5146\,in}{12650.0{,}85 - 0{,}6.17{,}64\,psia} + 0{,}125$$

= 0,1866 in

Dipilih tebal shell standar untuk jacket cooler (t) = 3/16 = 0,1875

(Brownell and Young, p.350 item-2)

Diameter luar shell jacket :

OD = ID + 2t

= 75.0086 + (2 x 0,1875)

= 75.3787 in = 1.9146 m

Menentukan tebal head jacket cooler :

Dipilih bentuk head "Torispherical dished head" (Brownell and Young, p.87)

Perbandingan mayor : minor = 1 : 1

Diambil OD = 78 (Brownell and Young, p.91 (5-7))

Koreksi ID = OD – 2t

= 78 - (2 x 3/16)

= 77.625 in = 1.9717 m

Tebal head

Dihitung dengan persamaan : 13 - 12 Brownell and Young, p.258

$$t = \frac{0{,}885.P.rc}{f.E - 0{,}1.P} + C$$

f = 12650

E = 0,85

C = 0,125

Diambil OD = 78 (Brownell and Young, p.90)

Icr = 4¾ = 4,75

r = 78

$$t = \frac{0{,}885.17{,}64.37{,}5018}{12650.0{,}85 - 0{,}1.17{,}64} + 0{,}125$$

= 0,1795 in

Dari table 5 – 6 Brownell and Young, p.88 dipakai tebal head standar = 3/16 in

Volume pada head jacket

$V = 0{,}000049\ di^3$ (Brownell and Young, p.88 (5-11))

$= 0{,}000049 \times (77.625)^3$

= 22.9193

Menentukan jarak puncak dengan straight flange

Dari tabel 5-6 Brownell and Young, p.88 Sf antara = 1½ – 2 in

Dipilih sf = 2 in

Common Types of Formed Heads and their selection (Brownell and Young, p.87) a = ID/2

= 77,625 / 2

= 38,8125 in

AB = ID/2 – icr

= a – icr

= 38,8125 - 4,75

= 34,0625 in

BC = r – icr

= 78 - 4,75

= 73,25 in

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

= $\sqrt{(73.25in^2 - 34.0625in^{2)}}$

= 64,8484 in

b = r – AC

= 78 – 64,8484

= 13.1516 in

OA = b + sf + t head

= 13,1516 + 2 + 0,1795

= 15,3311 in

Jadi tinggi head setelah ada jaket = 15,3311 in = 0,3894 m

Tinggi Reaktor setelah ada jaket = tinggi shell jaket + 2(tinggi head)

$= 2,8576 + 2(0,3894)$

$= 3.6365$

❖ **Pemipaan**

Meliputi :

a). Pada jacket cooler

- pipa pemasukan dan pipa pengeluaran untuk air pendingin
- pipa pengeluaran bahan keluar reactor yang melewati jacket cooler

b). Pada reaktor

- pipa pemasukan ethyl chloride dan pipa pengeluaran bahan campuran

a). Perhitungan pipa pada jacket cooler

Menghitung diameter pipa optimum untuk aliran turbulen dengan memakai persamaan 15

$Diopt = 3,9qf^{0,45}\rho^{0,13}$ (Timmerhause p.496)

Dimana :

qf = kecepatan alir massa, ft^3/dtk

ρ = densitas cairan, lb/ft^3

Di opt = diameter dalam pipa optimum, in

qf air pendingin = $0,0036 m^3/s \times 35,3147\ ft^3/s$

$= 0,1260\ ft^3/s$

ρ air pendingin = $62\ lb/ft^3$

μ air pendingin = 0,682 Cp = 0,000682 kg/m.s

$$Diopt = 3{,}9qf^{0{,}45}\rho^{0{,}13}$$

$$= 3{,}9 \times 0{,}1260^{0{,}45} \times 62^{0{,}13}$$

= 2.6254 in

Dipilih pipa = 3 in schedule 40 (Kern table 11, p.844)

OD = 3,5 in

ID = 3,068 in = 0,0779 m

Cek jenis aliran :

$$\text{Re} = \frac{4.G}{\pi.\mu.D}$$

G = qf, kecepatan alir massa fluida (Coulson, p.162)

$$= \frac{4.(3{,}6615 kg/dtk)}{3{,}14.(6{,}82.10^{-4} kg/m.dtk)(0{,}0779 m)}$$

= 84915.3526

Re > 2100 → aliran turbulen

b). Menentukan Ukuran Pipa C2H5Cl

komponen	massa (kg/jam)	fraksi berat Xi	densitas (ρ) (kg/lt)	viskositas (μ) (Cp)
C2H5Cl	1117.6376	0.9832	0.9170	0.385
H2O C2H5Cl	19.0502	0.0168	1	0.0031
Total	1136.6877	1		0.3881

$$\rho\, camp = \sum Xi\, \rho i$$

= (0.9832 x 0.9170) + (0.0168 x 1)

