APPENDIX A
PERHITUNGAN NERACA MASSA

Kapasitas Produksi	=	42.000	ton/tahun	
Waktu Operasi	=	1 tahun =	331	hari
	=	1 hari =	24	jam
Kapasitas Produksi	=	42.000	ton/tahun	
	=	5,2870	ton / jam	
	=	5.287,0091	kg / jam	
Basis Asetaldehid (99%)	=	1.717,0000	kg / jam	

Bahan Baku :

1. Formaldehid

Bahan diperoleh dari : PT. Dover Chemical

Komponen	Presentase	BM (kg/kmol)
CH_2O	37%	30,03
CH_3OH	1%	32,04
H_2O	62%	18,02
Total	100%	

2. Asetaldehid

Bahan diperoleh dari : PT. Indo Aciditama

Komponen	Presentase	BM (kg/kmol)
CH_3CHO	99%	44,05
H_2O	1%	18,02
Total	100%	

3. Kalsium Hidroksida

Bahan diperoleh dari : PT. Darnait Esa Artha

Komponen	Presentase	BM (kg/kmol)
$Ca(OH)_2$	95%	74,10
H_2O	5%	18,02
Total	100%	

4. Asam Format

Bahan diperoleh dari : PT. Sintas Kurama Perdana

Komponen	Presentase	BM (kg/kmol)
CH_2O_2	90%	46,02
H_2O	10%	18,02
Total	100%	

Produk yang akan dihasilkan

Komponen	BM (kg/kmol)
$C_5H_{12}O_4$	136,15
$Ca(HCOO)_2$	130,11
Total	

Rumus Neraca Massa

Massa Input = Massa Output ***(Himmelblau 9th, hal. 152)***

Reaksi Utama (Konversi 100%)

	$8\ CH_2O$	$+\ 2\ CH_3CHO$	$+\ 1\ Ca(OH)_2$	$\rightarrow 2\ C_5H_{12}O_4$	$+\ 1\ Ca(HCOO)_2$
M	173,6450	38,5878	38,5878		
R	154,3511	38,5878	19,2939	38,5878	19,2939
S	19,2939	0,0000	19,2939	38,5878	19,2939

Tabel Stokiometri

Komponen	**BM (kg/kmol)**	**Mula - mula (kmol/jam)**	**Reaksi (kmol/jam)**	**Sisa (kmol/jam)**
CH_2O	30,0260	173,6450	154,3511	19,2939
CH_3CHO	44,0510	38,5878	38,5878	0,0000
Ca(OH)2	74,1000	38,5878	19,2939	19,2939
$C_5H_{12}O_4$	136,1500		38,5878	38,5878
$Ca(HCOO)_2$	130,1100		19,2939	19,2939

Perhitungan Reaksi Utama

Mula-mula

CH_2O

= 173,6450 kg/jam x 30,03 kg/kmol

= 5.213,8642 kg/jam

CH_3CHO

= 38,5878 kg/jam x 44,05 kg/kmol

= 1.699,8300 kg/jam

$Ca(OH)_2$

= 38,5878 kg/jam x 74,10 kg/kmol
= 2.859,3540 kg/jam

Reaksi

CH_2O
= 154,3511 kg/jam x 30,026 kg/kmol
= 4.634,5459 kg/jam

CH_3CHO
= 38,5878 kg/jam x 44,051 kg/kmol
= 1.699,8300 kg/jam

$Ca(OH)_2$
= 19,2939 kg/jam x 74,100 kg/kmol
= 1.429,6770 kg/jam

$C_5H_{12}O_4$ terbentuk
= 38,5878 kg/jam x 136,15 kg/kmol
= 5.253,7253 kg/jam

$Ca(HCOO)_2$ terbentuk
= 19,2939 kg/jam x 130,11 kg/kmol
= 2.510,3276 kg/jam

Sisa

CH_2O
= 19,2939 kg/jam x 30,03 kg/kmol
= 579,3182 kg/jam

CH_3CHO
= 0,0000 kg/jam x 44,05 kg/kmol
= 0,0000 kg/jam

$Ca(OH)_2$
= 19,2939 kg/jam x 74,10 kg/kmol
= 1.429,6770 kg/jam

$C_5H_{12}O_4$ terbentuk
= 38,5878 kg/jam x 136,15 kg/kmol
= 5.253,7253 kg/jam

$Ca(HCOO)_2$ terbentuk
= 19,2939 kg/jam x 130,11 kg/kmol
= 2.510,3276 kg/jam

1. TANGKI PENCAMPURAN

Kode = M - 133

Fungsi = Mencampurkan Kalsium Hidroksida sesuai dengan konsentrasi yang diperlukan menjadi 50% dengan wujud *slur* **(Keyes)**

H_2O 2.708,9 kg/jam

Masuk				Keluar		
$Ca(OH)_2$	2.859,4	kg/jam	**TANGKI PENCAMPURAN**	$Ca(OH)_2$	2.859,4	kg/jam
H_2O	150,5	kg/jam		H_2O	2.859,4	kg/jam

Komponen	**Masuk (kg/jam)**	**Nilai Kelarutan**
		pada 100 parts Air
$Ca(OH)_2$	2.859,3540	0,185

(Perry 8th; hal. 2-10, Tabel 2-1)

Komposisi awal Kalsium Hidroksida

Komponen	Presentase	BM (kg/kmol)	Massa(kg/jam)
$Ca(OH)_2$	95%	74,10	2.859,3540
H_2O	5%	18,02	150,4923
Total	100%		3.009,8463

Komposisi target Kalsium Hidroksida

Komponen	Presentase	BM (kg/kmol)	Massa(kg/jam)
$Ca(OH)_2$	50%	74,10	2.859,3540
H_2O	50%	18,02	2.859,3540
Total	100%		5.718,7080

Perhitungan kebutuhan Air Proses

$Ca(OH)_2$ 99% → $Ca(OH)_2$ 50%
H_2O 1% → H_2O 50%

Perhitungan H_2O Target

100% = 50% $Ca(OH)_2$ + 50% H_2O

5.718,7080 kg/jam = 2.859,3540 kg/jam + 2.859,3540 kg/jam

H_2O Target = 2.859,3540 kg/jam

H_2O Proses = H_2O Target - H_2O Awal

= 2.859,3540 kg/jam - 150,4923 kg/jam

= 2.708,8617 kg/jam

Neraca Massa Tangki Pencampuran

Komponen	Masuk (kg/jam)	Komponen	Keluar (kg/jam)
$Ca(OH)_2$	2.859,3540	$Ca(OH)_2$	2.859,3540
H_2O	150,4923	H_2O	2.859,3540
Penambahan Air Proses			
H_2O	2.708,8617		
Total	5.718,7080	**Total**	5.718,7080

2. REAKTOR

Kode = R - 210

Fungsi = Tempat terjadi reaksi utama antara Formaldehid (37%), Asetaldehid (99%), dan Kalsium Hidroksida (50%) untuk membentuk Pentaeritritol dan Kalsium Format

$Ca(OH)_2$ 38,6 kmol
H_2O 158,7 kmol

CH_3CHO 38,59 kmol
H_2O 0,95 kmol

CH_2O 173,6 kmol
CH_3OH 4,4 kmol
H_2O 485,0 kmol

REAKTOR

CH_2O 19,3 kmol
CH_3OH 4,4 kmol
$Ca(OH)_2$ 19,3 kmol
H_2O 644,6 kmol
$C_5H_{12}O_4$ 38,6 kmol
$Ca(HCOO)_2$ 19,3 kmol

Reaksi Kondensasi (Konversi 100% terhadap Asetaldehid)

	$8\ CH_2O$	$+ 2\ CH_3CHO$	$+ 1\ Ca(OH)_2$	$\rightarrow 2\ C_5H_{12}O_4$	$+ 1\ Ca(HCOO)_2$
M	173,6450	38,5878	38,5878		
R	154,3511	38,5878	19,2939	38,5878	19,2939
S	19,2939	0,0000	19,2939	38,5878	19,2939

Data komposisi Bahan Baku

Komposisi Formaldehid

Komponen	Presentase	BM (kg/kmol)	Massa(kg/jam)
CH_2O	37%	30,03	5.213,8642
CH_3OH	1%	32,04	140,9152
H_2O	62%	18,02	8.736,7453
Total	100%		14.091,5248

Komposisi Asetaldehid

Komponen	Presentase	BM (kg/kmol)	Massa(kg/jam)
CH_3CHO	99%	44,05	1.699,8300
H_2O	1%	18,02	17,1700
Total	100%		1.717,0000

Komposisi Kalsium Hidroksida

Komponen	Presentase	BM (kg/kmol)	Massa(kg/jam)
$Ca(OH)_2$	50%	74,10	2.859,3540
H_2O	50%	18,02	2.859,3540
Total	100%		5.718,7080

Perhitungan Reaksi Kondensasi

Mula-mula

CH_2O

= 173,6450 kmol x 30,03 kg/kmol

= 5.213,8642 kg/jam

CH_3CHO

= 38,5878 kmol x 44,05 kg/kmol

= 1.699,8300 kg/jam

$Ca(OH)_2$

= 38,5878 kmol x 74,10 kg/kmol

= 2.859,3540 kg/jam

Reaksi

CH_2O

= 154,3511 kmol x 30,03 kg/kmol

= 4.634,5459 kg/jam

CH_3CHO

= 38,5878 kmol x 44,05 kg/kmol

= 1.699,8300 kg/jam

$Ca(OH)_2$
= 19,2939 kmol x 74,10 kg/kmol
= 1.429,6770 kg/jam
$C_5H_{12}O_4$ terbentuk
= 38,5878 kmol x 136,15 kg/kmol
= 5.253,7253 kg/jam
$Ca(HCOO)_2$ terbentuk
= 19,2939 kmol x 130,11 kg/kmol
= 2.510,3276 kg/jam

Sisa

CH_2O
= 19,2939 kmol x 30,03 kg/kmol
= 579,3182 kg/jam
CH_3CHO
= 0,0000 kmol x 44,05 kg/kmol
= 0,0000 kg/jam
$Ca(OH)_2$
= 19,2939 kmol x 74,10 kg/kmol
= 1.429,6770 kg/jam
$C_5H_{12}O_4$ terbentuk
= 38,5878 kmol x 136,15 kg/kmol
= 5.253,7253 kg/jam
$Ca(HCOO)_2$ terbentuk
= 19,2939 kmol x 130,11 kg/kmol
= 2.510,3276 kg/jam

Neraca Massa Reaktor Kondensasi

Komponen	Masuk (kg/jam)	Komponen	Keluar (kg/jam)
Formaldehid (37%)		CH_2O	579,3182
CH_2O	5.213,8642	CH_3OH	140,9152
CH_3OH	140,9152	CH_3CHO	0,0000
H_2O	8.736,7453	$Ca(OH)_2$	1.429,6770
Asetaldehid (99%)		H_2O	11.613,2693
CH_3CHO	1.699,8300	$C_5H_{12}O_4$	5.253,7253
H_2O	17,1700	$Ca(HCOO)_2$	2.510,3276
Kalsium Hidroksida (50%)			
$Ca(OH)_2$	2.859,3540		
H_2O	2.859,3540		
Total	21.527,2328	**Total**	21.527,2328

3. REAKTOR NETRALISASI

Kode = R - 220

Fungsi = Tempat terjadi reaksi netralisasi terhadap sisa Kalsium Hidroksida menggunakan Asam Format (99%)

CH_2O_2	38,6 kmol
H_2O	11,0 kmol

CH_2O	19,3 kmol
CH_3OH	4,4 kmol
$Ca(OH)_2$	19,3 kmol
H_2O	644,6 kmol
$C_5H_{12}O_4$	38,6 kmol
$Ca(HCOO)_2$	19,3 kmol

REAKTOR NETRALISASI

CH_2O	19,3 kmol
CH_3OH	4,4 kmol
H_2O	694,2 kmol
$C_5H_{12}O_4$	38,6 kmol
$Ca(HCOO)_2$	38,6 kmol

Komponen yang dinetralkan :

$$Ca(OH)_2 \text{ sisa} = \frac{1.429,6770 \text{ kg/jam}}{74,1000 \text{ kg/kmol}}$$

$$= 19,2939 \text{ kmol}$$

Reaksi Netralisasi

	$2\ CH_2O_2$	+ $1\ Ca(OH)_2$	$\rightarrow 1\ Ca(HCOO)_2$ +	$2\ H_2O$
M	38,5878	19,2939		
R	38,5878	19,2939	19,2939	38,5878
S	0,0000	0,0000	19,2939	38,5878

Data komposisi Bahan Baku

Komposisi Asam Format

Komponen	Presentase	BM (kg/kmol)	Massa(kg/jam)
CH_2O_2	90%	46,02	1.775,8093
H_2O	10%	18,02	197,3121
Total	100%		1.973,1214

Perhitungan Reaksi

Mula-mula

CH_2O_2

= 38,5878 kmol x 46,02 kg/kmol

= 1.775,8093 kg/jam

$Ca(OH)_2$

= 19,2939 kmol x 74,10 kg/kmol

= 1.429,6770 kg/jam

Reaksi

CH_2O_2

= 38,5878 kmol x 46,02 kg/kmol

= 1.775,8093 kg/jam

$Ca(OH)_2$

= 19,2939 kmol x 74,10 kg/kmol

= 1.429,6770 kg/jam

$Ca(HCOO)_2$ terbentuk

= 19,2939 kmol x 130,11 kg/kmol

= 2.510,3276 kg/jam

H_2O terbentuk

= 38,5878 kmol x 18,02 kg/kmol

= 695,1587 kg/jam

Sisa

CH_2O_2

= 0,0000 kmol x 46,02 kg/kmol

= 0,0000 kg/jam

$Ca(OH)_2$

= 0,0000 kmol x 74,10 kg/kmol

= 0,0000 kg/jam

$Ca(HCOO)_2$ terbentuk

= 19,2939 kmol x 130,11 kg/kmol

= 2.510,3276 kg/jam

H_2O terbentuk

= 38,5878 kmol x 18,02 kg/kmol

= 695,1587 kg/jam

Neraca Massa Reaktor Netralisasi

Komponen	Masuk (kg/jam)	Komponen	Keluar (kg/jam)
CH_2O	579,3182	CH_2O	579,3182
CH_3OH	140,9152	CH_3OH	140,9152
$Ca(OH)_2$	1.429,6770	$Ca(OH)_2$	0,0000
H_2O	11.613,2693	H_2O	12.505,7402
$C_5H_{12}O_4$	5.253,7253	$C_5H_{12}O_4$	5.253,7253
$Ca(HCOO)_2$	2.510,3276	$Ca(HCOO)_2$	5.020,6552
Dari Tangki Penyimpanan Asam Format		CH_2O_2	0,0000
CH_2O_2	1.775,8093		
H_2O	197,3121		
Total	23.500,3542	**Total**	23.500,3542

4. EVAPORATOR

Kode = V - 310

Fungsi = Tempat Pemekatan campuran hingga mencapai kondisi lewat jenuh dengan tujuan menunjang proses kristalisasi

H_2O 4.184,5 kg/jam
$CH_2O_{(g)}$ 202,8 kg/jam
$CH_3OH_{(g)}$ 49,3 kg/jam

Masuk		EVAPORATOR 1st EFFECT	Keluar	
H_2O	12.505,7 kg/jam		H_2O	8.321,3 kg/jam
$C_5H_{12}O_4$	5.253,7 kg/jam	→	$C_5H_{12}O_4$	5.253,7 kg/jam
$Ca(HCOO)_2$	5.020,7 kg/jam		$Ca(HCOO)_2$	5.020,7 kg/jam
CH2O	579,3 kg/jam		CH2O	376,6 kg/jam
CH3OH	140,9 kg/jam		CH3OH	91,6 kg/jam

Komponen	Masuk (kg/jam)
Dari Tangki Netralisasi	
H_2O	12.505,7402
$C_5H_{12}O_4$	5.253,7253
$Ca(HCOO)_2$	5.020,6552
CH3OH	140,9152
CH2O	579,3182
Total	23.500,3542

Campuran dipekatkan hingga mencapai Specific Gravity = 1,2700 ***(Keyes)***

Feed yang ingin diuapkan hingga 70%

Formaldehid yang Diuapkan

m CH2OH diuapkan = m CH2O feed x 70%
= 579,3182 x 70%
= 405,5228 kg / jam

Methanol yang Diuapkan

m CH3OH diuapkan = m CH3OH feed x 70%
= 140,9152 x 70%
= 98,6407 kg / jam

Perhitungan Specific Gravity Komponen

$$\text{Specific Gravity (SG)} = \frac{\text{Densitas Komponen (Pentaeritritol)}}{\text{Densitas Air}}$$

Densitas $= \dfrac{m}{v}$ ***(Young 13th, hal. 392)***

SG Pentaeritritol $= \dfrac{(m/v)\ \text{komponen}}{(m/v)\ \text{air}} = \dfrac{m\ \text{komponen}}{m\ \text{air}} \times \dfrac{kg}{kg}$

$= \dfrac{5.253,7253\ kg}{12.505,7402\ kg}$

$= 0,4201$

Target Specific Gravity = 1,2700 ***(Keyes, 1957)***

Perhitungan m H_2O target

$1,2700 = \dfrac{m\ C_5H_{12}O_4}{m\ H_2O\ \text{target}}$

$m\ H_2O\ \text{target} = \dfrac{m\ C_5H_{12}O_4}{1,2700}$

$= \dfrac{5.253,7253\ kg}{1,2700}$

$= 4.136,7916\ kg$

Perhitungan m H_2O yang diuapkan

$m\ H_2O$ diuapkan = $m\ H_2O$ awal - $m\ H_2O$ target

= 12.505,7402 k - 4.136,7916 kg

= 8.368,9486 kg

Neraca Massa Evaporator Efek Pertama

Komponen	**Masuk (kg/jam)**	**Komponen**	**Keluar (kg/jam)**
Dari Tangki Pemisah		Air Diuapkan	
H_2O	12.505,7402	H_2O	4.184,4743
C5H12O4	5.253,7253	$CH_2O_{(g)}$	202,7614
Ca(HCOO)2	5.020,6552	$CH_3OH_{(g)}$	49,3203
$CH_2O_{(aq)}$	579,3182	Campuran Menuju Evaporator Efek Kedua	
$CH_3OH_{(aq)}$	140,9152	H_2O	8.321,2659
		$C_5H_{12}O_4$	5.253,7253
		$Ca(HCOO)_2$	5.020,6552
		$CH_2O_{(aq)}$	376,5569
		$CH_3OH_{(aq)}$	91,5949
Total	23.500,3542	**Total**	23.500,3542

H_2O 4.184,5 kg/jam
$CH_2O_{(g)}$ 202,8 kg/jam
$CH_3OH_{(g)}$ 49,3 kg/jam

H_2O	8.321,3 kg/jam	**EVAPORATOR 2nd EFFECT**	H_2O	4.136,8 kg/jam
$C_5H_{12}O_4$	5.253,7 kg/jam		$C_5H_{12}O_4$	5.253,7 kg/jam
$Ca(HCOO)_2$	5.020,7 kg/jam		$Ca(HCOO)_2$	5.020,7 kg/jam
CH2O(aq)	376,6 kg/jam		$CH_2O_{(aq)}$	173,8 kg/jam
CH3OH(aq)	91,6 kg/jam		$CH_3OH_{(aq)}$	42,3 kg/jam

Neraca Massa Evaporator Efek Kedua

Komponen	Masuk (kg/jam)	Komponen	Keluar (kg/jam)
Dari Evaporator Efek Pertama		Air Diuapkan	
H_2O	8.321,2659	H_2O	4.184,4743
C5H12O4	5.253,7253	$CH_2O_{(g)}$	202,7614
Ca(HCOO)2	5.020,6552	$CH_3OH_{(g)}$	49,3203
$CH_2O_{(aq)}$	376,5569	Campuran Menuju Kristalizer	
$CH_3OH_{(aq)}$	91,5949	H_2O	4.136,7916
		$C_5H_{12}O_4$	5.253,7253
		$Ca(HCOO)_2$	5.020,6552
		$CH_2O_{(aq)}$	173,7955
		$CH_3OH_{(aq)}$	42,2746
Total	19.063,7982	**Total**	19.063,7982

5. KRISTALIZER

Kode = S - 330

Fungsi = Tempat Pembentukan padatan kristal dari Pentaeritritol ($C_5H_{12}O_4$) dengan prinsip pendinginan

$H_2O_{(l)}$	4.137 kg/jam	**KRISTALIZER**	$C_5H_{12}O_{4(s)}$	5.251 kg/jam
$C_5H_{12}O_{4(aq)}$	5.254 kg/jam		$C_5H_{12}O_{4(aq)}$	2 kg/jam
$Ca(HCOO)_{2(aq)}$	5.021 kg/jam		$Ca(HCOO)_{2(aq)}$	5.021 kg/jam
$CH_2O_{(aq)}$	173,8 kg/jam		$H_2O_{(l)}$	4.137 kg/jam
$CH_3OH_{(aq)}$	42,3 kg/jam		CH_2O	173,8 kg/jam
			CH_3OH	42,3 kg/jam

Komponen	Masuk (kg/jam)
Dari Evaporator Efek Kedua	
$H_2O_{(l)}$	4.136,7916
$C_5H_{12}O_{4(aq)}$	5.253,7253
$Ca(HCOO)_{2(aq)}$	5.020,6552
$CH_2O_{(aq)}$	173,7955
$CH_3OH_{(aq)}$	42,2746
Total	14.627,2422

Fraksi $C_5H_{12}O_4$ terhadap total feed masuk

$$X = \frac{m\ C_5H_{12}O_4}{\text{Total massa Feed masuk}} = \frac{5.253,7253\ \text{kg}}{14.627,2422\ \text{kg}} = 0,3592 = 36\%$$

Perhitungan kristalisasi

$$P = R\ \frac{100W_0 - S\ (H_0 - E)}{100 - S\ (R - 1)}$$ ***(Perry 8th; hal. 18-41, example 2)***

Keterangan :

P = Berat Kristal (kg)
R = Rasio BM antara larutan / kristal
S = Kelarutan pada temperatur mother liquor anhydrate
W_0 = Berat bahan yang akan dikristalkan pada feed (kg)
H_0 = Total bahan yang bersifat liquid pada feed (kg)
E = Total H_2O yang menguap (kg)

Rasio BM Kristal (R)

$$R = \frac{BM\ C_5H_{12}O_{4\ (s)}}{BM\ C_5H_{12}O_{4\ (aq)}} = \frac{136,150\ \text{kg/kmol}}{136,150\ \text{kg/kmol}} = 1$$

Kelarutan pada Mother Liquor (S)

S = 5.6 untuk 100 parts Air pada 30℃ ***(Perry 8th; hal. 2-43, Tabel. 2-2)***

$$= \frac{5,6}{100}$$

= 0,056

Berat bahan yang akan dikristalkan pada feed (W_0)

W_0 = m $C_5H_{12}O_4$

= 5.253,7253 kg/jam

Total bahan yang bersifat liquid pada feed (H_0)

H_0 = 4.136,7916 kg/jam

Total H_2O yang menguap (E)

Asumsi, tidak ada penguapan H_2O pada kristalisasi dingin **(30°C ; 1 atm)**

E = 0 kg/jam

Maka, pembentukan kristal sebanyak :

$$P = R \frac{100W_0 - S\ (H_0 - E)}{100 - S\ (R - 1)}$$ ***(Perry 8th; hal. 18-41, example 2)***

$$= 1 \frac{(100 \text{ x } 5{,}253.7253 \text{ kg/jam}) - 0.56 \text{ x } (4{,}136.7916 \text{ kg/jam} - 0))}{100 - 0.056 \text{ x } (1 - 1)}$$

$$= 1 \frac{525.372{,}5330 \text{ kg/jam} - 231{,}6603 \text{ kg/jam}}{100}$$

$$= 1 \frac{525.140{,}8726 \text{ kg/jam}}{100}$$

= 5.251,4087 kg/jam

Sehingga, $C_5H_{12}O_4$ yang tidak terbentuk menjadi kristal :

= $C_5H_{12}O_{4\ (awal)}$ - $C_5H_{12}O_{4\ (kristal)}$

= 5.253,7253 kg/jam - 5.251,4087 kg/jam

= 2,3166 kg/jam

Yield Kristalisasi

$$= \frac{C_5H_{12}O_{4\ (kristal)}}{C_5H_{12}O_{4\ (awal)}}$$

$$= \frac{5.251{,}4087 \text{ kg/jam}}{5.253{,}7253 \text{ kg/jam}}$$

= 99,96%

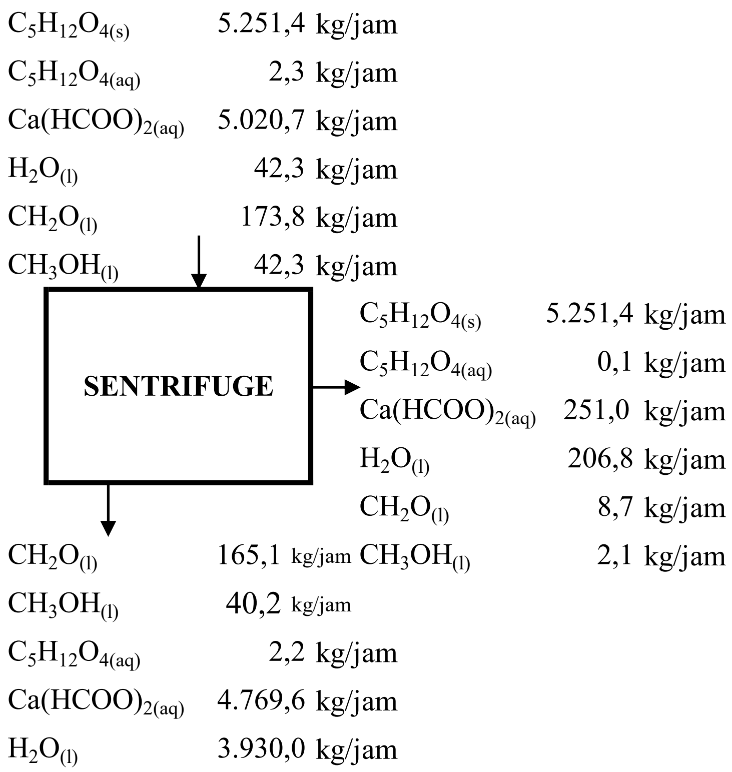
Neraca Massa Kristalizer

Komponen	Masuk (kg/jam)	Komponen	Keluar (kg/jam)
Dari Evaporator Efek Kedua		Kristal Terbentuk Menuju Sentrifuge	
$H_2O_{(l)}$	4.136,7916	$C_5H_{12}O_{4\,(s)}$	5.251,4087
$C_5H_{12}O_{4(aq)}$	5.253,7253	Campuran Menuju Sentrifuge	
$Ca(HCOO)_{2(aq)}$	5.020,6552	$H_2O_{(l)}$	4.136,7916
$CH_2O_{(aq)}$	173,7955	$C_5H_{12}O_{4\,(aq)}$	2,3166
$CH_3OH_{(aq)}$	42,2746	$Ca(HCOO)_{2(aq)}$	5.020,6552
		CH_2O	173,7955
		CH_3OH	42,2746
Total	14.627,2422	**Total**	14.627,2422

6. SENTRIFUGE

Kode = H - 340

Fungsi = Tempat pemisahan antara Kristal Pentaeritritol dengan Monther Liquor berdasarkan perbedaan nilai kelarutan terhadap Air



Komponen	Masuk (kg/jam)	
	Mother Liquor	Kristal
$C_5H_{12}O_4$	2,3166	5.251,4087
$Ca(HCOO)_{2(aq)}$	5.020,6552	
$H_2O_{(l)}$	4.136,7916	
$CH_2O_{(aq)}$	173,7955	
$CH_3OH_{(aq)}$	42,2746	
Subtotal	9.375,8334	5.251,4087
Total	14.627,2422	

Secara teoritis, Air yang terbawa produk adalah 2-10% dari berat kristal

Asumsi = 5% MLiq terbawa ***(Perry 8th; hal. 18-40)***

Perhitungan Mother Liquor terbawa produk

= m Mother Liquor x 5%

= 9.375,8334 kg/jam x 5%

= 468,7917 kg/jam

Perhitungan setiap komponen Mother Liquor terbawa produk

$$m = \frac{\text{m komponen}}{\text{m Mother Liquor}} \times \text{Air terbawa produk}$$

$$C_5H_{12}O_4 = \frac{2{,}3166 \text{ kg/jam}}{9.375{,}8334 \text{ kg/jam}} \times 468{,}7917 \text{ kg/jam}$$

$$= 0{,}1158 \text{ kg/jam}$$

$$Ca(HCOO)_2 = \frac{5.020{,}6552 \text{ kg/jam}}{9.375{,}8334 \text{ kg/jam}} \times 468{,}7917 \text{ kg/jam}$$

$$= 251{,}0328 \text{ kg/jam}$$

$$H_2O = \frac{4.136{,}7916 \text{ kg/jam}}{9.375{,}8334 \text{ kg/jam}} \times 468{,}7917 \text{ kg/jam}$$

$$= 206{,}8396 \text{ kg/jam}$$

$$CH2O(l) = \frac{173{,}7955 \text{ kg/jam}}{9.375{,}8334 \text{ kg/jam}} \times 468{,}7917 \text{ kg/jam}$$

$$= 8{,}6898 \text{ kg/jam}$$

$$CH3OH = \frac{42{,}2746 \text{ kg/jam}}{9.375{,}8334 \text{ kg/jam}} \times 468{,}7917 \text{ kg/jam}$$

$$= 2{,}1137 \text{ kg/jam}$$

Neraca Massa Sentrifuge

Komponen	Masuk (kg/jam)	Komponen	Keluar (kg/jam)
Dari Kristalizer		Liquid Menuju Tangki Penyimpanan	
$C_5H_{12}O_{4\,(s)}$	5.251,4087	$C_5H_{12}O_{4\,(aq)}$	2,2008
$C_5H_{12}O_{4\,(aq)}$	2,3166	$Ca(HCOO)_{2(aq)}$	4.769,6224
$Ca(HCOO)_{2(aq)}$	5.020,6552	$H_2O_{(l)}$	3.929,9520
H2O(l)	4.136,7916	$CH_2O_{(l)}$	165,1057
$CH_2O_{(l)}$	173,7955	$CH_3OH_{(l)}$	40,1608
$CH_3OH_{(l)}$	42,2746	Campuran Menuju Dryer	
		$C_5H_{12}O_{4\,(s)}$	5.251,4087
		$C_5H_{12}O_{4\,(aq)}$	0,1158
		$Ca(HCOO)_{2(aq)}$	251,0328
		$H_2O_{(l)}$	206,8396
		$CH_2O_{(l)}$	8,6898
		$CH_3OH_{(l)}$	2,1137
Total	14.627,2422	**Total**	14.627,2422

Spesifikasi Side Produk Kalsium Format

Komponen	Produk (kg/jam)	Presentase
$C_5H_{12}O_{4\,(aq)}$	2,2008	0,025%
$Ca(HCOO)_{2(aq)}$	4.769,6224	53,549%
$H_2O_{(l)}$	3.929,9520	44,122%
$CH_2O_{(l)}$	165,1057	1,854%
$CH_3OH_{(l)}$	40,1608	0,451%
Total	8.907,0418	100%

7. ROTARY DRYER

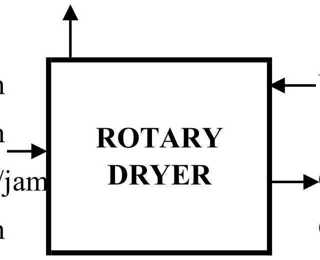
Kode = B - 350

Fungsi = Tempat pengeringan kristal basah dengan mengurangi kadar air

Udara Panas (keluar):

$C_5H_{12}O_{4(s)}$	52,5 kg/jam
$C_5H_{12}O_{4(aq)}$	0,1 kg/jam
$Ca(HCOO)_{2(aq)}$	248,5 kg/jam
$H_2O_{(l)}$	204,8 kg/jam
$CH_2O_{(l)}$	8,6 kg/jam
$CH_3OH_{(l)}$	2,1 kg/jam

Udara Panas



Udara Panas

Masuk:

$C_5H_{12}O_{4(s)}$	5.251,4 kg/jam
$C_5H_{12}O_{4(aq)}$	0,1 kg/jam
$Ca(HCOO)_{2(aq)}$	251,0 kg/jam
$H_2O_{(l)}$	206,8 kg/jam
$CH_2O_{(l)}$	8,7 kg/jam
$CH_3OH_{(l)}$	2,1 kg/jam

Keluar:

$C_5H_{12}O_{4(s)}$	5.198,9 kg/jam
$C_5H_{12}O_{4(aq)}$	0,0 kg/jam
$Ca(HCOO)_{2(}$	2,5 kg/jam
$H_2O_{(l)}$	2,1 kg/jam
$CH_2O_{(l)}$	0,1 kg/jam
$CH_3OH_{(l)}$	0,0 kg/jam

Komponen	Masuk (kg/jam)	BM
Campuran dari Sentrifuge		(kg/kmol)
$C_5H_{12}O_{4\ (s)}$	5.251,4087	136,15
$C_5H_{12}O_{4\ (aq)}$	0,1158	136,15
$Ca(HCOO)_{2(aq)}$	251,0328	130,11
$H_2O_{(l)}$	206,8396	
$CH_2O_{(aq)}$	8,6898	
$CH_3OH_{(aq)}$	2,1137	
Komponen dari Blower		
Udara		28,96
Total	5.720,2004	

(Perry 8th; Tabel. 2-32)

Efisiensi Dryer sebesar = 99% ***(Coker 4th, Vol.1, hal. 439, Tabel. 6-18)***

Kadar H_2O pada Feed = 3,62%

Berat Kristal = 5.251,4087 kg/jam

Berat Larutan = 468,7917 kg/jam

Kadar Larutan pada Feed = 8,20%

Perhitungan larutan dipisahkan dari Kristal Basah

m = m komponen x Larutan dipisahkan dari kristal m Larutan

$C_5H_{12}O_{4\,(aq)}$ = $\frac{0{,}1158 \text{ kg/jam}}{468{,}7917 \text{ kg/jam}}$ x 464,1038 kg/jam

= 0,1147 kg/jam

$Ca(HCOO)_2$ = $\frac{251{,}0328 \text{ kg/jam}}{468{,}7917 \text{ kg/jam}}$ x 464,1038 kg/jam

= 248,5224 kg/jam

H_2O = $\frac{206{,}8396 \text{ kg/jam}}{468{,}7917 \text{ kg/jam}}$ x 464,1038 kg/jam

= 204,7712 kg/jam

$CH_2O_{(l)}$ = $\frac{8{,}6898 \text{ kg/jam}}{468{,}7917}$ x 464,1038 kg/jam

= 8,6029 kg/jam

$CH_3OH_{(l)}$ = $\frac{2{,}1137 \text{ kg/jam}}{468{,}7917 \text{ kg/jam}}$ x 464,1038 kg/jam

= 2,0926 kg/jam

Efisiensi Pemisahan = 99% ***(Coker 4th, Vol.1, hal. 400)***

= 1% Partikel padat terbawa udara

Perhitungan kristal terbawa udara

m = m $C_5H_{12}O_{4\,(s)}$ x % Partikel padat terbawa udara

= 5.251,4087 kg/jam x 1%

= 52,5141 kg/jam

Perhitungan komponen terbawa Kristal

m = m komponen awal - m komponen dipisahkan dari kristal

$C_5H_{12}O_{4\,(aq)}$ = 0,1158 kg/jam - 0,1147 kg/jam

= 0,0012 kg/jam

$Ca(HCOO)_2$ = 251,0328 kg/jam - 248,5224 kg/jam

= 2,5103 kg/jam

H_2O = 206,8396 kg/jam - 204,7712 kg/jam

= 2,0684 kg/jam

CH2O(l) = 8,6898 kg/jam - 8,6029 kg/jam

= 0,0869 kg/jam

CH3OH(l) = 2,1137 kg/jam - 2,0926 kg/jam

= 0,0211 kg/jam

Neraca Massa Rotary Dryer

Komponen	Masuk (kg/jam)	Komponen	Keluar (kg/jam)
Dari Centrifuge		Keluar Menuju Cyclone	
$C_5H_{12}O_{4\,(s)}$	5.251,4087	$C_5H_{12}O_{4\,(s)}$	52,5141
$C_5H_{12}O_{4\,(aq)}$	0,1158	$C_5H_{12}O_{4\,(aq)}$	0,1147
$Ca(HCOO)_{2(aq)}$	251,0328	$Ca(HCOO)_{2(aq)}$	248,5224
$H_2O_{(l)}$	206,8396	$H_2O_{(l)}$	204,7712
$CH_2O_{(l)}$	8,6898	$CH_2O_{(l)}$	8,6029
$CH_3OH_{(l)}$	2,1137	$CH_3OH_{(l)}$	2,0926
Komponen dari Blower		Udara	
Udara		Keluar Menuju Cooling Screw Conveyor	
		$C_5H_{12}O_{4\,(s)}$	5.198,8946
		$C_5H_{12}O_{4\,(aq)}$	0,0012
		$Ca(HCOO)_{2(aq)}$	2,5103
		$H_2O_{(l)}$	2,0684
		$CH_2O_{(l)}$	0,0869
		$CH_3OH_{(l)}$	0,0211
Total	5.720,2004	**Total**	5.720,2004

8. CYCLONE

Kode = H - 351

Fungsi = Tempat pemisahan kristal Pentaeritritol yang terbawa udara keluar meninggalkan Dryer

$C_5H_{12}O_{4(s)}$	2,6 kg/jam
$C_5H_{12}O_{4(aq)}$	0,1 kg/jam
$Ca(HCOO)_{2(aq)}$	236,1 kg/jam
$H_2O_{(l)}$	194,5 kg/jam
CH2O	8,2 kg/jam
CH3OH	2,0 kg/jam

$C_5H_{12}O_{4(s)}$	52,5 kg/jam
$C_5H_{12}O_{4(aq)}$	0,1 kg/jam
$Ca(HCOO)_{2(aq)}$	248,5 kg/jam
$H_2O_{(l)}$	204,8 kg/jam
CH2O(l)	8,6 kg/jam
CH3OH(l)	2,1 kg/jam

CYCLONE

$C_5H_{12}O_{4(s)}$	49,9 kg/jam
$C_5H_{12}O_{4(aq)}$	0,0 kg/jam
$Ca(HCOO)_{2(aq)}$	12,4 kg/jam
$H_2O_{(l)}$	10,2 kg/jam
CH2O(l)	0,4 kg/jam
CH3OH(l)	0,1 kg/jam

Komponen	**Masuk (kg/jam)**
Campuran dari Dryer	
$C_5H_{12}O_{4\ (s)}$	52,5141
$C_5H_{12}O_{4\ (aq)}$	0,1147
$Ca(HCOO)_{2(aq)}$	248,5224
$H_2O_{(l)}$	204,7712
CH2O(l)	8,6029
CH3OH(l)	2,0926
Komponen dari Blower	
Udara	
Total	516,6178

Efisiensi kerja Cyclone = 95% ***(Coker 4th, Vol.1, hal. 401)***

Kristal yang terbuang = 5%

Perhitungan Komponen diepas ke lingkungan

m	=	m komponen awal	x	Presentase
m $C_5H_{12}O_4$ $_{(s)}$	=	m $C_5H_{12}O_4$ $_{(s)}$ awal	x	% Kristal yang terbuang
	=	52,5141 kg/jam	x	5%
	=	2,6257 kg/jam		
m $C_5H_{12}O_4$ $_{(aq)}$	=	m $C_5H_{12}O_4$ $_{(aq)}$ awal	x	% Efisiensi Cyclone
	=	0,1147 kg/jam	x	95%
	=	0,1089 kg/jam		
m $Ca(HCOO)_2$	=	m $Ca(HCOO)_2$ awal	x	% Efisiensi Cyclone
	=	248,5224 kg/jam	x	95%
	=	236,0963 kg/jam		
m H_2O	=	m H_2O awal	x	% Efisiensi Cyclone
	=	204,7712 kg/jam	x	95%
	=	194,5326 kg/jam		
m CH2O	=	8,6029 kg/jam	x	95%
	=	8,1727 kg/jam		
m CH3OH	=	2,0926 kg/jam	x	95%
		1,9880 kg/jam		

Perhitungan Komponen kembali ke Cooling Screw Conveyor

m	=	m komponen awal	-	n komponen dilepas ke lingkunga
m $C_5H_{12}O_4$ $_{(s)}$	=	52,5141 kg/jam	-	2,6257 kg/jam
	=	49,8884 kg/jam		
m $C_5H_{12}O_4$ $_{(aq)}$	=	0,1147 kg/jam	-	0,1089 kg/jam
	=	0,0057 kg/jam		
m $Ca(HCOO)_2$	=	248,5224 kg/jam	-	236,0963 kg/jam
	=	12,4261 kg/jam		
m H_2O	=	204,7712 kg/jam	-	194,5326 kg/jam
	=	10,2386 kg/jam		
m CH2O	=	8,6029 kg/jam	-	8,1727 kg/jam
	=	0,4301 kg/jam		
m CH3OH	=	2,0926 kg/jam	-	1,9880 kg/jam
	=	0,1046 kg/jam		

Neraca Massa Cyclone

Komponen	Masuk (kg/jam)	Komponen	Keluar (kg/jam)
Dari Dryer		Keluar Dilepas ke Lingkungan	
$C_5H_{12}O_{4\,(s)}$	52,5141	$C_5H_{12}O_{4\,(s)}$	2,6257
$C_5H_{12}O_{4\,(aq)}$	0,1147	$C_5H_{12}O_{4\,(aq)}$	0,1089
$Ca(HCOO)_2$	248,5224	$Ca(HCOO)_{2(aq)}$	236,0963
$H_2O_{(l)}$	204,7712	$H_2O_{(l)}$	194,5326
Udara		Udara	
CH2O(l)	8,6029	CH2O(l)	8,1727
CH3OH(l)	2,0926	CH3OH(l)	1,9880
		Keluar Menuju Cooling Screw Conveyor	
		$C_5H_{12}O_{4\,(s)}$	49,8884
		$C_5H_{12}O_{4\,(aq)}$	0,0057
		$Ca(HCOO)_{2(aq)}$	12,4261
		$H_2O_{(l)}$	10,2386
		CH2O(l)	0,4301
		CH3OH(l)	0,1046
Total	516,6178	**Total**	516,6178

9. COOLING SCREW CONVEYOR

Kode = J - 355

Fungsi = Alat transportasi komponen disertai penurunan suhu komponen keluar dari Dryer dan komponen kembali dari Cyclone

CH2O 0,4 kg/jam
$C_5H_{12}O_{4(s)}$ 49,9 kg/jam
$C_5H_{12}O_{4(aq)}$ 0,0 kg/jam
$Ca(HCOO)_{2(aq)}$ 12,4 kg/jam
$H_2O_{(l)}$ 10,2 kg/jam
CH3OH 0,1 kg/jam

$C_5H_{12}O_{4(s)}$ 5.198,9 kg/jam
$C_5H_{12}O_{4(aq)}$ 0,0 kg/jam
$Ca(HCOO)_{2(aq)}$ 2,5 kg/jam
$H_2O_{(l)}$ 2,1 kg/jam
CH2O 0,1 kg/jam
CH3OH 2,1 kg/jam

COOLING SCREW CONVEYOR

$C_5H_{12}O_{4(s)}$ 5.248,8 kg/jam
$C_5H_{12}O_{4(aq)}$ 0,0 kg/jam
$Ca(HCOO)_{2(aq)}$ 14,9 kg/jam
$H_2O_{(l)}$ 12,3 kg/jam
CH2O 12,3 kg/jam
CH3OH 12,3 kg/jam

Neraca Massa Cooling Screw Conveyor

Komponen	Masuk (kg/jam)	Komponen	Keluar (kg/jam)
Dari Dryer		Campuran Menuju Gudang Penyimpanan	
$C_5H_{12}O_{4\ (s)}$	5.198,8946	$C_5H_{12}O_{4\ (s)}$	5.248,7830
$C_5H_{12}O_{4\ (aq)}$	0,0012	$C_5H_{12}O_{4\ (aq)}$	0,0069
$Ca(HCOO)_{2(aq)}$	2,5103	$Ca(HCOO)_{2(aq)}$	14,9364
$H_2O_{(l)}$	2,0684	$H_2O_{(l)}$	12,3070
CH_2O	0,0869	CH_2O	0,5170
CH_3OH	2,1137	CH_3OH	2,2184
Dari Cyclone			
$C_5H_{12}O_{4\ (s)}$	49,8884		
$C_5H_{12}O_{4\ (aq)}$	0,0057		
$Ca(HCOO)_{2(aq)}$	12,4261		
$H_2O_{(l)}$	10,2386		
CH_2O	0,4301		
CH_3OH	0,1046		
Total	5.278,7687	**Total**	5.278,7687

Komponen	Produk (kg/jam)	Presentase
$C_5H_{12}O_{4\ (s)}$	5.248,7830	99,432%
$C_5H_{12}O_{4\ (aq)}$	0,0069	0,000%
$Ca(HCOO)_{2(aq)}$	14,9364	0,283%
$H_2O_{(l)}$	12,3070	0,233%
CH2O	0,5170	0,010%
CH3OH	2,2184	0,042%
Total	5.278,7687	100,0%

APPENDIX B
PERHITUNGAN NERACA PANAS

Kapasitas Produksi	=	42.000	ton/tahun		
Waktu Operasi	=	1 tahun	=	331	hari
	=	1 hari	=	24	jam

Kapasitas Produksi	=	42.000	ton/tahun
	=	5,2870	ton / jam
	=	5.287,0091	kg / jam
Basis Asetaldehid (99%)	=	1.717,0000	kg / jam

Data Thermodinamika Komponen

Komponen	Konstanta Cp				
	A	B	C	D	E
$CH_2O_{(aq)}$	34,43	-2,98E-02	1,51E-04	-1,27E-07	3,39E-11
$CH_2O_{2\,(l)}$	-16,11	8,72E-01	-2,37E-03	2,45E-06	
$CH_3OH_{(g)}$	40,05	-3,83E-02	2,45E-04	-2,17E-07	5,99E-11
$CH_3OH_{(l)}$	40,15	3,10E-01	-1,03E-03	1,46E-06	
$CH_3CHO_{(l)}$	45,06	4,49E-01	-1,66E-03	2,70E-06	
$H_2O_{(g)}$	33,93	-8,42E-03	2,99E-05	-1,78E-08	3,69E-12
$H_2O_{(l)}$	92,05	-4,00E-02	-2,11E-04	5,35E-07	
$C_5H_{12}O_{4(l)}$	-1.429,75	9,52E+00	-1,67E-02	1,03E-05	
$C_5H_{12}O_{4(s)}$	694,78	-3,73E+00	6,82E-03		

(Carl L. Yaws)

Komponen	Konstanta Cp				
	A	B	C	D	E
$Ca(OH)_{2\,(s)}$	89,50				

(Himmelblau 9th, hal. 945, Appendix F)

Perhitungan nilai Cp dengan Hukum Kopp

$$\frac{Cp}{(J/mol.K)} = \sum n_E \, \Delta_E$$

(Perry 8th; hal. 2-497, eq. 2-54)

Keterangan :

n_E = Jumlah suatu elemen dalam senyawa

Δ_E = Kontribusi elemen terhadap Cp untuk Hukum Kopp

Komponen	Δ_E
Ca	28,25
H	7,56
C	10,89
O	13,42
$Ca(HCOO)_2$	

(Perry 8th; hal. 2-498, Tabel 2-350)

$$\frac{Cp}{(J/mol.K)} = \sum n_E \, \Delta_E$$

(Perry 8th; hal. 2-497, eq. 2-54)

$= (1\,\Delta_E\ Ca) + (2\,\Delta_E\ H) + (2\,\Delta_E\ C) + (4\,\Delta_E\ O)$

$= 28{,}25 + 15{,}12 + 21{,}78 + 53{,}68$

$= 118{,}83$ J/mol.K

Komponen	Cp
	(J/mol.K)
$Ca(HCOO)_{2\,(aq)}$	118,83

Perhitungan Cp dengan Konstanta Heat Capacity

$$\frac{Cp}{(J/mol.K)} = (A) + (B.T) + (C.T)^2 + (D.T)^3 + (E.T)^4$$

(Carl L. Yaws, hal. 30)

Keterangan :

A, B, C, D, E = Konstanta Komponen

T = Temperatur

= $T_{Komponen} - T_{reference}$

$T_{reference}$ = 298 Kelvin

= 25 °C

Cp = Heat Capacity (J/mol.K)

Persamaan dalam kondisi Steady-State

$Q = \Delta H = H_1 + H_2$ ***(Himmelblau 9th, hal. 596, eq - 8.4)***

$\Delta H = F\,C_p\,\Delta T$ ***(Himmelblau 9th, hal. 642)***

$$\Delta H = n \int_{T1}^{T2} Cp\,dT$$

(Himmelblau 9th, hal. 624, eq - 8.14)

$$= n \int_{T1}^{T2} ((A) + (B.T) + (C.T)^2 + (D.T)^3 + (E.T)^4)\,dT$$

$$\Delta H = n \int_{T1}^{T2} \left[(A(T - Tref)) + \left(\frac{B}{2}(T^2 - Tref^2)\right) + \left(\frac{C}{3}(T^3 - Tref^3)\right) + \left(\frac{D}{4}(T^4 - Tref^4)\right) - \left(\frac{E}{5}(T^5 - Tref^5)\right) \right]$$

akumulasi = Energi in - Energi out + Energi terbentuk - Energi terkonsumsi

(Himmelblau 5th, hal. 410, eq - 4.22)

Komponen	**BM**	**ΔH_F^{298K}**		
	(g/mol)	**(kJ/mol)**	**(kJ/kmol)**	
CH_2O (aq)	30,03	-108,60	-108.600,00	***(Haynes 95th, hal. 5-19)***
CH_2O_2 (l)	46,02	-425,00	-425.000,00	***(Haynes 95th, hal. 5-19)***
CH_3OH (aq)	32,04	-239,20	-239.200,00	***(Haynes 95th, hal. 5-20)***
CH_3CHO (l)	44,05	-192,20	-192.200,00	***(Haynes 95th, hal. 5-22)***
$Ca(OH)_2$ (s)	74,10	-985,20	-985.200,00	***(Haynes 95th, hal. 5-8)***
$H_2O_{(l)}$	18,02	-285,80	-285.800,00	***(Haynes 95th, hal. 5-13)***
$C_5H_{12}O_4$ (aq)	136,15	-920,60	-920.600,00	***(Haynes 95th, hal. 5-30)***
$Ca(HCOO)_2$ (aq)	130,11	-1.353,50	-1.353.500,00	***(Franzosini, hal. 103)***

Q Loss

Dalam keadaan normal, heat loss berada pada rentang 5 hingga 15 persen dari panas yang di supply pada proses ***(Gael D. Ulrich, hal. 140)***

Asumsi, heat loss yang terjadi sebesar = 5% Q_{supply}

Steam

Steam menggunakan H_2O dengan temperatu = 130 °C

Pada tekanan konstan, Panas Laten (λ) steam sebesar = 2.173,6 kJ/kg

(Smith 9th; hal. 700, Appendix E)

Cooling Water

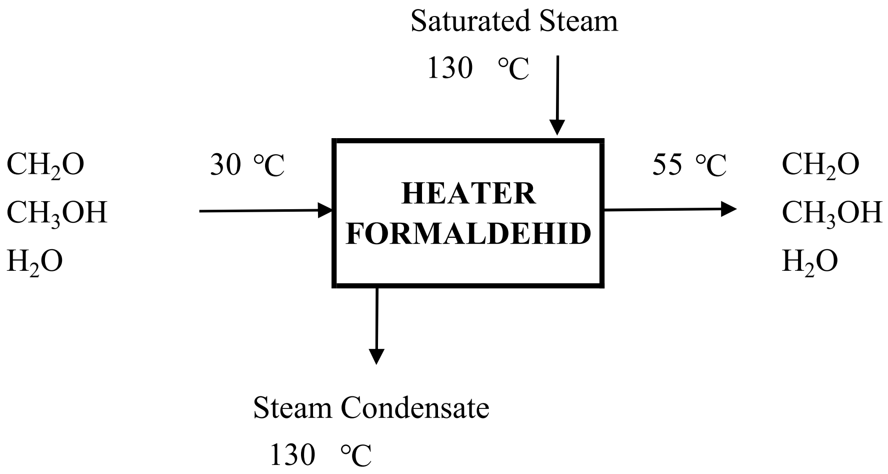
Air Pendingin menggunakan H_2O dengan temperatur 30 °C = 303 K

Pada tekanan konstan, memiliki kapasitas panas sebesar = 4,180 kJ/kg

(Bergman 7th; hal. 1003, Appendix A.6)

1. HEATER FORMALDEHID

Kode = F - 112



Kondisi Operasi:

Temperatur = 55 °C = 328 K

Tekanan = 1 atm

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

$T_{\text{Komponen keluar}}$ = 55 °C = 328 K

Data Komponen Dalam Heater Formaldehid

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
CH_2O	30,03	5.213,8642	173,6450
CH_3OH	32,04	140,9152	4,3981
H_2O	18,02	8.736,7453	484,9706
Total		14.091,5248	663,0137

ΔH CH_2O Masuk

$$= 173{,}645 \int_{298}^{303} \Big[(34.824\ (303 - 298)) + (-0.0298/2\ (303^2 - 298^2)) + (1.51\text{x}10^{-4}/3\ (303^3 - 298^3)) + (-1.27\text{x}10^{-7}/4\ (303^4 - 298^4)) + (3.39\text{x}10^{-11}/5\ (303^5 - 298^5))\Big]$$

$$= 173{,}645 \int_{298}^{303} [\ 172{,}14 + -44{,}77 + 68{,}26 + -17{,}30 + 1{,}38\ ]$$

$= 31.207{,}6435$ kJ/Jam

ΔH CH_3OH Masuk

$$= 4{,}398 \int_{298}^{303} [\ 200{,}76 + 466{,}70 + -465{,}11 + 198{,}37 + 0{,}00\ ]$$

$= 1.762{,}3854$ kJ/Jam

ΔH H_2O Masuk

$$= 484{,}971 \int_{298}^{303} [\ 460{,}265 + -60{,}06 + -95{,}38 + 72{,}66 + 0{,}00\ ]$$

$= 183.069{,}7968$ kJ/Jam

ΔH CH_2O Keluar

$$= 173{,}645 \int_{298}^{328} [\ 1032{,}84 + -279{,}76 + 444{,}68 + -117{,}57 + 9{,}82\ ]$$

$= 189.275{,}1977$ kJ/Jam

ΔH CH_3OH Keluar

$$= 4{,}398 \int_{298}^{328} [\ 1204{,}56 + 2916{,}62 + -3029{,}81 + 1347{,}93 + 0{,}00\ ]$$

$= 10.728{,}2680$ kJ/Jam

ΔH H_2O Keluar

$$= 484{,}971 \int_{298}^{328} [\ 2761{,}59 + -375{,}34 + -621{,}30 + 493{,}71 + 0{,}00\ ]$$

$= 1.095.385{,}9612$ kJ/Jam

Data Enthalpy Komponen Masuk dan Keluar

Komponen	ΔH (kJ/Jam)
Masuk	216.039,8257
Keluar	1.295.389,4269

Perhitungan Q Supply

$H_{\text{bahan masuk}} + Q_{\text{supply}} = H_{\text{bahan keluar}} + Q_{\text{loss}}$

216.039,8 kJ/Jam + Q_{supply} = 1.295.389,4 kJ/Jam + (5% Q_{Supply})

95 % (Q_{supply}) = $H_{\text{bahan keluar}} - H_{\text{bahan masuk}}$

= 1.295.389,4269 kJ/Jam - 216.039,8257 kJ/Jam

= 1.079.349,6012 kJ/Jam

Q_{supply} = 1.136.157,4750 kJ/Jam

Q_{loss} = 56.807,8737 kJ/Jam

Perhitungan Kebutuhan Steam

$$m\ \text{Steam} = \frac{Q_{\text{supply}}}{\lambda_{\text{saturated steam}}}$$

$$= \frac{1.136.157{,}4750\ \text{kJ/Jam}}{2.173{,}60\ \text{kJ/kg}}$$

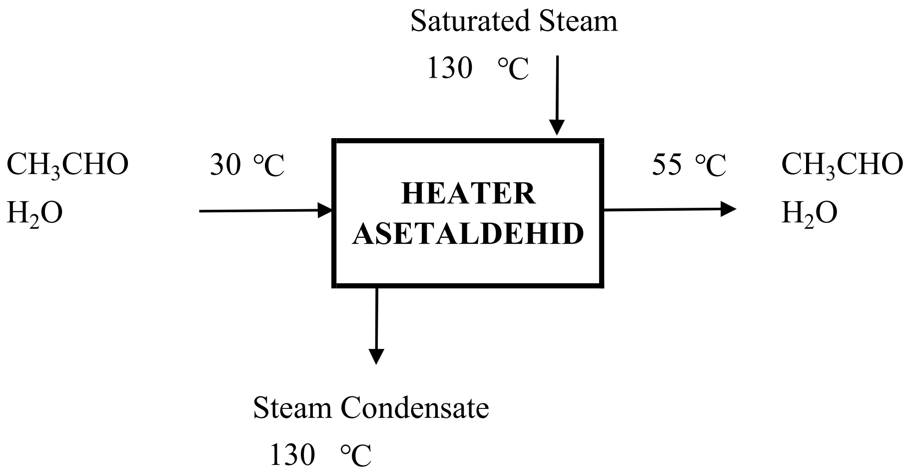
= 522,7077 kg/Jam

Neraca Energi Heater Formaldehid

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		**Keluar**	
CH_2O	31.207,6435	CH_2O	189.275,1977
CH_3OH	1.762,3854	CH_3OH	10.728,2680
H_2O	183.069,7968	H_2O	1.095.385,9612
Q_{supply}	1.136.157,4750	Q_{loss}	56.807,8737
Total	1.352.197,3006	**Total**	1.352.197,3006

2. HEATER ASETALDEHID

Kode = E - 122



Kondisi Operasi:

Temperatur = 55 °C = 328 K

Tekanan = 1 atm

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

$T_{\text{Komponen keluar}}$ = 55 °C = 328 K

Data Komponen Dalam Heater Asetaldehid

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
CH_3CHO	44,05	1.699,8300	38,5878
H_2O	18,02	17,1700	0,9531
Total		1.717,0000	39,5409

ΔH CH_3CHO Masuk

$$= \quad 38,588 \int_{298}^{303} [\quad 225,28 \quad + \quad 674,25 \quad + \quad -750,57 \quad + \quad 366,90 \quad + \quad 0,00 \quad]$$

