APPENDIX A
NERACA MASSA

Kapasitas produk	=	30000	ton/tahun
	=	90909	kg/hari
	=	3787.9	kg/jam
Waktu operasi	=	330	hari/tahun
	=	24	jam/hari
Basis perhitungan	=	1445.3	kg/jam

Data Berat Molekul masing-masing Komponen

Komponen	BM (kg/kmol
$C_8H_4O_3$	148.0000
$C_8H_{18}O$	130.0000
H_2O	18.0000
$C_{16}H_{36}O_4Ti$	340.0000
$C_{24}H_{38}O_4$	390.0000
$C_8H_6O_4$	166.0000
NaOH	40.0000
Karbon Aktif	12.0000
$C_{16}H_{35}O_4TiNa$	362
$C_8H_4O_4Na_2$	210
C_6H_6	78
Na_2CO_3	106

1. Melter

Fungsi : Untuk melelehkan $C_8H_4O_3$ sebelum masuk ke reaktor

Komposisi Phthalic anhydride

Komposisi	Kadar
$C_8H_4O_3$	99.7%
$C_8H_6O_4$	0.2%
H_2O	0.1%

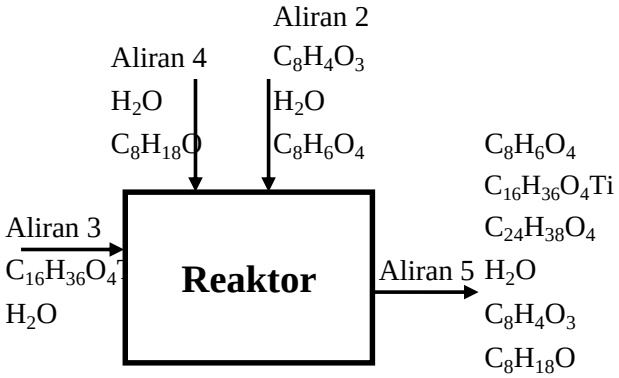
Kebutuhan phthalic anhydride

$C_8H_4O_3$ = 1449.7 x 99.7%
= 1445.3 Kg/Jam
$C_8H_6O_4$ = 1449.70 x 0.2%
= 2.8994 Kg/Jam
H_2O = 1449.70 x 0.1%
= 1.44970 Kg/Jam

NERACA MASSA MELTER			
Komponen Masuk		**Komponen Keluar**	
Phthalic Anhydride Dari Me		halic anhydride masuk reak	
Komponen	Massa (Kg/Jam	Komponen	Massa (Kg/Jam
$C_8H_4O_3$	1445.34966	$C_8H_4O_3$	1445.34966
$C_8H_6O_4$	2.89939751	$C_8H_6O_4$	2.89939751
H_2O	1.44970	H_2O	1.44969876
TOTAL	1449.69876	TOTAL	1449.69876

2. Reaktor

Fungsi : Tempat untuk mereaksikan $C_8H_4O_3$ dengan $C_8H_{18}O$ menggunakan katalis $C_{16}H_{36}O_4Ti$



Stokiometri

Konversi Rea = 99.8%

	$C_8H_4O_3$	+ $2C_8H_{18}O$	$C_{24}H_{38}O_4$	+ H_2O
m	9.7659	19.532	-	-
r	9.7463	19.4927	9.7463	9.7463
s	0.0195	0.0391	9.7463	9.7463

Kebutuhan Bahan Baku

1. Kebutuhan Phthalic Anhydride

Komponen	Massa (Kg/Jam
$C_8H_4O_3$	1445.34966
$C_8H_6O_4$	2.89939751
H_2O	1.44969876
TOTAL	1449.69876

2. Kebutuhan 2-Ethyl Hexanol

Komposisi	**Kadar**
$C_8H_{18}O$	99.5%
H_2O	0.5%

Massa C8H18O = 19.5318 kmol/Jar x 130.000
= 2539.1 Kg/Jam

Massa C8H18O + = $\frac{2539.1 \text{ Kg/Jam}}{99.5\%}$
= 2551.9 Kg/Jam

Massa H2O = 12.759 Kg/Jam

Komposisi	Massa (Kg/Jam
$C_8H_{18}O$	2539.12778
H_2O	12.7594361
Total	2551.88722

3. Kebutuhan Katalis

Komposisi	**Kadar**
$C_{16}H_{36}O_4Ti$	99.6%
H_2O	0.4%

Massa Katalis = Total Bahan I x 0.002%
C16H36O4Ti = 3984.47744 x 0.002%
= 0.05976716 Kg/Jam

massa C16H36O4Ti + = $\frac{0.05976716 \text{ Kg/Jam}}{99.6\%}$
= 0.06000719 Kg/Jam

massa H2O = 0.00024003 Kg/Jam

Komposisi	Massa (Kg/Jam
$C_{16}H_{36}O_4Ti$	0.05976716
H_2O	0.00024003
Total	0.06000719

Sisa Bahan Baku

1. Sisa Phthalic Anhydride
   Massa C_8H_4C = 2.89070 Kg/Jam

2. Sisa 2-Ethyl Hexanol
   Massa C8H1{ = 5.07826 Kg/Jam

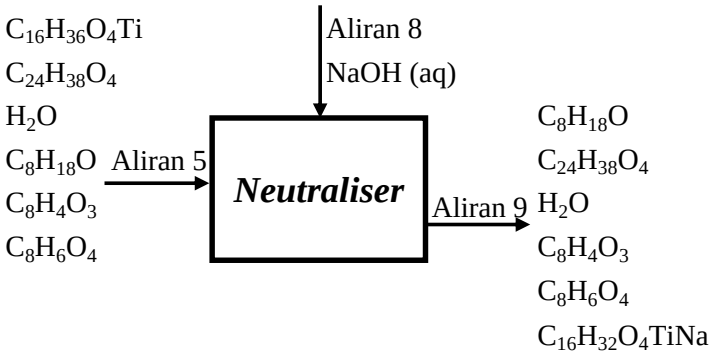
Produk Reaksi

Massa $C_{24}H_{38}O_4$ = 3801.07 Kg/Jam
Massa H2O = 175.43 Kg/Jam

NERACA MASSA REAKTOR			
Komponen Masuk		**Komponen Keluar**	
Phthalic Anhydride Dari Me		1. Produk Reaktor	
Komponen	Massa (Kg/Jam	Komponen	Massa (Kg/Jam
$C_8H_4O_3$	1445.34966	$C_8H_4O_3$	2.89069932
$C_8H_6O_4$	2.89939751	$C_8H_6O_4$	2.89939751
H_2O	1.44969876	$C_8H_{18}O$	5.07825556
Total	1449.69876	$C_{16}H_{36}O_4Ti$	0.05976716
		$C_{24}H_{38}O_4$	3801.07429
2. 2-Ethyl Hexanol		H_2O	189.643573
Komponen	Massa (Kg/Jam	Total	4001.64598
$C_8H_{18}O$	2539.12778		
H_2O	12.7594361		
Total	2551.88722		
3. Katalis			
Komponen	Massa (Kg/Jam		
$C_{16}H_{36}O_4Ti$	0.05976716		
H_2O	0.00024003		
Total	0.06000719		
TOTAL	4001.6460	TOTAL	4001.6460

3. Neutralizer

Fungsi : Untuk menetralkan katalis $C_{16}H_{36}O_4Ti$ menggunakan NaOH



Komponen Masuk

Komponen	Massa (Kg/Jam
$C_8H_4O_3$	##########
$C_8H_6O_4$	2.89939751
$C_8H_{18}O$	5.07825556
$C_{16}H_{36}O_4Ti$	0.05976716
$C_{24}H_{38}O_4$	3801.07429
Komponen	Massa (Kg/Jam
H_2O	189.643573
Total	4001.64598

Stokiometri Netrallizer

Reaksi 1

	$C_{16}H_{36}O_4Ti$	+ NaOH	$C_{16}H_{35}O_4TiNa$	+ H_2O
m	0.00017579	0.0002	-	-
r	0.00017579	0.0002	0.00017579	0
s	0	0	0.00017579	0

Kebutuhan Larutan NaOH 0.4%

Mol NaOH Total = 0.00017579 Kmol/Jam
Massa NaOH Tota = 0.00703143 Kg/Jam

Produk Terbentuk

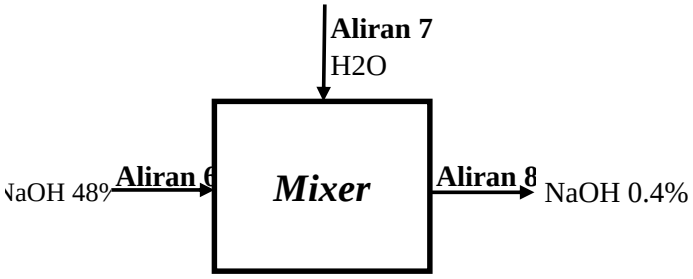
Massa $C_{16}H_{35}O_4T$ = 0.06363445 Kg/Jam
Massa H_2O RX 1 = 0.00316414 Kg/Jam

Massa H_2O Total = 0.00316414 Kg/Jam

NERACA MASSA NETRALLIZER			
Komponen Masuk		**Komponen Keluar**	
1. Produk Reaktor		1. Produk Netrallizer	
Komponen	Massa (Kg/Jam	Komponen	Massa (Kg/Jam
$C_8H_4O_3$	2.8906993	$C_8H_{18}O$	5.07825556
$C_8H_6O_4$	2.89939751	$C_{24}H_{38}O_4$	3801.07429
$C_8H_{18}O$	5.07825556	H_2O	189.646737
$C_{16}H_{36}O_4Ti$	0.05976716	$C_{16}H_{35}O_4TiNa$	0.063634
$C_{24}H_{38}O_4$	3801.07429	$C_8H_4O_3$	2.890699
H_2O	189.643573	$C_8H_6O_4$	2.89939751
Total	##########	Total	4001.65301
2. Larutan NaOH 0.4%			
Komponen	Massa (Kg/Jam		
$NaOH_{(aq)}$	0.00703143		
Total	0.00703143		
TOTAL	4001.65301	TOTAL	4001.65301

4. Tangki Pengenceran

Fungsi : Untuk mengencerkan NaOH 48% menjadi 0.4%



Kebutuhan NaOH Untuk Proses Netrallizer

Massa NaOH = 0.00703143 Kg/Jam

ρ Campuran = 2.13 Kg/L

Kebutuhan NaOH 48%

$$\frac{10 \times \% \times rho \times V1}{Mr} = \frac{10 \times \% \times rho \times V2}{Mr}$$

$$48\% \times V1 = 0.40\% \times V2$$

$$V1 = \frac{0.40\% \times V2}{48\%}$$

V1 = 2.751E-05 L/Jam
= 5.8595E-05 Kg/Jam
Kebutuhan H2O = 0.00697284 Kg/Jam

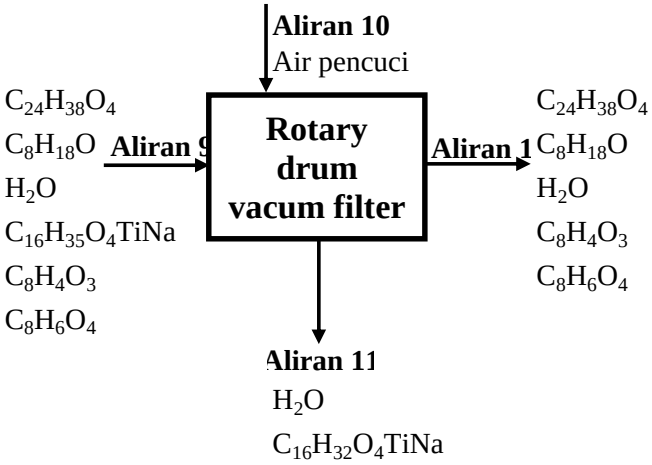
Kebutuhan H2O Untuk Pengenceran

Massa NaOH 0.4% = 0.00703143 Kg/Jam
Massa NaOH 48% = 5.8595E-05 Kg/Jam
Massa H2O = 0.00697284 Kg/Jam

NERACA MASSA TANGKI PENGENCERAN			
Komponen Masuk		**Komponen Keluar**	
1. NaOH 48%		1. NaOH 0.4%	
Komponen	Massa (Kg/Jam	Komponen	Massa (Kg/Jam
NaOH	2.8126E-05	$NaOH_{(aq)}$	0.00703143
H2O	3.047E-05	Total	0.00703143
Total	5.8595E-05		
2. Air Proses			
Komponen	Massa (Kg/Jam		
H2O	0.00697284		
Total	0.00697284		
Total	0.00703143	Total	0.00703143

5. Rotary Drum Vacum Filter

Fungsi : Untuk memisahkan slage dengan produk $C_{24}H_{38}O_4$



Kondisi operasi

Tekanan = 1 atm
Suhu Masuk = 95 ℃
Suhu Keluar = 95 ℃
Asumsi H_2O untuk pencuci = ##
Asumsi Liquid yang teriku = 2%

Aliran masuk dari Netralizer

Komponen	Massa (Kg/Jam
$C_8H_{18}O$	5.07825556
$C_{24}H_{38}O_4$	3801.07429
H_2O	189.646737
$C_{16}H_{35}O_4TiN$	0.06363445
$C_8H_4O_3$	##########
$C_8H_6O_4$	2.89939751
Total	4001.65301

Kebutuhan H_2O Pencucian

Air pencuci = ## x 4001.7 kg/jam
= 1400.6 kg/jam
Massa H_2O pencuci pada fi = ## x 1400.6 kg/jam
= 1372.6 kg/jam
Massa H_2O pencuci pada c = 2% x 1400.6 kg/jam
= 28.012 kg/jam

Asumsi komponen 98% padatan dan 2% mengand

Komponen	Massa (Kg/Jam)
$C_{16}H_{35}O_4TiN$	0.001298662
H_2O	0.001298662

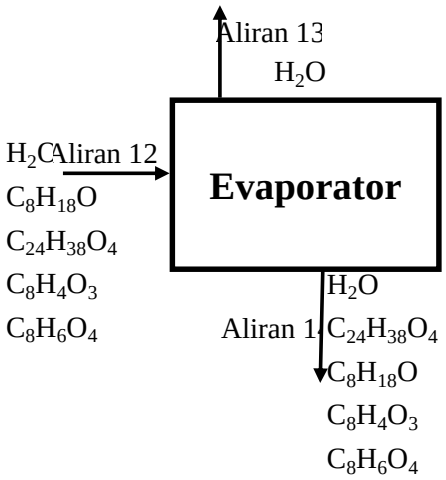
$C_{16}H_{35}O_4TiN$ = 0.06363445 kg/jam

H_2O = $\frac{2\%}{98\%}$ x 0 kg/jam
= 0.00129866 kg/jam

ERACA MASSA ROTARY DRUM VACUM FILTI			
Komponen Masuk		**Komponen Keluar**	
1. Produk Netralizer		roduk Rotary drum vacum f	
Komponen	Massa (Kg/Jam	Komponen	Massa (Kg/Jam
$C_8H_{18}O$	5.07825556	$C_8H_{18}O$	5.07825556
$C_{24}H_{38}O_4$	3801.07429	$C_{24}H_{38}O_4$	3801.07429
H_2O	189.646737	H_2O	1562.2124
$C_{16}H_{35}O_4TiN$	0.06363445	$C_8H_4O_3$	2.89069932
$C_8H_4O_3$	2.8906993	$C_8H_6O_4$	2.89939751
$C_8H_6O_4$	2.89939751	Total	5374.15506
Total	4001.65301		
2. Air Pencuci		2. Aliran Slurry	
Komponen	Massa (Kg/Jam	Komponen	Massa (Kg/Jam
H_2O	1400.57855	$C_{16}H_{35}O_4TiN$	0.06363445
Total	1400.57855	H_2O	28.0128697
		Total	28.0765042
Total	5402.2316	Total	5402.2316

6. Evaporator

Fungsi : Untuk menguapkan H_2O



Aliran masuk dari *rotary drum vacum filter*

Komponen	Massa (Kg/Jam
$C_8H_{18}O$	5.07825556
$C_{24}H_{38}O_4$	3801.07429
H_2O	1562.21242
$C_8H_4O_3$	2.89069932
$C_8H_6O_4$	2.89939751

Aliran keluaran dari kondensor

Asumsi H_2O 99,99% terpisahkan

$H_2O = \frac{100}{100} \times 1562.21$ kg/jam

$= 1562.06$ kg/jam

Aliran menuju tangki dekolorisasi

Asumsi $C_{24}H_{38}O_4$ 99.8%, sedangkan 0,2% mengandung H2O

$C_{24}H_{38}O = \frac{100}{100} \times 3801.1$ kg/jam

$= 3793.47$ kg/jam

$H_2O = \frac{0.2}{100} \times 3793.47$ kg/jam

$= 7.6021$ kg/jam

$= 7.7584$ kg/jam

$C_8H_{18}O = \frac{100}{100} \times 5.07826$ kg/jam

$= 5.0783$ kg/jam

$C_8H_4O_3 = \frac{100}{100} \times 2.89070$ kg/jam

$= 2.8907$ kg/jam

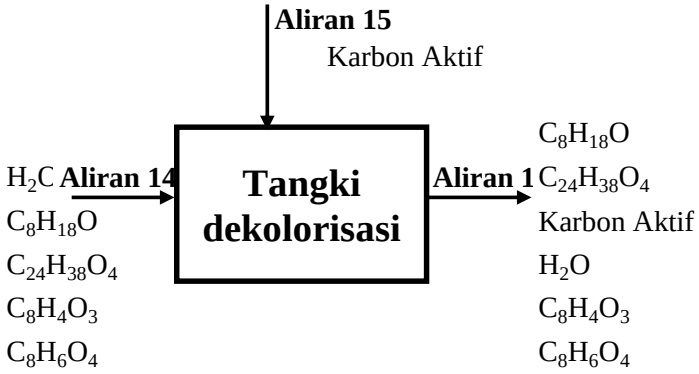
$C_8H_6O_4 = \frac{100}{100} \times 2.89940$ kg/jam

$= 2.8994$ kg/jam

NERACA MASSA EVAPORATOR			
Komponen Masuk		**Komponen Keluar**	
roduk rotary drum vacum f		1. Produk Evaporator	
Komponen	Massa (Kg/Jam	Komponen	Massa (Kg/Jam
$C_{24}H_{38}O_4$	##########	$C_8H_{18}O$	5.0782556
$C_8H_{18}O$	##########	$C_{24}H_{38}O_4$	3793.4721
H_2O	##########	H_2O	7.7583698
$C_8H_4O_3$	2.890699	$C_8H_4O_3$	2.8906993
$C_8H_6O_4$	2.899398	$C_8H_6O_4$	2.8993975
Total	5374.1551	Total	3812.09886
		2. Aliran menuju kondenso	
		Komponen	Massa (Kg/Jam
		H_2O	1562.0562
		Total	1562.0562
Total	5374.1551	Total	5374.1551

7. Tangki Dekolorisasi

Fungsi : Untuk menghilangkan warna pada produk dengan menambahkan karbon aktif



Aliran masuk dari evaporator

$C_8H_{18}O$	5.0782556
$C_{24}H_{38}O_4$	3793.4721
H_2O	7.7583698
$C_8H_4O_3$	2.8906993
$C_8H_6O_4$	2.8993975
Total	##########

Penambahan karbon aktif sebanyak 0.05% dari total massa produk

Karbon aktif = $\frac{0.05}{100}$ x 3812.10 kg/jam

= 1.906 kg/jam

Produk yang hilang karena proses adsorpsi sebesar 0,2-0,5% dari total massa produk

Karbon Aktif = 0.2% × 3812.10 kg/jam

= 7.6242 kg/jam

Massa total = 7.6242 kg/jam + 1.9060 kg/jam

= 9.5302 kg/jam

$C_{24}H_{38}O4$ teradso = 0.2% × 3793.47 kg/jam

= 7.5869 kg/jam

$C_{24}H_{38}O_4$ total = 3793.47 kg/jam - 7.5869 kg/jam

= 3785.89 kg/jam

$C_8H_{18}O$ teradsorp = 0.2% × 5.07826 kg/jam

= 0.0102 kg/jam

$C_8H_{18}O$ total = 5.078 kg/jam - 0.0102 kg/jam

= 5.068 kg/jam

$C_8H_4O_3$ teradsorp = 0.2% × 2.8907 kg/jam

= 0.0058 kg/jam

$C_8H_4O_3$ total = 2.891 kg/jam - 0.0058 kg/jam

= 2.885 kg/jam

$C_8H_6O_4$ teradsorp = 0.2% × 2.89940 kg/jam

= 0.0058 kg/jam

$C_8H_6O_4$ total = 2.899 kg/jam - 0.0058 kg/jam

= 2.894 kg/jam

H_2O teradsorpsi = 0.2% × 7.76 kg/jam

= 0.0155 kg/jam

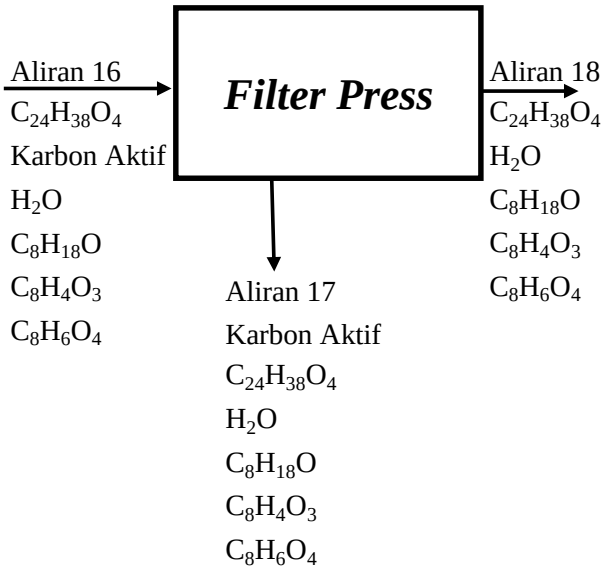
H_2O total = 7.758 kg/jam - 0.0155 kg/jam

= 7.743 kg/jam

NERACA MASSA TANGKI DEKOLORISASI			
Komponen Masuk		**Komponen Keluar**	
1. Produk evaporator		. Produk tangki dekolorisas	
Komponen	Massa (Kg/Jam	Komponen	Massa (Kg/Jam
$C_{24}H_{38}O_4$	3793.4721	$C_8H_{18}O$	5.0681
$C_8H_{18}O$	5.0783	$C_{24}H_{38}O_4$	3785.8852
$C_8H_4O_3$	2.8906993	$C_8H_4O_3$	2.8849179
$C_8H_6O_4$	2.8993975	$C_8H_6O_4$	2.8935987
H_2O	7.7584	H_2O	7.7428531
Total	3812.0989	Karbon aktif	9.5302472
		Total	3814.0049
2. Aliran karbon aktif			
Komponen	Massa (Kg/Jam		
Karbon aktif	1.90604943		
Total	1.90604943		
Total	3814.0049	Total	3814.0049

8. ***Filter Pewss***

Fungsi : Untuk memisahkan produk dari karbon aktif



Aliran masuk dari tangki dekolorisasi

Komponen	Massa (kg/jam
$C_8H_{18}O$	5.0681
$C_{24}H_{38}O_4$	3785.8852
$C_8H_4O_3$	2.8849179
$C_8H_6O_4$	2.8935987
H_2O	7.7428531
Karbon aktif	9.5302472

Aliran keluaran berupa cake dari *filter press*
Asumsi efisiensi pemisahan pada *filter press* 99,5%.
Jumlah filtrat yang tertahan dalam *cake* sebesar 0,5% dari jumlah padatan yang tertahan

$C_{24}H_{38}O_4$ = $\frac{0.5}{\#\#}$ x 3785.9 kg/jam
= 18.9294 kg/jam

$C_8H_{18}O$ = $\frac{0.5}{\#\#}$ x 5.06810 kg/jam
= 0.0253 kg/jam

$C_8H_4O_3$ = $\frac{0.5}{\#\#}$ x 2.88492 kg/jam
= 0.0144 kg/jam

$C_8H_6O_3$ = $\frac{0.5}{\#\#}$ x 2.89360 kg/jam
= 0.0145 kg/jam

H_2O = $\frac{0.5}{\#\#}$ x 7.74285 kg/jam
= 0.0387 kg/jam

Karbon Aktif = $\frac{\#\#}{\#\#}$ x 9.53025 kg/jam
= 9.5302 kg/jam

Aliran keluaran filtrat masuk tangki penyimpanan

$C_{24}H_{38}O$ = 3785.89 - 18.9294
= 3766.96 kg/jam

$C_8H_{18}O$ = 5.0681 - 0.0253

= 5.0428 kg/jam

$C_8H_4O_3$ = 2.8849 - 0.0144
= 2.8705 kg/jam

$C_8H_6O_4$ = 2.8936 - 0.0145
= 2.8791 kg/jam

H_2O = 7.7429 - 0.0387
= 7.7041 kg/jam

NERACA MASSA *FILTER PRESS*			
Komponen Masuk		**Komponen Keluar**	
. Produk tangki dekolorisas		1. Aliran cake	
Komponen	Massa (Kg/Jam	Komponen	Massa (Kg/Jam
$C_{24}H_{38}O_4$	3785.8852	$C_{24}H_{38}O_4$	18.9294
$C_8H_{18}O$	5.0681	$C_8H_{18}O$	0.02534
$C_8H_4O_3$	2.8849	$C_8H_4O_3$	0.01442
$C_8H_6O_4$	2.8936	$C_8H_6O_4$	0.01447
H_2O	7.7429	H_2O	0.03871
Karbon Aktif	9.5302	Karbon Aktif	9.53025
Total	3814.0049	Total	28.5526
		2. Produk *filter press*	
		Komponen	Massa (Kg/Jam
		$C_{24}H_{38}O_4$	3766.9558
		$C_8H_{18}O$	5.0428
		$C_8H_4O_3$	2.8705
		$C_8H_6O_4$	2.8791
		H_2O	7.7041
		Total	3785.4523
Total	3814.0049	Total	3814.0049

APPENDIX B
NERACA PANAS

Kapasitas produksi	=	30000	ton/jam
	=	30000 x 1000	kg/tahun
	=	30000000	kg/tahun
	=	$\frac{30000000}{330}$	kg/hari
	=	90909.09091	kg/hari
	=	$\frac{90909.09091}{24}$	kg/jam
	=	3787.878788	kg/jam
Waktu operasi	=	330	hari/tahun
	=	24	jam/hari

Kapasitas panas gas (Himmelblau, 2004 : 692) :

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

Sehingga, $\int Cp\, dT = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4 + \frac{E}{5}T^5$

Kapasitas panas *liquid* (Himmelblau, 2004 : 692) :

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

Sehingga, $\int Cp\, dT = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$

Kapasitas panas *solid* (Himmelblau, 2004 : 692) :

$Cp = A + BT + CT^2$

Sehingga, $\int Cp\, dT = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3$

keterangan :

Cp	=	kapasitas panas (kJ/mol.K)
A, B, C, D, E	=	konstanta
T	=	suhu (K)

Tabel B.1 Data Berat Molekul masing-masing Komponen

Komponen	BM (kg/kmol)
$C_8H_4O_3$	148.1140
$C_8H_{18}O$	130.2257
H_2O	18.0147
$C_{16}H_{36}O_4Ti$	340.3164
$C_{24}H_{38}O_4$	390.5507
$C_8H_6O_4$	166.1286
NaOH	39.9966

Tabel B.2 Data Kapasitas Panas L*iquid, solid* dan gas (J/mol.K) :

Komponen	A	B	C	D	E	Literatur
$C_8H_4O_{3(l)}$	-105.6270	1.98400	-0.00388	2.851E-06	-	(Yaws, 1999)
$C_8H_4O_{3(s)}$	26.3200	0.39060	0.00021	-	-	(Yaws, 1999)
$C_8H_{18}O_{(l)}$	-105.6270	0.97903	-0.00262	3.104E-06	-	(Yaws, 1999)
$C_{16}H_{36}O_4Ti_{(l)}$	Cp=	711.00000				(NIST, 2019)
$C_{24}H_{38}O_{4(l)}$	370.5240	1.98040	-0.00416	4.28E-06	-	(Yaws, 1999)
$NaOH_{(l)}$	87.6390	-0.00048	0.00000	1.19E-09	-	(Yaws, 1999)
$H_2O_{(g)}$	33.93300	-0.00842	0.000030	-1.78E-08	3.69E-12	(Yaws, 1999)
$H_2O_{(l)}$	92.0530	-0.03995	-0.00021	5.35E-07	-	(Yaws, 1999)
$H_2O_{(s)}$	9.6590	0.0750	-0.000016	-	-	(Yaws, 1999)
$C_8H_6O_{4(l)}$	-561.0000	3.46000	-0.00461	2.28E-06	-	(Yaws, 1999)
$C_8H_6O_{4(s)}$	22.0000	0.55600	0.00000	-	-	(Yaws, 1999)

Konversi Data Kapasitas Panas L*iquid, solid* dan gas (kkal/mol.K) :

Komponen	A	B	C	D	E
$C_8H_4O_{3(l)}$	-0.0252	0.0004742	-9.28E-07	6.815E-10	-
$C_8H_4O_{3(s)}$	0.0063	9.335E-05	5.081E-08	-	-
$C_8H_{18}O_{(l)}$	-0.0252	0.000234	-6.26E-07	7.419E-10	-
$C_{16}H_{36}O_4Ti_{(l)}$	Cp=	0.00004			
$C_{24}H_{38}O_{4(l)}$	0.08856	0.0004733	-9.94E-07	1.02E-09	-
$NaOH_{(l)}$	0.02095	1.156E-07	-1.09E-09	2.84E-13	-
$H_2O_{(g)}$	0.00811	-2.01E-06	7.148E-09	-4.26E-12	8.83E-16
$H_2O_{(l)}$	0.02200	-9.55E-06	-5.04E-08	1.28E-10	-
$H_2O_{(s)}$	0.00231	1.791E-05	-3.72E-09	-	-
$C_8H_6O_{4(l)}$	-0.13408	0.0008269	-1.1E-06	5.45E-10	-
$C_8H_6O_{4(s)}$	0.00526	0.0001329	0	-	-

Tabel B.4 Data Entalpi Pembentukan

Komponen	ΔHf (kJ/mol)	ΔHf (kkal/kmol)	
$C_8H_4O_3$	-393.1300	-93960.4288	(Yaws, 1999)
$C_8H_{18}O$	-365.3000	-87308.8918	(Yaws, 1999)
$C_{16}H_{36}O_4Ti$	-1668.3000	-398733.7098	(NIST, 2019)
$C_{24}H_{38}O_4$	-966.7200	-231051.8803	(Yaws, 1999)
$C_8H_6O_4$	-663.3300	-158539.8500	(Yaws, 1999)
NaOH	-423.1200	-101128.2187	(Chase, 1998)
H_2O	-240.5600	-57495.2834	(Yaws, 1999)

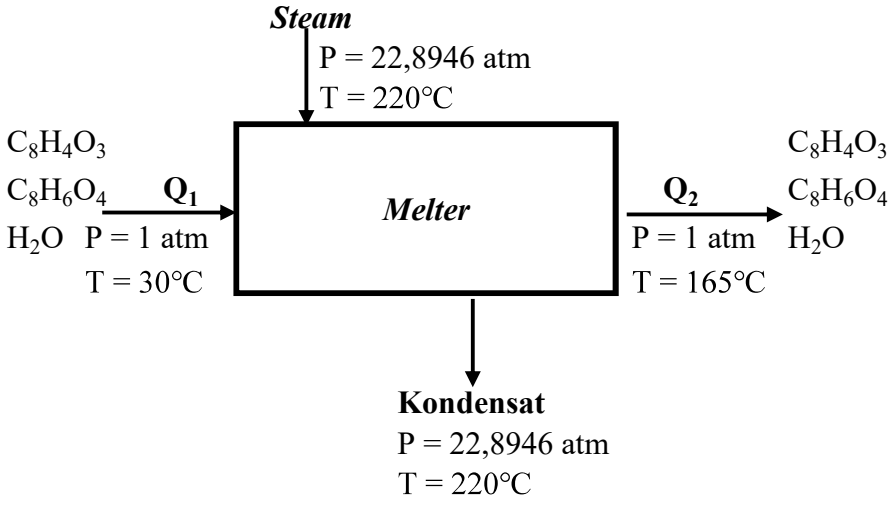
Komponen	ΔHv (kJ/gmol)
$C_8H_4O_3$	74.1900
$C_8H_{18}O$	48.6800
$C_{16}H_{36}O_4Ti$	47.6000
C_3H_8O	39.8700
$C_{24}H_{38}O_4$	66.1300
$C_8H_6O_4$	74.1900
NaOH	200.6700
H_2O	39.5000

Tabel B.5 Entalpi Penguapan (ΔHv) ((kJ/gmol))

Komponen	Tc (K)	Tb (K)	n	A	Literatur
$C_8H_4O_3$	800.0000	598.000	0.3740	124.140	(Yaws, 1999)
$C_8H_{18}O$	640.2500	457.750	0.6610	111.600	(Yaws, 1999)
$C_{16}H_{36}O_4Ti$	ΔHv	47.6000			(NIST, 2019)
C_3H_8O	508.31	355.410	0.3260	58.9830	(Yaws, 1999)
$C_{24}H_{38}O_4$	806.0000	657.150	0.4680	145.786	(Yaws, 1999)
$C_8H_6O_4$	800.0000	598.000	0.3740	124.140	(Yaws, 1999)
NaOH	2820.0000	1663.15	0.3800	281.536	(Yaws, 1999)
H_2O	647.1300	373.150	0.3210	52.0530	(Yaws, 1999)

1. *Melter* $C_8H_4O_3$

Fungsi : mengubah fase $C_8H_4O_{3(s)}$ ke fase $C_8H_4O_{3(l)}$



Panas masuk Melter

Tekanan	=	1	atm
Suhu Operasi	=	30	°C
	=	303.15	K
Treff	=	25	°C
	=	298.15	K

$$\int CpdT\ C_8H_4O_3 = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3$$

$$= 0.0314524 + 0.1403335 + 0.0229648$$

$$= 0.1947507 \text{ kkal/kmol.K}$$

$$\Delta H = n \times \int CpdT$$

$$= 9.7583621 \times 1.948E\text{-}01$$

$$= 1.90 \text{ kkal}$$

$$\int CpdT\ C_8H_6O_4 = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3$$

$$= 0.02629 + 0.1997579 + 0.0$$

$$= 0.2 \text{ kkal/kmol.K}$$

$$\Delta H = n \times \int CpdT$$

= 0.0174527 x 2.3E-01
= 0.0039 kkal

$\int CpdT\ H_2O = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3$

= 0.0115425 + 0.0269296 + 0.0
= 0.03679 kkal/kmol.K

$\Delta H = n \times \int CpdT$

= 0.0804732 x 3.7E-02
= 0.00296 kkal

Enthalpi Masuk

Komponen	Massa (kg)	n (kmol)	∫CpdT (kkal/kmol.K)	ΔH (kkal)
$C_8H_4O_3$	1445.34966	9.758362143	0.1947507	1.9004483
$C_8H_6O_4$	2.899397513	0.017452725	0.2260479	0.0039452
H_2O	1.449698756	0.080473189	0.0367887	0.0029605
Total				**1.907354**

Panas keluar Melter

Tekanan = 1 atm
Suhu Operasi = 165 °C
= 438.15 K
Treff = 25 °C
= 298.15 K

$\int CpdT\ C_8H_4O_3 = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$

= -3.534279 + 24.4 + -17.82935 + 4.9325015
= 8.0083796 kkal/kmol.K

$\Delta H = n \times \int CpdT$

= 9.7583621 x 8.0E+00
= 78.15 kkal

$\int CpdT\ C_8H_6O_4 = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$

= -18.77106 + 42.6 + -21.15821 + 3.9442021
= 6.636248 kkal/kmol.K

ΔH = n x ∫CpdT
= 0.0174527 x 6.6E+00
0.12 kkal

$\int CpdT\ H_2O = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$

= 3.0800934 + -0.492153 + -21.15821 + 0.9249673
= -17.6453 kkal/kmol.K

ΔH = n x ∫CpdT
= 0.0804732 x -1.8E+01
-1.42 kkal

Enthalpi Masuk

Komponen	Massa (kg)	n (kmol)	∫CpdT (kkal/kmol.K)	ΔH (kkal)
$C_8H_4O_3$	1445.34966	9.758362143	8.0083796	78.148668
$C_8H_6O_4$	2.899397513	0.017452725	6.6362480	0.1158206
H_2O	1.449698756	0.080473189	-17.6453010	-1.419974
Total				**76.844515**

Neraca Energi Total :

ΔH Bahan Masuk + Qsupply = ΔH Bahan Keluar + Qloss

Asumsi :

Qloss = 5% Qsupply

ΔH Bahan Masuk + Qsupply = ΔH Bahan Keluar + Qloss
1.907353978 + Qsupply = 76.84451506 + Qloss
95% Qsupply = 74.93716108 kkal/Jam
Qsupply = 78.88122219 kkal/Jam
Qloss = 3.94406111 kkal/Jam

(Ulrich : hal.432)

Kebutuhan steam:

Dipakai steam pada tekanan steam 22,9 atm dengan suhu steam 220°C

H_L = 943.7 kj/kg (Smith : Steam table F-1)

H_v = 2799.9 kj/kg (Smith : Steam table F-1)

λ_{steam} = Hv - HL

= 2799.9 - 943.7

= 1856.2 kj/kg

= 443.64294 kkal/kg

Q steam = M steam x λ_{steam}

M steam = $\frac{\text{Q steam}}{\lambda_{steam}}$

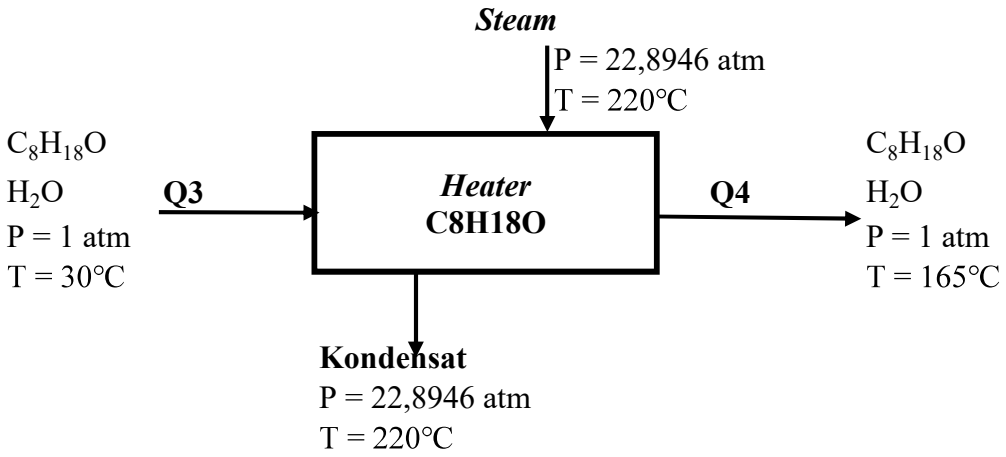
= $\frac{78.88122219 \text{ kkal/jam}}{443.6429372 \text{ kkal/kg}}$

= 0.177803399 kg/jam

NERACA PANAS MELTER			
Panas Masuk		**Panas Keluar**	
Komponen	**ΔH (kkal)**	**Komponen**	**ΔH (kkal)**
$C_8H_4O_3$	1.900448321	C8H4O3	78.1486681
$C_8H_6O_4$	0.003945151	$C_8H_6O_4$	0.115820613
H_2O	0.002960506	H2O	-1.419973647
Qsupply	78.88122219	Qloss	3.94406111
Total	**80.78857617**	**Total**	**80.78857617**

2. Heater $C_8H_{18}O$

Fungsi : Untuk memanaskan $C_8H_{18}O$ sebelum masuk kedalam reaktor



Panas masuk *Heater*

Tekanan	=	1	atm						
Suhu Operasi	=	30	°C						
	=	303.15	K						
Treff	=	25	°C						
	=	298.15	K						
Cp $C_8H_{18}O$ (l)	=	A	+	BT	+	CT^2	+	DT^3	
	=	-105.627	+	297	+	-240.5664	+	8.6E+01	
	=	37.080858	J/mol.K						
	=	37.080858	x	**0.24**					
	=	8.8625475	kal/mol.k						
	=	8.8625475	kkal/kmol.k						
	=	Cp / BM $C_8H_{18}O$							
	=	8.862547494 / 130.2257	kkal/kmol.k / kg/kmol						
	=	**0.068055277**	**kkal/kg.K**						
ΔH	=	m		x	cp		x	ΔT	
	=	2539.127781		x	0.068055277		x	5	
	=	864.005227	kkal						

Cp H_2O (l)	=	A	+	BT	+	CT^2	+	DT^3	
	=	92.053	+	-12	+	-19.39364	+	1.49E+01	
	=	7.54E+01	J/mol.K						
	=	75.443783	x	**0.24**					
	=	18.031517	kal/mol.k						
	=	18.031517	kkal/kmol.k						
	=	18.03151677 / 18.0147	kkal/kmol.k / kg/kmol						
	=	**1.000934614**	**kkal/kg.K**						
ΔH	=	m		x	cp		x	ΔT	
	=	12.75943609		x	1.000934614		x	5	
	=	63.85680616	kkal						

Enthalpi Masuk

Komponen	Massa (kg)	Cp (kkal/kg.k)	ΔT (K)	ΔH (kkal)
$C_8H_{18}O$	2539.127781	0.068055277	5	864.00523
H_2O	12.75943609	1.000934614	5	63.856806
Total				**927.86203**

Panas keluar *Heater*

Tekanan = 1 atm
Suhu Operasi = 165 °C
= 438.15 K
Treff = 25 °C
= 298.15 K

Cp $C_8H_{18}O$ (l) = A + BT + CT^2 + DT^3
= -105.627 + 429 + -502.5341 2.6E+02
= 81.907707 J/mol.K
= 81.907707 x **0.24**
= 19.576433 kal/mol.k
= 19.576433 kkal/kmol.k
= Cp / BM $C_8H_{18}O$
= 19.57643347 kkal/kmol.k / 130.2257 kg/kmol
= **0.150326936 kkal/kg.K**

ΔH = m x cp x ΔT
= 2539.127781 x 0.150326936 x 140
= 53437.9019 kkal

Cp H_2O (l) = A + BT + CT^2 + DT^3
= 92.053 + -17.50541 + -40.51257 4.50E+01
= 7.90E+01 J/mol.K
= 79.009951 x **0.24**
= 18.883852 kal/mol.k
= 18.883852 kkal/kmol.k
= 18.88385237 kkal/kmol.k / 18.0147 kg/kmol
= **1.048248005 kkal/kg.K**

ΔH	=	m	x	cp	x	ΔT
	=	12.75943609	x	1.048248005	x	140
	=	1872.507479	kkal			

Enthalpi keluar

Komponen	Massa (kg)	Cp (kkal/kg.k)	ΔT (K)	ΔH (kkal)
$C_8H_{18}O$	2539.127781	0.150326936	140	53437.902
H_2O	12.75943609	1.048248005	140	1872.5075
Total				**55310.409**

Neraca Energi Total :

$\Delta H_{bahan\ masuk}$	+	Q supply	=	ΔH bahan keluar	+	Q loss
927.8620332	+	Q supply	=	55310.40938	+	5% Qsupply
		Q supply	=	57244.78668	Kkal/jam	
		Qloss	=	2862.239334	Kkal/jam	
					(Ulrich : hal.432)	

Kebutuhan steam:

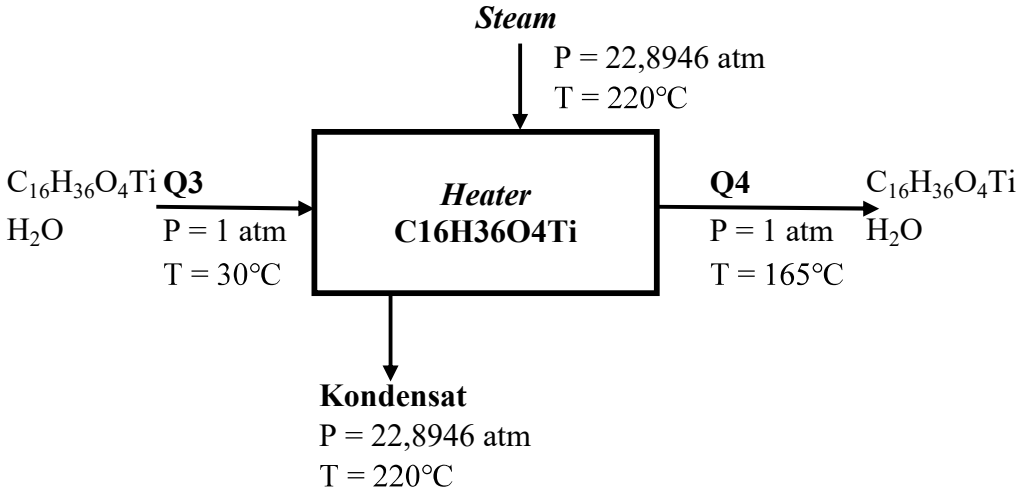
Dipakai steam pada tekanan steam 22,9 atm dengan suhu steam 220°C

λ steam	=	1856.2	kj/kg	(Smith : Steam table F-1)
	=	443.6318	kkal/kg	
Q steam	=	M steam	x λ	
M steam	=	$\frac{\text{Q steam}}{\lambda_{steam}}$		
	=	$\frac{57244.78668}{443.6318}$		
	=	129.0367072	kg/jam	

NERACA PANAS *HEATER*			
Panas Masuk		**Panas Keluar**	
Komponen	**ΔH (kkal)**	**Komponen**	**ΔH (kkal)**
$C_8H_{18}O$	864.005227	C8H18O	53437.9019
H_2O	63.85680616	H2O	1872.507479
Qsupply	57244.78668	Qloss	2862.239334
Total	**58172.64871**	**Total**	**58172.64871**

3. Heater $C_{16}H_{36}O_4Ti$

Fungsi : Untuk memanaskan $C_{16}H_{36}O_4Ti$ sebelum masuk kedalam reaktor



Panas masuk *Heater*

Tekanan	=	1	atm	
Suhu Operasi	=	30	°C	
	=	303.15	K	
Treff	=	25	°C	
	=	298.15	K	
Cp $C_{16}H_{36}O_4Ti$	=	711.00000	J/mol.K	
	=	711.0000	x	**0.24**
	=	169.93327	kal/mol.k	
	=	169.93327	kkal/kmol.k	
	=	Cp / BM $C_{16}H_{36}O_4Ti$		
	=	169.933266 / 340.3164	kkal/kmol.k / kg/kmol	
	=	**0.499338986**	**kkal/kg.K**	

ΔH	=	m	x	cp	x	ΔT
	=	0.059767162	x	0.499338986	x	5
	=	0.149220369	kkal			

Cp H_2O	=	A	+	BT	+	CT^2	+	DT^3
	=	92.053	+	-12.11175	+	-19.39364		1.49E+01
	=	75.443783	J/mol.K					
	=	75.443783	x	**0.24**		**(konversi ke Kal/mol.k)**		
	=	18.031517	kal/mol.k					
	=	18.031517	kkal/kmol.k					
	=	Cp / BM H_2O						
	=	18.03151677 / 18.0147	kkal/kmol.k / kg/kmol					
	=	**1.000934614**	**kkal/kg.K**					

ΔH	=	m	x	cp	x	ΔT
	=	0.000240029	x	1.000934614	x	5
	=	0.001201265	kkal			

Enthalpi Masuk

Komponen	Massa (kg)	Cp (kkal/kg.k)	ΔT (K)	ΔH (kkal)
$C_{16}H_{36}O_4Ti$	0.059767162	0.499338986	5	0.1492204
H_2O	0.000240029	1.000934614	5	0.0012013
Total				**0.1504216**

Panas keluar *Heater*

Tekanan	=	1	atm
Suhu Operasi	=	165	℃
	=	438.15	K
Treff	=	25	℃
	=	298.15	K

Cp $C_{16}H_{36}O_4Ti$	=	711.00000	J/mol.K		
	=	711.0000	x	**0.24**	**(konversi ke Kal/mol.k)**
	=	169.93327	kal/mol.k		
	=	169.93327	kkal/kmol.k		
	=	Cp / BM $C_{16}H_{36}O_4Ti$			
	=	169.933266 / 340.3164	kkal/kmol.k / kg/kmol		

= **0.499338986** **kkal/kg.K**

ΔH = m x cp x ΔT
= 0.059767162 x 0.499338986 x 140
= 4.178170341 kkal

Cp H_2O = A + BT + CT^2 + DT^3
= 92.0530 + -17.50541 + -40.51257 4.50E+01
= 79.0100 J/mol.K
= 79.009951 x **0.24** **(konversi ke Kal/mol.k)**
= 18.883852 kal/mol.k
= 18.883852 kkal/kmol.k
= $\frac{\text{Cp}}{\text{BM } H_2O}$
= $\frac{18.88385237 \text{ kkal/kmol.k}}{18.0147 \text{ kg/kmol}}$
= **1.048248005** **kkal/kg.K**

ΔH = m x cp x ΔT
= 0.000240029 x 1.048248005 x 140
= 0.035225354 kkal

Enthalpi keluar

Komponen	Massa (kg)	Cp (kkal/kg.k)	ΔT (K)	ΔH (kkal)
$C_{16}H_{36}O_4Ti$	0.059767162	0.499338986	140	4.1781703
H_2O	0.000240029	1.048248005	140	0.0352254
Total				**4.2133957**

Neraca Energi Total :

$\Delta H_{\text{bahan masuk}}$ + Q supply = ΔH bahan keluar + Q loss
0.150421635 + Q supply = 4.213395695 + 0.05 Qsupply
Q supply = 4.2768148 Kkal/jam
Qloss = 0.21384074 Kkal/jam
(Ulrich : hal.432)

Kebutuhan steam:
Dipakai steam pada tekanan steam 22,9 atm dengan suhu steam 220ºC
λ steam = 1856.2 kj/kg (Smith : Steam table F-1)
= 443.6318 kkal/kg
Q steam = M steam x λ_{steam}
M steam = $\frac{\text{Q steam}}{}$

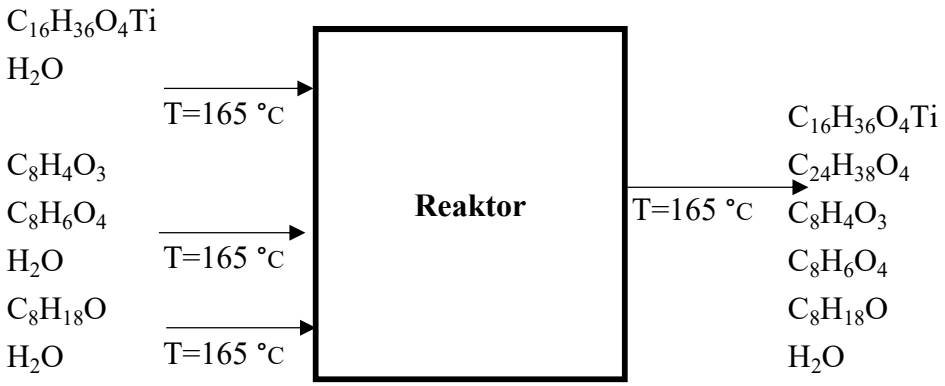
$$= \frac{\lambda_{steam}}{\frac{4.2768148}{443.6318}}$$

= 0.00964046 kg/jam

NERACA PANAS *HEATER*			
Panas Masuk		**Panas Keluar**	
Komponen	**ΔH (kkal)**	**Komponen**	**ΔH (kkal)**
$C_8H_{18}O$	0.149220369	C8H18O	4.178170341
H_2O	0.001201265	H2O	0.035225354
Qsupply	4.2768148	Qloss	0.21384074
Total	**4.427236435**	**Total**	**4.427236435**

4. Reaktor

Fungsi : Mereaksikan phthalic anhydride dan 2-Ethylhexanol menggunakan katalis tetrabutyl titanate



Enthalpi bahan masuk

Tekanan = 1 atm

T_{in} = 165 ^oC = 438.15 K

T_{ref} = 25 ^oC = 298.15 K

Panas masuk (phthalic anhydride)

Komponen	Feed in (kg/jam)	n (kmol/jam)	∫CpdT (kkal/kmol)	ΔH (kkal/Jam)
$C_8H_4O_3$	1445.35	9.76	8008.58	78150.63
$C_8H_6O_4$	2.89940	0.02	6636.41	0.1158235
H_2O	1.44970	0.08	2544.42	204.75770
Total				**78355.5**

Panas masuk (Katalis tetrabutyl titanate)

Komponen	Feed in (kg/jam)	n (kmol/jam)	∫CpdT (kkal/kmol)	ΔH (kkal/Jam)
$C_{16}H_{36}O_4Ti$	0.059767	0.000176	169.933	0.029844
H_2O	0.000240	0.000013	2544.421	0.033902
Total				**0.0637**

Panas masuk (2-Ethyl hexanol)

Komponen	Feed in (kg/jam)	n (kmol/jam)	∫CpdT (kkal/kmol)	ΔH (kkal/Jam)
$C_8H_{18}O$	2539.1278	19.4979	1881.47	36684.63
H_2O	12.7594	0.7083	2544.42	1802.1625
Total				**38486.8**

Panas masuk total = 116842.36

Menghitung Entalpi Panas Reaksi

T_{out} = 165 °C = 438 K

T_{ref} = 25 °C = 298 K

$\Delta H = H_{out} - H_{in}$

Untuk menghitung entalpi panas reaksi digunakan persamaan :

$Hf_{reaksi\ 298K} = \sum(n \times Hf)_{produk} - \sum(n \times Hf)_{reaktan}$

Reaksi yang terjadi :

$$C_8H_4O_3 + 2C_8H_{18}O \longrightarrow C_{24}H_{38}O_4 + H_2O$$

Tabel B.18 Entalpi Pembentukan Reaktan pada 298 K

Komponen	Massa (kg/jam)	n (kmol/jam)	Hf kkal/kmol	$Hf_{Reaktan}$ (kkal/Jam)
$C_8H_4O_3$	1445.3497	9.7584	-93960.4	-916899.9
$C_8H_4O_3$	2.8994	0.0175	-158539.8	-2767.0

$C_8H_{18}O$	2539.1278	19.4979	-87308.9	#########
H_2O	14.2094	0.7888	-57495.3	-45350.3
Total				#########

Tabel B.19 Entalpi Pembentukan Produk pada 298 K

Komponen	**Feed (kg/jam)**	**n (kmol/jam)**	**Hf kkal/kmol**	**$Hf_{Reaktan}$ (kkal/Jam)**
$C_{24}H_{38}O_4$	3801.0743	9.7326	#########	#########
H_2O	189.6436	10.5272	-57495.28	-605263
Total				#########

$Hf_{Reaksi(298K)}$ = $\sum(n \times Hf)_{Produk}$ - $\sum(n \times Hf)_{Reaktan}$
= -2853998.2770 - -2667357.0436
= -186641.2334 kkal/jam

Menghitung Entalpi Panas Produk Reaktor

T_{out} = 165 ˚C = 438 K
T_{ref} = 25 ˚C = 298 K

Panas Keluar Reaktor

Komponen	**Feed in (kg/jam)**	**n (kmol/jam)**	**∫CpdT (kkal/kmol)**	**ΔH (kkal/Jam)**
$C_{24}H_{38}O_4$	3801.0743	9.7326	25107.22	244358.55
$C_8H_4O_3$	2.8907	0.0195	17802.408	347.4447
$C_8H_6O_4$	2.8994	0.0175	15208.09	265.4226
$C_8H_{18}O$	5.0783	0.0390	-9226.43	-359.7919
$C_{16}H_{36}O_4Ti$	0.0598	0.0002	169.933	0.0298
H_2O	189.6436	10.5272	7700.68	81066.37
Total				**325678.0**

$Hf_{reaksi\ (438,15K)}$ = $(XA \times n + \Delta H_{298}) + (H_{out} - H_{in})$
= -185658.7588 + 208835.6584
= 23176.8996 kkal

Menghitung Kebutuhan Pendingin

Q yang diterima pendingin

Q_{lepas} = H_{Reaksi} + H_{Produk} - $H_{Reaktan}$

= 23176.8996 + 325678.0212 - 116842.3628

= 232012.5580 kkal

Pendingin menggunakan *cooling water* pada suhu 30°C dan keluar pada suhu 45°C.