= 0,9184 kg/lt

$= 918{,}3910\ kg/m^3$

$= 57\ 3333\ lb/ft^3$

$In\ \mu camp = \sum Xi\ In\ \mu i$

$= (0.9832 \times \ln(0.385)) + (0.0168 \times \ln(0.0031))$

$= -1.03555948\ Cp$

$\mu\ mix = 0.000695896\ lb/ft.s$

Kecepatan alir massa fluida (qf)

$$qf = \frac{M\ tot}{\rho\ camp}$$

$= 1136.6877 / 918{,}3910$

$= 0.0121\ ft^3/s$

Menentukan diameter pipa

Diperkirakan aliran di dalam pipa adalah turbulen, maka NRe > 2100 sehingga digunakan persamaan :

$$Diopt = 3{,}9 qf^{0{,}45} \rho^{0{,}13}$$

$$= 3{,}9 x\ (0.0554\ ft^3/s)^{0{,}45}\ x (56{,}2475\ lb/ft^3)^{0{,}13}$$

$= 0.9065$ in

Dipilih pipa dengan ukuran : tabel II Kern hal 844

IPS = 1 in

OD = 1,32 in

ID = 1,049 in = 0,0266 m

A' = 0,84 in^2 = 0,0060 m^2

No. Schedule = 40

Menghitung bilangan Reynold

Kecepatan linier (V) $= \frac{qf}{A'}$ = 0.0121 / 0,0060 = 2,0346 ft/s

$$Re = \frac{ID \rho V}{\mu}$$

$= \frac{0,0266 \times 57,3333 \times 2,0346}{0.000695896}$

= 4466,3085

Karena Re>2100, maka asumsi aliran turbulen terpenuhi (Benar)

c). Menentukan Ukuran Pipa H2SO4

komponen	massa (kg/jam)	fraksi berat Xi	densitas (ρ) (kg/lt)	viskositas (μ) (Cp)
H2SO4	58.4193	0.9800	1.7958	0.88
H2O	1.1922	0.0200	1	0.8959
Total	59.6116	1		1.7759

$\rho camp = \sum Xi \rho i$

= (0,9800 x 1,7958) + (0,0200 x 1) kg/lt

= 1779,8840 kg/m^3

= 111,1146 lb/ft^3

$In\ \mu camp = \sum Xi\ In\ \mu i$

= (0.9800 x ln(0.88)) + (0.0200 x ln(0.8959))

= -0.127475234 Cp

μmix = 8.56634 x 10^{-05} lb/ft s

Kecepatan alir massa fluida (qf)

$$qf = \frac{M\,tot}{\rho\,camp}$$

= 59.6116 / 1779,8840

= 0.0335 m³/jam

= 0.0003 ft³/s

Menentukan diameter pipa

Diperkirakan aliran di dalam pipa adalah turbulen, maka NRe > 2100 sehingga digunakan persamaan :

$$Diopt = 3{,}9 qf^{0{,}45} \rho^{0{,}13}$$

$$= 3{,}9\,x\,(0.0554\,ft^3/s)^{0{,}45}\,x\,(56{,}2475\,lb/ft^3)^{0{,}13}$$

= 0,1947 in

Dipilih pipa dengan ukuran : tabel II Kern hal 844

IPS = ¼ in

OD = 0,540 in

ID = 0,364 in = 0.0092456 m

A' = 0,104 in^2 = 0.0007176 m^2

No. Schedule = 40

Menghitung bilangan Reynold

Kecepatan linier (V) $= \frac{qf}{A'}$ = 0.0003 / 0.0007176 = 0.457385574 ft/s

$$Re = \frac{ID\,\rho\,V}{\mu}$$

$$Diopt = 3{,}9 qf^{0{,}45} \rho^{0{,}13}$$

$$= 3{,}9 x\ (0.0554\ ft^3/s)^{0{,}45}\ x (56{,}2475\ lb/ft^3)^{0{,}13}$$

$$= 0.7628 \text{ in}$$

Dipilih pipa dengan ukuran : tabel II Kern hal 844

IPS = 1 in

OD = 1,32 in

ID = 1,049 in = 0.0266446 m

A' = 0,864 in^2 = 0.0059616 m^2

No. Schedule = 40

Menghitung bilangan Reynold

Kecepatan linier (V) $= \dfrac{qf}{A'}$ = 0.0082 / 0.0059616 = 1.38189297 ft/s

$$Re = \frac{ID\,\rho V}{\mu}$$

$$= \frac{0.0266446 \times 57.9954 \times 1.38189297}{0.000815447}$$

$$= 2618{,}6744$$

Karena Re>2100, maka asumsi aliran turbulen terpenuhi (Benar)