LAMPIRAN

REAKTOR

Jenis	= Reaktor alir tangki Berpengaduk (RATB)
Fase	= Cair - Cair
Bentuk	= Tangki Silinder
Bahan	= Stainless Steel 316 AISI (18Cr, 12Ni, 2.5Mo)
Suhu Operasi	= 90 °C
Tekanan	= 1 atm
Waktu Tinggal (θ)	= 30 menit
Konversi terhadap Alkylbenzene	= 90%

A. Menghitung Densitas Cairan

Komponen	Massa (kg/jam)	Fraksi Massa (xi)	ρi (kg/m3)	ρi.xi (kg/m3)
H_2SO_4	12475.55	0.03	1752.04	51.30
H_2O dalam H_2SO_4	237035.46	0.56	965.78	537.24
$Na_2O.3,3SiO_2$	66224.21	0.16	4912.15	763.43
H_2O dalam $Na_2O.3,3SiO_2$	110373.69	0.26	965.78	250.16
Total	**426108.91**	**1.00**		**1602.13**

Densitas campuran = 1602,13 kg/m^3

$$\text{Volume cairan} \quad = \ \theta \text{ x } \frac{\text{massa}}{\text{densitas cairan}}$$

$$\text{Volume cairan} \quad = \ 0{,}5 \text{ jam x } \frac{426108{,}91\ ^{\text{kg}}/_{\text{jam}}}{1602{,}13\ ^{\text{kg}}/_{\text{m}^3}}$$

$$\text{Volume cairan} \quad = 132{,}98 \text{ m}^3$$

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 132,98 m^3

Volume reaktor =159,58 m^3 = 5635,46 ft^3

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

   Sehingga :

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

   Dipilih perbandingan D : H = 1 : 1,5

   $$5635{,}46 \text{ ft}^3 = \left(\frac{1}{4} \text{ x } \pi \text{ x } D^2 \text{ x H}\right) + [2 \text{ x } (0{,}000049) \text{x } (D^3)]$$

   $$5635{,}46 \text{ ft}^3 = \left(\frac{1}{4} \text{ x } 3{,}14 \text{ x } D^2 \text{ x } 1{,}5D\right) + [(0{,}000098) \text{x } (D^3)]$$

   $$5635{,}46 \text{ ft}^3 = D^3\left(\frac{4{,}71}{4} + 0{,}000098\right)$$

   $$5635{,}46 \text{ ft}^3 = D^3(1{,}1776)$$

   $$D^3 = \frac{5635{,}46 \text{ ft}^3}{1{,}1776}$$

   $$D = \sqrt[3]{4785{,}75 \text{ ft}^3}$$

   $$D = 16{,}85 \text{ ft} \quad = 202{,}22 \text{ in} \quad = 5{,}14 \text{ m}$$

   Maka tinggi reaktor :

   H = 1,5 D

   H = 1,5 x 16,85 ft

   H = 25,28 ft = 303,34 in = 7,70 m

2. Menghitung tinggi cairan

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

$$132{,}98 \text{ m}^3 = h_{cairan} \text{ x } \frac{3{,}14 \text{ x } (5{,}14 \text{ m})^2}{4}$$

$$132{,}98 \text{ m}^3 = h_{cairan} \text{ x } 20{,}71 \text{ m}^2$$

$$132{,}98 \text{ m}^3 = h_{cairan} \text{ x } 20{,}71 \text{ m}^2$$

$$h_{cairan} = \frac{132{,}98 \text{ m}^3}{20{,}71 \text{ m}^2}$$

$$h_{cairan} = 6{,}42 \text{ m}$$

P hidrostatis = ρ x g x h cairan

= 1602,13 kg/m3 x 9,8 x 6,42 m

= 100813 N/m^2

= 14,62 psia

3. Menghitung tebal dinding reaktor

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

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

Dengan :

Allowable stress (f) = 18847,948 psia

Sambungan yang dipilih = double wekded but joint

Efisiensi sambungan (E) = 80%

Corrosion allowance (C) = 0,125 in

Jari-jari reaktor (ri) = 101,11 in

Teakanan (P) = tekanan operasi + tekanan hidrostatis

= 14,7 psia + 14,62 psia

= 29,32 psia

Sehingga :

$$t_s = \frac{29{,}32 \text{ psia x } 101{,}11 \text{ in}}{(18847{,}948 \text{ psia x } 80\%) - (0{,}6 \text{ x } 29{,}32 \text{ psia})} + 0{,}125 \text{ in}$$

$$t_s = \frac{2964{,}5452 \text{ psia.in}}{15067{,}166 \text{ psia}} + 0{,}125 \text{ in}$$

$$t_s = 0{,}00865 + 0{,}125 \text{ in}$$

$$t_s = 0{,}3219 \text{ in}$$

Jadi, tebal shell minimum yang dibutuhkan sebesar 0,3219 in

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

ts = 3/8 in

= 0,375 in

ID shell = 202,22 in

OD shell = ID + 2ts

= 202,22 in + (2 x 0,375 in)

