

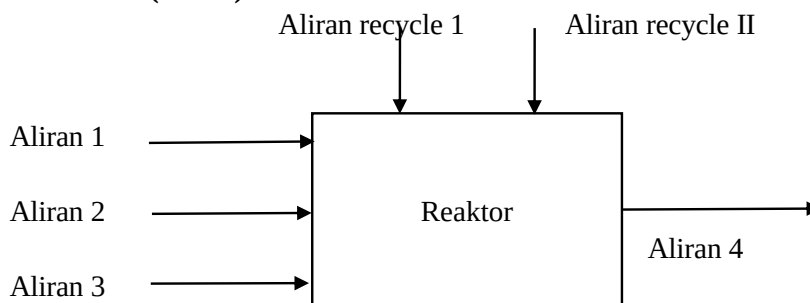


APPENDIX A PERHITUNGAN NERACA MASSA

Kapasitas Produksi = 33000 Ton / Tahun
= 100000 Kg / Hari
= 4166,67 Kg / Jam
Waktu Operasi = 330 Hari
24 Jam
Satuan = Kg/Jam
Basis Butanol = 5093,41 Kg/Jam

Komponen	BM (kg/kmol)
C_4H_9OH	74
H_2O	18
$C_{17}H_{33}COOC_4H_9$	338
$C_{15}H_{31}COOH$	256
$C_{17}H_{33}COOH$	282
H_2SO_4	98
$NaOH$	40
Na_2SO_4	142

1. Reaktor (R-210)



Fungsi : Tempat Mereaksikan Asam Oleat dan Butanol dengan Katalis Asam Sulfat

Kondisi Operasi :

Suhu = 120 °C

Tekanan = 1 atm



PRA RANCANGAN PABRIK

“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

Komposisi Awal Tangki Penyimpanan Butanol

Komponen	BM	Fraksi massa	massa (kg)	mol
C ₄ H ₉ OH	74	0,995	5067,94	68,486
H ₂ O	18	0,005	25,467	1,415
Total		1	5093,41	69,901

Komposisi awal Tangki Penyimpanan Asam Oleat

Komponen	BM	Fraksi massa	massa (kg)	mol
C ₁₇ H ₃₃ COOH	282	0,99	3862,59	13,697
C ₁₅ H ₃₁ COOH	256	0,01	38,626	0,151
Total		1	3901,22	13,848

Komposisi Tangki Penyimpanan Asam Sulfat

Komponen	BM	Fraksi massa	massa (kg)	mol
H ₂ SO ₄	98	0,98	82,55	0,8423
H ₂ O	18	0,02	1,68469	0,0936
Total		1	84,2347	0,9359

$$\begin{aligned}\text{Berat Katalis} &= 0,9365\% \times \text{Arus Total Masuk} \quad (\text{Othmer, 1950}) \\ &= 0,9365\% \times 8994,63 \text{ kg} \\ &= 84,23471 \text{ kg}\end{aligned}$$

Aliran Recycle I

Komponen	Massa (Kg)
C ₁₇ H ₃₃ COOH _(l)	0,039
C ₄ H ₉ OH _(l)	4133,172
C ₁₇ H ₃₃ COOC ₄ H ₉ _(l)	0,417
C ₁₅ H ₃₁ COOH _(l)	0,005
Total	4133,632

Aliran Recycle II

Komponen	Massa (Kg)
C ₁₇ H ₃₃ COOH _(l)	385,487
C ₄ H ₉ OH _(l)	4,13359E-05
C ₁₇ H ₃₃ COOC ₄ H ₉ _(l)	0,417
C ₁₅ H ₃₁ COOH _(l)	18,887



PRA RANCANGAN PABRIK

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Total	404,791

Menghitung Butanol dari Tangki Penyimpanan

$$\begin{aligned} \text{C}_4\text{H}_9\text{OH}_{(l)} \text{ yang diperlukan untuk reaksi} &= 5067,943 \text{ Kg/jam} \\ &= 17,971 \text{ Kmol/Kg} \end{aligned}$$

Kebutuhan Butanol dari Tangki penyimpanan :

$$\begin{aligned} \text{C}_4\text{H}_9\text{OH}_{(l)} \text{ yang dibutuhkan} &= \text{C}_4\text{H}_9\text{OH}_{(l)} \text{ yang dibutuhkan} - \\ &\quad \text{C}_4\text{H}_9\text{OH}_{(l)} \text{ recycle} \\ &= 5067,943 - 4133,172 \\ &= 934,771 \text{ Kg/jam} \end{aligned}$$

Feed Masuk

Aliran masuk dari Tangki Penyimpanan Butanol

Komponen	Massa (Kg)	Kmol/jam
$\text{C}_4\text{H}_9\text{OH}_{(l)}$	934,771	12,632
$\text{H}_2\text{O}_{(l)}$	4,697	0,261
Total	939,468	12,893

Menghitung Asam Oleat dari Tangki Penyimpanan

$$\begin{aligned} \text{C}_{17}\text{H}_{33}\text{COOH}_{(l)} \text{ yang diperlukan untuk reaksi} &= 3862,594 \text{ Kg/jam} \\ &= 13,697 \text{ Kmol/Kg} \end{aligned}$$

Kebutuhan Asam Oleat dari Gudang penyimpanan :

$$\begin{aligned} \text{C}_{17}\text{H}_{33}\text{COOH} \text{ yang dibutuhkan} &= \text{C}_{17}\text{H}_{33}\text{COOH}_{(l)} \text{ yang dibutuhkan} - \\ &\quad \text{C}_{17}\text{H}_{33}\text{COOH}_{(l)} \text{ recycle} \\ &= 3862,594 - 385,526 \\ &= 3477,069 \text{ Kg/jam} \end{aligned}$$

Aliran masuk dari Tangki Penyimpanan Asam Oleat

Komponen	% Berat	Massa (Kg)	Kmol/jam
$\text{C}_{17}\text{H}_{33}\text{COOH}_{(l)}$	99%	3477,069	12,330
$\text{C}_{15}\text{H}_{31}\text{COOH}_{(l)}$	1%	35,122	0,137
Total	100%	3512,191	12,467

Aliran masuk dari Tangki Penyimpanan Asam Sulfat

Komponen	% Berat	Massa (Kg)	Kmol/jam
H_2SO_4	98%	82,5500	0,84234713
H_2O	2%	1,6847	0,09359413
Total	100%	84,2347	0,93594125



PRA RANCANGAN PABRIK

“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
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Reaksi

	$C_{17}H_{33}COOH$	+	C_4H_9OH	$\rightarrow$	$C_{17}H_{33}COOC_4H_9$	+	H_2O
M	13,697		68,486				0,335
R	12,330		12,330		12,330		12,330
S	1,367		56,156		12,330		12,665

Konversi = 90%

Mol $C_{17}H_{33}COOH$ = Konversi x Mol mula-mula

$$= 90\% \times 13,6971 \text{ kmol/jam}$$

$$= 12,3299 \text{ kmol/jam}$$

Massa $C_{17}H_{33}COOH$ = Mol $C_{17}H_{33}COOH$ x Berat Molekul $C_{17}H_{33}COOH$

$$= 12,3299 \text{ kmol/jam} \times 282,47 \text{ kg/kmol}$$

$$= 3482,83 \text{ kg/jam}$$

Mol C_4H_9OH = 12,3299 kmol/jam

Massa C_4H_9OH = Mol C_4H_9OH x Berat Molekul

$$= 12,3299 \text{ kmol/jam} \times 74 \text{ kg/kmol}$$

$$= 912,412 \text{ kg/jam}$$

Mol H_2O = 12,3299 kmol/jam

Massa H_2O = Mol H_2O x Berat Molekul

$$= 12,3299 \text{ kmol/jam} \times 18$$

$$= 222,777 \text{ kg/jam}$$

Mol $C_{17}H_{33}COOC_4H_9$ = 12,3299 kmol/jam

Massa $C_{17}H_{33}COOC_4H_9$ = Mol $C_{17}H_{33}COOC_4H_9$ x Berat Molekul

$$= 12,3299 \text{ kmol/jam} \times 339 \text{ kg/kmol}$$

$$= 4174,53 \text{ kg/jam}$$

Feed Keluar

Sisa $C_{17}H_{33}COOH$ = Mol Mula-Mula - Mol yang bereaksi

$$= 13,6971 \text{ kmol/jam} - 12,3299 \text{ kmol/jam}$$

$$= 1,3672 \text{ kmol/jam}$$

Massa $C_{17}H_{33}COOH$ = Mol $C_{17}H_{33}COOH$ x Berat Molekul $C_{17}H_{33}COOH$

$$= 1,36725 \text{ kmol/jam} \times 282,47 \text{ kg/kmol}$$

$$= 386,207 \text{ kg/jam}$$

Sisa C_4H_9OH = Mol Mula-Mula - Mol yang bereaksi

$$= 68,4857 \text{ kmol/jam} - 12,3299 \text{ kmol/jam}$$

$$= 56,1558 \text{ kmol/jam}$$

Massa C_4H_9OH = Mol C_4H_9OH x Berat Molekul C_4H_9OH

$$= 56,1558 \text{ kmol/jam} \times 74 \text{ kg/kmol}$$

$$= 4155,53 \text{ kg/jam}$$



PRA RANCANGAN PABRIK

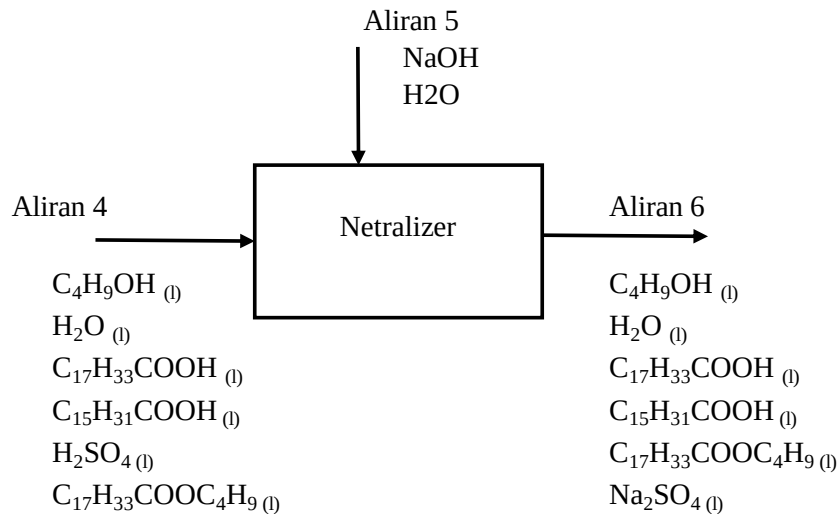
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$$\begin{aligned}
 \text{Total H}_2\text{O} &= \text{H}_2\text{O pada feed} + \text{H}_2\text{O hasil reaksi} \\
 &= (\text{H}_2\text{O dalam C}_4\text{H}_9\text{OH} + \text{H}_2\text{O dalam H}_2\text{SO}_4) + \\
 &\quad \text{H}_2\text{O hasil reaksi} \\
 &= 6,3820 \text{ kg/jam} + 222,777 \text{ kg/jam} \\
 &= 229,1592 \text{ kg/jam}
 \end{aligned}$$

Neraca Massa Reaktor (R-210)			
Aliran Masuk (Kg/jam)		Aliran Keluar (Kg/Jam)	
Komponen	massa	Komponen	massa (kg/jam)
dari tangki penyimpanan		Menuju netralizer	
H ₂ SO ₄	82,550	C ₄ H ₉ OH	4155,531
H ₂ O	1,685	H ₂ O	229,182
Total	84,235	C ₁₇ H ₃₃ COOH	385,564
		C ₁₅ H ₃₁ COOH	54,009
dari tangki penyimpanan		H ₂ SO ₄	82,550
C ₄ H ₉ OH	934,771	C ₁₇ H ₃₃ COOC ₄ H ₉	4167,504
H ₂ O	4,697		
Total	939,468		
dari tangki penyimpanan			
C ₁₇ H ₃₃ COOH	3477,069		
C ₁₅ H ₃₁ COOH	35,122		
Total	3512,191		
Aliran Recycle I			
C ₁₇ H ₃₃ COOH	0,039		
C ₄ H ₉ OH	4133,172		
C ₁₇ H ₃₃ COOC ₄ H ₉	0,417		
C ₁₅ H ₃₁ COOH	0,005		
Total	4133,632		
Aliran Recycle II			
C ₁₇ H ₃₃ COOH	385,487		
C ₄ H ₉ OH	0,000		
C ₁₇ H ₃₃ COOC ₄ H ₉	0,417		
C ₁₅ H ₃₁ COOH	18,887		
Total	404,791		
Total	9074,3168	Total	9074,3396



2. Netralizer (N-220)



Fungsi: untuk menetralkan katalis asam sulfat menggunakan Natrium Hidroksida (dengan asumsi reaksi netralisasi 100%)

Feed Masuk

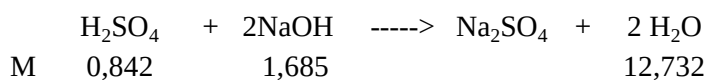
Aliran 4 (Keluaran Reaktor)

Komponen	Massa (kg/jam)	Kmol/jam
C ₄ H ₉ OH	4155,531	56,156
H ₂ O	229,182	12,732
C ₁₇ H ₃₃ COOH	385,564	1,367
C ₁₅ H ₃₁ COOH	54,009	0,211
H ₂ SO ₄	82,550	0,842
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,504	12,330
Total	9074,340	83,639

Aliran 5 (Komposisi Natrium Hidroksida)

Komponen	%Berat
NaOH	48%
H ₂ O	52%
Total	100%

Reaksi Netralisasi





PRA RANCANGAN PABRIK

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R	0,842	1,685	0,842	1,685
S	0	0	0,842	14,417

$$\begin{aligned}
 \text{Kebutuhan NaOH} &= \text{Mol NaOH yang Bereaksi} \times \text{BM NaOH} \\
 &= 1,6847 \times 40 \\
 &= 67,3878 \text{ Kg/Jam} \\
 \text{Air dari 48\% NaOH} &= \frac{\text{Kons H}_2\text{O}}{\text{Kons NaOH}} \times \text{Kebutuhan NaOH} \\
 &= \frac{52\%}{48\%} \times 67,3878 \text{ Kg/Jam} \\
 &= 73,0034 \text{ Kg/Jam} \\
 \text{Na}_2\text{SO}_4 \text{ Terbentuk} &= 0,8423 \text{ Kmolel/Jam} \\
 \text{Massa Na}_2\text{SO}_4 &= \text{Na}_2\text{SO}_4 \text{ Terbentuk} \times \text{Berat Molekul Na}_2\text{SO}_4 \\
 &= 0,8423 \text{ Kmolel/Jam} \times 142 \text{ Kg/Kmolel} \\
 &= 119,613292 \text{ Kg/Jam} \\
 \text{H}_2\text{O terbentuk} &= 1,6847 \text{ Kmolel/Jam} \\
 \text{Massa H}_2\text{O} &= \text{H}_2\text{O terbentuk} \times \text{Berat Molekul H}_2\text{O} \\
 &= 1,6847 \text{ Kmolel/Jam} \times 18 \text{ Kg/Kmolel} \\
 &= 30,3245 \text{ Kg/Jam} \\
 \text{Massa H}_2\text{O Total} &= \text{H}_2\text{O Aliran 4} + \text{H}_2\text{O Pada NaOH} + \text{H}_2\text{O dari reaksi} \\
 &= 229,182 + 73,003 + 30,324 \\
 &= 332,5097 \text{ Kg/Jam}
 \end{aligned}$$

Feed Keluar

Komponen	Massa (kg/jam)
C ₄ H ₉ OH	4155,53077
H ₂ O	332,5097
C ₁₇ H ₃₃ COOH	385,5642
C ₁₅ H ₃₁ COOH	54,0086
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,5043
Na ₂ SO ₄	119,6133
Total	9214,7308

Neraca Massa Netralizer (N-220)			
Aliran Masuk (Kg/jam)		Aliran Masuk (Kg/jam)	
Komponen	Massa	Komponen	Massa
C ₄ H ₉ OH	4155,531	C ₄ H ₉ OH	4155,531
H ₂ O	229,182	H ₂ O	332,510
C ₁₇ H ₃₃ COOH	385,564	C ₁₇ H ₃₃ COOH	385,564

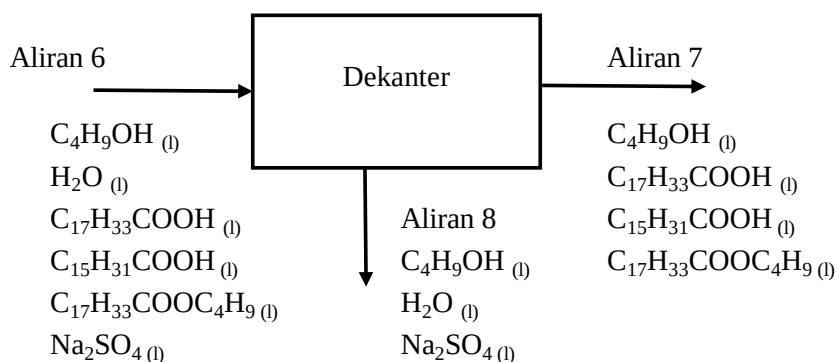


PRA RANCANGAN PABRIK

“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
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C ₁₅ H ₃₁ COOH	54,009	C ₁₅ H ₃₁ COOH	54,009
H ₂ SO ₄	82,550	C ₁₇ H ₃₃ COOC ₄ H ₉	4167,504
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,504	Na ₂ SO ₄	119,613
Total	9074,340		
Komponen	Massa		
NaOH	67,388		
H ₂ O	73,003		
Total	140,391		
Total	9214,731		

3. Dekanter (H-230)



Fungsi: untuk memisahkan fase berat dan ringan berdasarkan perbedaan densitas

Feed Masuk

Aliran 6

Komponen	Massa (kg)	Densitas (gr/ml)
C_4H_9OH	4155,5308	0,809
H_2O	332,5097	1
$C_{17}H_{33}COOH$	385,5642	0,895
$C_{15}H_{31}COOH$	54,0086	0,853
$C_{17}H_{33}COOC_4H_9$	4167,5043	0,87
Na_2SO_4	119,6133	2,66

Data Kelarutan Komponen dalam Air

1. Kelarutan butanol dalam air = 7,7 gram/100 gram air



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2. Kelarutan natrium sulfat dalam air = 44,45 gram/100 gram air
3. Asam Oleat, Asam Palmitat dan Butil Oleat tidak larut dalam air karena termasuk asam lemak

$$\text{Komponen yang terlarut} = \frac{\text{Data kelarutan (gr)}}{100 \text{ gr air}} \times \text{Massa Air}$$

Komponen	Massa (kg/jam)	Kelarutan (gr/100 gr air)	Komponen yang terlarut (kg)
C ₄ H ₉ OH	4155,53077	6,6	21,94564082
Na ₂ SO ₄	119,61	44,5	147,9668207

Butanol yang larut dalam air = 21,9456 kg

Natrium Sulfat yang larut dalam air = 147,966821 kg

Natrium sulfat yang terbentuk selama reaksi = 119,61 kg

Karena natrium sulfat yang larut dalam air dari perhitungan lebih besar

Maka seluruh Natrium Sulfat Larut dalam air

Aliran 7 (Komponen *Light Phase*)

Komponen	Fraksi massa (x)	Massa (kg)
C ₄ H ₉ OH	0,473	4133,585
C ₁₇ H ₃₃ COOH	0,044	385,564
C ₁₅ H ₃₁ COOH	0,006	54,009
C ₁₇ H ₃₃ COOC ₄ H ₉	0,477	4167,504
Total	1,000	8740,662

Aliran 8 (Komponen *Heavy Phase*)

Komponen	Fraksi massa (x)	Massa (kg)
C ₄ H ₉ OH	0,0463	21,9456
H ₂ O	0,7014	332,5097
Na ₂ SO ₄	0,2523	119,6133
Total	1,0000	474,0686

Neraca Massa Dekanter (H-230)			
Aliran Masuk (Kg/jam)		Aliran Keluar (Kg/jam)	
Komponen	Massa	Komponen	Massa

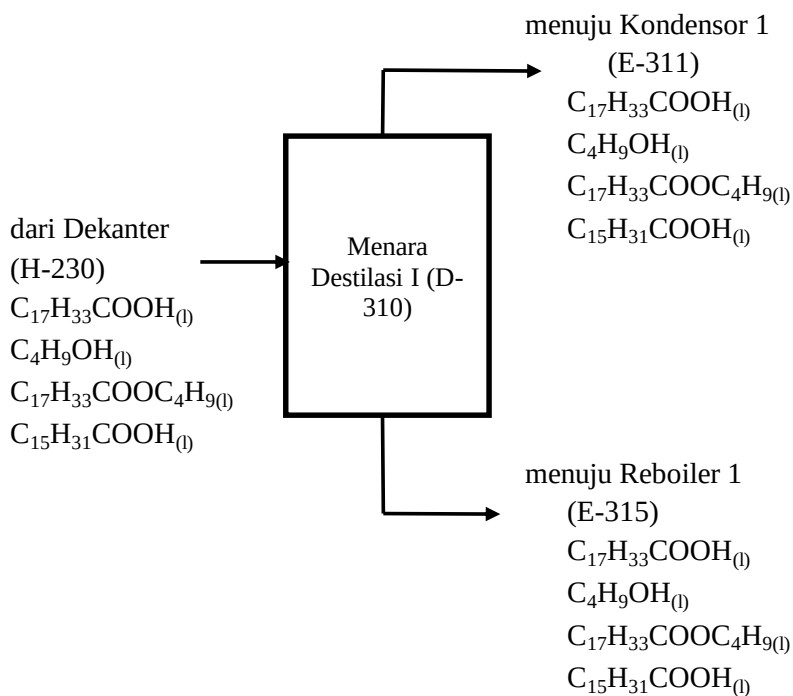


PRA RANCANGAN PABRIK

“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
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C ₄ H ₉ OH	4155,5308	C ₄ H ₉ OH	4133,5851
H ₂ O	332,5097	C ₁₇ H ₃₃ COOH	385,5642
C ₁₇ H ₃₃ COOH	385,5642	C ₁₅ H ₃₁ COOH	54,0086
C ₁₅ H ₃₁ COOH	54,0086	C ₁₇ H ₃₃ COOC ₄ H ₉	4167,5043
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,5043	Total	8740,6622
Na ₂ SO ₄	119,6133		
		Komponen	Massa
		Na ₂ SO ₄	119,6133
		C ₄ H ₉ OH	21,9456
		H ₂ O	332,5097
		Total	474,0686
Total	9214,7308	Total	9214,7308

4. Menara Distilasi 1 (D-310)



Feed Masuk

Komponen	Massa (kg)	BM (Kg/Kmol)
C ₄ H ₉ OH	4133,585	74



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$C_{17}H_{33}COOH$	385,564	282
$C_{15}H_{31}COOH$	54,009	256
$C_{17}H_{33}COOC_4H_9$	4167,504	338
Total	8740,662	-

Komposisi Bahan yang masuk ke Menara Distilasi

$$\begin{aligned}\text{Mol } C_4H_9OH &= \frac{\text{Massa } C_4H_9OH}{\text{BM } C_4H_9OH} \\ &= \frac{4133,5851}{74} \\ &= 55,8593 \text{ Kmol/jam}\end{aligned}$$

$$\begin{aligned}\text{Mol } C_{17}H_{33}COOH &= \frac{\text{Massa } C_{17}H_{33}COOH}{\text{BM } C_{17}H_{33}COOH} \\ &= \frac{385,5642}{282} \\ &= 1,3672 \text{ Kmol/jam}\end{aligned}$$

$$\begin{aligned}\text{Mol } C_{15}H_{31}COOH &= \frac{\text{Massa } C_{15}H_{31}COOH}{\text{BM } C_{15}H_{31}COOH} \\ &= \frac{54,0086}{256} \\ &= 0,2110 \text{ Kmol/jam}\end{aligned}$$

$$\begin{aligned}\text{Mol } C_{17}H_{33}COOC_4H_9 &= \frac{\text{Massa } C_{17}H_{33}COOC_4H_9}{\text{BM } C_{17}H_{33}COOC_4H_9} \\ &= \frac{4167,5043}{338} \\ &= 12,3299 \text{ Kmol/jam}\end{aligned}$$

Jumlah Komponen yang masuk = 69,7674 Kmol/Jam

Fraksi mol komponen yang masuk ke Menara Distilasi

$$\begin{aligned}\text{Fraksi mol } C_4H_9OH &= \frac{\text{Mol } C_4H_9OH}{\text{Jumlah Mol}} \\ &= \frac{55,8593}{69,7674} \\ &= 0,80065\end{aligned}$$



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$$\begin{aligned}\text{Fraksi mol } C_{17}H_{33}COOH &= \frac{\text{Fraksi mol } C_{17}H_{33}COOH}{\text{Jumlah Mol}} \\ &= \frac{1,3672}{69,7674} \\ &= 0,0196\end{aligned}$$

$$\begin{aligned}\text{Fraksi mol } C_{15}H_{31}COOH &= \frac{\text{mol } C_{15}H_{31}COOH}{\text{Jumlah Mol}} \\ &= \frac{0,2110}{69,7674} \\ &= 0,0030\end{aligned}$$

$$\begin{aligned}\text{Fraksi mol } C_{17}H_{33}COOC_4H_9 &= \frac{\text{mol } C_{17}H_{33}COOC_4H_9}{\text{Jumlah Mol}} \\ &= \frac{12,3299}{69,7674} \\ &= 0,1767\end{aligned}$$

Komponen	Massa (kg)	Fraksi Mol	Mol
C ₄ H ₉ OH	4133,585	0,801	55,859
C ₁₇ H ₃₃ COOH	385,564	0,020	1,367
C ₁₅ H ₃₁ COOH	54,009	0,003	0,211
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,504	0,177	12,330
Total	8740,662	1	69,767

Menghitung $p_{i\text{sat}}$ komponen

$$\log P_{i\text{sat}} = A + (B/(T)) + (C \log(T)) + DT + (ET^2)$$

Keterangan:

$P_{i\text{sat}}$ = tekanan saturated vapor (mmHg)

T = temperatur (K)

A, B, C, D, E = Koefisien Antoine

K-value (equilibrium ratio K_i)

$$K_i = \frac{P_{i\text{sat}}}{P} \quad (\text{Pers. (10.11) J. M. Smith 7th ed., 2005})$$

Keterangan:

K_i = equilibrium ratio K

P = tekanan operasi (mmHg)

Untuk bubble point:

$$\sum y_i = 1 \quad \text{dimana} \quad y_i = K_i x_i$$



$$\sum_i K_i x_i = 1 \quad (\text{Pers. (10.13) J. M. Smith 7th ed., 2005})$$

Untuk dew point:

$$\sum_i x_i = 1 \quad \text{dimana} \quad x_i = \frac{y_i}{K_i}$$

$$\sum_i \frac{y_i}{K_i} = 1 \quad (\text{Pers. (10.14) J. M. Smith 7th ed., 2005})$$

Data Konstanta Antoine Komponen (Yaws,1999)

Komponen	A	B	C	D	E
C ₄ H ₉ OH	39,67	-4001,7	-10,29	3,3E-10	-9E-07
C ₁₇ H ₃₃ COOH	78,69	-8822,7	-22,48	4,8E-11	2,7E-06
C ₁₅ H ₃₁ COOH	34,66	-5264,5	-8,86	0,0023	-4E-13
C ₁₇ H ₃₃ COOC ₄ H ₉	-1,28	-4920	8,95	-0,0257	1,1E-05

$$\text{Trial Bubble Point Feed} = 144,875 \text{ } ^\circ\text{C}$$

$$= 418,025 \text{ K}$$

$$\text{Tekanan Sistem (P):} = 1 \text{ Atm}$$

$$= 1,01325 \text{ Bar}$$

Komponen	Xi	Log Pi Sat	PiSat	Pi sat (bar)
C ₄ H ₉ OH	0,8007	2,9735	940,6991	1,2542
C ₁₇ H ₃₃ COOH	0,0196	-0,8755	0,1332031	0,0002
C ₁₅ H ₃₁ COOH	0,0030	-0,1961	0,6365860	0,0008
C ₁₇ H ₃₃ COOC ₄ H ₉	0,1767	1,5541	35,8202059	0,0478
Total	1			

Komponen	Ki	yi (Ki x Xi)
C ₄ H ₉ OH	1,2378	0,9910
C ₁₇ H ₃₃ COOH	0,0002	0,0000
C ₁₅ H ₃₁ COOH	0,0008	0,0000
C ₁₇ H ₃₃ COOC ₄ H ₉	0,0471	0,0083
Total		0,9993

Perhitungan Distribusi Komponen

Komponen yang diinginkan

Produk atas

$$\text{C}_4\text{H}_9\text{OH} = 99,99\%$$

$$\text{C}_{17}\text{H}_{33}\text{COOH} = 0,01\%$$



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$C_{15}H_{31}COOH = 0,01\%$

$C_{17}H_{33}COOC_4H_9 = 0,01\%$

Produk Bawah

$C_4H_9OH = 0,01\%$

$C_{17}H_{33}COOH = 99,99\%$

$C_{15}H_{31}COOH = 99,99\%$

$C_{17}H_{33}COOC_4H_9 = 99,99\%$

Komponen	Feed(Kg/jam)	XF	Distilat (Kg/jam)	XD
C_4H_9OH	4133,5851	0,47291	4133,1718	0,99989
$C_{17}H_{33}COOH$	385,5642	0,04411	0,0386	9,3E-06
$C_{15}H_{31}COOH$	54,0086	0,00618	0,0054	1,3E-06
$C_{17}H_{33}COOC_4H_9$	4167,5043	0,4768	0,4168	0,0001
Total	8740,6622	1	4133,6325	1

Komponen	Bottom (Kg/jam)	XB
C_4H_9OH	0,4134	8,97E-05
$C_{17}H_{33}COOH$	385,5256	8,37E-02
$C_{15}H_{31}COOH$	54,0032	1,17E-02
$C_{17}H_{33}COOC_4H_9$	4167,0875	9,05E-01
Total	4607,0297	1

Distribusi Mol masing masing Komponen

Komponen	Feed (Kmol/jam)	XF	Distilat (Kmol/jam)	XD
C_4H_9OH	55,8593	0,80065	55,8537	0,99998
$C_{17}H_{33}COOH$	1,3672	0,0196	0,0001	2,4E-06
$C_{15}H_{31}COOH$	0,2110	0,00302	0,0000	3,8E-07
$C_{17}H_{33}COOC_4H_9$	12,3299	0,17673	0,0012	2,2E-05
Total	69,7674	1	55,8551	1

Komponen	Bottom (Kmol/jam)	XB
C_4H_9OH	0,0056	0,0004
$C_{17}H_{33}COOH$	1,3671	0,0983
$C_{15}H_{31}COOH$	0,2110	0,0152



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$C_{17}H_{33}COOC_4H_9$	12,3287	0,8862
Total	13,9123	1,0000

Perhitungan kondisi suhu operasi bagian atas dan bawah menara distilasi

Kondisi operasi puncak menara distilasi pada dew point distilat

Trial dew point distilat = 137,073 °C

= 410,223 K

Tekanan Sistem (P): = 1 atm

= 1,01325 bar

Komponen	X_i	Log P_i Sat	P_i Sat	P_i sat (bar)
C_4H_9OH	1,0000	2,8812	760,6447	1,0141
$C_{17}H_{33}COOH$	2,4E-06	-1,1101	0,0776	0,0001
$C_{15}H_{31}COOH$	3,8E-07	-0,3811	0,4158	0,0006
$C_{17}H_{33}COOC_4H_9$	2,2E-05	1,3878	24,4214	0,0326
Total	1			

Komponen	K_i	$y_i (K_i \times X_i)$
C_4H_9OH	1,0008	1,0008
$C_{17}H_{33}COOH$	0,0001	0,0000
$C_{15}H_{31}COOH$	0,0005	0,0000
$C_{17}H_{33}COOC_4H_9$	0,0321	0,0000
Total		1,0008

Kondisi operasi dasar menara distilasi pada bubble point bottom

Trial bubble point bottom = 230,37 °C

= 503,52 K

Tekanan Sistem (P): = 1 Atm

= 1,01325 Bar

Komponen	X_i	Log P_i Sat	P_i Sat	P_i sat (bar)
C_4H_9OH	0,0004	3,6990	5000,1984	6,6664
$C_{17}H_{33}COOH$	0,0983	1,1010	12,6189	0,0168
$C_{15}H_{31}COOH$	0,0152	1,4228	26,4751	0,0353
$C_{17}H_{33}COOC_4H_9$	0,8862	2,9295	850,2142	1,1335
Total	1			

Komponen	K_i	$Y_i (K_i \times X_i)$
C_4H_9OH	6,5792	0,0026



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$C_{17}H_{33}COOH$	0,0166	0,0016
$C_{15}H_{31}COOH$	0,0348	0,0005
$C_{17}H_{33}COOC_4H_9$	1,1187	0,9914
Total		0,9962

Perhitungan Laju Alir Bagian Rectifying & Stripping untuk menentukan
Jumlah stage

Penentuan light key dan heavy key

Memisahkan Butanol dari campuran sebagai produk atas

Komponen	Ki
C_4H_9OH	1,2378
$C_{17}H_{33}COOH$	0,0002
$C_{15}H_{31}COOH$	0,0008
$C_{17}H_{33}COOC_4H_9$	0,0471

C_4H_9OH = Light Key
 $C_{17}H_{33}COOC_4H_9$ = Heavy Key

$$\alpha_{ij} = \frac{K_i}{K_j} \quad (\text{Seader 2nd Pers.7-1 Hal.256})$$

Keterangan:

α_{ij} = relative volatility

i = komponen

j = heavy key

$$\alpha \text{ average} = (\alpha_{LK} \text{ distilat} \times \alpha_{LK} \text{ bottom})^{0.5}$$

(Seader 2nd Pers.9-13 Hal.348)

Keterangan:

α_{LK} = relative volatility light key component

Komponen	Ki Feed	α_{ij} feed	Ki Distilat	α_{ij} Distilat
C_4H_9OH	1,2378	26,2617	1,0008	31,1465917
$C_{17}H_{33}COOH$	0,0002	0,0037	0,0001	0,00317747
$C_{15}H_{31}COOH$	0,0008	0,0178	0,0005	0,01702607
$C_{17}H_{33}COOC_4H_9$	0,0471	1,0000	0,0321	1

Komponen	Ki Bottom	α_{ij} Bottom
C_4H_9OH	6,5792	5,8811
$C_{17}H_{33}COOH$	0,0166	0,0148
$C_{15}H_{31}COOH$	0,0348	0,0311
$C_{17}H_{33}COOC_4H_9$	1,1187	1,0000

$$\begin{aligned} \alpha \text{ average} &= \left(\frac{31,1466}{5,8811} \right)^{0.5} \\ &= 13,5343 \end{aligned}$$



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$$N_{\min} = \frac{\log \left[\left(\frac{x_{LK}}{x_{HK}} \right)_D \times \left(\frac{x_{HK}}{x_{LK}} \right)_B \right]}{\log \alpha_{average}} \quad (\text{Seader 2nd Pers.9-12 Hal.348})$$

Keterangan:

$N_{\min}$ = minimum number of theoretical stages

x_{LK} = mol fraction of light key

x_{HK} = mol fraction of heavy key

$$N_{\min} = \frac{\log \left[\left(\frac{1,0000}{2,2E-05} \right)_D \times \left(\frac{0,8862}{0,0004} \right)_B \right]}{\log 13,5343}$$

$$N_{\min} = 7,070591885$$

θ = antara α_{HK} dan α_{LK} memenuhi, maka trial θ dilanjutkan memakai harga antara α_{HK} dan α_{LK} , untuk mendapatkan $R_{\min} + 1$ yang positif dan mendekati trial

Nilai θ di trial hingga

$$\sum \frac{\alpha_i \times x_{i,F}}{(\alpha_i - \theta)} = 0 \quad (\text{Seader 2nd Pers.9-28 Hal.351})$$

Trial $\theta = 1,211041164$

Komponen	X Feed	α_i	$\alpha_i \cdot x_F$	$\alpha_i - \theta$	$\frac{\alpha_i \cdot x_F}{\alpha_i - \theta}$
C_4H_9OH	0,8007	26,2617	21,0264	25,0506	0,8394
$C_{17}H_{33}COOH$	0,0196	0,0037	7,3E-05	-1,2073	-0,0001
$C_{15}H_{31}COOH$	0,00302	0,0178	5,4E-05	-1,1933	0,0000
$C_{17}H_{33}COOC_4H_9$	0,17673	1,0000	0,17673	-0,2110	-0,8374
Total	1				0,0018

Refluks minimum

$$R_{\min} + 1 = \sum_i \frac{\alpha_i x_D}{\alpha_i - \theta}$$

Keterangan:

(Pers. (13.37) Perry 8th ed., 2008)

$R_{\min}$ = minimum refluks ratio

x_D = fraksi mol distilat

θ = Parameter in underwood equations



$$\theta = 1,211041164$$

Komponen	x_D	α_i	$\alpha_i \cdot x_D$	$\alpha_i \cdot \theta$	$R_{min}+1$
C_4H_9OH	0,99998	31,1466	31,1458	29,9356	1,0404
$C_{17}H_{33}COOH$	2,4E-06	0,0032	7,8E-09	-1,2079	0,0000
$C_{15}H_{31}COOH$	3,8E-07	0,0170	6,4E-09	-1,1940	0,0000
$C_{17}H_{33}COOC_4H_9$	2,2E-05	1,0000	2,2E-05	-0,2110	-0,0001
Total	1				1,0403

Dari perhitungan diatas didapatkan:

$$\begin{aligned} R_{min}+1 &= 1,0403 \\ R_{min} &= 1,0403 - 1 \\ R_{min} &= 0,0403 \end{aligned}$$

$$\text{Optimum reflux ratio } (R_{opt}) = (1.2 - 1.5) \times R_{min} \quad (\text{Geankoplis, 1993})$$

$$\begin{aligned} \text{Digunakan } R_{opt} &= 1,5 \times R_{min} \\ R_{opt} &= 1,5 \times 0,0403 \\ &= 0,0605 \end{aligned}$$

Menentukan Jumlah Stage Ideal

Metode Gilliland :

$$\begin{aligned} x &= \frac{R_{op} - R_{min}}{R_{op} + 1} \quad (\text{Seader 2nd Pers.9-35 Hal.354}) \\ &= \frac{0,0605 - 0,04032}{0,0605 + 1} \\ &= 0,01901 \end{aligned}$$

$$\frac{N - N_{min}}{N + 1} = 1 - \exp \left[\left(\frac{1 + 54,4 x}{11 + 117,2 x} \right) \left(\frac{x - 1}{x^{0,5}} \right) \right] \quad (\text{Seader 2nd Pers.9-34 Hal.354})$$

$$\begin{aligned} \frac{N - 7}{N + 1} &= 1 - \exp \left[\left(\frac{2,03427}{13,2282} \right) \left(\frac{-7,1145}{1} \right) \right] \\ \frac{N - 7}{N + 1} &= 0,6652 \left(\frac{0,0403}{1} \right)^{0,567} \\ \frac{N - 7}{N + 1} &= 0,6652 (N + 1) \\ \frac{N - 7}{0,3348} &= 0,6652 N + 0,6652 \\ 0,3348 N &= 7,7357 \end{aligned}$$



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$$N = 23,1025$$

$$N = 23 \text{ Plate}$$

karena menggunakan kondensor total dan reboiler parsial, maka

$$\text{Plate idea} = N - 1$$

$$= 23 - 1$$

$$= 22 \text{ plate}$$

Menentukan Jumlah Stage Aktual dengan Efisiensi Murphree

$$E_o = \frac{\text{number of ideal stages}}{\text{number of real stages}} \times 100\%$$

$$= \frac{22}{23,1} \times 100\%$$

$$= 95,2\%$$

$$\begin{aligned} \text{Jumlah Plate aktual} &= \frac{23}{0,95} \\ &= 24,3 \\ &= 24 \text{ plate} \end{aligned}$$

Menentukan lokasi feed masuk dengan persamaan Kirk - Bride :

$$\log \left[\frac{N_r}{N_s} \right] = 0,206 \log \left[\left(\frac{B}{D} \right) \left(\frac{x_{f,HK}}{x_{f,LK}} \right) \left(\frac{x_{b,LK}}{x_{d,HK}} \right)^2 \right]$$

(Pers (11.62) ; Sinnott, 2008)

Dimana : N_R : jumlah stage pada bagian rectifying

N_S : jumlah stage pada bagian stripping

B : molar flow bottom

D : molar flow Top

$x_{f,HK}$: konsentrai Heavy Key di feed masuk

$x_{f,LK}$: konsentrasi light key di feed masuk

$x_{d,HK}$: konsentrasi heavy key di Top

$x_{b,LK}$: konsentrasi light key di bottom

data konsentrasi dari Appendix A

$$\log \frac{N_r}{N_s} = 0,206 \log \left(\frac{13,701}{55,855} \times \frac{0,0062}{0,0441} \times \left(\frac{0,00040}{0,0000} \right)^2 \right)$$

$$\log \frac{N_r}{N_s} = 0,2175$$

$$\frac{N_r}{N_s} = 1,2429 \quad \text{maka} \quad N_r = 1,2429 \quad N_s$$

dengan $N_r + N_s = N$



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$$\begin{aligned}
 23 &= N_r + N_s \\
 23 &= 1,2429 N_s + N_s \\
 23 &= 2,2429 N_s \\
 N_s &= 10,2545 = 11 \\
 \text{maka feed masuk pada plate ke} &= 11 \text{ dihitung dari plate paling bawah}
 \end{aligned}$$

Perhitungan Kondensor

Menghitung aliran masuk kondensor (L)

$$R_{opt} = L / D \quad (\text{Hal. (13-19) Perry 8th ed., 2008})$$

$$L = R_{opt} \times D$$

$$L = 0,0605 \times 55,8551$$

$$L = 3,3785 \text{ kmol}$$

Komposisi refluks (L)

Komponen	XL D	L (kmol/jam)	L (kg/jam)
C ₄ H ₉ OH	0,99998	3,378401	250,001693
C ₁₇ H ₃₃ COOH	2,4E-06	0,000008	0,002332
C ₁₅ H ₃₁ COOH	3,8E-07	0,000001	0,000327
C ₁₇ H ₃₃ COOC ₄ H ₉	2,2E-05	0,000075	0,025208
Total	1	3,3785	250,0296

Uap keluar menara distilasi menuju kondensor (V)

$$V = L + D$$

$$V = 3,3785 + 55,8551$$

$$V = 59,2335 \text{ kmol/jam}$$

Komposisi uap (V)

Komponen	XV D	V (kmol/jam)	V (kg/jam)
C ₄ H ₉ OH	0,9999751	59,23207	4383,1735
C ₁₇ H ₃₃ COOH	2,4479E-06	0,00014	0,0026
C ₁₅ H ₃₁ COOH	3,7771E-07	0,00002	0,0076
C ₁₇ H ₃₃ COOC ₄ H ₉	2,2075E-05	0,00131	0,3347
Total	1	59,2335	4383,5184

Perhitungan Reboiler

$$R = F + L$$

$$= 69,77 + 3,378$$

$$73,15 \text{ kmol/jam}$$

$$V = V$$

$$= 59,23 \text{ kmol/jam}$$



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Komposisi Reboiler (L)

Komponen	XL B	R (kmol/jam)	R (kg/jam)
C_4H_9OH	4,02E-04	59,23766	4383,5868
$C_{17}H_{33}COOH$	9,83E-02	1,36726	385,5665
$C_{15}H_{31}COOH$	1,52E-02	0,21097	54,0089
$C_{17}H_{33}COOC_4H_9$	8,86E-01	12,32997	4167,5295
Total	1	73,1459	8990,6917

Komposisi Uap Reboiler

Komponen	XV B	V(kmol/jam)	V (kg/jam)
C_4H_9OH	2,64E-03	59,23207	4383,1735
$C_{17}H_{33}COOH$	1,63E-03	0,00014	0,0409
$C_{15}H_{31}COOH$	5,28E-04	0,00002	0,0057
$C_{17}H_{33}COOC_4H_9$	9,91E-01	0,00131	0,4420
Total	0,99615877	59,2335	4383,6620

Neraca Massa Menara Destilasi 1 (D-310)			
Aliran Masuk (Kg/jam)		Aliran Keluar (Kg/jam)	
Komponen	Massa	Destilat	
C_4H_9OH	4133,585	Komponen	Massa
$C_{17}H_{33}COOH$	385,564	$C_{17}H_{33}COOH$	0,039
$C_{15}H_{31}COOH$	54,009	C_4H_9OH	4133,172
$C_{17}H_{33}COOC_4H_9$	4167,504	$C_{17}H_{33}COOC_4H_9$	0,417
		$C_{15}H_{31}COOH$	0,005
		Total	4133,632
		Bottom Product	
		Komponen	Massa
		C_4H_9OH	0,413
		$C_{17}H_{33}COOH$	385,526
		$C_{15}H_{31}COOH$	54,003
		$C_{17}H_{33}COOC_4H_9$	4167,088
		Total	4607,030
Total	8740,662	Total	8740,662

**5. Accumulator 1 (F-312)**

Fungsi = Tempat mengumpulkan kondensat pada menara distilasi 1

Aliran masuk

Aliran 9

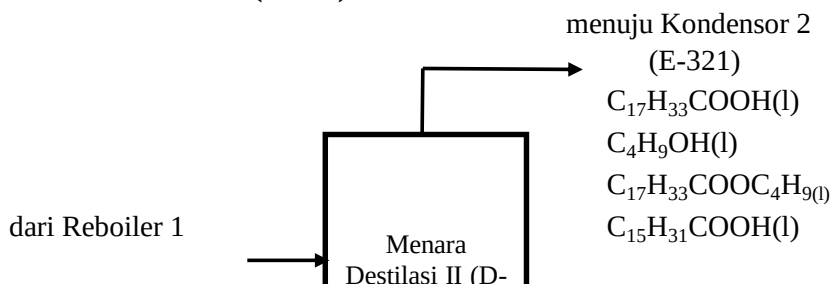
Komponen	Massa (kg)
C_4H_9OH	4133,1718
$C_{17}H_{33}COOH$	0,0386
$C_{15}H_{31}COOH$	0,0054
$C_{17}H_{33}COOC_4H_9$	0,4168
Total	4133,6325

Aliran Keluar

Aliran 9

Komponen	Massa (kg)
C_4H_9OH	4133,1718
$C_{17}H_{33}COOH$	0,0386
$C_{15}H_{31}COOH$	0,0054
$C_{17}H_{33}COOC_4H_9$	0,4168

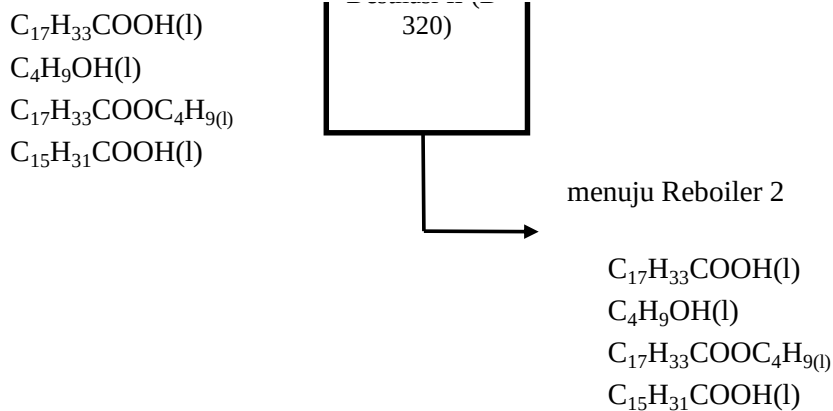
Neraca Massa Accumulator 1 (F-312)			
Aliran Masuk (Kg/jam)		Aliran Keluar (Kg/jam)	
Produk Menuju Accumulator		Produk direcycle ke reaktor	
Komponen	Massa	Komponen	Massa
$C_{17}H_{33}COOH$	0,0386	$C_{17}H_{33}COOH$	0,0386
C_4H_9OH	4133,1718	C_4H_9OH	4133,1718
$C_{17}H_{33}COOC_4H_9$	0,4168	$C_{17}H_{33}COOC_4H_9$	0,4168
$C_{15}H_{31}COOH$	0,0054	$C_{15}H_{31}COOH$	0,0054
Total	4133,63248	Total	4133,63248

6. Menara Distilasi II (D-320)



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Feed Masuk

Komponen	Massa (kg)	BM (Kg/Kmol)
C_4H_9OH	0,4134	74
$C_{17}H_{33}COOH$	385,5256	282
$C_{15}H_{31}COOH$	54,0032	256
$C_{17}H_{33}COOC_4H_9$	4167,0875	338
Total	4607,0297	

Komposisi Bahan yang masuk ke Menara Distilasi

$$\begin{aligned}
 \text{Mol } C_4H_9OH &= \frac{\text{Massa } C_4H_9OH}{\text{BM } C_4H_9OH} \\
 &= \frac{0,4134}{74} \\
 &= 0,00558593 \text{ Kmol/jam}
 \end{aligned}$$

$$\begin{aligned}
 \text{Mol } C_{17}H_{33}COOH &= \frac{\text{Massa } C_{17}H_{33}COOH}{\text{BM } C_{17}H_{33}COOH} \\
 &= \frac{385,5256}{282} \\
 &= 1,3671 \text{ Kmol/jam}
 \end{aligned}$$

$$\begin{aligned}
 \text{Mol } C_{15}H_{31}COOH &= \frac{\text{Massa } C_{15}H_{31}COOH}{\text{BM } C_{15}H_{31}COOH} \\
 &= \frac{54,0032}{256} \\
 &= 0,2110 \text{ Kmol/jam}
 \end{aligned}$$

$$\text{Mol } C_{17}H_{33}COOC_4H_9 = \frac{\text{Massa } C_{17}H_{33}COOC_4H_9}{\text{BM } C_{17}H_{33}COOC_4H_9}$$



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$$\begin{aligned} &= \frac{\text{BM } C_{17}H_{33}COOC_4H_9}{4167,0875} \\ &= \frac{338}{12,3287} \text{ Kmol/jam} \end{aligned}$$

Jumlah Komponen yang masuk = 13,9123 Kmol/Jam

Komposisi Bahan yang masuk ke Menara Distilasi

$$\begin{aligned} \text{Fraksi mol } C_4H_9OH &= \frac{\text{Mol } C_4H_9OH}{\text{Jumlah Mol}} \\ &= \frac{0,0056}{13,9123} \\ &= 0,0004 \end{aligned}$$

$$\begin{aligned} \text{Fraksi mol } C_{17}H_{33}COOH &= \frac{\text{Fraksi mol } C_{17}H_{33}COOF}{\text{Jumlah Mol}} \\ &= \frac{1,3671}{13,9123} \\ &= 0,0983 \end{aligned}$$

$$\begin{aligned} \text{Fraksi mol } C_{15}H_{31}COOH &= \frac{\text{mol } C_{15}H_{31}COOH}{\text{Jumlah Mol}} \\ &= \frac{0,2110}{13,9123} \\ &= 0,0152 \end{aligned}$$

$$\begin{aligned} \text{Fraksi mol } C_{17}H_{33}COOC_4H_9 &= \frac{\text{mol } C_{17}H_{33}COOC_4H_9}{\text{Jumlah Mol}} \\ &= \frac{12,3287}{13,9123} \\ &= 0,8862 \end{aligned}$$

Komponen	Massa (kg)	Fraksi Mol	Mol
C_4H_9OH	0,4134	0,0004	0,0056
$C_{17}H_{33}COOH$	385,5256	0,0983	1,3671
$C_{15}H_{31}COOH$	54,0032	0,0152	0,2110
$C_{17}H_{33}COOC_4H_9$	4167,0875	0,8862	12,3287
Total	4607,0297	1	13,9123



Menghitung $p_{i\text{sat}}$ komponen

$$\log P_{i\text{ sat}} = A + (B/T) + C \log(T) + DT + (ET^2)$$

Keterangan:

p_i^{sat} = tekanan saturated vapor (mmHg)

T = temperatur (K)

A, B, C, D, E = Koefisien Antoine

K-value (equilibrium ratio K_i)

$$K_i = \frac{p_i^{\text{sat}}}{P} \quad (\text{Pers. (10.11) J. M. Smith 7}^{\text{th}} \text{ ed., 2005})$$

Keterangan:

K_i = equilibrium ratio K

P = tekanan operasi (mmHg)

Untuk bubble point:

$$\sum_i y_i = 1 \quad \text{dimana} \quad y_i = K_i x_i$$

$$\sum_i K_i x_i = 1 \quad (\text{Pers. (10.13) J. M. Smith 7}^{\text{th}} \text{ ed., 2005})$$

Untuk dew point:

$$\sum_i x_i = 1 \quad \text{dimana} \quad x_i = \frac{y_i}{K_i}$$

$$\sum_i \frac{y_i}{K_i} = 1 \quad (\text{Pers. (10.14) J. M. Smith 7}^{\text{th}} \text{ ed., 2005})$$

Data Konstanta Antoine Komponen (Yaws, 1999)

Komponen	A	B	C	D	E
C ₄ H ₉ OH	39,67	-4001,7	-10,29	3,3E-10	-9E-07
C ₁₇ H ₃₃ COOH	78,69	-8822,7	-22,48	4,8E-11	2,7E-06
C ₁₅ H ₃₁ COOH	34,66	-5264,5	-8,86	0,0023	-4E-13
C ₁₇ H ₃₃ COOC ₄ H ₉	-1,28	-4920	8,95	-0,0257	1,1E-05

Trial Bubble Point Feed = 230,484 °C

= 503,634 K

Tekanan Sistem (P): = 1 atm

= 1,01325 Bar

Komponen	x_i	Log $P_{i\text{ Sat}}$	$P_{i\text{ Sat}}$	$P_{i\text{ sat}}$ (bar)
C ₄ H ₉ OH	0,0004	3,6997	5008,1345	6,6769
C ₁₇ H ₃₃ COOH	0,0983	1,1031	12,6790015	0,0169
C ₁₅ H ₃₁ COOH	0,0152	1,4246	26,5826599	0,0354



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$C_{17}H_{33}COOC_4H_9$	0,8862	2,9309	852,967144	1,1372
Total	1			

Komponen	Ki	yi (Ki x Xi)
C_4H_9OH	6,5896	0,0026
$C_{17}H_{33}COOH$	0,0167	0,0016
$C_{15}H_{31}COOH$	0,0350	0,0005
$C_{17}H_{33}COOC_4H_9$	1,1223	0,9946
Total		0,9994

Perhitungan Distribusi Komponen

Komponen yang diinginkan

Produk atas

C_4H_9OH	=	99,99%
$C_{17}H_{33}COOH$	=	0,01%
$C_{15}H_{31}COOH$	=	65,05%
$C_{17}H_{33}COOC_4H_9$	=	99,99%

Produk Bawah

C_4H_9OH	=	0,01%
$C_{17}H_{33}COOH$	=	99,99%
$C_{15}H_{31}COOH$	=	34,95%
$C_{17}H_{33}COOC_4H_9$	=	0,01%

Komponen	Feed (Kg/jam)	XF	Distilat (Kg/jam)	XD
C_4H_9OH	0,4134	9E-05	0,4133	9,8E-05
$C_{17}H_{33}COOH$	385,5256	0,08368	0,0386	9,2E-06
$C_{15}H_{31}COOH$	54,0392	0,01173	35,1525	0,00837
$C_{17}H_{33}COOC_4H_9$	4167,0875	0,9045	4166,6708	0,99153
TOTAL	4607,0657	1	4202,2752	1

Komponen	Bottom (Kg/jam)	XB
C_4H_9OH	0,0000	1,02E-07
$C_{17}H_{33}COOH$	385,4871	9,52E-01
$C_{15}H_{31}COOH$	18,8867	4,67E-02
$C_{17}H_{33}COOC_4H_9$	0,4167	1,03E-03



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Total	404,7905	1

Distribusi Mol masing masing Komponen

Komponen	Feed (Kmol/jam)	XF	Distilat (Kmol/Jam)	XD
C ₄ H ₉ OH	0,0056	0,0004	0,0056	0,00045
C ₁₇ H ₃₃ COOH	1,3671	0,09827	0,0001	1,1E-05
C ₁₅ H ₃₁ COOH	0,2110	0,01516	0,1373	0,01101
C ₁₇ H ₃₃ COOC ₄ H ₉	12,3287	0,88617	12,3274	0,98853
Total	13,9123	1	12,4705	1

Komponen	Bottom (Kmol/jam)	XB
C ₄ H ₉ OH	0,0000	0,0000
C ₁₇ H ₃₃ COOH	1,3670	0,9480
C ₁₅ H ₃₁ COOH	0,0738	0,0512
C ₁₇ H ₃₃ COOC ₄ H ₉	0,0012	0,0009
Total	1,4420	1,0000

Perhitungan kondisi suhu operasi bagian atas dan bawah menara distilasi

Kondisi operasi puncak menara distilasi pada dew point distilat

Trial dew point distilat = 226,744 C

= 499,894 K

Tekanan = 1 atm

= 1,01325 Bar

Komponen	Xi	Log Pi Sat	PiSat	Pi sat (bar)
C ₄ H ₉ OH	0,00045	3,6768	4751,06002	6,3342
C ₁₇ H ₃₃ COOH	1,1E-05	1,0348	10,8342513	0,0144
C ₁₅ H ₃₁ COOH	0,01101	1,3665	23,2521717	0,0310
C ₁₇ H ₃₃ COOC ₄ H ₉	0,98853	2,8844	#####	1,0218
Total	1			

Komponen	Ki	Yi (Ki x Xi)
C ₄ H ₉ OH	6,2514	0,0028
C ₁₇ H ₃₃ COOH	0,0143	0,0000
C ₁₅ H ₃₁ COOH	0,0306	0,0003
C ₁₇ H ₃₃ COOC ₄ H ₉	1,0084	0,9968
Total		1,0000



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Kondisi operasi dasar menara distilasi pada bubble point bottom

$$\begin{aligned}\text{Trial bubble point bottom} &= 362,217\text{ }^{\circ}\text{C} \\ &= 635,367\text{ K}\end{aligned}$$

$$\begin{aligned}\text{Tekanan} &= 1\text{ atm} \\ &= 1,01325\text{ Bar}\end{aligned}$$

Komponen	X_i	Log P_i^{Sat}	P_i^{Sat}	P_i^{sat} (bar)
$\text{C}_4\text{H}_9\text{OH}$	0,0000	4,1786	15087,8069	20,1154
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,9480	2,8658	734,229384	0,9789
$\text{C}_{15}\text{H}_{31}\text{COOH}$	0,0512	3,0008	1001,79962	1,3356
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	0,0009	4,0944	12429,2912	16,5710
Total	1			

Komponen	K_i	y_i ($K_i \times X_i$)
$\text{C}_4\text{H}_9\text{OH}$	19,8523	0,0000
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,9661	0,9158
$\text{C}_{15}\text{H}_{31}\text{COOH}$	1,3182	0,0674
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	16,3543	0,0140
Total		0,9973

Perhitungan Laju Alir Bagian Rectifying & Stripping untuk menentukan
Jumlah stage

Penentuan light key dan heavy key

Memisahkan Butil oleat dari campuran sebagai produk atas

Komponen	K_i Feed
$\text{C}_4\text{H}_9\text{OH}$	6,5896
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,0167
$\text{C}_{15}\text{H}_{31}\text{COOH}$	0,0350
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	1,1223

$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$ = Light Key

$\text{C}_{17}\text{H}_{33}\text{COOH}$ = Heavy Key

$$\alpha_{ij} = \frac{K_i}{K_j} \quad (\text{Seader 2nd Pers.7-1 Hal.256})$$

Keterangan:

α_{ij} = relative volatility

i = komponen

j = heavy key

$$\alpha_{\text{average}} = (\alpha_{\text{LK}}^{\text{distilat}} \times \alpha_{\text{LK}}^{\text{bottom}})^{0.5}$$

(Seader 2nd Pers.9-13 Hal.348)



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Keterangan:

α_{LK} = relative volatility light key component

Komponen	Ki Feed	α_{ij} feed	Ki Distilat	α_{ij} Distilat
C ₄ H ₉ OH	6,5896	394,9944	6,2514	438,5222
C ₁₇ H ₃₃ COOH	0,0167	1,0000	0,0143	1,0000
C ₁₅ H ₃₁ COOH	0,0350	2,0966	0,0306	2,1462
C ₁₇ H ₃₃ COOC ₄ H ₉	1,1223	67,2740	1,0084	70,7376

Komponen	Ki Bottom	α_{ij} Bottom
C ₄ H ₉ OH	19,8523	20,5492
C ₁₇ H ₃₃ COOH	0,9661	1,0000
C ₁₅ H ₃₁ COOH	1,3182	1,3644
C ₁₇ H ₃₃ COOC ₄ H ₉	16,3543	16,9283

$$\alpha_{\text{average}} = \left(\frac{70,7376}{16,9283} \right)^{0.5}$$

$$= 34,6045$$

$$N_{\min} = \frac{\log \left[\left(\frac{x_{LK}}{x_{HK}} \right)_D \times \left(\frac{x_{HK}}{x_{LK}} \right)_B \right]}{\log \alpha_{\text{average}}}$$

(Seader 2nd Pers.9-12 Hal.348)

Keterangan:

$N_{\min}$ = minimum number of theoritical stages

x_{LK} = mol fraction of light key

x_{HK} = mol fraction of heavy key

$$N_{\min} = \frac{\log \left[\left(\frac{0,9885}{1,1E-05} \right)_D \times \left(\frac{0,9480}{0,0009} \right)_B \right]}{\log 34,6045}$$

$$N_{\min} = 5,19768$$

θ = antara α_{HK} dan α_{LK} memenuhi, maka trial θ dilanjutkan memakai harga θ antara α_{HK} dan α_{LK} , untuk mendapatkan $R_{\min} + 1$ yang positif dan mendekati trial

Nilai θ di trial hingga

$$\sum \frac{\alpha_i \times x_{i,F}}{(\alpha_i - \theta)} = 0$$

(Seader 2nd Pers.9-28 Hal.351)



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Trial $\theta = 1,10424165$

Komponen	X Feed	α_i	$\alpha_i \cdot x_F$	$\alpha_i - \theta$	$\frac{\alpha_i \cdot x_F}{\alpha_i - \theta}$
C ₄ H ₉ OH	0,0004	394,9944	0,15859	393,8902	0,0004
C ₁₇ H ₃₃ COOH	0,09827	1,0000	0,09827	-0,1042	-0,9427
C ₁₅ H ₃₁ COOH	0,0152	2,0966	0,03179	0,9923	0,0320
C ₁₇ H ₃₃ COOC ₄ H ₉	0,88617	67,2740	59,6162	66,1698	0,9010
Total	1				-0,0093

Menghitung Refluks minimum

$$R_{\min} + 1 = \sum_i \frac{\alpha_i x_D}{\alpha_i - \theta}$$

Keterangan:

(Pers. (13.37) Perry 8th ed., 2008)

$R_{\min}$ = minimum refluks ratio

x_D = fraksi mol distilat

θ = Parameter in underwood equations

$\theta = 1,10424165$

Komponen	x_D	α_i	$\alpha_i \cdot x_D$	$\alpha_i - \theta$	$R_{\min} + 1$
C ₄ H ₉ OH	0,00045	438,5222	0,19641	437,4180	0,0004
C ₁₇ H ₃₃ COOH	1,1E-05	1,0000	1,1E-05	-0,1042	-0,0001
C ₁₅ H ₃₁ COOH	0,01101	2,1462	0,02363	1,0419	0,0227
C ₁₇ H ₃₃ COOC ₄ H ₉	0,98853	70,7376	69,9262	69,6333	1,0042
Total	1				1,0272

Dari perhitungan diatas didapatkan:

$$R_{\min} + 1 = 1,0272$$

$$R_{\min} = 1,0272 - 1$$

$$R_{\min} = 0,0272$$

$$\text{Optimum refluks ratio } (R_{\text{opt}}) = (1,2 - 1,5) \times R_{\min}$$

(Geankoplis, 1993)

$$\text{Digunakan } R_{\text{opt}} = 1,5 \times R_{\min}$$

$$R_{\text{opt}} = 1,5 \times R_{\min}$$

$$= 1,5 \times 0,0272$$

$$= 0,0408$$

Menentukan Jumlah Stage Ideal

Metode Gilliland :



$$\begin{aligned}
 x &= \frac{R_{op} - R_{min}}{R_{op} + 1} \quad (\text{Seader 2nd Pers.9-35 Hal.354}) \\
 &= \frac{0,0408 - 0,02723}{0,0408 + 1} \\
 &= 0,01308
 \end{aligned}$$

$$\frac{N - N_{min}}{N + 1} = 1 - \exp \left[\left(\frac{1 + 54,4 x}{11 + 117,2 x} \right) \left(\frac{x - 1}{x^{0,5}} \right) \right] \quad (\text{Seader 2nd Pers.9-34 Hal.354})$$

$$\frac{N - 5}{N + 1} = 1 - \exp \left[\left(\frac{1,71161}{12,5331} \right) \left(-8,629 \right) \right]$$

$$\frac{N - 5}{N + 1} = 0,6922$$

$$N - 5 = 0,6922 (N + 1)$$

$$N - 5 = 0,6922 N + 0,6922$$

$$0,3078 N = 5,8899$$

$$N = 19,1381$$

$$N = 19 \text{ Plate}$$

karena menggunakan kondensor total dan reboiler parsial, maka

$$\begin{aligned}
 \text{Plate idea} &= N - 1 \\
 &= 19 - 1 \\
 &= 18 \text{ plate}
 \end{aligned}$$

Menentukan Jumlah Stage Aktual dengan Efisiensi Murphree

$$\begin{aligned}
 E_o &= \frac{\text{number of ideal stages}}{\text{number of real stages}} \times 100\% \\
 &= \frac{18}{19,14} \times 100\% \\
 &= 94,1\%
 \end{aligned}$$

$$\begin{aligned}
 \text{Jumlah Plate aktual} &= \frac{19}{0,94} \\
 &= 20,2 \\
 &= 20 \text{ plate}
 \end{aligned}$$

Menentukan lokasi feed masuk dengan persamaan Kirk - Bride :

$$\log \left[\frac{N_r}{N_s} \right] = 0,206 \log \left[\left(\frac{B}{D} \right) \left(\frac{x_{f,HK}}{x_{f,LK}} \right) \left(\frac{x_{b,LK}}{x_{d,HK}} \right)^2 \right]$$

(Pers (11.62) ; Sinnott, 2008)

Dimana : N_R : jumlah stage pada bagian rectifying



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N_s : jumlah stage pada bagian stripping

B : molar flow bottom

D : molar flow Top

$x_{f,HK}$: konsentrai Heavy Key di feed masuk

$x_{f,LK}$: konsentrasi light key di feed masuk

$x_{d,HK}$: konsentrasi heavy key di Top

$x_{b,LK}$: konsentrasi light key di bottom

data konsentrasi dari Appendix A

$$\log \frac{N_r}{N_s} = 0,206 \log \left(\frac{385,904}{4167,12} \times \frac{0,9045}{0,0837} \times \left(\frac{0,94798}{0,9885} \right)^2 \right)$$

$$\log \frac{N_r}{N_s} = -0,0074$$

$$\frac{N_r}{N_s} = 0,9926 \quad \text{maka} \quad N_r = 0,9926 \quad N_s$$

dengan $N_r + N_s = N$

$$19 = N_r + N_s$$

$$19 = 0,9926 N_s + N_s$$

$$19 = 1,9926 N_s$$

$$N_s = 9,5352 = 10$$

maka feed masuk pada plate ke = 10 dihitung dari plate paling bawah

Perhitungan Kondensor

Menghitung aliran masuk kondensor (L)

$$R_{opt} = L / D \quad (\text{Hal. (13-19) Perry 8th ed., 2008})$$

$$L = R_{opt} \times D$$

$$L = 0,0408 \times 12,4705$$

$$L = 0,5094 \text{ kmol}$$

Komposisi refluks (L)

Komponen	XL D	L (kmol/jam)	L (kg/jam)
C_4H_9OH	0,00045	0,0002281	0,0169
$C_{17}H_{33}COOH$	1,1E-05	0,0000056	0,0016
$C_{15}H_{31}COOH$	0,01101	0,0056088	1,4358
$C_{17}H_{33}COOC_4H_9$	0,98853	0,5035273	170,1922
Total	1	0,5093698	171,6465

Uap keluar menara distilasi menuju kondensor (V)

$$V = L + D$$

$$V = 0,5094 + 12,4705$$

$$V = 12,9798 \text{ kmol/jam} \quad 4545,5682$$



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Komposisi uap (V)

Komponen	XV D	V (kmol/jam)	V (kg/jam)
C ₄ H ₉ OH	0,00044789	0,00581	0,4302
C ₁₇ H ₃₃ COOH	1,0963E-05	0,00014	0,0401
C ₁₅ H ₃₁ COOH	0,01101117	0,14292	36,5883
C ₁₇ H ₃₃ COOC ₄ H ₉	0,98852998	12,83096	4336,8630
Total	1	12,9798	4373,9217

Perhitungan Reboiler

$$\begin{aligned}
 L &= F + L \\
 &= 13,9123 + 0,5094 \\
 &= 14,4217 \text{ Kmol} \\
 V &= V \\
 &= 12,9798 \text{ Kmol}
 \end{aligned}$$

Komposisi Reboiler (L)

Komponen	XL B	L(kmol/jam)	L (kg/jam)
C ₄ H ₉ OH	1,02E-07	0,00581	0,4302
C ₁₇ H ₃₃ COOH	9,52E-01	1,36712	385,5272
C ₁₅ H ₃₁ COOH	4,67E-02	0,21656	55,4390
C ₁₇ H ₃₃ COOC ₄ H ₉	1,03E-03	12,83219	4337,2797
Total	1	14,4217	4778,6762

Komposisi Uap Reboiler (V)

Komponen	XV B	L(kmol/jam)	L (kg/jam)
C ₄ H ₉ OH	1,02E-07	0,00000	0,0001
C ₁₇ H ₃₃ COOH	9,52E-01	12,36086	3485,7622
C ₁₅ H ₃₁ COOH	4,67E-02	0,60561	155,0368
C ₁₇ H ₃₃ COOC ₄ H ₉	1,03E-03	0,01336	4,5164
Total	1	12,9798	3645,3155

Neraca Massa Menara Destilasi II (D-320)

Aliran Masuk (Kg/jam)		Aliran Keluar (Kg/jam)	
Komponen	Massa	Destilat	
C ₄ H ₉ OH	0,4134	Komponen	Massa
C ₁₇ H ₃₃ COOH	385,5256	C ₄ H ₉ OH	0,4133
C ₁₅ H ₃₁ COOH	54,0032	C ₁₇ H ₃₃ COOH	0,0386
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,0875	C ₁₅ H ₃₁ COOH	35,1525



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	$C_{17}H_{33}COOC_4H_9$		4166,6708
	Total		4202,2752
	Bottom Product		
	Komponen	Massa	
	$C_{17}H_{33}COOH$	385,4871	
	C_4H_9OH	4,1336E-05	
	$C_{17}H_{33}COOC_4H_9$	0,4167	
	$C_{15}H_{31}COOH$	18,8867	
	Total	404,7905	
Total		4607,0297	Total 4607,0656

7. Accumulator 2 (F-322)

Fungsi = Tempat mengumpulkan kondensat pada menara distilasi II

Aliran Masuk

Komponen	Massa (kg)
C_4H_9OH	0,4133
$C_{17}H_{33}COOH$	0,0386
$C_{15}H_{31}COOH$	35,1525
$C_{17}H_{33}COOC_4H_9$	4166,6708

Aliran Keluar

Aliran 18

Komponen	Massa (kg)
C_4H_9OH	0,4133
$C_{17}H_{33}COOH$	0,0386
$C_{15}H_{31}COOH$	35,1525
$C_{17}H_{33}COOC_4H_9$	4166,6708

Neraca Massa Accumulator II (F-322)			
Aliran Masuk (Kg/jam)		Aliran Keluar (Kg/jam)	
Produk Menuju Accumulator		Produk menuju cooler	
Komponen	Massa	Komponen	Massa
C_4H_9OH	0,4133	C_4H_9OH	0,4133
$C_{17}H_{33}COOH$	0,0386	$C_{17}H_{33}COOH$	0,0386
$C_{15}H_{31}COOH$	35,1525	$C_{15}H_{31}COOH$	35,1525
$C_{17}H_{33}COOC_4H_9$	4.166,6708	$C_{17}H_{33}COOC_4H_9$	4.166,6708



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Total	4.202,2752	Total	4.202,2752



APPENDIX B PERHITUNGAN NERACA PANAS

Kapasitas Produksi = 33000 ton/tahun
= 100000 kg/hari
Waktu operasi = 1 tahun = 330 hari
= 1 hari = 24 jam
Satuan Massa = kilogram/jam
Satuan Panas = kilokalori/jam
Basis waktu = 1 jam
Suhu Reference = 25 °C = 298,15 K

Data Berat Molekul

Komponen	BM
	(kg/kmol)
C ₁₇ H ₃₃ COOH	256,27
C ₄ H ₉ OH	74,12
C ₁₇ H ₃₃ COOC ₄ H ₉	338
C ₁₅ H ₃₁ COOH	256,27
H ₂ O	18
H ₂ SO ₄	98
NaOH	40
Na ₂ SO ₄	142,04

(Perry's 8th edition, 2008)

Data Kapasitas Panas Komponen pada Fase *Liquid* (J/molK)

$$C_p = A + BT + CT^2 + DT^3$$

Komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	278,69	2,5434	-0,005	4,92E-06
C ₄ H ₉ OH	83,877	0,5659	-0,002	2,28E-06
C ₁₇ H ₃₃ COOC ₄ H ₉	178,42	3,667	-0,008	7,1E-06
C ₁₅ H ₃₁ COOH	86,29	3,524	-0,007	6,1E-06
H ₂ O	92,053	-0,04	-2E-04	5E-07
H ₂ SO ₄	26,004	0,703	-0,001	1,03E-06
NaOH	87,639	-5E-04	-5E-06	1,19E-09



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Na ₂ SO ₄	233,52	-0,01	-3E-05	1,58E-06

(Yaws, 1999, Table 3-1 & 3-2)

Data Kapasitas Panas Komponen pada Fase Gas (J/molK)

$$C_p = A + BT + CT^2 + DT^3 + ET^4$$

Komponen	A	B	C	D	E
C ₁₇ H ₃₃ COOH	-55,66	1,99	-0,002	7E-08	-1E-10
C ₄ H ₉ OH	8,16	0,41	-2E-04	6E-08	-6E-12
C ₁₇ H ₃₃ COOC ₄ H ₉	-69,05	2,52	-0,002	1E-06	-3E-10
C ₁₅ H ₃₁ COOH	-54,49	1,81	-0,001	5E-07	-9E-11

(Yaws, 1999, Table 2-1 & 2-2)

$$\Delta H = n \times C_p \times \Delta T$$

$$\Delta H = n \int_{T_{ref}}^T C_p dT \quad (\text{Himmeblau 5th Ed, Eq. 4.8})$$

Penyederhanaan Intergrasi ΔH untuk Liquid

$$\begin{aligned} \Delta H &= n \times \int_{T_{ref}}^T C_p dT = n \times \int_{T_{ref}}^T (A + B.T + C.T^2 + D.T^3) dT \\ &= n \times (A(T - T_{ref}) + \frac{B}{2}(T^2 - T_{ref}^2) + \frac{C}{3}(T^3 - T_{ref}^3) + \frac{D}{4}(T^4 - T_{ref}^4)) \end{aligned}$$

Penyederhanaan Intergrasi ΔH untuk Gas

$$\begin{aligned} \Delta H &= n \times \int_{T_{ref}}^T C_p dT = n \times \int_{T_{ref}}^T (A + B.T + C.T^2 + D.T^3 + E.T^4) dT \\ &= n \times (A(T - T_{ref}) + \frac{B}{2}(T^2 - T_{ref}^2) + \frac{C}{3}(T^3 - T_{ref}^3) + \frac{D}{4}(T^4 - T_{ref}^4) \\ &\quad + \frac{E}{5}(T^5 - T_{ref}^5)) \end{aligned}$$

Keterangan:

n = mol

C_p = Kapasitas panas (J/mol.K)

ΔH = Entalpi (Joule)

T = Suhu bahan (K)



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$T_{\text{reff}} = \text{Suhu references (K)}$

1. Heater (E-122)

Fungsi : Tempat pemanasan awal (preheater) larutan asam sulfat sebelum masuk reaktor

Suhu bahan masuk = $30\text{ }^{\circ}\text{C} = 303,15\text{ K}$

Suhu bahan keluar = $120\text{ }^{\circ}\text{C} = 393,15\text{ K}$



Menghitung Entalpi Masuk

$T_{\text{in}} = 30\text{ }^{\circ}\text{C} = 303\text{ K}$

$T_{\text{ref}} = 25\text{ }^{\circ}\text{C} = 298\text{ K}$

Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
H ₂ SO ₄	82,54993	0,859574	698,5422963	143,5107065
H ₂ O	1,68469	0,095508	377,5465757	8,618240525
Total	84,23462	0,955082	1076,088872	152,128947

Menghitung Entalpi Keluar

$T_{\text{out}} = 120\text{ }^{\circ}\text{C} = 393\text{ K}$

$T_{\text{ref}} = 25\text{ }^{\circ}\text{C} = 298\text{ K}$

Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
H ₂ SO ₄	82,54993	0,859574	13795,91112	2834,274977
H ₂ O	1,68469	0,095508	7161,790985	163,4819152
Total	84,23462	0,955082	20957,7021	2997,756892

Neraca Panas Heater

Panas Masuk = Panas Keluar

Entalpi bahan masuk + Q supply = Entalpi bahan keluar + Q loss

Asumsi Q loss = 5% x Q supply



PRA RANCANGAN PABRIK
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$$\begin{aligned}
 152,13 + Q_{\text{supply}} &= 2997,8 + 5\% Q_{\text{supply}} \\
 Q_{\text{supply}} + 5\% Q_{\text{supply}} &= 2997,8 - 152,13 \\
 Q_{\text{supply}} &= \frac{2997,8 - 152,13}{0,95} \\
 Q_{\text{supply}} &= 2995,4 \text{ kkal/jam} \\
 Q_{\text{loss}} &= 149,77 \text{ kkal/jam}
 \end{aligned}$$

Menghitung Kebutuhan Steam

Steam yang digunakan jenis Low Pressure Steam dengan tekanan 4,51 atm dan suhu 148 °C

$$\begin{aligned}
 P &= 451,01 \text{ kPa} \\
 &= 4,5101 \text{ bar} \\
 H_v &= 2743 \text{ kJ/kg} && \text{(Smith Vannes 9th Ed, Table E.1)} \\
 H_L &= 623,5 \text{ kJ/kg} && \text{(Smith Vannes 9th Ed, Table E.1)} \\
 \lambda &= 2119,5 \text{ kJ/kg} \\
 &= 506,57 \text{ kkal/kg} \\
 c &= 1 \text{ Btu/lb}^\circ\text{F} \\
 &= 4,1867 \text{ kkal/kgK}
 \end{aligned}$$

$$\begin{aligned}
 Q_{\text{steam}} &= M_{\text{steam}} \times \lambda \\
 M_{\text{steam}} &= \frac{Q_{\text{steam}}}{\lambda} \\
 &= \frac{2995,398 \text{ kkal/jam}}{506,5727 \text{ kkal/kg}} \\
 &= 5,913067 \text{ kg/jam}
 \end{aligned}$$

Sehingga, didapatkan kebutuhan steam sebanyak 5,913067 kg/jam

Neraca Panas Heater (E-122)			
Input		Output	
Komponen	(kkal/jam)	Komponen	(kJ/jam)
H ₂ SO ₄	143,5107065	H ₂ SO ₄	2834,274977
H ₂ O	8,618240525	H ₂ O	163,4819152
Q supply	2995,397837	Q loss	149,7698919
Total	3147,526784	Total	3147,526784



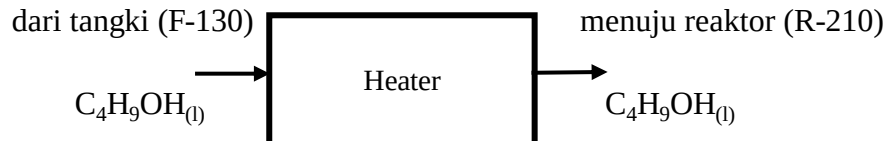
PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

2. Heater (E-132)

Fungsi : Tempat memanaskan larutan butanol sebelum masuk reaktor

Suhu bahan masuk = 30 °C = 303,15 K

Suhu bahan keluar = 120 °C = 393,15 K



Menghitung Entalpi Masuk

T in = 30 °C = 303,15 K

T ref = 25 °C = 298,15 K

Komponen	Massa (kg)	n (kmol)	∫cpdT (J/mol)	ΔH (kkal/jam)
C ₄ H ₉ OH	912,828	68,375	801,665	13100,780
H ₂ O	4,587	1,415	377,547	127,669
Total	917,415	69,790	1179,212	13228,449

Menghitung Entalpi Keluar

T out = 120 °C = 393,15 K

T ref = 25 °C = 298,15 K

Komponen	Massa (kg)	n (kmol)	∫cpdT (J/mol)	ΔH (kkal/jam)
C ₄ H ₉ OH	912,828	68,375	15995,230	261393,453
H ₂ O	4,587	1,415	7161,791	2421,786
Total	917,415	69,790	23157,021	263815,239

Neraca Panas Heater

Panas Masuk = Panas Keluar

Entalpi bahan masuk + Q supply = Entalpi bahan keluar + Q loss

Asumsi Q loss = 5% x Q supply

13228,45 + Q supply = 263815 + 5% Q supply



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$$\begin{aligned}
 Q_{\text{supply}} + 5\% Q_{\text{supply}} &= 263815 - 13228 \\
 Q_{\text{supply}} &= \frac{263815 - 13228}{0,95} \\
 Q_{\text{supply}} &= 263776 \text{ Kkal/jam} \\
 Q_{\text{loss}} &= 13189 \text{ Kkal/jam}
 \end{aligned}$$

Menghitung Kebutuhan Steam

Steam yang digunakan jenis Low Pressure Steam dengan tekanan 4,51 atm dan suhu 148 °C

$$\begin{aligned}
 P &= 451,01 \text{ kPa} \\
 &= 4,5101 \text{ bar} \\
 H_v &= 2743 \text{ kJ/kg} && \text{(Smith Vannes 9th Ed, Table E.1)} \\
 H_L &= 623,5 \text{ kJ/kg} && \text{(Smith Vannes 9th Ed, Table E.1)} \\
 \lambda &= 2119,5 \text{ kJ/kg} \\
 &= 506,57 \text{ kkal/kg} \\
 c &= 1 \text{ Btu/lb}^\circ\text{F} \\
 &= 4,1867 \text{ kkal/kgK}
 \end{aligned}$$

$$\begin{aligned}
 Q_{\text{steam}} &= M_{\text{steam}} \times \lambda \\
 M_{\text{steam}} &= \frac{Q_{\text{steam}}}{\lambda} \\
 &= \frac{263775,6 \text{ kkal/jam}}{506,5727 \text{ kkal/kg}} \\
 &= 520,7063 \text{ kg/jam}
 \end{aligned}$$

Sehingga, didapatkan kebutuhan steam sebanyak 520,7063 kg/jam

Neraca Panas Heater (E-132)			
Input		Output	
Komponen	(kkal/jam)	Komponen	(kkal/jam)
C ₄ H ₉ OH	13100,78008	C ₄ H ₉ OH	261393,4527
H ₂ O	127,6687642	H ₂ O	2421,785982
Q supply	263775,5683	Q loss	13188,77841
Total	277004,0171	Total	277004,0171

3. Heater (E-142)

Fungsi : Tempat pemanasan awal larutan asam oleat sebelum masuk reaktor



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Suhu bahan masuk = 30 °C = 303,15 K

Suhu bahan keluar = 120 °C = 393,15 K



Menghitung Entalpi Masuk

$T_{in} = 30\text{ °C} = 303\text{ K}$

$T_{ref} = 25\text{ °C} = 298\text{ K}$

Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	3477,069	13,507	3429,270	11070,141
$C_{15}H_{31}COOH$	35,122	0,152	3249,459	118,240
Total	3512,191	13,659	6678,729	11188,382

Menghitung Entalpi Keluar

$T_{out} = 120\text{ °C} = 393\text{ K}$

$T_{ref} = 25\text{ °C} = 298\text{ K}$

Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	3477,069	13,507	67593,084	218199,490
$C_{15}H_{31}COOH$	35,122	0,152	64692,154	2353,997
Total	3512,191	13,659	132285,238	220553,486

Neraca Panas

Panas Masuk = Panas Keluar

Entalpi bahan masuk + Q supply = Entalpi bahan keluar + Q loss

Asumsi Q loss = 5% x Q supply

$11188,38 + Q_{supply} = 220553 + 5\% Q_{supply}$

$Q_{supply} + 5\% Q_{supply} = 220553 - 11188$

$Q_{supply} = \frac{220553 - 11188}{0,95}$



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“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
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$$Q_{\text{supply}} = 220384 \text{ kkal/jam}$$

$$Q_{\text{loss}} = 11019 \text{ kkal/jam}$$

Menghitung Kebutuhan Steam

Steam yang digunakan jenis Low Pressure Steam dengan tekanan 4,51 atm dan suhu 148 °C

$$P = 451,01 \text{ kPa}$$

$$= 4,5101 \text{ bar}$$

$$H_v = 2743 \text{ kJ/kg} \quad (\text{Smith Vannes 9th Ed, Table E.1})$$

$$H_L = 623,5 \text{ kJ/kg} \quad (\text{Smith Vannes 9th Ed, Table E.1})$$

$$\lambda = 2119,5 \text{ kJ/kg}$$

$$= 506,57 \text{ kkal/kg}$$

$$c = 1 \text{ Btu/lb}^\circ\text{F}$$

$$= 4,1867 \text{ kkal/kgK}$$

$$Q_{\text{steam}} = M_{\text{steam}} \times \lambda$$

$$M_{\text{steam}} = \frac{Q_{\text{steam}}}{\lambda}$$

$$= \frac{220384,3 \text{ kkal/jam}}{506,5727 \text{ kkal/kg}}$$

$$= 435,0498 \text{ kg/jam}$$

Sehingga, didapatkan kebutuhan steam sebanyak 435,0498 kg/jam

Neraca Panas Heater (E-142)			
Input		Output	
Komponen	(kkal/jam)	Komponen	(kkal/jam)
C ₁₇ H ₃₃ COOH	11070,14143	C ₁₇ H ₃₃ COOH	218199,4897
C ₁₅ H ₃₁ COOH	118,2402313	C ₁₅ H ₃₁ COOH	2353,996589
Q supply	220384,3207	Q loss	11019,21603
Total	231572,7023	Total	231572,7023



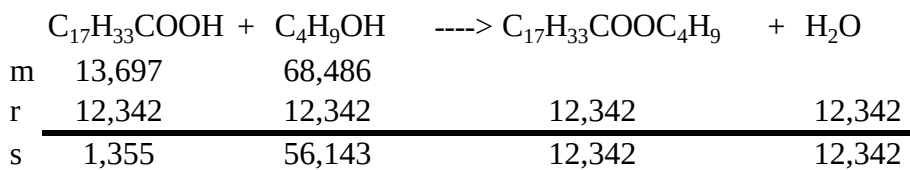
PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

4. Reaktor (R-210)

Fungsi : Tempat Mereaksikan Asam Oleat dan Butanol dengan katalis asam sulfat

Konversi = 90%
 Tekanan Operasi = 1 atm
 Suhu operasi = 120 °C
 Waktu Tinggal = 120 Menit
 = 2 jam

Reaksi yang terjadi



ΔH (suhu ref 273 K)

Suhu (K)	$\text{C}_{17}\text{H}_{33}\text{COOH}$	$\text{C}_4\text{H}_9\text{OH}$	$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	$\text{C}_{15}\text{H}_{31}\text{COOH}$	H_2O	H_2SO_4
298,15	14722,3302	2943,5	15360,4796	13232,5909	1659,99	2976,9
393,15	67337,2760	12015	68424,4187	59369,3751	7194,384	13640

Panas masuk 120 C (393,15 K)

Komponen	Massa (kg)	n (kmol)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
$\text{C}_{17}\text{H}_{33}\text{COOH}$	3862,5944	13,6971	67593,0840	221279,1933
$\text{C}_4\text{H}_9\text{OH}$	5067,9430	68,48572	15995,2305	261817,5922
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	0,8335	0,0025	74661,1732	44,0018
$\text{C}_{15}\text{H}_{31}\text{COOH}_{(l)}$	54,0140	0,2110	64692,1543	3262,3186
H_2O	6,2718	0,3484	7161,7910	596,4131
H_2SO_4	82,5499	0,8423	13795,9111	2777,4699
Total				489776,9889

Menghitung ΔH reaksi

Komponen	mol	ΔH_f (kJ/kmol)	ΔH°_f (kkal/jam)



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$C_{17}H_{33}COOH$	12,342	-746,8	-2201,10933
C_4H_9OH	12,342	-327,18	-964,3263935
$C_{17}H_{33}COOC_4H_9$	12,342	-816,88	-2407,662279
H_2O	12,342	-285,83	-842,4519013

$$\begin{aligned}\Delta H_f &= \Delta H \text{ Produk} - \Delta H \text{ reaktan} \\ &= -3250,114 - -3165,436 \\ &= -84,67846 \text{ kkal/jam}\end{aligned}$$

Menghitung Entalpi Keluar

$$T_{out} = 120 \text{ } ^\circ\text{C} = 393 \text{ K}$$

$$T_{ref} = 25 \text{ } ^\circ\text{C} = 298 \text{ K}$$

Komponen	Massa (kg)	n (kmol)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	385,564	1,355	67593,084	21884,512
C_4H_9OH	4155,531	56,143	15995,230	214632,826
$C_{17}H_{33}COOC_4H_9$	4167,504	12,342	74661,173	220245,030
$C_{15}H_{31}COOH$	54,009	0,137	64692,154	2121,280
H_2O	229,159	12,691	7161,791	21723,176
H_2SO_4	82,550	0,842	13795,911	2777,470
Total	9074,317	83,511	243899,344	433384,294

$$Q = [H \text{ produk}] - [H \text{ reaktan}]$$

Produk

$$\Delta H \text{ } C_{17}H_{33}COOH = 21884,512 \text{ kkal/jam}$$

$$\Delta H \text{ } C_4H_9OH = 214632,826 \text{ kkal/jam}$$

$$\Delta H \text{ } C_{17}H_{33}COOC_4H_9 = 220245,030 \text{ kkal/jam}$$

$$\Delta H \text{ } C_{15}H_{31}COOH = 2121,280 \text{ kkal/jam}$$

$$\Delta H \text{ } H_2O = 21723,176 \text{ kkal/jam}$$

$$\Delta H \text{ } H_2SO_4 = 2777,470 \text{ kkal/jam}$$

Reaktan

$$\Delta H \text{ } C_{17}H_{33}COOH = 221279,193 \text{ kkal/jam}$$

$$\Delta H \text{ } C_4H_9OH = 261817,592 \text{ kkal/jam}$$

$$\Delta H \text{ } C_{17}H_{33}COOC_4H_9 = 44,002 \text{ kkal/jam}$$



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“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

$$\begin{aligned}\Delta H \text{ C}_{15}\text{H}_{31}\text{COOH} &= 3262,319 \text{ kkal/jam} \\ \Delta H \text{ H}_2\text{O} &= 596,413 \text{ kkal/jam} \\ \Delta H \text{ H}_2\text{SO}_4 &= 2777,470 \text{ kkal/jam} \\ Q &= -6392,695 \text{ kkal/jam}\end{aligned}$$

$$\begin{aligned}Q \text{ input} &= Q \text{ output} \\ Q \text{ in} + Q_r &= Q \text{ out} + Q_p \\ Q_p &= 6477,374 \text{ kkal/jam}\end{aligned}$$

Menghitung Kebutuhan Air Pendingin

$$\begin{aligned}\text{Suhu air masuk} &= 30^\circ\text{C} = 303,15 \text{ K} && \text{(Ulrich, 1984)} \\ \text{Suhu air keluar} &= 45^\circ\text{C} = 318,15 \text{ K} && \text{(Ulrich, 1984)} \\ \text{Cp air pendingin} &= 1 \text{ kkal/kg}^\circ\text{C} && \text{(Geankoplis, 1997)}\end{aligned}$$

$$\begin{aligned}Q_p &= m \times C_p \times \Delta T \\ m \text{ air pendingin} &= \frac{Q \text{ pendingin}}{C_p \times \Delta T} \\ &= \frac{6477,374 \text{ kkal/jam}}{1 \text{ kkal/kgK} \times 15 \text{ K}} \\ &= 431,8249 \text{ kg}\end{aligned}$$

Sehingga didapatkan kebutuhan air pendingin sebesar 431,8249 kg/jam

Neraca Panas Reaktor (R-210)			
Input		Output	
Komponen	(kkal/jam)	Komponen	(kkal/jam)
Aliran 1		C ₁₇ H ₃₃ COOH	21884,51221
H ₂ SO ₄	2777,469901	C ₄ H ₉ OH	214632,8257
H ₂ O	160,2055138	C ₁₇ H ₃₃ COOC ₄ H ₉	220245,03
Total	2937,675415	C ₁₅ H ₃₁ COOH	2121,28028
Aliran 2		H ₂ O	21723,17553
C ₄ H ₉ OH	47158,05798	H ₂ SO ₄	2777,469901
H ₂ O	436,2075615		
Total	47594,26554		
Aliran 3			
C ₁₇ H ₃₃ COOH	199193,3128		

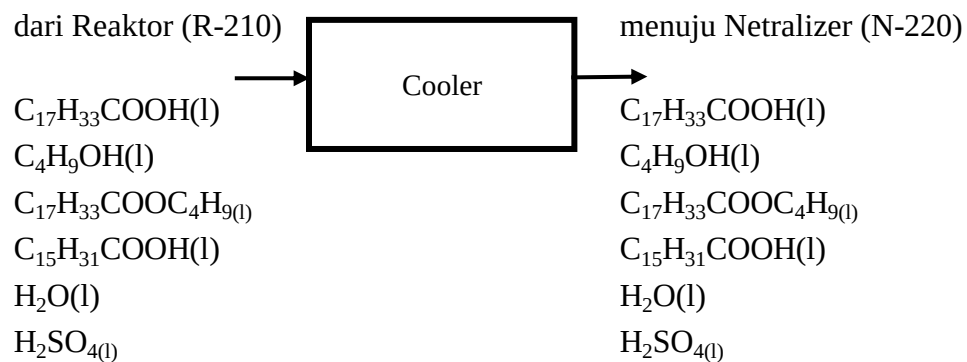


PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

C ₁₅ H ₃₁ COOH	2121,28028		
Total	201314,5931		
Aliran recyle I			
C ₁₇ H ₃₃ COOH	2,208808907		
C ₄ H ₉ OH	214659,5321		
C ₁₇ H ₃₃ COOC ₄ H ₉	22,00201655		
C ₁₅ H ₃₁ COOH	0,326199242		
Total	214684,0691		
Aliran recycle II			
C ₁₇ H ₃₃ COOH	22083,67167		
C ₄ H ₉ OH	0,00214681		
C ₁₇ H ₃₃ COOC ₄ H ₉	21,99981635		
C ₁₅ H ₃₁ COOH	1140,712141		
Total	23246,38578		
Δ H reaksi	-6392,6952		
Total	483384,294	Total	483384,294

5. Cooler (E-211)

Fungsi : Mendinginkan produk dari suhu 120°C menjadi 30°C untuk dialirkan menuju netralizer (N-220)



Suhu masuk = 120 °C = 393,15 K

Suhu keluar = 30 °C = 303,15 K

Menghitung Entalpi Masuk

T in = 120 °C = 393,15 K



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$$T_{\text{ref}} = 25\text{ }^{\circ}\text{C} = 298,15\text{ K}$$

Komponen	Massa (kg)	n (kmol)	$\int_{\text{cpdT}}$ (J/mol)	ΔH (kkal/jam)
$\text{C}_{17}\text{H}_{33}\text{COOH}$	385,5642	1,354647	67593,084	21884,51221
$\text{C}_4\text{H}_9\text{OH}$	4155,531	56,14322	15995,2305	214632,8257
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	4167,504	12,3425	74661,17319	220245,03
$\text{C}_{15}\text{H}_{31}\text{COOH}$	54,00861	0,137195	64692,15432	2121,28028
H_2O	229,159	12,69093	7161,790985	21723,17553
H_2SO_4	82,55002	0,842346	13795,91112	2777,469901
Total	9074,317	83,51083	243899,3441	483384,2937

Menghitung Entalpi Keluar

$$T_{\text{out}} = 30\text{ }^{\circ}\text{C} = 303\text{ K}$$

$$T_{\text{ref}} = 25\text{ }^{\circ}\text{C} = 298\text{ K}$$

Komponen	Massa (kg)	n (kmol)	$\int_{\text{cpdT}}$ (J/mol)	ΔH (kkal/jam)
$\text{C}_{17}\text{H}_{33}\text{COOH}$	385,5642	1,354647	3429,270164	1110,289697
$\text{C}_4\text{H}_9\text{OH}$	4155,531	56,14322	801,6650564	10757,18392
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	4167,504	12,3425	3765,12283	11106,83847
$\text{C}_{15}\text{H}_{31}\text{COOH}$	54,00861	0,137195	3249,458954	106,5509917
H_2O	229,159	12,69093	377,5465757	1145,175914
H_2SO_4	82,55002	0,842346	698,5422963	140,6344377
Total	9074,317	83,51083	12321,60588	24366,67344

Neraca Panas

$$\text{Panas masuk} = \text{Panas Keluar}$$

$$\Delta H_{\text{in}} = \Delta H_{\text{out}} + Q_{\text{serap}}$$

$$483384,2937 = 24366,67344 + Q_{\text{serap}}$$

$$Q_{\text{serap}} = 459017,6202\text{ kkal/jam}$$

Menghitung Kebutuhan Air Pendingin

$$\text{Suhu air masuk} = 30\text{ }^{\circ}\text{C} = 303,15\text{ K} \quad (\text{Ulrich, 1984})$$

$$\text{Suhu air keluar} = 45\text{ }^{\circ}\text{C} = 318,15\text{ K} \quad (\text{Ulrich, 1984})$$



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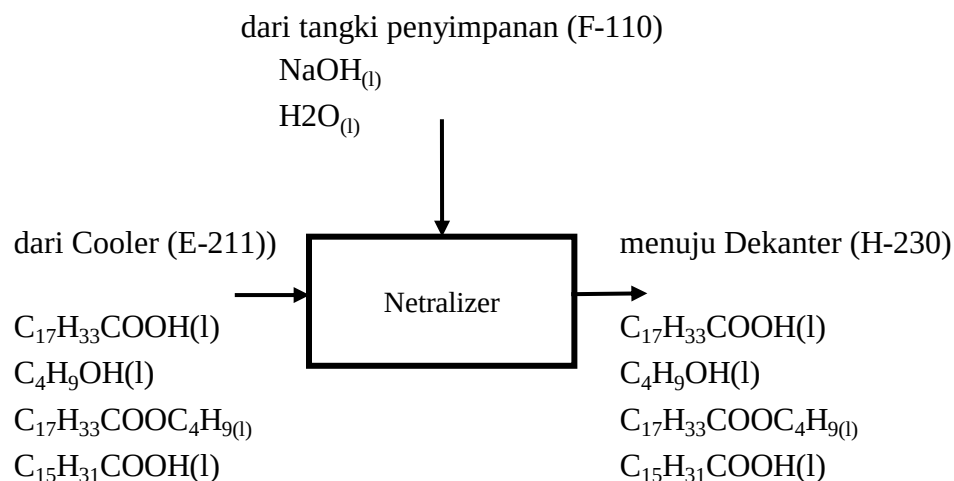
$$C_p \text{ air pendingin} = 1 \text{ kkal/kg}^0\text{C} \quad (\text{Geankoplis, 1997})$$

$$\begin{aligned} Q \text{ serap} &= m \times C_p \times \Delta T \\ m \text{ air pendingin} &= \frac{Q \text{ serap}}{C_p \times \Delta T} \\ &= \frac{459017,6 \text{ kkal/jam}}{1 \text{ kkal/kgK} \times 15 \text{ K}} \\ &= 30601,17 \text{ kg} \end{aligned}$$

Sehingga didapatkan kebutuhan air pendingin sebesar 30601,17 kg/jam

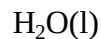
Neraca Panas Cooler (E-211)			
Input		Output	
Komponen	(kkal/jam)	Komponen	(kkal/jam)
C ₁₇ H ₃₃ COOH	21884,51221	C ₁₇ H ₃₃ COOH	1110,289697
C ₄ H ₉ OH	214632,8257	C ₄ H ₉ OH	10757,18392
C ₁₇ H ₃₃ COOC ₄ H ₉	220245,03	C ₁₇ H ₃₃ COOC ₄ H ₉	11106,83847
C ₁₅ H ₃₁ COOH	2121,28028	C ₁₅ H ₃₁ COOH	106,5509917
H ₂ O	21723,17553	H ₂ O	1145,175914
H ₂ SO ₄	2777,469901	H ₂ SO ₄	140,6344377
		Q serap	459017,6202
Total	483384,2937	Total	483384,2937

6. Netralizer (N-220)





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Menghitung Entalpi Masuk

Arus dari cooler (E-211)

$$T_{\text{out}} = 30 \text{ } ^\circ\text{C} = 303,15 \text{ K}$$

$$T_{\text{ref}} = 25 \text{ } ^\circ\text{C} = 298,15 \text{ K}$$

Komponen	Massa (kg)	n (kmol)	$\int_{\text{cpdT}}$ (J/mol)	ΔH (kkal/jam)
$\text{C}_{17}\text{H}_{33}\text{COOH}$	385,5642	1,354647	3429,270164	1110,289697
$\text{C}_4\text{H}_9\text{OH}$	4155,531	56,14322	801,6650564	10757,18392
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	4167,504	12,3425	3765,12283	11106,83847
$\text{C}_{15}\text{H}_{31}\text{COOH}$	54,00861	0,137195	3249,458954	106,5509917
H_2O	229,159	12,69093	377,5465757	1145,175914
H_2SO_4	82,55002	0,842346	698,5422963	140,6344377
Total	9074,317	83,51083	12321,60588	24366,67344

Arus dari Tangki Penyimpanan (F-110)

$$T_{\text{out}} = 30 \text{ } ^\circ\text{C} = 303,15 \text{ K}$$

$$T_{\text{ref}} = 25 \text{ } ^\circ\text{C} = 298,15 \text{ K}$$

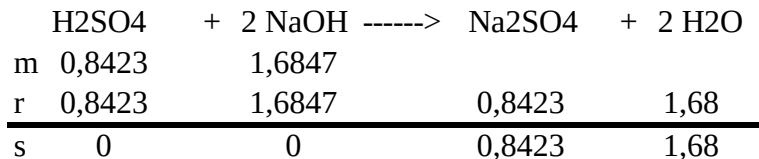
Komponen	Massa (kg)	n (kmol)	$\int_{\text{cpdT}}$ (J/mol)	ΔH (kkal/jam)
NaOH	67,38769	1,684692	435,576243	175,3852323
H_2O	73,00333	4,0558	377,5465757	365,9783465
Total	140,391	5,740492	435,576243	541,3635788

$$\begin{aligned} \text{Total Entalpi Masuk} &= 24366,67 \text{ kkal/jam} + 541,3636 \text{ kkal/jam} \\ &= 24908,04 \text{ kkal/jam} \end{aligned}$$



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Menghitung Entalpi Reaksi



Komponen	mol (kmol)	ΔH_f (kJ/kmol)	ΔH_f (kkal)
H ₂ SO ₄	0,8423	-735,13	-147,935
NaOH	1,6847	-425,62	-171,3005
Na ₂ SO ₄	0,8423	-1387,1	-279,1351
H ₂ O	1,6847	-285,8	-115,0268

$$\begin{aligned}\Delta H_f &= \Delta H_f \text{ produk} - \Delta H_f \text{ reaktan} \\ &= -509,1886 - -490,536 \\ &= -18,65 \text{ kkal}\end{aligned}$$

Menghitung Entalpi Keluar

$$\begin{aligned}T_{\text{out}} &= 30 \text{ }^\circ\text{C} = 303 \text{ K} \\ T_{\text{ref}} &= 25 \text{ }^\circ\text{C} = 298 \text{ K}\end{aligned}$$

Komponen	Massa (kg)	n (kmol)	$\int c_p dT$ (J/mol)	ΔH (kkal/jam)
C ₁₇ H ₃₃ COOH	385,5642	1,354647	3429,270164	896,1134441
C ₄ H ₉ OH	4155,531	56,14322	801,6650564	8682,109864
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,504	12,3425	3765,12283	8964,31562
C ₁₅ H ₃₁ COOH	54,00861	0,137195	3249,458954	85,99717389
H ₂ O	332,4868	18,43142	377,5465757	1342,345509
Na ₂ SO ₄	119,6131	0,842346	1352,270228	219,729826
Total	9214,708	89,25132	12975,33381	20190,61144

$$\begin{aligned}\Delta H_{\text{rxn}} &= \Delta H_{R, T_{\text{ref}}} + (\Delta H_{\text{Produk}} - \Delta H_{\text{Reaktan}}) \\ &= -4736,078 \text{ kkal/jam}\end{aligned}$$

