LAMPIRAN A

REAKTOR

(R-01 dan R-02)

Jenis = Reaktor alir tangki Berpengaduk (RATB)

Fase = Cair - Cair

Bentuk = Tangki Silinder

Bahan = Stainless Steel 316 AISI (18Cr, 12Ni, 2.5Mo)

Suhu Operasi = 55 °C

Tekanan = 1 atm

Waktu Tinggal (θ) = 1 jam

Konversi terhadap Alkylbenzene = 96%

A. Menghitung Densitas Cairan

Komponen	massa (kg/jam)	Fraksi Massa (xi)	ρi (kg/m3)	ρi.xi (kg/m3)
$C_6H_5.C_{12}H_{25}$	2.677,6385	0,4417	829,7402	366,4609
$C_{10}H_{21}C_6H_5$	37,4761	0,0062	831,0345	5,1370
$C_{14}H_{29}C_6H_5$	0,5431	0,0001	834,2542	0,0747
$H_2SO_4.SO_3$	3.347,0481	0,5521	1.790,0182	988,2183
Total	**6.062,7057**	**1,000**		**1.359,8909**

1. ***Design Equation***

$$Fv = \frac{\text{massa umpan}}{\rho \text{ campuran}}$$

= 4,4582 m^3/jam

= 4.458,2296 liter/jam

Cao = na/Fv

= 0,0024 kmol/liter

Cbo = nb/Fv

= 0,0080 kmol/liter

Reaksi :

$C_6H_5.C_{12}H_{25}$ + $H_2SO_4.SO_3$ ⟶ $C_6H_5.C_{12}H_{25}.SO_3$ + H_2SO_4

m :	Cao	Cbo		
r :	Cao.x	Cao.x	Cao.x	Cao.x
s :	Cao-Cao.x	Cbo-Cao.x	Cao.x	Cao.x

Reaksi merupakan reaksi orde dua, dimana kecepatan reaksi dinyatakan dengan :

-ra = k.Ca.Cb

x = 0,96

t = 1 jam

Ca = Cao - Cao.x

= 0,000098 kmol/L

Cb = Cbo - Cao.x

= 0,0056 kmol/L

$$k = \frac{CA0\ x}{t\ CA0\ (1-x)(CB0 - CA0\ x)}$$

= 4.278,7542 L/kmol.Jam

2. Menentukan Volume Reaktor

Rate of Input - Rate of Output - Rate of Reaction = Accumulation

Fv.Cao - Fv. Ca - (-ra).V = 0

Fv.Cao - Fv. Cao (1-x) - (k.Ca.Cb).V = 0

Fv.Cao - Fv. Cao (1-x) = (k.Ca.Cb). V

$$V = \frac{Fv\ (Cao - Cao\ (1-x))}{k.Ca.Cb}$$

$$V = \frac{Fv.\ Cao.\ X}{k.Ca.Cb}$$

V = 4.458,23 L

= 4,46 m^3

3. Optimasi Reaktor

$$\mathbf{V_n} = \frac{\mathbf{FA_o} \cdot (\mathbf{X}_{out} - \mathbf{X}_{in})}{(-ra)_{out}}$$ Fogler hal. 47

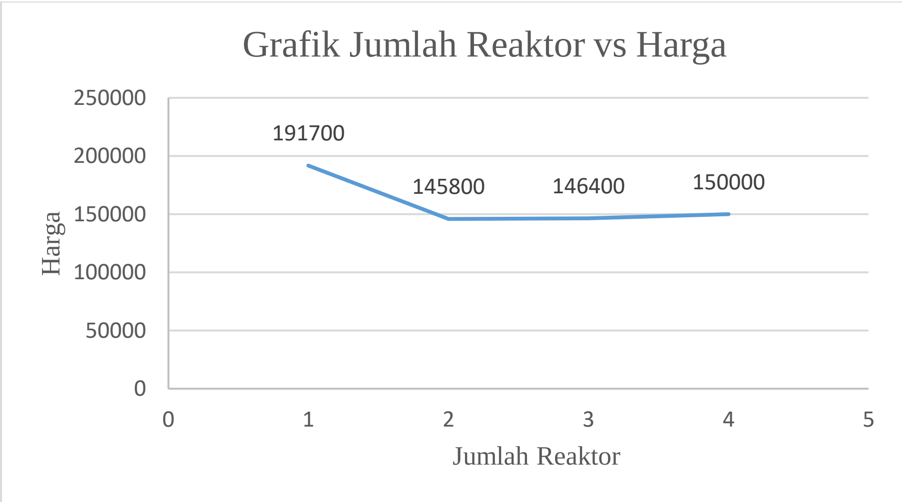
$$\mathbf{V_n} = \frac{\mathbf{FA_o} \cdot (\mathbf{X}_{out} - \mathbf{X}_{in})}{k.Ca.Cb}$$

$$\mathbf{V_n} = \frac{\mathbf{FA_o} \cdot (\mathbf{X}_{out} - \mathbf{X}_{in})}{k.Cao\,(1 - X_{out}).(Cbo - Cao.X_{out})}$$

Reaktor ke-	Xa, N-1	Xa, N	V (L)	Error V
1	0%	96%	4.458	0
1	0%	81%	719	0
2	81%	96%	719	0
1	0%	67%	337	0
2	67%	88%	337	0
3	88%	96%	337	0
1	0%	56%	205	0
2	56%	80%	205	0
3	80%	91%	205	0
4	91%	96%	205	0

n	Konversi	Volume (L)	Volume (gallon)	V over design (gallon)	Harga ($)	
					Unit	Total
1	96%	4.458	1.178	1.413	191.700	191.700
1	81%	719	190	228	72.900	145.800
2	96%	719	190	228	72.900	
1	67%	337	89	107	48.800	146.400
2	88%	337	89	107	48.800	
3	96%	337	89	107	48.800	
1	56%	205	54	65	37.500	150.000
2	80%	205	54	65	37.500	
3	91%	205	54	65	37.500	
4	96%	205	54	65	37.500	

