REAKTOR

Tugas : Mereaksikan Benzil Sianida ($C_6H_5CH_2CN$), Asam Sulfat (H_2SO_4) dan Air (H_2O) menjadi Asam Fenil Asetat ($C_6H_5CH_2COOH$). dengan kecepatan umpan Benzil Sianida = 2.696,5002 kg/j, kecepatan Asam Sulfat = 5.889,1564 kg/j dan kecepatan Air = 4.421,1047 kg/j

Jenis : RATB (Reaktor Alir Tangki Berpengaduk)

Reaksi :

$C_6H_5CH_2CN_{(l)}$ + $H_2SO_{4\,(l)}$ + 2 $H_2O_{(l)}$ → $C_6H_5CH_2COOH_{(l)}$ + $NH_4HSO_{4(l)}$

Kondisi operasi :

- Suhu (T) = 100 °C
- Tekanan (P) = 1 atm

Jenis reaksi : Irreversible

Dari perhitungan neraca panas di peroleh $\Delta Hr = -\ 521.765{,}5027\ \text{kJ/jam}$ maka dapat di simpulkan :

Sifat reaksi : Eksotermis

Data di peroleh dari (*Organic Syntheses. Vol , 1941*) di ketahui :

- Waktu tinggal (θ) = 180 menit = 3 jam
- Konversi (X_A) = 80 %
- Perbandingan mol $C_6H_5CH_2CN$: H_2SO_4 : H_2O = 1 : 2,607 : 10,657

Tabel berat molekul masing-masing komponen

No.	Nama Kimia	Rumus Kimia	BM $\left(\frac{Kg}{Kmol}\right)$
1	Asam Fenil Asetat	$C_6H_5CH_2COOH$	136
2	*Ammonium Hydrogen Sulfat*	NH_4HSO_4	115
3	Asam Sulfat	H_2SO_4	98
4	Benzil Sianida	$C_6H_5CH_2CN$	117
5	Air	H_2O	18

1. Neraca Massa Reaktor

Kapasitas Produksi = 20.000 $\frac{ton}{thn}$

Asumsi 1 Tahun = 330 hari

Kapasitas = 20.000 $\frac{ton}{thn} \times \frac{1\ thn}{330\ hari} \times \frac{1\ hari}{24\ jam} \times 1.000\ \frac{Kg}{Ton}$

= 2525,25 $\frac{Kg}{jam}$

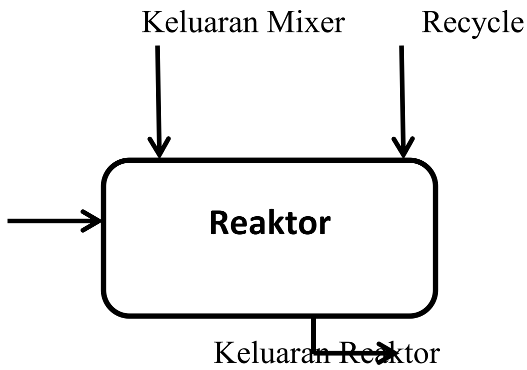
Konversi pada reaktor = 80 %

Diagram alir reaktor

Umpan

$C_6H_5CH_2CN$ 99 %

H_2O 2 %



Komposisi Masuk Reaktor:

a. Umpan $C_6H_5CH_2CN$ 99%

Komponen	BM	Kmol/jam	Kg/jam
$C_6H_5CH_2CN$	117	19,049	2.228,818
C_2H_5OH	46	0,4894	22,513
Total		19,539	2.251,331

b. Keluaran mixer

Komponen	BM	Kmol/jam	Kg/jam
H_2SO_4	117	61,385	6.015,734
H_2O	18	246,687	4.440,371
Total		308,0724	10.456,106

c. Recycle

Komponen	BM	Kmol/jam	Kg/jam
H_2O	18	4,2088	75,7576
$C_6H_5CH_2CN$	117	4,4926	525,638
$C_6H_5CH_2COOH$	136	0,1857	25,2525
Total		8,887	626,649

d. Total Umpan Masuk Reaktor

Dari perhitungan neraca massa, diperoleh komposisi umpan sebagai berikut :

Komponen	BM	Masuk		Xi	ρi (kg/L)	ρi.xi (kg/L)
		kmol/jam	kg/jam			
$C_6H_5CH_2CN$	117	23,5424	2.754,457	0,069962	1,095	0,07661
$C_6H_5CH_2COOH$	136	0,1857	25,2525	0,000518	1,135	0,000626
C_2H_5OH	46	0,4894	22,513	0,001454	0,7893	0.001147
NH_4HSO_4	115	0	0	0	1,78	0
H_2SO_4	98	61,385	6.015,734	0,18242	1,82	0,3321
H_2O	18	250,891	4.516,129	0,7456	0,998	0,7441
Total		336,498	13.334,086	1	7,617	1,15451

$$Fv = \frac{M}{P} = \frac{13.334,086}{1,15451} = 11.549,563 \text{ L/jam}$$

Maka didapat :

Konsentrasi awal $C_6H_5CH_2CN$

$$Cao = \frac{23,5424}{11.549,563} = 0,002038377 \text{ kmol/L}$$

Konsentrasi awal H_2SO_4

$$Cbo = \frac{61,385}{11.549,563} = 0,00531492 \text{ kmol/L}$$

Konsentrasi awal H_2O

$$Cco = \frac{250,891}{11.549,563} = 0,0217234 \text{ kmol/L}$$

$$M = \frac{Cbo}{Cao} = \frac{0,00531492}{0,002038377} = 2,61 \text{ kmol/L}$$

d. Komposisi Hasil Reaksi

Komponen	Mol (kmol/jam)	Massa (kg/jam)	Fraksi mol
$C_6H_5CH_2CN$	4,7085	550,8914	0,0158
$C_6H_5CH_2COOH$	19,0196	2.586,662	0,0636
C_2H_5OH	0,4894	22,5133	0,0016
NH_4HSO_4	18,8339	2.165,8979	0,063
H_2SO_4	42,5512	4.170,0127	0,1424
H_2O	213,2283	3.838,1091	0,7135
Total	298,8308	13.334,0867	1

2. Menentukan Konstanta Kecepatan Reaksi

Dari data di Perry's Hand Book diperoleh :

ρ $C_6H_5CH_2CN$ = 1,095 kg/lt

ρ $C_6H_5CH_2COOH$ = 1,135 kg/lt

ρ C_2H_5OH = 0,789 kg/lt

ρ NH_4HSO_4 = 1,78 kg/lt

ρ H_2SO_4 = 1,82 kg/lt

ρ H_2O = 0,998 kg/lt

Konstanta kecepatan reaksi untuk kondisi operasi T= 100°C dan P = 1 atm

Volume Cairan:

Komponen	Massa (kg)	Densitas (kg/lt)	Volume (lt)
$C_6H_5CH_2CN$	550,8914	1,095	503,097
$C_6H_5CH_2COOH$	2.586,662	1,135	2.278,997
C_2H_5OH	22,5133	0,789	28,523
NH_4HSO_4	2.165,8979	1,78	1.216,796
H_2SO_4	4.170,0127	1,82	2.291,215
H_2O	3.838,1091	0,998	3.845,8
Total			10.164,431

Kondisi awal :

Konsentrasi awal $C_6H_5CH_2CN$ = 0,002038377 kmol/L

Konsentrasi awal H_2SO_4 = 0,00531492 kmol/L

Konsentrasi awal H_2O = 0,0217234 kmol/L

Konversi Reaktor (Xa) = 0,8

Waktu reaksi dalam reaktor = 3 jam

Untuk Reaktor Alir Tangki Berpengaduk berlaku :

$$\frac{V_L}{F_V} = \frac{C_{A0} \times X_A}{-r_A}$$

$$\frac{V_L}{F_V} = \frac{C_{A0} \times X_A}{k \times C_{A0}^2 \times (1 - X_A) \times (M - X_A)} \quad ; \quad \text{Dimana : } \frac{V_L}{F_V} = \theta$$

$$\theta = \frac{X_A}{k \times C_{A0} \times (1 - X_A) \times (M - X_A)}$$

$$k = \frac{X_A}{\theta \times C_{A0} \times (1 - X_A) \times (M - X_A)} = \frac{0{,}8}{3 \times 0{,}002038377 \times (1-0{,}8) \times (2{,}61-0{,}8)}$$

$$= 361{,}3895 \text{ lt/(kmol.j)}$$

maka akan diperoleh nilai ln A dan (-E/R)

Reaksi	373 K	383 K
1/T	0,002681	0,002611
ln (k reaksi)	5,835208	6,528356

Maka akan diperoleh, ln A = 32,38274549

A = $1{,}15784 \times 10^{14}$

(-E/R) = -9902,231307

didapat persamaan k fungsi suhu (T):

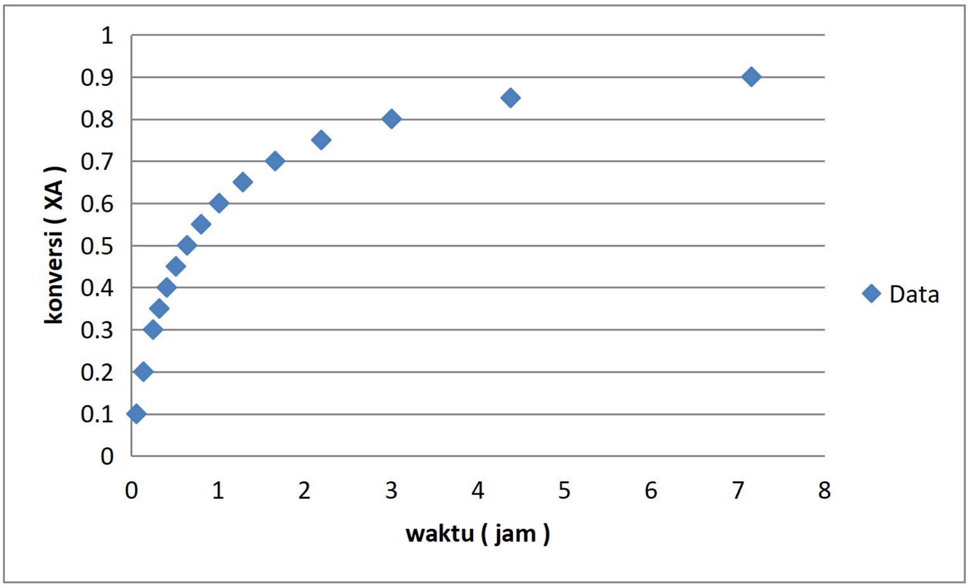
$$k = 1{,}15784 \times 10^{14} \exp \frac{-9902{,}231307}{T} \quad \frac{\text{liter}}{kmol\, jam}$$

$$\theta = \frac{X_A}{k \times C_{A0} \times (1 - X_A) \times (M - X_A)}$$

Dari rumus diatas dapat dibuat hubungan antara θ dan X_A

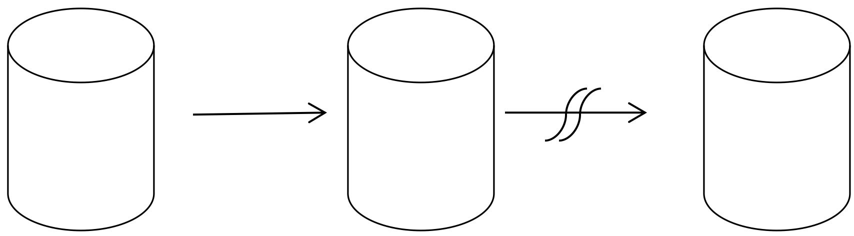
X_A	θ (jam)
0,2	0,1410
0,25	0,1919
0,3	0,2521
0,35	0,3238
0,4	0,4100
0,45	0,5148
0,5	0,6441
0,55	0,8064
0,6	1,0144
0,65	1,2879
0,7	1,6606

0,75	2,1925
0,8	3,0043
0,85	4,3771
0,9	7,1555



Grafik Hubungan waktu vs konversi

3. Konversi dan Optimasi Jumlah Reaktor



Diketahui :

k = 361,3895 liter/(kmol.jam)