Neraca Panas



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$$\text{Panas Masuk} = \text{Panas Keluar}$$

$$\Delta H \text{ bahan masuk} = \Delta H \text{ bahan keluar} + Q \text{ Supply} + \Delta H_{rxn}$$

$$24908,04 = 20191 + Q \text{ Serap} + -4736,078$$

$$Q \text{ Serap} = 9453,504 \text{ kkal/jam}$$

Menghitung Kebutuhan Air Pendingin

$$\text{Suhu air masuk} = 30^\circ\text{C} = 303,15 \text{ K} \quad (\text{Ulrich, 1984})$$

$$\text{Suhu air keluar} = 45^\circ\text{C} = 318,15 \text{ K} \quad (\text{Ulrich, 1984})$$

$$C_p \text{ air pendingin} = 1 \text{ kkal/kg}^\circ\text{C} \quad (\text{Geankoplis, 1997})$$

$$\begin{aligned} Q \text{ serap} &= m \times C_p \times \Delta T \\ m \text{ air pendingin} &= \frac{Q \text{ serap}}{C_p \times \Delta T} \\ &= \frac{9453,504 \text{ kkal/jam}}{1 \text{ kkal/kgK} \times 15 \text{ K}} \\ &= 630,2336 \text{ kg} \end{aligned}$$

Sehingga didapatkan kebutuhan air pendingin sebesar 630,2336 kg/jam

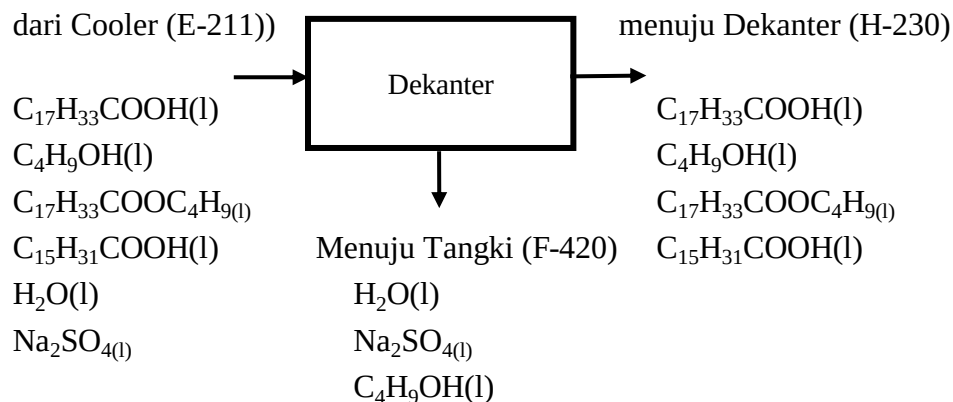
Neraca Panas Netralizer (N-220)			
Input		Output	
Komponen	(kkal/jam)	Komponen	(kkal/jam)
$\text{C}_{17}\text{H}_{33}\text{COOH}$	1110,289697	$\text{C}_{17}\text{H}_{33}\text{COOH}$	896,1134441
$\text{C}_4\text{H}_9\text{OH}$	10757,18392	$\text{C}_4\text{H}_9\text{OH}$	8682,109864
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	11106,83847	$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	8964,31562
$\text{C}_{15}\text{H}_{31}\text{COOH}$	106,5509917	$\text{C}_{15}\text{H}_{31}\text{COOH}$	85,99717389
H_2O	1511,15426	H_2O	1342,345509
H_2SO_4	140,6344377	Na_2SO_4	219,729826
NaOH	175,3852323	ΔH_{rxn}	-4736,07819
		Q serap	9453,503766
Total	24908,03702	Total	24908,03702

7. Dekanter (H-230)

Fungsi : Memisahkan produk butil oleat dengan natrium sulfat berdasarkan perbedaan densitas



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Menghitung Entalpi Bahan Masuk

$$T_{in} = 30\text{ }^{\circ}\text{C} = 303,15\text{ K}$$

$$T_{ref} = 25\text{ }^{\circ}\text{C} = 298,15\text{ K}$$

Komponen	Massa (kg)	n (kmol)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	385,5642	1,367249	3429,270164	1120,617974
C_4H_9OH	4155,531	56,15582	801,6650564	10759,59838
$C_{17}H_{33}COOC_4H_9$	4167,504	12,32989	3765,12283	11095,49868
$C_{15}H_{31}COOH$	54,00861	0,210971	3249,458954	163,8484696
H_2O	332,4869	18,4715	377,5465757	1666,7901
Na_2SO_4	119,6133	0,842347	1352,270228	272,2468792
Total	9214,708	89,37778	12975,33381	25078,60048

Menghitung Entalpi keluar

Arus menuju heater (E-231)

Pada *Light Phase*

$$T_{out} = 30\text{ }^{\circ}\text{C} = 303,15\text{ K}$$

$$T_{ref} = 25\text{ }^{\circ}\text{C} = 298,15\text{ K}$$

Komponen	Massa (kg)	n (kmol)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	385,5642	1,367249	3429,270164	1120,617974
C_4H_9OH	4155,531	56,15582	801,6650564	10759,59838
$C_{17}H_{33}COOC_4H_9$	4167,504	12,32989	3765,12283	11095,49868



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

$C_{15}H_{31}COOH$	54,00861	0,210971	3249,458954	163,8484696
Total	8762,608	70,06394	11245,517	23139,5635

Arus menuju Tangki Penyimpanan (F-420)

Pada *Heavy Phase*

$$T_{out} = 30\text{ }^{\circ}\text{C} = 303,15\text{ K}$$

$$T_{ref} = 25\text{ }^{\circ}\text{C} = 298,15\text{ K}$$

Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
C_4H_9OH	21,94414	0,296542	801,6650564	6E+01
H_2O	332,4869	18,4715	4E+02	2E+03
Na_2SO_4	119,6133	0,842347	1352,270228	272,2468792
Total	474,0443	19,61038	2531,481861	2E+03

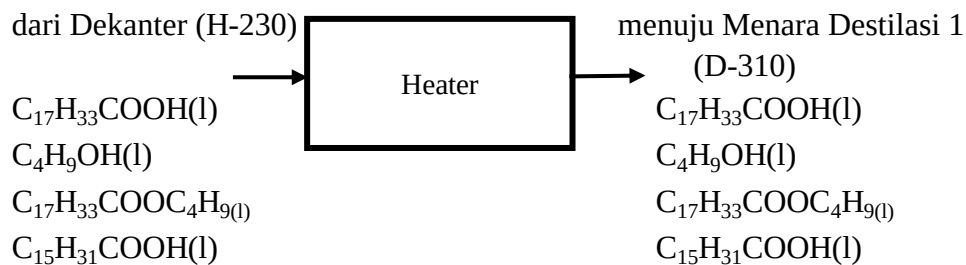
Neraca Panas Dekanter (H-230)			
Input		Output	
Komponen	(kkal/jam)	Komponen	(kkal/jam)
$C_{17}H_{33}COOH$	1120,617974	Arus ke Heater	
C_4H_9OH	10759,59838	$C_{17}H_{33}COOH$	1120,617974
$C_{17}H_{33}COOC_4H_9$	11095,49868	C_4H_9OH	10759,59838
$C_{15}H_{31}COOH$	163,8484696	$C_{17}H_{33}COOC_4H_9$	11095,49868
H_2O	1666,7901	$C_{15}H_{31}COOH$	163,8484696
Na_2SO_4	272,2468792		
		Arus ke Tangki	
		C_4H_9OH	56,81827587
		H_2O	1666,7901
		Na_2SO_4	272,2468792
Total	25135,41876	Total	25135,41875

8. Heater (E-232)

Fungsi : Tempat memanaskan liquid sebelum masuk menara destilasi dari suhu 30 C sampai 144 C



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”



Suhu masuk = 30 °C = 303,15 K

Suhu keluar = 144,87 °C = 418,02 K

Menghitung Entalpi Masuk

$T_{in} = 30\text{ °C} = 303,15\text{ K}$

$T_{ref} = 25\text{ °C} = 298,15\text{ K}$

Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	385,5642	1,367249	3429,270164	1120,617974
C_4H_9OH	4155,531	56,15582	801,6650564	10759,59838
$C_{17}H_{33}COOC_4H_9$	4167,504	12,32989	3765,12283	11095,49868
$C_{15}H_{31}COOH$	54,00861	0,210971	3249,458954	163,8484696
Total	8762,608	70,06394	11245,517	23139,5635

Menghitung Entalpi Keluar

$T_{out} = 144,87\text{ °C} = 418,02\text{ K}$

$T_{ref} = 25\text{ °C} = 298,15\text{ K}$

Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	385,5642	1,367249	86116,54849	28141,19258
C_4H_9OH	4155,531	56,15582	20528,55318	275525,2779
$C_{17}H_{33}COOC_4H_9$	4167,504	12,32989	95248,19356	280688,3741
$C_{15}H_{31}COOH$	54,00861	0,210971	82562,88977	4163,094018
Total	8762,608	70,06394	284456,185	588517,9386



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

Neraca Panas

$$\begin{aligned}
 \text{Panas Masuk} &= \text{Panas Keluar} \\
 \text{Entalpi bahan masuk} + Q_{\text{supply}} &= \text{Entalpi bahan keluar} + Q_{\text{loss}} \\
 \text{Asumsi } Q_{\text{loss}} &= 5\% \times Q_{\text{supply}} \\
 23139,56 + Q_{\text{supply}} &= 588518 + 5\% Q_{\text{supply}} \\
 Q_{\text{supply}} + 5\% Q_{\text{supply}} &= 588518 - 23140 \\
 Q_{\text{supply}} &= \frac{588518 - 23140}{0,95} \\
 Q_{\text{supply}} &= 595135 \text{ kJ/jam} \\
 Q_{\text{loss}} &= 29757 \text{ kJ/jam}
 \end{aligned}$$

Menghitung Kebutuhan Steam

Steam yang digunakan jenis Low Pressure Steam dengan tekanan 4,51 atm dan suhu 148 °C

$$\begin{aligned}
 P &= 451,01 \text{ kPa} \\
 &= 4,5101 \text{ bar} \\
 H_v &= 2743 \text{ kJ/kg} & (\text{Smith Vannes 9th Ed, Table E.1}) \\
 H_L &= 623,5 \text{ kJ/kg} & (\text{Smith Vannes 9th Ed, Table E.1}) \\
 \lambda &= 2119,5 \text{ kJ/kg} \\
 &= 506,57 \text{ kkal/kg} \\
 c &= 1 \text{ Btu/lb}^\circ\text{F} \\
 &= 4,1867 \text{ kkal/kgK}
 \end{aligned}$$

$$\begin{aligned}
 Q_{\text{steam}} &= M_{\text{steam}} \times \lambda \\
 M_{\text{steam}} &= \frac{Q_{\text{steam}}}{\lambda} \\
 &= \frac{595135,1 \text{ kkal/jam}}{506,5727 \text{ kkal/kg}} \\
 &= 1174,827 \text{ kg/jam}
 \end{aligned}$$

Sehingga, didapatkan kebutuhan steam sebanyak 1174,827 kg/jam

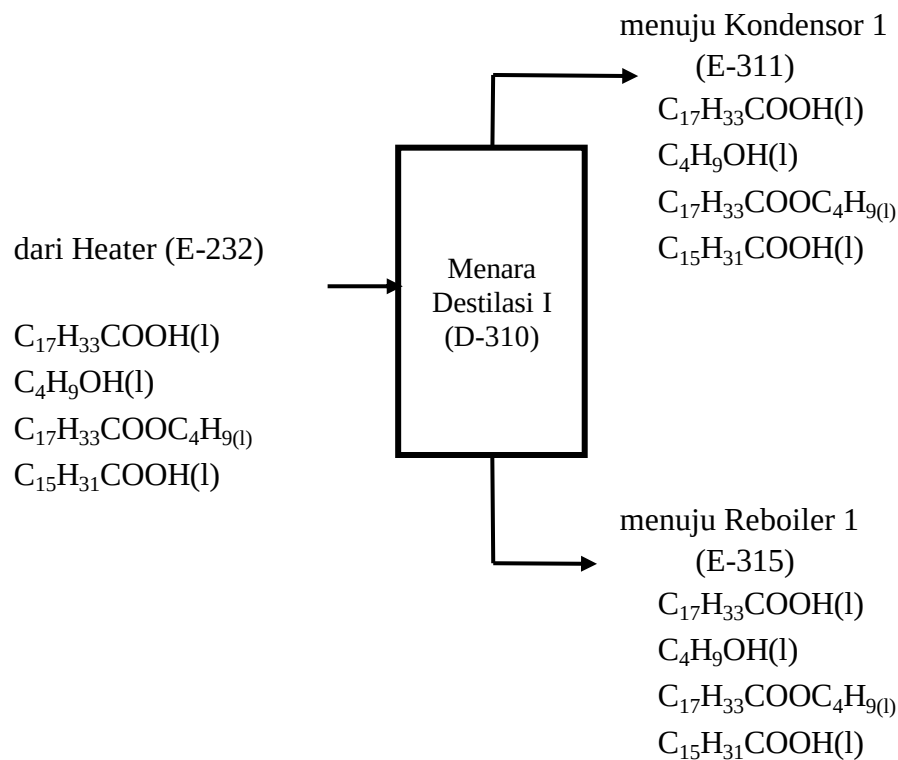
Neraca Panas Heater (E-232)			
Input		Output	
Komponen	kkal/jam	Komponen	kkal/jam
C ₁₇ H ₃₃ COOH	1120,617974	C ₁₇ H ₃₃ COOH	28141,19258
C ₄ H ₉ OH	10759,59838	C ₄ H ₉ OH	275525,2779



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

$C_{17}H_{33}COOC_4H_9$	11095,49868	$C_{17}H_{33}COOC_4H_9$	280688,3741
$C_{15}H_{31}COOH$	163,8484696	$C_{15}H_{31}COOH$	4163,094018
Q supply	595135,1317	Q loss	29756,75658
Total	618274,6952	Total	618274,6952

9. Menara Destilasi 1 (D-310)



Menghitung Entalpi masuk

$$T_{in} = 144,9 \quad C = 418,02 \text{ K}$$

$$T_{ref} = 25 \quad C = 298,15 \text{ K}$$

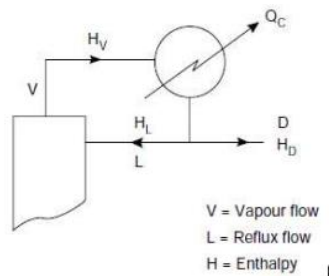
Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)	$\int cpdT$ (J/mol)
$C_{17}H_{33}COOH$	385,564	1,505	82823,031	29782,307	86116,548
C_4H_9OH	4155,531	56,065	19715,316	264182	20528,553
$C_{17}H_{33}COOC_4H_9$	4167,504	12,330	91584,383	269891,4	95248,194



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

$C_{15}H_{31}COOH$	54,009	0,211	79383,182	3998,545	82562,890
Total	8762,608	70,110	273505,912	567854,2	284456,185

1. Neraca Panas disekitar kondensor



Data dari neraca massa

Massa vapor (V)

Komponen

Komponen	V (kg/jam)
$C_{17}H_{33}COOH$	0,00261
C_4H_9OH	4406,448
$C_{17}H_{33}COOC_4H_9$	0,334738
$C_{15}H_{31}COOH$	0,007562
Total	4406,793

Massa Refluks (L)

Komponen	L (kg/jam)
$C_{17}H_{33}COOH$	0,002332
C_4H_9OH	251,3333
$C_{17}H_{33}COOC_4H_9$	0,025208
$C_{15}H_{31}COOH$	0,000327
Total	251,3611

Suhu pada destilat (D)

$$T = 137,07 \text{ C} = 410,22 \text{ K}$$

$$T_{\text{reff}} = 25 \text{ C} = 298,15 \text{ K}$$



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

Panas yang dibawa Reflux Keluar Kondensor (ΔH_L)

Komponen	L (kg/jam)	Mol (kmol/jam)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	0,002332	8,2567E-06	80268,87653	0,158402539
C_4H_9OH	251,3333	3,396395596	19086,8995	15493,94393
$C_{17}H_{33}COOC_4H_9$	0,025208	7,44991E-05	88744,06687	1,580151657
$C_{15}H_{31}COOH$	0,000327	1,27612E-06	76917,88364	0,023459869
Total	251,3611	3,396479628	265017,7265	15495,70594

Panas yang dibawa Uap Masuk Kondensor (ΔH_v)

Komponen	V (kg/jam)	Mol (kmol/jam)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	0,00261	9,23993E-06	80268,87653	0,17726551
C_4H_9OH	4406,448	59,54660127	19086,8995	271644,358
$C_{17}H_{33}COOC_4H_9$	0,334738	0,000989266	88744,06687	20,98266975
$C_{15}H_{31}COOH$	0,007562	2,95397E-05	76917,88364	0,543051506
Total	4406,793	59,54762932	265017,7265	271666,061

Panas yang dibawa Distilat Keluar Kondensor (ΔH_D)

Komponen	m Destilat (kg/jam)	Mol (kmol/jam)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	0,038556	0,000136502	80268,87653	2,618757119
C_4H_9OH	4155,115	56,15020568	19086,8995	256150,414
$C_{17}H_{33}COOC_4H_9$	0,41675	0,001231641	88744,06687	26,1235295
$C_{15}H_{31}COOH$	0,005401	2,10971E-05	76917,88364	0,387845414
Total	4155,576	56,15159492	265017,7265	256179,5442

Entalpi penguapan

Uap/Vapor juga memiliki energi laten (perubahan fase liquid menjadi vapor)

Panas laten uap pada kondensor = 137,07 °C = 410,22 K

Untuk menghitung entalpi panas penguapan (H_v)

digunakan persamaan Watson (Bhatt dan Vora, 2004) :

$$\frac{\lambda_{v1}}{\lambda_{v2}} = \left(\frac{T_c - T_1}{T_c - T_2} \right)^n$$

Dimana :



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λ_{v1} = Entalpi penguapan pada suhu tertentu (kkal/Kmol)

λ_{v2} = Entalpi penguapan pada suhu referensi (kkal/Kmol)

T_1 = Suhu (410 K)

T_2 = Suhu referensi komponen (298,15 K)

T_c = Titik kritis (K)

n = Konstanta persamaan (0,38)

$$H_{VAP} = A \left(1 - \frac{T}{T_c}\right)^n$$

Komponen	A	T_c	n	ΔH_v (Kj/mol)	ΔH_v (Kkal/kmol)
$C_{17}H_{33}COOH$	134,63	781	0,394	111,3934	26623,6554
C_4H_9OH	63,024	562,93	0,318	49,5837	11850,78931
$C_{17}H_{33}COOC_4H_9$	129,61	764	0,472	102,6228	24527,44619
$C_{15}H_{31}COOH$	92,115	776	0,208	83,27828	19903,98764

Komponen	n	T_c	T_2	λ_{v2} (kkal/kmol)	λ_{v1} (kkal/kmol)	Q (Kkal)
$C_{17}H_{33}COOH$	9E-06	781	298,15	26623,66	24081,41	0,222511
C_4H_9OH	59,547	562,93	298,15	11850,79	9614,298	572498,8
$C_{17}H_{33}COOC_4H_9$	0,001	764	298,15	24527,45	22092,06	21,85492
$C_{15}H_{31}COOH$	3E-05	776	298,15	19903,99	17981,74	0,531174
Total	59,548					572521,4

Neraca Panas Kondensor

$$Input = Output$$

$$\Delta H_v = \Delta H_D + \Delta H_L + Q_C$$

$$Q_c = \Delta H_V - \Delta H_L - \Delta H_D \quad (\text{Coulson dan Richardson, 2005})$$

Dimana :

Q_c = Panas kondensor (kkal/jam)

H_I = Panas distilat (kkal/jam)

H_I = Panas reflux (kkal/mol)

H_V = Jumlah panas laten dan panas sensibel (kkal/mol)



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$$\begin{aligned} Q_c &= \Delta H_V - \Delta H_L - \Delta H_D \\ &= (271666,1 + 572521,4) - 15495,71 - 256179,5442 \\ &= 572512,2 \text{ Kkal} \end{aligned}$$

Menghitung kebutuhan air pendingin

$$T \text{ air pendingin mas} = 30 \text{ } ^\circ\text{C} \quad (\text{Ulrich, 1984})$$

$$T \text{ air pendingin kelu} = 45 \text{ } ^\circ\text{C} \quad (\text{Ulrich, 1984})$$

$$\begin{aligned} C_p \text{ air pendingin} &= 0,9987 \text{ kkal/gr } ^\circ\text{C} \quad (\text{Geankoplis, 1997}) \\ &= 0,9987 \text{ kkal/Kg } ^\circ\text{C} \end{aligned}$$

maka diperoleh

$$\begin{aligned} Q &= m \times C_p \times \Delta T \\ 572512,18 &= m \times 0,9987 \times 15 \\ m &= 38217,16 \text{ kg} \end{aligned}$$

Sehingga didapatkan kebutuhan air pendingin sebanyak 38217,16 kg/jam

2. Neraca Panas disekitar Reboiler

Panas yang dibawa produk *bottom* keluar pada keadaan *bubble point*

$$T \text{ bottom} = 230,37 \text{ } ^\circ\text{C} = 503,52 \text{ K}$$

$$T \text{ ref} = 25 \text{ } ^\circ\text{C} = 298,15 \text{ K}$$

Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	385,5256	1,367112	152728,8832	49903,80121
C_4H_9OH	0,415553	0,005616	37868,71265	50,82573276
$C_{17}H_{33}COOC_4H_9$	4167,088	12,32866	169686,6924	500002,332
$C_{15}H_{31}COOH$	54,00321	0,21095	246968,68	12451,73251
Total	4607,032	13,91234	607252,9683	562408,6915

Menghitung Beban Reboiler (Qr)

Neraca Panas Total:

$$\begin{aligned} H \text{ masuk} + Q \text{ reboiling} &= H \text{ keluar} + Q \text{ condensation} + Q \text{ loss} \\ \Delta H_F + Q \text{ reboiling} &= \Delta H_D + \Delta H_B + Q \text{ condensation} + Q \text{ loss} \\ 567854,2474 + Q \text{ reboiling} &= 256179,5442 + 562408,6915 \\ &\quad + 572512,1809 + 0,05 Q \text{ reboiling} \\ Q \text{ reboiling} &= 866574,9149 \text{ kkal} \\ Q \text{ loss} &= 43328,7457 \text{ kkal} \end{aligned}$$



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Menghitung Jumlah Pemanas (Steam)

Panas di-supply menggunakan bantuan superheated steam. Suhu steam digunakan adalah 400°C (Appendix F : Steam Table from Smith dkk.,

$$\begin{aligned} T &= 400 \text{ }^{\circ}\text{C} \\ P &= 45 \text{ Bar} \\ H_l &= 2256,9 \text{ kJ/Kg} \\ H_v &= 3241,1 \text{ kJ/Kg} \\ \lambda &= H_v - H_l \\ &= 984,2 \text{ kJ/Kg} \\ &= 235,2 \text{ Kkal/Kg} \end{aligned}$$

Sehingga *steam* yang dibutuhkan :

$$\begin{aligned} m_{\text{steam}} &= \frac{QR}{\lambda} \\ &= \frac{866574,9149 \text{ Kkal}}{984,223 \text{ Kkal/kg}} \\ &= 880,466 \text{ kg/jam} \end{aligned}$$

Neraca Panas Menara Destilasi 1 (D-310)			
Input		Output	
Komponen	kcal/jam	Komponen	kcal/jam
C ₁₇ H ₃₃ COOH	29782,30743	Top Product	
C ₄ H ₉ OH	264181,9604	C ₁₇ H ₃₃ COOH	2,618757119
C ₁₇ H ₃₃ COOC ₄ H ₉	269891,4341	C ₄ H ₉ OH	256150,414
C ₁₅ H ₃₁ COOH	3998,545418	C ₁₇ H ₃₃ COOC ₄ H ₉	26,1235295
Q Reboiler	866574,9149	C ₁₅ H ₃₁ COOH	0,387845414
		Total	256179,5442
		Bottom Product	
		C ₁₇ H ₃₃ COOH	49903,80121
		C ₄ H ₉ OH	50,82573276
		C ₁₇ H ₃₃ COOC ₄ H ₉	500002,332
		C ₁₅ H ₃₁ COOH	12451,73251
		Total	562408,6915
		Q Kondensor	
		572512,1809	
		Q Loss	
		43328,7457	



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Total	1434429,162	Total	1434429,162

10. Accumulator

Menghitung Entalpi Bahan Masuk

$$T \text{ masuk} = 137,07^{\circ}\text{C} = 410,2228 \text{ K}$$

$$T \text{ reff} = 25^{\circ}\text{C} = 298,1500 \text{ K}$$

Komponen	Massa (kg/jam)	Mol (kmol/jam)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	0,038556	0,000136502	80268,87653	2,618757119
C_4H_9OH	4155,115	56,15020568	19086,8995	256150,414
$C_{17}H_{33}COOC_4H_9$	0,41675	0,001231641	88744,06687	26,1235295
$C_{15}H_{31}COOH$	0,005401	2,10971E-05	76917,88364	0,387845414
Total	4155,576	56,15159492	265017,7265	256179,5442

Menghitung Entalpi Bahan Keluar

$$T \text{ keluar} = 137,07^{\circ}\text{C} = 410,2228 \text{ K}$$

$$T \text{ reff} = 25^{\circ}\text{C} = 298,1500 \text{ K}$$

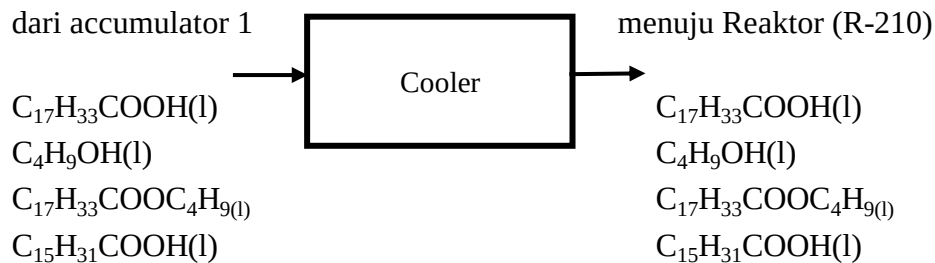
Komponen	Massa (kg/jam)	Mol (kmol/jam)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	0,038556	0,000136502	80268,87653	2,618757119
C_4H_9OH	4155,115	56,15020568	19086,8995	256150,414
$C_{17}H_{33}COOC_4H_9$	0,41675	0,001231641	88744,06687	26,1235295
$C_{15}H_{31}COOH$	0,005401	2,10971E-05	76917,88364	0,387845414
Total	4155,576	56,15159492	265017,7265	256179,5442

Neraca Panas Accumulator (F-312)			
Input		Output	
Komponen	kkal/jam	Komponen	kkal/jam
$C_{17}H_{33}COOH$	2,618757119	$C_{17}H_{33}COOH$	2,618757119
C_4H_9OH	256150,414	C_4H_9OH	256150,414
$C_{17}H_{33}COOC_4H_9$	26,1235295	$C_{17}H_{33}COOC_4H_9$	26,1235295
$C_{15}H_{31}COOH$	0,387845414	$C_{15}H_{31}COOH$	0,387845414
Total	256179,1563	Total	256179,1563



11. Cooler (E-314)

Fungsi : Untuk menurunkan butanol dari 137°C menjadi 120°C sebelum masuk ke reaktor



Suhu masuk = 137,07 °C = 410,22 K

Suhu keluar = 120 °C = 393,15 K

Menghitung Entalpi Masuk

T in = 137 °C = 410,22 K

T ref = 25 °C = 298,15 K

Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	0,038556	0,000137	80268,87653	2,623028851
C_4H_9OH	4155,115	56,15021	19086,8995	256150,414
$C_{17}H_{33}COOC_4H_9$	0,41675	0,001233	88744,06687	26,15212626
$C_{15}H_{31}COOH$	0,005401	2,11E-05	76917,88364	0,387845414
Total	4155,576	56,1516	265017,7265	256179,577

Menghitung Entalpi Keluar

T out = 120 °C = 393,15 K

T ref = 25 °C = 298,15 K

Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	0,038556	0,000137	67593,084	2,208808907
C_4H_9OH	4155,115	56,15021	15995,2305	214659,5321
$C_{17}H_{33}COOC_4H_9$	0,41675	0,001233	74661,17319	22,00201655



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$C_{15}H_{31}COOH$	0,005401	2,11E-05	64692,15432	0,326199242
Total	4155,576	56,1516	222941,642	214684,0691

Neraca Panas

$$\begin{aligned}\text{Panas masuk} &= \text{Panas Keluar} \\ \text{Entalpi masuk} &= \text{Entalpi keluar} + Q \text{ serap} \\ 256179,577 &= 214684,0691 + Q \text{ serap} \\ Q \text{ serap} &= 41495,50794 \text{ kkal/jam}\end{aligned}$$

Menghitung kebutuhan air pendingin

$$\begin{aligned}\text{Suhu air pendingin masuk} &= 30^\circ\text{C} = 86^\circ\text{F} \\ \text{Suhu air pendingin keluar} &= 45^\circ\text{C} = 113^\circ\text{F} \\ \text{Cp air pendingin} &= 0,9987 \text{ kkal/gr}^\circ\text{C} \quad (\text{Geankoplis, 1997}) \\ &= 0,9987 \text{ kkal/Kg}^\circ\text{C}\end{aligned}$$

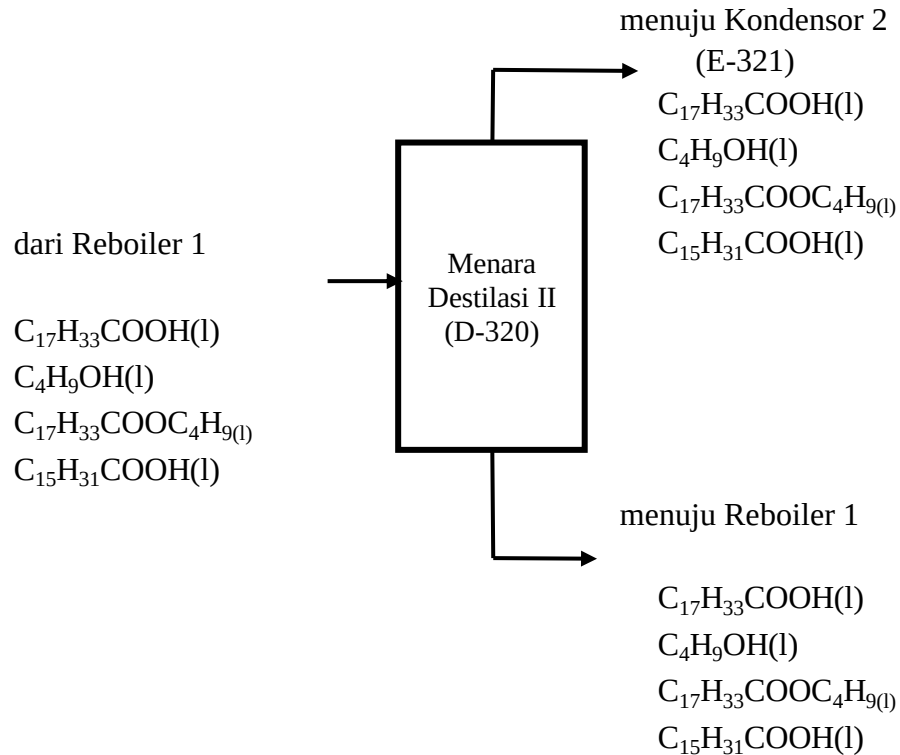
$$\begin{aligned}Q \text{ serap} &= m \times Cp \times \Delta T \\ m \text{ air pendingin} &= \frac{Q \text{ serap}}{Cp \times \Delta T} \\ &= \frac{41495,51 \text{ kkal/jam}}{0,9987 \text{ kkal/kg}^\circ\text{C} \times 15^\circ\text{C}} \\ &= 2769,968 \text{ kg}\end{aligned}$$

Sehingga didapatkan kebutuhan air pendingin sebesar 2769,968 kg/jam

Neraca Panas Cooler (E-314)			
Input		Output	
Komponen	(kkal/jam)	Komponen	(kkal/jam)
$C_{17}H_{33}COOH$	2,623028851	$C_{17}H_{33}COOH$	2,208808907
C_4H_9OH	256150,414	C_4H_9OH	214659,5321
$C_{17}H_{33}COOC_4H_9$	26,15212626	$C_{17}H_{33}COOC_4H_9$	22,00201655
$C_{15}H_{31}COOH$	0,387845414	$C_{15}H_{31}COOH$	0,326199242
		Q serap	41495,50794
Total	256179,577	Total	256179,577



12. Menara Destilasi 2



Menghitung Entalpi masuk

$$T_{in} = 230,48 \text{ } ^\circ\text{C} = 503,63 \text{ K}$$
$$T_{ref} = 25 \text{ } ^\circ\text{C} = 298,15 \text{ K}$$

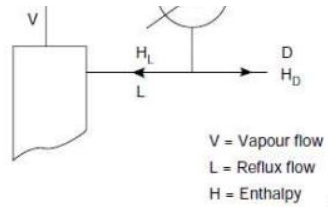
Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	385,5256	1,504373	152821,3488	54947,485
C_4H_9OH	0,415553	0,005606	37894,18818	50,77758288
$C_{17}H_{33}COOC_4H_9$	4167,088	12,32866	169790,523	500308,2814
$C_{15}H_{31}COOH$	54,0392	0,210868	147060,954	7411,683157
Total	4607,068	14,04951	507567,014	562718,2272

1. Neraca Panas disekitar kondensor





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Data dari neraca massa

Massa vapor (V)

Komponen

Komponen	V (kg/jam)
$C_{17}H_{33}COOH$	0,040127
C_4H_9OH	0,432484
$C_{17}H_{33}COOC_4H_9$	4336,863
$C_{15}H_{31}COOH$	36,58834
Total	4373,924

Massa Refluks (L)

Komponen	L (kg/jam)
$C_{17}H_{33}COOH$	0,001575
C_4H_9OH	0,016972
$C_{17}H_{33}COOC_4H_9$	170,1919
$C_{15}H_{31}COOH$	1,435839
Total	171,6462

Suhu pada destilat (D)

T = 226,74 C = 499,89 K

T reff = 25 C = 298,15 K

Komponen	L (kg/jam)	Mol (kmol/jam)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	0,001575	5,57501E-06	149797,3648	0,199599008
C_4H_9OH	0,016972	0,000229351	37063,32411	2,031672227
$C_{17}H_{33}COOC_4H_9$	170,1919	0,502975626	166395,6742	20003,09951
$C_{15}H_{31}COOH$	1,435839	0,005608747	144135,1975	193,2165037
Total	171,6462	0,508819299	497391,5605	20198,54728



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Panas yang dibawa Uap Masuk Kondensor (ΔH_v)

Komponen	V (kg/jam)	Mol (kmol/jam)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	0,040127	0,000142064	149797,3648	5,086221373
C_4H_9OH	0,432484	0,005844372	37063,32411	51,77147318
$C_{17}H_{33}COOC_4H_9$	4336,863	12,81692429	166395,6742	509722,9345
$C_{15}H_{31}COOH$	36,58834	0,142923199	144135,1975	4923,581129
Total	4373,924	12,96583392	497391,5605	514703,3733

Panas yang dibawa Distilat Keluar Kondensor (ΔH_D)

Komponen	m Destilat (kg/jam)	Mol (kmol/jam)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	0,038553	0,000136489	149797,3648	4,886622364
C_4H_9OH	0,415512	0,005615021	37063,32411	49,73980095
$C_{17}H_{33}COOC_4H_9$	4166,671	12,31394866	166395,6742	489719,835
$C_{15}H_{31}COOH$	35,1525	0,137314452	144135,1975	4730,364625
Total	4202,277	12,45701462	497391,5605	494504,826

Entalpi penguapan

Uap/Vapor juga memiliki energi laten (perubahan fase liquid menjadi vapor)

Panas laten uap pada kondensor = $226,74^\circ C = 499,89 K$

Untuk menghitung entalpi panas penguapan (H_v)

digunakan persamaan Watson (Bhatt dan Vora, 2004) :

$$\frac{\lambda_{v1}}{\lambda_{v2}} = \left(\frac{T_c - T_1}{T_c - T_2} \right)^n$$

Dimana :

λ_{v1} = Entalpi penguapan pada suhu tertentu (kkal/Kmol)

λ_{v2} = Entalpi penguapan pada suhu referensi (kkal/Kmol)

T_1 = Suhu ($499,89 K$)

T_2 = Suhu referensi komponen (298,15 K)

T_c = Titik kritis (K)

n = Konstanta persamaan ($0,38$)

$$H_{VAP} = A \left(1 - \frac{T}{T_c} \right)^n$$



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Komponen	A	Tc	n	ΔH_v (Kj/mol)	ΔH_v (Kkal/kmol)
$C_{17}H_{33}COOH$	134,63	781	0,394	111,3934	26623,6554
C_4H_9OH	63,024	562,93	0,318	49,5837	11850,78931
$C_{17}H_{33}COOC_4H_9$	129,61	764	0,472	102,6228	24527,44619
$C_{15}H_{31}COOH$	92,115	776	0,208	83,27828	19903,98764

Komponen	n	Tc	T2	λ_{v2} (kkal/kmol)	λ_{v1} (kkal/kmol)	Q (Kkal)
$C_{17}H_{33}COOH$	0,0001	781	298,15	26623,66	24081,41	3,421092
C_4H_9OH	0,0058	562,93	298,15	11850,79	9614,298	56,18953
$C_{17}H_{33}COOC_4H_9$	12,817	764	298,15	24527,45	22092,06	283152,2
$C_{15}H_{31}COOH$	0,1429	776	298,15	19903,99	17981,74	2570,007
Total	12,966					285781,9

Neraca Panas Kondensor

$$Input = Output$$

$$\Delta H_v = \Delta HD + \Delta HL + QC$$

$$Q_c = \Delta HV - \Delta HL - \Delta HD \quad (\text{Coulson dan Richardson, 2005})$$

Dimana :

Q_c = Panas kondensor (kkal/jam)

HD = Panas distilat (kkal/jam)

HL = Panas reflux (kkal/mol)

HV = Jumlah panas laten dan panas sensibel (kkal/mol)

$$\begin{aligned} Q_c &= \Delta HV - \Delta HL - \Delta HD \\ &= (514703,4 + 285781,85) - 20198,55 - 494504,826 \\ &= 285781,9 \text{ Kkal} \end{aligned}$$

Menghitung kebutuhan air pendingin

$$\text{Suhu dowtherm masuk} = 30^\circ\text{C} = 303 \text{ K}$$

$$\text{Suhu dowtherm keluar} = 80^\circ\text{C} = 353 \text{ K}$$

$$C_p \text{ pendingin masuk} = 0,374979 \text{ kkal/kgK}$$

$$C_p \text{ pendingin keluar} = 0,408416 \text{ kkal/kgK}$$



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$$\begin{aligned}
 Q_{\text{serap}} &= m \times C_p \times \Delta T \\
 m &= \frac{Q_{\text{serap}}}{C_p \times \Delta T} \\
 &= \frac{Q_{\text{serap}}}{C_{p1} \times \Delta T + C_{p2} \times \Delta T} \\
 &= \frac{285781,9 \text{ kkal/jam}}{1,8749 \text{ kkal/kgK} + 22,463 \text{ kkal/kgK}} \\
 m &= 11742,31 \text{ kg}
 \end{aligned}$$

Sehingga didapatkan kebutuhan air pendingin sebanyak 11742,31 kg

2. Neraca Panas disekitar Reboiler

Panas yang dibawa produk *bottom* keluar pada keadaan *bubble point*

$$T_{\text{bottom}} = 362,22 \text{ C} = 635,37 \text{ K}$$

$$T_{\text{ref}} = 25 \text{ C} = 298,15 \text{ K}$$

Komponen	Massa (kg)	n (kmol)	$\int c_p dT$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	385,4871	1,366975	278216,833	90897,60124
C_4H_9OH	4,16E-05	5,62E-07	78168,01951	0,01049137
$C_{17}H_{33}COOC_4H_9$	0,416709	0,001233	315259,0405	92,8948836
$C_{15}H_{31}COOH$	18,8867	0,073776	271124,0676	4780,711336
Total	404,7905	1,441985	942767,9606	95771,21795

Menghitung Beban Reboiler (Qr)

Neraca Panas Total:

$$\begin{aligned}
 H_{\text{masuk}} + Q_{\text{reboiling}} &= H_{\text{keluar}} + Q_{\text{condensation}} + Q_{\text{loss}} \\
 \Delta H_F + Q_{\text{reboiling}} &= \Delta H_D + \Delta H_B + Q_{\text{condensation}} + Q_{\text{loss}} \\
 562718,2272 + Q_{\text{reboiling}} &= 494504,826 + 95771,21795 \\
 &\quad + 285781,8521 + 0,05 Q_{\text{reboiling}} \\
 Q_{\text{reboiling}} &= 329831,2304 \text{ kkal} \\
 Q_{\text{loss}} &= 16491,56152 \text{ kkal}
 \end{aligned}$$

Menghitung Jumlah Pemanas (Steam)

Panas di-supply menggunakan bantuan superheated steam. Suhu steam digunakan adalah 400°C (**Appendiks B, Ulrich**)

$$T = 400 \text{ } ^\circ\text{C}$$

$$P = 45 \text{ bar}$$



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$$\begin{aligned}
 H_l &= 2256,9 \text{ kJ/Kg} && \text{(Steam Table from Smith dkk., 2005)} \\
 H_v &= 3241,1 \text{ kJ/Kg} && \text{(Steam Table from Smith dkk., 2005)} \\
 \lambda &= H_v - H_l \\
 &= 984,2 \text{ kJ/Kg} \\
 &= 235,2 \text{ Kkal/Kg}
 \end{aligned}$$

Sehingga *steam* yang dibutuhkan :

$$\begin{aligned}
 m_{\text{steam}} &= \frac{QR}{\lambda} \\
 &= \frac{329831,2304 \text{ Kkal}}{984,2 \text{ Kkal/kg}} \\
 &= 335,1187 \text{ kg/jam}
 \end{aligned}$$

Neraca Panas Menara Destilasi II (D-320)			
Input		Output	
Komponen	kcal/jam	Komponen	kcal/jam
C ₁₇ H ₃₃ COOH	54947,485	Top Product	
C ₄ H ₉ OH	50,77758288	C ₁₇ H ₃₃ COOH	4,886622364
C ₁₇ H ₃₃ COOC ₄ H ₉	500308,2814	C ₄ H ₉ OH	49,73980095
C ₁₅ H ₃₁ COOH	7411,683157	C ₁₇ H ₃₃ COOC ₄ H ₉	489719,835
Q Reboiler	329831,2304	C ₁₅ H ₃₁ COOH	4730,364625
		Total	494504,826
		Bottom Product	
		C ₁₇ H ₃₃ COOH	90897,60124
		C ₄ H ₉ OH	0,01049137
		C ₁₇ H ₃₃ COOC ₄ H ₉	92,8948836
		C ₁₅ H ₃₁ COOH	4780,711336
		Total	95771,21795
		Q Kondensor	285781,8521
		Q Loss	16491,5615
		Total	892549,4575
Total	892549,4575	Total	892549,4575



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13. Cooler (E-324)

Fungsi : Untuk menurunkan suhu produk dari 226,7°C menjadi 30°C

Suhu masuk = 226,74 °C = 499,89 K

Suhu keluar = 35 °C = 308,15 K

Menghitung Entalpi Masuk

T in = 227 °C = 499,89 K

T ref = 25 °C = 298,15 K

Komponen	Massa (kg)	n (kmol)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
C ₁₇ H ₃₃ COOH	0,038553	0,000137	149797,3648	4,89459345
C ₄ H ₉ OH	0,415512	0,005615	37063,32411	49,73980095
C ₁₇ H ₃₃ COOC ₄ H ₉	4166,671	12,32743	166395,6742	490255,9188
C ₁₅ H ₃₁ COOH	35,1525	0,137314	144135,1975	4730,364625
Total	4202,277	12,47049	497391,5605	495040,9178

Menghitung Entalpi Keluar

T out = 35 °C = 308,15 K

T ref = 25 °C = 298,15 K

Komponen	Massa (kg)	n (kmol)	$\int_{cpdT}$ (J/mol)	ΔH (kkal/jam)
C ₁₇ H ₃₃ COOH	0,038553	0,000137	6873,676916	0,224595767
C ₄ H ₉ OH	0,415512	0,005615	1607,083365	2,156741431
C ₁₇ H ₃₃ COOC ₄ H ₉	4166,671	12,32743	7549,984588	22244,71669
C ₁₅ H ₃₁ COOH	35,1525	0,137314	6518,111129	213,9175083
Total	4202,277	12,47049	22548,856	22461,01554

Neraca Panas

Panas masuk = Panas Keluar

Entalpi masuk = Entalpi keluar + Q serap

495040,9178 = 22461,01554 + Q serap

Q serap = 472579,9023 kkal/jam



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Menghitung kebutuhan pendingin

$$\text{Suhu dowtherm masuk} = 30^{\circ}\text{C} = 303 \text{ K}$$

$$\text{Suhu dowtherm keluar} = 80^{\circ}\text{C} = 353 \text{ K}$$

$$\text{Cp pendingin masuk} = 0,374979 \text{ kkal/kgK}$$

$$\text{Cp pendingin keluar} = 0,408416 \text{ kkal/kgK}$$

$$Q \text{ serap} = m \times \text{Cp} \times \Delta T$$

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

$$= \frac{Q \text{ serap}}{\text{Cp1} \times \Delta T + \text{Cp2} \times \Delta T}$$

$$= \frac{472579,9 \text{ kkal/jam}}{1,8749 \text{ kkal/kgK} + 22,463 \text{ kkal/kgK}}$$

$$m = 19417,53 \text{ kg}$$

Sehingga didapatkan kebutuhan dowtherm sebesar 19417,53 kg

Neraca Panas Cooler (E-324)			
Input		Output	
Komponen	(kkal/jam)	Komponen	(kkal/jam)
$\text{C}_{17}\text{H}_{33}\text{COOH}_{(l)}$	4,89459345	$\text{C}_{17}\text{H}_{33}\text{COOH}_{(l)}$	0,224595767
$\text{C}_4\text{H}_9\text{OH}_{(l)}$	49,73980095	$\text{C}_4\text{H}_9\text{OH}_{(l)}$	2,156741431
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9_{(l)}$	490255,9188	$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9_{(l)}$	22244,71669
$\text{C}_{15}\text{H}_{31}\text{COOH}_{(l)}$	4730,364625	$\text{C}_{15}\text{H}_{31}\text{COOH}_{(l)}$	213,9175083
		Q serap	472579,9023
Total	495040,9178	Total	495040,9178

14. Cooler (E-327)

Fungsi : Untuk menurunkan suhu asam oleat dari 362°C menjadi 120°C

$$\text{Suhu masuk} = 362,22^{\circ}\text{C} = 635,37 \text{ K}$$

$$\text{Suhu keluar} = 120^{\circ}\text{C} = 393,15 \text{ K}$$

Menghitung Entalpi Masuk

$$T_{\text{in}} = 362^{\circ}\text{C} = 635,37 \text{ K}$$

$$T_{\text{ref}} = 25^{\circ}\text{C} = 298,15 \text{ K}$$



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Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH$	385,4871	1,366975	268489,4211	87719,51024
C_4H_9OH	4,16E-05	5,62E-07	73671,75843	0,009887902
$C_{17}H_{33}COOC_4H_9$	0,416709	0,001233	301232,9185	88,76191736
$C_{15}H_{31}COOH$	18,8867	0,073776	259073,4557	4568,223757
Total	404,7905	1,441985	902467,5537	92376,50581

Menghitung Entalpi Keluar

$$T_{out} = 120 \text{ } ^\circ\text{C} = 393,15 \text{ K}$$

$$T_{ref} = 25 \text{ } ^\circ\text{C} = 298,15 \text{ K}$$

Komponen	Massa (kg)	n (kmol)	$\int cpdT$ (J/mol)	ΔH (kkal/jam)
$C_{17}H_{33}COOH_{(l)}$	385,4871	1,366975	67593,084	22083,67167
$C_4H_9OH_{(l)}$	4,16E-05	5,62E-07	15995,2305	0,00214681
$C_{17}H_{33}COOC_4H_9_{(l)}$	0,416709	0,001233	74661,17319	21,99981635
$C_{15}H_{31}COOH_{(l)}$	18,8867	0,073776	64692,15432	1140,712141
Total	404,7905	1,441985	222941,642	23246,38578

Neraca Panas

$$\text{Panas masuk} = \text{Panas Keluar}$$

$$\text{Entalpi masuk} = \text{Entalpi keluar} + Q_{\text{serap}}$$

$$92376,50581 = 23246,38578 + Q_{\text{serap}}$$

$$Q_{\text{serap}} = 69130,12003 \text{ kkal/jam}$$

Menghitung kebutuhan dowtherm

$$\text{Suhu dowtherm masuk} = 30 \text{ } ^\circ\text{C} = 303 \text{ K}$$

$$\text{Suhu dowtherm keluar} = 80 \text{ } ^\circ\text{C} = 353 \text{ K}$$

$$C_p \text{ pendingin masuk} = 0,374979 \text{ kkal/kgK}$$

$$C_p \text{ pendingin keluar} = 0,408416 \text{ kkal/kgK}$$

$$Q_{\text{serap}} = m \times C_p \times \Delta T$$

$$m = \frac{Q_{\text{serap}}}{C_p \times \Delta T}$$

$$= \frac{Q_{\text{serap}}}{C_{p1} \times \Delta T + C_{p2} \times \Delta T}$$



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$$\begin{aligned} &= 69130,12 \text{ kkal/jam} \\ &\quad 1,8749 \text{ kkal/kgK} + 22,463 \text{ kkal/kgK} \\ m &= 2840,443 \text{ kg} \end{aligned}$$

Sehingga didapatkan kebutuhan dowtherm sebesar 2840,443 kg/jam

Neraca Panas Cooler (E-327)			
Input		Output	
Komponen	(kkal/jam)	Komponen	(kkal/jam)
$C_{17}H_{33}COOH_{(l)}$	87719,51024	$C_{17}H_{33}COOH_{(l)}$	22083,67167
$C_4H_9OH_{(l)}$	0,009887902	$C_4H_9OH_{(l)}$	0,00214681
$C_{17}H_{33}COOC_4H_9_{(l)}$	88,76191736	$C_{17}H_{33}COOC_4H_9_{(l)}$	21,99981635
$C_{15}H_{31}COOH_{(l)}$	4568,223757	$C_{15}H_{31}COOH_{(l)}$	1140,712141
		Q serap	69130,12003
Total	92376,50581	Total	92376,50581



Tinjauan Termodinamika

Menghitung Panas Reaksi

Tinjauan secara termodinamika digunakan untuk mengetahui sifat reaksi berjalan secara eksotermis atau endotermis dengan menghitung panas pembentuk reaksi standar (ΔH_R°). Perubahan entalpi reaksi dapat dihitung menggunakan panas standar (ΔH_f°) pada suhu 298,15 K dari reaktan dan produk (Smith dan Van Ness, 2005). Berikut ini data harga panas pembentukan standar (ΔH_f°) setiap komponen

Komponen	ΔH_f° 298,15K (kJ/mol)
$C_{17}H_{33}COOH$	-671,78
C_4H_9OH	-274,43
$C_{17}H_{33}COOC_4H_9$	-706,2
H_2O	-241,8

$$\begin{aligned}
 \Delta H_{R\ 298,15K}^\circ &= \Delta H_f^\circ \text{ Produk} - \Delta H_f^\circ \text{ Reaktan} \\
 &= (\Delta H_f^\circ \text{ 298,15K } C_{17}H_{33}COOC_4H_9 + \Delta H_f^\circ \text{ 298,15K } H_2O) - \\
 &\quad (\Delta H_f^\circ \text{ 298,15K } C_{17}H_{33}COOH + \Delta H_f^\circ \text{ 298,15K } C_4H_9OH) \\
 &= (-706,2 + -241,8) - (-671,8 + -274,4) \\
 &= -1,79 \text{ kJ/mol}
 \end{aligned}$$

Panas reaksi operasi $\Delta H_{R\ 373,15K}^\circ$ dihitung menggunakan persamaan sebagai berikut

Komponen	A	B	C	D
$C_{17}H_{33}COOH$	278,69	2,5434	-0,005	4,92E-06
C_4H_9OH	83,877	0,5659	-0,002	2,28E-06
$C_{17}H_{33}COOC_4H_9$	178,42	3,667	-0,008	7,1E-06
H_2O	92,053	-0,04	-2E-04	5E-07

$$\Delta H = \int_{T_0}^T \frac{\Delta C_p}{R} dT$$



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$$= \left[\frac{A}{2} + B \times T_0 \times (\tau+1) + \frac{C}{3} \times T_0^2 \times (\tau^2+\tau+1) + \frac{D}{\tau T_0^2} \right] (T-T_0)$$

$$\text{dengan } \tau = \frac{T}{T_0} = \frac{393,15}{298,15} = 1,3186$$

Mencari nilai (Cp)H/R masing-masing komponen

$$\begin{aligned} \frac{(Cp)H}{R} \text{ asam oleat} &= \left(278,69 + \frac{2,5434}{2} \times 298,15 (1,3186 + 1) + \right. \\ &\quad \left. \frac{-0,005}{3} \times 88893 \times (1,7388 + 1,31863 + 1) + \right. \\ &\quad \left. \frac{0,000004924}{1,25 \times 298,15} \times (298,15 - 393,15) \right) \\ &= 504,3234 \text{ J/mol} \end{aligned}$$

$$\begin{aligned} \frac{(Cp)H}{R} \text{ butanol} &= \left(83,877 + \frac{0,5659}{2} \times 298,15 (1,3186 + 1) + \right. \\ &\quad \left. \frac{-0,002}{3} \times 88893 \times (1,7388 + 1,31863 + 1) + \right. \\ &\quad \left. \frac{0,000002276}{1,25 \times 1,25} \times (1,25 - 5E-06) \right) \\ &= 72,6058 \text{ J/mol} \end{aligned}$$

$$\begin{aligned} \frac{(Cp)H}{R} \text{ butil oleat} &= \left(178,42 + \frac{3,667}{2} \times 298,15 (1,3186 + 1) + \right. \\ &\quad \left. \frac{-0,008}{3} \times 88893 \times (1,7388 + 1,31863 + 1) + \right. \\ &\quad \left. \frac{0,00000071}{1,25 \times 1,25} \times (1,25 - 2E-06) \right) \\ &= 487,1673 \text{ J/mol} \end{aligned}$$

$$\begin{aligned} \frac{(Cp)H}{R} \text{ Air} &= \left(92,053 + \frac{-0,04}{2} \times 298,15 (1,3186 + 1) + \right. \\ &\quad \left. \frac{-2E-04}{3} \times 88893 \times (1,7388 + 1,31863 + 1) + \right. \\ &\quad \left. \frac{5E-07}{1,25 \times 1,25} \times (1,25 - 7E-06) \right) \end{aligned}$$



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$$= 52,8766 \text{ J/mol}$$

Maka,

$$\begin{aligned} \Delta H^{\circ}_{R \text{ Reaktan}} &= \int_{T_0}^T \frac{\Delta C_p}{R} dT \text{ C}_{17}\text{H}_{33}\text{COOH} + \int_{T_0}^T \frac{\Delta C_p}{R} dT \text{ C}_4\text{H}_9\text{OH} \\ &= 504,32 \times (298,15 - 393,15) + 72,606 \times \\ &\quad (298,15 - 393,15) \\ &= -54808,27 \text{ J/mol} \\ &= -54,80827 \text{ kJ/mol} \end{aligned}$$

$$\begin{aligned} \Delta H^{\circ}_{R \text{ Produk}} &= \int_{T_0}^T \frac{\Delta C_p}{R} dT \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 + \int_{T_0}^T \frac{\Delta C_p}{R} dT \text{ H}_2\text{O} \\ &= 487,17 \times (393,15 - 298,15) + 52,877 \times \\ &\quad (393,15 - 298,15) \\ &= 51304,17 \text{ J/mol} \\ &= 51,30417 \text{ kJ/mol} \end{aligned}$$

$$\begin{aligned} \Delta H^{\circ}_{R \text{ 373,15 K}} &= \Delta H^{\circ}_{R \text{ Produk 373,15 K}} + \Delta H^{\circ}_{R \text{ 298,15 K}} + \Delta H^{\circ}_{R \text{ Reaktan 373,15 K}} \\ &= 51,304 + (-1,79) + (-54,81) \\ &= -5,294106 \end{aligned}$$

Karena harga $\Delta H^{\circ}_{R \text{ 373,15 K}}$ bernilai negatif, maka reaksi bersifat eksotermis

Menghitung Energi bebas Gibbs

Energi bebas gibbs (ΔG°_R) menandakan apakah suatu reaksi berjalan spontan atau tidak spontan. Perhitungan energi bebas gibbs menggunakan energi bebas gibbs pembentukan (ΔG°_f) pada suhu 298,15K dari reaktan dan produk. Data harga energi gibbs (ΔG°_R) setiap komponen

Tabel Harga $\Delta G^{\circ}_f \text{ 298,15K}$ Setiap komponen

Komponen	$\Delta G^{\circ}_f \text{ (kJ/mol)}$
$\text{C}_{17}\text{H}_{33}\text{COOH}$	-189,69
$\text{C}_4\text{H}_9\text{OH}$	-150,2
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	-106,6
H_2O	-237,17



$$\begin{aligned}\Delta G_{R\ 298,15\ K}^0 &= \Delta G_{f\ produk}^0 - \Delta G_{f\ reaktan}^0 \\ &= -343,77 - (-339,89) \\ &= -3,88\ \text{kJ/mol}\end{aligned}$$

Karena harga $\Delta G_{R\ 298,15\ K}^0$ bernilai negatif maka reaksi berjalan spontan

Konstanta Keseimbangan Reaksi

Penentuan reaksi berjalan searah atau bolak balik dapat ditinjau dari konstanta keseimbangan reaksi (K) (Smith van ness, 2005). Nilai K dapat ditentukan melalui persamaan berikut

$$K_1 = \exp \left(- \frac{\Delta G_R^0}{RT_1} \right) \quad (2.4)$$

$$\ln \frac{K_2}{K_1} = - \frac{\Delta H_R^0}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \quad (2.5)$$

dengan,

K_1 = Konstanta keseimbangan pada suhu standar

K_2 = Konstanta keseimbangan pada suhu operasi

ΔG_R^0 = Energi gibbs pembentukan reaksi pada suhu standar (J/mol)

ΔH_R^0 = Panas reaksi pada suhu standar (J/mol)

T_1 = Suhu standar (298,15 K)

T_2 = Suhu operasi (373,15 K)

R = Konstanta gas ideal = 8,314 J/mol/K

Penentuan konstanta keseimbangan reaksi pembuatan n-butil oleat pada suhu 298,15 K mengikuti persamaan (2.4)

$$\begin{aligned}K_1 &= \exp \left(- \frac{\Delta G_R^0}{RT_1} \right) \\ &= \exp \left(\frac{-1 \times -3880}{8,314 \times 298,15} \right) \\ &= 4,783926\end{aligned}$$

Pada suhu 100 C (373,15 K) besarnya nilai konstanta keseimbangan dapat ditentukan mengikuti persamaan (2.5)

$$\ln \frac{K_2}{K_1} = - \frac{\Delta H_R^0}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$



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$$\frac{K_2}{K_1} = \exp \left[- \frac{\Delta H_R^0}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \right]$$

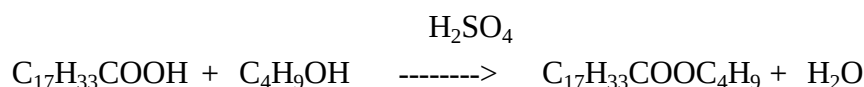
$$K_2 = 4,7839 \exp \left[\frac{-1790}{8,314} \left(\frac{1}{373} - \frac{1}{298} \right) \right]$$

$$= 5,5312$$

Berikut adalah perhitungan konversi kesetimbangan reaksi pada suhu 100 C
Maka dapat dilakukan perhitungan $\Delta G_{R \text{ operasi}}^0$ dengan rumus berikut

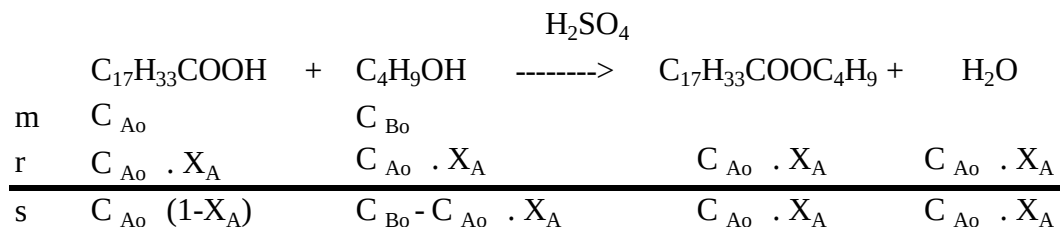
$$\begin{aligned} \Delta G_{R \text{ operasi}}^0 &= - R \cdot T_{\text{operasi}} \cdot \ln K_{T \text{ operasi}} \\ &= - (0,008314 \text{ kJ/mol K}) \times 373,15 \text{ K} \times \ln 5,5312 \\ &= -5,306295 \text{ kJ/mol} \end{aligned}$$

Reaksi



$$K = \frac{[\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9] [\text{H}_2\text{O}]}{[\text{C}_{17}\text{H}_{33}\text{COOH}] [\text{C}_4\text{H}_9\text{OH}]}$$

Stokiometri



$$K = \frac{[\text{C}_{A0} \cdot X_A] [\text{C}_{A0} \cdot X_A]}{[\text{C}_{A0} (1-X_A)] [\text{C}_{B0} - \text{C}_{A0} \cdot X_A]}$$

$$K = \frac{\text{C}_{A0}^2 \cdot X_A^2}{[\text{C}_{A0} (1-X_A)] [\text{C}_{A0} (\frac{\text{C}_{B0}}{\text{C}_{A0}} - X_A)]}$$



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$$K = \frac{X_A^2}{(1-X_A) \left(\frac{C_{Bo}}{C_{Ao}} - X_A \right)}$$

dengan

$$K = 5,53118$$

$$C_{Bo} = B = 5,1424$$

$$C_{Ao} = A$$

$$5,5312 = \frac{X_A^2}{(1-X_A) \left(\frac{5,14}{C_{Ao}} - X_A \right)}$$

$$\left(5,1424 - X_A - \frac{5,1424}{C_{Ao}} X_A + X_A^2 \right) \times 5,5312 = X_A^2$$

$$28,444 - 33,187 X_A + 5,5312 X_A^2 = X_A^2$$

$$28,444 - 33,187 X_A + 4,5312 X_A^2 = 0$$

Sehingga diperoleh

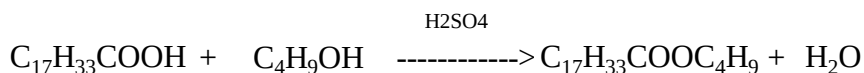
$$X_1 = 6,3337 \quad (\text{tidak memenuhi})$$

$$X_2 = 0,9011 \quad (\text{memenuhi})$$

Maka, nilai konversi kesetimbangannya adalah 90,11 %

Tinjauan Kinetika

Proses pembuatan n-butil oleat merupakan reaksi esterifikasi antara asam oleat dan n-butanol sesuai dengan persamaan reaksi berikut



Ditinjau dari kinetika reaksi antara asam oleat dengan n-butanol termasuk reaksi orde 2. persamaan kecepatan reaksi menurut othmer and rao, 1950

$$-r_A = K_1 C_A C_B - K_2 C_C C_D$$

$$K_1 = 104088,8 \exp \left(-42083 / RT \right)$$

dimana, $K = \frac{K_1}{K_2}$

maka persamaan menjadi



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$$-r_A = K_1 (C_A C_B - \frac{1}{K} C_C C_D)$$

dengan,

- r_A = kecepatan reaksi, mol/L.menit\
 K_1 = konstanta kecepatan reaksi ke arah produk, L/mol.menit
 K_2 = konstanta kecepatan reaksi ke arah reaktan, L/mol.menit
 K = konstanta kesetimbangan
 C_A = konsentrasi asam oelat, mol/L
 C_B = konsentrasi n-butanol, mol/L
 C_C = konsentrasi n-butil oleat, mol/L
 C_D = konsentrasi air, mol/L
 R = 8,314 j/mol.K
 T = suhu reaksi, K = 373,15 K

	$C_{17}H_{33}COC +$	C_4H_9OH	$\rightarrow$	$C_{17}H_{33}COOC_4H_9 +$	H_2O
M	13,6971	68,4857		0	0
R	12,3274	12,3274		12,3274288	12,327
S	1,3697	56,1583		12,3274288	12,327

$$-r_A = K_1 (C_A C_B - \frac{1}{K} C_C C_D)$$

$$K_1 = 104088,8 \exp \left(\frac{-42083}{RT} \right)$$

$$= 104088,8 \exp \left(\frac{-42083}{3102,4} \right)$$

$$= 0,133748$$

$$K = \frac{K_1}{K_2}$$

$$K = 5,5312$$

$$-r_A = K_1 (C_A C_B - \frac{1}{K} C_C C_D)$$

$$= 0,1337 \times (1,3697 \times 56,158 - \frac{1}{5,53} \times 12,327 \times 12,327)$$

$$= 6,613385 \text{ mol.L/menit}$$



APPENDIX C PERHITUNGAN SPESIFIKASI ALAT

Kapasitas Produksi = 33000 ton/tahun
= 100 ton/hari
= 4166,6667 kg/jam
Waktu operasi = 330 hari /tahun
= 24 jam/hari
Satuan massa = kilogram/jam
Satuan panas = kilokalori/jam

Data Densitas

Persamaan

$$\rho = A B^{-(1-\frac{T}{T_c})^n}$$

Dimana

ρ = Densitas liquid (gr/ml)
A,B,n = Konstanta
T = Temperature (K)
T_c = Temperature kritis (K)

Komponen	A	B	T _c	n
C ₁₇ H ₃₃ COOH	0,2824	0,26812	781	0,2897
C ₄ H ₉ OH	0,26891	0,2667	562,93	0,2457
C ₁₇ H ₃₃ COOC ₄ H ₉	0,24798	0,24	764	0,2857
C ₁₅ H ₃₁ COOH	0,2797	0,26805	776	0,2947
H ₂ O	0,3471	0,274	647,13	0,2857
H ₂ SO ₄	0,42169	0,1936	925	0,2857
NaOH	0,19975	0,0973	2820	0,2538
Na ₂ SO ₄	0,26141	0,1	3700	0,2857

(Yaws, 1999, Table 8-1)

Data Viskositas Untuk Liquid

Persamaan

$$\text{Log}_{10} n_{liq} = A + \frac{B}{T} + CT + DT^2$$



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Dimana

n_{liq} = Viskositas Larutan (cP)

A,B,C,D = Konstanta

T = Temperature (K)

Komponen	A	B	C	D
$C_{17}H_{33}COOH$	-6,13	1690	0,008	-6,45E-06
C_4H_9OH	-5,397	1325,6	0,006	-5,51E-06
$C_{17}H_{33}COOC_4H_9$	-15,2751	2934	0,02692	-1,808E-05
$C_{15}H_{31}COOH$	-9,45	2100	0,016	-0,0000126
H_2O	-10,2518	1792,5	0,01773	-1,263E-05
H_2SO_4	-18,7045	3496,2	0,03308	-1,701E-05
NaOH	-4,1939	2051,5	0,0027917	-6,159E-07
Na_2SO_4	11,2905	-4576,9	-0,0067848	9,244E-05

(Yaws, 1999, Table 22-1)

Data Viskositas Bahan Gas

Persamaan

$$n_{gas} = A + BT + CT^2$$

Dimana

n_{gas} = Viskositas gas

A,B,C = Konstanta

T = Temperature (K)

Komponen	A	B	C
$C_{17}H_{33}COOH$	-2,483	0,1505	-1,474E-05
C_4H_9OH	-11,144	0,2879	-0,0000562
$C_{17}H_{33}COOC_4H_9$	-2,15	0,133	-1,451E-05
$C_{15}H_{31}COOH$	-3,002	0,1515	-1,602E-05

(Yaws, 1999, Table 21-2)

Data Kapasitas Panas dari Liquid

Persamaan

$$C_p = A + BT + CT^2 + DT^3$$



PRA RANCANGAN PABRIK
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Dimana

C_p = Kapasitas Panas (J/mol.K)

A,B,C,D = Konstanta

T = Temperature (K)

Komponen	A	B	C	D
$C_{17}H_{33}COOH$	278,686	2,5434	-0,0054355	4,924E-06
C_4H_9OH	83,877	0,56628	-0,0017	0,0000023
$C_{17}H_{33}COOC_4H_9$	178,423	3,667	-0,007974	7,102E-06
$C_{15}H_{31}COOH$	86,29	3,5237	-0,00732	0,0000061
H_2O	92,053	-0,04	-0,0002	5,3E-07
H_2SO_4	26,004	0,70337	-0,0014	0,000001
Na_2SO_4	233,515	-0,0095276	-3,467E-05	-1,577E-08

(Yaws, 1999, Table 3-1 & 3-2)

Data Kapasitas Panas dari Gas

Persamaan

$$C_p = A + BT + CT^2 + DT^3 + ET^4$$

Dimana

C_p = Kapasitas Panas (J/mol.K)

A,B,C,D,E = Konstanta

T = Temperature (K)

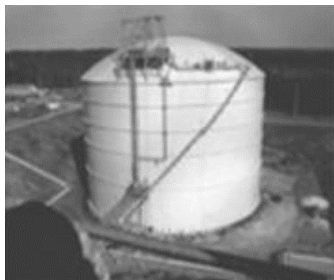
Komponen	A	B	C	D	E
$C_{17}H_{33}COOH$	-55,663	1,991	-0,0016	6,7E-07	-1E-10
C_4H_9OH	8,157	0,41032	-0,0002	6,7E-07	-1E-10
$C_{17}H_{33}COOC_4H_9$	-69,046	2,5211	-0,0021	1,1E-06	-3E-10
$C_{15}H_{31}COOH$	-54,487	1,804	-0,0013	5,4E-07	-9E-11

(Yaws, 1999, Table 2-1)



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

1. Tangki Penyimpanan Natrium Hidroksida (F-110)



Fungsi : Menyimpan bahan baku Natrium Hidroksida 48%
Tipe : Tangki berbentuk silinder tegak, tutup atas berupa
Torispherical dish tutup bawah datar
Dasar Pemilihan : Sesuai untuk penyimpanan liquida pada tekanan atmosferik

Kondisi operasi :

Tekanan = 1 atm
suhu = 30 °C
Waktu tinggal = 7 hari

Komposisi Bahan Masuk

komponen	massa (kg/jam)	Fraksi massa
NaOH	67,388	0,48
H ₂ O	73,003	0,52
Total	140,391	1

Rate Massa = 140,391 kg/jam
= 309,51 lb/jam

Menghitung Densitas Larutan

Komponen	A	B	T _c	n
NaOH	0,19975	0,0973	2820	0,2538
H ₂ O	0,3471	0,274	647,13	0,2857

$$T = 30 \text{ }^{\circ}\text{C} = 303,15 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

$$\begin{aligned}\rho \text{ NaOH} &= 2,0529 \text{ gr/ml} \\ \rho \text{ H}_2\text{O} &= 1,2668 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg/jam)		gr/ml	gr/ml
NaOH	67,3878	0,48	2,0529	0,9854
H ₂ O	73,0034	0,52	1,2668	0,6587
Total	140,3912	1		1,6441

$$\begin{aligned}\rho \text{ Campuran} &= 1,6441 \text{ gr/ml} \times 62,4 \\ &= 102,5941 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Rate volumetrik} &= \frac{\text{rate massa}}{\rho \text{ campuran}} \\ &= \frac{309,5096 \text{ lb/jam}}{102,5941 \text{ lb/cuft}} \\ &= 3,0168 \text{ cuft/jam} \\ &= 72,4041 \text{ cuft/hari}\end{aligned}$$

a. Menentukan Volume Tangki

Digunakan 1 buah tangki untuk penyimpanan 7 hari, maka

$$\begin{aligned}\text{Volume liquid} &= 72,4041 \text{ cuft/hari} \times 7 \text{ hari} \\ &= 506,829 \text{ cuft}\end{aligned}$$

Asumsi volume 80% volume tangki untuk faktor keamanan, sehingga :

$$\begin{aligned}\text{Volume tangki} &= \frac{\text{Volume cairan}}{80\%} \\ &= \frac{506,8285685 \text{ cuft}}{80\%} \\ &= 633,53571 \text{ cuft}\end{aligned}$$

b. Menentukan Dimensi Tangki

Dimensi ratio H/D = 2-5 (Ulrich : Table 4-27)

Asumsi Dimention ratio : H/D = 2

Volume tutup Torispherical dish head

$$\text{Volume tutup atas} = 0,000049 D^3 \quad (\text{Brownell,1959 Eq. 5.11})$$



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
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$$\text{Volume tangki} = \frac{1}{4} \times \pi \times D^2 \times H + 0,000049 D^3$$

$$633,5357107 = 1,57 D^3$$

$$D^3 = 403,513$$

$$D = 7,38957 \text{ ft}$$

$$= 2,25234 \text{ m}$$

$$= 88,6749 \text{ in}$$

$$H = 2 \times D$$

$$= 2 \times 7,38957 \text{ ft}$$

$$= 14,7791 \text{ ft}$$

$$= 4,50468 \text{ m}$$

$$= 177,35 \text{ in}$$

c. Menentukan tinggi cairan dalam tangki penyimpanan

$$\text{Volume liquid} = \frac{1}{4} \times \pi \times D^2 \times H + 0,000049 D^3$$

$$506,829 = 42,8655 H + 0,0197722$$

$$506,809 = 42,8655 H$$

$$H = 11,8232 \text{ ft}$$

$$= 3,60372 \text{ m}$$

$$= 141,879 \text{ in}$$

d. Menentukan Tekanan design

Jika dalam bejana terdapat liquid, maka bejana dirancang berdasarkan tekanan dalam :

$$P \text{ design} = P \text{ gauge} + P \text{ hidrostatik}$$

$$P \text{ design} = (P_i - P_o) + P \text{ hidrostatik}$$

$$P \text{ design} = (14,7 - 14,7) + P \text{ hidrostatik}$$

$$P \text{ design} = P \text{ hidrostatik}$$

$$P \text{ design} = \rho \times \frac{g}{g_c} \times H \text{ liq}$$

$$= 102,594 \frac{\text{lb}}{\text{cuft}} \times 1 \frac{\text{lbf}}{\text{lbm}} \times 11,8232 \text{ ft}$$

$$= 1212,9927 \frac{\text{lbf}}{\text{ft}^2}$$

$$= 8,4235605 \text{ psi}$$



PRA RANCANGAN PABRIK
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Proses Esterifikasi dan Katalis Asam Sulfat”

Asumsi P design 10% lebih besar untuk faktor keamanan

$$P_{\text{design}} = 1,1 \times 8,42356 \text{ Psi}$$

$$= 9,26592 \text{ Psi}$$

e. Menentukan tebal shell minimum

Tebal shell berdasarkan ASME code untuk cylindrical tank:

$$t_s = \frac{P_d \times r_i + C}{f_e - 0,6 P_d} \quad \text{(Brownell Eq. 13.1)}$$

dengan

t_s = tebal shell minimum (in)

P = tekanan tangki (Psi) = 9,26592 Psi

r_i = jari-jari tangki (in) = 44,3375 in

C = Faktor korosi (in); digunakan = 1/8 in

e = Faktor pengelasan; digunakan double welded = 0,8

(Brownell, Table 13.2)

f = Stress allowable bahan konstruksi Logam Paduan SB-575

= 98300 Psi **(ASMEBPVC.II.D.C-2017)**

sehingga,

Asumsi tebal shell = 3/16 in

$$t_s = \frac{P \times r_i + C}{f_e - 0,6 P}$$

$$\frac{3}{16} = \frac{9,26592 \times 44,3375 + 1/8}{0,8 f - 5,55955}$$

$$\frac{1}{16} = \frac{9,26592 \times 44,3375}{0,8 f - 5,5595499}$$

$$0,05 f - 0,34747 = 410,82718$$

$$0,05 f = 411,17465$$

$$f = 8223,493$$

f hitung lebih kecil dari f allowable, jadi tebal shell 3/16 in dapat digunakan

f. Menentukan Tebal Tutup Atas

Tutup atas dipilih Torispherical dish head

$$OD = ID + 2 t_s$$

$$= 88,6749 + 2 \times \frac{3}{16}$$

$$= 88,6749 + 0,375$$

$$= 88,6749 \text{ in}$$



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

Berdasarkan Brownell and Young, Tabel 5.7 dari data OD, diperoleh:

$$OD = 90 \text{ in}$$

$$icr = 5 \frac{1}{2} \text{ in}$$

$$rc = 90 \text{ in}$$

Cek nilai icr dengan nilai 6%rc

$$icr = 5,5 \text{ in}$$

$$6\% rc = 5,4 \text{ in}$$

Karena nilai icr tabel > nilai 6%rc, maka digunakan persamaan:

$$th = \frac{P \times rc \times W}{2 f e^{-0,2P}} + C \quad \text{(Brownell Eq. 7.77)}$$

$$W = \frac{1}{4} \times \left(3 + \frac{\sqrt{rc}}{rl} \right) \quad \text{(Brownell Eq. 7.76)}$$

dengan

$$Pd = \text{Tekanan design (Psi)} = 9,27 \text{ Psi}$$

$$rc = \text{Crown radius} = \text{jari-jari dalam (in)} = 90 \text{ in}$$

$$r_i/i = \text{Inside crown radius (in)} = 44,3375$$

$$E = \text{Faktor pengelasan} = 0,8$$

$$t = \text{Tebal dinding minimal (in)}$$

$$f = \text{Stress allowable bahan konstruksi SB-575} \\ = 98300 \text{ Psi} \quad \text{(ASMEBPVC.II.D.C-2017)}$$

$$C = \text{Faktor korosi (in)} = 1/8$$

Sehingga,

$$W = \frac{1}{4} \times \left(3 + \frac{\sqrt{r}}{rl} \right) \\ = \frac{1}{4} \times \left(3 + \frac{9,49}{44,3} \right) \\ = 0,80349$$

$$\text{Asumsi tebal tutup} = 3/16 \text{ in}$$

$$th = \frac{P \times rc \times W}{2 f e^{-0,2P}} + C \\ 3/16 = \frac{9,27 \times 90 \times 0,8}{1,6 f - 0,2 \times 9,27} + 1/8 \\ 1/16 = \frac{670,0582515}{1,6 f - 1,8531833} \\ 0,1 f - 0,115824 = 670,0582515 \\ 0,1 f = 670,1740754$$



$$f = 6701,740754$$

f hitung lebih kecil dari f allowable, jadi tebal shell $\frac{3}{16}$ in dapat digunakan

g. Menentukan Tinggi Tutup Tangki

$$sf = 2 \text{ in}$$

$$t = \frac{2}{8} \text{ in}$$

(Brownell, tabel 5.6, hal. 88)

Menghitung tinggi tutup

$$OA = b + sf + t$$

$$BC = rc - icr$$

$$\begin{aligned} BC &= 90 - 5,4 \\ &= 84,6 \text{ in} \end{aligned}$$

$$AB = \frac{1}{2} \times OD - icr$$

$$\begin{aligned} AB &= \frac{1}{2} \times 90 - 5,4 \\ &= 39,600 \text{ in} \end{aligned}$$

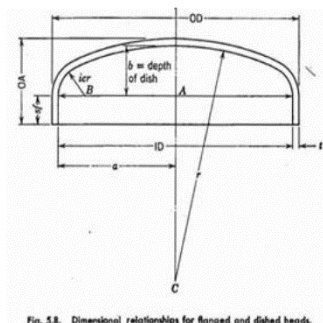


Fig. 5.8. Dimensional relationships for flanged and dished heads.

$$b = rc - (BC^2 - AB^2)^{0,5}$$

$$\begin{aligned} b &= 90 - (7157 - 1568)^{0,5} \\ &= 15,240 \end{aligned}$$

Tinggi tutup atas

$$OA = b + sf + t$$

$$= 17,428 \text{ in}$$

$$= 0,4427 \text{ m}$$

$$= 1,4523 \text{ ft}$$

h. Menentukan Tebal Tutup Bawah (Flatted Bottom)

Tebal tutup bawah datar karena menumpang di atas pondasi

Untuk flatted bottom, digunakan tebal tutup bawah $\frac{3}{16}$ in

(Brownell, Hal. 58)



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

Spesifikasi

Nama alat : Tangki Penyimpanan Natrium Hidroksida
Kode : F-110
Fungsi : Menyimpan bahan baku Natrium Hidroksida
Bentuk : Tangki berupa silinder tegak dengan tutup atas
Torispherical dish head dan tutup bawah plate
Bahan konstruksi : Logam Paduan SB-575
Jumlah : 1 buah

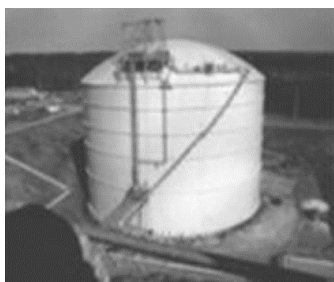
Kondisi Operasi

Suhu : 30 °C
Tekanan : 1 atm
waktu : 7 hari

Dimensi Tangki

Diameter tangki = 7,390 ft = 2,252 m
Tinggi tangki = 14,7791 ft = 4,50468 m
Volume Tangki = 633,536 cuft
Tebal shell = 3/16 in
Tebal Tutup Atas = 3/16 in
Tinggi Tutup Atas = 1,45232 in = 0,4427 m
Tebal Tutup Bawah = 3/16 in

2. Tangki Penyimpanan Asam Sulfat (F-120)



Fungsi : Menyimpan bahan baku Asam Sulfat 98%
Tipe : Tangki berbentuk silinder tegak, tutup atas berupa
Torispherical dish tutup bawah datar
Dasar Pemilihan : Sesuai untuk penyimpanan liquida pada tekanan atmosferik

Kondisi operasi :

Tekanan = 1 atm
suhu = 30 °C



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

Waktu tinggal = 7 hari

Komposisi Bahan

komponen	massa (kg/jam)	fraksi massa
H ₂ SO ₄	82,5499	0,98
H ₂ O	1,6847	0,02
Total	84,2346	1

Rate Massa = 84,2346 kg/jam
 = 185,706 lb/jam

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
H ₂ SO ₄	0,42169	0,1936	925	0,2857
H ₂ O	0,3471	0,274	647,13	0,2857

T = 30 °C = 303,15 K

$$\rho = Ax B^{-\left(1 - \frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

ρ H₂SO₄ = 1,8264 gr/ml
 ρ H₂O = 1,0229 gr/ml

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
H ₂ O	1,6847	0,02	1,0229	0,0205
H ₂ SO ₄	82,5500	0,98	1,8264	1,7899
Total	84,2347	1		1,8104

ρ Campuran = 1,8104 gr/ml x 62,4
 = 112,9676 lb/cuft

rate volumetrik = $\frac{\text{rate massa}}{\rho \text{ campuran}}$
 = $\frac{185,7056 \text{ lb/jam}}{112,9676 \text{ lb/cuft}}$
 = 1,6439 cuft/jam



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

$$= 39,4532 \text{ cuft/hari}$$

a. Menentukan Volume Tangki

digunakan 1 buah tangki untuk penyimpanan 7 hari, maka

$$\text{Volume liquid} = 39,4532 \text{ cuft/hari} \times 7 \text{ hari}$$

$$= 276,172 \text{ cuft}$$

Asumsi volume 80% volume tangki untuk faktor keamanan, sehingga :

$$\begin{aligned} \text{Volume tangki} &= \frac{\text{Volume cairan}}{80\%} \\ &= \frac{276,1723849}{80\%} \\ &= 345,21548 \text{ cuft} \end{aligned}$$

b. Menentukan Dimensi Tangki

$$\text{Asumsi Dimention ratio} : H/D = 2 - 5 \quad (\text{Ulrich : T.4-27})$$

$$\text{Asumsi rasio dimensi H/D} = 2$$

Volume tutup Torispherical dish head

$$\text{Volume tutup atas} = 0,000049 D^3 \quad (\text{Brownell Eq. 5.11})$$

$$\text{Volume tangki} = \frac{1}{4} \pi \times D^2 H + 0,000049 D^3$$

$$345,2154811 = 1,57 D^3$$

$$D^3 = 219,876$$

$$D = 6,03567 \text{ ft}$$

$$= 1,83967 \text{ m}$$

$$= 72,4281 \text{ in}$$

$$H = 2 \times D$$

$$= 2 \times 6,03567 \text{ ft}$$

$$= 12,0713 \text{ ft}$$

$$= 3,67935 \text{ m}$$

$$= 144,856 \text{ in}$$

c. Menentukan tinggi cairan dalam tangki penyimpanan

$$\text{Volume liquid} = \frac{1}{4} \pi \times D^2 H + 0,000049 D^3$$

$$276,172 = 28,597 H + 0,0107739$$



$$\begin{aligned}
 276,162 &= 28,597 \text{ H} \\
 \text{H} &= 9,657 \text{ ft} \\
 &= 2,94345 \text{ m} \\
 &= 115,884 \text{ in}
 \end{aligned}$$

d. Menentukan Tekanan design

Jika dalam bejana terdapat liquid, maka bejana dirancang berdasarkan tekanan dalam :

$$\begin{aligned}
 P_{\text{design}} &= P_{\text{gauge}} + P_{\text{hidrostatik}} \\
 P_{\text{design}} &= (P_i - P_o) + P_{\text{hidrostatik}} \\
 P_{\text{design}} &= (14,7 - 14,7) + P_{\text{hidrostatik}} \\
 P_{\text{design}} &= P_{\text{hidrostatik}} \\
 P_{\text{design}} &= \rho \times \frac{g}{g_c} \times H_{\text{liq}} \\
 &= 112,968 \frac{\text{lb}}{\text{cuft}} \times 1 \frac{\text{lbf}}{\text{lbfm}} \times 9,657 \text{ ft} \\
 &= 1090,9283 \frac{\text{lbf}}{\text{ft}^2} \\
 &= 7,5758912 \text{ psi}
 \end{aligned}$$

Asumsi P_{design} 10% lebih besar untuk faktor keamanan

$$\begin{aligned}
 P_{\text{design}} &= 1,1 \times 7,57589 \text{ Psi} \\
 &= 8,33348 \text{ Psi}
 \end{aligned}$$

e. Menentukan tebal shell minimum

Tebal shell berdasarkan ASME code untuk cylindrical tank:

$$t_s = \frac{P_d \times r_i + C}{f_e - 0,6 P_d} \quad \text{(Brownell Eq. 13.1)}$$

dengan

$$\begin{aligned}
 t_s &= \text{tebal shell minimum (in)} \\
 P &= \text{tekanan tangki (Psi)} = 8,33348 \text{ Psi} \\
 r_i &= \text{jari-jari tangki (in)} = 36,2141 \text{ in} \\
 C &= \text{Faktor korosi (in); digunakan} = 1/8 \text{ in} \\
 e &= \text{Faktor pengelasan; digunakan double welded} = 0,8 \\
 &\quad \text{(Brownell, Table 13.2)} \\
 f &= \text{stress allowable bahan konstruksi SB 575} \\
 &= 98300 \text{ Psi} \quad \text{(ASMEBPVC.II.D.C-2017)}
 \end{aligned}$$



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sehingga,

$$t_s = \frac{P \times r_i}{f \cdot E - 0,6P} + C \quad (\text{Brownell, Pers. 13-1})$$

$$t_s = \frac{8,3335 \times 36,214}{(98300 \times 0,8) - (0,6 \times 8,3335)} + 1/8$$

$$= 0,1288$$

Standarisasi $t_s = 1/8$ in
 f hitung lebih kecil dari f allowable, jadi tebal shell $1/8$ in
 dapat digunakan

f. Menentukan Tebal Tutup Atas

Tutup atas dipilih Torispherical dish head

$$\begin{aligned} OD &= ID + 2 t_s \\ &= 72,4281 + 2 \times 4/31 \\ &= 72,4281 + 25/97 \\ &= 72,6858 \text{ in} \end{aligned}$$

Berdasarkan Brownell and Young, Tabel 5.7 dari data OD, diperoleh:

$$\begin{aligned} icr &= 4 \frac{3}{4} \text{ in} \\ rc &= 78 \text{ in} \end{aligned}$$

Cek nilai icr dengan nilai $6\%rc$

$$\begin{aligned} icr &= 4,75 \text{ in} \\ 6\% rc &= 4,68 \text{ in} \end{aligned}$$

Karena nilai icr tabel $>$ nilai $6\%rc$, maka digunakan persamaan:

$$t_h = \frac{P \times rc \times W}{2 f_e - 0,2P} + C \quad (\text{Brownell Eq. 7.77})$$

$$W = \frac{1}{4} \times \left(3 + \frac{\sqrt{rc}}{rl} \right) \quad (\text{Brownell Eq. 7.76})$$

dengan

$$\begin{aligned} P_d &= \text{Tekanan design (Psi)} = 8,33 \text{ Psi} \\ rc &= \text{Crown radius} = \text{jari-jari dalam (in)} = 78 \text{ in} \\ r_i/i &= \text{Inside crown radius (in)} = 36,2141 \\ E &= \text{Faktor pengelasan} = 0,8 \\ t &= \text{Tebal dinding minimal (in)} \\ f &= \text{Stress allowable bahan SB 575} \\ &= 98500 \text{ psi} \quad (\text{ASMEBPVC.II.D.C-2017}) \\ C &= \text{Faktor korosi (in)} = 1/8 \end{aligned}$$

Sehingga,



$$W = \frac{1}{4} \times \left(3 + \frac{\sqrt{r}}{rl} \right)$$

$$= \frac{1}{4} \times \left(3 + \frac{8,83}{36,2} \right)$$

$$= 0,81097$$

$$\begin{aligned} \text{Asumsi tebal tutup} &= 3/16 \text{ in} \\ t_h &= \frac{P \times r_c \times W}{2 f_e - 0,2P} + C \\ 3/16 &= \frac{8,33 \times 78 \times 0,81}{1,6 f - 0,2 \times 8,33} + 1/8 \\ 1/16 &= \frac{527,1392447}{1,6 f - 1,6666961} \\ 0,1 f - 0,1041685 &= 527,1392447 \\ 0,1 f &= 527,2434132 \\ f &= 5272,434132 \end{aligned}$$

f hitung lebih kecil dari f allowable, jadi tebal shell 3/16 in dapat digunakan

g. Menentukan Tinggi Tutup Tangki

$$sf = 2 \text{ in}$$

$$t = 2/8 \text{ in}$$

(Brownell, tabel 5.6, hal. 88)

Menghitung tinggi tutup

$$OA = b + sf + t$$

$$* 1 \text{ ft} = 0,3 \text{ m}$$

$$1 \text{ ft} = 12 \text{ in}$$

$$BC = rc - icr$$

$$\begin{aligned} BC &= 78 - 4,68 \\ &= 73,320 \text{ in} \end{aligned}$$

$$AB = \frac{1}{2} \times OD - icr$$

$$\begin{aligned} AB &= \frac{1}{2} \times 72,6858 - 4,68 \\ &= 31,663 \text{ in} \end{aligned}$$

$$b = rc - (BC^2 - AB^2)^{0,5}$$

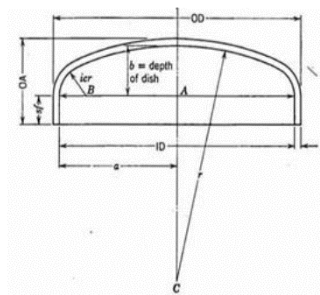


Fig. 5.8. Dimensional relationships for flanged and dished heads.



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$$b = 78 - (5376 - 1003)^{0,5}$$
$$= 11,869$$

Tinggi tutup atas

$$\begin{aligned} OA &= b + sf + t \\ &= 14,057 \text{ in} \\ &= 0,3570 \text{ m} \\ &= 1,1714 \text{ ft} \end{aligned}$$

h. Menentukan Tebal Tutup Bawah (Flatted Bottom)

Tebal tutup bawah datar karena menumpang di atas pondasi

Untuk flatted bottom, digunakan tebal tutup bawah $\frac{3}{16}$ in
(Brownell, Hal. 58)

Spesifikasi

Nama alat : Tangki Penyimpanan Asam Sulfat
Kode : F-120
Fungsi : Menyimpan bahan baku asam sulfat 98%
Bentuk : Tangki berupa silinder tegak dengan tutup atas
Torispherical dish head dan tutup bawah datar

Bahan konstruksi : Logam Paduan SB-575

Jumlah : 1 buah

Kondisi Operasi

Suhu : 30 °C

Tekanan : 1 atm

Waktu : 7 hari

Dimensi Tangki

Diameter tangki : 6,03567 ft = 1,83967 m

Tinggi tangki : 12,0713 ft = 3,67935 m

Volume Tangki : 345,215 cuft

Tebal shell : $\frac{2}{16}$ in

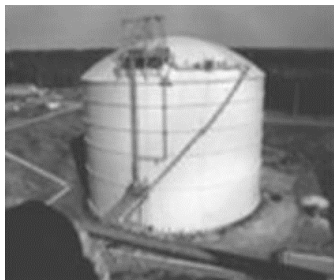
Tebal Tutup Atas : $\frac{3}{16}$ in

Tinggi Tutup Atas : 1,17139 ft = 0,3570 m

Tebal Tutup Bawah : $\frac{3}{16}$ in



3. Tangki Penyimpanan Butanol (F-130)



- Fungsi : Menyimpan bahan baku Butanol 99,5%
Tipe : Tangki berbentuk silinder tegak, tutup atas berupa
Torispherical dish tutup bawah datar
Dasar Pemilihan : Sesuai untuk penyimpanan liquida pada tekanan atmosferik

Kondisi operasi :

- Tekanan = 1 atm
suhu = 30 °C
Waktu tinggal = 7 hari

Komposisi bahan baku

komponen	BM (kg/kmol)	massa (kg/jam)	fraksi massa
C ₄ H ₉ OH	74	5067,938	0,995
H ₂ O	18	25,467	0,005
Total		5093,405	1

Menghitung Densitas Larutan

Komponen	A	B	T _c	n
C ₄ H ₉ OH	0,26891	0,2667	562,93	0,2457
H ₂ O	0,3471	0,274	647,13	0,2857

$$T = 30 \text{ }^{\circ}\text{C} = 303,15 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned}\rho \text{ C}_4\text{H}_9\text{OH} &= 0,8022 \text{ gr/ml} \\ \rho \text{ H}_2\text{O} &= 1,0229 \text{ gr/ml}\end{aligned}$$



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Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	kg/jam		gr/ml	gr/ml
C ₄ H ₉ OH	5067,938	0,995	1,0229	1,0178
H ₂ O	25,467	0,005	0,8022	0,0040
Total	5093,405	1		1,0218

$$\begin{aligned}\rho \text{ Campuran} &= 1,022 \text{ gr/ml} \times 62,4 \\ &= 63,759 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Rate massa} &= 5093,405 \text{ kg/jam} \\ &= 11229,035 \text{ lb/jam}\end{aligned}$$

$$\begin{aligned}\text{Rate volumetrik} &= \frac{\text{rate massa}}{\rho \text{ campuran}} \\ &= \frac{11229,035 \text{ lb/jam}}{63,758987 \text{ lb/cuft}} \\ &= 176,1169 \text{ cuft/jam} \\ &= 4226,8056 \text{ cuft/hari}\end{aligned}$$

a. Menentukan Volume Tangki

digunakan 5 buah tangki untuk penyimpanan 7 hari, maka

$$\begin{aligned}\text{Volume liquid} &= 4226,81 \text{ cuft/hari} \times 7 \text{ hari} \\ &= 29587,639 \text{ cuft}\end{aligned}$$

Volume liquid tiap tangki adalah

$$\begin{aligned}\text{Volume liquid} &= \frac{29587,639 \text{ cuft}}{5} \\ &= 5917,5279 \text{ cuft}\end{aligned}$$

Asumsi volume liquid mengisi 80% volume tangki untuk faktor keamanan, sehingga :

$$\begin{aligned}\text{Volume tangki} &= \frac{\text{Volume cairan}}{80\%} \\ &= \frac{5917,527871}{80\%} \\ &= 7396,9098 \text{ cuft}\end{aligned}$$



b. Menentukan Dimensi Tangki Penyimpanan

Asumsi Dimention ratio : $H/D = 2 - 5$ (Ulrich : T.4-27)

Asumsi rasio dimensi $H/D = 2$

Volume tutup Torispherical dish head

Volume tutup atas = $0,000049 D^3$ (Brownell Eq. 5.11)

Volume tangki = $\frac{1}{4} \times \pi \times D^2 H + 0,000049 D^3$

$$7396,909838 = 1,57005 D^3$$

$$D^3 = 4711,26 \text{ ft}^3$$

$$D = 16,7641 \text{ ft}$$

$$= 5,10968 \text{ m}$$

$$= 201,169 \text{ in}$$

$$H = 2 \times D$$

$$= 2 \times 16,7641 \text{ ft}$$

$$= 33,528107 \text{ ft}$$

$$= 10,219367 \text{ m}$$

$$= 402,3375 \text{ in}$$

c. Menentukan Tinggi Cairan dalam Tangki Penyimpanan

Volume liquid = $\frac{1}{4} \times \pi \times D^2 H + 0,000049 D^3$

$$5917,527871 = 220,611 H + 0,2308518$$

$$5917,297019 = 220,611 H$$

$$H = 26,8223 \text{ ft}$$

$$= 8,17543 \text{ m}$$

$$= 321,867 \text{ in}$$

d. Menentukan Tekanan design

Jika dalam bejana terdapat liquid, maka bejana dirancang berdasarkan tekanan dalam :

$$P \text{ design} = P \text{ gauge} + P \text{ hidrostatik}$$

$$P \text{ design} = (P_i - P_o) + P \text{ hidrostatik}$$

$$P \text{ design} = (14,7 - 14,7) + P \text{ hidrostatik}$$

$$P \text{ design} = P \text{ hidrostatik}$$

$$P \text{ design} = \rho \times \frac{g}{g_c} \times H \text{ liq}$$



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$$\begin{aligned}
 &= 63,758987 \frac{\text{lb}}{\text{cuft}} \times \frac{1 \text{ lbf}}{\text{lbm}} \times 26,822276 \text{ ft} \\
 &= 1710,16 \frac{\text{lbf}}{\text{ft}^2} \\
 &= 11,8761 \text{ psi}
 \end{aligned}$$

Asumsi P design 10% lebih besar untuk faktor keamanan

$$\begin{aligned}
 P_{\text{desi}} &= 1,1 \times 11,8761 \text{ Psi} \\
 &= 13,0637 \text{ Psi}
 \end{aligned}$$

e. Menentukan tebal shell minimum

Tebal shell berdasarkan ASME code untuk cylindrical tank:

$$t_s = \frac{P_d \times r_i + C}{f_e - 0,6 P_d} \quad (\text{Brownell Eq. 13.1})$$

dengan

t_s = tebal shell minimum (in)

P = tekanan tangki (Psi) = 13,0637 Psi

r_i = jari-jari tangki (in) = 100,584 in

C = Faktor korosi (in); digunakan = 1/8 in

e = Faktor pengelasan; digunakan double welded = 0,8

(Brownell, Table 13.2)

f = stress allowable bahan konstruksi Carbon Steel SA-283 Grade C

= 12650 Psi **(Brownell, hal.342)**

sehingga,

Asumsi tebal shell = 3/8 in

$$t_s = \frac{P \times r_i + C}{f_e - 0,6 P}$$

$$\frac{6}{16} = \frac{13,0637 \times 100,584 + \frac{1}{8}}{0,8 f - 7,83824}$$

$$\frac{4}{16} = \frac{13,0637 \times 100,584}{0,8 f - 7,8382387}$$

$$0,2 f - 1,95956 = 1314,0072$$

$$0,2 f = 1315,9668$$

$$f = 6579,834$$

f hitung lebih kecil dari f allowable, jadi tebal shell 3/8 in dapat digunakan



f. Menentukan Tebal Tutup Atas

Tutup atas dipilih Torispherical dish head

$$\begin{aligned} \text{OD} &= \text{ID} + 2 \text{ ts} \\ &= 201,169 + 2 \times \frac{3}{8} \\ &= 201,169 + 0,75 \\ &= 201,919 \text{ in} \end{aligned}$$

Berdasarkan Brownell and Young, Tabel 5.7 dari data OD, diperoleh:

$$\begin{aligned} \text{OD} &= 204 \text{ in} \\ \text{icr} &= 12 \frac{1}{4} \text{ in} \\ \text{rc} &= 170 \text{ in} \end{aligned}$$

Cek nilai icr dengan nilai 6%rc

$$\begin{aligned} \text{icr} &= 12,25 \text{ in} \\ 6\% \text{ rc} &= 10,2 \text{ in} \end{aligned}$$

Karena nilai icr tabel > nilai 6%rc, maka digunakan persamaan:

$$\text{th} = \frac{P \times \text{rc} \times W}{2 f e^{-0,2P}} + C \quad \text{(Brownell Eq. 7.77)}$$

$$W = \frac{1}{4} \times \left(3 + \frac{\sqrt{\text{rc}}}{\text{rl}} \right) \quad \text{(Brownell Eq. 7.76)}$$

dengan

$$\text{Pd} = \text{Tekanan design (Psi)} = 13,1 \text{ Psi}$$

$$\text{rc} = \text{Crown radius} = \text{jari-jari dalam (in)} = 170 \text{ in}$$

$$\text{ri/i} = \text{Inside crown radius (in)} = 12,25$$

$$E = \text{Faktor pengelasan} = 0,8$$

$$t = \text{Tebal dinding minimal (in)}$$

$$f = \text{Stress allowable bahan Carbon Steel SA-283 grade C}$$

$$= 12650 \text{ Psi} \quad \text{(Brownell hal. 342)}$$

$$C = \text{Faktor korosi (in)} = \frac{1}{8}$$

Sehingga,

$$\begin{aligned} W &= \frac{1}{4} \times \left(3 + \frac{\sqrt{\text{rc}}}{\text{rl}} \right) \\ &= \frac{1}{4} \times \left(3 + \frac{13}{12,3} \right) \\ &= 1,01609 \end{aligned}$$

$$\text{Asumsi tebal tutup} = \frac{3}{8} \text{ in}$$

$$\text{th} = \frac{P \times \text{rc} \times W}{2 f e^{-0,2P}} + C$$



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$$\begin{aligned} 6/16 &= \frac{13,1 \times 170 \times 1,02 + 1/8}{1,6 f - 0,2 \times 13,1} \\ 4/16 &= \frac{2256,567282}{1,6 f - 2,6127462} \\ 0,4 f - 0,6531866 &= 2256,567282 \\ 0,4 f &= 2257,220469 \\ f &= 5643,051172 \end{aligned}$$

f hitung lebih kecil dari f allowable, jadi tebal shell $3/8$ in dapat digunakan

g. Menentukan Tinggi Tutup Tangki

$$sf = 2 \text{ in}$$

$$t = 3/8 \text{ in}$$

(Brownell, tabel 5.6, hal. 88)

Menghitung tinggi tutup

$$OA = b + sf + t$$

$$* 1 \text{ ft} = 0,3 \text{ m}$$

$$1 \text{ ft} = 12 \text{ in}$$

$$BC = rc - icr$$

$$\begin{aligned} BC &= 170 - 12,25 \\ &= 157,750 \text{ in} \end{aligned}$$

$$AB = \frac{1}{2} \times OD - icr$$

$$\begin{aligned} AB &= \frac{1}{2} \times 204 - 12,3 \\ &= 89,750 \text{ in} \end{aligned}$$

$$b = rc - (BC^2 - AB^2)^{0,5}$$

$$\begin{aligned} b &= 170 - (24885 - 8055)^{0,5} \\ &= 40,270 \end{aligned}$$

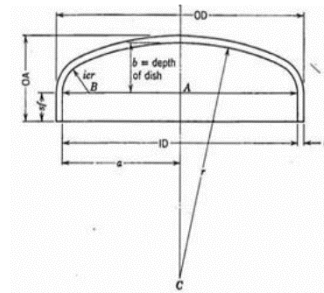


Fig. 5.8. Dimensional relationships for flanged and dished heads.