T_{in} = 30 °C = 303.15 K = 86 °F

T_{out} = 45 °C = 318.15 K = 113 °F

Cp = 4.1868 kJ/kg. °K (Smith *et al.,* 2005)

= 1.0000004 kkal/kg.K

$$m_{pendingin} = \frac{Q_{lepas}}{Cp \times \Delta T}$$

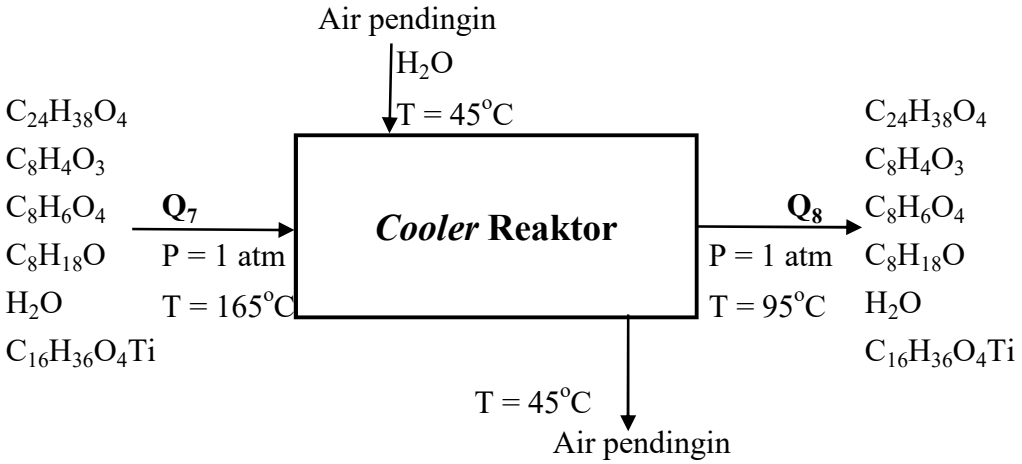
$$= \frac{232012.5580 \text{ kkal}}{15.000006492 \text{ kkal/kg}}$$

= 15467.497 kg/jam

NERACA PANAS REAKTOR			
Masuk		**Keluar**	
Komponen	**ΔH (kkal)**	**Komponen**	**ΔH (kkal)**
Dari melter			
$C_8H_4O_3$	78150.63	C24H38O4	244358.5457
$C_8H_6O_4$	0.1158235	C8H4O3	347.4446886
H_2O	204.75770	C8H6O4	265.422643
Dari tangki 2-Ethyl Hexanol		C8H18O	-359.7919087
$C_8H_{18}O$	36684.63	C16H36O4Ti	0.029844074
H_2O	1802.1625	H2O	81066.37032
Dari tangki Tetrabutyl titanate		ΔH reaksi	23176.89961
$C_{16}H_{36}O_4Ti$	0.029844	Qserap	-232012.558
H_2O	0.033902		
Total	**116842.3628**	**Total**	**116842.3628**

5. *Cooler* Reaktor

Fungsi : untuk menurunkan suhu produk keluar reaktor



Panas masuk Melter

Tekanan	=	1	atm
Suhu Operasi	=	165	°C
	=	438.15	K
Treff	=	25	°C
	=	298.15	K

Cp $C_{24}H_{38}O_4$	=	A	+	BT	+	CT^2	+	CT^3
	=	370.5240	+	867.71226	+	-798.66	+	360.18
	=	799.756	J/mol.K					
	=	799.756	x	**0.24**				
	=	191.14658	kal/mol.k					
	=	191.14658	kkal/kmol.k					
	=	191.14658	kkal/kmol.k					
		390.5507	kg/kmol					
	=	**0.4894283**	**kkal/kg.K**					
ΔH	=	m		x	cp		x	ΔT
	=	3801.074288		x	0.489428302		x	140
	=	260449.4668		kkal				

Cp $C_8H_4O_3$	=	A	+	BT	+	CT^2	+	CT^3
	=	-105.6270	+	869.28960	+	-745.7669	+	-326757.8
	=	-326740	J/mol.K					

	=	#########	x	**0.24**				
	=	-78092.79	kal/mol.k					
	=	-78092.79	kkal/kmol.k					
	=	-78092.79	kkal/kmol.k					
		148.1140	kg/kmol					
	=	**-527.248**	**kkal/kg.K**					
ΔH	=	m		x	cp		x	ΔT
	=	2.89069932		x	-527.2480206		x	140
	=	-213376.1693	kkal					
Cp $C_8H_6O_4$	=	A	+	BT	+	CT^2	+	CT^3
	=	-561.000	+	1515.9990	+	-885.0067	+	191.7800
	=	#########	J/mol.K					
	=	261.77229	x	**0.24**				
	=	62.565149	kal/mol.k					
	=	62.565149	kkal/kmol.k					
	=	62.565149	kkal/kmol.k					
		166.1286	kg/kmol					
	=	**0.3766066**	**kkal/kg.K**					
ΔH	=	m		x	cp		x	ΔT
	=	2.899397513		x	0.37660664		x	140
	=	152.8705296	kkal					
Cp $C_8H_{18}O$	=	A	+	BT	+	CT^2	+	CT^3
	=	-105.6270	+	428.9620	+	-502.5341	+	261.1068
	=	81.9077	J/mol.K					
	=	81.9077	x	**0.24**				
	=	19.576433	kal/mol.k					
	=	19.576433	kkal/kmol.k					
	=	19.576433	kkal/kmol.k					
		130.2257	kg/kmol					
	=	**0.1503269**	**kkal/kg.K**					
ΔH	=	m		x	cp		x	ΔT
	=	5.078255562		x	0.150326936		x	140
	=	106.8758038	kkal					

Cp H_2O	=	A	+	BT	+	CT^2	+	CT^3
	=	92.0530	+	-17.5054	+	-40.5126	+	44.9749
	=	79.00995	J/mol.K					
	=	79.00995	x	**0.24**				
	=	18.883852	kal/mol.k					
	=	18.883852	kkal/kmol.k					
	=	18.883852	kkal/kmol.k					
		18.0147	kg/kmol					
	=	**1.048248**	**kkal/kg.K**					
ΔH	=	m		x	cp	x	ΔT	
	=	189.6435728		x	1.048248005	x	140	
	=	27831.08955	kkal					

Cp $C_{16}H_{36}C$	=	711.00000	J/mol.K					
	=	711.00000	x	**0.24**				
	=	169.93327	kal/mol.k					
	=	169.93327	kkal/kmol.k					
	=	169.93327	kkal/kmol.k					
		340.3164	kg/kmol					
	=	**0.499339**	**kkal/kg.K**					
ΔH	=	m		x	cp	x	ΔT	
	=	0.059767162		x	0.499338986	x	140	
	=	4.178170341	kkal					

Enthalpi Masuk

Komponen	Massa (kg)	Cp (kkal/kg.k)	ΔT (K)	ΔH (kkal)
$C_{24}H_{38}O_4$	3801.074288	0.489428302	140	260449.47
$C_8H_4O_3$	2.890699320	-527.2480206	140	-213376.2
$C_8H_6O_4$	2.899397513	0.37660664	140	152.87053
$C_8H_{18}O$	5.078255562	0.150326936	140	106.8758
H_2O	189.6435728	1.048248005	140	27831.09
$C_{16}H_{36}O_4Ti$	0.059767162	0.499338986	140	4.1781703
Total				**75168.312**

Panas keluar Melter

Tekanan	=	1	atm
Suhu Operasi	=	95	℃
	=	368.15	K
Treff	=	25	℃
	=	298.15	K

Cp $C_{24}H_{38}C$	=	A	+	BT	+	CT^2	+	CT^3
	=	370.5240	+	729.08426	+	-563.85	+	213.66
	=	749.4169	J/mol.K					
	=	749.4169	x	**0.24**				
	=	179.11514	kal/mol.k					
	=	179.11514	kkal/kmol.k					
	=	179.11514	kkal/kmol.k					
		390.5507	kg/kmol					
	=	**0.458622**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	3801.074288		x		0.458621957	x	70
	=	122027.929		kkal				

Cp $C_8H_4O_3$	=	A	+	BT	+	CT^2	+	CT^3
	=	-105.6270	+	730.40960	+	-526.5106	+	-193834.9
	=	#########	J/mol.K					
	=	#########	x	**0.24**				
	=	-46304.21	kal/mol.k					
	=	-46304.21	kkal/kmol.k					
	=	-46304.21	kkal/kmol.k					
		148.1140	kg/kmol					
	=	**-312.6256**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	2.89069932		x		-312.6255524	x	70
	=	-63259.45302		kkal				

Cp $C_8H_6O_4$	=	A	+	BT	+	CT^2	+	CT^3
	=	-561.000	+	204.6914	+	-624.8137	+	113.7652
	=	-867.357	J/mol.K					
	=	-867.3571	x	**0.24**				
	=	-207.3036	kal/mol.k					

	=	-207.3036	kkal/kmol.k					
	=	-207.3036	kkal/kmol.k					
		166.1286	kg/kmol					
	=	**-1.24785**	**kkal/kg.K**					
ΔH	=	m		x	cp	x	ΔT	
	=	2.899397513		x	-1.247849612	x	70	
	=	-253.2608443	kkal					

Cp $C_8H_{18}O$	=	A	+	BT	+	CT^2	+	CT^3
	=	-105.6270	+	360.4299	+	-354.7885	+	154.8903
	=	54.90470	J/mol.K					
	=	54.90470	x	**0.24**				
	=	13.122552	kal/mol.k					
	=	13.122552	kkal/kmol.k					
	=	13.122552	kkal/kmol.k					
		130.2257	kg/kmol					
	=	**0.1007677**	**kkal/kg.K**					
ΔH	=	m		x	cp	x	ΔT	
	=	5.078255562		x	0.100767744	x	70	
	=	35.82070482	kkal					

Cp H_2O	=	A	+	BT	+	CT^2	+	CT^3
	=	92.0530	+	-14.7087	+	-28.6018	+	26.6794
	=	75.421900	J/mol.K					
	=	75.421900	x	**0.24**				
	=	18.026287	kal/mol.k					
	=	18.026287	kkal/kmol.k					
	=	18.026287	kkal/kmol.k					
		18.0147	kg/kmol					
	=	**1.0006443**	**kkal/kg.K**					
ΔH	=	m		x	cp	x	ΔT	
	=	189.6435728		x	1.000644281	x	70	
	=	13283.60296	kkal					

Cp $C_{16}H_{36}C$	=	711.00000	J/mol.K		
	=	711.00000	x	**0.24**	
	=	169.93327	kal/mol.k		
	=	169.93327	kkal/kmol.k		

$$= \frac{169.93327 \text{ kkal/kmol.k}}{340.3164 \text{ kg/kmol}}$$

$= \mathbf{0.499339\ kkal/kg.K}$

$\Delta H = m \times cp \times \Delta T$

$= 0.059767162 \times 0.499338986 \times 70$

$= 2.089085171$ kkal

Enthalpi Keluar

Komponen	Massa (kg)	Cp (kkal/kg.k)	ΔT (K)	ΔH (kkal)
$C_{24}H_{38}O_4$	3801.074288	0.458621957	70	122027.93
$C_8H_4O_3$	2.89069932	-312.6255524	70	-63259.45
$C_8H_6O_4$	2.899397513	-1.247849612	70	-253.2608
$C_8H_{18}O$	5.078255562	0.100767744	70	35.820705
H_2O	189.6435728	1.000644281	70	13283.603
$C_{16}H_{36}O_4Ti$	0.059767162	0.499338986	70	2.0890852
Total				**71836.728**

Q serap

Suhu air pendingin masuk = 30 °C = 303 K **(Ulrich : 427)**

Suhu reference = 25 °C = 298 K

Suhu air pendingin keluar = 45 °C = 318 K **(Ulrich : 427)**

Perhitungan kapasitas panas $H_2O_{(g)}$

$$\int_{}^{70} Cp\, dT = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4 + \frac{D}{5}T^5$$

$= 170 + -12.65526 + 13.516391 + -2.422218 + 0.1509042$

$= 168.25482$ J/mol.K

$= 168.25482 \times \mathbf{0.24}$

$= 40.213911$ kal/mol.k

$= 40.213911$ kkal/kmol.k

$$= \frac{40.213911 \text{ kkal/kmol.k}}{18.0147 \text{ kg/kmol}}$$

$= \mathbf{2.2322856\ kkal/kg.K}$

Qserap = m air pendingin x Cp air x ΔT
= m air pendingin x 2.2323 x 15
= m air pendingin x 33.4843
Qloss = 5% x Qserap
= 5% x m air pendingin x 33.4843
= m air pendingin x 1.6742

Neraca Panas Total :

ΔH bahan masuk = ΔH bahan keluar + Q serap + Q loss
75168.31157 = 71836.72788 + ($m_{air\ pendingin}$ x 33.484284)
+ ($m_{air\ pendingin}$ x 1.6742142)

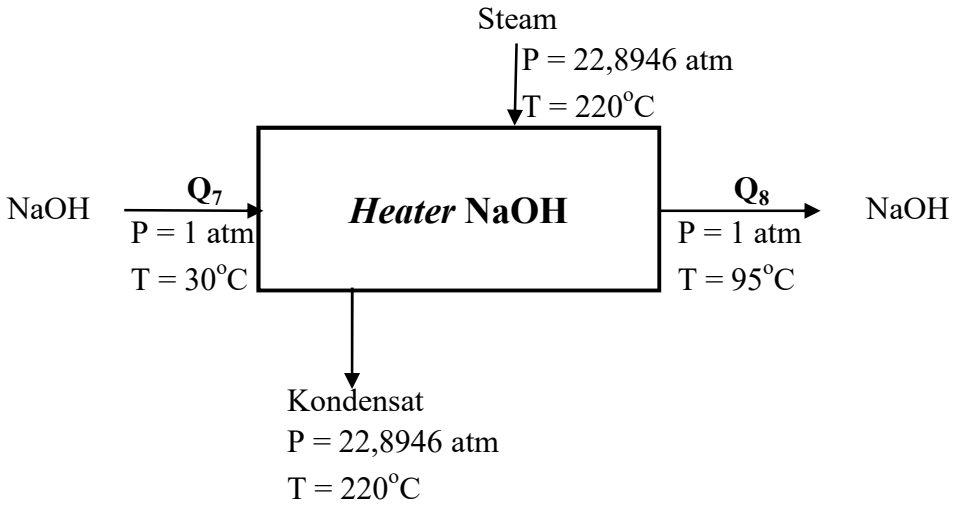
$m_{air\ pendingin}$ = 94.758987 kg

sehingga, Qserap = 3172.9368 kkal
Qloss = 158.6468 kkal

NERACA PANAS *COOLER*			
Panas Masuk		**Panas Keluar**	
Komponen	**ΔH (kkal)**	**Komponen**	**ΔH (kkal)**
$C_{24}H_{38}O_4$	260449.4668	$C_{24}H_{38}O_4$	122027.929
$C_8H_4O_3$	-213376.1693	$C_8H_4O_3$	-63259.45302
$C_8H_6O_4$	152.8705296	$C_8H_6O_4$	-253.2608443
$C_8H_{18}O$	106.8758038	$C_8H_{18}O$	35.82070482
H_2O	27831.08955	H_2O	13283.60296
$C_{16}H_{36}O_4Ti$	4.178170341	$C_{16}H_{36}O_4Ti$	2.089085171
		Q_{serap}	3172.9368
		Q_{loss}	158.6468
Total	**75168.31157**	**Total**	**75168.31157**

6. *Heater* NaOH

Fungsi: Memanaskan NaOH hingga 95°C sebelum masuk *neutraliser*



Panas masuk *Heater*

Tekanan	=	1	atm
Suhu Operasi	=	30	°C
	=	303.15	K
Treff	=	25	°C
	=	298.15	K

Cp NaOH	=	A	+	BT	+	CT^2	+	DT^3
	=	87.639	+	-0.14663	+	-0.41744		3.30E-02
	=	87.10799	J/mol.K					
	=	87.1080	x	**0.24**				
	=	20.819331	kal/mol.k					
	=	20.819331	kkal/kmol.k					
	=	20.819331	kkal/kmol.k					
		39.9966	kg/kmol					
	=	**0.520527**	**kkal/kg.K**					
ΔH	=	m		x	cp		x	ΔT
	=	0.007031431		x	0.520527001		x	5
	=	0.018300248	kkal					

Enthalpi Masuk

Komponen	Massa (kg)	Cp (kkal/kg.k)	ΔT (K)	ΔH (kkal)
NaOH	0.00703143	0.520527001	5	0.0183002
Total				**0.0183002**

Panas keluar *Heater*

Tekanan = 1 atm
Suhu Operasi = 95 °C
= 368.15 K
= 25 °C
= 298.15 K

Cp NaOH = A + BT + CT^2 + DT^3
= 87.639 + -0.17807 + -0.61564 5.92E-02
= 86.90449 J/mol.K
= 86.9045 x **0.24**
= 20.770694 kal/mol.k
= 20.770694 kkal/kmol.k
= 20.770694 kkal/kmol.k
39.9966 kg/kmol
= **0.519311 kkal/kg.K**

ΔH = m x cp x ΔT
= 0.007031431 x 0.519310974 x 70
= 0.255604941 kkal

Enthalpi Keluar

Komponen	Massa (kg)	Cp (kkal/kg.k)	ΔT (K)	ΔH (kkal)
NaOH	0.007031431	0.519310974	70	0.2556049
Total				**0.2556049**

Neraca Energi Total :

$\Delta H_{bahan\ masuk}$ + Q supply = ΔH bahan keluar + Q loss
0.018300248 + Q supply = 0.255604941 + 5% Qsupply
Q supply = 0.249794414 Kkal/jam
Qloss = 0.012489721 Kkal/jam

Kebutuhan steam:

Dipakai steam pada tekanan steam 22,9 atm dengan suhu steam 220°C

(Ulrich : hal.432)

λ steam = 1856.2 kj/kg (Smith : Steam table F-1)

= 443.6318 kkal/kg

Q steam = M steam x λ_{steam}

M steam = $\frac{\text{Q steam}}{\lambda_{steam}}$

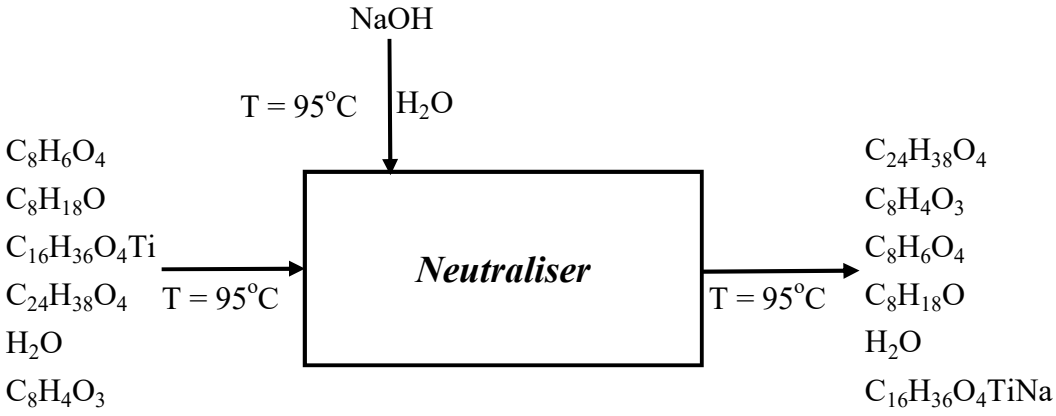
= $\frac{0.2497944143 \text{ kkal/jam}}{443.6318000000 \text{ kkal/kg}}$

= 0.000563067 kg/jam

NERACA PANAS *HEATER*			
Panas Masuk		**Panas Keluar**	
Komponen	**ΔH (kkal)**	**Komponen**	**ΔH (kkal)**
NaOH	0.018300248	NaOH	0.255604941
Qsupply	0.249794414	Qloss	0.012489721
Total	**0.268094662**	**Total**	**0.268094662**

B.7 *Neutraliser*

Fungsi : untuk menetralkan katalis $C_{16}H_{36}O_4Ti$ menggunakan NaOH



Enthalpi bahan masuk

T_{in} = 95 °C = 368.15 K

T_{ref} = 25 °C = 298.15 K

$\int CpdT\ C_{24}H_{38}O_4 = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$

= 6.2 + 11.037956 + -7.753265 + 2.68E+00

= 1.22E+01 kkal/kmol.K

ΔH = n x $\int CpdT$

= 9.733 x 1.2E+01

118.36 kkal

$\int CpdT\ C_8H_4O_3 = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$

= -1.8 + 11.058021 + -7.239823 + 1.8E+00

= 3.8343633 kkal/kmol.K

ΔH = n x $\int CpdT$

= 0.02 x 3.8E+00

0.074834 kkal

$\int CpdT\ C_8H_6O_4 = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$

= -9.4 + 19.284654 + -8.591547 + 1.43E+00

= 2.73E+00 kkal/kmol.K

ΔH = n x $\int CpdT$

= 0.02 x 2.7E+00

0.05 kkal

$\int CpdT\ C_8H_{18}O = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$

= -1.8 + 5.4567211 + -4.878545 + 1.9E+00

= 7.525E-01 kkal/kmol.K

ΔH = n x $\int CpdT$
= 0.0390 x 7.5E-01
0.029345 kkal

$\int CpdT\ C_{16}H_{36}O_4T$ = 0.00004 kkal/kmol.K

ΔH = n x $\int CpdT$
= 0.000176 x 4.1E-05
7.133E-09 kkal

$\int CpdT\ H_2O = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$
= 1.54 + -0.222682 + -0.393292 + 3.34E-01
= 1.2584872 kkal/kmol.K

ΔH = n x $\int CpdT$
= 10.53 x 1.3E+00
13.25 kkal

Panas masuk (dari reaktor)

Komponen	massa (kg/jam)	n (kmol/jam)	∫CpdT (kkal/kmol)	ΔH (kkal)
$C_{24}H_{38}O_4$	3801.0743	9.733	12.162	118.36
$C_8H_4O_3$	2.8907	0.02	3.8344	0.075
$C_8H_6O_4$	2.8994	0.02	2.7336	0.048
$C_8H_{18}O$	5.0783	0.0390	0.752513	0.029
$C_{16}H_{36}O_4Ti$	0.059767	0.000176	0.752513	0.000
H_2O	189.64357	10.53	1.258487	13.25
Total				**131.76**

$\int CpdT\ H_2O = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$
= 1.4662005 + 0.0026958 + -0.008465 + 7.42E-04
= 1.46E+00 kkal/kmol.K

ΔH = n x $\int CpdT$
= 0.00018 x 1.5E+00
0.0002569 kkal

Panas masuk (NaOH)

Komponen	massa (kg/jam)	n (kmol/jam)	∫CpdT (kkal/kmol	ΔH (kkal/jam)
NaOH	0.0070	0.0002	0.5193	0.2556
Total				**0.2556**

Total panas masuk = panas masuk (reaktor) + panas masuk (NaOH)
= 131.76 0.2556
= 132.02

$Q_{penetralan} = Q_{reaksi}$

$C_{16}H_{36}O_4Ti + NaOH \longrightarrow C_{16}H_{35}O_4TiNa + H_2O$

Tabel B.30 Entalpi Pembentukan Reaktan Reaksi pada 298 K

Komponen	massa (kg/jam)	n (kmol/jam)	Hf kkal/kmol	$Hf_{Reaktan}$ (kkal/Jam)
$C_{16}H_{36}O_4Ti$	0.0598	0.0002	-398733.7	-70.0265
H_2O	189.6436	10.5272	-57495.3	-605262.5
NaOH	0.0070	0.0002	-101128.2	-17.7784
Total				**-605350.3**

Tabel B.31 Entalpi Pembentukan Produk Reaksi pada 298 K

Komponen	massa (kg/jam)	n (kmol/jam)	Hf kkal/kmol	$Hf_{Reaktan}$ (kkal/Jam)
$C_{16}H_{35}O_4TiNa$	0.0636	0.0002	-398733.7	-74.5577
H_2O	0.0032	0.0002	-57495.28	-10.0986
Total				**-84.6563**

$Hf_{reaksi(298K)} = \sum(n \times Hf)_{produk} - \sum(n \times Hf)_{reaktan}$
= -84.656 - -605350.3439
= 605265.688 kkal/jam

Menghitung Panas Keluar *Neutraliser*

T_{Out} = 95 °C = 368 K

T_{Ref} = 25 °C = 298 K

$\int CpdT\ C_{24}H_{38}O_4 = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$

= 6.2 + 11.037956 + -7.753265 + 2.68E+00

= 1.22E+01 kkal/kmol.K

ΔH = n x $\int CpdT$

= 9.733 x 1.2E+01

118.36 kkal

$\int CpdT\ C_8H_4O_3 = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$

= -1.8 + 11.058021 + -7.239823 + 1.8E+00

= 3.8E+00 kkal/kmol.K

ΔH = n x $\int CpdT$

= 0.02 x 3.8E+00

0.074834 kkal

$\int CpdT\ C_8H_6O_4 = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$

= -9.4 + 19.284654 + -8.591547 + 1.43E+00

= 2.73E+00 kkal/kmol.K

ΔH = n x $\int CpdT$

= 0.02 x 2.7E+00

0.05 kkal

$\int CpdT\ C_8H_{18}O = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$

= -1.8 + 5.4567211 + -4.878545 + 1.9E+00

= 7.525E-01 kkal/kmol.K

ΔH = n x $\int CpdT$

= 0.0390 x 7.5E-01

0.029345 kkal

$\int CpdT\ C_{16}H_{35}O_4T$ = 0.00004 kkal/kmol.K

ΔH = n x $\int CpdT$
= 0.000187 x 4.1E-05
7.594E-09 kkal

$\int CpdT\ H_2O$ = $AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4$
= 1.54 + -0.222682 + -0.393292 + 3.34E-01
= 1.26E+00 kkal/kmol.K

ΔH = n x $\int CpdT$
= 10.53 x 1.3E+00
13.25 kkal

Tabel B.32 Panas Keluar *Neutraliser*

Komponen	massa (kg/jam)	n (kmol/jam)	∫CpdT (kkal/kmol	ΔH (kkal/Jam)
$C_{24}H_{38}O_4$	3801.0743	9.7326	12.162	118.36
$C_8H_4O_3$	2.890699	0.0195	3.834	0.0748
$C_8H_6O_4$	2.899398	0.0175	2.734	0.0477
$C_8H_{18}O$	5.078256	0.0390	0.753	0.0293
$C_{16}H_{35}O_4TiNa$	0.063634	0.0002	4.061E-05	0.0000
H_2O	189.6467	10.5273	1.2585	13.249
Total				**131.8**

Panas reaksi *neutraliser* :

$\Delta H_{368,15}$ = $(X_A \times n + \Delta H_{298})$ + $(H_{out} - H_{in})$
= -484212.5507 + -0.2553839
= -484212.8060 kkal/Jam

Nilai panas reaksi penetralan bernilai negatif (-) menunjukkan reaksi berlangsung indotermis

Menghitung Kebutuhan Pendingin

Q yang diterima pendingin

Q_{Lepas} = $(Q_{out} - Q_{in})$ + Q_{Reaksi}
= -0.255384 + -484212.8
= -484213 kkal/Jam

Sebagai pendingin digunakan *cooling water* pada suhu 30°C dan keluar pada suhu 45°C.

T_{in} = 30 °C = 303.15 K = 86 °F

T_{out} = 45 °C = 318.15 K = 113 °F

Cp = 4.1868 kJ/kg. °K (Smith *et al.*, 2005)

= 1.0000004 kkal/kg.K

$$m_{pendingin} = \frac{Q_{lepas}}{Cp \times \Delta T}$$

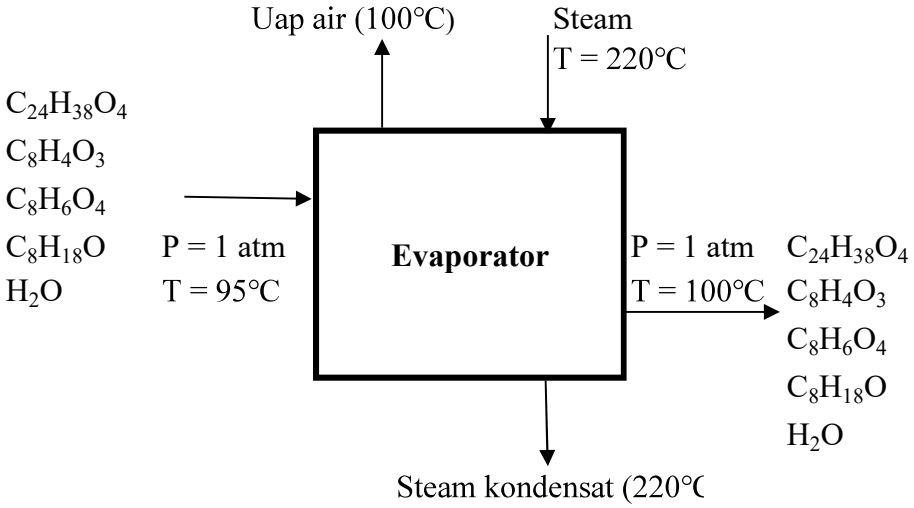
$$= \frac{484213.0614 \text{ kkal}}{62.8020 \text{ kkal/kg}}$$

= 7710.1535 kg/jam

NERACA PANAS NEUTRALISER			
Masuk		**Keluar**	
Komponen	**ΔH (kkal)**	**Komponen**	**ΔH (kkal)**
Dari Neutraliser			
$C_{24}H_{38}O_4$	118.3647032381910	$C_{24}H_{38}O_4$	118.36470324
$C_8H_4O_3$	0.0748342118156	$C_8H_4O_3$	0.0748342118
$C_8H_6O_4$	0.0477082522919	$C_8H_6O_4$	0.0477082523
$C_8H_{18}O$	0.0293448536690	$C_8H_{18}O$	0.0293448537
$C_{16}H_{36}O_4Ti$	0.0000000071326	$C_{16}H_{32}O_4TiNa$	0.0000000076
H_2O	13.248306784780	H_2O	13.248527829
Dari tangki NaOH		ΔH reaksi	-484212.8060
NaOH	0.255605	Qserap	484213.0614
Total	**132.0205023**	**Total**	**132.0205023**

B.8 Evaporator

Fungsi : Untuk memisahkan kandungan Dioctyl phthalate dari air



Enthalpi bahan masuk

Kondisi operasi

Tekanan	=	1 atm
Suhu bahan masuk	=	95 ℃
	=	368.15 K
Treff	=	25 ℃
	=	298.15 K

Cp $C_{24}H_{38}C$	=	A	+	BT	+	CT^2	+	CT^3
	=	370.5240	+	729.08426	+	-563.85	+	213.66
	=	749.4169	J/mol.K					
	=	749.4169	x	**0.24**				
	=	179.11514	kal/mol.k					
	=	179.11514	kkal/kmol.k					
	=	179.11514	kkal/kmol.k					
		390.5507	kg/kmol					
	=	**0.458622**	**kkal/kg.K**					

ΔH	=	m	x	cp	x	ΔT		
	=	3801.074288	x	0.458621957	x	70		
	=	122027.929	kkal					
Cp $C_8H_4O_3$	=	A	+	BT	+	CT^2	+	CT^3
	=	-105.6270	+	730.40960	+	-526.5106	+	142.271
	=	240.54	J/mol.K					
	=	240.54	x	**0.24**				
	=	57.491301	kal/mol.k					
	=	57.491301	kkal/kmol.k					
	=	57.491301	kkal/kmol.k					
		148.1140	kg/kmol					
	=	**0.3881559**	**kkal/kg.K**					
ΔH	=	m	x	cp	x	ΔT		
	=	2.89069932	x	0.388155857	x	70		
	=	78.54293108	kkal					
Cp $C_8H_6O_4$	=	A	+	BT	+	CT^2	+	CT^3
	=	-561.000	+	1273.7990	+	-624.8137	+	113.7652
	=	#########	J/mol.K					
	=	201.75047	x	**0.24**				
	=	48.219572	kal/mol.k					
	=	48.219572	kkal/kmol.k					
	=	48.219572	kkal/kmol.k					
		166.1286	kg/kmol					
	=	**0.2902544**	**kkal/kg.K**					
ΔH	=	m	x	cp	x	ΔT		
	=	2.899397513	x	0.29025442	x	70		
	=	58.90940609	kkal					
Cp $C_8H_{18}O$	=	A	+	BT	+	CT^2	+	CT^3
	=	-105.6270	+	360.4299	+	-354.7885	+	154.8903

= 54.9047 J/mol.K
= 54.9047 x **0.24**
= 13.122552 kal/mol.k
= 13.122552 kkal/kmol.k
= 13.122552 kkal/kmol.k
130.2257 kg/kmol
= **0.1007677 kkal/kg.K**

ΔH = m x cp x ΔT
= 5.078255562 x 0.100767744 x 70
= 35.82070482 kkal

Cp H_2O = A + BT + CT^2 + CT^3
= 92.0530 + -14.7087 + -28.6018 + 26.6794
= 75.42190 J/mol.K
= 75.42190 x **0.24**
= 18.026287 kal/mol.k
= 18.026287 kkal/kmol.k
= 18.026287 kkal/kmol.k
18.0147 kg/kmol
= **1.0006443 kkal/kg.K**

ΔH = m x cp x ΔT
= 1562.212421 x 1.000644281 x 70
= 109425.3248 kkal

Enthalpi Masuk

Komponen	Massa (kg)	Cp (kkal/kg.k)	ΔT (K)	ΔH (kkal)
$C_{24}H_{38}O_4$	3801.074288	0.458621957	70	122027.93
$C_8H_4O_3$	2.890699	0.388155857	70	78.542931
$C_8H_6O_4$	2.899398	0.29025442	70	58.909406
$C_8H_{18}O$	5.078255562	0.100767744	70	35.820705
H_2O	1562.212421	1.000644281	70	109425.32
Total				**231626.53**

Enthalpi bahan keluar

Kondisi operasi

Tekanan	=	1	atm
Suhu bahan keluar	=	100	℃
	=	373.15	K
Treff	=	25	℃
	=	298.15	K

Cp $C_{24}H_{38}C$	=	A	+	BT	+	CT^2	+	CT^3
	=	370.5240	+	738.98626	+	-579.27	+	222.48
	=	752.7233	J/mol.K					
	=	752.7233	x	**0.24**				
	=	179.90538	kal/mol.k					
	=	179.90538	kkal/kmol.k					
	=	179.90538	kkal/kmol.k					
		390.5507	kg/kmol					
	=	**0.4606454**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	3793.47214		x		0.460645357	x	75
	=	131058.3995	kkal					
Cp $C_8H_4O_3$	=	A	+	BT	+	CT^2	+	CT^3
	=	-105.6270	+	740.32960	+	-540.9092	+	148.1
	=	241.94	J/mol.K					
	=	241.94	x	**0.24**				
	=	57.825236	kal/mol.k					
	=	57.825236	kkal/kmol.k					
	=	57.825236	kkal/kmol.k					
		148.1140	kg/kmol					
	=	**0.3904104**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	2.89069932		x		0.39041044	x	75
	=	84.64193953	kkal					

Cp $C_8H_6O_4$	=	A	+	BT	+	CT^2	+	CT^3
	=	-561.000	+	1291.0990	+	-641.9007	+	118.4637
	=	206.662	J/mol.K					
	=	206.66202	x	**0.24**				
	=	49.393462	kal/mol.k					
	=	49.393462	kkal/kmol.k					
	=	49.393462	kkal/kmol.k					
		166.1286	kg/kmol					
	=	**0.2973206**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	2.899397513		x		0.297320572	x	75
	=	64.65378946		kkal				

Cp $C_8H_{18}O$	=	A	+	BT	+	CT^2	+	CT^3
	=	-105.6270	+	365.3250	+	-364.4910	+	161.2872
	=	56.49433	J/mol.K					
	=	56.49433	x	**0.24**				
	=	13.502484	kal/mol.k					
	=	13.502484	kkal/kmol.k					
	=	13.502484	kkal/kmol.k					
		130.2257	kg/kmol					
	=	**0.1036852**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	5.078255562		x		0.103685231	x	75
	=	39.49050747		kkal				

Cp H_2O	=	A	+	BT	+	CT^2	+	CT^3
	=	92.0530	+	-14.9085	+	-29.3840	+	27.7813
	=	75.541816	J/mol.K					
	=	75.541816	x	**0.24**				
	=	18.054947	kal/mol.k					
	=	18.054947	kkal/kmol.k					

= 18.054947 kkal/kmol
18.0147 kg/kmol
= **1.0022352 kkal/kg.K**

ΔH	=	m	x	cp	x	ΔT
	=	7.758369819	x	1.002235243	x	75
	=	583.1783747	kkal			

Enthalpi Keluar

Komponen	Massa (kg)	Cp (kkal/kg.k)	ΔT (K)	ΔH (kkal)
$C_{24}H_{38}O_4$	3793.4721	0.460645357	75	131058.4
$C_8H_4O_3$	2.8906993	0.39041044	75	84.64194
$C_8H_6O_4$	2.8993975	0.297320572	75	64.653789
$C_8H_{18}O$	5.0782556	0.103685231	75	39.490507
H_2O	7.7583698	1.002235243	75	583.17837
Total				**131830.36**

Entalpi uap air ke kondensor pada suhu 100°C (373,15 K),
Massa uap air = 1,562.0562 kg/jam = 86.7102 kmol/jam
λ H_2O = 9,717.0000 kkal/kmol (sherwood, Appendix A)

Cp H_2O = A + BT + CT^2 + CT^3 + CT^4
= 33.9 + -3.1414 + 4.1641 + -9.26E-01 + 0.00000
= 34.029592 J/mol.K
= 34.029592 x **0.24**
= 8.133277 kal/mol.k
= 8.133277 kkal/kmol.k

Enthalpi bahan = $\int_{Tref}^{T} Cp\,\Delta T$ + n x λ

H H2O uap = (Massa uap air x Cp H2O suhu 100) + (Massa uap air x lamda)
= **843268.0865** kkal/jam

Total entalpi bahan keluar = 131,830.36 + 843268.09
= 975098.45 kkal

Neraca Energi Total :
Entalpi bahan masuk + Q supply = Entalpi bahan keluar + Q loss
Asumsi Q loss = 5% dari Q supply
(kehilangan maksimum = 10% ; Ulrich : 432)
231,626.5 + Q supply = 975,098 + 5% dari Q supply
Q supply = 782,602 kkal/jam
Q loss = 39130.101 kkal/jam

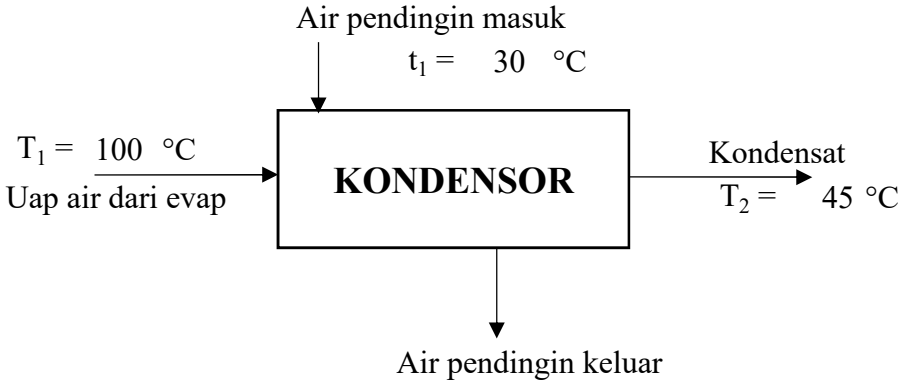
Kebututhan steam :
Digunakan steam dengan suhu 220°C dan tekanan 22,9 atm
(Ulrich, app B hal. 426)
Kebutuhan steam pada tekanan 22,9 atm dan suhu steam 220°C. (Ulrich, App. B)
λ_{steam} = 1856.2 kj/kg
= 443.6318 kkal/kg
Q_{steam} = m steam x λ_{steam}
M steam = $\frac{Qsteam}{\lambda\ steam}$
= $\frac{782,602.0250}{443.631800000}$
= 1764.080089 kg/jam

Steam ekonomi = $\frac{V}{S}$ = $\frac{H_2O\ menguap}{Kebutuhan\ steam}$
= $\frac{1,562.0562}{1764.0801}$
= **0.885479**
(Steam economy < 1,6 maka menggunakan Single Effect Evaporator)
(Wallas)

NERACA PANAS EVAPORATOR			
Panas Masuk		**Panas Keluar**	
Komponen	**ΔH (kkal)**	**Komponen**	**ΔH (kkal)**
$C_{24}H_{38}O_4$	122027.929	$C_{24}H_{38}O_4$	131058.3995
$C_8H_4O_3$	78.54293108	$C_8H_4O_3$	84.64193953
$C_8H_6O_4$	58.90940609	$C_8H_6O_4$	64.65378946
$C_8H_{18}O$	35.82070482	$C_8H_{18}O$	39.49050747
H_2O	109425.3248	H_2O	583.1783747
Total	231626.5268	Total	131830.3641
		$H_2O(g)$	843268.0865
Q_{serap}	782602.0250	Q_{loss}	39130.1013
Total	**1014228.5518**	**Total**	**1014228.5518**

9. Kondensor

Fungsi : Untuk mengubah uap air menjadi fase cair



Kondisi operasi:

Tekanan operasi = 1 atm (Tekanan atmofer)

Suhu operasi = 30 °C

Entalpi bahan masuk:

Entalpi bahan masuk kondensor Σ H = Σ H_{uap} keluar evaporator

$H_2O_{(g)}$ = 843,268 kkal/jam

Hv H_2O pada 100°C = 2,676.00 Kj/kg
= 639.5793 Kkal/kg
(Smith 7ed ; Steam Table F.1)

Asumsi :
Uap air yang lolos (non-condensat) = 1% uap air yang masuk
[Ludwig : 376]
Uap air yang lolos (non-condensat) = 1% x 1,562.056
= 15.6206 kg/jam
= 0.8671 kmol/jam
Entalpi Uap air yang lolos = 639.5793 x 15.6206
= 9990.5889 kkal/jam

Kondensat = Uap air yang masuk - Uap air non-condensat
Kondensat = 1,562.056200233 - 15.6206
Kondensat = 1,546.4356 kg/jam
= 85.8431 kmol/jam

Entalpi bahan keluar:
Uap air ke udara pada suhu 100°C

T_{masuk} = 100 °C = 373.15 K
T_{reff} = 25 °C = 298.15 K

$H_2O_{(g)}$ = A + BT + CT^2 + DT^3 + ET^4
= 33.9 + -3.1414 + 4.1641 + -9.26E-01 + 0.07161
= 34.101199 J/mol.K
= 34.101199 x **0.24**
= 8.150391 kal/mol.k
= 8.150391 kkal/kmol.k

$H_2O_{(g)}$ = n $\int_{Tref}^{T} Cp\,\Delta T$

= 85.8431 x 8.150391 x 75
= 52474.102 kkal/jam

Kondensat $H_2O_{(l)}$ ke Steam Condensat (SC) pada suhu 100°C

Massa kondensat = 1,546.4356 kg/jam = 85.843081 kmol/jam

λ H_2O = 5,456.8480 kkal/kmol (sherwood, Appendix A)

$H_2O_{(l)}$ = A + BT + CT^2 + DT^3 + ET^4

= 33.9 + -3.1414 + 4.1641 + 0.00E+00 + 0.00E+00

= 34.955738 J/mol.K

= 34.955738 x **0.24**

= 8.354631 kal/mol.k

= 8.354631 kkal/kmol.k

$H_2O_{(l)}$ = $n \int_{Tref}^{T} Cp\, \Delta T$

= 85.8431 x 8.354631 x 75

= 53789.046 kkal/jam

$H_2O_{(l)}$ = $\Delta H = n \int_{Tref}^{T} [Cp\, \Delta T] + n \times \lambda$ (Terjadi perubahan fase)

= 8.354631 + 85.8431 x 5,456.85

= 468441 kkal/jam

Total entalpi bahan keluar = 52,474.10 + 468,441

= 520,915 kkal/jam

Neraca Energi Total :

Q masuk = Q keluar + Qserap

843,268.0865 = 520,915 + Q serap

Q serap = 322,353.0 kkal/jam

Kebutuhan air pendingin

t air pendingin masuk (t_1) = 45 °C

t air pendingin keluar (t_2) = 30 °C

ΔT air pendingin = 45 - 30

= 15 °C

Dari Perry 5th ed. T. 3-176 P. 3-126, diketahui :

Cp air pendingin pada 30°C = 0.99866 kkal/kg.°C

Kebutuhan air pendingin

$$= \frac{Q}{Cp \times \Delta T}$$

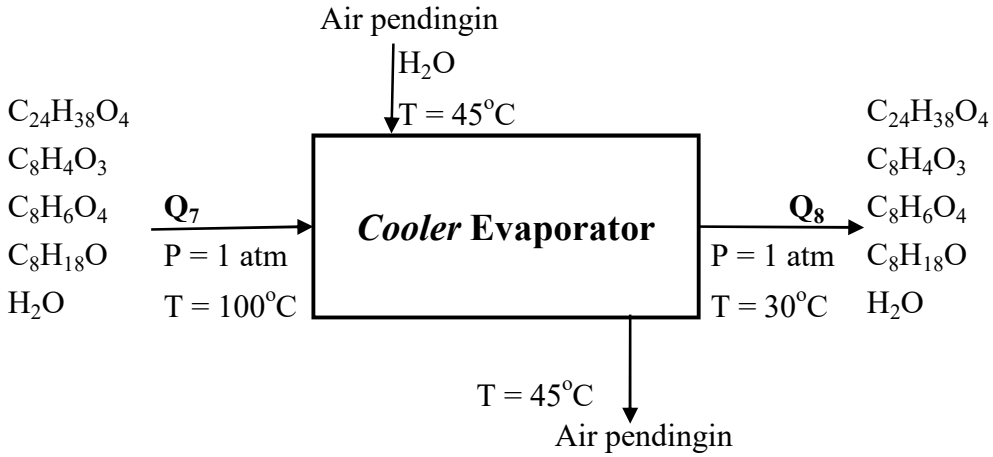
$$= \frac{322{,}352.9836}{0.99866 \times 15}$$

= 21,519.0344 kg/jam

NERACA PANAS KONDENSOR			
Masuk (kkal/jam)		**Keluar (kkal/jam)**	
Uap dari evaporator		Uap air yang lolos ke udara bebas	
$H_2O_{(g)}$	843,268.0865	$H_2O_{(g)}$	52,474.1022939323
		Kondensat	
		$H_2O_{(l)}$	468,441.0006514740
		Q serap	322,352.9835671930
Total	843,268.0865	**Total**	843,268.0865

10. *Cooler* Evaporator

Fungsi : untuk menurunkan suhu produk keluaran evaporator



Panas masuk *Cooler*

Tekanan = 1 atm

Suhu Operasi = 100 °C

= 373.15 K

Treff = 25 °C

= 298.15 K

Cp $C_{24}H_{38}C$	=	A	+	BT	+	CT^2	+	CT^3
	=	370.5240	+	738.98626	+	-579.27	+	222.48
	=	752.7233	J/mol.K					
	=	752.7233	x	**0.24**				
	=	179.90538	kal/mol.k					
	=	179.90538	kkal/kmol.k					
	=	179.90538	kkal/kmol.k					
		390.5507	kg/kmol					
	=	**0.4606454**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	3793.47214		x		0.460645357	x	75
	=	131058.3995		kkal				
Cp $C_8H_4O_3$	=	A	+	BT	+	CT^2	+	CT^3
	=	-105.6270	+	740.32960	+	-540.9092	+	148.147
	=	241.94	J/mol.K					
	=	241.94	x	**0.24**				
	=	57.825236	kal/mol.k					
	=	57.825236	kkal/kmol.k					
	=	57.825236	kkal/kmol.k					
		148.1140	kg/kmol					
	=	**0.3904104**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	2.89069932		x		0.39041044	x	75
	=	84.64193953		kkal				
Cp $C_8H_6O_4$	=	A	+	BT	+	CT^2	+	CT^3
	=	-561.000	+	1291.0990	+	-641.9007	+	118.4637
	=	#########	J/mol.K					
	=	206.66202	x	**0.24**				
	=	49.393462	kal/mol.k					
	=	49.393462	kkal/kmol.k					
	=	49.393462	kkal/kmol.k					
		166.1286	kg/kmol					
	=	**0.2973206**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	2.899397513		x		0.297320572	x	75
	=	64.65378946		kkal				

Cp $C_8H_{18}O$	=	A	+	BT	+	CT^2	+	CT^3
	=	-105.6270	+	365.3250	+	-364.4910	+	161.2872
	=	56.4943	J/mol.K					
	=	56.4943	x	**0.24**				
	=	13.502484	kal/mol.k					
	=	13.502484	kkal/kmol.k					
	=	13.502484	kkal/kmol.k					
		130.2257	kg/kmol					
	=	**0.1036852**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	5.078255562		x		0.103685231	x	75
	=	39.49050747		kkal				

Cp H_2O	=	A	+	BT	+	CT^2	+	CT^3
	=	92.0530	+	-14.9085	+	-29.3840	+	27.7813
	=	75.54182	J/mol.K					
	=	75.54182	x	**0.24**				
	=	18.054947	kal/mol.k					
	=	18.054947	kkal/kmol.k					
	=	18.054947	kkal/kmol.k					
		18.0147	kg/kmol					
	=	**1.0022352**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	7.758369819		x		1.002235243	x	75
	=	583.1783747		kkal				

Enthalpi Masuk

Komponen	Massa (kg)	Cp (kkal/kg.k)	ΔT (K)	ΔH (kkal)
$C_{24}H_{38}O_4$	3793.4721	0.460645357	75	131058.4
$C_8H_4O_3$	2.8906993	0.39041044	75	84.64194
$C_8H_6O_4$	2.8993975	0.297320572	75	64.653789
$C_8H_{18}O$	5.0782556	0.103685231	75	39.490507
H_2O	7.7583698	1.002235243	75	583.17837
Total				**131830.36**

Panas keluar *Cooler*

Tekanan	=	1 atm
Suhu Operasi	=	30 °C
	=	303.15 K
Treff	=	25 °C
	=	298.15 K

Cp $C_{24}H_{38}C$	=	A	+	BT	+	CT^2	+	CT^3
	=	370.5240	+	600.35826	+	-382.32	+	119.29
	=	707.8544	J/mol.K					
	=	707.8544	x	**0.24**				
	=	169.18145	kal/mol.k					
	=	169.18145	kkal/kmol.k					
	=	169.18145	kkal/kmol.k					
		390.5507	kg/kmol					
	=	**0.4331869**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	3793.47214		x		0.433186892	x	5
	=	8216.412037		kkal				

Cp $C_8H_4O_3$	=	A	+	BT	+	CT^2	+	CT^3
	=	-105.6270	+	601.44960	+	-357.0036	+	79.4
	=	218.25	J/mol.K					
	=	218.25	x	**0.24**				
	=	52.164172	kal/mol.k					
	=	52.164172	kkal/kmol.k					
	=	52.164172	kkal/kmol.k					
		148.1140	kg/kmol					
	=	**0.3521894**	**kkal/kg.K**					
ΔH	=	m		x		cp	x	ΔT
	=	2.89069932		x		0.352189434	x	5
	=	5.090368788		kkal				

Cp $C_8H_6O_4$	=	A	+	BT	+	CT^2	+	CT^3
	=	-561.000	+	1048.8990	+	-423.6586	+	63.5196
	=	127.760	J/mol.K					
	=	127.75993	x	**0.24**				
	=	30.53539	kal/mol.k					

	=	30.53539	kkal/kmol.k					
	=	30.53539	kkal/kmol.k					
		166.1286	kg/kmol					
	=	**0.1838057**	**kkal/kg.K**					
ΔH	=	m		x	cp	x	ΔT	
	=	2.899397513		x	0.183805692	x	5	
	=	2.664628838		kkal				
Cp $C_8H_{18}O$	=	A	+	BT	+	CT^2	+	CT^3
	=	-105.6270	+	296.7929	+	-240.5664	+	86.4813
	=	37.08086	J/mol.K					
	=	37.08086	x	**0.24**				
	=	8.8625475	kal/mol.k					
	=	8.8625475	kkal/kmol.k					
	=	8.8625475	kkal/kmol.k					
		130.2257	kg/kmol					
	=	**0.0680553**	**kkal/kg.K**					
ΔH	=	m		x	cp	x	ΔT	
	=	5.078255562		x	0.068055277	x	5	
	=	1.728010454		kkal				
Cp H_2O	=	A	+	BT	+	CT^2	+	CT^3
	=	92.0530	+	-12.1118	+	-19.3936	+	14.8962
	=	75.443783	J/mol.K					
	=	75.443783	x	**0.24**				
	=	18.031517	kal/mol.k					
	=	18.031517	kkal/kmol.k					
	=	18.031517	kkal/kmol.k					
		18.0147	kg/kmol					
	=	**1.0009346**	**kkal/kg.K**					
ΔH	=	m		x	cp	x	ΔT	
	=	7.758369819		x	1.000934614	x	5	
	=	38.8281045		kkal				

Enthalpi Keluar

Komponen	Massa (kg)	Cp (kkal/kg.k)	ΔT (K)	ΔH (kkal)
$C_{24}H_{38}O_4$	3793.4721	0.433186892	5	8216.412
$C_8H_4O_3$	2.8907	0.352189434	5	5.0903688
$C_8H_6O_4$	2.8994	0.183805692	5	2.6646288
$C_8H_{18}O$	5.0783	0.068055277	5	1.7280105
H_2O	7.7584	1.000934614	5	38.828104
Total				**8264.7231**

Q serap

Suhu air pendingin masuk = 30 °C = 303 K **(Ulrich : 427)**
Suhu reference = 25 °C = 298 K
Suhu air pendingin keluar = 45 °C = 318 K **(Ulrich : 427)**

Perhitungan kapasitas panas $H_2O_{(g)}$ 5

$$\int Cp\,dT = AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 + \frac{D}{4}T^4 + \frac{D}{5}T^5$$

$$= 170 + -12.65526 + 13.516391 + -2.422218 + 0.1509042$$

$$= 168.25482 \text{ J/mol.K}$$

$$= 168.25482 \times \mathbf{0.24}$$

$$= 40.213911 \text{ kal/mol.k}$$

$$= 40.213911 \text{ kkal/kmol.k}$$

$$= \frac{40.213911 \text{ kkal/kmol.k}}{18.0147 \text{ kg/kmol}}$$

$$= \mathbf{2.2322856 \text{ kkal/kg.K}}$$

Qserap = m air pendingin x Cp air x ΔT
= m air pendingin x 2.2323 x 15
= m air pendingin x 33.4843
Qloss = 5% x Qserap
= 5% x m air pendingin x 33.4843
= m air pendingin x 1.6742

Neraca Panas Total :

ΔH bahan masuk = ΔH bahan keluar + Q serap + Q loss

131830.3641 = 8264.723149 + ($m_{air\ pendingin}$ x 33.484284)

+ ($m_{air\ pendingin}$ x 1.6742142)

$$m_{air\ pendingin} = \frac{\Delta H \text{ bahan masuk} - \Delta H \text{ bahan keluar}}{33.484284 - 1.6742142}$$

$m_{air\ pendingin}$ = 3514.5312 kg

sehingga, Qserap = 117681.56 kkal

Qloss = 5884.0781 kkal

NERACA PANAS *COOLER*			
Panas Masuk		**Panas Keluar**	
Komponen	**ΔH (kkal)**	**Komponen**	**ΔH (kkal)**
$C_{24}H_{38}O_4$	131058.3995	$C_{24}H_{38}O_4$	8216.412037
$C_8H_4O_3$	84.64193953	$C_8H_4O_3$	5.090368788
$C_8H_6O_4$	64.65378946	$C_8H_6O_4$	2.664628838
$C_8H_{18}O$	39.49050747	$C_8H_{18}O$	1.728010454
H_2O	583.1783747	H_2O	38.8281045
		Q_{serap}	117681.5628
		Q_{loss}	5884.0781
Total	**131830.3641**	**Total**	**131830.3641**

APPENDIX C
SPESIFIKASI ALAT

1 GUDANG PENYIMPANAN KARBON AKTIF (F-110)

Temperatur = 30 C
Tekanan = 1 atm
Waktu penyimpanan = 30 hari
Fungsi = Untuk menyimpan bahan baku berupa karbon aktif
Tipe = berbentuk balok beratap asbes

Komponen karbon aktif masuk

Komponen	%Berat	Massa (Kg)	ρ (gr/ml)
Karbon akti	1	1.906049431	1.29568
Total	**1**	**1.906049431**	

$$\rho \text{ Campura} = \frac{1.000}{\text{Fraksi bera}} \times 62$$

$$\rho \text{ Kompon}$$

$$= \frac{1}{0.771796} \frac{\text{gr}}{\text{ml}} \times 62 \frac{\text{lbm/cu}}{\text{gr/ml}}$$

= 80.8893 lbm/cu

Rate massa = 1.906049 kg/jam
= 1.906049 x 2.205 **(konversi ke lb/jam)**
= 4.202839 lb/jam

$$\text{Rate volume} = \frac{\text{Rate Massa}}{\rho \text{ Campuran}}$$

$$= \frac{4.202839 \text{ lb/jam}}{80.8893 \text{ lb/cuft}}$$

= 0.051958 cuft/jar

DITENTUKAN

Waktu tinggal = 30 hari
= 720 jam
Tinggi = 1 H
Panjang = Lebar = 2 H
Volume bahan = Rate volum x Waktu tinggal (jam)
= 0.052 x 720
= 37.41 cuft

Volume gudang direncanakan 80% terisi bahan

$$\text{Volume gudang} = \frac{100}{80} \times 37$$

= 46.76 cuft

Volume gudang = P x L x H

46.76212 cuft = 2H x 2H x H
46.76212 cuft = 4 H^3
H^3 = 11.69 ft
= 2.27
3.28 **(Konversi ft ke m)**
= 0.692 m

Sehingga
Panjang = 2H = 1.384 m = 4.539 ft
Lebar = 2H = 1.384 m = 4.539 ft
Tinggi = H = 0.692 m = 2.27 ft

SPESIFIKASI GUDANG KARBON AKTIF

Nama = Gudang Garam Rakyat
Fungsi = Untuk menyimpan bahan baku berupa karbon aktif
Kapasitas = 37.40969 cuft
Panjang = 4.539152 ft
Lebar = 4.539152 ft
Tinggi = 2.269576 ft
Bahan Konstruksi = Beton
Jumlah = 1 buah

2 SCREW CONVEYOR (J-111)

Fungsi = memindahkan karbon aktif dari gudang ke bucket elevator
Type = Plain spouts or chutes.
Dasar pemilihan = Umum digunakan untuk padatan dengan sistem tertutup.

