LAMPIRAN A

REAKTOR

Jenis : Reaktor Alir Tangki Berpengaduk / RATB

(*Continuous Stirred Tank Reactor*)

Fungsi : Tempat berlangsungnya proses Hidrolisis antara Dimetil Tereftalat dan Air.

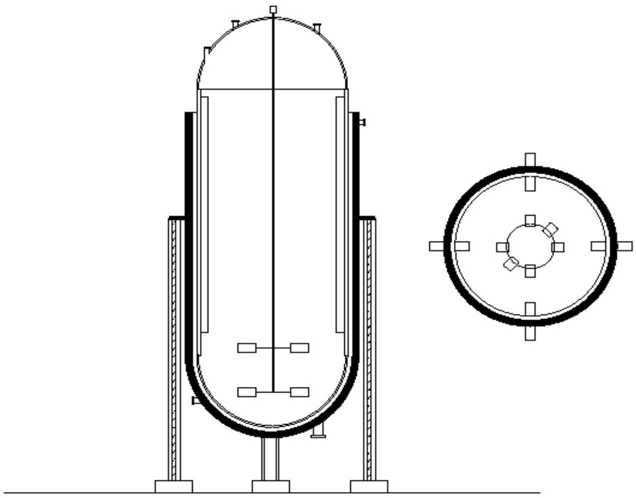
Kondisi Operasi : Suhu : 230 ^oC

Tekanan : 24 atm

Konversi : 95%

Reaksi yang terjadi di dalam Reaktor :

$$C_{10}H_{10}O_4 + H_2O \longrightarrow C_9H_8O_4 + CH_3OH$$



1) Dasar Pemilihan jenis Reaktor:

Dipilih reaktor jenis ini melalui beberapa pertimbangan sebagai berikut:

a) Zat pereaksi berupa fasa cair dan fasa cair dan prosesnya kontinyu.

b) Pada Reaktor Alir Tangki Berpengaduk suhu dan komposisi campuran dalam reactor selalu seragam. Hal ini memeungkinkan melakukan suatu proses isothermal dalam RATB.

c) Waktu tinggal kecil sehingga reaktan lebih cepat bereaksi.

2) Menentukan Konstanta Kecepatan Reaksi dan Optimasi Reaktor

Diketahui : Berat Molekul

$C_{10}H_{10}O_4$ = 194

$C_9H_8O_4$ = 180

$C_8H_6O_4$ = 166

H_2O = 18

CH_3OH = 32

Neraca massa bahan masuk reaktor

Komponen	Berat Molekul	Mol (kmol/jam)	Berat (Kg)	Berat Jenis (Kg/liter)
$C_{10}H_{10}O_4$	194	57,59153	11172,7581	995,0050
H_2O	18	3103,5439	55863,7905	806,1720

Total	67036,5486	3161,1354	67036,5486	1801,1770

A + B ⟶ C + D

$(-r_A) = \frac{dC_A}{dt} = k.C_A.C_B$ (Persamaan reaksi order 2)

	A	+	B	⟶	C	+	D
Mula-mula :	C_{A0}		C_{B0}		0		0
Bereaksi :	$C_{A0}.X_A$		$C_{A0}.X_A$		$C_{A0}.X_A$		$C_{A0}.X_A$
Sisa :	$C_{A0}(1-X_A)$		$C_{B0}-C_{A0}.X_A$		$C_{A0}.X_A$		$C_{A0}.X_A$

Jadi Konstanta Kecepatan Reaksi

Neraca Massa A

R input - R output - R reaksi = Accumulasi

Fa_0 - Fa - $(-r_A)\ V$ = 0

Dimana :

Fa = $Fa_0 - Fa_0 . x$

(-rA) = $k1.\ C_A . C_B$

C_A = $C_{A0}.(1 – X_A)$

C_B = $C_{B0}-C_{A0}.X_A$

= $C_{A0} – \left(\frac{CB0}{CA0} - XA\right)$

= C_{A0} (M -X)

Jadi :

$$Fa_0 \; - \; Fa_0 \; - \; Fa_0 \, . \, x = (-rA) \, V$$

$$V = \frac{Fa0 \, . \, X}{(-rA)}$$

$$\frac{Fv \, .CA0 \, . \, X}{(-rA)}$$

$$\frac{Fv \, .CA0 \, . \, X}{k \, . \, CA. \, CB}$$

$$\frac{Fv \, .CA0 \, . \, X}{k \, . \, CA0 \, (1-X).CA0 \, (M-X)}$$

$$\frac{Fv \, .CA0 \, . \, X}{k \, . \, CA0^2. \, (1-X).(M-X)}$$

$$\frac{Fv \, . \, X}{k \, . \, CA0 \, (1-X) \, (M-X)} \quad \ldots(1)$$

- Kecepatan Volumetrik Umpan (Fv)

$$Fv = \frac{Massa \, (kg)}{Densitas \, (\frac{kg}{m}^3)}$$

$$= \frac{67036{,}5486 \, kg}{1801{,}1770 \, \frac{kg}{m}^3}$$

$$= 80{,}5240 \, \frac{m^3}{jam}$$

$$= 80523{,}9734 \, \frac{L}{jam}$$

- Konsentrasi Umpan

  - Konsentari $C_{10}H_{10}O_4$ (C_{A0}) $= \frac{mol \, A \, (\frac{kmol}{jam})}{Fv \, m^3/jam}$

$$= \frac{57,5915 \frac{kmol}{jam}}{80,5240 \frac{m^3}{jam}}$$

$$= 0,7152 \frac{kmol}{m^3}$$

$$= 0,0007 \frac{kmol}{liter}$$

- Konsentari H_2O (C_{B0}) $= \frac{mol\ B\ (\frac{kmol}{jam})}{Fv\ m^3/jam}$

$$= \frac{3103,5439 \frac{kmol}{jam}}{80,5240 \frac{m^3}{jam}}$$

$$= 38,5419 \frac{kmol}{m^3}$$

$$= 0,0385 \frac{kmol}{liter}$$

- Harga K

k1	104,8016 L/kmol.jam	0,1048 m^3/kmol.jam
k2	22,2238 L/kmol.jam	0,0222 m^3/kmol.jam
K2	172,9671 L/kmol.jam	0,1727 m^3/kmol.jam
k-2	0,1285 L/kmol.jam	0,0001 m^3/kmol.jam

(Journal of chemical Engineering)

- Menentukan Ratio (M)

M $= \frac{CB0}{CA0}$

$$= \frac{38,5419 \frac{kmol}{m^3}}{0,7152 \frac{kmol}{m^3}}$$

= 53,8888

- Menentukan nilai C_A dan C_B

C_A $= C_{A0}.(1 - X_A)$

$= 0,7152 \frac{\mathbf{kmol}}{\mathbf{m^3}} (1 - 0,95)$

$= 0,0358 \frac{\mathbf{kmol}}{\mathbf{m^3}}$

$= 0,000036 \frac{\mathbf{kmol}}{\mathbf{liter}}$

C_B $= C_{B0} - C_{A0}.X_A$

$= C_{A0} - \left(\frac{\mathbf{CB0}}{\mathbf{CA0}} - \mathbf{XA}\right)$

$= C_{A0} (M - X)$

$= 38,5419 \frac{\mathbf{kmol}}{\mathbf{m^3}} -(0,7152 \frac{\mathbf{kmol}}{\mathbf{m^3}} .0,95)$

$= 37,8624 \frac{\mathbf{kmol}}{\mathbf{m^3}}$

$= 0,0379 \frac{\mathbf{kmol}}{\mathbf{liter}}$

- Menentukan nilai laju alir (-rA)

(-rA) $= k1.\ C_{A.}\ C_B$

$= 104,8016 \frac{\mathbf{liter}}{\mathbf{kmol.jam}} .\ 0,000036 \frac{\mathbf{kmol}}{\mathbf{liter}} .\ 0,0379 \frac{\mathbf{kmol}}{\mathbf{liter}}$

$= 0,0001419 \frac{\mathbf{kmol}}{\mathbf{liter.jam}}$

$= 0,1419 \frac{\mathbf{kmol}}{\mathbf{m^3.jam}}$

- Optimasi Reaktor

Pada persamaan (1) diperoleh volume sebesar :

1 buah Reaktor

X1= 0,95

$$V = \frac{\mathbf{Fv} \, . \, \mathbf{X}}{\mathbf{k} \, . \, \mathbf{CA0} \, (\mathbf{1-X}) \, (\mathbf{M-X})}$$

$$= \frac{\mathbf{80{,}5240} \, \frac{\mathbf{m^3}}{\mathbf{jam}} \, . \, \mathbf{0{,}95}}{\mathbf{0{,}1048 \, m3/kmol.jam} \, . \, \mathbf{0{,}7152} \, \frac{\mathbf{kmol}}{\mathbf{m^3}} \, (\mathbf{1-0{,}95}) \, (\mathbf{53{,}8888-0{,}95})}$$

= 385,5695 m^3

= 385.596,5437 liter

2 buah Reaktor

X2= 0,95

X1= 0,78

X0= 0

$$V1 = \frac{\mathbf{Fv} \, . \, (\mathbf{X2-X1})}{\mathbf{k} \, . \, \mathbf{CA0} \, (\mathbf{1-X2}) \, (\mathbf{M-X2})} \qquad \dots(2)$$

$$= \frac{\mathbf{80{,}5240} \, \frac{\mathbf{m^3}}{\mathbf{jam}} \, . \, (\mathbf{0{,}95-0{,}78})}{\mathbf{0{,}1048 \, m3/kmol.jam} \, . \, \mathbf{0{,}7152} \, \frac{\mathbf{kmol}}{\mathbf{m^3}} \, (\mathbf{1-0{,}95}) \, (\mathbf{53{,}8888-0{,}95})}$$