Tinggi tutup atas

$$\begin{aligned} OA &= b + sf + t \\ &= 42,645 \text{ in} \\ &= 1,0832 \text{ m} \\ &= 3,5537 \text{ ft} \end{aligned}$$



h. Menentukan Tebal Tutup Bawah (Flatted Bottom)

Tebal tutup bawah datar karena menumpang di atas pondasi

Untuk flatted bottom, digunakan tebal tutup bawah $\frac{3}{8}$ in
(Brownell, Hal. 58)

Spesifikasi

Nama alat : Tangki Penyimpanan Butanol
Kode : F-130
Fungsi : Menyimpan bahan baku butanol 99,5%
Bentuk : Tangki berupa silinder tegak dengan tutup atas
Torispherical dish head dan tutup bawah plate
Bahan konstruksi : Carbon steel SA-283 Grade C
Jumlah : 5 buah

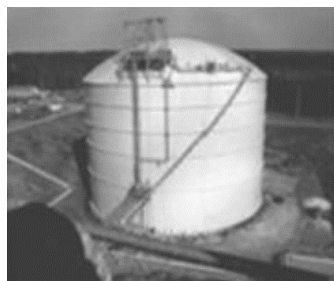
Kondisi Operasi

Suhu : 30 °C
Tekanan : 1 atm
waktu : 7 hari

Dimensi Tangki

Diameter tangki : 16,7641 ft = 5,10968 m
Tinggi tangki : 33,5281 ft = 10,2194 m
Volume Tangki : 7396,91 cuft
Tebal shell : $\frac{3}{8}$ in
Tebal Tutup Atas : $\frac{3}{8}$ in
Tinggi Tutup Atas : 3,55371 ft = 1,0832 m
Tebal Tutup Bawal : $\frac{3}{8}$ in

4. Tangki Penyimpanan Asam Oleat (F-140)



Fungsi : Menyimpan bahan baku Asam Oleat 99%



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Tipe : Tangki berbentuk silinder tegak, tutup atas berupa
Torispherical dish tutup bawah datar

Dasar Pemilihan : Sesuai untuk penyimpanan liquida pada tekanan atmosferik

Kondisi operasi :

Tekanan = 1 atm

suhu = 30 °C

Waktu tinggal = 7 hari

Komposisi Bahan

komponen	massa (kg/jam)	fraksi massa
C ₁₇ H ₃₃ COOH	3477,069	0,990
C ₁₅ H ₃₁ COOH	35,122	0,010
Total	3512,191	1

Rate Massa = 3512,19 kg/jam
 = 7743,05 lb/jam

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
C ₁₇ H ₃₃ COOH	0,2824	0,26812	781	0,2897
C ₁₅ H ₃₁ COOH	0,2797	0,26805	776	0,2947

$$T = 30 \text{ }^{\circ}\text{C} = 303,15 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{Tc}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned} \rho \text{ C}_{17}\text{H}_{33}\text{COOH} &= 1,0532597 \text{ gr/ml} \\ \rho \text{ C}_{15}\text{H}_{31}\text{COOH} &= 1,043462 \text{ gr/ml} \end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas gr/ml	ρ Campuran gr/ml
	(kg)			
C ₁₇ H ₃₃ COOH	3477,0687	0,99	1,04346	1,03303
C ₁₅ H ₃₁ COOH	35,1219	0,01	1,05326	0,01053
Total	3512,1906	1		1,04356

$$\rho \text{ Campuran} = 1,0436 \text{ gr/ml} \times 62,4$$



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$$= 65,1181 \text{ lb/cuft}$$

$$\begin{aligned} \text{rate volumetrik} &= \frac{\text{rate massa}}{\rho \text{ campuran}} \\ &= \frac{7743,0549 \text{ lb/jam}}{65,118145 \text{ lb/cuft}} \\ &= 118,90779 \text{ cuft/jam} \\ &= 2853,787 \text{ cuft/hari} \end{aligned}$$

a. Menentukan Volume Tangki

Digunakan 5 buah tangki untuk penyimpanan 7 hari, maka

$$\begin{aligned} \text{Volume liquid} &= 2853,79 \text{ cuft/hari} \times 7 \text{ hari} \\ &= 19976,5 \text{ cuft} \end{aligned}$$

Volume liquid untuk tiap tangki

$$\begin{aligned} \text{Volume liquid} &= \frac{19976,5 \text{ cuft}}{5} \\ &= 3995,3 \text{ cuft} \end{aligned}$$

Asumsi volume liquid mengisi 80% volume tangki untuk faktor keamanan, sehingga :

$$\begin{aligned} \text{Volume tangki} &= \frac{\text{Volume cairan}}{80\%} \\ &= \frac{3995,301823}{80\%} \\ &= 4994,1273 \text{ cuft} \end{aligned}$$

b. Menentukan Dimensi Tangki

Asumsi Dimention ratio : H/D = 2 - 5 (Ulrich : T.4-27)

Asumsi rasio dimensi H/D = 2

Volume tutup *Torispherical dish head*

$$\text{Volume tutup atas} = 0,000049 D^3 \quad (\text{Brownell Eq. 5.11})$$

$$\text{Volume tangki} = \frac{1}{4} \times \pi \times D^2 H + 0,000049 D^3$$

$$4994,127279 = 1,57 D^3$$

$$D^3 = 3180,87$$

$$D = 14,7067 \text{ ft}$$

$$= 4,4826 \text{ m}$$



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$$= 176,481 \text{ in}$$

$$\begin{aligned} H &= 2 \times D \\ &= 2 \times 14,7067 \text{ ft} \\ &= 29,4134 \text{ ft} \\ &= 8,96521 \text{ m} \\ &= 352,961 \text{ in} \end{aligned}$$

c. Menentukan tinggi cairan dalam tangki penyimpanan

$$\begin{aligned} \text{Volume liquid} &= \frac{1}{4} \times \pi \times D^2 \times H + 0,000049 \times D^3 \\ 2853,787 &= 169,785 \times H + 0,1558628 \\ 2853,6312 &= 169,785 \times H \\ H &= 16,8073 \text{ ft} \\ &= 5,12286 \text{ m} \\ &= 201,687 \text{ in} \end{aligned}$$

d. Menentukan Tekanan design

Jika dalam bejana terdapat liquid, maka bejana dirancang berdasarkan tekanan dalam :

$$\begin{aligned} P_{\text{design}} &= P_{\text{gauge}} + P_{\text{hidrostatik}} \\ P_{\text{design}} &= (P_i - P_o) + P_{\text{hidrostatik}} \\ P_{\text{design}} &= (14,7 - 14,7) + P_{\text{hidrostatik}} \\ P_{\text{design}} &= P_{\text{hidrostatik}} \\ P_{\text{design}} &= \rho \times \frac{g}{g_c} \times H_{\text{liq}} \\ &= 65,1181 \frac{\text{lb}}{\text{cuft}} \times \frac{1 \text{ lbf}}{\text{lbm}} \times 16,8073 \text{ ft} \\ &= 1094,4584 \frac{\text{lbf}}{\text{ft}^2} \\ &= 7,6004057 \text{ psi} \end{aligned}$$

Asumsi P_{design} 10% lebih besar untuk faktor keamanan

$$\begin{aligned} P_{\text{design}} &= 1,1 \times 7,60041 \text{ Psi} \\ &= 8,36045 \text{ Psi} \end{aligned}$$



e. Menentukan tebal shell minimum

Tebal shell berdasarkan ASME code untuk cylindrical tank:

$$t_s = \frac{P_d \times r_i + C}{f_e - 0,6 P_d} \quad \text{(Brownell Eq. 13.1)}$$

dengan

t_s = tebal shell minimum (in)

P = tekanan tangki (Psi) = 8,36045 Psi

r_i = jari-jari tangki (in) = 88,2403 in

C = Faktor korosi (in); digunakan = 1/8 in

e = Faktor pengelasan; digunakan double welded = 0,8

(Brownell, Table 13.2)

f = stress allowable bahan konstruksi Carbon Steel SA-283 Grade C
 = 12650 Psi **(Brownell, hal.342)**

sehingga,

Asumsi tebal shell = 3/8 in

$$t_s = \frac{P \times r_i + C}{f_e - 0,6 P}$$

$$6/16 = \frac{8,36045 \times 88,2403 + 1/8}{0,8 f - 5,01627}$$

$$4/16 = \frac{8,36045 \times 88,2403}{0,8 f - 5,0162678}$$

$$0,2 f - 1,25407 = 737,72825$$

$$0,2 f = 738,98232$$

$$f = 3694,9116$$

f hitung lebih kecil dari f allowable, jadi tebal shell 3/8 in dapat digunakan

f. Menentukan Tebal Tutup Atas

Tutup atas dipilih Torispherical dish head

$$\begin{aligned} OD &= ID + 2 t_s \\ &= 176,481 + 2 \times 3/8 \\ &= 176,481 + 0,75 \\ &= 176,481 \text{ in} \end{aligned}$$

Berdasarkan Brownell and Young, Tabel 5.7 dari data OD, diperoleh:

$$OD = 180 \text{ in}$$

$$icr = 11 \text{ in}$$

$$rc = 170 \text{ in}$$



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Cek nilai icr dengan nilai 6%rc

$$\text{icr} = 11 \text{ in}$$

$$6\% \text{ rc} = 10,2 \text{ in}$$

Karena nilai icr tabel > nilai 6%rc, maka digunakan persamaan:

$$t_h = \frac{P \times r_c \times W}{2 f_e - 0,2P} + C \quad \text{(Brownell Eq. 7.77)}$$

$$W = \frac{1}{4} \times \left(3 + \frac{\sqrt{r_c}}{r_l} \right) \quad \text{(Brownell Eq. 7.76)}$$

dengan

$$P_d = \text{Tekanan design (Psi)} = 8,36 \text{ Psi}$$

$$r_c = \text{Crown radius} = \text{jari-jari dalam (in)} = 170 \text{ in}$$

$$r_l/i = \text{Inside crown radius (in)} = 11$$

$$E = \text{Faktor pengelasan} = 0,8$$

$$t = \text{Tebal dinding minimal (in)}$$

$$f = \text{Stress allowable bahan Carbon Steel SA-283 grade C} \\ = 12650 \quad \text{(Brownell hal. 342)}$$

$$C = \text{Faktor korosi (in)} = 1/8$$

Sehingga,

$$\begin{aligned} W &= \frac{1}{4} \times \left(3 + \frac{\sqrt{r}}{r_l} \right) \\ &= \frac{1}{4} \times \left(3 + \frac{13}{11} \right) \\ &= 1,04633 \end{aligned}$$

$$\text{Asumsi tebal tutup} = 3/8 \text{ in}$$

$$\begin{aligned} t_h &= \frac{P \times r_c \times W}{2 f_e - 0,2P} + C \\ 3/8 &= \frac{8,36 \times 170 \times 1,05}{1,6 f - 0,2 \times 8,36} + 1/8 \\ 2/8 &= \frac{1487,119862}{1,6 f - 1,6720893} \\ 0,4 f - 0,4180223 &= 1487,120 \\ 0,4 f &= 1487,538 \\ f &= 3718,845 \end{aligned}$$

f hitung lebih kecil dari f allowable, jadi tebal shell 3/8 in dapat digunakan



g. Menentukan Tinggi Tutup Tangki

$$sf = 2 \text{ in}$$

$$t = 3/8 \text{ in}$$

(Brownell, tabel 5.6, hal. 88)

Menghitung tinggi tutup

$$OA = b + sf + t$$

$$* 1 \text{ ft} = 0,3 \text{ m}$$

$$1 \text{ ft} = 12 \text{ in}$$

$$BC = rc - icr$$

$$BC = 170 - 11$$

$$= 159,000 \text{ in}$$

$$AB = \frac{1}{2} \times OD - icr$$

$$AB = \frac{1}{2} \times 180 - 11$$

$$= 79,000 \text{ in}$$

$$b = rc - (BC^2 - AB^2)^{0,5}$$

$$b = 170 - (25281 - 6241)^{0,5}$$

$$= 32,014$$

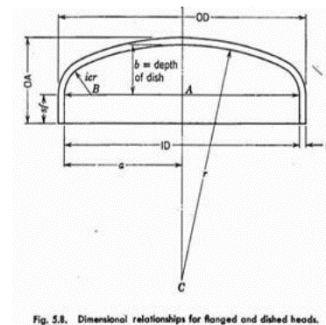


Fig. 5.8. Dimensional relationships for flanged and dished heads.

Tinggi tutup atas

$$OA = b + sf + t$$

$$= 34,389 \text{ in}$$

$$= 0,8735 \text{ m}$$

$$= 2,8658 \text{ ft}$$

h. Menentukan Tebal Tutup Bawah (Flatted Bottom)

Tebal tutup bawah datar karena menumpang di atas pondasi

Untuk flatted bottom, digunakan tebal tutup bawah $3/8 \text{ in}$

(Brownell, Hal. 58)

Spesifikasi

Nama alat : Tangki Penyimpanan Asam Oleat

Kode : F-140

Fungsi : Menyimpan bahan baku Asam Oleat 99%

Bentuk : Tangki berupa silinder tegak dengan tutup atas



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Torispherical dish head dan tutup bawah plate

Bahan konstruksi : Carbon steel SA-283 Grade A

Jumlah : 5 buah

Kondisi Operasi

Suhu : 30 °C

Tekanan : 1 atm

Waktu Tinggal : 7 hari

Dimensi Tangki

Diameter tangki : 14,707 ft = 4,483 m

Tinggi tangki : 29,413 ft = 8,965 m

Volume Tangki : 4994,13 cuft

Tebal shell : 3/8 in

Tebal Tutup Atas : 3/8 in

Tinggi Tutup Atas : 2,866 ft = 0,873 m

Tebal Tutup Bawah : 3/8 in

5. Pompa (L-111)



Fungsi = Untuk memindahkan natrium hidroksida dari tangki penyimpanan (F-110) menuju *Netralizer* (N-220)

Tipe = *Centrifugal pump*

Dasar Pemilihan = Umum digunakan untuk memompa liquid dengan viskositas rendah <10 cP

Komposisi Bahan Masuk

Komponen	Massa	Fraksi Massa
	(kg)	
NaOH	67,3878	0,48
H ₂ O	73,0034	0,52
Total	140,3912	1



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$$\begin{aligned}\text{Rate Massa} &= 140,391 \text{ kg/jam} \\ &= 309,51 \text{ lb/jam}\end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
NaOH	0,19975	0,0973	2820	0,2538
H ₂ O	0,3471	0,274	647,13	0,2857

$$T = 30 \text{ }^{\circ}\text{C} = 303,15 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{Tc}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned}\rho \text{ NaOH} &= 1,92125 \text{ gr/ml} \\ \rho \text{ H}_2\text{O} &= 1,02288 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
NaOH	67,388	0,48	1,02288	0,49098
H ₂ O	73,003	0,52	1,92125	0,99905
Total	140,391	1		1,49003

$$\begin{aligned}\rho \text{ Campuran} &= 1,49003 \text{ gr/ml} \times 62,4 \\ &= 92,97810 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Rate Volumetrik} &= \frac{\text{rate massa}}{\rho \text{ campuran}} \\ &= \frac{309,5096 \text{ lb/jam}}{92,9781 \text{ lb/cuft}} \\ &= 3,3288 \text{ cuft/jam} \\ &= 0,0555 \text{ cuft/menit} \\ &= 0,4150 \text{ gpm}\end{aligned}$$

$$\text{sg reff} = 1 \quad (\text{Kern, Table. 6 p. 808})$$

$$\mu \text{ reff} = 0,8 \text{ cP} \quad (\text{Kern, Fig. 14 p. 823})$$

$$\rho \text{ reff} = 62,4 \text{ lb/ft}^3$$



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$$\begin{aligned} \text{sg bahan} &= \frac{\rho \text{ bahan}}{\rho \text{ reff}} \\ &= \frac{92,9781 \text{ lb/ft}^3}{62,43 \text{ lb/ft}^3} \\ &= 1,48932 \end{aligned}$$

a. Menentukan diameter optimal pipa

asumsi aliran turbulen ($N_{re} > 2100$), maka digunakan persamaan

$$D_{i \text{ opt}} = 4 \times q_f^{0,45} \times \rho^{0,13} \quad \text{(Peters, 2004, eq. 15)}$$

Keterangan :

$D_{i \text{ opt}}$ = Diameter pipa bagian dalam optimal (in)

q_f = Rate volumetrik (ft^3/s)

ρ = Densitas larutan (lb/ft^3)

Sehingga,

$$\begin{aligned} D_{i \text{ opt}} &= 4 \times q_f^{0,45} \times \rho^{0,13} \\ &= 4 \times 0,27 \times 1,802559 \\ &= 1,91345 \text{ in} \end{aligned}$$

Dari Kern Table. 11, maka dipilih pipa dengan spesifikasi :

Pipe size = 2 in

Sch = 80

OD = 2,38 in = 0,2 ft = 0,06 m

ID = 1,93 in = 0,16 ft = 0,05 m

$$\begin{aligned} A &= \frac{1}{4} \times \pi \times ID^2 \\ &= \frac{1}{4} \times 3,14 \times 0,02585 \\ &= 0,02 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Kecepatan Aliran (V)} &= \frac{\text{Rate volumetrik}}{\text{Luas Area (A)}} \\ &= \frac{0,05548}{0,02029 \text{ ft}^2} \\ &= 2,73444 \text{ ft/s} \end{aligned}$$



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b. Menghitung Nre

Menghitung Viskositas Larutan

komponen	A	B	C	D
NaOH	-4,1939	2051,5	0,00279	-6E-07
H ₂ O	-10,216	1792,5	0,01773	-1E-05

$$T = 30 \text{ }^{\circ}\text{C} = 303,15 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \text{ NaOH} = 2,3072 \text{ cP}$$

$$\mu \text{ H}_2\text{O} = 0,8150 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
NaOH	67,3878	0,48	2,3072	1,1074
H ₂ O	73,0034	0,52	0,8150	0,4238
Total	140,3912	1		1,5313

$$\mu \text{ Campuran} = 1,5313 \text{ cP}$$

$$= 0,0010 \text{ lb/jam ft}$$

$$\text{Nre} = \frac{\text{ID} \times V \times \rho \text{ bahan}}{\mu}$$

$$= \frac{0,16 \times 2,73 \times 93}{0,001029}$$

$$= 39722,154 > 2100$$

maka termasuk Aliran turbulen

Dipilih bahan *commercial steel* , dengan

$$e = 0,000046 \text{ m} \quad (\text{Geankoplis 3ed. Fig.2.10-3, hal 88})$$



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$$\begin{aligned} e/D &= \frac{0,000046 \text{ m}}{0,0490024 \text{ m}} \\ &= 0,0009387 \\ f &= 0,006 && \text{(Geankoplis 3ed. Fig.2.10-3, hal 88)} \\ gc &= 32,174 \\ a &= 1 && \text{(aliran turbulen) (Peters \& Timmerhause 4th ed : 485)} \end{aligned}$$

c. Menghitung Panjang Ekuivalen Suction, Le

Perhitungan friksi berdasarkan Peters & Timmerhaus, 4ed Tabel 1 hh. 484

Sambungan	Lc/D
Elbow standard 90°	32
Gate valve	7

$$\text{ID pipa} = 0,160769 \text{ ft}$$

Taksiran panjang pipa lurus

$$\text{Jarak tangki penyimpanan ke netralizer} = 32,8084 \text{ ft}$$

$$\text{Tinggi Netralizer} = 17,4 \text{ ft}$$

$$\text{Panjang pipa masuk netralizer} = 4 \text{ ft}$$

$$\text{Taksiran panjang pipa lurus} = 54,2084 \text{ ft}$$

$$\begin{aligned} 3 \text{ elbow } 90^\circ &= 3 \times 32 \times 0,16 \text{ ft} \\ &= 15,4 \text{ ft} \end{aligned}$$

$$\begin{aligned} 1 \text{ gate valve} &= 1 \times 7 \times 0,16 \text{ ft} \\ &= 1,13 \text{ ft} \end{aligned}$$

$$\text{Panjang total pipa (Le)} = 70,7676 \text{ ft}$$

d. Perhitungan friksi

1. Friksi karena Gesekan Bahan dalam Pipa

$$gc = 32,17 \text{ lbf.ft/lbm.s}^2$$

$$\begin{aligned} F_1 &= \frac{2f \times V^2 \times Le}{gc \times D} && \text{(Geankoplis, 2014 eq. 2.10-6)} \\ &= \frac{0,01 \times 7,48 \times 70,8}{32,2 \times 0,16} \\ &= 1,22772 \text{ ft.lbf/lbm} \end{aligned}$$



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2. Friksi karena kontraksi dari tangki penyimpanan ke pipa

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times gc} \quad (\text{Peters 4ed, Tabel 1 hal 484-485})$$

dimana

$$\alpha = 0,5 \quad (\text{Peters 4ed, Tabel 1 hal 484-485})$$

Menentukan Kc [Peters 4 ed ; Page 484]

A tangki > A pipa maka dianggap = 0

Untuk A1 (tangki) dan A2 (pipa), maka A2/A1 = 0

maka,

$$K = 0,4 \times (1,25 - A2/A1)$$

$$K = 0,4 \times (1,25 - 0)$$

$$K = 0,5$$

sehingga,

$$\begin{aligned} F_2 &= \frac{0,5 \times 7,4771449 \text{ ft}^2/\text{s}^2}{2 \times 0,5 \times 32,17 \text{ lbf.ft/lbf.s}^2} \\ &= 0,11621 \text{ ft.lbf/lbm} \end{aligned}$$

3. Friksi karena ekspansi dari pipa ke tangki

$$\begin{aligned} F_3 &= \frac{\Delta V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-17, Hal.94}) \\ & \quad (V_1 \ll V_2 \text{ dianggap} = 0) \\ &= \frac{7,477144857 \text{ ft}^2/\text{s}^2}{2 \times 0,5 \times 32,17 \text{ lbf.ft/lbf.s}^2} \\ &= 0,23243 \text{ ft.lbf/lbm} \end{aligned}$$

4. Friksi karena elbow 90°

$$F_4 = n \times \frac{K_f \times V^2}{2 \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-17, Hal.94})$$

diketahui :

$$K_f = 0,75 \quad (\text{Geankoplis, 2014 T. 2.10-1 Hal.93})$$

$$\begin{aligned} F_4 &= \frac{3 \times 0,75 \times 7,4771449 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbf.ft/lbf.s}^2} \\ &= 0,26148 \text{ ft.lbf/lbm} \end{aligned}$$



5. Friksi karena gate valve

$$F_5 = n \times \frac{K_f \times V^2}{2 \times gc} \quad (\text{Geankoplis 3ed, T 2.10-1 Hal.93})$$

diketahui :

$$K_f \text{ gate valve (wide open)} = 0,17$$

$$\begin{aligned} F_5 &= \frac{1 \times 0,17 \times 7,4771449 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,01976 \text{ ft.lbf/lbm} \end{aligned}$$

6. Friksi Total

$$\begin{aligned} \Sigma F &= F_1 + F_2 + F_3 + F_4 + F_5 \\ &= 1,85759 \text{ ft.lbf/lbm} \end{aligned}$$

e. Perhitungan Energi Tekanan

$$H \text{ liquida} = 11,8232 \text{ ft}$$

$$\rho \text{ bahan} = 92,9781 \text{ lbm/ft}^3$$

$$g/gc = 1 \text{ lbf/lbm}$$

$$P_2 = 1 \text{ atm} = 2116,8 \text{ lbf/ft}^2$$

Energi Tekanan

$$\begin{aligned} P_1 &= P \text{ atm} + P \text{ hidrostatik} \\ &= 1 \text{ atm} + \left(\rho \times \frac{g}{gc} \times H \text{ liq} \right) \\ &= 2117 \text{ lbf/ft}^2 + \left(93 \text{ lbm/ft}^3 \times 1 \text{ lbf/lbm} \times 11,8 \text{ ft} \right) \\ &= 3216,1009 \text{ lbf/ft}^2 \end{aligned}$$

$$\begin{aligned} \frac{\Delta P}{\rho} &= \frac{(P_1 - P_2)}{\rho} \\ &= \frac{3216,1 - 2116,8}{92,9781025} \\ &= 11,8232 \text{ ft.lbf/lbm} \end{aligned}$$

f. Perhitungan Energi Kinetik

$$E_k = \frac{\Delta V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis, 2014 Eq. 2.7-5 p. 66})$$



$$= \frac{7,477144857}{2 \times 1 \times 32,17}$$

$$= 0,116213 \text{ ft.lbf/lbm}$$

g. Perhitungan Energi potensial

Diketahui

$$Z_1 = 11,8 \text{ ft}$$

$$Z_2 = 17,4 \text{ ft}$$

$$g/gc = 1 \text{ lbf/lbm}$$

Sehingga,

$$E_p = \Delta Z \times \frac{g}{gc} \quad (\text{Geankoplis, 2014 Eq. 2.7-5 p. 66})$$

$$= (17,4 - 11,8) \text{ ft} \times 1 \text{ lbf/lbm}$$

$$= 5,57681 \text{ ft.lbf/lbm}$$

h. Persamaan Bernouli

$$-W_f = \frac{\Delta P}{\rho} + \Delta Z \times \frac{g}{gc} + \frac{\Delta V^2}{2 \times \alpha \times gc} + \Sigma F$$

$$= 11,8232 + 5,57681 + 0,11621 + 1,85759$$

$$= 19,3738 \text{ ft.lbf/lbm}$$

i. Perhitungan Power Pompa

$$hp = \frac{-W_f \times \text{flowrate(gpm)} \times sg}{3960}$$

$$(\text{Perry 6ed ; Pers 6-11, Page 6-5})$$

$$= \frac{19,3738 \times 0,41502 \times 1,48932}{3960}$$

$$= 0,00302 \text{ hp}$$

$$\text{Efisiensi pompa} = 40\% \quad (\text{Peters 4 ed ; Figure 14 - 37 Page 520})$$

$$B_{hp} = \frac{B_{ph}}{\eta \text{ pompa}}$$

$$= \frac{0,003024 \text{ hp}}{40\%}$$

$$= 0,00756 \text{ hp}$$



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$$\begin{aligned}\text{Efisiensi motor} &= 80\% \\ \text{Power motor} &= \frac{\text{Bhp}}{\text{ef.Motor}} \\ &= \frac{0,00756}{80\%} \text{ hp} \\ &= 0,00945 \text{ hp} \\ \text{Maka digunakan power} &= 0,5 \text{ hp}\end{aligned}$$

Spesifikasi

Nama Alat	: Pompa
Kode	: L-111
Fungsi	: Memindahkan natrium hidroksida dari tangki penyimpanan (F-110) ke netralizer (N-220)
Tipe	: <i>Centrifugal pump</i>
Dasar Pemilihan	: Umum digunakan untuk memompa liquid dengan viskositas rendah < 10 cP
Bahan konstruksi	: Stainless Stell 316
Ukuran Pipa	: 2 in 80 sch
Rate volumetrik	: 3,32884 ft ³ /jam
Total Dynamic head	: 19,3738 ft.lbf/lbm
Efisiensi pompa	: 40%
Efisiensi motor	: 80%
BHp	: 0,00756 hp
Power	: 0,5 hp
Jumlah	: 1 buah

6. Pompa (L-121)



Fungsi	= Untuk memindahkan asam sulfat dari tangki penyimpanan (F-120) menuju Reaktor (R-210)
Tipe	= <i>Centrifugal pump</i>



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Dasar Pemilihan : Umum digunakan untuk memompa liquid dan untuk viskositas rendah

Komposisi Bahan Masuk

Komponen	Massa	Fraksi Massa
	(kg)	
H ₂ SO ₄	82,5500	0,98
H ₂ O	1,6847	0,02
Total	84,2347	1

$$\begin{aligned}\text{Rate massa bahan} &= 84,2347 \text{ kg/jam} \\ &= 185,7047 \text{ lb/jam}\end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	T _c	n
H ₂ SO ₄	0,42169	0,1936	925	0,2857
H ₂ O	0,3471	0,274	647,13	0,2857

$$T = 30 \text{ }^{\circ}\text{C} = 303,15 \text{ K}$$

$$\rho = Ax B^{-\left(1 - \frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\rho \text{ H}_2\text{SO}_4 = 1,82645 \text{ gr/ml}$$

$$\rho \text{ H}_2\text{O} = 1,02288 \text{ gr/ml}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
H ₂ SO ₄	82,55002	0,98	1,02288	1,00242
H ₂ O	1,68469	0,02	1,82645	0,03653
Total	84,23471	1		1,03895

$$\begin{aligned}\rho \text{ Campuran} &= 1,0389536 \text{ gr/ml} \times 62,4 \\ &= 64,830705 \text{ lb/cuft}\end{aligned}$$

$$\text{Rate volumetrik} = \frac{\text{rate massa}}{\rho \text{ campuran}}$$



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$$\begin{aligned}
 &= \frac{185,7047 \text{ lb/jam}}{64,8307 \text{ lb/cuft}} \\
 &= 2,8645 \text{ cuft/jam} \\
 &= 0,0180 \text{ cuft/detik} \\
 &= 8,0828 \text{ gpm}
 \end{aligned}$$

a. Menentukan diameter optimal pipa

asumsi aliran turbulen ($N_{re} > 2100$), maka digunakan persamaan

$$D_{i \text{ opt}} = 4 \times q_f^{0,45} \times \rho^{0,13} \quad (\text{Peters, 2004, eq. 15})$$

Keterangan :

$D_{i \text{ opt}}$ = Diameter pipa bagian dalam optimal (in)

q_f = Rate volumetrik (ft^3/s)

ρ = Densitas larutan (lb/ft^3)

Sehingga,

$$\begin{aligned}
 D_{i \text{ opt}} &= 4 \times q_f^{0,45} \times \rho^{0,13} \\
 &= 4 \times 0,16 \times 1,7200121 \\
 &= 1,1004 \text{ in}
 \end{aligned}$$

Dari Kern Table. 11, maka dipilih pipa dengan spesifikasi :

Pipe size = 1 1/4 in

Sch = 80

OD = 1,66 in = 0,14 ft = 0,04 m

ID = 1,28 in = 0,11 ft = 0,03 m

$$\begin{aligned}
 A &= \frac{1}{4} \times \pi \times ID^2 \\
 &= \frac{1}{4} \times 3,14 \times 0,01133 \\
 &= 0,01 \text{ ft}^2
 \end{aligned}$$

$$\begin{aligned}
 \text{Kecepatan Aliran (V)} &= \frac{\text{Rate volumetrik}}{\text{Luas Area (A)}} \\
 &= \frac{0,01801}{0,0089} \\
 &= 2,02422 \text{ ft/s}
 \end{aligned}$$



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b. Menghitung Nre

$$\text{sg reff} = 1 \quad (\text{Kern, Table. 6 p. 808})$$

$$\mu \text{ reff} = 0,8 \text{ cP} \quad (\text{Kern, Fig. 14 p. 823})$$

$$\rho \text{ reff} = 62,4 \text{ lb/ft}^3$$

$$\begin{aligned} \text{sg bahan} &= \frac{\rho \text{ bahan}}{\rho \text{ reff}} \\ &= \frac{64,8307 \text{ lb/ft}^3}{62,43 \text{ lb/ft}^3} \\ &= 1,03845 \end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
H ₂ SO ₄	-18,705	3496,2	0,03306	-2E-05
H ₂ O	-10,216	1792,5	0,01773	-1E-05

$$T = 30 \text{ } ^\circ\text{C} = 303,15 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \text{ H}_2\text{SO}_4 = 19,378753 \text{ cP}$$

$$\mu \text{ H}_2\text{O} = 0,8150345 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
H ₂ SO ₄	82,5500	0,98	19,378753	18,991178
H ₂ O	1,6847	0,02	0,815034	0,016301
Total	84,2347	1		19,007478

$$\begin{aligned} \mu \text{ Campuran} &= 19,0075 \text{ cP} \\ &= 0,0128 \text{ lb/ft.s} \end{aligned}$$

$$\text{Nre} = \frac{\text{ID} \times V \times \rho \text{ bahan}}{\mu}$$



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$$= \frac{0,11 \times 2,02 \times 64,8}{0,012773}$$

$$= 1093,7541 < 2100$$

maka termasuk dalam aliran laminar

Dipilih bahan commercial steel, dengan

$$e = 0,000046 \text{ m} \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$

$$\frac{e}{D} = \frac{0,000046}{0,0324482}$$

$$= 0,0014176$$

$$f = 0,007 \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$

$$g_c = 32,174 \text{ ft.lbm/detik}^2.\text{lbf}$$

$$a = 1/2 \quad (\text{Peters \& Timmerhause 4thed : 485})$$

c. Menghitung Panjang ekuivalen suction, L_e

Perhitungan friksi berdasarkan Peters & Timmerhaus, 4ed Tabel 1 hh. 484

Sambungan	L_c/D
Elbow standard 90°	32
Gate valve	7

$$\text{ID pipa} = 0,10646 \text{ ft}$$

Taksiran panjang pipa lurus

$$\text{Jarak tangki penyimpanan ke Reaktor} = 16,4042 \text{ ft}$$

$$\text{Tinggi Reaktor} = 17,4 \text{ ft}$$

$$\text{Panjang pipa masuk reaktor} = 4 \text{ ft}$$

$$\text{Taksiran panjang pipa lurus} = 37,8042 \text{ ft}$$

$$3 \text{ elbow } 90^\circ = 3 \times 32 \times 0,11 \text{ ft}$$

$$= 10,2 \text{ ft}$$

$$1 \text{ gate valve} = 1 \times 7 \times 0,11 \text{ ft}$$

$$= 0,75 \text{ ft}$$

$$\text{Panjang total pipa } (L_e) = 48,7693 \text{ ft}$$

d. Perhitungan friksi

1. Friksi karena Gesekan Bahan dalam Pipa

$$g_c = 32,17 \text{ lbm.ft/lbf.s}^2$$



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$$\begin{aligned}
 F_1 &= \frac{2f \times V^2 \times L_e}{g_c \times D} && \text{(Geankoplis, 2014 eq. 2.10-6)} \\
 &= \frac{0,01 \times 4,1 \times 48,8}{32,2 \times 0,11} \\
 &= 0,81689 \text{ ft.lbf/lbm}
 \end{aligned}$$

2. Friksi karena kontraksi dari tangki penyimpanan ke pipa

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times g_c} \quad \text{(Geankoplis, 2014 eq. 2.10-16)}$$

dimana

$\alpha = 1/2$ untuk aliran laminar (Peters & Timmerhause 4th ed : 485)

Menentukan Kc [Peters 4 ed ; Page 484]

A tangki > A pipa maka dianggap =0

Untuk A1 (tangki) dan A2 (pipa), maka A2/A1 = 0

maka, (Peters 4 ed ; Page 484)

$$K = 0,4 \times (1,25 - A2/A1)$$

$$K = 0,4 \times (1,25 - 0)$$

$$K = 0,5$$

sehingga,

$$\begin{aligned}
 F_2 &= \frac{0,5 \times 4,0974508 \text{ ft}^2/\text{s}^2}{2 \times 1/2 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\
 &= 0,06368 \text{ ft.lbf/lbm}
 \end{aligned}$$

3. Friksi karena ekspansi dari pipa ke tangki

$$F_3 = \frac{\Delta V^2}{2 \times \alpha \times g_c} \quad \text{(Geankoplis, 2014 eq. 2.10-15)}$$

($V_1 \ll V_2$ dianggap = 0)

$$\begin{aligned}
 &= \frac{4,097450826 \text{ ft}^2/\text{s}^2}{2 \times 0,5 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\
 &= 0,12737 \text{ ft.lbf/lbm}
 \end{aligned}$$

4. Friksi karena elbow 90°

$$F_4 = n \times \frac{K_f \times V^2}{2 \times g_c}$$

(Geankoplis 3ed, pers. 2.10-17 hal 94)

diketahui :

$$K_f = 0,75 \quad \text{(Geankoplis 3ed, Tabel 2.10-1 hal 93)}$$



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$$F_4 = \frac{3 \times 0,75 \times 4,0974508 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,14329 \text{ ft.lbf/lbm}$$

5. Friksi karena gate valve

$$F_5 = n \times \frac{K_f \times V^2}{2 \times gc} \quad (\text{Geankoplis 3ed, T 2.10-1 Hal 93})$$

diketahui :

$$K_f \text{ gate valve (wide open)} = 0,17$$

$$F_5 = \frac{1 \times 0,17 \times 4,0974508 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,01083 \text{ ft.lbf/lbm}$$

6. Friksi Total

$$\Sigma F = F_1 + F_2 + F_3 + F_4 + F_5$$

$$= 1,16206 \text{ ft.lbf/lbm}$$

e. Perhitungan Energi Tekanan

$$H \text{ liquida dalam tangki} = 9,657 \text{ ft}$$

$$\rho \text{ bahan} = 64,8307 \text{ lbm/ft}^3$$

$$g/gc = 1 \text{ lbf/lbm}$$

$$P_2 = 1 \text{ atm} = 2116,8 \text{ lbf/ft}^2$$

Energi Tekanan

$$P_1 = P_{\text{atm}} + P_{\text{hidrostatik}}$$

$$= 1 \text{ atm} + \left(\rho \times \frac{g}{gc} \times H_{\text{liq}} \right)$$

$$= 2117 \text{ lbf/ft}^2 + \left(64,8 \text{ lbm/ft}^3 \times 1 \text{ lbf/lbm} \times 9,66 \text{ ft} \right)$$

$$= 2742,8702 \text{ lbf/ft}^2$$

$$\frac{\Delta P}{\rho} = \frac{(P_1 - P_2)}{\rho}$$

$$= \frac{2742,87 - 2116,8}{64,83070481}$$

$$= 9,657 \text{ ft.lbf/lbm}$$



f. Perhitungan Energi Kinetik

$$\begin{aligned}
 E_k &= \frac{\Delta V^2}{2 \times \alpha \times g_c} && \text{(Geankoplis, 2014 Eq. 2.7-5 p. 66)} \\
 &= \frac{4,097450826}{2 \times 1 \times 32,17} \\
 &= 0,0636843 \text{ ft.lbf/lbm}
 \end{aligned}$$

g. Perhitungan Energi potensial

Diketahui

$$\begin{aligned}
 Z_1 &= 9,66 \text{ ft} \\
 Z_2 &= 17,4 \text{ ft} \\
 g/g_c &= 1 \text{ lbf/lbm}
 \end{aligned}$$

Sehingga,

$$\begin{aligned}
 E_p &= \Delta Z \times \frac{g}{g_c} && \text{(Geankoplis, 2014 Eq. 2.7-5 p. 66)} \\
 &= (17,4 - 9,66) \text{ ft} \times 1 \text{ lbf/lbm} \\
 &= 7,74303 \text{ ft.lbf/lbm}
 \end{aligned}$$

h. Persamaan Bernouli

$$\begin{aligned}
 -W_f &= \frac{\Delta P}{\rho} + \Delta Z \times \frac{g}{g_c} + \frac{\Delta V^2}{2 \times \alpha \times g_c} + \Sigma F \\
 &= 9,657 + 7,74303 + 0,06368 + 1,16206 \\
 &= 18,6258 \text{ ft.lbf/lbm}
 \end{aligned}$$

i. Perhitungan Power Pompa

$$\begin{aligned}
 hp &= \frac{-W_f \times \text{flowrate(gpm)} \times sg}{3960} \\
 &\quad \text{(Perry 6ed ; Pers 6-11, Page 6-5)} \\
 &= \frac{18,6258 \times 8,08279 \times 1,03845}{3960} \\
 &= 0,03948 \text{ hp}
 \end{aligned}$$

$$\text{Efisiensi pompa} = 40\% \quad \text{(Peters 4 ed ; Figure 14 - 37 Page 520)}$$

$$\begin{aligned}
 Bhp &= \frac{Bph}{\eta \text{ pompa}} \\
 &= \frac{0,0394792}{40\%} \text{ hp} \\
 &= 0,0986979 \text{ hp}
 \end{aligned}$$



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$$\begin{aligned}\text{Efisiensi motor} &= 80\% \\ \text{Power motor} &= \frac{\text{Bhp}}{\text{ef.Motor}} \\ &= \frac{0,0986979}{80\%} \text{ hp} \\ &= 0,1233724 \text{ hp} \\ \text{Maka digunakan power} &= 0,5 \text{ hp}\end{aligned}$$

Spesifikasi

Nama Alat	=	Pompa
Kode	=	L-121
Fungsi	=	Untuk memindahkan asam sulfat dari tangki penyimpanan (F-120) menuju reaktor (R-210)
Tipe	=	<i>Centrifugal pump</i>
Bahan konstruksi	=	Stainless Steel 316
Ukuran Pipa	=	1 1/4 in 80 sch
Kapasitas	=	185,705 lb/jam
Rate volumetrik	=	64,8307 ft ³ /jam
Total Dynamic head	=	18,6258 ft.lbf/lbm
Efisiensi pompa	=	40%
Efisiensi motor	=	80%
Power	=	0,5 hp
Jumlah	=	1 buah

7. Pompa (L-131)



Fungsi	=	Untuk memindahkan butanol dari tangki penyimpanan (F-130) menuju Reaktor (R-210)
Tipe	=	<i>Centrifugal pump</i>
Dasar Pemilihan	:	Umum digunakan untuk memompa liquid dan viskositas rendah <10 cP



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Komposisi Bahan Masuk

Komponen	Massa	Fraksi Massa
	(kg)	
C ₄ H ₉ OH	5067,94295	0,995
H ₂ O	25,46702596	0,005
Total	5093,409976	1

$$\begin{aligned}\text{rate massa bahan} &= 939,46697 \text{ kg/jam} \\ &= 2071,1583 \text{ lb/jam}\end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	T _c	n
C ₄ H ₉ OH	0,26891	0,2667	562,93	0,2457
H ₂ O	0,3471	0,274	647,13	0,2857

$$T = 30 \text{ }^{\circ}\text{C} = 303,15 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned}\rho \text{ C}_4\text{H}_9\text{OH} &= 0,80216 \text{ gr/ml} \\ \rho \text{ H}_2\text{O} &= 1,02288 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
C ₄ H ₉ OH	5067,943	0,995	1,02288	1,01777
H ₂ O	25,467	0,005	0,80216	0,00401
Total	5093,410	1		1,02178

$$\begin{aligned}\rho \text{ Campuran} &= 1,0217786 \text{ gr/ml} \times 62,4 \\ &= 63,758987 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Rate volumetrik} &= \frac{\text{rate massa bahan}}{\rho \text{ bahan}} \\ &= \frac{2071,1583 \text{ lb/jam}}{63,7590 \text{ lb/cuft}} \\ &= 32,4842 \text{ cuft/jam}\end{aligned}$$



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$$= 0,0090 \text{ cuft/detik}$$

$$= 4,0500 \text{ gpm}$$

a. Menentukan diameter optimal pipa

asumsi aliran turbulen ($N_{re} > 2100$), maka digunakan persamaan

$$D_{i \text{ opt}} = 4 \times q_f^{0,45} \times \rho^{0,13} \quad \text{(Peters, 2004, eq. 15)}$$

Keterangan :

$D_{i \text{ opt}}$ = Diameter pipa bagian dalam optimal (in)

q_f = Rate volumetrik (ft^3/s)

ρ = Densitas larutan (lb/ft^3)

Sehingga,

$$D_{i \text{ opt}} = 4 \times q_f^{0,45} \times \rho^{0,13}$$

$$= 4 \times 0,12 \times 1,72$$

$$= 0,8 \text{ in}$$

Dari Kern Table. 11, maka dipilih pipa dengan spesifikasi :

Pipe size = 2 in

Sch = 80

OD = 2,38 in = 0,2 ft = 0,06 m

ID = 1,94 in = 0,16 ft = 0,05 m

$$A = \frac{1}{4} \times \pi \times ID^2$$

$$= \frac{1}{4} \times 3,14 \times 0,02606$$

$$= 0,02 \text{ ft}^2$$

$$\text{Kecepatan Aliran (V)} = \frac{\text{Rate volumetrik}}{\text{Luas Area (A)}}$$

$$= \frac{0,00902}{0,02046}$$

$$= 0,44106 \text{ ft/s}$$

b. Menghitung N_{re}

$sg_{\text{reff}} = 1$ (Kern, Table. 6 p. 808)

$\mu_{\text{reff}} = 0,8 \text{ cP}$ (Kern, Fig. 14 p. 823)

$\rho_{\text{reff}} = 62,4 \text{ lb}/\text{ft}^3$



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$$\begin{aligned} \text{sg bahan} &= \frac{\rho \text{ bahan}}{\rho \text{ reff}} \\ &= \frac{63,759 \text{ lb/ft}^3}{62,43 \text{ lb/ft}^3} \\ &= 1,02129 \end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
C ₄ H ₉ OH	-5,397	1325,6	0,006	-6E-06
H ₂ O	-10,216	1792,5	0,01773	-1E-05

$$\begin{aligned} T &= 30 \text{ } ^\circ\text{C} = 303,15 \text{ K} \\ \text{Log10 } \mu &= A + \frac{B}{T} + CT + DT^2 \end{aligned}$$

Sehingga diperoleh

$$\begin{aligned} \mu \text{ C}_4\text{H}_9\text{OH} &= 1,9421564 \text{ cP} \\ \mu \text{ H}_2\text{O} &= 0,8150345 \text{ cP} \end{aligned}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
C ₄ H ₉ OH	5067,943	0,995	1,94216	1,93245
H ₂ O	25,467	0,005	0,81503	0,00408
Total	5093,410	1		1,93652

$$\begin{aligned} \mu \text{ Campuran} &= 1,9365 \text{ cP} \\ &= 0,0013 \text{ lb/ft s} \end{aligned}$$

$$\begin{aligned} \text{Nre} &= \frac{\text{ID} \times V \times \rho \text{ bahan}}{\mu} \\ &= \frac{0,16 \times 0,44 \times 63,8}{0,0013013} \\ &= 3488,598 > 2100 \\ &\text{(termasuk aliran turbulen)} \end{aligned}$$



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Dipilih bahan commercial steel, dengan

$$\begin{aligned} e &= 0,000046 \text{ m} \\ e/D &= \frac{0,000046}{0,0492055} \\ &= 0,0009349 \\ f &= 0,006 \quad \text{(Geankoplis 3ed, fig.2.10-3 : 88)} \\ g_c &= 32,174 \text{ ft.lbm/detik}^2.\text{lbf} \\ a &= 1 \quad \text{(aliran turbulen)} \end{aligned}$$

c. Menghitung Panjang ekuivalen suction, Le

Perhitungan friksi berdasarkan Peters & Timmerhaus, 4ed Tabel 1 hh. 484

Sambungan	Lc/D
Elbow standard 90°	32
Gate valve	7

$$\text{ID pipa} = 0,1614354 \text{ ft}$$

Taksiran panjang pipa lurus

$$\begin{aligned} \text{Jarak tangki penyimpanan ke Reaktor} &= 16,4042 \text{ ft} \\ \text{Tinggi Reaktor} &= 17,4 \text{ ft} \\ \text{Panjang pipa masuk reaktor} &= 4 \text{ ft} \\ \hline \text{Taksiran panjang pipa lurus} &= 37,8042 \text{ ft} \end{aligned}$$

$$\begin{aligned} 3 \text{ elbow } 90^\circ &= 3 \times 32 \times 0,16 \text{ ft} \\ &= 15,5 \text{ ft} \\ 1 \text{ gate valve} &= 1 \times 7 \times 0,16 \text{ ft} \\ &= 1,13 \text{ ft} \end{aligned}$$

$$\text{Panjang total pipa (Le)} = 54,4321 \text{ ft}$$

d. Perhitungan friksi

1. Friksi karena Gesekan Bahan dalam Pipa

$$\begin{aligned} g_c &= 32,17 \text{ lbm.ft/lbf .s}^2 \\ F_1 &= \frac{2f \times V^2 \times Le}{g_c \times D} \quad \text{(Geankoplis 3ed, Pers, 2.10-16, P.93)} \\ &= \frac{0,01 \times 0,19 \times 54,4}{32,2 \times 0,16} \\ &= 0,02447 \text{ ft.lbf/lbm} \end{aligned}$$



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2. Friksi karena kontraksi dari tangki penyimpanan ke pipa

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-6, P.89})$$

dimana

$\alpha = 1$ untuk aliran laminar (Geankoplis, 2014)

Menentukan Kc (Peters 4 ed ; Page 484)

$$A_{\text{tangki}} = \infty$$

$$A_{\text{pipa}} = 0,02046$$

Untuk A1 (tangki) dan A2 (pipa), maka $A_2/A_1 = 0$

maka,

$$K = 0,4 \times (1,25 - A_2/A_1) \quad (\text{Peters 4 ed ; Page 484})$$

$$K = 0,4 \times (1,25 - 0)$$

$$K = 0,5$$

sehingga,

$$\begin{aligned} F_2 &= \frac{0,5 \times 0,194538 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,00151 \text{ ft.lbf/lbm} \end{aligned}$$

3. Friksi karena ekspansi dari pipa ke tangki

$$F_3 = \frac{\Delta V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-15, P.93})$$

($V_1 \ll V_2$ dianggap = 0)

$$\begin{aligned} &= \frac{0,194537955 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,00302 \text{ ft.lbf/lbm} \end{aligned}$$

4. Friksi karena elbow 90°

$$F_4 = n \times \frac{K_f \times V^2}{2 \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-17, P.94})$$

diketahui :

$$K_f = 0,75 \quad (\text{Geankoplis 3ed, T.2.10-1, P. 93})$$



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$$F_4 = \frac{3 \times 0,75 \times 0,194538 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,0068 \text{ ft.lbf/lbm}$$

5. Friksi karena gate valve

$$F_5 = n \times \frac{K_f \times V^2}{2 \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-17, P.94})$$

diketahui :

$$K_f \text{ gate valve (wide open)} = 0,17 \quad (\text{Geankoplis 3ed, T.2.10-1, P. 93})$$

$$F_5 = \frac{1 \times 0,17 \times 0,194538 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,00051 \text{ ft.lbf/lbm}$$

6. Friksi Total

$$\Sigma F = F_1 + F_2 + F_3 + F_4 + F_5$$

$$= 0,03632 \text{ ft.lbf/lbm}$$

e. Perhitungan Energi Tekanan

$$H \text{ liquida dalam tangki} = 26,8223 \text{ ft}$$

$$\rho \text{ bahan} = 63,759 \text{ lbm/ft}^3$$

$$g/gc = 1 \text{ lbf/lbm}$$

$$P_2 = 1 \text{ atm} = 2116,8 \text{ lbf/ft}^2$$

Energi Tekanan

$$P_1 = P_{\text{atm}} + P_{\text{hidrostatik}}$$

$$= 1 \text{ atm} + \left(\rho \times \frac{g}{gc} \times H_{\text{liq}} \right)$$

$$= 2117 \text{ lbf/ft}^2 + \left(63,8 \text{ lbm/ft}^3 \times 1 \text{ lbf/lbm} \times 26,8 \text{ ft} \right)$$

$$= 3826,9612 \text{ lbf/ft}^2$$

$$\frac{\Delta P}{\rho} = \frac{(P_1 - P_2)}{\rho}$$

$$= \frac{3826,96 - 2116,8}{63,75898688}$$

$$= 26,8223 \text{ ft.lbf/lbm}$$



f. Perhitungan Energi Kinetik

$$\begin{aligned}
 E_k &= \frac{\Delta V^2}{2 \times \alpha \times g_c} && \text{(Geankoplis, 2014 Eq. 2.7-5 p. 66)} \\
 &= \frac{0,194537955}{2 \times 1 \times 32,17} \\
 &= 0,0030236 \text{ ft.lbf/lbm}
 \end{aligned}$$

g. Perhitungan Energi potensial

Diketahui

$$\begin{aligned}
 Z_1 &= 26,8 \text{ ft} \\
 Z_2 &= 17,4 \text{ ft} \\
 g/g_c &= 1 \text{ lbf/lbm}
 \end{aligned}$$

Sehingga,

$$\begin{aligned}
 E_p &= \Delta Z \times \frac{g}{g_c} && \text{(Geankoplis, 3ed Eq. 2.7-5 p. 66)} \\
 &= (17,4 - 26,8) \text{ ft} \times 1 \text{ lbf/lbm} \\
 &= 9,42224 \text{ ft.lbf/lbm}
 \end{aligned}$$

h. Persamaan Bernouli

$$\begin{aligned}
 -W_f &= \frac{\Delta P}{\rho} + \Delta Z \times \frac{g}{g_c} + \frac{\Delta V^2}{2 \times \alpha \times g_c} + \Sigma F \\
 &= 26,8223 + 9,42224 + 0,00302 + 0,03632 \\
 &= 36,2839 \text{ ft.lbf/lbm}
 \end{aligned}$$

i. Perhitungan Power Pompa

$$\begin{aligned}
 hp &= \frac{-W_f \times \text{flowrate(gpm)} \times sg}{3960} \\
 &\quad \text{(Perry 6ed ; Pers 6-11, Page 6-5)} \\
 &= \frac{36,2839 \times 4,04998 \times 1,02129}{3960} \\
 &= 0,0379 \text{ hp}
 \end{aligned}$$

$$\text{Efisiensi pompa} = 55\% \quad \text{(Peters 4 ed ; Figure 14 - 37 Page 520)}$$

$$\begin{aligned}
 B_{hp} &= \frac{B_{ph}}{\eta_{pompa}} \\
 &= \frac{0,0378982}{55\%} \text{ hp}
 \end{aligned}$$



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$$\begin{aligned} &= 0,0689059 \text{ hp} \\ \text{Efisiensi motor} &= 80\% \\ \text{Power motor} &= \frac{\text{Bhp}}{\text{ef.Motor}} \\ &= \frac{0,0689059}{80\%} \text{ hp} \\ &= 0,0861323 \text{ hp} \\ \text{Maka digunakan power} &= 0,5 \text{ hp} \end{aligned}$$

Spesifikasi

Nama Alat	: Pompa
Kode	: L-131
Fungsi	: Untuk memindahkan butanol dari tangki penyimpanan (F-131) menuju reaktor (R-210)
Tipe	: <i>Centrifugal pump</i>
Dasar Pemilihan	: Umum digunakan untuk memompa liquid
Bahan konstruksi	: <i>Commercial steel</i>
Ukuran Pipa	: 2 in 80 sch
Kapasitas	: 2071,2 lb/jam
Rate volumetrik	: 32,4842 ft ³ /jam
Total Dynamic head	: 36,2839 ft.lbf/lbm
Efisiensi pompa	: 55%
Efisiensi motor	: 80%
BHp	: 0,0379 hp
Power	: 0,50 hp
Jumlah	: 1 buah

8. Pompa (L-141)





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Fungsi = Untuk memindahkan asam oleat dari tangki penyimpanan (F-140) menuju Reaktor (R-210)
 Tipe = *Centrifugal pump*
 Dasar Pemilihan : Umum digunakan untuk memompa liquid

Komposisi Bahan Masuk

Komponen	Massa	Fraksi Massa
	(kg)	
C ₁₇ H ₃₃ COOH	3862,594356	0,990099
C ₁₅ H ₃₁ COOH	38,62594356	0,009901
Total	3901,2203	1

Rate massa bahan = 3512,1906 kg/jam
 = 7743,0106 lb/jam

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
C ₁₇ H ₃₃ COOH	0,2824	0,26812	781	0,2897
C ₁₅ H ₃₁ COOH	0,2797	0,26805	776	0,2947

$$T = 30 \text{ }^{\circ}\text{C} = 303,15 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{Tc}\right)^n}$$

Sehingga diperoleh

$$\rho \text{ C}_{17}\text{H}_{33}\text{COOH} = 0,8845005 \text{ gr/ml}$$

$$\rho \text{ C}_{15}\text{H}_{31}\text{COOH} = 0,8725909 \text{ gr/ml}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
C ₁₇ H ₃₃ COOH	3862,5944	0,99	0,8726	0,8640
C ₁₅ H ₃₁ COOH	38,6259	0,01	0,8845	0,0088
Total	3901,2203	1,00		0,8727

$$\begin{aligned} \rho \text{ Campuran} &= 0,8727 \text{ gr/ml} \times 62,4 \\ &= 54,457032 \text{ lb/cuft} \end{aligned}$$

$$\text{Rate volumetrik} = \frac{\text{rate massa bahan}}{\rho \text{ Campuran}}$$



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$$\begin{aligned}\rho \text{ bahan} &= \frac{7743,0106 \text{ lb/jam}}{54,4570 \text{ lb/cuft}} \\ &= 142,1857 \text{ cuft/jam} \\ &= 0,0395 \text{ cuft/detik} \\ &= 17,7270 \text{ gpm}\end{aligned}$$

a. Menentukan diameter optimal pipa

asumsi aliran turbulen ($N_{re} > 2100$), maka digunakan persamaan

$$D_{i \text{ opt}} = 3,9 \times q_f^{0,45} \times \rho^{0,13} \quad \text{(Peters 4ed, Pers, 12-15, P.501)}$$

Keterangan :

$D_{i \text{ opt}}$ = Diameter pipa bagian dalam optimal (in)

q_f = Rate volumetrik (ft^3/s)

ρ = Densitas larutan (lb/ft^3)

Sehingga,

$$\begin{aligned}D_{i \text{ opt}} &= 4 \times q_f^{0,45} \times \rho^{0,13} \\ &= 4 \times 0,23 \times 1,68 \\ &= 1,53 \text{ in}\end{aligned}$$

Dari Kern Table. 11, maka dipilih pipa dengan spesifikasi :

Pipe size = 1 1/2 in

Sch = 40

OD = 1,9 in = 0,16 ft = 0,05 m

ID = 1,61 in = 0,13 ft = 0,04 m

$$\begin{aligned}A &= \frac{1}{4} \times \pi \times ID^2 \\ &= \frac{1}{4} \times 3,14 \times 0,01799 \\ &= 0,01 \text{ ft}^2\end{aligned}$$

$$\begin{aligned}\text{Kecepatan Aliran (V)} &= \frac{\text{Rate volumetrik}}{\text{Luas Area (A)}} \\ &= \frac{0,0395}{0,01412} \\ &= 2,79732 \text{ ft/s}\end{aligned}$$



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b. Menghitung Nre

$$\text{sg reff} = 1 \quad (\text{Kern, Table. 6 p. 808})$$

$$\mu \text{ reff} = 0,8 \text{ cP} \quad (\text{Kern, Fig. 14 p. 823})$$

$$\rho \text{ reff} = 62,4 \text{ lb/ft}^3$$

$$\begin{aligned} \text{sg bahan} &= \frac{\rho \text{ bahan}}{\rho \text{ reff}} \\ &= \frac{54,457 \text{ lb/ft}^3}{62,43 \text{ lb/ft}^3} \\ &= 0,87229 \end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	-6,13	1690	0,008	-6E-06
C ₁₅ H ₃₁ COOH	-9,45	2100	0,016	-1E-05

$$T = 30 \text{ } ^\circ\text{C} = 303,15 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \text{ C}_{17}\text{H}_{33}\text{COOH} = 18,934047 \text{ cP}$$

$$\mu \text{ C}_{15}\text{H}_{31}\text{COOH} = 14,781711 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
C ₁₇ H ₃₃ COOH	3477,0687	0,99	18,93405	18,74471
C ₁₅ H ₃₁ COOH	35,121906	0,01	14,78171	0,14782
Total	3512,1906	1		18,89252

$$\begin{aligned} \mu \text{ Campuran} &= 18,892524 \text{ cP} \\ &= 0,0126958 \text{ lb/ft s} \end{aligned}$$

$$\begin{aligned} \text{Nre} &= \frac{\text{ID} \times V \times \rho \text{ bahan}}{\mu} \\ &= \frac{0,13 \times 2,8 \times 54,5}{0,01} \end{aligned}$$



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$$= 1609,1909 < 2100$$

(aliran laminar)

Dipilih bahan commercial steel, dengan

$$e = 0,000046 \text{ m} \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$

$$e/D = \frac{0,000046}{0,0408776}$$

$$= 0,0011253$$

$$f = 0,006 \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$

$$g_c = 32,174 \text{ ft.lbm/detik}^2.\text{lbf}$$

$$\alpha = 0,5 \quad (\text{Peters \& Timmerhause 4thed : 485})$$

c. Menghitung Panjang ekuivalen suction, Le

Perhitungan friksi berdasarkan Peters & Timmerhaus, 4ed Tabel 1 hh. 484

Sambungan	Lc/D
Elbow standard 90°	32
Gate valve	7

$$\text{ID pipa} = 0,134113 \text{ ft}$$

Taksiran panjang pipa lurus

$$\text{Jarak tangki penyimpanan ke Reaktor} = 16,4042 \text{ ft}$$

$$\text{Tinggi Reaktor} = 17,4 \text{ ft}$$

$$\text{Panjang pipa masuk reaktor} = 4 \text{ ft}$$

$$\text{Taksiran panjang pipa lurus} = 37,8042 \text{ ft}$$

$$\begin{aligned} 3 \text{ elbow } 90^\circ &= 3 \times 32 \times 0,13 \text{ ft} \\ &= 12,9 \text{ ft} \end{aligned}$$

$$\begin{aligned} 1 \text{ gate valve} &= 1 \times 7 \times 0,13 \text{ ft} \\ &= 0,94 \text{ ft} \end{aligned}$$

$$\text{Panjang total pipa (Le)} = 51,6179 \text{ ft}$$

d. Perhitungan friksi

1. Friksi karena Gesekan Bahan dalam Pipa

$$g_c = 32,17 \text{ lbm.ft/lbf.s}^2$$

$$F_1 = \frac{2f \times V^2 \times Le}{g_c \times D} \quad (\text{Geankoplis 3ed, Pers, 2.10-6, P.89})$$



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$$= \frac{0,01 \times 7,82 \times 51,6}{32,2 \times 0,13}$$

$$= 1,12342 \text{ ft.lbf/lbm}$$

2. Friksi karena kontraksi dari tangki penyimpanan ke pipa

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-16, P.93})$$

dimana

$$\alpha = 1/2$$

Menentukan Kc (Peters 4 ed ; Page 484)

A tangki > A pipa maka dianggap 0

Untuk A1 (tangki) dan A2 (pipa), maka A2/A1 = 0

maka, (Peters 4 ed ; Page 484)

$$K = 0,4 \times (1,25 - A2/A1)$$

$$K = 0,4 \times (1,25 - 0)$$

$$K = 0,5$$

sehingga,

$$F_2 = \frac{0,5 \times 7,8249928 \text{ ft}^2/\text{s}^2}{2 \times 1/2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,12162 \text{ ft.lbf/lbm}$$

3. Friksi karena ekspansi dari pipa ke tangki

$$F_3 = \frac{\Delta V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-15, P.93})$$

(V₁ <<<< V₂ dianggap = 0)

$$= \frac{7,824992804 \text{ ft}^2/\text{s}^2}{2 \times 0,5 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,24324 \text{ ft.lbf/lbm}$$

4. Friksi karena elbow 90°

$$F_4 = n \times \frac{K_f \times V^2}{2 \times gc}$$

(Geankoplis 3ed, Pers, 2.10-17, P.94)

diketahui :

$$K_f = 0,75 \quad (\text{Geankoplis 3ed, T.2.10-1, P. 93})$$



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$$F_4 = \frac{3 \times 0,75 \times 7,8249928 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,27364 \text{ ft.lbf/lbm}$$

5. Friksi karena gate valve

$$F_5 = n \times \frac{K_f \times V^2}{2 \times gc}$$

diketahui :

$$K_f \text{ gate valve (wide open)} = 0,17 \quad \textbf{(Geankoplis, 2014 T. 2.10-1)}$$

$$F_5 = \frac{1 \times 0,17 \times 7,8249928 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,02068 \text{ ft.lbf/lbm}$$

6. Friksi Total

$$\Sigma F = F_1 + F_2 + F_3 + F_4 + F_5$$

$$= 1,7826 \text{ ft.lbf/lbm}$$

e. Perhitungan Energi Tekanan

$$H \text{ liquida dalam tangki} = 16,8073 \text{ ft}$$

$$\rho \text{ bahan} = 54,457 \text{ lbm/ft}^3$$

$$g/gc = 1 \text{ lbf/lbm}$$

$$P_2 = 1 \text{ atm} = 2116,8 \text{ lbf/ft}^2$$

Energi Tekanan

$$P_1 = P \text{ atm} + P \text{ hidrostatik}$$

$$= 1 \text{ atm} + \left(\rho \times \frac{g}{gc} \times H \text{ liq} \right)$$

$$= 2117 \text{ lbf/ft}^2 + (54,5 \text{ lbm/ft}^3 \times 1 \text{ lbf/lbm} \times 16,8 \text{ ft})$$

$$= 3032,0742 \text{ lbf/ft}^2$$

$$\frac{\Delta P}{\rho} = \frac{(P_1 - P_2)}{\rho}$$

$$= \frac{3032,07 - 2116,8}{54,45703217}$$

$$= 16,8073 \text{ ft.lbf/lbm}$$



f. Perhitungan Energi Kinetik

$$\begin{aligned}
 E_k &= \frac{\Delta V^2}{2 \times \alpha \times g_c} && \text{(Geankoplis, 3ed Eq. 2.7-5 p. 66)} \\
 &= \frac{7,824992804}{2 \times 1 \times 32,17} \\
 &= 0,1216194 \text{ ft.lbf/lbm}
 \end{aligned}$$

g. Perhitungan Energi potensial

Diketahui

$$Z_1 = 16,8073 \text{ ft}$$

$$Z_2 = 17,4 \text{ ft}$$

$$g/g_c = 1 \text{ lbf/lbm}$$

Sehingga,

$$\begin{aligned}
 E_p &= \Delta Z \times \frac{g}{g_c} && \text{(Geankoplis, 2014 Eq. 2.7-5 p. 66)} \\
 &= (17,4 - 16,8) \text{ ft} \times 1 \text{ lbf/lbm} \\
 &= 0,59276 \text{ ft.lbf/lbm}
 \end{aligned}$$

h. Persamaan Bernouli

$$\begin{aligned}
 -W_f &= \frac{\Delta P}{\rho} + \Delta Z \times \frac{g}{g_c} + \frac{\Delta V^2}{2 \times \alpha \times g_c} + \Sigma F \\
 &= 16,8073 + 0,59276 + 0,12162 + 1,7826 \\
 &= 19,3043 \text{ ft.lbf/lbm}
 \end{aligned}$$

i. Perhitungan Power Pompa

$$\begin{aligned}
 hp &= \frac{-W_f \times \text{flowrate(gpm)} \times sg}{3960} \\
 &\quad \text{(Perry 6ed ; Pers 6-11, Page 6-5)} \\
 &= \frac{19,3043 \times 17,727 \times 0,87229}{3960} \\
 &= 0,07538 \text{ hp}
 \end{aligned}$$

$$\text{Efisiensi pompa} = 40\% \quad \text{(Peters 4 ed ; Figure 14 - 37 Page 520)}$$

$$B_{hp} = \frac{B_{ph}}{\eta_{pompa}}$$



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$$= \frac{0,0753798}{40\%} \text{ hp}$$

$$= 0,1884495 \text{ hp}$$

$$\text{Efisiensi motor} = 80\%$$

$$\text{Power motor} = \frac{\text{Bhp}}{\text{ef.Motor}}$$
$$= \frac{0,1884495}{80\%} \text{ hp}$$

$$= 0,2355618 \text{ hp}$$

$$\text{Maka digunakan power} = 0,5 \text{ hp}$$

Spesifikasi

Nama Alat	: Pompa
Kode	: L-141
Fungsi	: Untuk memindahkan asam oleat dari tangki penyimpanan (F-140) menuju reaktor (R-210)
Tipe	: <i>Centrifugal pump</i>
Dasar Pemilihan	: Umum digunakan untuk memompa liquid
Bahan konstruksi	: <i>Commercial steel</i>
Ukuran Pipa	: 1 1/2 in 40 sch
Kapasitas	: 7743,01 lb/jam
Rate volumetrik	: 142,186 ft ³ /jam
Total Dynamic head	: 19,3043 ft.lbf/lbm
Efisiensi pompa	: 40%
Efisiensi motor	: 80%
BHp	: 0,07538 hp
Power	: 0,5 hp
Jumlah	: 1 buah

9. Heater (E-122)





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Fungsi : Memanaskan larutan asam sulfat suhu 30°C menjadi 120°C

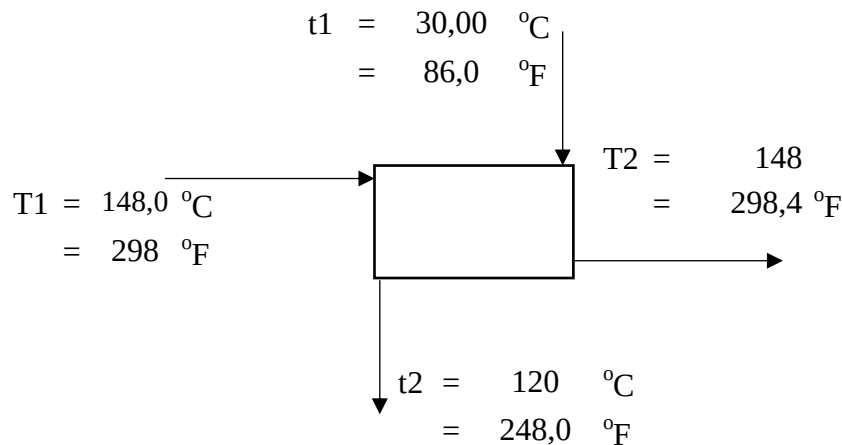
Tipe : Shell and Tube Exchanger

Dasar Pemilihan : Umum digunakan untuk menaikkan suhu liquida

Kondisi Operasi:

Tekanan = 1 atm

Suhu = 120 °C



Perhitungan

1. Data dari neraca massa dan neraca panas diperoleh:

Untuk Fluida panas : Steam

T masuk (T_1) = $148,0\text{ }^{\circ}\text{C} = 298,4\text{ }^{\circ}\text{F}$

T keluar (T_2) = $148\text{ }^{\circ}\text{C} = 298,4\text{ }^{\circ}\text{F}$

Untuk Fluida dingin : Larutan asam sulfat

T masuk (t_1) = $30,00\text{ }^{\circ}\text{C} = 86,0\text{ }^{\circ}\text{F}$

T keluar (t_2) = $120\text{ }^{\circ}\text{C} = 248,0\text{ }^{\circ}\text{F}$

massa bahan = 84,234623 kg/jam

= 186,24275 lb/jam

Panas yang dibutuhkan

$Q = 2995,3978\text{ kkal/jam}$

= 11878,849 Btu/jam



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Steam yang digunakan

$$\begin{aligned}\text{Massa steam} &= 4,56696 \text{ kg/jam} \\ &= 10,0975 \text{ lb/jam}\end{aligned}$$

2. Penentuan ΔT LMTD

Hot fluida		Cold fluida	diff
298,4	higher temp	248,0	50,4
298,4	lower temp	86,0	212
0,0		162,0	

$$\Delta t \text{ LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$

$$\begin{aligned}\Delta t \text{ LMTD} &= \frac{50 - 212}{\ln \frac{50}{212}} \\ &= 112,61887 \text{ F}\end{aligned}$$

$$\begin{aligned}R &= \frac{T_1 - T_2}{t_2 - t_1} && \text{(Kern, Eq 5.17)} \\ &= \frac{298 - 298}{248 - 86} \\ &= 0\end{aligned}$$

$$\begin{aligned}S &= \frac{t_2 - t_1}{T_1 - t_1} && \text{(Kern, Pers. 5.14, : 149)} \\ &= \frac{248 - 86}{298 - 86} \\ &= 0,76271\end{aligned}$$

$$\begin{aligned}F_T &= 1 && \text{(Kern Fig. 18, : 828)} \\ \Delta T &= \Delta T \text{ LMTD} \times F_T && \text{(Kern, Pers. 7.42 : 149)} \\ &= 112,619 \text{ }^\circ\text{F} \times 1 \\ &= 112,619 \text{ }^\circ\text{F}\end{aligned}$$



3. Tc dan tc

Tc = t average steam

$$\begin{aligned} T_c &= \frac{T_1 + T_2}{2} \\ &= \frac{298 + 298}{2} \\ &= 298 \text{ } ^\circ\text{F} \end{aligned}$$

tc = t average bahan

$$\begin{aligned} t_c &= \frac{t_1 + t_2}{2} \\ &= \frac{86,0 + 248}{2} \\ &= 167 \text{ } ^\circ\text{F} \\ &= 348,15 \text{ K} \end{aligned}$$

Menghitung Kapasitas Panas, Konduktifitas Thermal dan Viskositas
Fluida Panas

$$\begin{aligned} c_p &= 0,45 \text{ Btu/lb}^\circ\text{F} && \text{(Kern, Fig 3)} \\ k &= 0,016 && \text{(Kern, Table 5)} \\ \mu &= 0,014 \text{ cP} && \text{(Kern, Fig.15)} \end{aligned}$$

Fluida Dingin

Komponen	A	B	C	D
H ₂ SO ₄	26,004	0,70337	-0,0014	1E-06
H ₂ O	92,053	-0,04	-0,0002	5,3E-07

Menghitung nilai kapasitas panas

$$\begin{aligned} T &= 348,15 \text{ K} \\ C_p &= A + BT + CT^2 + DT^3 \end{aligned}$$

Sehingga diperoleh

$$\begin{aligned} C_p \text{ H}_2\text{SO}_4 &= 143,389 \text{ Kkal/KmolK} \\ C_p \text{ H}_2\text{O} &= 76,2506 \text{ Kkal/KmolK} \end{aligned}$$



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Komponen	BM	Cp	Fraksi	Cp
	Kg/Kmol	kcal/Kmol K	Xf	kcal/KmolK
H ₂ SO ₄	98	143,38919	0,98	1,46315
H ₂ O	18	76,250633	0,02	4,23615
Total			1	

$$C = \sum_i^n C_p \cdot X_f$$

$$C = 1,51861 \text{ Kkal/KmolK} \times 0,23885$$

$$C = 0,3627211 \text{ Btu/lb}^\circ\text{F}$$

Menghitung Viskositas Larutan

Komponen	A	B	C	D
H ₂ SO ₄	-18,705	3496,2	0,033	-1E-05
H ₂ O	-10,252	1792,5	0,018	-1E-05

$$T = 348,15 \text{ K}$$

$$\log_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu_{\text{H}_2\text{SO}_4} = 19,927236 \text{ cP}$$

$$\mu_{\text{H}_2\text{O}} = 0,4328294 \text{ cP}$$

Komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
H ₂ SO ₄	82,549934	0,98	19,927236	19,528691
H ₂ O	1,6846925	0,02	0,4328294	0,0086566
Total	84,234627	1		19,537348

$$\mu_{\text{Campuran}} = \sum_i^n C_p \cdot X_f$$

$$\mu_{\text{Campuran}} = 19,537348 \text{ cP}$$

Komponen	A	B	C	D
H ₂ SO ₄	-18,705	3496,2	0,033	-1E-05



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H ₂ O	-10,252	1792,5	0,018	-1E-05

$$T = 420,09 \text{ K}$$

$$\log_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu_{\text{H}_2\text{SO}_4} = 18,087546 \text{ cP}$$

$$\mu_{\text{H}_2\text{O}} = 0,2255122 \text{ cP}$$

Komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
H ₂ SO ₄	82,549934	0,98	18,087546	17,725795
H ₂ O	1,6846925	0,02	0,2255122	0,0045102
Total	84,234627	1		17,730306

$$\mu_{\text{Campuran}} = \sum_i^n C_p \cdot X_f$$

$$\mu_{\text{Campuran}} = 17,730306 \text{ cP}$$

Menghitung Densitas Larutan

Komponen	A	B	T _c	n
H ₂ SO ₄	0,42169	0,1936	925	0,2857
H ₂ O	0,3471	0,274	647,13	0,2857

$$T = 348,15 \text{ K}$$

$$\rho = A \times B^{-\left(1 - \frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\rho_{\text{H}_2\text{SO}_4} = 1,7704799$$

$$\rho_{\text{H}_2\text{O}} = 0,9803826$$

Komponen	Massa	Fraksi Massa	Densitas gr/ml	ρ Campuran gr/ml
	(kg)			
H ₂ SO ₄	82,549934	0,98	1,7704799	1,7350703
H ₂ O	1,6846925	0,02	0,9803826	0,0196077



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Total	84,234627	1		1,754678

$$\begin{aligned}\rho \text{ Campuran} &= 1,754678 \text{ gr/ml} \times 62,4 \\ &= 109,49191 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Sg} &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{109,49191 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 1,7538348\end{aligned}$$

$$\begin{aligned}\text{Kmix} &= \frac{0,0677}{\text{sg} [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{1,754 [1 - 0,0003 (167 - 32)]} \\ &= 0,0402 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243}\end{aligned}$$

Dipilih tipe : 1-2 Heat Exchanger

Digunakan shell and tube dengan ukuran :

Tube Side

$$\begin{aligned}\text{OD} &= 1 \frac{1}{2} \text{ in} \\ \text{BWG} &= 8 \\ \text{Pitch} &= 1 \frac{7}{8} \text{ in Square Pitch} \\ \text{L} &= 10 \text{ ft} \\ \text{ID} &= 1,17 \text{ in} \\ a't &= 1,075 \text{ in}^2 \\ a'' &= 0,165 \text{ ft}^2/\text{ft panjang}\end{aligned}$$

$$\text{Harga UD} = 6 - 60 \text{ Btu/jam.ft.}^\circ\text{F} \quad (\text{Kern, tabel 8 hal 840})$$

$$\text{Dipilih UD} = 20 \text{ Btu/jam.ft.}^\circ\text{F}$$

$$\begin{aligned}A &= \frac{Q}{\text{UD} \times \Delta t} \quad (\text{Kern Eq. 7.6}) \\ &= \frac{118788,492}{20 \times 112,619} \\ &= 52,7392 \text{ ft}^2\end{aligned}$$



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$$\begin{aligned} \text{Jumlah tube (Nt)} &= \frac{A}{a'' \times L} \\ &= \frac{52,7391616}{0,17 \times 10} \\ &= 31,9631 \text{ buah} \end{aligned}$$

Dipilih pipa ukuran standart **(Kern T.9)**

Untuk pipa 1 1/2 in
diperoleh :

$$\begin{aligned} \text{Tube Passes} &= 2 \\ \text{ID Shell} &= 17 \frac{1}{4} \text{ in} \\ \text{Shell Passes} &= 1 \end{aligned}$$

Koreksi UD

$$\begin{aligned} A &= Nt \times L \times a'' \\ &= 39 \times 10 \times 0,17 \\ &= 64,35 \end{aligned}$$

$$\begin{aligned} UD &= \frac{Q}{A \times \Delta t} \\ &= \frac{118788,492}{64,4 \times 112,619} \\ &= 16,391348 \end{aligned}$$

Menentukan nilai De :

$$\begin{aligned} De &= \frac{4 \left(Pt^2 - \pi \frac{OI^2}{4} \right)}{\pi OD} \\ &= \frac{4 \left(1,88^2 - 3,14 \times \frac{1,50^2}{4} \right)}{3,14 \times 1,5} \\ &= 1,48567 \text{ in} = 0,12 \text{ ft} \end{aligned}$$

Fluida Panas : Shell Side	Fluida Dingin :Tube Side
Steam	Asam Sulfat
4. Flow Area (as)	4. Flow Area (at) B = 0,25 ID



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$as = \frac{Nt \times at'}{144 \times n}$ (Kern, Eq 7.48) $= \frac{39 \times 1,08}{144 \times 2}$ $= 0,14625 \text{ ft}^2$	$= 4,3125$ $C = Pt - OD$ $= 1 \frac{7}{8} - 1 \frac{1}{2}$ $= 0,375$ $at = \frac{ID \times C' \times B}{144 \times Pt}$ (Kern, Eq. 7.1) $= \frac{17,25 \times 0,375 \times 4,3125}{144 \times 1,88}$ $= 0,1033203 \text{ ft}^2$
5. Mass Velocity $Gs = \frac{W}{at}$ $= \frac{10,097549}{0,14625}$ $= 69,043067 \text{ lb/jam ft}^2$	5. Mass Velocity (Gt) $Gt = \frac{W}{as}$ (Kern, Eq 7.2) $= \frac{1862,4275}{0,1033203}$ $= 18025,763 \text{ lb/jam ft}^2$
6. Bilangan Reynold (Res) $D = 0,10 \text{ ft}$ $\mu = 0,03388 \text{ lb/ft.jam}$ (Kern Fig.15) $Ret = \frac{De \times Gs}{\mu}$ $= \frac{0,10 \times 69,0431}{0,03388}$ $= 198,69242$	6. Bilangan Reynold (Ret) $De = 0,12 \text{ ft}$ $\mu = 1,95 \text{ lb/ft.jam}$ $Res = \frac{D \times Gt}{\mu}$ $= \frac{0,12 \times 18025,8}{1,95373}$ $= 1142,27$
	7. jH $jH = 12$ (Kern Fig-28, hal. 838) 8. $(C \times \mu / k)^{1/3}$ $= \frac{1,51861 \times 1,95373}{0,0402}$ $= 4,19359$



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9. h_{io} $h_{io} = 1500 \text{ Btu/hr ft}^2 \text{ } ^\circ\text{F}$ (Kern, Hal. 164)	9. h_o $h_o = jH \frac{k}{D} \left(\frac{c \mu}{k} \right)^{1/3} \phi_t$ $\frac{h_o}{\phi_t} = 12 \times \frac{0,0402}{0,12381} \times 4,19359$ $= 24,528614 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$
10. t_w $t_w = t_c + \frac{h_o/\phi_s}{h_{io}/\phi_t + h_o/\phi_s} (T_c - t_c)$ (Kern, Eq 5.31) $= 167 + \frac{1500}{1500 + 24,5} 131$ $= 296,286 \text{ } ^\circ\text{F}$	10. ϕ_t Pada $t_w = 296,28586 \text{ } ^\circ\text{F}$ $\mu_w = 17,730306 \text{ lb/jam ft}$ $\phi_t = (\mu/\mu_w)^{0.14}$ $= 0,73435$ 11.. h_{io} $= \frac{h_o}{\phi_t} \times \phi_t$ $= 18,0125 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$

12. Clean Overall Coefficient, U_c

$$U_c = \frac{h_{io} \times h_o}{h_{io} + h_o} \quad (\text{Kern, Eq 6.38})$$

$$= \frac{1500 \times 18}{1500 + 18}$$

$$= 17,8 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$$

13. Design Overall Coefficient, U_d

$$U_d = \frac{Q}{A \times \Delta t \text{ LMTD}}$$

$$= \frac{118788,49}{64,4 \times 113}$$

$$= 16,391348 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$$



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14. Dirt Factor, Rd

$$\begin{aligned} Rd &= \frac{U_c - U_d}{U_c \times U_d} \quad \text{(Kern, Eq 6.13)} \\ &= \frac{17,8 - 16,4}{17,8 \times 16,4} \\ &= 0,00482 \end{aligned}$$

Nilai Rd perhitungan > Rd

$$0,00482 > 0,002 \quad \text{(Kern, Table 12 Page 845)}$$

(Memenuhi karena Rd Perhitungan >> Rd allowabe)

Pressure Drop	
Fluida Panas : Shell Side	Fluida Dingin : Tube Side
Steam	Asam Sulfat
1. f $\begin{aligned} Re &= 198,69242 \\ f &= 0,0005 \end{aligned}$ (Kern, Fig 26) 2. dari tabel 7 kern, spesifik volume pada suhu 298,4 °F $\begin{aligned} \rho &= \frac{6,62 \text{ ft}^3/\text{lb}}{6,62} \\ &= 0,15106 \text{ lb/ft}^3 \\ s &= \frac{0,15106}{62,5} \\ &= 0,00242 \end{aligned}$ $\begin{aligned} \Delta P_t &= \frac{f G s^2 L n}{5,22 \times 10^{10} D s \phi} \\ &= 6,2E-08 \text{ psi} \end{aligned}$ $\Delta P_t < \Delta P \text{ allowable}$ $\Delta P_t < 10 \text{ psi}$, maka memenuhi	1. f $\begin{aligned} Re &= 1142,2697 \\ f &= 0,0035 \end{aligned}$ (Kern, Fig 29) 2. Number of crosses, N+1 $\begin{aligned} N+1 &= 12 \times \frac{L}{B} \\ &= 12 \times \frac{10}{4,31} \\ &= 27,8261 \end{aligned}$ 3. Pressure Drop (ΔP_s) $\begin{aligned} s &= 1,84 \end{aligned}$ (Kern, Table 6) $\begin{aligned} \Delta P_s &= \frac{f \times G t^2 \times L \times n}{5,22 \times 10^{10} \times ID \times s \times \phi t} \\ &= 0,0002601 \text{ psi} \end{aligned}$ (Kern, Eq 7.44) $\Delta P_s < \Delta P \text{ allowable}$ $\Delta P_s < 2 \text{ psi}$, maka memenuhi



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Spesifikasi Alat

Nama Alat : Heater
Kode : E-122
Fungsi : Memanaskan Asam sulfat dari suhu 30 °C menjadi 120°C
untuk dialirkan ke Reaktor
Tipe : 1-2 Shell and Tube Exchanger
Dasar Pemilihan : Umum digunakan untuk transfer panas
Kondisi Operasi : - Tekanan : 1 atm
- Suhu : 120 °C

Bagian Tube

OD : 1 1/2 in
BWG : 8
Panjang : 10 ft
Jumlah tube, Nt : 39
Passes : 2
Pitch : 1 7/8 in square pitch
Pressure drop : 6,2E-08 psi

Bagian Shell

ID : 17 1/4 in
Passes : 1
Baffle Spacing : 4,31 in
Pressure drop : 0,0002601 psi

10. Heater (E-132)



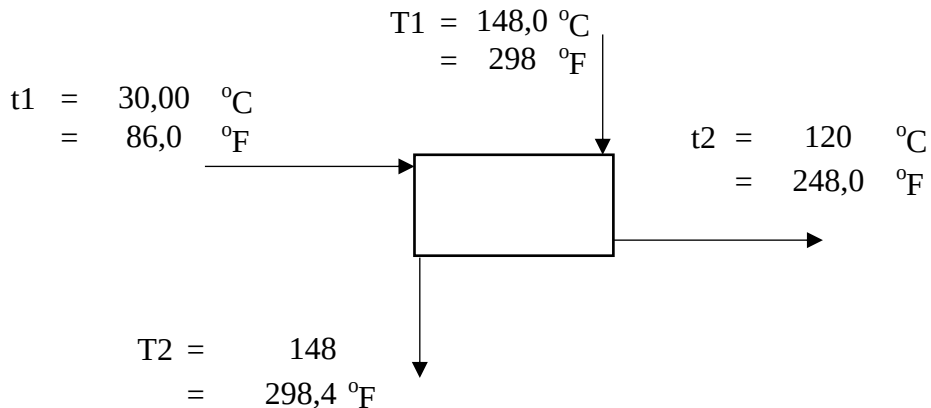
Fungsi : Untuk memanaskan butanol suhu 30°C menjadi 120°C
untuk dialirkan ke Reaktor (R-210)
Tipe : 1-2 Shell and Tube Exchanger
Dasar Pemilihan : Umum digunakan untuk memanaskan liquid



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Kondisi Operasi

Tekanan = 1 atm
Suhu = 120 °C



Perhitungan

1. Data dari neraca massa dan neraca panas diperoleh:

Untuk Fluida panas : Steam

T masuk (T_1) = $148,0\text{ }^{\circ}\text{C} = 298,4\text{ }^{\circ}\text{F}$

T keluar (T_2) = $148\text{ }^{\circ}\text{C} = 298,4\text{ }^{\circ}\text{F}$

Untuk Fluida dingin : Larutan butanol

T masuk (t_1) = $30,00\text{ }^{\circ}\text{C} = 86,0\text{ }^{\circ}\text{F}$

T keluar (t_2) = $120\text{ }^{\circ}\text{C} = 248,0\text{ }^{\circ}\text{F}$

massa bahan = 5093,4047 kg/jam
= 11261,518 lb/jam

Panas yang dibutuhkan

$Q = 202635\text{ kkal/jam}$
= 803589,62 Btu/jam

Steam yang digunakan

Massa steam = 520,706 kg/jam
= 1151,28 lb/jam



2. Penentuan ΔT LMTD

Hot fluida		Cold fluida	diff
298,4	higher temp	248,0	50,4
298,4	lower temp	86,0	212
0,0		162,0	

$$\Delta t \text{ LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$

$$\begin{aligned} \Delta t \text{ LMTD} &= \frac{50 - 212}{\ln \frac{50}{212}} \\ &= 112,61887 \text{ F} \end{aligned}$$

$$\begin{aligned} R &= \frac{T_1 - T_2}{t_2 - t_1} && \text{(Kern, Pers. 5.14, Hal.149)} \\ &= \frac{298 - 298}{248 - 86,0} \\ &= 0 \end{aligned}$$

$$\begin{aligned} S &= \frac{t_2 - t_1}{T_1 - t_1} && \text{(Kern, Pers. 5.14, Hal.149)} \\ &= \frac{248 - 86}{298 - 86,0} \\ &= 0,76271 \end{aligned}$$

$$\begin{aligned} FT &= 0,95 && \text{(Kern Fig. 18, : 828)} \\ \Delta T &= \Delta T \text{ LMTD} \times FT && \text{(Kern, Pers. 7.42 : 149)} \\ &= 112,619 \text{ } ^\circ\text{F} \times 0,95 \\ &= 106,988 \text{ } ^\circ\text{F} \end{aligned}$$

3. Tc dan tc

Tc = t average steam

$$\begin{aligned} T_c &= \frac{T_1 + T_2}{2} \\ &= \frac{298 + 298}{2} \end{aligned}$$



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$$= 298 \text{ }^{\circ}\text{F}$$

$t_c = t_{\text{average bahan}}$

$$\begin{aligned} t_c &= \frac{t_1 + t_2}{2} \\ &= \frac{86,0 + 248}{2} \\ &= 167 \text{ }^{\circ}\text{F} \\ &= 348,15 \text{ K} \end{aligned}$$

Menghitung Kapasitas Panas, Konduktivitas Thermal dan Viskositas

Fluida Panas

$$\begin{aligned} c_p &= 0,45 \text{ Btu/lb}^{\circ}\text{F} && \text{(Kern, Fig 3)} \\ k &= 0,016 && \text{(Kern, Table 5)} \\ \mu &= 0,014 \text{ cP} && \text{(Kern, Fig.15)} \end{aligned}$$

Fluida Dingin

Menghitung nilai kapasitas panas

Komponen	A	B	C	D
C ₄ H ₉ OH	83,877	0,56628	-0,0017	2,3E-06
H ₂ O	92,053	-0,04	-0,0002	5,3E-07

$$\begin{aligned} T &= 348,15 \text{ K} \\ C_p &= A + BT + CT^2 + DT^3 \end{aligned}$$

Sehingga diperoleh

$$\begin{aligned} C_p \text{ C}_4\text{H}_9\text{OH} &= 172,03 \text{ Kkal/KmolK} \\ C_p \text{ H}_2\text{O} &= 76,2506 \text{ Kkal/KmolK} \end{aligned}$$

Komponen	BM	C _p	Fraksi	C _p
	Kg/Kmol	kkal/Kmol K	X _f	kkal/Kg K
C ₄ H ₉ OH	74	172,0301	0,995	2,32473
H ₂ O	18	76,250633	0,005	4,23615
Total			1	

$$C = \sum_{i=1}^n C_p \cdot X_f$$



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$$C = 0,5575447 \text{ Btu/lb}^{\circ}\text{F}$$

Menghitung Viskositas Larutan

Komponen	A	B	C	D
C ₄ H ₉ OH	-5,397	1325,6	0,006	-6E-06
H ₂ O	-10,252	1792,5	0,018	-1E-05

$$T = 348,15 \text{ K}$$

$$\text{Log}10 \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \text{ C}_4\text{H}_9\text{OH} = 0,6785718 \text{ cP}$$

$$\mu \text{ H}_2\text{O} = 0,4328294 \text{ cP}$$

Komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
C ₄ H ₉ OH	5067,9377	0,995	0,6785718	0,6751789
H ₂ O	25,467024	0,005	0,4328294	0,0021641
Total	5093,4047	1		0,6773431

$$\mu \text{ Campuran} = \sum_i^n C_p \cdot X_f$$

$$\mu \text{ Campuran} = 0,6773431 \text{ cP}$$

Menghitung Viskositas Larutan

Komponen	A	B	C	D
C ₄ H ₉ OH	-5,397	1325,6	0,006	-6E-06
H ₂ O	-10,252	1792,5	0,018	-1E-05

$$T = 293,264 \text{ F}$$

$$= 418,297 \text{ K}$$

$$\text{Log}10 \mu = A + \frac{B}{T} + CT + DT^2$$



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Sehingga diperoleh

$$\mu \text{ C}_4\text{H}_9\text{OH} = 0,2078387 \text{ cP}$$

$$\mu \text{ H}_2\text{O} = 0,2281013 \text{ cP}$$

Komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
C ₄ H ₉ OH	5067,9377	0,995	0,2078387	0,2067995
H ₂ O	25,467024	0,005	0,2281013	0,0011405
Total	5093,4047	1		0,20794

$$\mu \text{ Campuran} = \sum_i^n c_p \cdot X_f$$

$$\mu \text{ Campuran} = 0,20794 \text{ cP}$$

Menghitung Densitas Larutan

Komponen	A	B	T _c	n
C ₄ H ₉ OH	0,26891	0,2667	562,93	0,2457
H ₂ O	0,3471	0,274	647,13	0,2857

$$T = 348,15 \text{ K}$$

$$\rho = A \times B^{-\left(1 - \frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\rho \text{ C}_4\text{H}_9\text{OH} = 0,7631091 \text{ gr/ml}$$

$$\rho \text{ H}_2\text{O} = 0,9803826 \text{ gr/ml}$$

Komponen	Massa	Fraksi Massa	Densitas gr/ml	ρ Campuran gr/ml
	(kg)			
C ₄ H ₉ OH	5067,9377	0,995	0,7631091	0,7592936
H ₂ O	25,467024	0,005	0,9803826	0,0049019
Total	5093,4047	1		0,7641955

$$\begin{aligned} \rho \text{ Campuran} &= 0,7641955 \text{ gr/ml} \times 62,4 \\ &= 47,685797 \text{ lb/cuft} \end{aligned}$$



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$$\begin{aligned} Sg &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{47,685797 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,7638282 \end{aligned}$$

$$\begin{aligned} K_{mix} &= \frac{0,0677}{\text{sg} [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{0,764 [1 - 0,0003 (167 - 32)]} \\ &= 0,0924 \text{ Btu/jam.ft.}^\circ\text{F} \quad \textbf{Perry ed 5 pers 3-89 hal 3-243} \end{aligned}$$

Dipilih tipe : 1-2 Heat Exchanger
 Digunakan shell and tube dengan ukuran :

Tube Side		Shell Side	
OD	= 1 1/2 in	Shell ID	= 17 1/4 in
BWG	= 8	Passes	= 1 in
Pitch	= 1 7/8 in	Square Pitch Baffle Spacing	= 4 in
L	= 10 ft		
Passes	= 2		
ID	= 1,17 in		
a't	= 1,075 in ²		
a"	= 0,3925 ft ² /ft panjang		

(kern, Table.10, Hal. 843)

Harga UD = 50 - 100 Btu/jam.ft.°F **(Kern, tabel 8 hal 840)**

Dipilih UD = 60 Btu/jam.ft.°F

$$\begin{aligned} A &= \frac{Q}{UD \times \Delta t} \quad (\text{Kern Eq. 7.6}) \\ &= \frac{803589,6195}{60 \times 106,988} \\ &= 125,184 \text{ ft}^2 \end{aligned}$$

$$\text{Jumlah tube (Nt)} = \frac{A}{a'' \times L}$$



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$$= \frac{125,1838518}{0,39 \times 10}$$

$$= 31,894 \text{ buah}$$

UD koreksi

$$A = N_t \times L \times a''$$

$$= 32 \times 10 \times 0,39$$

$$= 125,6$$

$$UD = \frac{Q}{A \times \Delta t}$$

$$= \frac{803589,6195}{126 \times 106,988}$$

$$= 59,801203$$

Menentukan nilai De :

$$De = \frac{4 \left(\frac{P_t^2}{4} - \pi \frac{O_L^2}{4} \right)}{\pi OD}$$

$$= \frac{4 \left(\frac{1,875^2}{4} - 3,14 \times \frac{1,50^2}{4} \right)}{3,14 \times 1,5}$$

$$= 1,48567 \text{ in} = 0,12 \text{ ft}$$

Fluida Panas : Shell Side	Fluida Dingin : Tube side
Steam	Butanol
4. Flow Area (as) $as = \frac{N_t \times at'}{144 \times n}$ (Kern, Eq 7.48) $= \frac{32 \times 1,08}{144 \times 2}$ $= 0,12 \text{ ft}^2$	4. Flow Area (at) asumsi B = 0,25 ID $= 4,3125$ $C = P_t - OD$ $= 1 \frac{7}{8} - 1 \frac{1}{2}$ $= 0,375$ $at = \frac{ID \times C' \times B}{144 \times P_t}$ (Kern, Eq. 7.1) $= \frac{17,25 \times 0,375 \times 4,3125}{144 \times 1,88}$



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	= 0,1033203 ft ²
5. Mass Velocity (Gs) $Gs = \frac{W}{at}$ $= \frac{1151,2816}{0,12}$ $= 9594,0134 \text{ lb/jam ft}^2$	5. Mass Velocity (Gt) $Gt = \frac{W}{as} \quad (\text{Kern, Eq 7.2})$ $= \frac{11261,518}{0,1033203}$ $= 108996,16 \text{ lb/jam ft}^2$
6. Bilangan Reynold (Res) $De = 0,12 \text{ ft}$ $\mu = 0,03388 \text{ lb/ft.jam}$ $Ret = \frac{De \times Gs}{\mu}$ $= \frac{0,12 \times 9594,01}{0,03388}$ $= 35058,836$	6. Bilangan Reynold (Ret) $D = 0,1 \text{ ft}$ $\mu = 1,64 \text{ lb/ft.jam}$ $Res = \frac{D \times Gt}{\mu}$ $= \frac{0,1 \times 108996}{1,63917}$ $= 6483,2091$
9. hio $hio = 1500 \text{ Btu/hr ft}^2 \text{ } ^\circ\text{F}$ (Kern, Hal. 164)	7. jH $jH = 30$ (Kern Fig-28, hal. 838) 8. $(C \times \mu / k)^{1/3}$ $= \frac{0,55754 \times 1,63917}{0,0924}$ $= 2,14677$ 9. ho $ho = jH \frac{k}{D} \left(\frac{c \mu}{k} \right)^{1/3} \varphi t$ $\frac{ho}{\varphi t} = 30 \times \frac{0,0924}{0,0975} \times 2,14677$ $= 61,017109 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$
10. tw	10. φt



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$t_w = t_c + \frac{h_o/\phi_s}{h_o/\phi_t + h_o/\phi_s} (T_c - t_c)$ (Kern, Eq 5.31) $= 167 + \frac{1500}{1500 + 61} 131$ $= 293,264 \text{ } ^\circ\text{F}$	Pada $t_w = 293,26383 \text{ } ^\circ\text{F}$ $\mu_w = 0,5073736 \text{ lb/jam ft}$ $\phi_t = (\mu/\mu_w)^{0.14}$ $= 1,17842$ 11.. $h_{io} = \frac{h_o}{\phi_t} \times \phi_t$ $= 71,904 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$

12. Clean Overall Coefficient, U_c

$$U_c = \frac{h_{io} \times h_o}{h_{io} + h_o} \quad \text{(Kern, Eq 6.38)}$$

$$= \frac{1500 \times 71,9}{1500 + 71,9}$$

$$= 68,6 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$$

13. Design Overall Coefficient, U_d

$$U_d = \frac{Q}{A \times \Delta t \text{ LMTD}}$$

$$= \frac{803589,62}{126 \times 107}$$

$$= 59,801203 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$$

14. Dirt Factor, R_d

$$R_d = \frac{U_c - U_d}{U_c \times U_d} \quad \text{(Kern, Eq 6.13)}$$

$$= \frac{68,6 - 59,8}{68,6 \times 59,8}$$

$$= 0,00215$$

Nilai R_d perhitungan $> R_d$

$0,00215 > 0,002$ **(Kern, Table 12 Page 845)**

(Memenuhi karena R_d Perhitungan $>> R_d$ allowabe)



PRA RANCANGAN PABRIK
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Pressure Drop	
Fluida Panas : Shell Side	Fluida Dingin : Tube Side
Steam	Butanol
1. f $Re_t = 35058,836$ $f = 0,000028$ (Kern, Fig 26) 2. dari tabel 7 kern, spesifik volume $= 6,62 \text{ ft}^3/\text{lb}$ $\rho = \frac{1}{6,62}$ $= 0,15106 \text{ lb/ft}^3$ $s = \frac{0,15106}{62,5}$ $= 0$ $\Delta P_t = \frac{f G s^2 L n}{5,22 \cdot 10^{10} D s \phi}$ $= 5,28E-05 \text{ psi}$ $\Delta P_t < \Delta P \text{ allowable}$ $\Delta P_t < 10 \text{ psi}$, maka memenuhi	1. f $Re_s = 6483,2091$ $f = 0,0027$ (Kern, Fig 29) 2. Number of crosses, $N+1$ $N+1 = 12 \times \frac{L}{B}$ $= 12 \times \frac{10}{4,31}$ $= 27,8261$ 3. Pressure Drop (ΔP_s) $s = 1,84$ (Kern, Table 6) $\Delta P_s = \frac{f \times G t^2 \times L \times n}{5,22 \times 10^{10} \times ID \times s \times \phi t}$ (Kern, Eq 7.44) $= 0,0045715 \text{ psi}$ $\Delta P_s < \Delta P \text{ allowable}$ $\Delta P_s < 2 \text{ psi}$, maka memenuhi

Spesifikasi Alat

Nama Alat : Heater
 Kode : E-132
 Fungsi : Memanaskan Butanol dari suhu 30 °C menjadi 120°C untuk dialirkan ke Reaktor (R-210)
 Tipe : 1-2 *Shell and Tube Exchanger*
 Kondisi Operasi: - Tekanan : 1 atm
 - Suhu : 120 °C

Bagian Tube

OD : 1 1/2 in
 BWG : 8



PRA RANCANGAN PABRIK
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Panjang : 10 ft
Jumlah tube, Nt : 32 buah
Passes : 2
Pitch : 1 7/8 in square pitch
Pressure drop : 5,28E-05 psi

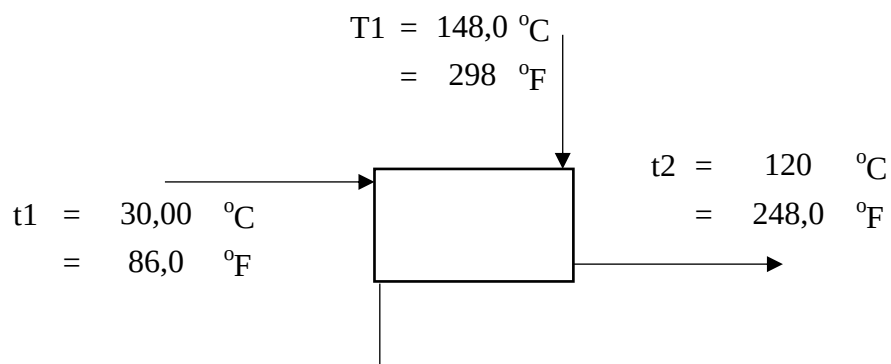
Bagian Shell

ID : 17 1/4 in
Passes : 1
Baffle Spacing : 4,31 in
Pressure drop : 0,0045715 psi

11. Heater (E-142)



Fungsi : Untuk memanaskan asam oleat suhu 30°C menjadi 120°C
untuk dialirkan ke Reaktor (R-210)
Tipe : 1-2 Shell and Tube Exchanger
Dasar Pemilihan : Umum digunakan untuk memanaskan liquid
Kondisi Operasi
Tekanan = 1 atm
Suhu = 120 °C





PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”



$$\begin{aligned} T_2 &= 148\text{ }^{\circ}\text{C} \\ &= 298,4\text{ }^{\circ}\text{F} \end{aligned}$$

Perhitungan

1. Data dari neraca massa dan neraca panas diperoleh:

Untuk Fluida panas : Steam

$$T \text{ masuk } (T_1) = 148,0\text{ }^{\circ}\text{C} = 298,4\text{ }^{\circ}\text{F}$$

$$T \text{ keluar } (T_2) = 148\text{ }^{\circ}\text{C} = 298,4\text{ }^{\circ}\text{F}$$

Untuk Fluida dingin : Larutan asam oleat

$$T \text{ masuk } (t_1) = 30\text{ }^{\circ}\text{C} = 86,0\text{ }^{\circ}\text{F}$$

$$T \text{ keluar } (t_2) = 120\text{ }^{\circ}\text{C} = 248,0\text{ }^{\circ}\text{F}$$

$$\begin{aligned} \text{massa bahan} &= 3512,1906\text{ kg/jam} \\ &= 7765,4535\text{ lb/jam} \end{aligned}$$

Panas yang dibutuhkan

$$\begin{aligned} Q &= 220384,32\text{ kkal/jam} \\ &= 873978,1\text{ Btu/jam} \end{aligned}$$

Steam yang digunakan

$$\begin{aligned} \text{Massa steam} &= 435,05\text{ kg/jam} \\ &= 961,895\text{ lb/jam} \end{aligned}$$

2. Penentuan ΔT LMTD

Hot fluida		Cold fluida	diff
298,4	higher temp	248,0	50,4
298,4	lower temp	86,0	212
0,0		162,0	

$$\Delta t \text{ LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$

$$\begin{aligned} \Delta t \text{ LMTD} &= \frac{50 - 212}{\ln \frac{50}{212}} \\ &= 112,61887\text{ }^{\circ}\text{F} \end{aligned}$$



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$$\begin{aligned} R &= \frac{T_1 - T_2}{t_2 - t_1} && \text{(Kern, Eq 5.17)} \\ &= \frac{298 - 298}{248 - 86,0} \\ &= 0 \end{aligned}$$

$$\begin{aligned} S &= \frac{t_2 - t_1}{T_1 - t_1} && \text{(Kern, Pers. 5.14, : 149)} \\ &= \frac{248 - 86}{298 - 86} \\ &= 0,76271 \end{aligned}$$

$$\begin{aligned} FT &= 0,96 && \text{(Kern Fig. 18, : 828)} \\ \Delta T &= \Delta T \text{ LMTD} \times FT && \text{(Kern, Pers. 7.42 : 149)} \\ &= 112,619 \text{ } ^\circ\text{F} \times 0,96 \\ &= 108,114 \text{ } ^\circ\text{F} \end{aligned}$$

3. Tc dan tc

Tc = t average steam

$$\begin{aligned} T_c &= \frac{T_1 + T_2}{2} \\ &= \frac{298 + 298}{2} \\ &= 298 \text{ } ^\circ\text{F} \end{aligned}$$

tc = t average bahan

$$\begin{aligned} t_c &= \frac{t_1 + t_2}{2} \\ &= \frac{86,0 + 248}{2} \\ &= 167 \text{ } ^\circ\text{F} \\ &= 348,15 \text{ K} \end{aligned}$$

Menghitung Kapasitas Panas, Konduktifitas Thermal dan Viskositas
Fluida Panas

$$\begin{aligned} c_p &= 0,45 \text{ Btu/lb}^\circ\text{F} && \text{(Kern, Fig 3)} \\ k &= 0,016 && \text{(Kern, Table 5)} \\ \mu &= 0,014 \text{ cP} && \text{(Kern, Fig.15)} \end{aligned}$$