= 19.905,8233 kJ/Jam

ΔH H_2O Masuk

$$= \quad 0,953 \int_{298}^{303} [\quad 460,27 \quad + \quad -60,06 \quad + \quad -95,38 \quad +$$

$$72{,}66 \quad + \quad 0{,}00 \quad]$$

$= \quad 359{,}7802$ kJ/Jam

ΔH CH_3CHO Keluar

$$= \quad 38{,}588 \int_{298}^{328} [\quad 1.351{,}68 \quad + \quad 4213{,}72 \quad + \quad -4889{,}33 \quad +$$

$$2493{,}09 \quad + \quad 0{,}00 \quad]$$

$= \quad 122.290{,}5784$ kJ/Jam

ΔH H_2O Keluar

$$= \quad 0{,}953 \int_{298}^{328} [\quad 2.761{,}59 \quad + \quad -375{,}34 \quad + \quad -621{,}30 \quad +$$

$$493{,}71 \quad + \quad 0{,}00 \quad]$$

$= \quad 2.152{,}7212$ kJ/Jam

Data Enthalpy Komponen Masuk dan Keluar

Komponen	ΔH (kJ/Jam)
Masuk	20.265,6035
Keluar	124.443,2997

Perhitungan Q Supply

$$H_{\text{bahan masuk}} + Q_{\text{supply}} = H_{\text{bahan keluar}} + Q_{\text{loss}}$$

$$20.265{,}6 \text{ kJ/Jam} + Q_{\text{supply}} = 124.443{,}3 \text{ kJ/Jam} + (5\%\ Q_{\text{Supply}})$$

$$95\ \%\ (Q_{\text{supply}}) = H_{\text{bahan keluar}} - H_{\text{bahan masuk}}$$

$$= 124.443{,}2997 \text{ kJ/Jam} - 20.265{,}6035 \text{ kJ/Jam}$$

$$= 104.177{,}6961 \text{ kJ/Jam}$$

$$Q_{\text{supply}} = 109.660{,}7327 \text{ kJ/Jam}$$

$$Q_{\text{loss}} = 5.483{,}0366 \text{ kJ/Jam}$$

Perhitungan Kebutuhan Steam

$$\text{m Steam} = \frac{Q_{\text{supply}}}{\lambda_{\text{saturated steam}}}$$

$$= \frac{109.660,7327 \text{ kJ/Jam}}{2.173,6000 \text{ kJ/kg}}$$

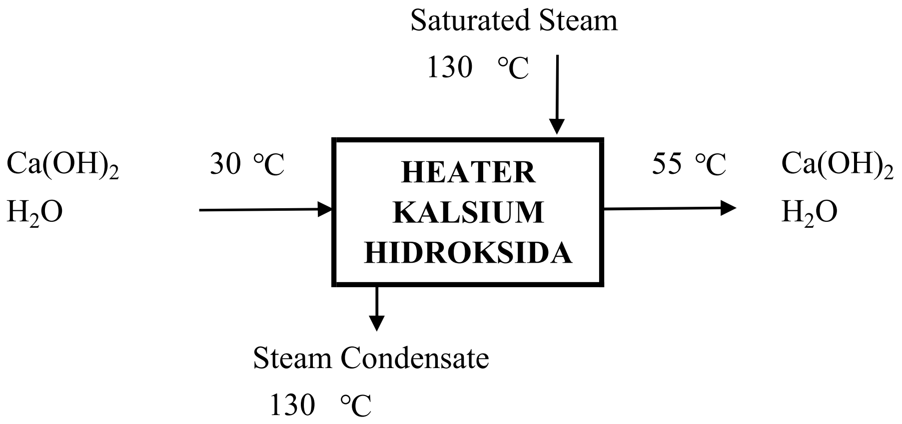
$$= 50,4512 \text{ kg/Jam}$$

Neraca Energi Heater Asetaldehid

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		**Keluar**	
CH_3CHO	19.905,8233	CH_3CHO	122.290,5784
H_2O	359,7802	H_2O	2.152,7212
Q_{supply}	109.660,7327	Q_{loss}	5.483,0366
Total	129.926,3363	**Total**	129.926,3363

3. HEATER KALSIUM HIDROKSIDA

Kode = E - 135



Kondisi Operasi:

Temperatur = 55 °C = 328 K

Tekanan = 1 atm

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

$T_{\text{Komponen keluar}}$ = 55 °C = 328 K

Data Komponen Dalam Heater Kalsium Hidroksida

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
$Ca(OH)_2$	74,10	2.859,3540	38,5878
H_2O	18,02	2.859,3540	158,7207
Total		5.718,7080	197,3085

ΔH $Ca(OH)_2$ Masuk

$$= 38,588 \int_{298}^{303} [\ 447,50 + 0,00 + 0,00 + 0,00 + 0,00\ ]$$

= 17.268,0285 kJ/Jam

ΔH H_2O Masuk

$$= 158,721 \int_{298}^{303} [\ 460,27 + -60,06 + -95,38 + 72,66 + 0,00\ ]$$

= 59.914,9151 kJ/Jam

ΔH $Ca(OH)_2$ Keluar

$$= 38,588 \int_{298}^{328} [\ 2.685,00 + 0,00 + 0,00 + 0,00 + 0,00\ ]$$

= 103.608,1712 kJ/Jam

ΔH H_2O Keluar

$$= 158,721 \int_{298}^{328} [\ 2.761,59 + -375,34 + -621,30 + 493,71 + 0,00\ ]$$

= 358.496,9120 kJ/Jam

Data Enthalpy Komponen Masuk dan Keluar

Komponen	ΔH (kJ/Jam)
Masuk	77.182,9436
Keluar	462.105,0832

Perhitungan Q Supply

$$H_{\text{bahan masuk}} + Q_{\text{supply}} = H_{\text{bahan keluar}} + Q_{\text{loss}}$$

$77.182{,}9 \ \text{kJ/Jam} + Q_{supply} = 462.105{,}1 \ \text{kJ/Jam} + (5\% \ Q_{Supply})$

$95\ \% \ (Q_{supply}) = H_{bahan\ keluar} - H_{bahan\ masuk}$

$= 462.105{,}0832 \ \text{kJ/Jam} - 77.182{,}9436 \ \text{kJ/Jam}$

$= 384.922{,}1396 \ \text{kJ/Jam}$

$Q_{supply} = 405.181{,}1996 \ \text{kJ/Jam}$

$Q_{loss} = 20.259{,}0600 \ \text{kJ/Jam}$

Perhitungan Kebutuhan Steam

$$m \ \text{Steam} = \frac{Q_{supply}}{\lambda_{saturated\ steam}}$$

$$= \frac{405.181{,}1996 \ \text{kJ/Jam}}{2.173{,}6000 \ \text{kJ/kg}}$$

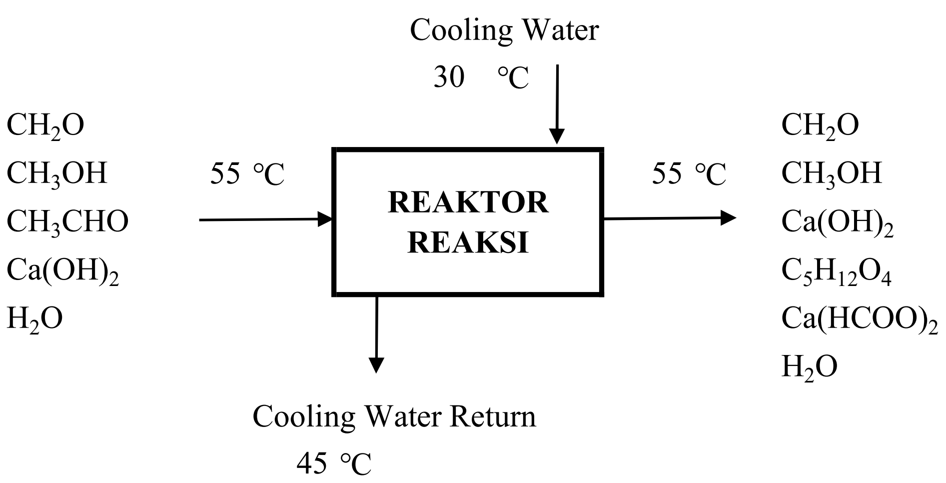
$$= 186{,}4102 \ \text{kg/Jam}$$

Neraca Energi Heater Kalsium Hidroksida

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		**Keluar**	
$Ca(OH)_2$	17.268,0285	$Ca(OH)_2$	103.608,1712
H_2O	59.914,9151	H_2O	358.496,9120
Q_{supply}	405.181,1996	Q_{loss}	20.259,0600
Total	482.364,1432	**Total**	482.364,1432

4. REAKTOR REAKSI

Kode = R - 210



Kondisi Operasi:

Temperatur = 55 °C = 328 K
Tekanan = 1 atm

$T_{\text{Komponen masuk}}$ = 55 °C = 328 K
$T_{\text{Komponen keluar}}$ = 55 °C = 328 K
$T_{\text{Air Pendingin in}}$ = 30 °C = 303 K
$T_{\text{Air Pendingin out}}$ = 45 °C = 318 K

Data Komponen Masuk Reaktor Kondensasi

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
CH_2O	30,03	5.213,8642	173,6450
CH_3OH	32,04	140,9152	4,3981
CH_3CHO	44,05	1.699,8300	38,5878
$Ca(OH)_2$	74,10	2.859,3540	38,5878
H_2O	18,02	11.613,2693	644,6444
Total		21.527,2328	899,8631

Reaksi Kondensasi

$$8\ CH_2O + 2\ CH_3CHO + 1\ Ca(OH)_2 \longrightarrow 2\ C_5H_{12}O_4 + 1\ Ca(HCOO)_2$$

ΔH CH_2O Masuk

$$= 173{,}645 \int_{298}^{328} [\ 1.032{,}84 + -279{,}76 + 444{,}68 + -117{,}57 + 9{,}82\ ]$$

$$= 189.275{,}1977 \text{ kJ/Jam}$$

ΔH CH_3OH Masuk

$$= 4{,}398 \int_{298}^{328} [\ 1.204{,}56 + 2.916{,}62 + -3.029{,}81 + 1.347{,}93 + 0{,}00\ ]$$

$$= 10.728{,}2680 \text{ kJ/Jam}$$

ΔH CH_3CHO Masuk

$$= 38{,}588 \int_{298}^{328} [\ 1.351{,}68 + 4.213{,}72 + -4.889{,}33 + 2.493{,}09\ ]$$

= 122.290,5784 kJ/Jam

ΔH $Ca(OH)_2$ Masuk

$$= 38{,}588 \int_{298}^{328} [\ 2.685{,}00 + 0{,}00 + 0{,}00 + 0{,}00\ ]$$

= 103.608,1712 kJ/Jam

ΔH H_2O Masuk

$$= 644{,}644 \int_{298}^{328} [\ 2.761{,}59 + -375{,}34 + -621{,}30 + 493{,}71 + 0{,}00\ ]$$

= 1.456.035,5943 kJ/Jam

Data Komponen Keluar Reaktor Kondensasi

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
CH_2O	30,03	579,3182	19,2939
CH_3OH	32,04	140,9152	4,3981
CH_3CHO	44,05	0,0000	0,0000
$Ca(OH)_2$	74,10	1.429,6770	19,2939
H_2O	18,02	11.613,2693	644,6444
$C_5H_{12}O_{4\ (aq)}$	136,15	5.253,7253	38,5878
$Ca(HCOO)_{2\ (aq)}$	130,11	2.510,3276	19,2939
Total		21.527,2328	745,5120

ΔH CH_2O Keluar

$$= 19{,}294 \int_{298}^{328} [\ 1.032{,}84 + -279{,}76 + 444{,}68 + -117{,}57 + 9{,}82\ ]$$

= 21.030,5775 kJ/Jam

ΔH CH_3OH Keluar

$$= 4{,}398 \int_{298}^{328} [\ 1.204{,}56 + 2.916{,}62 + -3.029{,}81 + 1.347{,}93 + 0{,}00\ ]$$

= 10.728,2680 kJ/Jam

ΔH $Ca(OH)_2$ Keluar

$$= 19{,}294 \int_{298}^{328} [\ 2.685{,}00 + 0{,}00 + 0{,}00 + 0{,}00\ ]$$

= 51.804,0856 J/Jam

ΔH H_2O Keluar

$$= 644{,}644 \int_{298}^{328} [\ 2.761{,}59 + -375{,}34 + -621{,}30 + 493{,}71 + 0{,}00\ ]$$

= 1.456.035,5943 kJ/Jam

ΔH $C_5H_{12}O_4$ Keluar

$$= 38{,}588 \int_{298}^{328} [\ -42.892{,}41 + 89.428{,}12 + -49.108{,}22 + 9.548{,}53 + 0{,}00\ ]$$

= 269.189,2566 kJ/Jam

ΔH $Ca(HCOO)_2$ Keluar

= 19,294 kmol/jam x 118,83 J/mol x (328 K - 298 K)

= 19,294 kmol/jam x 118,83 kJ/kmol x (30)

= 68.780,7765 kJ/Jam

Data Enthalpy Komponen Masuk dan Keluar Reaktor Kondensasi

Komponen	ΔH (kJ/Jam)
Masuk	1.881.937,8097
Keluar	1.877.568,5585

Data Enthalpy Pembentukan Komponen Masuk pada 298 K

Komponen	ΔH_F^{298K} (kJ/kmol)	Rate mol (kmol/jam)	ΔH_F^{298K} (kJ/jam)
CH_2O	-108.600,0000	154,3511	-16.762.528,7054
CH_3CHO	-192.200,0000	38,5878	-7.416.570,0211
$Ca(OH)_2$	-985.200,0000	19,2939	-19.008.337,1093
Total		212,2328	-43.187.435,8357

Data Enthalpy Pembentukan Komponen Keluar pada 298 K

Komponen	ΔH_F^{298K} (kJ/kmol)	Rate mol (kmol/jam)	ΔH_F^{298K} (kJ/jam)
$C_5H_{12}O_4$	-920.600,0000	38,5878	-35.523.904,0657
$Ca(HCOO)_2$	-1.353.500,0000	19,2939	-26.114.275,5556
Total		57,8817	-61.638.179,6213

Perhitungan ΔH reaksi pada 298 K

$$\Delta H \text{ reaksi}_{ref} \text{ (kJ/kmol.K)} = \left[\sum \Delta H_F \text{ produk} - \sum \Delta H_F \text{ reaktan} \right]$$

(Himmelblau 9th, hal. 713, eq - 9.1)

$$= [\, n_i \quad \Delta H_F \text{ produk} \; - \; n_i \quad \Delta H_F \text{ reaktan} \,]$$

$$= [\; -61.638.179,62 \text{ kJ/jam} - \; -43.187.435,84 \text{ kJ/jam} \;]$$

$$= \; -18.450.743,7856 \text{ kJ/jam}$$

Perhitungan ΔH reaksi pada 328 K

$$\Delta H \text{ reaksi}^{328K} \text{ (kJ/kmol.K)} = \Delta H \text{ reaksi}_{ref} + \left[\sum \Delta H \text{ produk} - \sum \Delta H \text{ reaktan} \right]$$

$$= \; -18.450.743,79 \text{ kJ/jam} + [\; 337.970,0331 \text{ kJ/jam} \; - \; 415.173,9474 \text{ kJ/jam} \;]$$

$$= \; -18.527.947,6999 \text{ kJ/jam}$$

= *negatif (-), maka reaksi berjalan secara eksotermis sehingga mengeluarkan energi panas dan meningkatkan suhu, maka diperlukan pendingin untuk menjaga suhu tetap konstan*

Perhitungan Q Serap

ΔH Masuk + ΔH Reaksi = ΔH Keluar + Q serap

(Himmelblau 5th, hal. 410, eq - 4.22)

1.881.937,81 + 18.527.947,6999 = 1.877.568,5585 + Q serap

20.409.885,5097 = 1.877.568,5585 + Q serap

Q serap = 18.532.316,9511 kJ/jam

Perhitungan Kebutuhan Air Pendingin

$$Q\ serap = m^{Air}\, C_p^{\ Air}\, \Delta T$$

$$m\ Air = \frac{Q\ serap}{C_p \times \Delta T}$$

$$= \frac{18.532.316,9511\ \text{kJ/jam}}{4,180\ \text{kJ/kg} \times (318\ K - 303\ K)}$$

= 295.571,2432 kg/jam

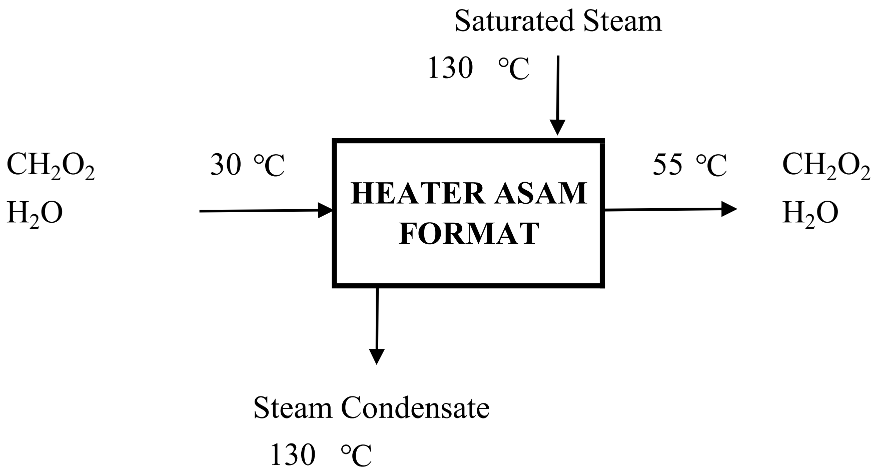
= 295,5712 ton/jam

Neraca Energi Reaktor Kondensasi

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		Keluar	
CH_2O	189.275,1977	CH_2O	21.030,5775
CH_3OH	10.728,2680	CH_3OH	10.728,2680
CH_3CHO	122.290,5784	CH_3CHO	0,0000
$Ca(OH)_2$	103.608,1712	$Ca(OH)_2$	51.804,0856
H_2O	1.456.035,5943	H_2O	1.456.035,5943
ΔH reaksi	18.527.947,6999	$C_5H_{12}O_4$	269.189,2566
		$Ca(HCOO)_2$	68.780,7765
		Q serap	18.532.316,9511
Total	20.409.885,5097	**Total**	20.409.885,5097

5. HEATER ASAM FORMAT

Kode = E - 142



Kondisi Operasi:

Temperatur	=	55 °C	=	328 K
Tekanan	=	1 atm		
$T_{\text{Komponen masuk}}$	=	30 °C	=	303 K
$T_{\text{Komponen keluar}}$	=	55 °C	=	328 K

Data Komponen Dalam Heater Asam Format

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
CH_2O_2	46,02	1.775,8093	38,5878
H_2O	18,02	197,3121	10,9527
Total		1.973,1214	49,5404

ΔH CH_2O_2 Masuk

$$= \quad 38,588 \int_{298}^{303} [\ -80,55 + 1.311,27 + -1.069,57 + 332,30 + 0,00\ ]$$

$$= \quad 19.041,2557 \text{ kJ/Jam}$$

ΔH H_2O Masuk

$$= \quad 10,953 \int_{298}^{303} [\ 460,27 + -60,06 + -95,38 + 72,66 + 0,00\ ]$$

= 4.134,4794 kJ/Jam

ΔH CH_2O_2 Keluar

$$= 38{,}588 \int_{298}^{328} [\ -483{,}30 + 8.194{,}73 + -6.967{,}30 + 2.258{,}00 + 0{,}00\ ]$$

= 115.845,3396 kJ/Jam

ΔH H_2O Keluar

$$= 10{,}953 \int_{298}^{328} [\ 2.761{,}59 + -375{,}34 + -621{,}30 + 493{,}71 + 0{,}00\ ]$$

= 24.738,3829 kJ/Jam

Data Enthalpy Komponen Masuk dan Keluar

Komponen	ΔH (kJ/Jam)
Masuk	23.175,7351
Keluar	140.583,7225

Perhitungan Q Supply

$H_{\text{bahan masuk}} + Q_{\text{supply}} = H_{\text{bahan keluar}} + Q_{\text{loss}}$

23.175,7 kJ/Jam + Q_{supply} = 140.583,7 kJ/Jam + (5% Q_{Supply})

95 % (Q_{supply}) = $H_{\text{bahan keluar}} - H_{\text{bahan masuk}}$

= 140.583,7225 kJ/Jam - 23.175,7351 kJ/Jam

= 117.407,9873 kJ/Jam

Q_{supply} = 123.587,3551 kJ/Jam

Q_{loss} = 6.179,3678 kJ/Jam

Perhitungan Kebutuhan Steam

$$m\ \text{Steam} = \frac{Q_{\text{supply}}}{\lambda_{\text{saturated steam}}}$$

$$= \frac{123.587{,}3551\ \text{kJ/Jam}}{2.173{,}6000\ \text{kJ/kg}}$$

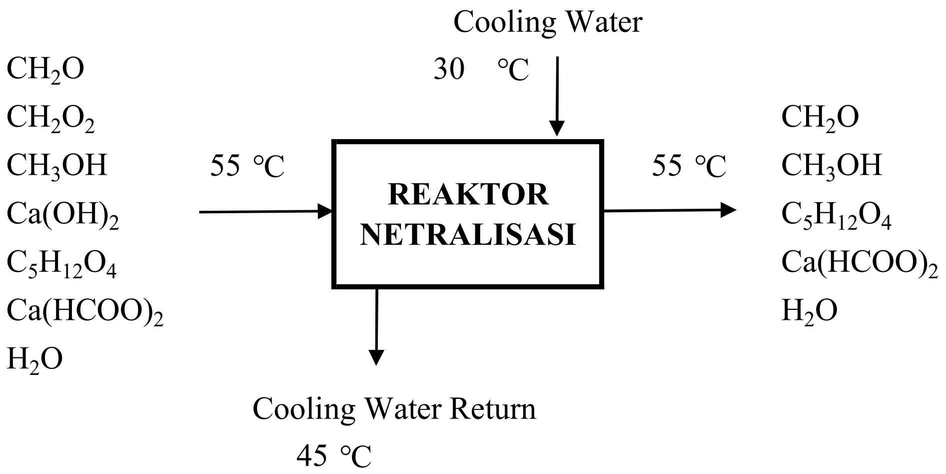
= 56,8584 kg/Jam

Neraca Energi Heater Asam Format

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		**Keluar**	
CH_2O_2	19.041,2557	$Ca(OH)_2$	115.845,3396
H_2O	4.134,4794	H_2O	24.738,3829
Q_{supply}	123.587,3551	Q_{loss}	6.179,3678
Total	146.763,0902	**Total**	146.763,0902

6. REAKTOR NETRALISASI

Kode = R - 220



Kondisi Operasi:

Temperatur	=	55 °C	=	328 K
Tekanan	=	1 atm		
$T_{Komponen\ masuk}$	=	55 °C	=	328 K
$T_{Komponen\ keluar}$	=	55 °C	=	328 K
$T_{Air\ Pendingin\ in}$	=	30 °C	=	303 K
$T_{Air\ Pendingin\ out}$	=	45 °C	=	318 K

Data Komponen Masuk Reaktor Netralisasi

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
CH_2O	30,03	579,3182	19,2939
CH_2O_2	46,02	1.775,8093	38,5878
CH_3OH	32,04	140,9152	4,3981
$Ca(OH)_2$	74,10	1.429,6770	19,2939
H_2O	18,02	11.810,5815	655,5971
$C_5H_{12}O_{4\ (aq)}$	136,15	5.253,7253	38,5878
$Ca(HCOO)_{2\ (aq)}$	130,11	2.510,3276	19,2939
Total		23.500,3542	737,1707

Reaksi Netralisasi

$$2\ CH_2O_2 + 1\ Ca(OH)_2 \rightarrow 1\ Ca(HCOO)_2 + 2\ H_2O$$

ΔH CH_2O Masuk

$$= 19{,}294 \int_{298}^{328} [\ 1.032{,}84 + -279{,}76 + 444{,}68 + -117{,}57 + 9{,}82\ ]$$

= 21.030,5775 kJ/Jam

ΔH CH_2O_2 Masuk

$$= 38{,}588 \int_{298}^{328} [\ -483{,}30 + 8.194{,}73 + -6.967{,}30 + 2.258{,}00 + 0{,}00\ ]$$

= 115.845,3396 kJ/Jam

ΔH CH_3OH Masuk

$$= 4{,}398 \int_{298}^{328} [\ 1.204{,}56 + 2.916{,}62 + -3.029{,}81 + 1.347{,}93\ ]$$

= 10.728,2680 kJ/Jam

ΔH $Ca(OH)_2$ Masuk

$$= 19{,}294 \int_{298}^{328} [\ 2.685{,}00 + 0{,}00 + 0{,}00 +$$

$0{,}00 \quad]$

$= \quad 51.804{,}0856$ kJ/Jam

ΔH H_2O Masuk

$$= 655{,}597 \int_{298}^{328} [\; 2.761{,}59 + -375{,}34 + -621{,}30 + 493{,}71 + 0{,}00 \;]$$

$= \quad 1.480.773{,}9772$ kJ/Jam

ΔH $C_5H_{12}O_4$ Masuk

$$= 38{,}588 \int_{298}^{328} [\; -42.892{,}41 + 89.428{,}12 + 20.085{,}20 + 9.548{,}53 + 0{,}00 \;]$$

$= \quad 2.939.209{,}1837$ kJ/Jam

ΔH $Ca(HCOO)_2$ Masuk

= 19,294 kmol/jam x 118,83 J/mol x (328 K - 298 K)

= 19,294 kmol/jam x 118,83 kJ/kmol x (30)

= 68.780,7765 kJ/Jam

Data Komponen Keluar Reaktor Netralisasi

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
CH_2O	30,03	579,3182	19,2939
CH_2O_2	46,02	0,0000	0,0000
CH_3OH	32,04	140,9152	4,3981
$Ca(OH)_2$	74,10	0,0000	0,0000
H_2O	18,02	12.505,7402	694,1849
$C_5H_{12}O_{4\,(aq)}$	136,15	5.253,7253	38,5878
$Ca(HCOO)_{2\,(aq)}$	130,11	5.020,6552	38,5878
Total		23.500,3542	795,0524

ΔH CH_2O Keluar

$$= 19{,}294 \int_{298}^{328} [\; 1.032{,}84 + -279{,}76 + 444{,}68 + -117{,}57 + 9{,}82 \;]$$

= 21.030,5775 kJ/Jam

ΔH CH_3OH Keluar

$$= 4{,}398 \int_{298}^{328} \left[1.204{,}56 + 2.916{,}62 + -3.029{,}81 + 1.347{,}93 + 0{,}00 \right]$$

= 10.728,2680 kJ/Jam

ΔH H_2O Keluar

$$= 694{,}185 \int_{298}^{328} \left[2.761{,}6 + -375{,}3 + -621{,}3 + 493{,}7 + 0{,}0 \right]$$

= 1.567.930,8175 kJ/Jam

ΔH $C_5H_{12}O_4$ Keluar

$$= 38{,}588 \int_{298}^{328} \left[-42.892{,}4 + 89.428{,}1 + -49.108{,}2 + 9.548{,}5 + 0{,}0 \right]$$

= 269.189,2566 kJ/Jam

ΔH $Ca(HCOO)_2$ Keluar

= 38,588 kmol/jam x 118,83 J/mol x (328 K - 298 K)

= 38,588 kmol/jam x 118,83 kJ/kmol x (30)

= 137.561,5529 kJ/Jam

Data Enthalpy Komponen Masuk dan Keluar Reaktor Netralisasi

Komponen	ΔH (kJ/Jam)
Masuk	4.688.172,2081
Keluar	2.006.440,4726

Data Enthalpy Pembentukan Komponen Masuk pada 298 K

Komponen	ΔH_F^{298K} (kJ/kmol)	Rate mol (kmol/jam)	ΔH_F^{298K} (kJ/jam)
CH_2O_2	-425.000,0000	38,5878	-16.399.803,6367
$Ca(OH)_2$	-985.200,0000	19,2939	-19.008.337,1093
Total		57,8817	-35.408.140,7460

Data Enthalpy Pembentukan Komponen Keluar pada 298 K

Komponen	ΔH_F^{298K} (kJ/kmol)	Rate mol (kmol/jam)	ΔH_F^{298K} (kJ/jam)
H_2O	-285.800,0000	38,5878	-11.028.385,5985
$Ca(HCOO)_{2\ (aq)}$	-1.353.500,0000	19,2939	-26.114.275,5556
Total		57,8817	-37.142.661,1541

Perhitungan ΔH reaksi pada 298 K

$$\Delta H\ \text{reaksi}_{ref}\ (\text{kJ/kmol.K}) = \left[\ \sum \Delta H_F\ \text{produk} - \sum \Delta H_F\ \text{reaktan}\ \right]$$

(Himmelblau 9th, hal. 713, eq - 9.1)

$= [\ n_i\ \ \Delta H_F\ \text{produk}\ -\ n_i\ \ \Delta H_F\ \text{reaktan}\ ]$

$= [\ -37.142.661,1541\ \text{kJ/jam} - -35.408.140,75\ \text{kJ/jam}\ ]$

$= -1.734.520,4082\ \text{kJ/jam}$

Perhitungan ΔH reaksi pada 328 K

$$\Delta H\ \text{reaksi}^{328K}\ (\text{kJ/kmol.K}) = \Delta H\ \text{reaksi}_{ref} + \left[\ \sum \Delta H\ \text{produk} - \sum \Delta H\ \text{reaktan}\ \right]$$

$= -1.734.520,4082\ \text{kJ/jam} + [\ 1.705.492,3705\ \text{kJ/jam} - 167.649,4252\ \text{kJ/jam}\ ]$

$= -196.677,4629\ \text{kJ/jam}$

= *negatif (-), maka reaksi berjalan secara eksotermis sehingga mengeluarkan energi panas dan meningkatkan suhu, maka diperlukan pendingin untuk menjaga suhu tetap konstan*

Perhitungan Q Serap

ΔH Masuk + ΔH Reaksi = ΔH Keluar + Q serap

(Himmelblau 5th, hal. 410, eq - 4.22)

4.688.172,21 + 196.677,4629 = 2.006.440,4726 + Q serap

4.884.849,6710 = 2.006.440,4726 + Q serap

Q serap = 2.878.409,1984 kJ/jam

Perhitungan Kebutuhan Air Pendingin

$$Q\ \text{serap} = m^{Air}\ C_p^{Air}\ \Delta T$$

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

$$= \frac{2.878.409{,}1984 \ \ \text{kJ/jam}}{4{,}180 \ \ \text{kJ/kg} \ \ \text{x} \ \ (\ \ 318 \ \text{K} \ \ - \ \ 303 \ \text{K} \ )}$$

$= \ \ 45.907{,}6427$ kg/jam

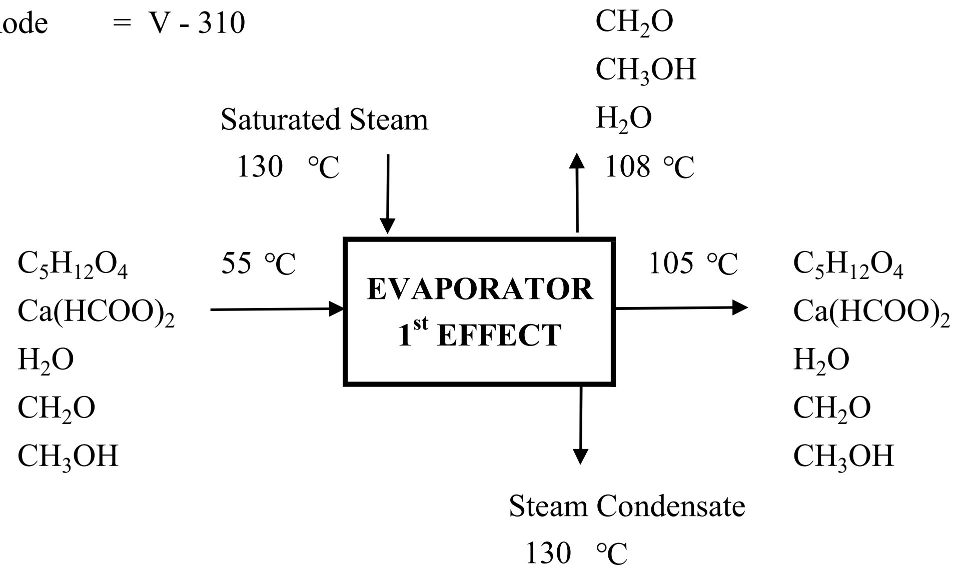
$= \ \ 45{,}9076$ ton/jam

Neraca Energi Reaktor Netralisasi

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		Keluar	
CH_2O	21.030,5775	CH_2O	21.030,5775
CH_2O_2	115.845,3396	CH_2O_2	0,0000
CH_3OH	10.728,2680	CH_3OH	10.728,2680
$Ca(OH)_2$	51.804,0856	$Ca(OH)_2$	0,0000
H_2O	1.480.773,9772	H_2O	1.567.930,8175
$C_5H_{12}O_4$	2.939.209,1837	$C_5H_{12}O_4$	269.189,2566
$Ca(HCOO)_2$	68.780,7765	$Ca(HCOO)_2$	137.561,5529
ΔH reaksi	196.677,4629	Q serap	2.878.409,1984
Total	4.884.849,6710	**Total**	4.884.849,6710

7. EVAPORATOR

Kode = V - 310



Kondisi Operasi:

Temperatur = 100 °C = 373 K

Tekanan = 1 atm

$T_{\text{Komponen masuk}}$ = 55 °C = 328 K
$T_{\text{Komponen keluar}}$ = 105 °C = 379 K
P_1 = 1 atm = 101,325 kPa
P_2 = 0,4 atm = 40,53 kPa
$T_{\text{Steam 1}}$ = 130 °C = 403 K = 266 °F
$T_{\text{Steam 2}}$ = 104 °C = 399 K = 219 °F
$T_{\text{Steam 3}}$ = 77 °C = 350 K = 171 °F

Data Komponen Masuk Evaporator Efek Pertama

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
$C_5H_{12}O_{4\,(aq)}$	136,15	5.253,7253	38,5878
$Ca(HCOO)_{2\,(aq)}$	130,11	5.020,6552	38,5878
H_2O	18,02	12.505,7402	694,1849
CH_2O	30,03	579,3182	19,2913
CH_3OH	32,04	140,9152	4,3978
Total		10.274,3805	77,1755

Campuran dipekatkan hingga mencapai Specific Gravity = 1,2700 ***(Keyes)***
m H_2O yang diuapkan = 8.368,9486 kg / Jam

Perhitungan Boiling Point Rise (ΔT_b)

$$= m \times Kb$$

$$= \frac{W_1}{Mr} \times \frac{1000}{W_2} \times Kb$$

Keterangan:

m = molalitas
Mr = Berat molekul zat terlarut
W_1 = massa zat terlarut ($C_5H_{12}O_4$)
W_2 = massa zat pelarut (H_2O)
Kb = tetapan kenaikan titik didih molal = 0,51 $K.kmol^{-1}$
= -458,75 $°F.kmol^{-1}$

(Atkins 8th; hal. 153 , Tabel 5.2)

$\Delta T_{b\,1}$

$$= \frac{5.253,7253 \text{ kg / Jam}}{136,1500 \text{ kg / kmol}} \times \frac{1.000}{12.505,7402 \text{ kg / Jam}} \times 0,5 \text{ K.kmol -1}$$

$$= 1,5737 \text{ K}$$

$\Delta T_{b\,2}$

$$= \frac{5.253{,}7253 \text{ kg / Jam}}{136{,}1500 \text{ kg / kmol}} \times \frac{1.000}{8.321{,}2659 \text{ kg / Jam}} \times 0{,}5 \text{ K.kmol -1}$$

$= 2{,}3650$ K

ΔT_b = BPR (Boiling Point Rise)

BPR_1 = 1,5737 K

BPR_2 = 2,3650 K

Perhitungan ΣΔT

$\Sigma\Delta T = T_{S1} - T_{S3} - (BPR_1 + BPR)$

$= 403 \text{ K} - 350 \text{ K} - (1{,}5737 \text{ K} + 2{,}3650 \text{ K})$

$= 49{,}0613$ K

Nilai Koefisien Perpindahan Panas

Untuk Short-Tube Vertical, Natural Circulation diperoleh nilai Overall U pada rentang 1100 - 2800 $W.m^2.K$ ***(Geankoplis 5th; hal. 1494 , Tabel 32.3-1)***

U_1 = 2.000 $W / m^2 . K$ = 1.111,11 $W / m^2 . F$

U_2 = 2.000 $W / m^2 . K$ = 1.111,11 $W / m^2 . F$

Perhitungan ΣΔT

$$\Delta T_1 = \frac{\Sigma\Delta T \times (1/U_1)}{(1/U_1) + (1/U_2)}$$

$$= \frac{49{,}0613 \text{ K} \times \left(\frac{1}{2.000 \text{ W / m}^2\text{ . K}}\right)}{\left(\frac{1}{2.000 \text{ W / m}^2\text{ . K}}\right) + \left(\frac{1}{2.000 \text{ W / m}^2\text{ . K}}\right)}$$

$= 24{,}5307$ K

$$\Delta T_2 = \frac{\Sigma\Delta T \times (1/U_2)}{(1/U_1) + (1/U_2)}$$

$$= \frac{49{,}0613 \text{ K} \times \left(\frac{1}{2.000 \text{ W / m}^2\text{ . K}}\right)}{\left(\frac{1}{2.000 \text{ W / m}^2\text{ . K}}\right) + \left(\frac{1}{2.000 \text{ W / m}^2\text{ . K}}\right)}$$

$= 24{,}5307$ K

Perhitungan Actual Boiling Point

$T_{Efek\ 1}$ = $T_{Steam\ 1}$ - ΔT_1
= 403,15 K - 24,5307 K
= 378,6 K = 105,5 °C

$T_{Efek\ 2}$ = $T_{Efek\ 1}$ - BPR_1 - ΔT_2
= 378,6 K - 1,5737 K - 24,5307 K
= 352,5 K = 79,4 °C

Komponen	Suhu (K)			Suhu (°C)		
	Efek 1	Efek 2	Out 2	Efek 1	Efek 2	Out 2
T_{Efek}	379	353	-	105	79	-
T_{Steam}	403	377	350	130	104	77

Data Steam Table

Aliran Steam	Suhu		Satd. Liquid (kJ.kg $^{-1}$)	Evaporation (λ) (kJ.kg -1)	Satd. Vapor (kJ.kg $^{-1}$)
	K	°C			
$T_{Steam\ 1}$	403,15	130	546,3	2.173,6	2.719,9
$T_{Steam\ 2}$	377,0	104	435,9	2.246,3	268,2
$T_{Steam\ 3}$	350,2	77	322,3	2.316,4	2.638,7

(Smith 9th; hal. 687, Appendix E)

Perhitungan Panas Laten

λ = H_{Steam} - h_{Steam} ***(Geankoplis 5th; hal. 1495 , eq. 32.4-2)***

Keterangan:

H_S = Entalpi Saturated Vapor pada Steam Table
h_S = Entalpi Saturated Liquid pada Steam Table

H_1 = H_S pada $T_{Steam\ 2}$ + 1.884 BPR_1
= 268,2 kJ / kg + (1,884 x 1,5737 K)
= 271,2 kJ / kg

$\lambda_{Steam\ 1}$ = H_S pada $T_{Steam\ 1}$ - h_S pada $T_{Steam\ 1}$
= 2.719,9 kJ / kg - 546,3 kJ / kg
= 2.173,6

H_2 = H_S pada $T_{Steam\ 3}$ + 1.884 BPR_2
= 2.638,7 kJ / kg + (1,884 x 2,3650 K)
= 2.643,2 kJ / kg

$\lambda_{Steam\ 2}$ = H_S pada $T_{Steam\ 2}$ - h_S pada $T_{Steam\ 2}$
= 268,2 kJ / kg - 435,9 kJ / kg
= -167,7 kJ / kg

Perhitungan Neraca Energi

F = L + V

(Geankoplis 5th; hal. 1496 , eq. 32.4-3)

$Fh_F + SH_S = Lh_l + VH_V + Sh_S$

(Geankoplis 5th; hal. 1496 , eq. 32.4-6)

Keterangan:

F = Feed
L = Liquid keluar Evaporator
V = Vapor keluar evaporator
hf = Entalpi Feed Masuk
Hs = Entalpi Steam (Saturated Vapor)
hl = Entalpi Liquid Keluar
Hv = Entalpi Vapor Keluar
hs = Entalpi Steam (Saturated Liquid)

ΔH $C_5H_{12}O_4$ Masuk Evaporator Efek Pertama

$$= 38{,}588 \int_{298}^{328} [\ -42.892{,}4 + 89.428{,}1 + -49.108{,}2 + 9.548{,}5 + 0{,}0\ ]$$

= 269.189,2566 kJ/Jam

ΔH $Ca(HCOO)_2$ Masuk Evaporator Efek Pertama

= 38,588 kmol/jam x 118,83 J/mol x (328 K - 298 K)
= 38,588 kmol/jam x 118,83 kJ/kmol x (30)
= 137.561,5529 kJ/Jam

ΔH H_2O Masuk Evaporator Efek Pertama

$$= 694{,}185 \int_{298}^{328} [\ 2.761{,}6 + -375{,}3 + -621{,}3 + 493{,}7 + 0{,}0\ ]$$

= 1.567.930,8175 kJ/Jam

ΔH CH_2O Masuk Evaporator Efek Pertama

$$= 19{,}291 \int_{298}^{328} [\ 1.032{,}8 + -279{,}8 + 444{,}7 + -117{,}6 + 0{,}0\ ]$$

= 20.838,3175 kJ/Jam

ΔH CH_3OH Masuk Evaporator Efek Pertama

$$= 4{,}398 \int_{298}^{328} [\ 1.204{,}6 + 2.916{,}6 + -3.029{,}8 + 1.347{,}9 + 0{,}0\ ]$$

= 10.727,5983 kJ/Jam

Data Komponen Keluar Evaporator Efek Pertama

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
$C_5H_{12}O_{4\ (aq)}$	136,15	5.253,7253	38,5878
$Ca(HCOO)_{2\ (aq)}$	130,11	5.020,6552	38,5878
H_2O	18,02	8.321,2659	461,9076
H_2O diuapkan	18,02	4.184,4743	232,2772
CH2O	30,03	376,5569	12,5394
CH2O diuapkan	30,03	202,7614	6,7520
CH3OH	32,04	91,5949	2,8586
CH3OH diuapkan	32,04	49,3203	1,5392
Total		23.500,3542	795,0496

ΔH $C_5H_{12}O_4$ Keluar Evaporator Efek Pertama

$$= 38{,}588 \int_{298}^{379} [\ -115.050{,}8 + 259.203{,}9 + -154.415{,}0 + 32.698{,}1 + 0{,}0\ ]$$

= 865.759,4850 kJ/Jam

ΔH $Ca(HCOO)_2$ Keluar Evaporator Efek Pertama

= 38,588 kmol/jam x 118,83 J/mol x (379 K - 298 K)

= 38,588 kmol/jam x 118,83 kJ/kmol x (80)

= 368.982,8550 kJ/Jam

ΔH H_2O dalam Liquid Keluar Evaporator Efek Pertama

$$= 461{,}908 \int_{298}^{379} [\ 7.407{,}4 + -1.087{,}9 + -1.953{,}6 + 1.690{,}7 + 0{,}0\ ]$$

= 2.797.594,2438 kJ/Jam

ΔH CH_2O Aqueous Keluar Evaporator Efek Pertama

$$= 12{,}539 \int_{298}^{379} [\ 2.770{,}4 + -810{,}9 + 1.398{,}3 + -402{,}6 + 0{,}0\ ]$$

= 37.055,8694 kJ/Jam

ΔH CH_3OH Aqueous Keluar Evaporator Efek Pertama

$$= 2{,}859 \int_{298}^{379} [\ 3.231{,}0 + 8.453{,}7 + -9.526{,}9 + 4.615{,}9 + 0{,}0\ ]$$

= 19.363,1471 kJ/Jam

ΔH H_2O Diuapkan Evaporator Efek Pertama

$$= 232{,}277 \int_{298}^{377} [\ 2.677{,}2 + -224{,}2 + 270{,}1 + -54{,}8 + 3{,}9\ ]$$

= 620.670,9642 kJ/Jam

ΔH CH_2O Diuapkan Evaporator Efek Pertama

$$= 6{,}752 \int_{298}^{377} [\ 2.716{,}2 + -793{,}2 + 1.364{,}3 + -391{,}8 + 35{,}7\ ]$$

= 19.791,6711 kJ/Jam

ΔH CH_3OH Diuapkan Evaporator Efek Pertama

$$= 1{,}539 \int_{298}^{377} [\ 3.159{,}5 + -1.019{,}8 + 2.215{,}7 + -667{,}1 + 63{,}1\ ]$$

= 5.774,2116 kJ/Jam

Perhitungan $\Delta H_{Vaporization}$

$$\frac{\Delta H_{Vap}}{kJ / mol.K} = A \left(1 - \frac{T}{T_C}\right)^n$$ ***(Yaws; hal. 109, eq. 5-1)***

Keterangan (untuk H_2O):

A = 52,05
T_C = 647,13
n = 0,32
T = Temperatur (K) ***(Yaws; hal. 131, Tabel 5-2)***

Untuk CH_2O :

A = 30,09
T_C = 408,00
n = 0,30

Untuk CH_3OH :

A = 52,72
T_C = 512,58
n = 0,38

$\Delta H_{Vaporization\ H2O}$

$$= 52,05 \left(1 - \frac{377\ K}{647,13}\right)^{0,321}$$

= 39,3214 kJ / mol.K
= 39.321,3832 kJ / kmol.K
= n x ΔH_{Vap}
= 232,2772 kmol / Jam x 39.321,3832 kJ / kmol.K
= 9.133.461,9967 kJ / Jam

$\Delta H_{Vaporization\ CH2O}$

$$= 30,09 \left(1 - \frac{377\ K}{408,00}\right)^{0,30}$$

= 13,9913 kJ / mol.K
= 13.991,3014 kJ / kmol.K
= n x ΔH_{Vap}
= 6,7520 kmol / Jam x 13.991,3014 kJ / kmol.K
= 94.468,7188 kJ / Jam

$\Delta H_{Vaporization\ CH3OH}$

$$= 52,72 \left(1 - \frac{377\ K}{512,58}\right)^{0,38}$$

= 31,9303 kJ / mol.K
= 31.930,2679 kJ / kmol.K

= n x ΔH_{Vap}
= 1,5392 kmol / Jam x 31.930,2679 kJ / kmol.K
= 49.148,3540 kJ / Jam

Perhitungan ΔH Penguapan

ΔH Penguapan = ΔH H_2O Diuapkan Evaporator 1 + $\Delta H_{Vaporization}$
= 620.670,9642 kJ / Jam + 9.133.461,9967 kJ / Jam
= 9.754.132,9609 kJ / Jam

ΔH Penguapan = ΔH CH_2O Diuapkan Evaporator 1 + $\Delta H_{Vaporization}$
= 19.791,6711 kJ / Jam + 94.468,7188 kJ / Jam
= 114.260,3899 kJ / Jam

ΔH Penguapan = ΔH CH_3OH Diuapkan Evaporator + $\Delta H_{Vaporization}$
= 5.774,2116 kJ / Jam + 49.148,3540 kJ / Jam
= 54.922,5656 kJ / Jam

ΔH Penguapan Total = 9.923.315,9164 kj/jam

Data Enthalpy Komponen Masuk dan Keluar Evaporator Efek Pertama

Komponen	ΔH (kJ/Jam)
Masuk	2.006.247,5429
Keluar	14.012.071,5166

Perhitungan Q Supply Evaporator Efek Pertama

$H_{bahan\ masuk}$ + Q_{supply} = $H_{bahan\ keluar}$ + Q_{loss}
2.006.248 kJ/Jam + Q_{supply} = 14.012.072 kJ/Jam + (5% Q_{Supply})
95 % (Q_{supply}) = $H_{bahan\ keluar}$ - $H_{bahan\ masuk}$
= 14.012.071,5 kJ/Jam - 2.006.247,5 kJ/Jam
= 12.005.823,9738 kJ/Jam
Q_{supply} = 12.637.709,4461 kJ/Jam
Q_{loss} = 631.885,4723 kJ/Jam

Perhitungan Kebutuhan Steam Evaporator Efek Pertama

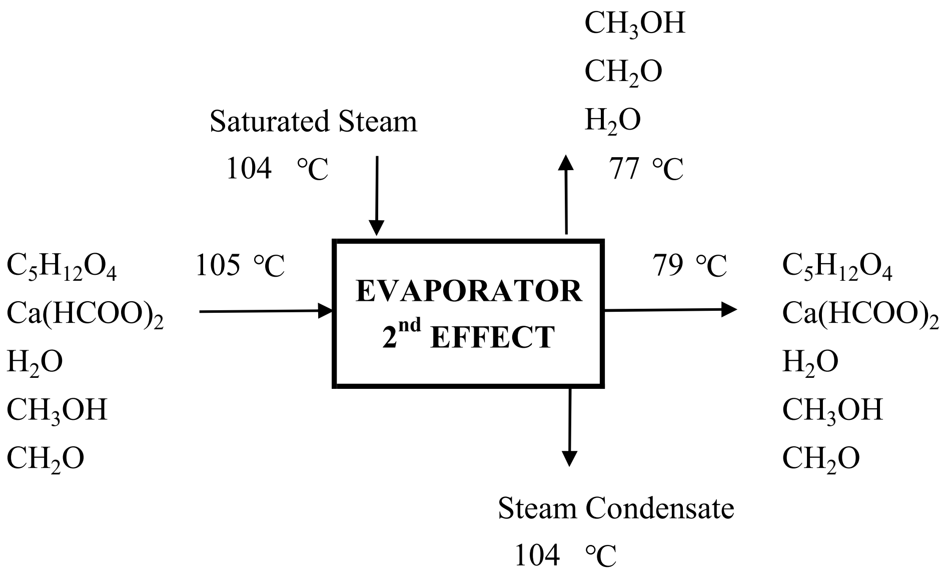
$$m\ Steam = \frac{Q_{supply}}{\lambda_{saturated\ steam}}$$

$$= \frac{12.637.709,4\ \text{kJ/Jam}}{2.173,6\ \text{kJ/kg}}$$

= 5.814,1836 kg/Jam

Neraca Energi Evaporator Efek Pertama

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		**Diuapkan**	
$C_5H_{12}O_4$	269.189,2566	H_2O	9.754.132,9609
$Ca(HCOO)_2$	137.561,5529	CH_2O	114.260,3899
H_2O	1.567.930,8175	CH_3OH	54.922,5656
Q_{supply}	12.637.709,4461	**Menuju Evaporator Efek Kedua**	
CH_2O	20.838,3175	$C_5H_{12}O_4$	865.759,4850
CH_3OH	10.727,5983	$Ca(HCOO)_2$	368.982,8550
		H_2O	2.797.594,2438
		CH_2O	37.055,8694
		CH_3OH	19.363,1471
		Q_{loss}	631.885,4723
Total	14.643.956,9889	**Total**	14.643.956,9889



Kondisi Operasi:

Temperatur	=	79 °C	=	352 K
$T_{Komponen\ masuk}$	=	105 °C	=	379 K
$T_{Komponen\ keluar}$	=	79 °C	=	353 K
P_1	=	1 atm	=	101,325 kPa
P_2	=	0,4 atm	=	40,53 kPa
$T_{Steam\ 1}$	=	130 °C	=	403 K

$T_{Steam\ 2}$ = 104 °C = 399 K
$T_{Steam\ 3}$ = 77 °C = 350 K

Data Komponen Masuk Evaporator Efek Kedua

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
$C_5H_{12}O_{4\ (aq)}$	136,15	5.253,7253	38,5878
$Ca(HCOO)_{2\ (aq)}$	130,11	5.020,6552	38,5878
H_2O	18,02	8.321,2659	461,9076
CH_3OH	32,04	91,5949	2,8586
CH_2O	30,03	376,5569	12,5394
Total		19.063,7982	554,4811

ΔH $C_5H_{12}O_4$ Masuk Evaporator Efek Kedua

$$= 38,588 \int_{298}^{379} [\ -115.051 + 259.203,9 + -154.415 + 32.698,1 + 0,0\ ]$$

= 865.759,4850 kJ/Jam

ΔH $Ca(HCOO)_2$ Masuk Evaporator Efek Kedua

= 38,588 kmol/jam x 118,83 J/mol x (379 K - 298 K)
= 38,588 kmol/jam x 118,83 kJ/kmol x (80)
= 368.982,8550 kJ/Jam

ΔH H_2O Masuk Evaporator Efek Kedua

$$= 461,908 \int_{298}^{379} [\ 7.407,4 + -1.087,9 + -1.953,6 + 1.690,7 + 0,0\ ]$$

= 2.797.594,2438 kJ/Jam

ΔH CH_2O Masuk Evaporator Efek Kedua

$$= 12,539 \int_{298}^{379} [\ 2.770,4 + -810,9 + 1.398,3 + -402,6 + 36,8\ ]$$

= 37.516,8767 kJ/Jam

ΔH CH_3OH Masuk Evaporator Efek Kedua

$$= 2{,}859 \int_{298}^{379} [\ 3.231{,}0 + 8.453{,}7 + -9.526{,}9 + 4.615{,}9 + 0{,}0\ ]$$

= 19.363,1471 kJ/Jam

Data Komponen Keluar Evaporator Efek Kedua

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
H_2O	18,02	4.136,7916	229,6304
$C_5H_{12}O_4$ (aq)	136,15	5.253,7253	38,5878
$Ca(HCOO)_2$ (aq)	130,11	5.020,6552	38,5878
H_2O diuapkan	18,02	4.184,4743	232,2772
CH_2O	30,03	173,7955	5,7874
CH_2O diuapkan	30,03	202,7614	6,7520
CH_3OH	32,04	42,2746	1,3193
CH_3OH diuapkan	32,04	49,3203	1,5392
Total		19.063,7982	554,4811

ΔH $C_5H_{12}O_4$ Keluar Evaporator Efek Kedua

$$= 229{,}630 \int_{298}^{353} [\ -77.728{,}2 + 168.363{,}2 + -96.201{,}0 + 19.493{,}3 + 0{,}0\ ]$$

= 3.198.135,5111 kJ/Jam

ΔH $Ca(HCOO)_2$ Keluar Evaporator Efek Kedua

= 38,588 kmol/jam x 118,83 J/mol x (353 K - 298 K)

= 38,588 kmol/jam x 118,83 kJ/kmol x (54)

= 249.284,4445 kJ/Jam

ΔH H_2O Keluar Evaporator Efek Kedua

$$= 229{,}630 \int_{298}^{353} [\ 5.004{,}5 + -706{,}6 + -1.217{,}1 + 1.007{,}9 + 0{,}0\ ]$$

= 938.875,4359 kJ/Jam

ΔH CH_2O Keluar Evaporator Efek Kedua

$$= 5{,}787 \int_{298}^{353} [\ 1.871{,}7 + -526{,}7 + 871{,}1 + -240{,}0 + 20{,}9\ ]$$

= 11.557,4500 kJ/Jam

ΔH CH_3OH Keluar Evaporator Efek Kedua

$$= 1{,}319 \int_{298}^{353} [\ 2.182{,}9 + 5.491{,}0 + -5.935{,}3 + 2.751{,}8 + 0{,}0\ ]$$

= 5.924,3936 kJ/Jam

ΔH H_2O Diuapkan Evaporator Efek Kedua

$$= 38{,}588 \int_{298}^{350} [\ 1.764{,}5 + -141{,}9 + 163{,}8 + -31{,}8 + 2{,}1\ ]$$

= 67.788,6712 kJ/Jam

ΔH CH_2O Diuapkan Evaporator Efek Kedua

$$= 6{,}752 \int_{298}^{350} [\ 1.790{,}3 + -501{,}9 + 827{,}0 + -227{,}0 + 19{,}7\ ]$$

= 12.883,2224 kJ/Jam

ΔH CH_3OH Diuapkan Evaporator Efek Kedua

$$= 1{,}539 \int_{298}^{350} [\ 2.082{,}4 + -645{,}4 + 1.343{,}1 + -386{,}4 + 34{,}8\ ]$$

= 3.738,1013 kJ/Jam

Perhitungan ΔH $_{Vaporization}$

$$\frac{\Delta H_{Vap}}{kJ / mol.K} = A \left(1 - \frac{T}{T_C} \right)^n$$ ***(Yaws; hal. 109, eq. 5-1)***

Keterangan:

A = 52,053

T_C = 647,13

n = 0,321

T = Temperatur (K) ***(Yaws; hal. 131, Tabel 5-2)***

Untuk CH_2O :

A = 30,09

T_C = 408,00

n = 0,30

Untuk CH_3OH :

A = 52,72

T_C = 512,58

n = 0,38

ΔH $_{\text{Vaporization H2O}}$

$$= 52,053 \left(1 - \frac{350\ K}{647,13}\right)^{0,321}$$

= 40,5381 kJ / mol.K

= 40.538,06 kJ / kmol.K

= n x ΔH_{Vap}

= 232,2772 kmol / Jam x 40.538,0556 kJ / kmol.K

= 9.416.067,3073 kJ / Jam

ΔH $_{\text{Vaporization CH2O}}$

$$= 30,09 \left(1 - \frac{350\ K}{408,00}\right)^{0,30}$$

= 16,8468 kJ / mol.K

= 16.846,82 kJ / kmol.K

= n x ΔH_{Vap}

= 6,7520 kmol / Jam x 16.846,8204 kJ / kmol.K

= 113.749,0719 kJ / Jam

ΔH $_{\text{Vaporization CH3OH}}$

$$= 52,72 \left(1 - \frac{350\ K}{512,58}\right)^{0,38}$$

= 34,1854 kJ / mol.K

= 34.185,44 kJ / kmol.K

= n x ΔH_{Vap}

= 1,5392 kmol / Jam x 34.185,4376 kJ / kmol.K

= 52.619,6021 kJ / Jam

Perhitungan ΔH Penguapan

ΔH Penguapan = ΔH H_2O Diuapkan Evaporator 2 + ΔH $_{Vaporization}$
= 67.788,6712 kJ / Jam + 9.416.067,3073 kJ / Jam
= 9.483.855,9785 kJ / Jam

ΔH Penguapan = ΔH CH_2O Diuapkan Evaporator 2 + ΔH $_{Vaporization}$
= 12.883,2224 kJ / Jam + 113.749,0719 kJ / Jam
= 126.632,2943 kJ / Jam

ΔH Penguapan = ΔH CH_3OH Diuapkan Evaporator + ΔH $_{Vaporization}$
= 3.738,1013 kJ / Jam + 52.619,6021 kJ / Jam
= 56.357,7034 kJ / Jam

Data Enthalpy Komponen Masuk dan Keluar Evaporator Efek Kedua

Komponen	ΔH (kJ/Jam)
Masuk	4.089.216,6075
Keluar	14.070.623,2114

Perhitungan Q Supply Evaporator Efek Kedua

H $_{bahan\ masuk}$ + Q $_{supply}$ = H $_{bahan\ keluar}$ + Q $_{loss}$
4.089.217 kJ/Jam + Q $_{supply}$ = 14.070.623,2 kJ/Jam + (5% Q $_{Supply}$)
95 % (Q $_{supply}$) = H $_{bahan\ keluar}$ - H $_{bahan\ masuk}$
= 14.070.623,2 kJ/Jam - 4.089.216,6 kJ/Jam
= 9.981.406,6 kJ/Jam
Q $_{supply}$ = 10.506.743,7935 kJ/Jam
Q $_{loss}$ = 525.337,1897 kJ/Jam