= 70,3448 m^3

= 70344,81774 liter

$$V2 = \frac{\mathbf{Fv} \, . \, (\mathbf{X1-X0})}{\mathbf{k} \, . \, \mathbf{CA0} \, (\mathbf{1-X1}) \, (\mathbf{M-X1})} \qquad \dots(3)$$

$$= \frac{\mathbf{80{,}5240} \, \frac{\mathbf{m^3}}{\mathbf{jam}} \, . \, (\mathbf{0{,}78-0})}{\mathbf{0{,}1048 \, m3/kmol.jam} \, . \, \mathbf{0{,}7152} \, \frac{\mathbf{kmol}}{\mathbf{m^3}} \, (\mathbf{1-0{,}78}) \, (\mathbf{53{,}8888-0{,}78})}$$

= 70,3448 m^3

= 70344,81774 liter

3 buah Reaktor

X3= 0,95

X2= 0,86

X1= 0,63

$$V1= \frac{\mathbf{Fv}\ .\ (X3-X2)}{k\ .\ CA0\ (\ 1-X3)\ (M-X3)} \qquad \ldots(4)$$

$$= \frac{80{,}5240\ \frac{m^3}{jam}\ .\ (0{,}95-0{,}86)}{0{,}1048\ \text{m3/kmol.jam}\ .\ 0{,}7152\ \frac{kmol}{m^3}\ (\ 1-0{,}95)\ (53{,}8888-0{,}95)}$$

= 34,7024 m^3

= 34702,4175 liter

$$V2= \frac{\mathbf{Fv}\ .\ (X2-X1)}{k\ .\ CA0\ (\ 1-X2)\ (M-X2)} \qquad \ldots(5)$$

$$= \frac{80{,}5240\ \frac{m^3}{jam}\ .\ (0{,}86-0{,}63)}{0{,}1048\ \text{m3/kmol.jam}\ .\ 0{,}7152\ \frac{kmol}{m^3}\ (\ 1-0{,}86)\ (53{,}8888-0{,}86)}$$

= 34,7024 m^3

= 34702,4175 liter

$$V3= \frac{\mathbf{Fv}\ .\ (X1-X0)}{k\ .\ CA0\ (\ 1-X1)\ (M-X1)} \qquad \ldots(6)$$

$$= \frac{80{,}5240\ \frac{m^3}{jam}\ .\ (0{,}63-0)}{0{,}1048\ \text{m3/kmol.jam}\ .\ 0{,}7152\ \frac{kmol}{m^3}\ (\ 1-0{,}63)\ (53{,}8888-0{,}63)}$$

= 34,7024 m^3

= 34702,4175 liter

4 buah Reaktor

X4= 0,95

X3= 0,89

X2= 0,78

X1= 0,53

X0= 0

V1= $\frac{\mathbf{Fv}\ .\ (\boldsymbol{X4}-\boldsymbol{X3})}{\boldsymbol{k}\ .\ \boldsymbol{CA0}\ (\ \mathbf{1}-\boldsymbol{X4})\ (\boldsymbol{M}-\boldsymbol{X4})}$ …(7)

= $\frac{\mathbf{80{,}5240}\,\frac{\boldsymbol{m^3}}{\boldsymbol{jam}}\ .\ (\mathbf{0{,}95}-\mathbf{0{,}89})}{\mathbf{0{,}1048\ m3/kmol.jam}\ .\ \mathbf{0{,}7152}\,\frac{\boldsymbol{kmol}}{\boldsymbol{m^3}}\ (\ \mathbf{1}-\mathbf{0{,}95})\ (\mathbf{53{,}8888}-\mathbf{0{,}95})}$

= 22,5520 m^3

= 22551,9674 liter

V2= $\frac{\mathbf{Fv}\ .\ (\boldsymbol{X3}-\boldsymbol{X2})}{\boldsymbol{k}\ .\ \boldsymbol{CA0}\ (\ \mathbf{1}-\boldsymbol{X3})\ (\boldsymbol{M}-\boldsymbol{X3})}$ …(8)

= $\frac{\mathbf{80{,}5240}\,\frac{\boldsymbol{m^3}}{\boldsymbol{jam}}\ .\ (\mathbf{0{,}89}-\mathbf{0{,}78})}{\mathbf{0{,}1048\ m3/kmol.jam}\ .\ \mathbf{0{,}7152}\,\frac{\boldsymbol{kmol}}{\boldsymbol{m^3}}\ (\ \mathbf{1}-\mathbf{0{,}89})\ (\mathbf{53{,}8888}-\mathbf{0{,}89})}$

= 22,5520 m^3

= 22551,9674 liter

V3= $\frac{\mathbf{Fv}\ .\ (\boldsymbol{X2}-\boldsymbol{X1})}{\boldsymbol{k}\ .\ \boldsymbol{CA0}\ (\ \mathbf{1}-\boldsymbol{X2})\ (\boldsymbol{M}-\boldsymbol{X2})}$ …(9)

= $\frac{\mathbf{80{,}5240}\,\frac{\boldsymbol{m^3}}{\boldsymbol{jam}}\ .\ (\mathbf{0{,}78}-\mathbf{0{,}53})}{\mathbf{0{,}1048\ m3/kmol.jam}\ .\ \mathbf{0{,}7152}\,\frac{\boldsymbol{kmol}}{\boldsymbol{m^3}}\ (\ \mathbf{1}-\mathbf{0{,}78})\ (\mathbf{53{,}8888}-\mathbf{0{,}78})}$

= 22,5520 m^3

= 22551,9674 liter

$$V4= \frac{\mathbf{Fv}\ .\ (X1-X0)}{k\ .\ CA0\ (1-X0)\ (M-X0)} \qquad \ldots(10)$$

$$= \frac{80{,}5240\ \frac{m^3}{jam}\ .\ (0{,}53-0)}{0{,}1048\ \text{m3/kmol.jam}\ .\ 0{,}7152\ \frac{kmol}{m^3}\ (1-0{,}53)\ (53{,}8888-0{,}53)}$$

= 22,5520 m^3

= 22551,9674 liter

Optimasi	Volume(m^3)	konversi					Waktu tinggal(jam)
		X0	X1	X2	X3	X4	
1	385,5695	0	0,95	-	-	-	4,7882
2	70,3448	0	0,78	0,95	-	-	0,8736
3	34,7024	0	0,63	0,86	0,95	-	0,4309
4	22,5520	0	0,53	0,78	0,89	0,95	0,2800

Untuk mengetahui jumlah reactor dilakukan optimasi dengan menggunkan data harga yang diambil dari buku Timmerhaus, page 731.

Dipilih *Carbon Steel* sebagai bahan pembuat reactor.

1 m^3 = 264,172 gallons

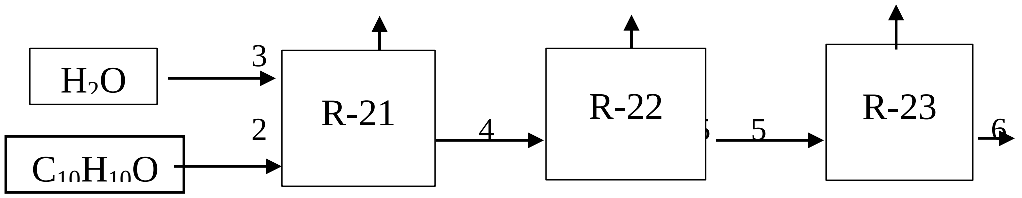
Volume over design 20%

Jumlah Reaktor	V (m^3)	V (gall)	Harga (USD)
1	462,6835	122228,1609	404152,5057
2	84,4138	22341,8018	291570,3928
3	41,6429	11021,7865	286229,8365

4	27,0624	7162,7865	294680,7074

Dari perhitungan optimasi reactor maka dipilih menggunkan 3 reaktor yaitu dengan volume 41,6429 m^3.