= 202,97 in

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

OD = 204 in

=5,18 m

ID = OD – 2ts

= 204 in – (2 x 0,375 in)

= 203,25 in = 16,94 ft =5,16 m

H = 1,5 x D

= 1,5 x 203,25 in

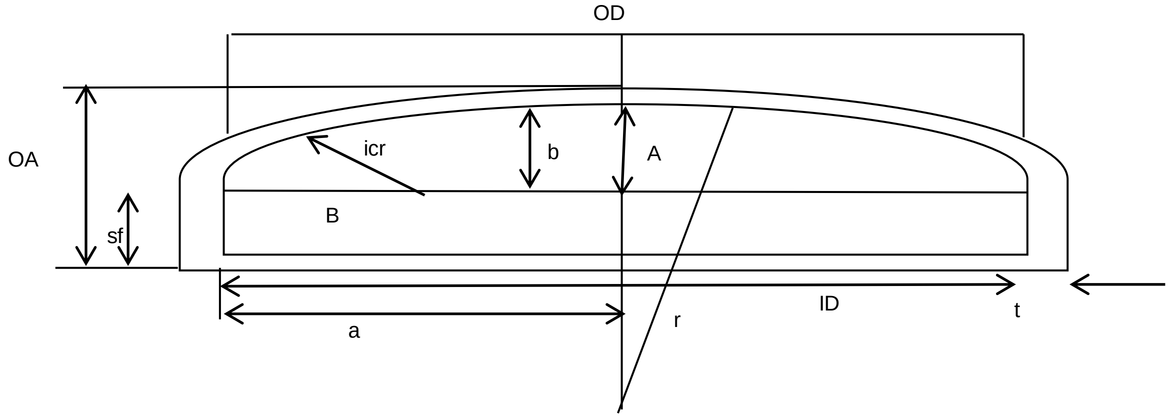
= 304,88 in = 25,41 ft = 7,74 m

icr = 12,250 in

rc = 170 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*

$$t_h = \frac{\mathrm{P\ x\ rc\ x\ W}}{(\mathrm{2\ x\ f\ x\ E}) - (\mathrm{0{,}2\ x\ P})} + \mathrm{C} \qquad \text{(Brownell \& Young 1959, Page 138)}$$

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

$$W = \frac{1}{4}\ x \left(3 + \sqrt{\frac{170\ in}{12{,}250\ \text{in}}}\right)$$

$$W = 1{,}6813$$

Sehingga :

$$t_h = \frac{29{,}32\ \text{psia x } 170\ \text{in x } 1{,}6813}{(2\ \text{x } 18847{,}948\ \text{psia x } 80\%) - (0{,}2\ \text{x } 29{,}32\ \text{psia})} + 0{,}125\ \text{in}$$

$$t_h = \frac{8380{,}27172\ \text{psia. in}}{30152{,}9764\ \text{psia}} + 0{,}125\ \text{in}$$

$$t_h = 0{,}2779\ \text{in} + 0{,}125\ \text{in}$$

$$t_h = 0{,}4030\ \text{in}$$

Berdasarkan tabel 5.6 Brownell & Young, dipilih th standar :

th = 7/16 in = 0,4375 in

2. Menghitung tinggi *head*

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

Sf = 3 in

ID = OD – 2th

= 204 in – (2 x 0,4375 in)

= 203,13 in

A = ID/2

= 203,13/2

= 101,56 in

AB = a – icr

= (101,56 – 12,250) in

= 89,31 in

BC = rc – icr

= (170 – 12,250) in

= 157,75 in

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

= $\sqrt{(157,75)^2 - (89,31)^2}$

= 130,03 in

B = rc – AC

= (170-130,03) in

= 39,97 in

Tinggi *head* total :

AO = sf + b + th

= (3 + 39,97 + 0,4375) in

= 43,41 in = 1,1025 m

D. Menghitung Dimensi Pengaduk

Volume cairan yang diaduk = 132,98 m3

= 35130,14 gallon

Kekentalan cairan yang diaduk (μ) = 1,0028 cp

= 0,000674 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)

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

$$= \frac{203{,}25 \text{ in}}{3}$$

$$= 67{,}75 \text{ in}$$

$$= 1{,}72 \text{ m}$$

$$= 5{,}65 \text{ ft}$$

b. Tinggi Cairan dalam Pengadukan (Zl)