Perhitungan :

Rate massa bahan masuk = 1.9060 kg/jam
= 4.2021 lb/jam

ρ campuran = 80.8893 lb/cuft

$$\text{Rate volumetri} = \frac{\text{Rate massa}}{\rho \text{ campuran}}$$

$$= \frac{4.2021}{80.8893}$$

= 0.0519 cuft/jam
= 0.0009 cuft/menit

Asumsi jarak screw conve = 5 ft = 1.524 m.
Untuk densitas 80.8893 lb/cuft, bahan termasuk kelas D dengan
F = 4 (Badger, Tabel 16-6)

$$\text{Power motor} = \frac{C \cdot L \cdot W \cdot F}{33{,}000}$$ **(Badger, pers. 16-4)**

dengan : C = kapasitas ; cuft/menit
L = panjang ; ft
W = densitas bahan ; lb/cuft
F = faktor bahan

Asumsi panjang screw = 20 ft = 6.096 m

$$\text{Power motor} = \frac{C \cdot L \cdot W \cdot F}{33{,}000}$$

$$= \frac{0.0009 \times 20 \times 80.8893 \times 4}{33{,}000}$$

$$= 0.0002 \text{ hp}$$

Untuk power < 2 hp, maka dikalikan 2 (Badger : 713)

Power motor = 0.0002 x 2
= 0.0003 hp

Effisiensi motor = 80%

Maka :

$$\text{Power motor} = \frac{0.0003}{80\%}$$

$$= 0.0004$$

$$\approx 0 \text{ hp}$$

Badger, fig. 16-20 untuk kapasitas = 0.051949 cuft/jam
digunakan ukuran :
Diameter = 4 in Dasar pemilihan ini(?)
Kecepatan putaran = 27 rpm

SPESIFIKASI SCREW CONVEYOR

Kapasitas	:	0.0519	cuft/jam		
Panjang	:	20	ft	=	6.0960 m
Diameter	:	4	in	=	0.1016 m
Kecepatan putaran	:	27	rpm		
Power	:	0.000424	hp		
Jumlah	:	1	buah		

3 BUCKET ELEVATOR (J-112)

Tempe = 30 C
Tekana = 1 atm
Fungsi = Mengangkut karbon aktif dari belt conveyor menuju hopper
Tipe = Continuous bucket elevator

PERHITUNGAN

Rate massa = 1.906 kg/jam
= 0.002 ton/jam
ρ Campura = 80.89 lbm/cuft

Dari perry 7 Ed. T 21-9 dipilih bucket elevator dengan spesifikasi :

Tinggi bucket = 18.71 ft
Putaran head shaft = 28 rpm
kapasitas maksimum = 35 ton/jam
bucket linear speed = 150 ft/mnt

maka, kecepatan bucket elevator = $\frac{\text{Rate massa}}{\text{kapasitas maksimu}} \times \text{bucket}$

$= \frac{0.001906049}{35} \times 150 \text{ ft/mnt}$

= 0.008 ft/mnt

Power head shaft = 1.8 hp
power tambahan = 0.06 hp tiap ft
= 0.06 x 19
= 1.12239 hp
power total = Pwr.head shaft + Pwr tambahan
= 1.8 + 1
= 2.92239 hp
ukuran bucket = Lebar x Proyeksi x Kedalaman
= "x5.5"x7.75
bucket spacing = 8 inch
efisiensi motor = 0.8

maka, motor penggerak yang = $\frac{\text{Power total}}{\text{fisiensi moto}}$

$= \frac{2.92239}{0.8}$

= 4 hp = 4 hp

SPESIFIKASI BUCKET ELEVATOR

Nama = Bucket Elevator 1
Fungsi = Memindahkan kristal garam dari gudang menuju tangki pelarutan garam
Tipe = Continuous bucket elevator
Kapasitas = 0.001906 ton/jam
Bucket = tinggi buck = 18.7065 ft
kecepatan = 0.0081688 ft/menit
bucket spa = 8 in
ukuran buc = "x5.5"x7.75
putaran hea = 28 rpm

power = 3.6529875 hp
jumlah = 1 buah

4 HOPPER KARBON AKTIF (F-113)

Temperatu = 30 C
Tekanan = 1 atm
Waktu ting = 1 jam
Fungsi = Menampung sementara karbon aktif sebelum masuk tangki dekolorisasi
Tipe = Silinder dengan tutup bawah berbentuk conical dalam posisi vertikal

PERHITUNGAN

Rate massa = 1.906049 kg/jam
= 4.202839 lb/cuft
ρ Campuran = 80.8893 lbm/cuft
Rate volumetrik = Rate Massa / ρ Campura
= 4.202839 lb/jam / 80.8893 lb/cuft
= 0.051958 cuft/jam

DITENTUKAN

Waktu tinggal = 1 jam
Tinggi (Hs) = 1.5 D
α = 45 °
Volume Bahan = 0.052 cuft
Volume tangki direncanakan 80% terisi bahan, maka
Volume tangki = 100 / 80 x 0.052
= 0.065 cuft
Volume silinde = (π/4) x D2 x Hs
= 3.14 x 2 2D^3
= 9.42 D^3
Volume konis = (π D3) / 24 tgα (Hesse, 92)
= 3.14 x D^3 / 12 x 1
= 0.262 D^3
Jadi, Volume t = Vsilind + V konis
0.064947 cuf = 9.42 D^3 + 0.2617 D^3
0.064947 cuf = 9.682 D^3
D = 5.215 ft

H = 2D = 10.429 ft

MENENTUKAN UKURAN HOPPER DAN KETEBALANNYA

Tinggi Conical

$H = \frac{tg\alpha \times (D - }{2}$ (Hesse, 92)

Keterangan

α = sudut conis = 45 °
D = diameter tangki = ft
m = flat spot center = 12 in
= 1 ft

Maka

$H = \frac{tg\alpha \times (D - m)}{2}$

$= tg45 \times \frac{5.214566238 - 1}{2}$

= 1.607283119 ft

Volume Conical = 0,262 H (D^2 + D.m (Hesse, 92)
= 0.262 x 1.607283 x 33.40627
= 14.06765233 cuft

Volume Shell = Volume Conical-Volume tangki
= 0.064947386 - 14.06765233
= 14.00270494 cuft

Volume Shell = $(\pi/4) \times D^2 \times H$

14.00270494 = 3.14 x 27.1917 x H

H = 0.16400078 ft

Jadi tinggi total = 10.42913248 + 0.16400078
= 10.59313326 ft

Tekanan Bahan = $\frac{Density \times H}{144}$

= $\frac{1.29568 \times 10.59313326}{144}$

= 0.095314659 psig

P operasi = 87.4385 psig

P design diambil 10% lebih besar dari P operasi untuk faktor keamanan.

P design = 110% x P perencanaan
= 110% x (87.4385 + 0.095315)
= 96.2872 psig

MENENTUKAN TEBAL MINIMUM SHELL

Tebal shell berdasarkan ASME Code untuk cylindrical tank :

$$t_{min} = \frac{P \times r}{fe - 0.6P} + C$$ (Brownell, pers 13-1 hal 266)

Dipilih

f	=	12650	bahan konstruksi carbon stell SA-283 grade C		
e	=	0.8			
c	=	0.125	in		
r	=	0.5	D	in	
	=	0.5	x	5.214566238	ft
	=	2.607283119	ft		
	=	31.28739743	in		

$$t_{min} = \frac{96.28719612 \times 31.28739743}{10120 - 57.77231767} + 0.125$$

$$= 0.424 \text{ in}$$

Maka dipilih ts = 7/16 in

PENENTUAN TEBAL HEAD

Jenis = Conical

Tipe Las = Single welded butt joint tanpa backing up strip dengan efisiensi

$$th = \frac{P \times D}{2 \cos \alpha - (f.E - 0.6\,P)} + C$$

$$= \frac{96.28719612 \times 31.28739743}{2 \cos \alpha - (10120 - 57.77231767)} + 0.125$$

$$= 1.09548465$$

maka digunakan th = 1 2/16 in

SPESIFIKASI HOPPER

Fungsi	=	Menampung garam rakyat sementara sebelum menuju tangki pelarutan garam	
Tipe	=	Silinder dengan tutup bawah berbentuk conical dalam posisi vertikal	
Kapasitas	=	0.051957909	cuft
Diameter dalam silinder	=	5.214566238	ft
Tinggi silinder	=	10.42913248	ft
Tebal silinder	=	7/16	in
Diameter atas conical	=	5.214566238	ft
Diameter bawah conical	=	1	ft
Tinggi conical	=	1.607283119	ft
Cone angel	=	45	^{o}
Tebal angel	=	1 2/16	in

Jumlah = 1 buah

5 TANGKI PENYIMPANAN NaOH

Fungsi = Menampung NaOH 48%
Type = silinder tegak, tutup bawah datar dan tutup atas dishead
Dasar pem = umum digunakan pada tekanan atmosfer
Jumlah = 1 buah
Kondisi Op = T = 30 °C = 303 K
P = 1 atm = 760 mmHg = 14 psi

Feed masuk = 0.007 kg/jam
= 0.016 lb/jam

Komponen	Massa (kg/jam)	Fraksi Massa	Sg	Fraksi/sg
NaOH	2.81257E-05	0.48	2.13	0.225352
H_2O	3.04695E-05	0.52	1	0.52
Total	**5.85953E-05**			0.745352

Densitas refrer = 62.43700000 lb/cuft
rho campuran = $\frac{62.43700}{\Sigma \text{ fr massa/sg}}$
= 83.768 lb/cuft
rate volumetrik = $\frac{0.015504}{83.7685}$
= 0.0002 cuft/jam
direncanakan penyimpanan untuk 7 hari dengan 1 buah tangki
volume tangki = $\frac{0.00019 \times 7.00 \times 24.000}{1.000}$
= 0.031 cuft
direncanakan tangki terisi 80%
sehingga volur = $\frac{0.03109}{0.80000}$
= 0.03887 cuft
menentukan ukuran tangki dan ketebalannya :
asumsi $\frac{H}{D}$ = 1.000
volume = phi / 4 x D2 x H
0.039 = 0.785 x D2 x 2.000 D
0.039 = 1.570 D3
D3 = 22.997
D = 10.000 ft = 120.00 in
H = 4.000 ft = 48.000 in

penentuan tinggi cairan dalam tangki :

Vol shell = Vol tangki = Vol baha = 0.038868 cuft

tinggi bahan = tinggi shell = 4.000000 ft

menentukan tebal minimum shell

tebal shell berdasarkan ASME Code untuk cylindrical tank

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

dengan :

tmi = tebal shell minimum, in

P = tekanan tangki, psi

ri = jari2 tangki, in (1/2 D)

C = faktor korosi, in (digunakan 1/8 in)

E = faktor pengelasan, digunakan double welded butt join, E=0,8

f = stress allowable, bahan komstruksi Carbon steel SA-283 grade C, maka f = 12650 psi (brownell&young)

Poperasi = Phidrostatis + Patmospheric

$$= \frac{rho \times g \times h}{144.000}$$

= 2.327 psi

Poperasi = 2.327 + 14.700

= 17.027 psi

Pdesign diambil 10% lebih besar dari dari Poperasi untuk faktor keamanan

Pdesig = 1.100 x 17.027

= 18.730 psi

ri = 60

= 60 in

$$tmin = \frac{18.730 \times 60}{(12650 \times 1) - (1 \times 19)} + 0$$

= 0.236 in

maka digunaka = 1/4 in

untuk tebal tutup atas karena tekanan atmospheric,

maka tebal tutup atas disamakan dengan tebal tutup

she = 1/4 in

untuk tebal tutup bawah datar karena tutup menumpang di atas semen,

maka tebal = 1/4 in (brownell, hal 58)

Tangki Penampung NaOH 48%

fungsi = Menampung NaOH 48%

type = silinder tegak, tutup bawah datar dan tutup atas dishead

volume = 0.031 cuf = 0.880 L

diameter = 10 ft = 3.048 m

tinggi = 4 ft = 1.219 m

Tebal shell = 1/4 in
tebal tutup = 1/4 in
tebal tutup = 1/4 in
bahan kons = carbon steel SA-283 grade C (brownell)
jumlah = 1 buah

6 POMPA NaOH (L-121)

Fungsi : Mengalirkan NaOH dari tangki penyimpanan NaOH menuju *mixe*
Tipe : *Centrifugal pump*
Jumlah : 1 buah

Menghitung Tenaga Pompa

Rate masu = 1449.699 kg/jam = 0.8878 lb/s
Densitas = 1876.707 kg/m³ = 117.1628 lb/ft³
μ = 1.164 cP = 0.0008 lb/ft.s

$$\textit{Rate}\ \text{volumetrik (Q)} = \frac{\text{massa}}{\text{r}}$$

$$= \frac{0.887779\ \text{lb/s}}{117.1628\ \text{lb/f}}$$

$$= 8.E\text{-}03\ \text{ft}^3/\text{s}$$

$$= 3.4009\ \text{gpm}$$

Diperkirakan aliran fluida laminar (Nre<2100), sehingga digunakan persamaan Di < 1 in yaitu :

$$\text{Di opt} = 4\ Q^{0,40}\ \mu^{0,20}$$ Eq. 48. (Peters & Timmerhaus, 1991:365)

Dimana :
Di opt = diameter dalam optimum, in
Q = kecepatan volumetrik, ft^3/s
μ = viskositas fluida, lb/ft.s
Sehingga:

$$\text{Di opt} = 3.6 \times (\ 8.E\text{-}03\ )^{0,40} \times (\ 0.001\ )^{0,20}$$

$$= 0.122\ \text{in}$$

Dari App. A.5-1 (Geankoplis, 1993:892) dipilih spesifikasi :
NPS = 1/8 in
OD = 0.405 in = 0.034 ft = 0 m
ID = 0.269 in = 0.022 ft = 0 m
A = 0.000 ft² = 0.372 in^2
Sch = 40

Menghitung kecepatan linier :
Kecepatan linier fluida dapat dicari dengan menggunakan persamaan sebagai berikut :

$$V = \frac{Q}{A}$$

Sehingga :

$$V = \frac{0.008 \text{ ft}^3/\text{s}}{0.000 \text{ ft}^2} = 18.94 \text{ ft/s} = 5.774 \text{ m/s}$$

Menghitung *Reynold Number* (Nre):

$$Nre = \frac{\rho \, v \, D}{\mu}$$

Sehingga:

$$Nre = \frac{117.2 \times 18.94 \times 0.02}{0.00}$$

$$= 63594.45 \quad \text{(asumsi aliran laminar benar)}$$

Instalasi pipa
Dari ***Fig*** . 127. (Brown, 1950:141) dengan NPS = 1/8 in

- 1 buah *gate valve fully open* ; Le	=	0.2	ft
∑Le = 1 × 0.2	=	0.2	ft
- 4 buah *standard elbow* ; Le	=	1	ft
∑Le = 4 × 1	=	4	ft
- 1 buah *sudden enlargement* ; Le	=	4.5	ft
∑Le = 1 × 4.5	=	4.5	ft
- 1 buah *sudden contraction* ; Le	=	2.5	ft
∑Le = 1 × 2.5	=	2.5	ft
- 1 buah *swing check valve* ; Le	=	2.5	ft
∑Le = 1 × 2.5	=	2.5	ft
- Panjang ekivalen pipa lurus, ∑Le	=	13.7	ft
Panjang pipa lurus	=	2	m
	=	6.562	ft
Panjang pipa total	=	20.26	ft
	=	6.176	m

Menghitung *friction loss*

$$\Sigma F = \frac{4f \, . \, v^2 \, . \, \Delta L}{2 \, . \, ID \, . \, gc}$$ (Eq. 2.10-6 Geankoplis, 1993: 89)

Dimana :
ΣF = *Friction lo* (ft.lbf/lbm)
f = Faktor friksi

v = Kecepatan linier fluida (ft/s)
ΔL = Panjang pipa (ft)
ID = Diameter dalam tangki (ft)
gc = 32.174 lbm.ft/lbf.s^2

Menghitung *Fanning Friction Factor* (f) :
Dari **Fig. 2.10-3. (**Geankoplis, 1993:88) didapat :
Untuk *commercial steel* → ε = 0.000048 m
= 0.000157 ft

Sehingga :

$$\frac{\varepsilon}{D} = \frac{0.0002}{0.022} = 0.0070$$

Dari **Fig. 2.10-3.** (Geankoplis, 1993:8 = 63594.45
didapatkan = 0.005 sehingga :

$$\Sigma F = \frac{4 \times 0.005 \times (18.94)^2 \times 20.26}{2 \times 0.0224 \times 32.174}$$

$$= 100.8111 \ \frac{lb_f \,.\, ft}{lb_m}$$

Menghitung *Static Head* :
Z_1 = 1 m = 3.28084 ft
Z_2 = 0.2 m = 0.656168 ft
ΔZ = Z_1-Z_2 = 2.6247 ft
g/gc = 1 lbf/lbm
ΔZ (g/gc) = 2.625 ft × 1 lbf/lbm
= 2.625 ft lbf/lbm
Menghitung *Velocity Head* :
V_1 = kecepatan linier fluida dari tangki hidrogen peroksida ke pipa
V_2 = kecepatan linier fluida ke *heater*
Karena pada 2 titik *reference* dianggap sa 18.9433 ft/s
Sehingga *velocity head* (ΔV^2 / 2agc) = 5.5767

Menghitung *Pressure Head* :
P_1 = P_2 = 14.7 Psi
ΔP = 0
Sehingga, ΔP/ρ = 0

Menghitung Energi Mekanik Pompa :

$$-Wf \quad \frac{\Delta V^2}{2 \times \alpha \times} + \Delta z \frac{g}{gc} + \frac{\Delta P}{\rho} + \sum F$$

Dimana :

Wf = tenaga yang ditambahkan ke dalam sistem per satuan massa

Sehingga :

$$-Wf = 5.58 + 3 \text{ ft. lbf/ll} + 0 + 100.8 \text{ ft. lbf/lbm}$$
$$= 109.0124 \text{ ft. lbf/lbm}$$

Menghitung *Broke Horse Power* (BHP):

$$BHP = \frac{m.(-Wf)}{550 \,.\, \eta}$$

dari **Fig. 14-37.** (Peters & Timmerhaus, 1991:520), untuk Qf 3.4009 gpm diperoleh η pompa = 0.40

Sehingga:

$$BHP = \frac{0.888 \times 109.0}{550 \times 0.400}$$
$$= 0.439905 \text{ Hp; maka digunakan } power$$
$$= 1 \text{ Hp}$$

Menghitung Tenaga Motor

Fig. 14.38., (Peters & Timmerhaus, 1991:521) untuk BH = 1.0 Hp diperoleh η mc = 0.80

Sehingga *power* motor yang diperlukan :

$$P \text{ motor} = \frac{BHP}{\eta}$$
$$= \frac{1}{0.80} \text{ Hp}$$
$$= 1.3 \text{ Hp}$$

Dipilih motor standar deng = 2 Hp (*Standard* NEMA)

Spesifikasi Pompa NaOH

Nama Alat	:	Pompa NaOH
Kode	:	L-121
Fungsi	:	Mengalirkan NaOH dari tangki penyimpanan NaOH menuju *mixer*
Tipe	:	*Centrifugal pump*
Bahan Konstruksi	:	*Commercial steel*
Jumlah	:	1 buah
Rate Volumetrik	:	8.E-03 ft^3/s
Kecepatan Aliran	:	18.9433 ft/s
Ukuran Pipa	:	NPS = 1/8 in

: *Sch. Numb* = 40
: OD = 0.0338 ft = 0.01 m
: ID = 0.0224 ft = 0.007 m
: *Flow Area* = 0.0004 ft^2 = 4E-05 m^2

Power Pompa : 1 Hp
Power Motor : 2 Hp

7 MIXER NaOH (M-122)

Fungsi : Menambahkan H_2O untuk mengencerkan NaOH
Tipe : Tangki berbentuk silinder tegak, tutup atas dan bawah berbentuk *torispherical*
Jumlah : 1 buah
Kondisi Op : T = 30 °C = 303 K
P = 1 atm = 760 mmHg = 14.7 psi

Menentukan Kapasitas Tangki

Massa Masuk		**MassaKeluar**	
1. NaOH 48%		1. NaOH 0.4%	
Komponen	assa (Kg/Ja	Komponen	assa (Kg/Jar
NaOH	2.81E-05	$NaOH_{(aq)}$	0.0070314
H2O	3.05E-05	Total	0.0070314
Total	5.86E-05		
2. Air Proses			
Komponen	assa (Kg/Ja		
H2O	0.006973		
Total	0.006973		
Total	0.007031	Total	0.007031

T = 30 °C = 303.15 K

Density : $A.B^{-(1-T/Tc)^n}$ (Yaws, 1989)

Komponen	**A**	**B**	**n**	**Tc (K)**	**ρ (kg/m^3)**
NaOH	0.2	0.098	0.254	2820	1909.231
H_2O	0.347	0.274	0.286	647.1	1022.875

Viscosity : $\log_{10} n_{liq} = A+B/T+CT+CT^2$ (Yaws, 1989)

Komponen	**A**	**B**	**C**	**D**	**μ (cP)**
NaOH	-4.19	#####	0.003	-6E-07	2307.170
H_2O	-10.2	1793	0.018	-1E-05	0.815

Komponen	%Berat	ρ (kg/m^3)	$\rho_{Campuran}$ (kg/m^3)	μ (cP)	$\mu_{campuran}$ (cP)
NaOH	0.0040	1909.231	0.0000	2307.170	2.E-06
H_2O	0.9960	1022.875	0.0010	0.8150	1.2220
Total	**1.0000**	**2932.107**	**0.0010**	**2307.985**	**1.2220**

$$\rho_{campuran} = \frac{\sum xi}{\sum xi/\rho} = \frac{1.0000}{0.0010} = 1024.778 \text{ kg/m}^3$$

$$= 63.9769 \text{ lb/ft}^3$$

$$\mu_{campuran} = \frac{\sum xi}{\sum xi/\mu} = \frac{1.0000}{1.2220} = 0.8183 \text{ cP}$$

$$= 0.0005 \text{ lb/ft.s}$$

Aliran keluar *mixer* dijaga selalu berada pada 0.007 kg/jam. Sehingga tidak terjadi defisit aliran pada *mixer*, karena beroperasi kontinyu (tidak ada waktu tinggal) dianggap pengadukan sempurna 100%. Maka :

$$V_{cairan} = \frac{m}{\rho} = \frac{0.007 \text{ kg/jam}}{1025 \text{ kg/m}^3} = 0.00001 \text{ m}^3 \quad 0.002$$

$$= 0.0002 \text{ ft}^3$$

Untuk perancangan diasumsikan tangki berisi 80% sehingga volume desain tangki sebagai berikut :

Volume tan = 0.000007 m^3 ÷ 80% = 0.000009 m^3

= 0.000303 ft^3

= 0.002266 galon

Menentukan Diameter dan Tinggi *Shell*

Tangki dirancang dengan tutup atas berupa *torispherical.*

Untuk ukuran optimum tangki silinder, harga $H_S/ID = 2$

Asumsi $H_S/ID = 2$

$H_S = 2$ ID

V_{tangki} = V silinder + 2 × V tutup

$V_{tangki} = (¼ \times (\pi \times ID^2) \times H_s + 2 \times (0{,}000049\ ID^3)$

$0.000009 = (¼ \times (3{,}14 \times ID^2) \times + 2 \times (0{,}000049\ ID^3)$

$0.000009 = 1{,}1775 + 2 \times (0{,}000049\ ID^3)$

$ID^3 = 0.000005$

ID = 0.0176 m = 0.058 ft = 0.692 in

$H_S = 2 \times ID$
$= 2 \times 0.0176 \text{ m}$
$= 0.035 \text{ m} = 0.1156 \text{ ft}$

Menentukan Tinggi Cairan pada Tangki

$$H_L = \frac{V_L}{¼ \times \pi \times} = \frac{0.0002}{¼ \times \pi \times 0.0578)^2} = 0.092 \text{ ft}$$

$= 0.028 \text{ m}$

Menentukan Tekanan Desain

$P_{operasi} = 1 \text{ atm} = 14.7 \text{ psi}$

$P_{hidrostatik} = \rho_{campuran\ cair} \times \frac{g}{gc} \times H_S$

$= 63.98 \text{ lb/ft}^3 \times 1 \times 0.1156 \text{ ft}$

$= 7.39 \text{ lb/ft}^2 = 0.0513 \text{ psi}$

$P_{desain} = P_{operasi} + P_{hidrostatik}$

$= 14.7 + 0.0513$

$= 14.7473 \text{ psi}$

Menentukan Tebal *Shell*

Dengan faktor keamanan 20%, maka :

P_d = tekanan desain = 1.2 × 14.75 psi = 17.70 Psi

r = jari-jari *shell* = 0.692 : 2 = 0.3459 in

f = *allowable stress* = 12650 psi

Carbon steel SA-283 *Grad* (Brownell & Young, 1959:251)

E = efisiensi pengelasan *double-we* = 80%

c = faktor korc = 0.125

Sehingga :

$$t_s = \frac{P_d.r}{f.E - 0{,}6\ P_d} + c$$

(Pers 13.1 Brownell & Young, 1959 : 254)

$$= \frac{17.6968 \times 0.3459}{12650 \times 80\% - 0.6 \times 17.70} + 0.125$$

$= 0.1256 \text{ in}$

$\approx$ 3/16 in **Tabel 5.7** (Brownell & Young, 1959:89)

Menentukan Diameter dan Tinggi yang Distandarkan

Diameter standar (Ds)

$OD = ID + 2\ t_s$

= 0.692 in + 2 × 3/16 in
= 1.067 in

Sehingga :

$OD_{standar}$ = 28 in **Tabel 5.7** (Brownell & Young, 1959:89)

ID = $OD_{standar}$ - 2 t_s
= 28 in - 2 × 3/16 in
= 28 in
= 0.7017 m

Diperoleh OD 28 in dengan :

icr = 1 3/4 in
r = 26 in

Tinggi standar (H_S)

H_S = 2 × 28 in
= 55 in
= 1.4034 m

Menentukan Dimensi pada Tutup

$$th = \frac{0.885\ P_d.r}{f.E - 0.1\ P_d} + c$$

$$= \frac{0.885 \times 17.70 \times 0.35}{12650 \times 80\% - 0.1 \times 17.70} + 0.125$$

= 0.1255 in

Digunakan tebal standar = 3/16 in (Brownell & Young, 1959:89)

Dari **Tabel 5.6** (Brownell & Young, 1959:88) untuk tebal tutup 3/16 in didapat nilai sf 1½ -2 in Diambil sf : 1 1/2 in

Dari ***Fig* . 5.8** (Brownell & Young, 1959:87), dihitung ukuran-ukuran sebagai berikut :

a = ½ ID = ½ × 28 = 13.8125 in
AB = a - icr = 13.813 - 1 3/4 = 12.06 in
BC = r - icr = 26 - 1 3/4 = 24.25 in
AC = $\sqrt{(BC)^2 - (AB)^2}$ = 21.0371 in
b = r - AC = 26 x 21.04 = 4.9629 in
OA = th + b + sf
= 0 + 4.9629 + 1 1/2 = 6.4629 in
= 0.1642 m

Tinggi tangki t = Hs + 2 OA
= 0.0352 + 2 × 0.1642
= 0.3635 m

Menentukan Jumlah Pengaduk

Dipilih jenis pengaduk *propeler three-blade*

$$SpGr = \frac{\rho_{campuran}}{\rho_{air}} = \frac{63.977 \text{ lb/ft}^3}{63.858 \text{ lb/ft}^3} = 1.0019$$

$$\text{umlah pengadu} = \frac{H_L \times S}{ID} = \frac{0.0282 \text{ m} \times 1.002}{0.7017 \text{ m}}$$

$$= 0.0402$$

$$\approx 1 \text{ buah}$$

Menentukan Diameter dan Tinggi Pengaduk

Diameter pengaduk

ID/d = 3 (Brown, 1950:507)

$$Da = \frac{ID}{ID/} = \frac{0.702}{3} = 0.2339 \text{ m}$$

$$= 9.2083 \text{ in}$$

$$= 0.7674 \text{ ft}$$

Jarak pengaduk dari dasar tangki

Zi/d = 0,75 - 1,3 ; (dipilih 0,75) (Brown, 1950:507)

$$Zi = 0{,}75 \times Da = 0.75 \times 0.2339 = 0.1754 \text{ m}$$

$$= 6.9062 \text{ in}$$

$$= 0.5755 \text{ ft}$$

Menentukan Dimensi Pengaduk

Tabel 3.4-1. (Geankoplis, 1993:144)

W/Da = 1/5
Dd/Da = 2/3
H/Dt = 1
L/Da = 1/4
J/Dt = 1/12

$$H = Dt = 28 \text{ in} = 0.711 \text{ m} = 2.333 \text{ ft}$$

$$Dd = 2/3 \times Da = 2/3 \times 9.2083 \text{ in}$$

$$= 6.139 \text{ in} = 0.156 \text{ m} = 0.512 \text{ ft}$$

$$L = 1/4 \times Da = 1/4 \times 9.2083 \text{ in}$$

$$= 2.302 \text{ in} = 0.058 \text{ m} = 0.192 \text{ ft}$$

$$W = 1/5 \times Da = 1/5 \times 9.2083 \text{ in}$$

$= 1.842 \text{ in} = 0.047 \text{ m} = 0.153 \text{ ft}$

$J = 1/12 \times OD = 1/12 \times 28 \text{ in}$
$= 2.333 \text{ in} = 0.059 \text{ m} = 0.194 \text{ ft}$

Menentukan Power Motor Pengaduk

Kecepatan putar pengaduk

$$WELH = \frac{\rho_{campuran}}{\rho_{air}} \times H_L = \frac{63.98 \text{ lb/ft}^3}{63.86 \text{ lb/ft}^3} \times 0.092 \text{ ft}$$
$$= 0.09 \text{ ft}$$

$$N = \frac{600}{\pi d}\sqrt{\frac{WELH}{2d}}$$ Eq. 8.8 (Rase & Holmes, 1977:338)

Keterangan:
Da = diameter pengaduk (ft)
N = kecepatan putar pengaduk (rpm)
WELH = *water equivalent liquid height* (ft)

$$N = \frac{600}{\pi d}\sqrt{\frac{WELH}{2d}} = \frac{600}{3.14 \times 0.7674}\sqrt{\frac{0.0926}{2 \times 0.7674}}$$
$$= 7.5145 \text{ rpm}$$

Diambil kecepatan pengaduk standar 320 rpm, maka (Walas, 1990:288) :
N = 320 rpm = 5.3333 rps

Bilangan Reynold

$$N_{Re} = \frac{\rho \times Da^2 \times N}{\mu}$$ Pers. 3.4-1 (Geankoplis, 1993:158)

$$= \frac{63.98 \text{ lb/f} \times 0.7674 \text{ }^2\text{ft} \times 5.333 \text{ rps}}{0.0005} \text{ lb/ft.s}$$
$$= 365915.88$$

Karena $N_{Re} > 10.000$, maka sesuai untuk digunakan *baffle*
(Perry, 1997:9-8)

Power pengaduk
Karena $N_{Re} > 10.000$ maka power tidak tergantung pada bilangan Reynold dan bukan merupakan fungsi viskositas. Maka untuk pengaduk jenis *propeller* 3 *blades* didapa 0.87 **Tabel 9.3**
(Mc Cabe et al., 1993:254). Sehingga :

$$P = \frac{Np.\rho.N^3.Da^5}{gc}$$ Pers. 9.20 (Mc Cabe et al., 1993:253)

Keterangan :
P = daya pengaduk (lb.ft/s)
Np = *power number*
ρ = densitas campuran (lb/ft^3)
N = kecepatan putar pengaduk (rps)
Da = diameter pengaduk (ft)
gc = percepatan gra = 32 lb.ft/lbf.s^2

$$P = \frac{0.87 \times 63.98 \times 5.3333^{3} \times 0.77^{5}}{32.1740}$$
= 69.83 lb.ft/s
= 0.13 hp

Selama proses pengadukan, pengaduk mengalami :
- *Gain Losses* diperhitungkan 10% dari daya masuk (dengan mempertimbangkan adanya kebocoran daya pada proses dan *bearing*) = 10% × Po *Gain* = 0.013 hp
- *Transmission Losses* diperhitungkan 20% dari daya masuk (dengan meninjau kemungkinan terjadinya kebocoran *belt* atau *gear*) = 20% × Po

Transmission l = 0.0254 hp
Power input = 0.1270 + 0.0127 + 0.0254
= 0.1650 hp

***Fig* . 14.38.** (Peters & Timmerhaus, 1991:521) didapat efisiensi motor pengaduk 80%, maka *power* motor pengaduk sebesar :

Power motor $= \frac{P}{\eta} = \frac{0.1650}{80\%} =$ 0.206 hp

Maka digunakan *power* motor pengad = 1 hp

Menentukan Poros Pengaduk

Jarak antara pengaduk

$$Hi = \frac{H_L - Zi}{4} = \frac{0.028 - 0.175}{4} =$$ -0.0368 m

Panjang po = $Z_T + Zp - Zi$

Keterangar Z_T = tinggi total tangki
Zp = jarak motor ke *bearing*
Zi = jarak pengaduk dari dasar tangki

Panjang po = 0.364 + 0.3048 − 0.175 = 0.493 m

Diameter poros

$$\tau = \frac{HP \times 75 \times 60}{2 \pi v}$$

Keterangan: HP = daya pengaduk
v = kecepatan putaran pengaduk

$$\tau = \frac{1 \times 75 \times 60}{2 \times 3.14 \times 320} = 2.239 \text{ kg.m}$$

Dengan faktor keamanan 50% maka:
Momen pu = 2 × 2.239 = 3.359 kg.m

$$\frac{\tau}{f_s} = \frac{\pi Dp^3}{16}$$

$$Dp^3 = \frac{16 \tau}{\pi f_s}$$

Keterangan:
fs = *shear stres* = 6E+06 kg/m^2
Dp = diameter poros

$$Dp^3 = \frac{16 \times 3.359}{3.14 \times \#\#\#\#\#}$$

Dp^3 = 0.0000 m^3
Dp = 0.0146 m
= 1.4600 cm
= 0.5748 in

Spesifikasi *Mixer* NaOH

Fungsi	:	Menambahkan H_2O untuk mengencerkan NaOH
Tipe	:	Tangki berbentuk silinder tegak, tutup atas dan bawah berbentuk *torispherical*
Tipe Pengaduk	:	*Propeler three-blade*
Bahan Konstru	:	*Carbon Steel* SA-283 *Grade* C
Jumlah	:	1 buah
Kondisi Opera	:	Temperatur 30^{o}C dan Tekanan 1 atm
Kapasitas	:	0.00001 m^3
Dimensi		
Shell		
Diameter	:	0.01761 m
Tinggi	:	0.03522 m
Tebal	:	0.12561 in

Tutup
Tinggi : 0.16416 m
Tebal : 0.12554 in
Tinggi Tangki : 0.36354 m
Jumlah Pengad : 2 buah
Power Motor : 1 hp

8 POMPA MIXER (L-123)

Fungsi : Mengalirkan NaOH dari *mixer* menuju *heater*
Tipe : *Centrifugal pump*
Jumlah : 1 buah

Menghitung Tenaga Pompa

Rate masu = 0.007 kg/jam = 0.0000 lb/s lb/s
Densitas = 1025 kg/m³ = 63.977 lb/f lb/ft³
μ = 1.164 cP = 0.0008 lb/f lb/ft.s

$$\textit{Rate volumetr} = \frac{\text{massa}}{\rho}$$

$$= \frac{0.000004 \text{ lb/s}}{63.98 \text{ lb/ft}^3} = 0.00000007 \text{ ft}^3/\text{s}$$

$$= 0.00003021 \text{ gpm}$$

Diperkirakan aliran fluida turbulen (Nre<2100), sehingga digunakan persamaan Di ≥ 1 in yaitu :

$$Di_{opt} = 3.9 \; Q^{0,45} \; \mu^{0,13}$$ Eq. 45. (Peters & Timmerhaus, 1991:365

Dimana :
Di opt = diameter dalam optimum, in
Q = kecepatan volumetrik, ft^3/s
μ = viskositas fluida, lb/ft.s

Sehingga :

$$Di_{opt} = 3.9 \times (0.0000)^{0,4:} \times (0.001)^{0,13}$$

$$= 0.00091165 \text{ in}$$

Dari App. A.5-1 (Geankoplis, 1993:892) dipilih spesifikasi :
NPS = 1/4 in
OD = 0.540 in = 0 ft = 0.014 m
ID = 0.364 in = 0 ft = 0.009 m

A = 0.001 ft² = 1 in^2
Sch = 40

Menghitung kecepatan linier :
Kecepatan linier fluida dapat dicari dengan menggunakan persamaan berikut :

$$V = \frac{Q}{A}$$

Sehingga:

$$V = \frac{0.000\ ft^3/s}{0.001\ ft^2}$$

= 9E-05 ft/s

= 3E-05 m/s

Menghitung *Reynold Number* (Nre) :

$$Nre = \frac{\rho\ v\ D}{\mu}$$

Sehingga :

$$Nre = \frac{63.98 \times 0.000 \times 0.0303}{0.0007823}$$

= 0.232 (asumsi aliran turbulen benar)

Instalasi pipa
Dari ***Fig*. 127.** (Brown, 1950:141 1/4 in

- 1 buah *gate valve fully open* ; Le = 0.26 ft
  ∑Le = 1 × 0.26 = 0.26 ft
- 3 buah *standard elbow* ; Le = 1.4 ft
  ∑Le = 3 × 1.4 = 4.2 ft
- 1 buah *sudden enlargement* ; Le = 1.4 ft
  ∑Le = 1 × 1.4 = 1.4 ft
- 1 buah *sudden contraction* ; Le = 0.52 ft
  ∑Le = 1 × 0.52 = 0.52 ft
- 1 buah *swing check valve* ; Le = 3 ft
  ∑Le = 1 × 3 = 3 ft
- Panjang ekivalen pipa lurus, ∑Le = 9.38 ft
  Panjang pipa lurus = 2 m
  = 6.562 ft

Panjang pipa total = 15.94 ft
= 4.859 m

Menghitung *friction loss*

$$\Sigma F = \frac{4f \cdot v^2 \cdot \Delta L}{2 \cdot ID \cdot gc}$$ Eq. 2.10-6 (Geankoplis, 1993:89)

Dimana :
ΣF = *Friction loss* (ft.lbf/lbm)
f = Faktor friksi
v = Kecepatan linier fluida (ft/s)
ΔL = Panjang pipa (ft)
ID = Diameter dalam tangki (ft)
gc = 32.174 lbm.ft/lbf.s^2

Menghitung *Fanning Friction Factor* (f):
Dari ***Fig*. 2.10-3. (**Geankoplis, 1993:88) didapat :
Untuk *commercial* → ε = 5E-05 m
= 0.0002 ft
Sehingga :

$$\frac{\varepsilon}{D} = \frac{0.00016}{0.0303} = 0.00519164$$

Dari **Fig. 2.10-3.** (Geankoplis, 1993:8 0.231879193
didapatkan nilai f = 0.0030 sehingga :

$$\Sigma F = \frac{4 \times 0.003 \times (0.000)^2 \times 15.94}{2 \times 0.0303 \times 32.17}$$

$$= 0.000000000856 \frac{lb_f \cdot ft}{lb_m}$$

Menghitung *Static Head* :
Z_1 = 1 m = 3.28084 ft
Z_2 = 0.2 m = 0.656168 ft
ΔZ = Z_1-Z_2 = 2.6247 ft
g/gc = 1 lbf/lbm
ΔZ (g/ = 3 ft × 1 lbf/lbm = 3 ft lbf/lbm

Menghitung *Velocity Head* :
V_1 = kecepatan linier fluida dari tangki hidrogen peroksida ke pipa
V_2 = kecepatan linier fluida ke *heater*

Karena pada 2 titik *reference* dianggap sama, maka $V_1 = V_2$ 0.00009348 ft/s
Sehingga *velocity head* $(\Delta V^2 / 2agc)$ = 0.000000000136

Menghitung *Pressure Head* :
$P_1 = P_2$ = 14.7 Psi
ΔP = 0
Sehingga, $\Delta P/\rho$ = 0

Menghitung Energi Mekanik Pompa :

$$-Wf = \frac{\Delta V^2}{2 \times \alpha \times gc} + \Delta z \frac{g}{gc} + \frac{\Delta P}{\rho} + \sum F$$

Dimana :
Wf = tenaga yang ditambahkan ke dalam sistem per satuan massa

Sehingga :

- Wf = 1E-10 + 2.625 ft. lbf/lbm + 0 + 9E-10 ft. lbf/lbm
= 2.625 ft. lbf/lbm

Menghitung *Broke Horse Power* (BHP) :

$$BHP = \frac{m.(-W}{550 \,.\, \eta}$$

dari ***Fig* . 14-37.** (Peters & Timmerhaus, 1991:520), untuk Qf = ########### gpm diperoleh η pon = 0.40

Sehingga :

$$BHP = \frac{0.0000 \times 2.6247}{550 \times 0.4000}$$

= 0.0000000514 Hp; maka digunaka = 1 Hp

Menghitung Tenaga Motor

***Fig.* 14.38**., (Peters & Timmerhaus, 1 = 1.0 Hp
diperoleh η mc = 0.80
Sehingga *power* motor yang diperlukan :

$$P\ motor = \frac{BHP}{\eta}$$

$$= \frac{1 \quad Hp}{0.80}$$

= 1.3 Hp

Dipilih motor standar deng = 2 Hp (*Standard* NEMA)

Spesifikasi Pompa *Mixer*

Kode	:	L-123					
Fungsi	:	Mengalirkan NaOH dari *mixer* menuju *heater*					
Tipe	:	*Centrifugal pump*					
Bahan Konstru	:	*Commercial steel*					
Jumlah	:	1 buah					
Rate Volumet	:	0.0000	ft^3/s				
Kecepatan Alir	:	0.0001	ft/s				
Ukuran Pipa	:	NPS	=	1/4	in		
	:	*Sch. Numb*	=	40			
	:	OD	=	0.0450	ft	=	0.014 m
	:	ID	=	0.0303	ft	=	0.009 m
	:	*Flow Area*	=	0.0007	ft^2	=	0.000 m^2
Power Pompa	:	1	Hp				
Power Motor	:	2	Hp				

9 HEATER NaOH (E-124)

Fungsi : Memanaskan natrium hidroksida sebelum masuk *neutraliser* suh 30 °C menjadi 95 °C

Tipe : *Double pipe heat exchanger*

Jumlah : 1 buah

KOMPONEN	Massa	FRAKSI (x)	ρ (g/ml)	x/ρ
NaOH	2.81E-05	0.00400000	2.13	0.001878
H2O	0.007003	0.99600000	1.00	1.000000
Total	0.01	1.00	3.13	1.00

ρ bahan = 0.998 x 62.43 $\frac{lb/ft^3}{gr/ml}$

= 62.31 lb/ft^3

Rate bahan = 0.01 lb/jam

Rate volumetri = $\frac{\text{Rate massa}}{\rho \text{ bahan}}$

= 0.0001128405 ft^3/jam

T bahan masuk	=	30.00	°C	=	86	°F	(t1)
T bahan keluar	=	95	°C	=	203	°F	(t2)
T steam masuk	=	220.00	°C	=	428	°F	(T1)
T steam keluar	=	220.00	°C	=	428	°F	(T2)

Q Supply	=	0.24979	kkal/jam
	=	0.98919	BTU/jam
Kebutuhan Steam	=	0.00056	kg/jam
	=	0.00124	lb/jam

Log Mean Temperature Difference (ΔT LMTD)

$$\Delta T\ LMTD = \frac{\Delta t2 - \Delta t1}{\ln \frac{\Delta t2}{\Delta t1}}$$

$\Delta t1 = T1 - t2$
$= 225\ ^oF$
$\Delta t2 = T2 - t1$
$= 342\ ^oF$
$\Delta T\ LMTD = 279.4\ ^oF$

Tc dan tc

tc = T bahan
= 144.5 ^oF
Tc = T stean
= 428 ^oF

Trial :

UD = 100 - 500
= 500
Tipe = 1-2 Heat Exchanger
Length = 10 ft
OD = 1.00 in
BWG = 14
Passes = 2
a't = 0.546 in^2
a" = 0.262 ft^2 / ft

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

$= 0.000007\ ft^2$

$$Nt = \frac{A}{L \times a"}$$

$= 1.00000$

Berdasarkan Tabel 9 kern dipilih ukuran yang paling mendekati :

OD tube = 1 in
Pitch = 1 1/4 in
Passes = 2 L/D = 86.96
Nt = 16
a" = 0.262 ft^2 / ft
Wall thickr = 0.083 in
ID tube = 1.38 in ; 0.115 ft
ID shell = 2.38 in
B space = 1.428 in
Passes = 1
A = Nt x L x a"
= 41.9 ft^2

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

= 0.000084447

Hot Fluid :	Cold fluid
o) Flow area, as as = ID x C' x B /144 Pr B = ID / 5 = 0 in C' = Pt - OD tube / 2 = 1/8 as = 8E-04 ft^2	o) Flow Area, at at = Nt x at / 144 n = 0.0303 ft^2
o) Mass Velocity, Gs Gs = w / as = 2 lb/jam.ft^2	o) Mass Velocity, Gt Gt = w / at = 0.23 lb/jam.ft^2
o) Bilangan Reynold, Ret Nre = Ds x Gt / μ tc = 428 °F μ = 0.016 cP = 0.039 lb/jam.ft Ds = 0.99 in = 0.083 ft Nre = 3.35490	o) Bilangan Reynold, Ret Nre = D x Gt / μ μ = 0.316 cP = 0.761 lb/jam.ft Nre = 0.03505
o) jH = 580	o) jH = 1000

Hot Fluid :	Cold fluid
o) k = 0.9 k_{water}	o) $(c\mu/k)^{1/3}$
= 0.36	tc = 144.5
c = 0.45	c = 0.36
$(c\mu/k)^{1/3}$ = 0.364	k = 0.45
	$(c\mu/k)^{1/3}$ = 0.8
o) ho = 1500 BTU/hr.ft^2.^{o}F x φt	**o)** hi = jH .k/D . $(c\mu/k)^{1/3}$ x φt
ho = 1500 BTU/hr.ft^2.^{o}F	hi = 276.32156
φs	φt
o) tw = tc + ho/φt (Tc-tc)	
hio/φt+ho/φs	
= 667.40	
φs = $\frac{(\mu)^{1/4}}{(\mu w)^{1/4}}$	φt = $\frac{(\mu)^{1/4}}{(\mu w)^{1/4}}$
φs = 0.938	$(\mu w)^{1/4}$ = 0.242
	φt = 1.331
o) ho = 1599	o) hio = 208

o) ho = 1599

Menghitung UC

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

= 183.689209 BTU/ft^2 ^{o}F jam

Menghitung Rd

$Rd = \frac{Uc - U_D}{Uc \times U_D}$

U_D = 0.0001

Rd = 11841.7 > 0.002000 (memenuhi)

Pressure Drop	
o) Nre = 3	o) Nre = 0.03505
f = 0.000001	f = 5E-04
v = 37.93145 ft^3/lb	s = 1
ρ = 0.0264 lb/ft^3	
s = 0.000422	
o) N+1 = 12 L/B	o) ΔP = fGt^2.L.ı