3) Neraca Massa



R-21

Konversi = 63 %

$C_{10}H_{10}O_4$ + H_2O ⟶ $C_9H_8O_4$ + CH_3OH

	$C_{10}H_{10}O_4$	H_2O	$C_9H_8O_4$	CH_3OH
M:	57,5915	3103,5439		
Rx:	63%. 57,5915 = 36,2827	63%. 57,5915 = 36,2827	63%. 57,5915 = 36,2827	63%. 57,5915 = 36,2827
S :	21,3089	3067,2612	36,2827	36,2827

Jadi :

$C_{10}H_{10}O_4$ mula-mula : 57,5915 $\frac{\textbf{kmol}}{\textbf{jam}}$ x 194 $\frac{\textbf{kg}}{\textbf{kmol}}$ = 11172,7581 kg/jam

$C_{10}H_{10}O_4$ bereaksi : 36,2827 $\frac{\textbf{kmol}}{\textbf{jam}}$ x 194 $\frac{\textbf{kg}}{\textbf{kmol}}$ = 7038,8376 kg/jam

$C_{10}H_{10}O_4$ sisa : 21,3089 $\frac{\textbf{kmol}}{\textbf{jam}}$ x 194 $\frac{\textbf{kg}}{\textbf{kmol}}$ = 4133,9205 kg/jam

H_2O mula-mula : 3103,5439 $\frac{\textbf{kmol}}{\textbf{jam}}$ x 18 $\frac{\textbf{kg}}{\textbf{kmol}}$ = 55863,79048 kg/jam

H_2O bereaksi : 36,2827 $\frac{kmol}{jam}$ x 18 $\frac{kg}{kmol}$ = 653,0880 kg/jam

H_2O sisa : 3067,2612 $\frac{kmol}{jam}$ x 18 $\frac{kg}{kmol}$ = 55210,7025 kg/jam

$C_9H_8O_4$ yang terbentuk : 36,2827 $\frac{kmol}{jam}$ x 180 $\frac{kg}{kmol}$ = 6530,8802 kg/jam

CH_3OH yang terbentuk : 36,2827 $\frac{kmol}{jam}$ x 32 $\frac{kg}{kmol}$ = 1161,0454 kg/jam

R-22

Konversi = 86 %

	$C_{10}H_{10}O_4$	+ H_2O	$\longrightarrow$ $C_9H_8O_4$	+ CH_3OH
M:	21,3089	3067,2612		-
Rx:	86%. 21,3089 = 18,3256	86%. 21,3089 = 18,3256	86%. 21,3089 = 18,3256	86%. 21,3089 = 18,3256
S :	2,9832	3048,9356	18,3256	18,3256

Jadi :

$C_{10}H_{10}O_4$ mula-mula : 21,3089 $\frac{kmol}{jam}$ x 194 $\frac{kg}{kmol}$ = 4133,9205 kg/jam

$C_{10}H_{10}O_4$ bereaksi : 18,3256 $\frac{kmol}{jam}$ x 194 $\frac{kg}{kmol}$ = 3555,1716 kg/jam

$C_{10}H_{10}O_4$ sisa : 2,9832 $\frac{kmol}{jam}$ x 194 $\frac{kg}{kmol}$ = 578,8613 kg/jam

H_2O mula-mula : 3067,2612 $\frac{kmol}{jam}$ x 18 $\frac{kg}{kmol}$ = 55210,7025 kg/jam

H_2O bereaksi : 18,3256 $\frac{kmol}{jam}$ x 18 $\frac{kg}{kmol}$ = 329,8613 kg/jam

H_2O sisa : 3048,9356 $\frac{kmol}{jam}$ x 18 $\frac{kg}{kmol}$ = 54880,8412 kg/jam

$C_9H_8O_4$ terbentuk R-21 : 36,2827 $\frac{kmol}{jam}$ x 180 $\frac{kg}{kmol}$ = 6530,8802 kg/jam

$C_9H_8O_4$ yang terbentuk : 18,3256 $\frac{kmol}{jam}$ x 180 $\frac{kg}{kmol}$ = 3298,6128 kg/jam

$C_9H_8O_4$ total : 6530,8802 kg/jam + 3298,6128 kg/jam

= 9829,4931 kg/jam

CH_3OH yang terbentuk : 18,3256 $\frac{kmol}{jam}$ x 32 $\frac{kg}{kmol}$ = 584,4201 kg/jam

R-23

Konversi = 95 %

	$C_{10}H_{10}O_4$	+	H_2O	$\longrightarrow$	$C_9H_8O_4$	+	CH_3OH
M:	2,9832		3048,9356		-		-
Rx:	86%. 2,9832 = 2,8341		86%. 2,9832 = 2,8341		86%. 2,9832 = 2,8341		86%. 2,9832 = 2,8341
S :	0,1492		3046,1015		2,8341		2,8341

Jadi :

$C_{10}H_{10}O_4$ mula-mula : 2,9832 $\frac{kmol}{jam}$ x 194 $\frac{kg}{kmol}$ = 578,861kg/jam

$C_{10}H_{10}O_4$ bereaksi : 2,8341 $\frac{kmol}{jam}$ x 194 $\frac{kg}{kmol}$ = 549,8114 kg/jam

$C_{10}H_{10}O_4$ sisa : 0,1492 $\frac{kmol}{jam}$ x 194 $\frac{kg}{kmol}$ = 28,9374 kg/jam

H_2O mula-mula : 3048,9356 $\frac{\text{kmol}}{\text{jam}}$ x 18 $\frac{\text{kg}}{\text{kmol}}$ = 54880,8412 kg/jam

H_2O bereaksi : 2,8341 $\frac{\text{kmol}}{\text{jam}}$ x 18 $\frac{\text{kg}}{\text{kmol}}$ = 51,0134 kg/jam

H_2O sisa : 3046,1015 $\frac{\text{kmol}}{\text{jam}}$ x 18 $\frac{\text{kg}}{\text{kmol}}$ = 54829,8277 kg/jam

$C_9H_8O_4$ yang terbentuk : 2,8341 $\frac{\text{kmol}}{\text{jam}}$ x 180 $\frac{\text{kg}}{\text{kmol}}$ = 510,1343 kg/jam

$C_9H_8O_4$ total : 9829,4931 kg/jam + 510,1343 kg/jam

= 10339,6274 kg/jam

CH_3OH yang terbentuk : 2,8341 $\frac{\text{kmol}}{\text{jam}}$ x 32 $\frac{\text{kg}}{\text{kmol}}$ = 90,6905 kg/jam

komponen	R-21 (Kg/jam)		R-22 (Kg/jam)		R-23 (Kg/jam)	
	aliran 2	aliran 3	aliran 4	aliran 5	aliran 5	aliran 6
$C_{10}H_{10}O_4$	11172,7581	4133,9205	4133,9205	578,7489	578,7489	28,9374
$C_9H_8O_4$		6530,8802	6530,8802	9829,4931	9829,4931	10339,6274
H_2O	55863,7905	55210,7025	55210,7025	54880,8412	54880,8412	54829,8277
CH_3OH		1161,0454		586,4201		90,6905
Total	67036,5486	67036,5486	65875,5032	65875,5032	65289,0831	65289,0831

4) Neraca Panas

R-21

Entalpi Bahan Masuk :

P = 24 atm

Tin = 230°C

Tout = 230°C

Entalpi Bahan Masuk :

- Entalpi $C_{10}H_{10}O_4$ pada suhu 230°C

Komponen	Berat (kg/jam)	BM	Kmol/jam	∫Cp.dT (kj/kmol)	Qin (kj/jam)	Qin (kkal/jam)
$C_{10}H_{10}O_4$	11172,7581	194	57,5915	74630,7931	4298102,049	1027272,1783
Total	11172,7581					1027272,1783

- Entalpi H_2O pada suhu 230°C

Komponen	Berat (kg/jam)	BM	Kmol/jam	∫Cp.dT (kj/kmol)	Qin (kj/jam)	Qin (kkal/jam)
H_2O	55863,7905	18	3103,5439	16002,7108	49665115,6003	11870260,6192
Total	55863,7905					11870260,6192

Entalpi Bahan Keluar :

- Entalpi Campuran $C_9H_8O_4$ pada suhu 230°C

Komponen	Berat (kg/jam)	BM	Kmol/jam	∫Cp.dT (kj/kmol)	Qin (kj/jam)	Qout (kkal/jam)
$C_{10}H_{10}O_4$	4133,9205	194	21,3089	74630,7931	1590297,7581	380090,7060
$C_9H_8O_4$	6530,8802	180	36,2827	61766,7608	2241062,8799	535627,4747
H_2O	55210,7025	18	3067,2612	16002,7108	49084494,5581	11731488,7064
Total	65875,5032					12647206,8870

- Entalpi CH_3OH pada suhu 230°C

Komponen	Berat (kg/jam)	BM	Kmol/jam	∫Cp.dT (kj/kmol)	Qin (kj/jam)	Qout (kkal/jam)
CH_3OH	1161,0454	32	36,2827	10265,6050	372463,5381	89021,0204
Total	1161,0454		36,2827	10265,6050	372463,5381	89021,02039

Panas reaksi:

Berdasarkan Himmelblau 7th ed halaman 769 :

Panas reaksi pada suhu 230^{o}C (503 K) :

ΔHR,503K = ΔHR,Tref + (ΔHproduk - ΔHreaktan)

ΔHreaktan = Entalpi bahan masuk

ΔHproduk = Entalpi bahan keluar

ΔHR,Tref = Panas reaksi pada suhu reference

Tref = suhu reference = 25^{o}C = 298 K

ΔHR,298K = ΔHf,produk - ΔHf,reaktan

$\Delta H^o f$ = Panas pembentukan bahan

1 Kilo joule = 0,24 Kilo Kalori

komponen	A	B	C	$\Delta H^o f$ (kJ/mol)	$\Delta H^o f$ (kkal/mol)
$C_{10}H_{10}O_4$	-604,1700	-0,1277	0,0001	-636,9887	-152,8773
$C_9H_8O_4$	-691,0400	-0,1048	0,0000	-717,8850	-172,2924
CH_3OH	-187,9900	-0,0498	0,0000	-200,8992	-48,2158
H_2O	-238,4100	-0,0123	0,0000	-241,8167	-58,0360
H_2O(uap)	-238,4100	-0,0123	0,0000	-241,8167	-58,0360

ΔHf = A+B*T+C*T^2

ΔHf (kJ/mol)

T (K) (Yaws, 2003)

Tinjauan panas reaksi :

Dari neraca massa : (kapasitas 70.000 ton/tahun)

mol $C_9H_8O_4$ = 36,2827 kmol = 36282,66804 mol

ΔH_{R289K} = ΔHf produk - ΔHf reaktan

=(-172,2924+(-48,2158))kkal/mol-(-152,8773+ -58,0360)kkal/mol

= -9,5949 kkal/mol

ΔH_{R289K} = -9,5949 kkal/mol x 36282,66804 mol

= -348128,3844 kkal/jam

Sehingga Reaksi bersifat eksotermis yaitu mengeluarkan panas.