Perhitungan Kebutuhan Steam Evaporator Efek Kedua

$$m\ Steam = \frac{Q_{supply}}{\lambda_{saturated\ steam}}$$

$$= \frac{10.506.743,8\ kJ/Jam}{2.246,3\ kJ/kg}$$

= 4.677,3556 kg/Jam

Neraca Energi Evaporator Efek Kedua

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		**Diuapkan**	
$C_5H_{12}O_4$	865.759,4850	H_2O	9.483.855,9785
$Ca(HCOO)_2$	368.982,8550	CH_2O	126.632,2943
H_2O	2.797.594,2438	CH_3OH	56.357,7034
Q_{supply}	10.506.743,7935	**Menuju Kristalizer**	
CH_2O	37.516,8767	H_2O	938.875,4359
CH_3OH	19.363,1471	$C_5H_{12}O_4$	3.198.135,5111
		$Ca(HCOO)_2$	249.284,4445
		CH_2O	11.557,4500
		CH_3OH	5.924,3936
		Q_{loss}	525.337,1897
Total	14.595.960,4010	**Total**	14.595.960,4010

Perhitungan Steam Economy

$$\text{Steam Economy} = \frac{\text{Massa Komponen yang diuapkan}}{\text{Massa Steam yang Diperlukan}}$$

$$= \frac{8.873,1121 \text{ kg/jam}}{5.814,1836 \text{ kg/jam}}$$

$$= 1,5261$$

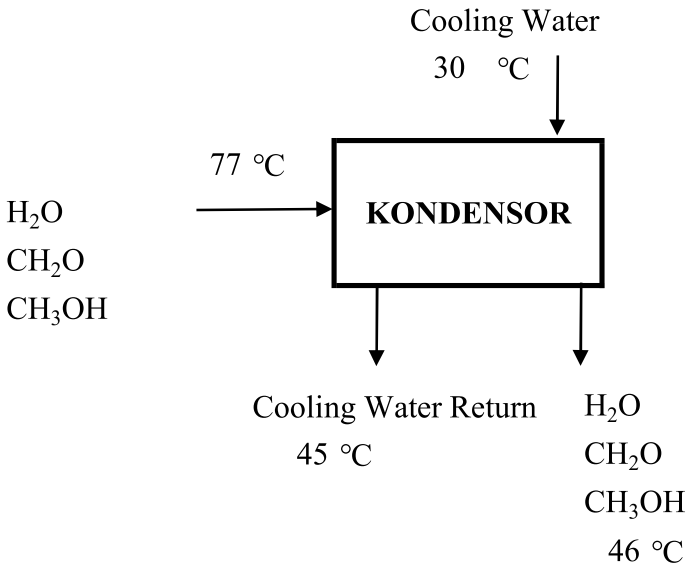
Penentuan Jumlah Efek

1.5 - 2.0 Steam Economy = Double Effect Evaporator

(American Institute of Chemical Engineers)

8. KONDENSOR

Kode = E - 321



Kondisi Operasi:

Temperatur	=	45 °C	=	318 K
Tekanan	=	1 atm		
$T_{\text{Komponen masuk}}$	=	77 °C	=	350 K
$T_{\text{Komponen keluar}}$	=	46 °C	=	319 K
$T_{\text{Air Pendingin in}}$	=	30 °C	=	303 K
$T_{\text{Air Pendingin out}}$	=	45 °C	=	318 K

Data Komponen Masuk Kondensor

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
H_2O	18,02	4.184,4743	232,2772
CH_2O	30,03	202,7614	6,7529
CH_3OH	32,04	49,3203	1,5392
Total		4.436,5560	240,5693

ΔH H_2O Masuk

$$= 232,277 \int_{298}^{350} \left[1.764,5 + -141,9 + 163,8 + -31,8 + 2,1 \right]$$

$$= 408.050,6206 \text{ kJ/Jam}$$

ΔH CH_2O Masuk

$$= 6{,}753 \int_{298}^{350} [\ 1.790{,}3 + -501{,}9 + 827{,}0 + -227{,}0 + 19{,}7\ ]$$

= 12.884,9387 kJ/Jam

ΔH CH_3OH Masuk

$$= 1{,}539 \int_{298}^{350} [\ 2.082{,}4 + -645{,}4 + 1.343{,}1 + -386{,}4 + 34{,}8\ ]$$

= 3.738,1013 kJ/Jam

Perhitungan Uap Air yang Tidak Terkondensasi

Uap yang tidak terkondensasi lebih kecil dari 1%

(Ludwig 3rd; hal. 376)

Asumsi, jumlah uap yang tidak terkondensasi = 0,9%

Data Komponen Keluar Kondensor

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
H_2O $_{Uap}$	18,02	37,6603	2,0905
H_2O $_{Terkondensasi}$	18,02	4.146,8140	230,1867
CH_2O uap	30,03	1,8249	0,0608
CH_2O $_{Terkondensasi}$	30,03	200,9365	6,6921
CH_3OH uap	32,04	0,4439	0,0139
CH_3OH $_{Terkondensasi}$	32,04	48,8765	1,5254
Total		4.436,5560	240,5693

ΔH H_2O Tidak Terkondensasi

$$= 2{,}090 \int_{298}^{350} [\ 1.764{,}5 + -141{,}9 + 163{,}8 + -31{,}8 + 2{,}1\ ]$$

= 3.672,4556 kJ/Jam

ΔH CH_2O Tidak Terkondensasi

$$= 0{,}061 \int_{298}^{350} [\ 1.790{,}3 + -501{,}9 + 827{,}0 +$$

-227,0 + 19,7]

= 115,9644 kJ/Jam

ΔH CH_3OH Tidak Terkondensasi

$= 0,014 \int_{298}^{350} [\ 2.082,4 + -645,4 + 1.343,1 +$

$-386,4 + 34,8\ ]$

= 33,6429 kJ/Jam

ΔH H_2O Terkondensasi

$= 230,187 \int_{298}^{319} [\ 1.933,1 + -259,0 + -422,3 +$

$330,5 + 0,0\ ]$

= 364.235,7938 kJ/Jam

ΔH CH_2O Terkondensasi

$= 6,692 \int_{298}^{319} [\ 723,0 + -193,0 + 302,3 +$

$-78,7 + 6,5\ ]$

= 5.086,0624 kJ/Jam

ΔH CH_3OH Terkondensasi

$= 1,525 \int_{298}^{319} [\ 843,2 + 2.012,3 + -2.059,6 +$

$902,4 + 0,0\ ]$

= 2.590,6318 kJ/Jam

Perhitungan Panas Laten H_2O Terkondensasi

$\lambda_{45°C}$ = 2.394,9 kJ / kg

(Smith 9th; hal. 698, Appendix E)

= 9.931.204,9568 kJ / Jam

Data Enthalpy Komponen Masuk dan Keluar

Komponen	ΔH (kJ/Jam)
Masuk	424.673,6606
Keluar	375.734,5509

Perhitungan Q Serap

ΔH Masuk = ΔH Keluar + Q serap

(Himmelblau 5th, hal. 410, eq - 4.22)

424.673,6606 kJ / Jam = 375.734,5509 kJ / Jam + Q serap

Q serap = 48.939,1096 kJ/jam

Perhitungan Kebutuhan Air Pendingin

$$Q\ serap = m^{Air}\ C_p^{\ Air}\ \Delta T$$

$$m\ Air = \frac{Q\ serap}{C_p \times \Delta T}$$

$$= \frac{48939{,}1096\ \text{kJ/jam}}{4{,}180\ \text{kJ/kg} \times (318\ K - 303\ K)}$$

$$= 780{,}5281\ \text{kg/jam}$$

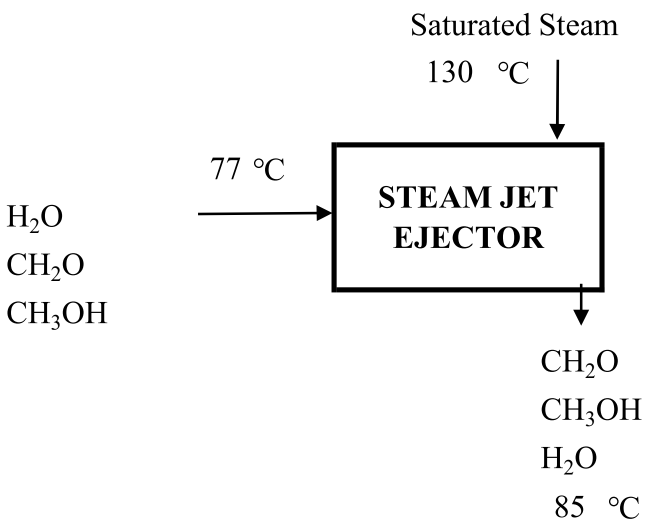
$$= 0{,}7805\ \text{ton/jam}$$

Neraca Energi Kondensor

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		**Tidak Terkondensasi**	
H_2O	408.050,6206	H_2O	3.672,4556
CH_2O	12.884,9387	CH_2O	115,9644
CH_3OH	3.738,1013	CH_3OH	33,6429
		Terkondensasi	
		H_2O	364.235,7938
		Q_{Serap}	48.939,1096
		CH_2O	5.086,0624
		CH_3OH	2.590,6318
Total	424.673,6606	**Total**	424.673,6606

9. STEAM JET EJECTOR

Kode = G - 322



Kondisi Operasi:

Temperatur = 85 °C = 358 K

Tekanan = 0,4 atm

$T_{\text{Komponen masuk}}$ = 77 °C = 350 K

$T_{\text{Komponen keluar}}$ = 85 °C = 358 K

Data Komponen Masuk Steam jet Ejector

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
H_2O	18,02	37,6603	2,0905
CH_2O	30,03	1,8249	0,0608
CH_3OH	32,04	0,4439	0,0139
Total		39,9290	2,1651

ΔH H_2O Masuk

$$= \quad 2,090 \int_{298}^{350} [\ 1.764,5 \ + \ -141,9 \ + \ 163,8 \ + \ -31,8 \ + \ 2,1\ ]$$

= 3.672,4556 kJ/Jam

ΔH CH_2O Masuk

$$= \quad 0,061 \int_{298}^{350} [\ 1.790,3 \ + \ -501,9 \ + \ 827,0 \ +$$

-227,0 + 19,7]

= 115,9644 kJ/Jam

ΔH CH_3OH Masuk

$$= 0{,}014 \int_{298}^{350} [\ 2.082{,}4 + -645{,}4 + 1.343{,}1 + -386{,}4 + 34{,}8\ ]$$

= 33,6450 kJ/Jam

Data Komponen Keluar Steam jet Ejector

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
H_2O	18,02	37,6603	2,0905
CH_2O	30,03	1,8249	0,0608
CH_3OH	32,04	0,4439	0,0139
Total		39,9290	2,1651

ΔH H_2O Keluar

$$= 2{,}090 \int_{298}^{358} [\ 2.036{,}0 + -165{,}8 + 193{,}8 + -38{,}1 + 2{,}6\ ]$$

= 4.240,5492 kJ/Jam

ΔH CH_2O Keluar

$$= 0{,}061 \int_{298}^{358} [\ 2.065{,}7 + -586{,}3 + 978{,}6 + -272{,}2 + 24{,}0\ ]$$

= 134,2959 kJ/Jam

ΔH CH_3OH Keluar

$$= 0{,}014 \int_{298}^{358} [\ 2.409{,}1 + 6.112{,}6 + -6.667{,}5 + 3.120{,}9 + 0{,}0\ ]$$

= 68,9260 kJ/Jam

Data Enthalpy Komponen Masuk dan Keluar

Komponen	ΔH (kJ/Jam)
Masuk	3.822,0650
Keluar	4.443,7712

Perhitungan Q Supply

$$H_{\text{bahan masuk}} + Q_{\text{supply}} = H_{\text{bahan keluar}} + Q_{\text{loss}}$$

$$3.822,1 \text{ kJ/Jam} + Q_{\text{supply}} = 4.443,8 \text{ kJ/Jam} + (5\%\ Q_{\text{Supply}})$$

$$95\ \%\ (Q_{\text{supply}}) = H_{\text{bahan keluar}} - H_{\text{bahan masuk}}$$

$$= 4.443,7712 \text{ kJ/Jam} - 3.822,0650 \text{ kJ/Jam}$$

$$= 621,7061 \text{ kJ/Jam}$$

$$Q_{\text{supply}} = 654,4275 \text{ kJ/Jam}$$

$$Q_{\text{loss}} = 32,7214 \text{ kJ/Jam}$$

Perhitungan Kebutuhan Steam

$$m \text{ Steam} = \frac{Q_{\text{supply}}}{H_{\text{saturated steam}}}$$

$$= \frac{654,4275 \text{ kJ/Jam}}{2.719,9 \text{ kJ/kg}}$$

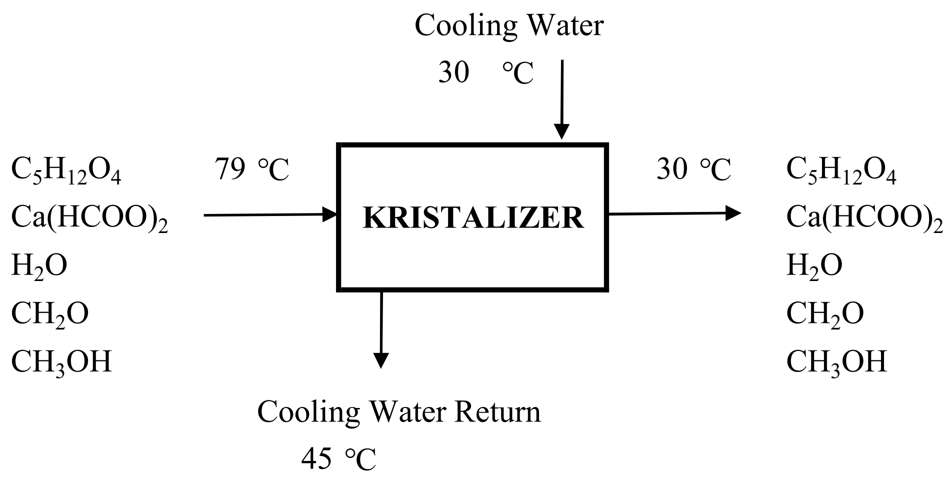
$$= 0,2406 \text{ kg/Jam}$$

Neraca Energi Steam Jet Ejector

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		**Tidak Terkondensasi**	
H_2O	3.672,4556	H_2O	4.240,5492
Q_{Supply}	654,4275	Q_{Loss}	32,7214
CH_2O	115,9644	CH_2O	134,2959
CH_3OH	33,6450	CH_3OH	68,9260
Total	4.476,4925	**Total**	4.476,4925

10. KRISTALIZER

Kode = S - 330



Kondisi Operasi:

Temperatur	=	30 °C	=	303 K
Tekanan	=	1 atm		
$T_{\text{Komponen masuk}}$	=	79 °C	=	353 K
$T_{\text{Komponen keluar}}$	=	30 °C	=	303 K
$T_{\text{Air Pendingin in}}$	=	30 °C	=	303 K
$T_{\text{Air Pendingin out}}$	=	45 °C	=	318 K

Data Komponen Masuk Kristalizer

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
$C_5H_{12}O_{4\,(aq)}$	136,15	5.253,7253	38,5878
$Ca(HCOO)_{2\,(aq)}$	130,11	5.020,6552	38,5878
H_2O	18,02	4.136,7916	229,6304
CH_2O	30,03	173,7955	5,7882
CH_3OH	32,04	42,2746	1,3194
Total		14.627,2422	313,9135

ΔH $C_5H_{12}O_4$ Masuk

$$= 38{,}588 \int_{298}^{353} [\ -77.728{,}2 + 168.363{,}2 + -96.201{,}0 + 19.493{,}3 + 0{,}0\ ]$$

$= 537.424{,}1812$ kJ/Jam

ΔH $Ca(HCOO)_2$ Masuk

= 38,588 kmol/jam x 118,83 J/mol x (353 K - 298 K)

= 38,588 kmol/jam x 118,83 kJ/kmol x (54)

= 249.284,4445 kJ/Jam

ΔH H_2O Masuk

$$= 229,630 \int_{298}^{353} [\ 5.004,5 + -706,6 + -1.217,1 + 1.007,9 + 0,0\ ]$$

= 938.875,4359 kJ/Jam

ΔH CH_2O Masuk

$$= 5,788 \int_{298}^{353} [\ 1.871,7 + -526,7 + 871,1 + -240,0 + 0,0\ ]$$

= 11.437,8659 kJ/Jam

ΔH CH_3OH Masuk

$$= 1,319 \int_{298}^{353} [\ 2.182,9 + 5.491,0 + -5.935,3 + 2.751,8 + 0,0\ ]$$

= 5.924,7635 kJ/Jam

Data Komponen Keluar Kristalizer

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
H_2O	18,02	4.136,7916	229,6304
$C_5H_{12}O_{4\ (aq)}$	136,15	2,3166	0,0170
$C_5H_{12}O_{4\ (s)}$	136,15	5.251,4087	38,5708
$Ca(HCOO)_{2\ (aq)}$	130,11	5.020,6552	38,5878
CH_2O	30,03	173,7955	5,7882
CH_3OH	32,04	42,2746	1,3194
Total		14.411,1721	306,8059

ΔH $C_5H_{12}O_4$ Keluar Sebagai Kristal

$$= 38,5708 \int_{298}^{303} [\ 3.473,9 + -5.600,7 + 3.083,3 +$$

$0{,}0 \quad + \quad 0{,}0 \quad]$

= 36.895,8248 kJ/Jam

ΔH $C_5H_{12}O_4$ Keluar

$= \quad 0{,}0170 \int_{298}^{303} [\quad -7.148{,}7 \quad + \quad 14.309{,}7 \quad + \quad -7.538{,}7 \quad +$

$1.405{,}2 \quad + \quad 0{,}0 \quad]$

= 17,4829 kJ/Jam

ΔH $Ca(HCOO)_2$ Keluar

= 38,5878 kmol/jam x 118,83 J/mol x (303 K - 298 K)

= 38,5878 kmol/jam x 118,83 kJ/kmol x (5)

= 22.926,9255 kJ/Jam

ΔH H_2O Keluar

$= \quad 229{,}6304 \int_{298}^{303} [\quad 460{,}3 \quad + \quad -60{,}1 \quad + \quad -95{,}4 \quad +$

$72{,}7 \quad + \quad 0{,}0 \quad]$

= 86.682,3476 kJ/Jam

ΔH CH_2O Keluar

$= \quad 5{,}7882 \int_{298}^{303} [\quad 172{,}1 \quad + \quad -44{,}8 \quad + \quad 68{,}3 \quad +$

$-17{,}3 \quad + \quad 0{,}0 \quad]$

= 1.032,2408 kJ/Jam

ΔH CH_3OH Keluar

$= \quad 1{,}3194 \int_{298}^{303} [\quad 200{,}8 \quad + \quad 466{,}7 \quad + \quad -465{,}1 \quad +$

$198{,}4 \quad + \quad 0{,}0 \quad]$

= 528,7156 kJ/Jam

Perhitungan Heat of Crystalization

$\Delta H_{Solution}$ = 198,07 kJ/kmol

$Q_{Kristalisasi}$ = m x $\Delta H_{Solution}$

= 38,5708 kmol x 198,07 kJ/kmol
= 7.639,7101 kJ/Jam

Data Enthalpy Komponen Masuk dan Keluar

Komponen	ΔH (kJ/Jam)
Masuk	1.742.946,6910
Keluar	148.083,5371

Perhitungan Q Serap

ΔH Masuk + Q Kristalisasi = ΔH Keluar + Q serap

(Himmelblau 5th, hal. 410, eq - 4.22)

1.742.946,7 kJ / Jam + 7.639,7 kJ/Jan = 148.083,5 kJ / Jam + Q serap

Q serap = 1.602.502,8639 kJ/jam

Perhitungan Kebutuhan Air Pendingin

$$Q\ serap = m^{Air}\ C_p^{\ Air}\ \Delta T$$

$$m\ Air = \frac{Q\ serap}{C_p\ x\ \ \Delta T}$$

$$= \frac{1.602.502,8639\ \ kJ/jam}{4,180\ \ kJ/kg\ \ x\ \ (\ 318\ \ K\ -\ 303\ \ K\ )}$$

= 25.558,2594 kg/jam
= 25,5583 ton/jam

Neraca Energi Kristalizer

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		**Kristal Keluar**	
H_2O	938.875,4359	$C_5H_{12}O_4$	36.895,8248
$C_5H_{12}O_4$	537.424,1812	**Campuran Keluar**	
$Ca(HCOO)_2$	249.284,4445	H_2O	86.682,3476
$Q_{Kristalisasi}$	7.639,7101	$C_5H_{12}O_4$	17,4829
CH_2O	11.437,8659	$Ca(HCOO)_2$	22.926,9255
CH_3OH	5.924,7635	CH_2O	1.032,2408
		CH_3OH	528,7156
		Q_{Serap}	1.602.502,8639
Total	1.750.586,4011	**Total**	1.750.586,4011

11. ROTARY DRYER

Kode = B - 350

H_2O
$C_5H_{12}O_4$
$Ca(HCOO)_2$
$CH_2O_{(l)}$
$CH_3OH_{(l)}$
Udara Panas
47 °C

90 °C

H_2O
$C_5H_{12}O_4$
$Ca(HCOO)_2$
$CH_2O_{(l)}$
$CH_3OH_{(l)}$
30 °C

ROTARY DRYER

Udara Panas

47 °C
H_2O
$C_5H_{12}O_4$
$Ca(HCOO)_2$
$CH_2O_{(l)}$
$CH_3OH_{(l)}$

Kondisi Operasi:

Temperatur	=	120 °C	=	393 K			
Tekanan	=	1 atm					
$T_{\text{Komponen masuk}}$	=	30 °C	=	303 K			
$T_{\text{Komponen keluar}}$	=	47 °C	=	320 K			
$T_{\text{Wet Bulb}}$ (t_W)	=	35 °C	=	308 K	=	95	°F
$T_{\text{Dry Bulb}}$ (t_{G1})	=	90 °C	=	363 K	=	194	°F

Kelembapan Udara di Subang, Jawa Barat, Indonesia

Jumat, 21 Februari 2025 = 66% ***(The Weather Channel)***

Berat Molekul Udara = 28,96 kg/kmol

(Perry 8th; hal. 2-176, Tabel 2-156)

Perhitungan Relative Humidity

$$\text{Relative Humidity} = 100 \times \frac{P_A}{P_{AS}}$$

Keterangan:

P_A = Vapor Pressure pada t_W (kPa) = 4,25 kPa

P_{AS} = Vapor Pressure pada t_G (kPa) = 70,14 kPa

(Geankoplis 5th; hal. 1646, App. A.2-9a)

$$\text{Relative Humidity} = 100 \times \frac{4,25}{70,14}$$

$$= 6,1\%$$

Dengan suhu t_G dan Relative Humidity yang diperoleh, didapatkan:

W_G = 0,028 lb/lb udara kering

(Himmelblau 9th; hal. 782, Fig. 10.8a)

Perhitungan Suhu Wet Bulb

$$W_W - W_G = \frac{h_G}{29 \times \lambda_W \times k_G} \left(t_G - t_W \right)$$

$$W_W - W_G = \left(\frac{h_G}{k_G \times M_G \times P} \right) \left(\frac{1}{\lambda_W} \right) \left(t_G - t_W \right)$$

(Badger; hal. 384, eq. 8-30)

$$\left(\frac{h_G}{k_G \times M_G \times P} \right) = 0,26$$

(Badger; hal. 384, Tabel 8-1)

Keterangan:

W_W = Humidity pada t_W

W_G = Humidity pada t_G

h_G = Heat transfer coefficient dari udara ke permukaan basah

k_G = Mass transfer coefficient dari permukaan basah ke udara

M_G = Molecular Weight Udara

P = Tekanan Operasi

t_G = Suhu Udara Panas masuk Dryer (°F)

t_W = Suhu Wet Bulb (°F)

λ_W = Panas Laten Udara pada t_W = 2403,7 kJ/kg

= 1033,4 Btu/lb ***(Smith 9th; hal. 698, Appendix E)***

$$W_W - W_G = \frac{0,26}{29 \times 1033,4 \text{ Btu/lb}} \left(194 \text{ °F} - 95 \text{ °F} \right)$$

$$= \frac{0,26}{29.967,2} \left(99 \right)$$

$$= 0,00086$$

$$W_W = 0,00086 + W_G$$

$$= 0,00086 + 0,028$$

$$= 0,02886$$

Perhitungan Suhu Udara Panas Keluar Dryer

$$NTU = \ln\left(\frac{t_{G1} - t_W}{t_{G2} - t_W}\right)$$ ***(Badger; hal. 508)***

Keterangan:

NTU = Number Transfer Unit = 1,5 ***(Badger; hal. 508)***

t_{G1} = Suhu Udara Panas masuk Dryer (°F)

t_{G2} = Suhu Udara Panas keluar Dryer (°F)

t_W = Suhu Wet Bulb (°F)

$$1{,}5 = \ln\left(\frac{194\ °F - 95\ °F}{t_{G2} - 95\ °F}\right)$$

$$4{,}48169 = \left(\frac{194\ °F - 95\ °F}{t_{G2} - 95\ °F}\right)$$

$$= \left(\frac{99\ °F}{t_{G2} - 95\ °F}\right)$$

t_{G2} = 117,09 °F

= 47,272 °C

Data Komponen Masuk Rotary Dryer

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
$C_5H_{12}O_{4\ (s)}$	136,15	5.251,4087	38,5708
$C_5H_{12}O_{4\ (aq)}$	136,15	0,1158	0,0009
$Ca(HCOO)_{2\ (aq)}$	130,11	251,0328	1,9294
H_2O	18,02	206,8396	11,4815
$CH_2O_{(l)}$	30,03	8,6898	0,2894
$CH_3OH_{(l)}$	32,04	2,1137	0,0660
Total		5.720,2004	52,3379

ΔH $C_5H_{12}O_4$ Masuk Sebagai Kristal

$$= 38{,}5708 \int_{298}^{303} [\ 3.473{,}9 + -5.600{,}7 + 3.083{,}3 + 0{,}0 + 0{,}0\ ]$$

= 36.895,8248 kJ/Jam

ΔH $C_5H_{12}O_4$ Masuk

$$= 0{,}0009 \int_{298}^{303} [\ -7.148{,}7 + 14.309{,}7 + -7.538{,}7 + 1.405{,}2 + 0{,}0\ ]$$

= 0,8741 kJ/Jam

ΔH $Ca(HCOO)_2$ Masuk

= 1,9294 kmol/jam x 118,83 J/mol x (303 K - 298 K)

= 1,9294 kmol/jam x 118,83 kJ/kmol x (5)

= 1146,3463 kJ/Jam

ΔH H_2O Masuk

$$= 11{,}4815 \int_{298}^{303} [\ 460{,}3 + -60{,}1 + -95{,}4 + 72{,}7 + 0{,}0\ ]$$

= 4.334,1174 kJ/Jam

ΔH CH_2O Masuk

$$= 0{,}2894 \int_{298}^{303} [\ 172{,}1 + -44{,}8 + 68{,}3 + -17{,}3 + 1{,}4\ ]$$

= 52,0127 kJ/Jam

ΔH CH_3OH Masuk

$$= 0{,}0660 \int_{298}^{303} [\ 200{,}8 + 466{,}7 + -465{,}1 + 198{,}4 + 0{,}0\ ]$$

= 26,4358 kJ/Jam

Data Komponen Keluar Menuju Cyclone

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
$C_5H_{12}O_{4\ (s)}$	136,15	52,5141	0,3857
$C_5H_{12}O_{4\ (aq)}$	136,15	0,1147	0,0008
$Ca(HCOO)_{2\ (aq)}$	130,11	248,5224	1,9101
H_2O	18,02	204,7712	11,3667
$CH_2O_{(l)}$	30,03	8,6029	0,2865
$CH_3OH_{(l)}$	32,04	2,0926	0,0653
Total		516,6178	14,0152

ΔH $C_5H_{12}O_{4\ Kristal}$ Menuju Cyclone

$$= 0{,}3857 \int_{298}^{320} [\ 15.474{,}3 + -25.664{,}4 + 14.540{,}8 + 0{,}0 + 0{,}0\ ]$$

= 1.678,0975 kJ/Jam

ΔH $C_5H_{12}O_4$ Menuju Cyclone

$$= 0{,}0008 \int_{298}^{320} [\ -31.843{,}6 + 65.572{,}7 + -35.552{,}2 + 6.822{,}9 + 0{,}0\ ]$$

= 4,2111 kJ/Jam

ΔH $Ca(HCOO)_2$ Menuju Cyclone

= 1,9101 kmol/jam x 118,83 J/mol x (320 K - 298 K)
= 1,9101 kmol/jam x 118,83 kJ/kmol x (22)
= 5.055,2580 kJ/Jam

ΔH H_2O Menuju Cyclone

$$= 11{,}3667 \int_{298}^{320} [\ 755{,}8 + -58{,}0 + 63{,}7 + -11{,}8 + 0{,}8\ ]$$

= 8.530,7834 kJ/Jam

ΔH CH_2O Menuju Cyclone

$$= 0{,}2865 \int_{298}^{320} [\ 766{,}8 + -205{,}1 + 321{,}9 +$$

-84,0 + 6,9]

= 231,0731 kJ/Jam

ΔH CH_3OH Menuju Cyclone

$$= 0{,}0653 \int_{298}^{320} [\ 894{,}3 + 2.138{,}6 + -2.193{,}5 + 963{,}2 + 0{,}0\ ]$$

= 117,7295 kJ/Jam

Data Komponen Keluar Menuju Cooling Conveyor

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
$C_5H_{12}O_{4\ (s)}$	136,15	5.198,8946	38,1851
$C_5H_{12}O_{4\ (aq)}$	136,15	0,0012	0,0000
$Ca(HCOO)_{2\ (aq)}$	130,11	2,5103	0,0193
H_2O	18,02	2,0684	0,1148
$CH_2O_{(l)}$	30,03	0,0869	0,0029
$CH_3OH_{(l)}$	32,04	0,0211	0,0007
Total		5.203,5826	38,3227

ΔH $C_5H_{12}O_4$ Kristal Menuju Cooling Conveyor

$$= 38{,}1851 \int_{298}^{320} [\ 15.474{,}3 + -25.664{,}4 + 14.540{,}8 + 0{,}0 + 0{,}0\ ]$$

= 166.131,6495 kJ/Jam

ΔH $C_5H_{12}O_4$ Menuju Cooling Conveyor

$$= 0{,}00001 \int_{298}^{320} [\ -31.843{,}6 + 65.572{,}7 + -35.552{,}2 + 6.822{,}9 + 0{,}0\ ]$$

= 0,0425 kJ/Jam

ΔH $Ca(HCOO)_2$ Menuju Cooling Conveyor

= 0,0193 kmol/jam x 118,83 J/mol x (320 K - 298 K)

= 0,0193 kmol/jam x 118,83 kJ/kmol x (22)

= 51,0632 kJ/Jam

ΔH H_2O Menuju Cooling Conveyor

$$= 0{,}1148 \int_{298}^{320} [\ 2.050{,}2 + -275{,}2 + -449{,}8 + 352{,}8 + 0{,}0\ ]$$

= 192,6590 kJ/Jam

ΔH CH_2O Menuju Cooling Conveyor

$$= 0{,}0029 \int_{298}^{320} [\ 766{,}8 + -205{,}1 + 321{,}9 + -84{,}0 + 6{,}9\ ]$$

= 2,3341 kJ/Jam

ΔH CH_3OH Menuju Cooling Conveyor

$$= 0{,}0007 \int_{298}^{320} [\ 894{,}3 + 2.138{,}6 + -2.193{,}5 + 963{,}2 + 0{,}0\ ]$$

= 1,1892 kJ/Jam

Data Enthalpy Komponen Masuk dan Keluar

Komponen	ΔH (kJ/Jam)
Masuk	42.455,6111
Keluar	181.996,0901

Data Enthalpy Udara

Komponen	Cp (Btu/lb.°F)	T °C	T °F	T ref °F	ΔT	Cp.ΔT Btu/lb	Cp.ΔT kJ/kg
Udara	0,251	90	194	77	117	29,3670	68,3076
	0,249	47	117		40	9,9824	23,2190

(Kern; hal. 805, App. Fig. 3)

Perhitungan Neraca Energi

$H_{\text{bahan masuk}} + Q_{\text{Udara in}} = H_{\text{bahan keluar}} + Q_{\text{Udara out}}$

42.455,6 + n x 68,3076 = 181.996,0901 + n x 23,2190

n x 68,3076 - n x 23,2190 = 181.996,0901 - 42.455,6111

n x 45,0886 = 139.540,4790

$$n = \frac{139.540,4790}{45,0886}$$

Udara yang diperlukan = 3.094,8047 kg/Jam

Perhitungan Entalpi Udara

Q = m . Cp . ΔT

$Q_{\text{Udara Masuk}}$ = 3.094,8047 kg x 68,3076 kJ/kg

= 211.398,8090 kJ/Jam

$Q_{\text{Udara Keluar}}$ = 3.094,8047 kg x 23,2190 kJ/kg

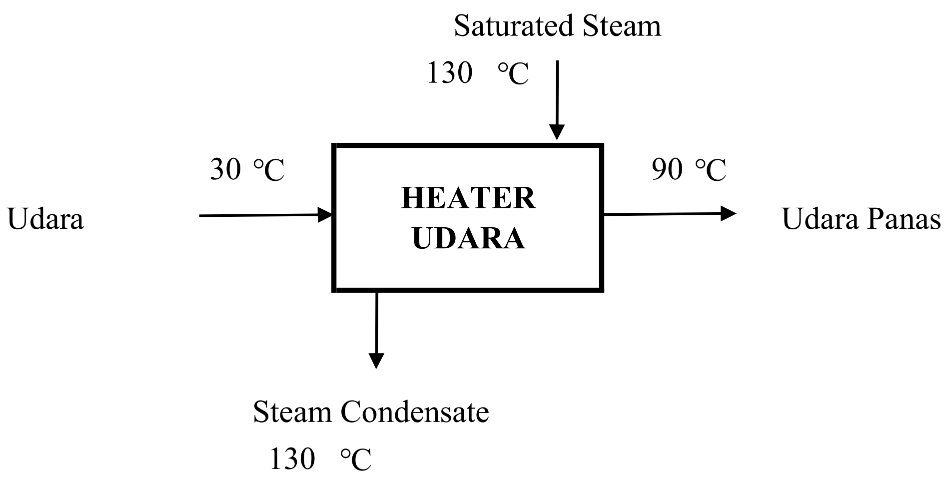
= 71.858,3300 kJ/Jam

Neraca Energi Rotary Dryer

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		**Menuju Cyclone**	
$C_5H_{12}O_{4\,(S)}$	36.895,8248	$C_5H_{12}O_{4\,(S)}$	1.678,0975
$C_5H_{12}O_4$	0,8741	$C_5H_{12}O_4$	4,2111
$Ca(HCOO)_2$	1.146,3463	$Ca(HCOO)_2$	5.055,2580
H_2O	4.334,1174	H_2O	8.530,7834
$CH_2O_{(l)}$	52,0127	$CH_2O_{(l)}$	231,0731
$CH_3OH_{(l)}$	26,4358	$CH_3OH_{(l)}$	117,7295
		Menuju Cooling Conveyor	
		$C_5H_{12}O_{4\,(S)}$	166.131,6495
		$C_5H_{12}O_4$	0,0425
		$Ca(HCOO)_2$	51,0632
		H_2O	192,6590
		$CH_2O_{(l)}$	2,3341
		$CH_3OH_{(l)}$	1,1892
$Q_{\text{Udara Masuk}}$	211.398,8090	$Q_{\text{Udara Keluar}}$	71.858,3300
Total	253.854,4201	**Total**	253.854,4201

12. HEATER UDARA

Kode = E - 354



Kondisi Operasi:

Temperatur	=	120 °C	=	393 K				
Tekanan	=	1 atm						
$T_{\text{Komponen masuk}}$	=	30 °C	=	303 K	=	86	°F	
$T_{\text{Komponen keluar}}$	=	90 °C	=	363 K	=	194	°F	
$T_{\text{reference}}$	=	25 °C	=	298 K	=	77	°F	

Data Komponen Dalam Heater Udara

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
Udara	28,96	3.094,8047	106,8648
Total		3.094,8047	106,8648

Data Enthalpy Udara

Komponen	Cp (Btu/lb.°F)	T °C	T °F	T_{ref} °F	ΔT	Cp.ΔT	
						Btu/lb	kJ/kg
Udara	0,247	30	86	77	9	2,2230	5,1707
	0,251	90	194		117	29,3670	68,3076

(Kern; hal. 805, App. Fig. 3)

Perhitungan Entalpi Udara

$Q = m \cdot Cp \cdot \Delta T$

$Q_{\text{Udara Masuk}}$ = 3.094,8047 kg x 5,1707 kJ/kg
= 16.002,3003 kJ/Jam

$Q_{\text{Udara Keluar}}$ = 3.094,8047 kg x 68,3076 kJ/kg
= 211.398,8090 kJ/Jam

Data Enthalpy Komponen Masuk dan Keluar

Komponen	ΔH (kJ/Jam)
Masuk	16002,3003
Keluar	211398,8090

Perhitungan Q Supply

$H_{\text{bahan masuk}} + Q_{\text{supply}} = H_{\text{bahan keluar}} + Q_{\text{loss}}$

16.002,3 kJ/Jam + Q_{supply} = 211.398,8 kJ/Jam + (5% Q_{Supply})

95 % (Q_{supply}) = $H_{\text{bahan keluar}} - H_{\text{bahan masuk}}$

= 211.398,8090 kJ/Jam - 16.002,3003 kJ/Jam

= 195.396,5087 kJ/Jam

Q_{supply} = 205.680,5355 kJ/Jam

Q_{loss} = 10.284,0268 kJ/Jam

Perhitungan Kebutuhan Steam

$$m\ \text{Steam} = \frac{Q_{\text{supply}}}{\lambda_{\text{saturated steam}}}$$

$$= \frac{205.680,5355\ \text{kJ/Jam}}{2.173,6000\ \text{kJ/kg}}$$

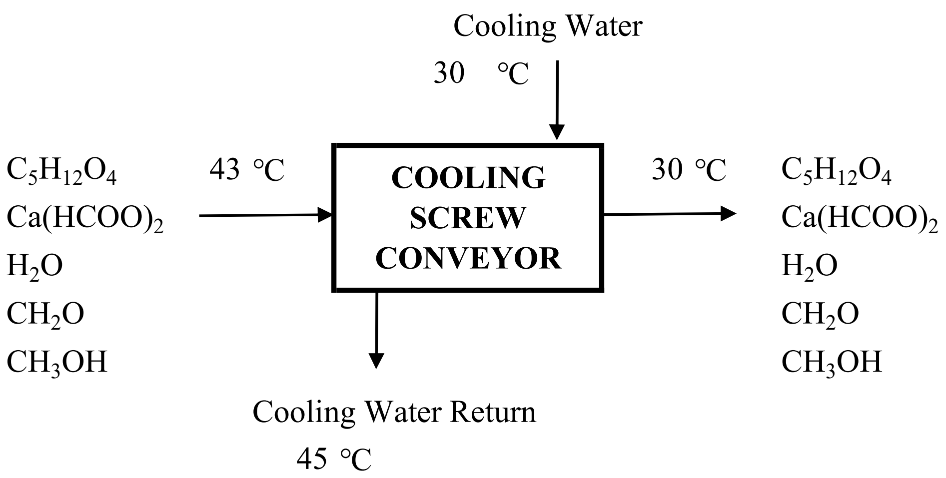
= 94,6267 kg/Jam

Neraca Energi Heater Udara

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk		**Keluar**	
Udara	16.002,3003	Udara	211.398,8090
Q_{Supply}	205.680,5355	Q_{Loss}	10.284,0268
Total	221.682,8358	**Total**	221.682,8358

13. COOLING SCREW CONVEYOR

Kode = J - 355



Temperatur = 30 °C = 303 K

Tekanan = 1 atm

$T_{\text{Komponen masuk}}$ = 43 °C = 316 K

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

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

$T_{\text{Air Pendingin out}}$ = 45 °C = 318 K

Data Komponen Masuk Cooling Screw Conveyor dari Rotary Dryer

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
$C_5H_{12}O_{4\,(s)}$	136,15	5.248,7830	38,5515
$C_5H_{12}O_{4\,(aq)}$	136,15	0,0069	0,0001
$Ca(HCOO)_{2\,(aq)}$	130,11	14,9364	0,1148
H_2O	18,02	12,3070	0,6832
CH_2O	30,03	0,0869	0,0029
CH_3OH	32,04	2,1137	0,0660
Total		5.278,2339	39,4183

ΔH $C_5H_{12}O_4$ Masuk Sebagai Kristal dari Rotary Dryer

$$= 38{,}5515 \int_{298}^{316} [\ 12.506{,}0 + -20.598{,}3 + 11.588{,}2 + 0{,}0 + 0{,}0\ ]$$

= 134.774,4162 kJ/Jam

ΔH $C_5H_{12}O_4$ Masuk dari Rotary Dryer

$$= 0{,}0001 \int_{298}^{316} \left[-25.735{,}4 + 52.628{,}8 + -28.333{,}1 + 5.398{,}3 + 0{,}0 \right]$$

= 0,2004 kJ/Jam

ΔH $Ca(HCOO)_2$ Masuk dari Rotary Dryer

= 0,1148 kmol/jam x 118,83 J/mol x (316 K - 298 K)

= 0,1148 kmol/jam x 118,83 kJ/kmol x (18)

= 245,5474 kJ/Jam

ΔH H_2O Masuk dari Rotary Dryer

$$= 0{,}6832 \int_{298}^{316} \left[1.657{,}0 + -220{,}9 + -358{,}5 + 279{,}1 + 0{,}0 \right]$$

= 926,8506 kJ/Jam

ΔH CH_2O Masuk dari Rotary Dryer

$$= 0{,}0029 \int_{298}^{316} \left[619{,}7 + -164{,}6 + 256{,}6 + -66{,}5 + 5{,}4 \right]$$

= 1,8829 kJ/Jam

ΔH CH_3OH Masuk dari Rotary Dryer

$$= 0{,}0660 \int_{298}^{316} \left[722{,}7 + 1.716{,}4 + -1.748{,}1 + 762{,}1 + 0{,}0 \right]$$

= 95,8687 kJ/Jam

Data Komponen Masuk Cooling Screw Conveyor dari Cyclone

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
$C_5H_{12}O_{4\ (s)}$	136,15	49,8884	0,3664
$C_5H_{12}O_{4\ (aq)}$	136,15	0,0057	0,0000
$Ca(HCOO)_{2\ (aq)}$	130,11	12,4261	0,0955
H_2O	18,02	10,2386	0,5683
CH_2O	30,03	0,4301	0,0143
CH_3OH	32,04	0,1046	0,0033
Total		73,0936	1,0479

ΔH $C_5H_{12}O_4$ Masuk Sebagai Kristal dari Cyclone

$$= 0{,}3664 \int_{298}^{316} [\ 12.506{,}0 + -20.598{,}3 + 11.588{,}2 + 0{,}0 + 0{,}0\ ]$$

= 1.280,9975 kJ/Jam

ΔH $C_5H_{12}O_4$ Masuk dari Cyclone

$$= 0{,}00004 \int_{298}^{316} [\ -25.735{,}4 + 52.628{,}8 + -28.333{,}1 + 5.398{,}3 + 0{,}0\ ]$$

= 0,1667 kJ/Jam

ΔH $Ca(HCOO)_2$ Masuk dari Cyclone

= 0,0955 kmol/jam x 118,83 J/mol x (316 K - 298 K)

= 0,0955 kmol/jam x 118,83 kJ/kmol x (18)

= 204,2789 kJ/Jam

ΔH H_2O Masuk dari Cyclone

$$= 0{,}5683 \int_{298}^{316} [\ 1.657{,}0 + -220{,}9 + -358{,}5 + 279{,}1 + 0{,}0\ ]$$

= 771,0774 kJ/Jam

ΔH CH_2O Masuk dari Cyclone

$$= 0{,}0143 \int_{298}^{316} [\ 619{,}7 + -164{,}6 + 256{,}6 +$$

-66,5 + 5,4]

= 9,3202 kJ/Jam

ΔH CH_3OH Masuk dari Cyclone

$$= 0{,}0033 \int_{298}^{316} [\ 722{,}7 + 1.716{,}4 + -1.748{,}1 +$$

$$762{,}1 + 0{,}0\ ]$$

= 4,7455 kJ/Jam

Data Komponen Keluar Cooling Conveyor

Komponen	BM (kg/kmol)	Massa (kg/jam)	Rate mol (kmol/jam)
$C_5H_{12}O_{4\ (s)}$	136,15	5.248,7830	38,5515
$C_5H_{12}O_{4\ (aq)}$	136,15	0,0069	0,0001
$Ca(HCOO)_{2\ (aq)}$	130,11	14,9364	0,1148
H_2O	18,02	12,3070	0,6832
CH_2O	30,03	0,5170	0,0172
CH_3OH	32,04	2,2184	0,0692
Total		5.278,7687	39,4359

ΔH $C_5H_{12}O_4$ Keluar Sebagai Kristal

$$= 38{,}5515 \int_{298}^{303} [\ 3.473{,}9 + -5.600{,}7 + 3.083{,}3 +$$

$$0{,}0 + 0{,}0\ ]$$

= 36.877,3768 kJ/Jam

ΔH $C_5H_{12}O_4$ Keluar

$$= 0{,}0001 \int_{298}^{303} [\ -7.148{,}7 + 14.309{,}7 + -7.538{,}7 +$$

$$1.405{,}2 + 0{,}0\ ]$$

= 0,0520 kJ/Jam

ΔH $Ca(HCOO)_2$ Keluar

= 0,1148 kmol/jam x 118,83 J/mol x (303 K - 298 K)

= 0,1148 kmol/jam x 118,83 kJ/kmol x (5)

= 68,2076 kJ/Jam

ΔH H_2O Keluar

$$= 0{,}6832 \int_{298}^{303} [\ 460{,}3 + -60{,}1 + -95{,}4 + 72{,}7 + 0{,}0\ ]$$

= 257,8800 kJ/Jam

ΔH CH_2O Keluar

$$= 0{,}0172 \int_{298}^{303} [\ 172{,}1 + -44{,}8 + 68{,}3 + -17{,}3 + 1{,}4\ ]$$

= 3,0948 kJ/Jam

ΔH CH_3OH Keluar

$$= 0{,}0692 \int_{298}^{303} [\ 200{,}8 + 466{,}7 + -465{,}1 + 198{,}4 + 0{,}0\ ]$$

= 27,7444 kJ/Jam

Data Enthalpy Komponen Masuk dan Keluar

Komponen	ΔH (kJ/Jam)
Masuk	138.315,3522
Keluar	37.234,3555

Perhitungan Q Serap

ΔH Masuk = ΔH Keluar + Q serap

(Himmelblau 5th, hal. 410, eq - 4.22)

138.315,3522 kJ / Jam = 37.234,3555 kJ / Jam + Q serap

Q serap = 101.080,9967 kJ/jam

Perhitungan Kebutuhan Air Pendingin

$$Q\ serap = m^{Air}\ C_p^{\ Air}\ \Delta T$$

$$m\ Air = \frac{Q\ serap}{C_p \times \Delta T}$$

$$= \frac{101.080,9967 \text{ kJ/jam}}{4,180 \text{ kJ/kg} \times (318 \text{ K} - 303 \text{ K})}$$

$= 1.612,1371$ kg/jam

$= 1,6121$ ton/jam

Neraca Energi Cooling Screw Conveyor

Komponen	Energi (kJ/jam)	Komponen	Energi (kJ/jam)
Masuk dari Rotary Dryer		**Keluar**	
$C_5H_{12}O_{4\,(s)}$	134.774,4162	$C_5H_{12}O_{4\,(s)}$	36.877,3768
$C_5H_{12}O_{4\,(aq)}$	0,2004	$C_5H_{12}O_{4\,(aq)}$	0,0520
$Ca(HCOO)_{2\,(aq)}$	245,5474	$Ca(HCOO)_{2\,(aq)}$	68,2076
H_2O	926,8506	H_2O	257,8800
CH_2O	1,8829	CH_2O	3,0948
CH_3OH	95,8687	CH_3OH	27,7444
Masuk dari Cyclone		Q_{Serap}	101.080,9967
$C_5H_{12}O_{4\,(s)}$	204,2789		
$C_5H_{12}O_{4\,(aq)}$	0,1667		
$Ca(HCOO)_{2\,(aq)}$	1.280,9975		
H_2O	771,0774		
CH_2O	9,3202		
CH_3OH	4,7455		
Total	138.315,3522	**Total**	138.315,3522

APPENDIX C

PERHITUNGAN SPESIFIKASI ALAT

Kapasitas Produksi = 42.000 ton/tahun
Waktu Operasi = 1 tahun = 331 hari
= 1 hari = 24 jam

Kapasitas Produksi = 42.000 ton/tahun
= 5,2870 ton / jam
= 5.287,0091 kg / jam
Basis Asetaldehid (99%) = 1.717,0000 kg / jam

1. TANGKI PENYIMPANAN FORMALDEHID

Kode Alat : F - 110
Fungsi : Menyimpan Formaldehid untuk Keperluan Produksi
Tipe : Tangki Silinder Tegak dengan Tutup Atas Torishperical Dish Head dan Tutup Bawah Datar
Material Konstruksi : *Stainless Steel 316 SA-167, Grade 11*
Dasar Pemilihan : Ekonomis dan umum digunakan untuk Fluida, disertai dengan Material untuk Bahan Korosif
Tekanan : 1 atm
Temperatur : 30 °C
Waktu Penyimpanan : 4 hari

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$CH_2O_{(aq)}$	37%	5.213,8642	0,7261	726,0991	45,3304
$CH_3OH_{(aq)}$	1%	140,9152	0,7827	782,6686	48,8620
$H_2O_{(l)}$	62%	8.736,7453	1,0229	1.022,8753	63,8581
Total	100%	14.091,5248			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

= 0,886 x 63,858 lb/cuft
= 56,5875 lb/cuft

Rate Massa = 14.091,5248 kg/jam

= 31.068,9938 lb/jam

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

= $\frac{31.068,9938 \text{ lb / Jam}}{56,5875 \text{ lb / cuft}}$

= 549,0431 cuft / Jam

Volume Komponen = Rate Volumetrik x Waktu Penyimpanan

= 549,04 cuft / Jam x 4 hari

= 52.708,1376 cuft

= 1.492,5142 m^3

= 1.492.525,7906 Liter

Direncanakan untuk penyimpanan dengan 6 buah tangki
(mempermudah pengeluaran dan pengisian), sehingga volume bahan:

Volume Komponen = $\frac{52.708,1376 \text{ cuft}}{6 \text{ Tangki}}$

= 8.784,6896 cuft

Dilakukan pengisian bahan sebanyak 80% volume (faktor keamanan)

Volume Bahan = 80% dari volume Tangki Penyimpanan

Volume Tangki (V_S) = $\frac{8.784,6896 \text{ cuft}}{80\%}$

= 10.980,8620 cuft

Perhitungan Dimensi Tangki

Tinggi (H) = 2 Diameter (D) ***(Ulrich; hal. 248; Tabel 4-27)***

$V_S = \frac{1}{4} \pi D^2 H$

$V_S = \frac{3,14}{4} \times 2 \times Ds^3$

$V_S = 1,57 \ Ds^3$

V tutup atas torispherical dish = 0,000049 Ds^3

(Brownell; hal. 88; eq. 5.11)

Volume Tangki = V_S + V tutup atas

10.980,8620 cuft = 1,57 Ds^3 + 0,000049 Ds^3

10.980,8620 cuft = 1,57 Ds^3

Ds^3 = 6.993,9613 cuft

Ds = 19,1238 ft = 229,4857 in = 5,8289 m

Hs = 38,2476 ft = 458,9714 in = 11,6579 m

Perhitungan Tinggi Komponen

Volume Bahan $= \frac{1}{4} \pi \; Ds^2 \; H_{liq}$

$8.784,6896 \text{ cuft} = \frac{3,14}{4} \times 19,1238^2 \times H_{liq}$

H_{liq} = 30,5991 ft = 367,1886 in = 9,3266 m

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

P = 1 atm = 14,6959 Psi

P_{Inside} = 14,6959 Psi

$P_{Outside}$ = 14,6959 Psi

$P_{Design} = P_{Inside} - P_{Outside} + P_{Hidrostatis}$

$= 14,7 \text{ Psi} - 14,7 \text{ Psi} + P_{Hidrostatis}$

$P_{Design} = P_{Hidrostatis}$

$P_{Hidrostatis} = \rho \text{ Campuran} \times \frac{g}{gc} \times H_{liq}$

= 56,5875 lbm/cuft x 1 lbf/lbm x 30,5991 ft

= 1.731,5247 lb/ft^2

= 12,0341 Psi

P_{Design} dibuat berlebih 10% (faktor keamanan)

P_{Design} = 1,1 x 12,0341 Psi

= 13,2375 Psi

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

t_{min} = Tebal Shell Minimum (in)

P = Tekanan Tangki (Psi)

ri = Jari - jari Tangki (in) (1/2 D)

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167*

Grade 11

= 18.750 Psi **(*Brownell; hal. 342; App. D, Item 4)***

$$t_{min} = \frac{13{,}2375 \text{ Psi} \times 114{,}7429 \text{ in}}{15.000 \text{ Psi} - 7{,}9425 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{1.518{,}9093}{14.992{,}0575} + 0{,}125 \text{ in}$$

= 0,2263 in

= (Digunakan t_S = $\frac{9}{8}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Shell

$$\frac{9}{8} \text{ in} = \frac{13{,}2375 \text{ Psi} \times 114{,}7429 \text{ in}}{f \times 0{,}80 - 7{,}9425 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 1.908,5648 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tebal tutup atas

Tutup atas berbentuk Torispherical Dished Head

OD = ID + (2 t_S)

= 229,4857 in + 2 x 1,13

= 231,7357 in

= (Digunakan OD = 240 in)

(Brownell; hal.91; Tabel 5.7)

Diperoleh:

icr = 14,44 in = 1,2026 ft

r_C = 180 in = 14,9940 ft

Cek nilai icr dengan 6% rc:

icr = 14,44 in

6% rc = 10,80 in

karena nilai icr > 6% rc, maka menggunakan persamaan

$$t = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$

(Brownell; hal.138; eq. 7.77)

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

(Brownell; hal.138; eq. 7.76)

Keterangan:

W = Faktor Stress

Pd = Tekanan design (P_{Design})

r_C = Radius Crown

r_1 or icr = Inside Crown Radius

E = Faktor Pengelasan = 0,80

t = Tebal dinding minimal

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi ***(Brownell; hal. 251; Tabel 13-1)***

C = Faktor Korosi (in) = 0,125 in

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

$$= \frac{1}{4}\left(3 + \sqrt[2]{(180 \text{ in} / 14 \text{ in})}\right)$$

$$= 1{,}6327$$

$$t_{Head} = \frac{Pd \times r_C \times W}{2f\,E - 0{,}2\,Pd} + C$$

$$= \frac{13{,}2375 \text{ Psi} \times 180 \text{ in} \times 1{,}6327}{37.500 \text{ Psi} \times 0{,}8 - 2{,}6475 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= 0{,}2547 \text{ in}$$

$$= (\text{Digunakan } t = \frac{9}{8} \text{ in})$$

(Brownell; hal. 89; Tabel 5.7)

Untuk Tebal Tutup Bawah, karena ditopang oleh permukaan semen, digunakan:

$$t_{Bottom} = \frac{5}{16} \text{ in}$$

(Brownell; hal. 58)

Perhitungan Koreksi Stress Allowable Head

$$\frac{9}{8} \text{ in} = \frac{13{,}2375 \text{ Psi} \times 293{,}8923 \text{ in}}{2\,f \times 0{,}80 - 2{,}6475 \text{ Psi}} + 0{,}125 \text{ in}$$

$$f = 2.433{,}1552 \text{ Psi} < f_{Allowable} \text{ (memenuhi)}$$

Perhitungan tinggi tutup atas:

$$Di = 229{,}4857 \text{ in}$$

$$a = \frac{Di}{2}$$

$$= \frac{229{,}4857 \text{ in}}{2}$$

= 114,7429 in

icr = 14,44 in

r_C = 180 in **(Brownell; hal. 91; Tabel 5.7)**

AB = $\frac{Di}{2}$ - icr

= $\frac{229{,}4857 \text{ in}}{2}$ - 14,438 in

= 100,3054 in

BC = r_C - icr

= 180 in - 14,44 in

= 165,5625 in

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

= √(27.410,9414 in - 10.061,1647 in)

= 131,7186 in

b = r_C - AC

= 180 in - 131,7186 in

= 48,2814 in

sf = 3 in **(Brownell; hal. 93; Tabel 5.8)**

t_{Head} = 1,1250 in

OA = t_{Head} + b + sf

= 1,1250 in + 48,2814 in + 3 in

= 52,4064 in

Maka, tinggi tutup atas = 52,4064 in

= 1,3311 m

Spesifikasi Tangki Penyimpanan Formaldehid

Fungsi	:	Menyimpan Formaldehid untuk Keperluan Produksi
Tipe	:	Tangki Silinder Tegak dengan Tutup Atas Torishperical Dish Head dan Tutup Bawah Datar
Tekanan	:	1 atm
Kapasitas / Volume	:	10.980,8620 cuft = 310,7584 m^3
Diameter	:	19,1238 ft = 5,8287 m
Tinggi	:	38,2476 ft = 11,6573 m
Tebal Shell	:	1,1250 in = 0,0286 m

Tinggi tutup atas	:	52,4064 in	=	1,3311	m
Tebal tutup atas	:	1,1250 in	=	0,0286	m
Tebal tutup bawah	:	0,3125 in	=	0,0079	m
Bahan konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*			
Waktu Penyimpanan	:	4 hari			
Jumlah	:	6 tangki			

2. POMPA 1

Kode Alat	:	L - 111
Fungsi	:	Memindahkan Formaldehid Cair dari Tangki Penyimpanan Formaldehid menuju Reaktor Kondensasi
Tipe	:	Centrifugal Pump
Dasar Pemilihan	:	Sesuai untuk Fluida Liquid dengan Viskositas <10 Cp
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$CH_2O_{(aq)}$	37%	5.213,8642	0,7261	726,0991	45,3304
$CH_3OH_{(aq)}$	1%	140,9152	0,7827	782,6686	48,8620
$H_2O_{(l)}$	62%	8.736,7453	1,0229	1.022,8753	63,8581
Total	100%	14.091,5248			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

$$= 0{,}886 \times 63{,}858\ \text{lb/cuft}$$

$$= 56{,}5875\ \text{lb/cuft}$$

$$= 906{,}4474\ \text{kg/m}^3$$

Rate Massa = 14.091,5248 kg/jam

= 31.068,9938 lb/jam

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

$$= \frac{31.068{,}9938\ \text{lb / Jam}}{56{,}5875\ \text{lb / cuft}}$$

= 549,0431 cuft / Jam
= 9,1507 cuft / menit
= 0,1525 cuft / sec
= 68,4565 gal / min