Jumlah Reaktor	Harga
1	191.700
2	145.800
3	146.400
4	150.000



B. Menghitung Dimensi Reaktor

Perancangan reaktor dibuat dengan over design sebesar 20%, sehingga volume reaktor menjadi :

Volume reaktor = 1,2 x volume cairan

Volume reaktor = 1,2 x 0,7191 m^3

Volume reaktor = 0,8629 m^3 = 30,4744 ft^3 = 228 gallon

1. Menghitung diameter dan tinggi reaktor

   Reaktor yang digunakan berbentuk silinder tegak

   Volume = volume silinder + volume tutup

   = volume silinder + 2 volume *head*

Tutup berbentuk *torispherical dished head*

Dengan :

Volume head = 0,000049 d^3 (Pers. 5.11., Brownell hal. 88)

Sehingga :

$$\text{volume} = \left(\frac{1}{4} \times \pi \times D^2 \times H\right) + [2 \times (0{,}000049) \times (D^3)]$$

Dipilih perbandingan D : H = 1 : 1,5

$$30{,}4744\ ft^3 = \left(\frac{1}{4} \times \pi \times D^2 \times H\right) + [2 \times (0{,}000049) \times (D^3)]$$

$$30{,}4744\ ft^3 = \left(\frac{1}{4} \times 3{,}14 \times D^2 \times 1{,}5D\right) + [(0{,}000098) \times (D^3)]$$

$$30{,}4744\ ft^3 = D^3\left(\frac{4{,}71}{4} + 0{,}000098\right)$$

$$30{,}4744\ ft^3 = D^3(1{,}1776)$$

$$D^3 = \frac{30{,}4744\ ft^3}{1{,}1776}$$

$$D = \sqrt[3]{25{,}8785\ ft^3}$$

$$D = 2{,}9579\ ft = 35{,}4945\ in = 0{,}9016\ m$$

Maka tinggi reaktor :

H = 1,5 D

H = 1,5 x 2,9579 ft

H = 4,4368 ft = 53,2417 in = 1,3523 m

2. Menghitung tinggi cairan

$$\text{Volume cairan} = h_{cairan} \times \frac{\pi D^2}{4}$$

$$0{,}7191\ m^3 = h_{cairan} \times \frac{3{,}14 \times (0{,}9016\ m)^2}{4}$$

$0{,}7191\ m^3 \quad = h_{cairan} \times 0{,}6381\ m^2$

$$h_{cairan} = \frac{0{,}7191\ m^3}{0{,}6381\ m^2}$$

$h_{cairan} = 1{,}1270\ m$

3. Menghitung tebal dinding reaktor

Persamaan 13.1 (*Brownell 1959, Page 254*) *:*

$$t_s = \frac{P \times ri}{(f \times E) - (0{,}6 \times P)} + C$$

Dengan :

Allowable stress (f) = 18.847,948 psia

Sambungan yang dipilih = double wekded but joint

Efisiensi sambungan (E) = 80%

Corrosion allowance (C) = 0,125 in

Jari-jari reaktor (ri) = 17,7472 in

Teakanan (P) = tekanan operasi + tekanan hidrostatis

= 14,7 psia + 2,1785 psia

= 16,8785 psia

Sehingga :

$$t_s = \frac{16{,}8785\ psia \times 17{,}7472\ in}{(18.847{,}984\ psia \times 80\%) - (0{,}6 \times 16{,}8785\ psia)} + 0{,}125\ in$$

$$t_s = \frac{299{,}5463\ psia.in}{15.068{,}2313\ psia} + 0{,}125\ in$$

$t_s = 0{,}0199\ in + 0{,}125\ in$

$t_s = 0{,}1449\ in$

Jadi, tebal shell minimum yang dibutuhkan sebesar 0,1449 in

Berdasarkan tabel 5.6 Brownell & Young, maka dipilih th standar :

th = 3/16 in

= 0,1875 in

ID shell = 35,4945 in

OD shell = ID + 2ts

= 35,4945 in + (2 x 0,1875 in)

= 35,8695 in

Berdasarkan tabel 5.7 (*Brownell & Young,1959*), untuk OD standar maka diambil OD terdekat yaitu :

OD = 36 in

= 0,9144 m

ID = OD – 2ts

= 36 in – (2 x 0,1875 in)

= 35,6250 in = 2,9688 ft = 0,9094 m

H = 1,5 x D

= 1,5 x 35,6250 in

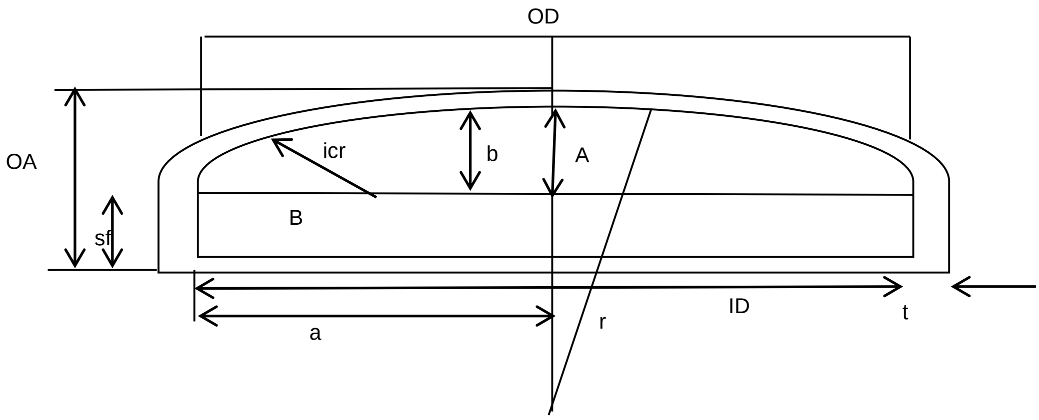
= 53,4375 in = 4,4531 ft = 1,3573 m

icr = 2,250 in

rc = 36 in

C. Menghitung Dimensi Head Reaktor

Dipilih head dengan bentuk *Torispherical Flanged & Dished Head*, dengan pertimbangan harganya cukup ekonomis dan digunakan untuk tekanan operasi hingga 15 bar.