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Fluida Dingin

Menghitung nilai kapasitas panas

Komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	278,686	2,5434	-0,0054	4,9E-06
C ₁₅ H ₃₁ COOH	86,29	3,5237	-0,0073	6,1E-06

$$T = 348,15 \text{ K}$$

$$C_p = A + BT + CT^2 + DT^3$$

Sehingga diperoleh

$$C_p \text{ C}_{17}\text{H}_{33}\text{COOH} = 713,129 \text{ Kkal/KmolK}$$

$$C_p \text{ C}_{15}\text{H}_{31}\text{COOH} = 683,233 \text{ Kkal/KmolK}$$

Komponen	BM	Cp	Fraksi	Cp
	Kg/Kmol	kcal/Kmol K	Xf	kcal/Kg K
C ₁₇ H ₃₃ COOH	282,46	713,12879	0,995	2,52471
C ₁₅ H ₃₁ COOH	256,43	683,23265	0,005	2,6644
Total			1	

$$C = \sum_i^n C_p \cdot Xf$$

$$C = 0,6031931 \text{ Btu/lb}^\circ\text{F}$$

Menghitung Viskositas Larutan

Komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	-6,1303	1689,3	0,00837	-6E-06
C ₁₅ H ₃₁ COOH	-9,4432	2098,3	0,01658	-1E-05

$$T = 348,15 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \text{ C}_{17}\text{H}_{33}\text{COOH} = 7,1692222 \text{ cP}$$

$$\mu \text{ C}_{15}\text{H}_{31}\text{COOH} = 6,8256442 \text{ cP}$$



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
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Komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
C ₁₇ H ₃₃ COOH	3494,6297	0,995	7,1692222	7,1333761
C ₁₅ H ₃₁ COOH	17,560953	0,005	6,8256442	0,0341282
Total	3512,1906	1		7,1675043

$$\mu \text{ Campuran} = \sum_i^n C_p \cdot X_f$$

$$\mu \text{ Campuran} = 7,1675043 \text{ cP}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
C ₁₇ H ₃₃ COOH	0,2824	0,26812	781	0,2897
C ₁₅ H ₃₁ COOH	0,2797	0,26805	776	0,2947

$$T = 348,15 \text{ K}$$

$$\rho = Ax B^{-\left(1 - \frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\rho \text{ C}_{17}\text{H}_{33}\text{COOH} = 0,8564314 \text{ gr/ml}$$

$$\rho \text{ C}_{15}\text{H}_{31}\text{COOH} = 0,8442299 \text{ gr/ml}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran gr/ml
	(kg)		gr/ml	
C ₁₇ H ₃₃ COOH	3494,6297	0,995	0,8564314	0,8521493
C ₁₅ H ₃₁ COOH	17,560953	0,005	0,8442299	0,0042211
Total	3512,1906	1		0,8563704

$$\begin{aligned} \rho \text{ Campuran} &= 0,8563704 \text{ gr/ml} \times 62,4 \\ &= 53,437514 \text{ lb/cuft} \end{aligned}$$

$$\begin{aligned} Sg &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{53,437514 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \end{aligned}$$



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$$= 0,8559589$$

$$K_{mix} = \frac{0,0677}{sg \left[1 - 0,0003 (t - 32) \right]}$$

$$= \frac{0,0677}{0,856 \left[1 - 0,0003 (167 - 32) \right]}$$

$$= 0,0824 \text{ Btu/jam.ft.}^{\circ}\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243}$$

Menghitung Viskositas

Komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	-6,1303	1689,3	0,00837	-6E-06
C ₁₅ H ₃₁ COOH	-9,4432	2098,3	0,01658	-1E-05

$$T = 295,063 \text{ F}$$

$$= 419,576 \text{ K}$$

$$\log_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu_{C_{17}H_{33}COOH} = 1,8787322 \text{ cP}$$

$$\mu_{C_{15}H_{31}COOH} = 2,0137402 \text{ cP}$$

Komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
C ₁₇ H ₃₃ COOH	3494,6297	0,995	1,8787322	1,8693386
C ₁₅ H ₃₁ COOH	17,560953	0,005	2,0137402	0,0100687
Total	3512,1906	1		1,8794073

$$\mu_{\text{Campuran}} = \sum_i^n C_p \cdot X_f$$

$$\mu_{\text{Campuran}} = 1,8794073 \text{ cP}$$

Dipilih tipe : 1-2 Heat Exchanger

Digunakan shell and tube dengan ukuran :

Tube Side

$$\text{OD} = 1 \frac{1}{2} \text{ in}$$

Shell Side

$$\text{Shell ID} = 19 \frac{1}{4} \text{ in}$$



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$$\begin{aligned}
 \text{BWG} &= 8 & \text{Passes} &= 1 \text{ in} \\
 \text{Pitch} &= 1 \frac{7}{8} \text{ in Square Pitch} \\
 L &= 10 \text{ ft} \\
 \text{Passes} &= 2 \\
 \text{ID} &= 1,17 \text{ in} \\
 a't &= 1,075 \text{ in}^2 \\
 a'' &= 0,3925 \text{ ft}^2/\text{ft panjang}
 \end{aligned}$$

(kern, Table.10, Hal. 843)

$$\begin{aligned}
 \text{Harga UD} &= 6 - 60 \text{ Btu/jam.ft.}^\circ\text{F} & \text{(Kern, tabel 8 hal 840)} \\
 \text{Dipilih UD} &= 40 \text{ Btu/jam.ft.}^\circ\text{F}
 \end{aligned}$$

$$\begin{aligned}
 A &= \frac{Q}{\text{UD} \times \Delta t} & \text{(Kern Eq. 7.6)} \\
 &= \frac{873978,1004}{40 \times 108,114} \\
 &= 202,096 \text{ ft}^2
 \end{aligned}$$

$$\begin{aligned}
 \text{Jumlah tube (Nt)} &= \frac{A}{a'' \times L} \\
 &= \frac{202,0962124}{0,39 \times 10} \\
 &= 51,4895 \text{ buah}
 \end{aligned}$$

UD koreksi

$$\begin{aligned}
 A &= Nt \times L \times a'' \\
 &= 50 \times 10 \times 0,39 \\
 &= 196,25
 \end{aligned}$$

$$\begin{aligned}
 \text{UD} &= \frac{Q}{A \times \Delta t} \\
 &= \frac{873978,1004}{196 \times 108,114} \\
 &= 41,191585
 \end{aligned}$$

Menentukan nilai De :



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$$\begin{aligned}
 De &= \frac{4 \left(\frac{Pt^2}{4} - \pi \frac{OI^2}{4} \right)}{\pi OD} \\
 &= \frac{4 \left(\frac{1,88^2}{4} - 3,14 \times \frac{1,50^2}{4} \right)}{3,14 \times 1,5} \\
 &= 1,48567 \text{ in} = 0,12 \text{ ft}
 \end{aligned}$$

Fluida Panas : Shell Side	Fluida Dingin : Tube Side
Steam	Asam Oleat
4. Flow Area (at) at' = 1,08 in² (Kern, Table 10) at = $\frac{Nt \times at'}{144 \times n}$ (Kern, Eq 7.48) = $\frac{50 \times 1,08}{144 \times 2}$ = 0,1866319 ft²	4. Flow Area (at) asums B = 0,25 ID = 4,8125 C = Pt - OD = 1 7/8 - 1 1/2 = 0,375 at = $\frac{ID \times C' \times B}{144 \times Pt}$ (Kern, Eq. 7.1) = $\frac{19,25 \times 0,375 \times 4,8125}{144 \times 1,88}$ = 0,1286675 ft²
5. Mass Velocity (Gs) Gs = $\frac{W}{at}$ = $\frac{961,89505}{0,1866319}$ = 5153,9679 lb/jam ft²	5. Mass Velocity (Gt) Gt = $\frac{W}{as}$ (Kern, Eq 7.2) = $\frac{7765,4535}{0,1286675}$ = 60352,859 lb/jam ft²
6. Bilangan Reynold (Ret) De = 0,12 ft μ = 0,03388 lb/ft.jam Res = $\frac{De \times Gt}{\mu}$ = $\frac{0,12 \times 5153,97}{0,03388}$	6. Bilangan Reynold (Ret) D = 0,10 ft μ = 17,3 lb/ft.jam Ret = $\frac{D \times Gs}{\mu}$ = $\frac{0,1 \times 60352,9}{17,3}$



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

$\frac{0,03388}{= 18833,841}$	$\frac{17,3454}{= 339,248}$
9. h_{io} $h_{io} = 1500 \text{ Btu/hr ft}^2 \text{ } ^\circ\text{F}$ (Kern, Hal. 164)	7. j_H $j_H = 9,2$ (Kern Fig-28, hal. 838) 8. $(C \times \mu / k)^{1/3}$ $= \frac{0,60319 \times 17,3454}{0,0824}$ $= 5,02554$ 9. h_o $h_o = j_H \frac{k}{D} \left(\frac{c \mu}{k} \right)^{1/3} \phi_t$ $\frac{h_o}{\phi_t} = 9,2 \times \frac{0,0824}{0,0975} \times 5,02554$ $= 39,089373 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$
10. t_w $t_w = t_c + \frac{h_o/\phi_s}{h_o/\phi_t + h_o/\phi_s} (T_c - t_c)$ (Kern, Eq 5.31) $= 167 + \frac{1500}{1500 + 39,1} 131$ $= 295,063 \text{ } ^\circ\text{F}$	10. ϕ_t Pada $t_w = 295,06274 \text{ } ^\circ\text{F}$ $\mu_w = 4,5481656 \text{ lb/jam ft}$ $\phi_t = (\mu/\mu_w)^{0.14}$ $= 1,20611$ 11. h_{io} $= \frac{h_o}{\phi_t} \times \phi_t$ $= 47,1463 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$

12. Clean Overall Coefficient, U_c

$$U_c = \frac{h_{io} \times h_o}{h_{io} + h_o} \quad \text{(Kern, Eq 6.38)}$$

$$= \frac{1500 \times 47,1}{1500 + 47,1}$$



PRA RANCANGAN PABRIK
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Proses Esterifikasi dan Katalis Asam Sulfat”

$$= 45,7 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$$

13. Design Overall Coefficient, Ud

$$\begin{aligned} U_d &= \frac{Q}{A \times \Delta t \text{ LMTD)}} \\ &= \frac{873978,1}{196 \times 108} \\ &= 41,191585 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F} \end{aligned}$$

14. Dirt Factor, Rd

$$\begin{aligned} R_d &= \frac{U_c - U_d}{U_c \times U_d} \quad \text{(Kern, Eq 6.13)} \\ &= \frac{45,7 - 41,2}{45,7 \times 41,2} \\ &= 0,0024 \end{aligned}$$

Nilai Rd perhitungan > Rd

$$0,0024 > 0,002 \quad \text{(Kern, Table 12 Page 845)}$$

(Memenuhi karena Rd Perhitungan >> Rd allowabe)

Pressure Drop	
Fluida Panas : Shell Side	Fluida Dingin :Tube Side
Steam	Butanol
1. f Ret = 18833,841 f = 0,00023 (Kern, Fig 26)	1. f Res = 339,24808 f = 0,0052 (Kern, Fig 29)
2. dari tabel 7 kern, spesifik volume 6,62 ft ³ /lb $\rho = \frac{1}{6,62}$ = 0,15106 lb/ft ³ s = $\frac{0,15106}{62,5}$ = 0	2. Number of crosses, N+1 N+1 = 12 x $\frac{L}{B}$ = 12 x $\frac{10}{4,81}$ = 24,9351
	3. Pressure Drop (ΔP_s) s = 1,84



PRA RANCANGAN PABRIK
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Proses Esterifikasi dan Katalis Asam Sulfat”

$DP_t = \frac{f G s^2 L n}{5,22 \cdot 10^{10} D s f}$ $= 0,0001252 \text{ psi}$ $\Delta P_t < \Delta P \text{ allowable}$ $\Delta P_t < 10 \text{ psi, maka memenuhi}$	$\Delta P_s = \frac{f \times G t^2 \times L \times n}{5,22 \times 10^{10} \times ID \times s \times \phi t}$ (Kern, Table 6) (Kern, Eq 7.44) $= 0,0021179 \text{ psi}$ $\Delta P_s < \Delta P \text{ allowable}$ $\Delta P_s < 2 \text{ psi, maka memenuhi}$

Spesifikasi Alat

Nama Alat : Heater
Kode : E-142
Fungsi : Memanaskan Asam Oleat dari suhu 30 °C menjadi 120°C
untuk dialirkan ke Reaktor (R-210)
Tipe : *Shell and Tube Exchanger*
Dasar Pemilihan : Umum digunakan untuk memanaskan liquid
Kondisi Operasi: - Tekanan : 1 atm
- Suhu : 120 °C

Bagian Tube

OD : 1 1/2 in
ID : 1,17 in
BWG : 8
Panjang : 10 ft
Jumlah tube, Nt : 50
Passes : 2
Pitch : 1 7/8 in square pitch
Pressure drop : 0,0001252 psi

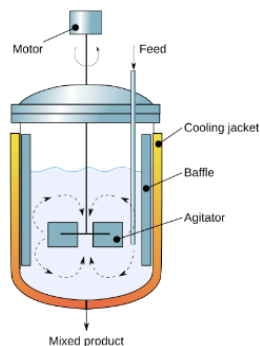
Bagian Shell

ID : 19 1/4 in
Passes : 1
Baffle Spacing : 4,81 in
Pressure drop : 0,0021179 psi



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

12. Reaktor (R-210)



Fungsi = Untuk mereaksikan asam oleat dan butanol dengan katalis asam sulfat

Tipe = Tangki berbentuk silinder tegak, tutup atas dan bawah berupa
Torispherical dish

Kondisi operasi :

Tekanan = 1 atm
suhu = 120 °C
waktu tinggal = 120 menit
= 2 jam

Komposisi bahan masuk

komponen	BM (kg/kmol)	massa (kg/jam)	fraksi massa
$C_{17}H_{33}COOH$	282	3862,594	0,42566
C_4H_9OH	74	5067,943	0,55849
$C_{17}H_{33}COOC_4H_9$	338	0,833	0,00009
$C_{15}H_{31}COOH$	256	54,014	0,00595
H_2O	98	6,382	0,00070
H_2SO_4	18	82,550	0,00910
Total		9074,317	1

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,24798	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

H ₂ O	0,3471	0,274	647,13	0,2857
H ₂ SO ₄	0,42169	0,1936	925	0,2857

$$T = 120 \text{ }^{\circ}\text{C} = 393,15 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned} \rho \text{ C}_{17}\text{H}_{33}\text{COOH} &= 0,8272009 \text{ gr/ml} \\ \rho \text{ C}_4\text{H}_9\text{OH} &= 0,7197156 \text{ gr/ml} \\ \rho \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,7917196 \text{ gr/ml} \\ \rho \text{ C}_{15}\text{H}_{31}\text{COOH} &= 0,8147097 \text{ gr/ml} \\ \rho \text{ H}_2\text{O} &= 0,935109 \text{ gr/ml} \\ \rho \text{ H}_2\text{SO}_4 &= 1,7131628 \text{ gr/ml} \end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
C ₁₇ H ₃₃ COOH	3862,5944	0,4256623	0,8272009	0,3521082
C ₄ H ₉ OH	5067,9430	0,5584931	0,7197156	0,4019562
C ₁₇ H ₃₃ COOC ₄ H ₉	0,8335	9,185E-05	0,7917196	7,272E-05
C ₁₅ H ₃₁ COOH	54,0140	0,0059524	0,8147097	0,0048495
H ₂ O	6,3820	0,0007033	0,935109	0,0006577
H ₂ SO ₄	82,5500	0,0090971	1,7131628	0,0155848
Total	9074,3168	1		0,7752291

$$\begin{aligned} \rho \text{ Campuran} &= 0,7752291 \text{ gr/ml} \times 62,4 \\ &= 48,374296 \text{ lb/cuft} \end{aligned}$$

$$\begin{aligned} \text{Sg} &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{48,374296 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,7748566 \end{aligned}$$

$$\begin{aligned} \text{Rate Massa} &= 9074,3168 \text{ kg/jam} \\ &= 20005,444 \text{ lb/jam} \end{aligned}$$



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$$\begin{aligned}
 \text{Rate volumetrik} &= \frac{\text{Rate massa}}{\rho \text{ campuran}} \\
 &= \frac{20005,444 \text{ lb/jam}}{48,374296 \text{ lb/cuft}} \\
 &= 413,55525 \text{ cuft/jam} \\
 &= 9925,326 \text{ cuft/hari}
 \end{aligned}$$

a. Menentukan Dimensi Reaktor

Dirancang waktu tinggal = 2 jam , maka

$$\begin{aligned}
 \text{Volume reaktor} &= 413,555 \text{ cuft/jam} \times 2 \text{ jam} \\
 &= 827,11 \text{ cuft}
 \end{aligned}$$

Asumsi volume liquid mengisi 80% volume tangki untuk faktor keamanan, sehingga :

V design > 20%

$$\begin{aligned}
 V_d \text{ reaktor} &= \frac{\text{volume reaktor}}{80\%} \\
 &= \frac{827,1104976}{80\%} \\
 &= 1033,8881 \text{ cuft}
 \end{aligned}$$

b. Menentukan Dimensi Shell Tangki

Asumsi rasio dimensi H/L = 2 (Ulrich, 1987)

$$\begin{aligned}
 \text{Volume silinder} &= \frac{1}{4} \times \pi \times D_i^2 \times H \\
 &= \frac{1}{4} \times 3,14 \times D_i^2 \times 2D \\
 &= 1,57 D_i^3
 \end{aligned}$$

Volume tutup atas dan bawah Torispherical dish head

$$\begin{aligned}
 \text{Volume tutup atas} &= 0,000049 D^3 \text{ (Brownell Eq. 5.11)} \\
 \text{volume tutup bawah} &= 0,000049 D^3
 \end{aligned}$$

$$\begin{aligned}
 \text{Volume tangki} &= V \text{ silinder} + V \text{ tutup atas} + V \text{ tutup bawah} \\
 1033,8881 &= 1,57 D_i^3 + 4,9E-05 D^3 + 4,9E-05 D^3 \\
 1033,8881 &= 1,57 D_i^3
 \end{aligned}$$



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$$\begin{aligned}
 1033,8881 &= 1,57005 D^3 \\
 D^3 &= 658,507 \\
 D &= 8,70002 \text{ ft} \\
 &= 2,65177 \text{ m} \\
 &= 104,4 \text{ in} \\
 \\
 H &= 2 \times D \\
 &= 2 \times 8,7 \text{ ft} \\
 &= 17,4 \text{ ft} \\
 &= 5,30353 \text{ m} \\
 &= 208,801 \text{ in}
 \end{aligned}$$

c. Menentukan tinggi cairan dalam tangki penyimpanan

$$\begin{aligned}
 \text{Volume liquid} &= \frac{1}{4} \times \pi \times D^2 \times H + 0,000049 D^3 \\
 827,1105 &= 59,4169 H + 0,03 \\
 827,07823 &= 59,4169 H \\
 H &= 13,9199 \text{ ft} \\
 &= 4,24279 \text{ m} \\
 &= 167,039 \text{ in}
 \end{aligned}$$

d. Menentukan Tekanan design

Jika dalam bejana terdapat liquid, maka bejana dirancang berdasarkan tekanan dalam :

$$\begin{aligned}
 P_{\text{design}} &= P_{\text{gauge}} + P_{\text{hidrostatik}} \\
 P_{\text{design}} &= (P_i - P_o) + P_{\text{hidrostatik}} \\
 P_{\text{design}} &= (14,7 - 14,7) + P_{\text{hidrostatik}} \\
 P_{\text{design}} &= P_{\text{hidrostatik}} \\
 P_{\text{design}} &= \rho \times \frac{g}{g_c} \times H_{\text{liq}} \\
 &= 48,3743 \frac{\text{lb}}{\text{cuft}} \times 1 \frac{\text{lbf}}{\text{lbf}} \times 13,9 \text{ ft} \\
 &= 673,366 \frac{\text{lbf}}{\text{ft}^2} \\
 &= 4,67615 \text{ psi}
 \end{aligned}$$

Asumsi P_{design} 10% lebih besar untuk faktor keamanan



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$$P_{\text{design}} = 1,1 \times 4,68 \text{ Psi}$$

$$= 5,14377 \text{ Psi}$$

Bejana didesain dengan tekanan dalam, P desain 5,14377 Psi

e. Menentukan tebal shell minimum

Tebal shell berdasarkan ASME code untuk cylindrical tank:

$$t_s = \frac{P_d \times r_i + C}{f_e - 0,6 P_d} \quad \text{(Brownell Eq. 13.1 hal.254)}$$

dengan

$t_{\min}$ = tebal shell minimum (in)

P = tekanan tangki (Psi) = 5,14 Psi

r_i = jari-jari tangki (in) = 52,2 in

C = Faktor korosi (in); digunakan = 1/8 in

e = Faktor pengelasan; digunakan double welded = 0,8
 (Brownell, Table 13.2)

f = stress allowable bahan konstruksi Logam Paduan SB-575
 = 98500 Psi (ASMEBPVC.II.D.C-2017)

sehingga,

Asumsi tebal shell = 3/16 in

$$t_s = \frac{P \times r_i + C}{f_e - 0,6 P}$$

$$3/16 = \frac{5,14377 \times 52,2001 + 1/8}{0,8 f - 3,08626}$$

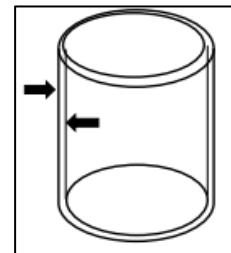
$$1/16 = \frac{5,14377 \times 52,2001}{0,8 f - 0,075}$$

$$0,05 f - 0,00469 = 268,50534$$

$$0,05 f = 268,51002$$

$$f = 5370,2005$$

f hitung lebih kecil dari f allowable, jadi tebal shell 3/16 in dapat digunakan



f. Menentukan Tebal Tutup atas dan bawah

Tutup atas dan bawah dipilih torispherical

$$OD = ID + 2 t_s$$

$$= 104,40021 \text{ in} + 2 \times 3/16$$

$$= 104,77521 \text{ in}$$



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Berdasarkan Brownell and Young, Tabel 5.7 dari data OD, diperoleh:

$$OD = 108$$

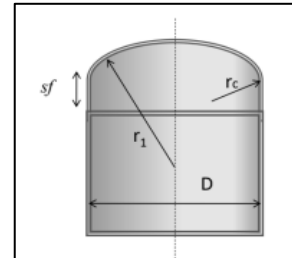
$$icr = 6 \frac{2}{4} \text{ in}$$

$$r = 102 \text{ in}$$

Cek nilai icr dengan nilai 6%rc

$$icr = 6,5 \text{ in}$$

$$6\% r = 6,12 \text{ in}$$



karena icr lebih besar dari 6% r maka digunakan persamaan 13.12
Brownell & Young hal. 258

$$t_h = \frac{P \times r_c \times W}{2 f e - 0.2 P} + C \quad W = \frac{1}{4} \left(3 + \sqrt{\frac{rc}{icr}} \right)$$

dengan

t_h = tebal tutup (head) shell minimum (in)

W = faktor stress intensif untuk torispherical

P = Tekanan design (Psi) = 5,14377

r_c = radius of curfative sama dengan diameter (in) = 102

E = Faktor pengelasan = 0,8

f = allowable stress, bahan konstruksi SB 575

= 98500 Psi (ASMEBPVC.II.D.C-2017)

C = Faktor korosi (in) = 0,125

$$\begin{aligned} W &= \frac{1}{4} \left(3 + \sqrt{\frac{rc}{icr}} \right) \\ &= \frac{1}{4} \left(3 + \sqrt{\frac{102}{6,5}} \right) \\ &= 1,74034 \end{aligned}$$

Asumsi tebal tutup $\frac{3}{16}$ in

$$t_h = \frac{P \times r_c \times W}{2 f e - 0.2 P} + C$$

$$\frac{3}{16} \text{ in} = \frac{5,1438 \times 102 \times 1,74034}{(f \times 1,6) - (0,2 \times 5,1438 \text{ psi})} + \frac{1}{8} \text{ in}$$

$$\frac{1}{16} \text{ in} = \frac{913,0936}{1,6 f - 1,02875}$$

$$0,1 f - 0,0643 = 913,0936$$



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$$f = 9131,5793 \text{ psi}$$

f hitung lebih kecil dari f allowable, jadi tebal shell $\frac{3}{16}$ in dapat digunakan

g. Menentukan Tinggi Tutup Tangki

$$sf = 2 \text{ in}$$

$$t = \frac{2}{8} \text{ in}$$

(Brownell, tabel 5.6, hal. 88)

Menghitung tinggi tutup

$$OA = b + sf + t$$

$$* 1 \text{ ft} = 0,3 \text{ m}$$

$$1 \text{ ft} = 12 \text{ in}$$

$$BC = rc - icr$$

$$\begin{aligned} BC &= 102 - 6,5 \\ &= 95,500 \text{ in} \end{aligned}$$

$$AB = \frac{1}{2} \times OD - icr$$

$$\begin{aligned} AB &= \frac{1}{2} \times 108 - 6,5 \\ &= 47,500 \text{ in} \end{aligned}$$

$$b = rc - (BC^2 - AB^2)^{0,5}$$

$$\begin{aligned} b &= 102 - (9120 - 2256)^{0,5} \\ &= 19,151 \end{aligned}$$

Tinggi tutup atas

$$\begin{aligned} OA &= b + sf + t \\ &= 21,338 \text{ in} \\ &= 0,5420 \text{ m} \\ &= 1,7782 \text{ ft} \end{aligned}$$

Total Tinggi Tangki

$$\begin{aligned} H_{\text{total}} &= (2 \times H_{\text{head}}) + H_{\text{silinder}} \\ &= (2 \times 1,78) + 17,400 \\ &= 20,9564 \text{ ft} \\ &= 6,3875 \text{ m} \end{aligned}$$



h. Perencanaan Sistem Pengaduk

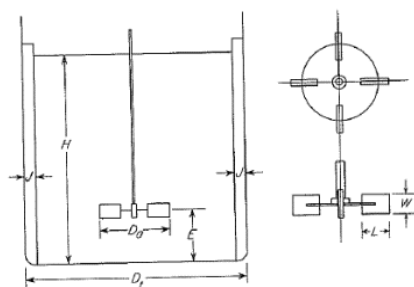
Dipakai impeller/pengaduk jenis turbin dengan 6 buah flat blade dengan 4 baffle

1. Penentuan Dimensi Pengaduk

$$\begin{aligned}\text{Tinggi liquid} \quad HL &= 13,9199 \text{ ft} \\ &= 152,097 \text{ in}\end{aligned}$$

$$\begin{aligned}\text{Diameter dalam} \quad Dt &= 8,70002 \text{ ft} \\ &= 217,205 \text{ in}\end{aligned}$$

Ukuran pengaduk diambil dari **Mc. Cabe ed 7th, hal 247**



Dimana

Dt = Diameter tangki

Da = Diameter impeller (pengaduk)

E = Jarak impeller dari dasar tangki

L = Panjang blade

W = Lebar blade pengaduk

J = Lebar baffle

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

$$\frac{E}{Dt} = \frac{1}{3} \qquad \frac{L}{Da} = \frac{1}{4}$$

$$\frac{W}{Da} = \frac{1}{5} \qquad \frac{J}{Dt} = \frac{1}{12}$$

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



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$$\begin{aligned}
 &= \frac{1}{3} \times 8,7 \text{ ft} \\
 &= 2,9 \text{ ft} \\
 W &= \frac{1}{5} \times Da \\
 &= \frac{1}{5} \times 2,9 \text{ ft} \\
 &= 0,58 \text{ ft} \\
 L &= \frac{1}{4} \times Da \\
 &= \frac{1}{4} \times 2,9 \text{ ft} \\
 &= 0,73 \text{ ft} \\
 E &= \frac{1}{3} \times Dt \\
 &= \frac{1}{3} \times 8,7 \text{ ft} \\
 &= 2,9 \text{ ft} \\
 J &= \frac{1}{12} \times Dt \\
 &= \frac{1}{12} \times 8,7 \text{ ft} \\
 &= 0,73 \text{ ft}
 \end{aligned}$$

$$\begin{aligned}
 \text{Tebal pengaduk} &= \frac{1}{10} \times 0,73 \\
 &= 0,07 \text{ ft}
 \end{aligned}$$

2. Penentuan Jumlah Pengaduk

$$\begin{aligned}
 \text{Jumlah impeller} &= \frac{H_{liq} \times sg}{Dt} && \text{(Joshi, Hal. 415)} \\
 \rho_{reference} &= 62,43 \text{ lb/cuft} \\
 \rho_{bahan} &= 48,374296 \text{ lb/cuft} \\
 sg &= \frac{\rho_{bahan}}{\rho_{reference}} \times sg_{reference} \\
 &= \frac{48,374296}{62,43} \times 1 \\
 &= 0,7748566
 \end{aligned}$$



maka,

$$\begin{aligned}\text{Jumlah impeller} &= \frac{13,9 \times 0,77486}{8,7} \\ &= 1,24 \\ &= 1 \text{ buah}\end{aligned}$$

Jadi, jumlah impeller yang digunakan 1 buah

$$\begin{aligned}\text{Jarak impeller (E)} &= 2 \times Da \\ &= 2 \times 2,90001 \\ &= 4,3500086 \text{ ft} \\ &= 1,3258826 \text{ m}\end{aligned}$$

3. Penentuan Putaran Pengaduk

$$V = \pi \times Da \times N \quad (\text{Joshi; hal.415})$$

Dimana,

V = peripheral speed (m/menit)

Untuk pengaduk jenis turbin

Peripheral speed = 200-350 m/menit (Joshi hal.389)

Da = Diameter pengaduk (m)

N = Putaran pengaduk (rpm)

Diambil putaran pengaduk

$$N = 120 \text{ rpm}$$

$$Da = 2,90001 \text{ ft}$$

$$= 0,88392 \text{ m}$$

$$\begin{aligned}V &= \pi \times Da \times N \\ &= 3,14 \times 0,88 \times 120 \\ &= 333 \text{ m/menit (memenuhi)}\end{aligned}$$

4. Penentuan Bilangan Reynold

$$N = 120 \text{ rpm}$$

$$= 2 \text{ rps}$$

$$\rho \text{ campuran} = 48,4 \text{ lb/cuft}$$

$$\text{Dari Kern T.6 hal. 808 didapat sg reference} = 1$$

$$\text{Dari Kern Fig.14 hal. 823 didapat } \mu \text{ reference} = 1 \text{ Cp}$$



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Menghitung Viskositas Larutan

Komponen	A	B	C	D
$C_{17}H_{33}COOH$	-6,13	1690	0,008	-6E-06
C_4H_9OH	-5,397	1325,6	0,006	-6E-06
$C_{17}H_{33}COOC_4H_9$	-15,2751	2934,5	0,02692	1,8E-05
$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05
H_2SO_4	-18,705	3496,2	0,033	-1E-05
H_2O	-10,252	1792,5	0,018	-1E-05

$$T = 393,15 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\begin{aligned} \mu_{C_{17}H_{33}COOH} &= 2,074231 \text{ cP} \\ \mu_{C_4H_9OH} &= 0,3033733 \text{ cP} \\ \mu_{C_{17}H_{33}COOC_4H_9} &= 3,6896539 \text{ cP} \\ \mu_{C_{15}H_{31}COOH} &= 1,7152582 \text{ cP} \\ \mu_{H_2SO_4} &= 1,639441 \text{ cP} \\ \mu_{H_2O} &= 0,2733287 \text{ cP} \end{aligned}$$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
$C_{17}H_{33}COOH$	3862,5944	0,4256623	2,074231	0,8829219
C_4H_9OH	5067,943	0,5584931	0,3033733	0,1694319
$C_{17}H_{33}COOC_4H_9$	0,8334592	9,185E-05	3,6896539	0,0003389
$C_{15}H_{31}COOH$	54,014008	0,0059524	1,7152582	0,0102099
H_2SO_4	6,3820291	0,0007033	1,639441	0,001153
H_2O	82,550019	0,0090971	0,2733287	0,0024865
Total	9074,3168	1		1,0665421

$$\begin{aligned} \mu_{\text{Campuran}} &= 1,0665421 \text{ cP} \\ &= 0,0007167 \text{ lb/ft s} \\ &= 2,5801786 \text{ lb/ft hr} \end{aligned}$$



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$$\begin{aligned} N_{re} &= \frac{\rho \times D_a \times N}{\mu} \\ &= \frac{48,4 \times 8,41 \times 2}{0,00072} \\ &= 1135259,397 \quad (\text{aliran turbulen}) \end{aligned}$$

Karena $N_{re} > 10000$, maka digunakan baffle. **(Perry ed.6 : hh.19-18)**
 Untuk $N_{re} > 10000$ diperlukan 4 buah baffle, sudut 90o

5. Penentuan Power Pengaduk

Untuk $N_{re} > 10000$ perhitungan power pengaduk dengan persamaan:

$$P = \frac{K_3 \times N^3 \times D_a^5 \times \rho}{g} \quad (\text{Ludwig, Vol.1 Pers.5.5 Hal. 299})$$

Dengan,

$$\begin{aligned} P &= \text{power pengaduk (hp)} \\ K_3 &= \text{Faktor mixer} = 6,30 \quad (\text{Ludwig, vol-1 T.5-1, hal 301}) \\ g &= \text{konstanta gravitasi} = 32,3 \text{ ft/dt}^2 \times \text{lbm/lbf} \\ \rho &= \text{Densitas campuran (lb/cuft)} = 48,3743 \text{ lb/cuft} \\ N &= \text{Kecepatan putaran impeller (rps)} = 2 \text{ rps} \\ D_a &= \text{Diameter impeller (ft)} = 2,90001 \text{ ft} \end{aligned}$$

Maka

$$\begin{aligned} P &= \frac{6,30 \times 8 \times 205,114 \times 48,4}{32,3} \\ &= 15482,4 \text{ lb.ft/dt} \\ &= 28,1497 \text{ Hp} \end{aligned}$$

6. Perhitungan Loss Pengaduk

$$\begin{aligned} \text{Gland losses (kebocoran tenaga akibat poros dan bearing)} &= 10\% \\ &\quad (\text{Joshi Hal.399}) \end{aligned}$$

$$\begin{aligned} \text{Gland losses} &= 10\% \times P \\ &= 10\% \times 28,1 \text{ Hp} \\ &= 2,81 \text{ Hp} \end{aligned}$$

$$\begin{aligned} \text{Power input dengan gland losses} &= \text{Gland losses} + P \\ &= 2,81 + 28,1497 \\ &= 30,964704 \text{ Hp} \end{aligned}$$

$$\text{Transmission losses} = 20\% \quad (\text{Joshi Hal. 424})$$



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$$\begin{aligned}\text{Transmission losses} &= 20\% \times \text{power input dengan gland losses} \\ &= 20\% \times 30,9647 \\ &= 6,1929407 \text{ Hp}\end{aligned}$$

$$\begin{aligned}\text{Power input dengan transmisson} &= 30,9647 + 6,19294 \\ &= 37,157644 \text{ Hp}\end{aligned}$$

$$\text{Efisiensi motor} = 85\% \quad (\text{Peters 5th Ed, Fig. 12-18})$$

Sehingga

$$\begin{aligned}\text{Power motor} &= \frac{\text{Power input dengan transmission losses}}{\text{Efisiensi motor}} \\ &= \frac{37,1576}{85\%} \\ &= 43,7149 \text{ Hp}\end{aligned}$$

Perencanaan Sistem Pendingin

Perhitungan Jaket Pendingin:

Perhitungan sistem penjaga suhu :

Dari neraca panas :

$$\text{Reaktor dijaga pada suhu} = 120 \text{ }^{\circ}\text{C} = 393 \text{ K} = 266 \text{ }^{\circ}\text{F}$$

$$\text{Tekanan Operasi} = 1 \text{ atm} = 14,7 \text{ Psia}$$

$$\text{Suhu Bahan Masuk (T}_1\text{)} = 120 \text{ }^{\circ}\text{C} = 248 \text{ }^{\circ}\text{F}$$

$$\text{Suhu Bahan Keluar (T}_2\text{)} = 120 \text{ }^{\circ}\text{C} = 248 \text{ }^{\circ}\text{F}$$

$$\text{Suhu Air Masuk (t}_1\text{)} = 30 \text{ }^{\circ}\text{C} = 86 \text{ }^{\circ}\text{F}$$

$$\text{Suhu Air Keluar (t}_2\text{)} = 45 \text{ }^{\circ}\text{C} = 113 \text{ }^{\circ}\text{F}$$

$$Q = 12.870,0689 \text{ kkal/jam}$$

$$= 3.245,3706 \text{ Btu/jam}$$

$$\text{Re}_i = \frac{[L^2 N \rho]^{2/3}}{\mu}$$

Dengan:

$$L = \text{diameter pengaduk} = 2,90 \text{ ft}$$

$$N = \text{putaran pengaduk,} = 2,0000 \text{ rps}$$

$$\rho = \text{densitas,} = 48,374 \text{ lb/cuft}$$

$$\mu = \text{viskositas} = 0,0007 \text{ lb/ft s} \quad 2,58018 \text{ lb/ft hr}$$



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$$Re_i = \frac{(2,90)^2 \times 2,0000 \times 48,3743}{0,0007}^{.2/3}$$

$$= 10882,535$$

$$K_{mix} = \frac{0,0677}{sg [1 - 0,0003 (t - 32)]}$$

$$= \frac{0,0677}{0,775 [1 - 0,0003 (212 - 32)]}$$

$$= 0,0924 \text{ Btu/jam.ft.}^{\circ}\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243}$$

Menghitung nilai kapasitas panas

Komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	278,686	2,5434	-0,0054	4,9E-06
C ₄ H ₉ OH	83,877	0,56628	-0,0017	2,3E-06
C ₁₇ H ₃₃ COOC ₄ H ₉	178,423	3,667	-0,00797	7,1E-06
C ₁₅ H ₃₁ COOH	86,29	3,5237	-0,0073	6,1E-06
H ₂ SO ₄	26,004	0,70337	-0,0014	1E-06
H ₂ O	92,053	-0,04	-0,0002	5,3E-07

$$T = 393,15 \text{ K}$$

$$C_p = A + BT + CT^2 + DT^3$$

Sehingga diperoleh

$$\begin{aligned} C_p \text{ C}_{17}\text{H}_{33}\text{COOH} &= 737,697 \text{ Kkal/KmolK} \\ C_p \text{ C}_4\text{H}_9\text{OH} &= 183,513 \text{ Kkal/KmolK} \\ C_p \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 819,143 \text{ Kkal/KmolK} \\ C_p \text{ C}_{15}\text{H}_{31}\text{COOH} &= 710,887 \text{ Kkal/KmolK} \\ C_p \text{ H}_2\text{SO}_4 &= 146,908 \text{ Kkal/KmolK} \\ C_p \text{ H}_2\text{O} &= 77,6206 \text{ Kkal/KmolK} \end{aligned}$$

komponen	BM	Cp	Fraksi	Cp
	Kg/Kmol	kkal/Kmol K	Xf	kkal/Kg K
C ₁₇ H ₃₃ COOH	282,47	737,69676	0,04249	2,61159
C ₄ H ₉ OH	74	183,51258	0,45794	2,4799
C ₁₇ H ₃₃ COOC ₄ H ₉	310,56	819,14341	0,45926	2,63763



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C ₁₅ H ₃₁ COOH	256,42	710,88749	0,00595	2,77236
H ₂ SO ₄	98	146,90821	0,02525	1,49906
H ₂ O	18	77,620648	0,0091	4,31226
Total			1	

$$1 \text{ kkal/kg K} = 0,23885 \text{ Btu/lb } ^\circ\text{F}$$

$$C = \sum_i^n C_p \cdot X_f$$

$$C = 0,6094441 \text{ Btu/lb } ^\circ\text{F}$$

$$\frac{[C \mu]^{1/3}}{k} = \frac{(0,6094 \times 2,5802)^{1/3}}{0,092358}$$

$$= 12,5908$$

$$\frac{[\mu]^{0,14}}{\mu_w} = \frac{[2,5802]^{0,14}}{1}$$

$$= 1,1419$$

$$h_c = 0,87 \times \left(\frac{L^2 N \rho}{\mu} \right)^{2/3} \times \left(\frac{C \mu}{k} \right)^{1/3} \times \left(\frac{\mu}{\mu_w} \right)^{0,14}$$

(Kern. Pers 20.4 hh.722)

$$h_c = 0,87 \times \frac{0,09236}{8,70} \times 10882,5349 \times 12,59 \times 1,1419$$

$$= 1445,0673 \text{ Btu/jam.ft. } ^\circ\text{F}$$

Koefisien perpindahan panas bagian dalam jaket (hi) :

Dari Kern tabel 10 hal.843, dipakai pipa 16 BWG dengan ukuran :

$$\begin{aligned} \text{OD} &= 0,75 \text{ in} = 0,063 \text{ ft} \\ \text{ID} &= 0,87 \text{ in} = 0,07 \text{ ft} \\ \text{Flow area (A)} &= 0,59 \text{ in}^2 = 0,0041 \text{ m}^2 \\ \text{Surface per lin ft (a)} &= 0,26 \text{ ft}^2 \end{aligned}$$

$$v = \frac{W}{\rho \times A} = \frac{858,0046}{1 \times 0,0041}$$

$$= 208001,25 \text{ m/jam}$$



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$$\begin{aligned} &= 58 \quad \text{m/s} \\ &= 190 \quad \text{fps} \end{aligned}$$

Dari **Kern hal 717** didapat harga $h_i = 100 \text{ Btu/jam.ft}^2.\text{°F}$
(Kern. Fig 25 halaman 835)

$$\begin{aligned} h_{io} &= h_i \times \frac{ID}{OD} \\ &= 100 \times \frac{0,870}{0,750} \\ &= 116,00 \text{ Btu/jam.ft}^2.\text{°F} \end{aligned}$$

$$\begin{aligned} U_c &= \frac{h_i \times h_{io}}{h_i + h_{io}} \\ &= \frac{100 \times 116,0}{100 + 116,0} \\ &= 53,704 \text{ Btu/jam.ft}^2.\text{°F} \end{aligned}$$

$$R_d = 0,001 \quad \text{(Kern, Tabel 12, hal 845)}$$

$$\begin{aligned} \frac{1}{U_D} &= \frac{1}{U_c} + R_d \\ &= \frac{1}{53,7} + 0,001 \\ U_D &= 50,967 \text{ Btu/jam.ft}^2.\text{°F} \end{aligned}$$

Penentuan ΔT LMTD

$$\begin{aligned} \Delta T \text{ LMTD} &= \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}} \\ \Delta T \text{ LMTD} &= \frac{135 - 162}{\ln \frac{135}{162}} \\ &= 148,1 \text{ °F} \end{aligned}$$

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



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$$= \frac{3.245,3706}{50,967 \times 148}$$

$$= 0,43 \text{ ft}^2$$

Menentukan Tinggi Jaket

$$\begin{aligned} \text{Tinggi jaket} &= \text{Tinggi shell} + \text{Tinggi tutup bawah} \\ &= 17,4 + 1,7782 \\ &= 19,1782 \text{ ft} \\ &= 5,84552 \text{ m} \end{aligned}$$

Asumsi :

$$\text{Jaket spacing (s)} = 2 \text{ in}$$

$$\text{Tebal jaket (tj)} = 1/4 \text{ in}$$

$$\text{Eff. Sambungan las (E)} = 0,8$$

$$\text{Faktor korosi (c)} = 1/8$$

Dipergunakan bahan konstruksi berupa SB-575 dengan

$$f \text{ allowable} = 98300 \text{ psi (ASMEBPVC.II.D.C-2017)}$$

$$\begin{aligned} D_{o,s} (\text{shell}) &= D_i + 2t_s \\ &= 104,40021 + 2 \times 0 \\ &= 104,40021 \text{ in} \end{aligned}$$

$$\begin{aligned} D_{i,j} (\text{jaket}) &= D_{o,s} + 2s \\ &= 104,40021 + 2 \times 2 \\ &= 108,40021 \text{ in} \end{aligned}$$

$$\begin{aligned} D_o (\text{jaket}) &= D_{i,j} + 2t_j \\ &= 108,40021 + 2 \times 1/4 \\ &= 108,90021 \text{ in} \end{aligned}$$

$$\begin{aligned} \text{Jaket spacing} &= \frac{D_i - D_{o,s}}{2} \\ &= \frac{108,40021 - 104,40021}{2} \\ &= 2 \end{aligned}$$

$$\begin{aligned} P \text{ desain jacket} &= P_o - P_i + P_h \\ &= 14,7 - 14,7 + \rho \times \frac{g}{g_c} \times H \text{ bahan} \\ &= 48,3743 \text{ lb} \times \frac{1}{\text{cuft}} \times \frac{\text{lbf}}{\text{lbm}} \times 13,919919 \text{ ft} \\ &= 673,366 \text{ lbf/ft}^2 \end{aligned}$$



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$$= 4,67615 \text{ psi}$$

Menentukan Tebal Minimum Shell

$$t_{\min} = \frac{P \times r_i}{f E - 0,6 P} + C$$

dimana

$t_{\min}$ = Tebal shell minimal (in)

P = Tekanan jaket(psi) = 4,67615

Di = jari-jari jaket (in) = 54,2001

e = faktor pengelasan, digunakan double welded, e = 0,8

f = Stress allowable bahan konstruksi SB-575

= 98300 psi (**ASMEBPVC.II.D.C-2017**)

C = Faktor korosi = 1/8

Asumsi tebal shell = 3/16 in

$$t_{\min} = \frac{P \times r_i}{f E - 0,6 P} + C$$

$$3/16 = \frac{4,6762 \times 54,2001}{f \cdot 0,8 - 2,8057} + 1/8 \text{ in}$$

$$1/16 = \frac{253,4481}{f \cdot 0,8 - 2,8057}$$

$$f = 5072,468492$$

karena f allowable > f hitung maka tebal jaket 3/16 in memenuhi

Spesifikasi

Nama Alat : Reaktor

Kode : R-210

Fungsi : Untuk mereaksikan asam oleat dan butanol dengan katalis asam sulfat

Tipe : Reaktor Alir Tangki Berpengaduk (RATB)/ Continuous Stirred Tank Reactor (CSTR) dilengkapi pengaduk dan jaket pendingin

Rate Volumetrik : 413,555 ft³/jam

Kondisi Operasi

Tekanan : 1 atm

Suhu : 120 °C

Waktu tinggal : 120 menit

Jumlah tangki : 1 buah



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Dimensi Reaktor

Diameter : 8,70 ft = 2,65177 m
Tinggi total reaktor : 17,40 ft = 5,30352 m
Tebal shell : 3/16 in
Tinggi shell : 17,4 ft = 5,30353 m
Tebal tutup atas : 3/16 in
Tinggi tutup atas : 1,7782 ft = 0,54199 m
Tebal tutup bawah : 3/16 in
Tinggi tutup bawah : 1,77819 ft = 0,54199 m
Bahan Konstruksi : SB-575

Dimensi Pengaduk

Tipe : Dipilih pengaduk type flat blade turbine dengan jumlah blade 6
Diameter impeller : 2,9 ft
Jarak impeller ke dasa : 4,35 ft
Lebar baffle : 0,73 ft
Jumlah impeller : 1 buah
Power : 43,7 hp

Dimensi Jaket Pendingin

Diameter dalam jaket : 108,40 in = 2,75337 m
Tinggi jaket : 19,1782 ft = 5,84552 m
Jaket spacing : 2 in
Tebal jaket : 3/16 in

13. Pompa (L-211)



Fungsi = Untuk memindahkan produk dari Reaktor (R-210) menuju *Netralizer* (N-220)
Tipe = *Centrifugal pump*
Dasar Pemilihan = Umum digunakan untuk memompa liquid dengan viskositas rendah



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Komposisi Bahan Masuk

Komponen	Massa	Fraksi Massa
	(kg)	
C ₁₇ H ₃₃ COOH	385,5641687	0,0424896
C ₄ H ₉ OH	4155,530773	0,4579442
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,504268	0,4592637
C ₁₅ H ₃₁ COOH	54,00860687	0,0059518
H ₂ O	229,159	0,0252536
H ₂ SO ₄	82,5500185	0,0090971
Total	9074,316835	1

$$\begin{aligned}\text{Rate massa bahan} &= 9074,3168 \text{ kg/jam} \\ &= 20005,33 \text{ lb/jam}\end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
C ₁₇ H ₃₃ COOH	0,2824	0,26812	781	0,2897
C ₄ H ₉ OH	0,26891	0,2667	562,93	0,2457
C ₁₇ H ₃₃ COOC ₄ H ₉	0,24798	0,24	764	0,2857
C ₁₅ H ₃₁ COOH	0,2797	0,26805	776	0,2947
H ₂ O	0,3471	0,274	647,13	0,2857
H ₂ SO ₄	0,42169	0,1936	925	0,2857

$$T = 120 \text{ }^{\circ}\text{C} = 393,15 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned}\rho \text{ C}_{17}\text{H}_{33}\text{COOH} &= 0,8272009 \text{ gr/ml} \\ \rho \text{ C}_4\text{H}_9\text{OH} &= 0,7197156 \text{ gr/ml} \\ \rho \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,7917196 \text{ gr/ml} \\ \rho \text{ C}_{15}\text{H}_{31}\text{COOH} &= 0,8147097 \text{ gr/ml} \\ \rho \text{ H}_2\text{O} &= 0,935109 \text{ gr/ml} \\ \rho \text{ H}_2\text{SO}_4 &= 1,7131628 \text{ gr/ml}\end{aligned}$$



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Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$C_{17}H_{33}COOH$	385,5641687	0,0424896	0,8272009	0,0351474
C_4H_9OH	4155,530773	0,4579442	0,7197156	0,3295896
$C_{17}H_{33}COOC_4H_9$	4167,504268	0,4592637	0,7917196	0,3636081
$C_{15}H_{31}COOH$	54,00860687	0,0059518	0,8147097	0,004849
H_2O	229,159	0,0252536	0,935109	0,0236149
H_2SO_4	82,5500185	0,0090971	1,7131628	0,0155848
Total	9074,316835	1		0,7723938

$$\begin{aligned}\rho \text{ Campuran} &= 0,7723938 \text{ gr/ml} \times 62,4 \\ &= 48,197373 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Rate volumetrik} &= \frac{\text{rate massa bahan}}{\rho \text{ bahan}} \\ &= \frac{20005,33 \text{ lb/jam}}{48,197373 \text{ lb/cuft}} \\ &= 415,07096 \text{ cuft/jam} \\ &= 0,1152975 \text{ cuft/detik} \\ &= 51,74911 \text{ gpm}\end{aligned}$$

a. Menentukan diameter optimal pipa

asumsi aliran turbulen ($N_{re} > 2100$), maka digunakan persamaan

$$D_{i \text{ opt}} = 3,9 \times qf^{0,45} \times \rho^{0,13} \quad (\text{Peters, 4}^{\text{ed}}, \text{ pers. 15 hal 496})$$

Keterangan :

$D_{i \text{ opt}}$ = Diameter pipa bagian dalam optimal (in)

qf = Rate volumetrik (ft^3/s)

ρ = Densitas larutan (lb/ft^3)

Sehingga,

$$\begin{aligned}D_{i \text{ opt}} &= 3,9 \times qf^{0,45} \times \rho^{0,13} \\ &= 3,9 \times 0,38 \times 1,65 \\ &= 2,44 \text{ in} \quad (\text{Peters, 4}^{\text{ed}}, \text{ pers 15 hal 496})\end{aligned}$$



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Dari Kern Table. 11, maka dipilih pipa dengan spesifikasi :

Pipe size = 2 1/2 in

Sch = 40

OD = 2,88 in = 0,24 ft = 0,07 m

ID = 2,47 in = 0,21 ft = 0,06 m

$$\begin{aligned} A &= \frac{1}{4} \times \pi \times ID^2 \\ &= \frac{1}{4} \times 3,14 \times 0,04223 \\ &= 0,03315 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Kecepatan Aliran (V)} &= \frac{\text{Rate volumetrik}}{\text{Luas Area (A)}} \\ &= \frac{0,1153}{0,03315} \\ &= 3,47794 \text{ ft/s} \end{aligned}$$

b. Menghitung Nre

sg reff = 1 (Kern, Table. 6 p. 808)

μ reff = 0,8 cP (Kern, Fig. 14 p. 823)

ρ reff = 62,4 lb/ft³

$$\begin{aligned} \text{sg bahan} &= \frac{\rho \text{ bahan}}{\rho \text{ reff}} \\ &= \frac{48,1974 \text{ lb/ft}^3}{62,43 \text{ lb/ft}^3} \\ &= 0,77202 \end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	-6,13	1690	0,008	-6E-06
C ₄ H ₉ OH	-5,397	1325,6	0,006	-6E-06
C ₁₇ H ₃₃ COOC ₄ H ₉	-15,2751	2934	0,02692	-1,8E-05
C ₁₅ H ₃₁ COOH	-9,45	2100	0,016	-1E-05
H ₂ SO ₄	-18,705	3496,2	0,033	-1E-05
H ₂ O	-10,252	1792,5	0,018	-1E-05



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$$T = 393,15 \text{ K}$$

$$\log_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu_{C_{17}H_{33}COOH} = 2,074231 \text{ cP}$$

$$\mu_{C_4H_9OH} = 0,3033733 \text{ cP}$$

$$\mu_{C_{17}H_{33}COOC_4H_9} = 0,9481631 \text{ cP}$$

$$\mu_{C_{15}H_{31}COOH} = 1,7152582 \text{ cP}$$

$$\mu_{H_2SO_4} = 16,39441 \text{ cP}$$

$$\mu_{H_2O} = 0,2733287 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
$C_{17}H_{33}COOH$	385,56417	0,0424896	2,074231	0,0881333
C_4H_9OH	4155,5308	0,4579442	0,3033733	0,138928
$C_{17}H_{33}COOC_4H_9$	4167,5043	0,4592637	0,9481631	0,4354569
$C_{15}H_{31}COOH$	54,008607	0,0059518	1,7152582	0,0102089
H_2SO_4	229,159	0,0252536	16,39441	0,4140176
H_2O	82,550019	0,0090971	0,2733287	0,0024865
Total	9074,3168	1		1,0892312

$$\begin{aligned} \mu_{\text{Campuran}} &= 1,0892312 \text{ cP} \\ &= 0,000732 \text{ lb/ft s} \end{aligned}$$

$$\begin{aligned} N_{re} &= \frac{ID \times V \times \rho_{\text{bahan}}}{\mu} \\ &= \frac{0,21 \times 3,48 \times 48,2}{0,000732} \\ &= 47061,967 > 2100 \\ &\text{asumsi aliran turbulen benar} \end{aligned}$$

$$\begin{aligned} e &= 0,000046 \text{ m} \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88}) \\ e/D &= \underline{0,000046} \end{aligned}$$



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$$\begin{aligned}
 &= 0,0626367 \\
 &= 0,0007344 \\
 f &= 0,006 \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88}) \\
 g_c &= 32,174 \text{ ft.lbm/detik}^2.\text{lbf} \\
 \alpha &= 1 \quad (\text{aliran turbulen}) \quad (\text{Peters \& Timmerhause 4th ed : 485})
 \end{aligned}$$

c. Menghitung Panjang ekuivalen suction, Le

Perhitungan friksi berdasarkan Peters & Timmerhaus, 4ed Tabel 1 hh. 484

Sambungan	Lc/D
Elbow standard 90°	32
Gate valve	7

$$\text{ID pipa} = 0,2055011 \text{ ft}$$

Taksiran panjang pipa lurus

$$\text{Jarak reaktor ke netralizer} = 32,8084 \text{ ft}$$

$$\text{Tinggi Netralizer} = 13,4167 \text{ ft}$$

$$\text{Panjang pipa masuk netralizer} = 4 \text{ ft}$$

$$\text{Taksiran panjang pipa lurus} = 50,2251 \text{ ft}$$

$$\begin{aligned}
 3 \text{ elbow } 90^\circ &= 3 \times 32 \times 0,21 \text{ ft} \\
 &= 19,7 \text{ ft}
 \end{aligned}$$

$$\begin{aligned}
 1 \text{ gate valve} &= 1 \times 7 \times 0,21 \text{ ft} \\
 &= 1,44 \text{ ft}
 \end{aligned}$$

$$\text{Panjang total pipa (Le)} = 71,3917 \text{ ft}$$

d. Perhitungan friksi

1. Friksi karena Gesekan Bahan dalam Pipa

$$g_c = 32,17 \text{ lbm.ft/lbf.s}^2$$

$$F_1 = \frac{2f \times V^2 \times Le}{g_c \times D} \quad (\text{Geankoplis 3ed, Pers, 2.10-6, P.89})$$

$$\begin{aligned}
 &= \frac{0,01 \times 12,1 \times 71,4}{32,2 \times 0,21} \\
 &= 1,5675 \text{ ft.lbf/lbm}
 \end{aligned}$$



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2. Friksi karena kontraksi dari tangki penyimpanan ke pipa

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-16, P.93})$$

dimana

$\alpha = 1$ untuk aliran turbulen

Menentukan Kc

A tangki > A pipa maka dianggap 0

Untuk A1 (tangki) dan A2 (pipa), maka A2/A1 = 0

maka, **(Peters 4 ed ; Page 484)**

$$K = 0,4 \times (1,25 - A2/A1)$$

$$K = 0,4 \times (1,25 - 0)$$

$$K = 0,5$$

sehingga,

$$\begin{aligned} F_2 &= \frac{0,5 \times 12,096055 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,094 \text{ ft.lbf/lbm} \end{aligned}$$

3. Friksi karena ekspansi dari pipa ke tangki

$$\begin{aligned} F_3 &= \frac{\Delta V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-15, P.93}) \\ (V_1 \ll V_2 \text{ dianggap } = 0) \\ &= \frac{12,0960555 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,188 \text{ ft.lbf/lbm} \end{aligned}$$

4. Friksi karena elbow 90°

$$F_4 = n \times \frac{K_f \times V^2}{2 \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-17, P.94})$$

diketahui :

$$K_f = 0,75$$

$$\begin{aligned} F_4 &= \frac{3 \times 0,75 \times 12,096055 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,423 \text{ ft.lbf/lbm} \end{aligned}$$



5. Friksi karena gate valve

$$F_5 = n \times \frac{K_f \times V^2}{2 \times gc} \quad (\text{Geankoplis 3ed Pers. 2.10-1})$$

diketahui :

$$K_f \text{ gate valve (wide open)} = 0,17$$

$$\begin{aligned} F_5 &= \frac{1 \times 0,17 \times 12,096055 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,03196 \text{ ft.lbf/lbm} \end{aligned}$$

6. Friksi Total

$$\begin{aligned} \Sigma F &= F_1 + F_2 + F_3 + F_4 + F_5 \\ &= 2,30447 \text{ ft.lbf/lbm} \end{aligned}$$

e. Perhitungan Energi Tekanan

$$H \text{ liquida} = 13,9199 \text{ ft}$$

$$\rho \text{ bahan} = 48,1974 \text{ lbm/ft}^3$$

$$g/gc = 1 \text{ lbf/lbm}$$

$$P_2 = 1 \text{ atm} = 2116,8 \text{ lbf/ft}^2$$

Energi Tekanan

$$\begin{aligned} P_1 &= P \text{ atm} + P \text{ hidrostatik} \\ &= 1 \text{ atm} + \left(\rho \times \frac{g}{gc} \times H \text{ liq} \right) \\ &= 2117 \text{ lbf/ft}^2 + (48,2 \text{ lbm/ft}^3 \times 1 \text{ lbf/lbm} \times 13,9 \text{ ft}) \\ &= 2787,7035 \text{ lbf/ft}^2 \end{aligned}$$

$$\begin{aligned} \frac{\Delta P}{\rho} &= \frac{(P_1 - P_2)}{\rho} \\ &= \frac{2787,7 - 2116,8}{48,19737294} \\ &= 13,9199 \text{ ft.lbf/lbm} \end{aligned}$$

f. Perhitungan Energi Kinetik

$$E_k = \frac{\Delta V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis, 3ed Eq. 2.7-5 p. 66})$$



$$= \frac{12,0960555}{2 \times 1 \times 32,17}$$

$$= 0,1880021 \text{ ft.lbf/lbm}$$

g. Perhitungan Energi potensial

Diketahui

$$Z_1 = 13,9 \text{ ft}$$

$$Z_2 = 13,4 \text{ ft}$$

$$g/gc = 1 \text{ lbf/lbm}$$

Sehingga,

$$E_p = \Delta Z \times \frac{g}{gc} \quad (\text{Geankoplis, 2014 Eq. 2.7-5 p. 66})$$

$$= (13,4 - 13,9) \text{ ft} \times 1 \text{ lbf/lbm}$$

$$= 0,50322 \text{ ft.lbf/lbm}$$

h. Persamaan Bernouli

$$-W_f = \frac{\Delta P}{\rho} + \Delta Z \times \frac{g}{gc} + \frac{\Delta V^2}{2 \times \alpha \times gc} + \Sigma F$$

$$= 13,9199 + 0,50322 + 0,188 + 2,30447$$

$$= 16,9156 \text{ ft.lbf/lbm}$$

i. Perhitungan Power Pompa

$$hp = \frac{-W_f \times \text{flowrate(gpm)} \times sg}{3960}$$

$$(\text{Perry 6ed ; Pers 6-11, Page 6-5})$$

$$= \frac{16,9156 \times 51,7491 \times 0,77202}{3960}$$

$$= 0,17066 \text{ hp}$$

$$\text{Efisiensi pompa} = 65\% \quad (\text{Peters 4 ed ; Figure 14 - 37 Page 520})$$

$$B_{hp} = \frac{B_{ph}}{\eta \text{ pompa}}$$

$$= \frac{0,1706575 \text{ hp}}{65\%}$$

$$= 0,2625501 \text{ hp}$$

$$\text{Efisiensi motor} = 80\%$$

$$\text{Power motor} = \frac{B_{hp}}{\eta \text{ motor}}$$



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$$\begin{aligned} & \frac{\text{ef.Motor}}{80\%} \\ &= \frac{0,2625501}{80\%} \text{ hp} \\ &= 0,3281876 \text{ hp} \end{aligned}$$

Maka digunakan power = 0,5 hp

Spesifikasi

Nama Alat	: Pompa
Kode	: L-211
Fungsi	: Untuk memindahkan produk dari reaktor (R-210) menuju netralizer (N-220)
Tipe	: <i>Centrifugal pump</i>
Bahan konstruksi	: <i>Commercial steel</i>
Dasar Pemilihan	: Umum digunakan untuk memompa liquid dengan viskositas rendah
Ukuran Pipa	: 2,5 in 40 sch
Kapasitas	: 20005,3 lb/jam
Rate volumetrik	: 415,071 ft ³ /jam
Total Dynamic head	: 16,9156 ft.lbf/lbm
Efisiensi pompa	: 65%
Efisiensi motor	: 80%
Power	: 0,5 hp
Jumlah	: 1 buah

14. Cooler (E-211)

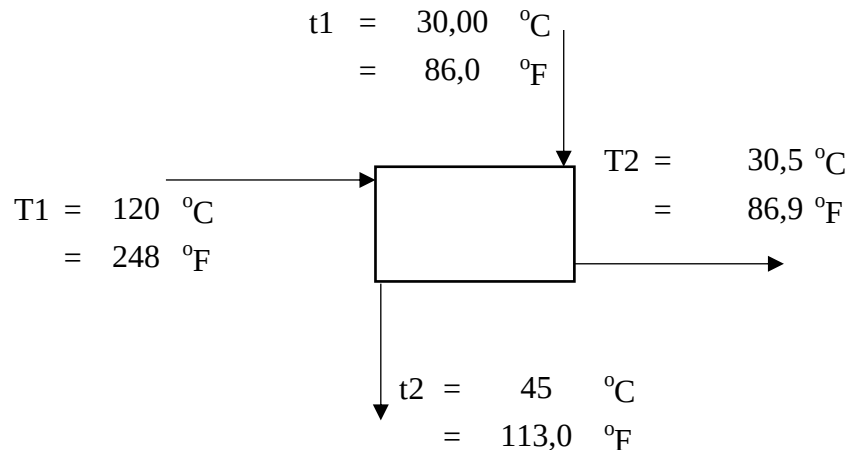


Fungsi	: Untuk mendinginkan produk dari suhu 120°C menjadi 30°C untuk dialirkan ke Netralizer (N-220)
Tipe	: <i>Shell and Tube Exchanger</i>
Dasar Pemilihan	: Umum digunakan untuk mendinginkan liquid
Kondisi Operasi	
Tekanan	= 1 atm



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Suhu = 30 °C



Perhitungan

1. Data dari neraca massa dan neraca panas diperoleh:

Untuk Fluida panas : Produk

T masuk (T1) = 120,0 °C = 248 F

T keluar (T2) = 30,5 °C = 86,9 F

Untuk Fluida dingin : Air Proses

T masuk (t1) = 30 °C = 86,0 F

T keluar (t2) = 45 °C = 113,0 F

massa bahan = 9074,3168 kg/jam

= 20063,314 lb/jam

Panas yang diserap

Q = 459027,55 kkal/jam

= 1820365,6 Btu/jam

Massa air pendingin

Air Pendingin yang dibutuhkan

W = 30601,837 kg/jam

= 67660,661 lb/jam



2. Penentuan ΔT LMTD

Hot fluida		Cold fluida	diff
248	higher temp	113,0	135
86,9	lower temp	86,0	0,9
161,1		27,0	

$$\Delta t \text{ LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$

$$\begin{aligned} \Delta t \text{ LMTD} &= \frac{135 - 1}{\ln \frac{135}{1}} \\ &= 26,763073 \text{ F} \end{aligned}$$

$$\begin{aligned} R &= \frac{T_1 - T_2}{t_2 - t_1} && \text{(Kern, Eq 5.17)} \\ &= \frac{248 - 86,9}{113 - 86,0} \\ &= 5,97 \end{aligned}$$

$$\begin{aligned} S &= \frac{t_2 - t_1}{T_1 - t_1} && \text{(Kern, Pers. 5.14, : 149)} \\ &= \frac{113 - 86}{248 - 86} \\ &= 0,16667 \end{aligned}$$

$$\begin{aligned} F_T &= 0,95 && \text{(Kern Fig. 18, : 828)} \\ \Delta T &= \Delta T \text{ LMTD} \times F_T && \text{(Kern, Pers. 7.42 : 149)} \\ &= 26,7631 \text{ }^\circ\text{F} \times 0,95 \\ &= 25,4249 \text{ }^\circ\text{F} \end{aligned}$$

3. T_c dan t_c

$T_c = t$ average bahan

$$\begin{aligned} T_c &= \frac{T_1 + T_2}{2} \\ &= \frac{248 + 86,9}{2} \end{aligned}$$



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$$= 167 \text{ }^{\circ}\text{F}$$

$$= 348 \text{ K}$$

$$t_c = t_{\text{average air}}$$

$$t_c = \frac{t_1 + t_2}{2}$$

$$= \frac{86,0 + 113}{2}$$

$$= 99,5 \text{ }^{\circ}\text{F}$$

$$= 310,65 \text{ K}$$

Menghitung Kapasitas Panas, Konduktifitas Thermal dan Viskositas
Fluida Dingin

$$c_p = 1 \text{ Btu/lb}^{\circ}\text{F} \quad (\text{Kern, Fig 2})$$

$$k = 0,37 \text{ BTU/hr ft}^2 \text{ }^{\circ}\text{F/ft} \quad (\text{Kern, Table 4})$$

$$\mu = 0,14 \text{ cP} \quad (\text{Kern, Fig.14})$$

Fluida Panas

Menghitung nilai kapasitas panas

komponen	A	B	C	D
$\text{C}_{17}\text{H}_{33}\text{COOH}$	278,686	2,5434	-0,0054	4,9E-06
$\text{C}_4\text{H}_9\text{OH}$	83,877	0,56628	-0,0017	2,3E-06
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	178,423	3,667	-0,00797	7,1E-06
$\text{C}_{15}\text{H}_{31}\text{COOH}$	86,29	3,5237	-0,0073	6,1E-06
H_2SO_4	26,004	0,70337	-0,0014	1E-06
H_2O	92,053	-0,04	-0,0002	5,3E-07

$$T = 348,4 \text{ K}$$

$$C_p = A + BT + CT^2 + DT^3$$

Sehingga diperoleh

$$C_p \text{ } \text{C}_{17}\text{H}_{33}\text{COOH} = 713,266 \text{ Kkal/KmolK}$$

$$C_p \text{ } \text{C}_4\text{H}_9\text{OH} = 172,085 \text{ Kkal/KmolK}$$

$$C_p \text{ } \text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 = 788,43 \text{ Kkal/KmolK}$$

$$C_p \text{ } \text{C}_{15}\text{H}_{31}\text{COOH} = 683,394 \text{ Kkal/KmolK}$$

$$C_p \text{ } \text{H}_2\text{SO}_4 = 143,412 \text{ Kkal/KmolK}$$

$$C_p \text{ } \text{H}_2\text{O} = 76,254 \text{ Kkal/KmolK}$$



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komponen	BM	Cp	Fraksi	Cp
	Kg/Kmol	kkal/Kmol K	Xf	kkal/Kg K
C ₁₇ H ₃₃ COOH	282,47	713,26606	0,04249	2,5251
C ₄ H ₉ OH	74	172,08487	0,45794	2,32547
C ₁₇ H ₃₃ COOC ₄ H ₉	310,56	788,42991	0,45926	2,53874
C ₁₅ H ₃₁ COOH	256,42	683,39381	0,00595	2,66513
H ₂ SO ₄	98	143,41221	0,02525	1,46339
H ₂ O	18	76,25402	0,0091	4,23633
Total			1	

$$1 \text{ kkal/kg K} = 0,23885 \text{ Btu/lb } ^\circ\text{F}$$

$$C = \sum_i^n C_p \cdot X_f$$

$$C = 0,5802839 \text{ Btu/lb } ^\circ\text{F}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	-6,13	1690	0,008	-6E-06
C ₄ H ₉ OH	-5,397	1325,6	0,006	-6E-06
C ₁₇ H ₃₃ COOC ₄ H ₉	-15,2751	2934	0,02692	-1,8E-05
C ₁₅ H ₃₁ COOH	-9,45	2100	0,016	-1E-05
H ₂ SO ₄	-18,705	3496,2	0,033	-1E-05
H ₂ O	-10,252	1792,5	0,018	-1E-05

$$T = 348,4 \text{ K}$$

$$\log_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \text{ C}_{17}\text{H}_{33}\text{COOH} = 5,309196 \text{ cP}$$

$$\mu \text{ C}_4\text{H}_9\text{OH} = 0,675156 \text{ cP}$$

$$\mu \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 = 2,1414477 \text{ cP}$$

$$\mu \text{ C}_{15}\text{H}_{31}\text{COOH} = 4,1930909 \text{ cP}$$



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$$\mu \quad \text{H}_2\text{SO}_4 \quad = \quad 19,874535 \text{ cP}$$

$$\mu \quad \text{H}_2\text{O} \quad = \quad 0,4314476 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
C ₁₇ H ₃₃ COOH	385,56417	0,0424896	5,309196	0,2255857
C ₄ H ₉ OH	4155,5308	0,4579442	0,675156	0,3091838
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,5043	0,4592637	2,1414477	0,9834892
C ₁₅ H ₃₁ COOH	54,008607	0,0059518	4,1930909	0,0249565
H ₂ SO ₄	229,159	0,0252536	19,874535	0,5019032
H ₂ O	82,550019	0,0090971	0,4314476	0,0039249
Total	9074,3168	1		2,0490432

$$\begin{aligned} \mu \text{ Campuran} &= 2,0490432 \text{ cP} \\ &= 0,001377 \text{ lb/ft s} \end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	-6,13	1690	0,008	-6E-06
C ₄ H ₉ OH	-5,397	1325,6	0,006	-6E-06
C ₁₇ H ₃₃ COOC ₄ H ₉	-15,2751	2934	0,02692	-1,8E-05
C ₁₅ H ₃₁ COOH	-9,45	2100	0,016	-1E-05
H ₂ SO ₄	-18,705	3496,2	0,033	-1E-05
H ₂ O	-10,252	1792,5	0,018	-1E-05

$$T = 106,357 \text{ F}$$

$$T = 313,138 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \quad \text{C}_{17}\text{H}_{33}\text{COOH} \quad = \quad 13,792029 \text{ cP}$$

$$\mu \quad \text{C}_4\text{H}_9\text{OH} \quad = \quad 1,4956158 \text{ cP}$$

$$\mu \quad \text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 \quad = \quad 5,6428972 \text{ cP}$$

$$\mu \quad \text{C}_{15}\text{H}_{31}\text{COOH} \quad = \quad 10,740346 \text{ cP}$$



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$$\mu \quad \text{H}_2\text{SO}_4 \quad = \quad 36,191061 \text{ cP}$$

$$\mu \quad \text{H}_2\text{O} \quad = \quad 0,7473071 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
$\text{C}_{17}\text{H}_{33}\text{COOH}$	385,56417	0,0424896	13,792029	0,5860179
$\text{C}_4\text{H}_9\text{OH}$	4155,5308	0,4579442	1,4956158	0,6849086
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	4167,5043	0,4592637	5,6428972	2,5915778
$\text{C}_{15}\text{H}_{31}\text{COOH}$	54,008607	0,0059518	10,740346	0,0639245
H_2SO_4	229,159	0,0252536	36,191061	0,9139539
H_2O	82,550019	0,0090971	0,7473071	0,0067983
Total	9074,3168	1		4,847181

$$\begin{aligned} \mu \text{ Campuran} &= 4,847181 \text{ cP} \\ &= 11,725759 \text{ lb/ft jam} \end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,2824	0,26812	781	0,2897
$\text{C}_4\text{H}_9\text{OH}$	0,26891	0,2667	562,93	0,2457
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	0,24798	0,24	764	0,2857
$\text{C}_{15}\text{H}_{31}\text{COOH}$	0,2797	0,26805	776	0,2947
H_2O	0,3471	0,274	647,13	0,2857
H_2SO_4	0,42169	0,1936	925	0,2857

$$T = 348,4 \text{ K}$$

$$\rho = Ax B^{-\left(1 - \frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\rho \text{ C}_{17}\text{H}_{33}\text{COOH} = 0,8272009 \text{ gr/ml}$$

$$\rho \text{ C}_4\text{H}_9\text{OH} = 0,7197156 \text{ gr/ml}$$

$$\rho \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 = 0,7917196 \text{ gr/ml}$$

$$\rho \text{ C}_{15}\text{H}_{31}\text{COOH} = 0,8147097 \text{ gr/ml}$$

$$\rho \text{ H}_2\text{SO}_4 = 1,7131628 \text{ gr/ml}$$



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$$\rho_{H_2O} = 0,935109 \text{ gr/ml}$$

komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)			
$C_{17}H_{33}COOH$	385,5641687	0,0424896	0,8272009	0,0351474
C_4H_9OH	4155,530773	0,4579442	0,7197156	0,3295896
$C_{17}H_{33}COOC_4H_9$	4167,504268	0,4592637	0,7917196	0,3636081
$C_{15}H_{31}COOH$	54,00860687	0,0059518	0,8147097	0,004849
H_2SO_4	229,159	0,0252536	0,935109	0,0236149
H_2O	82,5500185	0,0090971	1,7131628	0,756809
Total	9074,316835	1		1,5136179

$$\begin{aligned} \rho_{\text{Campuran}} &= 1,5136179 \text{ gr/ml} \times 62,4 \\ &= 94,44976 \text{ lb/cuft} \end{aligned}$$

$$\begin{aligned} Sg &= \frac{\rho_{\text{bahan}}}{\rho_{\text{reference}}(H_2O)} \times sg_{\text{reference}} \\ &= \frac{94,44976 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 1,5128906 \end{aligned}$$

$$\begin{aligned} K_{\text{mix}} &= \frac{0,0677}{sg [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{1,513 [1 - 0,0003 (100 - 32)]} \\ &= 0,0457 \text{ Btu/jam.ft.}^{\circ}\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243} \end{aligned}$$

Dipilih tipe : 1-2 Heat Exchanger

Digunakan shell and tube dengan ukuran :

Tube Side

$$\begin{aligned} \text{OD} &= 1 \frac{1}{2} \text{ in} \\ \text{BWG} &= 8 \\ \text{Pitch} &= 1 \frac{7}{8} \text{ in Square Pitch} \\ L &= 10 \text{ ft} \\ \text{Passes} &= 2 \\ \text{ID} &= 1,17 \text{ in} \end{aligned}$$

Shell Side

$$\begin{aligned} \text{Shell ID} &= 31 \text{ in} \\ \text{Passes} &= 1 \end{aligned}$$



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$$\begin{aligned} a't &= 1,075 \text{ in}^2 \\ a'' &= 0,3925 \text{ ft}^2/\text{ft panjang} \\ \text{(kern, Table.10, Hal. 843)} \end{aligned}$$

$$\begin{aligned} \text{Harga UD} &= 5 - 75 \text{ Btu/jam.ft.}^\circ\text{F} & \text{(Kern, tabel 8 hal 840)} \\ \text{Dipilih UD} &= 15 \text{ Btu/jam.ft.}^\circ\text{F} \end{aligned}$$

$$\begin{aligned} A &= \frac{Q}{UD \times \Delta t} & \text{(Kern Eq. 7.6)} \\ &= \frac{182036,5566}{15 \times 25,4249} \\ &= 477,318 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Jumlah tube (Nt)} &= \frac{A}{a'' \times L} \\ &= \frac{477,3179457}{0,39 \times 10} \\ &= 121,61 \text{ buah} \end{aligned}$$

$$\begin{aligned} \text{UD koreksi} \\ A &= Nt \times L \times a'' \\ &= 146 \times 10 \times 0,39 \\ &= 573,05 \end{aligned}$$

$$\begin{aligned} UD &= \frac{Q}{A \times \Delta t} \\ &= \frac{182036,5566}{573 \times 25,4249} \\ &= 12,494144 \end{aligned}$$

Menentukan nilai De :

$$\begin{aligned} De &= \frac{4 \left(Pt^2 - \pi \frac{OI^2}{4} \right)}{\pi OD} \\ &= \frac{4 \left(1,88^2 - 3,14 \times \frac{1,50^2}{4} \right)}{3,14 \times 1,5} \end{aligned}$$



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$$= 1,48567 \text{ in} = 0,12 \text{ ft}$$

Fluida Dingin : Tube Side	Fluida Panas :Shell Side
Air Pendingin	Produk
4. Flow Area (at) $at' = 1,08 \text{ in}^2 \quad \text{(Kern, Table 10)}$ $at = \frac{N_t \times at'}{144 \times n}$ $= \frac{146 \times 1,08}{144 \times 2}$ $= 0,5449653 \text{ ft}^2$ (Kern, Eq 7.48)	4. Flow Area (at) $B = 0,25 \text{ ID}$ $= 7,75$ $C = Pt - OD$ $= 1 \frac{7}{8} - 1 \frac{1}{2}$ $= 0,375$ $as = \frac{ID \times C' \times B}{144 \times Pt}$ $= \frac{31 \times 0,375 \times 7,75}{144 \times 1,88}$ $= 0,3336806 \text{ ft}^2$ (Kern, Eq. 7.1)
5. Mass Velocity (Gt) $Gt = \frac{W}{at}$ $= \frac{67660,661}{0,5449653}$ $= 124155,91 \text{ lb/jam ft}^2$	5. Mass Velocity (Gt) $Gs = \frac{W}{as} \quad \text{(Kern, Eq 7.2)}$ $= \frac{20063,314}{0,3336806}$ $= 60127,311 \text{ lb/jam ft}^2$
6. Bilangan Reynold (Ret) $De = 0,12 \text{ ft}$ $\mu = 0,3388 \text{ lb/ft.jam}$ $Ret = \frac{De \times Gs}{\mu}$ $= \frac{0,12 \times 124156}{0,3388}$ $= 45369,562$	6. Bilangan Reynold (Res) $D = 0,1 \text{ ft}$ $\mu = 4,96 \text{ lb/ft.jam}$ $Res = \frac{D \times Gt}{\mu}$ $= \frac{0,1 \times 60127,3}{4,95682}$ $= 1182,69$
7. jH $jH = 121 \quad \text{(Kern, Fig 24)}$	7. jH $jH = 16$



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8. $(c\mu/k)^{1/3}$ $\left(\frac{c \mu}{k} \right)^{1/3}$ $= \frac{1}{0,3700} \times 0,14$ $= 0,72328$ 9. h_i $h_i = jH \frac{k}{D} \left(\frac{c \mu}{k} \right)^{1/3} \phi_s$ (Kern, Eq 6.15b) $= 121 \times \frac{0,3700}{0,0975} \times 0,72328$ $= 332,11844 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$	(Kern Fig-28, hal. 838) 8. $(C \times \mu /k)^{1/3}$ $\left(\frac{c \mu}{k} \right)^{1/3}$ $= \frac{0,58028 \times 4,95682}{0,0457}$ $= 3,97856$ 9. h_o $h_o = jH \frac{k}{D} \left(\frac{c \mu}{k} \right)^{1/3} \phi_s$ (Kern, Eq 6.15b) $\frac{h_o}{\phi_t} = 16 \times \frac{0,0457}{0,0975} \times 3,97856$ $= 37,2751 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$
10 $\frac{h_{io}}{OD} = h_i \times \frac{ID}{OD}$ $= 259,052 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$	10. t_w $t_w = t_c + \frac{h_o/\phi_s}{h_{io}/\phi_t + h_o/\phi_s} (T_c - t_c)$ (Kern, Eq 5.31) $= 100 + \frac{37}{37 + 332} 68$ $= 106,357 \text{ } ^\circ\text{F}$ 10. ϕ_s Pada $t_w = 106,35676 \text{ } ^\circ\text{F}$ $\mu_w = 11,725759 \text{ lb/jam ft}$ $\phi_t = (\mu/\mu_w)^{0.14} \quad \textbf{(Kern, Fig.15)}$ $= 0,88644$ 11.. h_{io} $= \frac{h_o}{\phi_t} \times \phi_t$ $= 70,0772 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$



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12. Clean Overall Coefficient, U_c

$$\begin{aligned} U_c &= \frac{h_{io} \times h_o}{h_{io} + h_o} \quad \text{(Kern, Eq 6.38)} \\ &= \frac{259 \times 70,1}{259 + 70,1} \\ &= 55,2 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F} \end{aligned}$$

13. Design Overall Coefficient, U_d

$$\begin{aligned} U_d &= \frac{Q}{A \times \Delta t \text{ LMTD}} \\ &= \frac{459027,55}{573 \times 25,4} \\ &= 31,50552 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F} \end{aligned}$$

14. Dirt Factor, R_d

$$\begin{aligned} R_d &= \frac{U_c - U_d}{U_c \times U_d} \quad \text{(Kern, Eq 6.13)} \\ &= \frac{55,2 - 31,5}{55,2 \times 31,5} \\ &= 0,01361 \end{aligned}$$

Nilai R_d perhitungan > R_d ketentuan

$$0,01361 > 0,002$$

(Memenuhi karena R_d Perhitungan >> R_d allowabe)

Pressure Drop	
Fluida Dingin : Tube Side	Fluida Panas :Shell Side
Air Pendingin	Produk
1. f $Re_t = 45369,562$ $f = 0,00018$ (Kern, Fig 26)	1. f $Re_s = 1182,6925$ $f = 0,045$ (Kern, Fig 29)
2. dari tabel 6 kern, spesifik volume $s = 1$ $\Delta D_t = \frac{f G_s^2 L_n}{\dots}$	2. Number of crosses, $N+1$ $N+1 = 12 \times \frac{L}{B}$ $= 12 \times \frac{10}{\dots}$



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$\Delta P_t = 5,22 \times 10^{10} D s \phi$ $= 0,0085867 \text{ psi}$ $\Delta P_t < \Delta P \text{ allowable}$ $\Delta P_t < 2 \text{ psi}$, maka memenuhi	$= 7,75$ $= 15,4839$ 3. Pressure Drop (ΔP_s) $s = 1,51$$\Delta P_s = \frac{f \times G t^2 \times L \times n}{5,22 \times 10^{10} \times ID \times s \times \phi t}$ (Kern, Eq 7.44) $= 0,0116077 \text{ psi}$ $\Delta P_s < \Delta P \text{ allowable}$ $\Delta P_s < 10 \text{ psi}$, maka memenuhi

Spesifikasi

Nama Alat : Cooler
Kode : E-212
Fungsi : Mendinginkan produk reaktor dari suhu 120°C menjadi 30°C untuk dialirkan ke Netralizer (N-220)
Tipe : *Shell and Tube Exchanger*
Dasar Pemilihan : umum digunakan untuk menurunkan suhu pada liquid
Kondisi Operasi : - Tekanan : 1 atm
- Suhu : 30 °C

Bagian Tube

OD : 1 1/2 in
BWG : 8
Panjang : 10 ft
Jumlah tube, Nt : 146
Passes : 2
Pitch : 1 7/8 in square pitch
Pressure drop : 0,0085867 psi

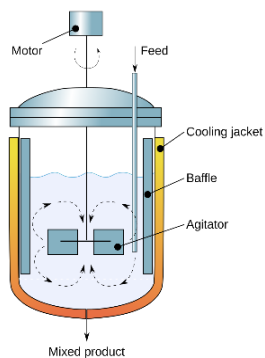
Bagian Shell

ID : 31 in
Passes : 1
Baffle Spacing : 7,75 in
Pressure drop : 0,0116077 psi



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15. Netralizer (N-220)



Fungsi = Mereaksikan Asam Sulfat dengan Natrium Hidroksida membentuk Natrium Sulfat

Tipe = Tangki berbentuk silinder tegak, tutup atas dan bawah berupa Torispherical dish

Jenis = Continous Stired Tank Reactor

Kondisi operasi :

- Tekanan = 1 atm
- suhu = 30 °C
- waktu tinggal = 60 menit
= 1 jam

Menghitung komposisi bahan masuk

komponen	BM (kg/kmol)	massa (kg/jam)	fraksi massa
$C_{17}H_{33}COOH$	282	385,5641687	0,041842257
C_4H_9OH	74	4155,530773	0,450967181
$C_{17}H_{33}COOC_4H_9$	338	4167,504268	0,452266571
$C_{15}H_{31}COOH$	256	54,00860687	0,005861131
H_2O	18	332,486788	0,036082185
Na_2SO_4	142	119,613132	0,012980676
Total		9214,707736	1

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897



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C ₄ H ₉ OH	0,26891	0,2667	562,93	0,2457
C ₁₇ H ₃₃ COOC ₄ H ₉	0,24798	0,24	764	0,2857
C ₁₅ H ₃₁ COOH	0,2797	0,26805	776	0,2947
H ₂ O	0,3471	0,274	647,13	0,2857
Na ₂ SO ₄	0,26141	0,1	3700	0,2857

$$T = 30^{\circ}\text{C} = 303,15 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned}\rho \text{ C}_{17}\text{H}_{33}\text{COOH} &= 0,8845005 \text{ gr/ml} \\ \rho \text{ C}_{4}\text{H}_{9}\text{OH} &= 0,8021585 \text{ gr/ml} \\ \rho \text{ C}_{17}\text{H}_{33}\text{COOC}_{4}\text{H}_{9} &= 0,8528228 \text{ gr/ml} \\ \rho \text{ C}_{15}\text{H}_{31}\text{COOH} &= 0,8725909 \text{ gr/ml} \\ \rho \text{ H}_{2}\text{O} &= 1,0228823 \text{ gr/ml} \\ \rho \text{ Na}_{2}\text{SO}_{4} &= 2,4728351 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
C ₁₇ H ₃₃ COOH	385,5641687	0,0418423	0,8845005	0,0370095
C ₄ H ₉ OH	4155,530773	0,4509672	0,8021585	0,3617472
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,504268	0,4522666	0,8528228	0,3857032
C ₁₅ H ₃₁ COOH	54,00860687	0,0058611	0,8725909	0,0051144
H ₂ O	332,486788	0,0360822	1,0228823	0,0369078
Na ₂ SO ₄	119,613132	0,0129807	2,4728351	0,0320991
Total	9214,707736	1		0,8585812

$$\begin{aligned}\rho \text{ Campuran} &= 0,8585812 \text{ gr/ml} \times 62,4 \\ &= 53,575466 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Sg} &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{53,575466 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1\end{aligned}$$



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$$= 0,8581686$$

$$\text{Rate Massa} = 9214,71 \text{ kg/jam}$$

$$= 20315 \text{ lb/jam}$$

$$\begin{aligned} \text{Rate volumetrik} &= \frac{\text{Rate massa}}{\rho \text{ campuran}} \\ &= \frac{20314,953 \text{ lb/jam}}{53,575466 \text{ lb/cuft}} \\ &= 379,18388 \text{ cuft/jam} \\ &= 9100,4131 \text{ cuft/hari} \end{aligned}$$

a. Menentukan Volume Cairan

$$\text{Dirancang waktu tinggal} = 1 \text{ jam, maka}$$

$$\begin{aligned} \text{Volume liquid} &= 379,184 \text{ cuft/jam} \times 1 \text{ jam} \\ &= 379,184 \text{ cuft} \end{aligned}$$

Asumsi volume liquid mengisi 80% volume tangki untuk faktor keamanan, sehingga :

$$\begin{aligned} \text{Volume Reakto} &= \frac{\text{Volume cairan}}{80\%} \\ &= \frac{379,1838799}{80\%} \\ &= 473,97985 \text{ cuft} \end{aligned}$$

b. Menentukan Dimensi Shell Tangki

$$\text{Asumsi rasio dimensi H/D} = 2 \text{ (Ulrich, 1987)}$$

$$\begin{aligned} \text{Volume silinder} &= \frac{1}{4} \times \pi \times D_i^2 \times H \\ &= \frac{1}{4} \times 3,14 \times D_i^2 \times 2D \\ &= 1,57 D_i^3 \end{aligned}$$

Volume tutup atas dan bawah Torispherical dish head

$$\text{Volume tutup atas} = 0,000049 D^3 \text{ (Brownell Eq. 5.11)}$$

$$\text{volume tutup bawah} = 0,000049 D^3$$

$$\text{Volume tangki} = V \text{ silinder} + V \text{ tutup atas} + V \text{ tutup bawah}$$



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$$\begin{aligned}
 473,97985 &= 1,57 D_i + 4,9E-05 D^3 + 4,9E-05 D^3 \\
 473,97985 &= 1,57 D_i^3 \\
 473,97985 &= 1,57005 D^3 \\
 D^3 &= 301,889 \\
 D &= 6,70835 \text{ ft} \\
 &= 2,0447 \text{ m} \\
 &= 80,5002 \text{ in} \\
 \\
 H &= 2 \times D \\
 &= 2 \times 6,71 \text{ ft} \\
 &= 13,4167 \text{ ft} \\
 &= 4,08941 \text{ m} \\
 &= 161 \text{ in}
 \end{aligned}$$

c. Menentukan tinggi cairan dalam tangki penyimpanan

$$\begin{aligned}
 \text{Volume liquid} &= \frac{1 \times \pi \times D^2 \times H}{4} + 0,000049 D^3 \\
 379,18388 &= 35,3265 H + 0,01 \\
 379,16909 &= 35,3265 H \\
 H &= 10,7333 \text{ ft} \\
 &= 3,2715 \text{ m} \\
 &= 128,799 \text{ in}
 \end{aligned}$$

d. Menentukan Tekanan design

Jika dalam bejana terdapat liquid, maka bejana dirancang berdasarkan tekanan dalam :

$$\begin{aligned}
 P_{\text{design}} &= P_{\text{gauge}} + P_{\text{hidrostatik}} \\
 P_{\text{design}} &= (P_i - P_o) + P_{\text{hidrostatik}} \\
 P_{\text{design}} &= (14,7 - 14,7) + P_{\text{hidrostatik}} \\
 P_{\text{design}} &= P_{\text{hidrostatik}} \\
 P_{\text{design}} &= \rho \times \frac{g}{g_c} \times H_{\text{liq}} \\
 &= 53,5755 \frac{\text{lb}}{\text{cuft}} \times 1 \frac{\text{lbf}}{\text{lbfm}} \times 10,7 \text{ ft} \\
 &= 575,04 \frac{\text{lbf}}{\text{ft}^2} \\
 &= 3,99333 \text{ psi}
 \end{aligned}$$



Asumsi P design 10% lebih besar untuk faktor keamanan

$$P_{\text{design}} = 1,1 \times 3,99 \text{ Psi}$$

$$= 4,39267 \text{ Psi}$$

Bejana didesain dengan tekanan dalam, P desain 4,39267 Psi

e. Menentukan tebal shell minimum

Tebal shell berdasarkan ASME code untuk cylindrical tank:

$$t_s = \frac{P \times r_i + C}{f_e - 0,6 P_d} \quad (\text{Brownell Eq. 13.1 hal.254})$$

dengan

$t_{\min}$ = tebal shell minimum (in)

P = tekanan tangki (Psi) = 4,39 Psi

r_i = jari-jari tangki (in) = 40,3 in

C = Faktor korosi (in); digunakan = 1/8 in

e = Faktor pengelasan; digunakan double welded = 0,8
(Brownell, Table 13.2)

f = stress allowable bahan konstruksi Logam Paduan SB 575
= 98300 Psi (ASMEBPVC.II.D.C-2017)

sehingga,

Asumsi tebal shell = 3/16 in

$$t_s = \frac{P \times r_i + C}{f_e - 0,6 P}$$

$$3/16 = \frac{4,39267 \times 40,2501 + 1/8}{0,8 f - 2,6356}$$

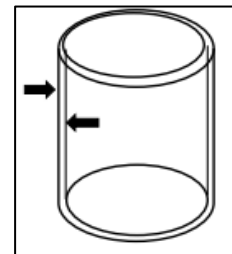
$$1/16 = \frac{4,39267 \times 40,2501}{0,8 f - 0,075}$$

$$1/16 f - 0,00469 = 176,80523$$

$$0,05 f = 176,80992$$

$$f = 3536,1983$$

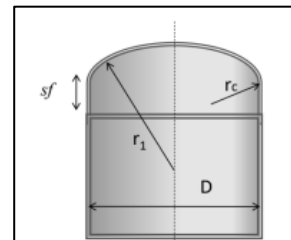
f hitung lebih kecil dari f allowable, jadi tebal shell 3/16 in dapat digunakan



f. Menentukan Tebal Tutup atas dan bawah

Tutup atas dan bawah dipilih torispherical

$$\begin{aligned} OD &= ID + 2 t_s \\ &= 80,500171 \text{ in} + 2 \times 3/16 \\ &= 80,875171 \text{ in} \end{aligned}$$





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Berdasarkan Brownell and Young, Tabel 5.7 dari data ~~OD, diperoleh.~~

$$\begin{aligned} \text{OD} &= 84 \text{ in} \\ t_{\text{shell}} &= 5/16 \text{ in} \\ \text{icr} &= 5 \frac{1}{8} \text{ in} \\ r &= 84 \text{ in} \end{aligned}$$

Cek nilai icr dengan nilai 6%rc

$$\begin{aligned} \text{icr} &= 5,125 \text{ in} \\ 6\% r &= 5,04 \text{ in} \end{aligned}$$

karena icr lebih besar dari 6% r maka digunakan persamaan 13.12
 Brownell & Young hal. 258

$$t_h = \frac{P \times r_c \times W}{2 f e - 0.2 P} + C \quad W = \frac{1}{4} \left(3 + \sqrt{\frac{rc}{icr}} \right)$$

dengan

$$\begin{aligned} t_h &= \text{tebal tutup (head) shell minimum (in)} \\ W &= \text{faktor stress intensif untuk torispherical} \\ P &= \text{Tekanan design (Psi)} = 4,39267 \\ r_c &= \text{radius of curfative sama dengan diameter (in)} = 84 \\ E &= \text{Faktor pengelasan} = 0,8 \\ f &= \text{allowable stress, bahan konstruksi SB 575} \\ &= 98300 \text{ Psi} \quad (\text{ASMEBPVC.II.D.C-2017}) \\ C &= \text{Faktor korosi (in)} = 0,125 \\ W &= \frac{1}{4} \left(3 + \sqrt{\frac{rc}{icr}} \right) \\ &= \frac{1}{4} \left(3 + \sqrt{\frac{84}{5,125}} \right) \\ &= 1,76212 \end{aligned}$$

Asumsi tebal tutup $3/16 \text{ in}$

$$\begin{aligned} t_h &= \frac{P \times r_c \times W}{2 f e - 0.2 P} + C \\ 3/16 \text{ in} &= \frac{4,3927 \times 84 \times 1,76212}{(f \times 1,6) - (0,2 \times 4,3927 \text{ psi})} + 1/8 \text{ in} \\ 1/16 \text{ in} &= \frac{650,1948}{1,6 f - 0,87853} \end{aligned}$$



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$$0,1 \quad f - 0,05491 = 650,1948$$

$$f = 6502,4968 \text{ psi}$$

f hitung lebih kecil dari f allowable, jadi tebal shell $\frac{3}{16}$ in dapat digunakan

g. Menentukan Tinggi Tutup Tangki

$$sf = 2 \text{ in}$$

$$t = \frac{3}{16} \text{ in}$$

(Brownell, tabel 5.6, hal. 88)

Menghitung tinggi tutup

$$OA = b + sf + t$$

$$* 1 \text{ ft} = 0,3 \text{ m}$$

$$1 \text{ ft} = 12 \text{ in}$$

$$BC = rc - icr$$

$$BC = 84 - 5,125$$

$$= 78,875 \text{ in}$$

$$AB = \frac{1}{2} \times OD - icr$$

$$AB = \frac{1}{2} \times 84 - 5,13$$

$$= 36,875 \text{ in}$$

$$b = rc - (BC^2 - AB^2)^{0,5}$$

$$b = 84 - (6221 - 1360)^{0,5}$$

$$= 14,276$$

Tinggi tutup atas

$$OA = b + sf + t$$

$$= 16,463 \text{ in}$$

$$= 0,4182 \text{ m}$$

$$= 1,3719 \text{ ft}$$

Total Tinggi Tangki

$$H \text{ total} = (2 \times H \text{ head}) + H \text{ silinder}$$

$$= (2 \times 1,37) + 13,417$$

$$= 16,1605 \text{ ft}$$

$$= 4,9257 \text{ m}$$



h. Perencanaan Sistem Pengaduk

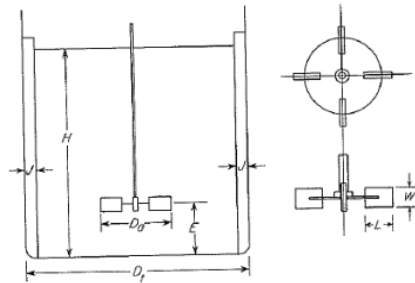
Dipakai impeller/pengaduk jenis turbin dengan 6 buah flat blade dengan 4 baffle

1. Penentuan Dimensi Pengaduk

$$\begin{aligned}\text{Tinggi liquid} \quad HL &= 10,7333 \text{ ft} \\ &= 152,097 \text{ in}\end{aligned}$$

$$\begin{aligned}\text{Diameter dalam} \quad Dt &= 6,70835 \text{ ft} \\ &= 217,205 \text{ in}\end{aligned}$$

Ukuran pengaduk diambil dari **Mc. Cabe ed 7th, hal 247**



Dimana

- Dt = Diameter tangki
 Da = Diameter impeller (pengaduk)
 E = Jarak impeller dari dasar tangki
 L = Panjang blade
 W = Lebar blade pengaduk
 J = Lebar baffle

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

$$\frac{E}{Dt} = \frac{1}{3} \qquad \frac{L}{Da} = \frac{1}{4}$$

$$\frac{W}{Da} = \frac{1}{5} \qquad \frac{J}{Dt} = \frac{1}{12}$$

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



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$$\begin{aligned}
 &= \frac{1}{3} \times 6,71 \text{ ft} \\
 &= 2,24 \text{ ft} \\
 W &= \frac{1}{5} \times Da \\
 &= \frac{1}{5} \times 2,24 \text{ ft} \\
 &= 0,45 \text{ ft} \\
 L &= \frac{1}{4} \times Da \\
 &= \frac{1}{4} \times 2,24 \text{ ft} \\
 &= 0,56 \text{ ft} \\
 E &= \frac{1}{3} \times Dt \\
 &= \frac{1}{3} \times 6,71 \text{ ft} \\
 &= 2,24 \text{ ft} \\
 J &= \frac{1}{12} \times Dt \\
 &= \frac{1}{12} \times 6,71 \text{ ft} \\
 &= 0,56 \text{ ft}
 \end{aligned}$$

$$\begin{aligned}
 \text{Tebal pengaduk} &= \frac{1}{10} \times 0,56 \\
 &= 0,06 \text{ ft}
 \end{aligned}$$

2. Penentuan Jumlah Pengaduk

$$\begin{aligned}
 \text{Jumlah impeller} &= \frac{H_{liq} \times sg}{Dt} && \text{(Joshi, Hal. 415)} \\
 \rho_{reference} &= 62,43 \text{ lb/cuft} \\
 \rho_{bahan} &= 53,575466 \text{ lb/cuft} \\
 sg &= \frac{\rho_{bahan}}{\rho_{reference}} \times sg_{reference} \\
 &= \frac{53,575466}{62,43} \times 1
 \end{aligned}$$



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$$= 0,8581686$$

maka,

$$\text{Jumlah impeller} = \frac{10,7 \times 0,85817}{6,71}$$

$$= 1,37$$

$$= 2 \text{ buah}$$

Jadi, jumlah impeller yang digunakan 2 buah **(Walas, hh. 288)**

$$\begin{aligned} \text{Jarak impeller (E)} &= 2 \times Da \\ &= 2 \times 2,23612 \\ &= 3,3541738 \text{ ft} \\ &= 1,0223522 \text{ m} \end{aligned}$$

3. Penentuan Putaran Pengaduk

$$V = \pi \times Da \times N \quad \text{(Joshi hal.389)}$$

Dimana,

V = pheripheral speed (m/menit)

Untuk pengaduk jenis turbin

V = 200-350 m/menit

Da = Diameter pengaduk (m)

N = Putaran pengaduk (rpm)

Diambil putaran pengaduk

$$N = 120 \text{ rpm}$$

$$Da = 2,23612 \text{ ft}$$

$$= 0,68157 \text{ m}$$

$$\begin{aligned} V &= \pi \times Da \times N \\ &= 3,14 \times 0,68 \times 120 \\ &= 257 \text{ m/menit (memenuhi)} \end{aligned}$$

4. Penentuan Bilangan Reynold

$$N = 120 \text{ rpm}$$

$$= 2 \text{ rps}$$

$$\rho \text{ campuran} = 53,6 \text{ lb/cuft}$$

$$\text{Dari Kern T.6 hal. 808 didapat sg reference} = 1$$

$$\text{Dari Kern Fig.14 hal. 823 didapat } \mu \text{ reference} = 1 \text{ Cp}$$



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Menghitung Viskositas Larutan

komponen	A	B	C	D
$C_{17}H_{33}COOH$	-6,13	1690	0,008	-6E-06
C_4H_9OH	-5,397	1325,6	0,006	-6E-06
$C_{17}H_{33}COOC_4H_9$	-15,275	2934	0,02692	-2E-05
$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05
Na_2SO_4	-18,705	3496,2	0,033	-1E-05
H_2O	-10,252	1792,5	0,018	-1E-05

$$T = 308,15 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\begin{aligned} \mu_{C_{17}H_{33}COOH} &= 2,074231 \text{ cP} \\ \mu_{C_4H_9OH} &= 0,3033733 \text{ cP} \\ \mu_{C_{17}H_{33}COOC_4H_9} &= 0,9481631 \text{ cP} \\ \mu_{C_{15}H_{31}COOH} &= 1,7152582 \text{ cP} \\ \mu_{Na_2SO_4} &= 16,39441 \text{ cP} \\ \mu_{H_2O} &= 0,2733287 \text{ cP} \end{aligned}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
$C_{17}H_{33}COOH$	385,56417	0,0418423	2,074231	0,0867905
C_4H_9OH	4155,5308	0,4509672	0,3033733	0,1368114
$C_{17}H_{33}COOC_4H_9$	4167,5043	0,4522666	0,9481631	0,4288225
$C_{15}H_{31}COOH$	54,008607	0,0058611	1,7152582	0,0100534
Na_2SO_4	332,48679	0,0360822	16,39441	0,5915461
H_2O	119,61313	0,0129807	0,2733287	0,003548
Total	9214,7077	1		1,2575719

$$\begin{aligned} \mu_{\text{Campuran}} &= 1,2575719 \text{ cP} \\ &= 0,0008451 \text{ lb/ft s} \\ &= 3,0423178 \text{ lb/ft hr} \end{aligned}$$



$$\begin{aligned}
 Nre &= \frac{\rho \times Da \times N}{\mu} \\
 &= \frac{53,6 \times 5 \times 2}{0,00085} \\
 &= 633990,0947 \quad (\text{aliran turbulen})
 \end{aligned}$$

Karena $Nre > 10000$, maka digunakan baffle.