Fv = 11.549,563 liter/jam

C_{ao} = 0,002038377 kmol/liter

M = C_{bo}/C_{ao}

= 2,61 kmol/liter

Dengan cara *trial and error* pada optimasi reaktor sehingga diperoleh volume cairan dalam RATB, jumlah reaktor serta konversi reaktor :

$$Xa_{n-1} = Xa_n - \frac{k.CAo.(1 - X_{An}).(M - X_{An}).V}{Fv}$$

A. Jumlah reaktor = 1, Xao = 0 dan Xa1= 0,8

Diperoleh V = 34.648,689 liter

Sehingga :

$$Xa_0 = Xa_1 - \frac{k.CAo.(1 - X_{a1}).(M - X_{a1}).V}{Fv}$$

= 0,8 – 329,007 x 0,00204258 (1-0,8) x (2,61-0,8) x 37.104,75

11.283,2265

Xao = 0

B. Jumlah reaktor = 2, Xao=0 dan Xa2=0,8

Diperoleh V = 10.971,098 liter

Sehingga :

$$Xa_1 = Xa_2 - \frac{k.CAo.(1-X_{a2}).(M-X_{a2}).V}{Fv}$$

= 0,8 – 329,007 x 0,00204258 (1-0,8) x (2,61-0,8) x 10.775,7

11.283,2265

Xa1 = 0,567669

$$Xa_0 = Xa_1 - \frac{k.CAo.(1-X_{a1}).(M-X_{a1}).V}{Fv}$$

= 0,5676 – 329,007 x 0,00204 (1-0,5676) x (2,61-0,5676) x 10.775,7

11.283,2265

Xao = 0

C. Jumlah reaktor = 3, Xao = 0, Xa3 = 0,8

Diperoleh V= 5.646,285 liter

Sehingga :

$$Xa_2 = Xa_3 - \frac{k.CAo.(1-X_{a3}).(M-X_{a3}).V}{Fv}$$

= 0,8 – 329,007 x 0,00204 (1-0,8) x (2,61-0,8) x 6.046,39

11.283,2265

= 0,6696

$$Xa_1 = Xa_2 - \frac{k.CAo.(1-X_{a2}).(M-X_{a2}).V}{Fv}$$

= 0,6696 – 329,007 x 0,00204 (1-0,6696) x (2,61-0,6696) x 6.046,39

11.283,2265

Xa_1 = 0,4387

$$Xa_0 = Xa_1 - \frac{k.CAo.(1-X_{a1}).(M-X_{a1}).V}{Fv}$$

= 0,438 – 329,007 x 0,00204 (1-0,438) x (2,61-0,438) x 6.046,39

11.283,2265

$Xa_0 = 0$

Dilakukan dengan cara yang sama, maka untuk:

D. Jumlah reaktor = 4, Xao = 0, Xa4 = 0,8

Diperoleh V = 3.888,895 Liter

Sehingga :

$Xa_3 = 0,71$

$Xa_2 = 0,5736$

$Xa_1 = 0,3583$

$Xa_0 = 0$

E. Jumlah reaktor = 5, Xao = 0, Xa5 = 0,8

Diperoleh V = 2.957,3749 Liter

Sehingga :

Xa4 = 0,731

Xa3 = 0,636

Xa2 = 0,501

Xa1 = 0,3035

Xa0 = 0

Mencari harga reaktor

Harga reaktor dihitung dengan rumus :

$$Ex = Ey \times \frac{Nx}{Ny}$$ (Aries, 1954)

Keterangan :

Ex = Biaya pembelian alat pada tahun x

Ey = Biaya pembelian alat pada tahun y

Nx = *Index Value for year* x

Ny = *Index Value for year* y

a. Nilai Ny

Nilai Ny didapat berdasarkan Tabel. 12 (Aries,1954). Nilai Ny pada tahun 1954 adalah 185

b. Nilai Nx

Niai Nx didapat berdasarkan linierisasi Tabel. 12 (Aries,1954) sampai tahun 2024. Didapat nilai Nx pada tahun 2024 sebesar 438,4

Maka harga 1 reaktor dengan volume 34.648,689 liter (9.153 gallon) :

$$Ex = Ey \times \frac{Nx}{Ny}$$

$$= 11000\ \$ \times \frac{438,4}{185}$$

$$= 26.067,027\ \$$$

Menghitung harga reaktor berdasarkan jumlah reaktor menggunakan rumus :

$$Eb = Ea \times (Cb/Ca)^{0,6} \times n$$

Keterangan :

Eb = Harga alat B

Ea = Harga alat A

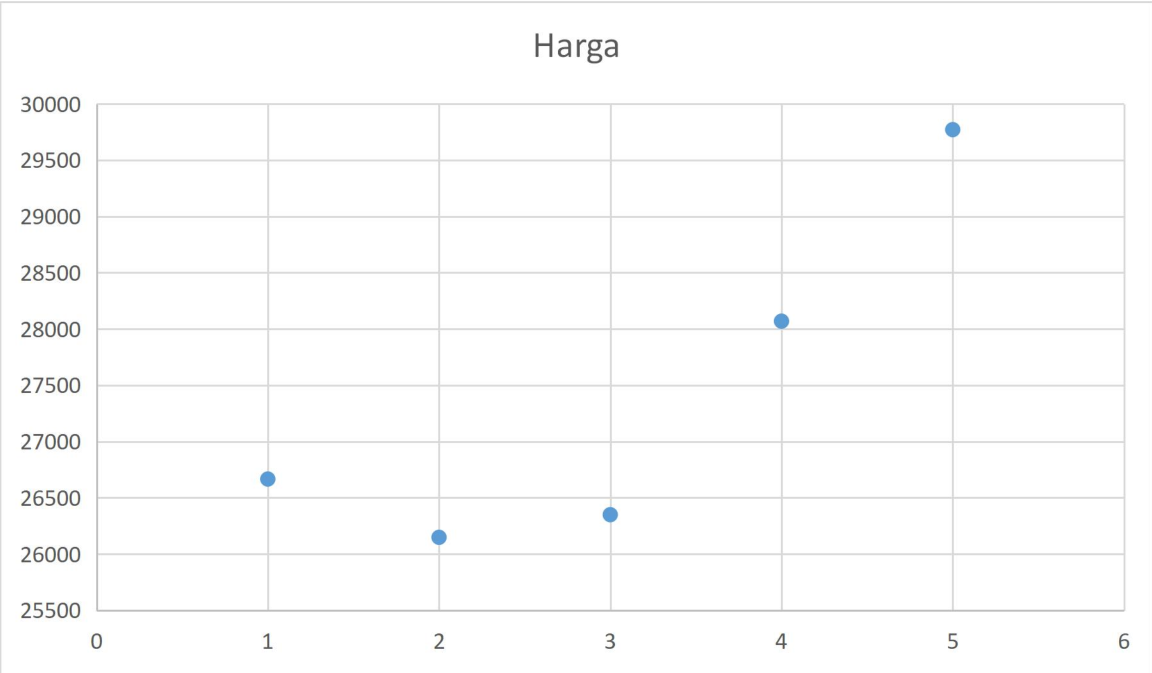
Cb = Kapasitas / Volume alat B

Ca = Kapasitas / Volume alat A

n = Jumlah reaktor

Dengan rumus diatas didapat data harga reaktor sebagai berikut :

Jumlah Reaktor	Volume (Liter)	Harga ($)
1	34.648,818	26.667,03
2	10.971,099	26.149,21
3	5.646,286	26.350,40
4	3.888,896	28.069,47
5	2.957,375	29.770,92



Grafik perbandingan harga reaktor dengan jumlah reactor

Dapat disimpulkan bahwa jumlah reaktor yang paling optimal untuk digunakan sebanyak dua reaktor.

Jika digunakan 2 reaktor maka waktu reaksi akan menjadi

$$\text{Waktu reaksi } (\Theta) = \frac{Vcairan}{Fv}$$

$$= \frac{10.971{,}098 \ liter}{11.549{,}563 \ \frac{liter}{jam}}$$

= 0,95 jam

4. Neraca Panas

Menghitung panas reaksi:

Tabel 11. Panas pembentukan zat pada 25 ^oC

Komponen	ΔHf° (kJ/mol)
$C_6H_5CH_2CN$	192,96
$C_6H_5CH_2COOH$	-322,19
H_2O	-241,80
H_2SO_4	-756,1512
NH_4HSO_4	747,34

(Yaws, 1999)

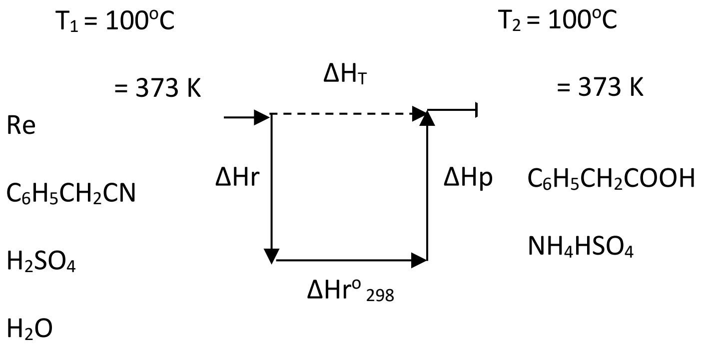
Tabel 12. Harga konstanta Cp fungsi suhu masing – masing komponen

Komponen	Cp (Joule/mol K)			
	A	B	C	D
$C_6H_5CH_2CN$	-21,289	6,197E-01	-4,116E-04	1,132E-07
$C_6H_5CH_2COOH$	-33,689	7,357E-01	-5,152E-04	1,475E-07
H_2O	92,053	-3,993E-02	-2,110E-04	5,347E-07
H_2SO_4	26,004	7,034E-01	-1,386E-03	1,034E-06
NH_4HSO_4	-4,768	1,096E+00	-3,309E-03	3,893E-06

Neraca Panas Reaktor 01

Persamaan reaksi

$C_6H_5CH_2CN + H_2SO_4 + 2H_2O \rightarrow C_6H_5CH_2COOH + NH_4HSO_4$



Panas yang ada (ΔH_T) dihitung menggunakan jalur yang ada pada gambar diatas.

$\Delta H_T = \Delta H_{reaktan} + \Delta H_R + \Delta H_{produk}$

Tabel 13. Panas dari reaktan (373K – 298 K)

Komponen	Mol (kmol/jam)	∫ Cp dT (kJ/kmol)	H = m ∫ Cp dT (kJ/jam)
$C_6H_5CH_2CN$	23,5424	10.831,943	255.009,9261
H_2SO_4	61,3850	10.868,630	2.235,99862
H_2O	250,8961	5.643,873	1.416.025,817
$C_6H_5CH_2COOH$	0,1857	12.040,919	667.170,8972
NH_4HSO_4	0	10.340,015	0
Total	336,0092		2.340.442,639

Enthalpi umpan masuk reaktor (Hr) = 2.340.442,639 kJ/j

Tabel 14. Panas dari produk pada (298 K – 373 K)

Komponen	Mol (kmol/jam)	∫ Cp dT (kJ/kmol)	H = m ∫ Cp dT (kJ/jam)
$C_6H_5CH_2CN$	10,1797	10.831,943	110.265,9302
H_2SO_4	48,0224	10.868,630	521.937,6973
H_2O	224,1708	5.643,873	1.265.191,526
$C_6H_5CH_2COOH$	13,5483	12.040,919	163.133,9829
NH_4HSO_4	13,3626	10.340,015	138.169,4844
Total	309.2838		2.198.698,621

Enthalpi produk (Hp) = 2.198.698,621 kJ/j

1. Panas Reaksi :

$\Delta H_R^o = (\sum (ni \times \Delta H_f^o))_{produk} - (\sum (ni \times \Delta H_f^o))_{reaktan}$

$= (\Delta H_f^o \; C_6H_5CH_2COOH + \Delta H_f^o \; NH_4HSO_4) - (\Delta H_f^o \; C_6H_5CH_2CN$

$+ \Delta H_f^o \; H_2SO_4 + 2 \text{ x } H_2O)$

= [-322,19 + (-747,34)] – [192,96 + (-756,15) + (-483,60)]
= -22,74 kJ/mol

Panas reaksi pada suhu 100 °C (373 K) = $\Delta H_R^o + {}_{298}\int^{373} \Delta \text{ Cp dT}$

dimana:

${}_{298}\int^{373} \Delta \text{ Cp dT} = {}_{298}\int^{373} (\sum Cp_{produk} - \sum Cp_{reaktan}) \text{ dT}$

$= [-33,689 \times (373\text{-}298) + \frac{7,357E-01}{2} \times (373^2\text{-}298^2) + \frac{-5,152E-04}{3} \times (373^3\text{-} 298^3) + \frac{1,475E-07}{4} \times (373^4\text{-}298^4) + (-4,768)\times (373\text{-}298) + \frac{1,096E+00}{2} \times (373^2\text{-}298^2) + \frac{-3,309E-03}{3} \times (373^3\text{-}298^3) + \frac{3,893E-06}{4} \times (373^4\text{-}298^4)]$

– [-21,289× (373-298) + $\frac{6,197E-01}{2}$ × (373^2-298^2) + $\frac{-4,116E-04}{3}$ × (373^3-298^3) + $\frac{1,132E-07}{4}$ × (373^4-298^4) + 26,004 × (373-298) + $\frac{7,034E-01}{2}$ × (373^2-298^2) + $\frac{-1,386E-03}{3}$ × (373^3-298^3) + $\frac{1,034E-06}{4}$ ×(373^4-298^4) + 92,053 × (373-298) + $\frac{-3,993E-02}{2}$ × (373^2-298^2) + $\frac{-2,110E-04}{3}$ × (373^3-298^3) + $\frac{5,347E-07}{4}$ ×(373^4-298^4)]

= (12.040,919 + 10.340,015) – (10831,943 + 10.868,631 +5.643,873)

= -4.963,513 Joule/mol

= -4,963512605 kJ/mol

maka:

Panas reaksi pada suhu 100 °C (373 K) = ΔH_R^o + $_{298}\int^{373}$ cp dT

= -22,74 kJ/mol + -4,963512605 kJ/mol

= -27,7035 kJ/mol

Panas reaksi total = ΔH_R^o × NAo × Xa

= -27,7035 kJ/mol × 1000 mol/kmol × 23,5424 kmol/jam × 0,5676

= -370.192,6242 kJ/jam

Jadi:

Panas reaktan (ΔHr) = 2.340.442,639 kJ/j

Panas produk (ΔHp) = 2.198.698,621 kJ/j

Panas Reaksi ($\Delta H_R^o\ _{298}$) = -370.192,6242 kJ/j

Menghitung panas yang diserap oleh pendingin:

Ql = ΔHr + $\Delta H_R^o\ _{298}$ + ΔHp

Dimana:

ΔHr = Enthalpi umpan masuk reaktor (kJ/mol)

ΔHp = Enthalpi hasil reaksi (kJ/mol)

$\Delta H_R^o\ _{298}$ = Panas reaksi (kJ/mol)

Q1 = Panas yang dibuang (kJ/mol)

Sehingga

Ql = ΔHr + $\Delta H_R^o\ _{298}$ + ΔHp

= -2.340.442,639 + (-370.192,6242) + 2.198.698,621

= -511.936,6422 kJ/j

Tabel 15. Neraca panas reaktor

Masuk	Keluar
Enthalpi umpan masuk reaktor pada suhu 100 °C (H1) = 2.340.442,639 kJ/jam	1. Enthalpi produk pada suhu 100 °C (H2) = 2.198.698,621 kJ/jam
2. Panas reaksi pada suhu 100 °C (Qr) = 370.192,6242 kJ/jam	2. Panas yang dibawa pendingin keluar reaktor (Q1) = 511.936,6422 kJ/jam

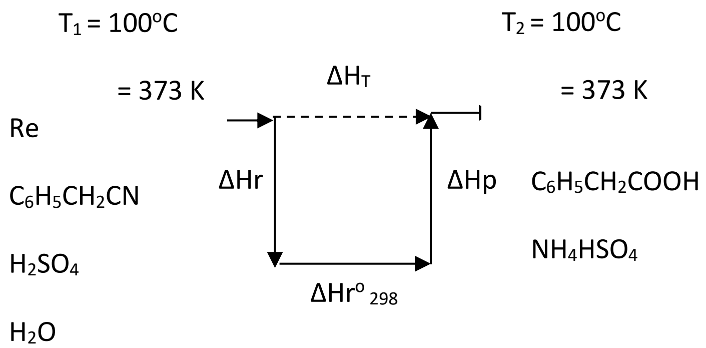
Total 2.710.635,263 kJ/jam

2.710.635,263 kJ/jam

Neraca Panas Reaktor 02

Persamaan reaksi

$C_6H_5CH_2CN + H_2SO_4 + 2H_2O \longrightarrow C_6H_5CH_2COOH + NH_4HSO_4$



Panas yang ada (ΔH_T) dihitung menggunakan jalur yang ada pada gambar diatas.

$\Delta H_T = \Delta H_{reaktan} + \Delta H_R + \Delta H_{produk}$

Tabel 16. Panas dari reaktan (373K – 298) K

Komponen	Mol (kmol/jam)	∫ Cp dT (kJ/kmol)	H = m ∫ Cp dT (kJ/jam)
$C_6H_5CH_2CN$	10,1797	10.831,943	110.265,9302
H_2SO_4	48,0224	10.868,630	521.937,6973
H_2O	224,1708	5.643,873	1.265.191,526
$C_6H_5CH_2COOH$	13,5483	12.040,919	163.133,9829
NH_4HSO_4	13,3626	10.340,015	138.169,4844
Total	309.2838		2.198.698,621

Enthalpi umpan reaktor (Hr) = 2.198.698,621 kJ/j

Tabel 17. Panas dari produk pada (298 K – 373 K)

Komponen	Mol (kmol/jam)	∫ Cp dT (kJ/kmol)	H = m ∫ Cp dT (kJ/jam)
$C_6H_5CH_2CN$	4,7085	10.831,943	51.001,91802
H_2SO_4	42,5512	10.868,630	462.472,74
H_2O	213,2283	5.643,873	1.203.433,414
$C_6H_5CH_2COOH$	19,0196	12.040,919	229.013,1643
NH_4HSO_4	18,8339	10.340,015	194.742,7649
Total	298,3413755		2.140.664,002

Enthalpi produk (Hp) = 2.140.664,002 kJ/j

2. Panas Reaksi :

$\Delta H_R^o = (\sum (ni \times \Delta H_f^o))_{produk} - (\sum (ni \times \Delta H_f^o))_{reaktan}$

$= (\Delta H_f^o\ C_6H_5CH_2COOH + \Delta H_f^o\ NH_4HSO_4) - (\Delta H_f^o\ C_6H_5CH_2CN + \Delta H_f^o\ H_2SO_4 + 2 \text{ x } H_2O)$

= [-322,19 + (-747,34)] – [192,96 + (-756,15) + (-483,60)]
= -22,74 kJ/mol

Panas reaksi pada suhu 100 °C (373 K) = $\Delta H_R^o + \int_{298}^{373} \Delta Cp\, dT$

dimana:

$\int_{298}^{373} \Delta Cp\, dT = \int_{298}^{373} (\sum Cp_{produk} - \sum Cp_{reaktan})\, dT$

$= [-33,689 \times (373-298) + \frac{7,357E-01}{2} \times (373^2-298^2) + \frac{-5,152E-04}{3} \times (373^3-298^3) + \frac{1,475E-07}{4} \times (373^4-298^4) + (-4,768) \times (373-298) + \frac{1,096E+00}{2} \times (373^2-298^2) + \frac{-3,309E-03}{3} \times (373^3-298^3) + \frac{3,893E-06}{4} \times (373^4-298^4)]$

$- [-21,289 \times (373-298) + \frac{6,197E-01}{2} \times (373^2-298^2) + \frac{-4,116E-04}{3} \times (373^3-298^3) + \frac{1,132E-07}{4} \times (373^4-298^4) + 26,004 \times (373-298) + \frac{7,034E-01}{2} \times (373^2-298^2) + \frac{-1,386E-03}{3} \times (373^3-298^3) + \frac{1,034E-06}{4} \times (373^4-298^4) + 92,053 \times (373-298) + \frac{-3,993E-02}{2} \times (373^2-298^2) + \frac{-2,110E-04}{3} \times (373^3-298^3) + \frac{5,347E-07}{4} \times (373^4-298^4)]$

= (12.040,919 + 10.340,015) – (10831,943 + 10.868,631 +5.643,873)

= -4.963,513 Joule/mol

= -4,963512605 kJ/mol

maka:

Panas reaksi pada suhu 100 ^oC (373 K) = ΔH_R^o + $_{298}\int^{373}$ cp dT

= -22,74 kJ/mol + -4,963512605

kJ/mol

= -27,7035 kJ/mol

Panas reaksi total = ΔH_R^o × NAo × Xa

= -27,7035 kJ/mol × 443 mol/kmol × 23,5424

kmol/jam × 0,233

= -67320,3588 kJ/jam

Jadi:

Panas reaktan (ΔHr) = 2.198.698,621 kJ/j

Panas produk (ΔHp) = 2.140.664,002 kJ/j

Panas Reaksi (ΔH_R^o $_{298}$) = - 67320,3588 kJ/j

Menghitung panas yang diserap oleh pendingin:

$Ql = \Delta Hr + \Delta H_R^o{}_{298} + \Delta Hp$

Dimana:

ΔHr = Enthalpi umpan masuk reaktor (kJ/mol)

ΔHp = Enthalpi hasil reaksi (kJ/mol)

$\Delta H_R^o{}_{298}$ = Panas reaksi (kJ/mol)

Q1 = Panas yang dibuang (kJ/mol)

Sehingga

$Ql = \Delta Hr + \Delta H_R^o{}_{298} + \Delta Hp$

= -2.198.698,621 + (- 67320,3588) + 2.140.664,002

= -125354,978 kJ/j

Tabel 18. Neraca panas reaktor

Masuk	Keluar
Enthalpi umpan masuk reaktor pada suhu 50 ^oC (H1) = 2.198.698,621 kJ/jam	1. Enthalpi produk pada suhu 50 ^oC (H2) = 2.140.664,002 kJ/jam
2. Panas reaksi pada suhu 50 ^oC (Qr) = 67320,3588 kJ/jam	2. Panas yang dibawa pendingin keluar reaktor (Q1) = 125354,978 kJ/jam

Total 2266018.98 kJ/jam 2266018.98 kJ/jam

5. Penentuan Dimensi Reaktor

Data neraca massa di sekitar reaktor 01

Komponen	Masuk		Keluar	
	kmol/jam	kg/jam	kmol/jam	kg/jam
$C_6H_5CH_2CN$	23,542	2.754,457	224,1708	4035,0739
$C_6H_5CH_2COOH$	0,1857	25,2525	0,4894	22,5133
C_2H_5OH	0,4894	22,513	10,1797	1191,0273
NH_4HSO_4	0	0	13,5483	1842,5727
H_2SO_4	61,385	6.015,734	48,0224	4706,1949
H_2O	250,896	4516,129	13,3626	1536,7046
Total	336,498	1.334,086	309,7733	13334,0867

Data neraca massa di sekitar reaktor 02

Komponen	Masuk		Keluar	
	kmol/jam	kg/jam	kmol/jam	kg/jam
$C_6H_5CH_2CN$	224,1708	4035,0739	4,708	550,891
$C_6H_5CH_2COOH$	0,4894	22,5133	19,019	2.586,662
C_2H_5OH	10,1797	1191,0273	0,4894	22,513
NH_4HSO_4	13,5483	1842,5727	18,834	2.165,897
H_2SO_4	48,0224	4706,1949	42,551	4.170,013
H_2O	13,3626	1536,7046	213,228	3.838,109
Total	309,7733	13334,0867	298,8308	13.334,0867

a. Perhitungan Volume Reaktor

Volume cairan dalam reaktor (V_L)

V_L = 10.971,098 liter

Untuk perancangan, volume reaktor diambil 120% dari volume larutan

Over desain 20%

Volume perancangan = $V_L \times$ (1 + Over desain)

= 10.971,098 × (1+ 0,2)

= 13.165,3176 liter = 13,165 m^3

b. Perhitungan Ukuran Reaktor

Bentuk : Silinder vertikal dengan alas datar dan head torispherical dished head.

Alasan : Mampu menahan tekanan hingga 15-200 psia dan relatif ekonomis

Pertitungan Reaktor 02 = Reaktor 01 , karena Volume Reaktor 01 = Reaktor 02

Asumsi D:H = 1:1,5

$V_{Reaktor} = (\frac{1}{4} \times \pi D^2 H) + \frac{\pi D^3}{12}$ (Brownell and young, 1959 hal.80)

$= (\frac{\pi D^2}{4} \times H) + \frac{\pi D^3}{12}$

Atau :

$D \text{ (Diameter)} = \sqrt[3]{\frac{Vreaktor}{1,443}}$

$= 2,089$ m

$= 82,24$ in $= 6,85$ ft

Diperoleh D = 6,85 ft

H (tinggi) = $1,5 \times D = 1,5 \times 6,85$ ft

= 10,275 ft = 3,13 m

Table 3.3. Typical Dimensions for Production Tanks (100, 101)
(Courtesy of American Petroleum Institute)

Nominal Capacity, bbl	Approximate Working Capacity, bbl	Outside Diameter, ft in.	Height, ft	Height of Overflow Connection, ft in.	Height of Walkway Lugs, ft in.	Location of Fill-Line Connection, in.	Size of Connec-tions, in.
90	72	7–11	10	9–6	7–7	14	3
200	166	12– 0	10	9–6	7–7	14	4
210	200	10– 0	15	14–6	12–7	14	4
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14	4
40	366	12– 0	20	19–6	17–7	14	4
H-500	479	15– 6	16	15–6	13–7	14	4
750	746	15– 6	24	23–6	21–7	14	4
L-500	407	21– 6	8	7–6	5–7	14	4
H-1000	923	21– 6	16	15–6	13–7	14	4
1500	1438	21– 6	24	23–6	21–7	14	4
L-1000	784	29– 9	8	7–6	5–7	14	4
2000	1774	29– 9	16	15–6	13–7	14	4
3000	2764	29– 9	24	23–6	21–7	14	4

(Tabel 3.3 Brownell and young,1959 hal 43)

Digunakan D dan H standar :

D = 10 ft = 120 in = 3,048 m

H = 15 ft = 180 in = 4,572 m

Dikembalikan ke perhitungan volume dengan D dan H standar

$V_{Reaktor} = (\frac{\pi D^2}{4} \times H) + \frac{\pi D^3}{12}$

$= \left(\frac{\pi 3{,}048^2}{4} \times 4{,}572\right) + \frac{\pi\, 3{,}048^3}{12}$

$= 35{,}79\ m^3$

c. Perhitungan tebal head reaktor (th)

Di pilih tutupnya jenis torispherical dished heads, karena tekanan operasi berada pada range untuk jenis head ini. Range jenis torispherical dished heads 15 – 200 psig (Brownell and Young, hal 88).