Pressure Drop	
= 84.03361 o) de = 0.9904 in = 0.0825 ft o) ΔPs = f . Gs^2 . Ds . (N 5,22 . 10^{10} . De = 9E-12 < 10 psi (memenuhi)	5,22 . 10^{10}.Dt. = 9E-14 < 2 psi (memenuhi)

Spesifikasi Heater NaOH

Type Heater = 2-4 Shell & Tube Exchanger
Jumlah = 1 buah

Bagian shell :

Jenis Bahan = Carbon steel
ID Shell = 2.38 in
Baffle Space = 1.428 in
Passes = 1

Bagian tube :

Jumlah & Panjang Tube = 1 buah, 10 ft
OD, BWG, pitch = 1 in , 14 BWG 1 1/4 Triangular
Passes = 2

10 GUDANG PENYIMPANAN PHTHALIC ANHYDRIDE (F-130)

Temperatur = 30 C
Tekanan = 1 atm
Waktu penyim = 30 hari
Fungsi = Untuk menyimpan bahan baku berupa phthalic anhydride
Tipe = berbentuk balok beratap asbes

Komponen karbon aktif masuk

Komponen	%Berat	Massa (Kg)	ρ (gr/ml)
$C_8H_4O_3$	0.997	1445.34966	1.53
$C_8H_6O_4$	0.002	2.899397513	1.52
H_2O	0.001	1.449698756	0.998
Total	**1**	**1449.698756**	

$$\rho \text{ Campura} = \frac{1.000}{\frac{\text{Fraksi bera}}{\rho \text{ Kompon}}} \times 62$$

$$= \frac{1}{\frac{0.653952}{\text{ml}}}\ \text{gr} \times 62\ \frac{\text{lbm/cu}}{\text{gr/ml}}$$

= 95.46575 lbm/cuf
Rate massa = 1449.699 kg/jam
= 1449.699 x 2.205 **konversi ke lb/jam)**
= 3196.586 ɔ/jam
Rate volumet = Rate Massa / ρ Campuran
= 3196.586 lb/jam / 95.46575 lb/cuft
= 33.48411 cuft/jam

DITENTUKAN

Waktu tinggal = 30 hari
= 720 jam
Tinggi = 1 H
Panjang = Lebar = 2 H
Volume bahan = Rate volume x Waktu tinggal (jam)
= 33.484109 x 720
= 24109 cuft

Volume gudang direncanakan 80% terisi bahan

Volume gudan = $\frac{100}{80}$ x 24109
= 30136 cuft

Volume gudan = P x L x H
30135.7 cuf = 2H x 2H x H
30135.7 cuf = 4 H^3
H^3 = 7534 ft
= 19.6
3.28 **(Konversi ft ke m)**
= 5.977 m

Sehingga

Panjang = 2H = 11.95 m = 39.21 ft
Lebar = 2H = 11.95 m = 39.21 ft
Tinggi = H = 5.977 m = 19.6 ft

SPESIFIKASI GUDANG PENYIMPANAN PHTHALIC ANHYDRIDE

Fungsi = Untuk menyimpan bahan baku berupa phthalic anhydride
Kapasitas = 24108.56 cuft
Panjang = 39.20761 ft
Lebar = 39.20761 ft
Tinggi = 19.60381 ft
Bahan Konst = Beton
Jumlah = 1 buah

11 BELT CONVEYOR PHTHALIC ANHYDRIDE (J-131)

Tempe = 30 C
Tekana = 1 atm
Fungsi = Mengangkut *phthalic anhydride* dari gudang menuju *bucket elevator*
Tipe = Troughed belt on 45° idlers with rolls of equal length
(Dipilih conveyor jenis belt sesuai dengan bahan)

PERHITUNGAN

Rate Mass = 1449.699 kg/jam
= 1.4497 ton/jam
Berdasarkan kapasitas bah = 1.45 ton/jam
Dari Perry 7 Ed. T 21-7 dan fig 21-4 dipilih belt conveyor dengan spesifikasi :
Kapasitas mak = 32 ton/jam
hp tiap 10 ft (li = 0.34 hp/ft

ASUMSI

Jarak Belt = 13 ft
Tinggi belt = 10 ft
Slope = α
tg α = $\frac{10}{13}$
α = 0.769230769
Panjang Belt = √(13^2+10^2)
= 16.40122 ft
Perhitungan Powe
hp/10 ft, lift = 0.34 hp/ft

hp = $\frac{16.40122}{10}$ x 0.3
= 0.557641 hp
Penambahan power untuk tripper = 2 hp
Power Total = 2.5576 hp = 3 hp

SPESIFIKASI BELT CONVEYOR

Nama = Belt Conveyor phthalic anhydride
Fungsi = Mengangkut *phthalic anhydride* dari gudang *menuju bucket elevator*
Kapasitas = 1.45 ton/jam
Bel :
Width = 14 in = 0.3556 m
Through wid = 9 in = 0.2286 m
Skirt Seal = 2 in = 0.0508 m

Belt speed = 1.45 x 100 ft/min
= 32
= 4.53 ft/min
Panjang = 16.4 ft
Power = 3 hp
Jumlah = 1 buah

12 BUCKET ELEVATOR PHTHALIC ANHYDRIDE (J-132)

Fungsi : Mengangkut *Phthalic Anhydride* dari *belt conveyor* menuju *hopper*
Jumlah : 1 buah
Kondisi Operasi : T = 30 °C = 303.15 K
P = 1 atm = 760 mmHg = 14.7 psi

Komposisi Bahan

Komponen	%Berat	Massa (Kg)	ρ (gr/ml)
C8H4O3	0.997	1445.34966	1.2
C8H6O4	0.002	2.899397513	1.526
H2O	0.001	1.449698756	0.997
Total	**1**	**1449.698756**	

$$\rho \text{ Campuran} = \frac{1.000}{\frac{\Sigma \text{ Fraksi berat}}{\Sigma \rho \text{ Komponen}}} \times 62.43$$

$$= \frac{1}{\frac{1}{1} + \frac{0}{2} + \frac{0.0}{1}} \times 62.43$$

= 1.2 x 62.43
= 74.9 lb/cuft
Rate massa = 1449.6988 kg/jam
= 1.4497 ton/jam
ρ Campuran = 74.9 lbm/cuft

Dari perry 7 Ed. T 21-9 dipilih bucket elevator dengan spesifikasi :
Tinggi bucket = 18.7065 ft
Putaran head shaft = 28 rpm
kapasitas maksimum = 35 ton/jam
bucket linear speed = 150 ft/mnt
maka, kecepatan bucket elevator = $\frac{\text{Rate massa}}{\text{kapasitas maksimum}} \times$ bucket

$$= \frac{1.4497}{35} \times 150 \text{ ft/mnt}$$

= 6.2130 ft/mnt
Power head shaft = 1.8 hp

power tambahan = 0.06 hp tiap ft
= 0.06 x 18.7065
= 1.12239 hp
power total = Pwr.head shaft + Pwr tambahan
= 1.8 + 1.12239
= 2.92239 hp
ukuran bucket = Lebar x Proyeksi x Kedalaman
= 8"x5.5"x7.75"
bucket spacing = 8 inch
efisiensi motor = 0.8
maka, motor penggerak yang digunakan = $\frac{\text{Power total}}{\text{efisiensi motor}}$

$= \frac{2.92239}{0.8}$

= 3.6529875 hp

SPESIFIKASI BUCKET ELEVATOR

Nama = *Bucket Elevator* $C_8H_4O_3$
Fungsi = Mengangkut *Phthalic Anhydride* dari belt conveyor menuju hopper
Tipe = Continuous bucket elevator
Kapasitas = 1.449698756 ton/jam
Bucket = tinggi bucket = 18.7065 ft
kecepatan = 6.21299467 ft/mnt
bucket spacing = 8 in
ukuran bucket = 8"x5.5"x7.75"
putaran head shaft = 28 rpm
power = 3.6529875 hp = 4 hp
jumlah = 1 buah

13 HOPPER PHTHALIC ANHYDRIDE (F-133)

Fungsi : Menampung sementara *phthalic anhydride* sebelum masuk *melter*
Tipe : Tangki silinder vertikal dengan tutup atas berupa *plate* dan tutup bawah berupa *conical*
Jumlah : 1 buah
Kondisi Operasi : T = 30 °C = 303.15 K
P = 1 atm = 760 mmHg
= 14.7 psi

Rate massa = 1449.6988 kg/jam
= 3196.5858 lb/cuft
ρ Campuran = 74.9 lbm/cuft

Rate volumetri = $\frac{\text{Rate Massa}}{\rho \text{ Campuran}}$

= $\frac{3196.5858 \text{ lb/jam}}{74.9328 \text{ lb/cuft}}$

= 42.6594 cuft/jam

Direncanakan penyimpanan untuk 1 Jam dengan 1 buah hopper

Volume : = $\frac{42.6594 \text{ x } 1 \text{ jam}}{43}$

= 1.0000 cuft

Asumsi volume bahan 80%

Volume Tangki = $\frac{1.0000}{80\%}$

= 1.2500 cuft = 9.350625 gal

Menentukan ukuran tangki tangki dan ketebalannya

Dimensi ratio = $\frac{H}{D}$ = 2 *[Ulrich; T.4-27:p.248]*

Dengan mengabaikan volume dished head.

Volume tangki = $\frac{\pi}{4}$ x D^2 x H

1.2500 = $\frac{3.14}{4}$ x D^2 x H

1.2500 = 1.57 x D^3

D^3 = 0.80 ft

D = 0.93 ft , H = 1.9 ft

= 11.12 in 22.2 in

= 0.28 m 0.6 m

Tinggi feed dalam tangki :

Volume feed = $\frac{\pi}{4}$ x D^2 x H

1.0000 = $\frac{3.14}{4}$ x 0.8590 x H

H feed = 1.4829 ft

P operasi = 1 atm = 14.7 psi

P design diambil 10% lebih besar dari P operasi untuk faktor keamanan.

P design = P operasi x 110% *[Walas; p.623]*

= 14.7 x 1

= 16.17 psi

Penentuan tebal shell :

$$t_{min} = \frac{P \times ri}{fE - 0{,}6P} + C \qquad \textit{[Brownell\&Young; eq.13-1]}$$

dengan

t_{min} = tebal shell mini ;in
P = tekanan tangki ; psi
ri = jari-jari tangki ; in (1/2 D)
C = faktor korosi ; in (digunakan 1/8)
E = faktor pengelasan, digunakan d E = 1
f = stress allowable,
bahan konstruksi Low-Alloy Steel SA-203 Grade C 2 1/2 Ni
f = 18750 psi *[Brownell&Young; T.13-1]*

ri = 1 x D
= 1 x 11.12 in
= 5.561 in

$$t_{min} = \frac{P \times ri}{fE - 0{,}6P} + C$$

$$= \frac{16.17 \times 5.561}{15000 - 9.702} + 0.125$$

$$= \frac{89.9217}{14990.30} + 0.125$$

= 0.006 + 0.125
= 0.131 in

digunal t_{min} = 4/16 in

Tutup bawah, conis : *[Brownell&Young; p.118]*

Tebal conica $= \frac{P.D}{2 \cos \alpha (fe - 0{,}6P)} + C$

Dengan α = 1/2 sudut conis = 60°/2 = 30

$$tc = \frac{P.D}{2 \cos \alpha (fE - 0{,}6P)} + C$$

$$tc = \frac{14.70 \times 11.1220}{1.73 \times 14990.30} + 1/8$$

$$= \frac{163.4941}{25967.94} + 1/8$$

= 0.13 in digunakan t = 4/16 in

Tinggi conical :

$$h = \frac{tg\ \alpha \times (D - m)}{2} \qquad \textit{[Hesse; eq.4-17]}$$

Keterangan = α = 1/2 sudut conis ; 30
D = diameter tangki (ft)
m = flat spot center ; 12 in 1 ft

$$h = \frac{tg\ \alpha \times (D - m)}{2}$$

$$= \frac{0.577 \times 0.0732}{2}$$

$$= 0.02 \text{ ft}$$

SPESIFIKASI HOPPER PHTHALIC ANHYDRIDE

fungsi	:	Menampung sementara *phthalic anhydride* sebelum masuk melter
type	:	Silinder tegak dengan tutup alas plat dan bawah conis
volume tangki	:	1.25 cuft
diameter tangki	:	0.93 ft
tinggi total	:	0.02 ft
tebal shell	:	4/16 in
tebal tutup bawah	:	4/16 in
bahan konstruksi	:	Low-Alloy Steel SA-203 Grade C 2 1/2 Ni
jumlah	:	1 buah

14 MELTER PHTHALIC ANHYDRIDE (X-134)

Fungsi	:	Tempat meleburkan *Phthalic Anhydride* padat menjadi *Phthalic Anhydride* cair, untuk keperluan proses
Tipe	:	silinder vertikal dengan alas dan tutup berbentuk *torispherical*
Bahan	:	*Carbon Steel SA-283 Grade C*
Jumlah	:	1 buah
Kondisi Operasi	:	T = 165 °C = 438.2 K
		P = 1 atm = 760 mmHg = 14.7 psi

Menentukan Kapasitas Tangki

Komponen	Massa kg/jam	%Berat	ρ (gr/m^3)	%Berat/ρ
C8H4O3	1445.35	0.997	1.53	0.651634
H2O	1.44970	0.001	0.997	0.001003
C8H6O4	2.899398	0.002	1.522	0.001314
Total	**1449.699**	**1**		**0.653951**

$$\rho_{campuran} = \frac{\sum xi}{\sum xi/\rho}$$

$$= \frac{1.000}{0.654}$$

$$= 1.529 \text{ kg/m}^3$$

Cp Campuran = $\frac{1}{1915}$ = 0.000522

Kebutuhan *Phthalic Anhydride* = 1445.350 kg/jam
= 3186.447 lb/jam

Densitas bahan = 1.529 kg/m^3 = 0.095 lb/ft^3

$V_{bahan} = \frac{m}{\rho}$

$= \frac{1445.350\ kg}{1.529166\ kg/m^3}$

$= 945.19\ m^3$

$= 26764.7\ ft^3$

Asumsi 80% volume tangki merupakan volume larutan, sehingga :

$Vt = \frac{V}{0.8} = \frac{945.1879}{0.8}\ m^3$

$= 1181.485\ m^3$

$= 200227.0$ galon

Diameter Tangki, D

$Vt = Vs + Vd$

$Vt = (1/4\ \pi\ D^2\ H) + (2 \times 0{,}000049 D^3)$

$= (1/4\ \pi\ 2\ D^3) + (2 \times 0{,}000049 D^3)$

$= D^3\ (2/4\ \pi + 0{,}000098)$

$D^3 = \frac{Vt}{2/4\ \pi + 0{,}000098}$

$= \frac{200227.0335}{2/4\ \pi + 0{,}000098}\ ft^3$

$= 1.5701\ ft^3$

D = 1.1623 ft
= 13.9473 in
= 0.3543

H = 2 D
H = 2 × 1.1623 ft
= 2.3246 ft
= 27.8946 in
= 0.7085 m

Tinggi Larutan

Volume larutan dalam *dish* = 5E-05 D^3

Pers. 5.11 (Brownell & Young, 1959)

$= 5E\text{-}05 \times 13.9473^{3}$
$= 0.13 \ ft^3$

Volume larutan dalam *shell* $= V_{larutan} - V_{dish}$
$= 26764.7 \ ft^3 - 0.13 \ ft^3$
$= 26764.6 \ ft^3$

Tinggi larutan dalam *shell* $= \dfrac{\text{Volume larutan dalam } shell}{1/4 \ \pi \ D^2}$

$= \dfrac{26764.6089 \ ft^3}{1/4 \ \pi \times 1.16^{2} \ ft^2}$

$= 25239 \ ft$
$= 7692.9 \ m$

Tekanan *Design*

Tekanan Hidrostatik, $P_H = \rho \times g/g_c \times Hs/144$
$= 0.0955 \times 1 \times 7692.870 / 144$
$= 5.1000 \ psia$

Tekanan *Design* ,$P_d = (P_{op} + P_H) \ Sf$; dengan faktor keamanan 10%
$= (14,7 + 5.1000) \times 1.1$
$= 21.7800 \ psia$

Penentuan Tebal *Shell*

$$ts = \frac{(Pd \times ri)}{(f \times E) - (0{,}6 \times Pd)} + C$$ Pers. 13.1 (Brownell & Young, 1959)

Dimana :
t_s = tebal dinding tangki, in
Pd = tekanan desain
ri = jari-jari tangki
f = *allowable stress*
E = effisiensi pengelasan
C = faktor korosi

Bahan konstruksi yang dipilih adalah *Carbon Steel* SA-283 *Grade* C :
f = 12650 psi **Tabel 13.1. (**Brownell & Young, 1959:251)
E = 80% **Tabel 13.2. (**Brownell & Young, 1959:254)
ri = D/2
C = 0.125

$$ts = \frac{21.7800 \times 6.9737}{(12650 \times 80\% - 0.6 \times 21.7800)} + 0$$

ts = 0.14003 in

Diambil tebal *shell* standard = 1/5 in (3/16)

Tabel 5.7. (Brownell & Young, 1959:89)

OD	= ID + (2 × ts)	=	14.3223 in
OD di standardkan	= 38 in	=	3.1667 ft
ID koreksi	= OD - 2ts	=	37.6250 in
		=	0.9557 m
		=	3.1354 ft

H koreksi = 2 x ID
= 2 × 0.95568 m
= 1.91135 m
= 6.27076 ft

Penentuan Tebal *Dish*

$$td = \frac{(0{,}885 \times Pd \times Rc)}{(f \times E) - (0{,}1 \times Pd)} + C$$

Rc = ID/2 = 18.8125 in

$$td = \frac{0.885 \times 21.78 \times 18.8125}{12650 \times 1 - 0.1 \times 21.8} + 0.125$$

= 0.1608 in

Dipakai tebal *dish* standar 3/16 in = 0.188 in

Penentuan Tinggi *Dish*

OD standard = 38 in

r = 36 in **Tabel 5.7.** (Brownell & Young, 1959:89)

icr = 2 3/8 in **Tabel 5.7.** (Brownell & Young, 1959:89)

AB = ID/2 - icr
= 16 4/9 in

BC = r - icr
= 33.625 in

b = $r-(BC^2-AB^2)^{1/2}$
= 6.6666 in Pers. 5.8. (Brownell & Young, 1959:87)

Tinggi *flange* , sf = 2 in **Tabel 5.8. (**Brownell & Young, 1959:93)

Tinggi tutup, OA = $b + sf + t_d$
= ##### in
= ##### ft

Tinggi Tangki Total

Ht = H + 2Hd
= 6.2708 ft + 2 × 0.7356 ft

= 7.7420 ft
= 92.9039 in = 2.36 m

Merancang Pengaduk

Komponen	Massa kg/jam	%Berat	μ (cP)	Massa/μ (cP
C8H4O3	1445.35	0.997	0.82	1.215854
H2O	1.44970	0.001	0.1606	0.006227
C8H6O4	2.899398	0.002	3.9398	0.000508
Total	**1449.699**	**1**		**1.222588**

$$\mu_{campuran} = \frac{\sum xi}{\sum xi/\mu}$$
$$= \frac{1.0000}{1.2226}$$
= 0.8179 cP

Menghitung Ukuran Pengaduk
Digunakan pengaduk jenis *Propeller three blades pitch,* karena viskositas cairan dalam *melter* 0.818 cP = 0.001 lb/ft.s

Dimana :
ID = diameter dalam tangki
d = diameter pengaduk
L = panjang *blade* pengaduk
Zi = jarak pengaduk dasar tangki
p = jarak antar *blade*
l = tinggi cairan

Data pengaduk diperoleh dari (Brown, 1950:507)
Ukuran Pengaduk :
Diameter pengaduk (d)
ID/d = 3
$d = \frac{0.956}{3.000}$
= 0.319 m
= 12.54 in
= 1.045 ft

Panjang *blade* pengaduk
L = d/4

$$L = \frac{0.31856}{4.00000}$$
$= 0.07964$ m
$= 3.13541$ in
$= 0.26127$ ft

Jarak pengaduk dan dasar tangki (Zi)
Zi/d = 0,75 - 1,3 ; (dipilih 0,75)
Zi = 1 × d
= 0.239 m
= 9.406 in
= 0.784 ft

Lebar *baffle* (W)
W = 0,1 × d
= 0.1 × 0.3186
= 0.0319 m
= 1.2542 in
= 0.1045 ft

Jarak antar *blade* (p)
p = 2 × d
= 2 × 0.3186
= 0.6371 m
= 25.0833 in
= 2.0902 ft

Kecepatan Putar Pengaduk (N)

$$N = 600/\pi d \sqrt{(WELH/2d)}$$ Eq. 8.8 (Rase & Holmes, 1977:338)

$WELH = ZL \times Sg$

Dimana :
N = kecepatan putar pengaduk, rpm
d = diameter pengaduk, m
ZL = tinggi cairan dalam tangki, m
Sg = *specific gravity*
WELH = *Water Equivalent Liquid Height*

$$Sg = \frac{\rho_{cairan}}{\rho_{air}}$$

$= \frac{1.52917 \text{ kg/liter}}{0.99700 \text{ kg/liter}}$

$= 1.53377$

Z_L = Tinggi cairan di dalam *shell*

= 7693 m

= 25239 ft

WELH = 7692.87 m x 1.5338

= 11799.08 m

= 38710.41 ft

Jumlah pengaduk $= \frac{\text{WELH}}{\text{ID}}$

$= \frac{11799}{0.9557} = 12346 \approx 12{,}346$ buah

$N = 600/\pi d \sqrt{(WELH/2d)} = 24880.59$ rpm

$= 414.68$ rps

$= 1492836$ rph

Menghitung *Power* Pengaduk (P)

$Nre = \frac{N.\, d^2.\, \rho}{\mu}$

$= \frac{414.6766 \times 1.0451^2 \times 73.2100}{0.0005}$

$= 60330514.30$

Karena nilai Nre (>10.000) maka digunakan pengaduk jenis *propeller* .

Power pengaduk merupakan fungsi dari Np = KT = 0.87

Tabel 9.3 (Mc Cabe et al., 1993:254) dan persamaan :

$P = \frac{Np.\rho.N^3.Da^5}{gc}$ Pers. 9.20 (Mc Cabe et al., 1993:253)

Dimana :

P = daya pengaduk, lb.ft/s

Np = *power number* K_T = 0.87

N = kecepatan putaran pengaduk = 414.6766 rps

ρ = densitas bahan = 0.0955 lb/ft³

d = diameter pengaduk = 1.0451 ft

gc = gravitasi = 32.1740 lbm/s².lbf

Sehingga :

$P = \frac{Np.\rho.N^3.d^5}{gc}$

$= \frac{0.87 \times 0.095 \times 414.68^3 \times 1.045^5}{32.1740}$

= ######## ft.lb/s

= 417.3436 Hp

Efesiensi motor penggerak (ή) = 80%

***Fig* . 14.38 (**Peters & Timmerhaus, 1991:521)

Daya penggerak motor = $P/\acute{\eta} = \frac{\#\#\#\#\#}{80\%} = \#\#\#\#\#$ Hp

Maka dipakai motor dengan daya = ##### Hp

Power motor yang digunakan = 1 Hp

Menghitung Poros Pengaduk

Panjang poros = $Z_T + Zp - Zi$

dimana :

ZT = tinggi total tangki = 2.35976 m

Zp = tinggi poros di atas tangki, diambil = 0.30000 m

Zi = tinggi poros di atas dasar tangki = 0.23892 m

Panjang poros = 2.360 + 0 – 0.239 = 2.421 m

Diameter Poros

Momen puntir (τ)

$$\tau = (HP \times 75 \times 60)/(2\,\pi\,v)$$

Dimana :

HP = Daya pengaduk = 521.6796 Hp

V = kecepatan putaran pengaduk = 24880.59 rpm

$$\tau = \frac{521.6796 \times 75 \times 60}{2 \times \pi \times 24880.59} = 15.0244 \text{ kg-m}$$

Diambil faktor keamanan 50%

Jadi, momen puntir = 1.5 × #####

= 22.536538 kg-m

$$fs = \frac{\tau}{tp} \qquad Zp = \frac{\pi\, Dp^3}{16} \qquad Zp = \frac{\tau}{fs}$$

$$\frac{\tau}{fs} = \frac{\pi\, Dp^3}{16}$$

dimana :

fs = *shear stress* = 550 kgf/cm^2

Dp = diameter poros

$$Dp^3 = \frac{16\,\tau}{\pi\,fs}$$

$$Dp^3 = \frac{16 \times 22.5365}{\pi \times 550 \times 10000} = 2.09E\text{-}05 \ m^3$$

Dp = 0.02754 m

= 2.75363 cm

= 1.08410 in

= 1.08410 in

Jadi, diameter poros pengaduk

Pemilihan *Bearing* (bantalan poros)

Tipe : *gear grove ball bearing*

Berat poros : $\frac{1}{4}\,\pi\,Dp^2 \times L_P \times \rho$

Dimana :

L_P = panjang poros = 2.421 m

D_p = diameter poros = 0.028 m

ρ = densitas baja = 0.283 lb/in^3

= 7924 kg/m^3

Berat poros (Wp) = 1/4 × 3, x 0.028 ^{2} × 2.421 × 7924

= 11.418 kg

Berat Pengaduk

Berat pengaduk = volume *blade* × ρ *blade*

Tebal *blade* = 1 in

Tinggi *blade* (h) = 0,2 d = 0.016 m = 0.627 in

Panjang *blade* (L) = 0.0796 m = 3.135 in

Densitas *blade* (ρ) = 0.2790 lb/in^3

Volume *blade* = 1 × 0.6271 × 3.135

= 1.966 in^3

Berat *blade* = Volume *blade* × Densitas *blade*

= 1.9662 × 0.2790

= 0.5486 lb

= 0.2488 kg

Berat radial = Berat poros + (3 × berat *blade*)
= 11.4180 + 3 × 0.2488
= 11.4180 kg
= 25.1724 lb

SISTEM PENDINGIN

Perhitungan sistem penjaga suhu : (Kern Hal .719)

Dari neraca panas, suhu yang dijaga : 165.000 C

Q = -484213 kal/jam
= -1921.480 BTU/jam

Suhu Feed masuk	=	165	C	=	329	F
Suhu Bahan Keluar	=	165	C	=	329	F
Suhu Air pendingin masuk	=	30	C	=	86	F
Suhu air pendingin keluar	=	45	C	=	113	F
ΔT1	=	216	F			
ΔT2	=	243	F			

Kebutuhan media = 7710.154 kg/jam
= 17000.889 lb/jam
Densitas media = 62.430 lb/cuft
Rate Volumetrik = $\frac{17000.889 \text{ lb/jam}}{62.430 \text{ lb/cuft}}$
= 272.319 cuft/jam
= 0.076 cuft/detik

Koefisien perpindahan panas bagian luar jaket :

$$hi = 0{,}36\,(k/Di)\,\frac{[L^2\,N\,\rho]^{2/3}}{\mu}\,\frac{[C\,.\,\mu\,]^{1/3}}{k}\,\frac{[\mu]^{0.14}}{\mu w}$$

(Kern pg.71 eq 20-1)

Keterangan :

L	=	Da (diameter impeller)	=	1.162	ft		
N	=	Putaran pengaduk	=	415	rpm	=	24881 rph
ρ	=	Berat jenis air	=	62.43	lb/cuft		

Pada suhu tangki penampungan = 30 C maka

μ = ##### cps = 1.985 lb/ft.jam
k = ##### btu/jam/ft2
c = 1 btu/lb.F

$$Re\,p = \frac{[L^2\,N\,\rho]^{2/3}}{\mu}$$

$$= \frac{(\ 1.35 \times 24881 \times 62.43\ )^{2/3}}{1.985}$$

$= 10375.85$

$\frac{[C \cdot \mu]^{1/3}}{k} = \frac{(1.000 \times 1.985)^{1/3}}{0.333}$

$= 3.776551447$

$\frac{[\mu]^{0.14}}{\mu w} = 1$ (Untuk air)

$hi = 0.36 \times \frac{0.3328}{1.1623} \times 10375.9 \times 3.7766 \times 1$

$= 4039.207$ Btu/jam .ft.F

Untuk air pendingin yang berada dalam jaket mengacu pada diameter dalam bejana hio = 100 Btu/jamft^2 F

Menghitung Uc :

$Uc = \frac{hi \times hio}{hi+hio}$

$= 97.5841$ Btu /jamft^2 F

Rd = 0.001 (Kern tabel 12 pg 845)

$hd = \frac{1}{Rd}$

$= 1000$

Menghitung Ud :

$Ud = \frac{Uc \times hd}{Uc + hd}$

$= 88.90806673$ Btu /jamft^2 F

A = π x Di x H Pengaduk + π/4 x Di2

$= 3.14 \times 1.16 \times 2.32 + 1.06$

$= 9.5440$ ft2

Penghitungan Tinggi Jaket :

Tinggi jaket = Tinggi shell

h = 2.3246 ft

Asumsi :

Tebal air pendingin (ts) = 2 in

Tebal jaket (tj) = 3/16 in

e = 0.8

C = 0.13

Dipergunakan bahan konstruksi yang terbuat dari carbon steel SA-283 Grade C

f allowable = 12650

Do (Shell) = Di + 2ts

= 13.9473 + 4

= 17.9473 in

Di (jaket) = Do (Shell) + 2tj

= 17.9473 + 0.375
= 18.3223 in

Do (Jaket) = Di (Jaket) + 2tj
= 18.3223 + 0.375
= 18.6973 in

P desain jaket = Po - Pi + Ph
= 14.7 - 14.7 + x g/gc x hli
= 62.43 $\frac{lbm}{cuft}$ x 1 $\frac{lbf}{lbm}$ x ##### ft
= 1575675 lbf/ft2
= 10942.19 psi

Penentuan tebal jaket :

Tebal jaket berdasarkan ASME Code :

$$tj = \frac{P \times Dij}{2.f.e - P} + C$$

$$2 = \frac{10942 \times 18.32}{1.6\ f - 10942} + 0$$

f = 73667.56669

f allowable > f desain

12650 > 73667.56669

Dipilih tebal jaket = (3/16) in

SPESIFIKASI MELTER PHTHALIC ANHYDRIDE

Fungsi	:	Tempat meleburkan *phthalic anhydride* padat menjadi *phthalic anhydride* cair
Tipe	:	silinder vertikal dengan alas dan tutup berbentuk *torispherical*
Bahan Konstruksi	:	*Carbon Steel* SA-283 *Grade* C
Jumlah	:	1 buah
Kondisi Operasi	:	Temperatur 165 ^{o}C dan Tekanan 1 atm
Kapasitas	:	1181.485 m^3
Dimensi		
Silinder		
Diameter	:	0.9557 m
Tinggi	:	1.9114 m
Tebal	:	3/16 in
Tutup		
Tebal	:	3/16 in
Tinggi	:	8.8274 in
Tinggi Tangki Tot	:	2.3598 m
Power Pengaduk	:	1 Hp

Sistem Pendingin :

Diameter jaket	=	18.3223	ft
Tinggi Jaket	=	2.3246	ft
Jaket Spacing	=	4	in
Tebal Jaket	=	(3/16)	in

15 POMPA MELTER (L-135)

Fungsi : Mengalirkan *phthalic anhydride* dari *melter* menuju reaktor
Tipe : *Centrifugal pump*
Jumlah : 1 buah

PERHITUNGAN

Bahan Masuk	=	1449.698756	kg/jam
	=	3196.585758	lb/jam
ρ Campuran	=	74.9	lb/cuft
Rate massa	=	1449.698756	lb/jam
Rate volumetrik	=	19.3	cuft/jam
	=	0.322444367	cuft/menit
	=	0.005374073	cuft/detik
	=	2.412206308	gpm

Asumsi aliran turbulen
(Di) optimum untuk aliran turbulen, NRe > 2100 digunakan persamaan :

Diameter optimum = $3.9 \times q_f^{0.45} \times \rho^{0.13}$ (Peters, 4ed, pers.15 : 496)

Keterangan =
in
q_f = Fluid flow rate; (cuft/detik)
ρ = Fluid Density; (lb/cuft)

Diameter pipa optimum, I = $3.9 \times (0.005)^{0,4} \times (74.93)^{0,13}$
= 1.1432 in

Dipilih pipa 4 in, sch 10s (Brownell and Young, APP-K)

OD	=	4.5	in
	=	0.375	ft
ID	=	4.216	in
	=	0.351	ft

A = $(^1/_4 \times \pi \times ID^2)$
= 0.25 x 3.14 x 0.351333333 ^2
= 0.096896562 ft^2

Kecepatan linear, v = $\frac{qf}{A}$
= $\frac{0.005374073 \text{ cuft/detik}}{0.096896562 \text{ ft}^2}$
= 0.055461955 ft/dtk

ρ reference = 62.43 lb/cuft

sg reference = 1
μ reference = 0.95
sg bahan = $\frac{\rho \text{ bahan}}{\rho \text{ reference}}$ x sg reference
= $\frac{74.9}{62.43}$ x 1
= 1.20026844

μ berdasarkan sg bahan
μ = $\frac{\text{sg bahan}}{\text{sg reference}}$ x μ reference
= $\frac{1.20026844}{1}$ x 0.95
= 1.140255018 cps
= 0.000766216 lbf/s
Nre = $\frac{D \; V \; \rho}{\mu}$
= $\frac{0.351333333 \text{ x } 0.055461955 \text{ x } 74.9}{0.000766216}$
= 1905.614399 > 2100 (Asumsi aliran turbulen benar)

Dipilih pipa commercial steel,
ε = 0.000046 m
ε/D = 0.00042945
f = 0.007

Digunakan persamaan Bernoulli :

$$-Wf = \frac{\Delta P}{\rho} + \Delta Z \frac{g}{gc} + \frac{\Delta V^2}{2 \alpha g} + \Sigma F$$

Perhitungan friksi berdasarkan **Geankoplis 3ed T 2.10-1, hal 93**

Taksiran panjang pipa lurus	=	29.4	ft	=	8.963414634	m
- 3 elbow 90°	=	3	x 35	x	0.351333	
	=	36.89	ft			
- 1 gate valve	=	1	x 9	x	0.351333	
	=	3.162	ft			
Panjang total pipa	=	69.452	ft			

Friksi yang terjadi:

1. Friksi karena gesekan bahan dalam pipa

$$F_1 = \frac{2f \text{ x } v^2 \text{ x } Le}{gc \text{ x } D}$$ *[Geankoplis ed.3; eq 2.10-6]*

$$= \frac{2 \text{ x } ##### \text{ x } 0.0555^2 \text{ x } 69.45}{32.22 \text{ x } 0.3513}$$

= 0.0003 ft lbf/lbm

2. Friksi karena kontraksi dari tangki ke pipa

$$F_2 = \frac{Kc \times v^2}{2 \times \alpha \times gc}$$ *(Geankoplis 3ed eq. 2.10-16)*

Kc = 0.55

untuk aliran turbulen :

α = 1

$\frac{A2}{A1} = \frac{0.096896562}{406944}$

= 2.38108E-07

$Kc = 1 - \frac{A2}{A1}$

= 0.999999762

Maka : $F_2 = \frac{0.999999762 \times 0.055461955 \text{ ^ } 2}{2 \times 1 \quad 32.271}$

= 4.76593E-05 ft lbf/lbm

3. Friksi karena enlargement (ekspansi) dari pipa ke tangki

$F_3 = \frac{\Delta v^2}{2 \times \alpha \times gc}$

$= \frac{v_2^2 - v_1^2}{2 \times \alpha \times gc}$; ($A_1 <<< A_2$, maka V_1 dianggap = 0)

$= \frac{0.055^2 - 0}{2 \times 1 \times 32.217}$

= 0.000 ft lbf/lbm

4. Friksi karena elbow 90°

$F_4 = n \times Kf \times \frac{v1^2}{2}$ n = jumlah elbow (Geankoplis 3ed, eq 2.10-17)

F4 = 3.000 x 0.750 x 0.002

= 0.003 ft lbf/lbm

5. Friksi karena Gate Valve

$F_5 = n \times Kf \times \frac{v1^2}{2}$

F_5 = 1 x 0.170 x 0.002

= 0.000 ft lbf/lbm

Sehingga :

$\Sigma F = F_1 + F_2 + F_3 + F_4 + F_5$

= 0.004 ft.lbf/lbm

1 atm = 14.6959 psi = 2116.2096 lbf/ft^2

P_1 = 1 atm + P hidrostatis

= 2116.2096 lbf/ft2 + (74.9 x 1 x 14.7)
= 2116.2096 + 1101.5
= 3217.721153 lbf/ft2

P_2 = 1 atm = 2116.2096 lbf/ft^2

ΔP = 3217.721153 - 2116.2096
= 1101.512 lbf/ft^2

$\frac{\Delta P}{\rho} = \frac{1101.512}{74.933} \frac{lbf/ft^2}{lb/cuft}$

= 14.700 $\frac{ft.lbf}{lbm}$

$\frac{\Delta v^2}{2 \times \alpha \times gc} = \frac{0.055462^2}{2 \times 1 \times 32.22}$

= 4.77392E-05 ft lbf/lbm

Asumsi :

Z1 = 13.400 ft
Z2 = 19.400 ft
ΔZ = (Z2 - Z1) = 6.000 ft

$\Delta Z \frac{g}{gc}$ = 6.000 ft x 1.000 $\frac{lbf}{lbm}$

= 6.000 $\frac{ft.lbf}{lbm}$

Persamaan Bernoulli

$-Wf = \frac{\Delta P}{\rho} + \Delta Z \frac{g}{gc} + \frac{\Delta V^2}{2 \alpha gc} + \Sigma F$

= 14.700 + 6.000 + 5E-05 + 0.004
= 20.70413 $\frac{ft.lbf}{lbm}$

$Hp = \frac{- Wf \times flowrate(gpm) \times sg}{3960}$

$= \frac{20.70413 \times 2.4122 \times 1.2}{3960}$

= 0.015

Effisiensi Pompa = 0.450 **(Peters 4ed ; Figure 14 - 37)**

$Bhp = \frac{Hp}{\eta \text{ pompa}}$

$= \frac{0.015}{0.450}$

= 0.033638925 Hp

Effisiensi motor = 0.800 **(Peters 4ed ; Figure 14 - 38)**

Power motor = Bhp

$$= \frac{\text{–}}{\eta \text{ motor}}$$

$$= \frac{0.034}{0.800}$$

= 0.042048656 Hp

SPESIFIKASI POMPA MELTER

Fungsi	=	Mengalirkan *phthalic anhydride* dari *melter* menuju reak
Type	=	Centrifugal Pump
		(Sesuai untuk viskositas <10 cP dan bahan liquid)
Power Motor	=	0.0420 Hp
Rate volumetrik	=	2.412206308 gpm
Total dynamic hea	=	20.704 ft.lbf/lbm
Efisiensi pompa	=	0.450
Efisiensi motor	=	0.800
Bahan konstruksi	=	Commercial Steel
Jumlah	=	1 buah

16 TANGKI PENYIMPANAN 2-ETHYL HEXANOL (F-140)

Fungsi : Menampung dan menyimpan bahan baku 2-e*thyl hexanol*

Tipe : *Cylindrical tank, flat bottom, torispherical dished head*

Jumlah : 7 buah

Kondisi Opera : T = 30 °C = 303.15 K

P = 1 atm

= 760 mmHg

= 14.7 psi

Komposisi	%berat	berat (kg/jam)	ρ (gr/cc)
$C_8H_{18}O$	0.995	2539.127781	0.833
H_2O	0.005	12.75943609	0.998
Total	1	2551.887217	

1 kg = ## lb

1 gr/cc = 62.4 lb/cuft

$$\text{Densitas Campuran} = \frac{1}{\frac{\text{fraksi berat}}{\rho \text{ komponen}}} \times 62.4$$

$$= \frac{1}{\frac{1.00}{0.833} + \frac{0.01}{1}} \times 62.43$$

= 0.83 gr/cc x 62.43

= 52.05 lb/cuft

$$\text{Rate Volumetrik} = \frac{\text{Rate Massa}}{\text{Densitas}}$$

$$= \frac{5624.36}{}$$

$$= \frac{}{52.0472}$$

$$= 108.0626 \text{ cuft/jam}$$

Direncanakan penyimpanan untuk 24 jam dengan 7 buah tangki (mempermudah pengeluaran dan pengisian), sehingga volume liquid adalah

$$\text{V liquid} = \frac{\#\#\#\#\# \text{ cuft/jam} \times 24 \text{ jam}}{7}$$

$$= 370.50 \text{ cuft}$$

Asumsi volume bahan (liquid) mengisi 80% volume tangki sehingga volume ruang kosong sebesar 20%

$$\text{Volume Tangki} = \frac{370.5005}{80\%}$$

$$= 463.1256 \text{ cuft} = 3464.179 \text{ gal}$$

Disarankan > 10000 gal, menggunakan vertical tank dan pondasi beton

[Walas ed.2; p.xvii]

Menentukan ukuran tangki tangki dan ketebalannya

$$\text{Dimensi ratio} = \frac{H}{D} = 2$$ *[Ulrich; T.4-27:p.248]*

$$\text{Volume tangki} = \frac{\pi}{4} \times D^2 \times H$$

$$463.1256 = \frac{3.14}{4} \times D^2 \times 2D$$

$$463.1256 = 2 \times D^3$$

$$D^3 = 294.9845 \text{ cuft}$$

$$D = 6.656813 \text{ ft} = 79.88176 \text{ in} = 1.997044 \text{ m}$$

Karena H = 2D, maka H:

$$H = 2 D$$

$$H = 2 \times 6.657 \text{ ft}$$

$$H = 13.31363 \text{ ft} = 159.7635 \text{ in} = 3.994088 \text{ m}$$

Tinggi liquid dalam tangki:

$$\text{Volume Liquid} = \frac{\pi}{4} \times D^2 \times H$$

$$370.50 = \frac{3.14}{4} \times 44.313164 \times H$$

$$H \text{ liq} = 10.65 \text{ ft}$$

Penentuan tebal shell :

$$t_{min} = \frac{P \times ri}{fE - 0{,}6P} + C$$ *[Brownell&Young; Eq.13-1]*

dengan

t_{min} = tebal shell minimum ; in

P = tekanan tangki ; psi

ri = jari-jari tangki ; in (1/2 D)
C = faktor korosi ; in (digunakan 1/8 in)
E = faktor pengelasan, digunakan double weld E = 0.8
f = Stress allowable, baha stainless steel 316
f = 35969.92 psi *[Perry ed.7; T.28-11]*

P operasi = 1 atm = 14.7 lb/in^2 (psi)

P hidrostatis = ρ x g/gc x Hliq
= 52.05 x 1 x 10.65
= 554.3498 lb/ft^2
= 3.8497 lb/in^2

P Design 10% lebih besar untuk faktor keamanan

P design = (P operasi + P hidrostatis) x 110%
= 14.7 + 3.8497 x 110%
= 20 psi

ri = 1 x D
= 1 x 79.8818
= 39.94088 in

$$t_{min} = \frac{P \times ri}{fE - 0{,}6P} + C$$

$$= \frac{20 \times 39.94088}{28775.9 - 12.2428} + 0.125$$

$$= \frac{814.9783}{28763.69} + 0.125$$

= 0.0283 + 0.125
= 0.1533 in

digunakan t_{min} = 4/16 in

Dimensi Tutup Atas :

Tutup atas berbentuk standart dished head

OD = D + 2 ts = 80 in
rc = 130 in *[Brownell&Young; T.5-7]*
= 10.8 ft

Tebal standart toripherical dished (atas) :

$$t_h = \frac{0{,}885 \times P \times rc}{fe - 0{,}1P} + C$$

dengan

t_h = tebal shell minimu ;in
P = tekanan tangki ; psi
rc = crown radius ; in
C = faktor korosi ; in (digunakan 1/8)
E = faktor pengelasan, digunakan double weld E = 0.8
f = tekanan tangki stainless steel 316

f = 35969.92 psi *[Perry ed.7; T.28-11]*

P design = 20.40 psi

$t_h = \frac{0{,}885 \times P \times rc}{f.E - 0{,}1.P} + C$

$= \frac{0.885 \times 20.40 \times 130}{28775.94 - 2.04} + 1/8$

= 0.207 in digunakan t = 4/16 in

$h = rc - \sqrt{rc^2 - \frac{D^2}{4}}$

= 0.52 ft

untuk tebal tutup bawah datar karena tutup menumpang diatas beton,
maka tebal tutup = 1/3 in *[Brownell&Young; p.58]*

Tangki Penyimpanan 2-Ethyl Hexanol

Dimensi Shell :

Diameter tangki	:	6.66 ft
Tinggi tang	:	13.31 ft
Tebal Shell	:	4/16 in
Tebal tutup atas	:	4/16 in
Tebal tutup bawah	:	1/3 in
Bahan konstruksi	:	Stainless steel 316
Jumlah tangki	:	7 buah

17 POMPA 2-ETHYL HEXANOL (L-141)

Fungsi : Mengalirkan 2-*ethyl hexanol* dari tangki penyimpanan 2-*ethyl hexanol* menuju *heater*

Tipe : *Centrifugal pump*

Jumlah : 1 buah

Perhitungan :

Bahan masuk = 2551.887 kg/jam = 5626.91 lb/jam

ρ Campuran = 52.05 lb/cuft

Rate volumetri $= \frac{\text{Rate massa}}{\rho \text{ campuran}}$

$= \frac{5626.91 \text{ lb/jam}}{52.04722 \text{ lb/cuft}}$

= 108.1117 cuft / jam

= 1.8019 cuft / menit

= 13.4797 gpm

= 0.0300 cuft/detik

Asumsi aliran turbulen

(Di) optimum untuk aliran turbulen, NRe > 2100 digunakan persamaan :

Diameter optimum = $3.9 \times q_f^{0.45} \times \rho^{0.13}$ in *[Peters ed.4; eq.15-496]*

Dengan :

q_f = Fluid flow rate; (cuft/detik)

ρ = Fluid Density; (lb/cuft)

Diameter pipa optimum, I = $3.9 \times 0.03^{0.45} \times 52.05^{0.13}$

= 1.3462 in

Dipilih pipa 2.5 in, sch 80 *[Kern; Tab.11]*

OD = 2.880 = 0.24 ft

ID = 2.323 = 0.1936 ft

A = $(^1/_4 \times \pi \times ID^2)$

= 1/4 x 3.14 x 0.1936^2

= 0.0294 ft^2

Kecepatan linier, v = $\frac{qf}{A}$

= $\frac{0.0300 \text{ cuft/detik}}{0.0294 \text{ ft}^2}$

= 1.0209 ft/ detik

ρ reference = 62.43 lb/cuft

sg reference = 1

μ reference = 0.89

sg bahan = $\frac{\rho \text{ bahan}}{\rho \text{ reference}} \times$ sg reference

= $\frac{52.0472}{62.430} \times 1$

= 0.8337

μ berdasarkan sg bahan :

μ bahan = $\frac{\text{Sg bahan}}{\text{Sg reference}} \times \mu$ reference

= $\frac{0.8337}{1} \times 0.89$

= 0.7420 cps = 0.000499 lb/ft s

NRe = $\frac{D \, v \, \rho}{\mu}$

= $\frac{0.194 \times 1.0209 \times 52.0472}{0.000499}$

= 20629.40 > 2100 (Asumsi turbulen benar)

Dipilih pipa Stainless Steel type 302 *(Cocok untuk [Perry ed.7; tab.28-2] [Peters ed.4; tab.12-4]*

ε = 0.000007 ft

ε/D = 0.00004

f (Fanning factor) = 0.0130 *[Moody Chart fanning factor]*

Digunakan persamaan Bernoulli : *(Mechanical energy balance eq.)*

$$-Wf = \frac{\Delta P}{\rho} + \Delta Z \frac{g}{gc} + \frac{\Delta V^2}{2\,\alpha\,gc} + \Sigma F$$

[Geankoplis ed.3; eq.2.10-20]

Perhitungan friksi berdasarkan *[Geankoplis ed.3; T2.10-1, p.93]*

Taksiran panjang pipa lurus = 35 ft = 10.6707 m

- 3 elbow 90° = 3 x 35 x 0.1936
  = 20.3263 ft
- 1 gate valve = 1 x 9 x 0.1936
  = 1.7423 ft

Panjang total pipa = 57.0685 ft

Friksi yang terjadi:

1. Friksi karena gesekan bahan dalam pipa

$$F_1 = \frac{2f \times v^2 \times Le}{gc \times D}$$ *[Geankoplis ed.3; eq 2.10-6]*

$$= \frac{2 \times 0.013 \times 1.0209^2 \times 57.07}{32.2170 \times 0.1936}$$

= 0.2479 ft lbf/lbm

2. Friksi karena kontraksi dari tangki ke pipa

$$F_2 = \frac{Kc \times v^2}{2 \times \alpha \times gc}$$ *[Geankoplis ed.3 eq. 2.10-16]*

untuk aliran turbulen :

D1 = 6.657 ft *(Diameter pre-pompa)*

α = 1

$$\frac{A2}{A1} = \frac{0.0294}{34.7858} = 8E\text{-}04$$

$$Kc = 0.55 \times \left(1 - \frac{A2}{A1}\right)$$

$$= 0.55 \times 1 - 0.0008 = 0.550$$

Maka :

$$F_2 = \frac{0.55 \times 1.02086^2}{2 \times 1 \times 0.013}$$

= 22.02677 ft lbf/lbm

3. Friksi karena enlargement (ekspansi) dari pipa ke tangki

D3 = 0.041 ft *(Diameter pasca-pompa)*

$$\frac{A2}{A3} = \frac{0.0294}{0.0013} = 22.18$$

$$Kex = 1 \times \left(1 - \frac{A2}{A3}\right)2$$

$= 1 \times 1 - 22.185 = 448.8$

Maka:

$$F_3 = \frac{Kex.\ \Delta v^2}{2 \times \alpha \times gc}$$ *[Geankoplis ed.3 eq. 2.10-15]*

$$= \frac{449 \times 1.021^{\,2} - 0}{2 \times 1 \times 32.2170}$$

$= 7.2586$ ft lbf/lbm

4. Friksi karena elbow 90°

$$F_4 = n \times Kf \times \frac{v1^2}{2}$$ n = jumlah elbow *[Geankoplis ed.3; eq 2.10-17]*

$F4 = 3 \times 0.75 \times 0.5211$

$= 1.1724$ ft lbf/lbm

5 Friksi karena Gate Valve

$$F_5 = n \times Kf \times \frac{v1^2}{2}$$

$F_5 = 1 \times 0.17 \times 0.5211$

$= 0.0886$ ft lbf/lbm

Sehingga :

$\Sigma F = F_1 + F_2 + F_3 + F_4 + F_5$

$= 30.794$ ft.lbf/lbm

1 at = 14.7 psi = 2117 lbf/ft2

P_1 = 1 atm + P hidrostatis *(H liquid pre-pump)*

$= 2116.8$ lbf/ft2 + (52.05 x 1 x 10.65)

$= 2116.8 + 554.35$

$= 2671.1$ lbf/ft2

$P_2 = 1$ atm = 2117 lbf/ft^2

$\Delta P = 2671 - 2116.80$

$= 554.3$ lbf/ft^2

$$\frac{\Delta P}{\rho} = \frac{554.3 \text{ lbf/ft}^2}{52.05 \text{ lb/cuft}} = 10.651 \frac{\text{ft.lbf}}{\text{lbm}}$$

$$\frac{\Delta v^2}{2 \times \alpha \times gc} = \frac{1.021^{\,2}}{2 \times 1 \times 32.217}$$

$= 0.016$ ft lbf/lbm

Asumsi Z1 = 3.281 ft Tinggi tutup bawah tangki

Z2 = 0.7 ft Tinggi total

$\Delta Z = Z1 - Z2 = 2.62$ ft reaktor + asumsi

$\Delta Z \frac{g}{gc} = 2.62 \text{ ft} \times 1 \frac{\text{lbf}}{\text{lbm}}$

$= 2.625 \frac{\text{ft.lbf}}{\text{lbm}}$

Persamaan Bernoulli

$-Wf = \frac{\Delta P}{\rho} + \Delta Z \frac{g}{gc} + \frac{\Delta V^2}{\alpha\, gc} + \Sigma F$

$= 10.65 + 2.625 + 0.0162 + 30.79$

$= 44.09 \frac{\text{ft.lbf}}{\text{lbm}}$

$hp = \frac{-Wf \times \text{flowrate(gpm)} \times sg}{3960}$

$= \frac{44.09 \times 13.4797 \times 0.834}{3960}$

$= 0.1251$ hp

Effisiensi Pompa = 30% *[Peters ed.4; Fig.14-36]*

$Bhp = \frac{hp}{\eta \text{ pompa}}$

$= \frac{0.1251}{30\%}$

$= 0.4170$ hp

Effisiensi motor = 82% *[Peters ed.4; Fig.14-38]*

$\text{Power motor} = \frac{Bhp}{\eta \text{ motor}}$

$= \frac{0.4170}{82\%}$

$= 0.5086$ hp

$= 1$ hp

SPESIFIKASI POMPA 2-ETHYL HEXANOL

Fungsi : Mengalirkan 2-*ethyl hexanol* dari tangki penyimpanan 2-ethyl hexanol menuju heater

Type : *Centrifugal pump*

Power Motor : 1 hp

Rate volumetrik : 13.4797 gpm

Total Dynamic Head : 44.0860 ft.lbf/lbm

Effisiensi Pompa : 30%

Effisiensi Motor : 82%

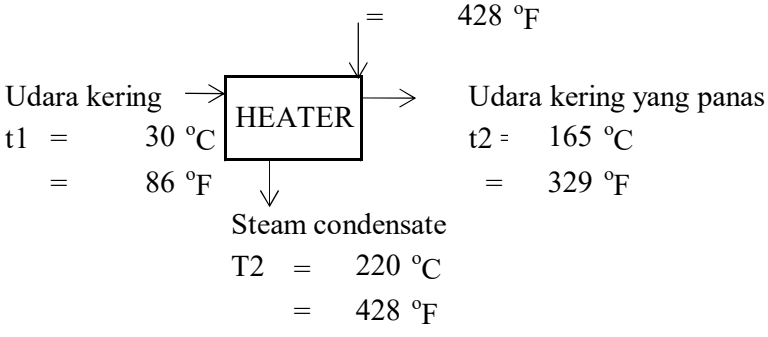
Bahan kontruksi pipa : Stainless Steel type 302