Keterangan gambar :

ID : diameter dalam *head*

OD : diameter luar *head*

a : jari-jari *head*

t : tebal *head*

r : jari-jari dalam *head*

icr : *inside corner radius*

b : *deep of dish*

sf : *straight of flanged*

OA : tinggi head

1. Menghitung tebal *head*

$$t_h = \frac{P \text{ x } rc \text{ x } W}{(2 \text{ x } f \text{ x } E) - (0{,}2 \text{ x } P)} + C$$

(Brownell & Young 1959, Page 138)

$$W = \frac{1}{4}\ x\ \left(3 + \sqrt{\frac{rc}{icr}}\right)$$

$$W = \frac{1}{4}\ x\ \left(3 + \sqrt{\frac{36\ in}{2{,}250\ \text{in}}}\right)$$

$$W = 1{,}7500$$

Sehingga :

$$\mathrm{t_h} = \frac{16{,}8785\ \text{psia x 36 in x}\ 1{,}7500}{(2\ \text{x}\ 18.847{,}948\ \text{psia x}\ 80\%) - (0{,}2\ \text{x}\ 16{,}8785\ \text{psia})} + 0{,}125\ \text{in}$$

$$\mathrm{t_h} = \frac{1.063{,}3439\ \text{psia.in}}{30.153{,}3411\ \text{psia}} + 0{,}125\ \text{in}$$

$$\mathrm{t_h} = 0{,}0353\ \text{in} + 0{,}125\ \text{in}$$

$$\mathrm{t_h} = 0{,}1603\ \text{in}$$

Berdasarkan tabel 5.6 Brownell & Young, dipilih th standar :

th = 3/16 in = 0,1875 in

2. Menghitung tinggi *head*

Berdasarkan tabel 5.8 (Brownell & Young, hal. 93), maka digunakan sf :

Sf = 2 in

ID = OD – 2th

= 36 in – (2 x 0,1875 in)

= 35,6250 in

A = ID/2

= 35,6250/2

= 17,8125 in

AB = a – icr

= (17,8125 – 2,250) in

= 15,5625 in

BC = rc – icr

= (36 – 2,250) in

= 33,7500 in

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

= $\sqrt{(33{,}7500)^2 - (15{,}5625)^2}$

= 29,9478 in

B = rc – AC

= (36 - 29,9478) in

= 6,0522 in

Tinggi *head* total :

AO = sf + b + th

= (2 + 6,0522 + 0,1875) in

= 8,2397 in = 0,2093 m

D. Menghitung Dimensi Pengaduk

Volume cairan yang diaduk = 0,7191 m3

= 190 gallon

Kekentalan cairan yang diaduk (μ) = 6,4843 cp

= 0,004357 lb/ft.s

Jenis pengaduk yang dipilih yaitu *marine propeller with 3 blades and pitch 2Di*, dengan alasan cocok untuk cairan dengan viskositas mencapai 4000 cp.

Perancangan untuk pengadukan dilakukan dengan prinsip similaritas menggunakan model sesuai dengan referensi buku Brown pada Fig. 477 kurva no. 15 halaman 507 dan tabelnya.

$$\frac{\mathrm{Dt}}{\mathrm{Di}} = 3$$

$$\frac{\mathrm{Zl}}{\mathrm{Di}} = 3{,}9$$

$$\frac{\mathrm{Zi}}{\mathrm{Di}} = 1{,}3$$

Maka diperoleh :

a. Diameter Pengaduk (Di)

$$\mathrm{Di} = \frac{\mathrm{Dt}}{3}$$

$$= \frac{35{,}6250 \text{ in}}{3}$$

$$= 11{,}8750 \text{ in}$$

$$= 0{,}3016 \text{ m}$$

$$= 0{,}9896 \text{ ft}$$

b. Tinggi Cairan dalam Pengadukan (Zl)

$$\mathrm{Zl} = \mathrm{Di} \times 3{,}9$$

$$= 11{,}8750 \text{ in} \times 3{,}9$$

$$= 46{,}3125 \text{ in}$$

$$= 1{,}1763 \text{ m}$$

$$= 3{,}8594 \text{ ft}$$

c. Jarak Pengaduk dari Dasar Tangki

$$\mathrm{Zi} = \mathrm{Di} \times 1{,}3$$

$= 11{,}8750 \text{ in x } 1{,}3$

$= 15{,}4375 \text{ in}$

$= 0{,}3921 \text{ m}$

$= 1{,}2865 \text{ ft}$

Menghitung jumlah pengaduk (sesuai referensi wallas halaman 288)

Rasio tinggi permukaan cairan dan diameter tangki = H/D

= 1,1270/0,9049

= 1,2455

Berdasarkan referensi Wallas, maka jumlah pengaduk yang dipakai = 1 buah

Trial nilai rpm (N) :