Bahan konstruksi yang digunakan adalah SA-167. tipe : 309 A. (Browneel and Young, hal : 342) , maka tegangan maximal yang diijinkan (fall) =18750 psia (Brownell and Young, hal 342).

Efisiensi sambungan yang dipakai adalah jenis double welded butt joint, E = 80% (Brownell and young, tabel 13.2, hal 254)

Faktor korosi (C) untuk stainless steel = 0,125 in (Peters, M.S., K.D., Timmerhaus, "Plant Design and Economics for Chemical Engineers", ed V)

P = 1 atm digunakan faktor kemanan sebesar 20 %, sehingga :

tekanan perancangan (P) = Poperasi (1 + over design)

= 1 atm × (1 + 20%)

= 1,2 atm × (14,6959 psia)/(1 atm)

= 17,635 psia

$$\text{thead} = \frac{P \cdot D}{2f \cdot E - 0{,}2 \cdot P} + C$$ (Brownell and Young, hal 256)

Dengan :

thead = tebal head

P = tekanan perancangan = 17,635 psia

E = welded joint efficiency = 80%

f = tekanan maksimum yang diijinkan = 18750 psia

C = corrosion allowance = 0,125 in (Peters, M.S., K.D., Timmerhaus, "Plant Design and Economics for Chemical Engineers", ed V)

$$\text{thead} = \frac{P \cdot D}{2f \cdot E - 0{,}2 \cdot P} + C$$

$$= \frac{17{,}635\ \text{psia} \times 120\ in}{(2 \times 18750\ psia \times 0{,}80) - 0{,}2x(17{,}635\ \text{psia})} + 0{,}125\ \text{in}$$

= 0,1955 in

Diambil tebal head standar = 1/4 in = 0,25 in

Table 5.6. Dimensions of Flanged and Standard Dished Heads
(Courtesy of Lukens Steel Company)

Thickness (in.) t	Standard Straight Flange (in.) sf	Inside-corner Radius (in.) icr
3/16	1½–2	9/16
1/4	1½–2½	3/4
5/16	1½–3	15/16
3/8	1½–3	1⅛
7/16	1½–3½	1 5/16
1/2	1½–3½	1½
5/8	1½–3½	1⅞
3/4	1½–3½	2¼
7/8	1½–4	2⅝
1	1½–4	3
1⅛	1½–4½	3⅜
1¼	1½–4½	3¾
1⅜	1½–4½	4⅛
1½	1½–4½	4½
1⅝	1½–4½	4⅞
1¾	1½–4½	5¼
1⅞	1½–4½	5⅝
2	1½–4½	6
2¼	1½–4½	6¾
2½	1½–4½	7½
2¾	1½–4½	8¼
3	1½–4½	9

(Tabel 5.6 Brownell and young,1959 hal 88)

d. Menentukan tinggi reaktor total

keterangan :

icr : *Inside-Corner Radius*

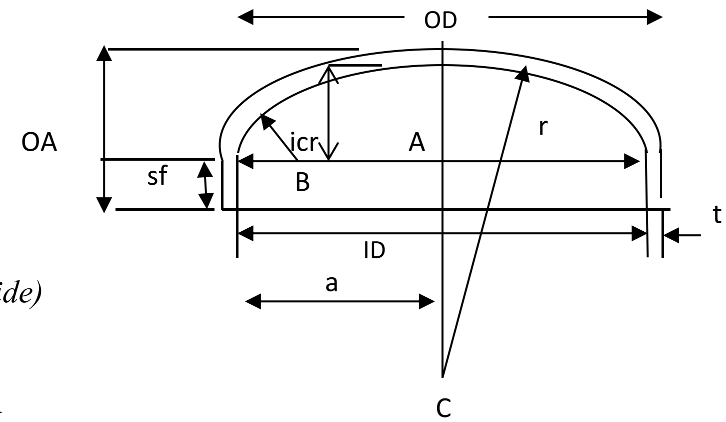
sf : *Straight Flange*

r : *Radius Of Dish*

OD : *Outside Diameter*

b : *Depth Of Dish (Inside)*

a : *Inside Radius*



IDs = diameter dalam shell = 144 in

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

$$a = \frac{120}{2} = 60 \text{ in}$$

ODs = IDs + (2 × thead standar)

= 120 in + (2 × 0,25 in)

= 120,5 in = 10,041 ft

Dari tabel 5.7 Brownell and Young, hal 90 digunakan OD standar = 126 in dengan r = 120 in , dengan tebal head 1/4 in diperoleh icr = 7,625 in

Table 5.7. Dimensions of ASME Code Flanged and Dished Heads (Continued)

OD	120		126		132		138		144		156		168	
t	icr	r	icr	r	icr	r	icr	r	icr	r	icr	r	icr	r
3/16														
1/4														
5/16														
3/8	7¼	114	7⅝	120										
7/16					8	130	8⅜	132	8¾	132	9⅜	144		
1/2													10⅛	144
5/8														
3/4						130								
7/8						120								
1		114												
1⅛		108												
1¼				120										
1⅜				114										
1½														
1⅝														
1¾														
1⅞								132						
2								130						
2¼	7¼													
2½	7½		7⅝		8									
2¾	8¼		8¼		8¼		8⅜		8¾					
3	9	108	9	114	9	120	9	130	9	132	9⅜	144	10⅛	144

(Tabel 5.7 Brownell and young,1959 hal 90)

$b = r - (BC^2 - AB^2)^{1/2}$ (Brownell and Young, hal 87)

AB = a – icr

= 60 in – 7,625 in

= 52,375 in

BC = r – icr

= 120 in – 7,625 in

= 112,375 in

Jadi :

$b = 120 \text{ in} - ((112{,}375 \text{ in})^2 - (52{,}375 \text{ in})^2)^{1/2}$

b = 20,58 in

Dari tabel 5.6 Brownell and Young, untuk tebal head 1/4 in diperoleh Sf = 2,5 in

tinggi head (OA) = t_{head} + b + sf

= 1/4 in + 20,58 in + 2,5 in

= 23,33 in

= 0,59 m

e. Volume cairan dalam head (Vhead)

$$V_{head} = \frac{\pi}{24} \cdot D^3$$

$V_{head} = \frac{\pi}{24} \cdot 3{,}048^3$

$V_{head} = 3{,}7\ m^3$

f. Volume cairan di shell

Vshell $= Vr – V_{head}$

$= 35{,}79\ m^3 – 3{,}7\ m^3$

$= 32{,}09\ m^3$

g. Tinggi cairan di shell

Vshell $= \frac{1}{4}\ \pi\ D^2\ H$

$t_{shell\ (H)} = \frac{Vshell.}{\pi.D^2}.4$

$= \frac{32{,}09}{\pi.3{,}048^2}.4$

$= 4{,}4\ m$

h. Tinggi reaktor (tR) :

$t_R = t_{shell} + 2$ (tinggi head)

$= 4{,}4\ m + 2\ (0{,}59)m$

$= 5{,}58\ m$

i. Menghitung tebal shell

Menentukan tebal dinding tangki

Bahan konstruksi yang digunakan : SA-167. tipe : 309 A. (Browneel and Young, hal : 342) dengan pertimbangan :

1. Memiliki struktur yang kuat.
2. Memiliki ketahanan yang baik terhadap korosi.
3. Harga relatif lebih murah dibanding jenis stainless steel yang lain.

Data –data yang digunakan :

- Tegangan maksimal yang diijinkan (fall) = 18750 psia.
- Effisiensi sambungan (E) untuk Double Welded Butt Joint = 0,8. (Brownell and young, tabel 13.2, hal 254)
- Faktor korosi (C) = 0,125 in.

(Peters, M.S., K.D., Timmerhaus, ”Plant Design and Economics for Chemical Engineers”, ed V)

- P = 1 atm digunakan factor kemanan sebesar 20 %, sehingga :

tekanan perancangan (P) = Poperasi (1 + over design)

= 1 atm × (1 + 20%)

= 1,2 atm × (14,6959 psia)/(1 atm)

= 17,635 psia

- Jari-jari reaktor

ri = ½ .D = 0,5 × 120 in = 60 in

$$\text{Tshell} = \frac{P \times ri}{f \times E - 0,6 \times P} + C$$

$$= \frac{17,635 \text{ psia} \times 60 \text{ in}}{(18750 \text{ psia} \times 80\%) - (0,6 \times 17,635 \text{ psia})} + 0,125 \text{ in}$$

= 0,1955 in

Diambil tebal shell standar = 1/4 in = 0,25 in

(Brownell and Young, hal 88)

j. Perancangan Pipa

a. Ukuran Pipa Pemasukan Umpan $C_6H_5CH_2CN$ dan Recycle (Umpan A)

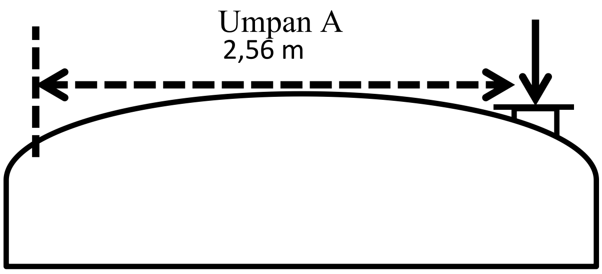
Komponen	Masuk	Komponen	Keluar		
	kg/jam		kg/jam	ρ (Kg/L)	Q (L/jam)
Umpan $C_6H_5CH_2CN$		$C_6H_5CH_2CN$	2.754,457	1,095	2.515,486
$C_6H_5CH_2CN$	2.228,818				
C_2H_5OH	22,513	C_2H_5OH	22,513	0,789	28,534
Umpan Recyle		H_2O	75,7576	0,998	75,909
H_2O	75,7576				
$C_6H_5CH_2CN$	525,6389	$C_6H_5CH_2COOH$	25,2525	1,135	22,248
$C_6H_5CH_2COOH$	25,2525				
Total	2.877,98	Total	2.877,98		2.642,178

- Umpan luas pipa pemasukan umpan A (A_{pipa})

Posisi pipa umpan A = 0,8 x OD

= 0,8 x 126 in

= 100,8 in = 2,56 m



Qumpan 1 = 2.642,178 L/jam = 2,642 m^3/jam

$A_{pipa} = \frac{Q_{umpan}}{\text{Kecepatan linier umpan}}$

Menurut Schweitzer, kecepatan linier umpan disyaratkan 0,6096 – 1 m/detik.

Diambil kecepatan linier umpan 1 m/detik.

$A_{pipa} = \frac{2{,}642 \ m^3/jam}{1 \ m/detik} \ x \ \frac{1 \ jam}{3600 \ detik}$

A_{pipa} = 0,0007338 m^2

- Menghitung diameter dalam pipa (ID)

$ID = \left(\frac{4.A_{pipa}}{\pi}\right)^{0,5}$

$ID = \left(\frac{4 \ x \ (0{,}0007338 \ ) \ m^2}{3{,}14}\right)^{0,5}$

$ID = 0{,}0305 \ m \ x \ \frac{1 \ inch}{0{,}0254} = 1{,}2 \ inch$

Berdasarkan ukuran ID yang telah dihitung, maka dapat disesuaikan dengan ukuran pipa standar dari Tabel 11 Kern,D.Q.,p : 844, 1965 sebagai berikut :

TABLE 11. DIMENSIONS OF STEEL PIPE (IPS)

Nominal pipe size, IPS, in.	OD, in.	Schedule No.	ID, in.	Flow area per pipe, in.^{2}	Surface per lin ft, ft.^{2}/ft. Outside	Surface per lin ft, ft.^{2}/ft. Inside	Weight per lin ft, lb steel
1/8	0.405	40*	0.269	0.058	0.106	0.070	0.25
		80†	0.215	0.036		0.056	0.32
1/4	0.540	40*	0.364	0.104	0.141	0.095	0.43
		80†	0.302	0.072		0.079	0.54
3/8	0.675	40*	0.493	0.192	0.177	0.129	0.57
		80†	0.423	0.141		0.111	0.74
1/2	0.840	40*	0.622	0.304	0.220	0.163	0.85
		80†	0.546	0.235		0.143	1.09
3/4	1.05	40*	0.824	0.534	0.275	0.216	1.13
		80†	0.742	0.432		0.194	1.48
1	1.32	40*	1.049	0.864	0.344	0.274	1.68
		80†	0.957	0.718		0.250	2.17
1¼	1.66	40*	1.380	1.50	0.435	0.362	2.28
		80†	1.278	1.28		0.335	3.00
1½	1.90	40*	1.610	2.04	0.498	0.422	2.72
		80†	1.500	1.76		0.393	3.64
2	2.38	40*	2.067	3.35	0.622	0.542	3.66
		80†	1.939	2.95		0.508	5.03
2½	2.88	40*	2.469	4.79	0.753	0.647	5.80
		80†	2.323	4.23		0.609	7.67
3	3.50	40*	3.068	7.38	0.917	0.804	7.58
		80†	2.900	6.61		0.760	10.3
4	4.50	40*	4.026	12.7	1.178	1.055	10.8
		80†	3.826	11.5		1.002	15.0
6	6.625	40*	6.065	28.9	1.734	1.590	19.0
		80†	5.761	26.1		1.510	28.6
8	8.625	40*	7.981	50.0	2.258	2.090	28.6
		80†	7.625	45.7		2.000	43.4
10	10.75	40*	10.02	78.8	2.814	2.62	40.5
		60	9.75	74.6		2.55	54.8
12	12.75	30	12.09	115	3.338	3.17	43.8
14	14.0	30	13.25	138	3.665	3.47	54.6
16	16.0	30	15.25	183	4.189	4.00	62.6
18	18.0	20‡	17.25	234	4.712	4.52	72.7
20	20.0	20	19.25	291	5.236	5.05	78.6
22	22.0	20‡	21.25	355	5.747	5.56	84.0
24	24.0	20	23.25	425	6.283	6.09	94.7