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

$$= 67{,}75 \text{ in} \times 3{,}9$$

$$= 264{,}23 \text{ in}$$

$$= 6{,}71 \text{ m}$$

$$= 22{,}02 \text{ ft}$$

c. Jarak Pengaduk dari Dasar Tangki

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

$$= 67{,}75 \text{ in} \times 1{,}3$$

$$= 88{,}08 \text{ in}$$

$$= 2{,}24 \text{ m}$$

$$= 7{,}34 \text{ ft}$$

Menghitung jumlah pengaduk (sesuai referensi wallas halaman 288)

Rasio tinggi permukaan cairan dan diameter tangki = H/D

= 6,42/5,16

= 1,2437

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

Trial nilai rpm (N) :

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

Dipilih πDN = 22,8 ft/s

$$N = \frac{22{,}8\ {}^{ft}/_{s}}{\pi D}$$

$$N = \frac{22{,}8\ {}^{ft}/_{s}}{3{,}14 \text{ x } 5{,}65 \text{ ft}}$$

$$N = 1{,}2862\ /s$$

Menghitung nilai Re :

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

$$Re = \frac{100{,}02\ {}^{lb}/_{ft^3} \text{ x } 1{,}2862/s \text{ x } (5{,}65ft)^2}{0{,}000674\ {}^{lb}/_{ft.s}}$$

$$Re = 6085072{,}81$$

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

Sehingga :

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

$$P = \frac{(1{,}2862/s)^3 \text{ x } (5{,}65 \text{ ft})^5 \text{ x } 100{,}02\ {}^{lb}/_{ft^3} \text{ x } 0{,}9}{32{,}174\ {}^{ft}/_{s^2}}$$

$$P = 28985{,}02\ {}^{lb.ft}/_{s}$$

$$P = 52{,}70 \text{ hp}$$

Diambil Hp/1000 gallon = 1,5

Hp = 1,5 Hp/1000 gallon x volume cairan

= 1,5 Hp/1000 gallon x 35130,14 gallon

= 52,70 hp

E. Menghitung Dimensi Jaket Pendingin

OD	= 204 in	= 5,18 m	= 17 ft
ID	= 203,25 in	= 5,16 m	= 16,94 ft
H	= 304,88 in	= 7,74 m	= 25,41 ft

Luas Selimut (A) = π.OD.H

= 3,14 x 17 ft x 25,41 ft

= 1356,19 ft^2

Q pendinginan = 41538344,85 kj/jam

= 39378350,92 btu/jam

1. Menghitung suhu LMTD

   Hot fluid

T_{in}	= 30 °C	= 303 K	= 86 °F
T_{out}	= 90 °C	= 363 K	= 194 °F

   Cold fluid

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 = (194 – 86) °F

   = 108 °F

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

   $$\Delta T_{LMTD} = \frac{(108 - 27)°F}{\ln\left(\frac{108\ °F}{27\ °F}\right)}$$

   $$\Delta T_{LMTD} = 54{,}43\ °F$$

2. Menghitung luas transfer panas

Untuk *cold fluid* = *water* dan *hot fluid* = *aqueous solutions*

Ud = 250 – 500 btu/ft^2.F.jam (Kern, Tabel 8 Hal.840)

Diambil harga Ud = 500 btu/ft^2.F.jam

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

$$A = \frac{39378350{,}92 \text{ btu/jam}}{450 \ {}^{\text{btu}}/_{\text{ft}^2.\text{F.jam}} \times 58{,}43 \ °F}$$

$$A = 1498 \text{ ft}^2$$

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

3. Menghitung kebutuhn air pendingin

Sifat fisis air pada Tf = 99,5 °F :

Cp = 4,1838 kj/kg.K

ρ = 1016,0968 kg/m3 = 63,4044 lb/ft3

μ = 0,6991 cp = 1,6919 lb/ft.jam

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

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

$$m \text{ air} = \frac{41538344{,}85 \text{ kj/jam}}{4{,}1838 \ {}^{\text{kj}}/_{\text{kg.K}} \times 15 \text{ K}}$$

$$m \text{ air} = 11914070{,}42 \text{ kg/jam}$$

$$= 26270525{,}28 \text{ lb/jam}$$

4. Menghitung kecepatan volumetrik air

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

$$Q_v = \frac{11914070{,}42\ ^{kg}/_{jam}}{1016{,}0968\ ^{kg}/_{m^3}}$$

$$Q_v = 11725{,}33\ ^{m^3}/_{jam}$$

5. Menentukan diameter standard

Dipilih diameter standard berdasarkan buku *Kern, 1965, tablle 11, page 844*

Nominal Pipe Size (IPS)	= 1 in	
OD	= 1,32 in	= 0,1100 ft
ID	= 1,049 in	= 0,0874 ft
Flow area per pipe (A’)	= 0,864 in2	= 0,0060 ft2
Surface per lin (A”)	= 0,344 ft2/ft	