Untuk $Nre > 10000$ diperlukan 4 buah baffle, sudut 90o
 (Perry ed.6 : hh.19-18)

5. Penentuan Power Pengaduk

Untuk $Nre > 10000$ perhitungan power pengaduk dengan persamaan:

$$P = \frac{K_3 \times N^3 \times Da^5 \times \rho}{g} \quad (\text{Ludwig, Vol.1 Pers.5.5 Hal. 299})$$

Dengan,

$$\begin{aligned}
 P &= \text{power pengaduk (hp)} \\
 K_3 &= \text{Faktor mixer} = 6,30 \quad (\text{Ludwig, vol-1 T.5-1, hal 301}) \\
 g &= \text{konstanta gravitasi} = 32,3 \text{ ft/dt}^2 \times \text{lbm/lbf} \\
 \rho &= \text{Densitas campuran (lb/cuft)} = 53,5755 \text{ lb/cuft} \\
 N &= \text{Kecepatan putaran impeller (rps)} = 2 \text{ rps} \\
 Da &= \text{Diameter impeller (ft)} = 2,23612 \text{ ft}
 \end{aligned}$$

Maka

$$\begin{aligned}
 P &= \frac{6,30 \times 8 \times 55,9077 \times 53,6}{32,3} \\
 &= 4673,75 \text{ lb.ft/dt} \\
 &= 8,49773 \text{ Hp}
 \end{aligned}$$

6. Perhitungan Loss Pengaduk

$$\begin{aligned}
 \text{Gland losses (kebocoran tenaga akibat poros dan bearing)} &= 10\% \\
 & \quad (\text{Joshi Hal.424})
 \end{aligned}$$

$$\begin{aligned}
 \text{Gland losses} &= 10\% \times P \\
 &= 10\% \times 8,5 \text{ Hp} \\
 &= 0,85 \text{ Hp}
 \end{aligned}$$

$$\begin{aligned}
 \text{Power input dengan gland losses} &= \text{Gland losses} + P \\
 &= 0,85 + 8,49773 \\
 &= 9,3474995 \text{ Hp}
 \end{aligned}$$



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$$\text{Transmission losses} = 20\% \quad (\text{Joshi Hal. 424})$$

$$\begin{aligned} \text{Transmission losses} &= 20\% \times \text{power input dengan gland losses} \\ &= 20\% \times 9,3475 \\ &= 1,8694999 \text{ Hp} \end{aligned}$$

$$\begin{aligned} \text{Power input dengan transmisson} &= 9,3475 + 1,8695 \\ &= 11,216999 \text{ Hp} \end{aligned}$$

$$\text{Efisiensi motor} = 85\% \quad (\text{Peters 5th Ed, Fig. 12-18})$$

Sehingga

$$\begin{aligned} \text{Power motor} &= \frac{\text{Power input dengan transmission losses}}{\text{Efisiensi motor}} \\ &= \frac{11,217}{85\%} \\ &= 13,1965 \text{ Hp} \end{aligned}$$

Perhitungan jaket pemanas

Menentukan Tinggi Jaket

$$\begin{aligned} \text{Tinggi jaket} &= \text{Tinggi shell} + \text{Tinggi tutup bawah} \\ &= 13,4167 + 1,3719 \\ &= 14,7886 \text{ ft} \\ &= 4,50757 \text{ m} \end{aligned}$$

Asumsi :

$$\text{Jaket spacing (s)} = 2 \text{ in}$$

$$\text{Tebal jaket (tj)} = 1/4 \text{ in}$$

$$\text{Eff. Sambungan las (E)} = 0,8$$

$$\text{Faktor korosi (c)} = 1/8$$

Dipergunakan bahan konstruksi yang terbuat dari SB-575

$$f \text{ allowable} = 98300 \text{ psi} \quad (\text{ASMEBPVC.II.D.C-2017})$$

$$\begin{aligned} D_{o,s} (\text{shell}) &= D_i + 2t_s \\ &= 80,500171 + 2 \times 3/16 \\ &= 80,875171 \text{ in} \end{aligned}$$

$$\begin{aligned} D_{i,j} (\text{jaket}) &= D_{o,s} + 2s \\ &= 80,875171 + 2 \times 2 \end{aligned}$$



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$$\begin{aligned}
 &= 84,875171 \text{ in} \\
 \text{Do (jaket)} &= D_{ij} + 2t_j \\
 &= 84,875171 + 2 \times \frac{1}{4} \\
 &= 85,375171 \text{ in} \\
 \text{Jaket spacing} &= \frac{D_i - D_o}{2} \\
 &= \frac{84,875171 - 80,875171}{2} \\
 &= \frac{4}{2} \\
 \text{P desain jacket} &= P_o - P_i + P_h \\
 &= 14,7 - 14,7 + \rho \times \frac{g}{g_c} \times H \text{ bahan} \\
 &= 53,5755 \text{ lb} \times \frac{1}{\text{cuft}} \times \frac{\text{lbf} \times 10,733272}{\text{lbf}} \text{ ft} \\
 &= 575,04 \text{ lbf/ft}^2 \\
 &= 3,99333 \text{ psi}
 \end{aligned}$$

Menentukan Tebal Minimum Shell

$$t_{\min} = \frac{P \times r_i}{f E - 0,6 P} + C$$

dimana

$$\begin{aligned}
 t_{\min} &= \text{Tebal shell minimal (in)} \\
 P &= \text{Tekanan jaket(psi)} = 3,99333 \\
 D_i &= \text{jari-jari jaket (in)} = 42,4376 \\
 e &= \text{faktor pengelasan, digunakan double welded, } e = 0,8 \\
 f &= \text{Stress allowable bahan konstruksi SB-575} \\
 &= 98300 \text{ psi} \quad (\text{ASMEBPVC.II.D.C-2017}) \\
 C &= \text{Faktor korosi} = \frac{1}{8}
 \end{aligned}$$

Asumsi tebal shell = $\frac{3}{16}$ in

$$\begin{aligned}
 t_{\min} &= \frac{P \times r_i}{f E - 0,6 P} + C \\
 t_{\min} &= \frac{3,9933 \times 42,4376}{78.640,0 - 2,3960} + \frac{1}{8} \text{ in} \\
 t_{\min} &= \frac{169,4674}{78.637,6} + \frac{1}{8} \text{ in} \\
 t_{\min} &= 0,127155043
 \end{aligned}$$



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karena $f_{allowable} > f_{hitung}$ maka tebal jaket $\frac{1}{4}$ in memenuhi

Spesifikasi

Nama Alat : Netralizer
Kode : N-220
Fungsi : Untuk mereaksikan asam sulfat dengan natrium hidroksida
Tipe : Reaktor Alir Tangki Berpengaduk (RATB) dengan pengaduk dan jaket pemanas

Kondisi Operasi

Tekanan : 1 atm
Suhu : 30 °C
Waktu tinggal : 1 jam
Proses : Kontinyu
Jumlah tangki : 1 buah

Dimensi Reaktor

Diameter : 6,708 ft = 2,0446 m
Tinggi total reaktor : 16,1605 ft = 4,92573 m
Tebal shell : 3/16 in
Tinggi shell : 13,4167 ft = 4,08941 m
Tebal tutup atas : 3/16 in
Tinggi tutup atas : 1,3719 ft = 0,41816 m
Tebal tutup bawah : 3/16 in
Tinggi tutup bawah : 1,37192 ft = 0,41816 m
Bahan Konstruksi : SB-575

Dimensi Pengaduk

Tipe : Dipilih pengaduk type flat blade turbine dengan jumlah blade 6
Diameter impeller : 2,23612 ft
Jarak impeller ke dasa : 3,35417 ft
Lebar baffle : 0,55903 ft
Jumlah impeller : 2 buah
Power : 13,1965 hp

Dimensi Jaket Pendingin

Diameter jaket : 84,8752 in = 2,15583 m
Tinggi jaket : 14,7886 ft = 4,50757 m
Jaket spacing : 2 in
Tebal jaket : 2/16 in



16. Pompa (L-221)



- Fungsi = Untuk memindahkan produk dari netralizer (N-220) menuju Dekanter (H-230)
- Tipe = *Centrifugal pump*
- Dasar Pemilihan : Umum digunakan untuk memompa liquid dengan viskositas rendah < 10 cP

Komposisi Bahan Masuk

Komponen	Massa	Fraksi Massa
	(kg)	
$C_{17}H_{33}COOH$	385,5641687	0,0418423
C_4H_9OH	4155,530773	0,4509672
$C_{17}H_{33}COOC_4H_9$	4167,504268	0,4522666
$C_{15}H_{31}COOH$	54,00860687	0,0058611
H_2O	332,486788	0,0360822
Na_2SO_4	119,613132	0,0129807
Total	9214,707736	1

$$\begin{aligned}\text{Rate massa bahan} &= 9214,7077 \text{ kg/jam} \\ &= 20314,837 \text{ lb/jam}\end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,2479	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947
H_2O	0,3471	0,274	647,13	0,2857



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Na ₂ SO ₄	0,26141	0,1	3800	0,2857

$$T = 30,5 \text{ }^{\circ}\text{C} = 303,65 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$\rho \text{ C}_{17}\text{H}_{33}\text{COOH}$	=	0,8841943	gr/ml
$\rho \text{ C}_4\text{H}_9\text{OH}$	=	0,8017437	gr/ml
$\rho \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	=	0,8522212	gr/ml
$\rho \text{ C}_{15}\text{H}_{31}\text{COOH}$	=	0,8722815	gr/ml
$\rho \text{ H}_2\text{O}$	=	1,022423	gr/ml
$\rho \text{ Na}_2\text{SO}_4$	=	2,4763356	gr/ml

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
C ₁₇ H ₃₃ COOH	385,5641687	0,0418423	0,8841943	0,0369967
C ₄ H ₉ OH	4155,530773	0,4509672	0,8017437	0,3615601
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,504268	0,4522666	0,8522212	0,3854312
C ₁₅ H ₃₁ COOH	54,00860687	0,0058611	0,8722815	0,0051126
H ₂ O	332,486788	0,0360822	1,022423	0,0368913
Na ₂ SO ₄	119,613132	0,0129807	2,4763356	0,0321445
Total	9214,707736	1		0,8581363

$$\begin{aligned} \rho \text{ Campuran} &= 0,8581363 \text{ gr/ml} \times 62,4 \\ &= 53,547704 \text{ lb/cuft} \end{aligned}$$

$$\begin{aligned} \text{Rate volumetrik} &= \frac{\text{rate massa bahan}}{\rho \text{ bahan}} \\ &= \frac{20314,837 \text{ lb/jam}}{53,547704 \text{ lb/cuft}} \\ &= 379,3783 \text{ cuft/jam} \\ &= 0,1053829 \text{ cuft/detik} \\ &= 47,299116 \text{ gpm} \end{aligned}$$



a. Menentukan diameter optimal pipa

asumsi aliran turbulen ($N_{re} > 2100$), maka digunakan persamaan

$$D_{i\text{ opt}} = 3,9 \times qf^{0,45} \times \rho^{0,13} \quad (\text{Peters, 4}^{\text{ed}}, \text{ pers. 15 hal 496})$$

Keterangan :

$D_{i\text{ opt}}$ = Diameter pipa bagian dalam optimal (in)

qf = Rate volumetrik (ft^3/s)

ρ = Densitas larutan (lb/ft^3)

Sehingga,

$$\begin{aligned} D_{i\text{ opt}} &= 3,9 \times qf^{0,45} \times \rho^{0,13} \\ &= 3,9 \times 0,36 \times 1,68 \\ &= 2,38 \text{ in} \end{aligned}$$

Dari Kern Table. 11, maka dipilih pipa dengan spesifikasi :

Pipe size = 2 1/2 in

Sch = 40

OD = 2,88 in = 0,24 ft = 0,07 m

ID = 2,46 in = 0,2 ft = 0,06 m

$$\begin{aligned} A &= \frac{1}{4} \times \pi \times ID^2 \\ &= \frac{1}{4} \times 3,14 \times 0,04199 \\ &= 0,03296 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Kecepatan Aliran (V)} &= \frac{\text{Rate volumetrik}}{\text{Luas Area (A)}} \\ &= \frac{0,10538}{0,03296} \\ &= 3,19698 \text{ ft/s} \end{aligned}$$

b. Menghitung N_{re}

$sg_{\text{ reff}} = 1$ (Kern, Table. 6 p. 808)

$\mu_{\text{ reff}} = 0,8 \text{ cP}$ (Kern, Fig. 14 p. 823)

$\rho_{\text{ reff}} = 62,4 \text{ lb}/\text{ft}^3$



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$$\begin{aligned}\text{sg bahan} &= \frac{\rho \text{ bahan}}{\rho \text{ reff}} \\ &= \frac{53,5477 \text{ lb/ft}^3}{62,43 \text{ lb/ft}^3} \\ &= 0,85772\end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	-6,13	1690	0,008	-6E-06
C ₄ H ₉ OH	-5,397	1325,6	0,006	-6E-06
C ₁₇ H ₃₃ COOC ₄ H ₉	-15,275	2934	0,02692	-2E-05
C ₁₅ H ₃₁ COOH	-9,45	2100	0,016	-1E-05
Na ₂ SO ₄	11,2905	-4576	-0,0068	9,2E-07
H ₂ O	-10,252	1792,5	0,018	-1E-05

$$\begin{aligned}T &= 308,15 \text{ K} \\ \text{Log}_{10} \mu &= A + \frac{B}{T} + CT + DT^2\end{aligned}$$

Sehingga diperoleh

μ C ₁₇ H ₃₃ COOH	$\mu = 16,109168 \text{ cP}$
μ C ₄ H ₉ OH	$\mu = 1,7001654 \text{ cP}$
μ C ₁₇ H ₃₃ COOC ₄ H ₉	$\mu = 6,6821751 \text{ cP}$
μ C ₁₅ H ₃₁ COOH	$\mu = 12,554863 \text{ cP}$
μ Na ₂ SO ₄	$\mu = 2,741\text{E-}06 \text{ cP}$
μ H ₂ O	$\mu = 0,8230407 \text{ cP}$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
C ₁₇ H ₃₃ COOH	385,56417	0,0418423	16,109168	0,674044
C ₄ H ₉ OH	4155,5308	0,4509672	1,7001654	0,7667188
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,5043	0,4522666	6,6821751	3,0221244
C ₁₅ H ₃₁ COOH	54,008607	0,0058611	12,554863	0,0735857
Na ₂ SO ₄	119,61313	0,0360822	2,741E-06	9,889E-08



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H ₂ O	332,48679	0,0129807	0,8230407	0,0106836
Total	9214,7077	1		4,5471566

$$\begin{aligned}\mu \text{ Campuran} &= 4,5471566 \text{ cP} \\ &= 0,0030557 \text{ lb/ft s}\end{aligned}$$

$$\begin{aligned}\text{Nre} &= \frac{\text{ID} \times \text{V} \times \rho \text{ bahan}}{\mu} \\ &= \frac{0,2 \times 3,2 \times 53,5}{0,0030557} \\ &= 11480,264 > 2100\end{aligned}$$

asumsi aliran turbulen benar

$$e = 0,000046 \text{ m} \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$

$$\begin{aligned}\frac{e}{D} &= \frac{0,000046}{0,062459} \\ &= 0,0007365\end{aligned}$$

$$f = 0,006 \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$

$$g_c = 32,174 \text{ ft.lbm/detik}^2.\text{lbf}$$

$$\alpha = 1 \quad (\text{aliran turbulen}) \quad (\text{Peters \& Timmerhause 4thed : 485})$$

c. Menghitung Panjang ekuivalen suction, Le

Perhitungan friksi berdasarkan Peters & Timmerhaus, 4ed Tabel 1 hh. 484

Sambungan	Lc/D
Elbow standard 90°	32
Gate valve	7

$$\text{ID pipa} = 0,204918 \text{ ft}$$

Taksiran panjang pipa lurus

$$\text{Jarak netralizer ke dekanter} = 16,4042 \text{ ft}$$

$$\text{Tinggi Dekanter} = 10,7345 \text{ ft}$$

$$\text{Panjang pipa masuk bak} = 4 \text{ ft}$$

$$\text{Taksiran panjang pipa lurus} = 31,1387 \text{ ft}$$

$$\begin{aligned}3 \text{ elbow } 90^\circ &= 3 \times 32 \times 0,2 \text{ ft} \\ &= 19,7 \text{ ft}\end{aligned}$$

$$\begin{aligned}1 \text{ gate valve} &= 1 \times 7 \times 0,2 \text{ ft} \\ &= 1,43 \text{ ft}\end{aligned}$$



$$\text{Panjang total pipa (Le)} = 52,2453 \text{ ft}$$

d. Perhitungan friksi

1. Friksi karena Gesekan Bahan dalam Pipa

$$\begin{aligned} g_c &= 32,17 \text{ lbm.ft/lbf.s}^2 \\ F_1 &= \frac{2f \times V^2 \times Le}{g_c \times D} \quad (\text{Geankoplis 3ed, Pers, 2.10-6, P.89}) \\ &= \frac{0,01 \times 10,2 \times 52,2}{32,2 \times 0,2} \\ &= 0,97203 \text{ ft.lbf/lbm} \end{aligned}$$

2. Friksi karena kontraksi dari tangki penyimpanan ke pipa

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times g_c} \quad (\text{Geankoplis 3ed, Pers, 2.10-16, P.93})$$

dimana

$$\alpha = 1 \text{ untuk aliran turbulen} \quad (\text{Geankoplis, 2014})$$

Menentukan Kc

A tangki > A pipa maka dianggap 0

Untuk A1 (tangki) dan A2 (pipa), maka A2/A1 = 0

maka, (Peters 4 ed ; Page 484)

$$\begin{aligned} K &= 0,4 \times (1,25 - A_2/A_1) \\ K &= 0,4 \times (1,25 - 0) \\ K &= 0,5 \end{aligned}$$

sehingga,

$$\begin{aligned} F_2 &= \frac{0,5 \times 10,22069 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,07943 \text{ ft.lbf/lbm} \end{aligned}$$

3. Friksi karena ekspansi dari pipa ke tangki

$$\begin{aligned} F_3 &= \frac{\Delta V^2}{2 \times \alpha \times g_c} \quad (\text{Geankoplis 3ed, Pers, 2.10-15, P.93}) \\ &= \frac{10,22069011 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,15885 \text{ ft.lbf/lbm} \end{aligned}$$



4. Friksi karena elbow 90°

$$F_4 = n \times \frac{K_f \times V^2}{2 \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-17, P.94})$$

diketahui :

$$K_f = 0,75 \quad (\text{Geankoplis 3ed, T.2.10-1, P. 93})$$

$$\begin{aligned} F_4 &= \frac{3 \times 0,75 \times 10,22069 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,35742 \text{ ft.lbf/lbm} \end{aligned}$$

5. Friksi karena gate valve

$$F_5 = n \times \frac{K_f \times V^2}{2 \times gc}$$

diketahui :

(Geankoplis 3ed Pers. 2.10-1)

$$K_f \text{ gate valve (wide open)} = 0,17$$

$$\begin{aligned} F_5 &= \frac{1 \times 0,17 \times 10,22069 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,02701 \text{ ft.lbf/lbm} \end{aligned}$$

6. Friksi Total

$$\begin{aligned} \Sigma F &= F_1 + F_2 + F_3 + F_4 + F_5 \\ &= 1,59473 \text{ ft.lbf/lbm} \end{aligned}$$

e. Perhitungan Energi Tekanan

$$H \text{ liquida netralizer} = 10,7333 \text{ ft}$$

$$\rho \text{ bahan} = 53,5477 \text{ lbm/ft}^3$$

$$g/gc = 1 \text{ lbf/lbm}$$

$$P_2 = 1 \text{ atm} = 2116,8 \text{ lbf/ft}^2$$

Energi Tekanan

$$\begin{aligned} P_1 &= P_{\text{atm}} + P_{\text{hidrostatik}} \\ &= 1 \text{ atm} + \left(\rho \times \frac{g}{gc} \times H_{\text{liq}} \right) \\ &= 2117 \text{ lbf/ft}^2 + (53,5 \text{ lbm/ft}^3 \times 1 \text{ lbf/lbm} \times 10,7 \text{ ft}) \\ &= 2691,5421 \text{ lbf/ft}^2 \end{aligned}$$



$$\begin{aligned}\frac{\Delta P}{\rho} &= \frac{(P_1 - P_2)}{\rho} \\ &= \frac{2691,54 - 2116,8}{53,5477039} \\ &= 10,7333 \text{ ft.lbf/lbm}\end{aligned}$$

f. Perhitungan Energi Kinetik

$$\begin{aligned}E_k &= \frac{\Delta V^2}{2 \times \alpha \times g_c} \quad (\text{Geankoplis, 3ed Eq. 2.7-5 p. 66}) \\ &= \frac{10,22069011}{2 \times 1 \times 32,17} \\ &= 0,1588544 \text{ ft.lbf/lbm}\end{aligned}$$

g. Perhitungan Energi potensial

Diketahui

$$\begin{aligned}Z_1 &= 10,7 \text{ ft} \\ Z_2 &= 5,37 \text{ ft} \\ g/g_c &= 1 \text{ lbf/lbm}\end{aligned}$$

Sehingga,

$$\begin{aligned}E_p &= \Delta Z \times \frac{g}{g_c} \quad (\text{Geankoplis, 2014 Eq. 2.7-5 p. 66}) \\ &= (5,37 - 10,7) \text{ ft} \times 1 \text{ lbf/lbm} \\ &= 5,366 \text{ ft.lbf/lbm}\end{aligned}$$

h. Persamaan Bernouli

$$\begin{aligned}-W_f &= \frac{\Delta P}{\rho} + \Delta Z \times \frac{g}{g_c} + \frac{\Delta V^2}{2 \times \alpha \times g_c} + \Sigma F \\ &= 10,7333 + 5,366 + 0,15885 + 1,59473 \\ &= 17,8529 \text{ ft.lbf/lbm}\end{aligned}$$

i. Perhitungan Power Pompa

$$\begin{aligned}hp &= \frac{-W_f \times \text{flowrate(gpm)} \times sg}{3960} \\ & \quad (\text{Perry 6ed ; Pers 6-11, Page 6-5})\end{aligned}$$



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$$= \frac{17,8529 \times 47,2991 \times 0,85772}{3960}$$

$$= 0,1829 \text{ hp}$$

$$\text{Efisiensi pompa} = 65\% \quad (\text{Peters 4 ed ; Figure 14 - 37 Page 520})$$

$$\begin{aligned} \text{Bhp} &= \frac{\text{Bph}}{\eta \text{ pompa}} \\ &= \frac{0,1828998 \text{ hp}}{65\%} \\ &= 0,2813843 \text{ hp} \end{aligned}$$

$$\begin{aligned} \text{Efisiensi motor} &= 80\% \\ \text{Power motor} &= \frac{\text{Bhp}}{\text{ef.Motor}} \\ &= \frac{0,2813843 \text{ hp}}{80\%} \\ &= 0,3517303 \text{ hp} \end{aligned}$$

$$\text{Maka digunakan power} = 0,5 \text{ hp}$$

Spesifikasi

Nama Alat	:	Pompa
Kode	:	L-211
Fungsi	:	Untuk memindahkan produk dari netralizer (N-220) menuju Dekanter (H-230)
Tipe	:	<i>Centrifugal pump</i>
Dasar Pemilihan	:	Umum digunakan untuk memompa liquid dengan viskositas rendah
Ukuran Pipa	:	2 1/2 in 40 sch
Kapasitas	:	20314,8 lb/jam
Rate volumetrik	:	379,378 ft ³ /jam
Total Dynamic head	:	17,8529 ft.lbf/lbm
Efisiensi pompa	:	65%
Efisiensi motor	:	80%
Power	:	1 hp
Jumlah	:	1 buah



17. Dekanter (H-230)



Fungsi : Untuk memisahkan butil oleat dengan impuritas lainnya
Tipe : Decanter horizontal dengan tutup berbentuk Dish
Kondisi Operasi :

- Temperature = $30\text{ }^{\circ}\text{C}$ = $303,15\text{ K}$
- Tekanan = 1 atm = $101,325\text{ kPa}$

rate massa bahan = $9214,7077\text{ kg/jam}$
= $20314,837\text{ lb/jam}$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,2824	0,26812	781	0,2897
$\text{C}_4\text{H}_9\text{OH}$	0,26891	0,2667	562,93	0,2457
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	0,2479	0,24	764	0,2857
$\text{C}_{15}\text{H}_{31}\text{COOH}$	0,2797	0,26805	776	0,2947
H_2O	0,3471	0,274	647,13	0,2857
Na_2SO_4	0,26141	0,1	3800	0,2857

$$T = 30\text{ }^{\circ}\text{C} = 303,15\text{ K}$$

$$\rho = Ax B^{-\left(1 - \frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\rho_{\text{C}_{17}\text{H}_{33}\text{COOH}} = 0,8845005\text{ gr/ml}$$

$$\rho_{\text{C}_4\text{H}_9\text{OH}} = 0,8021585\text{ gr/ml}$$



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$$\begin{aligned}\rho \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,8525477 \text{ gr/ml} \\ \rho \text{ C}_{15}\text{H}_{31}\text{COOH} &= 0,8725909 \text{ gr/ml} \\ \rho \text{ H}_2\text{O} &= 1,0228823 \text{ gr/ml} \\ \rho \text{ Na}_2\text{SO}_4 &= 2,4765631 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$\text{C}_{17}\text{H}_{33}\text{COOH}$	385,5641687	0,0418423	0,8845005	0,0370095
$\text{C}_4\text{H}_9\text{OH}$	4155,530773	0,4509672	0,8021585	0,3617472
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	4167,504268	0,4522666	0,8525477	0,3855788
$\text{C}_{15}\text{H}_{31}\text{COOH}$	54,00860687	0,0058611	0,8725909	0,0051144
H_2O	332,486788	0,0360822	1,0228823	0,0369078
Na_2SO_4	119,613132	0,0129807	2,4765631	0,0321475
Total	9214,707736	1		0,8585051

$$\begin{aligned}\rho \text{ Campuran} &= 0,8585051 \text{ gr/ml} \times 62,4 \\ &= 53,570721 \text{ lb/cuft}\end{aligned}$$

Komposisi bahan atas (*Light Phase*) :

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$\text{C}_{17}\text{H}_{33}\text{COOH}$	385,5641687	0,0441115	0,8845005	0,0390167
$\text{C}_4\text{H}_9\text{OH}$	4133,586637	0,4729145	0,8021585	0,3793524
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	4167,504268	0,4767949	0,8525477	0,4064904
$\text{C}_{15}\text{H}_{31}\text{COOH}$	54,00860687	0,006179	0,8725909	0,0053917
Total	8740,66368	1		0,8302513

$$\begin{aligned}\rho \text{ Campuran} &= 0,8302513 \text{ gr/ml} \times 62,4 \\ &= 51,807678 \text{ lb/cuft}\end{aligned}$$

Komposisi bahan bawah (*Heavy Phase*)

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$\text{C}_4\text{H}_9\text{OH}$	21,94413635	0,0462913	0,8021585	0,037133
H_2O	332,4869143	0,7013836	1,0228823	0,7174328



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Na ₂ SO ₄	119,6132921	0,2523251	2,4765631	0,6248991
Total	474,0443428	1		1,3794648

$$\begin{aligned}\rho \text{ Campuran} &= 1,3794648 \text{ gr/ml} \times 62,4 \\ &= 86,078607 \text{ lb/cuft}\end{aligned}$$

$$\frac{\mu_m}{\mu_L} = \frac{1 + 0.5 \phi_s}{(1 - \phi_s)^4} \quad \text{(Perry 5th ed)}$$

$$\phi_s = \frac{V_s}{V_L} = \frac{(m/\rho) \text{ padatan}}{(m/\rho) \text{ larutan}}$$

dimana : ϕ_s : Fraksi volume solid.
 μ_m : Viscositas campuran.
 μ_L : Viscositas pelarut.
 V_s : Laju alir volumetrik padatan.
 V_L : Laju alir volumetrik larutan.
 ρ : densitas campuran
 ρ_a : densitas bahan atas
 ρ_b : densitas bahan bawah

$$\begin{aligned}V_s &= \frac{m \text{ komponen bawah}}{\rho} \\ &= \frac{474,04434}{1379,4648} \\ &= 0,3436437 \text{ m}^3/\text{jam} \\ &= 3,6989803 \text{ cuft/jam}\end{aligned}$$

$$\begin{aligned}V_L &= \frac{m \text{ komponen atas}}{\rho} \\ &= \frac{8740,6637}{830,25125} \\ &= 10,527733 \text{ m}^3/\text{jam} \\ &= 113,32052 \text{ cuft/jam}\end{aligned}$$



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$$\varphi_s = \frac{3,6989803}{113,32052}$$

$$= 0,0326418 \text{ cuft/jam}$$

$$\mu \text{ pelarut pada } T = 30 \text{ }^{\circ}\text{C}$$

$$\rho = 0,8 \text{ cp} \quad (\text{Geankolpis, App A-2})$$

$$\frac{\mu_m}{\mu_L} = \frac{1 + 0,5 \varphi_s}{(1 - \varphi_s)^4}$$

$$\frac{\mu_m}{\mu_L} = \frac{1 + (0,5 \times 0,03264)}{(1 - 0,0326418)^4}$$

$$0,8007 \mu_m = 1,01864 \times 0,8007$$

$$\mu_m = 0,8156233 \text{ cP}$$

$$= 0,0005481 \text{ lb/ft s}$$

Penentuan Ukuran Decanter

Diameter fasa bawah dalam fasa atas (Dp)

$$D_p = 0,0007 \text{ (Ulrich table 4-23)}$$

$$K = D_p \left(\frac{g \times \rho_b \times (\rho_b - \rho_a)}{\mu_m} \right)^{1/3}$$

$$= 0,0007 \left(\frac{29499,9376}{0,000548074} \right)^{1/3}$$

$$= 0,26430$$

untuk $0 < K < 3,3$ maka persamaan untuk kecepatan terminal (Ut) :

$$U_t = g \left(\frac{D_p^2}{18 \times \mu_m} \right) (\rho_b - \rho_a)$$

$$= 9,8 \left(\frac{4,9\text{E-}07}{0,0099} \right) \times 34,2709$$

$$= 0,01668 \text{ m/s}$$

perbandingan panjang dengan diameter Decanter pada tekanan 1 atm :

$$\frac{L_s}{d_i} = 3 \quad (\text{Ulrich, 1984})$$

dengan :

$$\frac{L_s}{d_i} \geq \frac{0,5 \times U_{\text{average}}}{U_t}$$



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$$3 \geq \frac{0,5 \times U_{\text{average}}}{0,01668}$$

$$0,1 \geq U_{\text{average}}$$

U average maksimum harus $< 8 U_t$
 agar turbulensi pada permukaan dapat dicegah **(Ulrich hal 220)**

$$U_{\text{average}} < 8 \times U_t$$

$$0,1000892 < 8 \times 0,01668$$

$$0,1000892 < 0,133 \quad (\text{memenuhi})$$

Perhitungan Dimensi Tangki

$$\text{Rate massa} = 9214,708 \text{ kg/jam}$$

$$= 20314,745 \text{ lb/jam}$$

$$\text{Rate Volumetrik} = \frac{\text{Rate massa}}{\rho \text{ campuran}}$$

$$= \frac{20314,745}{53,5707}$$

$$= 379,2136 \text{ cuft/jam}$$

$$\text{Waktu tinggal} = 10 \text{ menit} \quad \textbf{(Coulson hal 441)}$$

$$= 0,16667 \text{ jam}$$

$$\begin{aligned} \text{Volume liquid} &= \text{Rate volumetrik} \times \text{waktu tinggal} \\ &= 379,2136 \text{ cuft/jam} \times 0,17 \text{ jam} \\ &= 63,2023 \text{ cuft} \end{aligned}$$

asumsi overdesign 20% (faktor keamanan)

$$\text{Volume tangki} = 1,2 \times 63,2023 \text{ cuft}$$

$$= 75,8427 \text{ cuft}$$

Menentukan ukuran tangki

$$\text{Asumsi : Dimensi ratio} = \frac{H}{D} = 2 \quad (\text{Ulrich T.4-27})$$

$$V_s = \frac{1}{4} \times \pi \times D_s^2 \times H_s$$

$$= \frac{1}{4} \times \pi \times D_s^2 \times 2 D_s$$



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$$= 1,57 \quad Ds^2$$

Tutup atas dan bawah dipilih tipe *torispherical*:

$$V = 0,000049 \quad D^3 \quad \text{(Pers 5.11 Brownell \& Young, hal 88)}$$

Sehingga, volume untuk kedua tutup:

$$V = 2 \times 0,000049 = 0,000098 \quad D^3$$

$$\text{Volume tangki} = \text{Vol. Silinder} + \text{Vol. Tutup}$$

$$\text{Volume tangki} = \frac{1}{4} \pi D^2 H + 0,000098 \quad D^3$$

$$\text{Volume tangki} = 1,57 \quad D^3 + 0,000098 \quad D^3$$

$$75,8427 = 2,355 \quad D^3 + 0,000098 \quad D^3$$

$$75,8427 = 2,3551 \quad D^3$$

$$D^3 = 32,2036 \quad \text{ft}$$

$$D = 10,7345 \quad \text{ft}$$

$$D = 128,8145 \quad \text{in}$$

$$= 3,2719 \quad \text{m}$$

$$\begin{aligned} Ls &= 2 \times di \\ &= 2 \times 10,7345 \quad \text{ft} \\ &= 21,4691 \quad \text{ft} \\ &= 257,6291 \quad \text{in} \\ &= 6,5438 \quad \text{m} \end{aligned}$$

Menghitung Tinggi Liquid dalam Shell

$$\begin{aligned} H \text{ larutan} &= 80\% \times di \\ &= 80\% \times 10,7345 \\ HL &= 8,58764 \quad \text{ft} \\ &= 103,0516 \quad \text{in} \\ &= 2,6175 \quad \text{m} \end{aligned}$$

Menghitung P desain

Tekanan hidrostatik dihitung dengan menggunakan persamaan :

$$\begin{aligned} P \text{ Hidrostatik} &= \rho \times \frac{g}{gc} \times H \text{ liq} \\ &= 53,5707 \frac{\text{lb}}{\text{cuft}} \times \frac{1 \text{ lbf}}{\text{lbm}} \times 8,59 \quad \text{ft} \end{aligned}$$



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$$= 460,046 \frac{\text{lbf}}{\text{ft}^2}$$

$$= 3,19476 \text{ psi}$$

$$\begin{aligned} P_{\text{gauge}} &= P_i - P_o \\ &= 14,7 - 14,7 \\ &= 0 \end{aligned}$$

Asumsi P design 10% lebih besar untuk faktor keamanan

$$\begin{aligned} P_{\text{design}} &= 1,1 \times (P_{\text{gauge}} + P_h) \\ &= 1,1 \times (0 + 3,19476) \text{ Psi} \\ &= 3,5142392 \text{ Psi} \end{aligned}$$

Menentukan tebal shell minimum

$$t_s = \frac{P \times r_i}{f_e - 0,6 P_d} + C \quad \text{(Brownell Eq. 13.1)}$$

dengan

t_s = tebal shell minimum (in)

P = tekanan tangki (Psi) = 3,5142 Psi

r_i = jari-jari tangki (in) = 64,4073 in

C = Faktor korosi (in); digunakan = 1/8 in

e = Faktor pengelasan; digunakan double welded = 0,8

(Brownell, Table 13.2)

f = allowable stress, bahan konstruksi carbon steel SA-283 grade C
 12650 Psi **(Brownell, hal.342)**

sehingga,

$$\begin{aligned} t_s &= \frac{P_d \times r_i}{f_e - 0,6 P_d} + C \\ t_s &= \frac{3,51 \times 64,4}{10120 - 0,6 \times 3,51424} + \frac{1}{8} \\ t_s &= \frac{226,34256}{10117,891} + \frac{1}{8} \\ t_s &= 0,0223705 + 0,125 \\ t_s &= 0,14737 \\ t_s &= 1/4 \text{ in} \end{aligned}$$



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f hitung lebih kecil dari f allowable, jadi tebal shell $\frac{1}{4}$ in dapat digunakan

Tebal shell distandarisasi dari Tabel 5.7 Brownell menjadi:

$$\begin{aligned} OD &= ID + 2 ts \\ &= 128,8145 + 2 \times \frac{1}{4} \\ &= 129,1093 \text{ in} \end{aligned}$$

Berdasarkan Brownell and Young, Tabel 5.7 dari data OD, diperoleh:

$$\begin{aligned} OD &= 132 \text{ in} \\ icr &= 8 \text{ in} \\ rc &= 130 \text{ in} \end{aligned}$$

Cek nilai icr dengan nilai 6%rc

$$\begin{aligned} icr &= 8 \text{ in} \\ 6\% rc &= 7,8 \text{ in} \end{aligned}$$

Design Tutup Kanan dan Kiri

Bahan Konstruksi :

Carbon Steel type SA - 283 grade A dari Brownell H Young diperoleh :

$$f \text{ allowed} = 10350 \text{ psi} \quad (\text{Brownell, table 13.1 hal 251})$$

$$\text{Efisiensi sambungan las (E)} = 0,8$$

$$\text{Faktor korosi (C)} = 0,125 \text{ in}$$

maka :

$$\begin{aligned} t_h &= \frac{0.885 Pd. rc}{fE - 0.1 Pd} + C \quad (\text{Brownell, 1959 : 270}) \\ &= \frac{0,885 \times 3,5142 \times 130}{10350 \times 0,8 - 0,1 \times 3,5142} + \frac{1}{8} \\ &= 0,1738 \text{ in} \end{aligned}$$

Sehingga diperoleh tebal tutup kanan dan kiri sebesar $\frac{1}{8}$ in

Standarisasi dari **Tabel 5.8 Brownell, hal.93** didapat :

Straight flange antara $1 \frac{1}{2}$ - $2 \frac{1}{4}$ in

$$\text{Diambil sf} = 2 \text{ in} = 0,0508 \text{ m}$$

$$icr = \frac{9}{16} \text{ in} = 0,0143 \text{ m}$$

Dari Brownell fig 5.8; 99 dihitung ukuran-ukuran sebagai berikut:

$$ID = ID \text{ shell} = 128,8145 \text{ in}$$

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



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$$= \frac{128,8145}{2}$$
$$= 64,4073 \text{ in}$$

$$AB = \frac{ID}{2} - icr$$
$$= \frac{128,8145}{2} - 8$$
$$= 56,4073 \text{ in}$$

$$BC = r - icr$$
$$= 130 - 8$$
$$= 122 \text{ in}$$

$$AC = \sqrt{(BC)^2 - (AB)^2}$$
$$= \sqrt{14884 - 3181,7802}$$
$$= 108,1768 \text{ in}$$

$$b = r - \sqrt{(BC)^2 - (AB)^2}$$
$$= 130 - 108,1768$$
$$= 21,823201 \text{ in}$$

$$sf = \text{straight flange} = \text{dipilih } 2 \text{ in } \textbf{(Brownell, T.5-6)}$$
$$t = \text{tebal dished} = \frac{1}{8} \text{ in} = 0,125 \text{ in}$$
$$OA = t + b + sf$$
$$= 0,125 + 21,823201 + 2$$
$$= 23,948201 \text{ in}$$
$$= 1,995683 \text{ ft}$$
$$= 0,6081 \text{ m}$$

Sehingga diperoleh tinggi tutup = 1,99967 ft

Tutup kiri juga menggunakan bentuk seperti tutup kanan
Design berbentuk horizontal , maka tinggi =lebar mendatar

$$L \text{ total} = L \text{ Tutup Kiri} + L \text{ Tangki} + L \text{ Tutup Kanan}$$
$$= 1,9996728 + 21,4691 + 1,9996728$$
$$= 25,4684 \text{ ft}$$



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$$= 7,7679 \text{ m}$$

Penentuan tinggi pipa dari dasar permukaan decanter. Asumsi feed masuk pada setengah bagian atas bejana dan cairan ringan pada 90 persen dari tinggi bejana, kemudian

$$\begin{aligned} \text{tinggi pipa fase ringan (z1)} &= 1 \times D_i \\ &= 1 \times 10,7345 \\ &= 9,66109 \text{ ft} \\ &= 2,9447 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{tinggi pipa feed (z3)} &= 1 \times D_i \\ &= 1 \times 10,7345 \\ &= 5,36727 \text{ ft} \\ &= 1,63594 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{tinggi pipa fase Massa (z2)} &= \frac{(z1 - z3) \rho_1 + z3}{\rho_2} \\ &= \frac{4,29382 \times 51,8077 + 5,36727}{86,0786} \\ &= 7,95157 \text{ ft} \\ &= 2,42364 \text{ m} \end{aligned}$$

Spesifikasi :

Nama Alat	: Dekanter
Kode	: H-230
Fungsi	: Untuk memisahkan <i>Light Phase</i> dan <i>Heavy Phase</i> berdasarkan perbedaan densitas
Tipe	: Decanter horizontal dengan tutup <i>torispherical Dish</i>
Rate Volumetrik	: 379,214 cuft/jam
Diameter	: 10,735 ft = 3,2719 m
Panjang	: 25,468 ft = 7,7628 m
Tebal Shell	: 3/16 in
Tebal Tutup	: 3/16 in
Bahan Kontruksi	: Carbon Steel type SA - 283 grade C
Jumlah	: 1 buah



18. Pompa (L-231)



- Fungsi : Untuk memindahkan produk dari Dekanter (H-230) menuju Menara Destilasi (D-310)
- Tipe : *Centrifugal pump*
- Dasar Pemilihan : Umum digunakan untuk memompa liquid dengan viskositas rendah < 10 cP

Komposisi Bahan Masuk

Komponen	Massa	Fraksi
	(kg)	
$C_{17}H_{33}COOH$	385,5641687	0,0441115
C_4H_9OH	4133,586637	0,4729145
$C_{17}H_{33}COOC_4H_9$	4167,504268	0,4767949
$C_{15}H_{31}COOH$	54,00860687	0,006179
Total	8740,66368	1

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,2479	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947

$$T = 30 \text{ } ^\circ\text{C} = 303,15 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\rho \text{ } C_{17}H_{33}COOH = 0,8845005 \text{ gr/ml}$$



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$$\begin{aligned}\rho \text{ C}_4\text{H}_9\text{OH} &= 0,8021585 \text{ gr/ml} \\ \rho \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,8525477 \text{ gr/ml} \\ \rho \text{ C}_{15}\text{H}_{31}\text{COOH} &= 0,8725909 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$\text{C}_{17}\text{H}_{33}\text{COOH}$	385,5641687	0,0441115	0,8845005	0,0390167
$\text{C}_4\text{H}_9\text{OH}$	4133,586637	0,4729145	0,8021585	0,3793524
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	4167,504268	0,4767949	0,8525477	0,4064904
$\text{C}_{15}\text{H}_{31}\text{COOH}$	54,00860687	0,006179	0,8725909	0,0053917
Total	8740,66368	1		0,8302513

$$\begin{aligned}\rho \text{ Campuran} &= 0,8302513 \text{ gr/ml} \times 62,4 \\ &= 51,807678 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Rate massa bahan} &= 8740,6637 \text{ kg/jam} \\ &= 19269,755 \text{ lb/jam}\end{aligned}$$

$$\begin{aligned}\text{Rate volumetrik} &= \frac{\text{rate massa bahan}}{\rho \text{ bahan}} \\ &= \frac{19269,755 \text{ lb/jam}}{51,807678 \text{ lb/cuft}} \\ &= 371,94785 \text{ cuft/jam} \\ &= 0,1033188 \text{ cuft/detik} \\ &= 46,372722 \text{ gpm}\end{aligned}$$

a. Menentukan diameter optimal pipa

asumsi aliran turbulen ($N_{re} > 2100$), maka digunakan persamaan

$$D_{i \text{ opt}} = 3,9 \times q_f^{0,45} \times \rho^{0,13} \quad (\text{Peters 4ed, Pers, 12-15, P.501})$$

Keterangan :

$$\begin{aligned}D_{i \text{ opt}} &= \text{Diameter pipa bagian dalam optimal (in)} \\ q_f &= \text{Rate volumetrik (ft}^3/\text{s)} \\ \rho &= \text{Densitas larutan (lb/ft}^3\text{)}\end{aligned}$$

Sehingga,



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$$\begin{aligned} D_{i \text{ opt}} &= 3,9 \times qf^{0,45} \times \rho^{0,13} \\ &= 3,9 \times 0,36 \times 1,67 \\ &= 2,35 \text{ in} \end{aligned}$$

Dari Kern Table. 11, maka dipilih pipa dengan spesifikasi :

Pipe size = 2 1/2 in

Sch = 40

OD = 2,88 in = 0,24 ft = 0,07 m

ID = 2,46 in = 0,2 ft = 0,06 m

$$\begin{aligned} A &= \frac{1}{4} \times \pi \times ID^2 \\ &= \frac{1}{4} \times 3,14 \times 0,04199 \\ &= 0,03296 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Kecepatan Aliran (V)} &= \frac{\text{Rate volumetrik}}{\text{Luas Area (A)}} \\ &= \frac{0,10332}{0,03296} \\ &= 3,13437 \text{ ft/s} \end{aligned}$$

b. Menghitung Nre

$$\text{sg reff} = 1 \quad (\text{Kern, Table. 6 p. 808})$$

$$\mu \text{ reff} = 0,8 \text{ cP} \quad (\text{Kern, Fig. 14 p. 823})$$

$$\rho \text{ reff} = 62,4 \text{ lb/ft}^3$$

$$\begin{aligned} \text{sg bahan} &= \frac{\rho \text{ bahan}}{\rho \text{ reff}} \\ &= \frac{51,8077 \text{ lb/ft}^3}{62,43 \text{ lb/ft}^3} \\ &= 0,82985 \end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	-6,13	1690	0,008	-6E-06
C ₄ H ₉ OH	-5,397	1325,6	0,006	-6E-06
C ₁₇ H ₃₃ COOC ₄ H ₉	-15,2751	2934	0,02692	-1,8E-05



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$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05

$$T = 30^{\circ}C = 303,15 \text{ K}$$

$$\text{Log10 } \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\begin{aligned} \mu_{C_{17}H_{33}COOH} &= 18,934047 \text{ cP} \\ \mu_{C_4H_9OH} &= 1,9421564 \text{ cP} \\ \mu_{C_{17}H_{33}COOC_4H_9} &= 7,9912799 \text{ cP} \\ \mu_{C_{15}H_{31}COOH} &= 14,781711 \text{ cP} \end{aligned}$$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
$C_{17}H_{33}COOH$	385,56417	0,0441115	18,934047	0,8352101
C_4H_9OH	4133,5866	0,4729145	1,9421564	0,9184739
$C_{17}H_{33}COOC_4H_9$	4167,5043	0,4767949	7,9912799	3,8102019
$C_{15}H_{31}COOH$	54,008607	0,006179	14,781711	0,0913363
Total	8740,6637	1		5,6552221

$$\begin{aligned} \mu_{\text{Campuran}} &= 5,6552221 \text{ cP} \\ &= 0,0038003 \text{ lb/ft s} \end{aligned}$$

$$\begin{aligned} N_{re} &= \frac{ID \times V \times \rho_{\text{bahan}}}{\mu} \\ &= \frac{0,2 \times 3,13 \times 51,8}{0,0038003} \\ &= 8755,9844 > 2100 \\ &\text{asumsi aliran turbulen benar} \end{aligned}$$

Dipilih bahan commercial steel, dengan

$$\begin{aligned} e &= 0,000046 \text{ m} \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88}) \\ \frac{e}{D} &= \frac{0,000046}{0,062459} \\ &= 0,0002245 \\ f &= 0,006 \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88}) \end{aligned}$$



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$$g_c = 32,174$$

$$\alpha = 1 \quad (\text{aliran turbulen}) \quad (\text{Peters \& Timmerhouse 4th ed : 485})$$

c. Menghitung Panjang Ekuivalen Suction, Le

Perhitungan friksi berdasarkan Peters & Timmerhaus, 4ed Tabel 1 hh. 484

Sambungan	Lc/D
Elbow standard 90°	32
Gate valve	7

$$\text{ID pipa} = 0,204918 \text{ ft}$$

Taksiran panjang pipa lurus

$$\text{Jarak dekanter ke menara destilasi} = 32,8084 \text{ ft}$$

$$\text{Tinggi menara destilasi} = 17,234 \text{ ft}$$

$$\text{Panjang pipa masuk} = 4 \text{ ft}$$

$$\text{Taksiran panjang pipa lurus} = 54,0429 \text{ ft}$$

$$2 \text{ elbow } 90^\circ = 2 \times 32 \times 0,2 \text{ ft}$$

$$= 13,1 \text{ ft}$$

$$1 \text{ gate valve} = 1 \times 7 \times 0,2 \text{ ft}$$

$$= 1,43 \text{ ft}$$

$$\text{Panjang total pipa (Le)} = 68,592 \text{ ft}$$

d. Perhitungan friksi

1. Friksi karena Gesekan Bahan dalam Pipa

$$g_c = 32,17 \text{ lbm.ft/lbf.s}^2$$

$$F_1 = \frac{2f \times V^2 \times Le}{g_c \times D} \quad (\text{Geankoplis 3ed, Pers, 2.10-16, P.93})$$

$$= \frac{0,01 \times 9,82 \times 68,6}{32,2 \times 0,2}$$

$$= 1,22666 \text{ ft.lbf/lbm}$$

2. Friksi karena kontraksi dari tangki penyimpanan ke pipa

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times g_c} \quad (\text{Geankoplis, 2014 eq. 2.10-16})$$

dimana

$$\alpha = 1 \text{ untuk aliran turbulen}$$



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Menentukan Kc [Peters 4 ed ; Page 484]

A dekanter > A pipa maka dianggap 0

Untuk A1 (dekanter) dan A2 (pipa), maka A2/A1 = 0

maka, **(Peters 4 ed ; Page 484)**

$$K = 0,4 \times (1,25 - A2/A1)$$

$$K = 0,4 \times (1,25 - 0)$$

$$K = 0,5$$

sehingga,

$$F_2 = \frac{0,5 \times 9,8242489 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} = 0,07635 \text{ ft.lbf/lbm}$$

3. Friksi karena ekspansi dari pipa ke tangki

$$F_3 = \frac{\Delta V^2}{2 \times gc} \quad \text{(Geankoplis 3ed, Pers, 2.10-15, P.93)}$$

(V₁ <<<< V₂ dianggap = 0)

$$= \frac{9,824248888 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} = 0,15269 \text{ ft.lbf/lbm}$$

4. Friksi karena elbow 90°

$$F_4 = n \times \frac{K_f \times V^2}{2 \times gc} \quad \text{(Geankoplis 3ed, Pers, 2.10-17, P.94)}$$

diketahui :

$$K_f = 0,75$$

$$F_4 = \frac{3 \times 0,75 \times 9,8242489 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2} = 0,34356 \text{ ft.lbf/lbm}$$

5. Friksi karena gate valve

$$F_5 = n \times \frac{K_f \times V^2}{2 \times gc} \quad \text{(Geankoplis 3ed Pers. 2.10-1)}$$

diketahui :

$$K_f \text{ gate valve (wide open)} = 0,17$$



$$F_5 = \frac{1 \times 0,17 \times 9,8242489 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,02596 \text{ ft.lbf/lbm}$$

6. Friksi Total

$$\Sigma F = F_1 + F_2 + F_3 + F_4 + F_5$$

$$= 1,82521 \text{ ft.lbf/lbm}$$

e. Perhitungan Energi Tekanan

$$H_{\text{liquida}} = 8,5876 \text{ ft}$$

$$\rho_{\text{bahan}} = 51,8077 \text{ lbm/ft}^3$$

$$g/gc = 1 \text{ lbf/lbm}$$

$$P_2 = 1 \text{ atm} = 2116,8 \text{ lbf/ft}^2$$

Energi Tekanan

$$P_1 = P_{\text{atm}} + P_{\text{hidrostatik}}$$

$$= 1 \text{ atm} + \left(\rho \times \frac{g}{gc} \times H_{\text{liq}} \right)$$

$$= 2117 \text{ lbf/ft}^2 + (51,8 \text{ lbm/ft}^3 \times 1 \text{ lbf/lbm} \times 8,59 \text{ ft})$$

$$= 2561,7055 \text{ lbf/ft}^2$$

$$\frac{\Delta P}{\rho} = \frac{(P_1 - P_2)}{\rho}$$

$$= \frac{2561,71 - 2116,8}{51,80767829}$$

$$= 8,58764 \text{ ft.lbf/lbm}$$

f. Perhitungan Energi Kinetik

$$E_k = \frac{\Delta V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis, 3ed Eq. 2.7-5 p. 66})$$

$$= \frac{9,824248888}{2 \times 1 \times 32,17}$$

$$= 0,1526927 \text{ ft.lbf/lbm}$$

g. Perhitungan Energi potensial

Diketahui



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$$\begin{aligned}
 Z_1 &= 8,5876 \text{ ft} \\
 Z_2 &= 17,234 \text{ ft} \\
 g/gc &= 1 \text{ lbf/lbm} \\
 \text{Sehingga,} \\
 E_p &= \Delta Z \times \frac{g}{gc} \quad \text{(Geankoplis, 2014 Eq. 2.7-5 p. 66)} \\
 &= (17,2 - 8,59) \text{ ft} \times 1 \text{ lbf/lbm} \\
 &= 8,64683 \text{ ft.lbf/lbm}
 \end{aligned}$$

h. Persamaan Bernouli

$$\begin{aligned}
 -W_f &= \frac{\Delta P}{\rho} + \Delta Z \times \frac{g}{gc} + \frac{\Delta V^2}{2 \times \alpha \times gc} + \Sigma F \\
 &= 8,58764 + 8,64683 + 0,15269 + 1,82521 \\
 &= 19,2124 \text{ ft.lbf/lbm}
 \end{aligned}$$

i. Perhitungan Power Pompa

$$\begin{aligned}
 hp &= \frac{-W_f \times \text{flowrate(gpm)} \times sg}{3960} \\
 &\quad \text{(Perry 6ed ; Pers 6-11, Page 6-5)} \\
 &= \frac{19,2124 \times 46,3727 \times 0,82985}{3960} \\
 &= 0,1867 \text{ hp}
 \end{aligned}$$

$$\text{Efisiensi pompa} = 65\% \quad \text{(Peters 4 ed ; Figure 14 - 37 Page 520)}$$

$$\begin{aligned}
 B_{hp} &= \frac{B_{ph}}{\eta_{pompa}} \\
 &= \frac{0,1867021 \text{ hp}}{65\%} \\
 &= 0,287234 \text{ hp}
 \end{aligned}$$

$$\begin{aligned}
 \text{Efisiensi motor} &= 80\% \\
 \text{Power motor} &= \frac{B_{hp}}{ef.Motor} \\
 &= \frac{0,287234 \text{ hp}}{80\%} \\
 &= 0,3590425 \text{ hp}
 \end{aligned}$$

$$\text{Maka digunakan power} = 0,5 \text{ hp}$$



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Spesifikasi

Nama Alat	: Pompa
Kode	: L-231
Fungsi	: Untuk memindahkan produk dari Dekanter (H-230) ke menara destilasi 1 (D-310)
Tipe	: <i>Centrifugal pump</i>
Bahan konstruksi	: <i>Commercial steel</i>
Dasar Pemilihan	: Umum digunakan untuk memompa liquid dengan viskositas rendah
Ukuran Pipa	: 2 1/2 in 40 sch
Kapasitas	: 19269,8 lb/jam
Rate volumetrik	: 371,948 ft ³ /jam
Total Dynamic head	: 19,2124 ft.lbf/lbm
Efisiensi pompa	: 65%
Efisiensi motor	: 80%
Power	: 0,5 hp
Jumlah	: 1 buah

18. Pompa (L-233)



Fungsi	: Untuk memindahkan hasil <i>heavy phase</i> dari Dekanter (H-230) menuju Tangki Penyimpanan (F-420)
Tipe	: <i>Centrifugal pump</i>
Dasar Pemilihan	: Umum digunakan untuk memompa liquid dengan viskositas rendah <10 cP

Komposisi Bahan Masuk

Komponen	Massa	Fraksi Massa
	(kg)	
C ₄ H ₉ OH	21,94413635	0,0462913
H ₂ O	332,4869143	0,7013836



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Na ₂ SO ₄	119,6132921	0,2523251
Total	474,0443428	1

Menghitung Densitas Larutan

Komponen	A	B	T _c	n
C ₄ H ₉ OH	0,26891	0,2667	562,93	0,2457
H ₂ O	0,3471	0,274	647,13	0,2857
Na ₂ SO ₄	0,26141	0,1	3700	0,2857

$$T = 30 \text{ }^{\circ}\text{C} = 303,15 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned}\rho \text{ C}_4\text{H}_9\text{OH} &= 0,8021585 \text{ gr/ml} \\ \rho \text{ H}_2\text{O} &= 1,0228823 \text{ gr/ml} \\ \rho \text{ Na}_2\text{SO}_4 &= 2,4728351 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
C ₄ H ₉ OH	21,94413635	0,0462913	0,8021585	0,037133
H ₂ O	332,4869143	0,7013836	1,0228823	0,7174328
Na ₂ SO ₄	119,6132921	0,2523251	2,4728351	0,6239584
Total	474,0443428	1		1,3785242

$$\begin{aligned}\rho \text{ Campuran} &= 1,3785242 \text{ gr/ml} \times 62,4 \\ &= 86,019909 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Rate massa bahan} &= 474,04434 \text{ kg/jam} \\ &= 1045,0829 \text{ lb/jam}\end{aligned}$$

$$\begin{aligned}\text{Rate volumetrik} &= \frac{\text{rate massa bahan}}{\rho \text{ bahan}} \\ &= \frac{1045,0829 \text{ lb/jam}}{86,019909 \text{ lb/cuft}} \\ &= 12,149314 \text{ cuft/jam}\end{aligned}$$



$$= 0,0033748 \text{ cuft/detik}$$

$$= 1,5147198 \text{ gpm}$$

a. Menentukan diameter optimal pipa

asumsi aliran turbulen ($N_{re} > 2100$), maka digunakan persamaan

$$D_{i \text{ opt}} = 3,9 \times qf^{0,45} \times \rho^{0,13} \quad (\text{Peters 4ed, Pers, 12-15, P.501})$$

Keterangan :

$D_{i \text{ opt}}$ = Diameter pipa bagian dalam optimal (in)

qf = Rate volumetrik (ft^3/s)

ρ = Densitas larutan (lb/ft^3)

Sehingga,

$$\begin{aligned} D_{i \text{ opt}} &= 3,9 \times qf^{0,45} \times \rho^{0,13} \\ &= 3,9 \times 0,08 \times 1,78 \\ &= 0,54 \text{ in} \end{aligned}$$

Dari Kern Table. 11, maka dipilih pipa dengan spesifikasi :

$$\text{Pipe size} = 3/4 \text{ in}$$

$$\text{Sch} = 40$$

$$\text{OD} = 1,05 \text{ in} = 0,09 \text{ ft} = 0,03 \text{ m}$$

$$\text{ID} = 0,74 \text{ in} = 0,06 \text{ ft} = 0,02 \text{ m}$$

$$\begin{aligned} A &= \frac{1}{4} \times \pi \times \text{ID}^2 \\ &= \frac{1}{4} \times 3,14 \times 0,00382 \\ &= 0,003 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Kecepatan Aliran (V)} &= \frac{\text{Rate volumetrik}}{\text{Luas Area (A)}} \\ &= \frac{0,00337}{0,003} \\ &= 1,12533 \text{ ft/s} \end{aligned}$$



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b. Menghitung Nre

$$\text{sg reff} = 1 \quad (\text{Kern, Table. 6 p. 808})$$

$$\mu \text{ reff} = 0,8 \text{ cP} \quad (\text{Kern, Fig. 14 p. 823})$$

$$\rho \text{ reff} = 62,4 \text{ lb/ft}^3$$

$$\begin{aligned} \text{sg bahan} &= \frac{\rho \text{ bahan}}{\rho \text{ reff}} \\ &= \frac{86,0199 \text{ lb/ft}^3}{62,43 \text{ lb/ft}^3} \\ &= 1,37786 \end{aligned}$$

Menghitung Viskositas Larutan

Komponen	A	B	C	D
C ₄ H ₉ OH	-5,397	1325,6	0,006	-6E-06
H ₂ O	-10,252	1792,5	0,01773	-1E-05
Na ₂ SO ₄	11,2905	-4576,9	-0,0068	9,2E-07

$$T = 303,15 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \text{ C}_4\text{H}_9\text{OH} = 1,9421564 \text{ cP}$$

$$\mu \text{ H}_2\text{O} = 0,7501981 \text{ cP}$$

$$\mu \text{ Na}_2\text{SO}_4 = 1,663\text{E-}06 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
C ₄ H ₉ OH	21,944136	0,0462913	1,9421564	0,089905
H ₂ O	332,48691	0,7013836	0,7501981	0,5261766
Na ₂ SO ₄	119,61329	0,2523251	1,663E-06	4,196E-07
Total	474,04434	1		0,616082

$$\begin{aligned} \mu \text{ Campuran} &= 0,616082 \text{ cP} \\ &= 0,000414 \text{ lb/ft s} \end{aligned}$$



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$$\begin{aligned} N_{re} &= \frac{ID \times V \times \rho \text{ bahan}}{\mu} \\ &= \frac{0,06 \times 1,13 \times 86}{0,000414} \\ &= 14451,797 > 2100 \\ &\text{asumsi aliran turbulen benar} \end{aligned}$$

$$\begin{aligned} e &= 0,000046 \text{ m} && \text{(Geankoplis 3ed, F.2.10-3, P. 88)} \\ e/D &= \frac{0,000046 \text{ m}}{0,0188393} \\ &= 0,0024417 \\ f &= 0,006 && \text{(Geankoplis 3ed, F.2.10-3, P. 88)} \\ g_c &= 32,174 \\ \alpha &= 1 \quad (\text{aliran turbulen}) && \text{(Peters \& Timmerhouse 4th ed : 485)} \end{aligned}$$

c. Menghitung Panjang Ekuivalen Suction, Le

Perhitungan friksi berdasarkan Peters & Timmerhaus, 4ed Tabel 1 hh. 484

Sambungan	Lc/D
Elbow standard 90°	32
Gate valve	7

$$ID \text{ pipa} = 0,0618086 \text{ ft}$$

Taksiran panjang pipa lurus

$$\text{Jarak dekanter ke tangki penyimpanan} = 32,8084 \text{ ft}$$

$$\text{Tinggi Tangki penyimpanan} = 26,720 \text{ ft}$$

$$\text{Panjang pipa masuk} = 4 \text{ ft}$$

$$\text{Taksiran panjang pipa lurus} = 63,5286 \text{ ft}$$

$$\begin{aligned} 3 \text{ elbow } 90^\circ &= 3 \times 32 \times 0,06 \text{ ft} \\ &= 5,93 \text{ ft} \end{aligned}$$

$$\begin{aligned} 1 \text{ gate valve} &= 1 \times 7 \times 0,06 \text{ ft} \\ &= 0,43 \text{ ft} \end{aligned}$$

$$\text{Panjang total pipa (Le)} = 69,8949 \text{ ft}$$

d. Perhitungan friksi

1. Friksi karena Gesekan Bahan dalam Pipa

$$g_c = 32,17 \text{ lbf.ft/lbm.s}^2$$



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$$\begin{aligned}
 F_1 &= \frac{2f \times V^2 \times L_e}{g_c \times D} && \text{(Geankoplis 3ed, Pers, 2.10-6, P.89)} \\
 &= \frac{0,01 \times 1,27 \times 69,9}{32,2 \times 0,06} \\
 &= 0,53418 \text{ ft.lbf/lbm}
 \end{aligned}$$

2. Friksi karena kontraksi dari tangki penyimpanan ke pipa

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times g_c} \quad \text{(Geankoplis 3ed, Pers, 2.10-16, P.93)}$$

dimana

$\alpha = 1$ untuk aliran turbulen

Menentukan Kc [Peters 4 ed ; Page 484]

A tangki > A pipa maka dianggap 0

Untuk A1 (tangki) dan A2 (pipa), maka A2/A1 = 0

maka,

$$K = 0,4 \times (1,25 - A_2/A_1) \quad \text{(Peters 4 ed ; Page 484)}$$

$$K = 0,4 \times (1,25 - 0)$$

$$K = 0,5$$

sehingga,

$$\begin{aligned}
 F_2 &= \frac{0,5 \times 1,2663787 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\
 &= 0,00984 \text{ ft.lbf/lbm}
 \end{aligned}$$

3. Friksi karena ekspansi dari pipa ke tangki

$$F_3 = \frac{\Delta V^2}{2 \times \alpha \times g_c} \quad \text{(Geankoplis 3ed, Pers, 2.10-15, P.93)}$$

($V_1 \ll V_2$ dianggap = 0)

$$\begin{aligned}
 &= \frac{1,266378658 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\
 &= 0,01968 \text{ ft.lbf/lbm}
 \end{aligned}$$

4. Friksi karena elbow 90°

$$F_4 = n \times \frac{K_f \times V^2}{2 \times g_c} \quad \text{(Geankoplis 3ed, Pers, 2.10-17, P.94)}$$

diketahui :

$$K_f = 0,75 \quad \text{(Geankoplis 3ed, T.2.10-1, P. 93)}$$



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$$F_4 = \frac{3 \times 0,75 \times 1,2663787 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,04429 \text{ ft.lbf/lbm}$$

5. Friksi karena gate valve

$$F_5 = n \times \frac{K_f \times V^2}{2 \times gc} \quad \text{(Geankoplis 3ed Pers. 2.10-1)}$$

diketahui :

$$K_f \text{ gate valve (wide open)} = 0,17$$

$$F_5 = \frac{1 \times 0,17 \times 1,2663787 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,00335 \text{ ft.lbf/lbm}$$

6. Friksi Total

$$\Sigma F = F_1 + F_2 + F_3 + F_4 + F_5$$

$$= 0,61134 \text{ ft.lbf/lbm}$$

e. Perhitungan Energi Tekanan

$$H \text{ liquida} = 8,5876 \text{ ft}$$

$$\rho \text{ bahan} = 86,0199 \text{ lbm/ft}^3$$

$$g/gc = 1 \text{ lbf/lbm}$$

$$P_2 = 1 \text{ atm} = 2116,8 \text{ lbf/ft}^2$$

Energi Tekanan

$$P_1 = P \text{ atm} + P \text{ hidrostatik}$$

$$= 1 \text{ atm} + \left(\rho \times \frac{g}{gc} \times H \text{ liq} \right)$$

$$= 2117 \text{ lbf/ft}^2 + \left(86 \text{ lbm/ft}^3 \times 1 \text{ lbf/lbm} \times 8,59 \text{ ft} \right)$$

$$= 2855,5077 \text{ lbf/ft}^2$$

$$\frac{\Delta P}{\rho} = \frac{(P_1 - P_2)}{\rho}$$

$$= \frac{2855,51 - 2116,8}{86,019909}$$

$$= 8,58764 \text{ ft.lbf/lbm}$$



f. Perhitungan Energi Kinetik

$$\begin{aligned}
 E_k &= \frac{\Delta V^2}{2 \times \alpha \times g_c} && \text{(Geankoplis, 3ed Eq. 2.7-5 p. 66)} \\
 &= \frac{1,266378658}{2 \times 1 \times 32,17} \\
 &= 0,0196826 \text{ ft.lbf/lbm}
 \end{aligned}$$

g. Perhitungan Energi potensial

Diketahui

$$Z_1 = 8,5876 \text{ ft} \quad (\text{Tinggi Larutan dari Dekanter})$$

$$Z_2 = 23,513 \text{ ft} \quad (\text{Tinggi Tangki Penyimpanan})$$

$$g/g_c = 1 \text{ lbf/lbm}$$

Sehingga,

$$\begin{aligned}
 E_p &= \Delta Z \times \frac{g}{g_c} && \text{(Geankoplis, 2014 Eq. 2.7-5 p. 66)} \\
 &= (23,5 - 8,59) \text{ ft} \times 1 \text{ lbf/lbm} \\
 &= 14,9258 \text{ ft.lbf/lbm}
 \end{aligned}$$

h. Persamaan Bernouli

$$\begin{aligned}
 -W_f &= \frac{\Delta P}{\rho} + \Delta Z \times \frac{g}{g_c} + \frac{\Delta V^2}{2 \times \alpha \times g_c} + \Sigma F \\
 &= 8,58764 + 14,9258 + 0,01968 + 0,61134 \\
 &= 24,1445 \text{ ft.lbf/lbm}
 \end{aligned}$$

i. Perhitungan Power Pompa

$$\begin{aligned}
 \text{hp} &= \frac{-W_f \times \text{flowrate(gpm)} \times \text{sg}}{3960} \\
 &\quad (\text{Perry 6ed ; Pers 6-11, Page 6-5}) \\
 &= \frac{24,1445 \times 1,51472 \times 1,37786}{3960} \\
 &= 0,01273 \text{ hp}
 \end{aligned}$$

$$\text{Efisiensi pompa} = 65\% \quad (\text{Peters 4 ed ; Figure 14 - 37 Page 520})$$

$$\begin{aligned}
 B_{hp} &= \frac{B_{ph}}{\eta \text{ pompa}} \\
 &= \frac{0,0127251}{\eta \text{ pompa}} \text{ hp}
 \end{aligned}$$



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$$\begin{aligned} & 65\% \\ & = 0,0195771 \text{ hp} \\ \text{Efisiensi motor} & = 80\% \\ \text{Power motor} & = \frac{\text{Bhp}}{\text{ef.Motor}} \\ & = \frac{0,0195771 \text{ hp}}{80\%} \\ & = 0,0244713 \text{ hp} \\ \text{Maka digunakan power} & = 0,5 \text{ hp} \end{aligned}$$

Spesifikasi

Nama Alat	: Pompa
Kode	: L-231
Fungsi	: Untuk memindahkan produk <i>heavy phase</i> dari Dekanter (H-230) ke Tangki Penyimpanan (F-420)
Tipe	: <i>Centrifugal pump</i>
Dasar Pemilihan	: Umum digunakan untuk memompa liquid dengan viskositas rendah
Ukuran Pipa	: 3/4 in 40 sch
Kapasitas	: 1045,08 lb/jam
Rate volumetrik	: 12,1493 ft ³ /jam
Total Dynamic head	: 24,1445 ft.lbf/lbm
Efisiensi pompa	: 65%
Efisiensi motor	: 80%
Power	: 0,5 hp
Jumlah	: 1 buah
	:

19. Heater (E-232)



Fungsi	: Untuk memanaskan produk suhu 35°C menjadi 144°C untuk dialirkan ke menara destilasi (D-310)
Tipe	: 1-2 Shell and Tube Exchanger



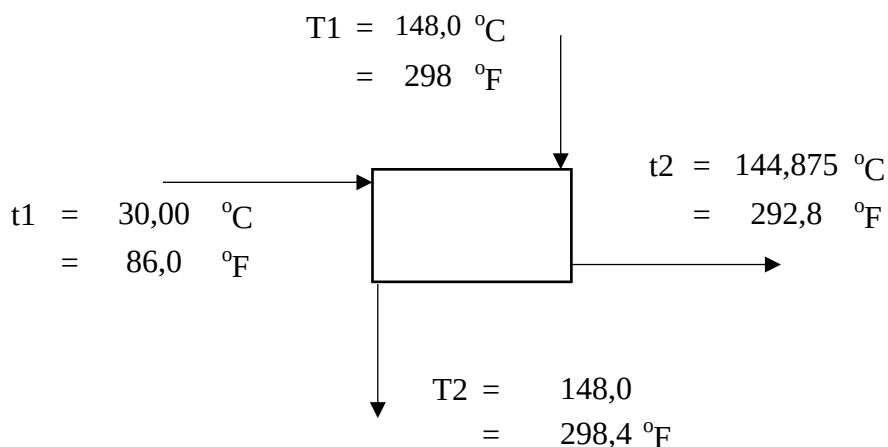
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Dasar Pemilihan : Umum digunakan untuk memanaskan liquid

Kondisi Operasi

Tekanan = 1 atm

Suhu = 144,875 °C



Perhitungan

1. Data dari neraca massa dan neraca panas diperoleh:

Untuk Fluida panas : Steam

T masuk (T1) = 148,0 °C = 298,4 F

T keluar (T2) = 148 °C = 298,4 F

Untuk Fluida dingin : Larutan Produk

T masuk (t1) = 30,00 °C = 86,0 F

T keluar (t2) = 144,875 °C = 292,8 F

massa bahan = 8740,6637 kg/jam

= 19325,607 lb/jam

Panas yang dibutuhkan

Q = 593663,4 kkal/jam

= 2354290,9 Btu/jam

Steam yang digunakan

Massa steam = 1171,92 kg/jam

= 2591,12 lb/jam

2. Penentuan ΔT LMTD

Hot fluida	Cold fluida	diff



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298,4	higher temp	292,8	5,63
298,4	lower temp	86,0	212
0,0		206,8	

$$\Delta t_{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$

$$\begin{aligned} \Delta t_{LMTD} &= \frac{6 - 212}{\ln \frac{6}{212}} \\ &= 56,943965 \text{ F} \end{aligned}$$

$$\begin{aligned} R &= \frac{T_1 - T_2}{t_2 - t_1} && \text{(Kern, Eq 5.17)} \\ &= \frac{298 - 298}{293 - 86} \\ &= 0 \end{aligned}$$

$$\begin{aligned} S &= \frac{t_2 - t_1}{T_1 - t_1} && \text{(Kern, Pers. 5.14, : 149)} \\ &= \frac{293 - 86}{298 - 86} \\ &= 0,97352 \end{aligned}$$

$$\begin{aligned} FT &= 1 && \text{(Kern Fig. 18, : 828)} \\ \Delta T &= \Delta T_{LMTD} \times FT && \text{(Kern, Pers. 7.42 : 149)} \\ &= 56,944 \text{ } ^\circ\text{F} \times 1 \\ &= 56,944 \text{ } ^\circ\text{F} \end{aligned}$$

3. Tc dan tc

$$T_c = t_{\text{average steam}}$$

$$\begin{aligned} T_c &= \frac{T_1 + T_2}{2} \\ &= \frac{298 + 298}{2} \\ &= 298 \text{ } ^\circ\text{F} \end{aligned}$$



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$$\begin{aligned}
 t_c &= t \text{ average bahan} \\
 t_c &= \frac{t_1 + t_2}{2} \\
 &= \frac{86 + 293}{2} \\
 &= 189,387 \text{ } ^\circ\text{F} \\
 &= 360,587 \text{ K}
 \end{aligned}$$

Menghitung Kapasitas Panas, Konduktivitas Thermal dan Viskositas
Fluida Panas

$$\begin{aligned}
 c_p &= 0,45 \text{ Btu/lb}^\circ\text{F} && \text{(Kern, Fig 3)} \\
 k &= 0,016 && \text{(Kern, Table 5)} \\
 \mu &= 0,014 \text{ cP} && \text{(Kern, Fig.15)}
 \end{aligned}$$

Fluida Dingin

Menghitung nilai kapasitas panas

komponen	A	B	C	D
$\text{C}_{17}\text{H}_{33}\text{COOH}$	278,686	2,5434	-0,0054	4,9E-06
$\text{C}_4\text{H}_9\text{OH}$	83,877	0,56628	-0,0017	2,3E-06
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	178,423	3,667	-0,008	7,1E-06
$\text{C}_{15}\text{H}_{31}\text{COOH}$	86,29	3,5237	-0,0073	6,1E-06

$$\begin{aligned}
 T &= 360,587 \text{ K} \\
 C_p &= A + BT + CT^2 + DT^3
 \end{aligned}$$

Sehingga diperoleh

$$\begin{aligned}
 C_p \text{ C}_{17}\text{H}_{33}\text{COOH} &= 719,923 \text{ Kkal/KmolK} \\
 C_p \text{ C}_4\text{H}_9\text{OH} &= 174,866 \text{ Kkal/KmolK} \\
 C_p \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 796,853 \text{ Kkal/KmolK} \\
 C_p \text{ C}_{15}\text{H}_{31}\text{COOH} &= 691,118 \text{ Kkal/KmolK}
 \end{aligned}$$

komponen	BM	Cp	Fraksi	Cp
	Kg/Kmol	kcal/Kmol K	Xf	kcal/Kg K
$\text{C}_{17}\text{H}_{33}\text{COOH}$	282,47	719,92303	0,04411	2,54867
$\text{C}_4\text{H}_9\text{OH}$	74	174,86581	0,47291	2,36305
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	310,56	796,85288	0,47679	2,56586



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$C_{15}H_{31}COOH$	256,42	691,11847	0,00618	2,69526
Total			1	

$$1 \text{ kkal/kg K} = 0,23885 \text{ Btu/lb } ^\circ\text{F}$$

$$C = \sum_i^n C_p \cdot X_f$$

$$C = 0,5899569 \text{ Btu/lb } ^\circ\text{F}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
$C_{17}H_{33}COOH$	-6,13	1690	0,008	-6E-06
C_4H_9OH	-5,397	1325,6	0,006	-6E-06
$C_{17}H_{33}COOC_4H_9$	-15,275	2934	0,02692	-2E-05
$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05

$$T = 360,58741 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu_{C_{17}H_{33}COOH} = 4,0072469 \text{ cP}$$

$$\mu_{C_4H_9OH} = 0,5325003 \text{ cP}$$

$$\mu_{C_{17}H_{33}COOC_4H_9} = 1,6517545 \text{ cP}$$

$$\mu_{C_{15}H_{31}COOH} = 3,1984223 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
$C_{17}H_{33}COOH$	385,56417	0,0441115	4,0072469	0,1767658
C_4H_9OH	4133,5866	0,4729145	0,5325003	0,2518271
$C_{17}H_{33}COOC_4H_9$	4167,5043	0,4767949	1,6517545	0,7875482
$C_{15}H_{31}COOH$	54,008607	0,006179	3,1984223	0,0197631
Total	8740,6637	1		1,2359043

$$\mu_{\text{Campuran}} = 1,2359043 \text{ cP}$$



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$$= 2,989776 \text{ lb/jam ft}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
$C_{17}H_{33}COOH$	-6,13	1690	0,008	-6E-06
C_4H_9OH	-5,397	1325,6	0,006	-6E-06
$C_{17}H_{33}COOC_4H_9$	-15,275	2934	0,02692	-2E-05
$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05

$$T = 295,09546 \text{ F} = 419,31414 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu_{C_{17}H_{33}COOH} = 1,3208004 \text{ cP}$$

$$\mu_{C_4H_9OH} = 0,2048546 \text{ cP}$$

$$\mu_{C_{17}H_{33}COOC_4H_9} = 0,6780299 \text{ cP}$$

$$\mu_{C_{15}H_{31}COOH} = 1,1267246 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
$C_{17}H_{33}COOH$	385,56417	0,0441115	1,3208004	0,0582625
C_4H_9OH	4133,5866	0,4729145	0,2048546	0,0968787
$C_{17}H_{33}COOC_4H_9$	4167,5043	0,4767949	0,6780299	0,3232812
$C_{15}H_{31}COOH$	54,008607	0,006179	1,1267246	0,006962
Total	8740,6637	1		0,4853845

$$\begin{aligned} \mu_{\text{Campuran}} &= 0,4853845 \text{ cP} \\ &= 1,1741937 \text{ lb/jam ft} \end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457



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$C_{17}H_{33}COOC_4H_9$	0,24798	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947

$$T = 360,587 \text{ K}$$

$$\rho = A \times B^{-\left(1 - \frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\rho \quad C_{17}H_{33}COOH = 0,78057 \text{ gr/ml}$$

$$\rho \quad C_4H_9OH = 0,6412 \text{ gr/ml}$$

$$\rho \quad C_{17}H_{33}COOC_4H_9 = 0,74198 \text{ gr/ml}$$

$$\rho \quad C_{15}H_{31}COOH = 0,76764 \text{ gr/ml}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$C_{17}H_{33}COOH$	385,56417	0,0441115	0,7805686	0,0344321
C_4H_9OH	4133,5866	0,4729145	0,6411988	0,3032322
$C_{17}H_{33}COOC_4H_9$	4167,5043	0,4767949	0,741981	0,3537728
$C_{15}H_{31}COOH$	54,008607	0,006179	0,7676388	0,0047432
Total	8740,6637	1		0,6961803

$$\begin{aligned} \rho \text{ Campuran} &= 0,6961803 \text{ gr/ml} \times 62,4 \\ &= 43,441653 \text{ lb/cuft} \end{aligned}$$

$$\begin{aligned} Sg &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{43,441653 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,6958458 \end{aligned}$$

$$\begin{aligned} K_{mix} &= \frac{0,0677}{\text{sg} [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{0,696 [1 - 0,0003 (0 - 32)]} \\ &= 0,0964 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243} \end{aligned}$$



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Dipilih tipe : 1-2 Heat Exchanger

Digunakan shell and tube dengan ukuran :

Tube Side		Shell Side	
OD	= 3/4 in	Shell ID	= 21 1/4 in
BWG	= 8	Passes	= 1 in
Pitch	= 1 in Square Pitch		
L	= 10 ft		
Passes	= 2		
ID	= 1,17 in		
a't	= 1,075 in ²		
a"	= 0,3925 ft ² /ft panjang		
Thickness	= 0,165 in		
(kern, Table.10, Hal. 843)			

Harga UD = 5 - 75 Btu/jam.ft.°F **(Kern, tabel 8 hal 840)**
Dipilih UD = 55 Btu/jam.ft.°F

$$\begin{aligned} A &= \frac{Q}{UD \times \Delta t} && \text{(Kern Eq. 7.6)} \\ &= \frac{2354290,926}{55 \times 56,944} \\ &= 751,709 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Jumlah tube (Nt)} &= \frac{A}{a'' \times L} \\ &= \frac{751,7089769}{0,39 \times 10} \\ &= 239,398 \text{ buah} \end{aligned}$$

UD koreksi

$$\begin{aligned} A &= Nt \times L \times a'' \\ &= 240 \times 10 \times 0,39 \\ &= 942,0 \end{aligned}$$



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$$\begin{aligned}
 UD &= \frac{Q}{A \times \Delta t} \\
 &= \frac{2354290,926}{942 \times 56,944} \\
 &= 43,88959
 \end{aligned}$$

Menentukan nilai De :

$$\begin{aligned}
 De &= \frac{4 \left(\frac{Pt^2}{4} - \pi \frac{OI^2}{4} \right)}{\pi OD} \\
 &= \frac{4 \left(1^2 - 3,14 \times \frac{0,75^2}{4} \right)}{3,14 \times 0,75} \\
 &= 0,94851 \text{ in} = 0,08 \text{ ft}
 \end{aligned}$$

Fluida Panas : Shell Tube	Fluida Dingin : Tube Side
Steam	Produk
4. Flow Area (at) $ \begin{aligned} as &= \frac{Nt \times at'}{144 \times n} \\ &= \frac{240 \times 1,08}{144 \times 2} \\ &= 0,9 \text{ ft}^2 \end{aligned} $ (Kern, Eq 7.48)	4. Flow Area (at) asums B = 0,25 ID $ \begin{aligned} &= 5,3125 \\ C &= Pt - OD \\ &= 1 - 3/4 \\ &= 0,25 \end{aligned} $ $ \begin{aligned} as &= \frac{ID \times C' \times B}{144 \times Pt} \\ &= \frac{21,25 \times 0,25 \times 5,3125}{144 \times 1} \\ &= 0,1959907 \text{ ft}^2 \end{aligned} $ (Kern, Eq. 7.1)
5. Mass Velocity (Gs) $ \begin{aligned} Gs &= \frac{W}{at} \\ &= \frac{2591,1185}{0,9} \\ &= 2879,0205 \text{ lb/jam ft}^2 \end{aligned} $	5. Mass Velocity (Gt) $ \begin{aligned} Gt &= \frac{W}{as} \\ &= \frac{19325,607}{0,1959907} \\ &= 98604,732 \text{ lb/jam ft}^2 \end{aligned} $ (Kern, Eq 7.2)



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6. Bilangan Reynold (Res) $\begin{aligned} De &= 0,1 \text{ ft} \\ \mu &= 2,99 \text{ lb/ft.jam} \end{aligned}$ $\begin{aligned} \text{Res} &= \frac{De \times Gs}{\mu} \\ &= \frac{0,08 \times 2879,02}{0,03388} \\ &= 6716,8182 \end{aligned}$	6. Bilangan Reynold (Ret) $\begin{aligned} D &= 0,08 \text{ ft} \\ \mu &= 0,03388 \text{ lb/ft.jam} \end{aligned}$ $\begin{aligned} \text{Ret} &= \frac{D \times Gt}{\mu} \\ &= \frac{0,08 \times 98604,7}{2,99089} \\ &= 2605,9123 \end{aligned}$
9. hio $\begin{aligned} hio &= 1500 \text{ Btu/hr ft}^2 \text{ } ^\circ\text{F} \\ &\text{(Kern, Hal. 164)} \end{aligned}$	7. jH $\begin{aligned} jH &= 17 \\ &\text{(Kern Fig-28, hal. 838)} \end{aligned}$ 8. $(C \times \mu / k)^{1/3}$ $\begin{aligned} &= \frac{0,58996 \times 2,99089}{0,0964} \\ &= 2,63571 \end{aligned}$ 9. ho $\begin{aligned} ho &= jH \frac{k}{D} \left(\frac{c \mu}{k} \right)^{1/3} \phi_t \\ \frac{ho}{\phi_t} &= 17 \times \frac{0,0964}{0,0975} \times 2,63571 \\ &= 47 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F} \end{aligned}$
10. tw $\begin{aligned} tw &= tc + \frac{ho/\phi_s}{hio/\phi_t + ho/\phi_s} (Tc - tc) \\ &\text{(Kern, Eq 5.31)} \\ &= 189 + \frac{1500}{1500 + 46,89} 109 \\ &= 295,095 \text{ } ^\circ\text{F} \end{aligned}$	10. ϕ_t $\begin{aligned} \text{Pada tw} &= 295,09546 \text{ } ^\circ\text{F} \\ \mu_w &= 1,1741937 \text{ lb/jam ft} \end{aligned}$ $\begin{aligned} \phi_t &= (\mu/\mu_w)^{0.14} \\ &= 1,13985 \end{aligned}$ 11.. hio $\begin{aligned} &= \frac{ho}{\phi_t} \times \phi_t \\ &= 53,4494 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F} \end{aligned}$



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12. Clean Overall Coefficient, U_c

$$\begin{aligned} U_c &= \frac{h_{io} \times h_o}{h_{io} + h_o} \quad \text{(Kern, Eq 6.38)} \\ &= \frac{1500 \times 53,4}{1500 + 53,4} \\ &= 51,6 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F} \end{aligned}$$

13. Design Overall Coefficient, U_d

$$\begin{aligned} U_d &= \frac{Q}{A \times \Delta t \text{ LMTD}} \\ &= \frac{2354290,9}{942 \times 56,9} \\ &= 43,88959 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F} \end{aligned}$$

14. Dirt Factor, R_d

$$\begin{aligned} R_d &= \frac{U_c - U_d}{U_c \times U_d} \quad \text{(Kern, Eq 6.13)} \\ &= \frac{51,6 - 43,9}{51,6 \times 43,9} \\ &= 0,00341 \end{aligned}$$

Nilai R_d perhitungan > R_d

0,00341 > 0,002 (Kern, Table 12 Page 845)

(Memenuhi karena R_d Perhitungan >> R_d allowabe)

Pressure Drop	
Fluida Panas : Shell Side	Fluida Dingin :TubeSide
Steam	Produk
1. f $Re_t = 6716,8182$ $f = 0,0031$ (Kern, Fig 26)	1. f $Re_s = 2605,9123$ $f = 0,0032$ (Kern, Fig 29)
2. dari tabel 7 kern, spesifik volume pada suhu 298,4 $^\circ\text{F}$ $6,62 \text{ ft}^3/\text{lb}$ $\rho = \underline{1}$	2. Number of crosses, $N+1$ $N+1 = 12 \times \frac{L}{B}$ $= 12 \times \underline{10}$



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$= \frac{6,62}{0,15106 \text{ lb/ft}^3}$ $s = \frac{0,15106}{62,5}$ $= 0$ $\Delta P_t = \frac{f G_s^2 L_n}{5,22 \times 10^{10} D s \phi}$ $= 0,0008245 \text{ psi}$ $\Delta P_t < \Delta P \text{ allowable}$ $\Delta P_t < 10 \text{ psi}$, maka memenuhi	$= \frac{5,31}{22,5882}$ 3. Pressure Drop (ΔP_s) $s = 1,84$ (Kern, Table 6) $\Delta P_s = \frac{f \times G_t^2 \times L \times n}{5,22 \times 10^{10} \times ID \times s \times \phi t}$ (Kern, Eq 7.44) $= 0,0030209 \text{ psi}$ $\Delta P_s < \Delta P \text{ allowable}$ $\Delta P_s < 2 \text{ psi}$, maka memenuhi

Spesifikasi Alat

Nama Alat : Heater
Kode : E-232
Fungsi : Untuk memanaskan produk suhu 35°C menjadi 144°C untuk dialirkan ke menara destilasi (D-310)
Tipe : 1-2 Shell and Tube Exchanger
Dasar Pemilihan : Umum digunakan untuk transfer panas
Kondisi Operasi : - Tekanan : 1 atm
- Suhu : 144,875 °C

Bagian Tube

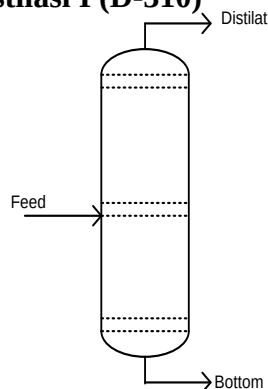
OD : 3/4 in
ID : 1,17 in
BWG : 8
Panjang : 10 ft
Jumlah tube, Nt : 240
Passes : 2
Pitch : 1 in square pitch
Pressure drop : 0,0008245 psi

Bagian Shell

ID : 21 1/4 in
Passes : 1
Baffle Spacing : 5,31 in
Pressure drop : 0,0030209 psi



20. Menara Distilasi I (D-310)



Type : Sieve Tray Colomn

Dasar Pemilihan :

- Efisiensi pemisahan lebih tinggi
- Harga lebih murah dari bubble cap colomn
- Perawatan dan perbaikan yang mudah

Kondisi operasi :

P operasi : 1 atm

T operasi : 144,8748 °C = 418,0248 K

Komponen di dalam Distilasi, dari perhitungan neraca massa (appendiks A) :

Komponen	Feed (kmol/jam)	Distilat (kmol/jam)	Bottom (kmol/jam)
$C_{17}H_{33}COOH$	1,5045	0,0001	1,3671
C_4H_9OH	55,7688	55,8537	0,0056
$C_{17}H_{33}COOC_4H_9$	12,3299	0,0012	12,3287
$C_{15}H_{31}COOH$	0,2107	0,0000	0,2110
Total	69,8140	55,8551	13,7014

Menghitung Densitas Komponen

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,24798	0,24	764	0,28571
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947



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$$T = 144,875 \text{ } ^\circ\text{C} = 418,025 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned}\rho \quad \text{C}_{17}\text{H}_{33}\text{COOH} &= 0,8104641 \\ \rho \quad \text{C}_4\text{H}_9\text{OH} &= 0,6931676 \\ \rho \quad \text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,7738654 \\ \rho \quad \text{C}_{15}\text{H}_{31}\text{COOH} &= 0,7978127\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$\text{C}_{17}\text{H}_{33}\text{COOH}$	4133,586637	0,4729145	0,8104641	0,3832802
$\text{C}_4\text{H}_9\text{OH}$	385,5641687	0,0441115	0,6931676	0,0305767
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	54,00860687	0,006179	0,7738654	0,0047817
$\text{C}_{15}\text{H}_{31}\text{COOH}$	4167,504268	0,4767949	0,7978127	0,3803931
Total	8740,66368	1		0,7990317

$$\begin{aligned}\rho_{Camp} \\ &= \sum_i^n C_p \cdot X_f\end{aligned}$$

$$\begin{aligned}\rho \text{ Campuran} &= 0,7990317 \text{ gr/ml} \times 62,4 \\ &= 49,859579 \text{ lb/cuft}\end{aligned}$$

1. Penentuan jumlah Stage

Menentukan jumlah stage minimum ($N_{\min}$) dengan persamaan Fenske :

$$\text{Dari appendix A, diperoleh } N_{\min} = 7$$

Menentukan $R_{\min}$ dengan persamaan Underwood :

$$\text{Dari appendix A, diperoleh } R_{\min} = 0,0403$$

Menentukan stage kesetimbangan dengan pers. Gilliland :

$$\text{Dari appendix A, diperoleh } R_{op} = 0,0605$$

Metode Gilliland :

dari persamaan 23-28, Henley and Seader Ed 2 :



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$$x = \frac{R_{op} - R_{min}}{R_{op} + 1} = \frac{0,0605 - 0,04032}{0,0605 + 1} = 0,01901$$

$$\frac{N - N_r}{N + 1} = 0,75 \left[1 - \left(\frac{R_{op} - R_{min}}{R_{op} + 1} \right)^{0,57} \right]$$

$$\frac{N - 7}{N + 1} = 0,75 \left[1 - \left(\frac{0,0605 - 0,0403}{0,0605 + 1} \right)^{0,57} \right]$$

$$\frac{N - 7}{N + 1} = 0,6707$$

$$\begin{aligned} N - 7 &= 0,6707 (N + 1) \\ N - 7 &= 0,6707 N + 0,6707 \\ 0,3293 N &= 7,7413 \\ N &= 23,5083 \\ N &= 24 \quad \text{Plate} \end{aligned}$$

karena menggunakan total kondensor dan total reboiler, jumlah plate =
 Plate ideal = 24

Menentukan Efisiensi Tray dengan efisiensi murphee, pada coulson pers. 11.65

$$E_o = \frac{N}{N_t} = \frac{23,5083}{24} \times 100\% = 98,0\%$$

$$\text{maka jumlah plate aktual} = \frac{24}{0,98} = 24,50 \approx 25 \text{ plate}$$

Menentukan lokasi feed stage dengan persamaan Kirk - Bride :

$$\log \left[\frac{N_r}{N_s} \right] = 0.206 \log \left[\left(\frac{B}{D} \right) \left(\frac{x_{f,HK}}{x_{f,LK}} \right) \left(\frac{x_{b,LK}}{x_{d,HK}} \right)^2 \right] \quad (11.62)$$

(Coulson, 1950 hal 520)

Dimana : N_R : jumlah stage pada bagian rectifying
 N_S : jumlah stage pada bagian stripping
 B : molar flow bottom
 D : molar flow Top
 $x_{f,HK}$: konsentrai Heavy Key di feed masuk



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xf, LK : konsentrasi light key di feed masuk

xd,HK : konsentrasi heavy key di Top

xb,LK : konsentrasi light key di bottom

data konsentrasi dari Appendix A

$$\log \frac{N_r}{N_s} = 0,21 \log \left(\frac{13,701}{55,8551} \times \frac{0,0062}{0,0441} \times \left(\frac{0,00040}{0,0000} \right)^2 \right)$$

$$\log \frac{N_r}{N_s} = 0,2175$$

$$\frac{N_r}{N_s} = 1,2429 \quad \text{maka} \quad N_r = 1,2429 \quad N_s$$

dengan $N_r + N_s = N$

$$25 = N_r + N_s$$

$$25 = 1,2429 \quad N_s + N_s$$

$$25 = 2,2429 \quad N_s$$

$$N_s = 11,1462 = 11$$

maka feed masuk pada plate ke : 11 dihitung dari plate paling bawah

2. Perhitungan Diameter Distilasi :

$$F = 8740,6637 \text{ kg} = 19273,163 \text{ lb}$$

dari Appendix A :

Top (bagian atas kolom distilasi)

$$T_{\text{atas}} = 137,0728 \text{ } ^\circ\text{C} = 410,0728 \text{ K}$$

Menghitung Densitas

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,24798	0,24	764	0,28571
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947

$$T = 137,073 \text{ } ^\circ\text{C} = 410,223 \text{ K}$$

$$\rho = A \times B^{-\left(1 - \frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\rho \text{ } C_{17}H_{33}COOH = 0,815762 \text{ gr/ml}$$

$$\rho \text{ } C_4H_9OH = 0,7017321 \text{ gr/ml}$$



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$$\rho_{C_{17}H_{33}COOC_4H_9} = 0,7795152 \text{ gr/ml}$$

$$\rho_{C_{15}H_{31}COOH} = 0,8031609 \text{ gr/ml}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$C_{17}H_{33}COOH$	0,038556417	9,327E-06	0,815762	7,609E-06
C_4H_9OH	4133,173278	0,9998885	0,7017321	0,7016539
$C_{17}H_{33}COOC_4H_9$	0,416750427	0,0001008	0,7795152	7,859E-05
$C_{15}H_{31}COOH$	0,005400861	1,307E-06	0,8031609	1,049E-06
Total	4133,633986	1		0,7017411

$$\begin{aligned}\rho_{\text{Campuran}} &= 0,7017411 \text{ gr/ml} \times 62,4 \\ &= 43,788648 \text{ lb/cuft}\end{aligned}$$

mencari pv :

(pada $T = 273,15 \text{ } ^\circ\text{K}$)

$$\begin{aligned}\text{asumsi gas ideal } 1 \text{ kmol} &= 22,4 \text{ m}^3 \\ &\text{(Coulson, 1950 hal 726)}\end{aligned}$$

dari Appendiks A :

$$\begin{aligned}V_{\text{Top}} (\text{kg}) &= 3883,4771 \text{ kg} = 8561,5135 \text{ lb} \\ n (\text{kmol}) &= 52,4762 \text{ kmol} \\ Vol_1 &= 52,476 \times 22,4 \\ &= 1175,4669 \text{ m}^3\end{aligned}$$

pada $T = 410,07 \text{ } ^\circ\text{K}$

berlaku: $Vol_1/T_1 = Vol_2/T_2$

$$\begin{aligned}Vol_2 &= \frac{Vol_1 \times T_2}{T_1} = \frac{1175,47 \times 410}{273} = 1764,7 \text{ m}^3 \\ &= 62271,8 \text{ ft}^3\end{aligned}$$

ρ_v campuran pada $T = 410,07 \text{ } ^\circ\text{K}$

$$\rho_v = \frac{m}{Vol_2} = \frac{8561,5 \text{ lb}}{62271,83301 \text{ ft}^3} = 0,1375 \text{ lb/cuft}$$

$$Q_v = \frac{Vol_2}{t} = \frac{62271,83 \text{ ft}^3}{1 \text{ jam}} = 62272 \text{ ft}^3/\text{jam}$$



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$$= 17,2977 \text{ ft}^3/\text{dt}$$

Bottom (bagian bawah kolom distilasi)

$$T_{\text{bawah}} = 230,3703 \text{ }^{\circ}\text{C} = 503,52 \text{ }^{\circ}\text{K}$$

Menghitung Densitas

Komponen	A	B	Tc	n
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,2824	0,26812	781	0,2897
$\text{C}_4\text{H}_9\text{OH}$	0,26891	0,2667	562,93	0,2457
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	0,24798	0,24	764	0,28571
$\text{C}_{15}\text{H}_{31}\text{COOH}$	0,2797	0,26805	776	0,2947

$$T = 230,37 \text{ }^{\circ}\text{C} = 503,52 \text{ K}$$

$$\rho = Ax B^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned} \rho \text{ } \text{C}_{17}\text{H}_{33}\text{COOH} &= 0,7489589 \text{ gr/ml} \\ \rho \text{ } \text{C}_4\text{H}_9\text{OH} &= 0,575353 \text{ gr/ml} \\ \rho \text{ } \text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,7082161 \text{ gr/ml} \\ \rho \text{ } \text{C}_{15}\text{H}_{31}\text{COOH} &= 0,735741 \text{ gr/ml} \end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$\text{C}_{17}\text{H}_{33}\text{COOH}$	385,5256122	0,083682	0,7489589	0,0626744
$\text{C}_4\text{H}_9\text{OH}$	0,413358664	8,972E-05	0,575353	5,162E-05
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	4167,087517	0,9045063	0,7082161	0,6405859
$\text{C}_{15}\text{H}_{31}\text{COOH}$	54,00320601	0,0117219	0,735741	0,0086243
Total	4607,029694	1		0,7119363

$$\begin{aligned} \rho \text{ Campuran} &= 0,7119363 \text{ gr/ml} \times 62,4 \\ &= 44,424823 \text{ lb/cuft} \end{aligned}$$

Mencari ρ_v :

$$(\text{pada } T = 273 \text{ }^{\circ}\text{K})$$

$$\text{asumsi gas ideal : } 1 \text{ kmol} = 22,4 \text{ m}^3$$



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(Coulson, 1950 hal 726)

dari Appendix A :

$$V \text{ bottom (kg)} = V \text{ top (kg)}$$

$$V \text{ bottom (kg)} = 4607,030 \text{ kg} = 10156,6577 \text{ lb}$$

$$n \text{ (kmol)} = 52,47620 \text{ kmol}$$

$$\begin{aligned} Vol_1 &= 52,476 \times 22,4 \\ &= 1175,47 \text{ m}^3 \end{aligned}$$

$$\text{Pada } T = 503,5 \text{ } ^\circ\text{K}$$

$$\text{berlaku: } Vol_1/T_1 = Vol_2/T_2$$

$$\begin{aligned} Vol_2 &= \frac{Vol_1 \times T_2}{T_1} = \frac{1175,47 \times 504}{273} = 2168,03 \text{ m}^3 \\ &= 76504,4 \text{ ft}^3 \end{aligned}$$

$$\rho_v \text{ campuran pada } T = 503,5 \text{ } ^\circ\text{K}$$

$$\rho_v = \frac{m}{Vol_2} = \frac{10156,658 \text{ lb}}{76504,373 \text{ ft}^3} = 0,1328 \text{ lb/cuft}$$

$$\begin{aligned} Q_v &= \frac{Vol_2}{t} = \frac{76504,37 \text{ ft}^3}{1 \text{ jam}} = 76504 \text{ ft}^3/\text{jam} \\ &= 21,2512 \text{ ft}^3/\text{dt} \end{aligned}$$

keterangan :

ρ_L :densitas liquid di Top (lb/ft³)

ρ_v :densitas vapor di top (lb/ft³)

Q_v :rate volumetrik vapor di top (ft³/s)

ρ_L' :densitas liquid di bottom (lb/ft³)

ρ_v' :densitas vapor di bottom (lb/ft³)

Q_v' :rate volumetrik vapor di btm (ft³/s)

Perencanaan Kolom dari Van Winkle :

Perhitungan didasarkan pada 80% flooding (Van Winkle : T-14.2)

dan menggunakan splash baffle :

$$\text{active area } A = AN = A - 2Ad$$



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Top	Bottom
1. $P_F = \frac{L}{V} \left(\frac{\rho_V}{\rho_L} \right)^{0,5}$ $= \frac{8369,0}{8561,5} \left(\frac{0,1375}{43,789} \right)^{0,5}$ $= 0,05477$ asumsi tray spacing = 12 in (Van Winkle,T. 14.2)	1. $P_F = \frac{L'}{V'} \left(\frac{\rho_{V'}}{\rho_{L'}} \right)^{0,5}$ $= \frac{9327}{10156,66} \left(\frac{0,1328}{44,425} \right)^{0,5}$ $= 0,0502$ asumsi tray spacing 12 in (Van Winkle,T. 14.2)
2. $P_C = 0,23$ (Van Winkle, fig. 13.21) (dimana sumbu y menunjukkan P_C)	2. $P_C = 0,24$ (Van Winkle, fig. 13.21) (dimana sumbu y menunjukkan P_C)
3. Untuk 100 % flood : $U_{VN} = (P_C) \left(\frac{\rho_L - \rho_V}{\rho_V} \right)^{0,5}$ $= 0,23 \left(\frac{43,651}{0,1375} \right)^{0,5}$ $= 4,0982 \text{ fps}$	3. Untuk 100 % flood : $U_{VN'} = (P_C) \left(\frac{\rho_{L'} - \rho_{V'}}{\rho_{V'}} \right)^{0,5}$ $= 0,24 \left(\frac{44,292}{0,1328} \right)^{0,5}$ $= 4,3837 \text{ fps}$
4. Untuk 80 % flood : $U_{80\%} = 80\% \times U_{VN}$ $= 80\% \times 4,0982$ $= 3,2786 \text{ fps}$ $A_N = \frac{Q_V}{U_{VN} \times 0,8}$ $= \frac{17,2977}{4,0982 \times 0,8}$ $= 5,2760 \text{ ft}^2$ asumsi : $Ad = 0,1 \text{ A}$	4. Untuk 80 % flood : $U_{80\%} = 80\% \times U_{VN}$ $= 80\% \times 4,3837$ $= 3,5070 \text{ fps}$ $A_{N'} = \frac{Q_{V'}}{U_{VN'} \times 0,8}$ $= \frac{21,2512}{4,3837 \times 0,8}$ $= 6,0597 \text{ ft}^2$ asumsi : $Ad = 0,1 \text{ A}$
5. $A = A_N + (2 Ad)$ $= A_N + (0,2 \text{ A})$ $A = \frac{A_N}{0,8} = \frac{5,2760}{0,8}$ $= 6,5950 \text{ ft}^2$	5. $A' = A_N + (2 Ad)$ $= A_N + (0,2 \text{ A})$ $A' = \frac{A_N}{0,8} = \frac{6,0597}{0,8}$ $= 7,5746 \text{ ft}^2$



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$\begin{aligned} 6. \quad D &= \left(\frac{A}{\pi / 4} \right)^{0,5} \\ &= \left(\frac{6,595}{0,7850} \right)^{0,5} \\ &= 3,3184 \text{ ft} \end{aligned}$	$\begin{aligned} 6. \quad D' &= \left(\frac{A'}{\pi / 4} \right)^{0,5} \\ &= \left(\frac{7,5746}{0,7850} \right)^{0,5} \\ &= 3,4982 \text{ ft} \end{aligned}$

Diambil rata-rata diameter kolom distil = $\frac{D + D'}{2} = 3,4083 \text{ ft}$

$D = 3,4083 \text{ ft} = 1,0388 \text{ m}$

maka diperoleh :

$$A = \frac{\pi}{4} D^2 = \frac{\pi}{4} 3,4083^2 = 9,1188 \text{ ft}^2$$

$$\begin{aligned} A_d &= 0,1 \quad A \\ &= 0,1 \times 9,1188 \\ &= 0,9119 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} A_N &= A - 2 \quad A_d \\ &= 9,1188 - (2 \times 0,9119) = 7,2950 \text{ ft}^2 \end{aligned}$$

$$A_h = 0,1 \quad A = 0,1 \times 9,1188 = 0,91 \text{ ft}^2$$

cek % flood :

$$\begin{aligned} \% \text{ flood atas} &= \frac{Q_V}{U_{VN} \times A_N} \times 100\% \\ &= \frac{17,2977}{4,0982 \times 6,595} \times 100\% = 64\% \end{aligned}$$

$$\begin{aligned} \% \text{ flood bawah} &= \frac{Q_{V'}}{U_{VN'} \times A_N} \times 100\% \\ &= \frac{21,2512}{4,3837 \times 7,575} \times 100\% = 64\% \end{aligned}$$

keterangan :

A : aktif area (ft²)

A_N : net area (ft²)

A_d : Downflow area (ft²)

A_h : Hole area (ft²)

U_{VN} (100% flood) : max velocity vapor in top (fps)

U_{VN'} (100% flood) : max velocity vapor in bottom (fps)



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D : diameter kolom destilasi (ft)

Digunakan tray jenis cross flow dengan data dari Van Winkle tabel 14.8 :

tray diameter	=	6	ft
dh (hole diameter)	=	1/8	in
p (hole pitch)	=	3	
hw (weir length)	=	1,5	in
Ad/A	=	0,10	(memenuhi)
Ah/A	=	0,10	(memenuhi)
An/A	=	0,80	(memenuhi)
tp gage (plate thickness)	=	12	gage = 0,0825 in

Dari **Van Winkle (tabel 14-10)**, untuk (Ad / A = 0,1 , diperoleh :

$$\begin{aligned}
 l_w / D &= L / D = 0,7267 \\
 l_w &= L = \text{panjang chord} \\
 &= 0,7267 \times D \\
 &= 0,7267 \times 3,4083 = 2,4768 \text{ ft} \\
 H / D &= 0,1565 \\
 H &= \text{tinggi chord} = 0,1565 \times D \\
 &= 0,1565 \times 3,4083 = 0,5334 \text{ ft}
 \end{aligned}$$