Nominal pipe size, Nps	= 1,25 inch
Schedule Number, Sch	= 80
Outside Diameter, OD	= 1,66 inch
Inside Diameter, ID	= 1,278 inch
Flow area per pipe	= 4,35 inch^2

b. Ukuran pipa pemasukan dari mixer (Umpan B)

Komponen	Kg/jam	Fraksi massa	ρ (Kg/l)	Q (L/jam)
H_2SO_4	6.015,734	0,5753	1,82	3.305,348
H_2O	4.440,37	0,4246	0,998	4.449,27
Jumlah	**10.456,106**	**1**		**7.754,618**

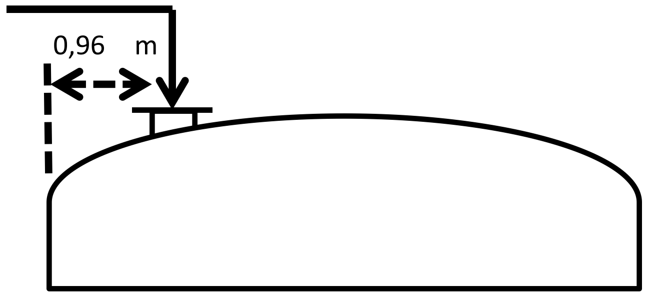
- Umpan luas pipa pemasukan umpan A (A_{pipa})

Posisi pipa umpan B = 0,3 x OD

= 0,3 x 126 in

= 37,8 in = 0,96 m

Umpan B



$Q_{umpan\ 1}$ = 7.754,618 L/jam = 7,754 m^3/jam

$$A_{pipa} = \frac{Q_{umpan}}{\text{Kecepatan linier umpan}}$$

Menurut Schweitzer, kecepatan linier umpan disyaratkan 0,6096 – 1 m/detik.

Diambil kecepatan linier umpan 1 m/detik.

$$A_{pipa} = \frac{7{,}754\ m^3/jam}{1\ m/detik} \times \frac{1\ jam}{3600\ detik}$$

A_{pipa} = 0,00215 m^2

- Menghitung diameter dalam pipa (ID)

$$ID = \left(\frac{4.A_{pipa}}{\pi}\right)^{0,5}$$

$$ID = \left(\frac{4 \times (0{,}00215)\ m^2}{3{,}14}\right)^{0,5}$$

$$ID = 0{,}0523\ m \times \frac{1\ inch}{0{,}0254} = 2{,}06\ inch$$

Berdasarkan ukuran ID yang telah dihitung, maka dapat disesuaikan dengan ukuran pipa standar dari Tabel 11 Kern,D.Q.,p : 844, 1965 sebagai berikut :

Table 11. Dimensions of Steel Pipe (IPS)

Nominal pipe size, IPS, in.	OD, in.	Schedule No.	ID, in.	Flow area per pipe, in.²	Surface per lin ft, ft.²/ft. Outside	Surface per lin ft, ft.²/ft. Inside	Weight per lin ft, lb steel
1/8	0.405	40*	0.269	0.058	0.106	0.070	0.25
		80†	0.215	0.036		0.056	0.32
1/4	0.540	40*	0.364	0.104	0.141	0.095	0.43
		80†	0.302	0.072		0.079	0.54
3/8	0.675	40*	0.493	0.192	0.177	0.129	0.57
		80†	0.423	0.141		0.111	0.74
1/2	0.840	40*	0.622	0.304	0.220	0.163	0.85
		80†	0.546	0.235		0.143	1.09
3/4	1.05	40*	0.824	0.534	0.275	0.216	1.13
		80†	0.742	0.432		0.194	1.48
1	1.32	40*	1.049	0.864	0.344	0.274	1.68
		80†	0.957	0.718		0.250	2.17
1 1/4	1.66	40*	1.380	1.50	0.435	0.362	2.28
		80†	1.278	1.28		0.335	3.00
1 1/2	1.90	40*	1.610	2.04	0.498	0.422	2.72
		80†	1.500	1.76		0.393	3.64
2	2.38	40*	2.067	3.35	0.622	0.542	3.66
		80†	1.939	2.95		0.508	5.03
2 1/2	2.88	40*	2.469	4.79	0.753	0.647	5.80
		80†	2.323	4.23		0.609	7.67
3	3.50	40*	3.068	7.38	0.917	0.804	7.58
		80†	2.900	6.61		0.760	10.3
4	4.50	40*	4.026	12.7	1.178	1.055	10.8
		80†	3.826	11.5		1.002	15.0
6	6.625	40*	6.065	28.9	1.734	1.590	19.0
		80†	5.761	26.1		1.510	28.6
8	8.625	40*	7.981	50.0	2.258	2.090	28.6
		80†	7.625	45.7		2.000	43.4
10	10.75	40*	10.02	78.8	2.814	2.62	40.5
		60	9.75	74.6		2.55	54.8
12	12.75	30	12.09	115	3.338	3.17	43.8
14	14.0	30	13.25	138	3.665	3.47	54.6
16	16.0	30	15.25	183	4.189	4.00	62.6
18	18.0	20‡	17.25	234	4.712	4.52	72.7
20	20.0	20	19.25	291	5.236	5.05	78.6
22	22.0	20‡	21.25	355	5.747	5.56	84.0
24	24.0	20	23.25	425	6.283	6.09	94.7

Nominal pipe size, Nps = 2 inch

Schedule Number, Sch = 40

Outside Diameter, OD = 2,38 inch

Inside Diameter, ID = 2,067 inch

Flow area per pipe = 3,35 $inch^2$

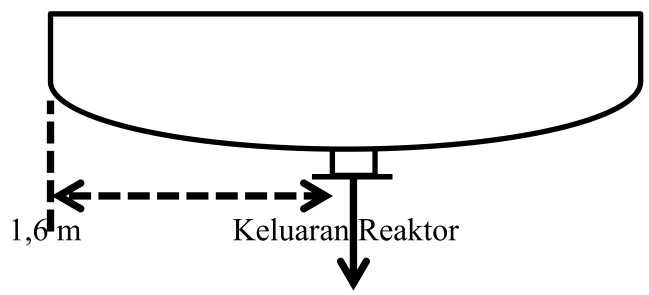
c. Ukuran pipa Keluaran Reaktor 02

Komponen	Kg/jam	Fraksi massa	ρ (Kg/l)	Q (L/jam)
$C_6H_5CH_2CN$	550,8914	0,0413	1,095	503,097
$C_6H_5CH_2COOH$	2.586,662	0,194	1,135	2.278,997
C_2H_5OH	22,5133	0,0017	0,789	28,523
NH_4HSO_4	2.165,8979	0,1624	1,78	1.216,796
H_2SO_4	4.170,0127	0,3127	1,82	2.291,215
H_2O	3.838,1091	0,2878	0,998	3.845,8
Jumlah	**13.334,0867**	**1**		**10.164,43**

Posisi pipa Keluaran Reaktor = 0,5 x OD

= 0,5 x 126 in

= 63 in = 1,6 m



Qumpan 1 = 10.164,43 L/jam = 10,164 m^3/jam

$$A_{pipa} = \frac{Q_{umpan}}{\text{Kecepatan linier umpan}}$$

Menurut Schweitzer, kecepatan linier umpan disyaratkan 0,6096 – 1 m/detik.

Diambil kecepatan linier umpan 1 m/detik.

$$A_{pipa} = \frac{10{,}164 \ m^3/jam}{1 \ m/detik} \times \frac{1 \ jam}{3600 \ detik}$$

A_{pipa} = 0,00282 m^2

- Menghitung diameter dalam pipa (ID)

$$ID = \left(\frac{4.A_{pipa}}{\pi}\right)^{0,5}$$

$$ID = \left(\frac{4 \times (0{,}00282) \ m^2}{3{,}14}\right)^{0,5}$$

$$ID = 0{,}0599 \ m \times \frac{1 \ inch}{0{,}0254} = 2{,}36 \ inch$$

Berdasarkan ukuran ID yang telah dihitung, maka dapat disesuaikan dengan ukuran pipa standar dari Tabel 11 Kern,D.Q.,p : 844, 1965 sebagai berikut :

TABLE 11. DIMENSIONS OF STEEL PIPE (IPS)

Nominal pipe size, IPS, in.	OD, in.	Schedule No.	ID, in.	Flow area per pipe, in.²	Surface per lin ft, ft.²/ft.		Weight per lin ft, lb steel
					Outside	Inside	
1/8	0.405	40*	0.269	0.058	0.106	0.070	0.25
		80†	0.215	0.036		0.056	0.32
1/4	0.540	40*	0.364	0.104	0.141	0.095	0.43
		80†	0.302	0.072		0.079	0.54
3/8	0.675	40*	0.493	0.192	0.177	0.129	0.57
		80†	0.423	0.141		0.111	0.74
1/2	0.840	40*	0.622	0.304	0.220	0.163	0.85
		80†	0.546	0.235		0.143	1.09
3/4	1.05	40*	0.824	0.534	0.275	0.216	1.13
		80†	0.742	0.432		0.194	1.48
1	1.32	40*	1.049	0.864	0.344	0.274	1.68
		80†	0.957	0.718		0.250	2.17
1 1/4	1.66	40*	1.380	1.50	0.435	0.362	2.28
		80†	1.278	1.28		0.335	3.00
1 1/2	1.90	40*	1.610	2.04	0.498	0.422	2.72
		80†	1.500	1.76		0.393	3.64
2	2.38	40*	2.067	3.35	0.622	0.542	3.66
		80†	1.939	2.95		0.508	5.03
2 1/2	2.88	40*	2.469	4.79	0.753	0.647	5.80
		80†	2.323	4.23		0.609	7.67
3	3.50	40*	3.068	7.38	0.917	0.804	7.58
		80†	2.900	6.61		0.760	10.3
4	4.50	40*	4.026	12.7	1.178	1.055	10.8
		80†	3.826	11.5		1.002	15.0
6	6.625	40*	6.065	28.9	1.734	1.590	19.0
		80†	5.761	26.1		1.510	28.6
8	8.625	40*	7.981	50.0	2.258	2.090	28.6
		80†	7.625	45.7		2.000	43.4
10	10.75	40*	10.02	78.8	2.814	2.62	40.5
		60	9.75	74.6		2.55	54.8
12	12.75	30	12.09	115	3.338	3.17	43.8
14	14.0	30	13.25	138	3.665	3.47	54.6
16	16.0	30	15.25	183	4.189	4.00	62.6
18	18.0	20‡	17.25	234	4.712	4.52	72.7
20	20.0	20	19.25	291	5.236	5.05	78.6
22	22.0	20‡	21.25	355	5.747	5.56	84.0
24	24.0	20	23.25	425	6.283	6.09	94.7

Nominal pipe size, Nps = 2,5 inch

Schedule Number, Sch = 40

Outside Diameter, OD = 2,88 inch

Inside Diameter, ID = 2,469 inch

Flow area per pipe = 0,753 inch^2

k. Perancangan Pengaduk Reaktor 01

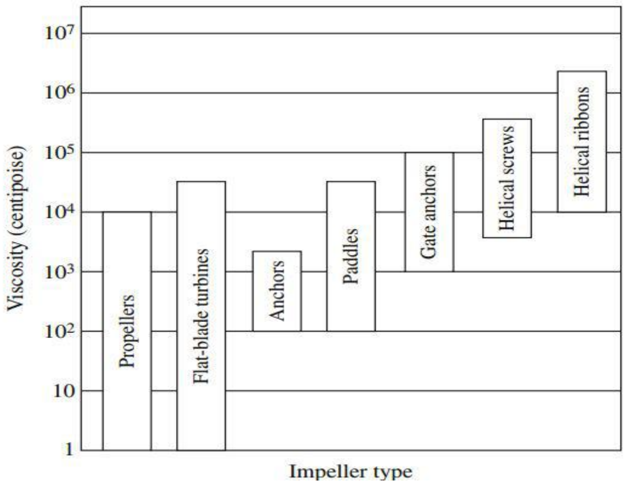
Jenis pengaduk dipilih berdasarkan viskositas fluida yang diaduk