Diambil πDN = 14,1 ft/s

$$N = \frac{14{,}1 \ ^{ft}/_{s}}{\pi D}$$

$$N = \frac{14{,}1 \ ^{ft}/_{s}}{3{,}14 \text{ x } 0{,}9896 \text{ ft}}$$

$$N = 4{,}5261 \ /s$$

Menghitung nilai Re :

$$Re = \frac{\rho \text{ x N x } Di^2}{\mu}$$

$$Re = \frac{84{,}8952 \ ^{lb}/_{ft^3} \text{ x } 4{,}5261/s \text{ x } (0{,}9896 \text{ ft})^2}{0{,}004357 \ ^{lb}/_{ft.\,s}}$$

$$Re = 86.357{,}7519$$

Power number (Po) yang didapat dari Fig. 477 Brown = 0,9

Sehingga :

$$P = \frac{N^3 \text{ x } Di^5 \text{ x } \rho \text{ x } Po}{gc}$$

$$P = \frac{(4{,}5261/s)^3 \text{ x } (0{,}9896 \text{ ft})^5 \text{ x } 84{,}8952 \ ^{lb}/_{ft^3} \text{ x } 0{,}9}{32{,}174 \ ^{ft}/_{s^2}}$$

$$P = 208{,}9571 \ ^{lb.ft}/_{s}$$

$$P = 0{,}3799 \text{ hp}$$

Pada reaksi dengan transfer panas, nilai Hp/1000 gallon = 1,5-5

Diambil Hp/1000 gallon = 2

Hp = 2 Hp/1000 gallon x volume cairan

= 2 Hp/1000 gallon x 190 gallon

= 0,3799 hp

E. Menghitung Dimensi *Coil* Pendingin

1. Reaktor 1 (R-01)

a. Menghitung suhu LMTD

Hot fluid (heavy organic)

T_{in} = 30 °C = 303 K = 86 °F

T_{out} = 55 °C = 328 K = 131 °F

Cold fluid (Air)

t_{in} = 30 °C = 303 K = 86 °F

t_{out} = 45 °C = 318 K = 113 °F

Δt_1 = (113 – 86) °F

= 27 °F

Δt_2 = (131 – 86) °F

= 45 °F

$$\Delta T_{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln\left(\frac{\Delta t_2}{\Delta t_1}\right)}$$

$$\Delta T_{LMTD} = \frac{(45 - 27)°F}{\ln\left(\frac{45\ °F}{27\ °F}\right)}$$

$$\Delta T_{LMTD} = 35{,}2371\ °F$$

b. Menghitung Luas Transfer Panas

Q pendinginan = 652.524,7681 kj/jam

= 618.593,4801 Btu/jam

untuk *cold fluid* = *water* dan *hot fluid* = *medium organic*

Ud = 50-125 btu/ft2. F. Jam (Kern, Table 8 Hal. 840)

Diambil Harga Ud = 115 btu/ft2. F. Jam

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

$$A = \frac{618593{,}4801\ btu/jam}{115\ {}^{btu}/_{ft^2.F.jam} \times 35{,}2371\ °F}$$

$$A = 152{,}6538\ ft^2$$

c. Menghitung Luas Selimut Reaktor

OD = 36 in

= 0,9144 m

= 3 ft

H = 53,4375 in

= 1,3573 m

= 4,4531 ft

A = π.OD.H

= 3,14 x 3 x 4,4531

A = 41,948 ft^2

Luas selimut < A (luas transfer panas) terhitung, sehingga luas selimut tidak mencukupi sebagai luas transfer panas, maka digunakan *coil* pendingin.

d. Menghitung kebutuhan air pendingin

$Qpendinginan = m\ air\ x\ Cp\ air\ \Delta T$

$m\ air = (Q\ pendinginan)/(Cp\ air\ \text{x}\Delta T)$

Cp air = 4,1838 kj/kg.K

T = 15 K

$$\text{m air} = \frac{\text{Q pendinginan}}{\text{Cp air x } \Delta \text{T}}$$

$$\text{m air} = \frac{652.524{,}7681\ \text{kj/jam}}{4{,}1838\ ^{\text{kj}}/_{\text{kg. K}}\ \text{x 15 K}}$$

$\text{m air} = 10.397{,}6566$ kg/jam

= 22.926,83286 lb/jam

Sifat fisis air pada Tf = 99,5 °F :

Cp = 4.183,7938 j/kg.K = 0,9999 btu/lb.F

ρ = 1.016,0968 kg/m3 = 63,4044 lb/ft3

μ = 0,6991 cp = 1,6919 lb/ft.jam

k = 0,3596 btu/jam.ft.F

e. Kecepatan Volumetrik Air

$$Q_v = \frac{m_{air}}{\rho_{air}}$$

$$Q_v = \frac{10.397,6566\ ^{kg}/_{jam}}{1.016,0968\ ^{kg}/_{m^3}}$$

$$Q_v = 16,2816\ ^{m^3}/_{jam}$$

f. Menentukan Diameter Minimum Koil

Untuk aliran dalam koil/tube, batasan kecepatan antara 1,5-2,5 m/s. (Coulson pg 527)

Dipilih :

Kecepatan pendingin = 2,5 m/s

Debit air pendingin = 10,2329 m^3/jam

V = 2,5 m/s

= 9000 m/jam

Luas Penampang A $= \frac{10,2329\ m3/jam}{9000\ m/jam}$

= 0,0011 m^2

= 0,0122 ft^2

= 1,7623 $inch^2$

A = (π.(ID)^2)/4

$$ID = \sqrt{\frac{4 \times A}{\pi}}$$

$$ID = \sqrt{\frac{4 \times 0,0011}{3,14}}$$

$ID = 0{,}0381\text{m} = 1{,}4983\text{in}$

Dipilih : diameter standard (Kern tabel 11 pg 844)