6. Menghitung nilai ho

$$Re = \frac{L^2 \times N \times \rho}{\mu}$$

Dengan :

L	= diameter Impeller	= 5,65 ft
N	= kecepatan putar pengaduk	= 4384/jam
ρ	= densitas fluida panas	= 76 lb/ft3
μ	= viskositas fluida panas	= 0,8170 lb/ft.jam
k	= konduktivitas panas	= 9.669 btu/jam.ft.F
cp	= kapasitas panas	= 0,9845 btu/lb.F

sehiingga,

$$Re = \frac{(5{,}65\ ft)^2 \times {}^{4384}/_{jam} \times 76\ ^{lb}/_{ft^3}}{0{,}8170\ ^{lb}/_{ft.\,jam}}$$

$$Re = 12932642$$

Berdasarkan buku Kern, Fig.28 maka didapatkan nilai JH= 2500

$$\text{ho} = \text{JH x } \frac{\text{k}}{\text{De}} \text{ x } \left(\frac{\text{c}\mu}{\text{k}}\right)^{1/3} \text{ x } \left(\frac{\mu}{\mu_\text{w}}\right)^{0,14}$$

$$\text{ho} = 2500 \text{ x } \frac{9.669}{16,94} \text{ x } \left(\frac{0,9845 \text{ x } 0,8170}{9.669}\right)^{1/3} \text{ x } (1)^{0,14}$$

$$\text{ho} \quad 62.302 \ {}^{\text{btu}}/_{\text{ft}^2.\text{jam.F}}$$

7. Menghitung nilai hio

$$\text{Re} = \frac{\rho \text{ x v x D}}{\mu}$$

$$\text{Re} = \frac{63,4044 \ {}^{\text{lb}}/_{\text{ft}^3} \text{ x } 1725424 \ {}^{\text{ft}}/_{\text{jam}} \text{ x } 0,0874 \text{ ft}}{1,6919 \ {}^{\text{lb}}/_{\text{ft.jam}}}$$

$$\text{Re} = 5652498$$

Berdasarkan buku Kern, Fig.24 maka didapatkan nilai JH =2500

$$\text{hi} = \text{JH x } \frac{\text{k}}{\text{De}} \text{ x } \left(\frac{\text{c}\mu}{\text{k}}\right)^{1/3} \text{ x } \left(\frac{\mu}{\mu_\text{w}}\right)^{0,14}$$

$$\text{hi} = 260 \text{ x } \frac{0,3596}{0,0874} \text{ x } \left(\frac{0,9999 \text{ x } 1,6919}{0,3596}\right)^{1/3} \text{ x } (1)^{0,14}$$

$$\text{hi} = 17233 \ {}^{\text{btu}}/_{\text{ft}^2.\text{jam.F}}$$

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

$$\text{hio} = 17233 \text{ x } \frac{0,0874}{0,1100}$$

$$\text{hio} = 13695 \ {}^{\text{btu}}/_{\text{ft}^2.\text{jam.F}}$$

8. Menghitung nilai Uc

$$\text{Uc} = \frac{\text{hio x ho}}{\text{hio + ho}}$$

$$\text{Uc} = \frac{13695 \text{ x } 62302}{13695 + 62302}$$

$\mathrm{Uc} = 11227$

9. Menghitung nilai Rd

$$\mathrm{Rd} = \frac{\mathrm{Uc} - \mathrm{Ud}}{\mathrm{Uc \times Ud}}$$

$$\mathrm{Rd} = \frac{11227 - 450}{11227 \times 450}$$

$$\mathrm{Rd} = 0{,}002$$

Syarat :

$\mathrm{Rd\ terhitung} \geq \mathrm{Rd\ yang\ diperlukan}$

$0{,}002 \geq 0{,}001$ (memenuhi syarat)

10. Menghitung jumlah lilitan

Luas satu lilitan (a) = π x D x surface per lin ft

= π x (0,8 x ID reaktor) x surface per lin ft

= 3,14 x (0,8 x 16,94 ft) x 0,344 ft^2/ft

= 15 ft^2

Jumlah lilitan = A/a

= 1498 ft^2 / 15 ft^2

= 102,3

= 102 lilitan

11. Menghitung tinggi tumpukan *coil*

x = jarak antar lilitan

Diambil x = 0,5 OD

= 0,5 x 0,033528 m

= 0,0168 m

Tinggi tumpukan *coil* = $(N_{lilitan} - 1) * x + N_{lilitan} * OD$

= (102-1) * 0,0168 m + (102 * 0,033528 m)

= 5,129 m

Tinggi cairan dalam shell = 6,4209 m

Sehingga *coil* masih tercelup di dalam cairan.