Viskositas Bahan = $\frac{\text{sg Bahan} \times \mu \text{ Reference } (H_2O)}{\text{sg Reference}}$

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s
= 0,5065 Cps
= 0,0005 Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi
= 0,9960

sg Bahan = $\frac{\rho \text{ Bahan}}{\rho \text{ Reference } (H_2O)}$

= $\frac{45{,}4 \text{ lb/cuft}}{63{,}9 \text{ lb/cuft}}$

= 0,7113

Viskositas Bahan = $\frac{0{,}7113 \times 0{,}0005 \text{ Pa.s}}{0{,}9960}$

= 0,0004 lb/ft.s
= 0,0005 Ns/m^2
= 0,5383 Cps

Perhitungan ID Optimum

Asumsi Aliran Turbulen, dengan $N_{Re} > 2100$, digunakan rumus:

$ID_{Optimum} = 3{,}9 \; qf^{0,45} \; \rho^{0,13}$ ***(Peters 4th; hal. 496; eq. 15)***

Keterangan:

ID = Optimum Pipe Inside Diameter, in
qf = Fluid Flow Rate, cuft/sec
ρ = Fluid Density, lb/cuft

$ID_{Optimum}$ = 3,9 x 0,4290 cuft/sec x 1,6899 lb/cuft
= 2,8275 in

Perhitungan Pipa

Dipilih pipa:

IPS, Size = 3,0 in
OD = 3,5000 in
Schedule = No. 40

ID = 3,0680 in *(McCabe7th; hal. 1090; App. 3)*
= 0,2557 ft
= 0,0779 m

$A_1 = \frac{1}{4} \pi \times ID_{Tangki}^{2}$

$= \frac{3,14}{4} \times (229,49 \text{ in})^2$

= 41.340,9990 in^2
= 287,0903 ft^2

$A_2 = \frac{1}{4} \pi \times ID^2$

$= \frac{3,14}{4} \times (3,07 \text{ in})^2$

= 7,3889 in^2
= 0,0513 ft^2

A_2 / A_1 = 0,0001787 < 0.715

$V = \frac{\text{Rate Volumetrik}}{A}$

$= \frac{0,1525 \ ft^3 / sec}{0,05 \ ft^2}$

= 2,9723 ft / sec
= 0,9059 m / sec

$N_{Re} = \frac{D \times V \times \rho}{\mu}$ *(Peters 4th; hal. 481; eq. 6)*

$= \frac{0,08 \text{ in} \times 0,91 \text{ m/s} \times 906,4 \text{ kg/m}^3}{0,0005 \text{ Pa.s}}$

= 118.871,7833 > 2,100 (Airan Turbulen)

Equivalent Roughness for Pipe (ε) untuk material Commercial Steel

ε = 0,00015 ft *(Peters 4th; hal. 482; Fig. 14-1)*
= 0,000046 m *(Geankoplis 3rd; hal. 88; Fig. 2.10-3)*
= 0,001800 in

$\frac{\varepsilon}{D}$ = 0,000587

f = 0,0045 *(Geankoplis 3rd; hal. 88; Fig. 2.10-3)*

Perhitungan Equivalent Suction (L_e)

Sambungan / Fitting	L_e / D	
90º Elbow Standard	35	***(Peters 4th; hal. 484; Tabel 1)***
Gate Valve, Open	9	***(Peters 4th; hal. 485; Tabel 1)***

3 Elbow std 90º = 3 x (L_e / D) x DI
= 35 x 0,2557 ft x 3
= 26,8450 ft
= 8,1820 m

1 Gate Valve $_{\text{Wide Open}}$ = 1 x (L_e / D) x DI
= 9 x 0,2557 ft
= 2,3010 ft
= 0,7013 m

Perhitungan Panjang Pipa

Pipa A ke B	= 3,50	m	=	11,4835 ft
Elbow 1 ke Elbow 2 (Tinggi total reaktor)	= 8,71	m	=	28,5773 ft
Elbow 2 ke Elbow 3	= 1,00	m	=	3,2810 ft
Elbow 3 ke Elbow Reaktor	= 1,00	m	=	3,2810 ft
Panjang Total Pipa Lurus	= 14,2099	m	=	46,6228 ft
Panjang Total Pipa Keseluruhan	= 23,0932	m	=	75,7688 ft

Perhitungan Friksi

Friksi karena Gesekan :

$$F_1 = \frac{2\,f \times V^2 \times L_e}{g_C \times D}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times g_C}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_3 = \frac{(V_2 - V_1)^2}{2 \times \alpha \times g_C}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_4 = n \times Kf \times \frac{V_1^2}{2 \times g_C}$$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

$$F_5 = n \times Kf \times \frac{V_1^2}{2 \times g_C}$$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

Keterangan

F_1 = Flow Through long straight pipe

F_2 = Sudden Contraction

F_3 = Sudden Enlargement
F_4 = Losses Fitting - Elbow 90º
F_5 = Losses Fitting - Gate Valve Open
V = Linear Velocity, ft/sec
= 2,9723 ft/sec
α = Correction Coefficient, Viscous (0.5), Turbulen (1.0)
= 1,0 Turbulen (>2100) ***(Peters 4th; hal. 480)***
L = Length of Pipe
= 75,7688 ft
D = Diameter of Pipe
= 3,0680 in = 0,2557 ft
f = Fanning Friction Factor
= 0,0040 ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***
g_C = Newton's Law Conversion Factor, ft.lbm / lbf
= 32,17 ft.lbm/lbf
A_1 = Luas Penampang Tangki Penyimpanan, ft^2
= 287,09 ft^2
A_2 = Luas Penampang Pipa, ft2
= 0,05 ft^2
K_C = Coefficient Friction Loss, (untuk $A_2/A_1 < 0.715$)

$$= 0,40 \times \left(1,25 - \frac{A_2}{A_1} \right)$$

= 0,4999 ***(Peters 4th; hal. 484; Tabel 1)***
K*f* = Number of Velocity Heads
= Elbow 90º = 0,7500
= Gate Valve Open = 0,1700
(Geankoplis 3rd; hal. 93; Tabel 2.10-1)

$$F_1 = \frac{2 \times 0,004 \times (3,0 \text{ ft/sec})^2 \times 75,8 \text{ ft}}{32,17 \text{ ft.lbm/lbf} \times 3,0680 \text{ in}}$$

= 0,0543 ft .lbf / lbm

$$F_2 = \frac{0,50 \times (3,0 \text{ ft/sec})^2}{2 \times 1,0 \times 32,17 \text{ ft.lbm/lbf}}$$

= 0,0686 ft .lbf / lbm
F_3 = Karena A_1 (Tangki) > A_2 (Pipa), Maka $V_1 = 0$

$= \dfrac{(\ 3{,}0\ \ \text{ft/sec}\ )^2}{2\ \ x\ \ 1{,}0\ \ x\ \ 32{,}17\ \ \text{ft.lbm/lbf}}$

$=\ \ 0{,}1373\ \ \text{ft .lbf / lbm}$

$F_4 = 3\ \ x\ \ 0{,}75\ \ \dfrac{x\ (\ 3{,}0\ \ \text{ft/sec}\ )^2}{2\ \ x\ \ 32{,}2\ \ \text{ft.lbm/lbf}}$

$=\ \ 0{,}3089\ \ \text{ft.lbf / lbm}$

$F_5 = 1\ \ x\ \ 0{,}41\ \ \dfrac{x\ (\ 3{,}0\ \ \text{ft/sec}\ )^2}{2\ \ x\ \ 32{,}2\ \ \text{ft.lbm/lbf}}$

$=\ \ 0{,}0556\ \ \text{ft.lbf / lbm}$

$\sum F = F_1 + F_2 + F_3 + F_4 + F_5$ ***(Geankoplis 3rd; hal. 95)***

$=\ \ 0{,}6247\ \ \text{ft .lbf / lbm}$

Persamaan Bernoulli

$$z_1 \frac{g}{g_C} + \frac{V_1^2}{2\alpha g_C} + \frac{P_1 - P_2}{\rho_1 - \rho_2} - W_f = z_2 \frac{g}{g_C} + \frac{V_2^2}{2\alpha g_C} + \sum F$$

(Geankoplis 3rd; hal. 95; eq. 2.10-20)

$$-W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

Keterangan :

W_S = Work done by Fluid ***(Geankoplis 3rd; hal. 62)***

z = Vertical Distance, ft

V = Linear Velocity, ft/sec

g = g_C = Gravity Constants

g / g_C = 1 lbf/lbm ***(Peters 4th; hal. 487; ex. 1)***

$\sum F$ = Total Friction Loss, ft.lbf/lbm

= 0,6247 ft .lbf / lbm

ρ = Densitas Campuran, lb/cuft

= 56,5875 lb/cuft

P = Tekanan, Psi

$P_1 = P_1 + P_{\text{Hidrostatis}}$

= 14,7 Psi + 12,0 Psi = 26,73 Psi

P_2 = 14,7 Psi

$\Delta P = P_1 - P_2$

= 26,7 Psi - 14,7 Psi

= 12,0 Psi

= 1732,9 lbf / ft^2

$$\frac{\Delta P}{\rho} = \frac{1732{,}91 \ \text{lbf / ft}^2}{56{,}59 \ \text{lb/cuft}}$$

$= 30{,}6235$ ft.lbf / lbm

Asumsi:

z_1 = 28,5773 ft

z_2 = 11,4835 ft

$$\Delta z \frac{g}{g_C} = (28{,}6 \ \text{ft} - 11{,}5 \ \text{ft}) \times 1 \ \text{lbf/lbm}$$

$= 17{,}0938$ ft.lbf / lbm

$$\frac{\Delta V^2}{2 \times \alpha \times g_C} = \frac{(2{,}9723 \ \text{ft/sec})^2}{2 \times 1{,}0 \times 32{,}2 \ \text{ft.lbm/lbf}}$$

$= 0{,}1373$ ft.lbf / lbm

$$-W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

$= 30{,}62 + 17{,}09 + 0{,}14 + 0{,}62$

$= 48{,}4793$ ft.lbf / lbm

Perhitungan Brake Horsepower (BHp)

Untuk Flowrate tersebut, diperoleh efisiensi pompa sebesar:

η_{Pompa} = 62% ***(Peters 4th; hal. 520; Fig. 14-37)***

$W_S = -\eta \times W_P$ ***(Geankoplis 3rd; hal. 65; eq. 2.7-30)***

$$W_P = \frac{-W_S}{\eta}$$

$$= \frac{48{,}5 \ \text{ft.lbf / lbm}}{62\%}$$

$= 78{,}1924$ ft.lbf / lbm

$$\text{BHp} = \frac{W_P \times \text{Flowrate}}{550}$$ ***(Geankoplis 3rd; hal. 66)***

$$= \frac{78{,}2 \ \text{ft.lbf / lbm} \times 17{,}5 \ \text{lb/sec}}{550}$$

$= 2{,}489$

≈ 3 hp

Perhitungan Power Motor

Untuk BHp tersebut, diperoleh efisiensi motor sebesar:

η_{Motor} = 83% ***(Peters 4th; hal. 521; Fig. 14-38)***

$$hp = \frac{BHp}{\eta_{Motor}} = \frac{3 \text{ hp}}{83\%} = 3{,}6145 \approx 4 \text{ hp}$$

Spesifikasi Pompa 1

Fungsi	:	Memindahkan Formaldehid Cair dari Tangki Penyimpanan Formaldehid menuju Reaktor Kondensasi
Tipe	:	Centrifugal Pump
Kecepatan Aliran	:	2,9723 ft/sec = 0,9059 ft/sec
Flowrate	:	0,1525 cuft/s = 68,4565 gal/min
Size Pipa, IPS	:	3 in
ID Pipa	:	3,0680 in
Schedule	:	No. 40
Efisiensi Pompa	:	62%
Power Pompa	:	3 hp
Efisiensi Motor	:	83%
Power Motor	:	4 hp
Jumlah	:	1 Pompa

3. HEATER FORMALDEHID

Kode Alat	:	E - 112
Fungsi	:	Memanaskan Formaldehid cair sebelum memasuki Reaktor Kondensasi
Tipe	:	Shell and Tube Heat Exchanger
Dasar Pemilihan	:	Umum digunakan untuk proses perpindahan panas
Tekanan	:	1 atm
Temperatur	:	55 °C
Waktu Operasi	:	Kontinyu

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$CH_2O_{(aq)}$	37%	5.213,8642	0,7261	726,0991	45,3304
$CH_3OH_{(aq)}$	1%	140,9152	0,7827	782,6686	48,8620
$H_2O_{(l)}$	62%	8.736,7453	1,0229	1.022,8753	63,8581
Total	100%	14.091,5248			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

$$= 0,886 \quad \times \quad 63,8581 \text{ lb/cuft}$$

$$= 56,5875 \text{ lb/cuft}$$

Rate Massa = 14.091,5248 kg/jam

= 31.068,9938 lb/jam

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

$$= \frac{31.068,9938 \text{ lb / Jam}}{56,5875 \text{ lb / cuft}}$$

$$= 549,0431 \text{ cuft / Jam}$$

$$\text{Viskositas Bahan} = \frac{\text{sg Bahan} \times \mu \text{ Reference } (H_2O)}{\text{sg Reference}}$$

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s

= 0,5065 Cps

= 0,0005 Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi

= 0,9960

$$\text{sg Bahan} = \frac{\rho \text{ Bahan}}{\rho \text{ Reference } (H_2O)}$$

$$= \frac{45,4 \text{ lb/cuft}}{63,9 \text{ lb/cuft}}$$

$$= 0,7113$$

$$\text{Viskositas Bahan} = \frac{0,7113 \times 0,0005 \text{ Pa.s}}{0,9960}$$

= 0,0004 lb/ft.s

= 0,0005 Ns/m^2

= 0,5383 Cps

Heat Balance

Panas yang dibutuhkan	:	1.136.157,4750	kJ/Jam
		1.076.926,5166	Btu/Jam
Steam yang digunakan	:	522,7077	kg/Jam
		1.152,5705	lb/Jam

Log Mean Temperature Difference (LMTD)

Suhu bahan masuk, t_1	=	30	°C	=	86	°F
Suhu banah keluar, t_2	=	55	°C	=	131	°F
Suhu steam masuk, T_1	=	130	°C	=	266	°F
Suhu steam kondensat, T_2	=	130	°C	=	266	°F

$\Delta T_1 = T_2 - t_2$

$\Delta T_2 = T_1 - t_1$ ***(Kern; hal. 90)***

$\Delta T_1 = 266\ °F - 131\ °F$

$= 135\ °F$

$\Delta T_2 = 266\ °F - 86\ °F$

$= 180\ °F$

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}$$ ***(Kern; hal. 89; eq. 5.14)***

$= 156{,}4227\ °F$

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$ ***(Kern; hal. 142)***

$$= \frac{266\ °F - 266\ °F}{131\ °F - 86\ °F}$$

$= 0{,}0000\ °F$

$$S = \frac{t_2 - t_1}{T_1 - t_1}$$ ***(Kern; hal. 142)***

$$= \frac{131\ °F - 86\ °F}{266\ °F - 86\ °F}$$

$= 0{,}2500\ °F$

$F_T = 1$ ***(Kern; hal. 828; Fig. 18)***

$\Delta t = F_T \times LMTD$ ***(Kern; hal. 149; eq. 7.42)***

$= 1 \times 156{,}42\ °F$

$= 156{,}42\ °F$

Perhitungan T_C dan t_C dipakai Temperature rata-tata

$T_C = T_{Average}$ Steam ***(Kern; hal. 113)***

$$= \frac{266\ °F + 266\ °F}{2}$$

$= 266\ °F$

$t_C = t_{Average}$ Bahan ***(Kern; hal. 113)***

$$= \frac{86\ °F + 131\ °F}{2}$$

$= 109\ °F$

Trial

Asumsi U_D untuk Larutan Formaldehid (Medium Organics)

$U_D = 5 - 100\ \text{Btu/jam.ft}^2.°F$

$= 100\ \text{Btu/jam.ft}^2.°F$ ***(Kern; hal. 840; Tabel. 8)***

$$A = \frac{Q}{\Delta t \times U_D}$$ ***(Kern; hal. 107; eq. 6.11)***

$$= \frac{1.076.926{,}5166\ \text{Btu/Jam}}{156{,}4\ °F \times 100\ \text{Btu/jam.ft}^2.°F}$$

$= 68{,}8472\ ft^2$

$= 9.913{,}9985\ in^2$

Digunakan OD pipa 3/4 in, sehingga diperoleh:

$a'' = 0{,}1963\ ft^2/\text{lin ft}$ ***(Kern; hal. 843; Tabel. 10)***

Digunakan panjang pipa:

$L = 40\ ft = 480\ in$ ***(Kern; hal. 103)***

Number of tubes

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

$$= \frac{68{,}8472\ ft^2}{40\ ft \times 0{,}1963\ ft^2/\text{lin ft}}$$

$= 8{,}7681 \approx 9$

Dipilih:

Tube				Shell			
OD	=	3/4	in	Pitch	=	1	in
BWG	=	16		Shell ID	=	10	in
a't	=	0,302	in^2	Passes	=	1	
a"	=	0,1963		Nt	=	61	
		Surface / lin ft, ft^2		B Space	=	2	in
Passes	=	2		OD	=	3/4	in
ID	=	0,620	in				
Wall Thicness	=	0,065	in				

(Kern; hal. 843; Tabel. 10) ***(Kern; hal. 842; Tabel. 9)***

A baru = Nt x L x a" ***(Kern; hal. 150)***

= 61 x 40 ft x 0,1963 Surface / lin ft, ft^2

= 478,97 ft^2

$$U_D \text{ baru} = \frac{Q}{A \text{ baru} \times \Delta T_{LMTD}}$$

$$= \frac{1.076.926,5166 \text{ Btu/Jam}}{478,97 \text{ ft}^2 \times 156,42 \text{ °F}}$$

= 14,3740 Btu/jam.ft^2.°F

Cold Fluid (Tube)	Hot Fluid (Shell)
Formaldehid	**Steam**
(4) Flow Area Tube (a_t)	(4') Flow Area Shell (a_s)
$a_t = \frac{Nt \times a't}{144 \times n}$	C" = Pitch - OD
	= 1 in - 3/4 in
$= \frac{61 \times 0,3}{144 \times 2}$	= 1/4 in
	$B = \frac{ID}{5} = \frac{10}{5}$
= 0,0640 ft^2	= 2 in
	$a_s = \frac{ID \times C'' \times B}{144 \text{ Pr}}$
	$= \frac{10 \text{ in} \times 1/4 \text{ in} \times 2 \text{ in}}{144 \times 1 \text{ in}}$
	= 0,0347 ft^2

(5) Mass Velocity Tube (Gt)

$$G_t = \frac{W_{bahan}}{a_t}$$

$$= \frac{31.069,0 \text{ lb/Jam}}{0,0640 \text{ ft}^2}$$

$$= 485.716,5460 \text{ lb/Jam.ft}^2$$

(6) Pada t_C = 108,5 °F

μ = 0,5383 cps
= 1,3027 lbm/Jam.ft

D_i = 0,62 in
= 0,0517 ft

$$Re_t = \frac{D \times G_t}{\mu}$$

$$= \frac{0,05 \text{ ft} \times 485.717 \text{ lb/Jam.ft}^2}{1,3027 \text{ lbm/Jam.ft}}$$

= 19.263,9076

(7) Heat Transfer Factor

j_H = 90

(Kern; hal. 834; Fig. 24)

(8) Konduktivitas Thermal pada t_C

k = 0,0100 Btu/Jam.ft².°F

(Yaws; hal. 508; Tabel 23-1)

Cp = 179,72 kj/kmol.°F
= 5,98 kj/kg.°F
= 13,19 kj/lb.°F
= 12,51 Btu/lb°F

$$\left(\frac{Cp \times \mu}{k}\right)^{1/3} = 11,7537$$

(5) Mass Velocity Shell (Gs)

$$G_s = \frac{W_{steam}}{a_s}$$

$$= \frac{1.152,6 \text{ lb/Jam}}{0,0347 \text{ ft}^2}$$

$$= 33.194,0303 \text{ lb/Jam.ft}^2$$

(6') Pada T_C = 266,0 °F

μ = 0,0135 cps

(Kern; hal. 825; Fig. 15)

= 0,0327 lbm/Jam.ft

D_e = 0,73 in
= 0,0608 ft

$$Re_s = \frac{D_e \times G_s}{\mu}$$

$$= \frac{0,06 \text{ ft} \times 33.194 \text{ lb/Jam.ft}^2}{0,0327 \text{ lbm/Jam.ft}}$$

= 61.809,1065

(7') Heat Transfer Factor

j_H = 160

(Kern; hal. 838; Fig. 28)

(8') Konduktivitas Thermal pada t_C

k = 0,0133 Btu/Jam.ft².°F

(Yaws; hal. 551; Tabel 24-2)

Cp = 0,46 Btu/lb°F

(Kern; hal. 805; Fig. 3)

$$\left(\frac{Cp \times \mu}{k}\right)^{1/3} = 1,0368$$

(9) Condensation of Steam

$$h_i = j_H \frac{k}{D_i} \left(\frac{Cp \times \mu}{k} \right)^{1/3} \varphi_t$$

(Kern; hal. 111; eq. 6.15a)

$= 39{,}7380$ Btu/Jam.ft^2.°F

$$h_{io} = h_i \frac{ID}{OD}$$

(Kern; hal. 105; eq. 6.5)

$= 32{,}8501$ Btu/Jam.ft^2.°F

(10) Pada t_w = 184,1935 °F

μ_w = 0,1182 Cps

(Yaws; hal.482; Tabel 22-1)

= 0,2860 lbm/Jam.ft

$$\varphi_t = \left(\frac{\mu}{\mu_w} \right)^{0,14}$$

$$= \left(\frac{1{,}3027 \text{ °F}}{0{,}2860 \text{ °F}} \right)^{0,14}$$

$= 1{,}2365$ Btu/Jam.ft^2.°F

(12) Corrected Coefficient

$$h_{io} = \frac{h_{io}}{\varphi_t} \times \varphi_t$$

(Kern; hal. 121; eq. 6.37)

$= 32{,}8501$ Btu/Jam.ft^2.°F

(9') Condensation of Steam

$$h_o = j_H \frac{k}{D_e} \left(\frac{Cp \times \mu}{k} \right)^{1/3} \varphi_s$$

(Kern; hal. 112; eq. 6.15b)

$= 35{,}5031$ Btu/Jam.ft^2.°F

(10') Tube Wall Temperature

$$t_w = t_c + \frac{h_{io}}{h_{io} + h_o} (T_c - t_c)$$

= 184,1935 °F

(13) Clean Overall Coefficient

$$U_C = \frac{h_{io} \times h_o}{h_{io} + h_o}$$

(Kern; hal. 121; eq. 6.38)

$$= \frac{32{,}850 \text{ Btu/jam.ft}^2\text{.°F} \times 35{,}5031}{32{,}850 \text{ Btu/jam.ft}^2\text{.°F} + 35{,}5031}$$

$= 17{,}0625$ Btu/jam.ft^2.°F

(14) Dirt Factor, Rd

$$R_d = \frac{U_C - U_D}{U_C \times U_D}$$

(Kern; hal. 108; eq. 6.13)

$$= \frac{17{,}1 \text{ Btu/jam.ft}^2.°F - 14{,}4 \text{ Btu/jam.ft}^2.°F}{17{,}1 \text{ Btu/jam.ft}^2.°F \times 14{,}4 \text{ Btu/jam.ft}^2.°F}$$

$= 0{,}0110$

Untuk R_d data, digunakan "Brackish Water" atau Air Payau dengan R_d

R_d data = 0,002 - 0,001 ***(Kern; hal. 845; Tabel 12)***

R_d perhitungan > R_d data

0,011 > 0,002

Maka, desain dapat digunakan

Cold Fluid	Hot Fluid
Formaldehid	**Steam**
Pressure Drop	
(a) Untuk Re_t = 19.263,9076 f = 0,0002 ***(Kern; hal. 836; Fig. 26)*** s = 1,1010 ***(PT. Intanwijaya Int.)***	(a') Untuk Re_s = 61.809,1065 f = 0,0015 ***(Kern; hal. 839; Fig. 29)*** s = 1,0000 ***(Kern; hal. 808; Tabel. 6)***
	(b') Number of times fluid crosses $N+1 = \frac{\text{Tube Length}}{\text{Baffle Space}} = \frac{12 \times L}{B}$ ***(Kern; hal. 147; eq. 7.43)*** $= \frac{480 \text{ in}}{2 \text{ in}}$ = 240
(c) Pressure drop in Tube or Pipes $\Delta P_t = \frac{f \times G_t^2 \times L \times n}{5.22 \times 10^{10} \times D_i \times s \times \varphi_t}$ ***(Kern; hal. 148; eq. 7.45)*** $= \frac{1.887.364.504{,}1}{3.671.571.280}$	(c') Pressure drop in Shell side $\Delta P_s = \frac{f \times G_s^2 \times D_s (N+1)}{5.22 \times 10^{10} \times D_e \times s \times \varphi_s}$ ***(Kern; hal. 147; eq. 7.44)*** $= \frac{24.130.376}{3.926.411.523}$

= 0,5140 Psi $\Delta P_t < 10$ psi (memenuhi)	= 0,0061 Psi $\Delta P_s < 10$ psi (memenuhi)

Spesifikasi Heater Formaldehid

Fungsi	:	Memanaskan Formaldehid cair sebelum memasuki Reaktor Kondensasi				
Tipe	:	Shell and Tube Heat Exchanger				
Tube						
Inside Diameter	:	0,62	in	=	0,0157	m
Outside Diameter	:	3/4	in	=	0,0191	m
Panjang	:	40	ft	=	12,1914	m
Jumlah Tube	:	9 buah				
Shell						
Pitch	:	1	in	=	0,0254	m
Inside Diameter	:	10	in	=	0,2540	m
OD Shell	:	3/4	in	=	0,0191	m
Jumlah Heater	:	1 buah				

4. Tangki Penampungan Sementara Formaldehid

Kode Alat	:	F - 113
Fungsi	:	Tempat penyimpanan sementara sebelum menuju ke Reaktor
Tipe	:	Tangki Silinder Tegak dengan tutup atas dan bawah Torispherical Dished Head, dilengkapi dengan Cooling Jacket
Material Konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*
Dasar Pemilihan	:	Ekonomis dan umum digunakan
	:	disertai dengan Material untuk Bahan Korosif
Tekanan	:	1 atm
Temperatur	:	55 °C
Waktu Operasi	:	1 Jam

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m³)	ρ (lb/ft³)
$CH_2O_{(aq)}$	37%	5.213,8642	0,7261	726,0991	45,3304

$CH_3OH_{(aq)}$	1%	140,9152	0,7827	782,6686	48,8620
$H_2O_{(l)}$	62%	8.736,7453	1,0229	1.022,8753	63,8581
Total	100%	14.091,5248			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

$= 0,886 \times 63,8581$ lb/cuft

$= 56,6$ lb/cuft

Rate Massa = 14.091,5248 kg/jam

= 31.068,9938 lb/jam

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

$$= \frac{31.068,9938\ \text{lb / Jam}}{56,5875\ \text{lb / cuft}}$$

= 549,0431 cuft / Jam

τ x rate volumetrik = Volume tangki (Vs)

1,25 jam x 549 cuft / Jam = Vs

686,3039 cuft = Vs

Ditetapkan pengisian bahan sebanyak 80% volume (faktor keamanan)

Volume Bahan = 80% dari volume Tangki

$$\text{Volume Tangki } (V_S) = \frac{686,3039\ \text{cuft}}{80\%}$$

= 857,8798 cuft

Perhitungan Dimensi Tangki

Tinggi (H) = 2 Diameter (D) ***(Ulrich; hal. 248; Tabel 4-27)***

$$V_S = \frac{1}{4}\ \pi\ D^2\ H$$

$$V_S = \frac{3,14}{4} \times 2 \times Ds^3$$

$$V_S = 1,57\ Ds^3$$

V tutup atas torispherical dish = $0,000049\ Ds^3$

(Brownell; hal. 88; eq. 5.11)

V tutup atas = V tutup bawah

Volume Tangki = V_S + 2 V tutup atas

$857,8798 \text{ cuft} = 1,57 \; Ds^3 + 0,000098 \; Ds^3$

$857,8798 \text{ cuft} = 1,57 \; Ds^3$

$Ds^3 = 546,3862 \text{ cuft}$

$Ds = 8,1752 \text{ ft} = 98,1027 \text{ in} = 2,4918 \text{ m}$

$Hs = 16,3505 \text{ ft} = 196,2055 \text{ in} = 4,9836 \text{ m}$

Perhitungan Tinggi Komponen

$$\text{Volume Bahan} = \frac{1}{4} \pi \; Ds^2 \; H_{liq}$$

$$549,0431 \text{ cuft} = \frac{3,14}{4} \times 8,1752^2 \times H_{liq}$$

$H_{liq} = 10,4649 \text{ ft} = 125,5793 \text{ in} = 3,1897 \text{ m}$

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

$P = 1 \text{ atm} = 14,6959 \text{ Psi}$

$P_{Inside} = 14,6959 \text{ Psi}$

$P_{Outside} = 14,6959 \text{ Psi}$

$P_{Design} = P_{Inside} - P_{Outside} + P_{Hidrostatis}$

$= 14,7 \text{ Psi} - 14,7 \text{ Psi} + P_{Hidrostatis}$

$P_{Design} = P_{Hidrostatis}$

$$P_{Hidrostatis} = \rho \text{ Campuran} \times \frac{g}{gc} \times H_{liq}$$

$= 56,5875 \text{ lbm/cuft} \times 1 \text{ lbf/lbm} \times 10,4649 \text{ ft}$

$= 592,1854 \text{ lb/ft}^2$

$= 4,1157 \text{ Psi}$

P_{Design} dibuat berlebih 10% (faktor keamanan)

$P_{Design} = 1,1 \times 4,1157 \text{ Psi}$

$= 4,5273 \text{ Psi}$

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167*

Grade 11

= 18.750 Psi *(Brownell; hal. 251; Tabel 13.1)*

$$t_{min} = \frac{4{,}5273 \text{ Psi} \times 49{,}0514 \text{ in}}{15.000 \text{ Psi} - 2{,}7164 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{222{,}0682}{14.997{,}2836} + 0{,}125 \text{ in}$$

= 0,1398 in

= (Digunakan $t_S = \frac{6}{16}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Shell

$$\frac{6}{16} \text{ in} = \frac{4{,}5273 \text{ Psi} \times 49{,}0514 \text{ in}}{f \times 0{,}80 - 2{,}7164 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 1.113,7364 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tebal tutup atas dan bawah

Tutup atas berbentuk Torispherical Dished Head

OD = ID + (2 t_S)

= 98,1027 in + 2 x 0,3750

= 98,8527 in

= (Digunakan OD = 108 in)

(Brownell; hal.91; Tabel 5.7)

Diperoleh:

icr = 6,5000 in = 0,5415 ft

r_C = 102 in = 8,4966 ft

Cek nilai icr dengan 6% rc:

icr = 6,50 in

6% rc = 6,12 in

karena nilai icr > 6% rc, maka menggunakan persamaan

$$t = \frac{Pd \times r_C \times W}{2f\,E - 0{,}2\,Pd} + C$$ *(Brownell; hal.138; eq. 7.77)*

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

(Brownell; hal.138; eq. 7.76)

Keterangan:

E = Faktor Pengelasan = 0,80

t = Tebal dinding minimal

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi **(Brownell; hal. 251; Tabel 13-1)**

C = Faktor Korosi (in) = 0,125 in

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

$$= \frac{1}{4}\left(3 + \sqrt[2]{(102 \text{ in} / 6{,}50 \text{ in})}\right)$$

$$= 1{,}7403$$

$$t_{Head} = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$

$$= \frac{4{,}5273 \text{ Psi} \times 102 \text{ in} \times 1{,}7403}{37.500 \text{ Psi} \times 0{,}8 - 0{,}9055 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= 0{,}1518 \text{ in}$$

$$= (\text{Digunakan } t = \frac{3}{16} \text{ in})$$

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Head

$$\frac{3}{16} \text{ in} = \frac{4{,}5273 \text{ Psi} \times 177{,}5145 \text{ in}}{2\ f \times 0{,}80 - 0{,}9055 \text{ Psi}} + 0{,}125 \text{ in}$$

$$f = 8.037{,}1035 \text{ Psi} < f_{Allowable} \text{ (memenuhi)}$$

Perhitungan tinggi tutup atas dan bawah:

$$Di = 98{,}1027 \text{ in}$$

$$a = \frac{Di}{2}$$

$$= \frac{98{,}1027 \text{ in}}{2}$$

$$= 49{,}0514 \text{ in}$$

$$icr = 6{,}5000 \text{ in}$$

r_C = 102 in **(Brownell; hal. 91; Tabel 5.7)**

$$AB = \frac{Di}{2} - icr$$

$$= \frac{98{,}1027 \text{ in}}{2} - 6{,}500 \text{ in}$$

$$= 42{,}5514 \text{ in}$$

BC = r_C - icr
= 102 in - 7 in
= 95,5000 in

AC = $\sqrt{(BC^2) - (AB^2)}$
= √(9.120,2500 in - 1.810,6192 in)
= 85,4964 in

b = r_C - AC
= 102 in - 85,4964 in
= 16,5036 in

sf = 3 in *(Brownell; hal. 93; Tabel 5.8)*

t_{Head} = 0,1875 in

OA = t_{Head} + b + sf
= 0,1875 in + 16,5036 in + 3 in
= 19,6911 in

Maka, tinggi tutup = 19,6911 in
= 0,5002 m
= 1,6409 ft

Perhitungan Tinggi Jaket

Tinggi Jaket = Tinggi Shell + Tinggi Tutup Bawah
= 16,3505 ft + 1,6409 ft
= 17,9914 ft

Asumsi:

Tebal air pendingin = 2

Tebal Jaket = 0,1875 = 3/16 in

Efisiensi Las = 0,8

Faktor Korosi = 0,125 in

Digunakan material *Stainless Steel SA-167 Grade 11*

f = 18.750

DO Shell = Di + 2ts
= 98,1027 in + 2 x 0,1875 in
= 98,4777 in

Di Jacket = DO Shell + 2 s
= 98,4777 in + 2 x 2,0000 in
= 102,4777 in

DO Jacket = Di Jacket + 2 t Jacket

$= 102{,}4777 \text{ in} + 2 \times 0{,}1875 \text{ in}$

$= 102{,}8527 \text{ in}$

P Design Jacket $=$ P Outside $-$ P Inside $+$ P Hidrostatis

$= 14{,}7 \text{ Psi} - 14{,}7 \text{ Psi} + \rho \text{ Campuran} \times g/gc \times H \text{ Liq}$

$= 56{,}59 \text{ lb/cuft} \times 1 \text{ lbf/lbm} \times 10{,}4649 \text{ ft}$

$= 592{,}1854 \text{ lbf/ft}^2$

$= 4{,}1124 \text{ Psi}$

Perhitungan Tebal Jaket

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

$$t_{Jacket} = \frac{P \times Dij}{2 f E - P} + C$$

Keteragan:

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi ***(Brownell; hal. 251; Tabel 13.1)***

$$t_{min} = \frac{4{,}1124 \text{ Psi} \times 102{,}4777 \text{ in}}{30.000 \text{ Psi} - 4{,}1124 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{421{,}4294}{29.995{,}8876} + 0{,}125 \text{ in}$$

$= 0{,}1390 \text{ in}$

$= \left(\text{Digunakan } t = \frac{3}{16} \text{ in}\right)$

(Brownell; hal. 89; Tabel 5.7)

Perancangan Penyangga Tangki

$$\text{Berat}_{Shell} = \frac{1}{4} \pi \left(OD^2 - ID^2\right) \times H_{Liq} \times \rho_{Steel}$$

ρ Steel $= 0{,}2790 \text{ lb/in}^3$ ***(Brownell; hal. 341, App. D, Item 3)***

$= 482{,}11 \text{ lb/ft}^3$

$$= \frac{3{,}14}{4} \times (67{,}9 \text{ ft} - 66{,}8 \text{ ft}) \times 10{,}5 \text{ ft} \times 482 \text{ lb/ft}^3$$

$= 4.062{,}7624 \text{ lb}$

$$\text{Berat}_{T\ Atas} = \frac{1}{4} \pi \left(OD^2 - ID^2\right) \times H_{Tutup} \times \rho_{Steel}$$

$= \frac{3,14}{4} \times (67,9 \text{ ft} - 66,8 \text{ ft}) \times 1,6 \text{ ft} \times 482 \text{ lb/ft}^3$

$= 637,0502$ lb

Berat $_{\text{T Bawah}}$ $= \frac{3,14}{4} \times (67,9 \text{ ft} - 66,8 \text{ ft}) \times 1,6 \text{ ft} \times 482 \text{ lb/ft}^3$

$= 637,0502$ lb

Berat $_{\text{Fluida}}$ = Berat Feed

= 14.091,5 kg

= 31.071,8 lb

Berat $_{\text{Mati Shel}}$ = Berat $_{\text{Shell}}$ + Berat $_{\text{Tutup Atas}}$ + Berat $_{\text{Tutup Bawah}}$ + Berat $_{\text{Fluida}}$

= 4.062,8 lb + 637,1 lb + 637,1 lb + 31.071,8 lb

= 36.408,6749 lb

= 16.511,8707 kg

Leg Planning

Berat untuk perancangan = 1,2 x berat mati tangki

= 1,2 x 36.408,7 lb

= 43.690,4099 lb

Kaki penyangga dilakukan pengelasan di tengah-tengah ketinggian (40% tinggi total bejana) dengan leg tipe I-Beam, Pondasi Concrete / Beton

H_{Leg} = 40% x H_{Tangki}

= 40% x 19,6323 ft

= 7,8529 ft

= 94,2351 in

= 2,3935 m

Digunakan Beams 12 x 5 in

Berat/ft	= 31,80	lb
Area of Section (A)	= 9,26	in^2
Kedalaman Beam	= 12,00	in
Lebar Flange	= 5,00	in
Tebal Rata-rata	= 0,54	in
Tebal Web	= 0,35	in

Peletakan dengan beban Ekstrensik (Axis 1-1)

I = 215,8 in^4

S = 36,0 in^3
r = 4,8 in

Peletakan tanpa beban Ekstrensik (Axis 2-2)

I = 9,5 in^4
S = 3,8 in^3
r = 1,0 in ***(Brownell; hal. 355; App. G)***

Beban Kompresi total maksimum tiap Leg (P):

$$\text{Beban tiap penyangga} = \frac{\text{Berat Perancangan}}{\text{Jumlah Penyangga}}$$

Asumsi jumlah penyangga = 4

$$\text{Maka beban tiap penyangga} = \frac{43.690,4099 \text{ lb}}{4}$$

P = 10.922,6025 lb untuk setiap penyangga

Cek peletakan sumbu Axis 1-1 maupun Axis 2-2

$$\text{Fc Allowable} = \frac{P}{A} = \frac{10.922,6 \text{ lb}}{9,26 \text{ in}^2} = 1.179,5 \text{ psi}$$

Pemeriksaan Leg Planning

Axis 1-1

$$\frac{l}{r} = \frac{94,2 \text{ in}}{4,8} = 19,5104$$

$$\text{Fc Pemeriksaan} = 17.000 - 0,485 \left(\frac{l}{r}\right)^2$$
$$= 17.000 - 0,485 \left(19,5 \right)^2$$
$$= 16.815,3825$$

Fc Pemeriksaan < Fc Allowable (Dapat digunakan)

Axis 2-2

$$\frac{l}{r} = \frac{94,2 \text{ ft}}{1,0} = 93,3021$$

$$\text{Fc Pemeriksaan} = 17.000 - 0,485 \left(\frac{l}{r}\right)^2$$
$$= 17.000 - 0,485 \left(93,3 \right)^2$$

= 12.777,9410

Fc Pemeriksaan < Fc Allowable (Dapat digunakan)

Lug Planning

Setiap penyangga memiliki 4 baut

$$P_{Bolt} = \frac{P}{n_{Bolt}}$$

$$= \frac{10.922,6 \text{ lb}}{4,0}$$

$$= 2.730,6506 \text{ lb}$$

Luas lubang Baut

$$A_{Bolt} = \frac{P_{Bolt}}{f_{Bolt}}$$ ***(Brownell; hal. 194; eq. 10.44)***

$$A_{Bolt} = \frac{2.730,7 \text{ lb}}{12.000,0 \text{ psi}}$$

$$= 0,2276 \text{ in}^2$$

Digunakan baut dengan diameter 1 in

Spesifikasi Penyimpanan Sementara Formaldehid

Fungsi	:	Tempat penyimpanan sementara sebelum menuju ke Reaktor			
Tipe	:	Tangki Silinder Tegak dengan tutup atas dan bawah Torispherical Dished Head, dilengkapi dengan Cooling Jacket			
Bahan konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*			
Tekanan	:	1 atm			
Kapasitas / Volume	:	857,8798 cuft	=	24,2780	m^3
Diameter Shell	:	8,1752 ft	=	2,4917	m
Tinggi Shell	:	16,3505 ft	=	4,9834	m
Tebal Shell	:	3/8 in	=	0,0095	m
Tinggi tutup atas	:	19,6911 in	=	0,5002	m
Tebal tutup atas	:	0,1875 in	=	0,0048	m
Tinggi tutup bawah	:	19,6911 in	=	0,5002	m
Tebal tutup bawah	:	0,1875 in	=	0,0048	m
Tinggi Total tangki	:	19,6323 ft	=	5,9836	m
Waktu Operasi	:	60 menit			

Diameter Heating Jacket (in)	:	102,4777 in	=	2,6029 m
Diameter Heating Jacket (out)	:	102,8527 in	=	2,6125 m
Tinggi Heating Jacket	:	17,9914 ft	=	5,4835 m
Tebal Heating Jacket	:	0,1875 in	=	0,0048 m
Tipe Penyangga	:	Beam		
Ukuran Peyangga	:	12 x 5 in		
Tinggi Kaki	:	7,8529 ft	=	2,3935 m
Lebar Flange	:	5 in	=	0,1270 m
Diameter Baut	:	1 in	=	0,0254 m
Jumlah	:	1 Tangki		

5. TANGKI PENYIMPANAN ASETALDEHID

Kode Alat : F - 140

Fungsi : Menyimpan Asetaldehid untuk Keperluan Proses Produksi

Tipe : Tangki Silinder Tegak dengan Tutup Atas Torispherical Dish Head dan Tutup Bawah Datar

Material Konstruksi : *Carbon Steel SA-283, grade C*

Dasar Pemilihan : Ekonomis dan umum digunakan untuk Fluida yang tidak Korosif

Tekanan : 1 atm

Temperatur : 30 °C

Waktu Penyimpanan : 5 hari

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$CH_3CHO_{(aq)}$	99%	1.699,8300	0,7670	766,9772	47,8824
$H_2O_{(l)}$	1%	17,1700	1,0229	1.022,8753	63,8581
Total	100%	1.717,0000			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

$= 0,769 \times 63,858$ lb/cuft

$= 49,1005$ lb/cuft

Rate Massa = 1.717,0000 kg/jam

= 3.785,6416 lb/jam

Rate Volumetrik = $\dfrac{\text{Rate Massa}}{\rho \text{ Campuran}}$

= $\dfrac{3.785,6416 \text{ lb / Jam}}{49,1005 \text{ lb / cuft}}$

= 77,0998 cuft / Jam

Volume Komponen = Rate Volumetrik x Waktu Penyimpanan

= 77,10 cuft / Jam x 5 hari

= 9.251,9741 cuft

= 261,9843 m^3

= 261.986,3 Liter

Direncanakan untuk penyimpanan dengan 2 buah tangki
(mempermudah pengeluaran dan pengisian), sehingga volume bahan:

Volume Komponen = $\dfrac{9.251,9741 \text{ cuft}}{2 \text{ Tangki}}$

= 4.625,9870 cuft

Dilakukan pengisian bahan sebanyak 80% volume (faktor keamanan)

Volume Bahan = 80% dari volume Tangki Penyimpanan

Volume Tangki (V_S) = $\dfrac{4.625,9870 \text{ cuft}}{80\%}$

= 5.782,4838 cuft

Perhitungan Dimensi Tangki

Tinggi (H) = 2 Diameter (D) ***(Ulrich; hal. 248; Tabel 4-27)***

$V_S = \dfrac{1}{4} \pi D^2 H$

$V_S = \dfrac{3,14}{4} \times 2 \times Ds^3$

$V_S = 1,57 \ Ds^3$

V tutup atas torispherical dish = 0,000049 Ds^3

(Brownell; hal. 88; eq. 5.11)

Volume Tangki = V_S + V tutup atas

5.782,4838 cuft = 1,57 Ds^3 + 0,000049 Ds^3

5.782,4838 cuft = 1,57 Ds^3

Ds^3 = 3.682,9958 cuft

Ds = 15,4431 ft = 185,3169 in = 4,7070 m

Hs = 30,8861 ft = 370,6338 in = 9,4141 m

Perhitungan Tinggi Komponen

Volume Bahan $= \frac{1}{4} \pi \ Ds^2 \ H_{liq}$

4.625,9870 cuft $= \frac{3,14}{4} \times 15,4431^2 \times H_{liq}$

H_{liq} = 24,7097 ft = 296,5163 in = 7,5315 m

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

P = 1 atm = 14,6959 Psi

P_{Inside} = 14,6959 Psi

$P_{Outside}$ = 14,6959 Psi

$P_{Design} = P_{Inside} - P_{Outside} + P_{Hidrostatis}$

$= 14,7 \text{ Psi} - 14,7 \text{ Psi} + P_{Hidrostatis}$

$P_{Design} = P_{Hidrostatis}$

$P_{Hidrostatis} = \rho \text{ Campuran} \times \frac{g}{gc} \times H_{liq}$

= 49,1005 lbm/cuft x 1 lbf/lbm x 24,7097 ft

= 1213,2592 lb/ft^2

= 8,4322 Psi

P_{Design} dibuat berlebih 10% (faktor keamanan)

P_{Design} = 1,1 x 8,4322 Psi

= 9,2754 Psi

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

t_{min} = Tebal Shell Minimum (in)

P = Tekanan Tangki (Psi)

ri = Jari - jari Tangki (in) (1/2 D)

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, bahan konstruksi *Carbon Steel SA - 283 Grade C*

= 12.650 ***(Brownell; hal. 342; App. D, Item 4)***

$$t_{min} = \frac{9{,}2754 \text{ Psi} \times 92{,}6584 \text{ in}}{10.120 \text{ Psi} - 5{,}5652 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{859{,}4410}{10.114{,}4348} + 0{,}125 \text{ in}$$

$$= 0{,}2100 \text{ in}$$

$$= (\text{Digunakan } t_S = \frac{5}{8} \text{ in})$$ **(Brownell; hal. 89; Tabel 5.7)**

Perhitungan Koreksi Stress Allowable Shell

$$\frac{5}{8} \text{ in} = \frac{9{,}2754 \text{ Psi} \times 92{,}6584 \text{ in}}{f \times 0{,}80 - 5{,}5652 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 2.155,5591 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tebal tutup atas

Tutup atas berbentuk Torispherical Dished Head

$$OD = ID + (2 \; t_S)$$

$$= 185{,}3169 \text{ in} + 2 \times 0{,}63$$

$$= 186{,}5669 \text{ in}$$

= (Digunakan OD = 192 in)

(Brownell; hal.91; Tabel 5.7)

Diperoleh:

icr = 11,50 in = 0,9580 ft

r_C = 170 in = 14,1610 ft

Cek nilai icr dengan 6% rc:

icr = 11,50 in

6% rc = 10,20 in

karena nilai icr > 6% rc, maka menggunakan persamaan

$$t = \frac{Pd \times r_C \times W}{2f\,E - 0{,}2\;Pd} + C$$ ***(Brownell; hal.138; eq. 7.77)***

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

(Brownell; hal.138; eq. 7.76)

Keterangan:

W = Faktor Stress

Pd = Tekanan design (P_{Design})

r_C = Radius Crown

r_1 or icr = Inside Crown Radius

E = Faktor Pengelasan = 0,80

t = Tebal dinding minimal

f = Stress Allowable, bahan konstruksi *Carbon Steel SA - 283 Grade C*

= 12.650 Psi ***(Brownell; hal. 251; Tabel 13-1)***

C = Faktor Korosi (in) = 0,125 in

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

$$= \frac{1}{4}\left(3 + \sqrt[2]{(170 \text{ in} / 12 \text{ in})}\right)$$

$$= 1{,}7112$$

$$t_{Head} = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$

$$= \frac{9{,}2754 \text{ Psi} \times 170 \text{ in} \times 1{,}7112}{25.300 \text{ Psi} \times 0{,}8 - 1{,}8551 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= 0{,}2583 \text{ in}$$

= (Digunakan t = $\frac{5}{8}$ in)

(Brownell; hal. 89; Tabel 5.7)

Untuk Tebal Tutup Bawah, karena ditopang oleh permukaan semen, digunakan:

$$t_{Bottom} = \frac{5}{16} \text{ in}$$

(Brownell; hal. 58)

Perhitungan Koreksi Stress Allowable Head

$$\frac{5}{8} \text{ in} = \frac{9{,}2754 \text{ Psi} \times 290{,}9047 \text{ in}}{2\ f \times 0{,}80 - 1{,}8551 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 3.373,9689 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tinggi tutup atas:

Di = 185,3169 in

$$a = \frac{Di}{2}$$

$$= \frac{185{,}3169 \text{ in}}{2}$$

$$= 92{,}6584 \text{ in}$$

icr = 11,50 in

r_C = 170 in ***(Brownell; hal. 91; Tabel 5.7)***

AB = $\dfrac{Di}{2}$ - icr

= $\dfrac{185{,}3169 \text{ in}}{2}$ - 11,5000 in

= 81,1584 in

BC = r_C - icr

= 170 in - 11,5 in

= 158,5000 in

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

= √ (25.122,2500 in - 6.586,6926 in)

= 136,1454 in

b = r_C - AC

= 170 in - 136,1454 in

= 33,8546 in

sf = 3 in ***(Brownell; hal. 93; Tabel 5.8)***

t_{Head} = 0,6250 in

OA = t_{Head} + b + sf

= 0,6250 in + 33,8546 in + 3 in

= 37,4796 in

Maka, tinggi tutup atas = 37,4796 in

= 0,9520 m

Spesifikasi Tangki Penyimpanan Asetaldehid

Fungsi	:	Menyimpan Asetaldehid untuk Keperluan Proses Produksi		
Tipe	:	Tangki Silinder Tegak dengan Tutup Atas Torispherical Dish Head dan Tutup Bawah Datar		
Tekanan	:	1 atm		
Kapasitas / Volume	:	5.782,4838 cuft	=	163,6443 m^3
Diameter	:	15,4431 ft	=	4,7068 m
Tinggi	:	30,8861 ft	=	9,4136 m
Tebal Shell	:	0,6250 in	=	0,0159 m
Tinggi tutup atas	:	37,4796 in	=	0,9520 m
Tebal tutup atas	:	0,6250 in	=	0,0159 m
Tebal tutup bawah	:	0,3125 in	=	0,0079 m
Bahan konstruksi	:	*Carbon Steel SA-283, grade C*		

Waktu Penyimpanan : 5 hari
Jumlah : 2 tangki

5. POMPA 2

Kode Alat : L - 121
Fungsi : Memindahkan Asetadehid Cair dari Tangki Penyimpanan Formaldehid menuju Reaktor Kondensasi
Tipe : Centrifugal Pump
Dasar Pemilihan : Sesuai untuk Fluida Liquid dengan Viskositas <10 Cp
Tekanan : 1 atm
Temperatur : 30 °C
Waktu Operasi : Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$CH_3CHO_{(aq)}$	99%	1.699,8300	0,7670	766,9772	47,8824
$H_2O_{(l)}$	1%	17,1700	1,0229	1.022,8753	63,8581
Total	100%	1.717,0000			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

$= 0,769 \times 63,858$ lb/cuft
$= 49,1005$ lb/cuft
$= 786,5171$ kg/m^3

Rate Massa $= 1.717,0000$ kg/jam
$= 3.785,6416$ lb/jam

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

$$= \frac{3.785,6416 \text{ lb / Jam}}{49,1005 \text{ lb / cuft}}$$

$= 77,0998$ cuft / Jam
$= 1,2850$ cuft / menit
$= 0,0214$ cuft / sec

= 9,6131 gal / min

Viskositas Bahan = $\dfrac{\text{sg Bahan} \times \mu \text{ Reference } (H_2O)}{\text{sg Reference}}$

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s
= 0,5065 Cps
= 0,0005 Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi
= 0,9960

sg Bahan = $\dfrac{\rho \text{ Bahan}}{\rho \text{ Reference } (H_2O)}$

= $\dfrac{47,9 \text{ lb/cuft}}{63,9 \text{ lb/cuft}}$

= 0,7498

Viskositas Bahan = $\dfrac{0,7498 \times 0,0005 \text{ Pa.s}}{0,9960}$

= 0,0004 lb/ft.s
= 0,0006 Ns/m^2
= 0,5675 Cps

Perhitungan ID Optimum

Asumsi Aliran Turbulen, dengan $N_{Re} > 2100$, digunakan rumus:

$ID_{Optimum} = 3,9 \; qf^{0,45} \; \rho^{0,13}$

(Peters 4th; hal. 496; eq. 15)

Keterangan:

ID = Optimum Pipe Inside Diameter, in
qf = Fluid Flow Rate, cuft/sec
ρ = Fluid Density, lb/cuft

$ID_{Optimum}$ = 3,9 x 0,1774 cuft/sec x 1,6590 lb/cuft
= 1,1475 in

Perhitungan Pipa

Dipilih pipa:

IPS, Size = 1 1/4 in
OD = 1,6600 in
Schedule = No. 40
ID = 1,3800 in ***(McCabe7th; hal. 1090; App. 3)***
= 0,1150 ft

$= 0{,}0351 \text{ m}$

$A_1 = \frac{1}{4} \pi \times ID_{Tangki}^2$

$= \frac{3{,}14}{4} \times (185{,}32 \text{ in})^2$

$= 26.958{,}7423 \text{ in}^2$

$= 187{,}2135 \text{ ft}^2$

$A_2 = \frac{1}{4} \pi \times ID^2$

$= \frac{3{,}14}{4} \times (1{,}38 \text{ in})^2$

$= 1{,}4950 \text{ in}^2$

$= 0{,}0104 \text{ ft}^2$

$A_2 / A_1 = 0{,}000055 < 0.715$

$V = \frac{\text{Rate Volumetrik}}{A}$

$= \frac{0{,}0214 \text{ ft}^3/\text{sec}}{0{,}01 \text{ ft}^2}$

$= 2{,}0629 \text{ ft/sec}$

$= 0{,}6288 \text{ m/sec}$

$N_{Re} = \frac{D \times V \times \rho}{\mu}$ ***(Peters 4th; hal. 481; eq. 6)***

$= \frac{0{,}04 \text{ in} \times 0{,}63 \text{ m/s} \times 786{,}5 \text{ kg/m}^3}{0{,}0006 \text{ Pa.s}}$

$= 30.547{,}1208 > 2{,}100$ (Airan Turbulen)

Equivalent Roughness for Pipe (ε) untuk material Commercial Steel

$\varepsilon = 0{,}00015 \text{ ft}$ ***(Peters 4th; hal. 482; Fig. 14-1)***

$= 0{,}000046 \text{ m}$ ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

$= 0{,}001800 \text{ in}$

$\frac{\varepsilon}{D} = 0{,}001304$

$f = 0{,}0071$ ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

Perhitungan Equivalent Suction (L_e)

Sambungan / Fitting	L_e / D
90º Elbow Standard	35

(Peters 4th; hal. 484; Tabel 1)

Gate Valve, Open	9	***(Peters 4th; hal. 485; Tabel 1)***

3 Elbow std 90º = 3 x (L_e / D) x DI
= 35 x 0,1150 ft
= 12,0750 ft
= 3,6803 m

1 Gate Valve $_{\text{Wide Open}}$ = 1 x (L_e / D) x DI
= 9 x 0,1150 ft
= 1,0350 ft
= 0,3155 m

Perhitungan Panjang Pipa

Pipa A ke B	=	3,50	m	=	11,4835	ft
Elbow 1 ke Elbow 2 (Tinggi total reaktor)	=	8,71	m	=	28,5773	ft
Elbow 2 ke Elbow 3	=	1,00	m	=	3,2810	ft
Elbow 3 ke Elbow Reaktor	=	1,00	m	=	3,2810	ft
Panjang Total Pipa Lurus	=	14,2099	m	=	46,6228	ft
Panjang Total Pipa Keseluruhan	=	18,2057	m	=	59,7328	ft

Perhitungan Friksi

Friksi karena Gesekan :

$$F_1 = \frac{2 f \times V^2 \times L_e}{g_C \times D}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times g_C}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_3 = \frac{(V_2 - V_1)^2}{2 \times \alpha \times g_C}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_4 = n \times Kf \times \frac{V_1^2}{2 \times g_C}$$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

$$F_5 = n \times Kf \times \frac{V_1^2}{2 \times g_C}$$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

Keterangan

F_1 = Flow Through long straight pipe
F_2 = Sudden Contraction
F_3 = Sudden Enlargement
F_4 = Losses Fitting - Elbow 90º
F_5 = Losses Fitting - Gate Valve Open

V = Linear Velocity, ft/sec
= 2,0629 ft/sec

α = Correction Coefficient, Viscous (0.5), Turbulen (1.0)
= 1,0 Turbulen (>2100) ***(Peters 4th; hal. 480)***

L = Length of Pipe
= 59,7328 ft

D = Diameter of Pipe
= 1,3800 in = 0,1150 ft

f = Fanning Friction Factor
= 0,0040 ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

g_C = Newton's Law Conversion Factor, ft.lbm / lbf
= 32,17 ft.lbm/lbf

A_1 = Luas Penampang Tangki Penyimpanan, ft^2
= 187,2135 ft^2

A_2 = Luas Penampang Pipa, ft2
= 0,0104 ft^2

K_C = Coefficient Friction Loss, (untuk $A_2/A_1 < 0.715$)

$$= 0,40 \times \left(1,25 - \frac{A_2}{A_1} \right)$$

= 0,5000 ***(Peters 4th; hal. 484; Tabel 1)***

K*f* = Number of Velocity Heads
= Elbow 90º = 0,7500
= Gate Valve Open = 0,1700
(Geankoplis 3rd; hal. 93; Tabel 2.10-1)

$$F_1 = \frac{2 \times 0,004 \times (2,1 \text{ ft/sec})^2 \times 59,7 \text{ ft}}{32,17 \text{ ft.lbm/lbf} \times 1,3800 \text{ in}}$$

= 0,0458 ft .lbf / lbm

$$F_2 = \frac{0,50 \times (2,1 \text{ ft/sec})^2}{2 \times 1,0 \times 32,17 \text{ ft.lbm/lbf}}$$

= 0,0331 ft .lbf / lbm

F_3 = Karena A_1 (Tangki) > A_2 (Pipa), Maka $V_1 = 0$

$$= \frac{(2,1 \text{ ft/sec})^2}{2 \times 1,0 \times 32,17 \text{ ft.lbm/lbf}}$$