NPS = 0,7500 in

Schedule Number = 40

OD = 1,05 in = 0,0875 ft

ID = 0,824 in = 0,0687 ft

Luas Penampang (A') = 0,5340 in^2 = 0,0037 ft^2

Luas Perpan/panjang (a") = 0,2750 ft^2/ft

g. Menentukan hi

ρ air pendingin = 1.016,0968 kg/m^3 = 63,4044 lb/ft^3

μ air pendingin = 0,6991 cP = 1,6912 lb/ft.jam

k air pendingin = 0,3596 W/m.K = 0,2079 Btu/ft.jam.^{o}F

Cp air pendingin = 4.183,7938 kJ/kmol

= 232,4330 kJ/kg

= 99,9462 Btu/lb

Gt = kecepatan aliran massa/luas penampang

Gt = W/A

$$Gt = \frac{22.926{,}83286\ \text{lb/jam}}{0{,}0037\ ft^2}$$

= 6.182.516,7272 lb/ft^2.jam

v = Gt/ρ

$$= \frac{6.182.516{,}7272\ \text{lb}/ft^2.\text{jam}}{63{,}4044\ \text{lb}/ft^3}$$

= 97509,2066 ft/jam

= 8,3 m/s

= 27,0859 ft/s

Jadi kecepatan pendingin yang digunakan masih dalam batasan

$$Ret = \frac{ID.Gt}{\mu}$$

$$Re = \frac{0{,}0037\ ft^2 \times 6.182.516{,}7272\ lb/ft^2.jam}{1{,}6912\ lb/ft.jam}$$

= 13.556,2118

jH = 50 (Kern fig 24 pg 834)

$$hi = JH \times \frac{k}{De} \times \left(\frac{c\mu}{k}\right)^{1/3} \times \left(\frac{\mu}{\mu_w}\right)^{0,14}$$ (Kern pg 104)

$$hi = 50 \times \frac{0{,}2079}{0{,}0037} \times \left(\frac{99{,}9462 \times 1{,}6912}{0{,}2079}\right)^{1/3} \times (1)^{0,14}$$

$$hi = 26.165{,}3856\ ^{btu}/_{ft^2.jam.F}$$

h. Menentukan hio

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

$$hio = 26.165{,}3856\ ^{btu}/_{ft^2.jam.F} \times \frac{0{,}0037\ ft^2}{0{,}0687\ ft}$$

$$hio = 1.413{,}0578\ ^{btu}/_{ft^2.jam.F}$$

Untuk koil, harga hio harus dikoreksi dengan faktor koreksi

$$hio_{koil} = hio_{pipa}\left(1 + 3.5\frac{D_{koil}}{D_{spiral koil}}\right)$$ (Kern pg 721)

Diambil : D spiral koil = 80%*Diameter tangki

D spiral koil = 0,8 x 36 in

= 28,8 in

= 2,3990 ft

hio koil = $1.413{,}0578\ ^{\text{btu}}/_{\text{ft}^2.\text{jam.F}} \times \left(1 + \left(3{,}5 \times \left(\frac{0{,}0037\ ft^2}{2{,}3990\ ft}\right)\right)\right)$

= 1.420,7027 Btu/ft^2.jam.°F

i. Menentukan ho

Untuk tangki berpengaduk yang dilengkapi dengan koil, maka koefisien perpindahan panas dihitung dengan :

$$ho = 0.87\left(\frac{k}{D}\right)\left(\frac{Lp^2.N.\rho}{\mu}\right)^{2/3}\left(\frac{cp.\mu}{k}\right)^{1/3}\left(\frac{\mu}{\mu w}\right)^{0.4}$$ (Kern pers 20.4 pg 722)

dengan :

Lp (Diameter Impeller)	= Di	= 0,9896 ft
N (Kecepatan Putar Pengaduk)	= 4,5261 rps	= 16.294 rpj
ρ (Densitas Fluida Panas)	= 1359,890874 kg/m^3	
	= 84,8572 lb/ft^3	
μ (Viskositas Fluida Panas)	= 15,6920 lb/ft.jam	
cp (Kapasitas Panas)	= 0,4606 Btu/lb	
k (konduktivitas Panas)	= 0,2357 Btu/ft.jam.°F	
OD	= 1,05 inch	
	= 0,0687 ft	
D	= 35,6250 in	
	= 2,9676 ft	
μ/μw	= 1,00	

$$ho = 0.87\left(\frac{0,2357}{2,9676}\right)\left(\frac{0,9896.16.294.84,8572}{15,6920}\right)^{2/3}\left(\frac{0,4606.15,6920}{0,2357}\right)^{1/3}.1^{0.4}$$

= 18.664,1487 Btu/jam.ft^2.F

j. Menentukan Uc

$$Uc = \frac{ho * hio}{ho + hio}$$

$$Uc = \frac{18.664,1487\frac{Btu}{jam}.ft^2.F \times 1.420,7027 Btu/ft2.jam.°F}{18.664,1487\frac{Btu}{jam}.ft^2.F + 1.420,7027 Btu/ft2.jam.°F}$$

= 1.320,2092 Btu/jam.ft^2.F

k. Menentukan Ud

Untuk kecepatan air = 2,5 m/s, maka

RD = 0,003 (Kern tabel 12 pg 845)

sehingga :

hD = 1/RD

= 1/0,003

= 333,3333 Btu/jam.ft^2.F

$$U_D = \frac{h_D * Uc}{h_D + Uc}$$

$$Ud = \frac{333,3333\ Btu/jam.ft^2.F \times 1.320,2092 Btu/jam.ft^2.F}{333,3333\ Btu/jam.ft^2.F + 1.320,2092 Btu/jam.ft^2}$$

= 266,1375 Btu/jam.ft^2.F

l. Menentukan Luas Bidang Transfer Panas

$$A = \frac{Q_{total}}{U_D * \Delta T_{LMTD}}$$

$$A = \frac{618.593,4801 \text{ Btu/jam}}{266,1375 \frac{\text{Btu}}{\text{jam}}.\text{ft}^2.\text{F} \times 35,2371\ °\text{F}}$$