Bahan konstruksi pump & val : Stainless Steel type 303

Jumlah : 1 Buah

18 HEATER 2-ETHYL HEXANOL (E-142)

Diagram suhu : Steam T1 = 220 °C = 428 °F



Fungsi : Memanaskan 2-*ethyl hexanol* cair sebelum masuk reaktor dari su 30 °C menjadi 165 °C

Tipe : Shell and Tube

Jumlah : 1 buah

Heat Balance

Data dari Appendix A dan Appendix B diperoleh :

Rate massa, W massa	=	2,552	kg/jam
	=	5,627	lb/jam
Q supply	=	57,245	Kkal/jam
	=	227,262	Btu/jam
W steam	=	129	kg/jam
	=	285	lb/jam

Log Mean Temperature Difference

Suhu bahan masuk	=	30 °C	=	86	°F (t_1)
Suhu bahan keluar	=	165 °C	=	329	°F (t_2)
Suhu steam masuk	=	220 °C	=	428	°F (T_1)
Suhu steam condensat	=	220 °C	=	428	°F (T_2)

$\Delta t_1 = T_2 - t_1$ = 428 - 86 = 342 °F

$\Delta t_2 = T_1 - t_2$ = 428 - 329 = 99 °F

(Kern : Hal. 90)

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{0}{243} = 0.000000000000$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{243}{342} = 0.711$$

$$\Delta t\ LMTD = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}}$$ *(Kern : Pers.5.14, Hal. 149)*

$$= \frac{99 - 342}{\ln \frac{99}{342}}$$

$$= 196\ ^oF$$

(Kern : Pers.5.14, Hal. 89)

$F_T = 1$ (Kern : Fig. 18, Hal. 828)

$\Delta t = \Delta t\ LMTD \times F_T$

$= 196.0166 \times 1$

$= 196\ ^oF$ *(Kern : Pers.7.42, Hal. 149)*

Temperatur Rata-rata

$t_c = t_{av}$ Udara $= \frac{86 + 329}{2}$

$= 207.5\ ^oF$

$T_c = T_{av}$ Steam $= \frac{428 + 428}{2}$

$= 428\ ^oF$

Trial Ukuran Heater

Asumsi:

Shell Side			**Tube Side**		
ID	=	35 in	Number and Length	=	1 16 0"
Baffle space	=	2 in	OD, BWG, pitch	=	1 in, 16 BWG, 1 1/4-in square
Passes	=	4	Passes	=	2

Berarti : a't = 0.639 in^2

a" = 0.262 ft^2/ft panjang *(Kern : T.10, Hal. 843)*

Heater Steam-Water, U_D = 100-500

$U_D = 500$ Btu/jam.ft^2.^oF

$$A = \frac{Q}{\Delta t\ LMTD \times U_D} = \frac{227{,}262}{196.0166 \times 500}$$

$= 2.3188\ ft^2$

$= 27.826\ in^2$

(Kern : Pers.7.6, Hal. 140)

$$N_t = \frac{A}{L \times a"} = \frac{2.3188}{16 \times 0.2618}$$

$= 0.5536$

$= 1$

Sehingga dipilih ukuran yang paling mendekati, yaitu:

OD tube = 1 in
ID tube = 0.902 in
Pitch = 1 1/4 in square
ID Shell = 35 in
Passes tube = 1
Jumlah tube = 1

Koreksi Nilai U_D (Overall Design Coefficient)

$A = N_t \times L \times a''$
$= 1 \times 16 \times 0.2618$
$= 2.32 \text{ ft}^2$

$$U_D = \frac{Q}{\Delta t \text{ LMTD} \times A}$$
$$= \frac{227{,}262}{196.0166 \times 2.32}$$
$$= 500 \text{ Btu/jam.ft}^2\,^{o}\text{F}$$

Fluida Panas (Tube Side) Steam	Fluida Dingin (Shell Side) Udara
(4) Flow area (a_t) $a_t = \frac{Nt \times a'_t}{144 \times n}$ $= \frac{1 \times 0.639}{144 \times 1}$	(4') Flow area (a_s) $C' = Pt - OD$ $= 1.25 - 1$ $= 1/4$ in $a_s = ID \times C' \times B$
Fluida Panas (Tube Side) Steam	Fluida Dingin (Shell Side) Udara
$= 0.0025 \text{ ft}^2$	$= \frac{144 \times Pt}{35 \times 1/4 \times 2}$ $144 \times 1\ 1/4$ $= 0.0972 \text{ ft}^2$
(5) Kecepatan massa (Gt) $G_t = \frac{W}{a_t}$ $= \frac{284.526}{0.0025}$ $= 115{,}826.930$ lb/jam ft^2	(5') Kecepatan massa (Gs) $Gs = \frac{W}{as}$ $= \frac{5{,}626.9113}{0.0972}$ $= 57{,}876.8021$ lb/jam ft^2
(6) Pada T_c = 428 ^{o}F μ = 0.014 cps	(6') Pada t_c = 208 ^{o}F μ = 0.02 cps

Fluida Panas (Tube Side) Steam	Fluida Dingin (Shell Side) Udara
$= 0.034$ lb/jam.ft	$= 0.048$ lb/jam.ft
$Di = \frac{0.902}{12}$ $= 0.075$ ft	$De = \frac{4 \times a_s}{\text{wetted perimeter}}$ $= \frac{4 \times 0.0972}{1 \times 3.14 \times \frac{1}{12}}$ $= 2.6847$ ft
$Re_t = \frac{Di \times G_t}{\mu}$ $= \frac{0.075 \times 115{,}826.930}{0.03388}$ $= 256975.3$	$Re_s = \frac{D_e \times G_s}{\mu}$ $= \frac{2.6847 \times 57{,}876.8021}{0.0484}$ $= 3210423.635$
(7) $jH = 250$ (Kern: Fig.24)	(7) $jH = 28$ (Kern: Fig.28)
	(8') Pada tc $= 208$ °F k = (Kern: T.5, Hal.801) $= 0.017$ Btu/hr.ft^2.(°F/ft) $Cp = 0.25$ Btu / lb.°F $\left(\frac{Cp.\mu}{k}\right) = \left(\frac{0.250 \times 0.048}{0.017225}\right)^{1/3}$ $= 0.8889$
(9) Condensation of steam : $hio = 1000$ Btu/hr.ft^2.°F (Kern:164)	(9') $ho = jH \times \frac{k}{De} \times \left(\frac{Cp.\mu}{k}\right)^{1/3} \varphi s$ $\frac{ho}{\varphi s} = 28 \times \frac{0.0172}{2.6847} \times 0.889$ $= 0.159694$
(10) tw* $tw = tc + \frac{hio}{hio + ho}(Tc - tc)$ $= 207.5 + \frac{1000}{1000.1597} \times 220.5$ $= 427.96479$ °F	(11') Pada tw $= 427.96479$ °F μw = (Kern: Fig.15) $= 0.0145$ cps $= 0.03509$ lb / jam.ft $\varphi s = (\mu/\mu w)^{0,14}$ $= 13.01946$

Fluida Panas (Tube Side) Steam	Fluida Dingin (Shell Side) Udara
	(12') Corrected Coefficient $ho = \frac{ho.\varphi s}{\varphi s}$ $= 2.079134$ Btu/hr.ft^2.^{o}F
(13) Clean Overall coefficient, Uc : $Uc = \frac{hio \times ho}{hio + ho}$ $= \frac{1000 \times 2.0791342}{1000 + 2.0791342}$ $= 2.074820357$ Btu/hr.ft^2.^{o}F (14) Dirt factor, Rd : $Rd = \frac{Uc - U_D}{Uc \times U_D}$ $= \frac{2.0748204 - 500}{2.0748204 \times 500}$ $= 0.479969437$ Btu/hr.ft^2.^{o}F	

0.002 (Kern: T-12, Hal. 845)

Pressure Drop

Fluida Panas (Tube Side) Steam	Fluida Dingin (Shell Side) Larutan NaOH
(1) Specific vol of steam from table 7 : $v = 6.3000$ ft^3/lb $s = \frac{0.1587}{62.5} = 0.0025$ $Re_t = 256975.3$ $f = 0.00011$ ft^2/in^2 (Kern: Fig.26, Hal. 836) $\Delta Pt = \frac{1}{2} \times \frac{f.Gt^2.L.n}{5.22 \times 10^{10} \times D \times s \times \varphi t}$ $= 1.1847$ Psi $\frac{V^2}{2g'} = 0.001$ (Kern: Fig.27, Hal. 837)	(1') Flow area (a_s) $N+1 = 12L/B$ $= 96$ $De' = \frac{4 \times \text{flow area}}{\text{frictional wetted perimeter}}$ $= \frac{4 \times 0.0972}{1 \times 3.14 \times \frac{1}{12} + 3.14 \times \frac{35}{12}}$ $= 0.0418$ ft $Re's = \frac{De' \times Gs}{\mu}$

Fluida Panas (Tube Side) Steam	Fluida Dingin (Shell Side) Larutan NaOH
$\Delta Pr = \frac{4\ n}{sg} \times \frac{V^2}{2g'}$ $= \frac{4}{0.16} \times \frac{1}{} \times 0.001$ $= 0.0252$ $\Delta P_T = \Delta Pt + \Delta Pr$ $= 1.1847 + 0.0252$ $= 0.0012$ psi $\Delta P_T < 2$ psi (memenuhi untuk steam)	$= \frac{0.0418 \times 57{,}876.8021}{0.0484}$ $= 49986.5381$ $f = 0.0015$ ft^2/in^2 (Kern: Fig.29, Hal. 839) $\Delta Ps = \frac{f.Gs^2.Ds.(N+1)}{5.22 \times 10^{10} \times De \times s \times \varphi s}$ $= \frac{1295014778.1730}{52102286941.7491}$ $= 0.0249$ Psi $\Delta P_S < 10$ psi (memenuhi untuk liquid)

SPESIFIKASI HEATER 2-ETHYL HEXANOL

Bagian Tube

OD	=	1	in
ID	=	0.902	in
BWG	=	16	
Panjang	=	16	ft
Pitch	=	1 1/4	in square
Jumlah tube, Nt	=	1	
Passes	=	1	

Bagian Shell

ID	=	35	in
Passes	=	4	
A	=	2.32	ft^2
U_D	=	500	Btu/jam.ft^2 ^{o}F
Jumlah heater	=	1	buah

19 TANGKI PENYIMPANAN TETRABUTYL TITANATE (F-150)

Fungsi	:	Tempat penyimpanan katalis *tetrabutyl titanate*
Tipe	:	Tangki silinder vertikal dengan *flat bottom* dan *conical roof*
Jumlah	:	1 buah
Kondisi Operasi	:	T = 30 °C = 303.15 K P = 1 atm

= 760 mmHg
= 14.7 psi

KOMPOSISI

Komponen	% Berat	berat (kg/jam)	**ρ (gr/cc)**
$C_{16}H_{36}O_4T$	0.996	0.059767162	0.998
H_2O	0.004	0.000240029	0.997
Total	1	0.06000719	

1 kg = 2.2 lb
1 gr/cc = 62.4 lb/cuft

$$\text{Densitas Campuran} = \frac{1}{\frac{\text{fraksi berat}}{\rho \text{ komponen}}} \times 62.4$$

$$= \frac{1}{\frac{0.996}{0.998} + \frac{0.004}{1}} \times 62.43$$

= 0.9980 gr/cc x 62.43
= 62.30 lb/cuft

$$\text{Rate Volumetrik} = \frac{\text{Rate Massa}}{\text{Densitas}}$$

$$= \frac{0.13}{62.3049}$$

= 0.0021 cuft/jam

Direncanakan penyimpanan untuk 30 hari dengan 1 buah tangki

$$\text{V liqui} = \frac{0.00 \text{ cuft/jar} \quad 24 \text{ jam} \quad 30 \text{ hari}}{1}$$

= 1.53 cuft

Asumsi volume bahan (liquid) mengisi 80% volume tangki sehingga volume ruang kosong sebesar 20%

$$\text{Volume Tangki} = \frac{1.5284}{80\%}$$

= 1.9104 cuft = 14.29015 gal

Disarankan > 10000 gal, menggunakan vertical tank dan pondasi beton

[Walas ed.2; p.xvii]

Menentukan ukuran tangki dan ketebalannya

$$\text{Dimensi ratio} = \frac{H}{D} = 2$$ *[Ulrich; T.4-27:p.248]*

Dengan mengabaikan volume dished head.

$$\text{Volume tangki} = \frac{\pi}{4} \times D^2 \times H$$

$$1.9104 = \frac{3.14}{4} \times D^2 \times 2D$$

$$1.9104 = 2 \times D^3$$

$$D^3 = 1.217 \text{ cuft}$$

$$D = 1.068 \text{ ft} = 12.811297 \text{ in} = 0.320282 \text{ m}$$

Karena H = 2D, maka H:

$$H = 2 D$$

$$H = 2 \times 1.0676081 \text{ ft}$$

$$H = 2.135216 \text{ ft} = 25.62259 \text{ in} = 0.640565 \text{ m}$$

Tinggi liquid dalam tangki:

$$\text{Volume Liquid} = \frac{\pi}{4} \times D^2 \times H$$

$$1.53 = \frac{3.14}{4} \times 1.1397871 \times H$$

$$H \text{ liq} = 1.708173 \text{ ft}$$

Penentuan tebal shell :

$$t_{min} = \frac{P \times ri}{fE - 0{,}6P} + C \qquad \textit{[Brownell\&Young; Eq.13-1]}$$

dengan

t_{min} = tebal shell minimum ; in
P = tekanan tangki ; psi
ri = jari-jari tangki ; in (1/2 D)
C = faktor korosi ; in (digunakan 1/8 in)
E = faktor pengelasan, digunakan double weld E = 1
f = Stress allowable, baha stainless steel 316
f = 35970 psi *[Perry ed.7; T.28-11]*

P operasi = 1 atm = 14.7 lb/in^2 (psi)

P hidrostatis = ρ x g/gc x Hliq
= 62.30 x 1 x 1.708
= 106.4275 lb/ft^2
= 0.7391 lb/in^2

P Design 10% lebih besar untuk faktor keamanan

P design = (P operasi + P hidrostatis) x 110%
= 14.7 + 0.7391 x 110%
= 17 psi

ri = 0.5 x D
= 0.5 x 12.81
= 6.405649 in

$t_{min} = \frac{P \times ri}{fE - 0{,}6P} + C$

$= \frac{17 \times 6.4056487}{28775.94 - 10.1898} + 0.125$

$= \frac{108.7871}{28765.75} + 0.125$

$= 0.0038 + 0.125$

$= 0.1288$ in

digunakan t_{min} = 4/16 in

Dimensi Tutup Atas :

Tutup atas berbentuk standart dished head

OD = D + 2 ts = 13 in

rc = 130 in *[Brownell&Young; T.5-7]*

= 10.8 ft

Tebal standart toripherical dished (atas) :

$t_h = \frac{0{,}885 \times P \times rc}{fe - 0{,}1P} + C$

dengan

t_h = tebal shell minimu ;in

P = tekanan tangki ; psi

rc = crown radius ; in

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

E = faktor pengelasan, digunakan double weld E = 1

f = faktor korosi stainless steel 316

f = 35970 psi *[Perry ed.7; T.28-11]*

P desigr = 14.70 psi

$t_h = \frac{0{,}885 \times P \times rc}{f.E - 0{,}1.P} + C$

$= \frac{0.885 \times 14.7 \times 130}{28775.94 - 1.47} + 1/8$

= 0.184 in digunakan t = 4/16 in

$h = rc - \sqrt{rc^2 - \frac{D^2}{4}}$

= 0.01 ft

untuk tebal tutup bawah datar karena tutup menumpang diatas beton,
maka tebal tutup = 1/3 in *[Brownell&Young; p.58]*

SPESIFIKASI TANGKI PENYIMPANAN TETRABUTYL TITANATE

Diameter tangki : 1.07 ft

Tinggi tang : 2.14 ft

Tebal Shell : 4/16 in
Tebal tutup atas : 4/16 in
Tebal tutup bawah : 1/3 in
Bahan konstruksi : Stainless steel 316
Jumlah tangki : 1 buah

20 POMPA TETRABUTYL TITANATE (L-151)

Fungsi : Mengalirkan *tetrabutyl titanate* dari tangki penyimpanan tetribut *titanate* menuju *heater*
Tipe : *Centrifugal pump*
Jumlah : 1 buah
Tujuan : 1. Menentukan tipe pompa
2. Menentukan bahan konstruksi pompa
3. Menghitung tenaga pompa
4. Menghitung tenaga motor

3) Menghitung Tenaga Pompa

Rate masuk	=	0.0600	kg/jam	=	0.0000367	lb/s
Densitas	=	0.9980	kg/m³	=	0.0623	lb/ft³
μ	=	1.2369	cP	=	0.0008	lb/ft.s

$$\text{Rate volumetrik (Q)} = \frac{\text{massa}}{\text{r}}$$

$$= \frac{0.000037 \text{ lb/s}}{0.0623 \text{ lb/ft}^3} = 0.000590 \text{ ft}^3/\text{s}$$

$$= 0.2647 \text{ gpm}$$

Diperkirakan aliran fluida laminar (Nre<2100), sehingga digunakan persamaan Di < 1 in yaitu :

$$Di_{opt} = 3.6 \; Q^{0,40} \; \mu^{0,20}$$ Eq. 48. (Peters & Timmerhaus, 1991:365

Dimana:
Di opt = diameter dalam optimum, in
Q = kecepatan volumetrik, ft^3/s
μ = viskositas fluida, lb/ft.s

Sehingga:

$$Di_{opt} = 3.6 \times (0.0005898)^{0,40} \times (0.000831)^{0,20}$$
$$= 0.0445 \text{ in}$$

Dari App. A.5-1 (Geankoplis, 1993:892) dipilih spesifikasi :

NPS	=	1/8	in					
OD	=	0.4050	in	=	0.03375	ft	=	0.010287 m
ID	=	0.2690	in	=	0.0224167	ft	=	0.006833 m
A	=	0.0004	ft²	=	0.3716	in^2		
Sch	=	40						

Menghitung kecepatan linier :

Kecepatan linier fluida dapat dicari dengan menggunakan persamaan berikut :

$$V = \frac{Q}{A}$$

Sehingga :

$$V = \frac{6.E\text{-}04 \quad ft^3/s}{0.0004 \quad ft^2} = 1.4745 \text{ ft/s} = 0.4494 \text{ m/s}$$

Menghitung *Reynold Number* (Nre) :

$$Nre = \frac{\rho \, v \, D}{\mu}$$

Sehingga :

$$Nre = \frac{0.0623 \times 1.4745 \times 0.0224}{0.0008}$$

$$= 2.4776 \quad \text{(asumsi aliran laminar benar)}$$

Instalasi pipa

Dari ***Fig*. 127** (Brown, 1950:141) dengan NPS = 1/8 in

- 1 buah *gate valve fully open* ; Le	=	0.2	ft
∑Le = 1 × 0.2	=	0.2	ft
- 4 buah *standard elbow* ; Le	=	1	ft
∑Le = 4 × 1	=	4	ft
- 1 buah *sudden enlargement* ; Le	=	4.5	ft
∑Le = 1 × 4.5	=	4.5	ft
- 1 buah *sudden contraction* ; Le	=	2.5	ft
∑Le = 1 × 2.5	=	2.5	ft
- 1 buah *swing check valve* ; Le	=	2.5	ft
∑Le = 1 × 2.5	=	2.5	ft
- Panjang ekivalen pipa lurus, ∑Le	=	13.7	ft
Panjang pipa lurus	=	2	m
	=	6.5616	ft
Panjang pipa total	=	20.2616	ft
	=	6.1757	m

Menghitung *friction loss*

$$\Sigma F = \frac{4f \cdot v^2 \cdot \Delta L}{2 \cdot ID \cdot gc}$$ Eq. 2.10-6 (Geankoplis, 1993:89)

Dimana :

ΣF = *Friction loss* (ft.lbf/lbm)
f = Faktor friksi
v = Kecepatan linier fluida (ft/s)
ΔL = Panjang pipa (ft)
ID = Diameter dalam tangki (ft)
gc = 32.1740 lbm.ft/lbf.s^2

Menghitung *Fanning Friction Factor* (f) :
Dari **Fig. 2.10-3. (**Geankoplis, 1993:88) didapat :
Untuk *commercial steel* → ε = 5.E-05 m
= 0.0002 ft

Sehingga :

$$\frac{\varepsilon}{D} = \frac{0.00016}{0.0224} = 0.0070$$

Untuk aliran laminar dari Eq. 2.10-7. (Geankoplis, 1993:92) diperoleh :

$$f = \frac{16}{N_{Re}} = \frac{16}{2.48E+00} = 6.4578$$

$$\Sigma F = \frac{4 \times 6.4578 \times (1.4745)^2 \times 20.2616}{2 \times 0.0224 \times 32.1740}$$

$$= 788.8724 \ \frac{lb_f \cdot ft}{lb_m}$$

Menghitung *Static Head* :

Z_1 = 1 m = 3.2808 ft
Z_2 = 0.2 m = 0.6562 ft
ΔZ = Z_1-Z_2 = 2.6247 ft
g/gc = 1 lbf/lbm
ΔZ (g/gc) = 2.624672 ft × 1 lbf/lbm = 2.624672 ft lbf/lbm

Menghitung *Velocity Head* :

V_1 = kecepatan linier fluida dari tangki hidrogen peroksida ke pipa

V_2 = kecepatan linier fluida ke *heater*

Karena pada 2 titik *reference* dianggap sama, maka $V_1 = V_2$: 1.4745 ft/s

Sehingga *velocity head* ($\Delta V^2 / 2agc$) = 0.03379

Menghitung *Pressure Head* :

P_1 = P_2 = 14.7 Psi

ΔP = 0

Sehingga, $\Delta P/\rho$ = 0

Menghitung Energi Mekanik Pompa :

$$-Wf = \frac{\Delta V^2}{2 \times \alpha \times gc} + \Delta z \frac{g}{gc} + \frac{\Delta P}{\rho} + \sum F$$

Dimana :

Wf = tenaga yang ditambahkan ke dalam sistem per satuan massa

Sehingga :

$$-Wf = 0.034 + 2.625 \frac{\text{ft.}}{\text{lbf/lbm}} + 0 + 788.8724 \frac{\text{ft.}}{\text{lbf/lb}}$$

$$= 791.5309 \text{ ft. lbf/lbm}$$

Menghitung *Broke Horse Power* (BHP) :

$$BHP = \frac{m.(-Wf)}{550 \,.\, \eta}$$

dari ***Fig* . 14-37.** (Peters & Timmerhaus, 1991:520), untuk Q 0.2647 gpm diperoleh η pompa = 0.40

Sehingga :

$$BHP = \frac{0.000037 \times 791.5309}{550 \times 0.40}$$

= 1.E-04 Hp; maka digunakan *power* = 1 Hp

4) Menghitung Tenaga Motor

***Fig* 14.38.** (Peters & Timmerhaus, 1991:521) untuk E = 1 Hp diperoleh η motor = 0.80

Sehingga *power* motor yang diperlukan :

$$P \text{ motor} = \frac{BHP}{\eta}$$

$$= \frac{1 \quad \text{Hp}}{0.8}$$

= 1.3 Hp

Dipilih motor standar dengan *pow* = 2 Hp (*Standard* NEMA)

Spesifikasi Pompa $C_{16}H_{36}O_4Ti$

Nama Alat	:	Pompa $C_{16}H_{36}O_4Ti$
Kode	:	L-151
Fungsi	:	Mengalirkan *tetrabutyl titanate* dari tangki penyimpa
		tetrabutyl titanate menuju *heater*
Tipe	:	*Centrifugal pump*
Bahan Konstruksi	:	*Commercial steel*
Jumlah	:	1 buah
Rate Volumetrik	:	0.00059 ft^3/s
Kecepatan Aliran	:	1.47451 ft/s
Ukuran Pipa	:	NPS = 1/8 in
	:	*Sch. Number* = 40
	:	OD = 0.0338 ft = 0.0103 m
	:	ID = 0.0224 ft = 0.0068 m
	:	*Flow Area* = 0.0004 ft^2 = 3.7E-05 m^2
Power Pompa	:	1.0 Hp
Power Motor	:	2.0 Hp

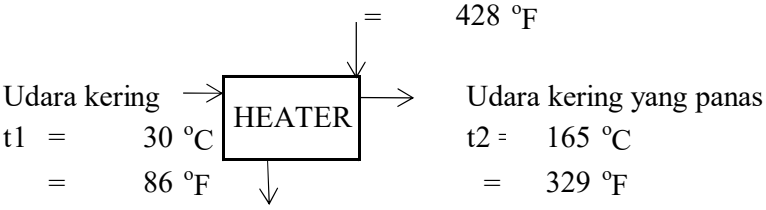
21 HEATER TETRABUTYL TITANATE (E-152)

Fungsi : Memanaskan katalis cair *tetrabutyl titanate* sebelum masuk reak
dari suhu = 30 °C menjadi = 165 °C

Tipe : Shell and Tube

Jumlah : 1 buah

Diagram suhu : Steam T1 = 220 °C
= 428 °F



Heat Balance

Data dari Appendix A dan Appendix B diperoleh :

Rate massa, W massa	=	0.0600	kg/jam
	=	0.1323	lb/jam
Q supply	=	4.2768	Kkal/jam

= 16.9790 Btu/jam
W steam = 0.0096 kg/jam
= 0.0213 lb/jam

Log Mean Temperature Difference

Suhu bahan masuk = 30 °C = 86 °F (t_1)
Suhu bahan keluar = 165 °C = 329 °F (t_2)
Suhu steam masuk = 220 °C = 428 °F (T_1)
Suhu steam condensat = 220 °C = 428 °F (T_2)

$$\Delta T \text{ LMTD} = \frac{342 - 99}{\ln 3.4545}$$

$$= 196.0166 \ ^oF$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{0}{243} = 0.0000$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{243}{342} = 0.711$$

Untuk type heater dipilih jenis 2-4 shell & tube exchanger
Untuk 2-4 shell & tube F_T = 0.97 *[Kern; App fig. 18]*

$$\Delta T = F_T \times \Delta T \text{ LMTD}$$
$$= 0.97 \times 196.02$$
$$= 190.1361 \ ^oF$$

Tc dan tc

Tc = T_{av} steam

$$Tc = \frac{T_1 + T_2}{2} = \frac{428 + 428}{2} = 428 \ ^oF$$

tc = t_{av} bahan

$$tc = \frac{t_1 + t_2}{2} = \frac{86 + 329}{2} = 208 \ ^oF$$

$$\text{Sg bahan} = \frac{\rho \text{ bahan}}{\rho \text{ reference}} \times \text{Sg reference}$$
$$= \frac{0.0727 \text{ lb/c}}{6.524 \text{ lb/c}} \times 1$$
$$= 0.0111$$

μ berdasarkan Sg bahan :
[Kern; tab.6 p. 808] didapat Sg reference = 1
[Kern; fig.14 , p. 823] didapat μ reference = 0.899 Cp

$$\mu \text{ bahan} = \frac{\text{Sg bahan}}{\text{Sg reference}} \times \mu \text{ reference}$$
$$= \frac{0.0111}{1} \times 0.899$$
$$= 0.0100 \text{ Cp}$$

Pemilihan UD Heater:
Hot Fluid : Steam
Cold Fluid : Gas
Sehingga di dapat nilai U_D dengan ran; 5 - 50 Btu/jam.ft^2 ^{0}F
[Kern; tab.8 , p.840]
Dipilih nilai U_D = 31 Btu/jam.ft^2 ^{0}F
Digunakan 1 buah heater, sehingga luas perpindahan panas heater:

$$A = \frac{Q}{UD \times \Delta T}$$

Dimana,
A = Luas Perpindahan Panas
Q = Q supply dari steam
UD = Overall Design Coefficients
ΔT = Perubahan Suhu

$$A = \frac{Q}{UD \times \Delta T}$$
$$= \frac{16.9790}{31 \times 190.1361}$$
$$= 0.0029 \text{ ft}^2$$
$$= 0.0003 \text{ m}^2$$

Dikarenakan luas perpindahan panas > 200 ft2, maka design heater menggunakan shell and tube *[Walas; p.xvi]*

$$\text{Jumlah tube (Nt)} = \frac{A}{L \times a''}$$
$$= \frac{0.0029}{16 \times 0.3271}$$
$$= 0.0006 \text{ buah}$$

Dalam perencanaan ini digunakan HEATER dengan spesifikasi :
Digunakan TUBE dengan ukuran : *[Kern; tab. 10, p. 843]*
OD, BWG = 1 1/4 in , 16 BWG
Pitch = 1 3/4 in triangular pitch *[Kern; tab.9]*
Panjang tube,L = 16 ft
Passes = 4
ID Tube = 1.120 in 0.0933 ft

a't = 0.985 in^2
a" = 0.3271 ft^2/lin ft
Digunakan Nt = 155 buah

Dari tube passes dan jumlah tube, didapat SHELL:
Untuk pipa 1 1/4 OD, 1 9/16 in triangular
ID shell = 25 in *[Kern; tab.9]*
Baffle = 20 in
Passes (n) = 2
*Koreksi U_D

$A = Nt \times L \times a''$
$= 811.2080\ ft^2$

$$U_D \text{ koreksi} = \frac{Q}{A \times \Delta T}$$

$$= \frac{16.979}{811.2 \times 190.1}$$

$= 0.00011\ Btu/jam.ft^2\ ^0F$

Nilai U_D asumsi sama dengan U_D koreksi (memenuhi)

Fluida Panas (Tube Side) Steam	**Fluida Dingin (Shell Side) Gas**
(4) Flow area (a_t) $a_t = \frac{Nt \times a'_t}{144 \times n}$ $= \frac{155 \times 0.99}{144 \times 4}$ $= ##### ft^2$	(4') Flow area (a_s) C' = Pitch - OD = 0.50 in $as = \frac{IDshell \times C' \times B}{144 \times P_T}$ $= \frac{25 \times 1/2 \times 20}{144 \times 1\ 3/4}$ $= 0.9921\ ft^2$
(5) Kecepatan massa (Gt) $G_t = \frac{W\ mass}{a_t}$ $= \frac{0.0213}{0.2651}$ $= 0.0802\ lb/jam\ ft^2$	(5') Kecepatan massa (Gs) $Gs = \frac{W\ mass}{as}$ $= \frac{0.1323}{0.9921}$ $= 0.1334\ lb/jam\ ft^2$
(6) pada tc = 208 ^oF μ steam = ##### cps = 0.036 lb/jam.ft *[Kern; Fig.15 p. 825]*	(6') Tc = 0 ^oF μ bahan = 0.023 cps = 0.056 lb/jam.ft De = 0.0758 ft *[Kern; Fig.28]*

Fluida Panas (Tube Side) Steam	**Fluida Dingin (Shell Side) Gas**
Di = 1.12 in = 0.0933 ft $Re_t = \frac{Di \times G_t}{\mu}$ = 0.206	$Re_s = \frac{D_e \times G_s}{\mu}$ = 0.1817 (7') jH = 150 *[Kern; Fig.28 shell side data]* (8') pada Tc = 428 °F k = 0.0198 Btu/hr.ft^2.(°F/ft) *[Kern; Tab.5] [Kern; fig.3]* Cp = 0.25 Btu / lb.°F $\left\lvert\frac{Cp.\mu}{k}\right\rvert^{1/3} = \frac{0.25 \times 0.056}{0.0198}$ = 0.8891
(9) Condensation of steam : hio = 1500 Btu/hr.ft^2.°F *[Kern; p.164]*	(9') $ho = J_H \times (k/De) \times (c \times \mu / k)^{1/3} \times \varphi s$ $\frac{ho}{\varphi s}$ = 35 Btu/hr.ft^2.F (10') φs = 1 ho = 35 Btu/hr.ft^2.F

(13) Clean Overall coefficient, Uc :

$Uc = \frac{hio \times ho}{hio + hc}$

= 34.0310 Btu/hr.ft^2.°F

(14) Dirt Factor, Rd :

Rd hitung = $\frac{U_C - U_D}{U_C \times U_D}$ *[Kern; T-12 p.845]* *(Air)*

= 0.0029 Btu/hr.ft^2.°F

Rd perhitungan > Rd data 0.0029 > 0.0020

Fluida Dingin (Tube Side) Steam	Fluida Panas (Shell Side) Gas
(1) Ret = 0.206 f = 0.00025 ft^2/in^2 *[Kern; Fig.26]* s = $\frac{6.52}{62.43}$ = 0 *[Kern; Tab 7]*	(1') Re's = 0.1817 f = 0.002 ft^2/in^2 *[Kern; Fig.29]* s = $\frac{0.0727}{62.43}$ = 0.0012 (2') N+1 = 12L/B

Fluida Dingin (Tube Side)	Fluida Panas (Shell Side)
Steam	Gas
$\Delta Pt = \frac{(1/2) \times f.Gt^2.L.n}{5.22 \times 10^{10} \times D \times s \times \varphi}$ $= 1/2 \frac{0.0001}{509129073}$ $= 0.000000$ Psi $\Delta P_T < 2$ psi (memenuhi)	$= 9.6$ Ds = 2.083 ft (2') $\Delta Ps = \frac{f.Gs^2.Ds.(N+1)}{5.22 \times 10^{10} \times De \times s \times \varphi s}$ $= \frac{0.0006}{4609690.0529}$ $= 1.31205E-10$ Psi $\Delta P_s < 10$ psi (memenuhi)

SPESIFIKASI HEATER TETRABUTYL TITANATE

Type Heater = 2-4 Shell & Tube Exchanger
Jumlah = 1 buah

Bagian shell :

Jenis Bahan = Carbon steel
ID Shell = 25 in
Baffle Space = 20 in
Passes = 2

Bagian tube :

Jumlah & Panjang Tul = 155 buah, 16 ft
OD, BWG, pitch = 1 1/4 in , 16 BWG 1 3/4 Triangular
Passes = 4

22 REAKTOR (R-210)

Temperatur = 165 C
Tekanan = 1 atm
Waktu Operas = 1,5 jam
Fungsi = Mereaksikan *phthalic anhydride* dengan 2-*ethyl hexanol* menggunakan katalis *tetrabutyl titanate* untuk membentuk *dioctyl phthalate*
Tipe = Silinder tegak, tutup atas dan bawah berbentuk eliptical dishead

PERHITUNGAN

Bahan Masuk

Komponen	%Berat	Massa (Kg)	ρ (gr/ml)
$C_8H_4O_3$	0.361189	1445.35	1.2
$C_8H_6O_4$	0.000725	2.899398	1.522

Komponen	%Berat	Massa (Kg)	ρ (gr/ml)
$C_8H_{18}O$	0.634521	2539.128	0.8207
$C_{16}H_{36}O_4$	1E-05	0.059767	0.998
H_2O	0.003551	14.20937	1
Total	**1**	**4001.646**	**5.5407**

$$\rho \text{ Campuran} = \frac{1.000}{\frac{\Sigma \text{ Fraksi berat}}{\Sigma \rho \text{ Komponen}}} \times 62$$

$$= \frac{1.000 \text{ gr}}{1.078 \text{ ml}} \times 62 \frac{\text{lbm/cuft}}{\text{gr/ml}}$$

$$= 57.90322 \text{ lbm/cuft}$$

Rate massa = 4001.646 kg/jam

= 4001.646 x 2.205 **(konversi ke lb/jam)**

= 8823.629 lb/jam

$$\text{Rate volumetrik} = \frac{\text{Rate Massa}}{\rho \text{ Campuran}}$$

$$= \frac{8823.629 \text{ lb/jam}}{57.90322 \text{ lb/cuft}}$$

= 152.3858 cuft/jam

DITENTUKAN

Waktu tinggal = 0.3 jam

Tinggi (Hs) = 1.5 D

Volume bahan = Rate volumetrik x Waktu tinggal (jam)

= 152.3858264 x 0.3

= 45.71574793 cuft

Volume tangki direncanakan 80% terisi bahan

$$\text{Volume tangki} = \frac{100}{80} \times 46 \text{ cuft}$$

= 57.144685 cuft

Volume silinder = (π/4) x D^2 x Hs

= 3.14 x D^2 x 2 x D

= 1.1775 D^3

Volume tutup atas = 0.000049 D^3 (*Brownell , hal 95)*

Volume tutup bawah = 0.000049 D^3 (*Brownell , hal 95)*

Volume tangki = V silinder + V tutup atas + V tutup bawah

57.14468 cuf = 1.1775 D^3 + 0.00005 D^3 + 5E-05 D^3

57.14468 cuf = 1.177598 D^3

D = 3.64748 ft

= 1.112037 m

= 43.76976 in
Hs = 1.5D = 5.47122 ft
= 65.65464 in

MENENTUKAN TEBAL SHELL

1 MENENTUKAN TINGGI LIQUIDA DALAM SHELL

DITENTUKAN

Tinggi liquida = 1.4023 tinggi shell
Hl = 1.4023 Hs
Hl = 1.4023 x 5.471220106 ft
= 7.672291955 ft
= 2.339113401 m

2 MENENTUKAN TEKANAN DESIGN

Apabila didalam bejana terdapat liquida, maka

Pdesign = Po-pi+P hidrostatis
Pdesign = 14.7 - 14.7 + P Hidrostatis
Pdesign = P hidrostatis
Pdesign = ρ x (g/gc) x h liquid
= 57.90322 $\frac{lbm}{cuft}$ x 1 $\frac{lbf}{lbm}$ x 7.672 ft
= 444.2504 $\frac{lbf}{ft^2}$
= 3.085072 psi

Pdesign diambil 20% lebih besar untuk faktor keamanan
Pdesign = 1.2 x (P operasi + P hidrostatis)
= 21.34208647 psi
Dipergunakan bahan konstruksi dari carbon steel dengan spesifik
SA 283 Grade C (Brownell T. 13-1)

f allowable = 12650 carbon stell SA-283 grade C
c = 0 in
Sambungan las dengan tipe double welded butt joint
efisiensi las (e) = 0.8
r = 0.5 x 43.77 in
= 21.88 in
Rumus tebal shell yang digunakan

$$tmin = \frac{P \times D}{2(f \times e) - (0.6 \times P)}$$

$$tmin = \frac{21.34 \times 43.77}{10120 - 1.851}$$

= 0.092 in

digunakan ts = 3/16 in

3 MENENTUKAN TEBAL TUTUP ATAS ELIPTICAL

Tutup alas berbentuk standart dished head

OD = ID + 2ts
= 43.76976085 + 0.375
= 44.14476085 in

rc = 22.07238043 in
= 1.839365035 ft

tinggi tutup (h = rc - (rc^2 - (D^2/4)^0.5
= 1.600124536 ft

Vol dished = 1,1 x h^2 x (3R-h)
= 1.1 x 2.5603985 x (5.52 - 1.60)
= 11.0347227 cuft

Bentuk = Flanged and standart dished head

Tebal standart eliptical dished (atas)

$$t = \frac{P \times Di}{2.f.e - 0.2P} + C$$

$$t = \frac{21.34 \times 43.77}{20240 - 4.268} + 0.1$$

= 0.171 in (*Brownell ,pers 13.10 hal 25*)

digunakan ts tebal head = 3/16 in

Asumsi = Tebal tutup atas = Tebal tutup bawah = 3/1 in

Sistem Pengaduk

Jumlah baffle = 4 buah

Jumlah impeller (pengaduk) antara 4-16 tetapi umumnya 6 atau 8 *(Mc Cabe 5 ed pg 243)*

Dipilih pengaduk type flat blade turbine dengan jumlah blade 6

1 PENENTUAN DIMENSI PENGADUK

Tinggi bahan total, HL	=	7.6723	ft
	=	92.0675	in
Diameter dalam tangki	=	3.6475	ft
Dt	=	43.7698	in

Ukuran pengaduk diambil dari Mc Cabe Ed 5th hal 243

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

$$\frac{L}{Da} = \frac{1}{4} \qquad \frac{J}{Dt} = \frac{1}{12}$$

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

Keterangan

Da = Diameter Impeller (pengaduk)
Dt = Diameter Tangki
L = Panjang Blade
W = Lebar Blade
E = Jarak Impeller dari dasar tangki
J = Lebar Blade

Diameter impeler (Da) = 1/3 Dt = 0.333333333 x 4
= 1.21582669 ft
Lebar blade (W) = 1/5Da = 0.2 x 1
= 0.243165338 ft
Panjang blade (L) = 1/4Da = 0.25 x 1
= 0.303956673 ft
jarak impeller dari dasar = 1/3 Dt = 0.333333333 x 4
= 1.21582669 ft
Lebar baffle (J) = 1/12Dt = 0.083333333 x 4
= 0.303956673 ft
Tebal pengaduk = $\frac{1}{10}$ x 0.303956673
= 0.030395667 ft

2 PENENTUAN JUMLAH PENGADUK

Tinggi bahan total, HL = 7.672292 ft
Diameter dalam tangki, Dt = 3.6474801 ft
sg = $\frac{\rho \text{ Bahan}}{\rho \text{ reference}}$
= $\frac{57.903216 \text{ lbm/cuft}}{62.43 \text{ lbm/cuft}}$
= 0.9274902
Jumlah impeler = $\frac{\text{tinggi larutan}}{\text{diameter bejana}}$ x sg
= $\frac{7.672292}{3.6474801}$ x 1
= 1.9509293
Jadi jumlah impeller sebanyak = 2 buah

3 PENENTUAN POWER MOTOR

sg reference = 1 *(Kern T.6 hal.808)*
μ reference = 0.95 cps *(Kern Fig.14 hal 822-823)*
μ bahan = $\frac{\text{sg bahan x μ reference}}{\text{sg reference}}$
= $\frac{0.92749 \text{ x } 0.95}{1}$

= 0.881115729 cps
= 0.000592082 lb/ft.s
ρ Campuran = 57.90321576 lb/cuft

Dari Joshi hal 415 didapat, kecepatan putaran pengadukan jenis turbin antara 200-250 m/min

Ditetapkan kecepatan pengaduk (N) = 190 rpm
= 3.167 rps

Putaran pengaduk (V) = π x N x Da
= 3.14 x 190 x 0.37
= 221.1470132 m/min (memenuhi)

Bilangan Reynold = $\frac{\rho \times Da^2 \times N}{\mu}$
= $\frac{57.9 \times 1.478 \times 3.17}{0.000592082}$
= ##### (Aliran Turbulen)

Perhitungan power pengaduk yang dibutuhkan :

Diperoleh nilai Nre > 10000, sehingga Np = KT

KT = Np = 5.75 *(Ludwig vol-1 T.5-1,hal301)*

P = $\frac{KT \times N^3 \times Da^5 \times \rho}{gc}$ *(McCabe %ed,tabel 9.2,hal254)*
(McCabe %ed,tabel 9.24,hal253)

P = $\frac{5.75 \times 31.75 \times 2.6568 \times 57.9}{32.2}$
= 872.3 ft.lbf/s
= $\frac{872.3}{550}$
= 1.586 hp

Power Losess pada gland 10% hp = 0.1 x 1.586051861
= 0.158605186 hp

Power input dengan gland losess = 1.586051861 + 0.158605186
= 1.744657047 hp

Transmision sistem losses 20% = 0.2 x 1.744657047
= 0.348931409 hp

Power total = 1.744657047 + 0.348931409
= 2.093588456 hp

Efisiensi motor = 0.8

Sehingga power moto: = $\frac{2.093588456}{0.8}$
= 2.61698557 hp

4 SISTEM PENDINGIN

Perhitungan sistem penjaga suhu : (Kern Hal .719)

Dari neraca panas, suhu yang dijaga : 165.000 C

Q = 232012.558 kal/jam
= 920.685 BTU/jam

Suhu Feed masuk	=	165	C	=	329	F
Suhu Bahan Keluar	=	165	C	=	329	F
Suhu Air pendingin masuk	=	30	C	=	86	F
Suhu air pendingin keluar	=	45	C	=	113	F
ΔT1	=	216	F			
ΔT2	=	243	F			

Kebutuhan media = 15467.50 kg/jam
= 34105.83 lb/jam
Densitas media = 62.430 lb/cuft
Rate Volumetrik = $\frac{34105.83 \text{ lb/jam}}{62.430 \text{ lb/cuft}}$
= 546.305 cuft/jam
= 0.152 cuft/detik

Koefisien perpindahan panas bagian luar jaket :

$$hi = 0{,}36\,(k/Di)\,\frac{[L^2 N \rho]^{2/3}}{\mu}\,\frac{[C \cdot \mu]^{1/3}}{k}\,\frac{[\mu]^{0.14}}{\mu w}$$

(Kern pg.71 eq 20-1)

Keterangan :

L = Da (diameter impeller) = 1.216 ft
N = Putaran pengaduk = 190 rpm = 11400 rph
ρ = Berat jenis air = 62.43 lb/cuft
Pada suhu tangki penampungan = 30 C maka
μ = 0.821 cps = 1.985 lb/ft.jam
k = 0.333 btu/jam/ft2
c = 1 btu/lb.F

$$Re\,p = \frac{[L^2 N \rho]^{2/3}}{\mu}$$

$$= \frac{(\ 1.478 \times 11400 \times 62.43\ )^{2/3}}{1.985}$$

= 6548.426

$$\frac{[C \cdot \mu]^{1/3}}{k} = \frac{(\ 1.000 \times 1.985\ )^{1/3}}{0.333}$$

= 3.776551447

$$\frac{[\mu]^{0.14}}{\mu w} = 1$$ (Untuk air)

hi = 0.36 x $\frac{0.333}{3.647}$ x 6548.4 x 3.7766 x 1

= 812.3164 Btu/jam .ft.F

Untuk air pendingin yang berada dalam jaket mengacu pada diameter dalam bejana hio = 100 Btu/jamft^2 F

Menghitung Uc :

Uc = $\frac{hi \times hio}{hi+hio}$

= 89.0389 Btu /jamft^2 F

Rd = 0.001 (Kern tabel 12 pg 845)

hd = $\frac{1}{Rd}$

= 1000

Menghitung Ud :

Ud = $\frac{Uc \times hd}{Uc + hd}$

= 81.75914643 Btu /jamft^2 F

A = π x Di x H Pengaduk + π/4 x Di2

= 3.14 x 3.65 x 5.47 + 10.44

= 73.1061 ft2

Penghitungan Tinggi Jaket :

Tinggi jaket = Tinggi shell

h = 5.4712 ft

Asumsi :

Tebal air pendingin (ts) = 2 in

Tebal jaket (tj) = 3/16 in

e = 0.8

C = 0.13

Dipergunakan bahan konstruksi yang terbuat dari carbon steel SA-283 Grade C

f allowable = 12650

Do (Shell) = Di + 2ts

= 43.7698 + 4

= 47.7698 in

Di (jaket) = Do (Shell) + 2tj

= 47.7698 + 0.375

= 48.1448 in

Do (Jaket) = Di (Jaket) + 2tj

= 48.1448 + 0.375

= 48.5198 in

P desain jaket = Po - Pi + Ph

$= 14.7 - 14.7 + x\ g/gc\ x\ hli$

$= 62.43 \frac{lbm}{cuft} \times 1 \frac{lbf}{lbm} \times 8\ ft$

$= 478.9812\ lbf/ft2$

$= 3.326258\ psi$

Penentuan tebal jaket :

Tebal jaket berdasarkan ASME Code :

$$tj = \frac{P \times Dij}{2.f.e - P} + C$$

$$2 = \frac{3.326 \times 48.14}{1.6\ f - 3.326} + 0.1$$

$f = 55.45954726$

f allowable > f desain

12650 > 55.45954726

Dipilih tebal jaket = 3/16 in

SPESIFIKASI REAKTOR

Reaktor

Dimensi Shell :

Diameter shell inside	=	3.647480071	ft
Tinggi Shell	=	5.471220106	ft
Tebal Shell	=	0.1875	in
Tebal tutup atas (Eliptical dished)	=	3/16	in
Tebal tutup bawah (eliptical dished)	=	3/16	in

Sistem Pengaduk :

Dipakai impeller jenis turbin dengan 6 buah flat blade dengan 2 impeller .