= 0,0661 ft .lbf / lbm

$F_4 = 3 \times 0{,}75 \dfrac{x\,(2{,}1 \text{ ft/sec})^2}{2 \times 32{,}2 \text{ ft.lbm/lbf}}$

$= 0{,}1488$ ft.lbf / lbm

$F_5 = 1 \times 0{,}41 \dfrac{x\,(2{,}1 \text{ ft/sec})^2}{2 \times 32{,}2 \text{ ft.lbm/lbf}}$

$= 0{,}0268$ ft.lbf / lbm

$\sum F = F_1 + F_2 + F_3 + F_4 + F_5$ ***(Geankoplis 3rd; hal. 95)***

$= 0{,}3206$ ft .lbf / lbm

Persamaan Bernoulli

$$z_1 \frac{g}{g_C} + \frac{V_1^2}{2\alpha g_C} + \frac{P_1 - P_2}{\rho_1 - \rho_2} - W_f = z_2 \frac{g}{g_C} + \frac{V_2^2}{2\alpha g_C} + \sum F$$

(Geankoplis 3rd; hal. 95; eq. 2.10-20)

$$-W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

Keterangan :

W_S = Work done by Fluid ***(Geankoplis 3rd; hal. 62)***

z = Vertical Distance, ft

V = Linear Velocity, ft/sec

g = g_C = Gravity Constants

g / g_C = 1 lbf/lbm ***(Peters 4th; hal. 487; ex. 1)***

$\sum F$ = Total Friction Loss, ft.lbf/lbm

= 0,3206 ft .lbf / lbm

ρ = Densitas Campuran, lb/cuft

= 49,1005 lb/cuft

P = Tekanan, Psi

$P_1 = P_1 + P_{\text{Hidrostatis}}$

= 14,7 Psi + 8,4 Psi = 23,13 Psi

P_2 = 14,7 Psi

$\Delta P = P_1 - P_2$

= 23,1 Psi - 14,7 Psi

= 8,4 Psi

= 1214,2 lbf / ft^2

$\dfrac{\Delta P}{\rho} = \dfrac{1214{,}23 \text{ lbf / ft}^2}{49{,}10 \text{ lb/cuft}}$

= 24,7295 ft.lbf / lbm

Asumsi:

$z_1 = 28,5773$ ft

$z_2 = 11,4835$ ft

$$\Delta z \frac{g}{g_C} = (28,6 \text{ ft} - 11,5 \text{ ft}) \times 1 \text{ lbf/lbm}$$

$$= 17,0938 \text{ ft.lbf / lbm}$$

$$\frac{\Delta V^2}{2 \times \alpha \times g_C} = \frac{(2,0629 \text{ ft/sec})^2}{2 \times 1,0 \times 32,2 \text{ ft.lbm/lbf}}$$

$$= 0,0661 \text{ ft.lbf / lbm}$$

$$-W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

$$= 24,73 + 17,09 + 0,07 + 0,32$$

$$= 42,2100 \text{ ft.lbf / lbm}$$

Perhitungan Brake Horsepower (BHp)

Untuk Flowrate tersebut, diperoleh efisiensi pompa sebesar:

$\eta_{Pompa} = 45\%$ ***(Peters 4th; hal. 520; Fig. 14-37)***

$W_S = -\eta \times W_P$ ***(Geankoplis 3rd; hal. 65; eq. 2.7-30)***

$$W_P = \frac{-W_S}{\eta}$$

$$= \frac{42,2 \text{ ft.lbf / lbm}}{45\%}$$

$$= 93,7999 \text{ ft.lbf / lbm}$$

$$\text{BHp} = \frac{W_P \times \text{Flowrate}}{550}$$ ***(Geankoplis 3rd; hal. 66)***

$$= \frac{93,8 \text{ ft.lbf / lbm} \times 2,5 \text{ lb/sec}}{550}$$

$$= 0,419$$

$$\approx 1 \text{ hp}$$

Perhitungan Power Motor

Untuk BHp tersebut, diperoleh efisiensi motor sebesar:

$\eta_{Motor} = 80\%$ ***(Peters 4th; hal. 521; Fig. 14-38)***

$$\text{hp} = \frac{\text{BHp}}{\eta_{Motor}}$$

$$= \frac{1 \text{ hp}}{80\%}$$

$= 1{,}2500$

≈ 2 hp

Spesifikasi Pompa 2

Fungsi	:	Memindahkan Asetadehid Cair dari Tangki Penyimpanan Formaldehid menuju Reaktor Kondensasi
Tipe	:	Centrifugal Pump
Kecepatan Aliran	:	2,0629 ft/sec = 0,6288 ft/sec
Flowrate	:	0,0214 cuft/s = 9,6131 gal/min
Size Pipa, IPS	:	1 1/4 in
ID Pipa	:	1,3800 in
Schedule	:	No. 40
Efisiensi Pompa	:	45%
Power Pompa	:	1 hp
Efisiensi Motor	:	80%
Power Motor	:	2 hp
Jumlah	:	1 Pompa

6. HEATER ASETALDEHID

Kode Alat	:	E - 122
Fungsi	:	Memanaskan Asetaldehid cair sebelum memasuki Reaktor Kondensasi
Tipe	:	Shell and Tube Heat Exchanger
Dasar Pemilihan	:	Umum digunakan untuk proses perpindahan panas
Tekanan	:	1 atm
Temperatur	:	55 °C
Waktu Operasi	:	Kontinyu

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$CH_3CHO_{(aq)}$	99%	1.699,8300	0,7670	766,9772	47,8824
$H_2O_{(l)}$	1%	17,1700	1,0229	1.022,8753	63,8581
Total	100%	1.717,0000			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

= 0,769 x 63,8581 lb/cuft

= 49,1005 lb/cuft

Rate Massa = 1.717,0000 kg/jam

= 3.785,6416 lb/jam

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

$$= \frac{3.785,6416 \text{ lb / Jam}}{49,1005 \text{ lb / cuft}}$$

= 77,0998 cuft / Jam

$$\text{Viskositas Bahan} = \frac{\text{sg Bahan} \times \mu \text{ Reference } (H_2O)}{\text{sg Reference}}$$

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s

= 0,5065 Cps

= 0,0005 Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi

= 0,9960

$$\text{sg Bahan} = \frac{\rho \text{ Bahan}}{\rho \text{ Reference } (H_2O)}$$

$$= \frac{47,9 \text{ lb/cuft}}{63,9 \text{ lb/cuft}}$$

= 0,7498

$$\text{Viskositas Bahan} = \frac{0,7498 \times 0,0005 \text{ Pa.s}}{0,9960}$$

= 0,0004 lb/ft.s

= 0,0006 Ns/m^2

= 0,5675 Cps

Heat Balance

Panas yang dibutuhkan	:	109.660,7327	kJ/Jam
		103.943,8225	Btu/Jam
Steam yang digunakan	:	50,4512	kg/Jam
		111,2449	lb/Jam

Log Mean Temperature Difference (LMTD)

Suhu bahan masuk, t_1 = 30 °C = 86 °F
Suhu banah keluar, t_2 = 55 °C = 131 °F
Suhu steam masuk, T_1 = 130 °C = 266 °F
Suhu steam kondensat, T_2 = 130 °C = 266 °F

$\Delta T_1 = T_2 - t_2$

$\Delta T_2 = T_1 - t_1$ ***(Kern; hal. 90)***

$\Delta T_1 = 266\ °F - 131\ °F$
$= 135\ °F$

$\Delta T_2 = 266\ °F - 86\ °F$
$= 180\ °F$

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}$$ ***(Kern; hal. 89; eq. 5.14)***

$= 156{,}4227\ °F$

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$ ***(Kern; hal. 142)***

$$= \frac{266\ °F - 266\ °F}{131\ °F - 86\ °F}$$

$= 0{,}0000\ °F$

$$S = \frac{t_2 - t_1}{T_1 - t_1}$$ ***(Kern; hal. 142)***

$$= \frac{131\ °F - 86\ °F}{266\ °F - 86\ °F}$$

$= 0{,}2500\ °F$

$F_T = 1$ ***(Kern; hal. 828; Fig. 18)***

$\Delta t = F_T \times LMTD$ ***(Kern; hal. 149; eq. 7.42)***
$= 1 \times 156{,}42\ °F$
$= 156{,}42\ °F$

Perhitungan T_C dan t_C dipakai Temperature rata-tata

$\mathbf{T_C} = T_{Average}$ Steam ***(Kern; hal. 113)***

$$= \frac{266\ °F + 266\ °F}{2}$$

$= 266\ °F$

$\mathbf{t_C} = t_{Average}$ Bahan ***(Kern; hal. 113)***

$$= \frac{86\ °F + 131\ °F}{2}$$

$= 109\ °F$

Trial

Asumsi U_D untuk Asetaldehid (Medium Organics)

U_D = 5 - 100 Btu/jam.ft^2.°F

= 100 Btu/jam.ft^2.°F ***(Kern; hal. 840; Tabel. 8)***

$$A = \frac{Q}{\Delta t \times U_D}$$ ***(Kern; hal. 107; eq. 6.11)***

$$= \frac{103.943,8225 \text{ Btu/Jam}}{156,4\ °F \times 100 \text{ Btu/jam.ft}^2.°F}$$

= 6,6451 ft^2

= 956,8888 in^2

Digunakan OD pipa 1/2 in, sehingga diperoleh:

a" = 0,1309 ft^2/lin ft ***(Kern; hal. 843; Tabel. 10)***

Digunakan panjang pipa:

L = 20 ft = 240 in ***(Kern; hal. 103)***

Number of tubes

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

$$= \frac{6,6451 \text{ ft}^2}{20 \text{ ft} \times 0,1309 \text{ ft}^2/\text{lin ft}}$$

= 2,5382 ≈ 3

Dipilih:

Tube	Shell
OD = 1/2 in	Pitch = 1 in
BWG = 12	Shell ID = 8 in
a't = 0,063 in^2	Passes = 1
a" = 0,1309 Surface / lin ft, ft^2	Nt = 36
Passes = 2	B Space = 2 in
ID = 0,620 in	OD = 3/4 in
Wall Thicness = 0,065 in	

(Kern; hal. 843; Tabel. 10) ***(Kern; hal. 842; Tabel. 9)***

A baru = Nt x L x a" ***(Kern; hal. 150)***

= 36 x 20 ft x 0,1309 Surface / lin ft, ft^2

= 94,25 ft^2

U_D baru = $\dfrac{Q}{A\ baru \times \Delta T_{LMTD}}$

= $\dfrac{103.943,8225 \text{ Btu/Jam}}{94,25 \text{ ft}^2 \times 156,42 \text{ °F}}$

= 7,0506 Btu/jam.ft^2.°F

Cold Fluid (Tube)	Hot Fluid (Shell)
Asetaldehid	**Steam**
(4) Flow Area Tube (a_t)	(4') Flow Area Shell (a_s)
$a_t = \dfrac{Nt \times a't}{144 \times n}$	C" = Pitch - OD
	= 1 in - 3/4 in
$= \dfrac{36 \times 0,1}{144 \times 2}$	= 1/5 in
= 0,0078 ft^2	B = ID = $\dfrac{8}{5}$
	= 2 in
	$a_s = \dfrac{ID \times C'' \times B}{144\ Pr}$
	$= \dfrac{8 \text{ in} \times 1/5 \text{ in} \times 2 \text{ in}}{144 \times 1 \text{ in}}$
	= 0,0178 ft^2
(5) Mass Velocity Tube (Gt)	(5) Mass Velocity Shell (Gs)
$G_t = \dfrac{W_{bahan}}{a_t}$	$G_s = \dfrac{W_{steam}}{a_s}$
$= \dfrac{3.785,6 \text{ lb/Jam}}{0,0078 \text{ ft}^2}$	$= \dfrac{111,2 \text{ lb/Jam}}{0,0178 \text{ ft}^2}$
= 484.562,1248 lb/Jam.ft^2	= 6.257,5257 lb/Jam.ft^2
(6) Pada t_C = 108,5 °F	(6') Pada T_C = 266,0 °F
μ = 0,5675 cps	μ = 0,0135 cps

$= 1{,}3732$ lbm/Jam.ft

$D_i = 0{,}62$ in

$= 0{,}0517$ ft

$$Re_t = \frac{D \times G_t}{\mu}$$

$$= \frac{0{,}05 \text{ ft} \times 484.562 \text{ lb/Jam.ft}^2}{1{,}3732 \text{ lbm/Jam.ft}}$$

$= 18.231{,}1423$

(7) Heat Transfer Factor

$j_H = 60$

(Kern; hal. 834; Fig. 24)

(8) Konduktivitas Thermal pada t_C

$k = 0{,}0928$ Btu/Jam.ft^2.°F

(Yaws; hal. 508; Tabel 23-1)

$Cp = 3169{,}2$ kj/kmol.°F

$= 105{,}53$ kj/kg.°F

$= 232{,}66$ kj/lb.°F

$= 220{,}53$ Btu/lb°F

$$\left(\frac{Cp \times \mu}{k}\right)^{1/3} = 14{,}8338$$

(9) Condensation of Steam

$$h_i = j_H \frac{k}{D_i} \left(\frac{Cp \times \mu}{k}\right)^{1/3} \varphi_t$$

(Kern; hal. 111; eq. 6.15a)

$= 264{,}7401$ Btu/Jam.ft^2.°F

$$h_{io} = h_i \frac{ID}{OD}$$

(Kern; hal. 105; eq. 6.5)

$= 328{,}2778$ Btu/Jam.ft^2.°F

(Kern; hal. 825; Fig. 15)

$= 0{,}0327$ lbm/Jam.ft

$D_e = 0{,}73$ in

$= 0{,}0608$ ft

$$Re_s = \frac{D_e \times G_s}{\mu}$$

$$= \frac{0{,}06 \text{ ft} \times 6.258 \text{ lb/Jam.ft}^2}{0{,}0327 \text{ lbm/Jam.ft}}$$

$= 11.651{,}8563$

(7') Heat Transfer Factor

$j_H = 60$

(Kern; hal. 838; Fig. 28)

(8') Konduktivitas Thermal pada t_C

$k = 0{,}0133$ Btu/Jam.ft^2.°F

(Yaws; hal. 551; Tabel 24-2)

$Cp = 0{,}46$ Btu/lb°F

(Kern; hal. 805; Fig. 3)

$$\left(\frac{Cp \times \mu}{k}\right)^{1/3} = 1{,}0368$$

(9') Condensation of Steam

$$h_o = j_H \frac{k}{D_e} \left(\frac{Cp \times \mu}{k}\right)^{1/3} \varphi_s$$

(Kern; hal. 112; eq. 6.15b)

$= 13{,}3136$ Btu/Jam.ft^2.°F

(10) Pada t_w = 259,8614 °F

μ_w = 0,1829 Cps

(Yaws; hal.482; Tabel 22-1)

= 0,4427 lbm/Jam.ft

$$\varphi_t = \left(\frac{\mu}{\mu_w}\right)^{0,14}$$

$$= \left(\frac{1,3732\ °F}{0,4427\ °F}\right)^{0,14}$$

= 1,1717 Btu/Jam.ft^2.°F

(12) Corrected Coefficient

$$h_{io} = \frac{h_{io}}{\varphi_t} \times \varphi_t$$

(Kern; hal. 121; eq. 6.37)

= 328,2778 Btu/Jam.ft^2.°F

(10') Tube Wall Temperature

$$t_w = t_c + \frac{h_{io}}{h_{io} + h_o}(T_c - t_c)$$

= 259,8614 °F

$$U_C = \frac{h_{io} \times h_o}{h_{io} + h_o}$$

(Kern; hal. 121; eq. 6.38)

$$= \frac{328,3\ \text{Btu/jam.ft}^2.°F \times 13,3136}{328,3\ \text{Btu/jam.ft}^2.°F + 13,3136}$$

= 12,7947 Btu/jam.ft^2.°F

(14) Dirt Factor, Rd

U_C x U_D ***(Kern; hal. 108; eq. 6.13)***

$$= \frac{12,8\ \text{Btu/jam.ft}^2.°F - 7,1\ \text{Btu/jam.ft}^2.°F}{12,8\ \text{Btu/jam.ft}^2.°F \times 7,1\ \text{Btu/jam.ft}^2.°F}$$

= 0,0637

Untuk R_d data, digunakan "Brackish Water" atau Air Payau dengan R_d

R_d data = 0,002 - 0,001 ***(Kern; hal. 845; Tabel 12)***

R_d perhitungan > R_d data

0,064 > 0,002

Maka, desain dapat digunakan

Cold Fluid	**Hot Fluid**
Asetaldehid	**Steam**
Pressure Drop	

(a) Untuk Re_t = 18.231,1423 f = 0,0001 ***(Kern; hal. 836; Fig. 26)*** s = 0,7498	(a') Untuk Re_s = 11.651,8563 f = 0,0018 ***(Kern; hal. 839; Fig. 29)*** s = 1,0000 ***(Kern; hal. 808; Tabel. 6)*** (b') Number of times fluid crosses $N+1 = \frac{\text{Tube Length}}{\text{Baffle Space}} = \frac{12 \times L}{B}$ ***(Kern; hal. 147; eq. 7.43)*** $= \frac{240 \text{ in}}{2 \text{ in}}$ = 240
(c) Pressure drop in Tube or Pipes $\Delta P_t = \frac{f \times G_t^2 \times L \times n}{5.22 \times 10^{10} \times D_i \times s \times \varphi_t}$ ***(Kern; hal. 148; eq. 7.45)*** $= \frac{528.301.018,8}{2.369.571.416}$ = 0,2230 Psi ΔP_t < 10 psi (memenuhi)	(c') Pressure drop in Shell side $\Delta P_s = \frac{f \times G_s^2 \times D_s (N+1)}{5.22 \times 10^{10} \times D_e \times s \times \varphi_s}$ ***(Kern; hal. 147; eq. 7.44)*** $= \frac{1.029.036}{3.720.841.653}$ = 0,0003 Psi ΔP_s < 10 psi (memenuhi)

Spesifikasi Heater Asetaldehid

Fungsi : Memanaskan Asetaldehid cair sebelum memasuki Reaktor Kondensasi

Tipe : Shell and Tube Heat Exchanger

Tube

Inside Diameter	:	0,62	in	=	0,0157	m
Outside Diameter	:	1/2	in	=	0,0127	m
Panjang	:	20	ft	=	6,0957	m
Jumlah Tube	:	3 buah				

Shell

Pitch	:	1	in	=	0,0238	m

Inside Diameter	:	8	in =	0,2032	m
OD Shell	:	3/4	in =	0,0191	m
Jumlah Heater	:	1 buah			

8. Tangki Penampungan Sementara Asetaldehid

Kode Alat : F - 123

Fungsi : Tempat penyimpanan Asetaldehid sementara sebelum menuju ke Reaktor

Tipe : Tangki Silinder Tegak dengan tutup atas dan bawah Torispherical Dished Head, dilengkapi dengan Cooling Jacket

Material Konstruksi : *Stainless Steel 316 SA-167, Grade 11*

Dasar Pemilihan : Ekonomis dan umum digunakan
: disertai dengan Material untuk Bahan Korosif

Tekanan : 1 atm

Temperatur : 55 °C

Waktu Operasi : 1 Jam

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
CH3CHO	99%	1.699,8300	0,7670	766,9772	47,8824
$H_2O_{(l)}$	1%	17,1700	1,0229	1.022,8753	63,8581
Total	100%	1.717,0000			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

$$= 0{,}769 \times 63{,}8581 \text{ lb/cuft}$$

$$= 49{,}1005 \text{ lb/cuft}$$

Rate Massa = 1.717,0000 kg/jam
= 3.785,6416 lb/jam

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

$$= \frac{3.785{,}6416 \text{ lb / Jam}}{49{,}1005 \text{ lb / cuft}}$$

$$= 77{,}0998 \text{ cuft / Jam}$$

τ x rate volumetrik = Volume tangki (Vs)

1,25 jam x 77 cuft / Jam = Vs

96,3747 cuft = Vs

Ditetapkan pengisian bahan sebanyak 80% volume (faktor keamanan)

Volume Bahan = 80% dari volume Tangki

$$\text{Volume Tangki } (V_S) = \frac{96{,}3747 \text{ cuft}}{80\%}$$

$$= 120{,}4684 \text{ cuft}$$

Perhitungan Dimensi Tangki

Tinggi (H) = 2 Diameter (D) ***(Ulrich; hal. 248; Tabel 4-27)***

$$V_S = \frac{1}{4}\ \pi\ D^2\ H$$

$$V_S = \frac{3{,}14}{4} \times 2 \times Ds^3$$

$$V_S = 1{,}57\ Ds^3$$

V tutup atas torispherical dish = $0{,}000049\ Ds^3$

(Brownell; hal. 88; eq. 5.11)

V tutup atas = V tutup bawah

Volume Tangki = V_S + 2 V tutup atas

120,4684 cuft = $1{,}57\ Ds^3 + 0{,}000098\ Ds^3$

120,4684 cuft = $1{,}57\ Ds^3$

Ds^3 = 76,7267 cuft

Ds = 4,2493 ft = 50,9914 in = 1,2952 m

Hs = 8,4986 ft = 101,9827 in = 2,5904 m

Perhitungan Tinggi Komponen

$$\text{Volume Bahan} = \frac{1}{4}\ \pi\ Ds^2\ H_{liq}$$

$$77{,}0998 \text{ cuft} = \frac{3{,}14}{4} \times 4{,}2493^2 \times H_{liq}$$

H_{liq} = 5,4394 ft = 65,2730 in = 1,6579 m

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

P = 1 atm = 14,6959 Psi

P_{Inside} = 14,6959 Psi

$P_{Outside}$ = 14,6959 Psi

$P_{Design} = P_{Inside} - P_{Outside} + P_{Hidrostatis}$

$= 14{,}7 \text{ Psi} - 14{,}7 \text{ Psi} + P_{Hidrostatis}$

$P_{Design} = P_{Hidrostatis}$

$$P_{Hidrostatis} = \rho \text{ Campuran} \times \frac{g}{gc} \times H_{liq}$$

$= 49{,}1005 \text{ lbm/cuft} \times 1 \text{ lbf/lbm} \times 5{,}4394 \text{ ft}$

$= 267{,}0785 \text{ lb/ft}^2$

$= 1{,}8562 \text{ Psi}$

P_{Design} dibuat berlebih 10% (faktor keamanan)

$P_{Design} = 1{,}1 \times 1{,}8562 \text{ Psi}$

$= 2{,}0418 \text{ Psi}$

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi ***(Brownell; hal. 251; Tabel 13.1)***

$$t_{min} = \frac{2{,}0418 \text{ Psi} \times 25{,}4957 \text{ in}}{15.000 \text{ Psi} - 1{,}2251 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{52{,}0575}{14.998{,}7749} + 0{,}125 \text{ in}$$

$= 0{,}1285 \text{ in}$

$= (\text{Digunakan } t_S = \frac{3}{16} \text{ in})$

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Shell

$$\frac{3}{16} \text{ in} = \frac{2{,}0418 \text{ Psi} \times 25{,}4957 \text{ in}}{f \times 0{,}80 - 1{,}2251 \text{ Psi}} + 0{,}125 \text{ in}$$

$f = 1.042{,}6809 \text{ Psi} < f_{Allowable}$ (memenuhi)

Perhitungan tebal tutup atas dan bawah

Tutup atas berbentuk Torispherical Dished Head

OD = ID + (2 t_S)
= 50,9914 in + 2 x 0,1875
= 51,3664 in
= (Digunakan OD = 54 in)

(Brownell; hal.91; Tabel 5.7)

Diperoleh:

icr = 3,2500 in = 0,2707 ft
r_C = 54 in = 4,4982 ft

Cek nilai icr dengan 6% rc:

icr = 3,25 in
6% rc = 3,24 in

karena nilai icr > 6% rc, maka menggunakan persamaan

$$t = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$ ***(Brownell; hal.138; eq. 7.77)***

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

(Brownell; hal.138; eq. 7.76)

Keterangan:

E = Faktor Pengelasan = 0,80
t = Tebal dinding minimal
f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*
= 18.750 Psi ***(Brownell; hal. 251; Tabel 13-1)***
C = Faktor Korosi (in) = 0,125 in

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

$$= \frac{1}{4}\left(3 + \sqrt[2]{(54\ \text{in} / 3{,}25\ \text{in})}\right)$$

$$= 1{,}7690$$

$$t_{Head} = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$

$$= \frac{2{,}0418\ \text{Psi} \times 54\ \text{in} \times 1{,}7690}{37.500\ \text{Psi} \times 0{,}8 - 0{,}4084\ \text{Psi}} + 0{,}125\ \text{in}$$

= 0,1315 in

= (Digunakan t = $\frac{3}{16}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Head

$$\frac{3}{16} \text{ in} = \frac{2{,}0418 \text{ Psi} \times 95{,}5287 \text{ in}}{2\, f \times 0{,}80 - 0{,}4084 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 1.950,7738 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tinggi tutup atas dan bawah:

Di = 50,9914 in

$a = \frac{Di}{2}$

$= \frac{50{,}9914 \text{ in}}{2}$

= 25,4957 in

icr = 3,2500 in

r_C = 54 in ***(Brownell; hal. 91; Tabel 5.7)***

$AB = \frac{Di}{2} - icr$

$= \frac{50{,}9914 \text{ in}}{2} - 3{,}250 \text{ in}$

= 22,2457 in

BC = r_C - icr

= 54 in - 3 in

= 50,7500 in

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

= √(2.575,5625 in - 494,8706 in)

= 45,6146 in

b = r_C - AC

= 54 in - 45,6146 in

= 8,3854 in

sf = 3 in ***(Brownell; hal. 93; Tabel 5.8)***

t_{Head} = 0,1875 in

OA = t_{Head} + b + sf

= 0,1875 in + 8,3854 in + 3 in

= 11,5729 in

Maka, tinggi tutup = 11,5729 in

$\sqrt{(BC^2)-(AB^2)}$ = 0,2940 m

= 0,9644 ft

Perhitungan Tinggi Jaket

Tinggi Jaket = Tinggi Shell + Tinggi Tutup Bawah

= 8,4986 ft + 0,9644 ft

= 9,4630 ft

Asumsi:

Tebal air pendingin = 2

Tebal Jaket = 0,1875 = 3/16 in

Efisiensi Las = 0,8

Faktor Korosi = 0,125 in

Digunakan material *Stainless Steel SA-167 Grade 11*

f = 18.750

DO Shell = Di + 2ts

= 50,9914 in + 2 x 0,1875 in

= 51,3664 in

Di Jacket = DO Shell + 2 s

= 51,3664 in + 2 x 2,0000 in

= 55,3664 in

DO Jacket = Di Jacket + 2 t Jacket

= 55,3664 in + 2 x 0,1875 in

= 55,7414 in

P Design Jacket = P Outside - P Inside + P Hidrostatis

= 14,7 Psi - 14,7 Psi + ρ Campuran x g/gc x H Liq

= 49,10 lb/cuft x 1 lbf/lbm x 5,4394 ft

= 267,0785 lbf/ft^2

= 1,8547 Psi

Perhitungan Tebal Jaket

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

$$t_{Jacket} = \frac{P \ x \ Dij}{2 \ f \ E \ - \ P} + C$$

Keteragan:

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi ***(Brownell; hal. 251; Tabel 13.1)***

$$t_{min} = \frac{1{,}8547 \text{ Psi} \times 55{,}3664 \text{ in}}{30.000 \text{ Psi} - 1{,}8547 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{102{,}6887}{29.998{,}1453} + 0{,}125 \text{ in}$$

$$= 0{,}1284 \text{ in}$$

= (Digunakan $t = \frac{3}{16}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perancangan Penyangga Tangki

$$\text{Berat}_{Shell} = \frac{1}{4}\pi \;(OD^2 - ID^2) \times H_{Liq} \times \rho_{Steel}$$

ρ Steel = 0,2790 lb/in^3 ***(Brownell; hal. 341, App. D, Item 3)***

= 482,11 lb/ft^3

$$= \frac{3{,}14}{4} \times (\;18{,}3 \text{ ft} - 18{,}1 \text{ ft}) \times 5{,}4 \text{ ft} \times 482 \text{ lb/ft}^3$$

= 548,7312 lb

$$\text{Berat}_{T\ Atas} = \frac{1}{4}\pi \;(OD^2 - ID^2) \times H_{Tutup} \times \rho_{Steel}$$

$$= \frac{3{,}14}{4} \times (\;18{,}3 \text{ ft} - 18{,}1 \text{ ft}) \times 1{,}0 \text{ ft} \times 482 \text{ lb/ft}^3$$

= 97,2900 lb

$$\text{Berat}_{T\ Bawah} = \frac{3{,}14}{4} \times (\;18{,}3 \text{ ft} - 18{,}1 \text{ ft}) \times 1{,}0 \text{ ft} \times 482 \text{ lb/ft}^3$$

= 97,2900 lb

Berat $_{Fluida}$ = Berat Feed

= 1.717,0 kg

= 3.786,0 lb

Berat $_{Mati\ Shel}$ = Berat $_{Shell}$ + Berat $_{Tutup\ Atas}$ + Berat $_{Tutup\ Bawah}$ + Berat $_{Fluida}$

= 548,7 lb + 97,3 lb + 97,3 lb + 3.786,0 lb

= 4.529,2961 lb

= 2.054,1025 kg

Leg Planning

Berat untuk perancangan = 1,2 x berat mati tangki
= 1,2 x 4.529,3 lb
= 5.435,1553 lb

Kaki penyangga dilakukan pengelasan di tengah-tengah ketinggian (40% tinggi total bejana) dengan leg tipe I-Beam, Pondasi Concrete / Beton

H_{Leg} = 40% x H_{Tangki}
= 40% x 10,4274 ft
= 4,1710 ft
= 50,0514 in
= 1,2712 m

Digunakan Beams 12 x 5 in

Berat/ft	=	31,80	lb
Area of Section (A)	=	9,26	in^2
Kedalaman Beam	=	12,00	in
Lebar Flange	=	5,00	in
Tebal Rata-rata	=	0,54	in
Tebal Web	=	0,35	in

Peletakan dengan beban Ekstrensik (Axis 1-1)

I = 215,8 in^4
S = 36,0 in^3
r = 4,8 in

Peletakan tanpa beban Ekstrensik (Axis 2-2)

I = 9,5 in^4
S = 3,8 in^3
r = 1,0 in ***(Brownell; hal. 355; App. G)***

Beban Kompresi total maksimum tiap Leg (P):

$$\text{Beban tiap penyangga} = \frac{\text{Berat Perancangan}}{\text{Jumlah Penyangga}}$$

Asumsi jumlah penyangga = 4

$$\text{Maka beban tiap penyangga} = \frac{5.435,1553 \text{ lb}}{4}$$

$P = 1.358,7888$ lb untuk setiap penyangga

Cek peletakan sumbu Axis 1-1 maupun Axis 2-2

$$Fc\ Allowable = \frac{P}{A} = \frac{1.358,8\ \text{lb}}{9,26\ \text{in}^2} = 146,7\ \text{psi}$$

Pemeriksaan Leg Planning

Axis 1-1

$$\frac{1}{r} = \frac{50,1\ \text{in}}{4,8} = 10,3626$$

$$Fc\ Pemeriksaan = 17.000 - 0,485\left(\frac{1}{r}\right)^2$$

$$= 17.000 - 0,485\ (10,4)^2$$

$$= 16.947,9189$$

Fc Pemeriksaan < Fc Allowable (Dapat digunakan)

Axis 2-2

$$\frac{1}{r} = \frac{50,1\ \text{ft}}{1,0} = 49,5559$$

$$Fc\ Pemeriksaan = 17.000 - 0,485\left(\frac{1}{r}\right)^2$$

$$= 17.000 - 0,485\ (49,6)^2$$

$$= 15.808,9451$$

Fc Pemeriksaan < Fc Allowable (Dapat digunakan)

Lug Planning

Setiap penyangga memiliki 4 baut

$$P_{Bolt} = \frac{P}{n_{Bolt}} = \frac{1.358,8\ \text{lb}}{4,0} = 339,6972\ \text{lb}$$

Luas lubang Baut

$$A_{Bolt} = \frac{P_{Bolt}}{f_{Bolt}}$$ ***(Brownell; hal. 194; eq. 10.44)***

$$A_{Bolt} = \frac{339{,}7 \text{ lb}}{12.000{,}0 \text{ psi}}$$

$$= 0{,}0283 \text{ in}^2$$

Digunakan baut dengan diameter 1 in

Spesifikasi Penyimpanan Sementara Formaldehid

Fungsi	:	Tempat penyimpanan Asetaldehid sementara sebelum menuju ke Reaktor				
Tipe	:	Tangki Silinder Tegak dengan tutup atas dan bawah Torispherical Dished Head, dilengkapi dengan Cooling Jacket				
Bahan konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*				
Tekanan	:	1 atm				
Kapasitas / Volume	:	120,4684	cuft	=	3,4093	m^3
Diameter Shell	:	4,2493	ft	=	1,2951	m
Tinggi Shell	:	8,4986	ft	=	2,5902	m
Tebal Shell	:	1/5	in	=	0,0048	m
Tinggi tutup atas	:	11,5729	in	=	0,2940	m
Tebal tutup atas	:	0,1875	in	=	0,0048	m
Tinggi tutup bawah	:	11,5729	in	=	0,2940	m
Tebal tutup bawah	:	0,1875	in	=	0,0048	m
Tinggi Total tangki	:	10,4274	ft	=	3,1781	m
Waktu Operasi	:	85	menit			
Diameter Heating Jacket (in)	:	55,3664	in	=	1,4063	m
Diameter Heating Jacket (out)	:	55,7414	in	=	1,4158	m
Tinggi Heating Jacket	:	9,4630	ft	=	2,8842	m
Tebal Heating Jacket	:	0,1875	in	=	0,0048	m
Tipe Penyangga	:	Beam				
Ukuran Peyangga	:	12 x 5	in			
Tinggi Kaki	:	4,1710	ft	=	1,2712	m
Lebar Flange	:	5	in	=	0,1270	m
Diameter Baut	:	1	in	=	0,0254	m
Jumlah	:	1	Tangki			

9. GUDANG PENYIMPANAN KALSIUM HIDROKSIDA

Kode Alat : F -130

Fungsi : Menampung Kalsium Hidroksida untuk Keperluan proses Produksi

Tipe : Bangunan Persegi empat, dengan atap Limas segi 4, dan lantai rata

Dasar Pemilihan : Ekonomis dan umum digunakan untuk Padatan

Tekanan : 1 atm

Temperatur : 30 °C

Waktu Penyimpanan : 21 hari

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$Ca(OH_2)_{(s)}$	95%	2.859,3540	2,2000	2.200,00	137,35
$H_2O_{(l)}$	5%	150,4923	1,0229	1.022,88	63,86
Total	100%	3.009,8463			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

= 2,080 x 63,8581 lb/cuft

= 132,8440 lb/cuft

Rate Massa = 3.009,8463 kg/jam

= 6.636,1092 lb/jam

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

$$= \frac{6.636,1092 \text{ lb / Jam}}{132,8440 \text{ lb / cuft}}$$

= 49,9542 cuft / Jam

Volume Komponen = Rate Volumetrik x Waktu Penyimpanan

= 49,95 cuft / Jam x 21 hari

= 25.176,8948 cuft

= 712,9235 m^3

= 712.929,0933 Liter

Dilakukan pengisian bahan sebanyak 80% volume (faktor keamanan)

Volume Bahan = 80% dari volume Gudang

Volume Gudang (V) = $\frac{25.176,8948 \text{ cuft}}{80\%}$

= 31.471,1184 cuft

Perhitungan Dimensi Gudang

Dipilih rasio:

Panjang (P) = 3 H

Lebar (L) = 3 H

Tinggi (H) = H

V = 3 H x 3 H x H

31471,1 cuft = 9 X^3

H^3 = 3496,8 ft^3

Tinggi (H)	=	15,1783	ft	=	4,6261	m
Panjang (P)	=	45,5349	ft	=	13,8784	m
Lebar (L)	=	45,5349	ft	=	13,8784	m

Atap dari Asbes dengan kemiringan 30°C

Tinggi Atap = tan 30 x $\frac{L}{2}$

= 1,0942 m

Spesifikasi Gudang Penyimpanan Kalsium Hidroksida

Fungsi	:	Menampung Kalsium Hidroksida untuk Keperluan proses Produksi
Tipe	:	Bangunan Persegi empat, dengan atap Limas segi 4, dan lantai rata
Tekanan	:	1 atm
Waktu Penyimpanan	:	21 hari
Kapasitas / Volume	:	31.471,1184 cuft
Panjang	:	13,8784 m
Lebar	:	13,8784 m
Tinggi	:	4,6261 m
Tinggi Atap	:	1,0942 m
Bahan konstruksi	:	Concrete (beton) dengan atap Asbes
Jumlah	:	1 Gudang

10. SCREW CONVEYOR 1

Kode Alat : J - 131

Fungsi : Memindahkan Kalsium Hidroksida Padat menuju ke Bucket Elevator

Tipe : *Plain spouts or chutes* , dengan *Discharge trough end*

Dasar Pemilihan : Umum digunakan untuk pemindahan komponen padatan halus, tidak lengket

Tekanan : 1 atm

Temperatur : 30 °C

Waktu Operasi : Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$Ca(OH_2)_{(s)}$	95%	2.859,3540	2,2000	2.200,00	137,35
$H_2O_{(l)}$	5,00%	150,4923	1,0229	1.022,8753	63,8581
Total	100%	3.009,8463			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

$$= 2{,}080 \quad x \quad 63{,}8581\ \text{lb/cuft}$$

$$= 132{,}8440\ \text{lb/cuft}$$

Rate Massa = 3.009,8463 kg/jam

= 6.636,1092 lb/jam

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

$$= \frac{6.636{,}1092\ \text{lb / Jam}}{132{,}8440\ \text{lb / cuft}}$$

$$= 49{,}9542\ \text{cuft / Jam}$$

$$\text{Bulk Density} = \frac{\text{Massa Kalsium Hidroksida}}{\text{Rate Volumetrik}}$$

$$= \frac{2.859{,}3540\ \text{kg/jam}}{49{,}9542\ \text{cuft/jam}}$$

$$= 57{,}24\ \text{kg/cuft}$$

Untuk bulk densitas 57,24 kg/cuft, maka menggunakan kelas c

diperoleh F = 2,0 - 2,5 ***(Badger; hal. 711, Tabel 16-6)***

= 2,0 (dipilih)

Perhitugnan Power Motor

$$hp = \frac{C\,L\,W\,F}{33000}$$ ***(Badger; hal. 713, eq. 16-4)***

Keterangan:

C = Kapasitas (cuft/m)

L = Panjang (ft)

W = Berat Meterial (lb/cuft)

F = Faktor Konstanta (Tabel 16-6)

Asumsi panjang = 30 ft

$$hp = \frac{0{,}8326 \text{ cuft/m} \times 30 \text{ ft} \times 132{,}8440 \text{ lb/cuft} \times 2{,}0}{33.000}$$

= 0,2011

Untuk power (hp) dibawah 2, maka dikalikan 2 ***(Badger; hal. 713)***

= 0,2011 x 2

= 0,4022

Berdasarkan kapasitas yang dimiliki, untuk kelas "c" diperoleh:

Diameter = 6 in

Kecepatan putaran = 100 rpm

(Badger; hal. 712, Fig. 16-20)

Spesifikasi Screw Conveyor 1

Fungsi	:	Memindahkan Kalsium Hidroksida Padat menuju ke Bucket Elevator
Tipe	:	Plain spouts or chutes, dengan Discharge trough end
Tekanan	:	1 atm
Kapasitas / Volume	:	49,9542 cuft
Diameter	:	6,0000 in
Panjang Conveyor	:	30,0000 ft = 9,1436 m
Kecepatan putaran	:	100 rpm
Power	:	0,4022 hp
Jumlah	:	1 Unit

11. BUCKET ELEVATOR 1

Kode Alat	:	J - 132
Fungsi	:	Memindahkan Padatan Kalsium Hidroksida dari Gudang Penyimpanan menuju Hopper Tangki

		Pencampuran
Tipe	:	*Continous Bucket Elevator*
Dasar Pemilihan	:	Umum dan cocok untuk transportasi vertikal komponen padatan
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Presentase	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$Ca(OH)_2$	95%	2.859,3540	2,2000	2.200,0000	137,35
H_2O	5%	150,4923	1,0229	1.022,8753	63,8581
Total	100%	3.009,8463			

Digunakan Bucket Elevator :

Ukuran Bucket	=	Lebar x Proyeksi x Kedalaman
	=	6 x 4 x 4 1/4 in
Jarak antar Bucket	=	12 in
Tinggi Elevator	=	25 ft
Kapasitas Maksimum	=	14 ton/jam
	=	14.000 kg/jam
Kecepatan Bucket	=	225 ft/min
	=	68,6 m/min
Putaran Head Shaft	=	43 r/min
Lebar Belt	=	7 in
Power yang dibutuhkan	=	1 hp untuk head shaft
Power tambahan	=	0,02 hp/ft
		(Perry 7th; hal. 21-15; Tabel 21-8)
	=	0,02 x 25 ft
	=	0,5 hp
Total Power	=	Power Head Shaft + Power Tambahan
	=	1 hp + 0,5 hp
	=	1,5 hp
Efisiensi Motor	=	80%

Power yang dibutuhkan = $\frac{\text{Total Power}}{\text{Efisiensi Motor}}$

= $\frac{1{,}5 \text{ hp}}{}$

80%

= 1,875 hp

Perhitungan Kecepatan Bucket Elevator

Kecepatan Bucket $= \dfrac{\text{Rate Massa}}{\text{Kapasitas maksimum}} \times$ Kecepatan Bucket

$= \dfrac{3.009{,}8463 \text{ kg/jam}}{14.000 \text{ kg/jam}} \times 225$ ft/mir

= 48,37 ft/min

Spesifikasi Bucket Elevator 1

Fungsi	=	Memindahkan Padatan Kalsium Hidroksida dari Gudang Penyimpanan menuju Hopper Tangki Pencampuran
Tipe	=	Continous Bucket Elevator
Tekanan	=	1 atm
Kapasitas / Volume	=	14 ton/jam
Ukuran Bucket	=	6 x 4 x 4 1/4 in
Tinggi Elevator	=	25 ft
Kecepatan Bucket	=	48,37 ft/min
Putaran Head Shaft	=	43 r/min
Power yang dibutuhkan	=	1,8750 hp
Jumlah	=	1 Unit

11. HOPPER

Kode Alat	:	F - 133
Fungsi	:	Menampung Padatan Kalsium Hidroksida dari Bucket Elevator menuju Tangki Pencampuran
Tipe	:	Silinder dengan tutup bawah berbentuk Conical dished dengan Posisi Vertical
Material Konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*
Dasar Pemilihan	:	Ekonomis dan umum digunakan untuk Padatan, disertai dengan Material untuk Bahan Korosif
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Penyimpanan	:	1 hari

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m³)	ρ (lb/ft³)
$Ca(OH_2)_{(s)}$	95%	2.859,3540	2,2000	2.200,0000	137,35
$H_2O_{(l)}$	5%	150,4923	1,0229	1.022,8753	63,8581
Total	100%	3.009,8463			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

= 2,080 x 63,858 lb/cuft

= 132,8440 lb/cuft

Rate Massa = 3.009,8463 kg/jam

= 6.636,1092 lb/jam

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

$$= \frac{6.636,1092 \text{ lb / Jam}}{132,8440 \text{ lb / cuft}}$$

= 49,9542 cuft / Jam

Volume Komponen = Rate Volumetrik x Waktu Penyimpanan

= 49,95 cuft / Jam x 1 hari

= 1.198,8998 cuft

= 33,9487 m^3

= 33.949,0044 Liter

Dilakukan pengisian bahan sebanyak 80% volume (faktor keamanan)

Volume Bahan = 80% dari volume Tangki Penyimpanan

$$\text{Volume Tangki } (V_S) = \frac{1.198,8998 \text{ cuft}}{80\%}$$

= 1.498,6247 cuft

Perhitungan Dimensi Tangki

Tinggi (H) = 2 Diameter (D) ***(Ulrich; hal. 248; Tabel 4-27)***

$$V_S = \frac{1}{4} \pi D^2 H$$

$$V_S = \frac{3,14}{4} \times 2 \times Ds^3$$

$$V_S = 1,57 \ Ds^3$$

V tutup atas torispherical dish = 0,000049 Ds^3

(Brownell; hal. 88; eq. 5.11)

Volume Tangki = V_S + V tutup atas

1.498,6247 cuft = 1,57 Ds^3 + 0,000049 Ds^3

1.498,6247 cuft = 1,57 Ds^3

Ds^3 = 954,5082 cuft

Ds = 9,8460 ft = 118,1520 in = 3,0011 m

Hs = 19,6920 ft = 236,3040 in = 6,0021 m

Perhitungan Tinggi Komponen

Volume Bahan = $\frac{1}{4}\pi\ Ds^2\ H_{liq}$

1.198,8998 cuft = $\frac{3,14}{4}$ x $9,8460^2$ x H_{liq}

$H_{Komponen}$ = 15,7541 ft = 189,0491 in = 4,8018 m

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

P = 1 atm = 14,6959 Psi

P_{Inside} = 14,6959 Psi

$P_{Outside}$ = 14,6959 Psi

P_{Design} = P_{Inside} - $P_{Outside}$ + $P_{Hidrostatis}$

= 14,7 Psi - 14,7 Psi + $P_{Hidrostatis}$

P_{Design} = $P_{Hidrostatis}$

$P_{Hidrostatis}$ = ρ Campuran x $\frac{g}{gc}$ x H_{liq}

= 132,8440 lbm/cuft x 1 lbf/lbm x 15,7541 ft

= 2092,8366 lb/ft^2

= 14,5452 Psi

P_{Design} dibuat berlebih 10% (faktor keamanan)

P_{Design} = 1,1 x 14,5452 Psi

= 15,9997 Psi

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

t_{min} = Tebal Shell Minimum (in)

P = Tekanan Tangki (Psi)

ri = Jari - jari Tangki (in) (1/2 D)
E = Faktor Pengelasan (digunakan double) = 0,80
C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in
f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*
= 18.750 ***(Brownell; hal. 251; Tabel 13.1)***

$$t_{min} = \frac{15{,}9997 \text{ Psi} \times 59{,}0760 \text{ in}}{15.000 \text{ Psi} - 9{,}5998 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{945{,}2005}{14.990{,}4002} + 0{,}125 \text{ in}$$

= 0,1881 in

= (Digunakan $t_S = \frac{3}{8}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Shell

$$\frac{3}{8} \text{ in} = \frac{15{,}9997 \text{ Psi} \times 59{,}0760 \text{ in}}{f \times 0{,}80 - 9{,}5998 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 4.738,0024 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tebal tutup bawah

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

(Brownell; hal. 118, eq. 6-154)

Keterangan:

tc_{min} = Tebal Conical, in
P = Tekanan Tangki, psi
= 15,9997 psi
D = Diameter tangki (D_C), in
= 118,1520 in
α = Sudut Conis, 30 °
f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*
= 18.750 psi ***(Brownell; hal. 251; Tabel 13.1)***
E = Faktor Pengelasan
= 0,8
C = Faktor Korosi

$$= 0{,}125$$

$$tc_{min} = \frac{15{,}9997 \times 118{,}1520}{2 \cos 30 \;(18.750 \times 0{,}8 - 0{,}6 \times 16{,}00)} + 0{,}13$$

$$= 0{,}5338 \text{ in}$$

$$= \frac{5}{8} \text{ in}$$

Perhitungan Koreksi tebal tutup bawah Minimum

$$\frac{5}{8} = \frac{15{,}9997 \text{ Psi} \times 118{,}1520 \text{ in}}{2 \cos 30^o \;(f \times 0{,}80 - 9{,}5998 \text{ Psi})} + 0{,}13 \text{ in}$$

$$0{,}6 = \frac{1.890{,}40 \text{ Psi}}{1{,}7321 \;(f \times 0{,}80 - 9{,}5998 \text{ Psi})} + 0{,}13 \text{ in}$$

$f = 2.740{,}5587$ Psi $< f_{Allowable}$ **(Memenuhi)**

Perhitungan Tinggi Conical

$$h_C = \frac{\tan \alpha \,(D - m)}{2}$$ ***(Hesse; hal. 92, eq.4-17)***

Keterangan:

α = Sudut Conis, 30 ^{o}

D = Diameter Tangki (D_C), ft

m = Flat Spot Diameter = 1 ft

$$h_C = \frac{\tan 30^o \times (9{,}8460 \text{ ft} - 1 \text{ ft})}{2}$$

$$= \frac{0{,}5774 \times (8{,}8460 \text{ ft})}{2}$$

$$= 2{,}5536 \text{ ft}$$

$$= 0{,}7783 \text{ m}$$

Spesifikasi Hopper

Fungsi	:	Menampung Padatan Kalsium Hidroksida dari Bucket Elevator menuju Tangki Pencampuran
Tipe	:	Silinder dengan tutup bawah berbentuk Conical dished dengan Posisi Vertical
Tekanan	:	1 atm
Kapasitas / Volume	:	1.498,6247 cuft = 42,4111 m^3
Diameter	:	9,8460 ft = 3,0009 m
Tinggi	:	19,6920 ft = 6,0018 m
Tebal Shell	:	0,3750 in = 0,0095 m

Tebal tutup bawah	:	0,6250 in	=	0,0159 m
Tinggi tutup bawah	:	30,6434 in	=	0,7783 m
Bahan konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*		
Waktu Penyimpanan	:	1 hari		
Jumlah	:	1 tangki		

12. TANGKI PENCAMPURAN

Kode Alat : M - 134

Fungsi : Mencampurkan Padatan Kalsium Hidroksida dengan Air

Tipe : Tangki Silinder Tegak Berpengaduk dengan tutup atas Torispherical Dished Head, dan tutup bawah Flat

Material Konstruksi : *Stainless Steel 316 SA-167, Grade 11*

Dasar Pemilihan : Ekonomis dan umum digunakan untuk pencampuran
: padat-cair, dengan Material untuk Bahan Korosif

Tekanan : 1 atm

Temperatur : 30 °C

Waktu Operasi : Kontinyu

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$Ca(OH)_{2(aq)}$	50,0%	2.859,3540	2,2000	2.200,0000	137,35
$H_2O_{(l)}$	50,0%	2.859,3540	1,0229	1.022,8753	63,86
Total	100%	5.718,7080			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

$$= 1{,}396 \times 63{,}8581 \text{ lb/cuft}$$

$$= 89{,}1760 \text{ lb/cuft}$$

Rate Massa = 5.718,7080 kg/jam

= 12.608,6074 lb/jam

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

$$= \frac{12.608{,}6074 \text{ lb / Jam}}{89{,}1760 \text{ lb / cuft}}$$

$$= 141{,}3902 \text{ cuft / Jam}$$

Ditetapkan pengisian bahan sebanyak 70% volume (faktor keamanan)

Volume Bahan = 70% dari volume Tangki

Volume Tangki (V_S) = $\frac{141{,}3902 \text{ cuft}}{70\%}$

= 201,9860 cuft

Perhitungan Dimensi Tangki

Tinggi (H) = 2 Diameter (D) ***(Ulrich; hal. 248; Tabel 4-27)***

$V_S = \frac{1}{4} \pi D^2 H$

$V_S = \frac{3{,}14}{4} \times 2 \times Ds^3$

$V_S = 1{,}57 \; Ds^3$

V tutup atas torispherical dish = $0{,}000049 \; Ds^3$

(Brownell; hal. 88; eq. 5.11)

V tutup atas = V tutup bawah

Volume Tangki = V_S + 2 V tutup atas

201,9860 cuft = $1{,}57 \; Ds^3 + 0{,}000098 \; Ds^3$

201,9860 cuft = $1{,}57 \; Ds^3$

Ds^3 = 128,6455 cuft

Ds = 5,0481 ft = 60,5777 in = 1,5387 m

Hs = 10,0963 ft = 121,1554 in = 3,0773 m

Perhitungan Tinggi Komponen

Volume Bahan = $\frac{1}{4} \pi \; Ds^2 \; H_{liq}$

141,3902 cuft = $\frac{3{,}14}{4} \times 5{,}0481^2 \times H_{liq}$

H_{liq} = 7,0678 ft = 84,8141 in = 2,1543 m

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

P = 1 atm = 14,6959 Psi

P_{Inside} = 14,6959 Psi

$P_{Outside}$ = 14,6959 Psi

P_{Design} = $P_{Inside} - P_{Outside} + P_{Hidrostatis}$

= 14,7 Psi - 14,7 Psi + $P_{Hidrostatis}$

$P_{Design} = P_{Hidrostatis}$

$P_{Hidrostatis} = \rho \text{ Campuran} \times \dfrac{g}{gc} \times H_{liq}$

$= 89{,}1760 \text{ lbm/cuft} \times 1 \text{ lbf/lbm} \times 7{,}0678 \text{ ft}$

$= 630{,}2814 \text{ lb/ft}^2$

$= 4{,}3805 \text{ Psi}$

P_{Design} dibuat berlebih 10% (faktor keamanan)

$P_{Design} = 1{,}1 \times 4{,}3805 \text{ Psi}$

$= 4{,}8185 \text{ Psi}$

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

t_{min} = Tebal Shell Minimum (in)

P = Tekanan Tangki (Psi)

ri = Jari - jari Tangki (in) (1/2 D)

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi ***(Brownell; hal. 251; Tabel 13.1)***

$$t_{min} = \frac{4{,}8185 \text{ Psi} \times 30{,}2888 \text{ in}}{15.000 \text{ Psi} - 2{,}8911 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{145{,}9468}{14.997{,}1089} + 0{,}125 \text{ in}$$

$= 0{,}1347$ in

= (Digunakan $t_S = \dfrac{3}{16}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Shell

$$\frac{3}{16} \text{ in} = \frac{4{,}8185 \text{ Psi} \times 30{,}2888 \text{ in}}{f \times 0{,}80 - 2{,}8911 \text{ Psi}} + 0{,}125 \text{ in}$$

$f = 2.922{,}5508 \text{ Psi} < f_{Allowable}$ (memenuhi)

Perhitungan tebal tutup atas dan bawah

Tutup atas berbentuk Torispherical Dished Head

OD = ID + (2 t_S)
= 60,5777 in + 2 x 0,1875
= 60,9527 in
= (Digunakan OD = 66 in)

(Brownell; hal.91; Tabel 5.7)

Diperoleh:

icr = 4,0000 in = 0,3332 ft
r_C = 66 in = 5,4978 ft

Cek nilai icr dengan 6% rc:

icr = 4,00 in
6% rc = 3,96 in

karena nilai icr > 6% rc, maka menggunakan persamaan

$$t = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$ ***(Brownell; hal.138; eq. 7.77)***

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

(Brownell; hal.138; eq. 7.76)

Keterangan:

W = Faktor Stress
Pd = Tekanan design (P_{Design})
r_C = Radius Crown
r_1 or icr = Inside Crown Radius
E = Faktor Pengelasan = 0,80
t = Tebal dinding minimal
f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*
= 18.750 Psi ***(Brownell; hal. 251; Tabel 13-1)***
C = Faktor Korosi (in) = 0,125 in

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

$$= \frac{1}{4}\left(3 + \sqrt[2]{(66\ \text{in} / 4{,}00\ \text{in})}\right)$$

$$= 1{,}7655$$

$$t_{Head} = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$

$$= \frac{4{,}8185 \text{ Psi} \times 66 \text{ in} \times 1{,}7655}{37.500 \text{ Psi} \times 0{,}8 - 0{,}9637 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= 0{,}1437 \text{ in}$$

$$= (\text{Digunakan } t = \frac{1}{4} \text{ in})$$

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Head

$$\frac{1}{4} \text{ in} = \frac{4{,}8185 \text{ Psi} \times 116{,}5233 \text{ in}}{2\ f \times 0{,}80 - 0{,}9637 \text{ Psi}} + 0{,}125 \text{ in}$$

$$f = 2.807{,}9411 \text{ Psi} < f_{Allowable} \text{ (memenuhi)}$$

Perhitungan tinggi tutup atas dan bawah:

$$Di = 60{,}5777 \text{ in}$$

$$a = \frac{Di}{2}$$

$$= \frac{60{,}5777 \text{ in}}{2}$$

$$= 30{,}2888 \text{ in}$$

$$icr = 4{,}0000 \text{ in}$$

$$r_C = 66 \text{ in}$$ ***(Brownell; hal. 91; Tabel 5.7)***

$$AB = \frac{Di}{2} - icr$$

$$= \frac{60{,}5777 \text{ in}}{2} - 4{,}000 \text{ in}$$

$$= 26{,}2888 \text{ in}$$

$$BC = r_C - icr$$

$$= 66 \text{ in} - 4 \text{ in}$$

$$= 62{,}0000 \text{ in}$$

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

$$= \sqrt{(3.844{,}0000 \text{ in} - 691{,}1035 \text{ in})}$$

$$= 56{,}1507 \text{ in}$$

$$b = r_C - AC$$

$$= 66 \text{ in} - 56{,}1507 \text{ in}$$

= 9,8493 in

sf = 3 in **(*Brownell; hal. 93; Tabel 5.8*)**

t_{Head} = 0,2500 in

OA = t_{Head} + b + sf

= 0,2500 in + 9,8493 in + 3 in

= 13,0993 in

Maka, tinggi tutup = 13,0993 in

= 0,3327 m

= 1,0916 ft

Perhitungan Sistem Pengaduk Slurry

$$\rho_m = \frac{100}{(C_w / \rho_s) + [(100 - C_w)/\rho_L]}$$

(*Menon; hal. 603; eq. 10.1*)

Keterangan:

ρ_m = Densitas Slurry (mixture), lb/cuft

C_w = Konsentrasi Solid (by weight), %

= 50% % = 50

ρ_s = Densitas Solid (in mixture), lb/cuft

= 137,3460 lb/ft^3

ρ_L = Densitas Luquid (in mixture), lb/cuft

= 63,8581 lb/ft^3

$$\rho_m = \frac{100}{\left(\frac{50{,}00}{137{,}3\ lb/ft^3}\right) + \left[\frac{(100 - 50{,}00)}{63{,}86\ lb/ft^3}\right]}$$

$$= \frac{100}{0{,}3640\ lb/ft^3 + [\ 0{,}7830\ lb/ft^3\ ]}$$

$$= 87{,}1817\ lb/ft^3$$

$$C_v = C_w \frac{\rho_m}{\rho_s}$$

(*Menon; hal. 604; eq. 10.4*)

Keterangan:

C_v = Konsentrasi Solid (by volume), %

$$C_v = 50\ \frac{87{,}1817\ lb/ft^3}{137{,}3460\ lb/ft^3}$$

= 31,7380

= 31,74%

$$\Phi = \frac{C_v}{100}$$ ***(Menon; hal. 604; eq. 10.2)***

Keterangan:

Φ = Fraksi Volume Slurry, dimensionless

$$\Phi = \frac{31,7380}{100}$$

= 0,3174

$$\mu_m = \mu_L \; [\, 1 + 2,5 \;\; \Phi + 10,05 \;\; \Phi^2 + 0,00273 \;\; \exp(16,6 \;\; \Phi) \,]$$