ΔHreaktan = 1027272,1783 kkal/jam + 11870260,6192 kkal/jam

= 12897532,7975 kkal/jam

ΔHproduk = 12647206,8870 kkal/jam + 89021,02039 kkal/jam

= 12736227,9074 kkal/jam

ΔH_{R358K} = Q reaksi

= ΔH_{R289K} + (ΔHproduk - ΔHreaktan)

= -348128,3844 kkal/jam + (12736227,9074 kkal/jam - 12897532,7975 kkal/jam)

= -509433,2744 kkal/jam

Neraca Panas :

Komponen	Qinput (kkal/jam)			Qoutput (kkal/jam)		
	3	4		5	6	
$C_{10}H_{10}O_4$	1027272,1783			380090,7060		
$C_9H_8O_4$				535627,4747		
H_2O				11731488,7064		
CH_3OH		11870260,6192			89021,0204	
ΔHreaksi			-509433,2744			
Qserap						-348128,3844
TOTAL	12388099,5230			12388099,5230		

R-22

Entalpi Bahan Masuk :

Komponen	Berat (kg/jam)	BM	Kmol/jam	∫Cp.dT (Kj/kmol)	Qin (kj/jam)	Qin (kkal/jam)
$C_{10}H_{10}O_4$	4133,9205	194	21,3089	74630,7931	1590297,758	380090,7060
$C_9H_8O_4$	6530,8802	180	36,2827	61766,76085	2241062,88	535627,4747
H_2O	55210,7025	18	3067,2612	16002,71076	49084494,56	11731488,7064
Total	65875,5032	392	3124,8528	152400,2647	52915855,2	12647206,89

Entapi Bahan Keluar :

Komponen	Berat (kg/jam)	BM	Kmol/jam	∫Cp.dT (Kj/kmol)	Qout (kj/jam)	Qin (kkal/jam)
$C_{10}H_{10}O_4$	578,7489	194,0000	2,9832	74630,7931	222641,6861	53212,6988
$C_9H_8O_4$	9829,4931	180,0000	54,6083	61766,7608	3372977,4964	806161,8595
H_2O	54880,8412	18,0000	3048,9356	16002,7108	48791234,8508	11661397,8767
Total	65289,0831		3106,5272	152400,2647	52386854,0334	12520772,4351

Komponen	Berat (kg/jam)	BM	Kmol/jam	∫Cp.dT (Kj/kmol)	Qout (kj/jam)	Qin (kkal/jam)
CH_3OH	586,4201	32	18,3256	10265,6050	188123,6473	44962,6805
Total	586,4201					44962,6805

mol $C_9H_8O_4$ = 54,6083 kmol = 54608,2950 mol

ΔH_{R289K} = ΔHf produk - ΔHf reaktan

=(-172,2924+(-48,2158))kkal/mol-(-152,8773+
-58,0360)kkal/mol

= -9,5949 kkal/mol

ΔH_{R289K} = -9,5949 kkal/mol x 54608,2950 mol

= -523960,8477 kkal/jam

Sehingga Reaksi bersifat eksotermis yaitu mengeluarkan panas.

ΔHreaktan = 12647206,89 kkal/jam

ΔHproduk = 12520772,4351kkal/jam + 44962,6805kkal/jam

= 12565735,1156 kkal/jam

ΔH_{R358K} = Q reaksi

= ΔH_{R289K} + (ΔHproduk - ΔHreaktan)

=-523960,8477 kkal/jam + (12565735,1156kkal/jam-

12647206,89 kkal/jam)

= -605432,6192 kkal/jam

Komponen	Qinput (kkal/jam)		Qoutput (kkal/jam)		
	3		5	6	7
$C_{10}H_{10}O_4$	380090,7060		53212,6988		
$C_9H_8O_4$	535627,4747		806161,8595		
H_2O	11731488,7064		11661397,8767		
CH_3OH				44962,6805	
ΔHreaksi		-605432,6192			
Qserap					-523960,8477
TOTAL	12041774,2678		12041774,2678		

Neraca Panas :

R23

Entalpi Bahan Masuk :

Komponen	Berat (kg/jam)	BM	Kmol/jam	∫Cp.dT (kj/kmol)	Qout (kj/jam)	Qin (kkal/jam)
$C_{10}H_{10}O_4$	28,9374	194,0000	0,1492	74630,7931	11132,0843	2660,6349
$C_9H_8O_4$	10339,6274	180,0000	57,4424	61766,7608	3548029,4081	848000,3167
H_2O	54829,8277	18,0000	3046,1015	16002,7108	48745881,8961	11650558,2484
Total	65198,3926			152400,2647	52305043,3884	12501219,2001

Entalpi Bahan Keluar :

Komponen	Berat (kg/jam)	BM	Kmol/jam	∫Cp.dT (kj/kmol)	Qout (kj/jam)	Qin (kkal/jam)
CH_3OH	90,6905	32,0000	2,8341	10265,6050	29093,5408	6953,5308
Total	90,6905					6953,5308

Komponen	Berat (kg/jam)	BM	Kmol/jam	∫Cp.dT (kj/kmol)	Qin (kj/jam)	Qin (kkal/jam)
$C_{10}H_{10}O_4$	578,7489	194,0000	2,9832	74630,7931	222641,6861	53212,6988
$C_9H_8O_4$	9829,4931	180,0000	54,6083	61766,7608	3372977,4964	806161,8595
H_2O	54880,8412	18,0000	3048,9356	16002,7108	48791234,8508	11661397,8767
Total	65289,0831		3106,5272	152400,2647	52386854,0334	12520772,4351

mol $C_9H_8O_4$ = 57,4424 kmol = 57442,3745 mol

ΔH_{R289K} = ΔHf produk - ΔHf reaktan

=(-172,2924+(-48,2158))kkal/mol- (-152,8773 + -57,4424)kkal/mol

= -9,5949 kkal/mol

ΔH_{R289K} = -9,5949 kkal/mol x 54608,2950 mol

= -551153,5426 kkal/jam

Sehingga Reaksi bersifat eksotermis yaitu mengeluarkan panas.

ΔHreaktan = 12520772,4351 kkal/jam

ΔHproduk = 12501219,2001 kkal/jam + 6953,5308 kkal/jam

= 12508172,7309 kkal/jam

ΔH_{R358K} = Q reaksi

= ΔH_{R289K} + (ΔHproduk - ΔHreaktan)

= -551153,5426 kkal/jam + (12508172,7309 kkal/jam - 12520772,4351 kkal/jam)

= -563753,2468 kkal/jam

Neraca Panas :

Komponen	Qinput (kkal/jam)		Qoutput (kkal/jam)		
	Q	Q	Q	Q	Q
$C_{10}H_{10}O_4$	53212,6988		2660,6349		
$C_9H_8O_4$	806161,8595		848000,3167		
H_2O	11661397,8767		11650558,2484		
CH_3OH				6953,5308	
ΔHreaksi		-563753,2468			
Qserap					-551153,5426
TOTAL	11957019,1883		11957019,1883		

5) Menentukan dimensi reaktor

Volume design reaktor sebesar 41,6429 m^3. Adapun rasio H/D yang digunakan adalah 2. Dengan diketahui besar volume reaktor maka dapat dihitung pula besar nilai D dan H dengan menggunakan perbandingan rasio.

$$\text{Volume} = \frac{\pi}{4}\, 2\, D^3 \qquad \text{Volume} = \frac{\pi}{4}\, D^2\, 2D \qquad D = \sqrt[3]{\frac{2\ \text{Volume}}{\pi}}$$

D : 2,9823 m

H : 5,9645 m

A. Menentukan Tinggi cairan sebelum menggunakan *Head*

Hcairan $= \frac{\mathbf{4.V}}{\boldsymbol{\pi}\mathbf{.D^2}}$

$= \frac{\mathbf{4\ .\ 41{,}6429\ m3}}{\mathbf{3{,}14\ .\ (2{,}9823\ m)^2}}$

= 5,9645 m

= 234,8246 in

B. Menentuka Tekanan *Design*

Pra rancangan ini dibuat dengan menggunkan reaktor faktor keamanan 20% terhadap tekanan operasi, sehingga:

Tekanan Operasi : 24 atm = 352,8 psia

- $P_{Hidrostatis} = \rho \cdot g \cdot h$

  Dengan:

  ρ campuran : 832,5042 kg/m^3

  g : 9,8 m/s^2

  gc : 32,15 ft/s^2

  h : 5,9645 m

  $P_{Hidrostatis}$ = 832,5042 kg/m^3 . 9,8 m/s^2 . 5,9645 m

  = 48711,62 pascal

  = 7,07 psia

  P_{design} = 1,2 x ($P_{operasi}$ + $P_{Hidrotatis}$)

  = 1,2 x (352,8 psia + 7,07 psia)

  = 431,84 psia

  = 417,14 psig

C. Menentukan tebal *shell*

$$t_s = \frac{P.\ r}{(fE\ - 0{,}6\ P)} + C$$ (Brownell, hal 254)

Dengan :

d = Diameter dalam *shell* (in)

f = maksimum *allowable stress* bahan yang digunakan

(Brownell,tabel 13-1, p.251)

ts = tebal *shell*, in

E = efisiensi pengelasan

P = tekanan *design*, psi

C = faktor korosi, in

Bahan yang digunakan untuk reaktor adalah *Carbon Steel*.