$= 65,9628 \text{ ft}^2$

$= 6,1279 \text{ m}^2$

m. Menentukan Panjang Koil

$$L_{pipakoil} = \frac{A}{a''}$$

$$\text{L pipa koil} = \frac{65,9628 \text{ ft}^2}{0,2750 \text{ ft}^2/ft}$$

$= 239,8649$ ft

$= 73,1108$ m

n. Menentukan Jumlah Lengkungan Koil

Dc = 0,8*(ID tangki reaktor)

Dc = 0,8 x 35,6250 in

= 28,5 inch

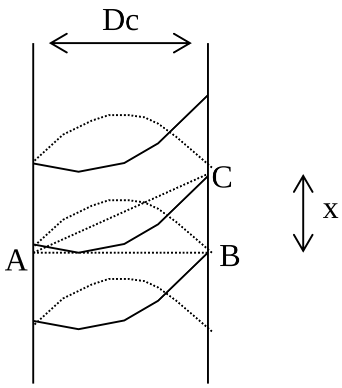
= 2,3750 ft

AB = ID

BC = x

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

$$AC = \sqrt{(ID)^2 + x^2}$$



busur AB = ½πDc

busur AC = ½πAC

Diambil :

x = 0,3*OD

x = 0,3 x 1,05 in

= 0,3150 in

= 0,0263 ft

Panjang 1 putaran

K lilitan = 1/2 putaran miring + 1/2 putaran datar

K lilitan = ½π(Dc) + ½π(AC)

K lilitan = ½π(Dc) + ½π((ID2+x2)½)

K lilitan =

$(0{,}5 \times 3{,}14 \times 2{,}3750\ ft) + (0{,}5 \times 3{,}14 \times$

$\left((2{,}9688\ ft^2) + (0{,}0263\ ft^2)\right)^{0{,}5}\Big)$ = 8,3899 ft

= 100,6784 inch

= 2,5572 m

o. Menentukan Banyak Lilitan

N lilitan $= \frac{239,8649\ ft}{8,3899\ ft}$

= 28,5898 ≈ 29 lilitan

Menentukan Tinggi Tumpukan dan Tinggi Cairan Setelah Ada Koil

Tinggi tumpukan koil = (N lilitan - 1)*x+N lilitan*OD

Tinggi tumpukan koil = ((29-1) x 0,0263 ft) + 29 x 0,0875 ft

= 3,2725 ft

= 0,9975 m

= 39,27 inch

Tinggi cairan dalam shell akan naik karena adanya volume dari koil.

Asumsi : koil ada dalam shell saja.

V shell = 0,7976 m^3

V koil $= \frac{3,14}{4 \times (0,038\ m)^2 \times 73,1108\ m}$

= 0,0831 m^3

A shell $= \frac{3,14}{4 \times (0,9094\ m)^2}$

= 0,6428 m^2

Zc $= \frac{(0,7976+0,0831) m^3}{0,6428\ m^3}$

= 1,3702 m

Karena tinggi tumpukan koil 0,9975 m, maka koil ada di shell saja.

Sehingga,

Tinggi cairan di dalam reaktor setelah ada koil :

Zc = Zc + b + sf

Zc = 1,3702 m + 0,1537 m + 0,0508 m

= 1,5747 m

Jarak dari dasar tangki ke bagian bawah koil = (tinggi cairan stl ada koil-tumpukan koil)/2

$$Hk = \frac{1,5747 - 0,9975}{2}$$

= 0,2886 m

b + sf = 0,0508 m + 0,1537 m

= 0,2045 in

= 0,0052 m

Karena jarak dasar tangki ke bagian bawah koil > (b+sf), maka asumsi bahwa koil tercelup di shell saja adalah benar.

2. Reaktor 2 (R-02)

a. Menghitung suhu LMTD

Hot fluid (heavy organic)

T_{in} = 55 °C = 328 K = 131 °F

T_{out} = 55 °C = 328 K = 131 °F

Cold fluid (Air)

t_{in} = 30 °C = 303 K = 86 °F

t_{out} = 45 °C = 318 K = 113 °F

ΔT_2 = (131 – 86) °F

= 45 °F

ΔT_1 = (131 – 113) °F

= 18 °F

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)}$$

$$\Delta T_{LMTD} = \frac{(45 - 18)°F}{\ln\left(\frac{45\ °F}{18\ °F}\right)}$$

$$\Delta T_{LMTD} = 29{,}4666\ °F$$

b. Menghitung Luas Transfer Panas

Q pendinginan = 386899,4133 kj/jam

= 366780,6438 Btu/jam

untuk *cold fluid* = *water* dan *hot fluid* = *medium organic*

Ud = 50-125 btu/ft2. F. Jam (Kern, Table 8 Hal. 840)

Diambil Harga Ud = 115 btu/ft2. F. Jam

$$A = \frac{Q}{Ud\ x\ \Delta T_{LMTD}}$$

$$A = \frac{366780{,}6438\ btu/jam}{115\ {}^{btu}/_{ft^2.F.jam}\ x\ 29{,}4666\ °F}$$

$$A = 108{,}2376\ ft^2$$

c. Menghitung Luas Selimut Reaktor

OD = 36 in

= 0,9144 m

= 3 ft

H = 53,4375 in

= 1,3573 m

= 4,4531 ft

A = π.OD.H

= 3,14 x 3 x 4,4531

A = 41,948 ft^2

Luas selimut < A (luas transfer panas) terhitung, sehingga luas selimut tidak mencukupi sebagai luas transfer panas, maka digunakan *coil* pendingin.

d. Menghitung kebutuhan air pendingin

$Qpendinginan = m\ air\ x\ Cp\ air\ \Delta T$

$m\ air = (Q\ pendinginan)/(Cp\ air\ x\Delta T)$

Cp air = 4,1838 kj/kg.K

T = 15 K

$$m\ air = \frac{Q\ pendinginan}{Cp\ air\ x\ \Delta T}$$

$$m\ air = \frac{366780{,}6438\ kj/jam}{4{,}1838\ ^{kj}/_{kg.K}\ x\ 15\ K}$$

$m\ air = 6165{,}0491$ kg/jam

= 13593,9333 lb/jam

Sifat fisis air pada Tf = 99,5 °F :