Viskositas cair = Exp (a + b / T + c . T + d T^2) (Chapter 22, Yaws)

Komponen	A	B	C	D
$C_6H_5CH_2CN$	-14,8844	3,03E+03	2,35E-02	-1,40E-05
$C_6H_5CH_2COOH$	7,1162	-8,26E+02	-1,49E-02	7,03E-06
C_2H_5OH	-6,4406	1,12E+03	1,37E-02	-1,55E-05
NH_4HSO_4	11,2905	-4,58E+03	-6,78E-03	9,24E-07
H_2SO_4	-18,7045	3,4962E+03	3,3080E-02	-1,7018E-05
H_2O	-10,2158	1,7925E+03	1,7730E-02	-1,2631E-05

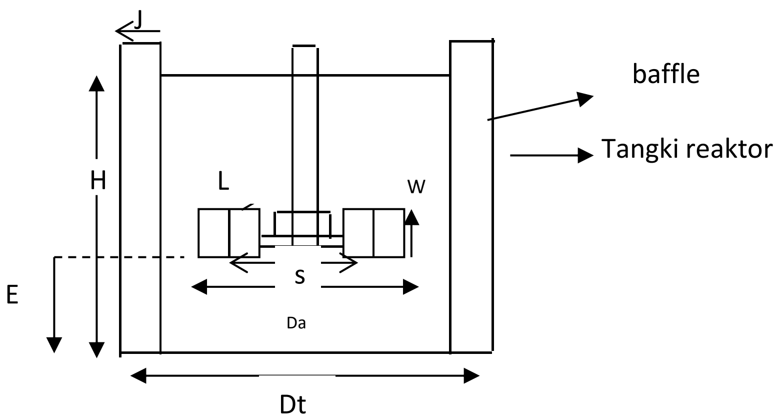
Komponen	Massa (Kg/Jam)	Fraksi massa (x)	μ (cP)	x . μ
$C_6H_5CH_2CN$	2.754,457	0,20657	1,159	0,2394
$C_6H_5CH_2COOH$	25,2525	0,00189	2,1013	0,004
C_2H_5OH	22,513	0,00168	0,3326	0,0006
NH_4HSO_4	0	0	0,0004	0
H_2SO_4	6.015,734	0,45115	4,3635	1,9686
H_2O	4516,129	0,33869	0,2791	0,0945
Total	1.334,086	1		2,3071

Maka jenis pengaduk yang dipilih adalah *Flat Blade Turbines*



Gambar 3. Jenis impeller berdasarkan viskositas

(Holland, F.A dan F.S., Chapman, Liquid Mixing and Processing in Stirred Tanks, 1966)



Keterangan :

Dt : diameter reaktor

Da : diameter impeller

E : jarak pengaduk dari dasar reaktor

W : tinggi impeller

L : lebar impeller

J : lebar baffle

Ketentuan:

Perbandingan diameter impeller dengan diameter tangki

$$\frac{Da}{Dt} = \frac{1}{3}$$

$$Da = \frac{1}{3} \times Dt$$

$$Da = \frac{1}{3} \times 120\ in = 40\ in \times \frac{0{,}0254\ m}{1\ in} = 1{,}016\ m$$

Perbandingan posisi jarak pengaduk dengan diameter impeller

$$\frac{E}{Da} = 1$$

E = Da = 1,016 m

Perbandingan tinggi impeller dengan diameter impeller

$$W = \frac{1}{5} \times Da$$

$W = \frac{1}{5} \times 40\ in = 8\ in \times \frac{0{,}0254\ m}{1\ in} = 0{,}2032\ m$

Perbandingan kedalaman baffle dengan diameter tangki

$\frac{j}{Dt} = \frac{1}{12}$

$j = \frac{1}{12} \times Dt$

$j = \frac{1}{12} \times 120\ in = 10\ in \times \frac{0{,}0254\ m}{1\ in} = 0{,}254$ m

Perbandingan panjang lebar impeller dengan diameter impeller

$\frac{L}{Da} = \frac{1}{4}$

$L = \frac{1}{4} \times Da$

$L = \frac{1}{4} \times 40\ in = 10\ in \times \frac{0{,}0254\ m}{1\ in} = 0{,}254\ m$

Menghitung tinggi cairan dengan ada nya baffle

Panjang baffle = Tinggi shell – Jarak pengaduk dari dasar shell

= 4,4 m - 1,016 m

= 3,384 m

Luas Reaktor = Luas Tangki – Jumlah baffle . Luas Baffle

= (¼ π D^2) – n .(Panjang . Lebar .Tinggi)

= (¼ . 3,14 . $3{,}048^2$ m^2) – 4 . (3,384 m . 0,254 . 0,2032 m)

= 6,59 m^2

Tinggi cairan = $\frac{\text{Volome Cairan}}{\text{Luas Reaktor}}$

= $\frac{10{,}971\ \text{m3}}{6{,}59\ m2}$

= 1,66 m

Tinggi cairan dengan baffle masih dibawah tinggi shell reaktor

Memperkirakan Kecepatan Putaran Pengaduk Reaktor

Komponen	Massa (Kg/jam)	Densitas (Kg/liter)	Fvi (lt/jam)
$C_6H_5CH_2CN$	2.754,457	1.0950	2.515,486
$C_6H_5CH_2COOH$	25,2525	1.1350	22,2489
C_2H_5OH	22,513	0.7893	28,523
NH_4HSO_4	0	1.7800	24.51
H_2SO_4	6.015,734	1.8200	3.305,3486
H_2O	4516,129	0.9980	4.525,179
TOTAL	1.334,086		10.396,786

ρ campuran = x $_{C6H5CH2CN}$. ρ $_{C6H5CH2CN}$ + x $_{C6H5CH2COOH}$. ρ $_{C6H5CH2COOH}$ + x $_{As.sulfat}$.

ρ $_{As.Sulfat}$ + x $_{Air}$. ρ $_{Air}$ + x $_{C2H5OH}$ ρ. $_{C2H5OH}$ + x $_{NH4HSO4}$ ρ. $_{NH4HSO4}$

ρ campuran = 1,1545 kg/L x (2,2046 lb / 1 kg) x (1 L / 0,0353 ft$^{3)}$

ρ campuran = 72,10228 lb/ft^3

μ campuran = 2,3071 Cp = 5,583156 lbm/ft.jam = 0,001551 lbm/ft.s

Dari tabel 8.2 halaman 338, Howard. F. Rase, diketahui kecepatan perputaran untuk pengaduk tipe *flat blade turbine impleller*, dengan 8 *flat blade* dan 4 baffle, yaitu sebesar :

N = 500 – 700 fpm.

Dipilih : N = 600

$$N = \frac{600}{\pi . Da}$$

$$N = \frac{600}{\pi . 3{,}3 ft}$$

N = 57,87 rpm

IMPELLER SPEED

With commercially available motors and speed reducers, standard speeds are 37, 45, 56, 68, 84, 100, 125, 155, 190, and 320 rpm. Power requirement usually are not great enough to justify the use of continuously adjustable steam turbine drives. Two-speed drives may be required when starting torques are high, as with a settled slurry.

(Walas, hal 288)

Digunakan power standard = 56 rpm = 4.080 rpj = 1,13 rps

Bilangan Reynold untuk pengadukan:

$$\text{Re} = \frac{Da^2.N.\rho}{\mu}$$

$$= \frac{(3{,}3^{\,2} ft^2)(1{,}13 \text{ rps})(72{,}10228 \frac{\text{lb}}{ft^3})}{0{,}001551 \frac{lbm}{ft.s}}$$

$$= \quad 572.062{,}55$$

Dipilih kurva no 9 untuk 8 flat blades turbin berdasarkan tabel *Power Cosumption Of Agitators* pada buku G. G Brown, hal 507.

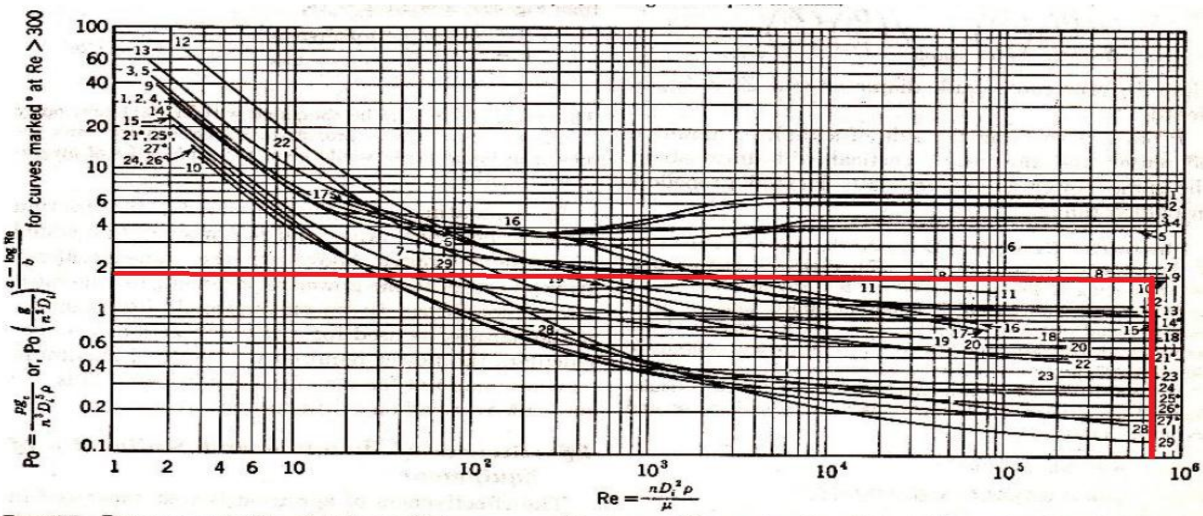


Fig. 477. Power consumption of various agitators expressed in terms of Po as a function of Reynolds number, Re. For curves marked with ° surface effects become important and the Froude number Fr = g/n^2D_i is included as indicated for Re > 300.

(Brown. Figure 477 hal 507)

Dari grafik didapat nilai Np = 1,9

Tenaga untuk pengadukan:

P $= Np..N^3.Di^5.\rho$

$$= \frac{1{,}9\ x\ (68\ rpm)^3 (3{,}3\ \ ft)^5 (72{,}10228 \frac{lb}{ft^3})}{(60\ detik/menit)^3}$$

$$= 78.045{,}036\ \text{lb.ft}^2/\text{detik}^3\ x \frac{1kg}{2{,}2046lb}\ x \frac{(0{,}3048m)^2}{(1ft)^2}$$

= 3.290,96 kg m^2/s^3 = 3.290,96 N m/s = 3.290,96 J/s

$$= 3.290{,}96\ \text{watt x}\ \frac{1Hp}{745{,}7watt}$$

= 4,4 Hp

Effisiensi motor 80% (tabel 3.1 Towler dan Sinnott, hlm. 111) maka:

Tenaga motor untuk pengaduk= 4,4 Hp / 0,8

= 5,5 Hp

Horsepower Ratings.[31] Standard NEMA ratings for induction motors are

General purpose: ½ , ¾ , 1, 1 ½ , 2, 3, 5, 7 ½ , 10, 15, 20, 25, 40, 50, 60, 75, 100, 125, 150, 200, 250, 300, 350, 400, 450, and 500.

Large motors: 250, 300, 350, 400, 450, 500, 600, 700, 800, 900, 1000, 1.250, 1.500, 1.750, 2.000, 2.250, 2.500, 3.000, 3.500, 4.000, 4.500, 5.000 and up to 30.000.