E : 0,85

f : 12635,30 psig

P : 417,1380 psig

C : 0,125

Maka nilai ts yang didapatkan sebesar 2,4595 in

Dipilih tebal dinding reaktor *standard* 2,5000 in

Dan diperoleh OD = ID + 2.ts

= 117,4123 in + (2 x 2,5000 in)

= 122,4123 in

(Brownell and Young, hal 88)

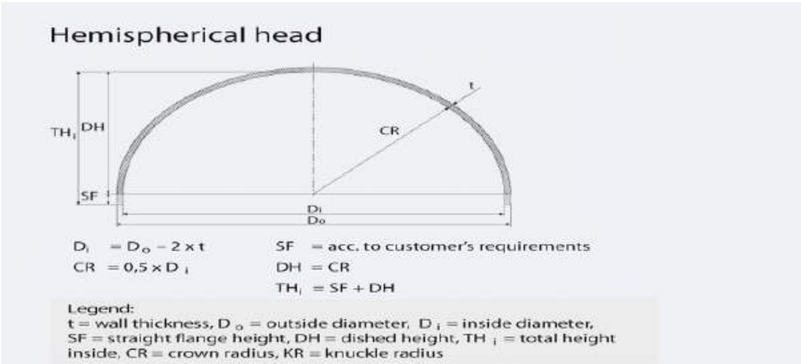
D. Menentukan tebal, tinggi, dan *volume head*

Menentukan jenis dan ukuran *head* dan *bottom* reaktor. Pertimbangannya meliputi:

- *Flanged and standard dished head* (jenis ini biasa digunakan untuk tekanan operasi rendah, harganya murah dan digunakan untuk tangki dengan diameter yang kecil).

- *Torispherical flanged and dished head* (jenis ini digunakan untuk tekanan operasi hingga 15 bar dan harganya cukup ekonomis).
- *Eliptical dished head* (jenis ini digunakan untuk tekanan operasi tinggi dan harganya cukup mahal).
- *Hemispherical head* (jenis ini digunakan untuk tekanan operasi sangat tinggi, kuat dan ukurannya sangat terbatas).

Berdasarkan pertimbangan-pertimbangan di atas dan tekanan operasi perancangan yang dibuat, maka dipilih bentuk *Hemispherical head.*



Untuk menghitung besarnya tebal head standar digunakan rumus sebagai berikut:

$$t_h = \frac{P.\ di}{(4fE\ - 0{,}4P)} + C$$

(Eq-7,88, Hal. 140, Brownell and Young,1959)

Pdesain	: 417,1380 psig
D	: 117,4123 in
f	: 12635,30 psig
E	: 0,85

k : 2

c : 0,125

Sehingga diperoleh tebal *head* 1,2695 in (Brownell and Young, hal 90)

Dengan tebal *head* reaktor standar 1,3750 in maka diperoleh:

Sf = 2,5 in

Icr = 7,625

r = 120

ID = OD-(2. Th)

= 122,4123 in – (2x1,370 in)

= 119,6623 in

DH=CR = 0,5 x ID

= 0,5 x 119,6623 in

= 59,8312 in

Tinggi *Head* = cr +sf + th

= 58,8312 in + 2,5 in + 1,3750 in

= 63,7062 in

= 1,6181 m

Tinggi *Bottom* = 1,6181 m

Maka Tinggi total= H*shell* + H*head* + H*Bottom*

= 5,9645 m + 1,6181 m + 1,6181 m

= 9,2008 m

Volume sebuah *head*

Vdish = $2/3. \pi. r^3$

= 2/3. 3,14. (59,8312 in)^3

= 448353,4635 in^3

Vsf = π/4. D^2. Sf/144

= 195,1470 in^3

= 0,0032 m^3

Volume sebuah head = 2 x (Vdish + Vdish)

= 448548,6105 in^3

= 7,3517 m^3

Maka Volume reaktor total = V*Shell* + V*head*

= 2989752,5049 in^3

= 48,9946 m^3

E. Perancangan Pengaduk

Jenis: Turbin 6 blade disk standar (Brown fig. 477 atau Coulson fig. 10.57). Dipilih jenis pengaduk ini karena turbin memiliki range volume yang besar dan dapat digunakan pada kecepatan putaran yang cukup tinggi.

Berikut merupakan spesifikasi pengaduk dari reaktor:

- Jumlah baffle : 4
- Di (Diameter impeller) = (1/3)*ID standar : 0,9941 m
  : 3,26145 ft
- Zi (Jarak tangki dengan pengaduk) = (1,3)*Di : 0,7456 m
  : 2.4461 ft
- Zl (tinggi cairan setelah ada *head*) = 4. Vr/ π.D^2 : 7,0173 m

: 23,0227 ft

- wb (Lebar baffle) = (0,17)*Di : 0,1690 m

  : 0,5545 ft

- L (lebar pengaduk) = (0,25)*(Di) : 0,2485 m

  : 0,8154 ft

- wi (tinggi pengaduk = Di/5 : 0,1988 m

  : 0,6523 ft

- r *(Impeller blade flange)* = (1/4*Di) : 0,2485 m

  : 0,8154 ft

- Offset 1 (jarak *baffle* dari tangki) = 1/2. Di : 0,4970 m

  : 1,6307 ft

- Offset 1 (jarak *baffle* dari tpermukaan cairan)

  = 1/6. Di : 0,1657 m

  : 0,5436 ft

- Dd (Diameter batang penyangga *impeller*)

  = 2/3.Di : 0,6627 m

  : 2,1743 ft

- WELH = Zl * (ρ camp / ρ air) : 1,96 buah

  : 2 buah

- Panjang *baffle* dan *Clearence* antar *baffle*

  Jumlah *baffle* = 4 buah

  Panjang *baffle* = Hs – (offset 1 + offset 2)

  = 5,9645 m – (0,4970 m + 0,1657 m)

= 5,3018 m

Clearance antar *baffle* = 0,15 x L

= 0,15 x 0,2485 m

= 0,0373 m

- Kecepatan putaran

Berdasarkan referensi Wallas, maka jumlah pengaduk yang dipakai = 2 buah

Menghitung kecepatan pengaduk

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

$$\mathbf{= \frac{600}{3,14\ x\ 3,26145\ ft}\sqrt{\frac{19,22\ ft}{2\ x\ 3,26145\ ft}}}$$

$$\mathbf{= 441\ rpm}$$

Kecepatan standar motor 441 rpm atau 7,35 rps. Dipilih tipe motor *fixed speed belt* karena paling ekonomis dan mudah dalam pemasangan.

Menghitung nilai Re:

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

$$\mathbf{Re = \frac{0,83\ {}^{gr}/_{cm^3}\ x\ 7,35\ rps\ x\ (99,41\ cm)^2}{0,0088\ {}^{g}/_{cm.s}}}$$

$$\mathbf{Re = 6892319,686}$$

Power number (Po) yang diperoleh dari *Fig. 477* Brown = 5,00

Sehingga:

$$\mathbf{P} \quad = \frac{\mathbf{N^3\ x\ Di^5\ x\ \rho\ x\ Po}}{\mathbf{550\ x\ gc}}$$

$$\mathbf{P} \quad = \frac{\mathbf{(7,35\ rps)^3\ x\ (99,411\ cm)^5\ x\ 0,83\ {}^{gr}/_{cm^3}\ x5}}{\mathbf{550\ x\ 980\ {}^{cm}/_{s^2}}}$$

$$\mathbf{P} \quad = \mathbf{2,5\ HP}$$

Efisiensi motor 88% maka *Power motor* 2,5 HP.

Dipilih *power motor* standar 3 HP

- Panjang Batang Sumbu Pengaduk (*axis length*)

Axis Length = tinggi total teaktor + jarak dari mortor ke bagian *bearing* – jarak pengaduk dari dasar tangka

= 9,2008 m + 0,3048 m - 0,746 m

= 8,7600 m

Tm = (1,5 atau 2,5). Tc

Tc = (p.75.60)/(2πN)

= (3. 75. 60)/(2. 3,14.441rpm)

= 4,8745 kg/m

M.V Joshi, Pers. 14.10, hal 400

Digunakan

Tm = 1,5. Tc

= 1,5 . 4,8745 kg/cm

= 7,3118 kg/m

Zp = Tm/fs

= (7,3118 x 100) kg/cm : 550 kg/cm^2

= 1,33294 cm

Dimana : Zp = *shear stress*

Tm = torsi maksimum

Fs = *section of shaft cross section*

Material sumbu yang digunakan adalah *commercial cold rolled steel*

Axis shear stress yang diizinkan, fs =550 kg/cm2

Batasan elastis pada tegangan =2460kg/cm2

Diameter Sumbu $= \frac{\mathbf{Zp\,.16}}{\boldsymbol{\pi}}$

D^3 $= \frac{\mathbf{1{,}3294\ cm\,.16}}{\mathbf{3{,}15}}$

= 6,7741 cm

D = 1,8921 cm

= 0,0189 m

F. Menghitung Kebutuhan Air Pendingin

Q air pendingin :	509433,2744	kj/jam	2020244,2535	Btu/jam
T in :	30	^oC	303	K
T out :	37	^oC	310	K