(Menon; hal. 605; eq. 10.6)

Keterangan:

μ_m = Viskositas Surry (mixture), cP

μ_L = Viskositas Liquid, cP

= 0,5065 cP

μ_m = 0,5 cP [1 + 0,79 + 1,01 + 0,53]

= 1,6896 cP

= 0,0114 lb/ft.s

= 0,0169 Ns/m^2

$$Sg_m = \frac{100}{(C_w / Sg_s) + [(100 - C_w)/Sg_L]}$$

Keterangan:

Sg_m = Specific Gravity Slurry

Sg_s = Specific Gravity Solid

= 1,55 ***(Perry 8th; hal. 2-11; Tabel 2.1)***

Sg_L = Specific Gravity Liquid

= 0,9960 ***(Kern; hal. 808; Tabel 6)***

$$Sg_m = \frac{100}{\left(\frac{50,00}{1,6}\right) + \left[\frac{(100 - 50,00)}{1,00}\right]}$$

$$= \frac{100}{32,2581 + [\; 50,2008 \;]}$$

= 1,2127

Dengan mempertimbangkan Viskositas Bahan dan Volume Tangki, dipilih Pengaduk Marine Propeller dengan 3 blade

Kecepatan Pengaduk = 420 rpm ***(Towler; hal. 617, Fig. 10.57)***

Perhitungan Dimensi Pengaduk

$\frac{D_t}{D_i} = 3$

$\frac{Z_t}{D_i} = 2{,}7 - 3{,}9 = 3{,}9$ (dipilih)

$\frac{Z_i}{D_i} = 0{,}75 - 1{,}3 = 1{,}3$ (dipilih)

$\frac{w}{D_t} = 0{,}1$

Pitch = 2 Di ***(Brown; hal. 507, Fig. 477)***

Keterangan:

D_t = Diameter Tangki
= 5,0481 ft

D_i = Diameter Impeller
$= \frac{5{,}0481 \text{ ft}}{3}$
= 1,6827 ft

Z_t = Tinggi Liquid dalam Tangki
= 3,9 x 1,6827 ft
= 6,5626 ft

Z_i = Jarak Impeller dari dasar Tangki
= 1,3 x 1,6827 ft
= 2,1875 ft

n = Revolusi Per detik

w = Lebar Baffle
= 0,1 x 5,0481 ft
= 0,5048 ft

Pitch = 2 x 1,6827 ft
= 3,3654 ft

Perhitungan Kecepatan Pengadukan

n = 300 - 500 meter/menit untuk Marine Propeller
(Joshi; hal. 416)

$n_{(rpm)} = \frac{n_{(m/min)}}{}$

$$= \frac{\pi \;\; x \; D_i}{\begin{matrix}300 \\ \hline 3{,}14 \;\; x \;\; 0{,}5181\end{matrix}}$$

$= 184{,}4$ rpm $\approx$ 185 rpm

Penentuan Baffle

$$N_{Re} = \frac{n \times D_i^2 \times \rho}{\mu}$$ ***(Brown; hal. 508)***

Keterangan:

N_{Re} = Bilangan Reynolds

ρ = Densitas Campuran, lb/cuft

= 89,1760 lb/cuft

D_i = Diameter Impeller, ft

= 1,6827 ft

n = Kecepatan Pengadukan, rps

= 185 rpm

= 3 rps

μ = Viskositas Bahan, Pa.s

= 0,0114 lb/ft.s

= 0,5436 Pa.s

$$N_{Re} = \frac{3 \text{ rps} \times 2{,}8315 \text{ ft} \times 89{,}1760 \text{ lb/cuft}}{0{,}5436 \text{ lb/ft.s}}$$

= 1.428

Karena N_{Re} > 10,000, termasuk aliran Turbulen

Maka diputuskan untuk menggunakan Baffle, dengan jumlah 4 buah

(Perry 8th; hal. 18-11)

W_B = Lebar Baffle, ft

= 0,1 D_t ***(Perry 8th; hal. 18-11)***

= 0,5048 ft

Penentuan Jumlah Pengaduk

$$\text{Jumlah Pengaduk} = \frac{H_{liq} \times \text{sg bahan}}{D_S}$$

(Joshi; hal. 415)

Keterangan:

H_{liq} = Tinggi Komponen,

= 7,0678 ft = 84,8141 in = 2,1543 m

Sg_m = Specific Gravity Slurry (mixture)
= 1,2127
D_S = Diameter Tangki
= 5,0481 ft = 60,5777 in = 1,5387 m

$$\text{Jumlah Pengaduk} = \frac{2{,}1543 \text{ m} \times 1{,}2127}{1{,}5387 \text{ m}}$$
= 1,70 ≈ 2 buah

Perhitungan Jarak Antar Pengaduk

Jarak antar pengaduk = 1 - 1,5 Diameter Pengaduk
(Joshi; hal. 415)
= 1,5 Diameter Pengaduk (dipilih)
= 1,5 x 1,6827 ft
= 2,5241 ft = 30,2888 in = 0,7693 m

Perhitungan Power Pengaduk

$$P = \frac{N_P \times n^3 \times D_i^5 \times \rho}{gc}$$
(McCabe 5th; hal. 253, eq. 920)

Keterangan:
P = Power, ft.lbf/s
N_P = Power Number
= Berdasarkan Pengamatan, dipastikan Curve 3
= 0,5 ***(Towler; hal. 618, Fig.10.58)***
n = Kecepatan Putaran, rps
= 3 rps
D_i = Diameter Impeller, ft
= 1,6827 ft
ρ = Densitas Campuran
= 89,1760 lb/cuft
gc = Gravity Constants, $(lb.ft)/(lbf/s^2)$
= 32,1740 $(lb.ft)/(lbf/s^2)$

$$P = \frac{0{,}5 \times 29 \text{ rps} \times 13{,}4912 \text{ ft} \times 89{,}1760 \text{ lb/cuft}}{32{,}1740 \ (lb.ft)/(lbf/s^2)}$$
= 543,6249 ft.lbf/s
= 1,0021 Hp

Maka, besar power untuk 2 pengaduk:
$Power_2$ = 2,0042 Hp

Power perhitungan akan ditambahkan dengan beberapa faktor

Glands Loss = 10% ***(Joshi; hal. 424)***

= 0,2004 Hp

Transmission Loss = 20% ***(Joshi; hal. 424)***

= 0,4008 Hp

Power Total = Power_2 + Glands Loss + Transmission Loss

= 2,0042 Hp + 0,2004 Hp + 0,4008 Hp

= 2,6055 Hp

Efisiensi Motor = 85%

Power Motor = $\dfrac{\text{Power Total}}{\text{Efisiensi}}$

= $\dfrac{2{,}6055 \text{ Hp}}{85\%}$

= 3,0653 Hp ≈ 4 Hp

Perancangan Penyangga Tangki

$\text{Berat}_{\text{Shell}} = \frac{1}{4}\pi\ (OD^2 - ID^2) \times H_{Liq} \times \rho_{Steel}$

ρ Steel = 0,2790 lb/in^3 ***(Brownell; hal. 341, App. D, Item 3)***

= 482,11 lb/ft^3

= $\dfrac{3{,}14}{4}$ x (25,8 ft- 25,5 ft) x 7,1 ft x 482 lb/ft^3

= 846,5603 lb

$\text{Berat}_{\text{T Atas}} = \frac{1}{4}\pi\ (OD^2 - ID^2) \times H_{Tutup} \times \rho_{Steel}$

= $\dfrac{3{,}14}{4}$ x (25,8 ft- 25,5 ft) x 1,1 ft x 482 lb/ft^3

= 130,7493 lb

$\text{Berat}_{\text{T Bawah}}$ = $\dfrac{3{,}14}{4}$ x (25,8 ft- 25,5 ft) x 1,1 ft x 482 lb/ft^3

= 130,7493 lb

$\text{Berat}_{\text{Fluida}}$ = Berat Feed

= 5.718,7 kg

= 12.609,8 lb

$\text{Berat}_{\text{Mati Shell}}$ = $\text{Berat}_{\text{Shell}}$ + $\text{Berat}_{\text{Tutup Atas}}$ + $\text{Berat}_{\text{Tutup Bawah}}$ + $\text{Berat}_{\text{Fluida}}$

= 846,6 lb + 130,7 lb + 130,7 lb + 12.609,8 lb

= 13.717,8100 lb
= 6.221,2290 kg

Leg Planning

Berat untuk perancangan = 1,2 x berat mati tangki
= 1,2 x 13.717,8 lb
= 16.461,3720 lb

Kaki penyangga dilakukan pengelasan di tengah-tengah ketinggian (40% tinggi total bejana) dengan leg tipe I-Beam, Pondasi Concrete / Beton

H_{Leg} = 40% x H_{Tangki}
= 40% x 12,2795 ft
= 4,9118 ft
= 58,9416 in
= 1,4970 m

Digunakan Beams 12 x 5 in

Berat/ft	=	31,80	lb
Area of Section (A)	=	9,26	in^2
Kedalaman Beam	=	12,00	in
Lebar Flange	=	5,00	in
Tebal Rata-rata	=	0,54	in
Tebal Web	=	0,35	in

Peletakan dengan beban Ekstrensik (Axis 1-1)

I = 215,8 in^4
S = 36,0 in^3
r = 4,8 in

Peletakan tanpa beban Ekstrensik (Axis 2-2)

I = 9,5 in^4
S = 3,8 in^3
r = 1,0 in ***(Brownell; hal. 355; App. G)***

Beban Kompresi total maksimum tiap Leg (P):

$$\text{Beban tiap penyangga} = \frac{\text{Berat Perancangan}}{\text{Jumlah Penyangga}}$$

Asumsi jumlah penyangga = 4

$$\text{Maka beban tiap penyangga} = \frac{16.461,3720\ \text{lb}}{4}$$

P = 4.115,3430 lb untuk setiap penyangga

Cek peletakan sumbu Axis 1-1 maupun Axis 2-2

$$\text{Fc Allowable} = \frac{P}{A} = \frac{4.115{,}3 \text{ lb}}{9{,}26 \text{ in}^2} = 444{,}4 \text{ psi}$$

Pemeriksaan Leg Planning

Axis 1-1

$$\frac{1}{r} = \frac{58{,}9 \text{ in}}{4{,}8} = 12{,}2032$$

$$\text{Fc Pemeriksaan} = 17.000 - 0{,}485 \left(\frac{1}{r}\right)^2$$

$$= 17.000 - 0{,}485 \ (12{,}2)^2$$

$$= 16.927{,}7743$$

Fc Pemeriksaan < Fc Allowable (Dapat digunakan)

Axis 2-2

$$\frac{1}{r} = \frac{58{,}9 \text{ ft}}{1{,}0} = 58{,}3580$$

$$\text{Fc Pemeriksaan} = 17.000 - 0{,}485 \left(\frac{1}{r}\right)^2$$

$$= 17.000 - 0{,}485 \ (58{,}4)^2$$

$$= 15.348{,}2541$$

Fc Pemeriksaan < Fc Allowable (Dapat digunakan)

Lug Planning

Setiap penyangga memiliki 4 baut

$$P_{Bolt} = \frac{P}{n_{Bolt}} = \frac{4.115{,}3 \text{ lb}}{4{,}0} = 1.028{,}8358 \text{ lb}$$

Luas lubang Baut

$$A_{Bolt} = \frac{P_{Bolt}}{f_{Bolt}}$$ ***(Brownell; hal. 194; eq. 10.44)***

$$A_{Bolt} = \frac{1.028{,}8 \text{ lb}}{12.000{,}0 \text{ psi}}$$

= 0,0857 in^2

Digunakan baut dengan diameter 1 in

Spesifikasi Tangki Pencampuran

Fungsi	:	Mencampurkan Padatan Kalsium Hidroksida dengan Air				
Tipe	:	Tangki Silinder Tegak Berpengaduk dengan tutup atas Torispherical Dished Head, dan tutup bawah Flat				
Bahan konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*				
Tekanan	:	1 atm				
Kapasitas / Volume	:	201,9860	cuft	=	5,7162	m^3
Diameter Shell	:	5,0481	ft	=	1,5386	m
Tinggi Shell	:	10,0963	ft	=	3,0772	m
Tebal Shell	:	0,1875	in	=	0,0048	m
Tinggi tutup atas	:	13,0993	in	=	0,3327	m
Tebal tutup atas	:	0,2500	in	=	0,0064	m
Tinggi tutup bawah	:	13,0993	in	=	0,3327	m
Tebal tutup bawah	:	0,2500	in	=	0,0064	m
Tinggi Total tangki	:	12,2795	ft	=	3,7426	m
Waktu Operasi	:	Kontinyu				
Tipe Pengaduk	:	*Marine Propeller,* dengan 3 buah *Blade*				
Diameter Pengaduk	:	1,6827	ft	=	0,5129	m
Jarak Pengaduk	:	2,1875	ft	=	0,6667	m
Pitch	:	3,3654	ft	=	1,0257	m
Jumlah Pengaduk	:	2 buah				
Jarak antar Pengaduk	:	2,5241	ft	=	0,7693	m
Power Pengaduk	:	4 hp = 2,9828 kWh				
Jumlah Baffle	:	4 buah				
Lebar Baffle	:	0,5048	ft	=	0,1539	m
Tipe Penyangga	:	Beam				
Ukuran Peyangga	:	12 x 5	in			
Tinggi Kaki	:	4,9118	ft	=	1,4970	m
Lebar Flange	:	5	in	=	0,1270	m
Diameter Baut	:	1	in	=	0,0254	m
Jumlah	:	1 Tangki				

14. POMPA 3

Kode Alat	:	L - 135
Fungsi	:	Memindahkan Campuran Kalsium Hidroksida dari Tangki Pencampuran menuju Reaktor Kondensasi
Tipe	:	Centrifugal Pump
Dasar Pemilihan	:	Sesuai untuk Fluida Liquid dengan Viskositas <10 Cp
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m³)	ρ (lb/ft³)
$Ca(OH)_{2(aq)}$	50%	2.859,3540	2,2000	2.200,0000	137,346
$H_2O_{(l)}$	50%	2.859,3540	1,0229	1.022,8753	63,8581
Total	100%	5.718,7080			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

= 1,396 x 63,858 lb/cuft

= 89,1760 lb/cuft

= 1.428,4654 kg/m³

Rate Massa = 5.718,7080 kg/jam

= 12.608,6074 lb/jam

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

$$= \frac{12.608,6074\ \text{lb / Jam}}{89,1760\ \text{lb / cuft}}$$

= 141,3902 cuft / Jam

= 2,3565 cuft / menit

= 0,0393 cuft / sec

= 17,6290 gal / min

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s

= 0,5065 Cps

= 0,0005 Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi

$= 0{,}9960$

$$\text{sg Bahan} = \frac{\rho \text{ Bahan}}{\rho \text{ Reference } (H_2O)}$$

$$= \frac{137{,}3 \text{ lb/cuft}}{63{,}9 \text{ lb/cuft}}$$

$= 2{,}1508$

Menghitung Viskositas Slurry

$$\rho_m = \frac{100}{(C_w/\rho_s) + [(100-C_w)/\rho_L]}$$ **(Menon; hal 603; eq. 10.1)**

Keterangan :

ρ_m = Densitas slurry (mixture), lb/cuft

Cw = Konsentrasi solid (by weight), %

= 50 %

ρs = Densitas Solid , lb/cuft

= 137,35 lb/ft^3

ρL = Densitas liquid, lb/cuft

= 63,86 lb/ft^3

$$\rho_m = \frac{100}{\left(\frac{50}{137{,}35 \text{ lb/ft}^3}\right) + \left[\left(\frac{100 - 50}{63{,}86 \text{ lb/ft}^3}\right)\right]}$$

$= 87{,}18 \text{ lb/ft}^3$

$$Cv = Cw\frac{\rho_m}{\rho s}$$ **(Menon; hal. 604; eq. 10.4)**

Keterangan :

Cv = Konsentrasi Solid (by volume), %

$$Cv = 50\,\frac{87{,}18}{137{,}35}\ (\text{lb/ft}^3)$$

$= 31{,}74\ \%$

$$\Phi = \frac{Cv}{100}$$

Keterangan :

Φ = Fraksi volume slurry, dimensionless

$$\Phi = \frac{31{,}74}{100}$$

$= 0{,}3174$

$\mu m = \mu L \ (\ 1 + 2{,}5 \ \Phi + 10{,}05 \ \Phi^2 + 0{,}00273 \ \exp(\ 16{,}6 \ \Phi \ )$

(Menon; hal 605; eq 10.6)

μm = Viskositas slurry, cP

μL = Viskositas liquid, cP

= ρ Reference cP = 0,5065 cP

μm = 0,5065 cP (1 + 0,79 + 1,01 + 0,53)

= 1,6896 cP

Perhitungan ID Optimum

Asumsi Aliran Turbulen, dengan $N_{Re} > 2100$, digunakan rumus:

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

(Peters 4th; hal. 496; eq. 15)

Keterangan:

ID = Optimum Pipe Inside Diameter, in

qf = Fluid Flow Rate, cuft/sec

ρ = Fluid Density, lb/cuft

$ID_{Optimum}$ = 3,9 x 0,2330 cuft/sec x 1,7928 lb/cuft

= 1,6291 in

Perhitungan Pipa

Dipilih pipa:

IPS, Size = 2 in

OD = 2,3750 in

Schedule = No. 40

ID = 2,0670 in ***(McCabe7th; hal. 1090; App. 3)***

= 0,1723 ft

= 0,0525 m

$A_1 = \frac{1}{4} \pi \times ID_{Tangki}^2$

$= \frac{3{,}14}{4} \times (\ 60{,}58 \ \text{in} \ )^2$

= 2.880,6807 in^2

= 20,0047 ft^2

$A_2 = \frac{1}{4} \pi \times ID^2$

$= \frac{3{,}14}{4} \times (\ 2{,}07 \ \text{in} \ )^2$

= 3,3539 in^2

= 0,0233 ft^2

A_2 / A_1 = 0,0011643 < 0.715

V = $\frac{\text{Rate Volumetrik}}{A}$

= $\frac{0{,}0393 \ ft^3 / sec}{0{,}02 \ ft^2}$

= 1,6863 ft / sec

= 0,5140 m / sec

N_{Re} = $\frac{D \times V \times \rho}{\mu}$ ***(Peters 4th; hal. 481; eq. 6)***

= $\frac{0{,}05 \ in \times 0{,}51 \ m/s \times 1428{,}5 \ kg/m^3}{0{,}00169 \ Pa.s}$

= 22.813,6451 > 2,100 (Airan Turbulen)

Equivalent Roughness for Pipe (ε) untuk material Commercial Steel

ε = 0,00015 ft ***(Peters 4th; hal. 482; Fig. 14-1)***

= 0,000046 m ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

= 0,001800 in

$\frac{\varepsilon}{D}$ = 0,000871

f = 0,0079 ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

Perhitungan Equivalent Suction (L_e)

Sambungan / Fitting	L_e / D	
90º Elbow Standard	35	***(Peters 4th; hal. 484; Tabel 1)***
Gate Valve, Open	9	***(Peters 4th; hal. 485; Tabel 1)***

3 Elbow std 90º = 3 x (L_e / D) x DI

= 35 x 0,1723 ft

= 18,0863 ft

= 5,5124 m

1 Gate Valve $_{\text{Wide Open}}$ = 1 x (L_e / D) x DI

= 9 x 0,1723 ft

= 1,5503 ft

= 0,4725 m

Perhitungan Panjang Pipa

Pipa A ke B = 3,50 m = 11,4835 ft

Elbow 1 ke Elbow 2 (Tinggi total reaktor)	=	8,71	m	=	28,5773	ft
Elbow 2 ke Elbow 3	=	1,00	m	=	3,2810	ft
Elbow 3 ke Elbow Reaktor	=	1,00	m	=	3,2810	ft
Panjang Total Pipa Lurus	=	14,2099	m	=	46,6228	ft
Panjang Total Pipa Keseluruhan	=	20,1948	m	=	66,2593	ft

Perhitungan Friksi

Friksi karena Gesekan :

$$F_1 = \frac{2\,f \times V^2 \times L_e}{g_C \times D}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times g_C}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_3 = \frac{(V_2 - V_1)^2}{2 \times \alpha \times g_C}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_4 = n \times Kf \times \frac{V_1^2}{2 \times g_C}$$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

$$F_5 = n \times Kf \times \frac{V_1^2}{2 \times g_C}$$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

Keterangan

F_1 = Flow Through long straight pipe

F_2 = Sudden Contraction

F_3 = Sudden Enlargement

F_4 = Losses Fitting - Elbow 90º

F_5 = Losses Fitting - Gate Valve Open

V = Linear Velocity, ft/sec

= 1,6863 ft/sec

α = Correction Coefficient, Viscous (0.5), Turbulen (1.0)

= 1,0 Turbulen (>2100) ***(Peters 4th; hal. 480)***

L = Length of Pipe

= 66,2593 ft

D = Diameter of Pipe

= 2,0670 in = 0,1723 ft

f = Fanning Friction Factor

= 0,0079 ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

g_C = Newton's Law Conversion Factor, ft.lbm / lbf

= 32,17 ft.lbm/lbf

A_1 = Luas Penampang Tangki Pencampuran, ft^2

= 20,0047 ft^2

A_2 = Luas Penampang Pipa, ft2

= 0,0233 ft^2

K_C = Coefficient Friction Loss, (untuk $A_2/A_1 < 0.715$)

$$= 0,40 \times \left(1,25 - \frac{A_2}{A_1}\right)$$

= 0,4995 ***(Peters 4th; hal. 484; Tabel 1)***

Kf = Number of Velocity Heads

= Elbow 90º = 0,7500

= Gate Valve Open = 0,1700

(Geankoplis 3rd; hal. 93; Tabel 2.10-1)

$$F_1 = \frac{2 \times 0,0079 \times (1,7 \text{ ft/sec})^2 \times 66,3 \text{ ft}}{32,17 \text{ ft.lbm/lbf} \times 2,0670 \text{ in}}$$

= 0,0448 ft .lbf / lbm

$$F_2 = \frac{0,50 \times (1,7 \text{ ft/sec})^2}{2 \times 1,0 \times 32,17 \text{ ft.lbm/lbf}}$$

= 0,0221 ft .lbf / lbm

F_3 = Karena A_1 (Tangki) > A_2 (Pipa), Maka $V_1 = 0$

$$= \frac{(1,7 \text{ ft/sec})^2}{2 \times 1,0 \times 32,17 \text{ ft.lbm/lbf}}$$

= 0,0442 ft .lbf / lbm

$$F_4 = 3 \times 0,75 \times \frac{(1,7 \text{ ft/sec})^2}{2 \times 32,2 \text{ ft.lbm/lbf}}$$

= 0,0994 ft.lbf / lbm

$$F_5 = 1 \times 0,41 \times \frac{(1,7 \text{ ft/sec})^2}{2 \times 32,2 \text{ ft.lbm/lbf}}$$

= 0,0179 ft.lbf / lbm

$\sum F$ = $F_1 + F_2 + F_3 + F_4 + F_5$ ***(Geankoplis 3rd; hal. 95)***

= 0,2284 ft .lbf / lbm

Persamaan Bernoulli

$$z_1 \, \underline{g} + \underline{V_1^2} + \underline{P_1 - P_2} - W_f = z_2 \, \underline{g} + \underline{V_2^2} + \sum F$$

g_C $2\alpha g_C$ $\rho_1 - \rho_2$ g_C $2\alpha g_C$

(Geankoplis 3rd; hal. 95; eq. 2.10-20)

$$- W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

Keterangan :

W_S = Work done by Fluid ***(Geankoplis 3rd; hal. 62)***

z = Vertical Distance, ft

V = Linear Velocity, ft/sec

g = g_C = Gravity Constants

g / g_C = 1 lbf/lbm ***(Peters 4th; hal. 487; ex. 1)***

$\sum F$ = Total Friction Loss, ft.lbf/lbm

= 0,2284 ft .lbf / lbm

ρ = Densitas Campuran, lb/cuft

= 89,1760 lb/cuft

P = Tekanan, Psi

P_1 = $P_1 + P_{\text{Hidrostatis}}$

= 14,7 Psi + 4,4 Psi = 19,08 Psi

P_2 = 14,7 Psi

ΔP = $P_1 - P_2$

= 19,1 Psi - 14,7 Psi

= 4,4 Psi

= 630,8 lbf / ft^2

$$\frac{\Delta P}{\rho} = \frac{630{,}79 \ lbf / ft^2}{89{,}18 \ lb/cuft}$$

= 7,0735 ft.lbf / lbm

Asumsi:

z_1 = 28,5773 ft

z_2 = 11,4835 ft

$\Delta z \frac{g}{g_C}$ = (28,6 ft - 11,5 ft) x 1 lbf/lbm

= 17,0938 ft.lbf / lbm

$$\frac{\Delta V^2}{2 \times \alpha \times g_C} = \frac{(1{,}6863 \ ft/sec)^2}{2 \times 1{,}0 \times 32{,}2 \ ft.lbm/lbf}$$

= 0,0442 ft.lbf / lbm

$$- W_S = \frac{\Delta P}{} + \Delta z \frac{g}{} + \frac{\Delta V^2}{} + \sum F$$

$\rho \qquad g_C \qquad 2\alpha g_C$

$= 7{,}07 + 17{,}09 + 0{,}04 + 0{,}23$

$= 24{,}4398$ ft.lbf / lbm

Perhitungan Brake Horsepower (BHp)

Untuk Flowrate tersebut, diperoleh efisiensi pompa sebesar:

$\eta_{Pompa} = 45\%$ *(Peters 4th; hal. 520; Fig. 14-37)*

$W_S = -\eta \times W_P$ *(Geankoplis 3rd; hal. 65; eq. 2.7-30)*

$W_P = \dfrac{-W_S}{\eta}$

$= \dfrac{24{,}4 \text{ ft.lbf / lbm}}{45\%}$

$= 54{,}3107$ ft.lbf / lbm

$BHp = \dfrac{W_P \times \text{Flowrate}}{550}$ *(Geankoplis 3rd; hal. 66)*

$= \dfrac{54{,}3 \text{ ft.lbf / lbm} \times 4{,}5 \text{ lb/sec}}{550}$

$= 0{,}445$

≈ 1 hp

Perhitungan Power Motor

Untuk BHp tersebut, diperoleh efisiensi motor sebesar:

$\eta_{Motor} = 80\%$ *(Peters 4th; hal. 521; Fig. 14-38)*

$hp = \dfrac{BHp}{\eta_{Motor}}$

$= \dfrac{1 \text{ hp}}{80\%}$

$= 1{,}2500$

≈ 2 hp

Spesifikasi Pompa 3

Fungsi	:	Memindahkan Campuran Kalsium Hidroksida dari Tangki Pencampuran menuju Reaktor Kondensasi
Tipe	:	Centrifugal Pump
Kecepatan Aliran	:	1,6863 ft/sec = 0,5140 ft/sec
Flowrate	:	0,0393 cuft/s = 17,6290 gal/min
Size Pipa, IPS	:	2 in
ID Pipa	:	2,0670 in

Schedule	:	No. 40
Efisiensi Pompa	:	45%
Power Pompa	:	1 hp
Efisiensi Motor	:	80%
Power Motor	:	2 hp
Jumlah	:	1 Pompa

15. HEATER KALSIUM HIDROKSIDA

Kode Alat	:	E - 136
Fungsi	:	Memanaskan Campuran Kalsium Hidroksida sebelum memasuki Reaktor Kondensasi
Tipe	:	Shell and Tube Heat Exchanger
Dasar Pemilihan	:	Umum digunakan untuk proses perpindahan panas
Tekanan	:	1 atm
Temperatur	:	55 °C
Waktu Operasi	:	Kontinyu

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$Ca(OH)_{2(aq)}$	50%	2.859,3540	2,2000	2.200,0000	137,35
$H_2O_{(l)}$	50%	2.859,3540	1,0229	1.022,8753	63,86
Total	100%	5.718,7080			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

$$= 1{,}396 \times 63{,}8581 \text{ lb/cuft}$$

$$= 89{,}1760 \text{ lb/cuft}$$

$$\text{Rate Massa} = 5.718{,}7080 \text{ kg/jam}$$

$$= 12.608{,}6074 \text{ lb/jam}$$

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

$$= \frac{12.608{,}6074 \text{ lb / Jam}}{89{,}1760 \text{ lb / cuft}}$$

$$= 141{,}3902 \text{ cuft / Jam}$$

$$\text{Viskositas Bahan} = \frac{\text{sg Bahan} \times \mu \text{ Reference } (H_2O)}{\text{sg Reference}}$$

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s
= 0,5065 Cps
= 0,0005 Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi
= 0,9960

$$\text{sg Bahan} = \frac{\rho\ \text{Bahan}}{\rho\ \text{Reference}\ (H_2O)} = \frac{137{,}3\ \text{lb/cuft}}{63{,}9\ \text{lb/cuft}} = 2{,}1508$$

$$\text{Viskositas Bahan} = \frac{2{,}1508 \times 0{,}0005\ \text{Pa.s}}{0{,}9960}$$

= 0,0011 lb/ft.s
= 0,0016 Ns/m^2
= 1,6277 Cps

Heat Balance

Panas yang dibutuhkan	:	405.181,1996	kJ/Jam
		384.058,0091	Btu/Jam
Steam yang digunakan	:	186,4102	kg/Jam
		411,0345	lb/Jam

Log Mean Temperature Difference (LMTD)

Suhu bahan masuk, t_1	=	30	°C	=	86	°F
Suhu banah keluar, t_2	=	55	°C	=	131	°F
Suhu steam masuk, T_1	=	130	°C	=	266	°F
Suhu steam kondensat, T_2	=	130	°C	=	266	°F

$\Delta T_1 = T_2 - t_2$

$\Delta T_2 = T_1 - t_1$ *(Kern; hal. 90)*

$\Delta T_1 = 266\ °F - 131\ °F$
$= 135\ °F$

$\Delta T_2 = 266\ °F - 86\ °F$
$= 180\ °F$

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}$$ *(Kern; hal. 89; eq. 5.14)*

= 156,4227 °F

R = $\dfrac{T_1 - T_2}{t_2 - t_1}$ ***(Kern; hal. 142)***

= $\dfrac{266\ °F - 266\ °F}{131\ °F - 86\ °F}$

= 0,0000 °F

S = $\dfrac{t_2 - t_1}{T_1 - t_1}$ ***(Kern; hal. 142)***

= $\dfrac{131\ °F - 86\ °F}{266\ °F - 86\ °F}$

= 0,2500 °F

F_T = 1 ***(Kern; hal. 828; Fig. 18)***

Δt = F_T x LMTD ***(Kern; hal. 149; eq. 7.42)***

= 1 x 156,42 °F

= 156,42 °F

Perhitungan T_C dan t_C dipakai Temperature rata-tata

T_C = $T_{Average}$ Steam ***(Kern; hal. 113)***

= $\dfrac{266\ °F + 266\ °F}{2}$

= 266 °F

t_C = $t_{Average}$ Bahan ***(Kern; hal. 113)***

= $\dfrac{86\ °F + 131\ °F}{2}$

= 109 °F

Trial

Asumsi U_D untuk Campuran Kalsium Hidroksida (Aqueous Soution < 2 Cp)

U_D = 200 - 700 Btu/jam.ft^2.°F

= 700 Btu/jam.ft^2.°F ***(Kern; hal. 840; Tabel. 8)***

A = $\dfrac{Q}{\Delta t \times U_D}$ ***(Kern; hal. 107; eq. 6.11)***

= $\dfrac{384.058{,}0091\ \text{Btu/Jam}}{156{,}4\ °F \times 700\ \text{Btu/jam.ft}^2.°F}$

= 3,5075 ft^2

= 505,0816 in^2

Digunakan OD pipa 1/2 in, sehingga diperoleh:

a" = 0,1309 ft^2/lin ft ***(Kern; hal. 843; Tabel. 10)***

Digunakan panjang pipa:

L = 25 ft = 300 in ***(Kern; hal. 103)***

Number of tubes

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

$$= \frac{3{,}5075 \ ft^2}{25 \ ft \times 0{,}1309 \ ft^2/\text{lin ft}}$$

$$= 1{,}0718 \approx 2$$

$$Q = k \frac{A}{L} \Delta t$$

(Kern; hal. 7; eq. 2.4)

Keterangan:

Q = Aliran Panas, Btu/jam

k = Konduktivitas Thermal, Btu/Jam.ft^2.°F

A = Area Perpindahan Panas, ft^2

L = Panjang Pipa, ft

Δt = Perbedaan Temperatur, °F

$$k = \frac{Q \times L}{A \times \Delta t}$$

$$= \frac{2.237{,}50 \ \text{Btu/Jam} \times 25 \ ft}{3{,}51 \ ft^2 \times 156{,}4 \ °F}$$

$$= 0{,}0283 \ \text{Btu/Jam.ft}^2.°F$$

Dipilih:

Tube	Shell
OD = 1/2 in	Pitch = 1 in
BWG = 12	Shell ID = 8 in
a't = 0,063 in^2	Passes = 1
a" = 0,1309 Surface / lin ft, ft^2	Nt = 36
	B Space = 2 in
Passes = 2	OD = 3/4 in
ID = 0,620 in	
Wall Thicness = 0,065 in	

(Kern; hal. 843; Tabel. 10) ***(Kern; hal. 842; Tabel. 9)***

A baru = Nt x L x a" ***(Kern; hal. 150)***

= 36 x 25 ft x 0,1309 Surface / lin ft, ft^2

= 117,81 ft^2

$$U_D \text{ baru} = \frac{Q}{A \text{ baru} \times \Delta T_{LMTD}}$$

$$= \frac{384.058{,}0091 \text{ Btu/Jam}}{117{,}81 \text{ ft}^2 \times 156{,}42 \text{ °F}}$$

= 20,8408 Btu/jam.ft^2.°F

Cold Fluid (Tube)	Hot Fluid (Shell)
Kalsium Hidroksida	**Steam**
(4) Flow Area Tube (a_t) $a_t = \frac{Nt \times a't}{144 \times n}$ $= \frac{36 \times 0{,}1}{144 \times 2}$ = 0,0078 ft^2	(4') Flow Area Shell (a_s) C" = Pitch - OD = 1 in - 3/4 in = 1/5 in $B = ID = \frac{8}{5}$ = 2 in $a_s = \frac{ID \times C'' \times B}{144 \ Pr}$ $= \frac{8 \text{ in} \times 1/5 \text{ in} \times 2 \text{ in}}{144 \times 1 \text{ in}}$ = 0,0178 ft^2
(5) Mass Velocity Tube (Gt) $G_t = \frac{W_{bahan}}{a_t}$ $= \frac{12.608{,}6 \text{ lb/Jam}}{0{,}0078 \text{ ft}^2}$ = 1.613.901,7 lb/Jam.ft^2	(5) Mass Velocity Shell (Gs) $G_s = \frac{W_{steam}}{a_s}$ $= \frac{411{,}0 \text{ lb/Jam}}{0{,}0178 \text{ ft}^2}$ = 23.120,6895 lb/Jam.ft^2
(6) Pada t_C = 108,5 °F μ = 1,6277 cps = 3,9390 lbm/Jam.ft D_i = 0,62 in	(6') Pada T_C = 266,0 °F μ = 0,0135 cps ***(Kern; hal. 825; Fig. 15)*** = 0,0327 lbm/Jam.ft

$= 0{,}0517$ ft

$Re_t = \dfrac{D \times G_t}{\mu}$

$= \dfrac{0{,}05 \text{ ft} \times 1.613.902 \text{ lb/Jam.ft}^2}{3{,}9390 \text{ lbm/Jam.ft}}$

$= 21.169{,}0461$

(7) Heat Transfer Factor

$j_H = 75$

(Kern; hal. 834; Fig. 24)

(8) Konduktivitas Thermal pada t_C

$k = 0{,}0283$ Btu/Jam.ft^2.°F

(Kern; hal. 7; eq. 2.4)

Cp = 447,5 kj/kmol.°F
= 14,90 kj/kg.°F
= 32,85 kj/lb.°F
= 31,14 Btu/lb°F

$\left(\dfrac{Cp \times \mu}{k}\right)^{1/3} = 16{,}3005$

(9) Condensation of Steam

$h_i = j_H \dfrac{k}{D_i} \left(\dfrac{Cp \times \mu}{k}\right)^{1/3} \varphi_t$

(Kern; hal. 111; eq. 6.15a)

$= 104{,}2365$ Btu/Jam.ft^2.°F

$h_{io} = h_i \dfrac{ID}{OD}$

(Kern; hal. 105; eq. 6.5)

$= 129{,}2532$ Btu/Jam.ft^2.°F

(10) Pada $t_w = 239{,}0961$ °F

$\mu_w = 1{,}6277$ Cps

$D_e = 0{,}73$ in

$= 0{,}0608$ ft

$Re_s = \dfrac{D_e \times G_s}{\mu}$

$= \dfrac{0{,}06 \text{ ft} \times 23.121 \text{ lb/Jam.ft}^2}{0{,}0327 \text{ lbm/Jam.ft}}$

$= 43.051{,}9930$

(7') Heat Transfer Factor

$j_H = 120$

(Kern; hal. 838; Fig. 28)

(8') Konduktivitas Thermal pada t_C

$k = 0{,}0133$ Btu/Jam.ft^2.°F

(Yaws; hal. 551; Tabel 24-2)

Cp = 0,46 Btu/lb°F

(Kern; hal. 805; Fig. 3)

$\left(\dfrac{Cp \times \mu}{k}\right)^{1/3} = 1{,}0368$

(9') Condensation of Steam

$h_o = j_H \dfrac{k}{D_e} \left(\dfrac{Cp \times \mu}{k}\right)^{1/3} \varphi_s$

(Kern; hal. 112; eq. 6.15b)

$= 26{,}6273$ Btu/Jam.ft^2.°F

(10') Tube Wall Temperature

$t_w = t_c + \dfrac{h_{io}}{\quad} (T_c - t_c)$

(Yaws; hal.482; Tabel 22-1) = 3,9390 lbm/Jam.ft $\varphi_t = \left(\frac{\mu}{\mu_w}\right)^{0,14}$ $= \left(\frac{3,9390\ °F}{3,9390\ °F}\right)^{0,14}$ = 1,0000 $Btu/Jam.ft^2.°F$ (12) Corrected Coefficient $h_{io} = \frac{h_{io}}{\varphi_t} \times \varphi_t$ ***(Kern; hal. 121; eq. 6.37)*** = 129,2532 $Btu/Jam.ft^2.°F$	$t_w = t_c + \frac{h_o}{h_{io} + h_o}(T_c - t_c)$ = 239,0961 °F

(13) Clean Overall Coefficient

$$U_C = \frac{h_{io} \times h_o}{h_{io} + h_o}$$ ***(Kern; hal. 121; eq. 6.38)***

$$= \frac{129,3\ Btu/jam.ft^2.°F \times 26,6273}{129,3\ Btu/jam.ft^2.°F + 26,6273}$$

$$= 22,0789\ Btu/jam.ft^2.°F$$

(14) Dirt Factor, Rd

$$R_d = \frac{U_C - U_D}{U_C \times U_D}$$ ***(Kern; hal. 108; eq. 6.13)***

$$= \frac{22,1\ Btu/jam.ft^2.°F - 20,8\ Btu/jam.ft^2.°F}{22,1\ Btu/jam.ft^2.°F \times 20,8\ Btu/jam.ft^2.°F}$$

$$= 0,0027$$

Untuk R_d data, digunakan "Brackish Water" atau Air Payau dengan R_d

R_d data = 0,002 - 0,001 ***(Kern; hal. 845; Tabel 12)***

R_d perhitungan > R_d data

0,003 > 0,002

Maka, desain dapat digunakan

Cold Fluid	**Hot Fluid**
Kalsium Hidroksida	**Steam**
Pressure Drop	
(a) Untuk Re_t = 21.169,0461	(a') Untuk Re_s = 43.051,9930

f = 0,0002	f = 0,0015
(Kern; hal. 836; Fig. 26)	***(Kern; hal. 839; Fig. 29)***
s = 2,1508	s = 1,0000
	(Kern; hal. 808; Tabel. 6)
	(b') Number of times fluid crosses
	$N+1 = \frac{\text{Tube Length}}{\text{Baffle Space}} = \frac{12 \times L}{B}$
	(Kern; hal. 147; eq. 7.43)
	$= \frac{300 \text{ in}}{2 \text{ in}}$
	= 240
(c) Pressure drop in Tube or Pipes	(c') Pressure drop in Shell side
$\Delta P_t = \frac{f \times G_t^2 \times L \times n}{5.22 \times 10^{10} \times D_i \times s \times \varphi_t}$	$\Delta P_s = \frac{f \times G_s^2 \times D_s (N+1)}{5.22 \times 10^{10} \times D_e \times s \times \varphi_s}$
(Kern; hal. 148; eq. 7.45)	***(Kern; hal. 147; eq. 7.44)***
$= \frac{12.209.432.094,0}{5.800.707.271}$	$= \frac{11.707.002}{3.175.500.000}$
= 2,1048 Psi	= 0,0037 Psi
$\Delta P_t < 10$ psi	$\Delta P_s < 10$ psi
(memenuhi)	(memenuhi)

Spesifikasi Heater Kalsium Hidroksida

Fungsi	:	Memanaskan Campuran Kalsium Hidroksida sebelum memasuki Reaktor Kondensasi				
Tipe	:	Shell and Tube Heat Exchanger				
Tube						
Inside Diameter	:	0,62	in	=	0,0157	m
Outside Diameter	:	1/2	in	=	0,0127	m
Panjang	:	25	ft	=	7,6196	m
Jumlah Tube	:	2 buah				
Shell						
Pitch	:	1	in	=	0,0238	m
Inside Diameter	:	8	in	=	0,2032	m
OD Shell	:	3/4	in	=	0,0191	m
Jumlah Heater	:	1 buah				

16. Tangki Penampungan Sementara Kalsium Hidroksida

Kode Alat	:	F - 137
Fungsi	:	Tempat penyimpanan Ca(OH)2 sementara sebelum menuju ke Reaktor
Tipe	:	Tangki Silinder Tegak dengan tutup atas dan bawah Torispherical Dished Head, dilengkapi dengan Cooling Jacket
Material Konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*
Dasar Pemilihan	:	Ekonomis dan umum digunakan
	:	disertai dengan Material untuk Bahan Korosif
Tekanan	:	1 atm
Temperatur	:	55 °C
Waktu Operasi	:	1 Jam

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
Ca(OH)2	50%	2.859,3540	2,2000	2.200,0000	137,346
$H_2O_{(l)}$	50%	2.859,3540	1,0229	1.022,8753	63,8581
Total	100%	5.718,7080			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

= 1,396 x 63,8581 lb/cuft

= 89,1760 lb/cuft

Rate Massa = 5.718,7080 kg/jam

= 12.608,6074 lb/jam

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

$$= \frac{12.608,6074 \text{ lb / Jam}}{89,1760 \text{ lb / cuft}}$$

= 141,3902 cuft / Jam

τ x rate volumetrik = Volume tangki (Vs)

1,25 jam x 141 cuft / Jam = Vs

176,7377 cuft = Vs

Ditetapkan pengisian bahan sebanyak 80% volume (faktor keamanan)

Volume Bahan = 80% dari volume Tangki

$$\text{Volume Tangki } (V_S) = \frac{176{,}7377 \text{ cuft}}{80\%}$$

$$= 220{,}9222 \text{ cuft}$$

Perhitungan Dimensi Tangki

Tinggi (H) = 2 Diameter (D) ***(Ulrich; hal. 248; Tabel 4-27)***

$$V_S = \frac{1}{4} \pi \; D^2 \; H$$

$$V_S = \frac{3{,}14}{4} \times 2 \times Ds^3$$

$$V_S = 1{,}57 \; Ds^3$$

V tutup atas torispherical dish = $0{,}000049 \; Ds^3$

(Brownell; hal. 88; eq. 5.11)

V tutup atas = V tutup bawah

Volume Tangki = V_S + 2 V tutup atas

220,9222 cuft = $1{,}57 \; Ds^3 + 0{,}000098 \; Ds^3$

220,9222 cuft = $1{,}57 \; Ds^3$

Ds^3 = 140,7060 cuft

Ds = 5,2012 ft = 62,4145 in = 1,5853 m

Hs = 10,4024 ft = 124,8290 in = 3,1707 m

Perhitungan Tinggi Komponen

$$\text{Volume Bahan} = \frac{1}{4} \pi \; Ds^2 \; H_{liq}$$

$$141{,}3902 \text{ cuft} = \frac{3{,}14}{4} \times 5{,}2012^2 \times H_{liq}$$

H_{liq} = 6,6580 ft = 79,8955 in = 2,0293 m

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

P = 1 atm = 14,6959 Psi

P_{Inside} = 14,6959 Psi

$P_{Outside}$ = 14,6959 Psi

P_{Design} = $P_{Inside} - P_{Outside} + P_{Hidrostatis}$

= 14,7 Psi - 14,7 Psi + $P_{Hidrostatis}$

P_{Design} = $P_{Hidrostatis}$

$P_{Hidrostatis} = \rho \text{ Campuran} \times \frac{g}{gc} \times H_{liq}$

$= 89{,}1760 \text{ lbm/cuft} \times 1 \text{ lbf/lbm} \times 6{,}6580 \text{ ft}$

$= 593{,}7302 \text{ lb/ft}^2$

$= 4{,}1264 \text{ Psi}$

P_{Design} dibuat berlebih 10% (faktor keamanan)

$P_{Design} = 1{,}1 \times 4{,}1264 \text{ Psi}$

$= 4{,}5391 \text{ Psi}$

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi ***(Brownell; hal. 251; Tabel 13.1)***

$$t_{min} = \frac{4{,}5391 \text{ Psi} \times 31{,}2072 \text{ in}}{15.000 \text{ Psi} - 2{,}7234 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{141{,}6518}{14.997{,}2766} + 0{,}125 \text{ in}$$

$= 0{,}1344 \text{ in}$

= (Digunakan $t_S = \frac{3}{16}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Shell

$$\frac{3}{16} \text{ in} = \frac{4{,}5391 \text{ Psi} \times 31{,}2072 \text{ in}}{f \times 0{,}80 - 2{,}7234 \text{ Psi}} + 0{,}125 \text{ in}$$

$f = 2.836{,}4399 \text{ Psi} < f_{Allowable}$ (memenuhi)

Perhitungan tebal tutup atas dan bawah

Tutup atas berbentuk Torispherical Dished Head

OD = ID + (2 t_S)
= 62,4145 in + 2 x 0,1875
= 62,7895 in
= (Digunakan OD = 66 in)

(Brownell; hal.91; Tabel 5.7)

Diperoleh:

icr = 4,0000 in = 0,3332 ft
r_C = 66 in = 5,4978 ft

Cek nilai icr dengan 6% rc:

icr = 4,00 in
6% rc = 3,96 in

karena nilai icr > 6% rc, maka menggunakan persamaan

$$t = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$

(Brownell; hal.138; eq. 7.77)

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

(Brownell; hal.138; eq. 7.76)

Keterangan:

E = Faktor Pengelasan = 0,80
t = Tebal dinding minimal
f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*
= 18.750 Psi ***(Brownell; hal. 251; Tabel 13-1)***
C = Faktor Korosi (in) = 0,125 in

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

$$= \frac{1}{4}\left(3 + \sqrt[2]{(66\ \text{in} / 4{,}00\ \text{in})}\right)$$

= 1,7655

$$t_{Head} = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$

$$= \frac{4{,}5391\ \text{Psi} \times 66\ \text{in} \times 1{,}7655}{37.500\ \text{Psi} \times 0{,}8 - 0{,}9078\ \text{Psi}} + 0{,}125\ \text{in}$$

= 0,1426 in
= (Digunakan t = 3 in)

16

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Head

$$\frac{3}{16}\ \text{in} = \frac{4{,}5391\ \text{Psi} \times 116{,}5233\ \text{in}}{2\ f \times 0{,}80 - 0{,}9078\ \text{Psi}} + 0{,}125\ \text{in}$$

f = 5.289,6390 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tinggi tutup atas dan bawah:

Di = 62,4145 in

$$a = \frac{Di}{2}$$

$$= \frac{62{,}4145\ \text{in}}{2}$$

= 31,2072 in

icr = 4,0000 in

r_C = 66 in ***(Brownell; hal. 91; Tabel 5.7)***

$$AB = \frac{Di}{2} - icr$$

$$= \frac{62{,}4145\ \text{in}}{2} - 4{,}000\ \text{in}$$

= 27,2072 in

BC = r_C - icr

= 66 in - 4 in

= 62,0000 in

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

= √ (3.844,0000 in - 740,2342 in)

= 55,7115 in

b = r_C - AC

= 66 in - 55,7115 in

= 10,2885 in

sf = 3 in ***(Brownell; hal. 93; Tabel 5.8)***

t_{Head} = 0,1875 in

OA = t_{Head} + b + sf

= 0,1875 in + 10,2885 in + 3 in

= 13,4760 in

Maka, tinggi tutup = 13,4760 in

$\sqrt{(BC^2)-(AB^2)}$ = 0,3423 m
= 1,1230 ft

Perhitungan Tinggi Jaket

Tinggi Jaket = Tinggi Shell + Tinggi Tutup Bawah
= 10,4024 ft + 1,1230 ft
= 11,5254 ft

Asumsi:

Tebal air pendingin = 2
Tebal Jaket = 0,1875 = 3/16 in
Efisiensi Las = 0,8
Faktor Korosi = 0,125 in

Digunakan material *Stainless Steel SA-167 Grade 11*

f = 18.750

DO Shell = Di + 2ts
= 62,4145 in + 2 x 0,1875 in
= 62,7895 in

Di Jacket = DO Shell + 2 s
= 62,7895 in + 2 x 2,0000 in
= 66,7895 in

DO Jacket = Di Jacket + 2 t Jacket
= 66,7895 in + 2 x 0,1875 in
= 67,1645 in

P Design Jacket = P Outside - P Inside + P Hidrostatis
= 14,7 Psi - 14,7 Psi + ρ Campuran x g/gc x H Liq
= 89,18 lb/cuft x 1 lbf/lbm x 6,6580 ft
= 593,7302 lbf/ft^2
= 4,1231 Psi

Perhitungan Tebal Jaket

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

$$t_{Jacket} = \frac{P \times Dij}{2\, f\, E - P} + C$$

Keteragan:

E = Faktor Pengelasan (digunakan double) = 0,80
C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in
f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167*

Grade 11

= 18.750 Psi **(Brownell; hal. 251; Tabel 13.1)**

$$t_{min} = \frac{4{,}1231 \text{ Psi} \times 66{,}7895 \text{ in}}{30.000 \text{ Psi} - 4{,}1231 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{275{,}3815}{29.995{,}8769} + 0{,}125 \text{ in}$$

= 0,1342 in

= (Digunakan t = $\frac{3}{16}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perancangan Penyangga Tangki

$\text{Berat}_{Shell} = \frac{1}{4}\pi \; (OD^2 - ID^2) \times H_{Liq} \times \rho_{Steel}$

ρ Steel = 0,2790 lb/in^3 **(Brownell; hal. 341, App. D, Item 3)**

= 482,11 lb/ft^3

$= \frac{3{,}14}{4} \times (27{,}4 \text{ ft} - 27{,}1 \text{ ft}) \times 6{,}7 \text{ ft} \times 482 \text{ lb/ft}^3$

= 821,5722 lb

$\text{Berat}_{T\ Atas} = \frac{1}{4}\pi \; (OD^2 - ID^2) \times H_{Tutup} \times \rho_{Steel}$

$= \frac{3{,}14}{4} \times (27{,}4 \text{ ft} - 27{,}1 \text{ ft}) \times 1{,}1 \text{ ft} \times 482 \text{ lb/ft}^3$

= 138,5753 lb

$\text{Berat}_{T\ Bawah} = \frac{3{,}14}{4} \times (27{,}4 \text{ ft} - 27{,}1 \text{ ft}) \times 1{,}1 \text{ ft} \times 482 \text{ lb/ft}^3$

= 138,5753 lb

Berat_{Fluida} = Berat Feed

= 5.718,7 kg

= 12.609,8 lb

$\text{Berat}_{Mati\ Shel}$ = $\text{Berat}_{Shell} + \text{Berat}_{Tutup\ Atas} + \text{Berat}_{Tutup\ Bawah} + \text{Berat}_{Fluida}$

= 821,6 lb + 138,6 lb + 138,6 lb + 12.609,8 lb

= 13.708,4740 lb

= 6.216,9950 kg

Leg Planning

Berat untuk perancangan = 1,2 x berat mati tangki
= 1,2 x 13.708,5 lb
= 16.450,1687 lb

Kaki penyangga dilakukan pengelasan di tengah-tengah ketinggian (40% tinggi total bejana) dengan leg tipe I-Beam, Pondasi Concrete / Beton

H_{Leg} = 40% x H_{Tangki}
= 40% x 12,6484 ft
= 5,0594 ft
= 60,7124 in
= 1,5420 m

Digunakan Beams 12 x 5 in

Berat/ft	=	31,80	lb
Area of Section (A)	=	9,26	in^2
Kedalaman Beam	=	12,00	in
Lebar Flange	=	5,00	in
Tebal Rata-rata	=	0,54	in
Tebal Web	=	0,35	in

Peletakan dengan beban Ekstrensik (Axis 1-1)

I = 215,8 in^4
S = 36,0 in^3
r = 4,8 in

Peletakan tanpa beban Ekstrensik (Axis 2-2)

I = 9,5 in^4
S = 3,8 in^3
r = 1,0 in ***(Brownell; hal. 355; App. G)***

Beban Kompresi total maksimum tiap Leg (P):

$$\text{Beban tiap penyangga} = \frac{\text{Berat Perancangan}}{\text{Jumlah Penyangga}}$$

Asumsi jumlah penyangga = 4

$$\text{Maka beban tiap penyangga} = \frac{16.450,1687 \text{ lb}}{4}$$

P = 4.112,5422 lb untuk setiap penyangga

Cek peletakan sumbu Axis 1-1 maupun Axis 2-2

Fc Allowable = $\frac{P}{\ }$

A

$$= \frac{4.112,5 \text{ lb}}{9,26 \text{ in}^2}$$

$$= 444,1 \text{ psi}$$

Pemeriksaan Leg Planning

Axis 1-1

$$\frac{l}{r} = \frac{60,7 \text{ in}}{4,8} = 12,5699$$

$$\text{Fc Pemeriksaan} = 17.000 - 0,485 \left(\frac{l}{r}\right)^2$$

$$= 17.000 - 0,485 (12,6)^2$$

$$= 16.923,3693$$

Fc Pemeriksaan < Fc Allowable (Dapat digunakan)

Axis 2-2

$$\frac{l}{r} = \frac{60,7 \text{ ft}}{1,0} = 60,1113$$

$$\text{Fc Pemeriksaan} = 17.000 - 0,485 \left(\frac{l}{r}\right)^2$$

$$= 17.000 - 0,485 (60,1)^2$$

$$= 15.247,5154$$

Fc Pemeriksaan < Fc Allowable (Dapat digunakan)

Lug Planning

Setiap penyangga memiliki 4 baut

$$P_{Bolt} = \frac{P}{n_{Bolt}}$$

$$= \frac{4.112,5 \text{ lb}}{4,0}$$

$$= 1.028,1355 \text{ lb}$$

Luas lubang Baut

$$A_{Bolt} = \frac{P_{Bolt}}{f_{Bolt}}$$ ***(Brownell; hal. 194; eq. 10.44)***

$$A_{Bolt} = \frac{1.028,1 \text{ lb}}{12.000,0 \text{ psi}}$$

$$= 0,0857 \text{ in}^2$$

Digunakan baut dengan diameter 1 in

Spesifikasi Penyimpanan Sementara Formaldehid

Fungsi	:	Tempat penyimpanan Ca(OH)2 sementara sebelum menuju ke Reaktor				
Tipe	:	Tangki Silinder Tegak dengan tutup atas dan bawah Torispherical Dished Head, dilengkapi dengan Cooling Jacket				
Bahan konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*				
Tekanan	:	1 atm				
Kapasitas / Volume	:	220,9222	cuft	=	6,2521	m^3
Diameter Shell	:	5,2012	ft	=	1,5853	m
Tinggi Shell	:	10,4024	ft	=	3,1705	m
Tebal Shell	:	1/5	in	=	0,0048	m
Tinggi tutup atas	:	13,4760	in	=	0,3423	m
Tebal tutup atas	:	0,1875	in	=	0,0048	m
Tinggi tutup bawah	:	13,4760	in	=	0,3423	m
Tebal tutup bawah	:	0,1875	in	=	0,0048	m
Tinggi Total tangki	:	12,6484	ft	=	3,8551	m
Waktu Operasi	:	85	menit			
Diameter Tinggi Jacket (in)	:	66,7895	in	=	1,6965	m
Diameter Tinggi Jacket (out)	:	67,1645	in	=	1,7060	m
Tinggi Heating Jacket	:	11,5254	ft	=	3,5128	m
Tebal Heating Jacket	:	0,1875	in	=	0,0048	m
Tipe Penyangga	:	Beam				
Ukuran Peyangga	:	12 x 5	in			
Tinggi Kaki	:	5,0594	ft	=	1,5420	m
Lebar Flange	:	5	in	=	0,1270	m
Diameter Baut	:	1	in	=	0,0254	m
Jumlah	:	1	Tangki			

17. REAKTOR KONDENSASI

Kode Alat	:	R - 210
Fungsi	:	Mereaksikan Formaldehid, Asetaldehid, dan Kalsium Hidroksida untuk membentuk Pentaeritritol dan KalsiumFormat

Tipe	:	Tangki Silinder Tegak Berpengaduk dengan tutup atas dan bawah Torispherical Dished Head, dilengkapi dengan Cooling Jacket
Material Konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*
Dasar Pemilihan	:	Ekonomis dan umum digunakan untuk reaksi padat cair
	:	disertai dengan Material untuk Bahan Korosif
Tekanan	:	1 atm
Temperatur	:	55 °C
Waktu Operasi	:	1 Jam

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$CH_2O_{(g)}$	24,220%	5.213,8642	0,7261	726,0991	45,3304
$CH_3OH_{(g)}$	0,655%	140,9152	0,7827	782,6686	48,8620
$CH_3CHO_{(l)}$	7,896%	1.699,8300	0,7670	766,9772	47,8824
$Ca(OH)_{2(aq)}$	13,282%	2.859,3540	2,2000	2.200,0000	137,35
$H_2O_{(l)}$	53,947%	11.613,2693	1,0229	1.022,8753	63,8581
$C_5H_{12}O_{4\,(aq)}$			1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$			2,0200	2.020,0000	126,11
Total	100%	21.527,2328			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

$= 0,968 \times 63,8581$ lb/cuft

$= 61,8387$ lb/cuft

Rate Massa = 21.527,2328 kg/jam

= 47.463,2428 lb/jam

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

$$= \frac{47.463,2428\ \text{lb / Jam}}{61,8387\ \text{lb / cuft}}$$

= 767,5331 cuft / Jam

Ditetapkan pengisian bahan sebanyak 80% volume (faktor keamanan)