(Walas, hal 289)

Digunakan standar = 7,5 Hp

l. Perancangan Pengaduk Reaktor 02

Jenis pengaduk dipilih berdasarkan viskositas fluida yang diaduk

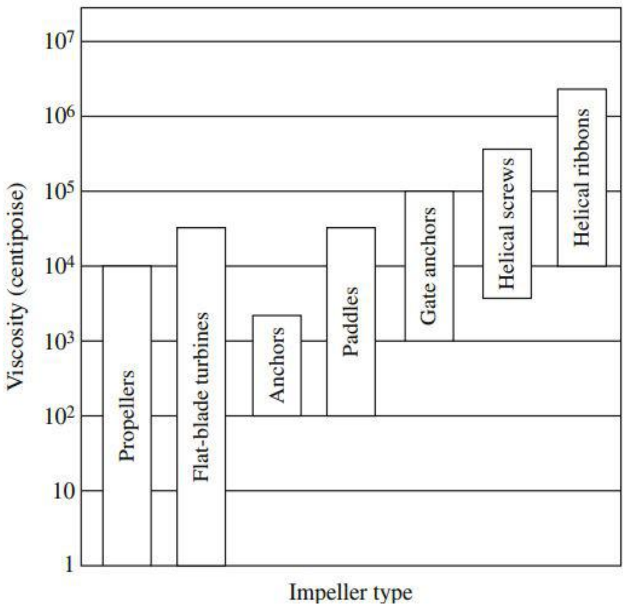
Viskositas cair = Exp (a + b / T + c . T + d T^2) (Chapter 22, Yaws)

Komponen	**A**	**B**	**C**	**D**
$C_6H_5CH_2CN$	-14,8844	3,03E+03	2,35E-02	-1,40E-05

$C_6H_5CH_2COOH$	7,1162	-8,26E+02	-1,49E-02	7,03E-06
C_2H_5OH	-6,4406	1,12E+03	1,37E-02	-1,55E-05
NH_4HSO_4	11,2905	-4,58E+03	-6,78E-03	9,24E-07
H_2SO_4	-18,7045	3,4962E+03	3,3080E-02	-1,7018E-05
H_2O	-10,2158	1,7925E+03	1,7730E-02	-1,2631E-05

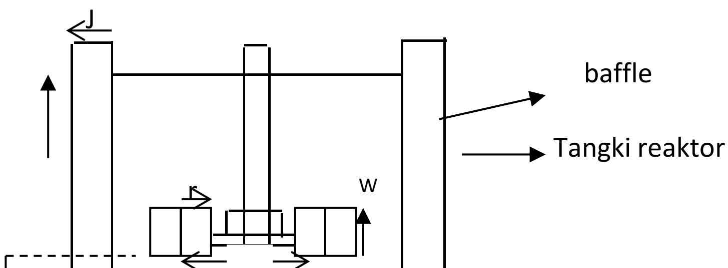
Komponen	**Massa (Kg/Jam)**	**Fraksi massa (x)**	**μ (cP)**	**x . μ**
$C_6H_5CH_2CN$	1.191,0273	0,089	1,159	0,103
$C_6H_5CH_2COOH$	1.842,5727	0,138	2,1013	0,289
C_2H_5OH	22,5133	0,00168	0,3326	0,00055
NH_4HSO_4	1.536,7046	0,115	0,0004	0,000046
H_2SO_4	4.706,1949	0,353	4,3635	1,54
H_2O	4.035,0739	0,303	0,2791	0,085
Total	13.334,0867	1		2,018

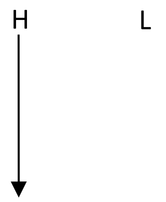
Maka jenis pengaduk yang dipilih adalah *Flat Blade Turbines*



Gambar 3. Jenis impeller berdasarkan viskositas

(Holland, F.A dan F.S., Chapman, Liquid Mixing and Processing in Stirred Tanks, 1966)





Keterangan :

Dt : diameter reaktor

Da : diameter impeller

E : jarak pengaduk dari dasar reaktor

W : tinggi impeller

L : lebar impeller

J : lebar baffle

Ketentuan:

Perbandingan diameter impeller dengan diameter tangki

$$\frac{Da}{Dt} = \frac{1}{3}$$

$$Da = \frac{1}{3} \times Dt$$

$$Da = \frac{1}{3} \times 120\ in = 40\ in \times \frac{0{,}0254\ m}{1\ in} = 1{,}016\ m$$

Perbandingan posisi jarak pengaduk dengan diameter impeller

$$\frac{E}{Da} = 1$$

E = Da = 1,016 m

Perbandingan tinggi impeller dengan diameter impeller

$$W = \frac{1}{5} \times Da$$

$$W = \frac{1}{5} \times 40\ in = 8\ in \times \frac{0{,}0254\ m}{1\ in} = 0{,}2032\ m$$

Perbandingan kedalaman baffle dengan diameter tangki

$$\frac{j}{Dt} = \frac{1}{12}$$

$$j = \frac{1}{12} \times Dt$$

$$j = \frac{1}{12} \times 120\ in = 10\ in \times \frac{0{,}0254\ m}{1\ in} = 0{,}254\ \text{m}$$

Perbandingan panjang lebar impeller dengan diameter impeller

$$\frac{L}{Da} = \frac{1}{4}$$

$$L = \frac{1}{4} \times Da$$

$$L = \frac{1}{4} \times 40\ in = 10\ in \times \frac{0{,}0254\ m}{1\ in} = 0{,}254\ m$$

Menghitung tinggi cairan dengan ada nya baffle

Panjang baffle = Tinggi shell – Jarak pengaduk dari dasar shell

= 4,4 m - 1,016 m

= 3,384 m

Luas Reaktor = Luas Tangki – Jumlah baffle . Luas Baffle

= (¼ π D^2) – n .(Panjang . Lebar .Tinggi)

= (¼ . 3,14 . $3{,}048^2$ m^2) – 4 . (3,384 m . 0,254 . 0,2032 m)

= 6,59 m^2

Tinggi cairan = $\frac{\text{Volome Cairan}}{\text{Luas Reaktor}}$

= $\frac{10{,}971\ \text{m3}}{6{,}59\ m2}$

= 1,66 m

Tinggi cairan dengan baffle masih dibawah tinggi shell reaktor.

Memperkirakan Kecepatan Putaran Pengaduk Reaktor

Komponen	Massa (Kg/jam)	Densitas (Kg/liter)	Fvi (lt/jam)
$C_6H_5CH_2CN$	1.191,0273	1.0950	1.087,69

$C_6H_5CH_2COOH$	1.842,5727	1.1350	1.623,41
C_2H_5OH	22,5133	0.7893	28,52
NH_4HSO_4	1.536,7046	1.7800	863,31
H_2SO_4	4.706,1949	1.8200	8.565,27
H_2O	4.035,0739	0.9980	4.027
TOTAL	13.334,0867		16.195,2

ρ campuran = x $_{C6H5CH2CN}$. ρ $_{C6H5CH2CN}$ + x $_{C6H5CH2COOH}$. ρ $_{C6H5CH2COOH}$ + x $_{As.sulfat}$. ρ $_{As.Sulfat}$ + x $_{Air}$. ρ $_{Air}$ + x $_{C2H5OH}$ ρ. $_{C2H5OH}$ + x $_{NH4HSO4}$ ρ. $_{NH4HSO4}$

ρ campuran = 1,1545 kg/L x (2,2046 lb / 1 kg) x (1 L / 0,0353 ft^3)

ρ campuran = 72,10228 lb/ft^3

μ campuran = 2,018 Cp = 4,88 lbm/ft.jam = 0,00136 lbm/ft.s

Dari tabel 8.2 halaman 338, Howard. F. Rase, diketahui kecepatan perputaran untuk pengaduk tipe *flat blade turbine impleller*, dengan 8 *flat blade* dan 4 baffle, yaitu sebesar :

N = 500 – 700 fpm.

Dipilih : N = 600

$$N = \frac{600}{\pi . Da}$$

$$N = \frac{600}{\pi . 3,3\,ft}$$

N = 57,87 rpm

IMPELLER SPEED

With commercially available motors and speed reducers, standard speeds are 37, 45, 56, 68, 84, 100, 125, 155, 190, and 320 rpm. Power requirement usually are not great enough to justify the use of continuously adjustable steam turbine drives. Two-speed drives may be required when starting torques are high, as with a settled slurry.

(Walas, hal 288)

Digunakan power standard = 56 rpm = 4.080 rpj = 1,13 rps

Bilangan Reynold untuk pengadukan:

$$Re = \frac{Da^2 . N . \rho}{\mu}$$

$$= \frac{(3{,}3^{\,2} ft^2)(0{,}96 \text{ rps})(72{,}10228 \frac{\text{lb}}{ft^3})}{0{,}00136 \frac{lbm}{ft.s}}$$

$$= 554.254{,}46$$

Dipilih kurva no 9 untuk 8 flat blades turbin berdasarkan tabel *Power Cosumption Of Agitators* pada buku G. G Brown, hal 507.

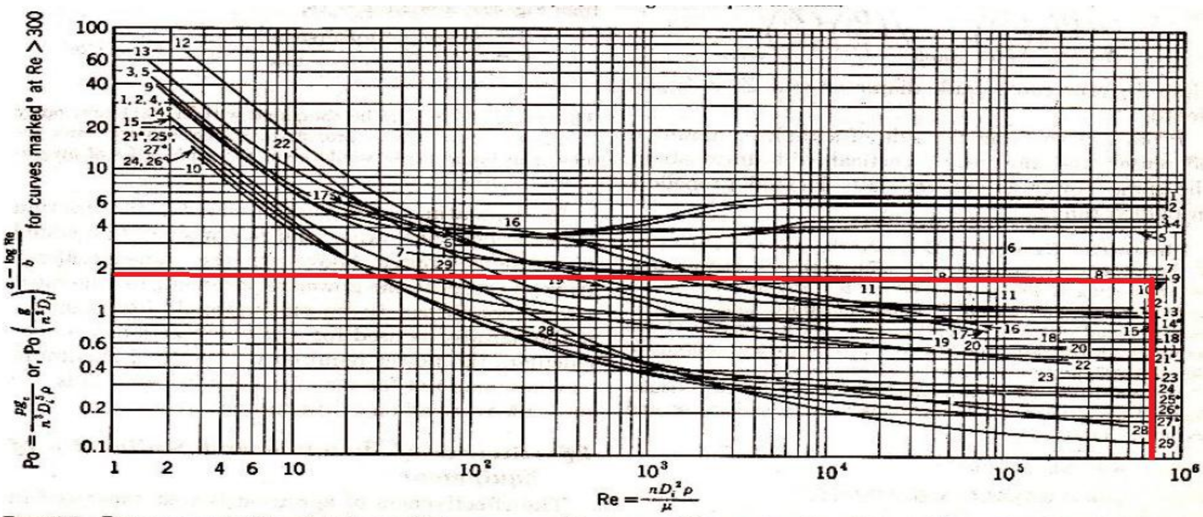


Fig. 477. Power consumption of various agitators expressed in terms of Po as a function of Reynolds number, Re. For curves marked with ° surface effects become important and the Froude number Fr = g/n^2D_i is included as indicated for Re > 300.

(Brown. Figure 477 hal 507)

Dari grafik didapat nilai Np = 1,9

Tenaga untuk pengadukan:

$$P = Np..N^3.Di^5.\rho$$

$$= \frac{1{,}9 \; x \; (68 \; rpm)^3 (3{,}3 \;\; ft)^5 (72{,}10228 \frac{lb}{ft^3})}{(60 \; detik/menit)^3}$$

$= \quad 78.045,036 \text{ lb.ft}^2/\text{detik}^3 \text{ x } \frac{1kg}{2,2046lb} \; x \frac{(0,3048m)^2}{(1ft)^2}$

$= 3.290,96 \text{ kg m}^2/\text{s}^3 = 3.290,96 \text{ N m/s} = 3.290,96 \text{ J/s}$

$= 3.290,96 \text{ watt x } \frac{1Hp}{745,7watt}$

= 4,4 Hp

Effisiensi motor 80% (tabel 3.1 Towler dan Sinnott, hlm. 111) maka:

Tenaga motor untuk pengaduk= 4,4 Hp / 0,8

= 5,5 Hp

Horsepower Ratings.[31] Standard NEMA ratings for induction motors are

General purpose: ½ , ¾ , 1, 1 ½ , 2, 3, 5, 7 ½ , 10, 15, 20, 25, 40, 50, 60, 75, 100, 125, 150, 200, 250, 300, 350, 400, 450, and 500.

Large motors: 250, 300, 350, 400, 450, 500, 600, 700, 800, 900, 1000, 1.250, 1.500, 1.750, 2.000, 2.250, 2.500, 3.000, 3.500, 4.000, 4.500, 5.000 and up to 30.000.

(Walas, hal 289)

Digunakan standar = 7,5 Hp

6. Perancangan pendingin Reaktor 01

Dipilih pendingin coil dengan media pendingin air.