Diameter impeller	=	1.21582669	ft
Panjang Blade	=	0.303956673	ft
Lebar blade	=	0.243165338	ft
Power Motor	=	3.61698557	hp
Bahan Konstruksi	=	Carbon Steel SA-283 Grade C	
Jumlah Tangki	=	1 buah	

Sistem Pendingin :

Diameter jaket	=	4.012063404	ft
Tinggi Jaket	=	5.4712	ft
Jaket Spacing	=	4	in
Tebal Jaket	=	3/16	in

23 POMPA REAKTOR (L-211)

Fungsi = Mengalirkan *dioctyl phthalate* dari reaktor menuju *cooler*

Tipe = Centrifugal Pump
(Sesuai untuk viskositas <10 cP dan bahan liquid)

PERHITUNGAN

Bahan Masuk = 4001.646 kg/jam
= 8823.629 lb/jam
ρ Campuran = 53.2404 lb/cuft
Rate massa = 8823.629 lb/jam
Rate volumetrik = 152.3858 cuft/jam
= 2.539764 cuft/menit
= 0.042329 cuft/detik
= 18.99997 gpm

Asumsi aliran turbulen
(Di) optimum untuk aliran turbulen, NRe < 2100 digunakan persamaan :

Diameter optir $3.9 \times q_f^{0.45} \times \rho^{0.13}$ (Peters, 4ed, pers.15 : 496)

Keterangan :
in
q_f = Fluid flow rate; (cuft/detik)
ρ = Fluid Density; (lb/cuft)

Diameter pipa optimum, Di
= 3.9 x 0.042 0 x 53.24 0
= 1.576 in

Dari App. A.5-1 (Geankoplis, 1993:892) dipilih spesifikasi :
OD = 0.675 in
= 0.056 ft
ID = 0.493 in
= 0.041 ft
A = $(^1/_4 \times \pi \times ID^2)$
= 0.25 x 3.14 x 0.041 ^2
= 0.001325 ft^2

Kecepatan linear, v = $\frac{qf}{A}$
= $\frac{0.0423294}{0.001325}$ cuft/detik ft^2
= 31.947808 ft/dtk

ρ reference = 62.43 lb/cuft
sg reference = 1
μ reference = 0.95
sg bahan = $\frac{\rho \text{ bahan}}{\rho \text{ reference}} \times$ sg reference
= $\frac{53.2404}{62.43} \times 1$

= 0.8528015

μ berdasarkan sg bahan

$$\mu = \frac{\text{sg bahan}}{\text{sg reference}} \times \mu \text{ reference}$$

$$= \frac{0.8528015}{1} \times 1$$

= 0.8101615 cps

= 0.0005444 lbf/s

$$Nre = \frac{D \; v \; \rho}{\mu}$$

$$= \frac{0.0410833 \times 31.95 \times 53.24}{0.000544403}$$

= 128359.27 > 2100 (Asumsi aliran turbulen benar)

Dipilih pipa commercial steel,

ε = 0.000048 m

ε/D = 0.003832211

f = 0.004

Digunakan persamaan Bernoulli :

$$-Wf = \frac{\Delta P}{\rho} + \Delta Z \frac{g}{gc} + \frac{\Delta V^2}{2\alpha} + \Sigma F$$

Perhitungan friksi berdasarkan **Geankoplis 3ed T 2.10-1, hal 93**

Taksiran panjang pipa lurus = 6.6 ft = 2 m

- 3 elbow 90° = 3 x 35 x 0.041
  = 4.3 ft
- 1 gate valve = 1 x 9 x 0.041
  = 0.4 ft

Panjang total pipa (Le) = 11 ft

Friksi yang terjadi:

1. Friksi karena gesekan bahan dalam pipa

$$\Sigma F = \frac{2f \times v^2 \times Le}{gc \times D}$$ (Geankoplis 3ed, eq 2.10-6)

$$= \frac{4 \times 0.004 \times 1020.7 \times 11.28}{32.27 \times 0.0411}$$

= 138.9849774 lbf/lbm

1 atm = 14.6959 psi = 2116.2096 lbf/ft^2

P_1 = 1 atm + P hidrostatis

$= 2116 \text{ lbf/ft2} \quad 53.24 \times 1 \times 7.672)$

$= 2116 + 408.5$

$= 2525 \text{ lbf/ft2}$

$P_2 = 1 \text{ atm} = 2116.2 \text{ lbf/ft}^2$

$\Delta P = 2525 - 2116$

$= 408.476 \text{ lbf/ft}^2$

$$\frac{\Delta P}{\rho} = \frac{408.476 \text{ lbf/ft}^2}{53.240 \text{ lb/cuft}}$$

$$= 7.672 \frac{\text{ft.lbf}}{\text{lbm}}$$

$$\frac{\Delta v^2}{2 \times \alpha \times gc} = \frac{31.95^2}{2 \times 1 \times 32.217}$$

$= 15.84 \text{ ft lbf/lbm}$

Asumsi :

$Z1 = 3.281 \text{ ft}$

$Z2 = 0.656 \text{ ft}$

$\Delta Z = (Z2 - Z1) = 2.625 \text{ ft}$

$$\Delta Z \frac{g}{gc} = 2.625 \text{ ft} \times 1 \frac{\text{lbf}}{\text{lbm}}$$

$$= 2.625 \frac{\text{ft.lbf}}{\text{lbm}}$$

Persamaan Bernoulli

$$-Wf = \frac{\Delta P}{\rho} + \Delta Z \frac{g}{gc} + \frac{\Delta V^2}{2 \alpha gc} + \Sigma F$$

$= 7.672 + 2.6247 + 15.84 + 138.985$

$$= 165.1224 \frac{\text{ft.lbf}}{\text{lbm}}$$

$$Hp = \frac{- Wf \times \text{flowrate(gpm)} \times sg}{3960}$$

$$= \frac{165.1224 \times 19 \times 0.853}{3960}$$

$= 0.675634$

Effisiensi Pompa $= 0.400$ **(Peters 4ed ; Figure 14 - 37)**

$$Bhp = \frac{Hp}{\eta \text{ pompa}}$$

$$= \frac{0.676}{0.400}$$

$= 1.689 \text{ Hp}$

Effisiensi motor $= 0.800$ **(Peters 4ed ; Figure 14 - 38)**

$$\text{Power motor} = \frac{Bhp}{\eta \text{ motor}}$$

$$= \frac{1.689}{0.800}$$

= 2.111 Hp

SPESIFIKASI POMPA REAKTOR

Fungsi	=	Mengalirkan *dioctyl phthalate* dari reaktor menuju *coole*	
Type	=	Centrifugal Pump	
		(Sesuai untuk viskositas <10 cP dan bahan liquid)	
Power Motor	=	2.111357179	Hp
Rate volumetrik	=	18.99997279	gpm
Total dynamic hea	=	165.122	ft.lbf/lbm
Efisiensi pompa	=	0.400	
Efisiensi motor	=	0.800	
Bahan konstruksi	=	Commercial Steel	
Jumlah	=	1 buah	

24 COOLER REAKTOR (E-212)

Fungsi : Mendinginkan produk reaktor sebelum masuk *neutraliser*

Komponen	kg/jam	Fraksi Berat	ρ (gr/cm$^{3)}$	fraksi/ρ
$C_8H_4O_3$	2.891	0.0007	1.200	0.0006
$C_8H_6O_4$	2.899	0.0007	1.522	0.0005
$C_8H_{18}O$	5.078	0.0013	0.821	0.0015
$C_{16}H_{36}O_4T$	0.060	0.0000	0.998	0.0000
$C_{24}H_{38}O_4$	3801.074	0.9499	0.984	0.9653
H_2O	189.644	0.047391392	1.000	0.0474
Total	4001.646	1.000	6.525	1.015

ρ bahan = 0.985 x 62.43 $\frac{lb/ft^3}{gr/ml}$

= 61.49 lb/ft^3

Rate bahan = 4001.65 lb/jam

Rate volumetrik = $\frac{\text{Rate massa}}{\rho \text{ bahan}}$

= 65.08 ft^3/jam

T bahan masuk	=	165.00 °C ;	329	°F	(t1)
T bahan keluar	=	95 °C ;	203	°F	(t2)
T air pendingin masuk	=	30.00 °C ;	86	°F	(T1)
T air pendingin keluar	=	45.00 °C ;	113	°F	(T2)

Q losss	=	232012.5580	kkal/jam
	=	918769.730	BTU/jam
n CW	=	15467.50	kg/jam
	=	34028.49	lb/jam

Log Mean Temperature Difference (ΔT LMTD)

$$\Delta T\ LMTD = \frac{\Delta t2 - \Delta t1}{\ln \frac{\Delta t2}{\Delta t1}}$$

$\Delta t1 = T1 - t2$
$= 117\ ^oF$
$\Delta t2 = T2 - t1$
$= 216\ ^oF$
$\Delta T\ LMTD = 161.5\ ^oF$

Tc dan tc

tc = T bahan
= 266 ^oF
Tc = T stean
= 99.5 ^oF

Trial :

UD = 75 - 150
= 75
Tipe = Double Pipe Heat Exchanger (DPHE)
Length = 20 ft
OD = 1.00 in
BWG = 14
Passes = 2
a't = 0.546 in^2
a" = 0.262 ft^2 / ft

$$A = \frac{Q}{\Delta T\ LMTD \times UD}$$
$= 75.87\ ft^2$

$$Nt = \frac{A}{L \times a"}$$
$= 15.00$

Berdasarkan Tabel 9 kern dipilih ukuran yang paling mendekati :

OD tube = 1 in
Pitch = 1 1/4 in
Passes = 2 L/D = 315.8
Nt = 220
a" = 0.262 ft^2 / ft
Wall thickr = 0.083 in
ID tube = 0.76 in ; 0.0633 ft
ID shell = 8 in
B space = 4.8 in
Passes = 1
A = Nt x L x a"
= 1152.8 ft^2

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

= 4.935737

Cold Fluid	Hot Fluid
o) Flow area, as as = ID x C' x B /144 Pr B = ID / 5 = 2 in C' = (Pt - OD tube) / 2 = 1/8 as = 0 ft^2	o) Flow Area, at at = Nt x at / 144 n = 0.4171 ft^2
o) Mass Velocity, Gs Gs = w / as = 3,828,206 lb/jam.ft^2	o) Mass Velocity, Gt Gt = w / at = 9,594 lb/jam.ft^2
o) Bilangan Reynold, Ret Nre = Ds x Gt / μ tc = 99.5 °F μ = 0.013 cP = 0.031 lb/jam.ft Ds = 0.99 in = 0.083 ft Nre = 10,039,001	o) Bilangan Reynold, Ret Nre = D x Gt / μ μ = 0.09 cP = 0.217 lb/jam.ft Nre = 2,801

Cold Fluid	Hot Fluid
o) jH = 1000	o) jH = 600
o) k = ## k_{water}	o) $(c\mu/k)^{1/3}$
= 0.3600	tc = 266
c = 0.45	c = 0.36
$(c\mu/k)^{1/3}$ = 0.34	k = 0.45
	$(c\mu/k)^{1/3}$ = 0.6
o) ho = 1500 BTU/hr.ft^2 x φs	o) hi = jH .k/D . $(c\mu/k)^{1/3}$ x φt
ho = 1500 BTU/hr.ft^2.^{o}F φs	hi / φt = 198.152711
o) tw = tc + ho/φt (Tc-tc) / hio/φt+ho/φs	
= #######	
$\varphi s = \frac{(\mu)^{1/4}}{(\mu w)^{1/4}}$	$\varphi t = \frac{(\mu)^{1/4}}{(\mu w)^{1/4}}$
φs = 0.891	$(\mu w)^{1/4}$ = 0.242
o) ho = 1684	φt = 0.973
	o) hio = 204
o) ho = 1684.202	

Menghitung UC

Uc = hio x ho / hio + ho

= 181.68 BTU/ft^2 ^{o}F jam

Menghitung Rd

Rd = Uc - U_D / Uc x U_D

U_D = 4.936

Rd = 0.20 > 0.002 (memenuhi)

Pressure Drop	
o) Nre = 10,039,001	o) Nre = 2,801
f = 1E-07	f = 0.0005
v = 37.93145 ft^3/lb	s = 1
ρ = 0.0264 lb/ft^3	

s = 0.000422 o) N+1 = 12 L/B = 50 o) de = 0.9904 in = 0.0825 ft o) ΔPs = $f . Gs^2 . Ds . (N+1)$ $5,22 . 10^{10} . De . S . \Phi s$ = 3.32640 < 10 psi (memenuhi)	o) ΔPt = $f.Gt^2.L.n$ $5,22 . 10^{10}.Dt.s.\varphi t$ = 0.00 < 2 psi (memenuhi)

SPESIFIKASI *COOLER REAKTOR*

Nama Alat : *Cooler* Reaktor
Fungsi : Mendinginkan produk reaktor sebelum masuk *neutraliser* dari suhu 165 °C menjadi 95 °C
Tipe : *Double Pipe Heat Exchanger*
- Inside Diameter = 0.76 in
- Outside Diameter = 1 in
- Panjang = 20 ft
- Pitch = 1 in
- Jumlah Tube = 220 buah

Shell
- Inside Diameter = 8 in
- Baffle space = 4 4/5 in

Jumlah cooler = 1

25 NEUTRALISER (M-220)

Fungsi : Menetralkan katalis *tetrabutyl titanate* menggunakan natrium hidroksida
Tipe : Tangki berbentuk silinder tegak, tutup atas dan bawah berbentuk *torispherical*
Jumlah : 1 buah
Kondisi Op : T = 95 °C = 368.15 K
P = 1 atm = 760 mmHg = 14.7 psi

1) Menentukan Kapasitas Tangki

Komponen	Massa (kg/jam)	%Berat
$C_{16}H_{36}O_4Ti$	0.0598	0.000015
$C_{16}H_{35}O_4TiNa$	0.0636	0.000016
$C_{24}H_{38}O_4$	3801.0743	0.949860
H_2O	189.6467	0.047391
NaOH	0.0070	0.000002
$C_8H_{18}O$	5.0783	0.001269
$C_8H_6O_4$	2.8994	0.000725
$C_8H_4O_3$	2.8907	0.000722
Total	**4001.7198**	**1.0000**

Komponen	%Berat	ρ (kg/m^3)	$\rho_{campuran}$ (kg/m^3)	μ (cP)	$\mu_{campuran}$ (cP)
$C_{16}H_{36}O_4Ti$	0.00001	809.2010	1.85E-08	1.4400	1.04E-05
$C_{16}H_{35}O_4TiNa$	0.00002	834.6840	1.91E-08	0.7720	2.06E-05
$C_{24}H_{38}O_4$	0.94986	919.0110	0.001034	3.3040	0.287488
H_2O	0.04739	960.6370	4.93E-05	0.2940	0.161195
NaOH	0.00000	1880.9150	9.34E-10	210.3030	8.36E-09
$C_8H_{18}O$	0.00127	774.0010	1.64E-06	0.9910	0.001281
$C_8H_6O_4$	0.00072	1243.5200	5.83E-07	155.9670	4.65E-06
$C_8H_4O_3$	0.00072	1241.1410	5.82E-07	3.9880	0.000181
Total	**1.0000**	**8663.11**	**0.0011**	**377.0590**	**4.50E-01**

$$\rho_{campuran} = \frac{\sum xi}{\sum xi/\rho} = \frac{1.0000}{0.0011} = 921.0 \text{ g/m}^3$$

$$= 57.50 \text{ b/ft}^3$$

$$\mu_{campuran} = \frac{\sum xi}{\sum xi/\mu} = \frac{1.0000}{0.4502} = 2.221 \text{ cP}$$

$$= 0.001 \text{ lb/ft.s}$$

Aliran keluar *neutraliser* dijaga selalu berada pad 4001.7 kg/jam. Sehingga tidak terjadi defisit aliran, karena beroperasi kontinyu (tidak ada waktu tinggal) dianggap pengadukan sempurna 100%. Maka :

$$V_{cairan} = \frac{m}{\rho} = \frac{4001.7198 \text{ kg/jam}}{921.0277 \text{ kg/m}^3} = 4.3448 \text{ m}^3$$

$= 153.4367 \text{ ft}^3$

Untuk perancangan diasumsikan tangki berisi 80% sehingga volume desain tangki sebagai berikut :

Volume tangki $= 4.345 \text{ m}^3 \div 80\% = 5.4311 \text{ m}^3$
$= 1434.732$ galon

2) Menentukan Diameter dan Tinggi *Shell*

Tangki dirancang dengan tutup atas berupa *torispherical.*

Untuk ukuran optimum tangki silinder, harga $H_S/ID = 2$

Asumsi : $H_S/ID = 2$

$H_S = 2 \text{ ID}$

Volume tangki = V silinder + 2 × V tutup

Volume tangki $= (¼ \times (\pi \times ID^2) \times H_S) + 2 \times (0{,}000049\ ID^3)$

$5.4311 = (¼ \times (3{,}14 \times ID^2) \times + 2 \times (0{,}000049\ ID^3)$

$5.4311 = 1{,}1775\ ID^3 + 2 \times (0{,}000049\ ID^3)$

$ID^3 = 3.459$

$ID = 1.512 \text{ m} = 4.962 \text{ ft} = 59.41 \text{ in}$

$H_S = 2 \times ID$

$= 2 \times 1.5124 \text{ m}$

$= 3.025 \text{ m} = 9.924 \text{ ft}$

3) Menentukan Tinggi Cairan pada Tangki

$$H_L = \frac{V_L}{¼ \times \pi \times D^2} = \frac{153.4367}{¼ \times \pi \times 4.962)^2} = 7.939 \text{ ft}$$

$= 2.420 \text{ m}$

$= 95.05 \text{ in}$

4) Menentukan Tekanan Desain

$P_{operasi} = 1 \text{ atm} = 14.7 \text{ psi}$

$$P_{hidrostatik} = \rho_{Campuran\ cair} \times \frac{g}{gc} \times H_S$$

$= 57.4998 \text{ lb/f} \times 1 \times 9.924 \text{ ft}$

$= 570.6023 \text{ lb/f} = 3.963 \text{ psi}$

$P_{desain} = P_{operasi} + P_{hidrostatik}$

= 14.6960 + 3.9627
= 18.6587 psi

5) Menentukan Tebal *Shell*

Dengan faktor keamanan 20%, maka :

P_d = tekanan desain = 1.2 × 18.66 psi = 22.39 Psi
r = jari-jari *shell* = 59.41 : 2 = 29.70 in
f = *allowable stress* = 12650 psi
Carbon Steel SA-283 *Grade* C (Brownell & Young, 1959:25
E = efisiensi pengelasan *double-welded butt joint* = 80%
c = faktor korosi = 0.1250

Sehingga : $t_s = \frac{P_d.r}{f.E - 0{,}6\,P_d} + c$

(Pers 13.1 Brownell & Young, 1959:254)

$= \frac{22.3904 \times 29.7026}{12650 \times 80\% - 1 \times 22.39} + 0.125$

= 0.191 in
≈ 1/4 in **Tabel 5.7. (**Brownell & Young, 1959:89)

6) Menentukan Diameter dan Tinggi yang Distandarkan

Diameter Standar (Ds)

OD = ID + 2 t_s
= 59.4051 in + 2 × 1/4 in
= 59.9051 in

Sehingga : $OD_{standar}$ = 60 in **Tabel 5.7.** (Brownell & Young, 1959:91)

ID = $OD_{standar}$ - 2 t_s
= 60 in - 2 × 1/4 in
= 60 in = 1.511 m = 4.958 ft

Diperoleh OD standar 60 in dengan :
icr = 3 5/8 in
r = 60 in

Tinggi Standar (H_S)

H_S = 2 × 60 in
= 120 in
= 3.048 m
= 393.7 ft

7) Menentukan Dimensi pada Tutup

Digunakan *head* jenis standard *dished/torispherical* dengan bahan konstruk yang sama dengan *shell mixer*

$$th = \frac{0.885\ P_d.r}{f.E - 0.1\ P_d} + c$$

$$= \frac{0.8850 \times 22.3904 \times 29.7026}{12650 \times 80\% - 0.1 \times 22.39} + 0$$

$$= 0.183 \text{ in}$$

Digunakan tebal stand = 3/16 in **Tabel 5.7.** (Brownell & Young, 1959:91)

Tabel 5.6. (Brownell & Young, 1959:88) untuk tebal tutup 3/16 in didapat r sf 1½ -2 in. Diambil sf : 1 1/2 in

***Fig*. 5.8.** (Brownell & Young, 1959:87), dihitung ukuran-ukuran sebagai berikut :

a = ½ ID = ½ × 60 = 29.75 in
AB = a - icr = 29.75 - 3 5/8 = 26.13 in
BC = r - icr = 60 - 3 5/8 = 56.38 in
AC = $\sqrt{(BC)^2 - (AB)^2}$ = 49.96 in
b = r - AC = 60 - 49.96 = 10.04 in
OA = th + b + sf
= 3/16 + 10.04 + 1 1/2 = 11.73 in
= 0.298 m

Tinggi tangki total = Hs + 2 OA
= 3.025 + 2 × 0.298
= 3.621 m = 142.2 in

8) Menentukan Jumlah Pengaduk

Dipilih jenis pengaduk *propeler three-blade* dengan alasan :
Karena campuran *liquid* mempunyai viskositas yang rendah dan hasil campuran diharapkan homogen karena pengaduk jenis ini cocok untuk viskositas rendah hingga sedang
persamaan berikut :

$$SpGr = \frac{\rho_{campuran}}{\rho_{air}} = \frac{57.50 \text{ lb/f}}{59.97 \text{ lb/ft}^3} = 0.959$$

$$\text{Jumlah pengaduk} = \frac{H_L \times SpGr}{ID} = \frac{2.420 \text{ m} \times 0.959}{1.5113 \text{ m}}$$

$$= 1.535$$

$$\approx 2 \text{ buah}$$

9) Menentukan Diameter dan Tinggi Pengaduk

Diameter Pengaduk

ID/d = 3 (Brown, 1950:507)

$$Da = \frac{ID}{ID/d} = \frac{1.511}{3} = 0.5038 \text{ m}$$

$= 19.83$ in

$= 1.65$ ft

Jarak Pngaduk dari Dasar Tangki

Zi/d = 0,75 - 1,3 ; ((Brown, 1950:507)

$Zi = 0{,}75 \times Da = 0.75 \times 0.504 = 0.378$ m

$= 14.87$ in

$= 1.240$ ft

10) Menentukan Dimensi Pengaduk

Dari **Tabel 3.4-1** (Geankoplis, 1993:144)

W/Da = 1/5

Dd/Da = 2/3

H/Dt = 1

L/Da = 1/4

J/Dt = 1/12

$H = Dt = 60$ in

$= 1.524$ m

$= 5.000$ ft

$Dd = 2/3 \times Da = 2/3 \times 19.83$ in

$= 13.22$ in

$= 0.336$ m

$= 1.102$ ft

$L = 1/4 \times Da = 1/4 \times 19.83$ in

$= 4.958$ in

$= 0.126$ m

$= 0.413$ ft

$W = 1/5 \times Da = 1/5 \times 19.83$ in

$= 3.967$ in

$= 0.101$ m

$= 0.331$ ft

J = 1/12 × OD = 1/12 × 60 in
= 5.000 in
= 0.127 m
= 0.417 ft

11) Menentukan *Power* Motor Pengaduk

Kecepatan Putar Pengaduk

$$WELH = \frac{\rho_{Campurar}}{\rho_{air}} \times H_L = \frac{57.50 \text{ lb/f}}{59.97 \text{ lb/ft}^3} \times 7.939 \text{ ft}$$
$$= 7.612 \text{ ft}$$

$$N = \frac{600}{\pi d}\sqrt{\frac{WELH}{2d}}$$ Eq. 8.8. (Rase & Holmes, 1977:338)

Keterangan :
Da = diameter pengaduk (ft)
N = kecepatan putar pengaduk (rpm)
WELH = *water equivalent liquid height* (ft)

$$N = \frac{600}{\pi d}\sqrt{\frac{WELH}{2d}} = \frac{600}{3{,}14 \times 1.653}\sqrt{\frac{7.6120}{2 \times 1.653}}$$
$$= 133.1166$$

Diambil kecepatan pengaduk standar 155 rpm, maka (Walas, 1990:288) :
N = 155 rpm
= ##### rps
= 9300 rph

Bilangan Reynold

$$N_{Re} = \frac{\rho \times Da^2 \times N}{\mu}$$ Pers. 3.4-1. (Geankoplis, 1993:158)

$$= \frac{57.4998 \text{ lb/ft}^3 \times 1.6528 \text{ }^2\text{ft} \times 2.5833 \text{ rps}}{0.0015 \text{ lb/ft.s}}$$
$$= 272230.9580$$

Karena N_{Re} > 10.000, maka sesuai untuk digunakan *baffle* (Perry, 1997:9-8)

***Power* Pengaduk**

Karena N_{Re} > 10.000 maka *power* tidak tergantung pada bilangan Reynold d bukan merupakan fungsi viskositas. Maka untuk pengaduk jenis *propeller* didapat Np = KT = 0,87 **Tabel 9.3.** (Mc Cabe et al., 1993:254). Sehingga :

$$P = \frac{Np.\rho.N^3.Da^5}{gc}$$ Pers. 9.20. (Mc Cabe et al., 1993:253)

Keterangan :

P = daya pengaduk (lb.ft/s)
Np = *power number*
ρ = densitas campuran (lb/ft^3)
N = kecepatan putar pengaduk (rps)
Da = diameter pengaduk (ft)
gc = percepatan gravitasi = 32.1740 $lb.ft/lbf.s^2$

$$P = \frac{0.87 \times 57.4998 \times 2.5833^{3} \times 1.6528^{5}}{32.1740}$$

= 330.5899 lb.ft/s
= 0.6011 hp

Selama proses pengadukan, pengaduk mengalami :

- *Gain Losses* diperhitungkan 10% dari daya masuk (dengan mempertimbangl adanya kebocoran daya pada proses dan *bearing*) = 10% × Po
  Gain losses = 0.0601 hp
- *Transmission Losses* diperhitungkan 20% dari daya masuk (dengan meninja kemungkinan terjadinya kebocoran *belt* atau *gear*) = 20% × Po
  Transmission losses = 0.1202 hp
  P*ower input* = 0.6011 + 0.0601 + 0.1202
  = 0.7814 hp

***Fig* . 14.38.** (Peters & Timmerhaus, 1991:521) didapat efisiensi motor pengaduk 80%, maka *power* motor pengaduk sebesar :

Power motor $= \frac{P}{\eta} = \frac{0.7814}{80\%} =$ 0.9767 hp

Maka digunakan *power* motor pengaduk standar sebesar 1 hp

12) Menentukan Pendingin *Neutraliser*

Q Pendingin = 255662.4 kJ/jam
= 242324.5 Btu/jam
m pendingin = 4070.928 kg/jam
= 3858.548 lb/jam

Suhu bahan masuk T_1 = 95 °C = 203 °F
Suhu bahan keluar T_2 = 95 °C = 203 °F
Suhu pendingin masuk t_1 = 30 °C = 86 °F
Suhu pendingin keluar t_2 = 45 °C = 113 °F

Fluida panas (^oF)		Fluida dingin (^oF)		Selisih (^oF)	
T_1	203	t_2	113	90	Δt_1
T_2	203	t_1	86	117	Δt_2

LMTD = $\dfrac{\Delta t_2 - \Delta t_1}{\ln(\frac{\Delta t_2}{\Delta t_1})}$

= $\dfrac{117 - 90}{\ln (117 : 90)}$

= 103 ^oF

Suhu rata-rata pemanas :

tc = $\dfrac{(t_1 + t_2)}{2}$

= $\dfrac{86 + 113}{2}$

= 100 ^oF

= 38 ^oC

ρ air = 960.6 kg/m^3

= 61.70 lb/ft^3

Debit a = $\dfrac{\text{massa air}}{\rho \text{ air}}$

= $\dfrac{3858.55}{61.70}$

= 62.54 ft^3/jam

= 1.771 m^3/jam

= 0.000 m^3/s

= 0.017 ft^3/s

Lama waktu tinggal dalam *coil* = 60 menit

Volum = $\dfrac{1.771 \times 60}{60}$

= 1.771 m^3

Menghitung Luas Penampang Aliran (A)

Harga kecepatan untuk cairan dalam pipa 1,5 - 2,5 m/s (Coulson, 1989:534)

Dipilih harga kecepata = 2.5 m/s

$$A = \frac{F_{vp}}{v} = \frac{\pi}{4}(ID)^2$$

$ID = \sqrt{\frac{4 . F_{vp}}{\pi . v}} =$

= 0.0158 m
= 0.0519 ft
= 0.6233 in

Dari **Tabel 11.** (Kern, 1965:844) dipilih :

IPS = 1 in
= 0.083 ft
= 0.025 m
OD = 1.32 in
= 0.110 ft
= 0.034 m
ID = 1.05 in
= 0.087 ft
= 0.027 m

$A^{I}\left(flowarea/pipe\right)$ = 0.864 in² = 0.0600 ft²

$A^{II}\left(surface/lin.ft\right)$ = 0.344 ft²/ft

Menghitung *Mass Velocity* (v)

$G_t = \frac{W_t}{A^I} = \frac{3858.548 \text{ lb/jam}}{0.0600 \text{ ft}^2}$
= 64309.55 lb/ft²jam

$v = \frac{G_t}{\rho_{air}} = \frac{64309.55 \text{ lb/ft}^2\text{jam}}{61.7017 \text{ lbm/ft}^3}$
= 1042.265 ft/jam
= 0.2895 ft/s

Menghitung h dan hio

μ air = 0.294 cp
= 0.711 lb/ft.jam

Re dalam pipa :

$\text{Re}_t = \frac{ID.G_t}{\mu} = \frac{0.087 \times 64309.55}{0.7112}$
= 7904.393 Btu/jam.ft² °F

Pada T = 100 °F
v = 0.290 ft/s,

maka diperoleh hi = 500 Btu/jam.ft² °F ***Fig* . 25.** (Kern, 1965:835)

$$h_{io} = h_i \cdot \frac{ID}{OD} = \frac{500 \times 0.0874}{0.1100}$$
$$= 397.3485$$

Menghitung Koefisien Transfer Panas

$$h_j = \frac{0.74 \cdot k}{Dt} \cdot \left[\frac{L^2 \cdot N \cdot \rho}{\mu}\right]^{2/3} \cdot \left[\frac{cp \cdot \mu}{k}\right]^{1/3} \cdot \left[\frac{\mu}{\mu_W}\right]^{0.14}$$

Dimana :

hc	=	Koefisien transfer panas *coil* , Btu/jam.ft².°F			
Dt	=	Diameter dalam tangki	=	4.958	ft
k	=	Konduktifitas panas	=	3.486	Btu/jam.ft.°F
L	=	Diameter putaran pengaduk	=	1.653	ft
N	=	Kecepatan putaran pengaduk	=	9300.000	rph
μ	=	Viskositas air	=	2.221	cp
			=	5.376	lb/jam.ft
ρ	=	Densitas campuran	=	57.4998	lb/ft³
Cp	=	Kapasitas panas	=	#REF!	Btu/lb.ft

$$Rej = \frac{N \cdot Dt^2 \cdot \rho}{\mu} = 2445633.87$$

$$\left(\frac{\mu}{\mu_w}\right)^{0,14} = 1$$

hc = ho = #REF! Btu/jam.ft².°F

Menghitung Uc dan Ud

***Eq* . 6. 38.** (Kern, 1965:231) :

$$U_C = \frac{h_o \cdot h_{io}}{h_o + h_{io}} = \frac{\#REF! \times 397.3485}{\#REF! + 397.3485}$$
$$= \#REF! \text{ Btu/jam.ft}^2.^\circ F$$

Diman: Uc = *clean overall coefficient*
Ud = *dirty overall coefficient*

Dirt Factors (Rd) = #####

$$\frac{1}{U_D} = \frac{1}{Uc} + R_d = \frac{1}{\#REF!} + 0.0020$$
$$= \#REF! \text{ Btu/ft}^2.\text{hr.}^\circ F$$

Menghitung Luas Permukaan Panas

$$A = \frac{Q}{U_D \times LMTD}$$

$$= \frac{242324.5375}{\#REF! \times 102.9}$$

$$= \#REF!\ ft^2$$

$$= \#REF!\ m^2$$

Menghitung Luas Selubung *Neutraliser*

$A = \pi D L$

$A = 3.14 \times 1.511\ m \times 3.048\ m$

$= 14.4642\ m^2$

Luas transfer panas *neutraliser* lebih kecil dibandingkan dengan selubung neutraliser sehingga digunakan *jacket* pendingin.

(A_{panas} = #REF! m^2 < $A_{selubung}$ = 14.46 m^2)

A yang diperoleh dari persamaan diatas tidak boleh lebih besar dari luas *bottom* + luas *shell* reaktor yang tercelup cairan

Maka :

A *Botto* = $(3,14/4) \times OD^2$

A *Shell* = $OD \times 3,14 \times H$

dimana :

OD = Diameter luar reaktor = 60 in = 4.9998 ft

L = Tinggi cairan di reaktc = 95.0541 in = 7.9212 ft

H = Tinggi total tangki = 142.2191 in = 11.8516 ft

A *botto* = 19.6234 ft²

A *Shell* = 186.0625 ft²

A total = A *bottom* + A Shell

= 19.6234 + 186.0625

= 205.6860 ft²

= 19.1089 m^2

Mencari nilai Ud

Dimana :

l = 0.1259 m = 0.4069 ft

N = 155 rpm = 9300 rpj

ρ = 921.0277 kg/m^3 = 57.50 lb/ft^3 (Yaws, 1999)
μ = 2.2213 cP = 5.3312 lb/ft hr (Yaws, 1999)

Sehingga :

$$Re_j = \frac{L^2 \times N \times \rho}{\mu}$$
= 16606.04

Diketahui :
Re_j = 16606.04
j = ##### ***Fig*. 24.** (Kern, 1965:834)
k = ##### Btu/ft.jam. **Tabel 4.** (Kern, 1965:800)
IDs = 1.51 m
= 4.88 ft

$$h_i = j \times (k/ID) \times (Cp \times \mu/k)^{1/3}$$
$$= 100 \times \left(\frac{0.33280}{4.88271}\right) \times \left(\frac{5.33120}{0.33280}\right)^{1/3}$$
= 36.3951

$$h_0 = jH \times (k/De) \times (Cp \times \mu/k)^{1/3}$$

Dimana :
Jarak dari *jacket* (*jacket spacing*) berkisar 1 - 4 in, di ambil 1 in
Jarak dari *jacket* = 1 in
= 0.083 ft
D_1 = Diameter dalam + (2 × tebal dinding)
= 4.883 + (2 x 1/4)
= 4.924 ft
D_2 = D_1 + (2 × jarak *jacket*)
= 4.924 + (2 x 0)
= 5.091 ft

$$De = \frac{D_2^2 - D_1^2}{D_1}$$
$$= \frac{5.091 - 4.924}{4.9244}$$
= 0.339 ft

$$h_0 = j \times (k/De) \times (Cp \times \mu/k)^{1/3}$$

$$= 100 \times \left(\frac{0.333}{0.339}\right) \times \left(\frac{5.3312}{0.3328}\right)^{1/3}$$
$$= 247.5036$$

$$hoi = ho \times \frac{ID}{OD}$$
$$= 247.5 \times \frac{4.9}{5.1}$$
$$= 239.4013$$

Menghitung Uc

$$Uc = \frac{hoi \times hi}{hoi + hi}$$
$$= \frac{239.4 \times 36.40}{239.4 + 36.40}$$
$$= 31.59$$

Menghitung Ud

$$\frac{1}{Ud} = \frac{1}{Uc} + Rd$$
$$\frac{1}{Ud} = \frac{1}{31.59} + 0.001$$
$$\frac{1}{Ud} = 0.03$$
$$Ud = 30.62$$

Menghitung A

$$A = \frac{Q}{Ud \times \Delta T}$$
$$= \frac{242324.54}{30.62 \times \#REF!}$$
$$= \#REF!\ ft^2$$
$$= \#REF!\ m^2$$

Massa air pendingin = 4070.9284 kg/jam

Kecepatan volumetris air

$$Fv = \frac{W}{\rho\ air}$$
$$Fv = \frac{4,070.93\ kg/jam}{960.6370\ kg/m^3}$$
$$= 4.2377\ m^3/jam$$

Diameter dalam *jacket* (Di) = $_{hell}$ + (2 × jarak *jac*
= 95 + (2 × 1)
= 97.05 in
= ##### ft
= ##### m

Tinggi *Jacket* = Tinggi total tangki - Tinggi tutupan atas
= ##### - 0.2980
= 3.3227 m
= 10.9010 ft
= 130.8124 in

Kecepatan *supercritical cooling* (v_i)

$$v_i = \frac{Fv}{A} = \frac{4.238\ m^3/jam}{\#REF!\ m^2} = \#REF!\ m/jam$$

Bahan *Carbon Steel* SA-283 *Grade* C

Tabel 13.1. (Brownell & Young, 1959:251)

f = 12650 psia
E = 0.8
H *jacket* = 130.8124 in
= 10.9006 ft
ρ air = 61.7017 lb/ft^3

$$Ph = \frac{(H - 1) \times \rho}{144} = \frac{(10.9006 - 1\ ft \times 61.70\ lb/ft^3)}{144} = 4.2422\ Psia$$

P *desig* = P + Ph
= 14.70 + #####
= 18.94 psia

Maka :

$$t = \frac{P \times D}{(f \times E) - (0{,}6 \times)} = \frac{18.9382\ psia \times 97.054128\ in}{2 \times (12650 \times 1) - (1 \times 18.94)}$$

= 0.0909 in

Maka dipilih tebal *jacket* standar 3/16 in = ##### m

Tabel 5.7. (Brownell & Young, 1959:89)

Diameter luar *jacket* = ID *jacket* + (2 × tebal *jacket*)
= 97.05 in + [2 × ##### in]
= 97.43 in
= 8.1191 ft

SPESIFIKASI NEUTRALISER

Nama Alat : *Neutraliser*
Kode : M-220
Fungsi : Menetralkan katalis *tetrabutyl titanate* menggunakan natrium hidroksida
Tipe : Tangki berbentuk silinder tegak, tutup atas dan bawah berbentuk *torispherical*
Bahan Konstru : *Carbon Steel* SA-283 *Grade* C
Jumlah : 1 buah
Kondisi Opera : Temperatur 95 ^{o}C dan Tekanan 1 atm
Kapasitas : 4.345 m^3
Dimensi
Silinder
Diameter : 1.512 m
Tinggi : 3.025 m
Tebal : 0.191 in
Tutup
Tebal : 0.183 in
Tinggi : 0.298 in
Tinggi Tangki Total : 3.621 m
Power Pengaduk : 1 Hp
Jacket Pendingin
Tinggi : 3.323 m
Diameter : 2.475 m

26 POMPA NEUTRALISER (L-221)

Fungsi : Mengalirkan *dioctyl phthalate* dari *neutraliser* menuju *rotary drum vacum filter*
Tipe : *Centrifugal pump*
Jumlah : 1 buah

1. Menentukan Bahan Konstruksi Pompa

Bahan konstruksi yang dipilih adalah *Commersial Steel* karena :

- Tahan terhadap korosi
- Memiliki batas tekanan yang diijinkan besar (s.d 22500 psi)
- Memiliki batas suhu yang diizinkan besar (-65°F s.d 650°F)

2. Menghitung Tenaga Pompa

Rate masuk = 4001.653 kg/jam = 2.4506 lb/s
Densitas = 789.4158 kg/m³ = 49.2832 lb/ft³
μ = 1.018 cP = 0.001 lb/ft.s

$$\textit{Rate volumetr} = \frac{\text{massa}}{\text{r}}$$
$$= \frac{2.4506 \text{ lb/s}}{49.2832 \text{ lb/ft}^3}$$
$$= 0.0497 \text{ ft}^3\text{/s}$$
$$= 22.3178 \text{ gpm}$$

Diperkirakan aliran fluida turbulen (Nre>2100), sehingga digunakan persama
Di ≥ 1 in yaitu :
Di opt = $4\ Q^{0,45}\ \mu^{0,13}$ *Eq*. 45. (Peters & Timmerhaus, 1991:365)

Dimana :
Di opt = diameter dalam optimum, in
Q = kecepatan volumetrik, ft^3/s
μ = viskositas fluida, lb/ft.s

Sehingga :
Di opt = $4 \times (0.050)^{0,45} \times (0.001)^{0,13}$
= 0.39179 in

Dari App. A.5-1 (Geankoplis, 1993:892) dipilih spesifikasi :
NP = 1/2 in
OD = 0.840 in = 0.070 ft = 0.021 m
ID = 0.622 in = 0.052 ft = 0.016 m
A = 0.002 ft² = 1.960 in^2
Sch = 40

Menghitung kecepatan linier :
Kecepatan linier fluida dapat dicari dengan menggunakan persamaan berikut

$$V = \frac{Q}{A}$$

Sehingga :

$$V = \frac{0.0497 \text{ ft}^3/\text{s}}{0.0021 \text{ ft}^2}$$

$$= 23.5660 \text{ ft/s}$$

$$= 7.1829 \text{ m/s}$$

Menghitung *Reynold Number* (Nre) :

$$Nre = \frac{\rho \, v \, D}{\mu}$$

Sehingga :

$$Nre = \frac{49.28 \times 23.57 \times 0.0518}{0.0007}$$

$$= 88042 \text{ (asumsi aliran turbulen benar)}$$

Instalasi pipa

Dari ***Fig* . 127.** (Brown, 1950:141) dengan NPS = 1/2 in

- 1 buah *gate valve fully open* ; Le	=	0.26	ft
∑L = 1 × 0	=	0.26	ft
- 3 buah *standard elbow* ; Le	=	1.4	ft
∑L = 3 × 1	=	4.2	ft
- 1 buah *sudden enlargement* ; Le	=	1.4	ft
∑L = 1 × 1	=	1.4	ft
- 1 buah *sudden contraction* ; Le	=	0.52	ft
∑L = 1 × 1	=	0.52	ft
- 1 buah *swing check valve* ; Le	=	3	ft
∑L = 1 × 3	=	3	ft
- Panjang ekivalen pipa lurus, ∑Le	=	9.38	ft
Panjang pipa lurus	=	2	m
	=	6.562	ft
Panjang pipa total	=	15.94	ft
	=	4.859	m

Menghitung *friction loss*

$$\Sigma F = \frac{4f \, . \, v^2 \, . \, \Delta L}{2 \, . \, ID \, . \, gc}$$ Eq. 2.10-6 (Geankoplis, 1993:89)

Dimana :

ΣF	=	*Friction loss* (ft.lbf/lbm)
f	=	Faktor friksi
v	=	Kecepatan linier fluida (ft/s)
ΔL	=	Panjang pipa (ft)
ID	=	Diameter dalam tangki (ft)
gc	=	32.174 lbm.ft/lbf.s^2

Menghitung *Fanning Friction Factor* (f) :
Dari ***Fig* . 2.10-3. (**Geankoplis, 1993:88) didapat :
Untuk *commercial* → ε = 5.E-05 m
= 0.0002 ft

Sehingga :
$\frac{\varepsilon}{D} = \frac{0.000}{0.052}$
= 0.003

Dari ***Fig* . 2.10-3.** (Geankoplis, 1993:88) dengan nilai Nr = 88042
didapatkan = 0.005 sehingga :
$\Sigma F = \frac{4 \times 0.005 \times (23.57)^2 \times 15.94}{2 \times 0.051833 \times 32.17400000}$
= 53.09 $\frac{lb_f . ft}{lb_m}$

Menghitung *Static Head* :
Z_1 = 1 m
= 3 ft
Z_2 = 0 m
= 1 ft
ΔZ = Z_1-Z_2
= 2.625 ft
g/gc = 1 lbf/lbm
ΔZ (g/gc) = 3 ft × 1 lbf/lbm
= 2.625 ft lbf/lbm
Menghitung *Velocity Head* :
V_1 = kecepatan linier fluida dari tangki hidrogen peroksida ke pipa
V_2 = kecepatan linier fluida ke *heater*
Karena pada 2 titik *reference* dianggap sama, maka $V_1 = V_2$ = 23.57 ft/s
Sehingga *velocity head* ($\Delta V^2 / 2agc$) = 8.630

Menghitung *Pressure Head* :
$P_1 = P_2$ = 14.7 Psi
ΔP = 0
Sehingga, $\Delta P/\rho$ = 0

Menghitung Energi Mekanik Pompa :

$$-Wf = \frac{\Delta V^2}{2 \times \alpha \times gc} + \Delta z \frac{g}{gc} + \frac{\Delta P}{\rho} + \sum F$$

Dimana :
Wf = tenaga yang ditambahkan ke dalam sistem per satuan massa

Sehingga :
- Wf = 9 + 3 ft. lbf/ll + 0 + 53.09 ft. lbf/lbm

= 64.34 ft. lbf/lbm

Menghitung *Broke Horse Power* (BHP) :

$$BH = \frac{m.(-Wf)}{550 \cdot \eta}$$

dari ***Fig*. 14-37.** (Peters & Timmerhaus, 1991:520), untu = 22.3178 gpm
diperoleh η pompa = 0.45

Sehingga :

$$= \frac{2.451 \times 64.34}{550 \times 0.45}$$

= 0.637 Hp; maka digunakan *power* = 1 Hp

3. Menghitung Tenaga Motor

***Fig.* 14.38**. (Peters & Timmerhaus, 1991:521) untuk BH = 1.0 Hp
diperoleh η motor = 0.80
Sehingga *power* motor yang diperlukan :

$$P\ moto = \frac{BHP}{\eta}$$

$$= \frac{1}{0.80} Hp$$

= 1.25 Hp

Dipilih motor standar dengan *power* = 2 Hp (*Standard* NEMA)

SPESIFIKASI POMPA NEUTRALISER

Nama Alat : Pompa *Neutraliser*
Kode : L-221
Fungsi : Mengalirkan *dioctyl phthalate* dari *neutraliser* menuju *rotary drum vacum filter*
Tipe : *Centrifugal pump*
Bahan Kor : *Commercial steel*
Jumlah : 1 buah
Rate Volu : 0.050 ft^3/s

Kecepatan : 23.5660 ft/s
Ukuran Pip : NPS = 1/2 in
: *Sch. Number* = 40
: OD = 0.0700 ft = 0.021 m
: ID = 0.0518 ft = 0.016 m
: *Flow Area* = 0.0021 ft^2 = 0.000 m^2
Power Pompa : 1 Hp
Power Motor : 2 Hp

27 ROTARY DRUM VACUM FILTER (H-310)

Fungsi : Memisahkan $C_{16}H_{35}O_4TiNa$ dari $C_8H_4O_3$ $C_8H_6O_4$, $C_{24}H_{38}O_4$, $C_8H_{18}O$, dan H_2O
Tipe : *Rotary Drum Vacuum Filter*
Jumlah : 1 buah
Kondisi Op : T = 95 °C = 368.15 K
P = 3 in H = 212.19 psf

Komposisi bahan masuk

Komponen	Berat (kg/jam)	Fraksi berat	ρ bahan (gr/ml)	ρ bahan x fraksi berat
$C_{24}H_{38}O_4$	3801.074	0.9499	0.984	0.935
$C_8H_{18}O$	5.0783	0.0013	0.833	0.001
$C_8H_4O_3$	2.8907	0.0007	1.2	0.001
$C_8H_6O_4$	2.8994	0.0007	1.526	0.001
6H35O4Ti	0.0636	0.0000	0.834684	0.000
H_2O	189.6467	0.0474	0.997	0.047
Total	4001.653	1		0.985

rate massa = 4001.653 kg/jam
= 8822.124 lb/jam

ρ campuran = $\sum \rho_i \, x \, X_i$
= 0.985 gr/ml
= 61.4897 lb/cuft

rate volumetrik = $\frac{\text{rate massa}}{\rho \text{ campuran}}$
= $\frac{8822.124 \text{ lb/jam}}{61.4897 \text{ lb/cuft}}$
= 143.4731 cuft/jam
= 17.8875 gal/min

sg = ρ bahan / ρ reference
= 61.4897 lb/cuft / 62.43 lb/cuft
= 0.9849

bahan = sg bahan / sg referenc x μ reference
= 0.9849 / 0.996 x 0.0009
= 0.0008 lb/ft s (berdasarkan sg bahan)
= ##### cP (1 lb/fts = 1488 cP)

Perhitungan

Asumsi tebal cake	=	3.81 cm	
Minimum Tebal Cake	=	6 cm	*(Perry 7ed ; T. 18-8)*
Berat Cake kering (tiap cycle)	=	10 kg/ m^2	*(Perry 7ed ; fig. 18-98)*
Θ_d/W untuk 25% moist	=	0.02	*(Perry 7ed ; fig. 18-102)*

Waktu Pengeringan Θd = Θd / W x W
= 0.02 x 10
= 0.2 Menit

Asumsi Waktu Pencucian	=	0.2 Menit	
% cycle dalam kondisi vaccun	=	80%	*(Perry Ed 7 T18-9)*
% cycle washing	=	29%	
% cycle discharge	=	20%	

% cycle untuk washing dan final dry
= % Cycle Total - % Cycle Washing - %Cycle Discharge
= 80% - 29% - 20%
= 31%

Cycle time = Θ Dry + Θ Wash / % Cycle
= 0 + 0 / 31%
= 2.581

Asumsi Overall Scale-Up faktor = 1 *Perry 18-87 ed 7*

Rate Filtrate = W / cycle time x (60 x scale up)
= 10 / 2.580645 x (60 x 0.9)
= 209.3 kg/jam m^2

Dry cake pada produk = 0.064 kg/jam

Total filtrate area = $\frac{\text{Dry Cake}}{\text{Rate Filtrate}}$

= $\frac{0.0636344}{0.0000159}$

= 4001.653 m^2

Dimensi Filter

Perbandingan L/D komersial untuk single unit L/D = 2

Total Filtrat Area (A) = 4001.653 m^2

$A = \pi D L$

$4001.65 = 3.14 \times D \times 2 D$

$D^2 = \frac{4001.653}{5.024}$

$D^2 = 796.5074$

$D = 28.2225$ m

$L = 45.1559$ m

Kondisi Vaccum

Waktu awal pengeringan = 2.5806 x 0

= 0.2065 Min ***Perry ed7 fig18-105***

Udara mengalir pd awal = 0.2065 x 1

= 0.2684 $m^3/m^2.min$

Akhir pengeringan

Udara mengalir pd akhir = 0.2 x 2.75

= 0.55 $m^3/m^2.min$

Total Filtra x Keamanan = 0.8184 $m^3/m^2.$ x 1

= 0.9002 $m^3/m^2.min$

Total Udara (Log P) = $\frac{0.9002}{2.5806}$

= 0.3488 $m^3/m^2.min$

= 1.4174 x 10

= 14.174 in Hg

Menghitung power rotary drum vacuum filter

Power total = $A^{0,75}$ ***(Ulrich T. 4 - 23, h : 222)***

Power total = 4001.653 0,75

= 503.1293 kWH

= 674.4360 Hp = 675 Hp

SPESIFIKASI ROTARY DRUM VACUM FILTER

Fungsi : Memisahkan $C_{16}H_{35}O_4TiNa$ dari $C_8H_4O_3$

$C_8H_6O_4$, $C_{24}H_{38}O_4$, $C_8H_{18}O$, dan H_2O

Type : Continuous Rotary Drum Vacuum Filter
Bahan : Carbon Steel
Diameter : 28.22 m area = 28234.13
Panjang : 45.16 m 92630.52 ft
Putaran : 6 rpm *(Perry ed7 18-96)*
Vaccum : 14.17 inHg
Power Total : 675 Hp
Jumlah : 1 Buah

28 POMPA ROTARY DRUM VACUM FILTER (L-311)

Fungsi : Mengalirkan *dioctyl phthalate* dari *rotary drum vacum filter* menuju evaporator
Tipe : *Centrifugal pump*
Jumlah : 1 buah

Komponen	Massa (kg/jam)	Fraksi berat	ρ bahan (gr/ml)	ρ bahan x fraksi berat
$C_{24}H_{38}O_4$	3801.074	0.7036	0.99	0.6966
$C_8H_{18}O$	5.0783	0.0009	0.8207	0.0008
$C_8H_4O_3$	2.8907	0.0005	1.2	0.0006
$C_8H_6O_4$	2.8994	0.0005	1.522	0.0008
6H35O4Ti	0.0636	0.0000	0.8346	0.0000
H_2O	1590.225	0.2944	1	0.2944
Total	5402.232	1		0.9932

rate massa = 5402.23 kg/jam
= 11909.87 lb/jam

ρ campuran = $\sum \rho_i \, x \, X_i$ = 0.9932 g/ml

= 62.002 lb/cuft

rate volumetrik = $\frac{\text{rate massa}}{\rho \text{ campuran}} = \frac{11909.87}{62.0023}$

= 192.0877 cuft/jam
= 0.0534 cuft/det
= 23.95 gpm

Asumsi aliran turbulen (Nre > 2100)

Diameter optimum = 3.9 x $Q^{0,45}$ x $\mu^{0,13}$
= 3.9 x 0.2674 x 1.71

= 1.784 inch

Dari *App* . A.5-1 (Geankoplis, 1993:892) dipilih spesifikasi :

NP = 3/8 in
OD = 0.675 in = 0.056 ft = 0.017 m
ID = 0.493 in = 0.041 ft = 0.013 m
A = 0.001 ft² = 1.236 in^2
Sch = 40

Menghitung kecepatan linier :

Kecepatan linier fluida dapat dicari dengan menggunakan persamaan berikut :

$$V = \frac{Q}{A}$$

Sehingga :

$$V = \frac{0.0534 \text{ ft}^3/\text{s}}{0.0013 \text{ ft}^2}$$

= 40.1186 ft/s
= 12.2281 m/s

Menghitung *Reynold Number* (Nre) :

$$Nre = \frac{\rho \, v \, D}{\mu}$$

Sehingga :

$$Nre = \frac{62.00 \times 40.12 \times 0.0411}{0.0002}$$

= 510961.8 (asumsi aliran turbulen benar)

Instalasi pipa

Dari ***Fig* . 127.** (Brown, 1950:141 = 3/8 in

- 1 buah *gate valve fully open* ; Le = 0.26 ft
  ∑Le = 1 × 0.26 = 0.26 ft
- 3 buah *standard elbow* ; Le = 1.4 ft
  ∑Le = 3 × 1.4 = 4.2 ft
- 1 buah *sudden enlargement* ; Le = 1.4 ft
  ∑Le = 1 × 1.4 = 1.4 ft
- 1 buah *sudden contraction* ; Le = 0.52 ft
  ∑Le = 1 × 0.52 = 0.52 ft
- 1 buah *swing check valve* ; Le = 3 ft
  ∑Le = 1 × 3 = 3 ft
- Panjang ekivalen pipa lurus, ∑Le = 9.38 ft
  Panjang pipa lurus = 2 m
  = 6.562 ft

Panjang pipa total = 15.94 ft
= 4.859 m

Menghitung *friction loss*

$$\Sigma F = \frac{4f \cdot v^2 \cdot \Delta L}{2 \cdot ID \cdot gc}$$ Eq. 2.10-6 (Geankoplis, 1993:89)

Dimana :
ΣF = *Friction lo* (ft.lbf/lbm)
f = Faktor friksi
v = Kecepatan linier fluida (ft/s)
ΔL = Panjang pipa (ft)
ID = Diameter dalam tangki (ft)
gc = 32.17 lbm.ft/lbf.s^2

Menghitung *Fanning Friction Factor* (f) :
Dari ***Fig* . 2.10-3. (**Geankoplis, 1993:88) didapat :
Untuk *commercia* → ε = 5.E-05 m
= 0.0002 ft

Sehingga :

$$\frac{\varepsilon}{D} = \frac{0.000}{0.041} = 0.004$$

Dari **Fig. 2.10-3.** (Geankoplis, 1993:88) dengan nilai Nre = 510962 didapatkan nilai f = 0.007 sehingga :

$$\Sigma F = \frac{4 \times 0.007 \times (40.1)^2 \times 15.9}{2 \times 0.0411 \times 32.1740}$$

$$= 271.7565 \ \frac{lb_f \cdot ft}{lb_m}$$

Menghitung *Static Head* :
Z_1 = 1 m = 3.281 ft
Z_2 = 0.2 m = 0.656 ft
ΔZ = Z_1-Z_2 = 2.625 ft
g/g = 1 lbf/lbm
ΔZ (g/g = 2.625 ft × 1 lbf/lbm
= 2.625 ft lbf/lbm
Menghitung *Velocity Head* :

V_1 = kecepatan linier fluida dari tangki hidrogen peroksida ke pipa
V_2 = kecepatan linier fluida ke *heater*
Karena pada 2 titik *reference* dianggap sama, maka $V_1 = V_2 =$ 40.1186 ft/s
Sehingga *velocity head* $(\Delta V^2 / 2agc)$ = 25.0124

Menghitung *Pressure Head* :
$P_1 = P_2 =$ 14.7 Psi
$\Delta P =$ 0
Sehingga, $\Delta P/\rho$ = 0

Menghitung Energi Mekanik Pompa :

$$-Wf = \frac{\Delta V^2}{2 \times \alpha \times gc} + \Delta z \frac{g}{gc} + \frac{\Delta P}{\rho} + \sum F$$

Dimana :
Wf = tenaga yang ditambahkan ke dalam sistem per satuan massa

Sehingga :
- Wf = 25 + 2.625 ft. lbf/lbm + 0 + 271.8 ft. lbf/lbm
= 299.4 ft. lbf/lbm

Menghitung *Broke Horse Power* (BHP) :

$$BHP = \frac{m.(-Wf)}{550 \cdot \eta}$$

dari ***Fig* . 14-37.** (Peters & Timmerhaus, 1991:520)
Qf = 23.9 gpm diperoleh η pompa = 0.45

Sehingga :

$$BHP = \frac{3.308 \times 299.4}{550 \times 0.45}$$

= 4.002 Hp; maka digunakan power = 4 Hp

4) Menghitung Tenaga Motor
Fig. 14.38. (Peters & Timmerhaus, 1991:521) untuk BHP = 4 Hp
diperoleh η motor = 1
Sehingga power motor yang diperlukan :

$$P\ moto = \frac{BHP}{\eta}$$

$$= \frac{4\ Hp}{1}$$

= 5 Hp

Dipilih motor standar dengan power = 5 Hp (Standard NEMA)

SPESIFIKASI POMPA ROTARY DRUM VACUM FILTER

Nama Alat : Pompa *Rotary Drum Vacum Filter*
Kode : L-311
Fungsi : Mengalirkan *dioctyl phthalate* dari *rotary drum vacum filter* menuju evaporator
Tipe : *Centrifugal pump*
Bahan Konstru : *Commercial steel*
Jumlah : 1 buah
Rate Volumet : 0.053 ft^3/s
Kecepatan Alir : 40.12 ft/s
Ukuran Pipa : NPS = 3/8 in
: *Sch. Number* = 40
: OD = 0.056 ft = 0.017 m
: ID = 0.041 ft = 0.013 m
: *Flow Area* = 0.001 ft^2 = 1.236 in^2
Power Pompa : 4 Hp
Power Motor : 5 Hp

29 EVAPORATOR (V-320)

Fungsi : untuk memisahkan kandungan C_3H_8O dan H_2O dari $C_8H_{18}O$ dan $C_{24}H_{38}O_4$
Tipe : Evaporator berbentuk *short vertical tube* dengan tutup atas dan bawah berbentuk *torispherical*
Jumlah : 1 buah
Kondisi Operasi : T_{in} = 95 °C = 368.2 K
T_{out} = 102.14 °C = 375.3 K
P = 1 atm = 760 mmHg = 14.7 psi

1 BTU/lb = 1 kkal/kg
1 kkal/kg = 2 btu/lb

KOMPOSISI

Komponen	Berat (kg)	Fraksi berat	ρ (gr/cc)	Cp (btu/lb
$C_8H_{18}O$	5.0783	0.0009	0.833	0.215773
$C_{24}H_{38}O_4$	3801.0743	0.7073	0.984	0.268309
H_2O	1562.2124	0.2907	0.997	0.516967
$C_8H_4O_3$	2.8907	0.0005	1.2	1.000481
$C_8H_6O_4$	2.8994	0.0005	1.526	1.000481
Total	5374.1551	1		

$$\text{Densitas Campuran} = \frac{1}{\frac{\text{fraksi berat}}{\rho \text{ komponen}}} \times 62.43$$

$$= \frac{1}{\frac{0}{1} + \frac{1}{1} + \frac{0}{1} + \frac{0}{1} + \frac{0}{2}} \times 62$$

$$= 0.99 \text{ gr/cc} \times 62$$

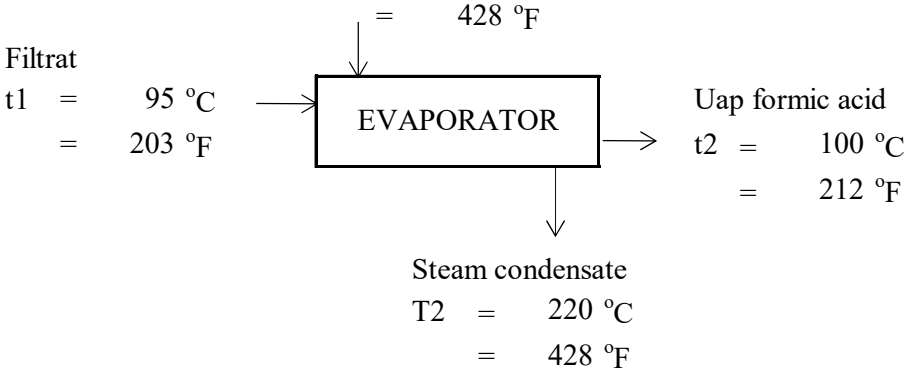
$$= 61.67 \text{ lb/cuft}$$

$$\text{Rate Volumetrik} = \frac{\text{Rate Massa}}{\text{Densitas}}$$

$$= \frac{5374.16}{61.6721}$$

$$= 87.1408 \text{ cuft/jam}$$

Diagram suhu : Steam T1 = 220 °C = 428 °F



1. Heat Balance

Data dari Appendix A dan Appendix B diperoleh :

Rate massa, W massa = 5,374 kg/jam
= 11,850 lb/jam
Q supply = 782,602 kkal/jam
= 3,106,930 Btu/jam
W steam = 1,764 kg/jam
= 3,890 lb/jam

2. Log Mean Temperature Difference

Suhu bahan masuk = 95 °C = 203 °F (t_1)
Suhu bahan keluar = 100 °C = 212 °F (t_2)
Suhu steam masuk = 220 °C = 428 °F (T_1)
Suhu steam condensat = 220 °C = 428 °F (T_2)

$$\Delta T \text{ LMTD} = \frac{225 - 216}{\ln 1.0417}$$

$$= 220.4694 \text{ °F}$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{0}{9} = 0.00$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{9}{225} = 0.04$$

Untuk type evaporator standart tube vertical dipilih jenis 2-4 shell & tube exchanger.