Cp = 4.183,7938 j/kg.K = 0,9999 btu/lb.F

ρ = 1.016,0968 kg/m3 = 63,4044 lb/ft3

μ = 0,6991 cp = 1,6919 lb/ft.jam

k = 0,3596 btu/jam.ft.F

e. Kecepatan Volumetrik Air

$$Q_v = \frac{m_{air}}{\rho_{air}}$$

$$Q_v = \frac{6165{,}0491\ {}^{kg}/_{jam}}{1.016{,}0968\ {}^{kg}/_{m^3}}$$

$$Q_v = 6{,}0674\ {}^{m^3}/_{jam}$$

f. Menentukan Diameter Minimum Koil

Untuk aliran dalam koil/tube, batasan kecepatan antara 1,5-2,5 m/s. (Coulson pg 527)

Dipilih :

Kecepatan pendingin = 2,5 m/s

Debit air pendingin = 6,0674 m^3/jam

V = 2,5 m/s

= 9000 m/jam

Luas Penampang A $= \frac{6{,}0674\ m^3/jam}{9000\ m/jam}$

= 0,0007 m^2

= 0,0073 ft^2

= 1,0449 $inch^2$

A = (π.(ID)^2)/4

$$ID = \sqrt{\frac{4 \times A}{\pi}}$$

$$ID = \sqrt{\frac{4 \times 0{,}0011}{3{,}14}}$$

$ID = 0{,}0293 \text{ m} = 1{,}1537 \text{ in}$

Dipilih : diameter standard (Kern tabel 11 pg 844)

NPS = 0,7500 in

Schedule Number = 40

OD = 1,05 in = 0,0875 ft

ID = 0,824 in = 0,0687 ft

Luas Penampang (A') = 0,5340 in^2 = 0,0037 ft^2

Luas Perpan/panjang (a") = 0,2750 ft^2/ft

g. Menentukan hi

ρ air pendingin = 1.016,0968 kg/m^3 = 63,4044 lb/ft^3

μ air pendingin = 0,6991 cP = 1,6912 lb/ft.jam

k air pendingin = 0,3596 W/m.K = 0,2079 Btu/ft.jam.°F

Cp air pendingin = 4.183,7938 kJ/kmol

= 232,4330 kJ/kg

= 99,9462 Btu/lb

Gt = kecepatan aliran massa/luas penampang

Gt = W/A

$$Gt = \frac{13.593{,}9333 \text{ lb/jam}}{0{,}0037\ ft^2}$$

= 3.665.779,7704 lb/ft^2.jam

v = Gt/ρ

$$= \frac{3.665.779{,}7704\ \text{lb}/ft^2.\text{jam}}{63{,}4044\ \text{lb}/ft^3}$$

= 57.815,8204 ft/jam

= 4,9 m/s

= 16,0600 ft/s

Jadi kecepatan pendingin yang digunakan masih dalam batasan

$$Ret = \frac{ID.Gt}{\mu}$$

$$Re = \frac{0{,}0037\ ft^2 \times 3.665.779{,}7704\ lb/ft^2.jam}{1{,}6912\ lb/ft.jam}$$

= 8037,8411

jH = 40 (Kern fig 24 pg 834)

$$hi = JH \times \frac{k}{De} \times \left(\frac{c\mu}{k}\right)^{1/3} \times \left(\frac{\mu}{\mu_w}\right)^{0{,}14}$$ (Kern pg 104)

$$hi = 40 \times \frac{0{,}2079}{0{,}0037} \times \left(\frac{99{,}9462 \times 1{,}6912}{0{,}2079}\right)^{1/3} \times (1)^{0{,}14}$$

$$hi = 20.932{,}3085\ ^{btu}/_{ft^2.jam.F}$$

h. Menentukan hio

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

$$hio = 20.932{,}3085\ ^{btu}/_{ft^2.jam.F} \times \frac{0{,}0037\ ft^2}{0{,}0687\ ft}$$

$$hio = 1.130{,}4463\ ^{btu}/_{ft^2.jam.F}$$

Untuk koil, harga hio harus dikoreksi dengan faktor koreksi

$$hio_{koil} = hio_{pipa}\left(1 + 3.5\frac{D_{koil}}{D_{spiral koil}}\right)$$ (Kern pg 721)

Diambil : D spiral koil = 80%*Diameter tangki

D spiral koil = 0,8 x 36 in

= 28,8 in

= 2,3990 ft

hio koil $= 1.130{,}4463\ ^{\mathrm{btu}}/_{\mathrm{ft^2.jam.F}} \times \left(1 + \left(3{,}5 \times \left(\frac{0{,}0037\ ft^2}{2{,}3990\ ft}\right)\right)\right)$

= 1.136,5622 Btu/ft^2.jam.°F

i. Menentukan ho

Untuk tangki berpengaduk yang dilengkapi dengan koil, maka koefisien perpindahan panas dihitung dengan :

$$ho = 0.87\left(\frac{k}{D}\right)\left(\frac{Lp^2.N.\rho}{\mu}\right)^{2/3}\left(\frac{cp.\mu}{k}\right)^{1/3}\left(\frac{\mu}{\mu w}\right)^{0.4}$$ (Kern pers 20.4 pg 722)

dengan :