Komponen	A	B	C	D
Air	92,053	-4,00E-02	-2,11E-04	5,35E-07

∫Cp.dT :	1129,7051	J/mol	1129,7051	kJ/kmol

Keb. Air pendingin :	1886,7570	kmol/jam	33961,6258	kg/jam

a) Menghitung $\Delta \mathbf{T_{LMTD}}$

Suhu fluida panas masuk :	230	^oC	446	^oF
Suhu fluida panas keluar :	230	^oC	446	^oF
Suhu fluida dingin masuk :	30	^oC	86	^oF
Suhu fluida dingin keluar :	45	^oC	113	^oF

Inisial	Fluida panas (ºF)		Fluida dingin (ºF)	ΔT (ºF)
ΔT_2	446	Lower Temp	86	360
ΔT_1	446	Higher Temp	113	333

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

$$\Delta \mathbf{T_{LMTD}} = \frac{(\mathbf{360} - \mathbf{333})°\mathbf{F}}{\mathbf{ln}\left(\frac{\mathbf{360}\ °\mathbf{F}}{\mathbf{333}\ °\mathbf{F}}\right)}$$

$$\Delta \mathbf{T_{LMTD}} = \mathbf{346,3246}\ °\mathbf{F}$$

b) Menghitung Luas Transfer Panas Dan Luas Selubung Reaktor

Untuk *cold fluid* = *water* dan *hot fluid* = *medium organics*

Ud = 50-125 btu/ft^2.^{o}F.jam (Kern, Tabel 8 Hal.840)

Diambil harga Ud = 50 btu/ft^2.F.jam

Luas Transfer Panas

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

$$\mathbf{A} \quad = \frac{\mathbf{2020244,2535\ btu/jam}}{\mathbf{50\ ^{btu}/_{ft^2.F.jam}\ x\ 346,3246\ °F}}$$

$$\mathbf{A} \quad = \mathbf{116,6676\ ft^2}$$

$$\mathbf{A} \quad = \mathbf{10,8384\ m^2}$$

Luas Selubung Reaktor

A = Luas Selimur reactor + luas penampang bawah reactor

$= \pi.\ D.\ Hs + \pi/4\ .\ D^2$

$= 62,836\ m^2$

Luas selimut > luas transfer panas , maka digunakan jaket pendingin.

G. Perancangan Jaket Pendingin

Reaksi yang terjadi adalah reaksi eksotermis , maka untuk memperhatikan suhu reaksi tetap 230 C. Reaktor dilengkapi jaket pendingin.

Q yang diserap = 2020244,253 Btu/jam

Rho air pendingin masuk = 1023,01997 kg/m^3

= 63,8364 lb/ft^3

M air pendingin = 33961,62583 kg/jam

Rate air pendingn = 33,19742215 m3/jam

= 0,009221506 m^3/s

Diambil spasi jaket = 2 in

Diameter dalam jaket (DI) = OD + (2 x jarak jaket)

= 122,4123 in + 4 in

Diameter dalam jaket (DI) = 126,4123 in

= 23,0227 ft

= 3,2109 m

Tebal Dinding Jaket :

H jaket = 276,2729 in

= 7,0173 m

Phidrostatis = $\frac{H-1}{144} x \rho$

= $\frac{23{,}0227\ ft - 1}{144} x\ 63{,}8364\ lb/ft^3$

= 9,7629 psia

P*design* = 14,7 psia + Phidrostatis

= 24,5 psia

$$t_j = \frac{P.\ D}{(2fE - 1{,}2P)} + C$$

Pdesain : 24,5 psia

D : 126,4123 in

f : 12650 psia

E : 0,85

c : 0,125

sehingga diperoleh tebal jaket 0,2690 in (Brownell and Young, hal 90)

Dengan tebal *head* jaket standar 0,3125 in.

Diameter luar jaket (OD) = ID + 2. Tj

= 126,4123 in + (2. 0,3125 in)

= 127,0373 in

= 3,2267 m

Luas yang dilalui air pendingin = $(\pi/4)$ x $(OD^2 – ID^2)$

=$(3,14/4)x((3,2267m)^2 – (3,2109m^2))$

= 0,0800 m^2

H. Perancangan *Nozzle*

Dipilih jenis pipa : *Carbon Steel*

a) Diameter saluran cairan umpan

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

(Coulson and Richardson vol.6, 1983, P.221, Eq 5.15)

Q = 13,4746 m^3/jam

= 0,1322 ft^3/s

ρ = 995,0050 kg/m^3

= 62,1162 lb/ft^3

Di = 3,9. $(0,1322\ ft^3/s)^{0,45}$ $(62,1162\ lb/ft^3)^{0,13}$

= 2,6835 in

Spesifikasi pipa dari (tabel.11,P.844,Kern,1980), dipilih ukuran *standart* (Sch 40) :

NPS = 3 in

Sch = 40

ID = 3,068 in

OD = 3,5 in

A = 7,38 in^2

Spesifikasi pipa dari (brownel and young, 1959, app F pg 349), dipilih ukuran *standart* (Sch 40) :

Size = 3 in

OD = 3,5000 in

Flange Nozzle Thickness (n) = 0,3

DR = 3,625 in

Distance from Bottom of tank to center of nozzle:

reguler, tipe H = 8

Low, type G = 5

b) Diameter saluran Air umpan

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

(Coulson and Richardson vol.6, 1983, P.221, Eq 5.15)

Q = 83,1542 m^3/jam

= 0,8157 ft^3/s

ρ = 806,1720 kg/m^3

= 50,3177 lb/ft^3

Di = 3,9. $(0{,}8157\ ft^3/s)^{0,45}\ (50{,}3177\ lb/ft^3)^{0,13}$

= 5,9223 in

Spesifikasi pipa dari (tabel.11,P.844,Kern,1980), dipilih ukuran *standart* (Sch 40) :

NPS = 6 in

Sch = 40

ID = 6,065 in

OD = 6,625 in

A = 28,9 in^2

Spesifikasi pipa dari (brownel and young, 1959, app F pg 349), dipilih ukuran *standart* (Sch 40) :

Size = 6 in

OD = 6,625 in

Flange Nozzle Thickness (n) = 0,432

DR = 6,75 in

Distance from Bottom of tank to center of nozzle:

reguler, tipe H = 11

Low, tipe G = 8,125

c) Diameter saluran produk keluar

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

(Coulson and Richardson vol.6, 1983, P.221, Eq 5.15)

Q = 97,3467 m^3/jam

= 0,9549 ft^3/s

ρ = 812,0520 kg/m^3

= 50,6948 lb/ft^3

Di = 3,9. $(0{,}9549\ ft^3/s)^{0,45}\ (50{,}6948\ lb/ft^3)^{0,13}$

= 6,3635 in

Spesifikasi pipa dari (tabel.11,P.844,Kern,1980), dipilih ukuran *standart* (Sch 40) :

NPS = 8 in

Sch = 40

ID = 7,981 in

OD = 8,625 in

A = 50 in^2

Spesifikasi pipa dari (brownel and young, 1959, app F pg 349), dipilih ukuran *standart* (Sch 40) :

Size = 8 in

OD = 8,625 in

Flange Nozzle Thickness (n) = 0,5

DR = 8,75 in

Distance from Bottom of tank to center of nozzle:

reguler, tipe H = 13

Low, type G = 10,125

d) Diameter saluran gas keluar

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

(Coulson and Richardson vol.6, 1983, P.221, Eq 5.15)

Q = 74,8257 m^3/jam

= 0,7340 ft^3/s

ρ = 18,6200 kg/m^3

= 1,1624 lb/ft^3

Di = $3{,}9.\ (0{,}7340\ ft^3/s)^{0{,}45}\ (1{,}1624\ lb/ft^3)^{0{,}13}$

= 3,4604 in

Spesifikasi pipa dari (tabel.11,P.844,Kern,1980), dipilih ukuran *standart* (Sch 40) :

NPS = 4 in

Sch = 40

ID = 4,026 in

OD = 4,500 in

A = 12,7 in^2

Spesifikasi pipa dari (brownel and young, 1959, app F pg 349), dipilih ukuran *standart* (Sch 40) :

Size = 4 in

OD = 4,5 in

Flange Nozzle Thickness (n) = 0,337

DR = 4,375 in

Distance from Bottom of tank to center of nozzle:

reguler, tipe H = 9

Low, type G = 6

e) Diameter air pendingin masuk

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

(Coulson and Richardson vol.6, 1983, P.221, Eq 5.15)

Q = 39,8369 m^3/jam

= 0,3908 ft^3/s

ρ = 1023,0200 kg/m^3

= 63,8651 lb/ft^3

Di = 3,9. $(0,3908\ ft^3/s)^{0,45}\ (63,8651\ lb/ft^3)^{0,13}$

= 4,3865 in

Spesifikasi pipa dari (tabel.11,P.844,Kern,1980), dipilih ukuran *standart* (Sch 40) :

NPS = 6 in

Sch = 40

ID = 6,065 in

OD = 6,625 in

A = 28,9 in^2

Spesifikasi pipa dari (brownel and young, 1959, app F pg 349), dipilih ukuran *standart* (Sch 40) :

Size = 6 in

OD = 6,625 in

Flange Nozzle Thickness (n) = 0,432

DR = 6,75 in

Distance from Bottom of tank to center of nozzle:

reguler, tipe H = 11

Low, tipe G = 8,125

f) Diameter air pendingin keluar

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

(Coulson and Richardson vol.6, 1983, P.221, Eq 5.15)