Untuk 2-4 shell & tube F_T = 0.97 *[Kern; App fig. 18]*

1'2 0.85

ΔT = F_T x ΔT LMTD
= 0.97 x 220.47
= 213.8553 ^oF

3. Tc dan tc

Tc = T_{av} steam

$$Tc = \frac{T_1 + T_2}{2} = \frac{428 + 428}{2} = 428\ ^oF$$

tc = t_{av} bahan

$$tc = \frac{t_1 + t_2}{2} = \frac{203 + 212}{2} = 208\ ^oF$$

$$\text{Sg bahan} = \frac{\rho \text{ bahan}}{\rho \text{ reference}} \times \text{Sg reference}$$

$$= \frac{61.6721 \text{ lb/c}}{62.43 \text{ lb/c}} \times 1$$

= 0.9879

μ berdasarkan Sg bahan :

[Kern; tab.6 p. 808] didapat Sg reference = 1

[Kern; fig.14 , p. 823] didapat μ reference = 0.899 Cp

$$\mu \text{ bahan} = \frac{\text{Sg bahan}}{\text{Sg reference}} \times \mu \text{ reference}$$

$$= \frac{0.9879}{1} \times 0.899$$

= 0.8881 Cp

Evaporator termasuk sistem heater karena :

Hot Fluid : Steam

Cold Fluid : Aqueous Solution dimana μ bahan kurang dari 2 Cp

Sehingga di dapat nilai U_D dengan rang 200 - 700 Btu/jam.ft^2 ^{0}F

[Kern; tab.8 , p.840]

Dipilih nilai U_D = 220 Btu/jam.ft^2 ^{0}F

Digunakan 1 buah evaporator, sehingga luas perpindahan panas evaporator :

$$A = \frac{Q}{UD \times \Delta T}$$

Dimana,

A = Luas Perpindahan Panas
Q = Q supply dari steam
UD = Overall Design Coefficients
ΔT = Perubahan Suhu

$$A = \frac{Q}{UD \times \Delta T}$$

$$= \frac{3{,}106{,}930.0393}{220 \times 213.8553}$$

$$= 66.0372 \ ft^2$$

$$= 7.3375 \ m^2$$

Dikarenakan luas perpindahan panas > 200 ft2, maka design heater menggunakan shell and tube *[Walas; p.xvi]*

$$\text{Jumlah tube (Nt)} = \frac{A}{L \times a''}$$

$$= \frac{66.0372}{16 \times 0.3271}$$

$$= 13 \text{ buah}$$

Dalam perencanaan ini digunakan HEATER dengan spesifikasi :
Digunakan TUBE dengan ukuran : *[Kern; tab. 10, p. 843]*

OD, BWG	=	1 1/4	in , 12 BWG	
Pitch	=	1 4/7	in triangular	*[Kern; tab.9]*
Panjang tube,L	=	16	ft	*(L tube: 7 - 13 ft)*
Passes	=	6		
ID Tube	=	1.030	in 0.1 ft	*(min ID: 1 in)*
a't	=	0.836	in^2	
a"	=	0.3271	ft^2/lin ft	
Digunakan Nt	=	91	buah	

Dari tube passes dan jumlah tube didapat SHELL:
Untuk pipa 1 1/4 OD tubes on 1 9/16 in square pitch

ID shell	=	21 1/4 in	*[Kern; tab.9]*
Baffle	=	5 in	
Passes (n)	=	2	

*Koreksi U_D

$$A = Nt \times L \times a''$$

$= 476.2576 \ ft^2$

U_D koreksi $= \dfrac{Q}{A \times \Delta T}$

$= \dfrac{3{,}106{,}930.039}{476.3 \times 213.9}$

$= 31 \ Btu/jam.ft^2 {}^0F$

Nilai U_D asumsi sama dengan U_D koreksi (memenuhi)

Fluida Panas (Tube Side) Steam	Fluida Dingin (Shell Side) Larutan NaOH
(4) Flow area (a_t) $a_t = \dfrac{Nt \times a'_t}{144 \ n}$ $= \dfrac{91 \times 0.84}{144 \times 6}$ $= 0.0881 \ ft^2$	(4') Flow area (a_s) $C' = Pt - OD = 0.31$ in $as = \dfrac{IDs \times C' \times B}{144 \times P_T}$ $= \dfrac{21.25 \times 1/3 \times 5}{144 \times 1\ 4/7}$ $= 0.1476 \ ft^2$
(5) Kecepatan massa (Gt) $G_t = \dfrac{W}{a_t}$ $= \dfrac{3{,}889.797}{0.0881}$ $= 44176.66883$ lb/jam ft^2	(5') Kecepatan massa (Gs) $Gs = \dfrac{W}{as}$ $= \dfrac{11{,}850.0119}{0.1476}$ $= 80{,}301.2572$ lb/jam ft^2
(6) pada tc $= 208 \ {}^oF$ μ stean $= 0.0140$ cps $= 0.034$ lb / jam.ft **(Kern, Fig 15 ; Page 825)**	(6') pada Tc $= 428 \ {}^oF$ μ bahan $= 0.888$ cps $= 2.1492$ lb/jam.ft
Di $= 1.03$ in $= 0.0858$ ft $Re_t = \dfrac{Di \times G_t}{\mu}$ $= 111919.4434$	De $= 0.0198$ ft $Re_s = \dfrac{D_e \times G_s}{\mu}$ $= 740.9834$
(7) jH $= 180$ [Fig.24]	(7') jH $= 110$ *[Fig.28 shell side data]*
	(8') pada Tc $= 428 \ {}^oF$ k $= 0.9 \ k_{water}$ $= 0.015$ Btu/hr.ft^2.(^{0}F/ft)

Fluida Panas (Tube Side) Steam	Fluida Dingin (Shell Side) Larutan NaOH
	Cp = 0.4500 Btu / lb $\left(\frac{Cp.\mu}{k}\right)^{1/3} = \frac{0.45 \times 0.034}{0.015}$ = 1.0068
(9) Condensation of steam : hio = 1500 Btu/hr.ft^2.^{o}F *[Kern:164]* (10) tw* $tw = tc + \frac{hio}{hio + ho}(Tc - tc)$ $= 208 + \frac{1500}{1583.430} \times 221$ = 416.382 ^{o}F	(9') $ho = J_H x(k/De)\ x(c \times \mu /k)^{1/3} x\varphi s$ $\frac{ho}{\varphi s}$ = 83.430 Btu/hr.ft^2.^{o}F (10') Pada tw = 416.382 ^{o}F μw = μwater [Fig.14] = 1.776 cps = 4.298 lb / jam.ft $\varphi s = (\mu/\mu w)^{0,14}$ = 0.9075 (11') Corrected coefficient $ho = \frac{ho.\varphi s}{\varphi s}$ = 75.714 Btu/hr.ft^2.^{o}F
(12) Clean Overall coefficient, Uc : $Uc = \frac{hio \times ho}{hio + ho}$ = 72.0761 Btu/hr.ft^2.^{o}F (13) Dirt Factor, Rd : Rd hitung = $\frac{U_C - U_D}{U_C \times U_D}$ = 0.0189 Btu/hr.ft^2.^{o}F **[Kern, T-12 Page 845]** Rd perhitungan > Rd data 0.0189 > 0.0030	
Fluida Panas (Tube Side) Steam	Fluida Dingin (Shell Side) Larutan Caustic Soda
(1) Sg bahan: $s = \frac{0.9879}{62.5} = 0.0158$ Ret = 111,919.443 f = 0.0002 ft^2/in^2 *[Fig.26]*	(1') Flow area (a_s) N+1 = 12L/B = 38.4 Ds = 1.7708 ft Re's = $\frac{Ds'.\ Gs}{\mu}$

Fluida Panas (Tube Side) Steam	Fluida Dingin (Shell Side) Larutan Caustic Soda
$\Delta Pt = \frac{1}{2} \times \frac{f.Gt^2.L.n}{5.22 \times 10^{10} \times D \times s \times \varphi t}$ = 0.2646 Psi	= 66,165.1882 f = 0.0012 ft^2/in^2 *[Fig.29]*
$\Delta P_T < 2$ psi (memenuhi)	(2') $\Delta Ps = \frac{f.Gs^2.Ds.(N+1)}{5.22 \times 10^{10} \times De \times s \times \varphi s}$ = 0.0280 Psi $\Delta P_s < 10$ psi (memenuhi)

Nilai U_D asumsi sama dengan U_D koreksi (memenuhi)

Menentukan dimensi evaporator

Panjang Tube (L) = 16 ft
Tinggi evaporator1.5 - 2) dari panjang tube *[Hugot ed.3; p.508]*
Tinggi evaporator = 2 x 16
= 24 ft = 7.2 m

Asumsi:

$\frac{H}{D} = 2$

$D = \frac{24}{2}$

= 12 ft = 3.6 m

Diameter Vessel = 4 m (max = 4 m) *[Ulrich; p.94]*
Diameter Center well = ## m (1/4 Diameter Vessel) *[Hugot ed.3; p.509]*
Tinggi Evaporator = ## m (3.6 - 4 m) *[Hugot ed.3; p.508]*

Menentukan volume shell

Volume cairan yang ditampung di evapora = 87.1408 cuft/jam
Waktu tinggal cairan : 2.8 menit untuk 3.03 m3 liquid
Menggunakan waktu ting = 15 menit *[Coulson ed.5 vol.2; p.901]*

Volume bahan = $87.1408 \frac{cuf}{jam} \times \frac{1 \text{ jam}}{60 \text{ menit}} \times 15$ menit
= 21.2944 cuf = 0.60 m3

Volume tangki = 26.6180 cuft

Tinggi cairan dalam evaporator :

$V = \frac{1}{4} \pi D^2 Z_L$

$$Z_L = \frac{4 \times 26.6180}{3.14 \times 144}$$

$= 0.2355$ ft $= 0.0754$ m

Menentukan Tekanan Design

Jika didalam bejana terdapat liquid , maka :

P operasi = 1 atm = 14.7 psi

P hidrostatis = $\rho \times g/gc \times h$

$= 61.67 \frac{lbm}{cuft} \times 1 \frac{lbf}{lbm} \times 0.2355$ ft

$= 14.52 \frac{lbf}{ft^2}$

$= 0.10$ psi

Asumsi P design 10% lebih besar untuk faktor keamanan

P total = P hidrostat + P Operasi

$= 0.10 + 14.7$

$= 14.80$ psi

P desig = 110% x 14.80

$= 16.28$ psi

Menentukan tebal minimum shell

Tebal shell berdasarkan ASME code untuk cylindrical tank :

$$t_{min} = \frac{P \times ri}{fe - 0{,}6P} + C$$ *[Brownell&Young; eq.13-1, p.254]*

dengan :

t_{min} = tebal shell minimu ;in

P = tekanan tangki ; psi

ri = jari-jari tangki ; in (1/2 D)

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

E = faktor pengelasan, digunakan dobel welde ##

f = stress allowable, bahan konstruksi Stainless steel 316 grade D, maka f = 35970

[Perry ed.7; T.28-11]

ri = 1 x 144

= 72 in

$$t_{min} = \frac{P \times ri}{fE - 0{,}6P} + C$$

$$= \frac{16.2809 \times 72}{28775.9 - 9.7686} + 0.125$$

$$= \frac{1172.23}{28766.17} + 0.125$$

$= 0.0408 + 0.125$

$= 0.1658$ in

digunakan tmin = 3/16 in

Dimensi tutup atas (Elliptical dished)

OD = ID + 2 ts
= 144 + 0.4
= 144.4 in

Berdasarkan *[Brownell & Young; Tab. 5-7]*

OD = 144 in
tshell = 3/16 in
icr = 7 5/8 in
rc = 120 in

karena icr lebih besar dari 6% maka digunakan persamaan berikut

[Brownell & Young; eq.13.12 p.258]

Tebal tutup atas Elliptical dished :

$$t_h = \frac{P \times r_c \times W}{2\ f.e - 0.2\ P} + C$$

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

$$= \frac{1}{4} \times (3 + 6)$$

$$= 2.344$$

dengan:

t_h = tebal tutup (head) shell minimu ; in
r_c = *radius of curfative* sama deng ; in
W = faktor stress intensif
P = tekanan tangki ; psia
E = faktor pengelasan, digunakan jenis *double welded* = 1
C = faktor korosi = 1/8 in
f = allowable stress, bahan konstruksi Stainless stell 316
maka f = 35970 psi *[Perry ed.7; T.28-11]*

$$t_h = \frac{P \times r_c \times W}{2\ f.E - 0.2\ P} + C$$

$$= \frac{16.2809 \times 120 \times \#\#\#\#\#}{57551.87 - 3.2562} + 1/8$$

$$= \frac{\#\#\#\#\#\#\#}{57548.62} + 1/8$$

$$= 0.2046$$

digunakan = 4/16 in

$$h = rc - \sqrt{rc^2 - \frac{D^2}{4}}$$

= 24.1409 in = 2.012 ft

Dimensi tutup bawah (Conical)

Tebal conical $= \frac{P.D}{2 \cos \alpha (fe - 0{,}6P)} + C$ *[Brownell&Young;*

Dengan α = 1/2 sudut conis = 60˚/2 = 30

$tc = \frac{P.D}{2 \cos \alpha (fe - 0{,}6P)} + C$

$tc = \frac{16.28 \times 1.0}{1.73 \times 28766.17} + 1/8$

$= \frac{16.28}{49824.46} + 1/8$

= 0.1253 in digunakan t = 3/16 in

Tinggi conical :

$h = \frac{tg \alpha \times (D - m)}{2}$ *[Hesse; eq.4-17]*

eterang: α = 1/2 sudut conis ; 30

D = diameter tangk ; ft

m = flat spot center ; 12 in = 1 ft

$h = \frac{tg \alpha \times (D - m)}{2}$

$= \frac{0.577 \times 11}{2} = 3.18$ ft

SPESIFIKASI EVAPORATOR

Type Heater : 2-4 Shell & Tube Exchanger

Jumlah = 1 buah

Bagian Shell :

Jenis Bahan	= Stainless steel 316	
Diameter Vessel	= 3.6	m
Diameter Centerwall	= 0.9	m
Tinggi Vessel	= 7.2	m
Tebal Shell	= 3/16	in
Tebal Tutup Atas	= 1/4	in
Tinggi Tutup Atas	= #####	ft
Tebal Tutup Bawah	= 3/16	in
Tinggi Tutup Bawah	= #####	ft
Tinggi total vessel	= 26.7872	ft
ID Shell	= 21 1/4	in
Baffle Space	= 5	in
Passes	= 2	

Bagian Tube :

Jumlah & Panjang Tub = 91 buah, 16 ft

OD, BWG, pitch = 1 in , 12 BWG 1 4/7 Triangular

Passes = 6

30 POMPA EVAPORATOR (L-321)

Fungsi : Mengalirkan *dioctyl phthalate* dari evaporator menuju tangki dekolorisasi
Tipe : *Centrifugal pump*
Jumlah : 1 buah
Tujuan : 1. Menentukan tipe pompa
2. Menentukan bahan konstruksi pompa
3. Menghitung tenaga pompa
4. Menghitung tenaga motor

3) Menghitung Tenaga Pompa

Rate masuk	=	3812.0989	kg/jam	=	2.3345	lb/s
Densitas	=	0.9879	kg/m³	=	0.0617	lb/ft³
μ	=	2.8134	cP	=	0.0019	lb/ft.s

$$\text{Rate volumetrik (Q)} = \frac{\text{massa}}{\text{r}}$$

$$= \frac{2.3345 \text{ lb/s}}{0.0617 \text{ lb/ft}^3} = 37.8532 \text{ ft}^3/\text{s}$$

$$= 16989.7011 \text{ gpm}$$

Diperkirakan aliran fluida turbulen (Nre>2100), sehingga digunakan persamaan Di ≥ 1 in yaitu :

$$\text{Di opt} = 3.9 \; Q^{0,45} \; \mu^{0,13}$$ Eq. 45. (Peters & Timmerhaus, 1991:365

Dimana :
Di opt = diameter dalam optimum, in
Q = kecepatan volumetrik, ft^3/s
μ = viskositas fluida, lb/ft.s

Sehingga :

$$\text{Di opt} = 3.9 \times (37.8532)^{0,45} \times (0.002)^{0,13}$$

$$= 8.8546 \text{ in}$$

Dari App. A.5-1 (Geankoplis, 1993:892) dipilih spesifikasi :

NPS	=	1/2	in					
OD	=	0.8400	in	=	0.07	ft	=	0.021336 m
ID	=	0.6220	in	=	0.0518333	ft	=	0.015799 m
A	=	0.0021	ft²	=	1.9603	in^2		

Sch = 40

Menghitung kecepatan linier :
Kecepatan linier fluida dapat dicari dengan menggunakan persamaan berikut :

$$V = \frac{Q}{A}$$

Sehingga :

$$V = \frac{37.8532 \quad ft^3/s}{0.0021 \quad ft^2} = 17939.9093 \quad ft/s = 5468.0844 \quad m/s$$

Menghitung *Reynold Number* (Nre) :

$$Nre = \frac{\rho \, v \, D}{\mu}$$

Sehingga :

$$Nre = \frac{0.0617 \times 17939.9093 \times 0.0518}{0.0019}$$

$$= 30333.14104 \quad \text{(asumsi aliran turbulen benar)}$$

Instalasi pipa
Dari ***Fig*. 127.** (Brown, 1950:141) dengan NPS = 1/2 in

- 1 buah *gate valve fully open* ; Le	=	0.35	ft
∑Le = 1 × 0.35	=	0.35	ft
- 4 buah *standard elbow* ; Le	=	1.7	ft
∑Le = 4 × 1.7	=	6.8	ft
- 1 buah *sudden enlargement* ; Le	=	1	ft
∑Le = 1 × 1	=	1	ft
- 1 buah *sudden contraction* ; Le	=	0.58	ft
∑Le = 1 × 0.58	=	0.58	ft
- 1 buah *swing check valve* ; Le	=	3.5	ft
∑Le = 1 × 3.5	=	3.5	ft
- Panjang ekivalen pipa lurus, ∑Le	=	12.23	ft
Panjang pipa lurus	=	2	m
	=	6.5616	ft
Panjang pipa total	=	18.7916	ft
	=	5.7277	m

Menghitung *friction loss*

$$\Sigma F = \frac{4f \, . \, v^2 \, . \, \Delta L}{2 \, . \, ID \, . \, gc}$$ Eq. 2.10-6 (Geankoplis, 1993:89)

Dimana :
ΣF = *Friction loss* (ft.lbf/lbm)

f = Faktor friksi
v = Kecepatan linier fluida (ft/s)
ΔL = Panjang pipa (ft)
ID = Diameter dalam tangki (ft)
gc = 32.1740 lbm.ft/lbf.s^2

Menghitung *Fanning Friction Factor* (f):
Dari ***Fig* . 2.10-3. (**Geankoplis, 1993:88) didapat :
Untuk *commercial steel* → ε = 5.E-05 m
= 0.0002 ft

Sehingga :

$$\frac{\varepsilon}{D} = \frac{0.0002}{0.0518} = 0.0030$$

Dari ***Fig* . 2.10-3.** (Geankoplis, 1993:88) dengan nilai Nre = 30333.1410 didapatkan nilai f = 0.008 sehingga :

$$\Sigma F = \frac{4 \times 0.0080 \times (17939.9093)^2 \times 18.7916}{2 \times 0.0518 \times 32.1740}$$

$$= 58024316.55 \quad \frac{lb_f \,.\, ft}{lb_m}$$

Menghitung *Static Head* :
Z_1 = 1 m = 3.28084 ft
Z_2 = 0.2 m = 0.656168 ft
ΔZ = Z_1-Z_2 = 2.6247 ft
g/gc = 1 lbf/lbm
ΔZ (g/gc) = 2.624672 ft × 1 lbf/lbm = 2.624672 ft lbf/lbm

Menghitung *Velocity Head* :
V_1 = kecepatan linier fluida dari tangki hidrogen peroksida ke pipa
V_2 = kecepatan linier fluida ke *heater*
Karena pada 2 titik *reference* dianggap sama, maka $V_1 = V_2$ 17939.91 ft/s
Sehingga *velocity head* (ΔV^2 / 2agc) = 5001559.442

Menghitung *Pressure Head* :
P_1 = P_2 = 14.7 Psi
ΔP = 0
Sehingga, ΔP/ρ = 0

Menghitung Energi Mekanik Pompa :

$$-Wf = \frac{\Delta V^2}{2 \times \alpha \times gc} + \Delta z \frac{g}{gc} + \frac{\Delta P}{\rho} + \sum F$$

Dimana :
Wf = tenaga yang ditambahkan ke dalam sistem per satuan massa

Sehingga :
- Wf = ######## + 3 ft. lbf/lbm + 0 + 58024317 ft. lbf/lbm

= 63025878.62 ft. lbf/lbm

Menghitung *Broke Horse Power* (BHP) :

$$BHP = \frac{m.(-Wf)}{550 \,.\, \eta}$$

dari ***Fig*. 14-37.** (Peters & Timmerhaus, 1991:520), untuk Qf = 16989.7011 gpm diperoleh η pompa = 0.40

Sehingga :

$$BHP = \frac{2.3345 \times 63025878.62}{550 \times 0.4000}$$

= 668786.8 Hp; maka digunakan *power* = 1 Hp

4) Menghitung Tenaga Motor

***Fig.* 14.38**. (Peters & Timmerhaus, 1991:521) untuk BH = 1.0 Hp diperoleh η motor = 0.80

Sehingga *power* motor yang diperlukan :

$$P\ motor = \frac{BHP}{\eta}$$

$$= \frac{1 \quad Hp}{0.80}$$

= 1.3 Hp

Dipilih motor standar dengan *power* = 2 Hp (*Standard* NEMA)

Spesifikasi Pompa Evaporator

Nama Alat	:	Pompa Evaporator
Kode	:	L-321
Fungsi	:	Mengalirkan *dioctyl phthalate* dari evaporator menuju tangki dekolorisasi
Tipe	:	*Centrifugal pump*
Bahan Konstruksi	:	*Commercial steel*
Jumlah	:	1 buah

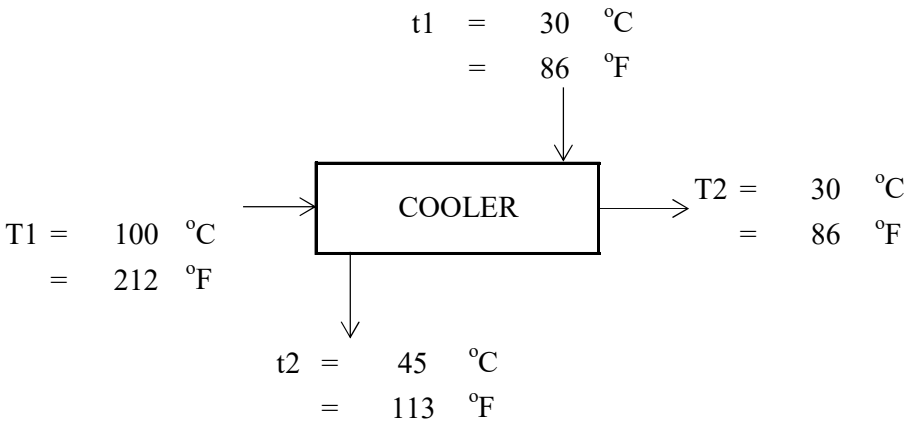
Rate Volumetrik	:	37.8532	ft^3/s					
Kecepatan Aliran	:	17939.9093	ft/s					
Ukuran Pipa	:	NPS	=	1/2	in			
	:	*Sch. Number*	=	40				
	:	OD	=	0.0700	ft	=	0.021336	m
	:	ID	=	0.0518	ft	=	0.015799	m
	:	*Flow Area*	=	0.0021	ft^2	=	0.0002	m^2
Power Pompa	:	1	Hp					
Power Motor	:	2	Hp					

31 COOLER EVAPORATOR (E-322)

Fungsi : Mendinginkan produk keluaran bawah evaporator sebelum masuk tangki dekolorisasi dari suhu 102,1353 °C menjadi 30 °C

Tipe : *Shell and Tube Heat Exchanger*

Jumlah : 1 buah



Perhitungan :

Komponen	Berat (kg/Jam)
$C_8H_{18}O$	5.07826
$C_{24}H_{38}O_4$	3793.47214
H_2O	7.75837
$C_8H_4O_3$	2.89070
$C_8H_6O_4$	2.89940
Total	3812.09886

Berat Bahan Masuk = 3812.0989 kg/jam
= 8405.6780 lb/cuft

Panas yang diserap (Q = 117681.56 Kkal/Jam
= 467195.80 BTU/Jam

Kebutuhan Cooling water = 3514.5312 Kg/Jam
= 7749.5414 Lb/Jam

a. Perhitungan ΔT LMTD **(pers 5.14, Kern, 2010)**

$$\Delta T\ LMTD = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}} = \frac{99 - 0}{\ln \frac{99}{0}}$$

= 21.5446 °F

Δt_1 = 0 °F

Δt_2 = 99 °F

$$R = \frac{T1-T2}{t2-t1} = 4.6667 \qquad S = \frac{t2-t1}{T1-t1} = 0.214286$$

Ft = 0.86 **(Kern, Fig. 18, Page. 828)**

ΔT LMTD = ΔT LMTD x Ft

= 18.5284 °F

b. Tc = Taverage bahan = 149 °F

tc = t average air = 99.5 °F

Trial :

a. Asumsi U_D **(Kern, 2010 Table.8 hal 840)**

U_D = 75 - 150 Btu/jam.ft².°F

dengan ketentuan : Pallow = 5-10 psi

Dirt factor (R_d) = 0.004

Sehingga, Trial U_D

U_D = 100 Btu/jam.ft².°F

$$A = \frac{Q}{\Delta t \times U_D} = \frac{467195.8043 \text{ Btu/jam}}{99.00\ ^oF \times 100 \text{ Btu/jam.ft}^2.^oF}$$

= 47.1915 ft²

= 566.2979 in²

a" = 0.1963 ft²/lin ft **(Kern, 2010 Table.10)**

Number of tubes $Nt = \frac{A}{L \times a''}$

$= \frac{566.2979}{12 \times 0.1963}$

$= 240.4050$

$= 240$

Berdasarkan Tabel 9 & 10 Kern Maka Dipilih

Tube			
OD	=	3/4	in
BWG	=	16	
a't	=	0.302	in²
a"	=	0.1963	surface/ lin ft, ft²
Pitch	=	1	in square pitch
Nt	=	240	
L	=	12	
Passes	=	6	
ID	=	0.62	in
Wall Thickness	=	0.065	in

Shell			
Shell ID	=	35	in
Passes	=	6	
B space	=	7	in

A baru = Nt x L x a"

= 566 ft²

Koreksi $U_D = \frac{Q}{\text{A baru} \times \Delta T_{LMTD}}$

= 100

Karena hasil U_D baru sama dengan U_D asumsi, maka asumsi dapat digunakan

antisipasi korosi : bahan di tube, dan air di shell

HOT FLUID: Tube	COLD FLUID : Shell
(Minyak)	(Air Pendingin)
(4) Flow area (a_t) =	(4') Flow area (a_s)
$a_t = \frac{Nt \times a't}{144 \times n}$	C" = $P_t - OD_{tube}$
$= \frac{240 \times 0.302}{144 \times 6}$	= 1 - 3/4
= 0.0840 ft²	= 1/4 in
	B = ID/5 = 35/5
	= 7.0 in
	a_s = ID x C" x B / 144 x Pr

HOT FLUID: Tube	**COLD FLUID : Shell**
(Minyak)	(Air Pendingin)
	$= \frac{35 \times 0 \times 7.0}{144 \times 1}$
	$= 0.4253$ ft²
(5) Mass Velocity, G_t	(5') Mass Velocity, G_s
$G_t = \frac{W}{at}$	$G_s = \frac{W}{as}$
$= \frac{8405.678}{0.0840}$	$= \frac{7749.541}{0.42535}$
$= 100031.3451$ lb/jam ft²	$= 18219.33$ lb/jam ft²
$\text{Velocity} = \frac{Gt}{3600 \times \rho}$	
$= \frac{100031.3451}{3600 \times \text{\#REF!}}$	
= #REF! ft/s	
(6) Pada T_c = 149 °F	(6') Pada t_c = 100 °F
μ = 7.5 cps *(fig 14)*	μ = 0.7 cps *(fig 14)*
= 18.15 lbm/jam.ft	= 1.694 lbm/jam.ft
$Di = \frac{0.62}{12}$ in	$De = \frac{0.95}{12}$ *(fig.28)*
= 0.0517 ft	= 0.079167 ft
$R_{et} = \frac{D \times G_t}{\mu}$	$R_{es} = \frac{De \times G_s}{\mu}$
$= \frac{0.0517 \times 100031.35}{18.15}$	$= \frac{0.079 \times 18219.33}{1.694}$
= 284.7540586	= 851.4543
(7) j_H = 3 *(fig.24)*	(7') j_H = 40 *(fig.28)*
	(8') Pada t_c = 100 °F
	k = 0.381 Btu/hr.ft²(°F/ft) *(Kern, T.4, hh:800)*
	Cp = 1 Btu/lb.°F *(Kern, F.2, hh:804)*
	$\left(\frac{Cp.\mu}{k}\right)^{1/2} = 2.1086$

HOT FLUID: Tube	**COLD FLUID : Shell**
(Minyak)	(Air Pendingin)
(9) h_i : h_i = 460 Btu/hr.ft².°F *(Kern; fig. 25)*	(9') $\frac{h_o}{\varphi s} = j_H \frac{k}{De} \left(\frac{c\mu}{k}\right)^{1/2}$ = 405.9166
(10) tw* $t_w = t_c + \frac{h_i}{h_i + h_o}(T_c - t_c)$ $= 149 + \frac{460}{865.9166}\ 50$ = 175.296 °F	(11') Pada t_w = 175.296 °F μ_w = 0.45 cps = 1.089 lbm/jam.ft $\varphi s = (\mu/\mu_w)^{0.14}$ = 1.06381 Btu/hr.ft².° (12') Corrected coefficient $h_o = \frac{h_o \times \varphi s}{\varphi s}$ = 431.8181
(11) h_{io} (eq. 6.5) $h_{io} = h_i \times ID/OD$ = 380.3 Btu/hr.ft^2/°F	

13. Clean overall coefficient, U_c :

$$U_c = \frac{h_{io} \times h_o}{h_{io} + h_o}$$

$$= \frac{460 \times 431.8181}{460 + 431.8181}$$

= 222.7319 Btu/hr ft² °F

14 Dirt factor, R_d :

$$R_d = \frac{U_c - U_D}{U_c \times U_D}$$

$$= \frac{222.732 - 100}{222.732 \times 100}$$

= 0.0055

Rd perhitungan > Rd data : 0.0055 > 0.004
(memenuhi) *(Kern, T.12, hh:845)*

HOT FLUID: Tube	**COLD FLUID : Shell**
(Bahan)	(Air Pendingin)
Pressure Drop	
a. Untuk R_{et} : 284.7540586 f = 0.001 ft²/in² *(Kern,Fig 26)* s = 0.55 *(Kern,Fig 6)*	a'. Untuk R_{es} : 851.4543 f = 0.0025 ft²/in² *(Kern,Fig 29)* s = 1 *(Kern, Table 6)*
b. $\Delta P_t = \frac{1}{2} \times \frac{f \times G_t^2 \times L \times n}{5{,}22 \times 10^{10} D. s.\varphi s}$ = 0.2283	b'. No of crosses $N + 1 = \frac{12L}{B}$ = 21
c. G_t = 100031.345 lb/jam ft² $\frac{V^2}{2g'}$ = 0.001 *(Kern, fig, 27)*	c'. $\Delta P_s = \frac{f \times G_s^2 \times De \times (N+1)}{5{,}22 \times 10^{10} \times De \times s \times \varphi s}$ = 0.000307 psi
$\Delta P_r = \frac{4n}{s} \times \frac{V^2}{2g'}$ $= \frac{24}{0.55} \times 0.001$ = 0.043636	
d. ΔP_T = ΔPt + ΔPr = 0.2719 psi ΔP_T < 10 psi (memenuhi)	ΔP_S < ΔP allowable (memenuhi)

SPESIFIKASI COOLER EVAPORATOR

Fungsi : Mendinginkan produk keluaran bawah evaporator sebelum masuk tangki dekolorisasi dari suhu 102,1353 °C menjadi 30 °C

Tipe : 1 - 2 Shell and Tube Heat Exchanger (Fixed Tube)

Inside Diameter	=	0.62	in
Outside Diameter	=	3/4	in
Panjang	=	12	ft
Pitch	=	1	in square pitch
Jumlah Tube	=	240	buah

Shell

Inside Diameter	=	35	in
Baffle space	=	7	in

Jumlah cooler = 1

32 CONDENSOR (E-323)

Fungsi = Mengembunkan uap formic acid
Type = Vertikal kondenser shell&tube

Komposisi vapor:

Komponen	Berat (kg)	Fraksi berat	ρ (gr/cc)
H2O	1562.0562	1.0000	1
	1562.0562	1.0000	

$$\text{Densitas Campuran} = \frac{1}{\frac{\text{fraksi berat}}{\rho \text{ komponen}}} \times 62.43$$

$$= \frac{1}{\frac{1.0}{1}} \times 62$$

$$= 1.00 \text{ gr/cc} \times 62$$

$$= 62.43 \text{ lb/cuft}$$

$$\text{Rate Volumetrik} = \frac{\text{Rate Massa}}{\text{Densitas}}$$

$$= \frac{3444.33}{62.4300}$$

$$= 55.1711 \text{ cuft/jam}$$

Diagram suhu :

t1 = 30 °C
CW = 86 °F

Uap asam format → kondenser → Liquid asam format
T1 = 100 °C = 212 °F
T2 = 45 °C = 113 °F

CWR
t2 = 45 °C = 113 °F

1. Heat Balance

Data dari Appendix A dan Appendix B diperoleh :

Rate massa, W massa	=	1,562	kg/jam
	=	3,444	lb/jam
Q air pendingin	=		btu/jam
M air pendingin	=	3,515	kg/jam
	=	7,750	lb/jam
Cp air pendingin	=	1	kkal/kg.C

2. Log Mean Temperature Difference

Suhu CW masuk = 30 °C = 86 °F (t_1)
Suhu CWR = 45 °C = 113 °F (t_2)
Suhu bahan masuk = 100 °C = 212 °F (T_1)
Suhu bahan keluar = 45 °C = 113 °F (T_2)

$$\Delta T\ LMTD = \frac{99 - 27}{\ln \frac{99}{27}}$$

$$= 55.4152\ ^oF$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{99}{27} = \#\#\#\#\#$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{27}{126} = 0.214$$

Dengan nilai R dan S tersebut, didapatkan Design Shell & Tube:
Untuk 2-4 Shell & Tube F = 0.95 *[Kern; fig.19]* 1 1'2

$$\Delta T = F_T \times \Delta T\ LMTD$$
$$= 0.95 \times 55.4152$$
$$= 52.6444\ ^oF$$

3. Tc dan tc

Tc = T_{av} vapor

$$Tc = \frac{T_1 + T_2}{2} = \frac{212 + 113}{2} = 163\ ^oF$$

tc = t_{av} water

$$tc = \frac{t_1 + t_2}{2} = \frac{86 + 113}{2} = 100\ ^oF$$

$$Sg\ bahan = \frac{\rho\ bahan}{\rho\ reference} \times Sg\ reference$$
$$= \frac{62.4300\ lb/c}{62.43\ lb/c} \times 1$$
$$= 1.0000$$

μ berdasarkan Sg bahan :
[Kern; tab.6 p. 808] didapat Sg reference = 1
[Kern; fig.14 , p. 823] didapat μ reference = 0.89 Cps

$$\mu\ bahan = \frac{Sg\ bahan}{Sg\ reference} \times \mu\ reference$$
$$= \frac{1.0000}{1.0000} \times 0.89$$
$$= 0.8900\ Cps$$

Komposisi kondenser
Hot Fluid : Uap formic *(> 1 cps, heavy organic)*
Cold Fluid : Air pendingin
Sehingga di dapat nilai U_D = 75 - 150 Btu/jam.ft^2 ^{0}F
dengan range *[Kern; tab.8 , p.840]*
Dipilih nilai U_D = 150 Btu/jam.ft^2 ^{0}F

$$A = \frac{Q}{UD \times \Delta T}$$

Dimana,
A = Luas Perpindahan Panas
Q = Q supply dari steam
UD = Overall Design Coefficients
ΔT = Perubahan Suhu

$$A = \frac{Q}{UD \times \Delta T}$$
$$= \frac{0.0000}{150 \times 52.6444}$$
$$= 0.0000 \text{ ft}^2$$
$$= 0.0000 \text{ m}^2$$

Dikarenakan luas perpindahan panas > 200 ft2, maka design kondenser menggunakan shell an *[Walas; p.xvi]*

$$\text{nlah tube (1} = \frac{A}{L \times a''}$$
$$= \frac{0.0000}{19 \times 0.327}$$
$$= 0 \text{ buah}$$

Dalam perencanaan ini digunakan Condenser dengan spesifikasi :
Digunakan TUBE dengan *[Kern; tab. 10, p. 843]*
OD, BWG = 1 1/4 in , 16 BWG
Pitch = 1 3/4 in triangular *[Kern; tab.9]*
Panjang tube,L = 19 ft
Passes = 1
ID Tube = 1.120 in 0.0933 ft
a't = 0.985 in^2
a" = 0.3271 ft^2/lin ft
Digunakan Nt = 235 buah

Dari tube passes dan jumlah tube didapat SHELL:
Untuk pipa 1 1/4 in, OD tubes on 1 3/4 in triangular pitch
ID shell = 29 in *[Kern; tab.9]*
Baffle = 20 in
Passes (n) = 2
*Koreksi U_D

$$A = Nt \times L \times a''$$
$$= 1460.502 \text{ ft}^2$$
$$U_D \text{ koreksi} = \frac{Q}{A \times \Delta T}$$
$$= \frac{0.000}{1461 \times 52.6}$$
$$= 0 \text{ Btu/jam.ft}^2\,^0\text{F}$$

Nilai U_D asumsi sama dengan U_D koreksi (memenuhi)

Fluida Panas (Shell Side) Water	**Fluida Dingin : (Tube side) Vapor**
(4') Flow area (a_s) C' = Pitch - OD = ## in as = IDshell x C' x B / 144 x P_T = 29 x 1/2 x 20 / 144 x 1 3/4 = 1.1508 ft^2	(1) Flow area (a'_t) a_t = Nt x a'_t / 144 x n = 235 x 0.99 / 144 x 1 = 1.6075 ft^2
(5') Kecepatan massa (Gs) Gs = W / as = 7,749.54 lb/jam / 1.1508 = 6,734 lb/jam ft^2	(2) Kecepatan massa (Gt) G_t = W / a_t = 3,444.334 / 1.6075 = 2,142.71 lb/jam ft^2
De = ##### *[Kern; fig 28]* Pada Tc = 163 ^{o}F , didapat μ μ = ## x 2.42 = 1 lb/ft.hr	Pada tc = 100 ^{o}F , didapat μ μ = ## x 2.42 = 2 lb/ft.hr
NRe = D_e x G_s / μ = 469	NR = Gt x ID / μ = 2,143 x 0.09 / 2.15 = 93
(3) Asumsi ho = 400 Btu/jam.ft^2 ^{o}F	(3') Menghitung hi

Fluida Panas (Shell Side) Water	**Fluida Dingin : (Tube side) Vapor**
$tw = tc + \frac{ho}{ho + hic}(Tc-tc)$ $= 135.3\ ^oF$ $tf = \frac{Tc + tw}{2}$ $= \frac{163 + 135.3}{2}$ $= 148.9\ ^oF$ Dari nilai tf tersebut, diperoleh: kf = 0.381 Btu/jam.ft^2 ^{o}F/ft sf = 1 *[Kern; Tab. 6]* µf = 0.6 cp *[Kern; Fig.14]* Dipilih vertical condenser $G' = \frac{W}{3.14 \times Nt \times D}$ $= \frac{7,749.5414}{3.14 \times 235 \times 0.09}$ $= 112.5231$ lb/jam lin ft Dari *[Kern; Fig 12-9, p.267]* di dapat : ho = 410 Btu/jam.ft^2 ^{0}F Karena nilai ho tersebut berbeda dengan ho trial, jika berbeda tidak boleh lebih dari 20%. Jika lebih dari 20% maka ulangi trial ho.	$v = \frac{G_t}{3600\ \rho}$ $\frac{2,143}{3600 \times 62.43}$ $= 0.010$ ft/s Dari *[Kern; Fig. 25]* Dari nilai tc dan v, diperoleh hi: hi = 340 Btu/jam.ft^2 ^{o}F $hio = hi \times \frac{ID}{OD}$ $= 340 \times \frac{1.12}{1\ 1/4}$ $= 305$ Btu/jam.ft^2 ^{0}F

(12) Clean Overall coefficient, Uc :

$Uc = \frac{hio \times ho}{hio + hc}$

$= 174.7767$ Btu/hr.ft^2.^{o}F

(13) Dirt Factor, Rd :

Rd hitu $= \frac{U_C - U_D}{U_C \times U_D}$

$= $ #DIV/0! Btu/hr.ft^2.^{o}F

Rd perhitungan > Rd data

#DIV/0! > 0.001 *[Kern; T-12, p.845]* (Condenser)

Rd Hitung > Rd Ketentuan , Alat dapat digunakan

Pressure Drop	
Bagian shell (water)	**Bagian tube (vapor)**
NR = 469 f = 0.0028 ft^2/in^2 *[Kern; fig.29 p.839]* N+ = 12L/B = 11.4 in s = 1.000 Ds = 2 ft *[Kern; Eq. 12-47 p.273]* $\Delta Ps = \frac{1}{2} \times \frac{f.Gs^2.Ds.(N+1)}{5.22 \times 10^{10} \times De \times s}$ = 1 x 0.000884 = 0.000 Psi	NR = 93 f = 4E-04 ft^2/in^2 *[Kern; fig.26 p.839]* *[Kern; eq.7-45 p.148]* $\Delta Pt = \frac{f.Gt^2.L.n}{5.22 \times 10^{10} \times D \times s \times \varphi t}$ = 0.00001 Psi $\Delta Pt = \frac{4\,n}{s} \times \frac{V^2}{2\,G'}$ Dari *[Kern; Fig.27 p.837]* Gt = 2,142.711 $lb/jam.ft^2$ Didapat harga $\frac{V^2}{2\,G}$ = 0.002 s = 1.000 $\Delta Pr = \frac{4\,n}{s} \times \frac{V^2}{2\,G'}$ $\Delta Pr = \frac{4}{1.000} \times 0.002$ = 0.00960 Psi ΔP_T Total = $\Delta Pt + \Delta Pr$ = 0.000 + 0.010 = 0.0096 psi

Jadi Pi = ΔPs + ΔPt total
= 0.0004 + 0.0096
= 0.0101 Psi

a. Menghitung diameter kondenser

Untuk counter-current Condenser dengan rate 1562.056 kg uap/jam
Diperoleh kondenser dengan H = 3 m *[Hugot ed.3; tab 40.2]*
Asumsi H = 2 D
D = 1.5 m

Spesifikasi :
Type Conden 2-4 Shell & Tube Exchanger
Jumlah = 2 bua *(+ Cooler)*
Bagian shell :
Jenis Bahan = Stainless Steel 302
Diameter kond = 1.5 m
Tinggi konden = 3 m
ID Shell = 29 in
Baffle Space = 20 in
Passes = 2
Bagian tube :
Jumlah & Panj = 235 bua 19 ft
OD, BWG, pit = 1.25 in , 16 BW(1 3/4 triangular
Passes = 1

33 TANGKI DEKOLORISASI (D-330)

Fungsi : Tempat karbon aktif melakukan proses penyerapan warna *Dioctyl Phthalate* menjadi bening
Tipe : Tangki silinder vertikal dengan alas dan tutup berbentuk *torispherical* serta pengaduk jenis *propeller*
Jumlah : 1 buah
Kondisi Op : T = 30 °C = 303.15 K
P = 1 atm = 760 mmHg = 14.7 psi

Menentukan Dimensi Tangki

Komponen	Laju Massa (kg/jam)	%Berat	ρ (g/ml)	$\rho_{Campuran}$ (kg/m^3)	μ (cP)	$\mu_{campuran}$ (cP)
$C_{24}H_{38}O_4$	3793.4721	0.99462	0.9840	1.0108	52.6447	0.0189
$C_8H_{18}O$	5.0783	0.00133	0.8330	2E-03	5.0819	0.0003
$C_8H_4O_3$	2.8906993	0.00076	1.2000	6E-04	3.9880	0.0002
$C_8H_6O_4$	2.8993975	0.00076	1.5260	5E-04	155.97	0.0000
H_2O	7.7584	0.00203	0.9970	2E-03	0.8150	0.0025
Karbon	1.9060	0.00050	460.00	1E-06	0.0000	0.00
Total	**3814.0049**	**1.0000**	**465.54**	**1.0156**	**218.497**	**0.02**

$$\rho_{campuran} = \frac{\sum xi}{\sum xi/\rho} = \frac{1.000}{1.016} = 0.985 \text{ kg/m}^3$$

$$= 0.061 \text{ lb/ft}^3$$

$\mu_{campurar} = \frac{\sum xi}{\sum xi/\mu} = \frac{1.0000}{218.4966} = 0.005$ cP

$= 0.000003$ lb/ft.s

Menentukan Volume Cairan dalam *mixer* (V_L) dan volume *mixer* (Vs)

Digunakan persamaan :

$V_L = m / \rho_{mix}$

dimana :

m = 3814.00 kg/jam

= 8408.43 lb/jam

maka :

$V_L = \frac{8408.432 \text{ lb/jam} \times 1 \text{ jam}}{0.061 \text{ lb/ft}^3}$

$= 136781.3 \text{ ft}^3$

$Vs = \left[1 + 0 \right] \times V_L$

$= 1.2 \times 136781.3 \text{ ft}^3$

$= 164137.5 \text{ ft}^3$

= 1227913 galon

Menentukan Diameter dan Tinggi *Shell*

Dipilih tangki silinder dengan rasio H_S/IDE = 1.5

Eq 3.10. (Brownell & Young, 1959:43)

$H_S/ID = 2$

$H_S = 2$ ID

Volume *head* bentuk = 0,000049 ID^3

(Brownell & Young, 1959:88)

Maka,

V_s = Volume silinder + 2 volume *head*

$V_s = (¼ \times (\pi \times ID^2 + (2 \times 0{,}000049\ ID^3)$

$164138 = (¼ \times (3{,}14 \times ID^2) + (2 \times 0{,}000049\ ID^3)$

$164138 = 1.178\ ID + 2 \times 5E\text{-}05\ ID^3$

$ID^3 = 139383.3$

ID = 51.8486 ft

ID = 15.8035 m

ID = 622.1818 in

Sehingga diameter *shell* (D_s) adalah sebesar = 15.8035 m

Maka tinggi *shell* :

$H_S = 1.5 \times ID$

$= 1.5 \times 51.8486$ ft
$= 77.7729$ ft
$= 23.7055$ m

Jadi diameter dan tinggi *shell* sebesar = 15.8035 m dan 23.7055 m

Menentukan Tinggi Larutan dalam Tangki

$$V_{larutan} = \left(\frac{\pi}{4} \times Di^{2}\right) \times H_{liquid}$$

$$H_{liquid} = \frac{V_{larutan}}{\left(\frac{\pi}{4} \times Di\right)^{2}}$$

$$= \frac{136781.2825 \text{ ft}^3}{\frac{3.14}{4} \times \left(51.85 \text{ ft}^{2}\right)}$$

$= 64.8161$ ft
$= 19.7560$ m

Menentukan Tebal *Shell*

$$t_s = \frac{P_d.r}{f.E - 0{,}6\,P} + C$$ Eq. 13.1. (Brownell & Young, 1959:254)

Dimana :
P_d = Tekanan desain

dengan :
$P_d = P_{operasi} + P_{hidrostatik}$
P_{op} = 1 atm = 14.7 psi

$$P_{hid} = \rho \times \frac{g}{gc} \times h$$

Dimana :
h = tinggi cairan dalam = 64.8161 ft
ρ = densitas cairan = 0.0615 lb/ft^3
maka,

$P_{hid} = 0.061$ lbm/ft^3 $\times$ 1 lbm/lbf $\times$ 64.82 ft
$= 3.984$ lbf/ft^2
$= 0.028$ psi

$P_d = P_{op} + P_{hid}$
$= 14.7$ psi $+ 0.0277$ psi
$= 14.7277$ psi

dengan faktor keamanan 20%, maka :

P_d = 1.2 × 14.7277 psi
= 17.6732 psi

r = jari-jari *shell* (D_S/2) = 311.0909 in

f = *Allowable stress* untuk *Carbon Steel* SA-283 *Grade* C sebesar = 12650 psi (Brownell & Young, 1959:251)

E = Efisiensi pengelasan, diambil *double-welded butt joint,* sebesar 80%

c = Faktor korosi sebesar 0,125

Maka,

$$t_s = \frac{17.6732 \times 311.0909}{(12650) \times (0,8) - (0,6) \times \text{x} \quad 17.6732} + 0.125$$

t_s = 0.6688 in

Digunakan tebal *shell* standar = 3/16 in

Tabel 5.7. (Brownell & Young, 1959:89)

Menentukan Diameter dan Tinggi yang Distandarkan

Diameter (Ds)

OD = ID + 2 t_S

Dimana :

ID = diameter *shell* (D_S)

Sehingga :

OD = 622.2 in + 2 x 0.1875 in
= 622.6 in

OD standar dapat dicari dari **Tabel 5.7.** (Brownell & Young, 1959:90), sehingga,

OD = 60 in = 1.524 m

ID = $OD_{standar}$ - 2 t_S
= 60 in - 2 x 0.1875 in
= 59.63 in
= 1.51 m

Diameter dalam *shell* standar = 59.6250 in
= 1.5145 m
= 4.9687 ft

Tinggi (H_S)

H_S = 1.5 × 59.6250
= 89.4375 in

= 2.2717 m

Tinggi *shell* standar ialah = 2.2717 m

Menentukan Tebal dan Tinggi *Head*

Tebal *Head*

Tebal tutup berupa *torispherical* mengikuti persamaan 7.57. (Brownell & Young, 1959:133) :

$$th = \frac{Pd \times ri \times w}{2\,(f.E - 0{,}1\,P_d)} + c$$

Dimana :

$$w = 1/4\left(3 + \frac{r}{icr}\right) + 0.5$$

r = 60 **Tabel 5.7.** (Brownell & Young, 1959:90)

icr = 3 5/8 **Tabel 5.7.** (Brownell & Young, 1959:90)

$$w = 1/4\left(3 + \frac{60}{3\ 5/8}\right) + 0.5$$

= 1.1054

Pd = 17.6732 psi

r = jari-jari *shell* ($D_S/2$) = 311.0909 in

f = *Allowable stress* untuk *Carbon Steel* SA-283 *grade* C sebesar = 12650 psi (Brownell & Young, 1959:251)

E = Efisiensi pengelasan, diambil *double-welded butt joint,* sebesar 80%

c = Faktor korosi sebesar 0,125

Maka :

$$th = \frac{17.67\ psi \times 311.1\ in \times 1.1054}{2\left[12650 \times 1 - 0.1 \times 17.67\ psi\right]} + 0.125$$

= 0.4253 in

Digunakan tebal *head* = 3/16 in

Tabel 5.7. (Brownell & Young, 1959:89)

Tabel 5.7. (Brownell & Young, 1959:90)