Lp (Diameter Impeller)	= Di	= 0,9896 ft
N (Kecepatan Putar Pengaduk)	= 4,5261 rps	= 16.294 rpj
ρ (Densitas Fluida Panas)	= 1359,890874 kg/m^3	
	= 84,8572 lb/ft^3	
μ (Viskositas Fluida Panas)	= 15,6920 lb/ft.jam	
cp (Kapasitas Panas)	= 0,4606 Btu/lb	
k (konduktivitas Panas)	= 0,2357 Btu/ft.jam.°F	
OD	= 1,05 inch	
	= 0,0687 ft	
D	= 35,6250 in	
	= 2,9676 ft	
μ/μw	= 1,00	

$$ho = 0.87\left(\frac{0,2357}{2,9676}\right)\left(\frac{0,9896 \times 16.294 \times 84,8572}{15,6920}\right)^{2/3}\left(\frac{0,4606 . 15,6920}{0,2357}\right)^{1/3} .1^{0.4}$$

= 18.664,1487 Btu/jam.ft^2.F

j. Menentukan Uc

$$Uc = \frac{ho * hio}{ho + hio}$$

$$Uc = \frac{18.664,1487 \frac{Btu}{jam}.ft^2.F \times 1.136,5622\ Btu/ft2.jam.°F}{18.664,1487 \frac{Btu}{jam}.ft^2.F + 1.136,5622\ Btu/ft2.jam.°F}$$

= 1071,3234 Btu/jam.ft^2.F

k. Menentukan Ud

Untuk kecepatan air = 2,5 m/s, maka

RD = 0,003 (Kern tabel 12 pg 845)

sehingga :

hD = 1/RD

= 1/0,003

= 333,3333 Btu/jam.ft^2.F

$$U_D = \frac{h_D * Uc}{h_D + Uc}$$

$$Ud = \frac{333,3333\ Btu/jam.ft^2.F \times 1071,3234\ Btu/jam.ft^2.F}{333,3333\ Btu/jam.ft^2.F + 1071,3234\ Btu/jam.ft^2}$$

= 254,2314 Btu/jam.ft^2.F

l. Menentukan Luas Bidang Transfer Panas

$$A = \frac{Q_{total}}{U_D * \Delta T_{LMTD}}$$

$$A = \frac{366780{,}6438 \text{ Btu/jam}}{254{,}2314 \frac{\text{Btu}}{\text{jam}}.\text{ft}^2.\text{F} \times 29{,}4666\ °\text{F}}$$

$= 48{,}9606\ ft^2$

$= 4{,}5484\ m^2$

m. Menentukan Panjang Koil

$$L_{pipakoil} = \frac{A}{a''}$$

$$L \text{ pipa koil} = \frac{48{,}9606 \text{ ft}^2}{0{,}2750 \text{ ft}^2/ft}$$

= 178,0386 ft

= 54,2662 m

n. Menentukan Jumlah Lengkungan Koil

Dc = 0,8*(ID tangki reaktor)

Dc = 0,8 x 35,6250 in

= 28,5 inch

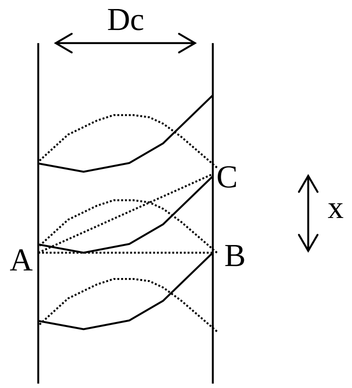
= 2,3750 ft

AB = ID

BC = x

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

$$AC = \sqrt{(ID)^2 + x^2}$$



busur AB = ½πDc

busur AC = ½πAC

Diambil :

x = 0,3*OD

x = 0,3 x 1,05 in

= 0,3150 in

= 0,0263 ft

Panjang 1 putaran

K lilitan = 1/2 putaran miring + 1/2 putaran datar

K lilitan = ½π(Dc) + ½π(AC)

K lilitan = ½π(Dc) + ½π((ID2+x2)½)

K lilitan $=(0{,}5 \times 3{,}14 \times 2{,}3750\ ft) + (0{,}5 \times 3{,}14\ \times$

$\left((2{,}9688\ ft^2) + (0{,}0263\ ft^2)\right)^{0{,}5}\Big)$

= 8,3899 ft

= 100,6784 inch

= 2,5572 m

o. Menentukan Banyak Lilitan

N lilitan $= \frac{178{,}0386\ ft}{8{,}3899\ ft}$

= 21,2207 ≈ 22 lilitan

Menentukan Tinggi Tumpukan dan Tinggi Cairan Setelah Ada Koil

Tinggi tumpukan koil = (N lilitan - 1)*x+N lilitan*OD

Tinggi tumpukan koil = ((22-1) x 0,0263 ft) + 22 x 0,0875 ft

= 2,4763 ft

= 0,7548 m

= 29,715 inch

Tinggi cairan dalam shell akan naik karena adanya volume dari koil.

Asumsi : koil ada dalam shell saja.

V shell = 0,7976 m^3

V koil $= \frac{3{,}14}{4 \times (0{,}0293\ m)^2 \times 54{,}2662\ m}$

= 0,0366 m^3

A shell $= \frac{3{,}14}{4 \times (0{,}0875\ m)^2}$

= 0,6428 m^2

Zc $= \frac{(0{,}7976+0{,}0366) m^3}{0{,}6428\ m^3}$

= 1,2978 m

Karena tinggi tumpukan koil 0,7548 m, maka koil ada di shell saja.

Sehingga,

Tinggi cairan di dalam reaktor setelah ada koil :

Zc = Zc + b + sf

Zc =1,2978 m + 0,1537 m + 0,0508 m

= 1,5023 m

Jarak dari dasar tangki ke bagian bawah koil = (tinggi cairan stl ada koil-tumpukan koil)/2

$$Hk = \frac{1{,}5023 - 0{,}7548}{2}$$

= 0,3738 m

b + sf = 0,0508 m + 0,1537 m

= 0,2045 in

= 0,0052 m

Karena jarak dasar tangki ke bagian bawah koil > (b+sf), maka asumsi bahwa koil tercelup di shell saja adalah benar.