3. Pressure Drop

Perhitungan didasarkan pada Van Winkle

$$\Delta H_T = \beta (h_w + h_{ow} + \beta/2) + h_o + l \text{ (table 13.2 hal 507)}$$

$$l_w = 2,4768 \text{ ft} = 29,721 \text{ in}$$

Top	Bottom
L = 8369,0 lb/jam	L' = 9327 lb/jam
$\rho_L = 43,789 \text{ lb/ft}^3$	$\rho_{L'} = 44,42 \text{ lb/ft}^3$
$Q_L = \frac{L}{\rho_L} = \frac{8369,0}{43,8}$	$Q_{L'} = \frac{L'}{\rho_{L'}} = \frac{9327}{44,4}$
= 191,122 ft^3/jam	= 210,0 ft^3/jam
= 23,8281 gpm	= 26,1766 gpm
$\frac{Q_L}{l_w^{2,5}} = \frac{23,8281}{2,48^{2,5}} = 2,4681$	$\frac{Q_{L'}}{l_w^{2,5}} = \frac{26,1766}{2,48^{2,5}} = 2,711$



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Dari fig. 13-7 plot : $lw/D = 0,7267 \text{ VS } \frac{QL}{lw^{2.5}}$ didapatkan : $Fw = 1,79$ $how = 0,48 \times Fw \left(\frac{QL}{lw} \right)^{###}$ $= 0,74$ $= 8,91 \text{ in}$ $h\sigma = \frac{0,04 \times \sigma}{\rho_L \times dh}$	Dari fig. 13-7 plot : $lw/D = 0,7267 \text{ VS } \frac{QL'}{lw^{2.5}}$ didapatkan : $Fw' = 1,97$ $how' = 0,48 \times Fw' \left(\frac{QL'}{lw} \right)^{###}$ $= 0,19$ $= 2,28 \text{ in}$

σ = surface tension campuran

$$\frac{\sigma}{\text{mN/m}} = \left[P \cdot \left(\frac{\rho_L - \rho_V}{10^3 \text{ kmol/m}^3} \right) \right]^4$$

(Perry ed 8, pers 2-114)

Karena $\rho_L > \rho_V$ maka ρ_V diabaikan

dengan **tabel 2-402 ; hal 2-373 Perry edisi 7**,

didapat P (parachor independent) = 209,5

$$\rho_L \text{ camp} = 44,4248 \text{ lb/ft}^3 = 711,61902 \text{ kg/m}^3$$

maka :

$$\sigma = P \times \left(\frac{\rho_L}{1000} \right)^4$$

$$\sigma = 210 \left(\frac{711,619}{1000} \right)^4$$

$$= 53,7247 \text{ m N/m} \quad (1 \text{ m N/m} = 1 \text{ dyne /cm})$$

$$= 53,7247 \text{ dyne/ cm}$$

dh = hole diameter = 0,125 in (Van Winkle, tabel 14.8)

$$h_\sigma = \frac{0.04\sigma}{\rho_L} \quad (13.22)$$



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$$\boxed{\rho_L a_h}$$

maka :

$$h\sigma = \frac{0,04 \times 5,3725E+01}{43,789 \times 0,125}$$

$$= 0,39 \text{ in}$$

$$h\sigma' = \frac{0,04 \times 53,7247}{44,425 \times 0,125}$$

$$= 0,39 \text{ in}$$

$$h_o = 0,19 \times \frac{\rho_v}{\rho_L} \times \left(\frac{U_{VN}}{Co} \right)^2 \quad (\text{pers. 13.16, van winkle hal 519})$$

$$Co = 0,75 \quad (\text{Van Winkle fig. 13-18})$$

maka :

$$h_o = 0,19 \times \frac{0,1375}{43,789} \times \left(\frac{4,0982}{0,75} \right)^2$$

$$= 0,0174 \text{ in}$$

$$h_o' = 0,19 \times \frac{0,1328}{44,425} \times \left(\frac{4,3837}{0,75} \right)^2$$

$$= 0,0190 \text{ in}$$

faktor for the active area :

$$Fva = Uva \times \rho_v^{0,50}$$

maka :

$$Fva = 4,0982 \times 0,1375^{0,5} = 1,51959$$

$$Fva' = 4,3837 \times 0,1328^{0,5} = 1,59725$$

Dari **Fig. 13-16 Van Winkle** diperoleh nilai aeration faktor (β)

$$\beta = 0,65 \quad \beta' = 0,30$$

$$\Delta H_T = \beta (h_w + h_{ow} + \beta/2) + h_o + h\sigma$$

maka pressure drop dari kolom distilasi ini :

$$\Delta H_T = 0,7 (1,5 + 8,91 + 0,3) + 0,01744 + 0,3926$$

$$= 7,3873 \text{ in of liquid}$$



$$\begin{aligned}\Delta H_T &= 0,3 (1,5 + 2,28 + 0,15) + 0,019 \\ &\quad + 0,3870 \\ &= 1,5855 \quad \text{in of liquid}\end{aligned}$$

Liquid Back Up Downcomer: H_D (eq 13.2b)

$$H_D = (\Delta H_T + (h_w + h_{ow} + h_o + h_\sigma) + h_d (1/\phi_d))$$

asumsi $\phi_d = 0,5$

$$\begin{aligned}h_d &= 0,03 \left(\frac{QL}{100 Ad} \right)^{2,0} & h_d' &= 0,03 \left(\frac{QL'}{100 Ad} \right)^{2,0} \\ &= 0,03 \left(\frac{191,122}{91,1875} \right)^{2,0} & &= 0,03 \left(\frac{209,959}{91,1875} \right)^{2,0} \\ &= 0,1318 \quad \text{ft} & &= 0,1590 \quad \text{ft} \\ &= 1,5814 \quad \text{in} & &= 1,909 \quad \text{in}\end{aligned}$$

maka :

$$H_D = 39,58 \quad \text{in} \qquad H_D' = 15,36 \quad \text{in}$$

4. Menentukan Tinggi Kolom

a. Tinggi total tray

$$\begin{aligned}(\Sigma \text{ tray} - 1) \times (\text{tray spacing}) + (\text{jarak untuk lubang masuk feed}) \\ \text{ditetapkan jarak untuk lubang masuk feed} &= 0,5 \text{ ft} = 6 \text{ in} \\ \text{Tinggi total tray} &= (N - 1) \times 12 + 6 \\ &= (25 - 1) \times 12 + 6 \\ &= 432 \text{ in} \\ &= 36 \text{ ft} \\ &= 10,9728 \text{ m}\end{aligned}$$

b. Tinggi ruang kosong diantara tray feed ditetapkan = 1 ft
 (0,5 ft di atas lubang pemasukan feed; 0,5 ft di bawah lubang pemasukan feed)

c. Tinggi hold up cairan (bagian bawah kolom)

ditetapkan waktu hold up, $t = 10 \text{ mnt} = 600 \text{ sec.}$

dimana (untuk bagian bawah kolom) : **(Ulrich, 1984 hal. 195)**

$$L' = 9327,39 \text{ lb / jam}$$

$$\rho_L' = 44,425 \text{ lb / ft}^3$$



$$A = 9,1188 \text{ ft}^2$$

$$D = 3,4083 \text{ ft} = 40,8991 \text{ in} = 1,0395 \text{ m}$$

$$\text{ditetapkan } S_f = 1 \frac{1}{2} \text{ in}$$

$$= 0,125 \text{ ft} \quad (\text{Tabel 5.6 Brownell \& Young})$$

$$\text{volume hold up cairan, } h = 0,000049 \text{ D}^3$$

$$(\text{Pers 5.11 Brownell \& Young})$$

$$= 0,000049 \times (3,4083)^3$$

$$= 0,0019 \text{ ft}^3$$

$$\text{volume hold up cairan} = \frac{\pi}{4} D^2 h$$

$$0,0019 = \frac{\pi}{4} \times (3,4083)^2 \times h$$

$$h = 0,0002 \text{ ft} = 0,0026 \text{ in}$$

$$\text{tinggi hold up cairan} = s_f + h$$

$$= 0,1250 + 0,0002$$

$$= 0,1252 \text{ ft}$$

Menentukan P design :

$$P \text{ hidrostatik} = \rho_L \times g/gc \times L$$

$$= \frac{43,79 \times 1 \times 0,0019}{144}$$

$$= 0,00059 \text{ Psia} \quad (\text{Brownell, pers 3.17, hal 46})$$

$$P \text{ operasi} = 1,00 \text{ atm} = 14,7 \text{ psia}$$

P design diambil 10% lebih besar dari P operasi untuk faktor keamanan.

$$P_{\text{design}} = 1,1 \times (14,7 + 0,00059)$$

$$= 16,2 \text{ psia}$$

5. Design Tutup Bejana bentuk : standart dish head

Menentukan Dimensi Tutup

Tutup dipilih Torispherical dish head

$$OD = ID + 2 t_s$$

$$= 40,8991 + 0,19$$

$$= 41,08664 \text{ in}$$

Berdasarkan **Brownell and Young, Tabel 5.7** dari data OD, diperoleh:

$$OD = 40 \text{ in}$$



$$icr = 2 \frac{1}{2} \text{ in}$$

$$rc = 40 \text{ in}$$

Cek nilai icr dengan nilai 6%rc

$$icr = 2,5 \text{ in}$$

$$6\% rc = 2,4 \text{ in}$$

Menentukan tebal shell minimum

Tebal shell berdasarkan ASME code untuk cylindrical tank:

$$ts = \frac{Pd \times ri + C}{fe - 0,6 Pd} \text{ (Brownell Eq. 13.1)}$$

dengan

$$ts = \text{tebal shell minimum (in)}$$

$$P = \text{tekanan tangki (Psi)} = 16,2 \text{ Psi}$$

$$ri = \text{jari-jari tangki (in)} = 20,4 \text{ in}$$

$$C = \text{Faktor korosi (in); digunakan} = \frac{1}{8} \text{ in}$$

$$e = \text{Faktor pengelasan; digunakan double welded} = 0,8$$

(Brownell, Table 13.2)

$$f = \text{stress allowable bahan konstruksi SB-575}$$

$$= 98300 \text{ Psi (ASMEBPVC.II.D.C-2017)}$$

sehingga,

$$ts = \frac{Pd \times ri + C}{fe - 0,6 Pd}$$

$$ts = \frac{16,1661 \times 20,4}{78640 - 1 \times 16,2} + \frac{1}{8}$$

$$ts = \frac{330,591}{78630,3} + \frac{1}{8}$$

$$ts = 0,0042 + 0,125$$

$$ts = 0,1292$$

$$ts = \frac{3}{16} \text{ in}$$

Menghitung Tinggi Tutup Tangki

$$sf = 1 \frac{1}{2} \text{ in}$$

$$t = \frac{2}{8} \text{ in}$$

(Brownell, tabel 5.6, hal. 88)

Menghitung tinggi tutup

$$OA = b + sf + t$$

$$* 1 \text{ ft} = 0,3 \text{ m}$$

$$1 \text{ ft} = 12 \text{ in}$$



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$$\begin{aligned} BC &= rc - icr \\ BC &= 40 - 2 \frac{1}{2} \\ &= 37,500 \text{ in} \end{aligned}$$

$$\begin{aligned} AB &= \frac{1}{2} \times OD - icr \\ AB &= \frac{1}{2} \times 41,0866 - 2,5 \\ &= 18,043 \text{ in} \end{aligned}$$

$$\begin{aligned} b &= rc - (BC^2 - AB^2)^{0,5} \\ b &= 40 - (1406 - 326)^{0,5} \\ &= 7,126 \end{aligned}$$

Tinggi tutup atas

$$\begin{aligned} OA &= b + sf + t \\ &= 8,814 \text{ in} \\ &= 0,7345 \text{ ft} \end{aligned}$$

Total Tinggi Tutup (atas+bawah)

digunakan tutup bawah sama dengan tutup atas , maka

$$\begin{aligned} \text{Tinggi Tutup total} &= 2 \times \text{Tinggi tutup atas} \\ &= 2 \times 8,81 \\ &= 17,6273 \text{ in} \\ &= 1,4689 \text{ ft} \\ &= 0,4477166 \text{ m} \end{aligned}$$

Tinggi Kolom Keseluruhan

$$\begin{aligned} \text{tingggi total tray} &= 432 \text{ in} = 36 \text{ ft} \\ \text{H liquid back up} &= 54,939 \text{ in} = 4,5783 \text{ ft} \\ \text{H tutup} &= 17,6273 \text{ in} = 1,4689 \text{ ft} \\ \text{H liquid hold up} &= 0,1252 \text{ ft} \\ \text{H refluk masuk} &= 1 \text{ ft} \quad (\text{Asumsi : 0,5 ft reboiler + 0,5 ft kondensor}) \\ \text{H ruang kosong diantara tray feed} &= 1 \text{ ft} \\ \text{H tower total} &= 44,172 \text{ ft} = 13,4638 \text{ m} \end{aligned}$$



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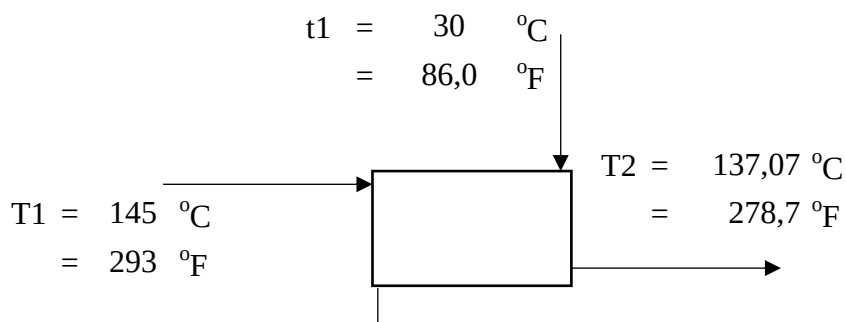
Spesifikasi :

Nama Alat	: Menara Destilasi 1
Kode	: D-310
Diameter	: 3,408 ft
Tinggi Kolom Distilasi	: 44,172 ft
Diameter lubang pada tray	: 3 in
Panjang weir	: 1,5 in
diameter tray	: 1/8 ft = 0,038 m
Tebal Tray	: 0,0825 in
Spasi antar tray	: 6 in
Jumlah plate	: 25
Tinggi Tower Total	: 44,1724 ft = 13,4638 m
feed masuk pada plate ke- 11	dihitung dari plate bawah

21. Kondensor I (E-311)



Fungsi	: Untuk mengkondensasikan produk atas destilasi berupa gas menjadi liquid
Tipe	: <i>Shell and Tube Heat Exchanger</i>
Dasar Pemilihan	: Umum digunakan untuk merubah fase gas menjadi liquid
Kondisi Operasi	
Tekanan	= 1 atm
Suhu	= 137 °C





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$$\begin{aligned} \downarrow t_2 &= 45 \text{ } ^\circ\text{C} \\ &= 113,0 \text{ } ^\circ\text{F} \end{aligned}$$

1. Data dari neraca Massa dan neraca panas diperoleh :

Untuk fluida panas : Larutan Produk

$$\begin{aligned} T \text{ masuk } (T_1) &= 144,9 \text{ } ^\circ\text{C} = 292,8 \text{ } ^\circ\text{F} \\ T \text{ keluar } (T_2) &= 137,07 \text{ } ^\circ\text{C} = 278,7 \text{ } ^\circ\text{F} \end{aligned}$$

Untuk fluida dingin : Air Proses

$$\begin{aligned} T \text{ masuk } (t_1) &= 30 \text{ } ^\circ\text{C} = 86 \text{ } ^\circ\text{F} \\ T \text{ keluar } (t_2) &= 45 \text{ } ^\circ\text{C} = 113 \text{ } ^\circ\text{F} \end{aligned}$$

$$\begin{aligned} \text{Bahan masuk} &= 8740,664 \text{ kg/jam} \\ &= 19269,842 \text{ lb/jam} \\ \text{Panas yang diserap, } Q &= 473697,715 \text{ kkal/jam} \\ &= 1892896,068 \text{ Btu/jam} \\ \text{Air pendingin yang} &= 31620,955 \text{ kg/jam} \\ \text{digunakan} &= 69712,190 \text{ lb/jam} \end{aligned}$$

Perhitungan :

2. Penentuan ΔT_{LMTD}

hot fluida		cold fluida	diff.
293	higher temp.	113	180
279	lower temp.	86	193
14		27	

$$\begin{aligned} \Delta t \text{ LMTD} &= \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}} \\ \Delta t \text{ LMTD} &= \frac{180 - 193}{\ln \frac{180}{193}} \\ &= 186,178 \text{ } ^\circ\text{F} \end{aligned}$$

$$R = \frac{\text{Hot Fluid}}{\text{Cold Fluid}} = \frac{14}{27} = 0,5$$



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$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{113 - 86}{293 - 86} = 0,13$$
$$F_T = 0,98 \quad (\text{Fig.18 Kern, hal. 828})$$
$$\Delta T = F_T \times \text{LMTD}$$
$$= 1 \times 186,178$$
$$= 182,454 \text{ } ^\circ\text{F}$$

3. Tc dan tc

Tc = Tav bahan

$$T_c = \frac{T_1 + T_2}{2}$$
$$= \frac{293 + 279}{2}$$
$$= 286 \text{ } ^\circ\text{F} = 429 \text{ K}$$

tc = tav air

$$t_c = \frac{t_1 + t_2}{2}$$
$$= \frac{113 + 86}{2}$$
$$= 100 \text{ } ^\circ\text{F}$$

Menghitung Kapasitas Panas, Konduktifitas Thermal dan Viskositas Fluida Dingin

$$c_p = 1 \text{ BTU/lb } ^\circ\text{F} \quad (\text{Kern, Fig 2})$$
$$k = 0,37 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F/ft} \quad (\text{Kern, Table 4})$$
$$\mu = 0,6 \text{ cP} \quad (\text{Kern, Fig.14})$$

Fluida Panas

Menghitung nilai kapasitas panas

komponen	A	B	C	D	E
C ₁₇ H ₃₃ COOH	-55,663	1,991	-0,0016	6,7E-07	-1E-10
C ₄ H ₉ OH	8,157	0,41032	-0,0002	6,7E-07	-1E-10
C ₁₇ H ₃₃ COOC ₄ H ₉	-69,046	2,5211	-0,0021	1,1E-06	-3E-10
C ₁₅ H ₃₁ COOH	-54,487	1,804	-0,0013	5,4E-07	-9E-11



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$$T = 429 \text{ K}$$

$$C_p = A + BT + CT^2 + DT^3 + ET^4$$

Sehingga diperoleh

$$C_p \text{ C}_{17}\text{H}_{33}\text{COOH} = 561,126 \text{ Kkal/KmolK}$$

$$C_p \text{ C}_4\text{H}_9\text{OH} = 196,307 \text{ Kkal/KmolK}$$

$$C_p \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 = 702 \text{ Kkal/KmolK}$$

$$C_p \text{ C}_{15}\text{H}_{31}\text{COOH} = 512,543 \text{ Kkal/KmolK}$$

komponen	BM	Cp	Fraksi	Cp
	Kg/Kmol	kcal/Kmol K	Xf	kcal/Kg K
C ₁₇ H ₃₃ COOH	282,47	561,12574	0,04411	1,9865
C ₄ H ₉ OH	74	196,3068	0,47291	2,65279
C ₁₇ H ₃₃ COOC ₄ H ₉	310,56	702,00003	0,47679	2,26043
C ₁₅ H ₃₁ COOH	256,42	512,5433	0,00618	1,99884
Total			1	

$$1 \text{ kkal/kg K} = 0,23885 \text{ Btu/lb } ^\circ\text{F}$$

$$C = \sum_i^n C_p \cdot X_f$$

$$C = 0,5810 \text{ Btu/lb } ^\circ\text{F}$$

Menghitung Viskositas Larutan

komponen	A	B	C
C ₁₇ H ₃₃ COOH	-2,483	0,1505	-1E-05
C ₄ H ₉ OH	-11,144	0,2879	-6E-05
C ₁₇ H ₃₃ COOC ₄ H ₉	-2,15	0,133	-1E-05
C ₁₅ H ₃₁ COOH	-3,002	0,1515	-2E-05

$$T = 429 \text{ K}$$

$$\mu = A + BT + CT^2$$

Sehingga diperoleh



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$$\begin{aligned}\mu \text{ C}_{17}\text{H}_{33}\text{COOH} &= 0,0059406 \text{ cP} \\ \mu \text{ C}_4\text{H}_9\text{OH} &= 0,0102087 \text{ cP} \\ \mu \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,0052269 \text{ cP} \\ \mu \text{ C}_{15}\text{H}_{31}\text{COOH} &= 0,0059081 \text{ cP}\end{aligned}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,0385564	9,327E-06	0,0059406	5,541E-08
$\text{C}_4\text{H}_9\text{OH}$	4133,1733	0,9998885	0,0102087	0,0102076
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	0,4167504	0,0001008	0,0052269	5,27E-07
$\text{C}_{15}\text{H}_{31}\text{COOH}$	0,0054009	1,307E-06	0,0059081	7,719E-09
Total	4133,634	1		0,0102082

$$\begin{aligned}\mu \text{ Campuran} &= 0,0102082 \text{ cP} \\ &= 0,0246945 \text{ lb/ft jam}\end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C
$\text{C}_{17}\text{H}_{33}\text{COOH}$	-2,483	0,1505	-1E-05
$\text{C}_4\text{H}_9\text{OH}$	-11,144	0,2879	-6E-05
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	-2,15	0,133	-1E-05
$\text{C}_{15}\text{H}_{31}\text{COOH}$	-3,002	0,1515	-2E-05

$$\begin{aligned}T &= 237,724 \text{ F} \\ T &= 389 \text{ K} \\ \mu &= A + BT + CT^2\end{aligned}$$

Sehingga diperoleh

$$\begin{aligned}\mu \text{ C}_{17}\text{H}_{33}\text{COOH} &= 1,0003987 \text{ cP} \\ \mu \text{ C}_4\text{H}_9\text{OH} &= 1,0004526 \text{ cP} \\ \mu \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 1,0003859 \text{ cP} \\ \mu \text{ C}_{15}\text{H}_{31}\text{COOH} &= 1,0003981 \text{ cP}\end{aligned}$$



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komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
C ₁₇ H ₃₃ COOH	0,0385564	9,327E-06	1,0003987	9,331E-06
C ₄ H ₉ OH	4133,1733	0,9998885	1,0004526	1,0003411
C ₁₇ H ₃₃ COOC ₄ H ₉	0,4167504	0,0001008	1,0003859	0,0001009
C ₁₅ H ₃₁ COOH	0,0054009	1,307E-06	1,0003981	1,307E-06
Total	4133,634	1		1,0004526

$$\begin{aligned}\mu \text{ Campuran} &= 1,0004526 \text{ cP} \\ &= 2,4201833 \text{ lb/ft jam}\end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	T _c	n
C ₁₇ H ₃₃ COOH	0,2824	0,26812	781	0,2897
C ₄ H ₉ OH	0,26891	0,2667	562,93	0,2457
C ₁₇ H ₃₃ COOC ₄ H ₉	0,24798	0,24	764	0,2857
C ₁₅ H ₃₁ COOH	0,2797	0,26805	776	0,2947

$$T = 429 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned}\rho \text{ C}_{17}\text{H}_{33}\text{COOH} &= 0,8272009 \text{ gr/ml} \\ \rho \text{ C}_4\text{H}_9\text{OH} &= 0,7197156 \text{ gr/ml} \\ \rho \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,8147097 \text{ gr/ml} \\ \rho \text{ C}_{15}\text{H}_{31}\text{COOH} &= 0,7917196 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas gr/ml	ρ Campuran gr/ml
	(kg)			
C ₁₇ H ₃₃ COOH	0,038556417	9,327E-06	0,8272009	7,716E-06
C ₄ H ₉ OH	4133,173278	0,9998885	0,7197156	0,7196354
C ₁₇ H ₃₃ COOC ₄ H ₉	0,416750427	0,0001008	0,8147097	8,214E-05
C ₁₅ H ₃₁ COOH	0,005400861	1,307E-06	0,7917196	1,034E-06



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Total	4133,633986	1		0,7197263

$$\begin{aligned}\rho \text{ Campuran} &= 0,7197263 \text{ gr/ml} \times 62,4 \\ &= 44,910921 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Sg} &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{44,910921 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,7193804\end{aligned}$$

$$\begin{aligned}\text{K}_{\text{mix}} &= \frac{0,0677}{\text{sg} [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{0,719 [1 - 0,0003 (286 - 32)]} \\ &= 0,1019 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243}\end{aligned}$$

Dipilih tipe : 1-2 Heat Exchanger

Digunakan Shell and Tube dengan ukuran :

OD, BWG = 1 1/2 in 8 BWG

Pitch = 1 7/8 in Square Pitch

Panjang Tube = 10 ft

Dari **Tabel 10 Kern** diperoleh

ID = 1,170 in

a't = 1,075 in²

a" = 0,3925 ft²/ft panjang

Harga UD = 2 - 50 Btu/jam ft °F (**Kern, T.8 : 840**)

Dipilih UD = 30 Btu/jam ft °F

$$\begin{aligned}A &= \frac{Q}{\text{UD} \times \Delta T} \\ &= \frac{1892896,068}{30 \times 182,45} \\ &= 345,821 \text{ ft}^2\end{aligned}$$

$$\text{Jumlah Tube (Nt)} = \frac{A}{a'' \times L}$$



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$$= \frac{345,821}{0,393 \times 10}$$

$$= 88,107 \text{ buah}$$

Dipilih pipa ukuran standart (**Kern T.9**)

Untuk pipa 1 1/2 in
diperoleh :

$$\begin{aligned} \text{ID Shell} &= 27 \text{ in} \\ \text{Tube Passes} &= 2 \\ \text{Shell Passes} &= 1 \end{aligned}$$

Koreksi U_D

$$\begin{aligned} A &= N_t \times L \times a'' \\ &= 108 \times 10 \times 0,3925 \\ &= 423,9000 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} U_D \text{ koreksi} &= \frac{Q}{A \times DT} \\ &= \frac{1892896,068}{423,9000 \times 182,454} \\ &= 24,4743 \text{ in ft}^2 \text{ } ^\circ\text{F} \end{aligned}$$

Menentukan nilai De :

$$\begin{aligned} De &= \frac{4 \left(Pt^2 - \pi \frac{OI^2}{4} \right)}{\pi OD} \\ &= \frac{4 \left(1,88^2 - 3,14 \times \frac{1,50^2}{4} \right)}{3,14 \times 1,5} \\ &= 1,48567 \text{ in} = 0,12 \text{ ft} \end{aligned}$$

Shell Fluida Panas, Produk	Tube Fluida Dingin, Air Pendingin
4'. Flow Area (as) $as = \frac{ID \times C' \times B}{144 \times PT}$ (Kern, Eq 7.1)	4. Flow Area (at) $at' = 1,08 \text{ in}^2 \text{ (Kern, Table 10)}$ $at = \frac{Nt \times at'}{144 \times n}$



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$$as = \frac{27 \times \text{##} \times 6,75}{144 \times 1 \frac{7}{8}}$$

$$= 0,253125 \text{ ft}^2$$

5'. Kecepatan Massa (Gs)

$$Gs = \frac{w}{as}$$

(Kern, Eq 7.2)

$$= \frac{19269,84}{0,253125}$$

$$= 76127,8 \text{ lb/hr ft}^2$$

6'. Bilangan Reynolds (Res)

$$De = 0,12 \text{ ft}$$

$$\mu = 0,02 \text{ lb/ft hr}$$

$$Res = \frac{De \times Gs}{\mu}$$

$$= \frac{0,12381 \times 76127,8}{0,024703786}$$

$$= 381522,52$$

7'. jH

$$jH = 170 \quad (\text{Kern, Fig 28})$$

8. $(c\mu/k)^{1/3}$

$$\left(\frac{c \mu}{k} \right)^{1/3}$$

$$= \left(\frac{0,58 \times 0,02}{0,1019} \right)^{1/3}$$

$$= 0,5203$$

9'. ho

$$ho = jH \frac{k}{De} \left(\frac{c \mu}{k} \right)^{1/3} \phi s$$

(Kern, Eq 7.48)

$$at = \frac{108 \times 1,075}{144 \times 2,000}$$

$$at = 0,40313 \text{ ft}^2$$

5. Kecepatan Massa (Gt)

$$Gt = \frac{W}{at}$$

$$= \frac{69712,18955}{0,403125}$$

$$= 172929 \text{ lb/hr ft}^2$$

6. Bilangan Reynolds (Ret)

$$D = 0,12 \text{ ft}$$

$$\mu = 1,452 \text{ lb/ft hr}$$

$$Ret = \frac{D \times Gt}{\mu}$$

$$= \frac{0,12381 \times 172929}{1,452}$$

$$= 14744,938$$

7. jH

$$L/D = 103$$

$$jH = 65 \quad (\text{Kern, Fig 24})$$

8. $(c\mu/k)^{1/3}$

$$\left(\frac{c \mu}{k} \right)^{1/3}$$

$$= \left(\frac{1 \times 1,5}{0,37} \right)^{1/3}$$

$$= 1,5773$$

9. hi

$$hi = jH \frac{k}{D} \left(\frac{c \mu}{k} \right)^{1/3} \phi t$$



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(Kern, Eq 6.15b) $\frac{h_o}{\phi_t} = 170 \times \frac{0,1}{0,12} \times 0,520$ $= 72,7815 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$ 10'. tw $tw = tc + \frac{h_o/\phi_s}{h_{io}/\phi_t + h_o/\phi_s} (T_c - t_c)$ (Kern, Eq 5.31) $= 100 + \frac{72,78149603}{25,3 + 72,8} 186,3$ $= 237,724 \text{ } ^\circ\text{F}$ 11'. Φ_s Pada tw = 237,724 °F $\mu_w = 2,420 \text{ lb/jam ft}$ $\phi_s = (\mu/\mu_w)^{0,14}$ $= 0,52632$ 12. ho $h_o = \frac{h_o}{\phi_s} \times \phi_s$ $= 38,3062 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$	(Kern, Eq 6.15a) $\frac{h_i}{\phi_t} = 65 \times \frac{0,370}{0,12} \times 1,577$ $= 306,405 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$ 10. hio/ϕ_t $\frac{h_{io}}{\phi_t} = \frac{h_i}{\phi_t} \times \frac{ID}{OD}$ (Kern, Eq 6.5) $\frac{h_{io}}{\phi_t} = 306 \times \frac{0,12}{1,50}$ $= 25,2898 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$ 11. ϕ_t Pada tw = 237,724 °F $\mu_w = 2,420 \text{ lb/jam ft}$ (Kern, Fig.14) $\phi_t = (\mu/\mu_w)^{0,14}$ $= 0,93097$ 12. hio $h_{ic} = \frac{h_{io}}{\phi_t} \times \phi_t$ $= 23,5441 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$

13. Clean Overall Coefficient, Uc

$$U_c = \frac{h_{io} \times h_o}{h_{io} + h_o} \quad (\text{Kern, Eq 6.38})$$

$$= \frac{23,5 \times 38,3}{23,5 + 38,3}$$

$$= 14,5817 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$$

14. Design Overall Coefficient, Ud

$$U_d = 24,4743 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$$

15. Dirt Factor, Rd

$$R_d = \frac{U_c - U_d}{U_c \times U_d} \quad (\text{Kern, Eq 6.13})$$



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$$= \frac{14,6 - 24,5}{14,6 \times 24,5}$$

$$= 0,0277197$$

Nilai Rd perhitungan > Rd

$$0,02772 > 0,003 \quad \text{(Kern, Table 12)}$$

Shell Fluida Panas, Produk	Tube Fluida Dingin, Air Pendingin
1'. f Res = 381522,52 f = 0,0016 (Kern, Fig 29) 2'. Number of crosses, N+1 N+1 = 12 x L / B = 12 x 10 / 6,75 = 17,7778 3'. Pressure Drop ΔP s = 0,81 (Kern, Table 6) $\Delta P = \frac{f \cdot Gs^2 \cdot IDs \cdot (N+1)}{5,22 \times 10^{10} \cdot De \cdot s \cdot \phi s}$ (Kern, Eq 7.44) = 1,615486 psi ΔP < 10 psi, maka memenuhi	1. f Ret = 14744,938 f = 0,00028 (Kern, Fig 26) 2. ΔPt s = 1 (Kern, Table 6) $\Delta Pt = \frac{f \cdot Gt^2 \cdot L \cdot n}{5,22 \times 10^{10} \cdot ID \cdot s \cdot \phi t}$ (Kern, Eq 7.45) = 0,02783 psi 3. ΔPr $\frac{v^2}{2g} = 0,0024$ (Kern, Fig 27) $\Delta Pr = \frac{4n}{s} \times \frac{v^2}{2g}$ (Kern, Eq 7.46) = 0,008333 psi ΔPT = ΔPt + ΔPr = 0,036168 psi ΔP < 10 psi, maka memenuhi

Spesifikasi

Nama Alat = Kondensor 1

Kode = E-311

Fungsi = Untuk mengkondensasikan produk atas destilasi

Tipe = Shell and Tube Heat Exchanger

Jumlah = 1 buah

Shell Side

ID = 27 in

Passes = 1

Tube Side



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OD = 1 1/2 in
 BWG = 8 BWG
 L = 10,0 ft
 Pitch = 1 7/8 in Square Pitch
 Jumlah Tube, Nt = 108 buah
 Bahan Kontruksi = Carbon Steel SA-283 Grade A

22. Tangki Accumulator (F-312)



Fungsi : Sebagai penampung arus keluaran kondensor pada Menara Distilasi untuk menjaga kontinuitas dan kestabilan aliran keluar.

Tipe : *Tangki silinder horizontal d* engan tutup berbentuk *standard dished head*

Dasar Pemilihan : Umum digunakan untuk penampungan sementara hasil keluaran kondensor

Kondisi operasi

Suhu : 137,1 °C

Tekanan : 1 atm = 14,7 psi

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,24798	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947

$$T = 137,07 \text{ } ^\circ\text{C} = 410,223 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$



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Sehingga diperoleh

$$\begin{aligned}\rho_{C_{17}H_{33}COOH} &= 0,815762 \text{ gr/ml} \\ \rho_{C_4H_9OH} &= 0,7017321 \text{ gr/ml} \\ \rho_{C_{17}H_{33}COOC_4H_9} &= 0,7795221 \text{ gr/ml} \\ \rho_{C_{15}H_{31}COOH} &= 0,8031609 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$C_{17}H_{33}COOH$	0,038556417	9,327E-06	0,815762	7,609E-06
C_4H_9OH	4133,173278	0,9998885	0,7017321	0,7016539
$C_{17}H_{33}COOC_4H_9$	0,416750427	0,0001008	0,7795221	7,859E-05
$C_{15}H_{31}COOH$	0,005400861	1,307E-06	0,8031609	1,049E-06
Total	4133,633986	1		0,7017411

$$\begin{aligned}\rho_{\text{Campuran}} &= 0,7017411 \text{ gr/ml} \times 62,4 \\ &= 43,788648 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}Sg &= \frac{\rho_{\text{bahan}}}{\rho_{\text{reference}} (H_2O)} \times sg_{\text{reference}} \\ &= \frac{43,788648 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,7014039\end{aligned}$$

$$\begin{aligned}K_{mix} &= \frac{0,0677}{sg [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{0,701 [1 - 0,0003 (0 - 32)]} \\ &= 0,0956 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243}\end{aligned}$$

$$\begin{aligned}\text{Rate massa} &= 4.133,6340 \text{ kg/jam} \times 2,2046 \text{ lb/kg} \\ &= 9.113,0095 \text{ lb/jam}\end{aligned}$$

$$\begin{aligned}\text{Rate volumetrik} &= \frac{\text{Rate massa}}{\text{Densitas}} \\ &= \frac{9.113,0095 \text{ lb/jam}}{43,7886 \text{ lb/cuft}} \\ &= 208,1135 \text{ cuft/jam}\end{aligned}$$



a. Menentukan Volume Cairan

$$\begin{aligned}\text{Dirancang waktu tinggal} &= 1 \text{ jam, maka} \\ \text{Volume liquid} &= 208,1135 \text{ cuft/jam} \times 1 \text{ jam} \\ &= 208,11352 \text{ cuft}\end{aligned}$$

Asumsi volume liquid mengisi 80% volume tangki untuk faktor keamanan, sehingga :

$$\begin{aligned}\text{Volume tangki} &= \frac{\text{Volume cairan}}{80\%} \\ &= \frac{208,1135178}{80\%} \\ &= 260,1419 \text{ cuft}\end{aligned}$$

b. Menentukan Dimensi Shell Tangki

Berdasarkan pers. 5.4 Brownell dan Young, untuk *vessel* berbentuk silinder horizontal with *elliptical dished*, maka :

$$\text{L/D ratio} = 3 - 5 \quad (\text{Tabel 4-27 Ulrich : 249})$$

$$\begin{aligned}\text{Asumsi rasio dimensi L/D} &= 3 \\ L &= 3 D\end{aligned}$$

Keterangan

L = Panjang tangki

D = Diameter Tangki

Tangki berbentuk silinder dengan tutup atas dan bawah *standard dished head*

$$V_{\text{tutup}} = 0,000049 D^3$$

$$\text{Volume tangki} = \frac{1}{4} \times \pi \times D^2 \times L + 2 \times 0,000049 D^3$$

$$260,1418972 = \frac{1}{4} \times 3,14 \times D^2 \times 3 D + 0,000098 D^3$$

$$260,1418972 = 2,355 D^3 + 9,8E-05 D^3$$

$$260,1418972 = 2,355098 D^3$$

$$D^3 = 110,45905$$

$$D = 4,7234186 \text{ ft} \quad (\text{Tinggi vessel/diameter})$$

$$= 56,681023 \text{ in}$$

$$= 1,4397155 \text{ m}$$

Sehingga panjang vessel



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$$\begin{aligned} L &= 3 \times D \\ &= 3,00 \times 4,7234186 \\ &= 14,17 \text{ ft} \\ &= 170,04307 \text{ in} \\ &= 4,3191465 \text{ m} \end{aligned}$$

c. Menentukan tinggi cairan dalam vessel

$$\begin{aligned} D_{\text{liquid}} &= D_{\text{shell}} = 4,7234186 \text{ ft} \\ \text{Volume liquid} &= \frac{1}{4} \times 3,14 \times D^2 \times 3 D + 0,000098 D^3 \\ 208,11352 &= 2,355 D^3 + 9,8E-05 D^3 \\ 208,11352 &= 2,3551 D^3 \\ D^3 &= 88,3672 \text{ ft} \\ D &= 4,3881 \text{ ft} \\ &= 52,6572 \text{ in} \\ &= 1,33751 \text{ m} \end{aligned}$$

d. Menentukan Tekanan design

Jika dalam bejana terdapat liquid, maka bejana dirancang berdasarkan tekanan dalam :

$$\begin{aligned} P_{\text{Hidrostatik}} &= \rho \times \frac{g}{g_c} \times H_{\text{liq}} \\ &= 43,7886 \frac{\text{lb}}{\text{cuft}} \times 1 \frac{\text{lbf}}{\text{lbm}} \times 4,39 \text{ ft} \\ &= 192,149 \frac{\text{lbf}}{\text{ft}^2} \\ &= 1,33437 \text{ psi} \end{aligned}$$

$$\begin{aligned} P_{\text{gauge}} &= P_i - P_o \\ &= 14,7 - 14,7 \\ &= 0 \end{aligned}$$

$$\begin{aligned} \text{Asumsi } P_{\text{design}} &= 10\% \text{ lebih besar untuk faktor keamanan} \\ P_{\text{design}} &= 1,1 \times (P_{\text{gauge}} + P_h) \\ &= 1,1 \times (0 + 1,33437) \text{ Psi} \\ &= 1,4678033 \text{ Psi} \end{aligned}$$



e. Menentukan tebal shell minimum

Tebal shell berdasarkan ASME code untuk cylindrical tank:

$$t_s = \frac{P d \times r_i + C}{f_e - 0,6 P d} \quad \text{(Brownell Eq. 13.1)}$$

dengan

t_s = tebal shell minimum (in)

P = tekanan tangki (Psi) = 1,47 Psi

r_i = jari-jari tangki (in) = 44,2 in

C = Faktor korosi (in); digunakan = 1/8 in

e = Faktor pengelasan; digunakan double welded = 0,8

(Brownell, Table 13.2)

f = stress allowable bahan konstruksi Carbon Steel SA-283 Grade A

= 10350 Psi **(Brownell, hal.342)**

sehingga,

$$\begin{aligned} t_s &= \frac{P d \times r_i + C}{f_e - 0,6 P d} \\ t_s &= \frac{1,4678 \times 44,2}{8280 - 1 \times 1,4678} + \frac{1}{8} \\ t_s &= \frac{64,8529}{8279,12} + \frac{1}{8} \\ t_s &= 0,00783 + 0,125 \\ t_s &= 0,13283 \\ t_s &= 3/16 \text{ in} \end{aligned}$$

Sehingga diperoleh tebal sheel sebesar 3/16 in

f. Menentukan Tebal Tutup Atas dan Bawah

Tutup atas dipilih Torispherical dish head

$$\begin{aligned} OD &= ID + 2 t_s \\ &= 56,681 + 2 \times 3/16 \\ &= 56,681 + 0,375 \\ &= 56,681 \text{ in} \end{aligned}$$

Berdasarkan Brownell and Young, Tabel 5.7 dari data OD, diperoleh:

$$\begin{aligned} OD &= 60 \text{ in} \\ i_{cr} &= 3 \frac{5}{8} \text{ in} \end{aligned}$$



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$$\begin{aligned} r_c &= 60 \text{ in} \\ \text{Cek nilai } i_{cr} &\text{ dengan nilai } 6\%r_c \\ i_{cr} &= 3,625 \text{ in} \\ 6\% r_c &= 3,6 \text{ in} \end{aligned}$$

Karena nilai i_{cr} tabel $>$ nilai $6\%r_c$, maka digunakan persamaan:

$$t_h = \frac{P \times r_c \times W}{2 f_e - 0,2P} + C \quad \text{(Brownell Eq. 7.77)}$$

$$W = \frac{1}{4} \times \left(3 + \frac{\sqrt{r_c}}{r_l} \right) \quad \text{(Brownell Eq. 7.76)}$$

dengan

$$P_d = \text{Tekanan design (Psi)} = 1,47 \text{ Psi}$$

$$r_c = \text{Crown radius} = \text{jari-jari dalam (in)} = 60 \text{ in}$$

$$r_l/i = \text{Inside crown radius (in)} = 85,0215$$

$$E = \text{Faktor pengelasan} = 0,8$$

$$t = \text{Tebal dinding minimal (in)}$$

$$f = \text{Stress allowable bahan Carbon Steel SA-283 grade A}$$

$$= 10350 \text{ Psi} \quad \text{(Brownell hal. 342)}$$

$$C = \text{Faktor korosi (in)} = 1/8$$

Sehingga,

$$\begin{aligned} W &= \frac{1}{4} \times \left(3 + \frac{\sqrt{r}}{r_l} \right) \\ &= \frac{1}{4} \times \left(3 + \frac{7,75}{85} \right) \\ &= 0,77278 \end{aligned}$$

$$\text{Asumsi tebal tutup} = 3/16 \text{ in}$$

$$t_h = \frac{P \times r_c \times W}{2 f_e - 0,2P} + C$$

$$3/16 = \frac{1,47 \times 60 \times 0,77 +}{1,6 f - 0,2 \times 1,47}$$

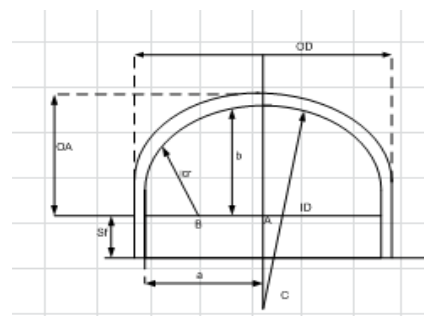
$$1/16 = \frac{68,05703191}{1,6 f - 0,2935607}$$

$$0,1 f - 0,0183475 = 68,05703191$$

$$0,1 f = 68,07537945$$

$$f = 680,7537945$$

f hitung lebih kecil dari f allowable, jadi tebal shell $3/16 \text{ in}$ dapat digunakan



**g. Menentukan Tinggi Tutup Tangki**

$$sf = 2 \text{ in}$$

$$t = 2/8 \text{ in}$$

(Brownell, tabel 5.6, hal. 88)

Menghitung tinggi tutup

$$OA = b + sf + t$$

$$* 1 \text{ ft} = 0,3 \text{ m}$$

$$1 \text{ ft} = 12 \text{ in}$$

$$BC = rc - icr$$

$$BC = 60 - 3,6$$

$$= 56,400 \text{ in}$$

$$AB = \frac{1}{2} \times OD - icr$$

$$AB = \frac{1}{2} \times 60 - 3,6$$

$$= 26,400 \text{ in}$$

$$b = rc - (BC^2 - AB^2)^{0,5}$$

$$b = 60 - (3181 - 69$$

$$= 10,160$$

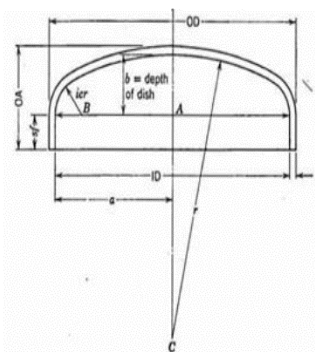


Fig. 5.8. Dimensional relationships for flanged and dished heads.

Tinggi tutup atas

$$OA = b + sf + t$$

$$= 12,348 \text{ in}$$

$$= 0,3136 \text{ m}$$

$$= 1,0290 \text{ ft}$$

Spesifikasi

Nama Alat : Tangki Accumulator

Kode : F-312

Fungsi : Sebagai penampung arus keluaran kondensor pada menara distilasi untuk menjaga kontinuitas dan kestabilan aliran keluar

Dasar Pemilihan : Umum digunakan untuk penampungan sementara hasil keluaran kondensor

Jumlah : 1 buah

Tipe : Tangki silinder *horizontal* dengan tutup berbentuk *standard dished head*



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Bahan Konstruksi : *Carbon steel SA-283 Grade C*

Kondisi Operasi

Suhu : 137,07 °C

Tekanan : 1 atm

Waktu Tinggal : 1 Jam

Dimensi Tangki

Tinggi : 4,7234 ft = 1,43972 m

Panjang : 14,17 ft = 4,31915 m

Volume : 260,1419 ft³

Tebal *Shell* : 3/16 in

Tebal Tutup : 3/16 in

Tinggi tutup : 1,0290 ft = 0,3136 m

23. Pompa (L-313)



Fungsi = Untuk memindahkan hasil *top product* dari accumulator (F-312) menuju Reaktor (R-210)

Tipe = *Centrifugal pump*

Dasar Pemilihan : Umum digunakan untuk memompa liquid dengan viskositas rendah < 10 cP

Komposisi Bahan Masuk

Komponen	Massa	Fraksi Massa
	(kg)	
C ₁₇ H ₃₃ COOH	0,038556417	9,327E-06
C ₄ H ₉ OH	4133,173278	0,9998885
C ₁₇ H ₃₃ COOC ₄ H ₉	0,416750427	0,0001008
C ₁₅ H ₃₁ COOH	0,005400861	1,307E-06
Total	4133,633986	1



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$$\begin{aligned}\text{Rate massa bahan} &= 4133,634 \text{ kg/jam} \\ &= 9113,0508 \text{ lb/jam}\end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,2479	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947

$$T = 137,07 \text{ } ^\circ\text{C} = 410,223 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned}\rho \text{ } C_{17}H_{33}COOH &= 0,815762 \text{ gr/ml} \\ \rho \text{ } C_4H_9OH &= 0,7017321 \text{ gr/ml} \\ \rho \text{ } C_{17}H_{33}COOC_4H_9 &= 0,7792706 \text{ gr/ml} \\ \rho \text{ } C_{15}H_{31}COOH &= 0,8031609 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$C_{17}H_{33}COOH$	0,038556417	9,327E-06	0,815762	7,609E-06
C_4H_9OH	4133,173278	0,9998885	0,7017321	0,7016539
$C_{17}H_{33}COOC_4H_9$	0,416750427	0,0001008	0,7792706	7,857E-05
$C_{15}H_{31}COOH$	0,005400861	1,307E-06	0,8031609	1,049E-06
Total	4133,633986	1		0,7017411

$$\begin{aligned}\rho \text{ Campuran} &= 0,7017411 \text{ gr/ml} \times 62,4 \\ &= 43,788646 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Rate volumetrik} &= \frac{\text{rate massa bahan}}{\rho \text{ bahan}} \\ &= \frac{9113,0508 \text{ lb/jam}}{43,788646 \text{ lb/cuft}}\end{aligned}$$



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$$\begin{aligned} &= 208,11447 \text{ cuft/jam} \\ &= 0,0578096 \text{ cuft/detik} \\ &= 25,946741 \text{ gpm} \end{aligned}$$

a. Menentukan diameter optimal pipa

asumsi aliran turbulen ($N_{re} > 2100$), maka digunakan persamaan

$$D_{i \text{ opt}} = 3,9 \times q_f^{0,45} \times \rho^{0,13} \quad \text{(Peters, 4^{ed}, pers. 15 hal 496)}$$

Keterangan :

$D_{i \text{ opt}}$ = Diameter pipa bagian dalam optimal (in)

q_f = Rate volumetrik (ft^3/s)

ρ = Densitas larutan (lb/ft^3)

Sehingga,

$$\begin{aligned} D_{i \text{ opt}} &= 3,9 \times q_f^{0,45} \times \rho^{0,13} \\ &= 3,9 \times 0,28 \times 1,63 \\ &= 1,77 \text{ in} \end{aligned}$$

Dari Kern Table. 11, maka dipilih pipa dengan spesifikasi :

Pipe size = 2 in

Sch = 80

OD = 2,38 in = 0,2 ft = 0,06 m

ID = 1,93 in = 0,16 ft = 0,05 m

$$\begin{aligned} A &= \frac{1}{4} \times \pi \times ID^2 \\ &= \frac{1}{4} \times 3,14 \times 0,02585 \\ &= 0,02029 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Kecepatan Aliran (V)} &= \frac{\text{Rate volumetrik}}{\text{Luas Area (A)}} \\ &= \frac{0,05781}{0,02029} \\ &= 2,84922 \text{ ft/s} \end{aligned}$$



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b. Menghitung Nre

$$\text{sg reff} = 1 \quad (\text{Kern, Table. 6 p. 808})$$

$$\mu \text{ reff} = 0,8 \text{ cP} \quad (\text{Kern, Fig. 14 p. 823})$$

$$\rho \text{ reff} = 62,4 \text{ lb/ft}^3$$

$$\begin{aligned} \text{sg bahan} &= \frac{\rho \text{ bahan}}{\rho \text{ reff}} \\ &= \frac{43,7886 \text{ lb/ft}^3}{62,43 \text{ lb/ft}^3} \\ &= 0,7014 \end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
$\text{C}_{17}\text{H}_{33}\text{COOH}$	-6,13	1690	0,008	-6E-06
$\text{C}_4\text{H}_9\text{OH}$	-5,397	1325,6	0,006	-6E-06
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	-15,275	2934	0,02692	-2E-05
$\text{C}_{15}\text{H}_{31}\text{COOH}$	-9,45	2100	0,016	-1E-05

$$T = 410,223 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \text{ C}_{17}\text{H}_{33}\text{COOH} = 1,5348697 \text{ cP}$$

$$\mu \text{ C}_4\text{H}_9\text{OH} = 0,2336221 \text{ cP}$$

$$\mu \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 = 0,7549622 \text{ cP}$$

$$\mu \text{ C}_{15}\text{H}_{31}\text{COOH} = 1,2953046 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,0385564	9,327E-06	1,5348697	1,432E-05
$\text{C}_4\text{H}_9\text{OH}$	4133,1733	0,9998885	0,2336221	0,233596
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	0,4167504	0,0001008	0,7549622	7,611E-05
$\text{C}_{15}\text{H}_{31}\text{COOH}$	0,0054009	1,307E-06	1,2953046	1,692E-06
Total	4133,634	1		0,2336882



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$$\begin{aligned}\mu \text{ Campuran} &= 0,2336882 \text{ cP} \\ &= 0,000157 \text{ lb/ft s}\end{aligned}$$

$$\begin{aligned}\text{Nre} &= \frac{\text{ID} \times V \times \rho \text{ bahan}}{\mu} \\ &= \frac{0,16 \times 2,85 \times 43,8}{0,000157} \\ &= 127727,18 > 2100 \\ &\text{asumsi aliran turbulen benar}\end{aligned}$$

Dipilih bahan commercial steel, dengan

$$e = 0,000046 \text{ m} \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$

$$\begin{aligned}e/D &= \frac{0,000046 \text{ m}}{0,0490024} \\ &= 0,0009387\end{aligned}$$

$$f = 0,006 \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$

$$g_c = 32,174 \text{ ft.lbm/detik}^2.\text{lbf}$$

$$\alpha = 1 \quad (\text{aliran turbulen}) \quad (\text{Peters \& Timmerhause 4}^{\text{th}} \text{ ed : 485})$$

c. Menghitung Panjang ekuivalen suction, Le

Perhitungan friksi berdasarkan Peters & Timmerhaus, 4ed Tabel 1 hh. 484

Sambungan	Lc/D
Elbow standard 90°	32
Gate valve	7

$$\text{ID pipa} = 0,160769 \text{ ft}$$

Taksiran panjang pipa lurus

$$\text{Jarak accumulator ke reaktor} = 98,4252 \text{ ft}$$

$$\text{Tinggi reaktor} = 17,4000 \text{ ft}$$

$$\text{Panjang pipa masuk reaktor} = 6 \text{ ft}$$

$$\text{Taksiran panjang pipa lurus} = 121,825 \text{ ft}$$

$$\begin{aligned}3 \text{ elbow } 90^\circ &= 3 \times 32 \times 0,16 \text{ ft} \\ &= 15,4 \text{ ft}\end{aligned}$$

$$\begin{aligned}1 \text{ gate valve} &= 1 \times 7 \times 0,16 \text{ ft} \\ &= 1,13 \text{ ft}\end{aligned}$$

$$\text{Panjang total pipa (Le)} = 138,384 \text{ ft}$$



d. Perhitungan friksi

1. Friksi karena Gesekan Bahan dalam Pipa

$$\begin{aligned}
 gc &= 32,17 \text{ lbf.ft/lbm.s}^2 \\
 F_1 &= \frac{2f \times V^2 \times L}{gc \times D} \quad (\text{Geankoplis 3ed, Pers, 2.10-6, P.89}) \\
 &= \frac{0,01 \times 8,12 \times 138}{32,2 \times 0,16} \\
 &= 2,60655 \text{ ft.lbf/lbm}
 \end{aligned}$$

2. Friksi karena kontraksi dari tangki penyimpanan ke pipa

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-16, P.93})$$

dimana

$\alpha = 1$ untuk aliran turbulen

Menentukan Kc

A tangki > A pipa maka dianggap 0

Untuk A1 (tangki) dan A2 (pipa), maka $A2/A1 = 0$

maka,

$$K = 0,4 \times (1,25 - A2/A1) \quad (\text{Peters 4 ed ; Page 484})$$

$$K = 0,4 \times (1,25 - 0)$$

$$K = 0,5$$

sehingga,

$$\begin{aligned}
 F_2 &= \frac{0,5 \times 8,1180364 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbf.ft/lbm.s}^2} \\
 &= 0,06309 \text{ ft.lbf/lbm}
 \end{aligned}$$

3. Friksi karena ekspansi dari pipa ke tangki

$$F_3 = \frac{\Delta V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-15, P.93})$$

($V_1 \ll V_2$ dianggap = 0)

$$\begin{aligned}
 &= \frac{8,118036413 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbf.ft/lbm.s}^2} \\
 &= 0,12617 \text{ ft.lbf/lbm}
 \end{aligned}$$



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4. Friksi karena elbow 90°

$$F_4 = n \times \frac{K_f \times V^2}{2 \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-17, P.94})$$

diketahui :

$$K_f = 0,75 \quad (\text{Geankoplis 3ed, T.2.10-1, P. 93})$$

$$F_4 = \frac{3 \times 0,75 \times 8,1180364 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2} = 0,28389 \text{ ft.lbf/lbm}$$

5. Friksi karena gate valve

$$F_5 = n \times \frac{K_f \times V^2}{2 \times gc} \quad (\text{Geankoplis 3ed Pers. 2.10-1})$$

diketahui :

$$K_f \text{ gate valve (wide open)} = 0,17$$

$$F_5 = \frac{1 \times 0,17 \times 8,1180364 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2} = 0,02145 \text{ ft.lbf/lbm}$$

6. Friksi Total

$$\begin{aligned} \Sigma F &= F_1 + F_2 + F_3 + F_4 + F_5 \\ &= 3,10115 \text{ ft.lbf/lbm} \end{aligned}$$

e. Perhitungan Energi Tekanan

$$H \text{ liquida} = 4,3881 \text{ ft}$$

$$\rho \text{ bahan} = 43,7886 \text{ lbm/ft}^3$$

$$g/gc = 1 \text{ lbf/lbm}$$

$$P_2 = 1 \text{ atm} = 2116,8 \text{ lbf/ft}^2$$

Energi Tekanan

$$\begin{aligned} P_1 &= P \text{ atm} + P \text{ hidrostatik} \\ &= 1 \text{ atm} + \left(\rho \times \frac{g}{gc} \times H \text{ liq} \right) \\ &= 2117 \text{ lbf/ft}^2 + \left(43,8 \text{ lbm/ft}^3 \times 1 \text{ lbf/lbm} \times 4,39 \text{ ft} \right) \\ &= 2308,9488 \text{ lbf/ft}^2 \end{aligned}$$



$$\begin{aligned}\frac{\Delta P}{\rho} &= \frac{(P_1 - P_2)}{\rho} \\ &= \frac{2308,95 - 2116,8}{43,78864599} \\ &= 4,3881 \text{ ft.lbf/lbm}\end{aligned}$$

f. Perhitungan Energi Kinetik

$$\begin{aligned}E_k &= \frac{\Delta V^2}{2 \times \alpha \times g_c} \quad (\text{Geankoplis, 3ed Eq. 2.7-5 p. 66}) \\ &= \frac{8,118036413}{2 \times 1 \times 32,17} \\ &= 0,126174 \text{ ft.lbf/lbm}\end{aligned}$$

g. Perhitungan Energi potensial

Diketahui

$$Z_1 = 4,3881 \text{ ft (Tinggi Larutan dari accumulator)}$$

$$Z_2 = 17,4000 \text{ ft (Tinggi pipa menuju reaktor)}$$

$$g/g_c = 1 \text{ lbf/lbm}$$

Sehingga,

$$\begin{aligned}E_p &= \Delta Z \times \frac{g}{g_c} \quad (\text{Geankoplis, 2014 Eq. 2.7-5 p. 66}) \\ &= (17,4 - 4,39) \text{ ft} \times 1 \text{ lbf/lbm} \\ &= 13,0119 \text{ ft.lbf/lbm}\end{aligned}$$

h. Persamaan Bernouli

$$\begin{aligned}-W_f &= \frac{\Delta P}{\rho} + \Delta Z \times \frac{g}{g_c} + \frac{\Delta V^2}{2 \times \alpha \times g_c} + \Sigma F \\ &= 4,3881 + 13,0119 + 0,12617 + 3,10115 \\ &= 20,6274 \text{ ft.lbf/lbm}\end{aligned}$$

i. Perhitungan Power Pompa

$$\begin{aligned}hp &= \frac{-W_f \times \text{flowrate(gpm)} \times sg}{3960} \\ &\quad (\text{Perry 6ed ; Pers 6-11, Page 6-5}) \\ &= \frac{20,6274 \times 25,9467 \times 0,7014}{3960} \\ &= 0,0948 \text{ hp}\end{aligned}$$



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Efisiensi pompa = 65% (Peters 4 ed ; Figure 14 - 37 Page 520)

$$\begin{aligned} \text{Bhp} &= \frac{\text{Bph}}{\eta \text{ pompa}} \\ &= \frac{0,0947981}{65\%} \text{ hp} \end{aligned}$$

$$= 0,1458432 \text{ hp}$$

Efisiensi motor = 80%

$$\begin{aligned} \text{Power motor} &= \frac{\text{Bhp}}{\text{ef.Motor}} \\ &= \frac{0,1458432}{80\%} \text{ hp} \end{aligned}$$

$$= 0,182304 \text{ hp}$$

Maka digunakan power = 0,5 hp

Spesifikasi

Nama Alat	: Pompa
Kode	: L-313
Fungsi	: Untuk Memindahkan produk dari accumulator (F-310) menuju Reaktor (R-210)
Tipe	: <i>Centrifugal pump</i>
Dasar Pemilihan	: Umum digunakan untuk memompa liquid dengan viskositas rendah
Bahan konstruksi	: <i>Commercial steel</i>
Ukuran Pipa	: 2 in 80 sch
Kapasitas	: 9113,05 lb/jam
Rate volumetrik	: 208,114 ft ³ /jam
Total Dynamic head	: 20,6274 ft.lbf/lbm
Efisiensi pompa	: 65%
Efisiensi motor	: 80%
Power	: 0,5 hp
Jumlah	: 1 buah



24. Cooler (E-314)



Fungsi : Menurunkan suhu butanol dari 137°C menjadi 120°C

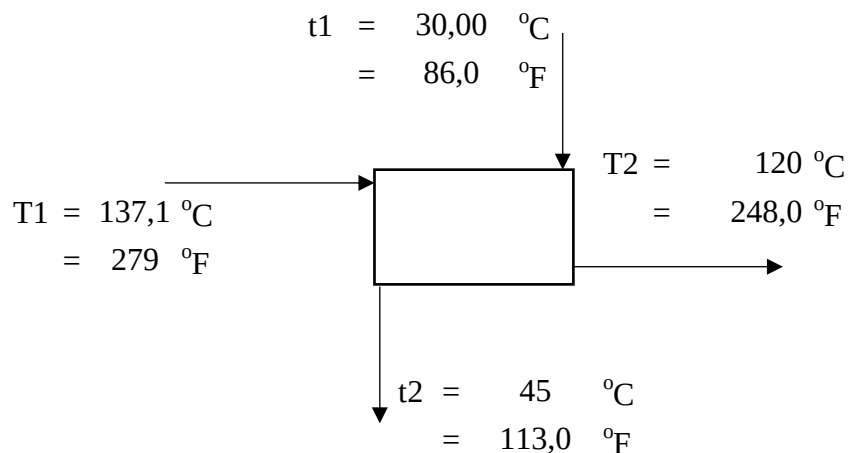
Tipe : 1-2 Shell and Tube Exchanger

Dasar Pemilihan : Umum digunakan untuk menurunkan suhu liquida

Kondisi Operasi :

Tekanan = 1 atm

Suhu = 120 °C



Perhitungan

1. Data dari neraca massa dan neraca panas diperoleh:

Untuk Fluida panas : Larutan Butanol

T masuk (T1) = 137,1 °C = 278,731 F

T keluar (T2) = 120 °C = 248,0 F

Untuk Fluida dingin : Air Proses

T masuk (t1) = 30 °C = 86,0 F

T keluar (t2) = 45 °C = 113,0 F



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$$\begin{aligned}\text{massa bahan} &= 4133,634 \text{ kg/jam} \\ &= 9139,4647 \text{ lb/jam}\end{aligned}$$

Panas yang diserap

$$\begin{aligned}Q &= 41276,407 \text{ kkal/jam} \\ &= 163689,85 \text{ Btu/jam}\end{aligned}$$

Steam yang digunakan

Air Pendingin yang dibutuhkan

$$\begin{aligned}W &= 2755,34 \text{ kg/jam} \\ &= 6092,06 \text{ lb/jam}\end{aligned}$$

2. Penentuan ΔT LMTD

Hot fluida		Cold fluida	diff
278,731	higher temp	113,0	166
248,0	lower temp	86,0	162
30,7		27,0	

$$\Delta t \text{ LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$

$$\begin{aligned}\Delta t \text{ LMTD} &= \frac{166 - 162}{\ln \frac{166}{162}} \\ &= 163,8584 \text{ F}\end{aligned}$$

$$\begin{aligned}R &= \frac{T_1 - T_2}{t_2 - t_1} && \text{(Kern, Eq 5.17)} \\ &= \frac{279 - 248,0}{113 - 86,0} \\ &= 1,14\end{aligned}$$

$$\begin{aligned}S &= \frac{t_2 - t_1}{T_1 - t_1} && \text{(Kern, Pers. 5.14, : 149)} \\ &= \frac{113 - 86}{279 - 86} \\ &= 0,14009\end{aligned}$$

$$FT = 0,96 \quad \text{(Kern Fig. 18, : 828)}$$



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$$\begin{aligned}\Delta T &= \Delta T \text{ LMTD} \times FT && \text{(Kern, Pers. 7.42 : 149)} \\ &= 163,858 \text{ }^{\circ}\text{F} \times 0,96 \\ &= 157,304 \text{ }^{\circ}\text{F}\end{aligned}$$

3. Tc dan tc

Tc = t average bahan

$$\begin{aligned}T_c &= \frac{T_1 + T_2}{2} \\ &= \frac{279 + 248}{2} \\ &= 263 \text{ }^{\circ}\text{F} \\ &= 402 \text{ K}\end{aligned}$$

tc = t average air

$$\begin{aligned}t_c &= \frac{t_1 + t_2}{2} \\ &= \frac{86,0 + 113}{2} \\ &= 99,5 \text{ }^{\circ}\text{F} \\ &= 310,65 \text{ K}\end{aligned}$$

Menghitung Kapasitas Panas, Konduktifitas Thermal dan Viskositas

Fluida Dingin

$$\begin{aligned}c_p &= 1 \text{ Btu/lb}^{\circ}\text{F} && \text{(Kern, Fig 2)} \\ k &= 0,37 \text{ BTU/hr ft}^2 \text{ }^{\circ}\text{F/ft} && \text{(Kern, Table 4)} \\ \mu &= 0,13 \text{ cP} && \text{(Kern, Fig.14)}\end{aligned}$$

Fluida Panas

Menghitung nilai kapasitas panas

komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	278,686	2,5434	-0,0054	4,9E-06
C ₄ H ₉ OH	83,877	0,56628	-0,0017	2,3E-06
C ₁₇ H ₃₃ COOC ₄ H ₉	178,423	3,667	-0,00797	7,1E-06
C ₁₅ H ₃₁ COOH	86,29	3,5237	-0,0073	6,1E-06

$$\begin{aligned}T &= 401,686 \text{ K} \\ C_p &= A + BT + CT^2 + DT^3\end{aligned}$$



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Sehingga diperoleh

$$\begin{aligned} C_p \text{ C}_{17}\text{H}_{33}\text{COOH} &= 713,266 \text{ Kkal/KmolK} \\ C_p \text{ C}_4\text{H}_9\text{OH} &= 172,085 \text{ Kkal/KmolK} \\ C_p \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 788,43 \text{ Kkal/KmolK} \\ C_p \text{ C}_{15}\text{H}_{31}\text{COOH} &= 683,394 \text{ Kkal/KmolK} \end{aligned}$$

komponen	BM	Cp	Fraksi	Cp
	Kg/Kmol	kcal/Kmol K	Xf	kcal/Kg K
C ₁₇ H ₃₃ COOH	282,47	713,26606	9,3E-06	2,5251
C ₄ H ₉ OH	74	172,08487	0,99989	2,32547
C ₁₇ H ₃₃ COOC ₄ H ₉	310,56	788,42991	0,0001	2,53874
C ₁₅ H ₃₁ COOH	256,42	683,39381	1,3E-06	2,66513
Total			1	

$$1 \text{ kkal/kg K} = 0,23885 \text{ Btu/lb } ^\circ\text{F}$$

$$C = \sum_i^n C_p \cdot X_f$$

$$C = 0,555435 \text{ Btu/lb}^\circ\text{F}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	-6,13	1690	0,008	-6E-06
C ₄ H ₉ OH	-5,397	1325,6	0,006	-6E-06
C ₁₇ H ₃₃ COOC ₄ H ₉	-15,2751	2934	0,02692	-1,8E-05
C ₁₅ H ₃₁ COOH	-9,45	2100	0,016	-1E-05

$$T = 401,686 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\begin{aligned} \mu \text{ C}_{17}\text{H}_{33}\text{COOH} &= 5,309196 \text{ cP} \\ \mu \text{ C}_4\text{H}_9\text{OH} &= 0,675156 \text{ cP} \\ \mu \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 2,1414477 \text{ cP} \end{aligned}$$



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$$\mu \quad C_{15}H_{31}COOH = 4,1930909 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
$C_{17}H_{33}COOH$	0,0385564	9,327E-06	5,309196	4,952E-05
C_4H_9OH	4133,1733	0,9998885	0,675156	0,6750808
$C_{17}H_{33}COOC_4H_9$	0,4167504	0,0001008	2,1414477	0,0002159
$C_{15}H_{31}COOH$	0,0054009	1,307E-06	4,1930909	5,479E-06
Total	4133,634	1		0,6753517

$$\begin{aligned} \mu \text{ Campuran} &= 0,6753517 \text{ cP} \\ &= 0,0004538 \text{ lb/ft s} \end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,24798	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947

$$T = 401,686 \text{ K}$$

$$\rho = Ax B^{-\left(1 - \frac{T}{Tc}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned} \rho \quad C_{17}H_{33}COOH &= 0,8272009 \text{ gr/ml} \\ \rho \quad C_4H_9OH &= 0,7197156 \text{ gr/ml} \\ \rho \quad C_{17}H_{33}COOC_4H_9 &= 0,7917196 \text{ gr/ml} \\ \rho \quad C_{15}H_{31}COOH &= 0,8147097 \text{ gr/ml} \end{aligned}$$

komponen	Massa	Fraksi Massa	Densitas gr/ml	ρ Campuran gr/ml
	(kg)			
$C_{17}H_{33}COOH$	0,038556417	9,327E-06	0,8272009	7,716E-06
C_4H_9OH	4133,173278	0,9998885	0,7197156	0,7196354
$C_{17}H_{33}COOC_4H_9$	0,416750427	0,0001008	0,7917196	7,982E-05
$C_{15}H_{31}COOH$	0,005400861	1,307E-06	0,8147097	1,064E-06



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Total	4133,633986	1		0,719724

$$\begin{aligned}\rho \text{ Campuran} &= 0,719724 \text{ gr/ml} \times 62,4 \\ &= 44,910778 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}Sg &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{44,910778 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,7193782\end{aligned}$$

$$\begin{aligned}K_{\text{mix}} &= \frac{0,0677}{\text{sg} [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{0,719 [1 - 0,0003 (100 - 32)]} \\ &= 0,0961 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243}\end{aligned}$$

Dipilih tipe : 1-2 Heat Exchanger

Digunakan shell and tube dengan ukuran :

Tube Side

$$\begin{aligned}\text{OD} &= 1 \text{ in} \\ \text{BWG} &= 8 \\ \text{Pitch} &= 1 \frac{1}{4} \text{ in Square Pitch} \\ L &= 10 \text{ ft} \\ \text{Passes} &= 2 \\ \text{ID} &= 0,67 \text{ in} \\ a't &= 0,355 \text{ in}^2 \\ a'' &= 0,2618 \text{ ft}^2/\text{ft panjang}\end{aligned}$$

(kern, Table.10, Hal. 843)

Shell Side

$$\begin{aligned}\text{Shell ID} &= 10 \text{ in} \\ \text{Passes} &= 1 \text{ in}\end{aligned}$$

$$\text{Harga UD} = 5 - 75 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{(Kern, tabel 8 hal 840)}$$

$$\text{Dipilih UD} = 25 \text{ Btu/jam.ft.}^\circ\text{F}$$

$$\begin{aligned}A &= \frac{Q}{\text{UD} \times \Delta t} \quad \text{(Kern Eq. 7.6)} \\ &= \frac{163689,8464}{}\end{aligned}$$



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$$= 25 \times 157,304$$

$$= 41,6238 \text{ ft}^2$$

$$\text{Jumlah tube (Nt)} = \frac{A}{a'' \times L}$$

$$= \frac{41,62380598}{0,26 \times 10}$$

$$= 31,7982 \text{ buah}$$

Sehingga dipilih ukuran yang paling mendekati, yaitu:

$$\begin{aligned} \text{ukuran pipa} &= 3/4 \text{ in} \\ \text{ID tube} &= 0,67 \\ \text{BWG} &= 8 \\ \text{Pitch} &= 1 \text{ in Square Pitch} \\ \text{ID shell} &= 10 \\ \text{Passes tube} &= 2 \\ \text{Jumlah tube} &= 36 \end{aligned}$$

UD koreksi

$$\begin{aligned} A &= Nt \times L \times a'' \\ &= 36 \times 10 \times 0,26 \\ &= 94,248 \end{aligned}$$

$$\begin{aligned} \text{UD} &= \frac{Q}{A \times \Delta t} \\ &= \frac{163689,8464}{94,2 \times 157,304} \\ &= 11,041032 \end{aligned}$$

Menentukan nilai De :

$$\begin{aligned} \text{De} &= \frac{4 \left(\text{Pt}^2 - \pi \frac{\text{OI}^2}{4} \right)}{\pi \text{OD}} \\ &= \frac{4 \left(1,25^2 - 3,14 \times \frac{1,00^2}{4} \right)}{3,14 \times 1} \\ &= 0,99045 \text{ in} = 0,08 \text{ ft} \end{aligned}$$



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Fluida Dingin : Tube Side	Fluida Panas :Shell Side
Air Pendingin	Produk
4. Flow Area (at) $at = \frac{N_t \times at'}{144 \times n}$ (Kern, Eq 7.48) $= \frac{36 \times 0,36}{144 \times 2}$ $= 0,045 \text{ ft}^2$	4. Flow Area (at) asums B = 0,25 ID $= 2,5$ $C = Pt - OD$ $= 1 \frac{1}{4} - 1$ $= 0,25$ $as = \frac{ID \times C' \times B}{144 \times Pt}$ (Kern, Eq. 7.1) $= \frac{10 \times 0,25 \times 2,5}{144 \times 1,25}$ $= 0,0347222 \text{ ft}^2$
5. Mass Velocity (Gt) $Gt = \frac{W}{at}$ $= \frac{6092,062}{0,045}$ $= 135379,16 \text{ lb/jam ft}^2$	5. Mass Velocity (Gs) $Gs = \frac{W}{as}$ (Kern, Eq 7.2) $= \frac{9139,4647}{0,0347222}$ $= 263216,58 \text{ lb/jam ft}^2$
6. Bilangan Reynold (Ret) $De = 0,08 \text{ ft}$ $\mu = 0,3146 \text{ lb/ft.jam}$ $Ret = \frac{De \times Gs}{\mu}$ $= \frac{0,08 \times 135379}{0,3146}$ $= 35517,501$	6. Bilangan Reynold (Res) $D = 0,06 \text{ ft}$ $\mu = 1,63 \text{ lb/ft.jam}$ $Res = \frac{D \times Gt}{\mu}$ $= \frac{0,06 \times 263217}{1,63435}$ $= 8992,0711$
	7. jH $L/D = 179,105$ $jH = 24$



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9. h_{io} $h_{io} = 1500 \text{ Btu/hr ft}^2 \text{ } ^\circ\text{F}$ (Kern, Hal. 164)	(Kern Fig-28, hal. 838) 8. $(C \times \mu / k)^{1/3}$ $= \frac{0,55543 \times 1,63435}{0,0961}$ $= 2,11424$ 9. h_o $h_o = jH \frac{k}{D} \left(\frac{c \mu}{k} \right)^{1/3} \phi_s$ (Kern, Eq 6.15b) $\frac{h_o}{\phi_t} = 24 \times \frac{0,0961 \times 2,11424}{0,05583}$ $= 87,295067 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$
10. t_w $t_w = t_c + \frac{h_o/\phi_s}{h_{io}/\phi_t + h_o/\phi_s} (T_c - t_c)$ (Kern, Eq 5.31) $= 100 + \frac{1500}{1500 + 87,30} 164$ $= 254,354 \text{ } ^\circ\text{F}$	10. ϕ_s Pada $t_w = 254,35351 \text{ } ^\circ\text{F}$ $\mu_w = 0,8094 \text{ lb/jam ft}$ $\phi_t = (\mu/\mu_w)^{0.14}$ (Kern, Fig.15) $= 1,10338$ 11. h_{io} $= \frac{h_o}{\phi_t} \times \phi_t$ $= 96,3197 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$

12. Clean Overall Coefficient, U_c

$$\begin{aligned}
 U_c &= \frac{h_{io} \times h_o}{h_{io} + h_o} \quad \textbf{(Kern, Eq 6.38)} \\
 &= \frac{1500 \times 96,3}{1500 + 96,3} \\
 &= 90,5 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}
 \end{aligned}$$

13. Design Overall Coefficient, U_d



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$$\begin{aligned}
 U_d &= \frac{Q}{A \times \Delta t \text{ LMTD}} \\
 &= \frac{163689,85}{94,2 \times 157} \\
 &= 11,041032 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}
 \end{aligned}$$

14. Dirt Factor, R_d

$$\begin{aligned}
 R_d &= \frac{U_c - U_d}{U_c \times U_d} \quad \text{(Kern, Eq 6.13)} \\
 &= \frac{90,5 - 11}{90,5 \times 11} \\
 &= 0,07952
 \end{aligned}$$

Nilai R_d perhitungan > R_d

$$0,07952 > 0,002 \quad \text{(Kern, Table 12 Page 845)}$$

(Memenuhi karena R_d Perhitungan >> R_d allowabe)

Pressure Drop	
Fluida Panas : Tube Side	Fluida Dingin : Shell Side
Steam	Butanol
1. f $ \begin{aligned} Re_t &= 35517,501 \\ f &= 0,00023 \\ &\quad \text{(Kern, Fig 26)} \end{aligned} $ 2. ρ $ \begin{aligned} \rho &= \frac{1}{6,62} \\ &= 0,15106 \text{ lb/ft}^3 \\ s &= \frac{0,15106}{62,5} \\ &= 0,00242 \\ \Delta P_t &= \frac{f G_s^2 L_n}{5,22 \times 10^{10} D s \phi} \\ &= 0,1295387 \text{ psi} \end{aligned} $	1. f $ \begin{aligned} Re_s &= 8992,0711 \\ f &= 0,0032 \\ &\quad \text{(Kern, Fig 29)} \end{aligned} $ 2. Number of crosses, $N+1$ $ \begin{aligned} N+1 &= 12 \times \frac{L}{B} \\ &= 12 \times \frac{10}{2,5} \\ &= 48 \end{aligned} $ 3. Pressure Drop (ΔP_s) $ \begin{aligned} s &= 1,84 \\ &\quad \text{(Kern, Table 6)} \\ \Delta P_s &= \frac{f \times G_t^2 \times L \times n}{5,22 \times 10^{10} \times ID \times s \times \phi_t} \end{aligned} $



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$\Delta P_t < \Delta P \text{ allowable}$ $\Delta P_t < 2 \text{ psi}$, maka memenuhi	(Kern, Eq 7.44) $= 0,1004162 \text{ psi}$ $\Delta P_s < \Delta P \text{ allowable}$ $\Delta P_s < 2 \text{ psi}$, maka memenuhi

Spesifikasi Alat

Nama Alat : Cooler
Kode : E-314
Fungsi : Mendinginkan larutanbutanol menjadi suhu 120C
untuk dialirkan ke Reaktor
Tipe : 1-2 *Shell and Tube Exchanger*
Dasar Pemilihan : Umum digunakan untuk transfer panas
Kondisi Operasi : - Tekanan : 1 atm
- Suhu : 120 °C

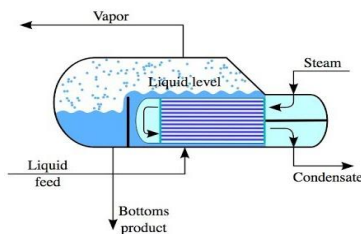
Bagian Tube

OD : 1 in
BWG : 8
Panjang : 10 ft
Jumlah tube, Nt : 36
Passes : 2
Pitch : 1 1/4 in square pitch
Pressure drop : 0,1295387 psi

Bagian Shell

ID : 10 in
Passes : 1
Baffle Spacing : 2,5 in
Pressure drop : 0,1004162 psi

25. Reboiler (E-315)



Fungsi : Untuk menguapkan sebagian cairan dibawah kolom dan mensupply



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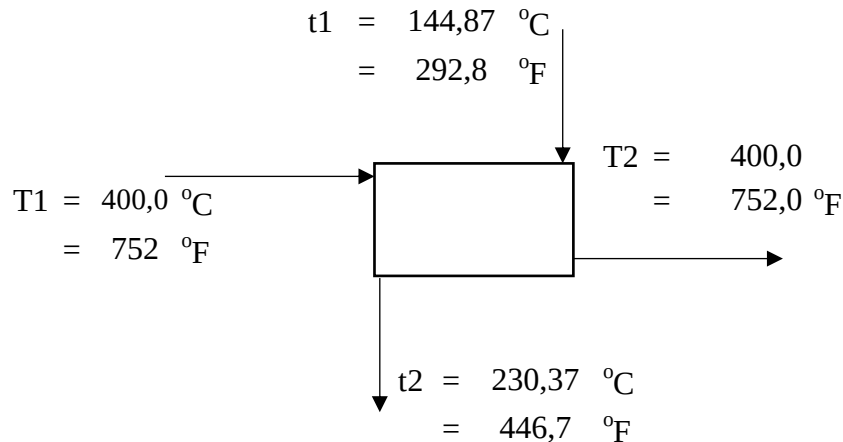
pamas ke kolom destilasi

Tipe : 1-2 Shell and Tube Exchanger

Kondisi Operasi:

Tekanan = 1 atm

Suhu = 230,37 °C



Perhitungan

1. Data dari neraca massa dan neraca panas diperoleh:

Untuk Fluida panas : Steam

T masuk (T1) = 400,0 °C = 752 F

T keluar (T2) = 400 °C = 752,0 F

Untuk Fluida dingin : Produk

T masuk (t1) = 144,87 °C = 292,8 F

T keluar (t2) = 230,37 °C = 446,7 F

Rate massa bahan yang masuk = 4607,0297 kg/jam
= 10186,143 lb/jam

Panas yang dibutuhkan

Q = 762604,05 kkal/jam

= 3024258,9 Btu/jam

Kebutuhan Steam yang digunakan

Massa steam = 774,829 kg/jam

= 1713,15 lb/jam



2. Penentuan ΔT LMTD

Hot fluida		Cold fluida	diff
752	higher temp	446,7	305
752	lower temp	292,8	459
0		153,9	

$$\Delta t \text{ LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$

$$\begin{aligned} \Delta t \text{ LMTD} &= \frac{305 - 459}{\ln \frac{305}{459}} \\ &= 377,0598 \text{ F} \end{aligned}$$

$$\begin{aligned} R &= \frac{T_1 - T_2}{t_2 - t_1} && \text{(Kern, Eq 5.17)} \\ &= \frac{752 - 752}{447 - 293} \\ &= 0 \end{aligned}$$

$$\begin{aligned} S &= \frac{t_2 - t_1}{T_1 - t_1} && \text{(Kern, Pers. 5.14, : 149)} \\ &= \frac{447 - 293}{752 - 293} \\ &= 0,33511 \end{aligned}$$

$$\begin{aligned} FT &= 0,96 && \text{(Kern Fig. 18, : 828)} \\ \Delta T &= \Delta T \text{ LMTD} \times FT && \text{(Kern, Pers. 7.42 : 149)} \\ &= 377,06 \text{ }^\circ\text{F} \times 0,96 \\ &= 361,977 \text{ }^\circ\text{F} \end{aligned}$$

3. Tc dan tc

Tc = t average steam

$$\begin{aligned} T_c &= \frac{T_1 + T_2}{2} \\ &= \frac{752 + 752}{2} \end{aligned}$$



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$$= 752 \text{ }^{\circ}\text{F}$$

$t_c = t \text{ average bahan}$

$$t_c = \frac{t_1 + t_2}{2}$$

$$= \frac{293 + 447}{2}$$

$$= 369,721 \text{ }^{\circ}\text{F}$$

$$= 460,773 \text{ K}$$

Menghitung Kapasitas Panas, Konduktivitas Thermal dan Viskositas

Fluida Panas

$$c_p = 0,45 \text{ Btu/lb}^{\circ}\text{F} \quad (\text{Kern, Fig 3})$$

$$k = 0,016 \quad (\text{Kern, Table 5})$$

$$\mu = 0,014 \text{ cP} \quad (\text{Kern, Fig.15})$$

Fluida Dingin

Menghitung nilai kapasitas panas

komponen	A	B	C	D
$\text{C}_{17}\text{H}_{33}\text{COOH}$	278,686	2,5434	-0,0054	4,9E-06
$\text{C}_4\text{H}_9\text{OH}$	83,877	0,56628	-0,0017	2,3E-06
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	178,423	3,667	-0,00797	7,1E-06
$\text{C}_{15}\text{H}_{31}\text{COOH}$	86,29	3,5237	-0,0073	6,1E-06

$$T = 460,773 \text{ K}$$

$$C_p = A + BT + CT^2 + DT^3$$

Sehingga diperoleh

$$C_p \text{ C}_{17}\text{H}_{33}\text{COOH} = 778,298 \text{ Kkal/KmolK}$$

$$C_p \text{ C}_4\text{H}_9\text{OH} = 208,877 \text{ Kkal/KmolK}$$

$$C_p \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 = 869,845 \text{ Kkal/KmolK}$$

$$C_p \text{ C}_{15}\text{H}_{31}\text{COOH} = 752,541 \text{ Kkal/KmolK}$$

komponen	BM	Cp	Fraksi	Cp
	Kg/Kmol	kcal/Kmol K	Xf	kcal/Kg K
$\text{C}_{17}\text{H}_{33}\text{COOH}$	282,47	778,29793	0,08368	2,75533



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C ₄ H ₉ OH	74	208,87665	9E-05	2,82266
C ₁₇ H ₃₃ COOC ₄ H ₉	310,56	869,845	0,90451	2,80089
C ₁₅ H ₃₁ COOH	256,42	752,54137	0,01172	2,9348
Total			1	

$$1 \text{ kkal/kg K} = 0,23885 \text{ Btu/lb } ^\circ\text{F}$$

$$C = \sum_i^n C_p \cdot X_f$$

$$C = 0,6684577 \text{ Btu/lb } ^\circ\text{F}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	-6,13	1690	0,008	-6E-06
C ₄ H ₉ OH	-5,397	1325,6	0,006	-6E-06
C ₁₇ H ₃₃ COOC ₄ H ₉	-15,275	2934	0,02692	-2E-05
C ₁₅ H ₃₁ COOH	-9,45	2100	0,016	-1E-05

$$T = 460,77256 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu_{\text{C}_{17}\text{H}_{33}\text{COOH}} = 0,7153612 \text{ cP}$$

$$\mu_{\text{C}_4\text{H}_9\text{OH}} = 0,1187701 \text{ cP}$$

$$\mu_{\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9} = 0,4550793 \text{ cP}$$

$$\mu_{\text{C}_{15}\text{H}_{31}\text{COOH}} = 0,6379711 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
C ₁₇ H ₃₃ COOH	385,52561	0,083682	0,7153612	0,0598629
C ₄ H ₉ OH	0,4133587	8,972E-05	0,1187701	1,066E-05
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,0875	0,9045063	0,4550793	0,4116221
C ₁₅ H ₃₁ COOH	54,003206	0,0117219	0,6379711	0,0074782
Total	4607,0297	1		0,4789739



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$$\begin{aligned}\mu \text{ Campuran} &= 0,4789739 \text{ cP} \\ &= 1,1586857 \text{ lb/jam ft}\end{aligned}$$

komponen	A	B	C	D
$C_{17}H_{33}COOH$	-6,13	1690	0,008	-6E-06
C_4H_9OH	-5,397	1325,6	0,006	-6E-06
$C_{17}H_{33}COOC_4H_9$	-15,275	2934	0,02692	-2E-05
$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05

$$\begin{aligned}T &= 739,86291 \text{ F} = 666,40717 \text{ K} \\ \text{Log}_{10} \mu &= A + \frac{B}{T} + CT + DT^2\end{aligned}$$

Sehingga diperoleh

$$\begin{aligned}\mu \text{ } C_{17}H_{33}COOH &= 0,0746121 \text{ cP} \\ \mu \text{ } C_4H_9OH &= 0,0139198 \text{ cP} \\ \mu \text{ } C_{17}H_{33}COOC_4H_9 &= 0,1092541 \text{ cP} \\ \mu \text{ } C_{15}H_{31}COOH &= 0,0586273 \text{ cP}\end{aligned}$$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
$C_{17}H_{33}COOH$	385,52561	0,083682	0,0746121	0,0062437
C_4H_9OH	0,4133587	8,972E-05	0,0139198	1,249E-06
$C_{17}H_{33}COOC_4H_9$	4167,0875	0,9045063	0,1092541	0,098821
$C_{15}H_{31}COOH$	54,003206	0,0117219	0,0586273	0,0006872
Total	4607,0297	1		0,1057532

$$\begin{aligned}\mu \text{ Campuran} &= 0,1057532 \text{ cP} \\ &= 0,2558275 \text{ lb/jam ft}\end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,24798	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947



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$$T = 460,773 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\rho \quad C_{17}H_{33}COOH = 0,78057 \text{ gr/ml}$$

$$\rho \quad C_4H_9OH = 0,6412 \text{ gr/ml}$$

$$\rho \quad C_{17}H_{33}COOC_4H_9 = 0,74198 \text{ gr/ml}$$

$$\rho \quad C_{15}H_{31}COOH = 0,76764 \text{ gr/ml}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$C_{17}H_{33}COOH$	385,52561	0,083682	0,7805686	0,0653196
C_4H_9OH	0,4133587	8,972E-05	0,6411988	5,753E-05
$C_{17}H_{33}COOC_4H_9$	4167,0875	0,9045063	0,741981	0,6711265
$C_{15}H_{31}COOH$	54,003206	0,0117219	0,7676388	0,0089982
Total	4607,0297	1		0,7455018

$$\begin{aligned} \rho \text{ Campuran} &= 0,7455018 \text{ gr/ml} \times 62,4 \\ &= 46,519314 \text{ lb/cuft} \end{aligned}$$

$$\begin{aligned} Sg &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{46,519314 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,7451436 \end{aligned}$$

$$\begin{aligned} K_{mix} &= \frac{0,0677}{\text{sg} [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{0,745 [1 - 0,0003 (0 - 32)]} \\ &= 0,0900 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243} \end{aligned}$$

Dipilih tipe : 1-2 Heat Exchanger

Digunakan shell and tube dengan ukuran :



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Tube Side

$$\begin{aligned} \text{OD} &= 1 \frac{1}{2} \text{ in} \\ \text{BWG} &= 8 \\ \text{Pitch} &= 1 \frac{7}{8} \text{ in Square Pitch} \\ \text{L} &= 10 \text{ ft} \\ \text{Passes} &= 2 \\ \text{ID} &= 1,17 \text{ in} \\ a't &= 1,075 \text{ in}^2 \\ a'' &= 0,3925 \text{ ft}^2/\text{ft panjang} \\ \text{Thickness} &= 0,165 \text{ in} \end{aligned}$$

(kern, Table.10, Hal. 843)

Shell Side

$$\begin{aligned} \text{Shell ID} &= 21 \frac{1}{4} \text{ in} \\ \text{Passes} &= 1 \text{ in} \end{aligned}$$

$$\begin{aligned} \text{Harga UD} &= 6 - 60 \text{ Btu/jam.ft.}^\circ\text{F} && \text{(Kern, tabel 8 hal 840)} \\ \text{Dipilih UD} &= 35 \text{ Btu/jam.ft.}^\circ\text{F} \end{aligned}$$

$$\begin{aligned} A &= \frac{Q}{\text{UD} \times \Delta t} && \text{(Kern Eq. 7.6)} \\ &= \frac{3024258,878}{35 \times 361,977} \\ &= 238,709 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Jumlah tube (Nt)} &= \frac{A}{a'' \times L} \\ &= \frac{238,7093631}{0,39 \times 10} \\ &= 60,8177 \text{ buah} \end{aligned}$$

UD koreksi

$$\begin{aligned} A &= \text{Nt} \times L \times a'' \\ &= 72 \times 10 \times 0,39 \\ &= 282,6 \end{aligned}$$

$$\begin{aligned} \text{UD} &= \frac{Q}{A \times \Delta t} \\ &= \frac{3024258,878}{283 \times 361,977} \end{aligned}$$



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$$= 29,564146$$

Menentukan nilai De :

$$\begin{aligned} De &= \frac{4 \left(\frac{Pt^2}{\pi OD} - \frac{\pi OI^2}{4} \right)}{\pi OD} \\ &= \frac{4 \left(\frac{1,88^2}{3,14 \times 1,5} - \frac{3,14 \times 1,50^2}{4} \right)}{3,14 \times 1,5} \\ &= 1,48567 \text{ in} = 0,12 \text{ ft} \end{aligned}$$

Fluida Panas :Shell Side	Fluida Dingin:Tube Side
Steam	Produk
4. Flow Area (as) $C = Pt - OD$ $= 1 \frac{7}{8} - 1 \frac{1}{2}$ $= 0,375$ $as = \frac{ID \times C' \times B}{144 \times Pt}$ (Kern, Eq. 7.1) $= \frac{21,25 \times 0,375 \times 4}{144 \times 1 \frac{7}{8}}$ $= 0,1180556 \text{ ft}^2$ 5. Mass Velocity (Gs) $Gs = \frac{W}{at}$ $= \frac{1713,1459}{0,1180556}$ $= 14511,353 \text{ lb/jam ft}^2$ 6. Bilangan Reynold (Res) $De = 0,12 \text{ ft}$ $= 1,49 \text{ in}$ $\mu = 0,026 \text{ cP}$ $= 0,06292 \text{ lb/ft.jam}$ $Ret = \frac{De \times Gs}{\mu}$	4. Flow Area (at) $at' = 1,08 \text{ in}^2 \quad \text{(Kern, Table 10)}$ $at = \frac{Nt \times at'}{144 \times n}$ (Kern, Eq 7.48) $= \frac{72 \times 1,08}{144 \times 2}$ $= 0,26875 \text{ ft}^2$ 5. Mass Velocity (Gs) $Gs = \frac{W}{as} \quad \text{(Kern, Eq 7.2)}$ $= \frac{10186,143}{0,26875}$ $= 37901,926 \text{ lb/jam ft}^2$ 6. Bilangan Reynold (Ret) $D = 1,17 \text{ in}$ $= 0,1 \text{ ft}$ $\mu = 0,479 \text{ cP}$ $= 1,16 \text{ lb/ft.jam}$ $Res = \frac{D \times Gt}{\mu}$



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$= \frac{0,12 \times 14511,4}{0,06292}$ $= 28553,528$	$= \frac{0,1 \times 37901,9}{1,15912}$ $= 3188,1369$
7. Faktor panas (jH) untuk steam jH tidak perlu dicari	7. Faktor panas (jH) L/D = 102,565 jH = 26 (Kern Fig-24, hal. 834)
8. $(C \times \mu / k)^{1/3}$ K = 0,2 btu/jam.ft².F Cp = 0,48 btu/lb.F μ = 0,026 cP = 0,06 lb/ft.jam $= \frac{0,48 \times 0,06292}{0,2000}$ = 0,53252 (Kern,1965; F.3)	8. $(C \times \mu / k)^{1/3}$ K = 0,09 btu/jam.ft².F Cp = 0,67 btu/lb.F μ = 0,479 cP = 1,16 lb/ft.jam $= \frac{0,66846 \times 1,15912}{0,0900}$ = 2,04959 (Kern,1965; F.3)
9. hio hio = 1500 Btu/hr ft² °F (Kern, Hal. 164)	9. ho $ho = jH \frac{k}{D} \left(\frac{c \mu}{k} \right)^{1/3} \phi_t$ $\frac{ho}{\phi_t} = 26 \times \frac{0,0900}{0,0975} \times 2,04959$ = 49,1855 BTU/hr ft² °F (Kern,pers.6.15)
10. tube wall temperature $tw = tc + \frac{ho/\phi_s}{hio/\phi_t + ho/\phi_s} (Tc - tc)$ (Kern, Eq 5.31) $= 370 + \frac{1500}{1500 + 49,2} 382$ = 739,863 °F 11. ϕ_t Pada tw = 739,86291 °F μ_w = 0,26 lb/jam ft (Kern, F.14,hal.823) $\phi_t = (\mu/\mu_w)^{0,14}$	10. ϕ_t Pada tw = 739,86291 °F μ_w = 0,2558275 lb/jam ft (Kern, F.14,hal.823) $\phi_t = (\mu/\mu_w)^{0,14}$ = 1,23556 11.. hio $= \frac{ho}{\phi_t} \times \phi_t$ = 60,7718 BTU/hr ft² °F



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$$= 0,81985$$

12. Clean Overall Coefficient, U_c

$$\begin{aligned} U_c &= \frac{h_{io} \times h_o}{h_{io} + h_o} \quad \text{(Kern, Eq 6.38)} \\ &= \frac{1500 \times 60,8}{1500 + 60,8} \\ &= 58,4 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F} \end{aligned}$$

13. Design Overall Coefficient, U_d

$$\begin{aligned} U_d &= \frac{Q}{A \times \Delta t \text{ LMTD}} \\ &= \frac{3024258,9}{283 \times 362} \\ &= 29,564146 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F} \end{aligned}$$

14. Dirt Factor, R_d

$$\begin{aligned} R_d &= \frac{U_c - U_d}{U_c \times U_d} \quad \text{(Kern, Eq 6.13)} \\ &= \frac{58,4 - 29,6}{58,4 \times 29,6} \\ &= 0,0167 \end{aligned}$$

Nilai R_d perhitungan $> R_d$

$$0,0167 > 0,002 \quad \text{(Kern, Table 12 Page 845)}$$

(Memenuhi karena R_d Perhitungan $>> R_d$ allowabe)

Pressure Drop	
Fluida Dingin :Tube Side	Fluida Panas : Shell Side
Produk	Steam
1. f $Re_t = 3188,1369$ $f = 0,0045$ (Kern, Fig 26)	1. f $Re_s = 28553,528$ $f = 0,0024$ (Kern, Fig 29)
2. $\rho = \frac{1}{6,62}$	2. Number of crosses, $N+1$ $N+1 = 12 \times L$



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$= 0,15 \text{ lb/ft}^3$ $s = \frac{0,15106}{62,5}$ $= 0,00242$ $\Delta P_t = \frac{f G s^2 L n}{5,22 \cdot 10^{10} D s \phi}$ $= 0,0194136 \text{ psi}$ $\Delta P_t < \Delta P \text{ allowable}$ $\Delta P_t < 10 \text{ psi}$, maka memenuhi	$= 12 \times \frac{B}{4}$ $= 30$ 3. Pressure Drop (ΔP_s) $s = 1,84$ (Kern, Table 6) $\Delta P_s = \frac{f \times G t^2 \times L \times n}{5,22 \times 10^{10} \times ID \times s \times \phi t}$ (Kern, Eq 7.44) $= 0,0004101 \text{ psi}$ $\Delta P_s < \Delta P \text{ allowable}$ $\Delta P_s < 2 \text{ psi}$, maka memenuhi

Spesifikasi Alat

Nama Alat : Reboiler
Kode : E-315
Fungsi : Untuk menguapkan sebagian cairan dibawah kolom dan mensupply panas ke kolom destilasi
Tipe : 1-2 *Shell and Tube Exchanger*
Dasar Pemilihan : Umum digunakan untuk transfer panas
Kondisi Operasi : - Tekanan : 1 atm
- Suhu : 230,37 °C

Bagian Tube

OD : 1 1/2 in
BWG : 8
Panjang : 10 ft
Jumlah tube, Nt : 72
Passes : 2
Pitch : 1 7/8 in square pitch
Pressure drop : 0,0194136 psi

Bagian Shell

ID : 21 1/4 in
Passes : 1
Pressure drop : 0,0004101 psi



26. Pompa (L-316)



- Fungsi = Untuk memindahkan bottom product menara destilasi 1 (D-310) menuju menara destilasi 2 (D-320)
- Tipe = *Centrifugal pump*
- Dasar Pemilihan : Umum digunakan untuk memompa liquid dengan viskositas rendah

Komposisi Bahan Masuk

Komponen	Massa	Fraksi Massa
	(kg)	
$C_{17}H_{33}COOH$	385,5256122	0,083682
C_4H_9OH	0,413358664	8,972E-05
$C_{17}H_{33}COOC_4H_9$	4167,087517	0,9045063
$C_{15}H_{31}COOH$	54,00320601	0,0117219
Total	4607,029694	1

$$\begin{aligned}\text{Rate massa bahan} &= 4607,0297 \text{ kg/jam} \\ &= 10156,704 \text{ lb/jam}\end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,2479	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947

$$T = 230,37 \text{ } ^\circ\text{C} = 503,52 \text{ K}$$

$$\rho = Ax B^{-\left(1 - \frac{T}{T_c}\right)^n}$$



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Sehingga diperoleh

$$\begin{aligned}\rho \quad C_{17}H_{33}COOH &= 0,7489589 \text{ gr/ml} \\ \rho \quad C_4H_9OH &= 0,575353 \text{ gr/ml} \\ \rho \quad C_{17}H_{33}COOC_4H_9 &= 0,7079956 \text{ gr/ml} \\ \rho \quad C_{15}H_{31}COOH &= 0,735741 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$C_{17}H_{33}COOH$	385,5256122	0,083682	0,7489589	0,0626744
C_4H_9OH	0,413358664	8,972E-05	0,575353	5,162E-05
$C_{17}H_{33}COOC_4H_9$	4167,087517	0,9045063	0,7079956	0,6403865
$C_{15}H_{31}COOH$	54,00320601	0,0117219	0,735741	0,0086243
Total	4607,029694	1		0,7117368

$$\begin{aligned}\rho \text{ Campuran} &= 0,7117368 \text{ gr/ml} \times 62,4 \\ &= 44,412379 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Rate volumetrik} &= \frac{\text{rate massa bahan}}{\rho \text{ bahan}} \\ &= \frac{10156,704 \text{ lb/jam}}{44,412379 \text{ lb/cuft}} \\ &= 228,69083 \text{ cuft/jam} \\ &= 0,0635252 \text{ cuft/detik} \\ &= 28,512106 \text{ gpm}\end{aligned}$$

a. Menentukan diameter optimal pipa

asumsi aliran turbulen ($N_{re} > 2100$), maka digunakan persamaan

$$D_{i \text{ opt}} = 3,9 \times qf^{0,45} \times \rho^{0,13} \quad (\text{Peters, 4}^{ed}, \text{ pers. 15 hal 496})$$

Keterangan :

$$\begin{aligned}D_{i \text{ opt}} &= \text{Diameter pipa bagian dalam optimal (in)} \\ qf &= \text{Rate volumetrik (ft}^3/\text{s)} \\ \rho &= \text{Densitas larutan (lb/ft}^3\text{)}\end{aligned}$$

Sehingga,



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$$\begin{aligned} D_{i \text{ opt}} &= 3,9 \times qf^{0,45} \times \rho^{0,13} \\ &= 3,9 \times 0,29 \times 1,64 \\ &= 1,85 \text{ in} \end{aligned}$$

Dari Kern Table. 11, maka dipilih pipa dengan spesifikasi :

$$\begin{aligned} \text{Pipe size} &= 2 \text{ in} \\ \text{Sch} &= 80 \\ \text{OD} &= 2,38 \text{ in} = 0,2 \text{ ft} = 0,06 \text{ m} \\ \text{ID} &= 1,93 \text{ in} = 0,16 \text{ ft} = 0,05 \text{ m} \\ A &= \frac{1}{4} \times \pi \times \text{ID}^2 \\ &= \frac{1}{4} \times 3,14 \times 0,02585 \\ &= 0,02029 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Kecepatan Aliran (V)} &= \frac{\text{Rate volumetrik}}{\text{Luas Area (A)}} \\ &= \frac{0,06353}{0,02029} \\ &= 3,13092 \text{ ft/s} \end{aligned}$$

b. Menghitung Nre

$$\begin{aligned} \text{sg reff} &= 1 && \text{(Kern, Table. 6 p. 808)} \\ \mu \text{ reff} &= 0,8 \text{ cP} && \text{(Kern, Fig. 14 p. 823)} \\ \rho \text{ reff} &= 62,4 \text{ lb/ft}^3 \end{aligned}$$

$$\begin{aligned} \text{sg bahan} &= \frac{\rho \text{ bahan}}{\rho \text{ reff}} \\ &= \frac{44,4124 \text{ lb/ft}^3}{62,43 \text{ lb/ft}^3} \\ &= 0,71139 \end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	-6,13	1690	0,008	-6E-06
C ₄ H ₉ OH	-5,397	1325,6	0,006	-6E-06
C ₁₇ H ₃₃ COOC ₄ H ₉	-15,275	2934	0,02692	-2E-05



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$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05

$$T = 503,52 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu_{C_{17}H_{33}COOH} = 0,416146 \text{ cP}$$

$$\mu_{C_4H_9OH} = 0,0724138 \text{ cP}$$

$$\mu_{C_{17}H_{33}COOC_4H_9} = 0,3334445 \text{ cP}$$

$$\mu_{C_{15}H_{31}COOH} = 0,3823395 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
$C_{17}H_{33}COOH$	385,52561	0,083682	0,416146	0,0348239
C_4H_9OH	0,4133587	8,972E-05	0,0724138	6,497E-06
$C_{17}H_{33}COOC_4H_9$	4167,0875	0,9045063	0,3334445	0,3016027
$C_{15}H_{31}COOH$	54,003206	0,0117219	0,3823395	0,0044818
Total	4607,0297	1		0,3409149

$$\begin{aligned} \mu_{\text{Campuran}} &= 0,3409149 \text{ cP} \\ &= 0,0002291 \text{ lb/ft s} \end{aligned}$$

$$\begin{aligned} N_{re} &= \frac{ID \times V \times \rho_{\text{bahan}}}{\mu} \\ &= \frac{0,16 \times 3,13 \times 44,4}{0,0002291} \\ &= 97580,514 > 2100 \\ &\text{asumsi aliran turbulen benar} \end{aligned}$$