OD = 60 in

r = 60 in

icr = 3 5/8 in

Sehingga untuk dimensi tutup atas dan bawah dapat dihitung sebagai berikut

a = 0.5 × ID = 29.81 in

AB = a - icr

= 29.81 in - 3 5/8 in

= 26.19 in

BC = r - icr
= 60 - 3 5/8
= 56.38 in

AC = $(BC^2 - AB^2)^{1/2}$
= 49.92 in

b = r - $(BC^2 - AB^2)^{1/2}$
= 10.08 in

Tinggi *straight flange* (sf)
Untuk tebal *head* = 3/16 in **Tabel 5.7.** (Brownell & Young, 1959:89)
nilai sf 1 1/2-2 diambil :
sf = 1 1/2 in
Dari data di atas dapat dihitung tinggi tutup tangki (OA) yaitu sebesar :
OA = b + sf + t
= 10.08 + 1 1/2 + 0.1875
= 11.76 in
= 0.299 m
Karena tutup atas dan bawah sama maka tutup bawah juga mempunyai tingg
sebesar = 11.76 in atau 0.2995 m
Sehingga didapat tinggi total *shell* (H_V)

$H_{V\,(total)}$ = H_S + 2 x tinggi head
= 2.272 + 0.5990
= 2.871 m

Menentukan Dimensi Pengaduk

Menentukan Jenis Pengaduk dan Jumlah *Impeller*

Dipilih jenis pengaduk *three blade propeller* dengan alasan
Untuk menentukan jumlah pengaduk ditentukan berdasarkan data berikut (Walas, 1965:288) :

Viscosity	***Maximum level***	***Number of***
[cP (Pa sec)]	**h/Dt**	***Impellers***
<25.000 (<25)	1.4	1
<25.000 (<25)	2.1	2
>25.000 (>25)	0.8	1
>25.000 (>25)	1.6	2

Maksimum level = $\frac{H_L}{D_s}$

= $\frac{64.82}{4.969}$ ft

= 13.04

Jadi jumlah pengaduk (*impeller*) untuk h/Dt sebesar = 2 buah

Menentukan Dimensi Pengaduk

Tabel 3.4-1. (Geankoplis, 1993:144) didapat data berikut :

Da/Dt = 0,3 - 0,5 (diambil 0,3)
W/Da = 1/5
L/Da = 1/4
C/Dt = 1/3
J/Dt = 1/12

Dimana :
Da = diameter *impeller*
C = jarak pengaduk dari dasar tangki
Dt = diameter luar tangki = OD
L = panjang *propeller*
W = tinggi *propeller*

Sehingga dimensi pengaduk dapat dihitung sebagai berikut :

Diameter *impeller* (Da)

Da = 0.3 × OD
Da = 0.3 × 66
Da = 19.8 in
= 1.65 ft
= 0.50 m

Jarak pengaduk dari dasar tangki (C)

C = 1/3 × OD
C = 1/3 × 66
C = 22 in
= 1.83 ft
= 0.56 m

Panjang *flat* (L)

L = 1/4 × Da
L = 1/4 × 19.8
L = 4.95 in
= 0.41 ft
= 0.13 m

Tinggi *flat* (W)

W = 1/5 × Da
W = 1/5 × 19.8
W = 3.96 in
= 0.33 ft

= 0.10 m

Menentukan *Power* Motor

a. **Menentukan Kecepatan Putar Pengaduk**

$$N = \frac{v}{p \times Da}$$ (Joshi, hal 389)

Dimana :
Da = diameter *impeller*
N = putaran putar pengaduk (rpm)
v = kecepatan linier untuk = 300 mpm
Sehingga,
N = ##### rpm = 3.1662 rps
Diambil kecepatan pengaduk standar (komersial) 190 rpm (Walas, 1965:288
N = 190 rpm = 3.1667 rps

Menentukan Bilangan Reynolds (N_{Re})

Dengan menggunakan persamaan :

$$Nre = \frac{r \times Da^2 \times N}{m}$$

$$= \frac{0.061 \times \left(1.650\right)^2 \times 3.167}{0.0000030709860}$$

NRe = 172576.1

Menentukan *Power* Pengaduk

Karena tangki yang digunakan tanpa *baffle* maka perhitungan *power* sebagai berikut :

$$N_{FR} = \frac{n^2 \times Da}{g}$$

$$= \frac{3.167^2 \times 1.650}{32.1740}$$

= 0.5143

Dari **Tabel 9.1.** (Mc Cabe at al., 1993:252) didapatkan nilai konstanta a dan
a = 1
b = 40

maka :

$$m = \frac{1 - \log_{10} Nre}{40}$$

= -0.1059 Eq. 9.19 (Mc Cabe et al., 1993:251)

Np = *power number*, dari Grafik 9.12 didapatkan sebes 1

maka :

Np *correct* = Np × NFR ^{m}

= 1 × $\left(0.514\right)^{-0.106}$

= 1.073

$$P = \frac{p \times \rho \times N^3 \times D}{gc}$$

$$= \frac{1.073 \times 0.061 \times 3.1667^{3} \times 1.650^{5}}{32.1740}$$

= 0.796 ft/lbf.s

= 0.001 hp

***Fig* . 14.38.** (Peters & Timmerhaus, 1991:521) didapat efisiensi motor penggerak sebesar 80% maka daya penggerak motornya sebesar :

power mot = P/η

$$= \frac{0.001}{80\%}$$

= 0.002 hp

Maka digunakan *power* motor = 0 hp

SPESIFIKASI TANGKI DEKOLORISASI

Nama Alat : Tangki Dekolorisasi

Kode : M-330

Fungsi : Tempat karbon aktif melakukan proses penyerapan warna *dioctyl phthalate* menjadi bening

Tipe : Tangki berupa silinder vertikal dengan alas dan tutup berbentuk *torispherical* serta pengaduk jenis *propeller*

Bahan Kor : *Carbon Steel* SA-283 *Grade* C

Jumlah : 1 buah

Kondisi Operasi

Tekanan : 1 atm

Suhu : 30 ^{o}C

Kapasitas : 164137.5 ft^3

Tekanan D : 14.73 psi

Dimensi

Silinder

Diameter Dalam : 622.2 in = 15.8034 m

Diameter Luar : 60 in = 1.5240 m

Tebal : 3/16 in = 0.0048 m
Tinggi : 89.44 in = 2.2717 m

Tutup

Jenis : *Torispherical Dished Head*
Tebal Tutup Atas : 3/16 in = 0.005 m
Tebal Tutup Bawah : 3/16 in = 0.005 m
Tinggi : 11.76 in = 0.299 m
Tinggi Tangki Total : 113.0 in = 2.871 m

Pengaduk

Jenis : *Three Blade Propeller*
Jumlah : 1 buah
Diameter : 19.8 in = 0.5029 m
Kecepatan : 190 rpn = 3.1667 rps
Power : 0 hp

34 POMPA TANGKI DEKOLORISASI (L-331)

Fungsi : Mengalirkan *dioctyl phthalate* dari tangki dekolorisasi menuju *filter press*
Tipe : *Centrifugal pump*
Jumlah : 1 buah
Tujuan : 1. Menentukan tipe pompa
2. Menentukan bahan konstruksi pompa
3. Menghitung tenaga pompa
4. Menghitung tenaga motor

3) Menghitung Tenaga Pompa

Rate masuk	=	3814.0049	kg/jam	=	2.3357	lb/s
Densitas	=	0.9847	kg/m³	=	0.0615	lb/ft³
μ	=	2.8134	cP	=	0.0019	lb/ft.s

$$\text{Rate volumetrik (Q)} = \frac{\text{massa}}{\text{r}}$$

$$= \frac{2.3357 \quad \text{lb/s}}{0.0615 \quad \text{lb/ft}^3} = 37.9945 \quad \text{ft}^3\text{/s}$$

$$= 17053.0973 \quad \text{gpm}$$

Diperkirakan aliran fluida turbulen (Nre>2100), sehingga digunakan persamaan Di ≥ 1 in yaitu :

$$\text{Di opt} = 3.9 \quad Q^{0,45} \quad \mu^{0,13}$$ Eq. 45. (Peters & Timmerhaus, 1991:365

Dimana :

Di opt = diameter dalam optimum, in

Q = kecepatan volumetrik, ft^3/s

μ = viskositas fluida, lb/ft.s

Sehingga :

Di opt = 3.9 × (37.9945)^{0,45} × (0.0019)^{0,13}

= 8.8695 in

Dari App. A.5-1 (Geankoplis, 1993:892) dipilih spesifikasi :

NPS = 1/2 in

OD = 0.8400 in = 0.07 ft = 0.021336 m

ID = 0.6220 in = 0.0518333 ft = 0.015799 m

A = 0.0021 ft² = 1.9603 in^2

Sch = 40

Menghitung kecepatan linier :

Kecepatan linier fluida dapat dicari dengan menggunakan persamaan berikut :

$$V = \frac{Q}{A}$$

Sehingga :

$$V = \frac{37.9945 \ ft^3/s}{0.0021 \ ft^2} = 18006.8512 \ ft/s = 5488.4882 \ m/s$$

Menghitung *Reynold Number* (Nre) :

$$Nre = \frac{\rho \ v \ D}{\mu}$$

Sehingga :

$$Nre = \frac{0.0615 \times 18006.8512 \times 0.0518}{0.0019}$$

= 30348.30761 (asumsi aliran turbulen benar)

Instalasi pipa

Dari ***Fig*. 127.** (Brown, 1950:141) dengan NPS = 1/2 in

- 1 buah *gate valve fully open* ; Le = 0.35 ft

  ∑Le = 1 × 0.35 = 0.35 ft
- 4 buah *standard elbow* ; Le = 1.5 ft

  ∑Le = 4 × 1.5 = 6 ft
- 1 buah *sudden enlargement* ; Le = 1 ft

	∑Le = 1 × 1	=	1	ft
-	1 buah *sudden contraction* ; Le	=	0.52	ft
	∑Le = 1 × 0.52	=	0.52	ft
-	1 buah *swing check valve* ; Le	=	3.5	ft
	∑Le = 1 × 3.5	=	3.5	ft
-	Panjang ekivalen pipa lurus, ∑Le	=	11.37	ft
	Panjang pipa lurus	=	2	m
		=	6.5616	ft
	Panjang pipa total	=	17.9316	ft
		=	5.4656	m

Menghitung *friction loss*

$$\Sigma F = \frac{4f \cdot v^2 \cdot \Delta L}{2 \cdot ID \cdot gc}$$ Eq. 2.10-6 (Geankoplis, 1993:89)

Dimana :

ΣF = *Friction loss* (ft.lbf/lbm)
f = Faktor friksi
v = Kecepatan linier fluida (ft/s)
ΔL = Panjang pipa (ft)
ID = Diameter dalam tangki (ft)
gc = 32.1740 lbm.ft/lbf.s^2

Menghitung *Fanning Friction Factor* (f) :
Dari ***Fig* . 2.10-3. (**Geankoplis, 1993:88) didapat :
Untuk *commercial steel* → ε = 5.E-05 m
= 0.0002 ft

Sehingga :

$$\frac{\varepsilon}{D} = \frac{0.0002}{0.0518} = 0.0030$$

Dari ***Fig* . 2.10-3.** (Geankoplis, 1993:88) dengan nilai Nre = 30348.3076
didapatkan nilai f = 0.0055 sehingga :

$$\Sigma F = \frac{4 \times 0.0055 \times (18006.8512)^2 \times 17.9316}{2 \times 0.0518 \times 32.1740}$$

$$= 38350681.2230 \ \frac{lb_f \cdot ft}{lb_m}$$

Menghitung *Static Head* :

Z_1 = 1 m = 3.28084 ft
Z_2 = 0.2 m = 0.656168 ft
ΔZ = Z_1-Z_2 = 2.6247 ft
g/gc = 1 lbf/lbm
ΔZ (g/gc) = 2.624672 ft × 1 lbf/lbm = 2.624672 ft lbf/lbm

Menghitung *Velocity Head* :
V_1 = kecepatan linier fluida dari tangki hidrogen peroksida ke pipa
V_2 = kecepatan linier fluida ke *heater*
Karena pada 2 titik *reference* dianggap sama, maka $V_1 = V_2$ 18006.8512 ft/s
Sehingga *velocity head* (ΔV^2 / 2agc) = 5038955.2101

Menghitung *Pressure Head* :
P_1 = P_2 = 14.7 Psi
ΔP = 0
Sehingga, $\Delta P/\rho$ = 0

Menghitung Energi Mekanik Pompa :

$$-Wf = \frac{\Delta V^2}{2 \times \alpha \times gc} + \Delta z \frac{g}{gc} + \frac{\Delta P}{\rho} + \sum F$$

Dimana :
Wf = tenaga yang ditambahkan ke dalam sistem per satuan massa

Sehingga :
- Wf = 5038955 + 2.625 ft. lbf/lbm + 0 + 38350681 ft. lbf/lbm

= 43389639.06 ft. lbf/lbm

Menghitung *Broke Horse Power* (BHP) :

$$BHP = \frac{m.(-Wf)}{550 \cdot \eta}$$

dari ***Fig* . 14-37.** (Peters & Timmerhaus, 1991:520), untuk Qf = 17053.0973 gpm diperoleh η pompa = 0.40

Sehingga :

$$BHP = \frac{2.3357 \times 43389639.06}{550 \times 0.4000}$$

= 460650.9 Hp; maka digunakan *power* = 1 Hp

4) Menghitung Tenaga Motor

***Fig.* 14.38**. (Peters & Timmerhaus, 1991:521) untuk BH = 1.0 Hp diperoleh η motor = 0.80

Sehingga *power* motor yang diperlukan :

$$\text{P motor} = \frac{\text{BHP}}{\eta} = \frac{1 \text{ Hp}}{0.80} = 1.3 \text{ Hp}$$

Dipilih motor standar dengan *power* = 2 Hp (*Standard* NEMA)

Spesifikasi Pompa Tangki Dekolorisasi

Nama Alat	:	Pompa Tangki Dekolorisasi
Kode	:	L-331
Fungsi	:	Mengalirkan *dioctyl phthalate* dari tangki dekolorisas menuju *filter press*
Tipe	:	*Centrifugal pump*
Bahan Konstruksi	:	*Commercial steel*
Jumlah	:	1 buah
Rate Volumetrik	:	37.9945 ft^3/s
Kecepatan Aliran	:	18006.8512 ft/s
Ukuran Pipa	:	NPS = 1/2 in
	:	*Sch. Number* = 40
	:	OD = 0.0700 ft = 0.021336 m
	:	ID = 0.0518 ft = 0.015799 m
	:	*Flow Area* = 0.0021 ft^2 = 0.0002 m^2
Power Pompa	:	1 Hp
Power Motor	:	2 Hp

35) FILTER PRESS (H-340)

Fungsi	:	Memisahkan *dioctyl phthalate* dari karbon aktif
Tipe	:	*Plate and Frame Filter Press*
Jumlah	:	1 buah
Kondisi Operasi	:	T = 30 °C = 303.15 K
		P = 1 atm = 760 mmHg = 14.7 psi

Komposisi filtrat

Komponen	Massa (kg/jam)	Fraksi berat	ρ bahan (g/ml)	ρ bahan x fraksi berat (x)
$C_{24}H_{38}O_4$	3766.9558	0.9951	0.984	0.9792
$C_8H_{18}O$	5.0428	0.0013	0.833	0.0011
$C_8H_4O_3$	2.8704933	0.0008	1.2	0.0009
$C_8H_6O_4$	2.8791307	0.0008	1.526	0.0012
H_2O	7.7041388	0.0020	0.997	0.0020
Total	3785.4522910	1.0000	5.5400	0.9844

Komposisi cake

Komponen	Massa (kg/jam)	Fraksi berat	ρ bahan (g/ml)	ρ bahan x fraksi berat (x)
$C_{24}H_{38}O_4$	18.9294	0.6630	0.984	0.6524
$C_8H_{18}O$	0.0253	0.0009	0.833	0.0007
$C_8H_4O_3$	0.0144246	0.0005	1.2	0.0006
$C_8H_6O_4$	0.0144246	0.0005	1.526	0.0008
H_2O	0.0387143	0.0014	0.997	0.0014
Karbon Aktif	9.5302472	0.3338	0.4600	0.1535
Total	28.5525771	1.0000	6.0000	0.8094

rate massa filtrat = 3785.4523 kg/jam
= 8345.4838 lb/jam

ρ campuran = $\sum \rho_i \times X_i$ = 0.9844 gr/ml
= 61.45418032 lb/cuft

rate volumetrik filtrat = $\frac{\text{rate massa filtrat}}{\rho \text{ campuran}} = \frac{8345.4838}{61.4542}$
= 135.8001 cuft/jam

waktu pembersihan = 0.5
waktu siklus operasi = 1
Volume filtrat = rate volumetrik filtrat x waktu operasi
= 135.8001 x 1
= 135.8001 cuft = 1015.853 gal

rate massa cake = 28.5526 kg/jam
= 62.9470 lb/jam

ρ campuran = 0.8094 gr/ml
= 50.5271 lb/cuft

rate volumetrik cake = $\frac{\text{rate massa cake}}{\rho \text{ campuran}} = \frac{62.9470}{50.5271}$
= 1.2458 cuft/jam

Volume cake = rate volumetrik cake x waktu operasi
= 1.2458 x 1
= 1.2458 cuft
= 9.3193 gal

Dari literatur perry 5th ed. Tabel 19-18 didapatkan
rate filtrasi = 5 - 20 gal/ft^2 . Jam (diambil 20 gal/ft^2.jam)

Luas frame total = $\frac{\text{Volume filtrat}}{\text{rate filtrasi x waktu operasi}}$
= $\frac{1015.8526}{20 \text{ x } 1}$
= 50.7926 ft^2
= 4.7188 m^2

Digunakan ukuran plate and frame = 18 x 18 inch
Dari literatur perry 5th ed. Didapatkan
Luas efektif = 3.9 ft^2
Total Kapasitas = 0.16 ft^2 / in tebal
Jumlah frame

N = $\frac{\text{Luas total}}{\text{Luas efektif}}$
= $\frac{50.7926}{3.9}$
= 13.0238 buah
= 128 buah

Plate & Frame yang dipakai = (2 x N) - 1
= (2 x 128) - 1
= 255 buah

Volume cake tiap frame = $\frac{\text{rate volumetrik cake}}{\text{jumlah frame}}$
= $\frac{1.2458}{128}$
= 0.0097 cuft
= 0.0003 m^3

Tebal frame = $\frac{\text{Volume cake tiap frame}}{\text{luas efektif}}$

= $\frac{0.0097}{3.9}$

= 0.0025 ft = 0.0299 inch = 1 inch

Diambil tebal frame

Panjang total filter press = jumlah plate & frame x tebal frame

= 255 x 1

= 255 inch

= 6.48 m

Pressure drop

Dari literatur Christopher, halamann 469 didapatkan Filtrasi dilakukan pada pressure drop(DP) yang konstan sebesar = 30 psi

SPESIFIKASI FILTER PRESS

Fungsi	=	Memisahkan *dioctyl phthalate* dari karbon aktif
Type	=	Plate & Frame filter press
Jumlah plate	=	127
Jumlah frame	=	128
Tebal frame	=	1 inch
Panjang alat	=	6.48 m
Pressure drop	=	30 psi
Bahan konstruksi	=	Stainless steel
Jumlah	=	1 buah

36) POMPA FILTER PRESS (L-341)

Fungsi : Mengalirkan *dioctyl phthalate* dari *filter press* menuju tangki penyimpanan *dioctyl phthalate*

Tipe : *Centrifugal pump*

Jumlah : 1 buah

Tujuan : 1. Menentukan tipe pompa
2. Menentukan bahan konstruksi pompa
3. Menghitung tenaga pompa
4. Menghitung tenaga motor

3) Menghitung Tenaga Pompa

Rate masuk	=	3785.4523	kg/jam	=	2.3182	lb/s
Densitas	=	0.9842	kg/m³	=	0.0614	lb/ft³
μ	=	52.8232	cP	=	0.0355	lb/ft.s

Rate volumetrik (Q) $= \frac{\text{massa}}{\text{r}}$

$= \frac{2.3182 \quad \text{lb/s}}{0.0614 \quad \text{lb/ft}^3} = 37.7288 \quad \text{ft}^3\text{/s}$

$= 16933.8780 \quad \text{gpm}$

Diperkirakan aliran fluida laminer (Nre<2100), sehingga digunakan persamaan Di < 1 in yaitu :

$\text{Di opt} = 3.6 \quad Q^{0,40} \quad \mu^{0,20}$ *Eq* . 48. (Peters & Timmerhaus, 1991:365

Dimana :

Di opt = diameter dalam optimum, in

Q = kecepatan volumetrik, ft^3/s

μ = viskositas fluida, lb/ft.s

Sehingga :

$\text{Di opt} = 3.6 \times (\quad 37.7288 \quad)^{0,40} \times (\quad 0.0355 \quad)^{0,20}$

$= \quad 7.8888 \quad \text{in}$

Dari *App* . A.5-1 (Geankoplis, 1993:892) dipilih spesifikasi :

NPS = 1/2 in

OD = 0.8400 in = 0.07 ft = 0.021336 m

ID = 0.6220 in = 0.0518333 ft = 0.015799 m

A = 0.0021 ft^2 = 1.9603 in^2

Sch = 40

Menghitung kecepatan linier :

Kecepatan linier fluida dapat dicari dengan menggunakan persamaan berikut :

$V = \frac{Q}{A}$

Sehingga :

$V = \frac{37.7288 \quad \text{ft}^3\text{/s}}{0.0021 \quad \text{ft}^2} = 17880.9642 \quad \text{ft/s} = 5450.118 \quad \text{m/s}$

Menghitung *Reynold Number* (Nre) :

$\text{Nre} = \frac{\rho \, v \, D}{\mu}$

Sehingga :

$$Nre = \frac{0.0614 \times 17880.9642 \times 0.0518}{0.0355}$$

$$= 1604.2712 \quad \text{(asumsi aliran laminer benar)}$$

Instalasi pipa

Dari ***Fig*. 127.** (Brown, 1950:141) dengan NPS = 1/2 in

- 1 buah *gate valve fully open* ; Le	=	0.35	ft
∑Le = 1 × 0.35	=	0.35	ft
- 4 buah *standard elbow* ; Le	=	1.5	ft
∑Le = 4 × 1.5	=	6	ft
- 1 buah *sudden enlargement* ; Le	=	1	ft
∑Le = 1 × 1	=	1	ft
- 1 buah *sudden contraction* ; Le	=	0.57	ft
∑Le = 1 × 0.57	=	0.57	ft
- 1 buah *swing check valve* ; Le	=	3.5	ft
∑Le = 1 × 3.5	=	3.5	ft
- Panjang ekivalen pipa lurus, ∑Le	=	11.42	ft
Panjang pipa lurus	=	2	m
	=	6.5616	ft
Panjang pipa total	=	17.9816	ft
	=	5.4808	m

Menghitung *friction loss*

$$\Sigma F = \frac{4f \cdot v^2 \cdot \Delta L}{2 \cdot ID \cdot gc}$$ Eq. 2.10-6 (Geankoplis, 1993:89)

Dimana :

ΣF = *Friction loss* (ft.lbf/lbm)
f = Faktor friksi
v = Kecepatan linier fluida (ft/s)
ΔL = Panjang pipa (ft)
ID = Diameter dalam tangki (ft)
gc = 32.1740 lbm.ft/lbf.s^2

Menghitung *Fanning Friction Factor* (f) :

Dari ***Fig*. 2.10-3. (**Geankoplis, 1993:88) didapat :

Untuk *commercial steel* → ε = 5.E-05 m
= 0.0002 ft

Sehingga :

$$\frac{\varepsilon}{D} = \frac{0.0002}{0.0518} = 0.0030$$

Dari **Fig. 2.10-3.** (Geankoplis, 1993:88) dengan nilai 1604.2712 didapatkan nilai f = 0.04 sehingga :

$$\Sigma F = \frac{4 \times 0.0400 \times (17880.9642)^2 \times 17.9816}{2 \times 0.0518 \times 32.1740}$$

$$= 275794746.68 \ \frac{lb_f \,.\, ft}{lb_m}$$

Menghitung *Static Head* :

Z_1 = 1 m = 3.28084 ft

Z_2 = 0.2 m = 0.656168 ft

ΔZ = Z_1-Z_2 = 2.6247 ft

g/gc = 1 lbf/lbm

ΔZ (g/gc) = 2.624672 ft × 1 lbf/lbm = 2.624672 ft lbf/lbm

Menghitung *Velocity Head* :

V_1 = kecepatan linier fluida dari tangki hidrogen peroksida ke pipa

V_2 = kecepatan linier fluida ke *heater*

Karena pada 2 titik *reference* dianggap sama, maka V_1 = 17880.9642 ft/s

Sehingga *velocity head* (ΔV^2 / 2agc) = ##########

Menghitung *Pressure Head* :

P_1 = P_2 = 14.7 Psi

ΔP = 0

Sehingga, $\Delta P/\rho$ = 0

Menghitung Energi Mekanik Pompa :

$$-Wf = \frac{\Delta V^2}{2 \times \alpha \times gc} + \Delta z \frac{g}{gc} + \frac{\Delta P}{\rho} + \sum F$$

Dimana :

Wf = tenaga yang ditambahkan ke dalam sistem per satuan massa

Sehingga :

- Wf = 4968746 + 2.625 ft. lbf/lbm + 0
+ 275794746.7 ft. lbf/lbm
= 280763495.494 ft. lbf/lbm

Menghitung *Broke Horse Power* (BHP) :

$$BHP = \frac{m.(-Wf)}{550 \cdot \eta}$$

dari ***Fig*. 14-37.** (Peters & Timmerhaus, 1991:520), untuk Qf = 16933.8780 gpm diperoleh η pompa = 0.40

Sehingga :

$$BHP = \frac{2.3182 \times 280763495.5}{550 \times 0.4000}$$

= ######## Hp; maka digunakan *power* = 2.0 Hp

4) Menghitung Tenaga Motor

***Fig.* 14.38**. (Peters & Timmerhaus, 1991:521) untuk = 2.0 Hp diperoleh η motor = 0.83

Sehingga *power* motor yang diperlukan :

$$P\ motor = \frac{BHP}{\eta}$$

$$= \frac{2\ Hp}{0.83}$$

= 2.4 Hp

Dipilih motor standar dengan *pow* = 3 Hp (*Standard* NEMA)

Spesifikasi Pompa *Filter Press*

Nama Alat	:	Pompa *Filter Press*
Kode	:	L-341
Fungsi	:	Mengalirkan *dioctyl phthalate* dari *filter press* menuj tangki penyimpanan *dioctyl phthalate*
Tipe	:	*Centrifugal pump*
Bahan Konstruksi	:	*Commercial steel*
Jumlah	:	1 buah
Rate Volumetrik	:	37.7288 ft^3/s
Kecepatan Aliran	:	17880.9642 ft/s
Ukuran Pipa	:	NPS = 1/2 in
	:	*Sch. Number* = 40
	:	OD = 0.0700 ft = 0.021336 m
	:	ID = 0.0518 ft = 0.015799 m
	:	*Flow Area* = 0.0021 ft^2 = 0.0002 m^2
Power Pompa	:	2.0 Hp
Power Motor	:	3 Hp

37 TANGKI PENYIMPANAN DIOCTYL PHTHALATE (F-410)

Fungsi	:	Tempat menyimpan produk *Dioctyl Phthalate*
Tipe	:	*Cylindrical Tank, Flat Bottom, Conical Roof*

Jumlah : 1 buah
Kondisi Operasi : T = 30 °C = 303.15 K
P = 1 atm = 760 mmHg
= 14.7 psi

Komposisi

Komponen	Massa (Kg/Jam)	Fraksi berat	ρ bahan (g/ml)	ρ bahan x fraksi berat (x)
$C_{24}H_{38}O_4$	3766.9558	0.9951	0.984	0.9792
$C_8H_{18}O$	5.0428	0.0013	0.833	0.0011
$C_8H_4O_3$	2.8705	0.0008	1.2	0.0009
$C_8H_6O_4$	2.8791	0.0008	1.526	0.0012
H_2O	7.7041	0.0020	0.997	0.0020
Total	3785.4523	1.0000	5.5400	0.9844

$$\text{Densitas Campuran} = \frac{1}{\frac{\text{fraksi berat}}{\rho \text{ komponen}}} \times 62.43$$

$$= \frac{1}{\frac{}{0.18}} \times 62.43$$

$$= 345.86 \times 62.43$$

$$= 21592.18 \text{ lb/cuft}$$

$$\text{Rate Volumetrik} = \frac{\text{Rate Massa}}{\text{Densitas}}$$

$$= \frac{8346.92}{21592.1771}$$

$$= 0.3866 \text{ cuft/jam}$$

Direncanakan penyimpanan untuk 14 har dengan jumlah tangki 1 buah sehingga volume liquid adalah

$$\text{V liquid} = \frac{0.39 \times 24 \times 14}{1}$$

$$= 129.89 \text{ cuft}$$

Asumsi volume bahan (liquid) mengisi 80% volume tangki sehingga volume ruang kosong sebesar 20%

$$\text{Volume Tangki} = \frac{129.8881}{80\%}$$

$$= 162.3601 \text{ cuft} = 1214.453 \text{ gal}$$

Disarankan > 10000 gal, menggunakan vertical tank dan pondasi beton

[Walas ed.2; p.xvii]

Menentukan ukuran tangki tangki dan ketebalannya

Dimensi ratio $= \frac{H}{D} = 2$ *[Ulrich; T.4-27:p.248]*

Volume tangki $= \frac{\pi}{4} \times D^2 \times H$

$162.3601 = \frac{3.14}{4} \times D^2 \times 2D$

$162.3601 = 2 \times D^3$

$D^3 = 103.4141$ cuft

$D = 4.6938$ ft $= 56.32585$ in $= 1.408146$ m

Karena H = 2D, maka H:

$H = 2\ D$

$H = 2 \times 4.693821$ ft

$H = 9.387642$ ft $= 112.6517$ in $= 2.816293$ m

Tinggi liquid dalam tangki:

Volume Liquid $= \frac{\pi}{4} \times D^2 \times H$

$129.89 = \frac{3.14}{4} \times 22.0320 \times H$

H liq $= 7.51$ ft $= 2.253034$ m

P design

P operasi $= 1$ atm $= 14.7$ lb/in^2 (psi)

P hidrostatis $= \rho \times g/gc \times Hliq$

$= 21592.18 \times 1 \times 7.5101$

$= 162159.7$ lb/ft^2

$= 1126.1$ lb/in^2

P Design 10% lebih besar untuk faktor keamanan

P design $= (P\ operasi + P\ hidrostatis) \times 110\%$

$= 14.7 + 1126.1091 \times 110\%$

$= 1255$ psi

Penentuan tebal shell :

$t_{min} = \frac{P \times ri}{fE - 0{,}6P} + C$ *[Brownell&Young; Eq.13-1]*

dengan :

t_{min} = tebal shell minimum ; in

P = tekanan tangki ; psi

ri = jari-jari tangki ; in (1/2 D)

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

E = faktor pengelasan, digunakan double welded E = 0.8

f = Stress allowable, bahan konstruksi stainless steel 316

f = 35969.92 psi *[Perry ed.7; T.28-11]*

ri = 1 x D
= 1 x 56.33
= 28.1629 in

$t_{min} = \frac{P \times ri}{fE - 0{,}6P} + C$
$= \frac{1255 \times 28.16}{28776 - 752.93} + 0.125$
$= \frac{35341.37}{28023.00} + 0.125$
= 1.261 + 0.125
= 1.386 in

digunakan t_{min} = 4/16 in

Dimensi Tutup Atas :

Tutup atas berbentuk standart dished head

OD = D + 2 ts = 57 in
rc = 57 in 47 *[Brownell&Young; T.5-7]*
= 4.7 ft Rumus iman

Tebal standart toripherical dished (atas) :

$t_h = \frac{0{,}885 \times P \times rc}{fe - 0{,}1P} + C$

dengan

t_h = tebal shell minimum ;in
P = tekanan tangki ; psi
rc = crown radius ; in *[Brownell and Young, T-5.7]*
C = faktor korosi ; in (digunakan 1/8)
E = faktor pengelasan, digunakan dobel welded E = 1
f = Stress allowable, bahan konstruksi stainless steel 316
f = 35970 psi *[Perry ed.7; T.28-11]*

P design = 1254.89 psi

$t_h = \frac{0{,}885 \times P \times rc}{f.E - 0{,}1.P} + C$
$= \frac{0.885 \times ##### \times 57}{28775.94 - 125.49} + 1/8$
= 2.328 in digunakan t = 5/16 in

$h = rc - \sqrt{rc^2 - \frac{D^2}{4}}$
= 0.62 ft

Tutup bawah

untuk tebal tutup bawah datar karena tutup menumpang diatas beton,
maka tebal tutup = 1/3 in *[Brownell&Young; p.58]*

SPESIFIKASI TANGKI PENYIMPANAN DIOCTYL PHTHALATE

Dimensi Shell :

Diameter tangki	:	4.69	ft
Tinggi tangki	:	9.39	ft
Tebal Shell	:	4/16	in
Tebal tutup atas	:	5/16	in
Tinggi tutup atas	:	10/16	ft
Tebal tutup bawah	:	1/3	in
Bahan konstruksi	:	Stainless steel 316	
Jumlah tangki	:	1 buah	

APPENDIX D
PERHITUNGAN ANALISA EKONOMI

Kapasitas Produksi	=	30,000	ton/tahun			
	=	3,787.8788	kg/jam			
Waktu operasi	=	330	hari			
Asumsi kurs dollar	=	Rp 15,279	,-/US $	(BI, Februari 2020)		
Dengan bahan baku :						
$C_8H_4O_3$	=	$ 1,000	=	Rp	15,279,000	/Ton
$C_8H_{18}O$	=	$ 850	=	Rp	12,987,150	/Ton
$C_{16}H_{36}O_4Ti$	=	$ 0.80	=	Rp	12,223	/Kg
NaOH 48%	=	$ 0.70	=	Rp	10,695	/Kg
Karbon Aktif	=	$ 600	=	Rp	9,167,400	/Ton
Produk yang dihasilkan :						
$C_{24}H_{38}O_4$	=	$ 2.20	=	Rp	33,614	/Kg
$C_{16}H_{35}O_4TiNa$	=	$ 0.30	=	Rp	4,584	/Liter

Analisa ekonomi di dalam suatu perencanaan pabrik adalah sangat penting, karena perhitungan ekonomi ini dapat diketahui apakah pabrik yang direncanakan ini layak untuk didirikan atau tidak dalam artian Faktor-faktor yang perlu untuk ditinjau antara lain:

1. Laju pengembalian modal (*Rate of Return, ROR*)
2. Laju investasi yang sehat (*Rate of Investment, ROI)*
3. Lama pengembalian modal (*Pay-Out Periode*)
4. Perhitungan Resiko Hutang (*Rate on Equity*)
5. Titik impas (*Break Even Point, BEP*)

Untuk meninjau faktor-faktor diatas, perlu adanya penaksiran terhadap 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 Expenses*)
3. 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 :

$$Cp = \frac{Ip}{Io} \times Co$$

Dimana :

Cp = Harga alat pada tahun 2024
Co = Harga alat pada tahun data 2014
Ip = Cost Index pada tahun 2019
Io = Cost Index pada tahun data 2014

Perhitungan peralatan didasarkan pada cost equipment www.matche.com. Sedangkan Cost indeks didasarkan pada 'Peters and Timmerhauss 5ed Plant De -sign and Economic for Chemical Engineering'

Tabel D.1 Indeks harga Peralatan

Tahun	Indeks
2011	585.7
2012	584.6
2013	567.3
2014	576.1
2015	556.8
2016	541.7
2017	562.1
2018	603.1
2019	607.5
2020	596.2
2021	708

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 tersebut dibentuk dalam persamaan :

$$Y = a + bX$$

keterangan :

Y = indeks harga peralatan pada tahun ke-n
X = tahun ke-n

n	X	Y	X^2	Y^2	XY
1	2011	585.7	4,044,121	343,044	1,177,843
2	2012	584.6	4,048,144	341,757	1,176,215
3	2013	567.3	4,052,169	321,829	1,141,975
4	2014	576.1	4,056,196	331,891	1,160,265
5	2015	556.8	4,060,225	310,026	1,121,952
6	2016	541.7	4,064,256	293,439	1,092,067
7	2017	562.1	4,068,289	315,956	1,133,756
8	2018	603.1	4,072,324	363,730	1,217,056

n	X	Y	X^2	Y^2	XY
9	2019	607.5	4,076,361	369,056	1,226,543
10	2020	596.2	4,080,400	355,454	1,204,324
11	2021	708	4,084,441	501,264	1,430,868
Total	22176	6489	44,706,926	3,847,448	13,082,863

Jumlah data = n = 11

Dengan menggunakan metode Least Square Pers 17-21, Peters&Timmerhauss, diperoleh :

$$\sum(\bar{x}-x)^2 = \sum x^2 - \frac{(\sum x)^2}{n} \quad = \quad 110$$

$$\sum(\bar{y}-y)^2 = \sum y^2 - \frac{(\sum y)^2}{n} \quad = \quad 19{,}409.9$$

Pers 17-20, Peters & Timmerhauss

$$\sum(\bar{x}-x)(\bar{y}-y) = \sum xy - \frac{\sum x \sum y}{n} \quad = \quad 837.8$$

$$b = \frac{\sum(\bar{x}-x)(\bar{y}-y)}{\sum(\bar{x}-x)^2} \quad = \quad 7.62$$

Rata-rata y = Sy / 9 = a = 590
Rata-rata x = Sx /9 = c = 2016

y = a + b (x-c)
= 589.918 + 7.62 (x - 2016)
= 589.918 + 7.62 x - 15354.6
= -14764.7 + 7.62 x

Dari persamaan di atas diperoleh indeks harga pada tahun 2025 sebesar
y = -14764.7 + 7.62 x (2025)
= 658.4655

Kurs Dollar pada tahun 2025
(US $) 1 = Rp 15,449 **http://www.kursdollar.net**

Contoh perhitungan harga peralatan

1. Screw conveyor - 1
   Panjang : 20 ft
   Diameter : 4 in
   Indeks harga tahun 2014 = 708 (US $)

Indeks harga tahun 2025 = 658.47 (US $)
Harga alat pada tahun 2014 = 3500 (US $)

http://matche.com/equipcost

$$\text{Harga alat pada tahun 2025} = \frac{\text{Index Tahun 2025}}{\text{Index tahun 2021}} \times \frac{\text{Harga Alat tahun}}{2021}$$

$$\text{Harga alat pada tahun 2025} = \frac{658.47}{708} \times 3500$$

= 3255.13 (US $)
= $ 3,255.13 x Rp 15,449
= Rp 50,288,439.02

Tabel I-2. Hasil Perhitungan Peralatan Proses

No	Nama Alat	Harga Unit (US $)		Jml	Harga
		2014	2025		(US $)
1	Gudang karbon aktif (F-110)	391	447	1	447
2	Screw Conveyor (J-111)	2,100	2,400	1	2,400
3	Bucket Elevator-1	10,800	12,344	1	12,344
4	Hopper-1 (J-112)	600	686	1	686
5	Tangki NaOH (F-120)	5,200	5,943	1	5,943
6	Pompa-1 (L-121)	400	457	1	457
7	Mixer NaOH (M-22)	55,800	63,778	1	63,778
8	Pompa-2 (L-123)	400	457	1	457
9	Heater-1 (E-124)	700	800	1	800
10	Gudang Phthalic Anhidride (F-130)	5,500	6,286	1	6,286
11	Belt Conveyor (J-131)	9,400	10,744	1	10,744
12	Bucket Elevator-2 (J-132)	10,800	12,344	1	12,344
13	Hopper-2 (F-133)	400	457	1	457
14	Melter (X-134)	42,400	48,462	1	48,462
15	Pompa-3 (L-135)	400	457	1	457
16	Tangki 2-Ethylhexanol (F-140	87,400	99,896	7	699,270
17	Pompa-4 (L-141)	400	457	1	457
18	Heater-2 (E-142)	18,800	21,488	1	21,488
19	Tangki Tetrabutyl Titanate (F-150)	5,600	6,401	1	6,401
20	Pompa-5 (L-151)	400	457	1	457
21	Heater-3 (E-152)	650	743	1	743
22	Reaktor (R-210)	22,000	25,145	1	25,145
23	Pompa-6 (L-211)	400	457	1	457
24	Cooler-1 (E-212)	20,300	23,202	1	23,202
25	Neutraliser (M-220)	44,000	50,291	1	50,291
26	Pompa-7 (L-221)	400	457	1	457

No	Nama Alat	Harga Unit (US $)		Jml	Harga
		2014	2025		(US $)
27	Rotary Drum Vacum Filter (H-310)	117,500	134,299	1	134299.064
28	Pompa-8 (L-311)	400	457	1	457
29	Evaporator (V-320)	25,300	28,917	1	28,917
30	Pompa-9 (L-321)	400	457	1	457
31	Cooler-2 (E-322)	93,600	106,982	1	106,982
32	Tangki Dekolorisasi (D-330)	39,600	45,262	1	45,262
33	Pompa-10 (L-331)	400	457	1	457
34	Filter Press (H-340)	68,900	78,751	1	78,751
35	Pompa-11 (L-341)	400	457	1	457
36	Tangki Dioctyl Phthalate (F-410)	174,800	199,791	1	199,791
TOTAL					1,590,262

Tabel I-3. Hasil Perhitungan Peralatan Utilitas

No.	Nama Alat	Harga unit (US $)		Jumla	Harga Total
		2021	2025	Unit	(US $)
1	Boiler	375,700	429,414	1	429414.11
2	Cooling tower	197,600	225,851	1	225851.022
3	Pompa air sungai	9,700	11,087	1	11086.8164
4	Bak penampung air sungai	5,500	6,286	1	6286.3392
5	Pompa tangki koagulasi	9,700	11,087	1	11086.8164
6	Tangki koagulasi	14,600	16,687	1	16687.3731
7	Tangki Flokulasi	20,100	22,974	1	22973.7123
8	Pompa clarifier	7,000	8,001	1	8000.7953
9	Clarifier	20,300	23,202	1	23202.3064
11	Bak penampung flok	1,500	1,714	1	1714.4561
12	Bak penampung air bersih-1	1,500	1,714	1	1714.4561
13	Pompa sand filter	9,700	11,087	1	11086.8164
14	Sand filter	8,500	9,715	2	19430.5029
15	Bak penampung air bersih-2	1,500	1,714	1	1714.4561
16	Pompa tangki kation exchange	6,300	7,201	1	7200.7158
17	Kation exchanger	12,500	14,287	1	14287.1345
18	Pompa tangki anion exchanger	6,300	7,201	1	7200.7158
19	Anion exchager	12,000	13,716	1	13715.6491
20	Pompa air umpan boiler	4,900	5,601	2	11201.1134
21	Bak penampung air lunak	2,500	2,857	1	2857.4269
22	Pompa bak air sanitasi	3,200	3,658	1	3657.5064
23	Bak penampung air sanitasi	1,800	2,057	1	2057.3474
24	Pompa Bak air pendingin	8,600	9,830	1	9829.5485

No.	Nama Alat	Harga unit (US $)		Jumla Unit	Harga Total (US $)
		2021	2025		
25	Pompa air pendingin dari CT	8,600	9,830	1	9829.5485
26	Pompa air pendingin	8,600	9,830	1	9829.5485
27	Pompa recycle air pendingin	8,600	9,830	1	9829.5485
28	Bak penampung air pendingin	2,500	2,857	1	2857.4269
29	Generator set	30,000	34,289	2	68578.2456
30	Tangki penyimpan bahan baka	85,000	97,153	1	97152.515
Jumlah					1,060,334

Total harga peralatan = Harga peralatan proses + Harga peralatan utilitas
= $ 1,590,262 + $ 1,060,334
= $ 2,650,596
= **Rp 40,949,058,424**

II. Harga Bahan Baku

1. Phthalic Anhidryde
   Harga = $ 1,000.00 per Ton
   Kebutuhan per jam = 1,445.35 Kg/jam
   Biaya per tahun (330 hari) = $ 11,447,169 per tahun
   = Rp 174,901,299,852 per tahun

2 2-Ethyl Hexanol
   Harga = $ 850.00 per Ton
   Kebutuhan per jam = 2,539.13 Kg/jam
   Biaya per tahun (330 hari) = $ 17,093,408 per tahun
   = Rp 261,170,184,239 per tahun

3 Tetrabutyl Titanate
   Harga = Rp 12,223.20 per Kg
   Kebutuhan per jam = 0.05976716 Kg/jam
   Biaya per tahun (330 hari) = Rp 5,785,924.08 per tahun

4 Natrium Hidroksida
   Harga = Rp 10,695.30 per Kg
   Kebutuhan per jam = 0.0070314 Kg/jam
   Biaya per tahun (330 hari) = Rp 595,609.83 per tahun

5 Karbon aktif
   Harga = $ 600.00 per Ton
   Kebutuhan per jam = 1.91 Kg/jam
   Biaya per tahun (330 hari) = $ 9,058 per tahun

= Rp 138,390,259 per tahun

Total biaya bahan baku per tahun Rp 436,216,255,884

III. Harga Jual Produk

Produk Utama : Dioctyl Phthalate

Produk yang dihasilkan	=	3,766.96	Ton/jam
Harga produk yang dihasilkan	= $	2.200	/Ton
Harga produk per tahun	= $	65,635,437	
	= Rp	1,014,001,871,305	

Total harga jual produk per tah = Rp 1,014,001,871,305

IV. Biaya Pengemasan

Produk Utama : Disodium Phosphat hephydrat

Produk yang dihasilkan	=	29,834,290	Kg/tahun
Produk dikemas dalam bag	=	100	Kg
Kebutuhan bag per tahun	=	298,343	buah
Harga 1 bag	= Rp	2,000	
Biaya pengemasan per tahu	= Rp	596,685,794	

Total biaya pengemasan per tahun	= Rp	596,685,794	
Biaya pendukung (15% pengemasan)	= Rp	89,502,869	+
Total biaya pengemasan produk	= Rp	686,188,663	

Total biaya penjualan = Total harga jual produk + Biaya pengemasan
= **Rp1,014,688,059,968**

V. Gaji Karyawan

No	Jabatan	Gaji per Bulan	Orang	Jumlah Gaji per Bulan
1	Direktur Utama	Rp. 40,000,000	1	Rp. 40,000,000
2	Direktur Komersil	Rp. 25,000,000	1	Rp. 25,000,000
3	Direktur Teknik dan Produksi	Rp. 25,000,000	1	Rp. 25,000,000
4	Direktur SDM dan Umum	Rp. 25,000,000	2	Rp. 50,000,000
5	Staff Ahli	Rp. 25,000,000	4	Rp. 100,000,000
6	Litbang	Rp. 15,000,000	1	Rp. 15,000,000
7	Kepala Bagian Produksi	Rp. 9,500,000	1	Rp. 9,500,000
8	Kepala Bagian Teknik	Rp. 9,500,000	1	Rp. 9,500,000
9	Kepala Bagian SDM	Rp. 9,500,000	1	Rp. 9,500,000
10	Kepala Bagian Umum	Rp. 9,500,000	1	Rp. 9,500,000
11	Kepala Bagian Keuangan	Rp. 9,500,000	1	Rp. 9,500,000

No	Jabatan	Gaji per Bulan	Orang	Jumlah Gaji per Bulan
12	Kepala Bagian Pemasaran	Rp. 9,500,000	1	Rp. 9,500,000
13	Kepala Bagian Proses	Rp. 7,000,000	1	Rp. 7,000,000
14	Kepala Seksi Pengendalian	Rp. 7,000,000	1	Rp. 7,000,000
15	Kepala Seksi Laboratorium	Rp. 7,000,000	1	Rp. 7,000,000
16	Kepala Seksi K3 dan Lingkung	Rp. 7,000,000	1	Rp. 7,000,000
17	Kepala Seksi Pemeliharaan	Rp. 7,000,000	1	Rp. 7,000,000
18	Kepala Seksi Utilitas	Rp. 7,000,000	1	Rp. 7,000,000
19	Kepala Seksi Administrasi	Rp. 7,000,000	1	Rp. 7,000,000
20	Kepala Seksi Akuntansi	Rp. 7,000,000	1	Rp. 7,000,000
21	Kepala Seksi Pembelian	Rp. 7,000,000	1	Rp. 7,000,000
22	Kepala Seksi Penjualan	Rp. 7,000,000	1	Rp. 7,000,000
23	Kepala Seksi Personalia	Rp. 7,000,000	1	Rp. 7,000,000
24	Kepala Seksi Diklat	Rp. 7,000,000	1	Rp. 7,000,000
25	Kepala Seksi Humas	Rp. 7,000,000	1	Rp. 7,000,000
26	Kepala Seksi Pelayanan Umun	Rp. 7,000,000	1	Rp. 7,000,000
27	Sekretaris	Rp. 6,000,000	4	Rp. 24,000,000
28	Karyawan Bagian Proses	Rp. 4,500,000	32	Rp. 144,000,000
29	Karyawan Bagian Pengendalia	Rp. 4,500,000	10	Rp. 45,000,000
30	Karyawan Bagian Laboratoriu	Rp. 4,500,000	10	Rp. 45,000,000
31	Karyawan K3 dan Lingkungan	Rp. 4,500,000	7	Rp. 31,500,000
32	Karyawan Bagian Pemeliharaa	Rp. 4,500,000	7	Rp. 31,500,000
33	Karyawan Bagian Utilitas	Rp. 4,500,000	12	Rp. 54,000,000
34	Karyawan Bagian Administras	Rp. 4,500,000	4	Rp. 18,000,000
35	Karyawan Bagian Akuntansi	Rp. 4,500,000	4	Rp. 18,000,000
36	Karyawan Bagian Pembelian	Rp. 4,500,000	4	Rp. 18,000,000
37	Karyawan Bagian Penjualan	Rp. 4,500,000	4	Rp. 18,000,000
38	Karyawan Bagian Personalia	Rp. 4,500,000	4	Rp. 18,000,000
39	Karyawan Bagian Diklat	Rp. 4,500,000	4	Rp. 18,000,000
40	Karyawan Bagian Humas	Rp. 4,500,000	4	Rp. 18,000,000
41	Karyawan Pelayanan Umum	Rp. 4,500,000	4	Rp. 18,000,000
42	Dokter	Rp. 7,500,000	2	Rp. 15,000,000
43	Perawat	Rp. 5,000,000	4	Rp. 20,000,000
44	Sopir dan Pesuruh	Rp. 4,200,000	4	Rp. 16,800,000
45	Kebersihan dan Keamanan	Rp. 4,200,000	10	Rp. 42,000,000
Jumlah			**Rp.**	**1,022,800,000**

Gaji karyawan per tahun = Rp 1,022,800,000
= Rp 1,022,800,000 x 13 bulan
= **Rp 13,296,400,000**

VI. Biaya Utilitas

a. Kebutuhan Air

1. Air Sanitasi

Kebutuhan per hari	=		41.904	m^3/hari
Harga air mengolah sendiri	=	Rp	150	/m^3
Biaya pengolahan per tahun	=	Rp	2,074,248	

2. Air Umpan Boiler

Kebutuhan air umpan boile	=		65.4416	m^3/hari
H. air boiler mengolah send	=	Rp	500	/m^3
Biaya pengolahan per tahun	=	Rp	10,797,859	

3. Air Pendingin

Kebutuhan air pendingin	=		1,159.5432	m^3/hari
Harga air pendingin	=	Rp	300	/m^3
Biaya pengolahan per tahun	=	Rp	114,794,781	

b. Kebutuhan Penunjang Pengolahan Air

Kebutuhan $Al_2(SO_4)_3$	=		9030	kg/tahun
Harga $Al_2(SO_4)_3$	=	Rp	4,000	/kg
Biaya $Al_2(SO_4)_3$ per tahun	=	Rp	36,121,534	
Kebutuhan PAC	=		1355	kg/tahun
Harga PAC	=	Rp	15,500	/kg
			(tokopedia.com)	
Biaya PAC per tahun	=	Rp	20,997,321	
Kebutuhan resin kation	=		14,348.0637	L/tahun
Harga resin dowex	=	Rp	1,281,000	/25 L (tokopedia.com)
Biaya Dowex per tahun	=	Rp	735,194,784	
Kebutuhan resin anion	=		12,913.2573	L/tahun
Harga resin dowex	=	Rp	2,671,100	/25 L (tokopedia.com)
Biaya APS per tahun	=	Rp	1,379,704,065	
Kebutuhan HCl 33%	=		714.1423	liter/tahun
Harga HCl	=	Rp	10,000	/liter
Biaya HCl per tahun	=	Rp	7,141,423	
Kebutuhan NaOH	=		571	kg/tahun

Harga NaOH	=	Rp 19,000	/kg
Biaya NaOH per tahun	=	Rp 10,848,598	

c. Kebutuhan Bahan Bakar (*fuel oil*)

Kebutuhan bahan bakar	=	91.6386	liter/jam
	=	725,777.9089	liter/tahun
Harga bahan bakar	=	Rp 18,700	/liter
		(solarindustri.com)	
Biaya bahan bakar per tahu	=	Rp 13,572,046,897	

d. Kebutuhan Listrik

Kebutuhan listrik	=	59.0760	kWh/jam
	=	467,881.9200	kWh/tahun
Harga listrik	=	Rp 1,444	/kWh
		(PLN per Oktober 2022)	
Biaya listrik per tahun	=	Rp 675,621,492	

Total biaya utilitas per tahur = Rp 16,565,343,001

VII. Harga Tanah dan Bangunan

Luas tanah	=	20,465	m^2
Harga tanah per m^2	=	Rp 1,200,000	
Harga tanah total	=	Rp 24,557,520,000	
Luas bangunan pabrik	=	15,431	m^2
Harga bangunan pabrik per m^2	=	Rp 2,000,000	
Harga bangunan pabrik total	=	Rp 30,862,000,000	
Luas bangunan gedung	=	1,750	m^2
Harga bangunan gedung per m^2	=	Rp 1,500,000	
		(urbanindo.com)	
Harga bangunan gedung total	=	Rp 2,625,000,000	
Harga bangunan total	=	Rp 33,487,000,000	
Total harga tanah dan banguna	**=**	**Rp 58,044,520,000**	