Q = 39,8369 m^3/jam

= 0,3908 ft^3/s

ρ = 1023,0200 kg/m^3

= 63,8651 lb/ft^3

Di = $3{,}9.\ (0{,}3908\ ft^3/s)^{0{,}45}\ (63{,}8651\ lb/ft^3)^{0{,}13}$

= 4,3865 in

Spesifikasi pipa dari (tabel.11,P.844,Kern,1980), dipilih ukuran *standart* (Sch 40) :

NPS = 6 in

Sch = 40

ID = 6,065 in

OD = 6,625 in

A = 28,9 in^2

Spesifikasi pipa dari (brownel and young, 1959, app F pg 349), dipilih ukuran *standart* (Sch 40) :

Size = 6 in

OD = 6,625 in

Flange Nozzle Thickness (n) = 0,432

DR = 6,75 in

Distance from Bottom of tank to center of nozzle:

reguler, tipe H = 11

Low, tipe G = 8,125

I. Perancangan Tebal Isolasi

Dari fig. 11.42 Perry, 1984 untuk range suhu 0°F- 300°F digunakan isolasi polyisocyanurate. Pertimbangan lain digunakannya isolasi *polyisocyanurate*.

a) Bahan ini dapat digunakan untuk range suhu 0° - 900° F.

b) *Thermal conductivity* relatif tetap pada suhu 0° - 900° F.

c) Mudah didapat

Diinginkan suhu dinding isolasi = 50°C = 122°F

Data-data fisis :

k isolasi = 0,0125 Btu/j.ft.°F

Ts = 50^oC = 122°F

Tud = 30^oC = 86°F

Tf = (Ts+Tud)/2

= (122°F + 86°F) / 2

= 104°F

Δf = Ts - Tf

= 122°F - 104°F

= 18°F

β = 1 / Tf

= 1/ (104°F+460)

= 0,0018/R

dengan :

Tf = suhu film, °F

β = koefisien muai volume, /R

Sifat-sifat udara pada Tf = 104 F (tabel 3.212, Perry, 1984)

ρf =1,1308 kg/m3

= 0,0706 lb/ft3

cpf = 1,0066 kJ/kg°C

= 0,2405 Btu/lb°F

μf = 0,000019 Pa.s

= 0,0460 lb/ft.j

kf = 0,0272 W/m°C

= 0,0157 Btu/j.lb°F

Dengan :

Gr = bilangan Grashoff

Pr = bilangan Prandtl

Ra = bilangan Rayleigh

Gr $= \frac{l^3 \rho f^2 \beta . gc . \Delta f}{\mu f^2}$

Pr $= \frac{cpf . \mu f}{kf}$

Ra = Gr x Pr

Bila : Raf : 10E+4 – 10E+9 , maka hc = 0.29 (Δt/2)0.25

Raf : 10E+9 – 10E+12, maka hc = 0.19 (Δt)1/3

Dimana hc adalah koefisien perpindahan panas konveksi.

ℓ = L = tinggi silinder + tinggi *bottom* + tinggi *head*

ℓ = L = Zr + 2 (b + sf)

= 234,8246 in + 2 (59,8312 in + 2,5 in)

= 359,4869 in

= 9,1310 m

= 29,9496 ft

Gr $= \frac{(\mathbf{29{,}9496\ ft})^3\left(\mathbf{0{,}0706}\frac{\mathbf{lb}}{\mathbf{ft3}}\right)^2(\mathbf{0740374{,}4681/lbF}).\mathbf{18°F}}{\mathbf{0{,}0460\ lb/ft.j}}$

= 843616676066

Pr $= \frac{\mathbf{0{,}2405}\frac{\mathbf{Btu}}{\mathbf{lb}}\mathbf{°F}\ .\mathbf{0{,}0460\ lb/ft.j}}{\mathbf{0{,}0157\ Btu/j.lb°F}}$

= 0,70

cek ℓ

Ra = Gr x Pr

= 843616676066 x 0,70

= 5,93E+11 > 1E+09

Raf : 10E+9 – 10E+12, maka hc = 0.19 (Δt)1/3

sehingga :

hc = 0.19 (18°F)1/3

hc = 0,50 Btu/ft2.j.°F

Perpindahan panas karena radiasi dapat diabaikan karena suhu dinding reaktor kecil (50^{o}C)

ID = 126,4123 in

= 10,5317 ft

OD = 127,0373 in

= 10,5837 ft

T1 = 230 °C

= 446 °F

T2 = 50 °C

= 122 °F

Perpindahan panas konveksi :

q konveksi = hc*π*(OD+2*X isolasi)*L*Δt

hc*π*OD*L*Δt = 0,50 Btu/ft2.j.°F x 3,14 x 10,5837 ft x 29,9496 ft x 18°F

= 8920,92 Btu

hc*π*2*L*Δt = 0,50 Btu/ft2.j.°F x 3,14 x 2 x 29,9496 ft x 18°F

= 1685,78 Btu/ft

q konveksi = 8920,92 + 1685,78 x isolasi

Perpindahan panas konduksi melalui dinding reaktor dan isolasi

Dinding reaktor berupa *Carbon Steel*, dari table 3 Kern, diperoleh k =26 Btu/j.ft.F.

Perpindahan panas konduksi sama dengan perpindahan panas konveksi, Dengan trial 'n error didapatkan hasil sebagai berikut :

X isolasi = 0,4345 ft

= 13,24 cm

q konduksi $= \dfrac{2\pi(T1-Ts)}{\frac{1}{kL}\ln\left(\frac{OD}{ID}\right)+\frac{1}{Kb.L}\ln\left(OD+\frac{2Xis}{OD}\right)}$

$$=\frac{2\,.3{,}14(446\ °\mathrm{F}-122\ °\mathrm{F})}{\frac{1}{26\ \mathrm{Btu/j.ft.F.}29{,}9496\ \mathrm{ft}}\ln\left(\frac{10{,}5837\ \mathrm{ft}}{10{,}5317\ \mathrm{ft}}\right)+\frac{1}{0{,}0125\ \mathrm{Btu/j.ft.°F.}29{,}9496\ \mathrm{ft}}\ln\left(10{,}5837\ \mathrm{ft}+\frac{2.0{,}4345\ ft}{10{,}5837\ \mathrm{ft}}\right)}$$

= 9652,63 Btu/jam

Maka q konveksi = 8920,92 Btu + (1685,78 Btu/ft x 0,4345 ft)

= 0,9652,63 Btu/jam

Tebal isolasi agar dinding isolasi 50°C = 13,24 cm

= 0,1324 m

Panas yang hilang setelah diisolasi = 9653,41 Btu/jam

Menghitung Persentase panas yang hilang sesudah dan sebelum diisolasi

panas yang pilang sebelum dipasang Isolasi adalah sbb :

Ts = 230^{o}C

= 446°F

Tud = 30^{o}C

= 86°F

Tf = (Ts+Tud)/2

= (446°F + 86°F) /2

= 266 °F

Δf = Ts - Tf

= 446°F - 266 °F

= 180 °F

β = 1 / Tf

= 1,38E-03 /R

Sifat-sifat udara pada Tf = 403 K (tabel A-5 , Holman pg 658) ρf = 0,88 kg/m^3

= 0,0547 lb/ft^3

cpf = 1,0144 kJ/kg°C

=0,2423 Btu/lb°F

µf = 0,00002 Pa.s

= 0,0556 lb/ft.j

kf = 0,03097 w/m°C

=0,0179 Btu/lb°F

Pr = 0,75

Gr = 2,70E+12

Raf = 2,03E+12

Karena 1E+9 < Raf < 1E+12, maka :

hc = 0.19 (180 °F)1/3

hc = 1,07 Btu/lb°F

q konveksi = hc.π.OD.L.ΔT

q konveksi = 192195,30 Btu/jam

Sehingga didapatkan panas yang hilang sebelum dinding melter diisolasi

Sebesar 192195,30 Btu/jam

Persentase Panas yang Hilang setelah diisolasi adalah :

%panas yang hilang $= \frac{qkonveksi\ setelah\ isolasi}{qkonveksi\ sebelum\ isolasi}$

$= \frac{\mathbf{9653{,}41\ Btu/jam}}{\mathbf{192195{,}30\ Btu/jam}}$

= 0,05

= 5,02%

J. Perancangan Penyangga Reaktor

a) Berat *Shell*

ID = 117,4123 in

OD = 122,4123 in

H = 234,8246 in

ρ = 7750 kg/m^3

= 0,1270 kg/in^3

Berat *Shell* = 1/4π(OD^2-ID^2) H. ρ

= 1/4. 3,14 ($(122,4123\ in)^2$- (= $117,4123\ in)^2$). 234,8246 in. 0,1270 kg/in^3

= 28072,4843 kg

b) Berat *Head*

OD = 122,4123 in

Sf = 2,5 in

Icr = 7,625 in

Th = 1,375 in

P = 7750 kg/m^3

= 0,1270 kg/in^3

Bd = OD + OD/42 + 2.Sf+ 2/3icr

= 136,0456 in

Berat *dish* = 2(1/4π.bd^2.th.ρ*steel*)

$= 2(1/4\pi.(136{,}0456\ in)^2.\ 1{,}375\ in.\ 0{,}1270\ kg/in^3)$

= 5074,2913 kg

c) Berat Aksesoris Reaktor

- Berat *Nozzle* 1

  Ukuran = 3 in

  Berat = 10 lb (Fig 12.2, brownell and young pg 221)