Dipilih bahan commercial steel, dengan

$$e = 0,000046 \text{ m} \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$

$$\begin{aligned} e/D &= \frac{0,000046}{0,0490024} \\ &= 0,0009387 \end{aligned}$$

$$f = 0,006 \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$



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$$gc = 32,174 \text{ ft.lbm/detik}^2.\text{lbf}$$

$$\alpha = 1 \quad (\text{aliran turbulen}) \quad (\text{Peters \& Timmerhause 4}^{\text{th}} \text{ ed : 485})$$

c. Menghitung Panjang ekuivalen suction, Le

Perhitungan friksi berdasarkan Peters & Timmerhaus, 4ed Tabel 1 hh. 484

Sambungan	Lc/D
Elbow standard 90°	32
Gate valve	7

$$\text{ID pipa} = 0,160769 \text{ ft}$$

Taksiran panjang pipa lurus

$$\begin{aligned} \text{Jarak reboiler ke menara destilasi 2} &= 32,8084 \text{ ft} \\ \text{Tinggi menara destilasi 2} &= 15,5663 \text{ ft} \\ \text{Panjang pipa masuk reaktor} &= 6 \text{ ft} \\ \hline \text{Taksiran panjang pipa lurus} &= 54,3747 \text{ ft} \end{aligned}$$

$$\begin{aligned} 3 \text{ elbow } 90^\circ &= 3 \times 32 \times 0,16 \text{ ft} \\ &= 15,4 \text{ ft} \\ 1 \text{ gate valve} &= 1 \times 7 \times 0,16 \text{ ft} \\ &= 1,13 \text{ ft} \end{aligned}$$

$$\text{Panjang total pipa (Le)} = 70,9339 \text{ ft}$$

d. Perhitungan friksi

1. Friksi karena Gesekan Bahan dalam Pipa

$$\begin{aligned} gc &= 32,17 \text{ lbm.ft/lbf.s}^2 \\ F_1 &= \frac{2f \times V^2 \times Le}{gc \times D} \quad (\text{Geankoplis 3ed, Pers, 2.10-6, P.89}) \\ &= \frac{0,01 \times 9,8 \times 70,9}{32,2 \times 0,16} \\ &= 1,61334 \text{ ft.lbf/lbm} \end{aligned}$$

2. Friksi karena kontraksi dari tangki penyimpanan ke pipa

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-16, P.93})$$

dimana

$$\alpha = 1 \quad \text{untuk aliran turbulen}$$



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Menentukan Kc

A tangki > A pipa maka dianggap 0

Untuk A1 (tangki) dan A2 (pipa), maka $A_2/A_1 = 0$
 maka,

$$K = 0,4 \times (1,25 - A_2/A_1) \quad \text{(Peters 4 ed ; Page 484)}$$

$$K = 0,4 \times (1,25 - 0)$$

$$K = 0,5$$

sehingga,

$$F_2 = \frac{0,5 \times 9,8026602 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} = 0,07618 \text{ ft.lbf/lbm}$$

3. Friksi karena ekspansi dari pipa ke tangki

$$F_3 = \frac{\Delta V^2}{2 \times gc} \quad \text{(Geankoplis 3ed, Pers, 2.10-15, P.93)}$$

($V_1 \ll V_2$ dianggap = 0)

$$= \frac{9,802660178 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} = 0,15236 \text{ ft.lbf/lbm}$$

4. Friksi karena elbow 90°

$$F_4 = n \times \frac{K_f \times V^2}{2 \times gc} \quad \text{(Geankoplis 3ed, Pers, 2.10-17, P.94)}$$

diketahui :

$$K_f = 0,75 \quad \text{(Geankoplis 3ed, T.2.10-1, P. 93)}$$

$$F_4 = \frac{3 \times 0,75 \times 9,8026602 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2} = 0,3428 \text{ ft.lbf/lbm}$$

5. Friksi karena gate valve

$$F_5 = n \times \frac{K_f \times V^2}{2 \times gc} \quad \text{(Geankoplis 3ed Pers. 2.10-1)}$$

diketahui :

K_f gate valve (wide open) = 0,17

$$F_5 = \frac{1 \times 0,17 \times 9,8026602 \text{ ft}^2/\text{s}^2}{2 \times gc}$$



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$$= \frac{2 \times 32,17 \text{ lbf} \cdot \text{ft} / \text{lbf} \cdot \text{s}^2}{0,0259 \text{ ft} \cdot \text{lbf} / \text{lbm}}$$

6. Friksi Total

$$\begin{aligned} \Sigma F &= F_1 + F_2 + F_3 + F_4 + F_5 \\ &= 2,21058 \text{ ft} \cdot \text{lbf} / \text{lbm} \end{aligned}$$

e. Perhitungan Energi Tekanan

$$\begin{aligned} H_{\text{liquida}} &= 1,77013 \text{ ft} \\ \rho_{\text{bahan}} &= 44,4124 \text{ lbm} / \text{ft}^3 \\ g/gc &= 1 \text{ lbf} / \text{lbm} \\ P_2 &= 1 \text{ atm} = 2116,8 \text{ lbf} / \text{ft}^2 \end{aligned}$$

Energi Tekanan

$$\begin{aligned} P_1 &= P_{\text{atm}} + P_{\text{hidrostatik}} \\ &= 1 \text{ atm} + \left(\rho \times \frac{g}{gc} \times H_{\text{liq}} \right) \\ &= 2117 \text{ lbf} / \text{ft}^2 + \left(44,4 \text{ lbm} / \text{ft}^3 \times 1 \text{ lbf} / \text{lbm} \times 1,77 \text{ ft} \right) \\ &= 2195,4155 \text{ lbf} / \text{ft}^2 \end{aligned}$$

$$\begin{aligned} \frac{\Delta P}{\rho} &= \frac{(P_1 - P_2)}{\rho} \\ &= \frac{2195,42 - 2116,8}{44,4123785} \\ &= 1,77013 \text{ ft} \cdot \text{lbf} / \text{lbm} \end{aligned}$$

f. Perhitungan Energi Kinetik

$$\begin{aligned} E_k &= \frac{\Delta V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis, 3ed Eq. 2.7-5 p. 66}) \\ &= \frac{9,802660178}{2 \times 1 \times 32,17} \\ &= 0,1523572 \text{ ft} \cdot \text{lbf} / \text{lbm} \end{aligned}$$

g. Perhitungan Energi potensial

Diketahui

$$Z_1 = 1,77013 \text{ ft} \text{ (Tinggi Larutan dari reboiler=diameter sheel)}$$



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$$\begin{aligned}
 Z_2 &= 15,5663 \text{ ft (Tinggi pipa menuju menara destilasi 2)} \\
 g/gc &= 1 \text{ lbf/lbm} \\
 \text{Sehingga,} \\
 E_p &= \Delta Z \times \frac{g}{gc} \quad \text{(Geankoplis, 2014 Eq. 2.7-5 p. 66)} \\
 &= (15,6 - 1,77) \text{ ft} \times 1 \text{ lbf/lbm} \\
 &= 13,7961 \text{ ft.lbf/lbm}
 \end{aligned}$$

h. Persamaan Bernouli

$$\begin{aligned}
 -W_f &= \frac{\Delta P}{\rho} + \Delta Z \times \frac{g}{gc} + \frac{\Delta V^2}{2 \times \alpha \times gc} + \Sigma F \\
 &= 1,77013 + 13,7961 + 0,15236 + 2,21058 \\
 &= 17,9292 \text{ ft.lbf/lbm}
 \end{aligned}$$

i. Perhitungan Power Pompa

$$\begin{aligned}
 \text{hp} &= \frac{-W_f \times \text{flowrate(gpm)} \times sg}{3960} \\
 &\quad \text{(Perry 6ed ; Pers 6-11, Page 6-5)} \\
 &= \frac{17,9292 \times 28,5121 \times 0,71139}{3960} \\
 &= 0,09183 \text{ hp}
 \end{aligned}$$

$$\text{Efisiensi pompa} = 65\% \quad \text{(Peters 4 ed ; Figure 14 - 37 Page 520)}$$

$$\begin{aligned}
 B_{hp} &= \frac{B_{ph}}{\eta_{pompa}} \\
 &= \frac{0,0918345 \text{ hp}}{65\%} \\
 &= 0,1412839 \text{ hp}
 \end{aligned}$$

$$\begin{aligned}
 \text{Efisiensi motor} &= 80\% \\
 \text{Power motor} &= \frac{B_{hp}}{ef.Motor} \\
 &= \frac{0,1412839 \text{ hp}}{80\%} \\
 &= 0,1766048 \text{ hp}
 \end{aligned}$$

$$\text{Maka digunakan power} = 0,5 \text{ hp}$$

Spesifikasi

Nama Alat : Pompa



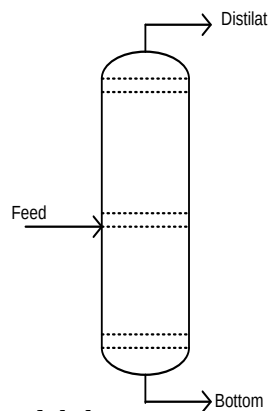
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Kode	:	L-316
Fungsi	:	Memindahkan bottom product dari menara destilasi 1 (D-310) menuju menara destilasi 2 (D-320)
Tipe	:	<i>Centrifugal pump</i>
Bahan konstruksi	:	<i>Commercial steel</i>
Dasar Pemilihan	:	Umum digunakan untuk memompa liquid dengan viskositas rendah
Ukuran Pipa	:	2 in 80 sch
Kapasitas	:	10156,7 lb/jam
Rate volumetrik	:	228,691 ft ³ /jam
Total Dynamic head	:	17,9292 ft.lbf/lbm
Efisiensi pompa	:	65%
Efisiensi motor	:	80%
Power	:	0,5 hp
Jumlah	:	1 buah

27. Menara Distilasi II (D-320)

Fungsi : Memisahkan Butil Oleat dari asam oleat dan asam palmitat

Type : Sieve Tray Column



Dasar Pemilihan :

- Efisiensi pemisahan lebih tinggi
- Harga lebih murah dari bubble cap column
- Perawatan dan perbaikan yang mudah

Kondisi operasi :

P operasi : 1 atm

T operasi : 230,3703 °C = 503,5203 K



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Komponen di dalam Distilasi, dari perhitungan neraca massa (appendiks A) :

Komponen	Feed (kmol/jam)	Distilat (kmol/jam)	Bottom (kmol/jam)
C ₁₇ H ₃₃ COOH	385,5256	0,0386	385,4871
C ₄ H ₉ OH	0,4134	0,4133	0,0000
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,0875	4166,6708	0,4167
C ₁₅ H ₃₁ COOH	54,0392	35,1525	18,8867
Total	4607,0657	4167,1227	385,9038

Menghitung Densitas Komponen

Komponen	A	B	T _c	n
C ₁₇ H ₃₃ COOH	0,2824	0,26812	781	0,2897
C ₄ H ₉ OH	0,26891	0,2667	562,93	0,2457
C ₁₇ H ₃₃ COOC ₄ H ₉	0,24798	0,24	764	0,28571
C ₁₅ H ₃₁ COOH	0,2797	0,26805	776	0,2947

$$T = 230,37 \text{ }^{\circ}\text{C} = 503,52 \text{ K}$$

$$\rho = Ax B^{-\left(1 - \frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned} \rho \quad \text{C}_{17}\text{H}_{33}\text{COOH} &= 0,8104641 \\ \rho \quad \text{C}_4\text{H}_9\text{OH} &= 0,6931676 \\ \rho \quad \text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,7738654 \\ \rho \quad \text{C}_{15}\text{H}_{31}\text{COOH} &= 0,7978127 \end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
C ₁₇ H ₃₃ COOH	385,5256122	0,0836814	0,8104641	0,0678208
C ₄ H ₉ OH	0,413358664	8,972E-05	0,6931676	6,219E-05
C ₁₇ H ₃₃ COOC ₄ H ₉	4167,087517	0,9044993	0,7738654	0,6999607
C ₁₅ H ₃₁ COOH	54,0392	0,0117296	0,7978127	0,0093581
Total	4607,065688	1		0,7772017

ρ_{Camp}



$$= \sum_{i=1}^n C_p \cdot X_f$$

$$\begin{aligned} \rho_{\text{Campuran}} &= 0,7772017 \text{ gr/ml} \times 62,4 \\ &= 48,497387 \text{ lb/cuft} \end{aligned}$$

1. Penentuan jumlah Stage

Menentukan jumlah stage minimum ($N_{\min}$) dengan persamaan Fenske :

Dari appendix A, diperoleh $N_{\min} = 5$

Menentukan $R_{\min}$ dengan persamaan Underwood :

Dari appendix A, diperoleh $R_{\min} = 0,0272$

Menentukan stage kesetimbangan dengan pers. Gilliland :

Dari appendix A, diperoleh $R_{\text{op}} = 0,0408$

Metode Gilliland :

dari persamaan 23-28, Henley and Seader Ed 2 :

$$x = \frac{R_{\text{op}} - R_{\min}}{R_{\text{op}} + 1} = \frac{0,0408 - 0,02723}{0,0408 + 1} = 0,01308$$

$$\frac{N - N_{\text{tr}}}{N + 1} = 0,75 \left[1 - \left(\frac{R_{\text{op}} - R_{\min}}{R_{\text{op}} + 1} \right)^{0,57} \right]$$

$$\frac{N - 5}{N + 1} = 0,75 \left[1 - \left(\frac{0,0408 - 0,0272}{0,0408 + 1} \right)^{0,57} \right]$$

$$\frac{N - 5}{N + 1} = 0,6858$$

$$N - 5 = 0,6858 (N + 1)$$

$$N - 5 = 0,6858 N + 0,6858$$

$$0,3142 N = 5,835$$

$$N = 18,7284$$

$$N = 19 \text{ Plate}$$

karena menggunakan total kondensor dan total reboiler, jumlah plate =

Plate ideal = 19

Menentukan Efisiensi Tray dengan efisiesi murphee, pada coulson pers. 11.65



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$$E_o = \frac{N}{N_t} = \frac{18,7284}{19} \times 100\% = 98,6\%$$

maka jumlah plate aktual = $\frac{19}{0,99} = 19,28 \approx 20$ plate

Menentukan lokasi feed stage dengan persamaan Kirk - Bride :

$$\log \left[\frac{N_r}{N_s} \right] = 0.206 \log \left[\left(\frac{B}{D} \right) \left(\frac{x_{f,HK}}{x_{f,LK}} \right) \left(\frac{x_{b,LK}}{x_{d,HK}} \right)^2 \right] \quad (11.62)$$

(Coulson, 1950 Hal 526)

Dimana : N_R : jumlah stage pada bagian rectifying
 N_S : jumlah stage pada bagian stripping
 B : molar flow bottom
 D : molar flow Top
 $x_{f,HK}$: konsentrai Heavy Key di feed masuk
 $x_{f,LK}$: konsentrasi light key di feed masuk
 $x_{d,HK}$: konsentrasi heavy key di Top
 $x_{b,LK}$: konsentrasi light key di bottom

data konsentrasi dari Appendix A

$$\log \frac{N_r}{N_s} = 0,21 \log \left(\frac{385,904}{4167,12} \times \frac{0,9045}{0,0837} \times \left(\frac{0,94798}{0,9885} \right)^2 \right)$$

$$\log \frac{N_r}{N_s} = -0,0074$$

$$\frac{N_r}{N_s} = 0,9926 \quad \text{maka} \quad N_r = 0,9926 \quad N_s$$

dengan $N_r + N_s = N$

$$20 = N_r + N_s$$

$$20 = 0,9926 \quad N_s + N_s$$

$$20 = 1,9926 \quad N_s$$

$$N_s = 10,0370 = 10$$

maka feed masuk pada plate ke : 10 dihitung dari plate paling bawah

2. Perhitungan Diameter Distilasi :

$$F = 4202,2752 \text{ kg} = 9266,0168 \text{ lb}$$



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dari Appendix A :

Top (bagian atas kolom distilasi)

$$T_{\text{atas}} = 226,7439 \text{ }^{\circ}\text{C} = 499,7439 \text{ K}$$

Menghitung Densitas

Komponen	A	B	Tc	n
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,2824	0,26812	781	0,2897
$\text{C}_4\text{H}_9\text{OH}$	0,26891	0,2667	562,93	0,2457
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	0,24798	0,24	764	0,28571
$\text{C}_{15}\text{H}_{31}\text{COOH}$	0,2797	0,26805	776	0,2947

$$T = 226,744 \text{ }^{\circ}\text{C} = 499,894 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{Tc}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned} \rho \quad \text{C}_{17}\text{H}_{33}\text{COOH} &= 0,751717 \text{ gr/ml} \\ \rho \quad \text{C}_4\text{H}_9\text{OH} &= 0,5818062 \text{ gr/ml} \\ \rho \quad \text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,7111638 \text{ gr/ml} \\ \rho \quad \text{C}_{15}\text{H}_{31}\text{COOH} &= 0,7385241 \text{ gr/ml} \end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,038552561	9,174E-06	0,751717	6,896E-06
$\text{C}_4\text{H}_9\text{OH}$	0,413317328	9,836E-05	0,5818062	5,722E-05
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	4166,670808	0,9915274	0,7111638	0,7051384
$\text{C}_{15}\text{H}_{31}\text{COOH}$	35,1524996	0,0083651	0,7385241	0,0061778
Total	4202,275178	1		0,7113803

$$\begin{aligned} \rho \text{ Campuran} &= 0,7113803 \text{ gr/ml} \times 62,4 \\ &= 44,390133 \text{ lb/cuft} \end{aligned}$$

mencari pv :

(pada T= 273,15 $^{\circ}\text{K}$)

$$\text{asumsi gas ideal } 1 \text{ kmol} = 22,4 \text{ m}^3$$

(Coulson, 1950 hal 726)

dari Appendix A :



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$$\begin{aligned} V \text{ Top (kg)} &= 4202,2752 \text{ kg} = 9264,3359 \text{ lb} \\ n \text{ (kmol)} &= 12,4570 \text{ kmol} \\ \text{Vol 1} &= 12,457 \times 22,4 \\ &= 279,0365 \text{ m}^3 \end{aligned}$$

pada $T = 499,74 \text{ } ^\circ\text{K}$

berlaku: $\text{Vol}_1/T_1 = \text{Vol}_2/T_2$

$$\begin{aligned} \text{Vol}_2 &= \frac{\text{Vol}_1 \times T_2}{T_1} = \frac{279,036 \times 500}{273} = 510,514 \text{ m}^3 \\ &= 18014,8 \text{ ft}^3 \end{aligned}$$

ρ_v campuran pada $T = 499,74 \text{ } ^\circ\text{K}$

$$\rho_v = \frac{m}{\text{Vol}_2} = \frac{9264,3 \text{ lb}}{18014,77272 \text{ ft}^3} = 0,5143 \text{ lb/cuft}$$

$$\begin{aligned} Q_v &= \frac{\text{Vol}_2}{t} = \frac{18014,77 \text{ ft}^3}{1 \text{ jam}} = 18015 \text{ ft}^3/\text{jam} \\ &= 50,0410 \text{ ft}^3/\text{dt} \end{aligned}$$

Bottom (bagian bawah kolom distilasi)

$$T_{\text{bawah}} = 362,2168 \text{ } ^\circ\text{C} = 635,37 \text{ } ^\circ\text{K}$$

Menghitung Densitas

Komponen	A	B	Tc	n
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,2824	0,26812	781	0,2897
$\text{C}_4\text{H}_9\text{OH}$	0,26891	0,2667	562,93	0,2457
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	0,24798	0,24	764	0,28571
$\text{C}_{15}\text{H}_{31}\text{COOH}$	0,2797	0,26805	776	0,2947

$$T = 362,217 \text{ } ^\circ\text{C} = 635,367 \text{ K}$$

$$\rho = A \times B^{-\left(1 - \frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned} \rho \quad \text{C}_{17}\text{H}_{33}\text{COOH} &= 0,8474284 \text{ gr/ml} \\ \rho \quad \text{C}_4\text{H}_9\text{OH} &= 0,7500843 \text{ gr/ml} \\ \rho \quad \text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,8132812 \text{ gr/ml} \end{aligned}$$



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$$\rho_{C_{15}H_{31}COOH} = 0,8351361 \text{ gr/ml}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$C_{17}H_{33}COOH$	385,4870597	0,9523125	0,8474284	0,8070166
C_4H_9OH	4,13359E-05	1,021E-07	0,7500843	7,66E-08
$C_{17}H_{33}COOC_4H_9$	0,416708752	0,0010294	0,8132812	0,0008372
$C_{15}H_{31}COOH$	18,8867004	0,046658	0,8351361	0,0389658
Total	404,7905102	1		0,8468197

$$\begin{aligned}\rho_{\text{Campuran}} &= 0,8468197 \text{ gr/ml} \times 62,4 \\ &= 52,841548 \text{ lb/cuft}\end{aligned}$$

Mencari ρ_v :

(pada $T = 273^\circ K$)

$$\begin{aligned}\text{asumsi gas ideal : } 1 \text{ kmol} &= 22,4 \text{ m}^3 \\ &\text{(Coulson, 1950 hal 726)}\end{aligned}$$

dari Appendiks A :

V bottom (kg)

$$V_{\text{bottom}} (\text{kg}) = 404,791 \text{ kg} = 892,4012 \text{ lb}$$

$$n (\text{kmol}) = 1,44198 \text{ kmol}$$

$$\begin{aligned}Vol_1 &= 1,442 \times 22,4 \\ &= 32,3005 \text{ m}^3\end{aligned}$$

Pada $T = 635,4^\circ K$

berlaku: $Vol_1/T_1 = Vol_2/T_2$

$$\begin{aligned}Vol_2 &= \frac{Vol_1 \times T_2}{T_1} = \frac{32,3005 \times 635}{273} = 75,1745 \text{ m}^3 \\ &= 2652,72 \text{ ft}^3\end{aligned}$$

ρ_v campuran pada $T = 635,4^\circ K$

$$\rho_v = \frac{m}{Vol_2} = \frac{892,4012 \text{ lb}}{2652,7244 \text{ ft}^3} = 0,3364 \text{ lb/cuft}$$

$$Q_v = \frac{Vol_2}{t} = \frac{2652,72 \text{ ft}^3}{t} = 2653 \text{ ft}^3/\text{jam}$$



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$$t = \frac{1}{1} \text{ jam} = 3600 \text{ s/jam}$$

$$= 73,6868 \text{ ft}^3/\text{dt}$$

keterangan :

ρ_L :densitas liquid di Top (lb/ft³)

ρ_v :densitas vapor di top (lb/ft³)

Q_v :rate volumetrik vapor di top (ft³/s)

$\rho_{L'}$:densitas liquid di bottom (lb/ft³)

$\rho_{v'}$:densitas vapor di bottom (lb/ft³)

$Q_{v'}$:rate volumetrik vapor di btm (ft³/s)

Perencanaan Kolom dari Van Winkle :

Perhitungan didasarkan pada 80% flooding (Van Winkle : T-14.2)

dan menggunakan splash baffle :

active area $A = AN = A - 2Ad$

Top	Bottom
1. $P_F = \frac{L}{V} \left(\frac{\rho_v}{\rho_L} \right)^{0,5}$ $= \frac{8507,9}{9264,3} \left(\frac{0,5143}{44,390} \right)^{0,5}$ $= 0,09885$ asumsi tray spacing = 12 in (Van Winkle,T. 14.2)	1. $P_F = \frac{L'}{V'} \left(\frac{\rho_{v'}}{\rho_{L'}} \right)^{0,5}$ $= \frac{820}{892,40} \left(\frac{0,3364}{52,842} \right)^{0,5}$ $= 0,0733$ asumsi tray spacing 12 in (Van Winkle,T. 14.2)
2. $P_C = 0,23$ (Van Winkle, fig. 13.21)	2. $P_C = 0,24$ (Van Winkle, fig. 13.21)
3. Untuk 100 % flood : $U_{VN} = (P_C) \left(\frac{\rho_L - \rho_v}{\rho_v} \right)^{0,5}$ $= 0,23 \left(\frac{43,876}{0,5143} \right)^{0,5}$ $= 2,1245 \text{ fps}$	3. Untuk 100 % flood : $U_{VN'} = (P_C) \left(\frac{\rho_{L'} - \rho_{v'}}{\rho_{v'}} \right)^{0,5}$ $= 0,24 \left(\frac{52,505}{0,3364} \right)^{0,5}$ $= 2,9983 \text{ fps}$
4. Untuk 80 % flood :	4. Untuk 80 % flood :



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$$\begin{aligned} U_{80\%} &= 80\% \times U_{VN} \\ &= 80\% \times 2,1245 \\ &= 1,6996 \text{ fps} \end{aligned}$$

$$\begin{aligned} A_N &= \frac{Q_V}{U_{VN} \times 0,8} \\ &= \frac{50,0410}{2,1245 \times 0,8} \\ &= 29,4434 \text{ ft}^2 \end{aligned}$$

asumsi : $Ad = 0,1 \text{ A}$

$$\begin{aligned} 5. \quad A &= A_N + (2 \text{ Ad}) \\ &= A_N + (0,2 \text{ A}) \\ A &= \frac{A_N}{0,8} = \frac{29,4434}{0,8} \\ &= 36,8043 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} 6. \quad D &= \left(\frac{A}{\pi / 4} \right)^{0,5} \\ &= \left(\frac{36,804}{0,7850} \right)^{0,5} \\ &= 6,8472 \text{ ft} \end{aligned}$$

$$\begin{aligned} U_{80\%} &= 80\% \times U_{VN} \\ &= 80\% \times 2,9983 \\ &= 2,3987 \text{ fps} \end{aligned}$$

$$\begin{aligned} A_{N'} &= \frac{Q_{V'}}{U_{VN'} \times 0,8} \\ &= \frac{73,6868}{2,9983 \times 0,8} \\ &= 30,7200 \text{ ft}^2 \end{aligned}$$

asumsi : $Ad = 0,1 \text{ A}$

$$\begin{aligned} 5. \quad A' &= A_N + (2 \text{ Ad}) \\ &= A_N + (0,2 \text{ A}) \\ A' &= \frac{A_N}{0,8} = \frac{30,7200}{0,8} \\ &= 38,4000 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} 6. \quad D' &= \left(\frac{A'}{\pi / 4} \right)^{0,5} \\ &= \left(\frac{38,4000}{0,7850} \right)^{0,5} \\ &= 6,9941 \text{ ft} \end{aligned}$$

Diambil rata-rata diameter kolom distil = $\frac{D + D'}{2} = 6,9207 \text{ ft}$

$D = 6,9207 \text{ ft} = 2,1094 \text{ m}$

maka diperoleh :

$$A = \frac{\pi}{4} D^2 = \frac{\pi}{4} (6,9207)^2 = 37,5979 \text{ ft}^2$$

$$\begin{aligned} Ad &= 0,1 \text{ A} \\ &= 0,1 \times 37,5979 \\ &= 3,7598 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} A_N &= A - 2 \text{ Ad} \\ &= 37,5979 - (2 \times 3,7598) = 30,0783 \text{ ft}^2 \end{aligned}$$

$$Ah = 0,1 \text{ A} = 0,1 \times 37,5979 = 3,76 \text{ ft}^2$$

cek % flood :

$$\% \text{ flood atas} = \frac{Q_V}{\dots} \times 100\%$$



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$$\begin{aligned}
 \% \text{ flood atas} &= \frac{U_{VN} \times A_N}{50,0410} \times 100\% \\
 &= \frac{2,1245 \times 36,804}{50,0410} \times 100\% = 64\% \\
 \% \text{ flood bawah} &= \frac{Q_{V'}}{U_{VN'} \times A_N} \times 100\% \\
 &= \frac{73,6868}{2,9983 \times 38,400} \times 100\% = 64\%
 \end{aligned}$$

keterangan :

A : aktif area (ft²)

AN : net area (ft²)

Ad : Downflow area (ft²)

Ah : Hole area (ft²)

UVN (100% flood) : max velocity vapor in top (fps)

UVN' (100% flood) : max velocity vapor in bottom (fps)

D : diameter kolom destilasi (ft)

Digunakan tray jenis cross flow dengan data dari Van Winkle tabel 14.8 :

tray diameter	=	6	ft
dh (hole diameter)	=	1/8	in
p (hole pitch)	=	3	in
hw (weir length)	=	1,5	in
Ad/A	=	0,10	(memenuhi)
Ah/A	=	0,10	(memenuhi)
An/A	=	0,80	(memenuhi)
tp gage (plate thickness)	=	12	gage = 0,0825 in

Dari **Van Winkle (tabel 14-10)**, untuk (Ad = 0,1 , diperoleh :

$$\begin{aligned}
 lw / D &= L / D = 0,7267 \\
 lw &= L = \text{panjang chord} \\
 &= 0,7267 \times D \\
 &= 0,7267 \times 6,9207 = 5,0292 \text{ ft} \\
 H / D &= 0,1565 \\
 H &= \text{tinggi chord} = 0,1565 \times D \\
 &= 0,1565 \times 6,9207 = 1,0831 \text{ ft}
 \end{aligned}$$

3. Pressure Drop

Perhitungan didasarkan pada Van Winkle



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$$\Delta H_T = \beta (h_w + h_{ow} + \beta/2) + h_o + l \text{ (table 13.2 hal 507)}$$

$$l_w = 5,0292 \text{ ft} = 60,351 \text{ in}$$

Top	Bottom
$L = 8507,9 \text{ lb/jam}$	$L' = 820 \text{ lb/jam}$
$\rho_L = 44,390 \text{ lb/ft}^3$	$\rho_L = 52,84 \text{ lb/ft}^3$
$Q_L = \frac{L}{\rho_L} = \frac{8507,9}{44,4}$	$Q_L = \frac{L'}{\rho_L} = \frac{820}{52,8}$
$= 191,663 \text{ ft}^3/\text{jam}$	$= 15,5 \text{ ft}^3/\text{jam}$
$= 23,8955 \text{ gpm}$	$= 1,9336 \text{ gpm}$
$\frac{Q_L}{l_w^{2,5}} = \frac{23,8955}{5,03^{2,5}} = 0,4213$	$\frac{Q_L'}{l_w^{2,5}} = \frac{1,9336}{5,03^{2,5}} = 0,034$
Dari fig. 13-7 plot :	Dari fig. 13-7 plot :
$l_w/D = 0,7267 \text{ VS } \frac{Q_L}{l_w^{2,5}}$	$l_w/D = 0,7267 \text{ VS } \frac{Q_L'}{l_w^{2,5}}$
didapatkan :	didapatkan :
$F_w = 0,31$	$F_w' = 0,02$
$h_{ow} = 0,48 \times F_w \left(\frac{Q_L}{l_w} \right)^{###}$	$h_{ow}' = 0,48 \times F_w' \left(\frac{Q_L'}{l_w} \right)^{###}$
$= 0,07899$	$= 7,925E-05$
$= 0,95 \text{ in}$	$= 0,000951 \text{ in}$
$h\sigma = \frac{0,04 \times \sigma}{\rho_L \times dh}$	

σ = surface tension campuran

$$\frac{\sigma}{\text{mN/m}} = \left[P \cdot \left(\frac{\rho_L - \rho_V}{10^3 \text{ kmol/m}^3} \right) \right]^4$$

(Perry ed 8, pers 2-114)

Karena $\rho_L > \rho_V$ maka ρ_V diabaikan



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dengan **tabel 2-402 ; hal 2-373 Perry edisi 7**,

didapat P (parachor independent) = 209,5

$$\rho_L \text{ camp} = 52,8415 \text{ lb/ft}^3 = 846,44233 \text{ kg/m}^3$$

maka :

$$\sigma = P \times \left(\frac{\rho_L}{1000} \right)^4$$

$$\sigma = 210 \left(\frac{846,442}{1000} \right)^4$$

$$= 107,5409 \text{ m N/m} \quad (1 \text{ m N/m} = 1 \text{ dyne /cm})$$

$$= 107,5409 \text{ dyne/ cm}$$

dh = hole diameter = 0,125 in (Van Winkle, tabel 14.8)

$$h_\sigma = \frac{0,04\sigma}{\rho_L d_h} \quad (13.22)$$

maka :

$$h_\sigma = \frac{0,04 \times 1,0754E+02}{44,390 \times 0,125} = 0,78 \text{ in} \left[\right]$$

$$h_{\sigma'} = \frac{0,04 \times 107,5409}{52,842 \times 0,125} = 0,65 \text{ in} \left[\right]$$

$$h_o = 0,19 \times \frac{\rho_v}{\rho_L} \times \left(\frac{U_{VN}}{Co} \right)^2 \quad (\text{pers. 13.16, van winkle hal 519})$$

Co = 0,75 (Van Winkle fig. 13-18)

maka :

$$h_o = 0,19 \times \frac{0,5143}{44,390} \times \left(\frac{2,1245}{0,75} \right)^2$$

$$= 0,0173 \text{ in}$$

$$h_{o'} = 0,19 \times \frac{0,3364}{44,390} \times \left(\frac{2,9983}{0,75} \right)^2$$



$$= \frac{52,842}{0,0189} \left(0,75 \right)$$

faktor for the active area :

$$Fva = Uva \times \rho_v^{0,50}$$

maka :

$$Fva = 2,1245 \times 0,5143^{0,5} = 1,52349$$

$$Fva' = 2,9983 \times 0,3364^{0,5} = 1,73905$$

Dari **Fig. 13-16 Van Winkle** diperoleh nilai aeration faktor (β)

$$\beta = 0,65 \quad \beta' = 0,30$$

$$\Delta H_T = \beta (hw + how + \beta/2) + ho + h\sigma$$

maka pressure drop dari kolom distilasi ini :

$$\begin{aligned} \Delta H_T &= 0,7 (1,5 + 0,95 + 0,3) \\ &\quad 0,01729 + 0,7752 \\ &= 2,5949 \text{ in of liquid} \end{aligned}$$

$$\begin{aligned} \Delta H'_T &= 0,3 (1,5 + 0,00 + 0,15) + 0,019 \\ &\quad + 0,6513 \\ &= 1,1655 \text{ in of liquid} \end{aligned}$$

Liquid Back Up Downcomer: H_D (eq 13.2b)

$$H_D = (\Delta H_T + (hw + how + ho + h\sigma) + h_d (1/\phi_d))$$

asumsi $\phi_d = 0,5$

$$\begin{aligned} h_d &= 0,03 \left(\frac{QL}{100 Ad} \right)^{2,0} & h'_d &= 0,03 \left(\frac{QL'}{100 Ad} \right)^{2,0} \\ &= 0,03 \left(\frac{191,663}{375,979} \right)^{2,0} & &= 0,03 \left(\frac{15,509}{375,979} \right)^{2,0} \\ &= 0,0078 \text{ ft} & &= 0,0001 \text{ ft} \\ &= 0,0936 \text{ in} & &= 0,001 \text{ in} \end{aligned}$$

maka :

$$H_D = 11,86 \text{ in} \quad H'_D = 6,67 \text{ in}$$

4. Menentukan Tinggi Kolom

a. Tinggi total tray



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$$\begin{aligned}
 & (\Sigma \text{ tray} - 1) \times (\text{tray spacing}) + (\text{jarak untuk lubang masuk feed}) \\
 & \text{ditetapkan jarak untuk lubang masuk feed} = 0,5 \text{ ft} = 6 \text{ in} \\
 & \text{Tinggi total tray} = (N - 1) \times (12 + 6) \\
 & \quad = (20 - 1) \times (12 + 6) \\
 & \quad = 342 \text{ in} \\
 & \quad = 28 \text{ ft} \\
 & \quad = 8,6925 \text{ m}
 \end{aligned}$$

b. Tinggi ruang kosong diantara tray feed ditetapkan = 1 ft
(0,5 ft di atas lubang pemasukan feed; 0,5 ft di bawah lubang pemasukan feed)

c. *Tinggi hold up cairan (bagian bawah kolom)*
ditetapkan waktu hold up, $t = 10 \text{ mnt} = 600 \text{ sec.}$
dimana (untuk bagian bawah kolom) : **(Ulrich, 1984 hal. 195)**

$$L' = 819,54 \text{ lb / jam}$$

$$\rho_L' = 52,842 \text{ lb / ft}^3$$

$$A = 37,5979 \text{ ft}^2$$

$$D = 6,9207 \text{ ft} = 83,0478 \text{ in} = 2,1108 \text{ m}$$

$$\text{ditetapkan } S_f = 1 \frac{1}{2} \text{ in}$$

$$= 0,125 \text{ ft} \quad \text{(Tabel 5.6 Brownell \& Young)}$$

$$\text{volume hold up cairan, } h = 0,000049 D^3$$

(Pers 5.11 Brownell \& Young)

$$= 0,000049 \times (6,9207)^3$$

$$= 0,0162 \text{ ft}^3$$

$$\text{volume hold up cairan} = \frac{\pi}{4} D^2 h$$

$$0,0162 = \frac{\pi}{4} \times (6,9207)^2 \times h$$

$$h = 0,0004 \text{ ft} = 0,0052 \text{ in}$$

$$\begin{aligned}
 \text{tinggi hold up cairan} &= s_f + h \\
 &= 0,1250 + 0,0004 \\
 &= 0,1254 \text{ ft}
 \end{aligned}$$

Menentukan P design :

$$P \text{ hidrostatik} = \rho_L \times g/gc \times L$$



$$= \frac{44,39 \times 1 \times 0,0162}{144}$$

$$= 0,00501 \text{ Psia} \quad (\text{Brownel, pers 3.17, hal 46})$$

P operasi = 1,00 atm = 14,7 psia

P design diambil 10% lebih besar dari P operasi untuk faktor keamanan.

$$P_{\text{design}} = 1,1 \times (14,7 + 0,00501)$$

$$= 16,2 \text{ psia}$$

5. Design Tutup Bejana bentuk : standart dished head

Menentukan Dimensi Tutup

Tutup dipilih Torispherical dish head

$$OD = ID + 2 t_s$$

$$= 83,0478 + 0,19$$

$$= 83,235338 \text{ in}$$

Berdasarkan **Brownell and Young, Tabel 5.7** dari data OD, diperoleh:

$$OD = 90 \text{ in}$$

$$i_{cr} = 5 \frac{1}{2} \text{ in}$$

$$r_c = 90 \text{ in}$$

Cek nilai i_{cr} dengan nilai $6\% r_c$

$$i_{cr} = 5,5 \text{ in}$$

$$6\% r_c = 5,4 \text{ in}$$

Menentukan tebal shell minimum

Tebal shell berdasarkan ASME code untuk cylindrical tank:

$$t_s = \frac{P_d \times r_i + C}{f_e - 0,6 P_d} \quad (\text{Brownell Eq. 13.1})$$

dengan

$$t_s = \text{tebal shell minimum (in)}$$

$$P = \text{tekanan tangki (Psi)} = 16,2 \text{ Psi}$$

$$r_i = \text{jari-jari tangki (in)} = 41,5 \text{ in}$$

$$C = \text{Faktor korosi (in); digunakan} = 1/8 \text{ in}$$

$$e = \text{Faktor pengelasan; digunakan double welded} = 0,8$$

(Brownell, Table 13.2)

$$f = \text{stress allowable bahan konstruksi Carbon Steel SA-283 Grade A}$$

$$= 10350 \text{ Psi} \quad (\text{Brownell, hal.342})$$

sehingga,



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$$ts = \frac{Pd \times ri + C}{fe - 0,6 Pd}$$

$$ts = \frac{16,171 \times 41,5}{8280 - 1 \times 16,2} + \frac{1}{8}$$

$$ts = \frac{671,483}{8270,3} + \frac{1}{8}$$

$$ts = 0,08119 + 0,125$$

$$ts = 0,20619$$

$$ts = 3/16 \text{ in}$$

Menghitung Tinggi Tutup Tangki

$$sf = 2 \text{ in}$$

$$t = 2/8 \text{ in}$$

(Brownell, tabel 5.6, hal. 88)

Menghitung tinggi tutup

$$OA = b + sf + t$$

$$* 1 \text{ ft} = 0,3 \text{ m}$$

$$1 \text{ ft} = 12 \text{ in}$$

$$BC = rc - icr$$

$$BC = 90 - 5 \frac{1}{2}$$

$$= 84,500 \text{ in}$$

$$AB = \frac{1}{2} \times OD - icr$$

$$AB = \frac{1}{2} \times 83,2353 - 5,5$$

$$= 36,118 \text{ in}$$

$$b = rc - (BC^2 - AB^2)^{0,5}$$

$$b = 90 - (7140 - 1304)^{0,5}$$

$$= 14$$

Tinggi tutup atas

$$OA = b + sf + t$$

$$= 15,795 \text{ in}$$

$$= 1,3163 \text{ ft}$$



Total Tinggi Tutup (atas+bawah)

digunakan tutup bawah sama dengan tutup atas , maka

$$\begin{aligned}\text{Tinggi Tutup total} &= 2 \times \text{Tinggi tutup atas} \\ &= 2 \times 15,80 \\ &= 31,5907 \text{ in} \\ &= 2,6324 \text{ ft}\end{aligned}$$

Tinggi Kolom Keseluruhan

$$\begin{aligned}\text{tinggi total tray} &= 342 \text{ in} = 28,5 \text{ ft} \\ \text{H liquid back up} &= 18,532 \text{ in} = 1,5443 \text{ ft} \\ \text{H tutup} &= 31,5907 \text{ in} = 2,6326 \text{ ft} \\ \text{H liquid hold up} &= 0,1254 \text{ ft} \\ \text{H refluk masuk} &= 1 \text{ ft} \quad (\text{Asumsi : } 0,5 \text{ ft reboiler} + 0,5 \text{ ft kondensor}) \\ \text{H ruang kosong diantara tray feed} &= 1 \text{ ft} \\ \text{H tower total} &= 34,802 \text{ ft} = 11 \text{ m}\end{aligned}$$

Spesifikasi :

Bahan konstruksi	: Carbon steel SA - 283 grade A
Diameter	: 6,921 ft
Tinggi Kolom Distilasi	: 34,802 ft
Diameter lubang pada tray	: 3 in
Panjang weir	: 1,5 in
diameter tray	: 1/8 ft = 0,038 m
Tebal Tray	: 0,0825 in
Spasi antar tray	: 6 in
Jumlah plate	: 20
feed masuk pada plate ke-	10 dihitung dari plate bawah

28. Kondensor II (E-321)



Fungsi : Untuk mengkondensasikan produk atas destilasi



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berupa gas menjadi liquid

Tipe : Shell and Tube Heat Exchanger

Dasar Pemilihan : Umum digunakan untuk merubah fase gas menjadi liquid

Kondisi Operasi

Tekanan = 1 atm

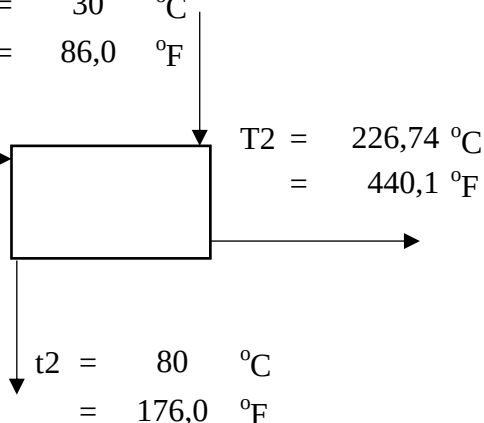
Suhu = 230 °C

t1 = 30 °C

= 86,0 °F

T1 = 230 °C

= 447 °F



1. Data dari neraca Massa dan neraca panas diperoleh :

Untuk fluida panas : Larutan Produk

T masuk (T1) = 230,5 °C = 446,9 F

T keluar (T2) = 226,74 °C = 440,1 F

Untuk fluida dingin : Pendingin Dowtherm

T masuk (t1) = 30 °C = 86 F

T keluar (t2) = 80 °C = 176 F

Bahan masuk = 4202,275 kg/jam

= 9264,420 lb/jam

Panas yang diserap, Q = 285781,580 kkal/jam

= 1141983,192 Btu/jam

Air pendingin yang = 11742,295 kg/jam

digunakan = 25887,298 lb/jam

Perhitungan :

2. Penentuan ΔT_{LMTD}

hot fluida		cold fluida	diff.
447	higher temp.	176	271
440	lower temp.	86	354



7

90

$$\begin{aligned}\Delta t \text{ LMTD} &= \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}} \\ \Delta t \text{ LMTD} &= \frac{271 - 354}{\ln \frac{271}{354}} \\ &= 310,648 \text{ } ^\circ\text{F}\end{aligned}$$

$$\begin{aligned}R &= \frac{\text{Hot Fluid}}{\text{Cold Fluid}} = \frac{7}{90} = 0,1 \\ S &= \frac{t_2 - t_1}{T_1 - t_1} = \frac{176 - 86}{447 - 86} = 0,25 \\ F_T &= 1 \quad (\text{Fig.18 Kern : 828}) \\ \Delta T &= F_T \times \text{LMTD} \\ &= 1 \times 310,648 \\ &= 279,583 \text{ } ^\circ\text{F}\end{aligned}$$

3. Tc dan tc

Tc = Tav bahan

$$\begin{aligned}T_c &= \frac{T_1 + T_2}{2} \\ &= \frac{447 + 440}{2} \\ &= 444 \text{ } ^\circ\text{F} = 429 \text{ K}\end{aligned}$$

tc = tav air

$$\begin{aligned}t_c &= \frac{t_1 + t_2}{2} \\ &= \frac{176 + 86}{2} \\ &= 131 \text{ } ^\circ\text{F}\end{aligned}$$

Menghitung Kapasitas Panas, Konduktifitas Thermal dan Viskositas



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Fluida Dingin

$$\begin{aligned} c_p &= 1,6 \text{ BTU/lb } ^\circ\text{F} \\ k &= 0,14 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F/ft} \\ \mu &= 3,97 \text{ cP} \end{aligned}$$

Fluida Panas

Menghitung nilai kapasitas panas

komponen	A	B	C	D	E
$\text{C}_{17}\text{H}_{33}\text{COOH}$	-55,663	1,991	-0,0016	6,7E-07	-1E-10
$\text{C}_4\text{H}_9\text{OH}$	8,157	0,41032	-0,0002	6,7E-07	-1E-10
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	-69,046	2,5211	-0,0021	1,1E-06	-3E-10
$\text{C}_{15}\text{H}_{31}\text{COOH}$	-54,487	1,804	-0,0013	5,4E-07	-9E-11

$$\begin{aligned} T &= 429 \text{ K} \\ C_p &= A + BT + CT^2 + DT^3 + ET^4 \end{aligned}$$

Sehingga diperoleh

$$\begin{aligned} C_p \text{ } \text{C}_{17}\text{H}_{33}\text{COOH} &= 561,126 \text{ Kkal/KmolK} \\ C_p \text{ } \text{C}_4\text{H}_9\text{OH} &= 196,307 \text{ Kkal/KmolK} \\ C_p \text{ } \text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 702 \text{ Kkal/KmolK} \\ C_p \text{ } \text{C}_{15}\text{H}_{31}\text{COOH} &= 512,543 \text{ Kkal/KmolK} \end{aligned}$$

komponen	BM	Cp	Fraksi	Cp
	Kg/Kmol	kcal/Kmol K	Xf	kcal/Kg K
$\text{C}_{17}\text{H}_{33}\text{COOH}$	282,47	561,12574	9,2E-06	1,9865
$\text{C}_4\text{H}_9\text{OH}$	74	196,3068	9,8E-05	2,65279
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	310,56	702,00003	0,99153	2,26043
$\text{C}_{15}\text{H}_{31}\text{COOH}$	256,42	512,5433	0,00837	1,99884
Total			1	

$$1 \text{ kkal/kg K} = 0,23885 \text{ Btu/lb } ^\circ\text{F}$$

$$C = \sum_i^n C_p \cdot X_f$$

$$C = 0,5394 \text{ Btu/lb } ^\circ\text{F}$$



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Menghitung Viskositas Larutan

komponen	A	B	C
$C_{17}H_{33}COOH$	-2,483	0,1505	-1E-05
C_4H_9OH	-11,144	0,2879	-6E-05
$C_{17}H_{33}COOC_4H_9$	-2,15	0,133	-1E-05
$C_{15}H_{31}COOH$	-3,002	0,1515	-2E-05

$$T = 429 \text{ K}$$

$$\mu = A + BT + CT^2$$

Sehingga diperoleh

$$\begin{aligned} \mu_{C_{17}H_{33}COOH} &= 0,0059406 \text{ cP} \\ \mu_{C_4H_9OH} &= 0,0102087 \text{ cP} \\ \mu_{C_{17}H_{33}COOC_4H_9} &= 0,0052269 \text{ cP} \\ \mu_{C_{15}H_{31}COOH} &= 0,0059081 \text{ cP} \end{aligned}$$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
$C_{17}H_{33}COOH$	0,0385526	9,174E-06	0,0059406	5,45E-08
C_4H_9OH	0,4133173	9,836E-05	0,0102087	1,004E-06
$C_{17}H_{33}COOC_4H_9$	4166,6708	0,9915274	0,0052269	0,0051826
$C_{15}H_{31}COOH$	35,1525	0,0083651	0,0059081	4,942E-05
Total	4202,2752	1		0,0052331

$$\begin{aligned} \mu_{\text{Campuran}} &= 0,0052331 \text{ cP} \\ &= 0,0125594 \text{ lb/ft jam} \end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C
$C_{17}H_{33}COOH$	-2,483	0,1505	-1E-05
C_4H_9OH	-11,144	0,2879	-6E-05
$C_{17}H_{33}COOC_4H_9$	-2,15	0,133	-1E-05
$C_{15}H_{31}COOH$	-3,002	0,1515	-2E-05



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$$T = 279,308 \text{ F}$$

$$T = 441,113 \text{ K}$$

$$\mu = A + BT + CT^2$$

Sehingga diperoleh

$$\mu \text{ C}_{17}\text{H}_{33}\text{COOH} = 0,0061036 \text{ cP}$$

$$\mu \text{ C}_4\text{H}_9\text{OH} = 0,0104917 \text{ cP}$$

$$\mu \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 = 0,0053694 \text{ cP}$$

$$\mu \text{ C}_{15}\text{H}_{31}\text{COOH} = 0,006071 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
C ₁₇ H ₃₃ COOH	0,0385526	9,174E-06	0,0061036	5,6E-08
C ₄ H ₉ OH	0,4133173	9,836E-05	0,0104917	1,032E-06
C ₁₇ H ₃₃ COOC ₄ H ₉	4166,6708	0,9915274	0,0053694	0,0053239
C ₁₅ H ₃₁ COOH	35,1525	0,0083651	0,006071	5,078E-05
Total	4202,2752	1		0,0053758

$$\begin{aligned} \mu \text{ Campuran} &= 0,0053758 \text{ cP} \\ &= 0,0130046 \text{ lb/ft jam} \end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
C ₁₇ H ₃₃ COOH	0,2824	0,26812	781	0,2897
C ₄ H ₉ OH	0,26891	0,2667	562,93	0,2457
C ₁₇ H ₃₃ COOC ₄ H ₉	0,24798	0,24	764	0,2857
C ₁₅ H ₃₁ COOH	0,2797	0,26805	776	0,2947

$$T = 429 \text{ K}$$

$$\rho = A \times B - \left(1 - \frac{T}{T_c}\right)^n$$



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Sehingga diperoleh

$$\begin{aligned}\rho \quad C_{17}H_{33}COOH &= 0,8272009 \text{ gr/ml} \\ \rho \quad C_4H_9OH &= 0,7197156 \text{ gr/ml} \\ \rho \quad C_{17}H_{33}COOC_4H_9 &= 0,8147097 \text{ gr/ml} \\ \rho \quad C_{15}H_{31}COOH &= 0,7917196 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$C_{17}H_{33}COOH$	0,038552561	9,174E-06	0,8272009	7,589E-06
C_4H_9OH	0,413317328	9,836E-05	0,7197156	7,079E-05
$C_{17}H_{33}COOC_4H_9$	4166,670808	0,9915274	0,8147097	0,807807
$C_{15}H_{31}COOH$	35,1524996	0,0083651	0,7917196	0,0066228
Total	4202,275178	1		0,8145082

$$\begin{aligned}\rho \text{ Campuran} &= 0,8145082 \text{ gr/ml} \times 62,4 \\ &= 50,82531 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}Sg &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times sg \text{ reference} \\ &= \frac{50,82531 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,8141168\end{aligned}$$

$$\begin{aligned}K_{mix} &= \frac{0,0677}{sg [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{0,814 [1 - 0,0003 (444 - 32)]} \\ &= 0,0949 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243}\end{aligned}$$

Dipilih tipe : 1-2 Heat Exchanger

Digunakan Shell and Tube dengan ukuran :

OD, BWG = 1 1/2 in 8 BWG

Pitch = 1 7/8 in Square Pitch

Panjang Tube = 10 ft

Dari **Tabel 10 Kern** diperoleh

ID = 1,170 in



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$$a't = 1,075 \text{ in}^2$$

$$a'' = 0,3925 \text{ ft}^2/\text{ft panjang}$$

$$\text{Harga UD} = 10 - 40 \text{ Btu/jam ft } ^\circ\text{F} \quad (\text{Kern, T.8 : 840})$$

$$\text{Dipilih UD} = 15 \text{ Btu/jam ft } ^\circ\text{F}$$

$$A = \frac{Q}{\text{UD} \times \Delta T}$$

$$= \frac{1141983,192}{15 \times 279,58}$$

$$= 272,306 \text{ ft}^2$$

$$\text{Jumlah Tube (Nt)} = \frac{A}{a'' \times L}$$

$$= \frac{272,306}{0,393 \times 10}$$

$$= 69,377 \text{ buah}$$

Dipilih pipa ukuran standart **(Kern T.9)**

Untuk pipa 1 1/2 in

diperoleh :

$$\text{ID Shell} = 23 \frac{1}{4} \text{ in}$$

$$\text{Tube Passes} = 2$$

$$\text{Shell Passes} = 1$$

Koreksi U_D

$$A = N_t \times L \times a''$$

$$= 74 \times 10 \times 0,3925$$

$$= 290,4500 \text{ ft}^2$$

$$U_D \text{ koreksi} = \frac{Q}{A \times \Delta T}$$

$$= \frac{1141983,192}{290,4500 \times 279,583}$$

$$= 14,063 \text{ Btu/jam ft}^2 \text{ } ^\circ\text{F}$$

Menentukan nilai De :



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$$\begin{aligned}
 De &= \frac{4 \left(\frac{Pt^2}{\pi OD} - \pi \frac{OI^2}{4} \right)}{\pi OD} \\
 &= \frac{4 \left(\frac{1,88^2}{\pi \times 3,14} - \pi \times \frac{1,50^2}{4} \right)}{\pi \times 3,14 \times 1,5} \\
 &= 1,48567 \text{ in} = 0,12 \text{ ft}
 \end{aligned}$$

Shell Fluida Panas	Tube Fluida Dingin
4'. Flow Area (as) $as = \frac{ID \times C' \times B}{144 \times PT}$ (Kern, Eq 7.1) $as = \frac{23,3 \times 0,38 \times 18,6}{144 \times 1 \frac{7}{8}}$ $= 0,600625 \text{ ft}^2$	4. Flow Area (at) $at' = 1,08 \text{ in}^2 \text{ (Kern, Table 10)}$ $at = \frac{Nt \times at'}{144 \times n}$ (Kern, Eq 7.48) $at = \frac{74 \times 1,075}{144 \times 2,000}$ $at = 0,27622 \text{ ft}^2$
5'. Kecepatan Massa (Gs) $Gs = \frac{W}{as}$ (Kern, Eq 7.2) $= \frac{9264,42}{0,600625}$ $= 15424,6 \text{ lb/hr ft}^2$	5. Kecepatan Massa (Gt) $Gt = \frac{W}{at}$ $= \frac{25887,29833}{0,276215278}$ $= 93721,5 \text{ lb/hr ft}^2$
6'. Bilangan Reynolds (Res) $De = 0,12 \text{ ft}$ $\mu = 0,01 \text{ lb/ft hr}$ $Res = \frac{De \times Gs}{\mu}$ $= \frac{0,12381 \times 15424,6}{0,012664093}$ $= 150793,05$	6. Bilangan Reynolds (Ret) $D = 0,12 \text{ ft}$ $\mu = 9,607 \text{ lb/ft hr}$ $Ret = \frac{D \times Gt}{\mu}$ $= \frac{0,12381 \times 93721,5}{9,607}$ $= 1207,7408$
7'. jH $jH = 460 \text{ (Kern, Fig 28)}$	7. jH $L/D = 103$



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$$jH = 190 \quad (\text{Kern, Fig 24})$$

8. $(c\mu/k)^{1/3}$ $\left(\frac{c \mu}{k}\right)^{1/3} = \left(\frac{## \times ##}{0,0949}\right)^{1/3}$ $= 0,4160$ 9'. h_o $h_o = jH \frac{k}{De} \left(\frac{c \mu}{k}\right)^{1/3} \phi_s$ (Kern, Eq 6.15b) $\frac{h_o}{\phi_t} = 460 \times \frac{0,09}{0,12} \times 0,41602$ $= 146,643 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$ 10'. tw $tw = tc + \frac{h_o/\phi_s}{h_{io}/\phi_t + h_o/\phi_s} (T_c - t_c)$ (Kern, Eq 5.31) $= 131 + \frac{146,6426844}{162 + 147} 313$ $= 279,308 \text{ } ^\circ\text{F}$ 11'. Φ_s Pada $tw = 279,308 \text{ } ^\circ\text{F}$ $\mu_w = 1,57 \text{ lb/jam ft}$ $\phi_s = (\mu/\mu_w)^{0,14}$ $= 0,50925$ 12. h_o $h_o = \frac{h_o}{\phi_s} \times \phi_s$ $= 74,6784 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$	8. $(c\mu/k)^{1/3}$ $\left(\frac{c \mu}{k}\right)^{1/3} = \left(\frac{2 \times ##}{0,37}\right)^{1/3}$ $= 3,4642$ 9. h_i $h_i = jH \frac{k}{D} \left(\frac{c \mu}{k}\right)^{1/3} \phi_t$ (Kern, Eq 6.15a) $\frac{h_i}{\phi_t} = 190 \times \frac{0,37}{0,12} \times 3,464$ $= 1967,04 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$ 10. h_{io}/ϕ_t $\frac{h_{io}}{\phi_t} = \frac{h_i}{\phi_t} \times \frac{ID}{OD}$ (Kern, Eq 6.5) $\frac{h_{io}}{\phi_t} = 1967 \times \frac{0,12}{1,50}$ $= 162,354 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$ 11. ϕ_t Pada $tw = 279,308 \text{ } ^\circ\text{F}$ $\mu_w = 0,013 \text{ lb/jam ft}$ (Kern, Fig.14) $\phi_t = (\mu/\mu_w)^{0,14}$ $= 2,52111$ 12. h_{io} $h_{ic} = \frac{h_{io}}{\phi_t} \times \phi_t$ $= 409,312 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$

13. Clean Overall Coefficient, U_c

$$U_c = \frac{h_{io} \times h_o}{h_{io} + h_o} \quad (\text{Kern, Eq 6.38})$$

$$= \frac{409 \times 74,7}{409 + 74,7}$$

$$= 63,1557 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$$

14. Design Overall Coefficient, U_d



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$$U_d = 14,063 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$$

15. Dirt Factor, R_d

$$R_d = \frac{U_c - U_d}{U_c \times U_d} \quad \text{(Kern, Eq 6.13)}$$

$$= \frac{63,2 - 14,1}{63,2 \times 14,1}$$

$$= 0,0552748$$

Nilai R_d perhitungan $> R_d$

$$0,05527 > 0,003 \quad \text{(Kern, Table 12)}$$

Shell Fluida Panas	Tube Fluida Dingin
1'. f $Res = 150793,05$ $f = 0,00085$ (Kern, Fig 29) 2'. Number of crosses, $N+1$ $N+1 = 12 \times L / B$ $= 12 \times 10 / 18,6$ $= 6,45161$ 3'. Pressure Drop ΔP $s = 0,81$ (Kern, Table 6) $\Delta P = \frac{f \cdot Gs^2 \cdot IDs \cdot (N+1)}{5,22 \times 10^{10} \cdot De \cdot s \cdot \phi s}$ (Kern, Eq 7.44) $= 0,0113791 \text{ psi}$ $\Delta P < 10 \text{ psi}$, maka memenuhi	1. f $Ret = 1207,7408$ $f = 0,00018$ (Kern, Fig 26) 2. ΔP_t $s = 1$ (Kern, Table 6) $\Delta P_t = \frac{f \times Gt^2 \times L \times n}{5,22 \times 10^{10} \times ID \times s \times \phi t}$ (Kern, Eq 7.45) $= 0,00194 \text{ psi}$ 3. ΔP_r $\frac{v^2}{2g} = 0,0024$ (Kern, Fig 27) $\Delta P_r = \frac{4n}{s} \times \frac{v^2}{2g}$ (Kern, Eq 7.46) $= 0,008333 \text{ psi}$ $\Delta P_T = \Delta P_t + \Delta P_r$ $= 0,010274 \text{ psi}$ $\Delta P < 10 \text{ psi}$, maka memenuhi

Spesifikasi

Nama Alat = Kondensor 2

Kode = E-321

Tipe = Shell and Tube Exchanger

Jumlah = 1 buah

Shell Side

ID = 23 1/4 in



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Passes = 1
Tube Side
 OD = 1 1/2 in , 8 BWG
 L = 10,0 ft
 Pitch = 1,875 in Square Pitch
 Jumlah Tube, Nt = 74 buah
 Bahan Kontruksi = Carbon Steel SA-283 Grade A

29. Tangki Accumulator (F-322)



Fungsi : Sebagai penampung arus keluaran kondensor pada Menara Distilasi untuk menjaga kontinuitas dan kestabilan aliran keluar.
 Tipe : *Tangki silinder horizontal d engan tutup berbentuk standard dished head*
 Dasar Pemilihar : Umum digunakan untuk penampungan sementara hasil keluaran ko|buah
 Kondisi operasi
 Temperatur (T) : 226,744 °C
 Tekanan (P) : 1 atm

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,24798	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947

$$T = 227 \text{ }^{\circ}\text{C} = 499,894 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{Tc}\right)^n}$$



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Sehingga diperoleh

$$\begin{aligned}\rho_{C_{17}H_{33}COOH} &= 0,751717 \text{ gr/ml} \\ \rho_{C_4H_9OH} &= 0,5818062 \text{ gr/ml} \\ \rho_{C_{17}H_{33}COOC_4H_9} &= 0,7111718 \text{ gr/ml} \\ \rho_{C_{15}H_{31}COOH} &= 0,7385241 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$C_{17}H_{33}COOH$	0,038552561	9,327E-06	0,751717	7,011E-06
C_4H_9OH	0,413317328	9,999E-05	0,5818062	5,817E-05
$C_{17}H_{33}COOC_4H_9$	4166,670808	1,0079922	0,7111718	0,7168556
$C_{15}H_{31}COOH$	35,1524996	0,008504	0,7385241	0,0062804
Total	4202,275178	1,0166055		0,7232012

$$\begin{aligned}\rho_{\text{Campuran}} &= 0,7232012 \text{ gr/ml} \times 62,4 \\ &= 45,127756 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}Sg &= \frac{\rho_{\text{bahan}}}{\rho_{\text{reference}} (H_2O)} \times sg_{\text{reference}} \\ &= \frac{45,127756 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,7228537\end{aligned}$$

$$\begin{aligned}K_{\text{mix}} &= \frac{0,0677}{sg [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{0,723 [1 - 0,0003 (0 - 32)]} \\ &= 0,0928 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243}\end{aligned}$$

$$\begin{aligned}\text{Rate massa} &= 4.202,2752 \text{ kg/jam} \times 2,2046 \text{ lb/kg} \\ &= 9.264,3359 \text{ lb/jam}\end{aligned}$$

$$\begin{aligned}\text{Rate volumetrik} &= \frac{\text{Rate massa}}{\text{Densitas}} \\ &= \frac{9.264,3359 \text{ lb/jam}}{45,1278 \text{ lb/cuft}} \\ &= 205,2913 \text{ cuft/jam}\end{aligned}$$



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a. Menentukan Volume Cairan

$$\begin{aligned}\text{Dirancang waktu tinggal} &= 1 \text{ jam, maka} \\ \text{Volume liquid} &= 205,2913 \text{ cuft/jam} \times 1 \text{ jam} \\ &= 205,2913 \text{ cuft}\end{aligned}$$

Asumsi volume liquid mengisi 80% volume tangki untuk faktor keamanan, sehingga :

$$\begin{aligned}\text{Volume tangki} &= \frac{\text{Volume cairan}}{80\%} \\ &= \frac{205,2913045}{80\%} \\ &= 256,61413 \text{ cuft}\end{aligned}$$

b. Menentukan Dimensi Shell Tangki

Berdasarkan pers. 5.4 Brownell dan Young, untuk *vessel* berbentuk silinder horisontal *elliptical dished*, maka :

$$\text{L/D ratio} = 3 - 5 \quad (\text{Tabel 4-27 Ulrich : 249})$$

$$\text{Asumsi rasio dimensi L/D} = 3$$

$$L = 3 D$$

$$\begin{aligned}\text{Volume tangki} &= \frac{1}{4} \times \pi \times D^2 \times L + \frac{1}{12} \times \pi \times D^3 \\ 256,6141307 &= \frac{1}{4} \times 3,14 \times D^2 \times 3 D + \frac{1}{12} \times 3,14 \times D^3 \\ 256,6141307 &= 2,355 D^3 + 0,26167 D^3 \\ 256,6141307 &= 2,6166667 D^3 \\ D^3 &= 98,069095 \\ D &= 4,5415658 \text{ ft} \\ &= 54,49879 \text{ in} \\ &= 1,3842861 \text{ m}\end{aligned}$$

Sehingga panjang vessel

$$\begin{aligned}L &= 3 \times D \\ &= 3,00 \times 4,5415658 \\ &= 13,62 \text{ ft} \\ &= 163,49637 \text{ in} \\ &= 4,1528583 \text{ m}\end{aligned}$$



c. Menentukan tinggi cairan dalam vessel

$$\begin{aligned} H_{liq} &= 80\% \times D_i \\ &= 80\% \times 4,54157 \text{ ft} \\ &= 3,63325 \text{ ft} \\ &= 43,599 \text{ in} \\ &= 1,10743 \text{ m} \end{aligned}$$

d. Menentukan Tekanan design

Jika dalam bejana terdapat liquid, maka bejana dirancang berdasarkan tekanan dalam :

$$\begin{aligned} P_{Hidrostatik} &= \rho \times \frac{g}{g_c} \times H_{liq} \\ &= 45,1278 \frac{\text{lb}}{\text{cuft}} \times 1 \frac{\text{lb}_f}{\text{lb}_m} \times 3,63 \text{ ft} \\ &= 163,961 \frac{\text{lb}_f}{\text{ft}^2} \\ &= 1,13861 \text{ psi} \end{aligned}$$

$$\begin{aligned} P_{gauge} &= P_i - P_o \\ &= 14,7 - 14,7 \\ &= 0 \end{aligned}$$

Asumsi P_{design} 10% lebih besar untuk faktor keamanan

$$\begin{aligned} P_{design} &= 1,1 \times (P_{gau} + P_h) \\ &= 1,1 \times (0 + 1,13861) \text{ Psi} \\ &= 1,2524763 \text{ Psi} \end{aligned}$$

e. Menentukan tebal shell minimum

Tebal shell berdasarkan ASME code untuk cylindrical tank:

$$t_s = \frac{P_d \times r_i + C}{f_e - 0,6 P_d} \quad \text{(Brownell Eq. 13.1)}$$

dengan

t_s = tebal shell minimum (in)

P = tekanan tangki (Psi) = 1,25 Psi

r_i = jari-jari tangki (in) = 27,2 in

C = Faktor korosi (in); digunakan = 1/8 in

e = Faktor pengelasan; digunakan double welded = 0,8
 (Brownell, Table 13.2)

f = stress allowable bahan konstruksi Carbon Steel SA-283 Grade A



$$= 10350 \text{ Psi} \quad (\text{Brownell, hal.342})$$

sehingga,

$$\begin{aligned} ts &= \frac{Pd \times ri + C}{f_e - 0,6 Pd} \\ ts &= \frac{1,25248 \times 27,2}{8280 - 1 \times 1,25248} + \frac{1}{8} \\ ts &= \frac{34,1292 + 1}{8279,25} \\ ts &= 0,00412 + 0,125 \\ ts &= 0,12912 \\ ts &= 3/16 \text{ in} \end{aligned}$$

Sehingga diperoleh tebal sheel sebesar $3/16$ in

f. Menentukan Tebal Tutup Atas dan Bawah

Tutup atas dipilih Torispherical dish head

$$\begin{aligned} OD &= ID + 2 ts \\ &= 54,4988 + 2 \times 3/16 \\ &= 54,4988 + 0,375 \\ &= 54,4988 \text{ in} \end{aligned}$$

Berdasarkan Brownell and Young, Tabel 5.7 dari data OD, diperoleh:

$$\begin{aligned} OD &= 60 \text{ in} \\ icr &= 3 \frac{5}{8} \text{ in} \\ rc &= 60 \text{ in} \end{aligned}$$

Cek nilai icr dengan nilai 6%rc

$$\begin{aligned} icr &= 3,625 \text{ in} \\ 6\% rc &= 3,6 \text{ in} \end{aligned}$$

Karena nilai icr tabel > nilai 6%rc, maka digunakan persamaan:

$$th = \frac{P \times rc \times W}{2 f_e - 0,2P} + C \quad (\text{Brownell Eq. 7.77})$$

$$W = \frac{1}{4} \times \left(3 + \frac{\sqrt{rc}}{rl} \right) \quad (\text{Brownell Eq. 7.76})$$

dengan

$$\begin{aligned} Pd &= \text{Tekanan design (Psi)} = 1,25 \text{ Psi} \\ rc &= \text{Crown radius} = \text{jari-jari dalam (in)} = 60 \text{ in} \end{aligned}$$



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$$\begin{aligned} r_i/i &= \text{Inside crown radius (in)} = 27,2494 \\ E &= \text{Faktor pengelasan} = 0,8 \\ t &= \text{Tebal dinding minimal (in)} \\ f &= \text{Stress allowable bahan Carbon Steel SA-283 grade A} \\ &= 13750 \text{ Psi} \quad \textbf{(Brownell hal. 342)} \\ C &= \text{Faktor korosi (in)} = 1/8 \end{aligned}$$

Sehingga,

$$\begin{aligned} W &= \frac{1}{4} \times \left(3 + \frac{\sqrt{r}}{r_i} \right) \\ &= \frac{1}{4} \times \left(3 + \frac{7,75}{27,2} \right) \\ &= 0,82107 \end{aligned}$$

$$\begin{aligned} \text{Asumsi tebal tutup} &= 3/16 \text{ in} \\ t_h &= \frac{P \times r_c \times W}{2 f_e - 0,2P} + C \\ 3/16 &= \frac{1,25 \times 60 \times 0,82 + 1/8}{1,6 f - 0,2 \times 1,25} \\ 1/16 &= \frac{61,70190626}{1,6 f - 0,2504953} \\ 0,1 f - 0,015656 &= 61,70190626 \\ 0,1 f &= 61,71756221 \\ f &= 617,1756221 \end{aligned}$$

f hitung lebih kecil dari f allowable, jadi tebal tutup 3/16 in dapat digunakan

g. Menentukan Tinggi Tutup Tangki

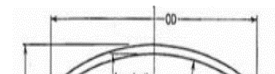
$$\begin{aligned} s_f &= 2 \text{ in} \\ t &= 2/8 \text{ in} \quad \textbf{(Brownell, tabel 5.6, hal. 88)} \end{aligned}$$

Menghitung tinggi tutup

$$\begin{aligned} OA &= b + s_f + t & * 1 \text{ ft} &= 0,3 \text{ m} \\ & & 1 \text{ ft} &= 12 \text{ in} \end{aligned}$$

$$\begin{aligned} BC &= r_c - i_{cr} \\ BC &= 60 - 3,6 \\ &= 56,400 \text{ in} \end{aligned}$$

$$\Delta R = \frac{1}{2} \times OD - i_{cr}$$





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$$AB = \frac{1}{2} \times \sqrt{60^2 - 3,6^2}$$
$$= 26,400 \text{ in}$$

$$b = \sqrt{rc^2 - (BC^2 - AB^2)^{0,5}}$$
$$b = \sqrt{60^2 - (3181 - 697)}$$
$$= 10,160$$

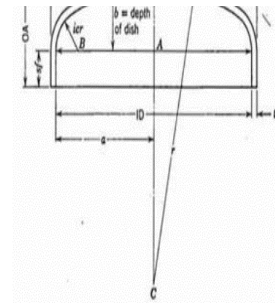


Fig. 5.8. Dimensional relationships for flanged and dished heads.

Tinggi tutup atas

$$OA = b + sf + t$$
$$= 12,348 \text{ in}$$
$$= 0,3136 \text{ m}$$
$$= 1,0290 \text{ ft}$$

Spesifikasi

Nama Alat : Tangki *Accumulator*
Kode : F-322
Fungsi : Sebagai penampung arus keluaran kondensor pada menara distilasi untuk menjaga kontinuitas dan kestabilan aliran keluar
Dasar Pemilihan : Umum digunakan untuk penampungan sementara hasil keluaran kondensor
Jumlah : 1 buah
Tipe : Tangki silinder *horizontal* dengan tutup berbentuk *standard dished head*
Bahan Konstruksi : *Carbon steel SA-283 Grade C*

Kondisi Operasi

Suhu : 226,74 °C
Tekanan : 1 atm
Waktu Tinggal : 1 Jam

Dimensi Tangki

Tinggi : 4,54162 ft = 1,3843 m
Panjang : 13,6247 ft = 4,15286 m
Volume : 256,6141 ft³
Tebal *Shell* : 3/16 in
Tebal Tutup : 3/16 in



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Tinggi Tutup : 1,02898 ft = 0,3136 m

30. Pompa (L-323)



Fungsi = Untuk memindahkan *top product* dari menara destilasi (D-310) menuju Tangki Penyimpanan (F-410)
Tipe = *Centrifugal pump*
Dasar Pemilihan : Umum digunakan untuk memompa liquid dengan viskositas rendah

Komposisi Bahan Masuk

Komponen	Massa	Fraksi Massa
	(kg)	
$C_{17}H_{33}COOH$	0,038552561	9,174E-06
C_4H_9OH	0,413317328	9,836E-05
$C_{17}H_{33}COOC_4H_9$	4166,670808	0,9915274
$C_{15}H_{31}COOH$	35,1524996	0,0083651
Total	4202,275178	1

Rate massa bahan = 4202,2752 kg/jam
= 9264,3779 lb/jam

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,2479	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947

$T = 226,744\text{ }^{\circ}\text{C} = 499,894\text{ K}$ dew point destilat



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$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned}\rho \quad C_{17}H_{33}COOH &= 0,751717 \text{ gr/ml} \\ \rho \quad C_4H_9OH &= 0,5818062 \text{ gr/ml} \\ \rho \quad C_{17}H_{33}COOC_4H_9 &= 0,7109424 \text{ gr/ml} \\ \rho \quad C_{15}H_{31}COOH &= 0,7385241 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$C_{17}H_{33}COOH$	0,038552561	9,174E-06	0,751717	6,896E-06
C_4H_9OH	0,413317328	9,836E-05	0,5818062	5,722E-05
$C_{17}H_{33}COOC_4H_9$	4166,670808	0,9915274	0,7109424	0,7049188
$C_{15}H_{31}COOH$	35,1524996	0,0083651	0,7385241	0,0061778
Total	4202,275178	1		0,7111607

$$\begin{aligned}\rho \text{ Campuran} &= 0,7111607 \text{ gr/ml} \times 62,4 \\ &= 44,376431 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Rate volumetrik} &= \frac{\text{rate massa bahan}}{\rho \text{ bahan}} \\ &= \frac{9264,3779 \text{ lb/jam}}{44,376431 \text{ lb/cuft}} \\ &= 208,76798 \text{ cuft/jam} \\ &= 0,0579911 \text{ cuft/detik} \\ &= 26,028218 \text{ gpm}\end{aligned}$$

a. Menentukan diameter optimal pipa

asumsi aliran turbulen ($N_{re} > 2100$), maka digunakan persamaan

$$D_{i \text{ opt}} = 3,9 \times qf^{0,45} \times \rho^{0,13} \quad (\text{Peters, 4}^{ed}, \text{ pers. 15 hal 496})$$

Keterangan :

$$\begin{aligned}D_{i \text{ opt}} &= \text{Diameter pipa bagian dalam optimal (in)} \\ qf &= \text{Rate volumetrik (ft}^3/\text{s)} \\ \rho &= \text{Densitas larutan (lb/ft}^3)\end{aligned}$$



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Sehingga,

$$\begin{aligned}D_{i \text{ opt}} &= 3,9 \times qf^{0,45} \times \rho^{0,13} \\&= 3,9 \times 0,28 \times 1,64 \\&= 1,77 \text{ in}\end{aligned}$$

Dari Kern Table. 11, maka dipilih pipa dengan spesifikasi :

$$\begin{aligned}\text{Pipe size} &= 2 \text{ in} \\ \text{Sch} &= 80 \\ \text{OD} &= 2,38 \text{ in} = 0,2 \text{ ft} = 0,06 \text{ m} \\ \text{ID} &= 1,93 \text{ in} = 0,16 \text{ ft} = 0,05 \text{ m} \\ A &= \frac{1}{4} \times \pi \times \text{ID}^2 \\&= \frac{1}{4} \times 3,14 \times 0,02585 \\&= 0,02029 \text{ ft}^2\end{aligned}$$

$$\begin{aligned}\text{Kecepatan Aliran (V)} &= \frac{\text{Rate volumetrik}}{\text{Luas Area (A)}} \\&= \frac{0,05799}{0,02029} \\&= 2,85816 \text{ ft/s}\end{aligned}$$

b. Menghitung Nre

$$\begin{aligned}\text{sg reff} &= 1 && \text{(Kern, Table. 6 p. 808)} \\ \mu \text{ reff} &= 0,8 \text{ cP} && \text{(Kern, Fig. 14 p. 823)} \\ \rho \text{ reff} &= 62,4 \text{ lb/ft}^3\end{aligned}$$

$$\begin{aligned}\text{sg bahan} &= \frac{\rho \text{ bahan}}{\rho \text{ reff}} \\&= \frac{44,3764 \text{ lb/ft}^3}{62,43 \text{ lb/ft}^3} \\&= 0,71082\end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
C ₁₇ H ₃₃ COOH	-6,13	1690	0,008	-6E-06



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C_4H_9OH	-5,397	1325,6	0,006	-6E-06
$C_{17}H_{33}COOC_4H_9$	-15,275	2934	0,02692	-2E-05
$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05

$$T = 499,894 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \quad C_{17}H_{33}COOH \quad \mu = 0,4345631 \text{ cP}$$

$$\mu \quad C_4H_9OH \quad \mu = 0,0753721 \text{ cP}$$

$$\mu \quad C_{17}H_{33}COOC_4H_9 \quad \mu = 0,3415523 \text{ cP}$$

$$\mu \quad C_{15}H_{31}COOH \quad \mu = 0,3985938 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
$C_{17}H_{33}COOH$	0,0385526	9,174E-06	0,4345631	3,987E-06
C_4H_9OH	0,4133173	9,836E-05	0,0753721	7,413E-06
$C_{17}H_{33}COOC_4H_9$	4166,6708	0,9915274	0,3415523	0,3386585
$C_{15}H_{31}COOH$	35,1525	0,0083651	0,3985938	0,0033343
Total	4202,2752	1		0,3420041

$$\begin{aligned} \mu \text{ Campuran} &= 0,3420041 \text{ cP} \\ &= 0,0002298 \text{ lb/ft s} \end{aligned}$$

$$\begin{aligned} N_{re} &= \frac{ID \times V \times \rho \text{ bahan}}{\mu} \\ &= \frac{0,16 \times 2,86 \times 44,4}{0,0002298} \\ &= 88724,01 > 2100 \\ &\text{asumsi aliran turbulen benar} \end{aligned}$$

Dipilih bahan commercial steel, dengan

$$e = 0,000046 \text{ m} \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$

$$\frac{e/D}{0,0490024}$$



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$$\begin{aligned}
 &= 0,0002861 \\
 f &= 0,006 && \text{(Geankoplis 3ed, F.2.10-3, P. 88)} \\
 gc &= 32,174 \\
 \alpha &= 1 && \text{(aliran turbulen) (Peters \& Timmerhause 4th ed : 485)}
 \end{aligned}$$

c. Menghitung Panjang ekuivalen suction, Le

Perhitungan friksi berdasarkan Peters & Timmerhaus, 4ed Tabel 1 hh. 484

Sambungan	Lc/D
Elbow standard 90°	32
Gate valve	7

$$\text{ID pipa} = 0,160769 \text{ ft}$$

Taksiran panjang pipa lurus

$$\text{Jarak accumulator ke tangki penyimpanan} = 32,8084 \text{ ft}$$

$$\text{Tinggi tangki} = 33,4005 \text{ ft}$$

$$\text{Panjang pipa masuk tangki} = 6 \text{ ft}$$

$$\text{Taksiran panjang pipa lurus} = 72,2089 \text{ ft}$$

$$\begin{aligned}
 3 \text{ elbow } 90^\circ &= 3 \times 32 \times 0,16 \text{ ft} \\
 &= 15,4 \text{ ft}
 \end{aligned}$$

$$\begin{aligned}
 1 \text{ gate valve} &= 1 \times 7 \times 0,16 \text{ ft} \\
 &= 1,13 \text{ ft}
 \end{aligned}$$

$$\text{Panjang total pipa (Le)} = 88,7681 \text{ ft}$$

d. Perhitungan friksi

1. Friksi karena Gesekan Bahan dalam Pipa

$$gc = 32,17 \text{ lbm.ft/lbf.s}^2$$

$$F_1 = \frac{2f \times V^2 \times Le}{gc \times D} \quad \text{(Geankoplis 3ed, Pers, 2.10-6, P.89)}$$

$$= \frac{0,01 \times 8,17 \times 88,8}{32,2 \times 0,16}$$

$$= 1,68252 \text{ ft.lbf/lbm}$$

2. Friksi karena kontraksi dari tangki penyimpanan ke pipa

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times gc} \quad \text{(Geankoplis 3ed, Pers, 2.10-16,)}$$



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dimana

$\alpha = 1$ untuk aliran turbulen

Menentukan K_c

A tangki > A pipa maka dianggap 0

Untuk A_1 (tangki) dan A_2 (pipa), maka $A_2/A_1 = 0$

maka,

$$K = 0,4 \times (1,25 - A_2/A_1) \quad \text{(Peters 4 ed ; Page 484)}$$

$$K = 0,4 \times (1,25 - 0)$$

$$K = 0,5$$

sehingga,

$$\begin{aligned} F_2 &= \frac{0,5 \times 8,1691003 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,06348 \text{ ft.lbf/lbm} \end{aligned}$$

3. Friksi karena ekspansi dari pipa ke tangki

$$F_3 = \frac{\Delta V^2}{2 \times gc} \quad \text{(Geankoplis 3ed, Pers, 2.10-15, P.93)}$$

($V_1 \ll V_2$ dianggap = 0)

$$\begin{aligned} &= \frac{8,169100292 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,12697 \text{ ft.lbf/lbm} \end{aligned}$$

4. Friksi karena elbow 90°

$$F_4 = n \times \frac{K_f \times V^2}{2 \times gc} \quad \text{(Geankoplis 3ed, Pers, 2.10-17, P.94)}$$

diketahui :

$$K_f = 0,75 \quad \text{(Geankoplis 3ed, T.2.10-1, P. 93)}$$

$$\begin{aligned} F_4 &= \frac{3 \times 0,75 \times 8,1691003 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2} \\ &= 0,28568 \text{ ft.lbf/lbm} \end{aligned}$$

5. Friksi karena gate valve

$$F_5 = n \times \frac{K_f \times V^2}{2 \times gc} \quad \text{(Geankoplis 3ed Pers. 2.10-1)}$$

diketahui :



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$$K_f \text{ gate valve (wide open)} = 0,17$$

$$F_5 = \frac{1 \times 0,17 \times 8,1691003 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,02158 \text{ ft.lbf/lbm}$$

6. Friksi Total

$$\Sigma F = F_1 + F_2 + F_3 + F_4 + F_5$$

$$= 2,18023 \text{ ft.lbf/lbm}$$

e. Perhitungan Energi Tekanan

$$H \text{ liquida} = 3,63325 \text{ ft}$$

$$\rho \text{ bahan} = 44,3764 \text{ lbm/ft}^3$$

$$g/gc = 1 \text{ lbf/lbm}$$

$$P_2 = 1 \text{ atm} = 2116,8 \text{ lbf/ft}^2$$

Energi Tekanan

$$P_1 = P \text{ atm} + P \text{ hidrostatik}$$

$$= 1 \text{ atm} + \left(\rho \times \frac{g}{gc} \times H \text{ liq} \right)$$

$$= 2117 \text{ lbf/ft}^2 + \left(44,4 \text{ lbm/ft}^3 \times 1 \text{ lbf/lbm} \times 3,63 \text{ ft} \right)$$

$$= 2278,0308 \text{ lbf/ft}^2$$

$$\frac{\Delta P}{\rho} = \frac{(P_1 - P_2)}{\rho}$$

$$= \frac{2278,03 - 2116,8}{44,37643077}$$

$$= 3,63325 \text{ ft.lbf/lbm}$$

f. Perhitungan Energi Kinetik

$$E_k = \frac{\Delta V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis, 3ed Eq. 2.7-5 p. 66})$$

$$= \frac{8,169100292}{2 \times 1 \times 32,17}$$

$$= 0,1269677 \text{ ft.lbf/lbm}$$

g. Perhitungan Energi potensial



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Diketahui

$$Z_1 = 3,63325 \text{ ft}$$

$$Z_2 = 33,4005 \text{ ft}$$

$$g/gc = 1 \text{ lbf/lbm}$$

Sehingga,

$$\begin{aligned} E_p &= \Delta Z \times \frac{g}{gc} && \text{(Geankoplis, 2014 Eq. 2.7-5 p. 66)} \\ &= (33,4 - 3,63) \text{ ft} \times 1 \text{ lbf/lbm} \\ &= 29,7672 \text{ ft.lbf/lbm} \end{aligned}$$

h. Persamaan Bernouli

$$\begin{aligned} -W_f &= \frac{\Delta P}{\rho} + \Delta Z \times \frac{g}{gc} + \frac{\Delta V^2}{2 \times \alpha \times gc} + \Sigma F \\ &= 3,63325 + 29,7672 + 0,12697 + 2,18023 \\ &= 35,7077 \text{ ft.lbf/lbm} \end{aligned}$$

i. Perhitungan Power Pompa

$$\begin{aligned} \text{hp} &= \frac{-W_f \times \text{flowrate(gpm)} \times sg}{3960} \\ &\quad \text{(Perry 6ed ; Pers 6-11, Page 6-5)} \\ &= \frac{35,7077 \times 26,0282 \times 0,71082}{3960} \\ &= 0,16683 \text{ hp} \end{aligned}$$

$$\text{Efisiensi pompa} = 65\% \quad \text{(Peters 4 ed ; Figure 14 - 37 Page 520)}$$

$$\begin{aligned} \text{Bhp} &= \frac{\text{Bph}}{\eta \text{ pompa}} \\ &= \frac{0,1668284 \text{ hp}}{65\%} \\ &= 0,2566591 \text{ hp} \end{aligned}$$

$$\text{Efisiensi motor} = 80\%$$

$$\begin{aligned} \text{Power motor} &= \frac{\text{Bhp}}{\text{ef.Motor}} \\ &= \frac{0,2566591 \text{ hp}}{80\%} \\ &= 0,3208238 \text{ hp} \end{aligned}$$

$$\text{Maka digunakan power} = 0,5 \text{ hp}$$



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Spesifikasi

Nama Alat	:	Pompa
Kode	:	L-323
Fungsi	:	Untuk memindahkan produk dari Accumulator (F-320) menuju Tangki Penyimpanan (F-410)
Tipe	:	<i>Centrifugal pump</i>
Bahan konstruksi	:	<i>Commercial steel</i>
Dasar Pemilihan	:	Umum digunakan untuk memompa liquid dengan viskositas rendah
Ukuran Pipa	:	2 in 80 sch
Kapasitas	:	9264,38 lb/jam
Rate volumetrik	:	208,768 ft ³ /jam
Total Dynamic head	:	35,7077 ft.lbf/lbm
Efisiensi pompa	:	65%
Efisiensi motor	:	80%
Power	:	0,5 hp
Jumlah	:	1 buah

31. Cooler (E-324)



Fungsi	:	Mendinginkan produk suhu 226,4°C menjadi 30°C
Tipe	:	1-2 Shell and Tube Exchanger
Dasar Pemilihan	:	Umum digunakan untuk mendinginkan fluida

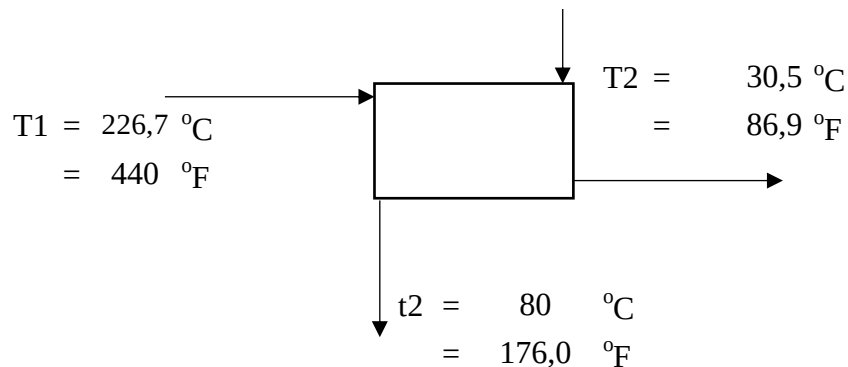
Kondisi Operasi:

Tekanan	=	1 atm
Suhu	=	35 °C

$$\begin{aligned} t_1 &= 30,00 \text{ }^{\circ}\text{C} \\ &= 86,0 \text{ }^{\circ}\text{F} \end{aligned}$$



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Perhitungan

1. Data dari neraca massa dan neraca panas diperoleh:

Untuk Fluida panas : Larutan Produk

$$T \text{ masuk } (T1) = 226,7 \text{ }^{\circ}\text{C} = 440,139 \text{ F}$$

$$T \text{ keluar } (T2) = 30,5 \text{ }^{\circ}\text{C} = 86,9 \text{ F}$$

Untuk Fluida dingin : Pendingin

$$T \text{ masuk } (t1) = 30 \text{ }^{\circ}\text{C} = 86,0 \text{ F}$$

$$T \text{ keluar } (t2) = 80 \text{ }^{\circ}\text{C} = 176,0 \text{ F}$$

$$\begin{aligned} \text{massa bahan} &= 4202,2752 \text{ kg/jam} \\ &= 9291,2304 \text{ lb/jam} \end{aligned}$$

Panas yang diserap

$$\begin{aligned} Q &= 285781,58 \text{ kkal/jam} \\ &= 1133324 \text{ Btu/jam} \end{aligned}$$

Pendingin yang dibutuhkan

$$\begin{aligned} W &= 11742,3 \text{ kg/jam} \\ &= 25962,2 \text{ lb/jam} \end{aligned}$$

2. Penentuan ΔT LMTD

Hot fluida		Cold fluida	diff
440,139	higher temp	176,0	264
86,9	lower temp	86,0	0,9
353,2		90,0	

$$\Delta t \text{ LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$



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$$\Delta t_{LMTD} = \frac{\Delta t_1}{\ln \frac{264}{1}}$$

$$= 46,329922 \text{ } ^\circ\text{F}$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} \quad (\text{Kern, Eq 5.17})$$

$$= \frac{440 - 86,9}{176 - 86,0}$$

$$= 3,92$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} \quad (\text{Kern, Pers. 5.14, : 149})$$

$$= \frac{176 - 86}{440 - 86}$$

$$= 0,25414$$

$$F_T = 1 \quad (\text{Kern Fig. 18, : 828})$$

$$\Delta T = \Delta T_{LMTD} \times F_T \quad (\text{Kern, Pers. 7.42 : 149})$$

$$= 46,3299 \text{ } ^\circ\text{F} \times 1$$

$$= 46,3299 \text{ } ^\circ\text{F}$$

3. Tc dan tc

Tc = t average bahan

$$T_c = \frac{T_1 + T_2}{2}$$

$$= \frac{440 + 86,9}{2}$$

$$= 264 \text{ } ^\circ\text{F}$$

$$= 402 \text{ } \text{K}$$

tc = t average pendingin

$$t_c = \frac{t_1 + t_2}{2}$$

$$= \frac{86,0 + 176}{2}$$

$$= 131 \text{ } ^\circ\text{F}$$



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$$= 328,15 \text{ K}$$

Menghitung Kapasitas Panas, Konduktifitas Thermal dan Viskositas

Fluida Dingin

$$\begin{aligned} cp &= 1,601 \text{ Btu/lb}^\circ\text{F} \\ k &= 0,13 \text{ BTU/hr ft}^2 \text{ }^\circ\text{F/ft} \\ \mu &= 3,9 \text{ cP} \end{aligned}$$

Fluida Panas

Menghitung nilai kapasitas panas

komponen	A	B	C	D
$C_{17}H_{33}COOH$	278,686	2,5434	-0,0054	4,9E-06
C_4H_9OH	83,877	0,56628	-0,0017	2,3E-06
$C_{17}H_{33}COOC_4H_9$	178,423	3,667	-0,008	7,1E-06
$C_{15}H_{31}COOH$	86,29	3,5237	-0,0073	6,1E-06

$$T = 401,772 \text{ K}$$

$$C_p = A + BT + CT^2 + DT^3$$

Sehingga diperoleh

$$\begin{aligned} C_p \text{ } C_{17}H_{33}COOH &= 742,493 \text{ Kkal/KmolK} \\ C_p \text{ } C_4H_9OH &= 186,142 \text{ Kkal/KmolK} \\ C_p \text{ } C_{17}H_{33}COOC_4H_9 &= 825,128 \text{ Kkal/KmolK} \\ C_p \text{ } C_{15}H_{31}COOH &= 716,026 \text{ Kkal/KmolK} \end{aligned}$$

komponen	BM	Cp	Fraksi	Cp
	Kg/Kmol	kkal/Kmol K	Xf	kkal/Kg K
$C_{17}H_{33}COOH$	282,47	742,49318	9,2E-06	2,62857
C_4H_9OH	74	186,14214	9,8E-05	2,51543
$C_{17}H_{33}COOC_4H_9$	310,56	825,12793	0,99153	2,6569
$C_{15}H_{31}COOH$	256,42	716,02558	0,00837	2,79239
Total			1	

$$1 \text{ kkal/kg K} = 0,23885 \text{ Btu/lb }^\circ\text{F}$$

$$C = \sum_i^n C_p \cdot Xf$$



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$$C = 0,6348578 \text{ Btu/lb}^{\circ}\text{F}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
$\text{C}_{17}\text{H}_{33}\text{COOH}$	-6,13	1690	0,008	-6E-06
$\text{C}_4\text{H}_9\text{OH}$	-5,397	1325,6	0,006	-6E-06
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	-15,275	2934	0,02692	-2E-05
$\text{C}_{15}\text{H}_{31}\text{COOH}$	-9,45	2100	0,016	-1E-05

$$T = 401,772 \text{ K}$$

$$\log_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \text{ C}_{17}\text{H}_{33}\text{COOH} = 1,775736 \text{ cP}$$

$$\mu \text{ C}_4\text{H}_9\text{OH} = 0,2652087 \text{ cP}$$

$$\mu \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 = 0,8412522 \text{ cP}$$

$$\mu \text{ C}_{15}\text{H}_{31}\text{COOH} = 1,4835292 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,0385526	9,174E-06	1,775736	1,629E-05
$\text{C}_4\text{H}_9\text{OH}$	0,4133173	9,836E-05	0,2652087	2,608E-05
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	4166,6708	0,9915274	0,8412522	0,8341246
$\text{C}_{15}\text{H}_{31}\text{COOH}$	35,1525	0,0083651	1,4835292	0,0124099
Total	4202,2752	1		0,8465769

$$\begin{aligned} \mu \text{ Campuran} &= 0,8465769 \text{ cP} \\ &= 0,0005689 \text{ lb/ft s} \end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
$\text{C}_{17}\text{H}_{33}\text{COOH}$	-6,13	1690	0,008	-6E-06
$\text{C}_4\text{H}_9\text{OH}$	-5,397	1325,6	0,006	-6E-06
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	-15,275	2934	0,02692	-2E-05



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$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05

$$T = 256,981 \text{ F}$$

$$T = 399,322 \text{ K}$$

$$\log_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \quad C_{17}H_{33}COOH = 1,8545778 \text{ cP}$$

$$\mu \quad C_4H_9OH = 0,2753879 \text{ cP}$$

$$\mu \quad C_{17}H_{33}COOC_4H_9 = 0,8694806 \text{ cP}$$

$$\mu \quad C_{15}H_{31}COOH = 1,5448784 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
$C_{17}H_{33}COOH$	0,0385526	9,174E-06	1,8545778	1,701E-05
C_4H_9OH	0,4133173	9,836E-05	0,2753879	2,709E-05
$C_{17}H_{33}COOC_4H_9$	4166,6708	0,9915274	0,8694806	0,8621138
$C_{15}H_{31}COOH$	35,1525	0,0083651	1,5448784	0,0129231
Total	4202,2752	1		0,875081

$$\begin{aligned} \mu \text{ Campuran} &= 0,875081 \text{ cP} \\ &= 2,1168982 \text{ lb/ft jam} \end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,24798	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947

$$T = 401,772 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{Tc}\right)^n}$$



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Sehingga diperoleh

$$\rho \text{ C}_{17}\text{H}_{33}\text{COOH} = 0,8214499 \text{ gr/ml}$$

$$\rho \text{ C}_4\text{H}_9\text{OH} = 0,7107565 \text{ gr/ml}$$

$$\rho \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 = 0,7855874 \text{ gr/ml}$$

$$\rho \text{ C}_{15}\text{H}_{31}\text{COOH} = 0,8089032 \text{ gr/ml}$$

komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,038552561	9,174E-06	0,8214499	7,536E-06
$\text{C}_4\text{H}_9\text{OH}$	0,413317328	9,836E-05	0,7107565	6,991E-05
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	4166,670808	0,9915274	0,7855874	0,7789314
$\text{C}_{15}\text{H}_{31}\text{COOH}$	35,1524996	0,0083651	0,8089032	0,0067666
Total	4202,275178	1		0,7857754

$$\begin{aligned}\rho \text{ Campuran} &= 0,7857754 \text{ gr/ml} \times 62,4 \\ &= 49,032384 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Sg} &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{49,032384 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,7853978\end{aligned}$$

$$\begin{aligned}\text{Kmix} &= \frac{0,0677}{\text{sg} [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{0,785 [1 - 0,0003 (131 - 32)]} \\ &= 0,0888 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243}\end{aligned}$$

Dipilih tipe : 1-2 Heat Exchanger

Digunakan shell and tube dengan ukuran :

Tube Side

$$\text{OD} = 1 \text{ in}$$

Shell Side

$$\text{Shell ID} = 12 \text{ in}$$



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$$\begin{aligned}\text{BWG} &= 8 & \text{Passes} &= 1 \text{ in} \\ \text{Pitch} &= 1 \frac{1}{4} \text{ in Square Pitch} \\ L &= 10 \text{ ft} \\ \text{Passes} &= 2 \\ \text{ID} &= 0,67 \text{ in} \\ a't &= 0,355 \text{ in}^2 \\ a'' &= 0,2618 \text{ ft}^2/\text{ft panjang} \\ &\textbf{(kern, Table.10, Hal. 843)}\end{aligned}$$

$$\begin{aligned}\text{Harga UD} &= 50 - 125 \text{ Btu/jam.ft.}^\circ\text{F} & \textbf{(Kern, tabel 8 hal 840)} \\ \text{Dipilih UD} &= 115 \text{ Btu/jam.ft.}^\circ\text{F}\end{aligned}$$

$$\begin{aligned}A &= \frac{Q}{\text{UD} \times \Delta t} & \textbf{(Kern Eq. 7.6)} \\ &= \frac{1133324,01}{115 \times 46,3299} \\ &= 212,713 \text{ ft}^2\end{aligned}$$

$$\begin{aligned}\text{Jumlah tube (Nt)} &= \frac{A}{a'' \times L} \\ &= \frac{212,7133182}{0,26 \times 10} \\ &= 81,2503 \text{ buah}\end{aligned}$$

Sehingga dipilih ukuran yang paling mendekati, yaitu:

$$\begin{aligned}\text{ID tube} &= 0,67 \\ \text{BWG} &= 8 \\ \text{Pitch} &= 1 \frac{1}{4} \text{ in Square Pitch} \\ \text{ID shell} &= 12 \\ \text{Passes tube} &= 1 \\ \text{Jumlah tube} &= 81\end{aligned}$$

UD koreksi

$$\begin{aligned}A &= \text{Nt} \times L \times a'' \\ &= 81 \times 10 \times 0,26 \\ &= 212,058\end{aligned}$$



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$$\begin{aligned}
 UD &= \frac{Q}{A \times \Delta t} \\
 &= \frac{1133324,01}{212 \times 46,3299} \\
 &= 115,35538
 \end{aligned}$$

Menentukan nilai De :

$$\begin{aligned}
 De &= \frac{4 \left(\frac{Pt^2}{4} - \pi \frac{OI^2}{4} \right)}{\pi OD} \\
 &= \frac{4 \left(\frac{1,25^2}{4} - 3,14 \times \frac{1,00^2}{4} \right)}{3,14 \times 1} \\
 &= 0,99045 \text{ in} = 0,08 \text{ ft}
 \end{aligned}$$

Fluida Dingin : Tube Side	Fluida Panas :Shell Side
Pendingin	Produk
4. Flow Area (at) $ \begin{aligned} at &= \frac{Nt \times at'}{144 \times n} \\ &= \frac{81 \times 0,36}{144 \times 2} \quad (\text{Kern, Eq 7.48}) \\ &= 0,0998438 \text{ ft}^2 \end{aligned} $	4. Flow Area (at) asums B = 0,25 ID $ \begin{aligned} &= 3 \\ C &= Pt - OD \\ &= 1 \frac{1}{4} - 1 \\ &= 0,25 \\ as &= \frac{ID \times C' \times B}{144 \times Pt} \\ &= \frac{12 \times 0,25 \times 3}{144 \times 1,25} \quad (\text{Kern, Eq. 7.1}) \\ &= 0,05 \text{ ft}^2 \end{aligned} $
5. Mass Velocity (Gt) $ \begin{aligned} Gt &= \frac{W}{at} \\ &= \frac{25962,214}{0,0998438} \\ &= 260028,44 \text{ lb/jam ft}^2 \end{aligned} $	5. Mass Velocity (Gt) $ \begin{aligned} Gs &= \frac{W}{as} \quad (\text{Kern, Eq 7.2}) \\ &= \frac{9291,2304}{0,05} \\ &= 185824,61 \text{ lb/jam ft}^2 \end{aligned} $



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6. Bilangan Reynold (Ret) $\begin{aligned} De &= 0,08 \text{ ft} \\ \mu &= 9,438 \text{ lb/ft.jam} \end{aligned}$ $\begin{aligned} Ret &= \frac{De \times Gs}{\mu} \\ &= \frac{0,08 \times 260028}{9,438} \\ &= 2273,9986 \end{aligned}$	6. Bilangan Reynold (Res) $\begin{aligned} D &= 0,06 \text{ ft} \\ \mu &= 2,05 \text{ lb/ft.jam} \end{aligned}$ $\begin{aligned} Res &= \frac{D \times Gt}{\mu} \\ &= \frac{0,06 \times 185825}{2,04872} \\ &= 5064,23 \end{aligned}$
9. hio $\begin{aligned} hio &= 1500 \text{ Btu/hr ft}^2 \text{ } ^\circ\text{F} \\ &\text{(Kern, Hal. 164)} \end{aligned}$	7. jH $\begin{aligned} L/D &= 179,105 \\ jH &= 20 \\ &\text{(Kern Fig-28, hal. 838)} \end{aligned}$ 8. $(C \times \mu / k)^{1/3}$ $\begin{aligned} &= \frac{0,63486 \times 2,04872}{0,0888} \\ &= 2,44637 \end{aligned}$ 9. ho $\begin{aligned} ho &= jH \frac{k}{D} \left(\frac{c \mu}{k} \right)^{1/3} \phi_s \\ &\text{(Kern, Eq 6.15b)} \end{aligned}$ $\begin{aligned} \frac{ho}{\phi_t} &= 20 \times \frac{0,0888 \times 2,44637}{0,05583} \\ &= 77,848975 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F} \end{aligned}$
10. tw $\begin{aligned} tw &= tc + \frac{ho/\phi_s}{hio/\phi_t + ho/\phi_s} (Tc - tc) \\ &\text{(Kern, Eq 5.31)} \\ &= 131 + \frac{1500}{1500 + 77,85} 133 \\ &= 256,981 \text{ } ^\circ\text{F} \end{aligned}$	10. ϕ_s $\begin{aligned} \text{Pada } tw &= 256,98117 \text{ } ^\circ\text{F} \\ \mu_w &= 2,1168982 \text{ lb/jam ft} \end{aligned}$ $\begin{aligned} \phi_t &= (\mu/\mu_w)^{0.14} \text{ (Kern, Fig.15)} \\ &= 0,99543 \end{aligned}$ 11.. hio $= \frac{ho}{\phi_t} \times \phi_t$



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$$= 77,493 \text{ BTU/hr ft}^2 \text{ }^{\circ}\text{F}$$

12. Clean Overall Coefficient, U_c

$$\begin{aligned} U_c &= \frac{h_{io} \times h_o}{h_{io} + h_o} \quad \text{(Kern, Eq 6.38)} \\ &= \frac{1500 \times 77,5}{1500 + 77,5} \\ &= 73,7 \text{ BTU/hr ft}^2 \text{ }^{\circ}\text{F} \end{aligned}$$