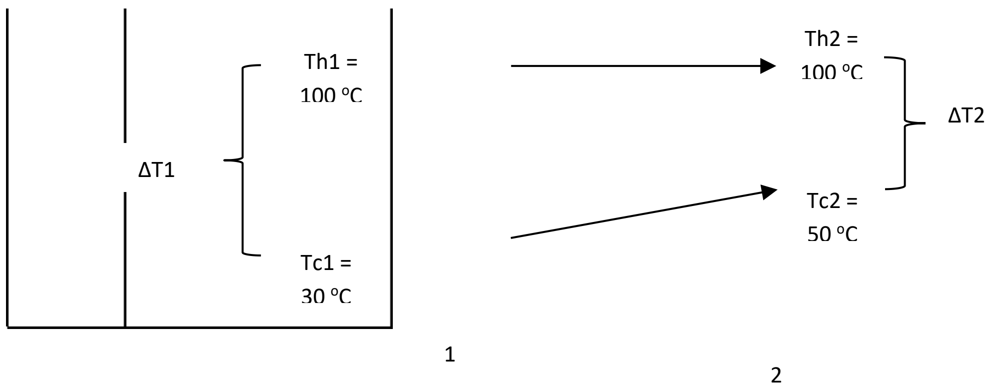
Suhu masuk = 30 °C = 303 K = 86 F

Suhu keluar = 50 °C = 323 K = 122 F

Suhu reaksi = 100 °C = 373 K = 212 F

Suhu rata-rata = 40 °C = 313 K = 104 F

ΔT = 20 °C = 293 K = 68 F



Gambar 5. Profil Suhu

Sifat – sifat fisis air pada 30 °C

Cp = 1 kkal/kg.C

= 4,186 kJ/kg. °C

ρ = 1,1013 kg/l

= 1101,3 kg/m^3

Kebutuhan air pendingin (Wa)

$$Wa = \left(\frac{Q}{Cp\,.\,dT}\right)$$

dengan :

Q : Jumlah panas yang harus diserap = 2.710.635,263 kJ/jam

dT : beda suhu pendingin = 20 °C

$$Wa = \left(\frac{2.710.635{,}263\ \text{kJ/jam}}{4{,}186\ \text{kJ/kg.}\,^0\text{C} \times 20^0C}\right)$$

maka diperoleh :

Wa = 32.377,39206 kg/jam

1. Pemilihan pendingin

Beda suhu rerata

Dihitung dengan persamaan:

$$\Delta T\ LMTD = \frac{\Delta T2 - \Delta T1}{\ln\left(\frac{\Delta T2}{\Delta T1}\right)} = \frac{(212\ F - 122\ F) - (212\ F - 86\ F)}{\ln\left(\frac{90\ F}{126\ F}\right)} = 106{,}99\ F$$

Ud untuk air pendingin (Kern,tabel 8)

Dengan hot fluid heavy organic dan cold fluid water = 5 – 75 BTU/jam.ft°F

Diambil Ud = 60 BTU/jam ft°F

Maka diperoleh luas perpindahan panas sebagai berikut:

$$A = \frac{Q}{Ud \times \Delta T\ LMTD}$$

Dengan:

Q = Jumlah panas yang diserap (BTU/jam)

Ud = Koefisien perpindahan panas (BTU/jam ft^{o}F)

ΔT LMTD = Selisih temperature logaritmik rata – rata (^{o}F)

$$A = \frac{2.710.635{,}263 \text{ BTU/jam}}{60 \frac{BTU}{\text{jam ft}^{o}\text{F}} \times 106{,}99\ ^{0}F}$$

A = 422,25 ft^2

= 39,2 m^2

Menentukan pendingin menggunakan jacket atau coil:

Luas selimut = $\pi \times Dt \times HI$

= $\pi \times 3{,}048\ m \times 4{,}572$ m

= 43,78 m^2

Luas selimut tangki yang tersedia 43,78 m^2> dari luas perpindahan panas yang dibutuhkan 39,2 m^2, maka digunakan jacket sebagai pendingin.

2. Perancangan Jaket Pendingin

Volume air (q_a) pendingin:

$$q_a = \frac{Wa}{\rho\ air}$$

Dengan:

q_a = Laju alir volume pendingin (m^3/jam)

Wa = Laju alir massa air pendingin (kg/jam)

ρ air = Densitas air pendingin pada T = 30 ^{o}C

$$q_a = \left(\frac{32.377{,}39206 \text{ kg/jam}}{1101{,}3 \text{ kg/m3}}\right) = 29{,}399\ m^3/jam$$

Diameter jaket dalam:

Asumsi = 1 jam operasi

$Vj = \theta \times qa$

Dengan:

Vj = Volume jaket (m^3)

Ɵ = Waktu (Jam)

q_a = Laju alir volume pendingin (m^3/jam)

maka:

Vj = 1 jam × 29,399 m^3/jam

= 29,399 m^3

$$Vj = \frac{Dji^2}{4} \times H - \frac{OD}{4} \times H$$

Dengan:

Vj = Volume jaket (m^3)

Dji = Diameter dalam jaket (m)

H = tinggi reaktor (m)

OD = Diameter luar reaktor (m)

Sehingga:

$$Dji = \sqrt[2]{\left(Vj + \frac{OD^2}{4} \times H\right) \times \frac{4}{H}}$$

$$Dji = \sqrt[2]{\left(29{,}399\ \text{m}^3 + \frac{(3{,}0607\ m)^2}{4} \times 4{,}572\ m\right) \times \frac{4}{4{,}572\ m}}$$

Dji = 5,92 m

Dji = 233,07 in

Tebal jaket pendingin (tj):

$$tj = \frac{Pd\ .\ rji}{(S\ .\ E) + (0{,}4.Pd)} + CA$$

Dengan:

tj = Tebal jaket pendingin (in)

Pd = Tekan design (psi)

rji = jari – jari dalam jaket (in)

S = Allowable stress (psi)

E = Efisiensi sambungan

CA = Faktor korosi

Maka,

$$tj = \frac{17{,}635\ psi\ .\ \dfrac{233{,}07\ \text{in}}{2}}{(18.750\ psi\ .\ 0{,}8) + (0{,}4\ .\ 17{,}635\ psi)} + 0{,}125\ in$$

= 0,262 in

Diameter luar jaket (Djo)

Djo = Dji + (2 × tj)

Djo = 233,07 in + (2 × 0,262 in)

Djo = 233,594 in

Djo = $233{,}594\ \text{in} \times \frac{0{,}0254\ m}{1\ in}$ = 5,933 m

7. Perancangan pendingin Reaktor 02

Dipilih pendingin coil dengan media pendingin air.

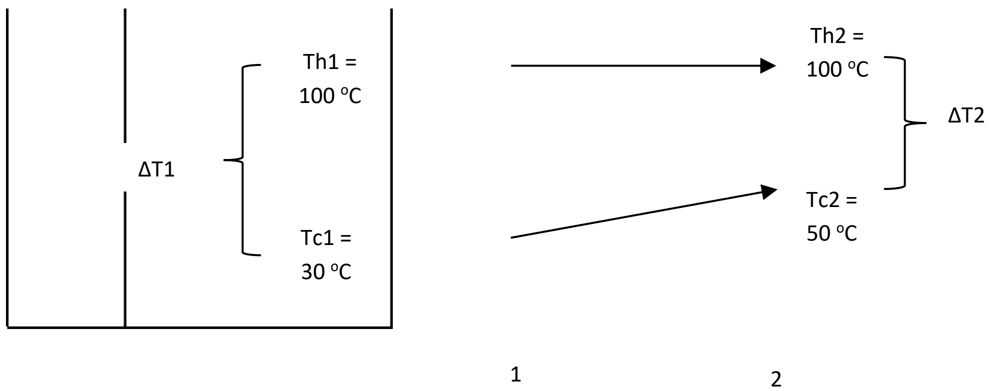
Suhu masuk = 30 ^oC = 303 K = 86 F

Suhu keluar = 50 ^oC = 323 K = 122 F

Suhu reaksi = 100 ^oC = 373 K = 212 F

Suhu rata-rata = 40 ^oC = 313 K = 104 F

ΔT = 20 ^oC = 293 K = 68 F



Gambar 5. Profil Suhu

Sifat – sifat fisis air pada 30 ^oC

Cp = 1 kkal/kg.C

= 4,186 kJ/kg. ^oC

ρ = 1,1013 kg/l

= 1101,3 kg/m^3

Kebutuhan air pendingin (Wa)

$$Wa = \left(\frac{Q}{Cp\,.\,dT}\right)$$

dengan :

Q : Jumlah panas yang harus diserap = 2.720.464,124 kJ/jam

dT : beda suhu pendingin = 20 ^{o}C

$$Wa = \left(\frac{2.720.464{,}124\ \text{kJ/jam}}{4{,}186\ \text{kJ/kg.}^{0}\text{C} \times 20^{0}C}\right)$$

maka diperoleh :

Wa = 32.494,79365 kg/jam

3. Pemilihan pendingin

Beda suhu rerata

Dihitung dengan persamaan:

$$\Delta T\ LMTD = \frac{\Delta T2 - \Delta T1}{\ln\left(\frac{\Delta T2}{\Delta T1}\right)} = \frac{(212\ F - 122\ F) - (212\ F - 86\ F)}{\ln\left(\frac{90\ F}{126\ F}\right)} = 106{,}99\ F$$

Ud untuk air pendingin (Kern,tabel 8)

Dengan hot fluid heavy organic dan cold fluid water = 5 – 75 BTU/jam.ft^{o}F

Diambil Ud = 60 BTU/jam ft^{o}F

Maka diperoleh luas perpindahan panas sebagai berikut:

$$A = \frac{Q}{Ud \times \Delta T\ LMTD}$$

Dengan:

Q = Jumlah panas yang diserap (BTU/jam)

Ud = Koefisien perpindahan panas (BTU/jam ft^{o}F)

ΔT LMTD = Selisih temperature logaritmik rata – rata (^{o}F)

$$A = \frac{2.720.464{,}124\ \text{BTU/jam}}{60\frac{BTU}{\text{jam ft}^{0}\text{F}} \times 106{,}99\ ^{0}F}$$

A = 423,78 ft^{2}

= 39,37 m^{2}

Menentukan pendingin menggunakan jacket atau coil:

Luas selimut = $\pi \times Dt \times HI$

= $\pi \times 3{,}048\ m \times 4{,}572$ m

= 43,78 m^{2}

Luas selimut tangki yang tersedia 43,78 m^2> dari luas perpindahan panas yang dibutuhkan 39,37 m^2, maka digunakan jacket sebagai pendingin.

4. Perancangan Jaket Pendingin

Volume air (q_a) pendingin:

$$q_a = \frac{Wa}{\rho\ air}$$

Dengan:

q_a = Laju alir volume pendingin (m^3/jam)

Wa = Laju alir massa air pendingin (kg/jam)

ρ air = Densitas air pendingin pada T = 30 °C

$$q_a = \left(\frac{32.494{,}79365\ \text{kg/jam}}{1101{,}3\ \text{kg/m3}}\right) = 29{,}5\ m^3/jam$$

Diameter jaket dalam:

Asumsi = 1 jam operasi

$$Vj = \theta \times qa$$

Dengan:

Vj = Volume jaket (m^3)

Θ = Waktu (Jam)

q_a = Laju alir volume pendingin (m^3/jam)

maka:

Vj = 1 jam × 29,5 m^3/jam

= 29,5 m^3

$$Vj = \frac{Dji^2}{4} \times H - \frac{OD}{4} \times H$$

Dengan:

Vj = Volume jaket (m^3)

Dji = Diameter dalam jaket (m)

H = tinggi reaktor (m)

OD = Diameter luar reaktor (m)

Sehingga:

$$Dji = \sqrt[2]{\left(Vj + \frac{OD^2}{4} \times H\right) \times \frac{4}{H}}$$

$$Dji = \sqrt[2]{\left(29,5\ \mathrm{m}^3 + \frac{(3,0607\ m)^2}{4}\ \times 4,572\ m\right)\ \times\ \frac{4}{4,572\ m}}$$

Dji = 5,93 m

Dji = 233,46 in

Tebal jaket pendingin (tj):

$$tj = \frac{Pd\ .\ rji}{(S\ .\ E) + (0,4.Pd)} + CA$$

Dengan:

tj = Tebal jaket pendingin (in)

Pd = Tekan design (psi)

rji = jari – jari dalam jaket (in)

S = Allowable stress (psi)

E = Efisiensi sambungan

CA = Faktor korosi

Maka,

$$tj = \frac{17,635\ psi\ .\ \frac{233,46\ \mathrm{in}}{2}}{(18.750\ psi\ .\ 0,8) + (0,4\ .\ 17,635\ psi)} + 0,125\ in$$

= 0,262 in

Diameter luar jaket (Djo)

Djo = Dji + (2 × tj)

Djo = 233,46 in + (2 × 0,262 in)

Djo = 233,984 in

Djo = $229,65\ \mathrm{in}\ \times\ \frac{0,0254\ m}{1\ in}$ = 5,94 m

KESIMPULAN REAKTOR

Tugas : Mereaksikan Benzil Sianida ($C_6H_5CH_2CN$) dan Asam Sulfat (H_2SO_4) menjadi Asam Fenil Asetat ($C_6H_5CH_2COOH$). Dengan kecepatan umpan Benzil Sianida sebesar 2.754,4572 kg/j dan kecepatan Asam Sulfat sebesar 6.015,7345 kg/j.

Jenis Reaktor : Reaktor Alir Tangki Berpengaduk (RATB)

Kondisi Operasi :

Tekanan = 1 atm

Suhu = 100 ℃

Diperoleh Ukuran Reaktor :

Jumlah Reaktor = 2

Diameter = 3,048 m

Tinggi = 4,572 m

Volume cairan dalam head = 3,7 m^3

Volume cairan dibadan RATB = 10,971 m^3

Tinggi cairan dibadan RATB = 4,4 m

Dipilih Tebal shell = 1/4 in

Tebal Head = 1/4 in

Diameter impeler = 1,016 m

Tinggi Impeler = 0,2032 m

Lebar Buffle = 0,254 m

Digunakan motor dengan daya = 7,5 Hp

Jenis pendingin = *Jacket*

Suhu pendingin masuk = 30 ^oC

Suhu pendingin keluar = 50 ^oC

Tebal jacket = 0,262 in

Diameter jacket dalam = 5,92 m

Diameter jacket luar = 5,933 m