- Berat *Nozzle* 2

  Ukuran = 6 in

  Berat = 24 lb

- Berat *Nozzle* 3

  Ukuran = 8 in

  Berat = 24 lb

- Berat *Nozzle* 4

  Ukuran = 4 in

  Berat = 15 lb

- Berat *Nozzle* 5

  Ukuran = 6 in

  Berat = 24 lb

- Berat *Nozzle* 6

  Ukuran = 6 in

  Berat = 24 lb

  Berat Nozzle Total = 121 lb

  = 54,884632 kg

d) Berat Sistem Pengaduk

- Berat impeler

Di = 39,1374 in

W = 7,8275 in

T = 9,7844 in

ρ = 7750 kg/m^3

= 0,1270 kg/in^3

Berat Total *six blade* = 6*(Di/2).W. t. ρ

= 6*(39,1374 in /2). 7,8275 in. 9,7844 in. 0,1270 kg/in^3

= 1142,0160 kg

- Berat Sumbu

L = 8,7600 m

D = 0,0189 m

ρ = 7750 kg/m^3

Berat sumbu = $1/4\pi d^2 L\rho$

= ¼. 3,14. $(0,0189\ m)^2$ 8,7600 m. 7750 kg/m^3

= 19,0801 kg

Berat Total = berat impeller + berat sumbu

= 1142,0160 kg + 19,0801 kg

= 1161,0961 kg

e) Berat *Baffle*

Panjang *Baffle*(H) = 5,3018 m

Lebar *Baffle* (w) = 0,1690 m

Tebal *Baffle* (W) = 0,1988 m

Jumlah = 4 buah

ρ = 7750 kg/m^3

Berat total *baffle* = n*tinggi*lebar*tebal*ρ

= 4. 5,3018 m. 0,1690 m. 0,1988 m. 7750 kg/m^3

= 5522,2696 kg

f) Berat Fluida dalam Reaktor

- Berat Bahan Baku

Laju alir Massa = 67036,5486 Kg/jam

Waktu tinggal = 0,4310 Jam

Berat Bahan Baku = (Laju alir Massa) X (Waktu tinggal)

= 67036,5486 Kg/jam. 0,4310 Jam

= 28889,9094 Kg

= 63691,2719 lb

- Berat Air Pendingin

Volume air pendingin = 33,1974 m^3

ρ Air Pendingin = 1023,0200 kg/m^3

Berat Air Pendingin = 33961,6258 kg

= 74872,47954 lb

Berat Total Fluida = Berat Bahan Baku + Berat Air Pendingin

= 28889,9094 kg + 33961,6258 kg

= 62851,5351 kg

= 138563,7515 lb

Berat Total Reaktor = Berat *Shell* + Berat Head + Berat *Bottom* + Berat Pengaduk + Berat *Buffle* + Berat Fluida

= 28072,4843 kg + 5074,2913 kg+ 5074,2913 kg + 1161,0961 kg + 5522,2696 kg +62851,5351 kg

= 102736,561 kg

g) Desain Sistem Penyangga

Berat untuk perancangan = 1,2 x Berat mati reaktor

= 1,2 x 102736,561 kg

= 123283,8732 kg

Penyangga reaktor menggunakan 4 kaki, untuk kaki penyangga dilas pada ketinggian 50% dari total tinggi reaktor

h) Tinggi kaki penyangga

Digunakan kaki penyangga tipe *I-beam* dengan pondasi cor atau beton Hk = 1/2 Hr + L

Hk = 6,1244 m

= 20,0932 ft

= 241,1185 in

L adalah jarak antara bottom reaktor dengan pondasi dan di pilih 5 ft

Dipilih digunakan I-beam 10 in

Dimensi I-*beam*

Kedalaman *Beam* = 10 in

Lebar *Flange* = 4,944 in

Web Thickness = 0,594 in

Ketebalan rata-rata *Flange* = 0,491 in

Area of Section = 10,22 in^2

Berat/ft = 35 lb

Peletakan dengan beban eksentrik *(axis 1-1)*

I = 145,8 in^4

S = 29,2 in^5

r = 3,78 in

Peletakan dengan beban eksentrik *(axis 2-2)*

I = 8,5 in^4

S = 3,4 in^5

r = 0,91 in

Axis 1-1

Hleg/r = (6,1244 m x 39,3701)/3,78 in

= 63,7880 (memenuhi, <120)

Axis 2-2

= (6,1244 m x 39,3701)/ 0,91 in

= 264,9654

Stress kompresif yang diizinkan (fc)

F*c* = 18000/(1+(l^2/(18000×r^2)))

= 18000/(1+(241,1185 in ^2/(18000×3,78 in ^2)))

Fc = 14681,29013 lb/in^2 (<15000 psi)

Jarak antara *center line* kolom penyangga dengan *center line shell* (a)

a = 1/2 . Lebar *flange* + 1,5

= 1/2 . 4,944 in + 1,5

= 3,972 in

y = 1/2 . lebar *flange*

= 1/2. 4,944 in

= 2,472 in

Z = I/y

= 145,8 in^4/2,472 in

= 58,9806 in^3

i) Mencari beban angin

P $= \frac{4.PW\ (H-L)}{n\ Dbc} + \frac{\Sigma W}{n}$

= 30820,9683 kg

= 67948,5231 lb

w = berat total reaktor

n = jumlah penyangga

- Menghitung Beban Eksentrik

Fec = P . a / Z

= (67948,5231 lb x 10,22 in^2)/ 58,9806 in^3

= 11773,9411 lb/in^2

f = fc - fec

= 14681,29013 lb/in^2 - 11773,9411 lb/in^2

= 2907,3490 lb/in^2

Luas Penampang lintang

A = p/f

= 67948,5231 lb / 2907,3490 lb/in^2

= 23,3713 in^2

Jika A < A tabel (35,13 in2) Maka memenuhi

Lug Planing

p = 67948,5231 lb

Masing masing penyangga memiliki 6 baut maka beban maksimum masing masing

P*bolt* = p/nb

= 67948,52314 lb/ 6

= 11324,7539 lb

Luas lubang baut (A*bolt*) = P*bolt*/f*bolt*

= 1324,7539 lb / 12650 lb/in^3

= 0,8952 in^2

Digunakan lubang *standard* 1 in.

b/*l* = (*h*+1,56 √rt)/l

b/l = 1,3751

sehingga ɣ1 = 0,211

Ketebalan plat kompresi

h = tinggi *gusset* = 12 in

t = *web thickness*

l = jarak radial dari luar horizontal plate luar ke luar isolator = 10 in

Ketebalan plat kompresi

My $= \frac{\boldsymbol{Pbolt}}{\boldsymbol{4\pi}} \boldsymbol{x}[(\mathbf{1}+\boldsymbol{\mu})\boldsymbol{ln}.\frac{\mathbf{2}\boldsymbol{l}}{\boldsymbol{\pi e}} + (\mathbf{1}-\boldsymbol{\gamma}\mathbf{1})$

(pers.10.40 Brownell & Young, 1059:192

My $= \frac{\mathbf{11324,75386\ lb}}{\mathbf{4.3,14}} \boldsymbol{x}[(\mathbf{1}+\mathbf{0,3})\boldsymbol{ln}.\frac{\mathbf{2.10}\boldsymbol{in}}{\mathbf{3,14.1}} + (\mathbf{1}-\mathbf{0,211})$

= 2881,6470 lb/in

thp = 1,1691 in digunakan plat standart 1 1/16 in.

Ketebalan *Gusset*

Tg = 3/8. thp

= 3/8. 1,1691 in

= 0,4384 in

Base Plate Planing

Digunakan I-*beam* ukuran 20 in dan 120 lb/ft

Panjang Kaki = 6,1244 m

Sehingga berat 1 kaki = 20,1273 ft

Sehingga beat satu *lug* = 20,1273 ft x 35 lb/ft

= 704,4568 lb

beban *base plate* (Pb)

Pb = berat 1 *lug* + P

= 704,4568 lb + 67948,5231 lb

= 68652,9799 lb

Abp = Pb/f / 2907,3490 lb/in^2

= 68652,9799 lb/

= 125,9688 in^2

Abp = lebar (le) x panjang (pa)

= (0,8. Fw + 2n)(0,95.Hb + 2n)

= (0,8 x 4,944 + 2 n) x (0,95 x 24 + 2 n)

= (3,9552+ 2n) x (22,8 + 2n)

125,9688 in^2= (3,9552+ 2.4,4014) x (22,8 + 2.4,4014)

125,9688 in^2= 125,9688 in^2

Untuk

fw = 4,944 in

hb = 24 in

n = *trial and error* yaitu 4,4014

le =(0,8.fw +2n)

= (0,8. 4,944 in + 2. 4,4014 in)

= 12,7581 in

pa1=(0,95 . Hb +2n)

= (0,95. 24 in + 2. 4,4014 in)

= 31,6029 in

Umumnya dibuat pa=le, maka dibuat pa=le= 12,7581 in

Abp,baru =le x pa

= 12,7581 in x 12,7581 in

= 162,7689 in^2

n,baru = (le - 0,8fw)/2

= (12,7581 in – 0,8. 4,944 in)

= 4,4014 in

m,baru = Pa - (0,95hb)

= 31,6029 in – (0,95. 24 in)

= 4,4014 in

Tekanan Aktual

Pa = P /Abp baru

= 68652,9799 lb / 162,7689 in^2

= 421,7820 lb/in^2

Tebal *base plate*

Tbp = l((3fc)/f allow)

= 34,8173 in