13. Design Overall Coefficient, U_d

$$\begin{aligned} U_d &= \frac{Q}{A \times \Delta t \text{ LMTD}} \\ &= \frac{113332,4}{212 \times 46,3} \\ &= 11,535538 \text{ BTU/hr ft}^2 \text{ }^{\circ}\text{F} \end{aligned}$$

14. Dirt Factor, R_d

$$\begin{aligned} R_d &= \frac{U_c - U_d}{U_c \times U_d} \quad \text{(Kern, Eq 6.13)} \\ &= \frac{73,7 - 11,5}{73,7 \times 11,5} \\ &= 0,07312 \end{aligned}$$

Nilai R_d perhitungan > R_d

$$0,07312 > 0,002 \quad \text{(Kern, Table 12 Page 845)}$$

(Memenuhi karena R_d Perhitungan >> R_d allowabe)

Pressure Drop	
Fluida Panas : Tube Side	Fluida Dingin :Shell Side
Steam	Asam Sulfat
1. f $Re_t = 2273,9986$ $f = 0,00018$ (Kern, Fig 26)	1. f $Re_s = 5064,2283$ $f = 0,045$ (Kern, Fig 29)



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$\rho = \frac{1}{6,62}$ $= 0,15106 \text{ lb/ft}^3$ $s = \frac{0,15106}{62,5}$ $= 0,00242$ $\Delta P_t = \frac{f G s^2 L n}{5,22 \cdot 10^{10} D s \phi}$ $= 0 \text{ psi}$ $\Delta P_t < \Delta P \text{ allowable}$ $\Delta P_t < 2 \text{ psi}$, maka memenuhi	$2. \text{ Number of crosses, } N+1$ $N+1 = 12 \times \frac{L}{B}$ $= 12 \times \frac{10}{3}$ $= 40$ $3. \text{ Pressure Drop } (\Delta P_s)$ $s = 1,84$ (Kern, Table 6) $\Delta P_s = \frac{f \times G t^2 \times L \times n}{5,22 \times 10^{10} \times ID \times s \times \phi t}$ (Kern, Eq 7.44) $= 0,5417513 \text{ psi}$ $\Delta P_s < \Delta P \text{ allowable}$ $\Delta P_s < 2 \text{ psi}$, maka memenuhi

Spesifikasi Alat

Nama Alat : Cooler
Kode : E-324
Fungsi : Mendinginkan larutan produk suhu 226°C menjadi 35°C untuk dialirkan ke tangki penyimpanan (F-410)
Tipe : 1-2 Shell and Tube Exchanger (Fixed Tube) -Counter Flow
Dasar Pemilihan : Umum digunakan untuk transfer panas
Kondisi Operasi : - Tekanan : 1 atm
- Suhu : 35 °C

Bagian Tube

OD : 1 in
BWG : 8
Panjang : 10 ft
Jumlah tube, Nt : 81
Passes : 2
Pitch : 1 1/4 in square pitch
Pressure drop : 0,3740093 psi

Bagian Shell

ID : 12 in



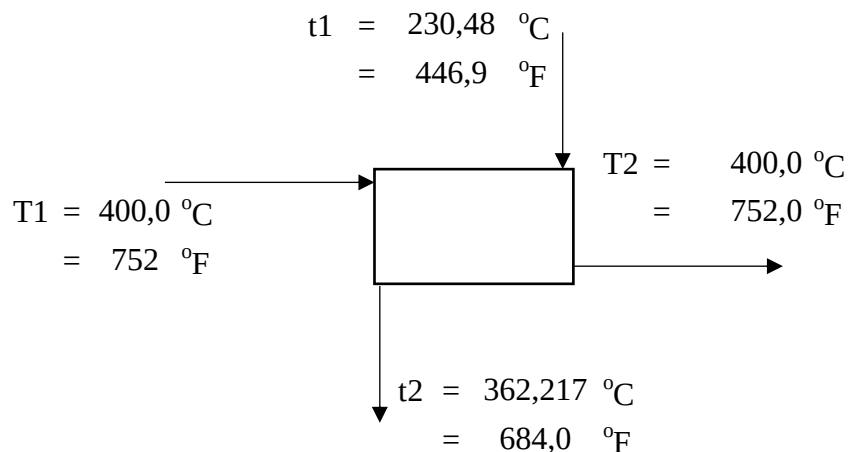
PRA RANCANGAN PABRIK
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Passes : 1
Baffle Spacing : 3 in
Pressure drop : 0,5417513 psi

32. Reboiler (E-325)



Fungsi : Untuk menguapkan sebagian cairan dibawah kolom dan
: mensupply panas ke kolom distilasi
Tipe : Shell and Tube Heat Exchanger
Dasar Pemilihan : Umum digunakan untuk transfer panas
Kondisi Operasi
Tekanan = 1 atm
Suhu = 362,217 °C



Perhitungan



PRA RANCANGAN PABRIK
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1. Data dari neraca massa dan neraca panas diperoleh:

Untuk Fluida panas : Steam

$$T \text{ masuk } (T_1) = 400,0 \text{ } ^\circ\text{C} = 752 \text{ F}$$

$$T \text{ keluar } (T_2) = 400 \text{ } ^\circ\text{C} = 752,0 \text{ F}$$

Untuk Fluida dingin : Larutan Produk

$$T \text{ masuk } (t_1) = 230,48 \text{ } ^\circ\text{C} = 446,9 \text{ F}$$

$$T \text{ keluar } (t_2) = 362,217 \text{ } ^\circ\text{C} = 684,0 \text{ F}$$

$$\text{massa bahan} = 404,79051 \text{ kg/jam}$$

$$= 894,99182 \text{ lb/jam}$$

Panas yang dibutuhkan

$$Q = 329830,95 \text{ kkal/jam}$$

$$= 1308010,6 \text{ Btu/jam}$$

Steam yang digunakan

$$\text{Massa steam} = 335,118 \text{ kg/jam}$$

$$= 740,947 \text{ lb/jam}$$

2. Penentuan ΔT LMTD

Hot fluida		Cold fluida	diff
752	higher temp	684,0	68
752,0	lower temp	446,9	305
0,0		237,1	

$$\Delta t \text{ LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$

$$\Delta t \text{ LMTD} = \frac{68 - 305}{\ln \frac{68}{305}}$$

$$= 157,96514 \text{ F}$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} \quad (\text{Kern, Eq 5.17})$$

$$= \frac{752 - 752}{684 - 447}$$

$$= 0$$



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$$\begin{aligned} S &= \frac{t_2 - t_1}{T_1 - t_1} && \text{(Kern, Pers. 5.14, : 149)} \\ &= \frac{684 - 447}{752 - 447} \\ &= 0,77711 \end{aligned}$$

$$\begin{aligned} FT &= 1 && \text{(Kern Fig. 18, : 828)} \\ \Delta T &= \Delta T_{LMTD} \times FT && \text{(Kern, Pers. 7.42 : 149)} \\ &= 157,965 \text{ } ^\circ\text{F} \times 1 \\ &= 157,965 \text{ } ^\circ\text{F} \end{aligned}$$

3. Tc dan tc

$$T_c = t_{\text{average steam}}$$

$$\begin{aligned} T_c &= \frac{T_1 + T_2}{2} \\ &= \frac{752 + 752}{2} \\ &= 752 \text{ } ^\circ\text{F} \end{aligned}$$

$$t_c = t_{\text{average bahan}}$$

$$\begin{aligned} t_c &= \frac{t_1 + t_2}{2} \\ &= \frac{447 + 684}{2} \\ &= 565,431 \text{ } ^\circ\text{F} \\ &= 569,501 \text{ K} \end{aligned}$$

Menghitung Kapasitas Panas, Konduktivitas Thermal dan Viskositas

Fluida Panas

$$\begin{aligned} c_p &= 0,48 \text{ Btu/lb}^\circ\text{F} && \text{(Kern, Fig 3)} \\ k &= 0,2 \text{ Btu/hr.ft}^3\text{.(F/ft)} && \text{(Kern, Table 5)} \\ \mu &= 0,024 \text{ cP} && \text{(Kern, Fig.15)} \end{aligned}$$

Fluida Dingin

Menghitung nilai kapasitas panas



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komponen	A	B	C	D
$C_{17}H_{33}COOH$	278,686	2,5434	-0,0054	4,9E-06
C_4H_9OH	83,877	0,56628	-0,0017	2,3E-06
$C_{17}H_{33}COOC_4H_9$	178,423	3,667	-0,00797	7,1E-06
$C_{15}H_{31}COOH$	86,29	3,5237	-0,0073	6,1E-06

$$T = 569,501 \text{ K}$$

$$C_p = A + BT + CT^2 + DT^3$$

Sehingga diperoleh

$$C_p C_{17}H_{33}COOH = 873,749 \text{ Kkal/KmolK}$$

$$C_p C_4H_9OH = 279,837 \text{ Kkal/KmolK}$$

$$C_p C_{17}H_{33}COOC_4H_9 = 992,298 \text{ Kkal/KmolK}$$

$$C_p C_{15}H_{31}COOH = 845,647 \text{ Kkal/KmolK}$$

komponen	BM	Cp	Fraksi	Cp
	Kg/Kmol	kcal/Kmol K	Xf	kcal/Kg K
$C_{17}H_{33}COOH$	282,47	873,74864	0,95231	3,09324
C_4H_9OH	74	279,83654	1E-07	3,78157
$C_{17}H_{33}COOC_4H_9$	310,56	992,29814	0,00103	3,19519
$C_{15}H_{31}COOH$	256,42	845,64747	0,04666	3,2979
Total			1	

$$1 \text{ kkal/kg K} = 0,23885 \text{ Btu/lb } ^\circ\text{F}$$

$$C = \sum_i^n C_p \cdot X_f$$

$$C = 0,7411272 \text{ Btu/lb}^\circ\text{F}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
$C_{17}H_{33}COOH$	-6,13	1690	0,008	-6E-06
C_4H_9OH	-5,397	1325,6	0,006	-6E-06
$C_{17}H_{33}COOC_4H_9$	-15,275	2934	0,02692	-2E-05
$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05



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$$T = 569,50061 \text{ K}$$

$$\text{Log10 } \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu_{C_{17}H_{33}COOH} = 0,2002546 \text{ cP}$$

$$\mu_{C_4H_9OH} = 0,0363575 \text{ cP}$$

$$\mu_{C_{17}H_{33}COOC_4H_9} = 0,2208815 \text{ cP}$$

$$\mu_{C_{15}H_{31}COOH} = 0,1831813 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
$C_{17}H_{33}COOH$	385,48706	0,9523125	0,2002546	0,190705
C_4H_9OH	4,134E-05	1,021E-07	0,0363575	3,713E-09
$C_{17}H_{33}COOC_4H_9$	0,4167088	0,0010294	0,2208815	0,0002274
$C_{15}H_{31}COOH$	18,8867	0,046658	0,1831813	0,0085469
Total	404,79051	1		0,1994792

$$\begin{aligned} \mu_{\text{Campuran}} &= 0,1994792 \text{ cP} \\ &= 0,000134 \text{ lb/ft s} \end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
$C_{17}H_{33}COOH$	-6,13	1690	0,008	-6E-06
C_4H_9OH	-5,397	1325,6	0,006	-6E-06
$C_{17}H_{33}COOC_4H_9$	-15,275	2934	0,02692	-2E-05
$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05

$$T = 745,47956 \text{ F}$$

$$T = 633,722 \text{ K}$$

$$\text{Log10 } \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh



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$$\begin{aligned}\mu \text{ C}_{17}\text{H}_{33}\text{COOH} &= 0,1038048 \text{ cP} \\ \mu \text{ C}_4\text{H}_9\text{OH} &= 0,0192427 \text{ cP} \\ \mu \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,1425265 \text{ cP} \\ \mu \text{ C}_{15}\text{H}_{31}\text{COOH} &= 0,0877209 \text{ cP}\end{aligned}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
$\text{C}_{17}\text{H}_{33}\text{COOH}$	385,48706	0,9523125	0,1038048	0,0988546
$\text{C}_4\text{H}_9\text{OH}$	4,134E-05	1,021E-07	0,0192427	1,965E-09
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	0,4167088	0,0010294	0,1425265	0,0001467
$\text{C}_{15}\text{H}_{31}\text{COOH}$	18,8867	0,046658	0,0877209	0,0040929
Total	404,79051	1		0,1030942

$$\begin{aligned}\mu \text{ Campuran} &= 0,1030942 \text{ cP} \\ &= 0,2493952 \text{ lb/jam ft}\end{aligned}$$

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$\text{C}_{17}\text{H}_{33}\text{COOH}$	0,2824	0,26812	781	0,2897
$\text{C}_4\text{H}_9\text{OH}$	0,26891	0,2667	596,23	0,2457
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	0,24798	0,24	764	0,2857
$\text{C}_{15}\text{H}_{31}\text{COOH}$	0,2797	0,26805	776	0,2947

$$T = 569,501 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{Tc}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned}\rho \text{ C}_{17}\text{H}_{33}\text{COOH} &= 0,69569 \text{ gr/ml} \\ \rho \text{ C}_4\text{H}_9\text{OH} &= 0,49805 \text{ gr/ml} \\ \rho \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,65115 \text{ gr/ml} \\ \rho \text{ C}_{15}\text{H}_{31}\text{COOH} &= 0,68198 \text{ gr/ml}\end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran



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KOMPONEN	(kg)	FAKSI MASSA	gr/ml	gr/ml
$C_{17}H_{33}COOH$	385,48706	0,9523125	0,695688	0,6625124
C_4H_9OH	4,134E-05	1,021E-07	0,4980453	5,086E-08
$C_{17}H_{33}COOC_4H_9$	0,4167088	0,0010294	0,6511498	0,0006703
$C_{15}H_{31}COOH$	18,8867	0,046658	0,6819753	0,0318196
Total	404,79051	1		0,6950024

$$\begin{aligned}\rho \text{ Campuran} &= 0,6950024 \text{ gr/ml} \times 62,4 \\ &= 43,368147 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}Sg &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{43,368147 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,6946684\end{aligned}$$

$$\begin{aligned}K_{mix} &= \frac{0,0677}{\text{sg} [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{0,695 [1 - 0,0003 (0 - 32)]} \\ &= 0,0965 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243}\end{aligned}$$

Dipilih tipe : 1-2 Heat Exchanger

Digunakan shell and tube dengan ukuran :

Tube Side		Shell Side	
OD	= 1 1/4 in	Shell ID	= 17 1/4 in
BWG	= 8	Passes	= 1 in
Pitch	= 1 9/16 in Square Pitch		
L	= 10 ft		
Passes	= 2		
ID	= 0,165 in		
a't	= 0,665 in ²		
a"	= 0,3271 ft ² /ft panjang		
Thickness	= 0,165 in		

(kern, Table.10, Hal. 843)



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$$\begin{aligned}\text{Harga UD} &= 6 - 60 \text{ Btu/jam.ft.}^{\circ}\text{F} && \text{(Kern, tabel 8 hal 840)} \\ \text{Dipilih UD} &= 50 \text{ Btu/jam.ft.}^{\circ}\text{F}\end{aligned}$$

$$\begin{aligned}A &= \frac{Q}{UD \times \Delta t} && \text{(Kern Eq. 7.6)} \\ &= \frac{1308010,595}{50 \times 157,965} \\ &= 165,608 \text{ ft}^2\end{aligned}$$

$$\begin{aligned}\text{Jumlah tube (Nt)} &= \frac{A}{a'' \times L} \\ &= \frac{165,6075003}{0,33 \times 10} \\ &= 50,629 \text{ buah}\end{aligned}$$

UD koreksi

$$\begin{aligned}A &= Nt \times L \times a'' \\ &= 53 \times 10 \times 0,33 \\ &= 173,363\end{aligned}$$

$$\begin{aligned}UD &= \frac{Q}{A \times \Delta t} \\ &= \frac{1308010,595}{173 \times 157,965} \\ &= 47,763219\end{aligned}$$

Menentukan nilai De :

$$\begin{aligned}De &= \frac{4 \left(Pt^2 - \pi \frac{OI^2}{4} \right)}{\pi OD} \\ &= \frac{4 \left(1,56^2 - 3,14 \times \frac{1,25^2}{4} \right)}{3,14 \times 1,25} \\ &= 1,23806 \text{ in} = 0,10 \text{ ft}\end{aligned}$$



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Fluida Panas : Tube Side	Fluida Dingin : Shell Side
Steam	Larutan dingin
4. Flow Area (at) $at' = 0,67 \text{ in}^2 \quad (\text{Kern, Table 10})$ $at = \frac{N_t \times at'}{144 \times n}$ $= \frac{53 \times 0,67}{144 \times 2}$ $= 0,1223785 \text{ ft}^2$	4. Flow Area (at) $C = Pt - OD$ $= 1 \frac{4}{7} - 1 \frac{1}{4}$ $= 0,3125$ $as = \frac{ID \times C' \times B}{144 \times Pt}$ $= \frac{17,25 \times 0,3125 \times 4}{144 \times 1,56}$ $= 0,0958333 \text{ ft}^2$
5. Mass Velocity (Gs) $Gs = \frac{W}{at}$ $= \frac{740,94674}{0,1223785}$ $= 6054,5513 \text{ lb/jam ft}^2$	5. Mass Velocity (Gs) $Gs = \frac{W}{as} \quad (\text{Kern, Eq 7.2})$ $= \frac{894,99182}{0,0958333}$ $= 9339,0451 \text{ lb/jam ft}^2$
6. Bilangan Reynold (Res) $De = 0,10 \text{ ft}$ $\mu = 0,05808 \text{ lb/ft.jam}$ $Ret = \frac{De \times Gs}{\mu}$ $= \frac{0,1 \times 6054,55}{0,05808}$ $= 10755,106$	6. Bilangan Reynold (Ret) $D = 0,01 \text{ ft}$ $\mu = 0,48 \text{ lb/ft.jam}$ $Res = \frac{D \times Gt}{\mu}$ $= \frac{0,01 \times 9339,05}{0,48274}$ $= 266,005$
	7. jH $L/D = 727,276$ $jH = 5$ (Kern Fig-28, hal. 838)



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9. h_{io} $h_{io} = 1500 \text{ Btu/hr ft}^2 \text{ } ^\circ\text{F}$ (Kern, Hal. 164)	8. $(C \times \mu / k)^{1/3}$ $= \frac{0,74113 \times 0,48274}{0,0965}$ $= 1,54756$ 9. h_o $h_o = jH \frac{k}{D} \left(\frac{c \mu}{k} \right)^{1/3} \phi_t$ $\frac{h_o}{\phi_t} = 5 \times \frac{0,0965}{0,01375} \times 1,54756$ $= 54,322383 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$
10. t_w $t_w = t_c + \frac{h_o/\phi_s}{h_{io}/\phi_t + h_o/\phi_s} (T_c - t_c)$ (Kern, Eq 5.31) $= 565 + \frac{1500}{1500 + 54,3} 187$ $= 745,48 \text{ } ^\circ\text{F}$	10. ϕ_t Pada $t_w = 745,47956 \text{ } ^\circ\text{F}$ $\mu_w = 0,2493952 \text{ lb/jam ft}$ $\phi_t = (\mu/\mu_w)^{0.14}$ $= 1,09687$ 11.. h_{io} $= \frac{h_o}{\phi_t} \times \phi_t$ $= 59,5846 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$

12. Clean Overall Coefficient, U_c

$$U_c = \frac{h_{io} \times h_o}{h_{io} + h_o} \quad \text{(Kern, Eq 6.38)}$$

$$= \frac{1500 \times 59,6}{1500 + 59,6}$$

$$= 57,3 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$$

13. Design Overall Coefficient, U_d

$$U_d = \frac{Q}{A \times \Delta t \text{ LMTD}}$$

$$= \frac{1308010,6}{\dots}$$



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$$\frac{173}{1} \times 158$$

$$= 47,763219 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$$

14. Dirt Factor, Rd

$$R_d = \frac{U_c - U_d}{U_c \times U_d} \quad \text{(Kern, Eq 6.13)}$$

$$= \frac{57,3 - 47,8}{57,3 \times 47,8}$$

$$= 0,00349$$

Nilai Rd perhitungan > Rd

$$0,00349 > 0,002 \quad \text{(Kern, Table 12 Page 845)}$$

(Memenuhi karena Rd Perhitungan >> Rd allowabe)

Pressure Drop	
Fluida Panas : Tube Side	Fluida Dingin : Shell Side
Steam	Produk
1. f $Re_t = 10755,106$ $f = 0,00018$ (Kern, Fig 26) 2. $\rho = \frac{1}{2,33}$ $= 0,42918 \text{ lb/ft}^3$ $s = \frac{0,42918}{62,5}$ $= 0,00687$ $\Delta P_t = \frac{f G_s^2 L_n}{5,22 \times 10^{10} D s \phi}$ $= 5,709E-05 \text{ psi}$ $\Delta P_t < \Delta P \text{ allowable}$ $\Delta P_t < 2 \text{ psi}$, maka memenuhi	1. f $Re_s = 266,00539$ $f = 0,0013$ (Kern, Fig 29) 2. Number of crosses, N+1 $N+1 = \frac{12 \times L}{B}$ $= 12 \times \frac{10}{4}$ $= 30$ 3. Pressure Drop (ΔP_s) $s = 1,84$ (Kern, Table 6) $\Delta P_s = \frac{f \times G_t^2 \times L \times n}{5,22 \times 10^{10} \times ID \times s \times \phi t}$ (Kern, Eq 7.44) $= 1,872E-05 \text{ psi}$ $\Delta P_s < \Delta P \text{ allowable}$



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$$\Delta P_s < 2 \text{ psi, maka memenuhi}$$

Spesifikasi Alat

Nama Alat : Reboiler
Kode : E-326
Fungsi : Untuk menguapkan sebagian cairan dibawah kolom dan mensupply panas ke kolom distilasi
Tipe : *Shell and Tube Heat Exchanger*
Dasar Pemilihan : Umum digunakan untuk transfer panas
Kondisi Operasi : - Tekanan : 1 atm
- Suhu : 362,217 °C

Bagian Tube

OD : 1 1/4 in
BWG : 8
Panjang : 10 ft
Jumlah tube, Nt : 53
Passes : 2
Pitch : 1 4/7 in square pitch
Pressure drop : 5,709E-05 psi

Bagian Shell

ID : 17 1/4 in
Passes : 1
Baffle Spacing : 0 in
Pressure drop : 1,872E-05 psi

33. Pompa (L-326)



Fungsi : Untuk memindahkan *bottom product* menara destilasi II (D-320) menuju Reaktor (R-210)



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

Tipe : *Centrifugal pump*
 Dasar Pemilihan : Umum digunakan untuk memompa liquid dengan viskositas rendah

Komposisi Bahan Masuk

Komponen	Massa	Fraksi Massa
	(kg)	
C ₁₇ H ₃₃ COOH	385,4870597	0,9523125
C ₄ H ₉ OH	4,13359E-05	1,021E-07
C ₁₇ H ₃₃ COOC ₄ H ₉	0,416708752	0,0010294
C ₁₅ H ₃₁ COOH	18,8867004	0,046658
Total	404,7905102	1

Rate massa bahan = 404,79051 kg/jam
 = 892,40521 lb/jam

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
C ₁₇ H ₃₃ COOH	0,2824	0,26812	781	0,2897
C ₄ H ₉ OH	0,26891	0,2667	663	0,2457
C ₁₇ H ₃₃ COOC ₄ H ₉	0,2479	0,24	764	0,2857
C ₁₅ H ₃₁ COOH	0,2797	0,26805	776	0,2947

$$T = 362,22 \text{ }^{\circ}\text{C} = 635,367 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

ρ C₁₇H₃₃COOH = 0,6343032 gr/ml
 ρ C₄H₉OH = 0,4926265 gr/ml
 ρ C₁₇H₃₃COOC₄H₉ = 0,5845584 gr/ml
 ρ C₁₅H₃₁COOH = 0,6199239 gr/ml

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
C ₁₇ H ₃₃ COOH	385,4870597	0,9523125	0,6343032	0,6040549



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C ₄ H ₉ OH	4,13359E-05	1,021E-07	0,4926265	5,031E-08
C ₁₇ H ₃₃ COOC ₄ H ₉	0,416708752	0,0010294	0,5845584	0,0006018
C ₁₅ H ₃₁ COOH	18,8867004	0,046658	0,6199239	0,0289244
Total	404,7905102	1		0,6335811

$$\begin{aligned}\rho \text{ Campuran} &= 0,6335811 \text{ gr/ml} \times 62,4 \\ &= 39,535459 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Rate volumetrik} &= \frac{\text{rate massa bahan}}{\rho \text{ bahan}} \\ &= \frac{892,40521 \text{ lb/jam}}{39,535459 \text{ lb/cuft}} \\ &= 22,572274 \text{ cuft/jam} \\ &= 0,0062701 \text{ cuft/detik} \\ &= 2,8142058 \text{ gpm}\end{aligned}$$

a. Menentukan diameter optimal pipa

asumsi aliran turbulen ($N_{re} > 2100$), maka digunakan persamaan

$$D_{i \text{ opt}} = 3,9 \times qf^{0,45} \times \rho^{0,13} \quad (\text{Peters, 4}^{\text{ed}}, \text{ pers. 15 hal 496})$$

Keterangan :

$$\begin{aligned}D_{i \text{ opt}} &= \text{Diameter pipa bagian dalam optimal (in)} \\ qf &= \text{Rate volumetrik (ft}^3/\text{s)} \\ \rho &= \text{Densitas larutan (lb/ft}^3\text{)}\end{aligned}$$

Sehingga,

$$\begin{aligned}D_{i \text{ opt}} &= 3,9 \times qf^{0,45} \times \rho^{0,13} \\ &= 3,9 \times 0,1 \times 1,61 \\ &= 0,64 \text{ in}\end{aligned}$$

Dari Kern Table. 11, maka dipilih pipa dengan spesifikasi :

$$\begin{aligned}\text{Pipe size} &= 1/2 \text{ in} \\ \text{Sch} &= 40 \\ \text{OD} &= 0,84 \text{ in} = 0,07 \text{ ft} = 0,02 \text{ m} \\ \text{ID} &= 0,62 \text{ in} = 0,05 \text{ ft} = 0,02 \text{ m}\end{aligned}$$



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$$A = \frac{1}{4} \times \pi \times ID^2$$

$$= \frac{1}{4} \times 3,14 \times 0,00268$$

$$= 0,00211 \text{ ft}^2$$

$$\text{Kecepatan Aliran (V)} = \frac{\text{Rate volumetrik}}{\text{Luas Area (A)}}$$

$$= \frac{0,00627}{0,00211}$$

$$= 2,97531 \text{ ft/s}$$

b. Menghitung Nre

$$\text{sg reff} = 1 \quad (\text{Kern, Table. 6 p. 808})$$

$$\mu \text{ reff} = 0,8 \text{ cP} \quad (\text{Kern, Fig. 14 p. 823})$$

$$\rho \text{ reff} = 62,4 \text{ lb/ft}^3$$

$$\text{sg bahan} = \frac{\rho \text{ bahan}}{\rho \text{ reff}}$$

$$= \frac{39,5355 \text{ lb/ft}^3}{62,43 \text{ lb/ft}^3}$$

$$= 0,63328$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
$C_{17}H_{33}COOH$	-6,13	1690	0,008	-6E-06
C_4H_9OH	-5,397	1325,6	0,006	-6E-06
$C_{17}H_{33}COOC_4H_9$	-15,275	2934	0,02692	-2E-05
$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05

$$T = 635,367 \text{ K}$$

$$\text{Log}_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu_{C_{17}H_{33}COOH} = 0,102096 \text{ cP}$$



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$$\mu \text{ C}_4\text{H}_9\text{OH} = 0,0189329 \text{ cP}$$

$$\mu \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 = 0,1407506 \text{ cP}$$

$$\mu \text{ C}_{15}\text{H}_{31}\text{COOH} = 0,0860083 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
$\text{C}_{17}\text{H}_{33}\text{COOH}$	385,48706	0,9523125	0,102096	0,0972273
$\text{C}_4\text{H}_9\text{OH}$	4,134E-05	1,021E-07	0,0189329	1,933E-09
$\text{C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9$	0,4167088	0,0010294	0,1407506	0,0001449
$\text{C}_{15}\text{H}_{31}\text{COOH}$	18,8867	0,046658	0,0860083	0,004013
Total	404,79051	1		0,1013852

$$\begin{aligned} \mu \text{ Campuran} &= 0,1013852 \text{ cP} \\ &= 6,813\text{E-}05 \text{ lb/ft s} \end{aligned}$$

$$\begin{aligned} \text{Nre} &= \frac{\text{ID} \times V \times \rho \text{ bahan}}{\mu} \\ &= \frac{0,05 \times 2,98 \times 39,5}{6,813\text{E-}05} \\ &= 89456,293 > 2100 \\ &\text{asumsi aliran turbulen benar} \end{aligned}$$

Dipilih bahan commercial steel, dengan

$$e = 0,000046 \text{ m} \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$

$$\begin{aligned} e/D &= \frac{0,000046}{0,0157925} \\ &= 0,0008878 \end{aligned}$$

$$f = 0,006 \quad (\text{Geankoplis 3ed, F.2.10-3, P. 88})$$

$$gc = 32,174$$

$$\alpha = 1 \quad (\text{aliran turbulen}) \quad (\text{Peters \& Timmerhause 4th ed : 485})$$

c. Menghitung Panjang ekuivalen suction, L_e

Perhitungan friksi berdasarkan Peters & Timmerhaus, 4ed Tabel 1 hh. 484

Sambungan	L_c/D
Elbow standard 90°	32
Gate valve	7



$$\text{ID pipa} = 0,0518126 \text{ ft}$$

Taksiran panjang pipa lurus

Jarak reboiler ke reaktor (R-210)	=	131,234 ft
Tinggi Reaktor	=	17,4000 ft
Panjang pipa masuk reaktor	=	6 ft
Taksiran panjang pipa lurus		154,634 ft

$$\begin{aligned} 3 \text{ elbow } 90^\circ &= 3 \times 32 \times 0,05 \text{ ft} \\ &= 4,97 \text{ ft} \end{aligned}$$

$$\begin{aligned} 1 \text{ gate valve} &= 1 \times 7 \times 0,05 \text{ ft} \\ &= 0,36 \text{ ft} \end{aligned}$$

$$\text{Panjang total pipa (Le)} = 159,97 \text{ ft}$$

d. Perhitungan friksi

1. Friksi karena Gesekan Bahan dalam Pipa

$$\begin{aligned} g_c &= 32,17 \text{ lbm.ft/lbf.s}^2 \\ F_1 &= \frac{2f \times V^2 \times Le}{g_c \times D} \quad (\text{Geankoplis 3ed, Pers, 2.10-6, P.89}) \\ &= \frac{0,01 \times 8,85 \times 160}{32,2 \times 0,05} \\ &= 10,1953 \text{ ft.lbf/lbm} \end{aligned}$$

2. Friksi karena kontraksi dari tangki penyimpanan ke pipa

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times g_c} \quad (\text{Geankoplis 3ed, Pers, 2.10-16, P.93})$$

dimana

$\alpha = 1$ untuk aliran turbulen

Menentukan Kc

A tangki > A pipa maka dianggap 0

Untuk A1 (tangki) dan A2 (pipa), maka $A_2/A_1 = 0$

maka,

$$K = 0,4 \times (1,25 - A_2/A_1) \quad (\text{Peters 4 ed ; Page 484})$$

$$K = 0,4 \times (1,25 - 0)$$

$$K = 0,5$$

sehingga,



$$F_2 = \frac{0,5 \times 8,8524761 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,06879 \text{ ft.lbf/lbm}$$

3. Friksi karena ekspansi dari pipa ke tangki

$$F_3 = \frac{\Delta V^2}{2 \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-15, P.93})$$

($V_1 \ll V_2$ dianggap = 0)

$$= \frac{8,852476065 \text{ ft}^2/\text{s}^2}{2 \times 1 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,13759 \text{ ft.lbf/lbm}$$

4. Friksi karena elbow 90°

$$F_4 = n \times \frac{K_f \times V^2}{2 \times gc} \quad (\text{Geankoplis 3ed, Pers, 2.10-17, P.94})$$

diketahui :

$$K_f = 0,75 \quad (\text{Geankoplis 3ed, T.2.10-1, P. 93})$$

$$F_4 = \frac{3 \times 0,75 \times 8,8524761 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,30958 \text{ ft.lbf/lbm}$$

5. Friksi karena gate valve

$$F_5 = n \times \frac{K_f \times V^2}{2 \times gc} \quad (\text{Geankoplis 3ed Pers. 2.10-1})$$

diketahui :

$$K_f \text{ gate valve (wide open)} = 0,17$$

$$F_5 = \frac{1 \times 0,17 \times 8,8524761 \text{ ft}^2/\text{s}^2}{2 \times 32,17 \text{ lbm.ft/lbf.s}^2}$$

$$= 0,02339 \text{ ft.lbf/lbm}$$

6. Friksi Total

$$\Sigma F = F_1 + F_2 + F_3 + F_4 + F_5$$

$$= 10,7346 \text{ ft.lbf/lbm}$$



e. Perhitungan Energi Tekanan

$$H_{\text{liquida}} = 1,4375 \text{ ft}$$

$$\rho_{\text{bahan}} = 39,5355 \text{ lbm/ft}^3$$

$$g/gc = 1 \text{ lbf/lbm}$$

$$P_2 = 1 \text{ atm} = 2116,8 \text{ lbf/ft}^2$$

Energi Tekanan

$$P_1 = P_{\text{atm}} + P_{\text{hidrostatik}}$$

$$= 1 \text{ atm} + \left(\rho \times \frac{g}{gc} \times H_{\text{liq}} \right)$$

$$= 2117 \text{ lbf/ft}^2 + (39,5 \text{ lbm/ft}^3 \times 1 \text{ lbf/lbm} \times 1,44 \text{ ft})$$

$$= 2173,6322 \text{ lbf/ft}^2$$

$$\begin{aligned} \frac{\Delta P}{\rho} &= \frac{(P_1 - P_2)}{\rho} \\ &= \frac{2173,63 - 2116,8}{39,53545899} \\ &= 1,4375 \text{ ft.lbf/lbm} \end{aligned}$$

f. Perhitungan Energi Kinetik

$$\begin{aligned} E_k &= \frac{\Delta V^2}{2 \times \alpha \times gc} \quad (\text{Geankoplis, 3ed Eq. 2.7-5 p. 66}) \\ &= \frac{8,852476065}{2 \times 1 \times 32,17} \\ &= 0,137589 \text{ ft.lbf/lbm} \end{aligned}$$

g. Perhitungan Energi potensial

Diketahui

$$Z_1 = 1,4375 \text{ ft}$$

(Dianggap : Produk yang keluar Reboiler memiliki tinggi = Diamete

$$Z_2 = 17,4000 \text{ ft (Tinggi pipa menuju Reaktor)}$$

$$g/gc = 1 \text{ lbf/lbm}$$

Sehingga,

$$\begin{aligned} E_p &= \Delta Z \times \frac{g}{gc} \quad (\text{Geankoplis, 2014 Eq. 2.7-5 p. 66}) \\ &= (17,4 - 1,44) \text{ ft} \times 1 \text{ lbf/lbm} \end{aligned}$$



$$= 15,9625 \text{ ft.lbf/lbm}$$

h. Persamaan Bernouli

$$\begin{aligned} -W_f &= \frac{\Delta P}{\rho} + \Delta Z \times \frac{g}{g_c} + \frac{\Delta V^2}{2 \times \alpha \times g_c} + \Sigma F \\ &= 1,4375 + 15,9625 + 0,13759 + 10,7346 \\ &= 28,2722 \text{ ft.lbf/lbm} \end{aligned}$$

i. Perhitungan Power Pompa

$$\begin{aligned} \text{hp} &= \frac{-W_f \times \text{flowrate(gpm)} \times \text{sg}}{3960} \\ &\quad (\text{Perry 6ed ; Pers 6-11, Page 6-5}) \\ &= \frac{28,2722 \times 2,81421 \times 0,63328}{3960} \\ &= 0,01272 \text{ hp} \end{aligned}$$

$$\text{Efisiensi pompa} = 65\% \quad (\text{Peters 4 ed ; Figure 14 - 37 Page 520})$$

$$\begin{aligned} \text{Bhp} &= \frac{\text{Bph}}{\eta \text{ pompa}} \\ &= \frac{0,0127237 \text{ hp}}{65\%} \\ &= 0,019575 \text{ hp} \end{aligned}$$

$$\begin{aligned} \text{Efisiensi motor} &= 80\% \\ \text{Power motor} &= \frac{\text{Bhp}}{\text{ef.Motor}} \\ &= \frac{0,019575 \text{ hp}}{80\%} \\ &= 0,0244687 \text{ hp} \end{aligned}$$

$$\text{Maka digunakan power} = 0,5 \text{ hp}$$

Spesifikasi

Nama Alat	: Pompa
Kode	: L-326
Fungsi	: Untuk memindahkan bottom product dari menara destilasi (D-320) menuju Reaktor (R-210)
Tipe	: <i>Centrifugal pump</i>
Bahan konstruksi	: <i>Commercial steel</i>
Dasar Pemilihan	: Umum digunakan untuk memompa liquid dengan viskosita



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	rendah
Ukuran Pipa	: 0,5 in 40 sch
Kapasitas	: 892,405 lb/jam
Rate volumetrik	: 22,5723 ft ³ /jam
Total Dynamic head	: 28,2722 ft.lbf/lbm
Efisiensi pompa	: 65%
Efisiensi motor	: 80%
Bhp	: 0,01957 hp
Power	: 0,5 hp
Jumlah	: 1 buah

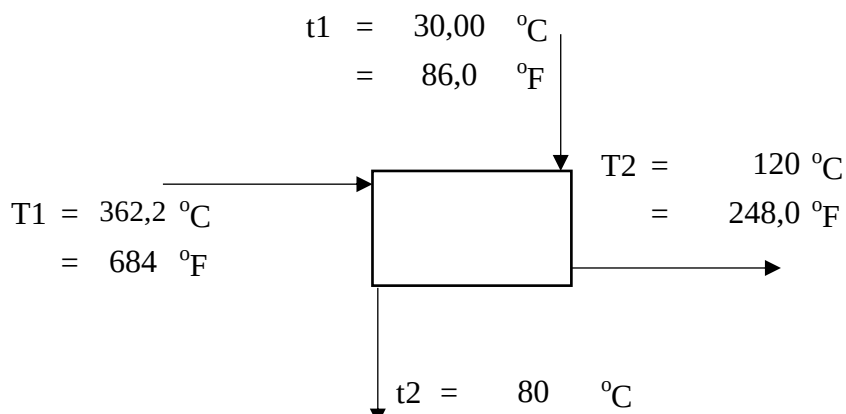
34. Cooler (E-327)



Fungsi : Mendinginkan asam oleat dari suhu 361°C menjadi 120°C
Tipe : 1-2 Shell and Tube Exchanger
Dasar Pemilihan : Umum digunakan untuk mendinginkan liquida

Kondisi Operasi:

Tekanan = 1 atm
Suhu = 120 °C





PRA RANCANGAN PABRIK
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Proses Esterifikasi dan Katalis Asam Sulfat”

$$\nabla = 176,0 \text{ } ^\circ\text{F}$$

Perhitungan

1. Data dari neraca massa dan neraca panas diperoleh:

Untuk Fluida panas : Asam Oleat

$$T \text{ masuk } (T_1) = 362,2 \text{ } ^\circ\text{C} = 683,99 \text{ } ^\circ\text{F}$$

$$T \text{ keluar } (T_2) = 120 \text{ } ^\circ\text{C} = 248,0 \text{ } ^\circ\text{F}$$

Untuk Fluida dingin : Dowtherm

$$T \text{ masuk } (t_1) = 30 \text{ } ^\circ\text{C} = 86,0 \text{ } ^\circ\text{F}$$

$$T \text{ keluar } (t_2) = 80 \text{ } ^\circ\text{C} = 176,0 \text{ } ^\circ\text{F}$$

$$\text{massa bahan} = 404,79051 \text{ kg/jam}$$

$$= 894,99182 \text{ lb/jam}$$

Panas yang diserap

$$Q = 69130,12 \text{ kkal/jam}$$

$$= 274149,32 \text{ Btu/jam}$$

Dowtherm yang dibutuhkan

$$W = 2840,44 \text{ kg/jam}$$

$$= 6280,22 \text{ lb/jam}$$

2. Penentuan ΔT LMTD

Hot fluida		Cold fluida	diff
683,99	higher temp	176,0	508
248,0	lower temp	86,0	162
436,0		90,0	

$$\Delta t \text{ LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$

$$\Delta t \text{ LMTD} = \frac{508 - 162}{\ln \frac{508}{162}}$$

$$= 302,73911 \text{ } ^\circ\text{F}$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} \quad \text{(Kern, Eq 5.17)}$$



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Proses Esterifikasi dan Katalis Asam Sulfat”

$$\begin{aligned} &= \frac{684 - 248,0}{176 - 86,0} \\ &= 4,84 \end{aligned}$$

$$\begin{aligned} S &= \frac{t_2 - t_1}{T_1 - t_1} && \text{(Kern, Pers. 5.14, : 149)} \\ &= \frac{176 - 86}{684 - 86} \\ &= 0,1505 \end{aligned}$$

$$\begin{aligned} FT &= 0,98 && \text{(Kern Fig. 18, : 828)} \\ \Delta T &= \Delta T_{LMTD} \times FT && \text{(Kern, Pers. 7.42 : 149)} \\ &= 302,739 \text{ } ^\circ\text{F} \times 0,98 \\ &= 296,684 \text{ } ^\circ\text{F} \end{aligned}$$

3. Tc dan tc

Tc = t average bahan

$$\begin{aligned} T_c &= \frac{T_1 + T_2}{2} \\ &= \frac{684 + 248}{2} \\ &= 466 \text{ } ^\circ\text{F} \\ &= 514 \text{ K} \end{aligned}$$

tc = t average dowtherm

$$\begin{aligned} t_c &= \frac{t_1 + t_2}{2} \\ &= \frac{86,0 + 176}{2} \\ &= 131 \text{ } ^\circ\text{F} \\ &= 328,15 \text{ K} \end{aligned}$$

Menghitung Kapasitas Panas, Konduktifitas Thermal dan Viskositas **Fluida Dingin**

$$\begin{aligned} c_p &= 0,4 \text{ Btu/lb}^\circ\text{F} \\ k &= 0,0769 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F/ft} \\ \mu &= 1,96 \text{ cP} \end{aligned}$$



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Proses Esterifikasi dan Katalis Asam Sulfat”

Fluida Panas

Menghitung nilai kapasitas panas

komponen	A	B	C	D
$C_{17}H_{33}COOH$	278,686	2,5434	-0,0054	4,9E-06
C_4H_9OH	83,877	0,56628	-0,0017	2,3E-06
$C_{17}H_{33}COOC_4H_9$	178,423	3,667	-0,008	7,1E-06
$C_{15}H_{31}COOH$	86,29	3,5237	-0,0073	6,1E-06

$$T = 514,258 \text{ K}$$

$$C_p = A + BT + CT^2 + DT^3$$

Sehingga diperoleh

$$C_p \text{ } C_{17}H_{33}COOH = 818,841 \text{ Kkal/KmolK}$$

$$C_p \text{ } C_4H_9OH = 238,31 \text{ Kkal/KmolK}$$

$$C_p \text{ } C_{17}H_{33}COOC_4H_9 = 921,234 \text{ Kkal/KmolK}$$

$$C_p \text{ } C_{15}H_{31}COOH = 792,133 \text{ Kkal/KmolK}$$

komponen	BM	Cp	Fraksi	Cp
	Kg/Kmol	kkal/Kmol K	Xf	kkal/Kg K
$C_{17}H_{33}COOH$	282,47	818,84135	0,95231	2,89886
C_4H_9OH	74	238,31014	1E-07	3,22041
$C_{17}H_{33}COOC_4H_9$	310,56	921,23385	0,00103	2,96636
$C_{15}H_{31}COOH$	256,42	792,13272	0,04666	3,0892
Total			1	

$$1 \text{ kkal/kg K} = 0,23885 \text{ Btu/lb } ^\circ\text{F}$$

$$C = \sum_i^n C_p \cdot Xf$$

$$C = 0,6945189 \text{ Btu/lb}^\circ\text{F}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
$C_{17}H_{33}COOH$	-6,13	1690	0,008	-6E-06
C_4H_9OH	-5,397	1325,6	0,006	-6E-06
$C_{17}H_{33}COOC_4H_9$	-15,275	2934	0,02692	-2E-05



PRA RANCANGAN PABRIK
“Pabrik Butil Oleat dari Butanol dan Asam Oleat dengan
Proses Esterifikasi dan Katalis Asam Sulfat”

$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05

$$T = 514,258 \text{ K}$$

$$\log_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh

$$\mu \quad C_{17}H_{33}COOH = 0,366923 \text{ cP}$$

$$\mu \quad C_4H_9OH = 0,0644257 \text{ cP}$$

$$\mu \quad C_{17}H_{33}COOC_4H_9 = 0,3110542 \text{ cP}$$

$$\mu \quad C_{15}H_{31}COOH = 0,3384288 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas (cP)	μ Campuran (cP)
	(kg)			
$C_{17}H_{33}COOH$	385,48706	0,9523125	0,366923	0,3494254
C_4H_9OH	4,134E-05	1,021E-07	0,0644257	6,579E-09
$C_{17}H_{33}COOC_4H_9$	0,4167088	0,0010294	0,3110542	0,0003202
$C_{15}H_{31}COOH$	18,8867	0,046658	0,3384288	0,0157904
Total	404,79051	1		0,365536

$$\begin{aligned} \mu \text{ Campuran} &= 0,365536 \text{ cP} \\ &= 0,0002456 \text{ lb/ft s} \end{aligned}$$

Menghitung Viskositas Larutan

komponen	A	B	C	D
$C_{17}H_{33}COOH$	-6,13	1690	0,008	-6E-06
C_4H_9OH	-5,397	1325,6	0,006	-6E-06
$C_{17}H_{33}COOC_4H_9$	-15,275	2934	0,02692	-2E-05
$C_{15}H_{31}COOH$	-9,45	2100	0,016	-1E-05

$$T = 457,006 \text{ F}$$

$$T = 496,733 \text{ K}$$

$$\log_{10} \mu = A + \frac{B}{T} + CT + DT^2$$

Sehingga diperoleh



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$$\mu \quad C_{17}H_{33}COOH = 0,4514373 \text{ cP}$$

$$\mu \quad C_4H_9OH = 0,0780688 \text{ cP}$$

$$\mu \quad C_{17}H_{33}COOC_4H_9 = 0,3488729 \text{ cP}$$

$$\mu \quad C_{15}H_{31}COOH = 0,41341 \text{ cP}$$

komponen	Massa	Fraksi Massa	Viskositas	μ Campuran
	(kg)		(cP)	(cP)
$C_{17}H_{33}COOH$	385,48706	0,9523125	0,4514373	0,4299094
C_4H_9OH	4,134E-05	1,021E-07	0,0780688	7,972E-09
$C_{17}H_{33}COOC_4H_9$	0,4167088	0,0010294	0,3488729	0,0003591
$C_{15}H_{31}COOH$	18,8867	0,046658	0,41341	0,0192889
Total	404,79051	1		0,4495574

$$\begin{aligned} \mu \text{ Campuran} &= 0,4495574 \text{ cP} \\ &= 1,0875191 \text{ lb/ft jam} \end{aligned}$$

Menghitung Densitas

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,24798	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947

$$T = 514,258 \text{ K}$$

$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\rho \quad C_{17}H_{33}COOH = 0,7407 \text{ gr/ml}$$

$$\rho \quad C_4H_9OH = 0,5548094 \text{ gr/ml}$$

$$\rho \quad C_{17}H_{33}COOC_4H_9 = 0,6993941 \text{ gr/ml}$$

$$\rho \quad C_{15}H_{31}COOH = 0,7274069 \text{ gr/ml}$$

komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
$C_{17}H_{33}COOH$	385,4870597	0,9523125	0,7407	0,7053779



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C ₄ H ₉ OH	4,13359E-05	1,021E-07	0,5548094	5,666E-08
C ₁₇ H ₃₃ COOC ₄ H ₉	0,416708752	0,0010294	0,6993941	0,00072
C ₁₅ H ₃₁ COOH	18,8867004	0,046658	0,7274069	0,0339393
Total	404,7905102	1		0,7400372

$$\begin{aligned}\rho \text{ Campuran} &= 0,7400372 \text{ gr/ml} \times 62,4 \\ &= 46,178323 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Sg} &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{46,178323 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,7396816\end{aligned}$$

$$\begin{aligned}\text{Kmix} &= \frac{0,0677}{\text{sg} [1 - 0,0003 (t - 32)]} \\ &= \frac{0,0677}{0,740 [1 - 0,0003 (131 - 32)]} \\ &= 0,0943 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{Perry ed 5 pers 3-89 hal 3-243}\end{aligned}$$

Dipilih tipe : 1-2 Heat Exchanger

Digunakan shell and tube dengan ukuran :

Tube Side		Shell Side	
OD	= 1 1/4 in	Shell ID	= 8 in
BWG	= 8	Passes	= 1 in
Pitch	= 1 4/7 in Square Pitch		
L	= 10 ft		
Passes	= 2		
ID	= 0,92 in		
a't	= 0,665 in ²		
a"	= 0,3271 ft ² /ft panjang		

(kern, Table.10, Hal. 843)

$$\begin{aligned}\text{Harga UD} &= 10 - 40 \text{ Btu/jam.ft.}^\circ\text{F} \quad \text{(Kern, tabel 8 hal 840)} \\ \text{Dipilih UD} &= 15 \text{ Btu/jam.ft.}^\circ\text{F}\end{aligned}$$



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$$\begin{aligned} A &= \frac{Q}{UD \times \Delta t} \quad \text{(Kern Eq. 7.6)} \\ &= \frac{274149,3168}{15 \times 296,684} \\ &= 61,6029 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Jumlah tube (Nt)} &= \frac{A}{a'' \times L} \\ &= \frac{61,60292003}{0,33 \times 10} \\ &= 18,8331 \text{ buah} \end{aligned}$$

Sehingga dipilih ukuran yang paling mendekati, yaitu:

ukuran pipa = 1 1/4 in
ID tube = 0,92
BWG = 8
Pitch = 1 4/7 in Square Pitch
ID shell = 12
Passes tube = 2
Jumlah tube = 24

UD koreksi

$$\begin{aligned} A &= Nt \times L \times a'' \\ &= 24 \times 10 \times 0,33 \\ &= 78,504 \end{aligned}$$

$$\begin{aligned} UD &= \frac{Q}{A \times \Delta t} \\ &= \frac{274149,3168}{78,5 \times 296,684} \\ &= 11,770659 \end{aligned}$$

Menentukan nilai De :

$$De = \frac{4 \left(\frac{Pt^2}{\pi} - \frac{\pi OI^2}{4} \right)}{\pi OD}$$



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$$= \frac{4 \left(1,56^2 - 3,14 \times \frac{1,25^2}{4} \right)}{3,14 \times 1,25}$$

$$= 1,23806 \text{ in} = 0,10 \text{ ft}$$

Fluida Dingin : Tube Side	Fluida Panas :Shell Side
Dowtherm	Produk
4. Flow Area (at) $at = \frac{N_t \times at'}{144 \times n}$ (Kern, Eq 7.48) $= \frac{24 \times 0,67}{144 \times 2}$ $= 0,0558333 \text{ ft}^2$	4. Flow Area (at) asums B = 0,25 ID $= \frac{1}{2}$ $C = Pt - OD$ $= 1 \frac{4}{7} - 1 \frac{1}{4}$ $= 0,3125$ $as = \frac{ID \times C' \times B}{144 \times Pt}$ (Kern, Eq. 7.1) $= \frac{8 \times 0,3125 \times 2}{144 \times 1,56}$ $= 0,0222222 \text{ ft}^2$
5. Mass Velocity (Gt) $Gt = \frac{W}{at}$ $= \frac{6280,2193}{0,0558333}$ $= 112481,54 \text{ lb/jam ft}^2$	5. Mass Velocity (Gs) $Gs = \frac{W}{as} \quad \text{(Kern, Eq 7.2)}$ $= \frac{894,99182}{0,0222222}$ $= 40274,632 \text{ lb/jam ft}^2$
6. Bilangan Reynold (Ret) $De = 0,10 \text{ ft}$ $\mu = 4,7432 \text{ lb/ft.jam}$ $Ret = \frac{De \times Gs}{\mu}$ $= \frac{0,1 \times 112482}{4,7432}$ $= 2446,6348$	6. Bilangan Reynold (Res) $D = 0,08 \text{ ft}$ $\mu = 0,88 \text{ lb/ft.jam}$ $Res = \frac{D \times Gt}{\mu}$ $= \frac{0,08 \times 40274,6}{0,8846}$ $= 3490,53$



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9. h_{io} $h_{io} = 1500 \text{ Btu/hr ft}^2 \text{ } ^\circ\text{F}$ (Kern, Hal. 164)	7. j_H $L/D = 130,435$ $j_H = 18$ (Kern Fig-28, hal. 838) 8. $(C \times \mu / k)^{1/3}$ $= \frac{0,69452 \times 0,8846}{0,0943}$ $= 1,86751$ 9. h_o $h_o = j_H \frac{k}{D} \left(\frac{c \mu}{k} \right)^{1/3} \phi_s$ (Kern, Eq 6.15b) $\frac{h_o}{\phi_t} = 18 \times \frac{0,0943}{0,07667} \times 1,86751$ $= 41,35894 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$
10. t_w $t_w = t_c + \frac{h_o/\phi_s}{h_{io}/\phi_t + h_o/\phi_s} (T_c - t_c)$ (Kern, Eq 5.31) $= 131 + \frac{1500}{1500 + 41,36} 335$ $= 457,006 \text{ } ^\circ\text{F}$	10. ϕ_s Pada $t_w = 457,00623 \text{ } ^\circ\text{F}$ $\mu_w = 1,0875191 \text{ lb/jam ft}$ $\phi_t = (\mu/\mu_w)^{0.14}$ (Kern, Fig.15) $= 0,9715$ 11. h_{io} $= \frac{h_o}{\phi_t} \times \phi_t$ $= 40,1802 \text{ BTU/hr ft}^2 \text{ } ^\circ\text{F}$

12. Clean Overall Coefficient, U_c

$$U_c = \frac{h_{io} \times h_o}{h_{io} + h_o} \quad \text{(Kern, Eq 6.38)}$$

$$= \frac{1500 \times 40,2}{1500 + 40,2}$$



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$$= 39,1 \text{ BTU/hr ft}^2 \text{ }^{\circ}\text{F}$$

13. Design Overall Coefficient, U_d

$$\begin{aligned} U_d &= \frac{Q}{A \times \Delta t \text{ LMTD}} \\ &= \frac{274149,32}{78,5 \times 297} \\ &= 11,770659 \text{ BTU/hr ft}^2 \text{ }^{\circ}\text{F} \end{aligned}$$

14. Dirt Factor, R_d

$$\begin{aligned} R_d &= \frac{U_c - U_d}{U_c \times U_d} \quad (\text{Kern, Eq 6.13}) \\ &= \frac{39,1 - 11,8}{39,1 \times 11,8} \\ &= 0,0594 \end{aligned}$$

Nilai R_d perhitungan > R_d

$$0,0594 > 0,002 \quad (\text{Kern, Table 12 Page 845})$$

(Memenuhi karena R_d Perhitungan >> R_d allowabe)

Pressure Drop	
Fluida dingin : Tube Side	Fluida Panas: Shell Side
Pendingin	Produk
1. f $\begin{aligned} Re_t &= 2446,6348 \\ f &= 0,00018 \\ & \quad (\text{Kern, Fig 26}) \end{aligned}$ 2. $\rho_s = \frac{1}{62,4}$ $\begin{aligned} &= 0,01603 \text{ lb/ft}^3 \\ \rho_s &= \frac{0,01603}{62,5} \\ &= 0,00026 \end{aligned}$ $\begin{aligned} \Delta P_t &= \frac{f G_s^2 L_n}{5,22 \cdot 10^{10} D_s \phi} \\ &= 0,5277397 \text{ psi} \end{aligned}$	1. f $\begin{aligned} Re_s &= 3490,5261 \\ f &= 0,045 \\ & \quad (\text{Kern, Fig 29}) \end{aligned}$ 2. Number of crosses, $N+1$ $\begin{aligned} N+1 &= 12 \times \frac{L}{B} \\ &= 12 \times \frac{10}{2} \\ &= 60 \end{aligned}$ 3. Pressure Drop (ΔP_s) $s = 1,84$



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	(Kern, Table 6)
$\Delta P_t < \Delta P \text{ allowable}$ $\Delta P_t < 2 \text{ psi}$, maka memenuhi	$\Delta P_s = \frac{f \times G t^2 \times L \times n}{5,22 \times 10^{10} \times ID \times s \times \phi t}$ (Kern, Eq 7.44) $= 0,0586686 \text{ psi}$ $\Delta P_s < \Delta P \text{ allowable}$ $\Delta P_s < 2 \text{ psi}$, maka memenuhi

Spesifikasi Alat

Nama Alat : Cooler
Kode : E-324
Fungsi : Mendinginkan larutan produk suhu 226°C menjadi 30°C
untuk dialirkan ke tangki penyimpanan (F-410)
Tipe : 1-2 Shell and Tube Exchanger
Dasar Pemilihan : Umum digunakan untuk transfer panas

Bagian Tube

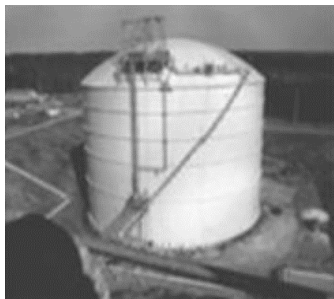
OD : 1 1/4 in
BWG : 8
Panjang : 10 ft
Jumlah tube, Nt : 24
Passes : 2
Pitch : 1 4/7 in square pitch
Pressure drop : 0,5277397 psi

Bagian Shell

ID : 8 in
Passes : 1
Baffle Spacing : 2 in
Pressure drop : 0,0586686 psi



35. Tangki Penyimpanan Natrium Sulfat (F-420)



Fungsi : Menyimpan Natrium Sulfat
Tipe : Tangki berbentuk silinder tegak, tutup atas berupa
Torispherical dish tutup bawah datar
Dasar Pemilihan : Sesuai untuk penyimpanan liquida pada tekanan atmosferik

Kondisi operasi :

Tekanan = 1 atm
suhu = 30 °C
Waktu tinggal = 7 hari

Komposisi Bahan Masuk

Komponen	massa (kg)
Na_2SO_4	119,6132921
$\text{C}_4\text{H}_9\text{OH}$	21,94413635
H_2O	332,4869143
Total	474,0443428

Rate Massa = 474,04434 kg/jam
= 1045,0889 lb/jam

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
H_2O	0,3471	0,274	647,13	0,2857
Na_2SO_4	0,26141	0,1	3700	0,2857
$\text{C}_4\text{H}_9\text{OH}$	0,26891	0,2667	562,93	0,2457

$T = 30\text{ }^{\circ}\text{C} = 303,15\text{ K}$



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$$\rho = AxB^{-\left(1-\frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\rho \text{ H}_2\text{O} = 1,0228823 \text{ gr/ml}$$

$$\rho \text{ Na}_2\text{SO}_4 = 2,4728351 \text{ gr/ml}$$

$$\rho \text{ C}_4\text{H}_9\text{OH} = 0,8021585 \text{ gr/ml}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
H ₂ O	332,4869143	0,7013836	1,0228823	0,7174328
Na ₂ SO ₄	119,6132921	0,2523251	2,4728351	0,6239584
C ₄ H ₉ OH	21,94413635	0,0462913	0,8021585	0,037133
Total	474,0443428	1		1,3785242

$$\begin{aligned}\rho \text{ Campuran} &= 1,3785242 \text{ gr/ml} \times 62,4 \\ &= 86,019909 \text{ lb/cuft}\end{aligned}$$

$$\begin{aligned}\text{Sg} &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{86,019909 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 1,3778617\end{aligned}$$

$$\begin{aligned}\text{rate volumetrik} &= \frac{\text{rate massa}}{\rho \text{ campuran}} \\ &= \frac{1045,0889 \text{ lb/jam}}{86,019909 \text{ lb/cuft}} \\ &= 12,149384 \text{ cuft/jam} \\ &= 291,58521 \text{ cuft/hari}\end{aligned}$$

a. Menentukan Volume Tangki

digunakan 1 buah tangki untuk penyimpanan 7 hari, maka

$$\begin{aligned}\text{Volume liquid} &= 291,585 \text{ cuft/hari} \times 7 \text{ hari} \\ &= 2041,1 \text{ cuft}\end{aligned}$$

Asumsi volume liquid mengisi 80% volume tangki untuk faktor keamanan, sehingga :



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$$\begin{aligned}\text{Volume tangki} &= \frac{\text{Volume cairan}}{80\%} \\ &= \frac{2041,096444}{80\%} \\ &= 2551,3706 \text{ cuft}\end{aligned}$$

b. Menentukan Dimensi Tangki

Asumsi Dimention ratio : H/D = 2 - 5 (Ulrich : T.4-27)
 Asumsi rasio dimensi H/D = 2

Volume tutup Torispherical dish head
 Volume tutup atas = $0,000049 D^3$ (Brownell Eq. 5.11)
 Volume tangki = $\frac{1}{4} \pi D^2 H + 0,000049 D^3$
 $2551,37055 = 1,57 D^3$
 $D^3 = 1625,03 \text{ ft}^3$
 $D = 11,7567 \text{ ft}$
 $= 3,58345 \text{ m}$
 $= 141,081 \text{ in}$

 $H = 2 \times D$
 $= 2 \times 11,7567 \text{ ft}$
 $= 23,5135 \text{ ft}$
 $= 7,16691 \text{ m}$
 $= 282,162 \text{ in}$

c. Menentukan tinggi cairan dalam tangki penyimpanan

Volume liquid = $\frac{1}{4} \pi D^2 H + 0,000049 D^3$
 $2041,0964 = 108,503 H + 0,0796263$
 $2041,0168 = 108,503 H$
 $H = 18,8106 \text{ ft}$
 $= 5,73348 \text{ m}$
 $= 225,728 \text{ in}$

d. Menentukan Tekanan design

Jika dalam bejana terdapat liquid, maka bejana dirancang berdasarkan tekanan dalam :



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$$\begin{aligned}
 P_{\text{design}} &= P_{\text{gauge}} + P_{\text{hidrostatik}} \\
 P_{\text{design}} &= (P_i - P_o) + P_{\text{hidrostatik}} \\
 P_{\text{design}} &= (14,7 - 14,7) + P_{\text{hidrostatik}} \\
 P_{\text{design}} &= P_{\text{hidrostatik}} \\
 P_{\text{design}} &= \rho \times \frac{g}{g_c} \times H_{\text{liq}} \\
 &= 86,0199 \frac{\text{lb}}{\text{cuft}} \times 1 \frac{\text{lbf}}{\text{lbm}} \times 18,8106 \text{ ft} \\
 &= 1618,0888 \frac{\text{lbf}}{\text{ft}^2} \\
 &= 11,236728 \text{ psi}
 \end{aligned}$$

Asumsi P_{design} 10% lebih besar untuk faktor keamanan

$$\begin{aligned}
 P_{\text{design}} &= 1,1 \times 11,2367 \text{ Psi} \\
 &= 12,3604 \text{ Psi}
 \end{aligned}$$

e. Menentukan tebal shell minimum

Tebal shell berdasarkan ASME code untuk cylindrical tank:

$$t_s = \frac{P_d \times r_i}{f_e - 0,6 P_d} \quad (\text{Brownell Eq. 13.1})$$

dengan

t_s = tebal shell minimum (in)

P = tekanan tangki (Psi) = 12,3604 Psi

r_i = jari-jari tangki (in) = 70,5405 in

C = Faktor korosi (in); digunakan = 1/8 in

e = Faktor pengelasan; digunakan double welded = 0,8

(Brownell, Table 13.2)

f = stress allowable bahan konstruksi SB-575

= 98300 Psi **(ASMEBPVC.II.D.C-2017)**

sehingga,

Asumsi tebal shell = 3/8 in

$$t_s = \frac{P \times r_i}{f_e - 0,6 P} + C$$

$$t_s = \frac{12,3604 \times 70,5405}{78640 - 7,41624} + 1/8$$

$$t_s = \frac{871,90829}{78632,584} + 0$$



$$t_s = 0,13609$$

f hitung lebih kecil dari f allowable, jadi tebal shell 1/8 in dapat digunakan

f. Menentukan Tebal Tutup Atas

Tutup atas dipilih Torispherical dish head

$$\begin{aligned} OD &= ID + 2 t_s \\ &= 141,081 + 2 \times 1/8 \\ &= 141,081 + 0,27218 \\ &= 141,081 \text{ in} \end{aligned}$$

Berdasarkan Brownell and Young, Tabel 5.7 dari data OD, diperoleh:

$$\begin{aligned} OD &= 144 \text{ in} \\ icr &= 8 \frac{3}{4} \text{ in} \\ rc &= 132 \text{ in} \end{aligned}$$

Cek nilai icr dengan nilai 6%rc

$$\begin{aligned} icr &= 8,75 \text{ in} \\ 6\% rc &= 7,92 \text{ in} \end{aligned}$$

Karena nilai icr tabel > nilai 6%rc, maka digunakan persamaan:

$$t_h = \frac{P \times rc \times W}{2 f e - 0,2P} + C \quad \text{(Brownell Eq. 7.77)}$$

$$W = \frac{1}{4} \times \left(3 + \frac{\sqrt{rc}}{rl} \right) \quad \text{(Brownell Eq. 7.76)}$$

dengan

$$P_d = \text{Tekanan design (Psi)} = 12,4 \text{ Psi}$$

$$rc = \text{Crown radius} = \text{jari-jari dalam (in)} = 132 \text{ in}$$

$$r_i/i = \text{Inside crown radius (in)} = 70,5405$$

$$E = \text{Faktor pengelasan} = 0,8$$

$$t = \text{Tebal dinding minimal (in)}$$

$$f = \text{Stress allowable bahan SB-575}$$

$$= 98300 \text{ Psi} \quad \text{(ASMEBPVC.II.D.C-2017)}$$

$$C = \text{Faktor korosi (in)} = 1/8$$

Sehingga,

$$\begin{aligned} W &= \frac{1}{4} \times \left(3 + \frac{\sqrt{r}}{rl} \right) \\ &= \frac{1}{4} \times \left(3 + \frac{11,5}{70,5} \right) \\ &= 0,79072 \end{aligned}$$



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$$\begin{aligned} \text{Asumsi tebal tutup} &= 3/16 \text{ in} \\ t_h &= \frac{P \times r_c \times W}{2 f_e - 0,2P} + C \\ 3/16 &= \frac{12,4 \times 132 \times 0,79}{1,6 f - 0,2 \times 12,4} + 1/8 \\ 1/16 &= \frac{1290,114383}{1,6 f - 2,4720801} \\ 0,1 f - 0,154505 &= 1290,114383 \\ 0,1 f &= 1290,268888 \\ f &= 12902,68888 \end{aligned}$$

f hitung lebih kecil dari f allowable, jadi tebal shell 3/16 in dapat digunakan

g. Menentukan Tinggi Tutup Tangki

$$sf = 2 \text{ in}$$

$$t = 2/8 \text{ in}$$

(Brownell, tabel 5.6, hal. 88)

Menghitung tinggi tutup

$$OA = b + sf + t$$

$$* 1 \text{ ft} = 0,3 \text{ m}$$

$$1 \text{ ft} = 12 \text{ in}$$

$$BC = r_c - i_{cr}$$

$$BC = 132 - 8 \frac{3}{4}$$

$$= 123,250 \text{ in}$$

$$AB = \frac{1}{2} \times OD - i_{cr}$$

$$AB = \frac{1}{2} \times 144 - 7,92$$

$$= 64,080 \text{ in}$$

$$b = r_c - (BC^2 - AB^2)^{0,5}$$

$$b = 132 - (15191 - 4106)^{0,5}$$

$$= 26,718$$

Tinggi tutup atas



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$$\begin{aligned} \text{OA} &= b + sf + t \\ &= 28,905 \text{ in} \\ &= 0,7342 \text{ m} \\ &= 2,4088 \text{ ft} \end{aligned}$$

h. Menentukan Tebal Tutup Bawah (Flatted Bottom)

Tebal tutup bawah datar karena menumpang di atas pondasi

Untuk flatted bottom, digunakan tebal tutup bawah $\frac{1}{4}$ in
(Brownell, Hal. 58)

Spesifikasi

Nama alat : Tangki Penyimpanan Natrium Sulfat
Kode : F-420
Fungsi : Menyimpan bahan baku Natrium Sulfat
Bentuk : Tangki berupa silinder tegak dengan tutup atas
Torispherical dish head dan tutup bawah plate
Bahan konstruksi : SB-575
Jumlah : 1 buah

Kondisi Operasi

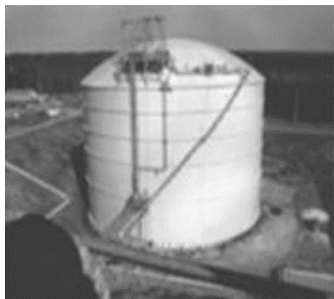
Suhu : 30 °C
Tekanan : 1 atm
waktu : 7 hari

Dimensi Tangki

Diameter tangki : 11,7567 ft = 3,58345 m
Tinggi tangki : 23,5135 ft = 7,16691 m
Kapasitas tangki : 2551,37
Tebal shell : $\frac{1}{8}$ in
Tebal Tutup Atas : $\frac{1}{4}$ in
Tinggi Tutup Atas : 2,40879 ft = 0,7342 m
Tebal Tutup Bawah : $\frac{1}{4}$ in



36. Tangki Penyimpanan Butil Oleat (F-410)



Fungsi : Menyimpan hasil produk Butil Oleat
Tipe : Tangki berbentuk silinder tegak, tutup atas berupa
Torispherical dish tutup bawah datar
Dasar Pemilihan : Sesuai untuk penyimpanan liquida pada tekanan atmosferik

Kondisi operasi :

Tekanan = 1 atm
suhu = 35 °C
Waktu tinggal = 7 hari

Komposisi Bahan Masuk

Komponen	massa (kg/jam)
$C_{17}H_{33}COOH$	0,038552561
C_4H_9OH	0,413317328
$C_{17}H_{33}COOC_4H_9$	4166,670808
$C_{15}H_{31}COOH$	35,1524996
Total	4202,275178

Rate Massa = 4202,2752 kg/jam
= 9264,4308 lb/jam

Menghitung Densitas Larutan

Komponen	A	B	Tc	n
$C_{17}H_{33}COOH$	0,2824	0,26812	781	0,2897
C_4H_9OH	0,26891	0,2667	562,93	0,2457
$C_{17}H_{33}COOC_4H_9$	0,2479	0,24	764	0,2857
$C_{15}H_{31}COOH$	0,2797	0,26805	776	0,2947



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$$T = 30 \text{ }^{\circ}\text{C} = 303,15 \text{ K}$$

$$\rho = A \times B^{-\left(1 - \frac{T}{T_c}\right)^n}$$

Sehingga diperoleh

$$\begin{aligned} \rho \text{ C}_{17}\text{H}_{33}\text{COOH} &= 0,8845005 \text{ gr/ml} \\ \rho \text{ C}_4\text{H}_9\text{OH} &= 0,8021585 \text{ gr/ml} \\ \rho \text{ C}_{17}\text{H}_{33}\text{COOC}_4\text{H}_9 &= 0,8525477 \text{ gr/ml} \\ \rho \text{ C}_{15}\text{H}_{31}\text{COOH} &= 0,8725909 \text{ gr/ml} \end{aligned}$$

Komponen	Massa	Fraksi Massa	Densitas	ρ Campuran
	(kg)		gr/ml	gr/ml
C ₁₇ H ₃₃ COOH	0,038552561	9,174E-06	0,8845005	8,115E-06
C ₄ H ₉ OH	0,413317328	9,836E-05	0,8021585	7,89E-05
C ₁₇ H ₃₃ COOC ₄ H ₉	4166,670808	0,9915274	0,8525477	0,8453244
C ₁₅ H ₃₁ COOH	35,1524996	0,0083651	0,8725909	0,0072993
Total	4202,275178	1		0,8527107

$$\begin{aligned} \rho \text{ Campuran} &= 0,8527107 \text{ gr/ml} \times 62,4 \\ &= 53,209147 \text{ lb/cuft} \end{aligned}$$

$$\begin{aligned} \text{Sg} &= \frac{\rho \text{ bahan}}{\rho \text{ reference (H}_2\text{O)}} \times \text{sg reference} \\ &= \frac{53,209147 \text{ lb/cuft}}{62,43 \text{ lb/cuft}} \times 1 \\ &= 0,8523009 \end{aligned}$$

$$\begin{aligned} \text{Rate volumetrik} &= \frac{\text{rate massa}}{\rho \text{ campuran}} \\ &= \frac{9264,4308 \text{ lb/jam}}{53,209147 \text{ lb/cuft}} \\ &= 174,1135 \text{ cuft/jam} \\ &= 4178,724 \text{ cuft/hari} \end{aligned}$$

a. Menentukan Volume Tangki

digunakan 3 buah tangki untuk penyimpanan 7 hari, maka



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$$\begin{aligned}\text{Volume liquid} &= 4178,72 \text{ cuft/hari} \times 7 \text{ hari} \\ &= 29251,1 \text{ cuft}\end{aligned}$$

Volume liquid tiap tangki adalah

$$\begin{aligned}\text{Volume liquid} &= \frac{29251,068}{5} \\ &= 5850,2136\end{aligned}$$

Asumsi volume liquid mengisi 80% volume tangki untuk faktor keamanan, sehingga :

$$\begin{aligned}\text{Volume tangki} &= \frac{\text{Volume cairan}}{80\%} \\ &= \frac{5850,213613}{80\%} \\ &= 7312,767 \text{ cuft}\end{aligned}$$

b. Menentukan Dimensi Tangki

$$\text{Asumsi Dimention ratio} : H/D = 2 - 5 \quad (\text{Ulrich : T.4-27})$$

$$\text{Asumsi rasio dimensi H/D} = 2$$

Volume tutup Torispherical dish head

$$\text{Volume tutup atas} = 0,000049 D^3 \quad (\text{Brownell Eq. 5.11})$$

$$\text{Volume tangki} = \frac{1}{4} \times \pi \times D^2 H + 0,000049 D^3$$

$$7312,767016 = 1,57 D^3$$

$$D^3 = 4657,67 \text{ ft}^3$$

$$D = 16,7002 \text{ ft}$$

$$= 5,09023 \text{ m}$$

$$= 200,403 \text{ in}$$

$$H = 2 \times D$$

$$= 2 \times 16,7002 \text{ ft}$$

$$= 33,4005 \text{ ft}$$

$$= 10,1805 \text{ m}$$

$$= 400,806 \text{ in}$$

c. Menentukan tinggi cairan dalam tangki penyimpanan

$$\text{Volume liquid} = \frac{1}{4} \times \pi \times D^2 H + 0,000049 D^3$$



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$$\begin{aligned}5850,2136 &= 218,935 \text{ H} + 0,2282257 \\5849,9854 &= 218,935 \text{ H} \\ \text{H} &= 26,7202 \text{ ft} \\ &= 8,14431 \text{ m} \\ &= 320,642 \text{ in}\end{aligned}$$

d. Menentukan Tekanan design

Jika dalam bejana terdapat liquid, maka bejana dirancang berdasarkan tekanan dalam :

$$\begin{aligned}P \text{ design} &= P \text{ gauge} + P \text{ hidrostatik} \\P \text{ design} &= (P_i - P_o) + P \text{ hidrostatik} \\P \text{ design} &= (14,7 - 14,7) + P \text{ hidrostatik} \\P \text{ design} &= P \text{ hidrostatik} \\P \text{ design} &= \rho \times \frac{g}{g_c} \times H \text{ liq} \\ &= 53,2091 \frac{\text{lb}}{\text{cuft}} \times 1 \frac{\text{lbf}}{\text{lbm}} \times 26,7202 \text{ ft} \\ &= 1421,7582 \frac{\text{lbf}}{\text{ft}^2} \\ &= 9,8733207 \text{ psi}\end{aligned}$$

Asumsi P design 10% lebih besar untuk faktor keamanan

$$\begin{aligned}P \text{ design} &= 1,1 \times 9,87332 \text{ Psi} \\ &= 10,8607 \text{ Psi}\end{aligned}$$

e. Menentukan tebal shell minimum

Tebal shell berdasarkan ASME code untuk cylindrical tank:

$$t_s = \frac{P_d \times r_i + C}{f e - 0,6 P_d} \quad \text{(Brownell Eq. 13.1)}$$

dengan

$$t_s = \text{tebal shell minimum (in)}$$

$$P = \text{tekanan tangki (Psi)} = 10,8607 \text{ Psi}$$

$$r_i = \text{jari-jari tangki (in)} = 100,202 \text{ in}$$

$$C = \text{Faktor korosi (in); digunakan} = 1/8 \text{ in}$$

$$e = \text{Faktor pengelasan; digunakan double welded} = 0,8$$

(Brownell, Table 13.2)

$$\begin{aligned}f &= \text{stress allowable bahan konstruksi Carbon Steel SA-283 Grade A} \\ &= 10350 \text{ Psi} \quad \text{(Brownell, hal.342)}\end{aligned}$$



sehingga,

Asumsi tebal shell = 3/8 in

$$t_s = \frac{P \times r_i}{f_e - 0,6 P} + C$$

$$6/16 = \frac{10,8607 \times 100,202}{0,8 f - 6,51639} + 1/8$$

$$4/16 = \frac{10,8607 \times 100,202}{0,8 f - 6,5163916}$$

$$0,2 f - 1,6291 = 1088,254$$

$$0,2 f = 1089,8831$$

$$f = 5449,4153$$

f hitung lebih kecil dari f allowable, jadi tebal shell 3/8 in dapat digunakan

f. Menentukan Tebal Tutup Atas

Tutup atas dipilih Torispherical dish head

$$OD = ID + 2 t_s$$

$$= 200,403 + 2 \times 3/8$$

$$= 200,403 + 0,75$$

$$= 200,403 \text{ in}$$

Berdasarkan Brownell and Young, Tabel 5.7 dari data OD, diperoleh:

$$OD = 204$$

$$i_{cr} = 12 \frac{4}{16} \text{ in}$$

$$r_c = 170 \text{ in}$$

Cek nilai i_{cr} dengan nilai 6% r_c

$$i_{cr} = 12,25 \text{ in}$$

$$6\% r_c = 10,2 \text{ in}$$

Karena nilai i_{cr} tabel > nilai 6% r_c , maka digunakan persamaan:

$$t_h = \frac{P \times r_c \times W}{2 f_e - 0,2 P} + C \quad \text{(Brownell Eq. 7.77)}$$

$$W = \frac{1}{4} \times \left(3 + \sqrt{\frac{r_c}{r_l}} \right) \quad \text{(Brownell Eq. 7.76)}$$

dengan

$$P_d = \text{Tekanan design (Psi)} = 10,9 \text{ Psi}$$

$$r_c = \text{Crown radius} = \text{jari-jari dalam (in)} = 170 \text{ in}$$

$$r_l/i = \text{Inside crown radius (in)} = 100,202$$



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$$E = \text{Faktor pengelasan} = 0,8$$

$$t = \text{Tebal dinding minimal (in)}$$

$$f = \text{Stress allowable bahan Carbon Steel SA-283 grade A} \\ = 10850 \text{ Psi} \quad (\text{Brownell hal. 342})$$

$$C = \text{Faktor korosi (in)} = 1/8$$

Sehingga,

$$W = \frac{1}{4} \times \left(3 + \frac{\sqrt{r}}{rl} \right) \\ = \frac{1}{4} \times \left(3 + \frac{13}{100} \right) \\ = 0,78253$$

$$\text{Asumsi tebal tutup} = 1/4 \text{ in}$$

$$t_h = \frac{P \times r_c \times W}{2 f_e - 0,2P} + C$$

$$4/16 = \frac{10,9 \times 170 \times 0,78 + 1/8}{1,6 f - 0,2 \times 10,9}$$

$$2/16 = \frac{1444,794558}{1,6 f - 2,1721305}$$

$$0,2 f - 0,2715163 = 1444,794558$$

$$0,2 f = 1445,066075$$

$$f = 7225,330373$$

f hitung lebih kecil dari f allowable, jadi tebal shell 1/4 in dapat digunakan

g. Menentukan Tinggi Tutup Tangki

$$sf = 2 \text{ in}$$

$$t = 2/8 \text{ in}$$

(Brownell, tabel 5.6, hal. 88)

Menghitung tinggi tutup

$$OA = b + sf + t$$

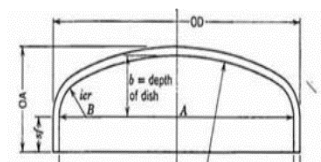
$$* 1 \text{ ft} = 0,3 \text{ m}$$

$$1 \text{ ft} = 12 \text{ in}$$

$$BC = rc - icr$$

$$BC = 170 - 12,25 \\ = 157,750 \text{ in}$$

$$AB = \frac{1}{2} \times OD - icr$$





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$$\begin{aligned} AB &= \frac{1}{2} \times 204 - 12,3 \\ &= 89,750 \text{ in} \end{aligned}$$

$$b = rc - (BC^2 - AB^2)^{0,5}$$

$$\begin{aligned} b &= 170 - (24885 - 8055)^{0,5} \\ &= 40,270 \end{aligned}$$

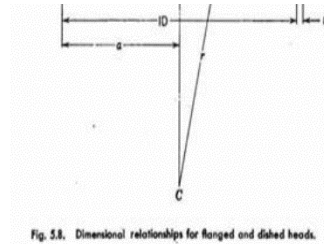


Fig. 5.8. Dimensional relationships for flanged and dished heads.

Tinggi tutup atas

$$\begin{aligned} OA &= b + sf + t \\ &= 42,520 \text{ in} \\ &= 1,0800 \text{ m} \\ &= 3,5433 \text{ ft} \end{aligned}$$

h. Menentukan Tebal Tutup Bawah (Flatted Bottom)

Tebal tutup bawah datar karena menumpang di atas pondasi

Untuk flatted bottom, digunakan tebal tutup bawah $\frac{4}{16}$ in
(Brownell, Hal. 58)

Spesifikasi

Nama alat : Tangki Penyimpanan Butil Oleat
Kode : F-410
Fungsi : Menyimpan Produk Butil Oleat
Bentuk : Tangki berupa silinder tegak dengan tutup atas
Torispherical dish head dan tutup bawah plate

Bahan konstruksi : Carbon steel SA-283 Grade A

Jumlah : 5 buah

Kondisi Operasi

Suhu : 30 °C

Tekanan : 1 atm

waktu : 7 hari

Dimensi Tangki

Diameter tangki = 16,7002 ft = 5,09023 m

Tinggi tangki = 33,4005 ft = 10,1805 m

Volume Tangki = 7312,77 cuft

Tebal shell = $\frac{3}{8}$ in



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Tebal Tutup Atas = 1/4 in

Tinggi Tutup Atas = 3,54329 ft = 1,0800 m

Tebal Tutup Bawah = 1/4 in



APPENDIX D ANALISA EKONOMI

Kapasitas produksi = 33000 ton/tahun
= 100 ton/hari
= 4166,666667 kg/jam

Waktu operasi = 330 hari/tahun
= 24 jam/hari

Dengan bahan baku :

Asam Oleat = 3862,594 kg/jam
Butanol = 5067,943 kg/jam
Asam Sulfat = 82,550 kg/jam

Menghasilkan produk

Butil Oleat = 4166,67 kg/jam
Natrium Sulfat = 119,6133 kg/jam

Faktor-Faktor yang perlu untuk ditinjau antara lain :

1. Laju pengembalian modal (*Rate of Return*)
2. Lama pengembalian modal (*Pay Back Periode*)
3. Titik impas (*Break Event Point*)

Untuk meninjau faktor-faktor diatas, perlu adanya penaksiran terhadap beberapa beberapa faktor, yaitu :

1. Penaksiran modal industri (*Total Capital Investment*) yang terdiri atas :
 - a. Modal Tetap (*Fixed Capital Investment*)
 - b. Modal Kerja (*Working Capital Investment*)
2. Penentuan biaya produksi total (*Production Cost*) yang terdiri atas :
 - a. Biaya Pembuatan (*Manufacturing Cost*)
 - b. Biaya Pengeluaran Umum (*General Expences*)
 - c. Total Pendapatan

1. HARGA PERALATAN

Harga peralatan berubah menurut waktu resmi sesuai dengan kondisi ekonomi dunia. Untuk memperkirakan harga peralatan saat ini, digunakan indeks seperti



pada persamaan sebagai berikut :

$$C_p = \frac{I_p}{I_o} \times C_o$$

dengan,

C_p = Harga alat pada tahun 2025

C_o = Harga alat pada tahun data 2022

I_p = Cost Index pada tahun 2025

I_o = Cost Index pada tahun data 2022

Perhitungan peralatan didasarkan pada Cost Equipment sedangkan Cost Indeks didasarkan pada Peters and Timmerhauss " Plant Design and Economic for Chemical Engineering ". Perhitungan Engineering berdasarkan Chemical Engineering Plant Cost Index (CEPCI), Chemical tabel D-1.

Tabel D.1 Indeks Harga Peralatan

Tahun	Indeks
2014	576,1
2015	556,8
2016	541,7
2017	567,5
2018	603,1
2019	607,5
2020	596,2
2021	761,4
2022	821,3
2023	797,9

Sumber : CEPCI Tahun 2022 Annual Index

Dengan metode least square dan data-data pada tabel di atas dilakukan pendekatan atau penafsiran indeks harga peralatan pada awal tahun dimana data-data :

Keterangan :

Y = Indeks harga peralatan pada tahun ke- n

X = Tahun ke- n



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n	X	Y	X ²	Y ²	XY
1	2014	576,1	4056196	331891,2	1160265
2	2015	556,8	4060225	310026,2	1121952
3	2016	541,7	4064256	293438,9	1092067
4	2017	567,5	4068289	322056,3	1144648
5	2018	603,1	4072324	363729,6	1217056
6	2019	607,5	4076361	369056,3	1226543
7	2020	596,2	4080400	355454,4	1204324
8	2021	761,4	4084441	579730	1538789
9	2022	821,3	4088484	674533,7	1660669
10	2023	797,9	4092529	636644,4	1614152
	20185	6429,5	40743505	4236561	12980464

Jumlah Data (n) = 10

Persamaan 17-21, Peters and Timmerhauss :

$$\sum (\bar{x} - x)^2 = \sum x^2 - \frac{(\sum x)^2}{n} = 82,50$$

$$\sum (\bar{y} - y)^2 = \sum y^2 - \frac{(\sum y)^2}{n} = 102713,93$$

Persamaan 20, Peters and Timmerhauss :

$$\sum (\bar{x} - x)(\bar{y} - y) = \sum xy - \frac{\sum x \sum y}{n} = 2518,35$$

$$b = \frac{\sum (\bar{x} - x)(\bar{y} - y)}{\sum (\bar{x} - x)^2} = 30,5255$$

$$\sum y / n = a = 642,95$$

$$\sum x / n = c = 2019$$

$$\begin{aligned} y &= a + b (x - c) \\ &= 642,95 + [30,5255 (x - 2019)] \\ &= 30,5255 x - 60973 \end{aligned}$$

Dari persamaan di atas diperoleh indeks harga pada ta 2029 sebesar :

$$y = 30,52545 x - 60973$$

$$y = 963,4673$$

Kurs dollar pada tahun 2025

$$\text{\$1} = \text{Rp16.372,00} \quad (\text{www.kursdollar.org/diakses 22-08-2025})$$



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Indeks harga tahun 2029 = 963,47

Indeks harga tahun 2025 = 841,37

Dari (Peter & Timmerhauss hal 164) :

$$\text{Harga Pada Tahun 2029} = \frac{\text{Indeks harga th 2029}}{\text{Indeks harga th 2025}} \times \text{Harga Alat pada th 2025}$$

Tabel D.2 Hasil Perhitungan Harga Peralatan Proses

No	Kode	Nama Alat	Harga per unit (\$)		Jumlah	Harga total US \$
			2025	2029		
1	F-110	Tangki Penyimpanan Natrium Hidroksida	3000	3435,37	1	3435,37
2	L-111	Pompa-1	4000	4580,494	1	4580,5
3	F-120	Tangki Penyimpanan Asam Sulfat	3000	3435,37	1	3435,4
4	L-121	Pompa 2	4000	4580,494	1	4580,49
5	E-122	Heater-1	2800	3206,346	1	3206,35
6	F-130	Tangki Penyimpanan Butanol	3000	3435,37	5	17176,85
7	L-131	Pompa-3	4000	4580,494	1	4580,49
8	E-133	Heater-2	2800	3206,346	1	3206,35
9	F-140	Tangki Penyimpanan Asam Oleat	3000	3435,37	5	17176,85
10	L-141	Pompa-4	4000	4580,494	1	4580,49
11	E-143	Heater-3	2800	3206,346	1	3206,35
12	R-120	Reaktor	29900	34239,19	1	34239,19
13	L-211	Pompa-5	4000	4580,494	1	4580,49
14	E-212	Cooler-1	2800	3206,346	1	3206,35
15	N-220	Netralizer	29900	34239,19	1	34239,2
16	L-221	Pompa-6	4000	4580,494	1	4580,49
17	H-230	Dekanter	30000	34353,7	1	34353,70
18	L-231	Pompa-7	4000	4580,494	1	4580,49
19	E-232	Heater-4	2800	3206,346	1	3206,35
20	L-233	Pompa-7	2000	2290,247	1	2290,25
21	D-310	Menara Distilasi -1	40000	45804,94	1	45804,94
22	E-311	Kondensor-1	2800	3206,346	1	3206,346
23	F-312	Accumulator-1	10000	11451,23	1	11451,23



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24	L-313	Pompa-8	4000	4580,494	1	4580,494
25	E-314	Cooler-3	2800	3206,346	1	3206,346
26	E-314	Reboiler-1	1000	1145,123	1	1145,123
27	L-316	Pompa-9	4000	4580,494	1	4580,494
28	D-320	Menara Distilasi -2	40000	45804,94	1	45804,94
29	E-321	Kondensor-2	2800	3206,346	1	3206,346
30	F-322	Accumulator-2	10000	11451,23	1	11451,23
31	L-323	Pompa-10	4000	4580,494	1	4580,494
32	E-324	Cooler-4	2800	3206,346	1	3206,346
33	E-325	Reboiler-2	1000	1145,123	1	1145,123
34	L-326	Pompa-11	4000	4580,494	1	4580,494
35	E-327	Cooler-3	2800	3206,346	1	3206,346
36	F-410	Tangki Penyimpanan Butil Oleat	3000	3435,37	5	17176,85
37	F-420	Tangki Penyimpanan Natrium Sulfat	3000	3435,37	1	3435,37
Total					366210,46	

Tabel D.3 Hasil Perhitungan Harga Peralatan Utilitas

No	Nama Alat	Harga per unit (\$)		Jml	Harga total
		2025	2029		US \$
1	Cooling Tower	5000	5726	1	5726
2	Boiler	7700	8817	1	8817
3	Pompa air sungai	1800	2061	1	2061
4	Bak penampung air sungai	150	172	5	859
5	Pompa tangki koagulasi	1800	2061	1	2061
6	Tangki koagulasi	485,7	556	1	556
7	Pompa tangki Flokulasi	1800	2061	1	2061
8	Tangki Flokulasi	485,7	556	1	556
9	Pompa clarifier	1800	2061	1	2061
10	Clarifier	13000	14887	1	14887
11	Bak penampung flok	143	164	1	164
12	Bak air dari clarifier	143	164	1	164
13	Pompa e sand filter	1800	2061	1	2061
14	Sand filter	3002	3438	2	6875
15	Bak penampung air bersih	143	164	1	164
16	Pompa ke air sanitasi	1800	2061	1	2061



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17	Bak penampung air Sanitasi	143	164	1	164
18	Pompa kation exchanger	1800	2061	1	2061
19	Kation exchanger	2000	2290,247	1	2290,247
20	Pompa anion exchanger	1800	2061	1	2061
21	Anion exchanger	2000	2290,247	1	2290,247
22	Pompa air demineral ke boiler	1800	2061	1	2061
23	Bak air demineralisasi	143	164	1	164
24	Pompa dowerm ke plant	1800	2061,222	1	2061,222
25	Cooler	2800	3206,346	1	3206,346
26	Pompa CT ke bak air pendingin	1800	2061,222	1	2061
27	Pompa air pendingin ke CT	1800	2061,222	1	2061,222
28	Pompa dowerm	1800	2061,222	1	2061,222
29	Pompa air pendingin ke plant	1800	2061,222	1	2061,222
30	Pompa recycle air pendingin	1800	2061	1	2061
31	Bak Penampung Air Pendingin	143	164	1	164
32	Tangki bahan bakar genset	3000	3435	1	3435
33	Generator Set	4500	5153	1	5153
Total					80827

Total harga peralatan = Harga peralatan proses + harga peralatan utilitas
= \$366.210,46 + \$80.826,70
= \$447.037,17
= **Rp7.318.892.507,94**

II. Harga Bahan Baku

1. Asam Oleat

Jumlah kebutuhan = 3862,5944 kg/jam = 3,8626 ton/jam
Harga asam oleat = \$6,30 / kg
Biaya pertahun = Rp103.113,78 x 3862,594 x 24 x 330
= Rp3.154.430.761.627,10 /kg/tahun
(PT.Sinarmas)

2. Butanol

Jumlah kebutuhan = 5067,9430 kg/jam = 5,0679 ton/jam
Harga butanol = \$0,80 / kg
Rp 13.123,6 / kg



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$$\begin{aligned}\text{Biaya pertahun} &= \text{Rp}13.123,57 \times 5067,943 \times 24 \times 330 \\ &= \text{Rp}526.755.362.515,42 \quad / \text{kg/tahun} \\ &\quad \text{(PT.Petro Oxo Nusantara)}\end{aligned}$$

3. Asam Sulfat

$$\begin{aligned}\text{Jumlah kebutuhan} &= 82,5500 \quad \text{kg/jam} = 0,0826 \quad \text{ton/jam} \\ \text{Harga H}_2\text{SO}_4 &= \$0,46 \quad / \text{kg} \\ &\quad \text{Rp} \quad 7.499,2 \quad / \text{kg} \\ \text{Biaya pertahun} &= \text{Rp}7.499,18 \times 82,5500 \times 24 \times 330 \\ &= \text{Rp}4.902.937.682,26 \quad / \text{kg/tahun} \\ &\quad \text{(PT.Petrokimia Gresik)}\end{aligned}$$

4. Natrium Hidroksida

$$\begin{aligned}\text{Jumlah kebutuhan} &= 67,3878 \quad \text{kg/jam} = 0,0674 \quad \text{ton/jam} \\ \text{Harga NaOH} &= \$0,44 \quad / \text{kg} \\ &\quad \text{Rp} \quad 7.124,2 \quad / \text{kg} \\ \text{Biaya pertahun} &= \text{Rp}7.124,22 \times 67,3878 \times 24 \times 330 \\ &= \text{Rp}3.802.278.202,57 \quad / \text{kg/tahun} \\ &\quad \text{(PT.Asahimas Chemical)}\end{aligned}$$

$$\text{Total biaya bahan baku} = \text{Rp}3.689.891.340.027$$

III. Harga Jual Produk

1. Harga Jual Produk Utama (Butil Oleat)

$$\begin{aligned}\text{Hasil Produksi} &= 4166,6708 \quad \text{Kg/Jam} \\ \text{Harga jual pabrik} &= \$ \quad 12,6 \quad / \text{kg} \quad \text{(Alibaba.com)} \\ \text{Harga jual pabrik} &= \text{Rp} \quad 206.227,56 \quad / \text{kg} \\ &= \text{Rp} \quad 206.227,56 \times 4166,671 \times 24 \times 330 \\ \text{Harga per tahun} &= \text{Rp} \quad 6.805.516.375.188,28\end{aligned}$$

$$\text{Total Penjualan Per Tahun} = \text{Rp}6.805.516.375.188$$

2. Harga Jual Produk Samping (Natrium Sulfat)

$$\begin{aligned}\text{Hasil Produksi} &= 119,6133 \quad \text{kg/Jam} = 0,1196 \quad \text{ton} \\ \text{Harga jual pabrik} &= \$ \quad 0,69 \quad / \text{kg} \quad \text{(Alibaba.com)} \\ \text{Harga jual pabrik} &= \text{Rp} \quad 11.248,78 \quad / \text{kg}\end{aligned}$$



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$$\begin{aligned}\text{Harga per tahun} &= \text{Rp } 11.248,78 \times 119,613 \times 24 \times 330 \\ &= \text{Rp } 10.656.384.962,46\end{aligned}$$

$$\text{Total Penjualan Per Tahun} = \text{Rp}10.656.384.962$$

$$\text{Total Penjualan Per Tahun} = \text{Rp}6.816.172.760.151$$

IV. Biaya Pengemasan Produk

$$\text{Produk yang dihasilkan Butil Oleat} = 33.000.033 \text{ kg/tahun}$$

$$\text{Produk dikemas dalam drum} = 25 \text{ liter}$$

$$= 28,409 \text{ kg}$$

$$\text{Kebutuhan drum per tahun} = 1.161.601 \text{ buah/tahun}$$

$$\text{Harga drum} = \$ 1,3 / \text{pcs (Alibaba.com)}$$

$$= \text{Rp}21.284 / \text{pcs}$$

$$\text{Biaya pengemasan per tahun} = \text{Rp}24.723.054.335,65$$

$$\text{Biaya pendukung (10% pengemasan)} = \text{Rp}2.472.305.433,56$$

$$\text{Total Biaya Pengemasan Per Tahun} = \text{Rp}27.195.359.769,21$$

Produk yang dihasilkan natrium sulfat

$$= 947.337 \text{ kg/tahun}$$

$$\text{Produk dikemas dalam drum} = 25 \text{ liter}$$

$$= 9,3985 \text{ kg}$$

$$\text{Kebutuhan drum per tahun} = 100.797 \text{ buah/tahun}$$

$$\text{Harga drum} = \$2,9 / \text{pcs (Alibaba.com)}$$

$$= \text{Rp}47.479 / \text{pcs}$$

$$\text{Biaya pengemasan per tahun} = \text{Rp}4.785.705.678,16$$

$$\text{Biaya pendukung (10% pengemasan)} = \text{Rp}478.570.567,82$$

$$\text{Total Biaya Pengemasan Per Tahun} = \text{Rp}5.264.276.245,98$$

$$\text{Total Biaya Pengemasan Per Tahun} = \text{Rp}32.459.636.015,19$$

Modal Kerja (*Working Capital Investment*)

V. Gaji Karyawan

No	Jabatan	Gaji/orang/bulan	Jumlah	Gaji/bulan
1	Direktur Utama	Rp 50.000.000	1	Rp 50.000.000
2	Direktur Produksi & Teknik	Rp 40.000.000	1	Rp 40.000.000



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3	Direktur Keuangan & Administrasi	Rp 40.000.000	1	Rp 40.000.000
4	Sekretaris Direktur	Rp 13.000.000	1	Rp 13.000.000
5	Staff Ahli	Rp 15.000.000	5	Rp 75.000.000
6	Kepala Bagian Produksi	Rp 12.000.000	1	Rp 12.000.000
7	Kepala Bagian Teknik	Rp 12.000.000	1	Rp 12.000.000
8	Kepala Bagian Pemasaran	Rp 12.000.000	1	Rp 12.000.000
9	Kepala Bagian Umum	Rp 12.000.000	1	Rp 12.000.000
10	Kepala Bagian Keuangan	Rp 12.000.000	1	Rp 12.000.000
11	Kasi Proses	Rp 8.000.000	1	Rp 8.000.000
12	Kasi Riset & Pengembangan	Rp 8.000.000	1	Rp 8.000.000
13	Kasi Utilitas & Energi	Rp 8.000.000	1	Rp 8.000.000
14	Kasi Pemeliharaan & Perbaikan	Rp 8.000.000	1	Rp 8.000.000
15	Kasi Anggaran	Rp 8.000.000	1	Rp 8.000.000
16	Kasi Pembelian	Rp 8.000.000	1	Rp 8.000.000
17	Kasi Gudang	Rp 8.000.000	1	Rp 8.000.000
18	Kasi Pemasaran & Penjualan	Rp 8.000.000	1	Rp 8.000.000
19	Kasi Administrasi	Rp 8.000.000	1	Rp 8.000.000
20	Kasi Personalia & Kesejahteraan	Rp 8.000.000	1	Rp 8.000.000
21	Kasi Keamanan	Rp 8.000.000	1	Rp 8.000.000
22	Karyawan Bagian Proses(Kepala)	Rp 8.000.000	3	Rp 24.000.000
23	Karyawan Bagian Proses(Regu)	Rp 6.500.000	104	Rp 676.938.238
24	Karyawan Bagian Laboratorium	Rp 5.200.000	3	Rp 15.600.000
25	Karyawan Bagian Utilitas	Rp 5.200.000	4	Rp 20.800.000
26	Karyawan Bagian Personalia	Rp 5.200.000	3	Rp 15.600.000
27	Karyawan Bagian Pemasaran	Rp 5.200.000	4	Rp 20.800.000
28	Karyawan Bagian Administrasi	Rp 5.200.000	2	Rp 10.400.000
29	Karyawan Bagian Pembelian	Rp 5.200.000	3	Rp 15.600.000



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30	Karyawan Bagian Pemelih	Rp 5.200.000	3	Rp 15.600.000
31	Karyawan Bagian Gudang	Rp 5.200.000	2	Rp 10.400.000
32	Karyawan Bagian Kebersih	Rp 5.200.000	3	Rp 15.600.000
33	Dokter	Rp 6.000.000	1	Rp 6.000.000
34	Perawat	Rp 5.500.000	2	Rp 11.000.000
35	Supir	Rp 5.200.000	4	Rp 20.800.000
36	Satpam	Rp 5.200.000	2	Rp 10.400.000
Total			168	Rp 1.255.538.238

Gaji per bulan = Rp 1.255.538.238

Gaji per tahun = Rp 18.833.073.567

VI. Kebutuhan Utilitas

A. Kebutuhan air

1. Air Sanitasi

Kebutuhan air tiap hari = 42,0532 m³/hari

Harga air = Rp1.000 m³/hari

Biaya air tiap hari = 42,0532 x Rp1.000
= Rp42.053,20 / hari

Biaya pengolahan per tahun = Rp13.877.554,81

2. Air Umpan Boiler

Kebutuhan air tiap hari = 138,9949 m³/hari

Harga air = Rp1.000 m³/hari

Biaya air tiap hari = 138,9949 x Rp1.000
= Rp138.994,92 / hari

Biaya pengolahan per tahun = Rp45.868.323,74

3. Air Pendingin

Kebutuhan air tiap hari = 1914,231932 m³/hari

Harga air = Rp1.000 m³/hari

Biaya air tiap hari = 1914,2319 x Rp1.000
= Rp1.914.231,93 / hari

Biaya pengolahan per tahun = Rp20.964.437.562,57



B. Kebutuhan Penunjang Pengolahan Air

- 1 Kebutuhan $\text{Al}_2(\text{SO}_4)_3$ = 34505,4744 kg/tahun
Harga $\text{Al}_2(\text{SO}_4)_3$ = Rp2.748,30 / kg (Alibaba.com)
Biaya tawas per tahun = Rp94.831.263,14
- 2 Kebutuhan PAC = 5175,8212 kg/tahun
Harga PAC = Rp2.290,25 / kg (Alibaba.com)
Biaya PAC per tahun = Rp11.853.907,89
3. Kebutuhan Resin Kation = 153092,642 L/tahun
Harga resin dowex = Rp 14.527 /liter (Alibaba.com)
Biaya resin dowex per tahun = Rp 2.223.976.804
4. Kebutuhan resin anion = 102265,9 L/tahun
Harga resin dowex = Rp14.527 /liter (Alibaba.com)
Biaya resin dowex per tahun = Rp1.485.616.504,94
5. Kebutuhan dowtherm = 34000,26 kg/jam
Harga dowtherm = Rp23.669 /kg (Alibaba.com)
Biaya dowtherm pertahun = Rp804.742.253,70
6. Kebutuhan HCl 33% = 32125,21 L/tahun
Harga HCl = Rp5.068,00 /liter (Alibaba.com)
Biaya HCl per tahun = Rp162.810.570,77
7. Kebutuhan NaOH 40% = 3569,389 L/tahun
Harga NaOH = Rp1.689 /liter (Alibaba.com)
Biaya NaOH per tahun = Rp6.028.699

**Total kebutuhan penunjang
pengolahan air tiap tahun = Rp4.789.860.003,06**

C. Bahan Bakar

1 Diesel Oil

- Kebutuhan bahan bakar tiap har = 3.563.458,7040 L/tahun
Harga bahan bakar/liter = Rp15.974,47 / L



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(www.liputan6.com)

Biaya bahan bakar tiap tahun = Rp56.924.369.423,38

Total bahan bakar tiap tahun = Rp56.924.369.423,38

D. Listrik

Kebutuhan listrik = 400,3448 kWh/hari

Biaya listrik per kWh = Rp 1.141 (www.detik.com)

Biaya listrik tiap tahun = Rp150.793.379,30

VII. Luas Tanah dan Bangunan

Luas Tanah = 53764 m²

Harga tanah/m² = Rp4.924.030,63 (rumah123.com)

Total harga tanah = Rp264.735.583.016,35

Luas bangunan pabrik = 27500 m²

Harga bangunan pabrik per m² = Rp8.015.863,82 (rumah123.com)

Total harga bangunan pabrik = Rp220.436.255.135,05

Luas bangunan gedung = 4657 m²

Harga bangunan gedung = Rp10.306.110,63 (rumah123.com)

Total harga bangunan gedung = Rp47.995.557.202,47

Total harga bangunan = Rp268.431.812.337,52

Total harga tanah dan bangunan = Rp533.167.395.353,87



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