Volume Bahan = 80% dari volume Tangki

Volume Tangki (V_S) = 767,5331 cuft

80%

= 959,4163 cuft

Perhitungan Dimensi Tangki

Tinggi (H) = 2 Diameter (D) ***(Ulrich; hal. 248; Tabel 4-27)***

$$V_S = \frac{1}{4}\ \pi\ D^2\ H$$

$$V_S = \frac{3{,}14}{4} \times 2 \times Ds^3$$

$$V_S = 1{,}57\ Ds^3$$

V tutup atas torispherical dish = 0,000049 Ds^3

(Brownell; hal. 88; eq. 5.11)

V tutup atas = V tutup bawah

Volume Tangki = V_S + 2 V tutup atas

959,4163 cuft = 1,57 Ds^3 + 0,000098 Ds^3

959,4163 cuft = 1,57 Ds^3

Ds^3 = 611,0551 cuft

Ds = 8,4858 ft = 101,8298 in = 2,5865 m

Hs = 16,9716 ft = 203,6595 in = 5,1730 m

Perhitungan Tinggi Komponen

$$\text{Volume Bahan} = \frac{1}{4}\ \pi\ Ds^2\ H_{liq}$$

$$767{,}5331 \text{ cuft} = \frac{3{,}14}{4} \times 8{,}4858^2 \times H_{liq}$$

H_{liq} = 13,5781 ft = 162,9378 in = 4,1386 m

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

P = 1 atm = 14,6959 Psi

P_{Inside} = 14,6959 Psi

$P_{Outside}$ = 14,6959 Psi

P_{Design} = P_{Inside} - $P_{Outside}$ + $P_{Hidrostatis}$

= 14,7 Psi - 14,7 Psi + $P_{Hidrostatis}$

P_{Design} = $P_{Hidrostatis}$

$$P_{Hidrostatis} = \rho\ \text{Campuran} \times \frac{g}{gc} \times H_{liq}$$

= 61,8387 lbm/cuft x 1 lbf/lbm x 13,5781 ft

= 839,6549 lb/ft^2

= 5,8356 Psi

P_{Design} dibuat berlebih 10% (faktor keamanan)

P_{Design} = 1,1 x 5,8356 Psi

= 6,4192 Psi

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

t_{min} = Tebal Shell Minimum (in)

P = Tekanan Tangki (Psi)

ri = Jari - jari Tangki (in) (1/2 D)

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi ***(Brownell; hal. 251; Tabel 13.1)***

$$t_{min} = \frac{6{,}4192 \text{ Psi} \times 50{,}9149 \text{ in}}{15.000 \text{ Psi} - 3{,}8515 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{326{,}8308}{14.996{,}1485} + 0{,}125 \text{ in}$$

= 0,1468 in

= (Digunakan t_S = $\frac{6}{16}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Shell

$$\frac{6}{16} \text{ in} = \frac{6{,}4192 \text{ Psi} \times 50{,}9149 \text{ in}}{f \times 0{,}80 - 3{,}8515 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 1.638,9686 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tebal tutup atas dan bawah

Tutup atas berbentuk Torispherical Dished Head

OD = ID + (2 t_S)

= 101,8298 in + 2 x 0,3750

= 102,5798 in

= (Digunakan OD = 108 in)

(Brownell; hal.91; Tabel 5.7)

Diperoleh:

icr = 6,5000 in = 0,5415 ft

r_C = 102 in = 8,4966 ft

Cek nilai icr dengan 6% rc:

icr = 6,50 in

6% rc = 6,12 in

karena nilai icr > 6% rc, maka menggunakan persamaan

$$t = \frac{Pd \times r_C \times W}{2f\,E - 0{,}2\,Pd} + C$$

(Brownell; hal.138; eq. 7.77)

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

(Brownell; hal.138; eq. 7.76)

Keterangan:

W = Faktor Stress

Pd = Tekanan design (P_{Design})

r_C = Radius Crown

r_1 or icr = Inside Crown Radius

E = Faktor Pengelasan = 0,80

t = Tebal dinding minimal

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi ***(Brownell; hal. 251; Tabel 13-1)***

C = Faktor Korosi (in) = 0,125 in

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

$$= \frac{1}{4}\left(3 + \sqrt[2]{(102 \text{ in} / 6{,}50 \text{ in})}\right)$$

$$= 1{,}7403$$

$$t_{Head} = \frac{Pd \times r_C \times W}{2f\,E - 0{,}2\,Pd} + C$$

$$= \frac{6{,}4192 \text{ Psi} \times 102 \text{ in} \times 1{,}7403}{37.500 \text{ Psi} \times 0{,}8 - 1{,}2838 \text{ Psi}} + 0{,}125 \text{ in}$$

$= 0{,}1630 \text{ in}$

$= \text{(Digunakan } t = \frac{3}{16} \text{ in)}$

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Head

$$\frac{3}{16} \text{ in} = \frac{6{,}4192 \text{ Psi} \times 177{,}5145 \text{ in}}{2 f \times 0{,}80 - 1{,}2838 \text{ Psi}} + 0{,}125 \text{ in}$$

$f = 11.395{,}7439 \text{ Psi} < f_{Allowable}$ (memenuhi)

Perhitungan tinggi tutup atas dan bawah:

$Di = 101{,}8298 \text{ in}$

$a = \frac{Di}{2}$

$= \frac{101{,}8298 \text{ in}}{2}$

$= 50{,}9149 \text{ in}$

$icr = 6{,}5000 \text{ in}$

$r_C = 102 \text{ in}$ ***(Brownell; hal. 91; Tabel 5.7)***

$AB = \frac{Di}{2} - icr$

$= \frac{101{,}8298 \text{ in}}{2} - 6{,}500 \text{ in}$

$= 44{,}4149 \text{ in}$

$BC = r_C - icr$

$= 102 \text{ in} - 7 \text{ in}$

$= 95{,}5000 \text{ in}$

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

$= \sqrt{(9.120{,}2500 \text{ in} - 1.972{,}6813 \text{ in})}$

$= 84{,}5433 \text{ in}$

$b = r_C - AC$

$= 102 \text{ in} - 84{,}5433 \text{ in}$

$= 17{,}4567 \text{ in}$

$sf = 3 \text{ in}$ ***(Brownell; hal. 93; Tabel 5.8)***

$t_{Head} = 0{,}1875 \text{ in}$

$OA = t_{Head} + b + sf$

$= 0{,}1875 \text{ in} + 17{,}4567 \text{ in} + 3 \text{ in}$

= 20,6442 in

Maka, tinggi tutup = 20,6442 in
= 0,5244 m
= 1,7204 ft

Perhitungan Sistem Pengaduk

$$\text{Viskositas Bahan} = \frac{\text{sg Bahan} \times \mu \text{ Reference } (H_2O)}{\text{sg Reference}}$$

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s
= 0,5065 Cps
= 0,0005 Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi
= 0,9960

$$\text{sg Bahan} = \frac{\rho \text{ Bahan}}{\rho \text{ Reference } (H_2O)}$$

$$= \frac{61{,}8 \text{ lb/cuft}}{63{,}9 \text{ lb/cuft}}$$

= 0,9684

$$\text{Viskositas Bahan} = \frac{0{,}9684 \times 0{,}0005 \text{ Pa.s}}{0{,}9960}$$

= 0,0005 lb/ft.s
= 0,0007 Ns/m^2 = 0,7329 Cps

Dengan mempertimbangkan Viskositas Bahan dan Volume Tangki, dipilih Pengaduk Marine Propeller dengan 3 blade

Kecepatan Pengaduk = 420 rpm ***(Towler; hal. 617, Fig. 10.57)***

Perhitungan Dimensi Pengaduk

$$\frac{D_t}{D_i} = 3$$

$$\frac{Z_t}{D_i} = 2{,}7 - 3{,}9 = 3{,}9 \text{ (dipilih)}$$

$$\frac{Z_i}{D_i} = 0{,}75 - 1{,}3 = 1{,}3 \text{ (dipilih)}$$

$$\frac{w}{D_t} = 0{,}1$$

Pitch = 2 Di ***(Brown; hal. 507, Fig. 477)***

Keterangan:

D_t = Diameter Tangki
= 8,4858 ft

D_i = Diameter Impeller

$$= \frac{8{,}4858 \text{ ft}}{3}$$

= 2,8286 ft

Z_t = Tinggi Liquid dalam Tangki
= 3,9 x 2,8286 ft
= 11,0316 ft

Z_i = Jarak Impeller dari dasar Tangki
= 1,3 x 2,8286 ft
= 3,6772 ft

n = Revolusi Per detik

w = Lebar Baffle
= 0,1 x 8,4858 ft
= 0,8486 ft

Pitch = 2 x 2,8286 ft
= 5,6572 ft

Perhitungan Kecepatan Pengadukan

n = 300 - 500 meter/menit untuk Marine Propeller

(Joshi; hal. 416)

$$n_{(rpm)} = \frac{n_{(m/min)}}{\pi \times D_i}$$

$$= \frac{300}{3{,}14 \times 0{,}8708}$$

= 109,7 rpm ≈ 110 rpm

Penentuan Baffle

$$N_{Re} = \frac{n \times D_i^2 \times \rho}{\mu}$$ ***(Brown; hal. 508)***

Keterangan:

N_{Re} = Bilangan Reynolds

ρ = Densitas Campuran, lb/cuft
= 61,8387 lb/cuft

D_i = Diameter Impeller, ft
= 2,8286 ft

n = Kecepatan Pengadukan, rps
= 110 rpm
= 2 rps

μ = Viskositas Bahan, Pa.s
= 0,0005 lb/ft.s
= 0,0236 Pa.s

$$N_{Re} = \frac{2 \text{ rps} \times 8{,}0010 \text{ ft} \times 61{,}8387 \text{ lb/cuft}}{0{,}0236 \text{ lb/ft.s}}$$

= 38.470

Karena N_{Re} > 10,000, termasuk aliran Turbulen

Maka diputuskan untuk menggunakan Baffle, dengan jumlah 4 buah

(Perry 8th; hal. 18-11)

W_B = Lebar Baffle, ft
= 0,1 D_t ***(Perry 8th; hal. 18-11)***
= 0,8486 ft

Penentuan Jumlah Pengaduk

$$\text{Jumlah Pengaduk} = \frac{H_{liq} \times \text{sg bahan}}{D_S}$$

(Joshi; hal. 415)

Keterangan:

H_{liq} = Tinggi Komponen,
= 13,5781 ft = 162,9378 in = 4,1386 m

sg bahan = Specific Gravity Bahan
= 0,9684

D_S = Diameter Tangki
= 8,4858 ft = 101,8298 in = 2,5865 m

$$\text{Jumlah Pengaduk} = \frac{4{,}1386 \text{ m} \times 0{,}9684}{2{,}5865 \text{ m}}$$

= 1,55 ≈ 2 buah

Perhitungan Jarak Antar Pengaduk

Jarak antar pengaduk = 1 - 1,5 Diameter Pengaduk

(Joshi; hal. 415)

= 1,5 Diameter Pengaduk (dipilih)
= 1,5 x 2,8286 ft
= 4,2429 ft 50,9149 in = 1,2932 m

Perhitungan Power Pengaduk

$$P = \frac{N_P \times n^3 \times D_i^5 \times \rho}{gc}$$ ***(McCabe 5th; hal. 253, eq. 920)***

Keterangan:

P = Power, ft.lbf/s

N_P = Power Number

= Berdasarkan Pengamatan, dipastikan Curve 3

= 0,5 ***(Towler; hal. 618, Fig.10.58)***

n = Kecepatan Putaran, rps

= 2 rps

D_i = Diameter Impeller, ft

= 2,8286 ft

ρ = Densitas Campuran

= 61,8387 lb/cuft

gc = Gravity Constants, $(lb.ft)/(lbf/s^2)$

= 32,1740 $(lb.ft)/(lbf/s^2)$

$$P = \frac{0{,}5 \times 6 \text{ rps} \times 181{,}0760 \text{ ft} \times 61{,}8387 \text{ lb/cuft}}{32{,}1740 \ (lb.ft)/(lbf/s^2)}$$

= 1.072,2858 ft.lbf/s

= 1,9767 Hp

Maka, besar power untuk 2 pengaduk:

$Power_2$ = 3,9533 Hp

Power perhitungan akan ditambahkan dengan beberapa faktor

Glands Loss = 10% ***(Joshi; hal. 424)***

= 0,3953 Hp

Transmission Loss = 20% ***(Joshi; hal. 424)***

= 0,7907 Hp

Power Total = $Power_2$ + Glands Loss + Transmission Loss

= 3,9533 Hp + 0,3953 Hp + 0,7907 Hp

= 5,1393 Hp

Efisiensi Motor = 85%

$$\text{Power Motor} = \frac{\text{Power Total}}{\text{Efisiensi}}$$

$$= \frac{5{,}1393 \text{ Hp}}{85\%}$$

= 6,0462 Hp ≈ 7 Hp

Perhitungan Sistem Pendingin

Keb. air Pendingin = 294.409,6059 kg/Jam
= 649.061,3053 lb/Jam

Rate Volumetrik = $\frac{649.061,3053 \text{ lb/Jam}}{63,86 \text{ lb/cuft}}$
= 10.164,1182 cuft/Jam
= 2,8234 cuft/detik

Suhu Komponen $_{In}$ = 55 °C = 131,0 °F
Suhu Komponen $_{Out}$ = 55 °C = 131,0 °F
Suhu Air Pendingin $_{In}$ = 25 °C = 77,0 °F
Suhu Air Pendingin $_{O}$ = 45 °C = 113,0 °F

Pendingin dirancang untuk mempertahankan suhu tetap pada 55°C

Q Serap = 18.459.482,2880 kJ/Jam
= 4.411.922,1530 kKal/Jam
= 17.497.139,6095 Btu/Jam

ΔT_1 = Suhu Komponen $_{In}$ - Suhu Air Pendingin $_{In}$
= 131 °F - 113 °F
= 18 °F

ΔT_2 = Suhu Komponen $_{Out}$ - Suhu Air Pendingin $_{Out}$
= 131 °F - 77 °F
= 54 °F

$$\Delta T_{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_2}{\Delta T_1}}$$ ***(Kern; hal. 89, eq. 5.14)***

$$= \frac{18,00 \text{ °F} - 54,00 \text{ °F}}{\ln \frac{18,00 \text{ °F}}{54,00 \text{ °F}}}$$

= 32,7686 °F

Koefisien perpindahan panas luar jaket

$$h_i = 0,36 \frac{k}{D_i} \times \left(\frac{L^2 N \rho}{\mu}\right)^{2/3} \left(\frac{c\mu}{k}\right)^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

(Kern; hal. 718, eq. 20.1)

Keterangan:

L = D_i (Diameter Pengaduk), ft

= 2,8286 ft = 33,9433 in = 0,8622 m

N = Kecepatan Pengaduk, rph
= 6.600 rph

ρ = Densitas Air, lb/cuft
= 63,8581 lb/cuft

μ = Viskositas Bahan, cps
= 0,0005 lb/ft.s
= 1,7728 lb/ft.jam
= 0,7328 cps

k = Konduktivitas Thermal

$$= \frac{0{,}0677 \text{ Btu/jam.ft}^2\text{°F}}{sg \times [1 - 0{,}0003 (\Delta T_{LMTD} - 32)]}$$

$$= \frac{0{,}0677 \text{ Btu/jam.ft}^2\text{°F}}{0{,}9684 \times [1 - 0{,}0003 (32{,}77 \text{ °F} - 32)]}$$

= 0,0699 Btu/Jam.ft^2.°F

c = Kapasitas Panas Campuran

Komponen	BM (kg/kmol)	%	Cp (Kj/kmol)	Cp (Kkal/kmol
CH_2O (aq)	30,03	2,69%	1.090,01	260,52
CH_3OH (l)	32,04	0,65%	2.439,29	583,01
$Ca(OH)_2$ (aq)	74,10	6,64%	2.685,00	641,73
CH_3CHO (l)	44,05	0,00%	0,00	0,00
$H_2O_{(l)}$	18,02	53,95%	2.258,66	539,83
$C_5H_{12}O_{4(aq)}$	136,15	24,41%	6.976,02	1.667,31
$Ca(HCOO)_{2(aq)}$	130,11	11,66%	3.564,90	852,03
Total	464,49			

c = 1 kkal/kmol.°C = 0,053 Btu/lb°F
= Σ % Cp
= 850,9337 kkal
= 45,0995 Btu/lb.°F

$$\left(\frac{L^2N\rho}{\mu}\right)^{2/3} = \left(\frac{(2{,}8286^2 \times 6.600 \text{ rph} \times 63{,}86 \text{ lb/cu})}{1{,}7728 \text{ lb/ft.Jam}}\right)^{2/3}$$

= 15.351,76

$$\left(\frac{c\mu}{k}\right)^{1/3} = \left(\frac{45{,}0995 \text{ Btu/lb.°F} \times 1{,}7728 \text{ lb/ft.Jam}}{0{,}0699 \text{ Btu/jam.ft.°F}}\right)^{1/3}$$

$= 10{,}4568$

$$\left(\frac{\mu}{\mu_w}\right)^{0.14} = \left(\frac{1{,}7728}{1}\right)^{0.14}$$

$= 1{,}0056$

$$h_i = 0{,}36\ \frac{K}{D_i} \times 15.351{,}7639 \times 10{,}4568 \times 1{,}0056$$

$$= 0{,}36\ \frac{0{,}07\ \text{Btu/jam.ft.°F}}{8{,}49\ \text{ft}} \times 161.426{,}1418$$

$= 478{,}8808$ Btu/jam.ft.°F

Dari tabel, dipilih pipa dengan ukuran:

OD = 1,50 in

ID = 1,40 in

flow area = 1,54 in^2 = 0,00099 m^2

Surface Area per 1 in = 0,39 ft^2

(Kern; hal. 843, Tabel 10)

$$v = \frac{W}{\rho \times A}$$

$$= \frac{649.061{,}3053\ \text{lb/Jam}}{63{,}86\ \text{lb/cuft} \times 0{,}3925\ ft^2}$$

$= 25.896$

h_i = 478,8808 x Correction Factor

= 478,8808 x 0,85 ***(Kern; hal. 835, Fig.25)***

= 407,0487 Btu/Jam.ft^2.°F

$$h_{io} = h_i \times \frac{ID}{OD}$$

$$= 407{,}0487\ \text{Btu/Jam.ft}^2\text{.°F} \times \frac{1{,}4}{1{,}5}$$

$= 379{,}9121$

$$U_C = \frac{h_i \times h_{io}}{h_i + h_{io}}$$

$$= \frac{407{,}0487\ \text{Btu/Jam.ft}^2\text{.°F} \times 379{,}9121\ \text{Btu/Jam.ft}^2\text{.°F}}{407{,}0487\ \text{Btu/Jam.ft}^2\text{.°F} + 379{,}9121\ \text{Btu/Jam.ft}^2\text{.°F}}$$

$= 196{,}5063$

R_d = Fouling Factor

$= 0{,}001$ ***(Kern; hal. 845, Tabel 12)***

$$\frac{1}{U_D} = \frac{1}{U_C} + Rd$$

$$= \frac{1}{196{,}5} + 0{,}001$$

$$= 0{,}0061$$

$$U_D = 164{,}2334 \text{ Btu/Jam.ft}^2.°\text{F}$$

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

$$= \frac{17.497.139{,}6095 \text{ Btu/Jam}}{164{,}2 \text{ Btu/Jam.ft}^2.°\text{F} \times 32{,}8 \text{ °F}}$$

$$= 3.251{,}2292 \text{ ft}^2$$

Perhitungan Tinggi Jaket

Tinggi Jaket = Tinggi Shell + Tinggi Tutup Bawah
= 16,9716 ft + 1,7204 ft
= 18,6920 ft

Asumsi:

Tebal air pendingin = 2
Tebal Jaket = 0,1875 = 3/16 in
Efisiensi Las = 0,8
Faktor Korosi = 0,125 in
Digunakan material *Stainless Steel SA-167 Grade 11*
f = 18.750
DO Shell = Di + 2ts
= 101,8298 in + 2 x 0,1875 in
= 102,2048 in
Di Jacket = DO Shell + 2 s
= 102,2048 in + 2 x 2,0000 in
= 106,2048 in
DO Jacket = Di Jacket + 2 t Jacket
= 106,2048 in + 2 x 0,1875 in
= 106,5798 in
P Design Jacket = P Outside - P Inside + P Hidrostatis
= 14,7 Psi - 14,7 Psi + ρ Campuran x g/gc x H Liq

$= 61{,}84 \text{ lb/cuft} \times 1 \text{ lbf/lbm} \times 13{,}5781 \text{ ft}$

$= 839{,}6549 \text{ lbf/ft}^2$

$= 5{,}8309 \text{ Psi}$

Perhitungan Tebal Jaket

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

$$t_{Jacket} = \frac{P \times Dij}{2 f E - P} + C$$

Keteragan:

t_{min} = Tebal Shell Minimum (in)

P = Tekanan Tangki (Psi)

Dij = Diameter dalam Jaket (in)

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi ***(Brownell; hal. 251; Tabel 13.1)***

$$t_{min} = \frac{5{,}8309 \text{ Psi} \times 106{,}2048 \text{ in}}{30.000 \text{ Psi} - 5{,}8309 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{619{,}2732}{29.994{,}1691} + 0{,}125 \text{ in}$$

$= 0{,}1456$ in

= (Digunakan $t = \frac{3}{16}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perancangan Penyangga Tangki

$$\text{Berat}_{Shell} = \frac{1}{4}\pi \ (OD^2 - ID^2) \times H_{Liq} \times \rho_{Steel}$$

ρ Steel = 0,2790 lb/in^3 ***(Brownell; hal. 341, App. D, Item 3)***

= 482,11 lb/ft^3

$$= \frac{3{,}14}{4} \times (73{,}1 \text{ ft} - 72{,}0 \text{ ft}) \times 13{,}6 \text{ ft} \times 482 \text{ lb/ft}^3$$

= 5.470,8902 lb

$$\text{Berat}_{T\ Atas} = \frac{1}{4}\pi \ (OD^2 - ID^2) \times H_{Tutup} \times \rho_{Steel}$$

$$= \frac{3{,}14}{} \times (73{,}1 \text{ ft} - 72{,}0 \text{ ft}) \times 1{,}7 \text{ ft} \times 482 \text{ lb/ft}^3$$

4

= 693,1614 lb

Berat $_{T\ Bawah}$ = $\frac{3,14}{4}$ x (73,1 ft- 72,0 ft) x 1,7 ft x 482 lb/ft^3

= 693,1614 lb

Berat $_{Fluida}$ = Berat Feed

= 21.527,2 kg

= 47.467,5 lb

Berat $_{Mati\ Shel}$ = Berat $_{Shell}$ + Berat $_{Tutup\ Atas}$ + Berat $_{Tutup\ Bawah}$ + Berat $_{Fluida}$

= 5.470,9 lb + 693,2 lb + 693,2 lb + 47.467,5 lb

= 54.324,7613 lb

= 24.637,0800 kg

Leg Planning

Berat untuk perancangan = 1,2 x berat mati tangki

= 1,2 x 54.324,8 lb

= 65.189,7136 lb

Kaki penyangga dilakukan pengelasan di tengah-tengah ketinggian (40% tinggi total bejana) dengan leg tipe I-Beam, Pondasi Concrete / Beton

H $_{Leg}$ = 40% x H $_{Tangki}$

= 40% x 20,4123 ft

= 8,1649 ft

= 97,9792 in

= 2,4885 m

Digunakan Beams 12 x 5 in

Berat/ft	=	31,80	lb
Area of Section (A)	=	9,26	in^2
Kedalaman Beam	=	12,00	in
Lebar Flange	=	5,00	in
Tebal Rata-rata	=	0,54	in
Tebal Web	=	0,35	in

Peletakan dengan beban Ekstrensik (Axis 1-1)

I = 215,8 in^4

S = 36,0 in^3

r = 4,8 in

Peletakan tanpa beban Ekstrensik (Axis 2-2)

I = 9,5 in^4

S = 3,8 in^3

r = 1,0 in **(Brownell; hal. 355; App. G)**

Beban Kompresi total maksimum tiap Leg (P):

Beban tiap penyangga = $\frac{\text{Berat Perancangan}}{\text{Jumlah Penyangga}}$

Asumsi jumlah penyangga = 4

Maka beban tiap penyangga = $\frac{65.189,7136 \text{ lb}}{4}$

P = 16.297,4284 lb untuk setiap penyangga

Cek peletakan sumbu Axis 1-1 maupun Axis 2-2

Fc Allowable = $\frac{P}{A}$

= $\frac{16.297,4 \text{ lb}}{9,26 \text{ in}^2}$

= 1.760,0 psi

Pemeriksaan Leg Planning

Axis 1-1

$\frac{1}{r}$ = $\frac{98,0 \text{ in}}{4,8}$ = 20,2855

Fc Pemeriksaan = 17.000 - 0,485 $\left(\frac{1}{r}\right)^2$

= 17.000 - 0,485 (20,3) ^{2}

= 16.800,4209

Fc Pemeriksaan < Fc Allowable (Dapat digunakan)

Axis 2-2

$\frac{1}{r}$ = $\frac{98,0 \text{ ft}}{1,0}$ = 97,0091

Fc Pemeriksaan = 17.000 - 0,485 $\left(\frac{1}{r}\right)^2$

= 17.000 - 0,485 (97,0) ^{2}

= 12.435,7809

Fc Pemeriksaan < Fc Allowable (Dapat digunakan)

Lug Planning

Setiap penyangga memiliki 4 baut

$$P_{Bolt} = \frac{P}{n_{Bolt}}$$

$$= \frac{16.297,4 \text{ lb}}{4,0}$$

$$= 4.074,3571 \text{ lb}$$

Luas lubang Baut

$$A_{Bolt} = \frac{P_{Bolt}}{f_{Bolt}}$$ ***(Brownell; hal. 194; eq. 10.44)***

$$A_{Bolt} = \frac{4.074,4 \text{ lb}}{12.000,0 \text{ psi}}$$

$$= 0,3395 \text{ in}^2$$

Digunakan baut dengan diameter 1 in

Spesifikasi Reaktor Kondensasi

Fungsi	:	Mereaksikan Formaldehid, Asetaldehid, dan Kalsium Hidroksida untuk membentuk Pentaeritritol dan KalsiumFormat				
Tipe	:	Tangki Silinder Tegak Berpengaduk dengan tutup atas dan bawah Torispherical Dished Head, dilengkapi dengan Cooling Jacket				
Bahan konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*				
Tekanan	:	1 atm				
Kapasitas / Volume	:	959,4163	cuft	=	27,1515	m^3
Diameter Shell	:	8,4858	ft	=	2,5863	m
Tinggi Shell	:	16,9716	ft	=	5,1727	m
Tebal Shell	:	3/8	in	=	0,0095	m
Tinggi tutup atas	:	20,6442	in	=	0,5244	m
Tebal tutup atas	:	0,1875	in	=	0,0048	m
Tinggi tutup bawah	:	20,6442	in	=	0,5244	m
Tebal tutup bawah	:	0,1875	in	=	0,0048	m
Tinggi Total tangki	:	20,4123	ft	=	6,2214	m
Waktu Operasi	:	60 menit				
Tipe Pengaduk	:	*Marine Propeller,* dengan 3 buah *Blade*				

Diameter Pengaduk	:	2,8286	ft	=	0,8621	m
Jarak Pengaduk	:	3,6772	ft	=	1,1208	m
Pitch	:	5,6572	ft	=	1,7242	m
Jumlah Pengaduk	:	2	buah			
Jarak antar Pengaduk	:	4,2429	ft	=	1,2932	m
Power Pengaduk	:	7	hp =	5,2200	kWh	
Jumlah Baffle	:	4	buah			
Lebar Baffle	:	0,8486	ft	=	0,2586	m
Diameter Cooling Jacket (in)	:	106,2048	in	=	2,6976	m
Diameter Cooling Jacket (out)	:	106,5798	in	=	2,7071	m
Tinggi Cooling Jacket	:	18,6920	ft	=	5,6970	m
Tebal Cooling Jacket	:	0,1875	in	=	0,0048	m
Luas Heat Transfer	:	3.251,2292	ft^2	=		
Tipe Penyangga	:	Beam				
Ukuran Peyangga	:	12 x 5	in			
Tinggi Kaki	:	8,1649	ft	=	2,4885	m
Lebar Flange	:	5	in	=	0,1270	m
Diameter Baut	:	1	in	=	0,0254	m
Jumlah	:	1	Tangki			

17. TANGKI PENYIMPANAN ASAM FORMAT

Kode Alat	:	F - 140
Fungsi	:	Menyimpan Asam Format untuk Keperluan Proses Proses Produksi
Tipe	:	Tangki Silinder Tegak dengan Tutup Atas Torispherical Dish Head dan Tutup Bawah Datar
Material Konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*
Dasar Pemilihan	:	Ekonomis dan umum digunakan untuk Fluida, disertai dengan Material untuk Bahan Korosif
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Penyimpanan	:	7 hari

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)

$CH_2O_{2(aq)}$	90%	1.775,8093	1,2076	1.207,5708	75,3886
$H_2O_{(l)}$	10%	197,3121	1,0229	1.022,8753	63,8581
Total	100%	1.973,1214			

ρ Campuran = $\dfrac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}}$ x $\dfrac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$

= 1,1862 x 63,8581 lb/cuft

= 75,7455 lb/cuft

Rate Massa = 1.973,1214 kg/jam

= 4.350,3381 lb/jam

Rate Volumetrik = $\dfrac{\text{Rate Massa}}{\rho \text{ Campuran}}$

= $\dfrac{4.350,3381 \text{ lb / Jam}}{75,7455 \text{ lb / cuft}}$

= 57,4336 cuft / Jam

Volume Komponen = Rate Volumetrik x Waktu Penyimpanan

= 57,4336 cuft / Jam x 7 hari

= 9.648,8504 cuft

= 273,2224 m^3

= 273.224,5665 Liter

Direncanakan untuk penyimpanan dengan 2 buah tangki
(mempermudah pengeluaran dan pengisian), sehingga volume bahan:

Volume Komponen = $\dfrac{9.648,8504 \text{ cuft}}{2 \text{ Tangki}}$

= 4.824,4252 cuft

Dilakukan pengisian bahan sebanyak 80% volume (faktor keamanan)

Volume Bahan = 80% dari volume Tangki Penyimpanan

Volume Tangki (V_S) = $\dfrac{4.824,4252 \text{ cuft}}{80\%}$

= 6.030,5315 cuft

Perhitungan Dimensi Tangki

Tinggi (H) = 2 Diameter (D) ***(Ulrich; hal. 248; Tabel 4-27)***

$V_S = \dfrac{1}{4} \pi D^2 H$

$V_S = \dfrac{3,14}{\ } \text{ x } 2 \text{ x } D_S^3$

$\frac{\quad}{4}$ x 2 x Ds

V_S = 1,57 Ds^3

V tutup atas torispherical dish = 0,000049 Ds^3

(Brownell; hal. 88; eq. 5.11)

Volume Tangki = V_S + V tutup atas

6.030,5315 cuft = 1,57 Ds^3 + 0,000049 Ds^3

6.030,5315 cuft = 1,57 Ds^3

Ds^3 = 3.840,9830 cuft

Ds = 15,6608 ft = 187,9297 in = 4,7734 m

Hs = 31,3216 ft = 375,8594 in = 9,5468 m

Perhitungan Tinggi Komponen

Volume Bahan = $\frac{1}{4}\pi\ Ds^2\ H_{liq}$

4.824,4252 cuft = $\frac{3,14}{4}$ x $15,6608^2$ x H_{liq}

H_{liq} = 25,0581 ft = 300,6969 in = 7,6377 m

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

P = 1 atm = 14,6959 Psi

P_{Inside} = 14,6959 Psi

$P_{Outside}$ = 14,6959 Psi

P_{Design} = P_{Inside} - $P_{Outside}$ + $P_{Hidrostatis}$

= 14,7 Psi - 14,7 Psi + $P_{Hidrostatis}$

P_{Design} = $P_{Hidrostatis}$

$P_{Hidrostatis}$ = ρ Campuran x $\frac{g}{gc}$ x H_{liq}

= 75,7455 lbm/cuft x 1 lbf/lbm x 25,0581 ft

= 1.898,0357 lb/ft^2

= 13,1913 Psi

P_{Design} dibuat berlebih 10% (faktor keamanan)

P_{Design} = 1,1 x 13,1913 Psi

= 14,5105 Psi

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

t_{min} = Tebal Shell Minimum (in)

P = Tekanan Tangki (Psi)

ri = Jari - jari Tangki (in) (1/2 D)

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi ***(Brownell; hal. 342; App. D, Item 4)***

$$t_{min} = \frac{14{,}5105 \text{ Psi} \times 93{,}9648 \text{ in}}{15.000 \text{ Psi} - 8{,}7063 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{1.363{,}4752}{14.991{,}2937} + 0{,}125 \text{ in}$$

= 0,2160 in

= (Digunakan $t_S = \frac{5}{8}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Shell

$$\frac{9}{8} \text{ in} = \frac{14{,}5105 \text{ Psi} \times 93{,}9648 \text{ in}}{f \times 0{,}80 - 8{,}7063 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 1.715,2269 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tebal tutup atas

Tutup atas berbentuk Torispherical Dished Head

OD = ID + (2 t_S)

= 187,9297 in + 2 x 0,63

= 189,1797 in

= (Digunakan OD = 192 in)

(Brownell; hal.91; Tabel 5.7)

Diperoleh:

icr = 11,5 in = 0,9580 ft

r_C = 170 in = 14,1610 ft

Cek nilai icr dengan 6% rc:

icr = 11,50 in

6% rc = 10,20 in

karena nilai icr > 6% rc, maka menggunakan persamaan

$$t = \frac{Pd \times r_C \times W}{2f\,E - 0{,}2\,Pd} + C$$ ***(Brownell; hal.138; eq. 7.77)***

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

(Brownell; hal.138; eq. 7.76)

Keterangan:

W	=	Faktor Stress		
Pd	=	Tekanan design (P_{Design})		
r_C	=	Radius Crown		
r_1 or icr	=	Inside Crown Radius		
E	=	Faktor Pengelasan	=	0,80
t	=	Tebal dinding minimal		
f	=	Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*		
	=	18.750 Psi		***(Brownell; hal. 251; Tabel 13-1)***
C	=	Faktor Korosi (in)	=	0,125 in

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

$$= \frac{1}{4}\left(3 + \sqrt[2]{(170 \text{ in} / 12 \text{ in})}\right)$$

$$= 1{,}7112$$

$$t_{Head} = \frac{Pd \times r_C \times W}{2f\,E - 0{,}2\,Pd} + C$$

$$= \frac{14{,}5105 \text{ Psi} \times 170 \text{ in} \times 1{,}7112}{37.500 \text{ Psi} \times 0{,}8 - 2{,}9021 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= 0{,}2657 \text{ in}$$

$= \left(\text{Digunakan } t = \frac{5}{8} \text{ in}\right)$

(Brownell; hal. 89; Tabel 5.7)

Untuk Tebal Tutup Bawah, karena ditopang oleh permukaan semen, digunakan:

$$t_{Bottom} = \frac{5}{16} \text{ in}$$ ***(Brownell; hal. 58)***

Perhitungan Koreksi Stress Allowable Head

$$\frac{5}{8}\ \text{in} = \frac{14{,}5105\ \text{Psi} \times 290{,}9047\ \text{in}}{2\ f \times 0{,}80 - 2{,}9021\ \text{Psi}} + 0{,}125\ \text{in}$$

f = 5.278,2730 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tinggi tutup atas:

Di = 187,9297 in

$$a = \frac{Di}{2}$$

$$= \frac{187{,}9297\ \text{in}}{2}$$

= 93,9648 in

icr = 12 in

r_C = 170 in *(Brownell; hal. 91; Tabel 5.7)*

$$AB = \frac{Di}{2} - icr$$

$$= \frac{187{,}9297\ \text{in}}{2} - 11{,}500\ \text{in}$$

= 82,4648 in

BC = r_C - icr

= 170 in - 12 in

= 158,5000 in

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

= √(25.122,2500 in - 6.800,4498 in)

= 135,3580 in

b = r_C - AC

= 170 in - 135,3580 in

= 34,6420 in

sf = 3 in *(Brownell; hal. 93; Tabel 5.8)*

t_{Head} = 0,6250 in

OA = t_{Head} + b + sf

= 0,6250 in + 34,6420 in + 3 in

= 38,2670 in

Maka, tinggi tutup atas = 38,2670 in

= 0,9720 m

Spesifikasi Tangki Penyimpanan Asam Format

Fungsi	:	Menyimpan Asam Format untuk Keperluan Proses Proses Produksi				
Tipe	:	Tangki Silinder Tegak dengan Tutup Atas Torispherical Dish Head dan Tutup Bawah Datar				
Tekanan	:	1 atm				
Kapasitas / Volume	:	6.030,5315	cuft	=	170,6640	m^3
Diameter	:	15,6608	ft	=	4,7732	m
Tinggi Shell	:	31,3216	ft	=	9,5464	m
Tebal Shell	:	0,6250	in	=	0,0159	m
Tinggi tutup atas	:	38,2670	in	=	0,9720	m
Tebal tutup atas	:	0,6250	in	=	0,0159	m
Tebal tutup bawah	:	0,3125	in	=	0,0079	m
Bahan konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*				
Waktu Penyimpanan	:	7 hari				
Jumlah	:	2 tangki				

18. POMPA 4

Kode Alat	:	L - 141
Fungsi	:	Memindahkan Asam Format Cair dari Tangki Penyimpanan menuju Reaktor Netralisasi
Tipe	:	Centrifugal Pump
Dasar Pemilihan	:	Sesuai untuk Fluida Liquid dengan Viskositas <10 Cp
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$Ca(OH)_{2(aq)}$	90%	1.775,8093	1,2076	1.207,5708	75,3886
$H_2O_{(l)}$	10%	197,3121	1,0229	1.022,8753	63,8581
Total	100%	1.973,1214			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

$$= 1{,}186 \times 63{,}858 \text{ lb/cuft}$$

$$= 75{,}7455 \text{ lb/cuft}$$

= 1.213,3290 kg/m^3

Rate Massa = 1.973,1214 kg/jam

= 4.350,3381 lb/jam

Rate Volumetrik = $\dfrac{\text{Rate Massa}}{\rho \text{ Campuran}}$

= $\dfrac{4.350,3381 \text{ lb / Jam}}{75,7455 \text{ lb / cuft}}$

= 57,4336 cuft / Jam

= 0,9572 cuft / menit

= 0,0160 cuft / sec

= 7,1610 gal / min

Viskositas Bahan = $\dfrac{\text{sg Bahan} \times \mu \text{ Reference } (H_2O)}{\text{sg Reference}}$

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s

= 0,5065 Cps

= 0,0005 Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi

= 0,9960

sg Bahan = $\dfrac{\rho \text{ Bahan}}{\rho \text{ Reference } (H_2O)}$

= $\dfrac{75,4 \text{ lb/cuft}}{63,9 \text{ lb/cuft}}$

= 1,1806

Viskositas Bahan = $\dfrac{1,1806 \times 0,0005 \text{ Pa.s}}{0,9960}$

= 0,0006 lb/ft.s

= 0,0009 Ns/m^2

= 0,8934 Cps

Perhitungan ID Optimum

Asumsi Aliran Turbulen, dengan N_{Re} > 2100, digunakan rumus:

$ID_{Optimum} = 3,9 \; qf^{0,45} \; \rho^{0,13}$

(Peters 4th; hal. 496; eq. 15)

Keterangan:

ID = Optimum Pipe Inside Diameter, in

qf = Fluid Flow Rate, cuft/sec
ρ = Fluid Density, lb/cuft

$ID_{Optimum}$ = 3,9 x 0,1553 cuft/sec x 1,7552 lb/cuft
= 1,0633 in

Perhitungan Pipa

Dipilih pipa:

IPS, Size = 1 1/4 in
OD = 1,6600 in
Schedule = No. 40
ID = 1,0490 in ***(McCabe7th; hal. 1090; App. 3)***
= 0,0874 ft
= 0,0266 m

$A_1 = \frac{1}{4} \pi \times ID_{Tangki}^2$

$= \frac{3,14}{4} \times (187,93 \text{ in})^2$

$= 27.724,2882 \text{ in}^2$

$= 192,5298 \text{ ft}^2$

$A_2 = \frac{1}{4} \pi \times ID^2$

$= \frac{3,14}{4} \times (1,05 \text{ in})^2$

$= 0,8638 \text{ in}^2$

$= 0,0060 \text{ ft}^2$

$A_2 / A_1 = 0,0000312 < 0.715$

$V = \frac{\text{Rate Volumetrik}}{A}$

$= \frac{0,0160 \text{ ft}^3/\text{sec}}{0,01 \text{ ft}^2}$

= 2,6595 ft / sec
= 0,8106 m / sec

$N_{Re} = \frac{D \times V \times \rho}{\mu}$ ***(Peters 4th; hal. 481; eq. 6)***

$= \frac{0,03 \text{ in} \times 0,81 \text{ m/s} \times 1213,3 \text{ kg/m}^3}{}$

0,0009 Pa.s

= 29.331,0269 > 2,100 (Airan Turbulen)

Equivalent Roughness for Pipe (ε) untuk material Commercial Steel

ε = 0,00015 ft ***(Peters 4th; hal. 482; Fig. 14-1)***

= 0,000046 m ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

= 0,001800 in

$\frac{\varepsilon}{D}$ = 0,001716

f = 0,0075 ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

Perhitungan Equivalent Suction (L_e)

Sambungan / Fitting	L_e / D	
90º Elbow Standard	35	***(Peters 4th; hal. 484; Tabel 1)***
Gate Valve, Open	9	***(Peters 4th; hal. 485; Tabel 1)***

3 Elbow std 90º = 3 x (L_e / D) x DI
= 35 x 0,0874 ft
= 9,1788 ft
= 2,7975 m

1 Gate Valve $_{\text{Wide Open}}$ = 1 x (L_e / D) x DI
= 9 x 0,0874 ft
= 0,7868 ft
= 0,2398 m

Perhitungan Panjang Pipa

Pipa A ke B	= 3,50	m	=	11,4835 ft
Elbow 1 ke Elbow 2 (Tinggi total reaktor)	= 8,71	m	=	28,5773 ft
Elbow 2 ke Elbow 3	= 1,00	m	=	3,2810 ft
Elbow 3 ke Elbow Reaktor	= 1,00	m	=	3,2810 ft
Panjang Total Pipa Lurus	= 14,2099	m	=	46,6228 ft
Panjang Total Pipa Keseluruhan	= 17,2473	m	=	56,5883 ft

Perhitungan Friksi

Friksi karena Gesekan :

$$F_1 = \frac{2\, f \times V^2 \times L_e}{g_C \times D}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times g_C}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$F_3 = \dfrac{(V_2 - V_1)^2}{2 \times \alpha \times g_C}$ ***(Peters 4th; hal. 484; Tabel 1)***

$F_4 = n \times Kf \times \dfrac{V_1^2}{2 \times g_C}$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

$F_5 = n \times Kf \times \dfrac{V_1^2}{2 \times g_C}$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

Keterangan

F_1 = Flow Through long straight pipe

F_2 = Sudden Contraction

F_3 = Sudden Enlargement

F_4 = Losses Fitting - Elbow 90º

F_5 = Losses Fitting - Gate Valve Open

V = Linear Velocity, ft/sec

= 2,6595 ft/sec

α = Correction Coefficient, Viscous (0.5), Turbulen (1.0)

= 1,0 Turbulen (>2100) ***(Peters 4th; hal. 480)***

L = Length of Pipe

= 56,5883 ft

D = Diameter of Pipe

= 1,0490 in = 0,0874 ft

f = Fanning Friction Factor

= 0,0075 ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

g_C = Newton's Law Conversion Factor, ft.lbm / lbf

= 32,17 ft.lbm/lbf

A_1 = Luas Penampang Tangki Penyimpanan, ft^2

= 192,5298 ft^2

A_2 = Luas Penampang Pipa, ft2

= 0,0060 ft^2

K_C = Coefficient Friction Loss, (untuk $A_2/A_1 < 0.715$)

$= 0{,}40 \times \left(1{,}25 - \dfrac{A_2}{A_1} \right)$

= 0,5000 ***(Peters 4th; hal. 484; Tabel 1)***

K*f* = Number of Velocity Heads

= Elbow 90º = 0,7500

= Gate Valve Open = 0,1700

(Geankoplis 3rd; hal. 93; Tabel 2.10-1)

$$F_1 = \frac{2 \times 0{,}0075 \times (2{,}7 \text{ ft/sec})^2 \times 56{,}6 \text{ ft}}{32{,}17 \text{ ft.lbm/lbf} \times 1{,}0490 \text{ in}}$$

$$= 0{,}1779 \text{ ft.lbf / lbm}$$

$$F_2 = \frac{0{,}50 \times (2{,}7 \text{ ft/sec})^2}{2 \times 1{,}0 \times 32{,}17 \text{ ft.lbm/lbf}}$$

$$= 0{,}0550 \text{ ft.lbf / lbm}$$

F_3 = Karena A_1 (Tangki) > A_2 (Pipa), Maka $V_1 = 0$

$$= \frac{(2{,}7 \text{ ft/sec})^2}{2 \times 1{,}0 \times 32{,}17 \text{ ft.lbm/lbf}}$$

$$= 0{,}1099 \text{ ft.lbf / lbm}$$

$$F_4 = 3 \times 0{,}75 \; \frac{\times (2{,}7 \text{ ft/sec})^2}{2 \times 32{,}2 \text{ ft.lbm/lbf}}$$

$$= 0{,}2473 \text{ ft.lbf / lbm}$$

$$F_5 = 1 \times 0{,}41 \; \frac{\times (2{,}7 \text{ ft/sec})^2}{2 \times 32{,}2 \text{ ft.lbm/lbf}}$$

$$= 0{,}0445 \text{ ft.lbf / lbm}$$

$\sum F = F_1 + F_2 + F_3 + F_4 + F_5$ ***(Geankoplis 3rd; hal. 95)***

$$= 0{,}6346 \text{ ft.lbf / lbm}$$

Persamaan Bernoulli

$$z_1 \frac{g}{g_C} + \frac{V_1^2}{2\alpha g_C} + \frac{P_1 - P_2}{\rho_1 - \rho_2} - W_f = z_2 \frac{g}{g_C} + \frac{V_2^2}{2\alpha g_C} + \sum F$$

(Geankoplis 3rd; hal. 95; eq. 2.10-20)

$$-W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

Keterangan :

W_S = Work done by Fluid ***(Geankoplis 3rd; hal. 62)***

z = Vertical Distance, ft

V = Linear Velocity, ft/sec

g = g_C = Gravity Constants

g / g_C = 1 lbf/lbm ***(Peters 4th; hal. 487; ex. 1)***

$\sum F$ = Total Friction Loss, ft.lbf/lbm

$= 0{,}6346 \text{ ft .lbf / lbm}$

ρ = Densitas Campuran, lb/cuft

$= 75{,}7455 \text{ lb/cuft}$

P = Tekanan, Psi

$P_1 = P_1 + P_{\text{Hidrostatis}}$

$= 14{,}7 \text{ Psi} + 13{,}2 \text{ Psi} = 27{,}89 \text{ Psi}$

$P_2 = 14{,}7 \text{ Psi}$

$\Delta P = P_1 - P_2$

$= 27{,}9 \text{ Psi} - 14{,}7 \text{ Psi}$

$= 13{,}2 \text{ Psi}$

$= 1899{,}6 \text{ lbf / ft}^2$

$$\frac{\Delta P}{\rho} = \frac{1899{,}55 \text{ lbf / ft}^2}{75{,}75 \text{ lb/cuft}}$$

$= 25{,}0781 \text{ ft.lbf / lbm}$

Asumsi:

$z_1 = 28{,}5773 \text{ ft}$

$z_2 = 11{,}4835 \text{ ft}$

$$\Delta z \frac{g}{g_C} = (28{,}6 \text{ ft} - 11{,}5 \text{ ft}) \times 1 \text{ lbf/lbm}$$

$= 17{,}0938 \text{ ft.lbf / lbm}$

$$\frac{\Delta V^2}{2 \times \alpha \times g_C} = \frac{(2{,}6595 \text{ ft/sec})^2}{2 \times 1{,}0 \times 32{,}2 \text{ ft.lbm/lbf}}$$

$= 0{,}1099 \text{ ft.lbf / lbm}$

$$-W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

$= 25{,}08 + 17{,}09 + 0{,}11 + 0{,}63$

$= 42{,}9165 \text{ ft.lbf / lbm}$

Perhitungan Brake Horsepower (BHp)

Untuk Flowrate tersebut, diperoleh efisiensi pompa sebesar:

$\eta_{\text{Pompa}} = 45\%$ ***(Peters 4th; hal. 520; Fig. 14-37)***

$W_S = -\eta \times W_P$ ***(Geankoplis 3rd; hal. 65; eq. 2.7-30)***

$$W_P = \frac{-W_S}{\eta}$$

$$= \frac{42{,}9 \text{ ft.lbf / lbm}}{}$$

45%

= 95,3699 ft.lbf / lbm

BHp = $\dfrac{W_P \times \text{Flowrate}}{550}$ ***(Geankoplis 3rd; hal. 66)***

= $\dfrac{95{,}4 \text{ ft.lbf / lbm} \times 1{,}8 \text{ lb/sec}}{550}$

= 0,318

≈ 1 hp

Perhitungan Power Motor

Untuk BHp tersebut, diperoleh efisiensi motor sebesar:

η_{Motor} = 80% ***(Peters 4th; hal. 521; Fig. 14-38)***

hp = $\dfrac{BHp}{\eta_{Motor}}$

= $\dfrac{1 \text{ hp}}{80\%}$

= 1,2500

≈ 2 hp

Spesifikasi Pompa 4

Fungsi	:	Memindahkan Asam Format Cair dari Tangki Penyimpanan menuju Reaktor Netralisasi
Tipe	:	Centrifugal Pump
Kecepatan Aliran	:	2,6595 ft/sec = 0,8106 ft/sec
Flowrate	:	0,0160 cuft/s = 7,1610 gal/min
Size Pipa, IPS	:	1 1/4 in
ID Pipa	:	1,0490 in
Schedule	:	No. 40
Efisiensi Pompa	:	45%
Power Pompa	:	1 hp
Efisiensi Motor	:	80%
Power Motor	:	2 hp
Jumlah	:	1 Pompa

19. HEATER ASAM FORMAT

Kode Alat : E - 142

Fungsi	:	Memanaskan Asam Format cair sebelum memasuki Reaktor Netralisasi
Tipe	:	Shell and Tube Heat Exchanger
Dasar Pemilihan	:	Umum digunakan untuk proses perpindahan panas
Tekanan	:	1 atm
Temperatur	:	55 °C
Waktu Operasi	:	Kontinyu

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$CH_2O_{2\ (aq)}$	90%	1.775,8093	1,2076	1.207,5708	75,3886
$H_2O_{(l)}$	10%	197,3121	1,0229	1.022,8753	63,8581
Total	100%	1.973,1214			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

$= 1,186 \times 63,8581$ lb/cuft

$= 75,7455$ lb/cuft

Rate Massa $= 1.973,1214$ kg/jam

$= 4.350,3381$ lb/jam

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

$$= \frac{4.350,3381\ \text{lb / Jam}}{75,7455\ \text{lb / cuft}}$$

$= 57,4336$ cuft / Jam

$$\text{Viskositas Bahan} = \frac{\text{sg Bahan} \times \mu\ \text{Reference} (H_2O)}{\text{sg Reference}}$$

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s

$= 0,5065$ Cps

$= 0,0005$ Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi

$= 0,9960$

$$\text{sg Bahan} = \frac{\rho\ \text{Bahan}}{\rho\ \text{Reference} (H_2O)}$$

$$= \frac{75,4\ \text{lb/cuft}}{63,9\ \text{lb/cuft}}$$

= 1,1806

Viskositas Bahan = $\dfrac{1{,}1806 \times 0{,}0005 \text{ Pa.s}}{0{,}9960}$

= 0,0006 lb/ft.s

= 0,0009 Ns/m^2

= 0,8934 Cps

Heat Balance

Panas yang dibutuhkan	:	123.587,3551	kJ/Jam
		117.144,4124	Btu/Jam
Steam yang digunakan	:	56,8584	kg/Jam
		125,3727	lb/Jam

Log Mean Temperature Difference (LMTD)

Suhu bahan masuk, t_1	=	30	°C	=	86	°F
Suhu banah keluar, t_2	=	55	°C	=	131	°F
Suhu steam masuk, T_1	=	130	°C	=	266	°F
Suhu steam kondensat, T_2	=	130	°C	=	266	°F

$\Delta T_1 = T_2 - t_2$

$\Delta T_2 = T_1 - t_1$ ***(Kern; hal. 90)***

$\Delta T_1 = 266 \text{ °F} - 131 \text{ °F}$

$= 135 \text{ °F}$

$\Delta T_2 = 266 \text{ °F} - 86 \text{ °F}$

$= 180 \text{ °F}$

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln \dfrac{\Delta T_2}{\Delta T_1}}$$ ***(Kern; hal. 89; eq. 5.14)***

$= 156{,}4227 \text{ °F}$

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$ ***(Kern; hal. 142)***

$$= \frac{266 \text{ °F} - 266 \text{ °F}}{131 \text{ °F} - 86 \text{ °F}}$$

$= 0{,}0000 \text{ °F}$

$S = \dfrac{t_2 - t_1}{T_1 - t_1}$ ***(Kern; hal. 142)***

$= \dfrac{131\ °F - 86\ °F}{266\ °F - 86\ °F}$

$= 0{,}2500\ °F$

$F_T = 1$ ***(Kern; hal. 828; Fig. 18)***

$\Delta t = F_T \times LMTD$ ***(Kern; hal. 149; eq. 7.42)***

$= 1 \times 156{,}42\ °F$

$= 156{,}42\ °F$

Perhitungan T_C dan t_C dipakai Temperature rata-tata

$T_C = T_{Average}$ Steam ***(Kern; hal. 113)***

$= \dfrac{266\ °F + 266\ °F}{2}$

$= 266\ °F$

$t_C = t_{Average}$ Bahan ***(Kern; hal. 113)***

$= \dfrac{86\ °F + 131\ °F}{2}$

$= 109\ °F$

Trial

Asumsi U_D untuk Asam Format (Medium Organics)

$U_D = 50 - 100$ Btu/jam.ft^2.°F

$= 100$ Btu/jam.ft^2.°F ***(Kern; hal. 840; Tabel. 8)***

$A = \dfrac{Q}{\Delta t \times U_D}$ ***(Kern; hal. 107; eq. 6.11)***

$= \dfrac{117.144{,}4124\ \text{Btu/Jam}}{156{,}4\ °F \times 100\ \text{Btu/jam.ft}^2.°F}$

$= 7{,}4890\ ft^2$

$= 1.078{,}4111\ in^2$

Digunakan OD pipa 1/2 in, sehingga diperoleh:

a" $= 0{,}1309$ ft^2/lin ft ***(Kern; hal. 843; Tabel. 10)***

Digunakan panjang pipa:

$L = 40\ ft = 480\ in$ ***(Kern; hal. 103)***

Number of tubes

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

$$= \frac{7{,}4890 \ ft^2}{40 \ ft \times 0{,}1309 \ ft^2/lin\ ft}$$

$$= 1{,}4303 \approx 2$$

Dipilih:

Tube				Shell			
OD	=	1/2	in	Pitch	=	1	in
BWG	=	12		Shell ID	=	8	in
a't	=	0,063	in^2	Passes	=	8	
a"	=	0,1309		Nt	=	18	
		Surface / lin ft, ft^2		B Space	=	2	in
Passes	=	2		OD	=	3/4	in
ID	=	0,620	in				
Wall Thicness	=	0,065	in				

(Kern; hal. 843; Tabel. 10) ***(Kern; hal. 842; Tabel. 9)***

A baru = Nt x L x a" ***(Kern; hal. 150)***

$$= 18 \times 40 \ ft \times 0{,}1309 \ \text{Surface / lin ft, } ft^2$$

$$= 94{,}25 \ ft^2$$

$$U_D \text{ baru} = \frac{Q}{A \text{ baru} \times \Delta T_{LMTD}}$$

$$= \frac{117.144{,}4124 \ Btu/Jam}{94{,}25 \ ft^2 \times 156{,}42 \ °F}$$

$$= 7{,}9460 \ Btu/jam.ft^2.°F$$

Cold Fluid (Tube)	**Hot Fluid (Shell)**
Asam Format	**Steam**
(4) Flow Area Tube (a_t)	(4') Flow Area Shell (a_s)
$a_t = \frac{Nt \times a't}{144 \times n}$	C" = Pitch - OD
	= 1 in - 3/4 in

$= \dfrac{18 \times 0{,}1}{144 \times 2}$

$= 0{,}0039 \ ft^2$

(5) Mass Velocity Tube (Gt)

$G_t = \dfrac{W_{bahan}}{a_t}$

$= \dfrac{4.350{,}3 \ lb/Jam}{0{,}0039 \ ft^2}$

$= 1.113.686{,}56 \ lb/Jam.ft^2$

(6) Pada t_C = 108,5 °F

μ = 0,8934 cps

= 2,1621 lbm/Jam.ft

D_i = 0,62 in

= 0,0517 ft

$Re_t = \dfrac{D \times G_t}{\mu}$

$= \dfrac{0{,}05 \ ft \times 1.113.687 \ lb/Jam.ft^2}{2{,}1621 \ lbm/Jam.ft}$

= 26.613,2102

(7) Heat Transfer Factor

j_H = 50

(Kern; hal. 834; Fig. 24)

(8) Konduktivitas Thermal pada t_C

k = 0,1549 Btu/Jam.ft^2.°F

= 1/5 in

$B = ID = \dfrac{8}{5}$

= 2 in

$a_s = \dfrac{ID \times C'' \times B}{144 \ Pr}$

$= \dfrac{8 \ in \times 1/5 \ in \times 2 \ in}{144 \times 1 \ in}$

$= 0{,}0178 \ ft^2$

(5) Mass Velocity Shell (Gs)

$G_s = \dfrac{W_{steam}}{a_s}$

$= \dfrac{125{,}4 \ lb/Jam}{0{,}0178 \ ft^2}$

$= 7.052{,}2148 \ lb/Jam.ft^2$

(6') Pada T_C = 266,0 °F

μ = 0,0135 cps

(Kern; hal. 825; Fig. 15)

= 0,0327 lbm/Jam.ft

D_e = 0,73 in

= 0,0608 ft

$Re_s = \dfrac{D_e \times G_s}{\mu}$

$= \dfrac{0{,}06 \ ft \times 7.052 \ lb/Jam.ft^2}{0{,}0327 \ lbm/Jam.ft}$

= 13.131,6111

(7') Heat Transfer Factor

j_H = 60

(Kern; hal. 838; Fig. 28)

(8') Konduktivitas Thermal pada t_C

k = 0,0133 Btu/Jam.ft^2.°F

(Yaws; hal. 508; Tabel 23-1)

Cp = 3002,1 kj/kmol.°F
= 99,97 kj/kg.°F
= 220,40 kj/lb.°F
= 208,91 Btu/lb°F

$$\left(\frac{Cp \times \mu}{k}\right)^{1/3} = 14,2863$$

(9) Condensation of Steam

$$h_i = j_H \frac{k}{D_i}\left(\frac{Cp \times \mu}{k}\right)^{1/3} \varphi_t$$

(Kern; hal. 111; eq. 6.15a)

= 363,7534 Btu/Jam.ft^2.°F

$$h_{io} = h_i \frac{ID}{OD}$$

(Kern; hal. 105; eq. 6.5)

= 451,0542 Btu/Jam.ft^2.°F

(10) Pada t_w = 261,4844 °F

μ_w = 0,9393 Cps

(Yaws; hal.482; Tabel 22-1)

= 2,2732 lbm/Jam.ft

$$\varphi_t = \left(\frac{\mu}{\mu_w}\right)^{0,14}$$

$$= \left(\frac{2,1621\ °F}{2,2732\ °F}\right)^{0,14}$$

= 0,9930 Btu/Jam.ft^2.°F

(12) Corrected Coefficient

$$h_{io} = \frac{h_{io}}{\varphi_t} \times \varphi_t$$

(Kern; hal. 121; eq. 6.37)

= 451,0542 Btu/Jam.ft^2.°F

(Yaws; hal. 551; Tabel 24-2)

Cp = 0,46 Btu/lb°F

(Kern; hal. 805; Fig. 3)

$$\left(\frac{Cp \times \mu}{k}\right)^{1/3} = 1,0368$$

(9') Condensation of Steam

$$h_o = j_H \frac{k}{D_e}\left(\frac{Cp \times \mu}{k}\right)^{1/3} \varphi_s$$

(Kern; hal. 112; eq. 6.15b)

= 13,3136 Btu/Jam.ft^2.°F

(10') Tube Wall Temperature

$$t_w = t_c + \frac{h_{io}}{h_{io} + h_o}(T_c - t_c)$$

= 261,4844 °F

(13) Clean Overall Coefficient

$$U_C = \frac{h_{io} \times h_o}{}$$

$h_{io} + h_o$ ***(Kern; hal. 121; eq. 6.38)***

$$= \frac{451{,}1 \text{ Btu/jam.ft}^2.°F \times 13{,}3136}{451{,}1 \text{ Btu/jam.ft}^2.°F + 13{,}3136}$$

$= 12{,}9319$ Btu/jam.ft^2.°F

(14) Dirt Factor, Rd

$$R_d = \frac{U_C - U_D}{U_C \times U_D}$$ ***(Kern; hal. 108; eq. 6.13)***

$$= \frac{12{,}9 \text{ Btu/jam.ft}^2.°F - 7{,}9 \text{ Btu/jam.ft}^2.°F}{12{,}9 \text{ Btu/jam.ft}^2.°F \times 7{,}9 \text{ Btu/jam.ft}^2.°F}$$

$= 0{,}0485$

Untuk R_d data, digunakan "Brackish Water" atau Air Payau dengan R_d

R_d data = 0,002 - 0,001 ***(Kern; hal. 845; Tabel 12)***

R_d perhitungan > R_d data

0,049 > 0,002

Maka, desain dapat digunakan

Cold Fluid	Hot Fluid
Asam Format	**Steam**
Pressure Drop	
(a) Untuk Re_t = 26.613,2102 f = 0,0003 ***(Kern; hal. 836; Fig. 26)*** s = 1,1806	(a') Untuk Re_s = 13.131,6111 f = 0,0021 ***(Kern; hal. 839; Fig. 29)*** s = 1,0000 ***(Kern; hal. 808; Tabel. 6)***
	(b') Number of times fluid crosses $N+1 = \frac{\text{Tube Length}}{\text{Baffle Space}} = \frac{12 \times L}{B}$ ***(Kern; hal. 147; eq. 7.43)*** $= \frac{480 \text{ in}}{2 \text{ in}}$ = 240
(c) Pressure drop in Tube or Pipes $\Delta P_t = \frac{f \times G_t^2 \times L \times n}{5.22 \times 10^{10} \times D_i \times s \times \varphi_t}$	(c') Pressure drop in Shell side $\Delta P_s = \frac{f \times G_s^2 \times D_s (N+1)}{5.22 \times 10^{10} \times D_e \times s \times \varphi_s}$

(Kern; hal. 148; eq. 7.45)	***(Kern; hal. 147; eq. 7.44)***
$= \dfrac{13.023.126.438{,}9}{3.161.728.075}$	$= \dfrac{1.524.836}{3.153.303.484}$
= 4,1190 Psi	= 0,0005 Psi
$\Delta P_t < 10$ psi	$\Delta P_s < 10$ psi
(memenuhi)	(memenuhi)

Spesifikasi Heater Asam Format

Fungsi	:	Memanaskan Asam Format cair sebelum memasuki Reaktor Netralisasi				
Tipe	:	Shell and Tube Heat Exchanger				
Tube						
Inside Diameter	:	0,62	in	=	0,0157	m
Outside Diameter	:	1/2	in	=	0,0127	m
Panjang	:	40	ft	=	12,1914	m
Jumlah Tube	:	2 buah				
Shell						
Pitch	:	1	in	=	0,0238	m
Inside Diameter	:	8	in	=	0,2032	m
OD Shell	:	3/4	in	=	0,0191	m
Jumlah Heater	:	1 buah				

20. POMPA 5

Kode Alat	:	L - 211
Fungsi	:	Memindahkan Campuran dari Reaktor Kondensasi menuju Reaktor Netralisasi
Tipe	:	Centrifugal Pump
Dasar Pemilihan	:	Sesuai untuk Fluida Liquid dengan Viskositas <10 Cp
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$CH_2O_{(aq)}$	3%	579,3182	0,7261	726,0991	45,3304

$CH_3OH_{(l)}$	1%	140,9152	0,7827	782,6686	48,8620
$CH_3CHO_{(l)}$	0%	0,0000	0,7670	766,9772	47,8824
$Ca(OH)_{2\,(aq)}$	7%	1.429,6770	2,2000	2.200,0000	137,35
$H_2O_{(l)}$	54%	11.613,2693	1,0229	1.022,8753	63,8581
$C_5H_{12}O_{4(aq)}$	24%	5.253,7253	1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$	12%	2.510,3276	2,0200	2.020,0000	126,11
Total	100%	21.527,2328			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

= 1,126 x 63,858 lb/cuft

= 71,9042 lb/cuft

= 1.151,7980 kg/m^3

Rate Massa = 21.527,2328 kg/jam

= 47.463,2428 lb/jam

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

$$= \frac{47.463,2428 \text{ lb / Jam}}{71,9042 \text{ lb / cuft}}$$

= 660,0897 cuft / Jam

= 11,0015 cuft / menit

= 0,1834 cuft / sec

= 82,3022 gal / min

$$\text{Viskositas Bahan} = \frac{\text{sg Bahan} \times \mu \text{ Reference } (H_2O)}{\text{sg Reference}}$$

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s

= 0,5065 Cps

= 0,0005 Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi

= 0,9960

$$\text{sg Bahan} = \frac{\rho \text{ Bahan}}{\rho \text{ Reference } (H_2O)}$$

$$= \frac{90,6 \text{ lb/cuft}}{63,9 \text{ lb/cuft}}$$

= 1,4187

Viskositas Bahan $= \dfrac{1,4187 \times 0,0005 \text{ Pa.s}}{0,9960}$

$= 0,0007$ lb/ft.s

$= 0,0011$ Ns/m^2

$= 1,0736$ Cps

Perhitungan ID Optimum

Asumsi Aliran Turbulen, dengan $N_{Re} > 2100$, digunakan rumus:

$ID_{Optimum} = 3,9 \; qf^{0,45} \; \rho^{0,13}$

(Peters 4th; hal. 496; eq. 15)

Keterangan:

ID = Optimum Pipe Inside Diameter, in

qf = Fluid Flow Rate, cuft/sec

ρ = Fluid Density, lb/cuft

$ID_{Optimum}$ = 3,9 x 0,4661 cuft/sec x 1,7433 lb/cuft

= 3,1690 in

Perhitungan Pipa

Dipilih pipa:

IPS, Size = 3 1/2 in

OD = 4,0000 in

Schedule = No. 40

ID = 3,5480 in ***(McCabe7th; hal. 1090; App. 3)***

= 0,2957 ft

= 0,0901 m

$A_1 = \dfrac{1}{4} \pi \times ID_{Tangki}^2$

$= \dfrac{3,14}{4} \times (101,83 \text{ in})^2$

$= 8.139,8996 \text{ in}^2$

$= 56,5271 \text{ ft}^2$

$A_2 = \dfrac{1}{4} \pi \times ID^2$

$= \dfrac{3,14}{4} \times (3,55 \text{ in})^2$

$= 9{,}8818\ in^2$

$= 0{,}0686\ ft^2$

$A_2 / A_1 = 0{,}0012140 < 0.715$

$V = \dfrac{\text{Rate Volumetrik}}{A}$

$= \dfrac{0{,}1834\ ft^3/sec}{0{,}07\ ft^2}$

$= 2{,}6719\ ft/sec$

$= 0{,}8144\ m/sec$

$N_{Re} = \dfrac{D \times V \times \rho}{\mu}$ ***(Peters 4th; hal. 481; eq. 6)***

$= \dfrac{0{,}09\ in \times 0{,}81\ m/s \times 1151{,}8\ kg/m^3}{0{,}0011\ Pa.s}$

$= 78.732{,}4581 > 2{,}100$ (Airan Turbulen)

Equivalent Roughness for Pipe (ε) untuk material Commercial Steel

$\varepsilon = 0{,}00015\ ft$ ***(Peters 4th; hal. 482; Fig. 14-1)***

$= 0{,}000046\ m$ ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

$= 0{,}001800\ in$

$\dfrac{\varepsilon}{D} = 0{,}000507$

$f = 0{,}0051$ ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

Perhitungan Equivalent Suction (L_e)

Sambungan / Fitting	L_e / D	
90º Elbow Standard	35	***(Peters 4th; hal. 484; Tabel 1)***
Gate Valve, Open	9	***(Peters 4th; hal. 485; Tabel 1)***

3 Elbow std 90º $= 3 \times (L_e / D) \times DI$

$= 35 \times 0{,}2957\ ft$

$= 31{,}0450\ ft$

$= 9{,}4621\ m$

1 Gate Valve $_{\text{Wide Open}}$ $= 1 \times (L_e / D) \times DI$

$= 9 \times 0{,}2957\ ft$

$= 2{,}6610\ ft$

$= 0{,}8110\ m$

Perhitungan Panjang Pipa

Pipa A ke B	=	3,50	m	=	11,4835	ft
Elbow 1 ke Elbow 2 (Tinggi total reaktor netralisasi)	=	6,19	m	=	20,3171	ft
Elbow 2 ke Elbow 3	=	1,00	m	=	3,2810	ft
Elbow 3 ke Elbow Reaktor	=	1,00	m	=	3,2810	ft
Panjang Total Pipa Lurus	=	11,6923	m	=	38,3626	ft
Panjang Total Pipa Keseluruhan	=	21,9654	m	=	72,0686	ft

Perhitungan Friksi

Friksi karena Gesekan :

$$F_1 = \frac{2\, f \times V^2 \times L_e}{g_C \times D}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times g_C}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_3 = \frac{(V_2 - V_1)^2}{2 \times \alpha \times g_C}$$ ***(Peters 4th; hal. 484; Tabel 1)***

$$F_4 = n \times Kf \times \frac{V_1^2}{2 \times g_C}$$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

$$F_5 = n \times Kf \times \frac{V_1^2}{2 \times g_C}$$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

Keterangan

F_1 = Flow Through long straight pipe

F_2 = Sudden Contraction

F_3 = Sudden Enlargement

F_4 = Losses Fitting - Elbow 90°

F_5 = Losses Fitting - Gate Valve Open

V = Linear Velocity, ft/sec

= 2,6719 ft/sec

α = Correction Coefficient, Viscous (0.5), Turbulen (1.0)

= 1,0 Turbulen (>2100) ***(Peters 4th; hal. 480)***

L = Length of Pipe

= 72,0686 ft

D = Diameter of Pipe

= 3,5480 in = 0,2957 ft

f = Fanning Friction Factor

= 0,0051 ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

g_C = Newton's Law Conversion Factor, ft.lbm / lbf

= 32,17 ft.lbm/lbf

A_1 = Luas Penampang Reaktor Kondensasi, ft^2

= 56,5271 ft^2

A_2 = Luas Penampang Pipa, ft2

= 0,0686 ft^2

K_C = Coefficient Friction Loss, (untuk $A_2/A_1 < 0.715$)

$$= 0{,}40 \times \left(1{,}25 - \frac{A_2}{A_1}\right)$$

= 0,4995 ***(Peters 4th; hal. 484; Tabel 1)***

K_f = Number of Velocity Heads

= Elbow 90º = 0,7500

= Gate Valve Open = 0,1700

(Geankoplis 3rd; hal. 93; Tabel 2.10-1)

$$F_1 = \frac{2 \times 0{,}0051 \times (2{,}7\ \text{ft/sec})^2 \times 72{,}1\ \text{ft}}{32{,}17\ \text{ft.lbm/lbf} \times 3{,}5480\ \text{in}}$$

= 0,0460 ft .lbf / lbm

$$F_2 = \frac{0{,}50 \times (2{,}7\ \text{ft/sec})^2}{2 \times 1{,}0 \times 32{,}17\ \text{ft.lbm/lbf}}$$

= 0,0554 ft .lbf / lbm

F_3 = Karena A_1 (Tangki) > A_2 (Pipa), Maka $V_1 = 0$

$$= \frac{(2{,}7\ \text{ft/sec})^2}{2 \times 1{,}0 \times 32{,}17\ \text{ft.lbm/lbf}}$$

= 0,1110 ft .lbf / lbm

$$F_4 = 3 \times 0{,}75 \times \frac{(2{,}7\ \text{ft/sec})^2}{2 \times 32{,}2\ \text{ft.lbm/lbf}}$$

= 0,2496 ft.lbf / lbm

$$F_5 = 1 \times 0{,}41 \times \frac{(2{,}7\ \text{ft/sec})^2}{2 \times 32{,}2\ \text{ft.lbm/lbf}}$$

= 0,0449 ft.lbf / lbm

$\sum F$ = $F_1 + F_2 + F_3 + F_4 + F_5$ ***(Geankoplis 3rd; hal. 95)***

= 0,5069 ft .lbf / lbm

Persamaan Bernoulli

$$z_1 \frac{g}{g_C} + \frac{V_1^2}{2\alpha g_C} + \frac{P_1 - P_2}{\rho_1 - \rho_2} - W_f = z_2 \frac{g}{g_C} + \frac{V_2^2}{2\alpha g_C} + \sum F$$

(Geankoplis 3rd; hal. 95; eq. 2.10-20)

$$-W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

Keterangan :

W_S	=	Work done by Fluid ***(Geankoplis 3rd; hal. 62)***
z	=	Vertical Distance, ft
V	=	Linear Velocity, ft/sec
g	=	g_C = Gravity Constants
g / g_C	=	1 lbf/lbm ***(Peters 4th; hal. 487; ex. 1)***
$\sum F$	=	Total Friction Loss, ft.lbf/lbm
	=	0,5069 ft .lbf / lbm
ρ	=	Densitas Campuran, lb/cuft
	=	71,9042 lb/cuft
P	=	Tekanan, Psi
P_1	=	$P_1 + P_{\text{Hidrostatis}}$
	=	14,7 Psi + 5,8 Psi = 20,54 Psi
P_2	=	14,7 Psi
ΔP	=	$P_1 - P_2$
	=	20,5 Psi - 14,7 Psi
	=	5,8 Psi
	=	840,3 lbf / ft^2

$$\frac{\Delta P}{\rho} = \frac{840,33 \text{ lbf / ft}^2}{71,90 \text{ lb/cuft}}$$

= 11,6867 ft.lbf / lbm

Asumsi:

z_1 = 20,3171 ft

z_2 = 11,4835 ft

$$\Delta z \frac{g}{g_C} = (20,3 \text{ ft} - 11,5 \text{ ft}) \times 1 \text{ lbf/lbm}$$

= 8,8336 ft.lbf / lbm

$$\frac{\Delta V^2}{} = \frac{(2,6719 \text{ ft/sec})^2}{}$$

$2 \times \alpha \times g_C \quad 2 \times 1{,}0 \times 32{,}2$ ft.lbm/lbf

$= 0{,}1110$ ft.lbf / lbm

$$-W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

$= 11{,}69 + 8{,}83 + 0{,}11 + 0{,}51$

$= 21{,}1382$ ft.lbf / lbm

Perhitungan Brake Horsepower (BHp)

Untuk Flowrate tersebut, diperoleh efisiensi pompa sebesar:

$\eta_{Pompa} = 64\%$ ***(Peters 4th; hal. 520; Fig. 14-37)***

$W_S = -\eta \times W_P$ ***(Geankoplis 3rd; hal. 65; eq. 2.7-30)***

$$W_P = \frac{-W_S}{\eta}$$

$$= \frac{21{,}1 \text{ ft.lbf / lbm}}{64\%}$$

$= 33{,}0285$ ft.lbf / lbm

$$BHp = \frac{W_P \times \text{Flowrate}}{550}$$ ***(Geankoplis 3rd; hal. 66)***

$$= \frac{33{,}0 \text{ ft.lbf / lbm} \times 21{,}0 \text{ lb/sec}}{550}$$

$= 1{,}264$

≈ 2 hp

Perhitungan Power Motor

Untuk BHp tersebut, diperoleh efisiensi motor sebesar:

$\eta_{Motor} = 83\%$ ***(Peters 4th; hal. 521; Fig. 14-38)***

$$hp = \frac{BHp}{\eta_{Motor}}$$

$$= \frac{2 \text{ hp}}{83\%}$$

$= 2{,}4096$

≈ 3 hp

Spesifikasi Pompa 5

Fungsi : Memindahkan Campuran dari Reaktor Kondensasi menuju Reaktor Netralisasi

Tipe	:	Centrifugal Pump
Kecepatan Aliran	:	2,6719 ft/sec = 0,8144 ft/sec
Flowrate	:	0,1834 cuft/s = 82,3022 gal/min
Size Pipa, IPS	:	3 1/2 in
ID Pipa	:	3,5480 in
Schedule	:	No. 40
Efisiensi Pompa	:	64%
Power Pompa	:	2 hp
Efisiensi Motor	:	83%
Power Motor	:	3 hp
Jumlah	:	1 Pompa

22. REAKTOR NETRALISASI

Kode Alat	:	R - 220
Fungsi	:	Mereaksikan Kalsium Hidroksida sisa dengan Asam Format menjadi Kalsium Format dan H_2O
Tipe	:	Tangki Silinder Tegak Berpengaduk dengan tutup atas dan bawah Torispherical Dished Head, dilengkapi dengan Cooling Jacket
Material Konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*
Dasar Pemilihan	:	Ekonomis dan umum digunakan untuk reaksi padat cair
	:	disertai dengan Material untuk Bahan Korosif
Tekanan	:	1 atm
Temperatur	:	55 °C
Waktu Operasi	:	1 Jam

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$CH_2O_{(g)}$	2,465%	579,3182	0,7261	726,0991	45,33
$CH_3OH_{(g)}$	0,600%	140,9152	0,7827	782,6686	48,86
$CH_2O_{2(l)}$	7,557%	1.775,8093	0,7670	766,9772	47,88
$Ca(OH)_{2(aq)}$	6,084%	1.429,6770	2,2000	2.200,0000	137,35
$H_2O_{(l)}$	50,257%	11.810,5815	1,0229	1.022,8753	63,86
$C_5H_{12}O_{4\,(aq)}$	22,356%	5.253,7253	1,0734	1.073,4411	67,01
$Ca(HCOO)_{2(aq)}$	10,682%	2.510,3276	2,0200	2.020,0000	126,11

Total	100%	23.500,3542			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

= 1,087 x 63,8581 lb/cuft

= 69,3910 lb/cuft

Rate Massa = 23.500,3542 kg/jam

= 51.813,5809 lb/jam

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

$$= \frac{51.813,5809\ \text{lb / Jam}}{69,3910\ \text{lb / cuft}}$$

= 746,6904 cuft / Jam

Ditetapkan pengisian bahan sebanyak 80% volume (faktor keamanan)

Volume Bahan = 80% dari volume Tangki

$$\text{Volume Tangki } (V_S) = \frac{746,6904\ \text{cuft}}{80\%}$$

= 933,3630 cuft

Perhitungan Dimensi Tangki

Tinggi (H) = 2 Diameter (D) ***(Ulrich; hal. 248; Tabel 4-27)***

$$V_S = \frac{1}{4}\ \pi\ D^2\ H$$

$$V_S = \frac{3,14}{4} \times 2 \times Ds^3$$

V_S = 1,57 Ds^3

V tutup atas torispherical dish = 0,000049 Ds^3

(Brownell; hal. 88; eq. 5.11)

V tutup atas = V tutup bawah

Volume Tangki = V_S + 2 V tutup atas

933,3630 cuft = 1,57 Ds^3 + 0,000098 Ds^3

933,3630 cuft = 1,57 Ds^3

Ds^3 = 594,4616 cuft

Ds = 8,4083 ft = 100,8995 in = 2,5628 m

Hs = 16,8166 ft = 201,7991 in = 5,1257 m

Perhitungan Tinggi Komponen

Volume Bahan = $\frac{1}{4}\ \pi\ Ds^2\ \ H_{liq}$

746,6904 cuft = $\frac{3,14}{4}$ x 8,4083 ^{2} x H_{liq}

H_{liq} = 13,4541 ft = 161,4493 in = 4,1008 m

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

P = 1 atm = 14,6959 Psi

P_{Inside} = 14,6959 Psi

$P_{Outside}$ = 14,6959 Psi

P_{Design} = P_{Inside} - $P_{Outside}$ + $P_{Hidrostatis}$

= 14,7 Psi - 14,7 Psi + $P_{Hidrostatis}$

P_{Design} = $P_{Hidrostatis}$

$P_{Hidrostatis}$ = ρ Campuran x $\frac{g}{gc}$ x H_{liq}

= 69,3910 lbm/cuft x 1 lbf/lbm x 13,4541 ft

= 933,5941 lb/ft^2

= 6,4885 Psi

P_{Design} dibuat berlebih 10% (faktor keamanan)

P_{Design} = 1,1 x 6,4885 Psi

= 7,1373 Psi

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

t_{min} = Tebal Shell Minimum (in)

P = Tekanan Tangki (Psi)

ri = Jari - jari Tangki (in) (1/2 D)

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi ***(Brownell; hal. 251; Tabel 13.1)***

$$t_{min} = \frac{7{,}1373 \text{ Psi} \times 50{,}4498 \text{ in}}{15.000 \text{ Psi} - 4{,}2824 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{360{,}0765}{14.995{,}7176} + 0{,}125 \text{ in}$$

$$= 0{,}1490 \text{ in}$$

$$= \left(\text{Digunakan } t_S = \frac{5}{16} \text{ in}\right)$$

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Shell

$$\frac{5}{16} \text{ in} = \frac{7{,}1373 \text{ Psi} \times 50{,}4498 \text{ in}}{f \times 0{,}80 - 4{,}2824 \text{ Psi}} + 0{,}125 \text{ in}$$

$$f = 2.405{,}8629 \text{ Psi} < f_{Allowable} \text{ (memenuhi)}$$

Perhitungan tebal tutup atas dan bawah

Tutup atas berbentuk Torispherical Dished Head

$$OD = ID + (2\ t_S)$$

$$= 100{,}8995 \text{ in} + 2 \times 0{,}3125$$

$$= 101{,}5245 \text{ in}$$

$$= (\text{Digunakan OD} = 102 \text{ in})$$

(Brownell; hal.91; Tabel 5.7)

Diperoleh:

icr = 6,1250 in = 0,5102 ft

r_C = 96 in = 7,9968 ft

Cek nilai icr dengan 6% rc:

icr = 6,13 in

6% rc = 5,76 in

karena nilai icr > 6% rc, maka menggunakan persamaan

$$t = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$

(Brownell; hal.138; eq. 7.77)

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

(Brownell; hal.138; eq. 7.76)

Keterangan:

W = Faktor Stress

Pd = Tekanan design (P_{Design})
r_C = Radius Crown
r_1 or icr = Inside Crown Radius
E = Faktor Pengelasan = 0,80
t = Tebal dinding minimal
f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*
= 18.750 Psi **(Brownell; hal. 251; Tabel 13-1)**
C = Faktor Korosi (in) = 0,125 in

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

$$= \frac{1}{4}\left(3 + \sqrt[2]{(96 \text{ in} / 6{,}13 \text{ in})}\right)$$

$$= 1{,}7397$$

$$t_{Head} = \frac{Pd \times r_C \times W}{2f\,E - 0{,}2\ Pd} + C$$

$$= \frac{7{,}1373 \text{ Psi} \times 96 \text{ in} \times 1{,}7397}{37.500 \text{ Psi} \times 0{,}8 - 1{,}4275 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= 0{,}1647 \text{ in}$$

= (Digunakan t = $\frac{3}{16}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Head

$$\frac{3}{16} \text{ in} = \frac{7{,}1373 \text{ Psi} \times 167{,}0154 \text{ in}}{2\ f \times 0{,}80 - 1{,}4275 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 11.921,3237 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tinggi tutup atas dan bawah:

Di = 100,8995 in

$$a = \frac{Di}{2}$$

$$= \frac{100{,}8995 \text{ in}}{2}$$

= 50,4498 in

icr = 6,1250 in

r_C = 96 in **(*Brownell; hal. 91; Tabel 5.7*)**

AB = $\frac{Di}{2}$ - icr

= $\frac{100,8995 \text{ in}}{2}$ - 6,125 in

= 44,3248 in

BC = r_C - icr

= 96 in - 6 in

= 89,8750 in

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

= √ (8.077,5156 in - 1.964,6852 in)

= 78,1846 in

b = r_C - AC

= 96 in - 78,1846 in

= 17,8154 in

sf = 3 in **(*Brownell; hal. 93; Tabel 5.8*)**

t_{Head} = 0,1875 in

OA = t_{Head} + b + sf

= 0,1875 in + 17,8154 in + 3 in

= 21,0029 in

Maka, tinggi tutup = 21,0029 in

= 0,5335 m

= 1,7502 ft

Perhitungan Sistem Pengaduk

Viskositas Bahan = $\frac{\text{sg Bahan} \times \mu \text{ Reference } (H_2O)}{\text{sg Reference}}$

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s

= 0,5065 Cps

= 0,0005 Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi

= 0,9960

sg Bahan = $\frac{\rho \text{ Bahan}}{}$

$$= \frac{69{,}4 \text{ lb/cuft}}{63{,}9 \text{ lb/cuft}} \quad \rho \text{ Reference } (H_2O)$$

$= 1{,}0866$

Viskositas Bahan $= \dfrac{1{,}0866 \times 0{,}0005 \text{ Pa.s}}{0{,}9960}$

$= 0{,}0006$ lb/ft.s

$= 0{,}0008$ Ns/m^2 $= 0{,}8224$ Cps

Dengan mempertimbangkan Viskositas Bahan dan Volume Tangki, dipilih Pengaduk Marine Propeller dengan 3 blade

Kecepatan Pengaduk = 420 rpm ***(Towler; hal. 617, Fig. 10.57)***

Perhitungan Dimensi Pengaduk

$\dfrac{D_t}{D_i} = 3$

$\dfrac{Z_t}{D_i} = 2{,}7 - 3{,}9 = 3{,}9$ (dipilih)

$\dfrac{Z_i}{D_i} = 0{,}75 - 1{,}3 = 1{,}3$ (dipilih)

$\dfrac{w}{D_t} = 0{,}1$

Pitch = 2 Di ***(Brown; hal. 507, Fig. 477)***

Keterangan:

D_t = Diameter Tangki
= 8,4083 ft

D_i = Diameter Impeller
$= \dfrac{8{,}4083 \text{ ft}}{3}$
= 2,8028 ft

Z_t = Tinggi Liquid dalam Tangki
= 3,9 x 2,8028 ft
= 10,9308 ft

Z_i = Jarak Impeller dari dasar Tangki
= 1,3 x 2,8028 ft
= 3,6436 ft

n = Revolusi Per detik

w = Lebar Baffle

= 0,1 x 8,4083 ft

= 0,8408 ft

Pitch = 2 x 2,8028 ft

= 5,6055 ft

Perhitungan Kecepatan Pengadukan

n = 300 - 500 meter/menit untuk Marine Propeller

(Joshi; hal. 416)

$$n_{(rpm)} = \frac{n_{(m/min)}}{\pi \times D_i}$$

$$= \frac{300}{3,14 \times 0,8629}$$

= 110,72 rpm ≈ 111 rpm

Penentuan Baffle

$$N_{Re} = \frac{n \times D_i^2 \times \rho}{\mu}$$ ***(Brown; hal. 508)***

Keterangan:

N_{Re} = Bilangan Reynolds

ρ = Densitas Campuran, lb/cuft

= 69,3910 lb/cuft

D_i = Diameter Impeller, ft

= 2,8028 ft

n = Kecepatan Pengadukan, rps

= 111 rpm

= 2 rps

μ = Viskositas Bahan, Pa.s

= 0,0006 lb/ft.s

= 0,0265 Pa.s

$$N_{Re} = \frac{2 \text{ rps} \times 7,8555 \text{ ft} \times 69,3910 \text{ lb/cuft}}{0,0265 \text{ lb/ft.s}}$$

= 38.114

Karena N_{Re} > 10,000, termasuk aliran Turbulen

Maka diputuskan untuk menggunakan Baffle, dengan jumlah 4 buah

(Perry 8th; hal. 18-11)

W_B = Lebar Baffle, ft

= 0,1 D_t ***(Perry 8th; hal. 18-11)***

= 0,8408 ft

Penentuan Jumlah Pengaduk

$$\text{Jumlah Pengaduk} = \frac{H_{liq} \times \text{sg bahan}}{D_S}$$

(Joshi; hal. 415)

Keterangan:

H_{liq} = Tinggi Komponen,

= 13,4541 ft = 161,4493 in = 4,1008 m

sg bahan = Specific Gravity Bahan

= 1,0866

D_S = Diameter Tangki

= 8,4083 ft = 100,8995 in = 2,5628 m

$$\text{Jumlah Pengaduk} = \frac{4{,}1008 \text{ m} \times 1{,}0866}{2{,}5628 \text{ m}}$$

= 1,74 ≈ 2 buah

Perhitungan Jarak Antar Pengaduk

Jarak antar pengaduk = 1 - 1,5 Diameter Pengaduk

(Joshi; hal. 415)

= 1,5 Diameter Pengaduk (dipilih)

= 1,5 x 2,8028 ft

= 4,2041 ft 50,4498 in = 1,2814 m

Perhitungan Power Pengaduk

$$P = \frac{N_P \times n^3 \times D_i^5 \times \rho}{gc}$$

(McCabe 5th; hal. 253, eq. 920)

Keterangan:

P = Power, ft.lbf/s

N_P = Power Number

= Berdasarkan Pengamatan, dipastikan Curve 3

= 0,5 ***(Towler; hal. 618, Fig.10.58)***

n = Kecepatan Putaran, rps

= 2 rps

D_i = Diameter Impeller, ft
= 2,8028 ft

ρ = Densitas Campuran
= 69,3910 lb/cuft

gc = Gravity Constants, $(lb.ft)/(lbf/s^2)$
= 32,1740 $(lb.ft)/(lbf/s^2)$

$$P = \frac{0,5 \times 6 \text{ rps} \times 172,9551 \text{ ft} \times 69,3910 \text{ lb/cuft}}{32,1740 \ (lb.ft)/(lbf/s^2)}$$

= 1.180,9094 ft.lbf/s
= 2,1769 Hp

Maka, besar power untuk 2 pengaduk:

$Power_2$ = 4,3538 Hp

Power perhitungan akan ditambahkan dengan beberapa faktor

Glands Loss = 10% ***(Joshi; hal. 424)***
= 0,4354 Hp

Transmission Loss = 20% ***(Joshi; hal. 424)***
= 0,8708 Hp

Power Total = $Power_2$ + Glands Loss + Transmission Loss
= 4,3538 Hp + 0,4354 Hp + 0,8708 Hp
= 5,6599 Hp

Efisiensi Motor = 85%

$$\text{Power Motor} = \frac{\text{Power Total}}{\text{Efisiensi}}$$

$$= \frac{5,6599 \text{ Hp}}{85\%}$$

= 6,6587 Hp ≈ 7 Hp

Perhitungan Sistem Pendingin

Keb. air Pendingin = 113.205,4845 kg/Jam
= 249.575,0753 lb/Jam

$$\text{Rate Volumetrik} = \frac{249.575,0753 \text{ lb/Jam}}{63,86 \text{ lb/cuft}}$$

= 3.908,2758 cuft/Jam
= 1,0856 cuft/detik

Suhu Komponen $_{In}$ = 55 °C = 131,0 °F
Suhu Komponen $_{Out}$ = 55 °C = 131,0 °F
Suhu Air Pendingin $_{In}$ = 25 °C = 77,0 °F
Suhu Air Pendingin $_{O}$ = 45 °C = 113,0 °F

Pendingin dirancang untuk mempertahankan suhu tetap pada 55°C

Q Serap = 7.097.983,8791 kJ/Jam
= 1.696.458,8621 kKal/Jam
= 6.727.946,8049 Btu/Jam

ΔT_1 = Suhu Komponen $_{In}$ - Suhu Air Pendingin $_{In}$
= 131 °F - 113 °F
= 18 °F

ΔT_2 = Suhu Komponen $_{Out}$ - Suhu Air Pendingin $_{Out}$
= 131 °F - 77 °F
= 54 °F

$$\Delta T_{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln \dfrac{\Delta T_2}{\Delta T_1}}$$ ***(Kern; hal. 89, eq. 5.14)***

$$= \frac{18{,}00\ °F - 54{,}00\ °F}{\ln \dfrac{18{,}00\ °F}{54{,}00\ °F}}$$

= 32,7686 °F

Koefisien perpindahan panas luar jaket

$$h_i = 0{,}36\ \frac{k}{D_i} \times \left(\frac{L^2 N\rho}{\mu}\right)^{2/3} \left(\frac{c\mu}{k}\right)^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

(Kern; hal. 718, eq. 20.1)

Keterangan:

L = D_i (Diameter Pengaduk), ft
= 2,8028 ft = 33,6332 in = 0,8543 m

N = Kecepatan Pengaduk, rph
= 6.660 rph

ρ = Densitas Air, lb/cuft
= 63,8581 lb/cuft

μ = Viskositas Bahan, cps
= 0,0006 lb/ft.s

= 1,9893 lb/ft.jam

= 0,8224 cps

k = Konduktivitas Thermal

$$= \frac{0{,}0677 \text{ Btu/jam.ft}^2{}^\circ\text{F}}{\text{sg} \times [\,1 - 0{,}0003\,(\Delta T\ \text{LMTD} - 32\,)\,]}$$

$$= \frac{0{,}0677 \text{ Btu/jam.ft}^2{}^\circ\text{F}}{1{,}0866 \times [\,1 - 0{,}0003\,(32{,}77\ ^\circ\text{F} - 32\,)\,]}$$

= 0,0623 Btu/Jam.ft^2.°F

c = Kapasitas Panas Campuran

Komponen	BM (kg/kmol)	%	Cp (Kj/kmol)	Cp (Kkal/kmol
$CH_2O_{(aq)}$	30,03	2,47%	1.090,01	260,52
$CH_3OH_{(l)}$	32,04	0,60%	2.439,29	583,01
$CH_2O_{2\ (l)}$	74,10	0,00%	0,00	0,00
$Ca(OH)_{2\ (aq)}$	46,02	0,00%	0,00	0,00
$H_2O_{(l)}$	18,02	53,22%	2.258,66	539,83
$C_5H_{12}O_{4(aq)}$	136,15	22,36%	6.976,02	1.667,31
$Ca(HCOO)_{2(aq)}$	130,11	21,36%	3.564,90	852,03
Total	466,46			

c = 1 kkal/kmol.°C = 0,053 Btu/lb°F

= Σ % Cp

= 851,9635 kkal

= 45,1541 Btu/lb.°F

$$\left(\frac{L^2N\rho}{\mu}\right)^{2/3} = \left(\frac{(2{,}8028^2 \times 6.660 \text{ rph} \times 63{,}9 \text{ lb/cuft})}{1{,}9893 \text{ lb/ft.Jam}}\right)^{2/3}$$

= 14.128,71

$$\left(\frac{c\mu}{k}\right)^{1/3} = \left(\frac{45{,}1541 \text{ Btu/lb.}^\circ\text{F} \times 1{,}9893 \text{ lb/ft.Jan}}{0{,}0623 \text{ Btu/jam.ft.}^\circ\text{F}}\right)^{1/3}$$

= 11,2963

$$\left(\frac{\mu}{\mu_w}\right)^{0.14} = \left(\frac{1{,}9893}{1}\right)^{0.14}$$

= 1,0067

$$h_i = 0{,}36\ \frac{k}{D_i} \times 14.128{,}7141 \times 11{,}2963 \times 1{,}0067$$

$= 0{,}36 \dfrac{0{,}06 \text{ Btu/jam.ft.°F}}{8{,}41 \text{ ft}} \times 160.672{,}5431$

$= 428{,}6847$ Btu/jam.ft.°F

Dari tabel, dipilih pipa dengan ukuran:

OD = 1,50 in

ID = 1,40 in

flow area = 1,54 in^2 = 0,00099 m^2

Surface Area per 1 in = 0,39 ft^2

(Kern; hal. 843, Tabel 10)

$v = \dfrac{W}{\rho \times A}$

$= \dfrac{249.575{,}0753 \text{ lb/Jam}}{63{,}86 \text{ lb/cuft} \times 0{,}3925 \text{ ft}^2}$

$= 9.957$

$h_i = 428{,}6847 \times$ Correction Factor

$= 428{,}6847 \times 0{,}85$ ***(Kern; hal. 835, Fig.25)***

$= 364{,}3820$ Btu/Jam.ft^2.°F

$h_{io} = h_i \times \dfrac{ID}{OD}$ ***(Kern; hal. 105; eq. 6.5)***

$= 364{,}3820 \text{ Btu/Jam.ft}^2\text{.°F} \times \dfrac{1{,}4}{1{,}5}$

$= 340{,}0899$

$U_C = \dfrac{h_i \times h_{io}}{h_i + h_{io}}$

$= \dfrac{364{,}3820 \text{ Btu/Jam.ft}^2\text{.°F} \times 340{,}0899 \text{ Btu/Jam.ft}^2\text{.°F}}{364{,}3820 \text{ Btu/Jam.ft}^2\text{.°F} + 340{,}0899 \text{ Btu/Jam.ft}^2\text{.°F}}$

$= 175{,}9086$

R_d = Fouling Factor

= 0,001 ***(Kern; hal. 845, Tabel 12)***

$\dfrac{1}{U_D} = \dfrac{1}{U_C} + Rd$ ***(Kern; hal. 107, eq. 6.10)***

$= \dfrac{1}{175{,}9} + 0{,}001$

$= 0{,}0067$

$U_D = 149{,}5937$ Btu/Jam.ft^2.°F

$$A = \frac{Q}{U_D \times \Delta T_{LMTD}}$$ ***(Kern; hal. 107, eq. 6.11)***

$$= \frac{6.727.946,8049 \text{ Btu/Jam}}{149,6 \text{ Btu/Jam.ft}^2.°F \times 32,8 \text{ °F}}$$

$$= 1.372,4960 \text{ ft}^2$$

Perhitungan Tinggi Jaket

Tinggi Jaket = Tinggi Shell + Tinggi Tutup Bawah
= 16,8166 ft + 1,7502 ft
= 18,5668 ft

Asumsi:

Tebal air pendingin = 2
Tebal Jaket = 0,1875 = 3/16 in
Efisiensi Las = 0,8
Faktor Korosi = 0,125 in

Digunakan material *Stainless Steel SA-167 Grade 11*

f = 18.750

DO Shell = Di + 2ts
= 100,8995 in + 2 x 0,1875 in
= 101,2745 in

Di Jacket = DO Shell + 2 s
= 101,2745 in + 2 x 2,0000 in
= 105,2745 in

DO Jacket = Di Jacket + 2 t Jacket
= 105,2745 in + 2 x 0,1875 in
= 105,6495 in

P Design Jacket = P Outside - P Inside + P Hidrostatis
= 14,7 Psi - 14,7 Psi + ρ Campuran x g/gc x H Liq
= 69,39 lb/cuft x 1 lbf/lbm x 13,4541 ft
= 933,5941 lbf/ft^2
= 6,4833 Psi

Perhitungan Tebal Jaket

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

$$t_{Jacket} = \frac{P \times Dij}{2 f E - P} + C$$

Keteragan:

t_{min} = Tebal Shell Minimum (in)

P = Tekanan Tangki (Psi)

Dij = Diameter dalam Jaket (in)

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, Material Konstruksi *Stainless Steel 316 SA-167 Grade 11*

= 18.750 Psi **(*Brownell; hal. 251; Tabel 13.1)***

$$t_{min} = \frac{6{,}4833 \text{ Psi} \times 105{,}2745 \text{ in}}{30.000 \text{ Psi} - 6{,}4833 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{682{,}5256}{29.993{,}5167} + 0{,}125 \text{ in}$$

$$= 0{,}1478 \text{ in}$$

= (Digunakan t = $\frac{3}{16}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perancangan Penyangga Tangki

$$\text{Berat}_{Shell} = \frac{1}{4}\pi \ (OD^2 - ID^2) \times H_{Liq} \times \rho_{Steel}$$

ρ Steel = 0,2790 lb/in^3 ***(Brownell; hal. 341, App. D, Item 3)***

= 482,11 lb/ft^3

$$= \frac{3{,}14}{4} \times (71{,}6 \text{ ft} - 70{,}7 \text{ ft}) \times 13{,}5 \text{ ft} \times 482 \text{ lb/ft}^3$$

= 4.473,5503 lb

$$\text{Berat}_{T\,Atas} = \frac{1}{4}\pi \ (OD^2 - ID^2) \times H_{Tutup} \times \rho_{Steel}$$

$$= \frac{3{,}14}{4} \times (71{,}6 \text{ ft} - 70{,}7 \text{ ft}) \times 1{,}8 \text{ ft} \times 482 \text{ lb/ft}^3$$

= 581,9631 lb

$$\text{Berat}_{T\,Bawah} = \frac{3{,}14}{4} \times (71{,}6 \text{ ft} - 70{,}7 \text{ ft}) \times 1{,}8 \text{ ft} \times 482 \text{ lb/ft}^3$$

= 581,9631 lb

Berat_{Fluida} = Berat Feed

= 23.500,4 kg
= 51.818,3 lb

Berat $_{Mati\ Shell}$ = Berat $_{Shell}$ + Berat $_{Tutup\ Atas}$ + Berat $_{Tutup\ Bawah}$ + Berat $_{Fluida}$
= 4.473,6 lb + 582,0 lb + 582,0 lb + 51.818,3 lb
= 57.455,7575 lb
= 26.057,0329 kg

Leg Planning

Berat untuk perancangan = 1,2 x berat mati tangki
= 1,2 x 57.455,8 lb
= 68.946,9090 lb

Kaki penyangga dilakukan pengelasan di tengah-tengah ketinggian (40% tinggi total bejana) dengan leg tipe I-Beam, Pondasi Concrete / Beton

H $_{Leg}$ = 40% x H $_{Tangki}$
= 40% x 20,3171 ft
= 8,1268 ft
= 97,5220 in
= 2,4769 m

Digunakan Beams 12 x 5 in

Berat/ft	=	31,80 lb
Area of Section (A)	=	9,26 in^2
Kedalaman Beam	=	12,00 in
Lebar Flange	=	5,00 in
Tebal Rata-rata	=	0,54 in
Tebal Web	=	0,35 in

Peletakan dengan beban Ekstrensik (Axis 1-1)

I = 215,8 in^4
S = 36,0 in^3
r = 4,8 in

Peletakan tanpa beban Ekstrensik (Axis 2-2)

I = 9,5 in^4
S = 3,8 in^3
r = 1,0 in ***(Brownell; hal. 355; App. G)***

Beban Kompresi total maksimum tiap Leg (P):

$$\text{Beban tiap penyangga} = \frac{\text{Berat Perancangan}}{\text{Jumlah Penyangga}}$$

Asumsi jumlah penyangga = 4

Maka beban tiap penyangga = $\frac{68.946,9090 \text{ lb}}{4}$

P = 17.236,7273 lb untuk setiap penyangga

Cek peletakan sumbu Axis 1-1 maupun Axis 2-2

Fc Allowable $= \frac{P}{A}$

$= \frac{17.236,7 \text{ lb}}{9,26 \text{ in}^2}$

$= 1.861,4$ psi

Pemeriksaan Leg Planning

Axis 1-1

$\frac{1}{r} = \frac{97,5 \text{ in}}{4,8} = 20,1909$

Fc Pemeriksaan $= 17.000 - 0,485 \left(\frac{1}{r}\right)^2$

$= 17.000 - 0,485 \ (20,2)^2$

$= 16.802,2792$

Fc Pemeriksaan < Fc Allowable (Dapat digunakan)

Axis 2-2

$\frac{1}{r} = \frac{97,5 \text{ ft}}{1,0} = 96,5564$

Fc Pemeriksaan $= 17.000 - 0,485 \left(\frac{1}{r}\right)^2$

$= 17.000 - 0,485 \ (96,6)^2$

$= 12.478,2785$

Fc Pemeriksaan < Fc Allowable (Dapat digunakan)

Lug Planning

Setiap penyangga memiliki 4 baut

$P_{Bolt} = \frac{P}{n_{Bolt}}$

$= \frac{17.236,7 \text{ lb}}{4,0}$

$= 4.309,1818$ lb

Luas lubang Baut

$$A_{Bolt} = \frac{P_{Bolt}}{f_{Bolt}}$$ ***(Brownell; hal. 194; eq. 10.44)***

$$A_{Bolt} = \frac{4.309{,}2 \text{ lb}}{12.000{,}0 \text{ psi}}$$

$$= 0{,}3591 \text{ in}^2$$

Digunakan baut dengan diameter 1 in

Spesifikasi Reaktor Netralisasi

Fungsi	:	Mereaksikan Kalsium Hidroksida sisa dengan Asam Format menjadi Kalsium Format dan H2O				
Tipe	:	Tangki Silinder Tegak Berpengaduk dengan tutup atas dan bawah Torispherical Dished Head, dilengkapi dengan Cooling Jacket				
Bahan konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*				
Tekanan	:	1 atm				
Kapasitas / Volume	:	933,3630	cuft	=	26,4142	m^3
Diameter Shell	:	8,4083	ft	=	2,5627	m
Tinggi Shell	:	16,8166	ft	=	5,1254	m
Tebal Shell	:	0,3125	in	=	0,0079	m
Tinggi tutup atas	:	21,0029	in	=	0,5335	m
Tebal tutup atas	:	0,1875	in	=	0,0048	m
Tinggi tutup bawah	:	21,0029	in	=	0,5335	m
Tebal tutup bawah	:	0,1875	in	=	0,0048	m
Tinggi Total tangki	:	20,3171	ft	=	6,1923	m
Waktu Operasi	:	60 menit				
Tipe Pengaduk	:	*Marine Propeller,* dengan 3 buah *Blade*				
Diameter Pengaduk	:	2,8028	ft	=	0,8542	m
Jarak Pengaduk	:	3,6436	ft	=	1,1105	m
Pitch	:	5,6055	ft	=	1,7085	m
Jumlah Pengaduk	:	2 buah				
Jarak antar Pengaduk	:	4,2041	ft	=	1,2814	m
Power Pengaduk	:	7 hp = 5,2200 kWh				
Jumlah Baffle	:	4 buah				
Lebar Baffle	:	0,8408	ft	=	0,2563	m
Diameter Cooling Jacket (in)	:	105,2745	in	=	2,6740	m

Diameter Cooling Jacket (out)	:	105,6495	in	=	2,6835	m
Tinggi Cooling Jacket	:	18,5668	ft	=	5,6589	m
Tebal Cooling Jacket	:	0,1875	in	=	0,0048	m
Luas Heat Transfer	:	1.372,4960	ft^2	=		
Tipe Penyangga	:	Beam				
Ukuran Peyangga	:	12 x 5	in			
Tinggi Kaki	:	8,1268	ft	=	2,4769	m
Lebar Flange	:	5	in	=	0,1270	m
Diameter Baut	:	1	in	=	0,0254	m
Jumlah	:	1	tangki			

23. POMPA 6

Kode Alat	:	L - 221
Fungsi	:	Memindahkan Campuran dari Tangki Netralisasi menuju Evaporator Efek Pertama
Tipe	:	Centrifugal Pump
Dasar Pemilihan	:	Sesuai untuk Fluida Liquid dengan Viskositas <10 Cp
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4(aq)}$	22%	5.253,7253	1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$	21%	5.020,6552	2,0200	2.020,0000	126,11
$H_2O_{(l)}$	53%	12.505,7402	1,0229	1.022,8753	63,8581
CH_2O	2%	579,3182	0,7261	726,0991	45,3304
CH_3OH	1%	140,9152	0,7827	782,6686	48,8620
Total	100%	23.500,3542			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

$= 1,199 \times 63,858$ lb/cuft

$= 76,5430$ lb/cuft

$= 1.226,1037$ kg/m^3

Rate Massa = 23.500,3542 kg/jam

= 51.813,5810 lb/jam

Rate Volumetrik = $\dfrac{\text{Rate Massa}}{\rho \text{ Campuran}}$

= $\dfrac{51.813,5810 \text{ lb / Jam}}{76,5430 \text{ lb / cuft}}$

= 676,9214 cuft / Jam

= 11,2820 cuft / menit

= 0,1880 cuft / sec

= 84,4008 gal / min

Viskositas Bahan = $\dfrac{\text{sg Bahan} \times \mu \text{ Reference } (H_2O)}{\text{sg Reference}}$

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s

= 0,5065 Cps

= 0,0005 Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi

= 0,9960

sg Bahan = $\dfrac{\rho \text{ Bahan}}{\rho \text{ Reference } (H_2O)}$

= $\dfrac{89,6 \text{ lb/cuft}}{63,9 \text{ lb/cuft}}$

= 1,4033

Viskositas Bahan = $\dfrac{1,4033 \times 0,0005 \text{ Pa.s}}{0,9960}$

= 0,0007 lb/ft.s

= 0,0011 Ns/m^2

= 1,0620 Cps

Perhitungan ID Optimum

Asumsi Aliran Turbulen, dengan N_{Re} > 2100, digunakan rumus:

$ID_{Optimum} = 3,9 \; qf^{0,45} \; \rho^{0,13}$

(Peters 4th; hal. 496; eq. 15)

Keterangan:

ID = Optimum Pipe Inside Diameter, in

qf = Fluid Flow Rate, cuft/sec

ρ = Fluid Density, lb/cuft

$ID_{Optimum} = 3{,}9 \times 0{,}4714$ cuft/sec $\times$ 1,76 lb/cuft
= 3,2313 in

Perhitungan Pipa

Dipilih pipa:

IPS, Size = 3 1/2 in

OD = 4,0000 in

Schedule = No. 40

ID = 3,5480 in *(McCabe7th; hal. 1090; App. 3)*
= 0,2957 ft
= 0,0901 m

$$A_1 = \frac{1}{4} \pi \times ID_{Tangki}^{2}$$

$$= \frac{3{,}14}{4} \times (100{,}90 \text{ in})^2$$

$= 7.991{,}8628$ in^2
$= 55{,}4990$ ft^2

$$A_2 = \frac{1}{4} \pi \times ID^2$$

$$= \frac{3{,}14}{4} \times (3{,}55 \text{ in})^2$$

$= 9{,}8818$ in^2
$= 0{,}0686$ ft^2

$A_2 / A_1 = 0{,}0012365 < 0.715$

$$V = \frac{\text{Rate Volumetrik}}{A}$$

$$= \frac{0{,}1880 \text{ ft}^3/\text{sec}}{0{,}07 \text{ ft}^2}$$

= 2,7401 ft / sec
= 0,8351 m / sec

$$N_{Re} = \frac{D \times V \times \rho}{\mu}$$ *(Peters 4th; hal. 481; eq. 6)*

$$= \frac{0{,}09 \text{ in} \times 0{,}84 \text{ m/s} \times 1226{,}1 \text{ kg/m}^3}{0{,}0011 \text{ Pa.s}}$$

$= 86.894{,}0147 > 2{,}100$ (Airan Turbulen)

Equivalent Roughness for Pipe (ε) untuk material Commercial Steel

ε = 0,00015 ft *(Peters 4th; hal. 482; Fig. 14-1)*
= 0,000046 m *(Geankoplis 3rd; hal. 88; Fig. 2.10-3)*
= 0,001800 in

$\frac{\varepsilon}{D}$ = 0,000507

f = 0,0051 *(Geankoplis 3rd; hal. 88; Fig. 2.10-3)*

Perhitungan Equivalent Suction (L_e)

Sambungan / Fitting	L_e / D	
90º Elbow Standard	35	*(Peters 4th; hal. 484; Tabel 1)*
Gate Valve, Open	9	*(Peters 4th; hal. 485; Tabel 1)*

3 Elbow std 90º = 3 x (L_e / D) x DI
= 35 x 0,2957 ft
= 31,0450 ft
= 9,4621 m

1 Gate Valve $_{\text{Wide Open}}$ = 1 x (L_e / D) x DI
= 9 x 0,2957 ft
= 2,6610 ft
= 0,8110 m

Perhitungan Panjang Pipa

Pipa A ke B	= 1,50	m	=	4,9215	ft
Elbow 1 ke Elbow 2 (Tinggi Evaporator Efek 1)	= 8,99	m	=	29,4899	ft
Elbow 2 ke Elbow 3	= 1,00	m	=	3,2810	ft
Elbow 3 ke Elbow Reaktor	= 1,00	m	=	3,2810	ft
Panjang Total Pipa Lurus	= 12,4881	m	=	40,9734	ft
Panjang Total Pipa Keseluruhan	= 22,7612	m	=	74,6794	ft

Perhitungan Friksi

Friksi karena Gesekan :

$$F_1 = \frac{2\,f \times V^2 \times L_e}{g_C \times D}$$ *(Peters 4th; hal. 484; Tabel 1)*

$$F_2 = \frac{K \times V^2}{2 \times \alpha \times g_C}$$ *(Peters 4th; hal. 484; Tabel 1)*

$$F_3 = \frac{(V_2 - V_1)^2}{2 \times \alpha \times g_C}$$ *(Peters 4th; hal. 484; Tabel 1)*

$$F_4 = n \times Kf \times \underline{V_1^2}$$

$2 \times g_C$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

$$F_5 = n \times K_f \times \frac{V_1^2}{2 \times g_C}$$

(Geankoplis 3rd; hal. 94; eq. 2.10-17)

Keterangan

F_1 = Flow Through long straight pipe

F_2 = Sudden Contraction

F_3 = Sudden Enlargement

F_4 = Losses Fitting - Elbow 90º

F_5 = Losses Fitting - Gate Valve Open

V = Linear Velocity, ft/sec

= 2,7401 ft/sec

α = Correction Coefficient, Viscous (0.5), Turbulen (1.0)

= 1,0 Turbulen (>2100) ***(Peters 4th; hal. 480)***

L = Length of Pipe

= 74,6794 ft

D = Diameter of Pipe

= 3,5480 in = 0,2957 ft

f = Fanning Friction Factor

= 0,0051 ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

g_C = Newton's Law Conversion Factor, ft.lbm / lbf

= 32,17 ft.lbm/lbf

A_1 = Luas Penampang Tangki Pemisah, ft^2

= 55,4990 ft^2

A_2 = Luas Penampang Pipa, ft2

= 0,0686 ft^2

K_C = Coefficient Friction Loss, (untuk $A_2/A_1 < 0.715$)

$$= 0,40 \times \left(1,25 - \frac{A_2}{A_1}\right)$$

= 0,4995 ***(Peters 4th; hal. 484; Tabel 1)***

K_f = Number of Velocity Heads

= Elbow 90º = 0,7500

= Gate Valve Open = 0,1700

(Geankoplis 3rd; hal. 93; Tabel 2.10-1)

F_1 = $2 \times 0,0051 \times (2,7 \text{ ft/sec})^2 \times 74,7 \text{ ft}$

$$\overline{32{,}17 \quad ft.lbm/lbf} \times \overline{3{,}5480 \quad in}$$

$= 0{,}0501 \quad ft.lbf/lbm$

$F_2 = \dfrac{0{,}50 \times (2{,}7 \; ft/sec)^2}{2 \times 1{,}0 \times 32{,}17 \; ft.lbm/lbf}$

$= 0{,}0583 \quad ft.lbf/lbm$

F_3 = Karena A_1 (Tangki) > A_2 (Pipa), Maka $V_1 = 0$

$= \dfrac{(2{,}7 \; ft/sec)^2}{2 \times 1{,}0 \times 32{,}17 \; ft.lbm/lbf}$

$= 0{,}1167 \quad ft.lbf/lbm$

$F_4 = 3 \times 0{,}75 \times \dfrac{(2{,}7 \; ft/sec)^2}{2 \times 32{,}2 \; ft.lbm/lbf}$

$= 0{,}2625 \quad ft.lbf/lbm$

$F_5 = 1 \times 0{,}41 \times \dfrac{(2{,}7 \; ft/sec)^2}{2 \times 32{,}2 \; ft.lbm/lbf}$

$= 0{,}0473 \quad ft.lbf/lbm$

$\sum F = F_1 + F_2 + F_3 + F_4 + F_5$ ***(Geankoplis 3rd; hal. 95)***

$= 0{,}5349 \quad ft.lbf/lbm$

Persamaan Bernoulli

$$z_1 \frac{g}{g_C} + \frac{V_1^2}{2\alpha g_C} + \frac{P_1 - P_2}{\rho_1 - \rho_2} - W_f = z_2 \frac{g}{g_C} + \frac{V_2^2}{2\alpha g_C} + \sum F$$

(Geankoplis 3rd; hal. 95; eq. 2.10-20)

$$-W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

Keterangan :

W_S = Work done by Fluid ***(Geankoplis 3rd; hal. 62)***

z = Vertical Distance, ft

V = Linear Velocity, ft/sec

g = g_C = Gravity Constants

g / g_C = 1 lbf/lbm ***(Peters 4th; hal. 487; ex. 1)***

$\sum F$ = Total Friction Loss, ft.lbf/lbm

= 0,5349 ft.lbf/lbm

ρ = Densitas Campuran, lb/cuft

= 76,5430 lb/cuft

P = Tekanan, Psi

$P_1 = P_1 + P_{\text{Hidrostatis}}$

$= 14{,}7 \text{ Psi} + 6{,}5 \text{ Psi} = 21{,}19 \text{ Psi}$

$P_2 = 14{,}7 \text{ Psi}$

$\Delta P = P_1 - P_2$

$= 21{,}2 \text{ Psi} - 14{,}7 \text{ Psi}$

$= 6{,}5 \text{ Psi}$

$= 934{,}3 \text{ lbf / ft}^2$

$$\frac{\Delta P}{\rho} = \frac{934{,}34 \text{ lbf / ft}^2}{76{,}54 \text{ lb/cuft}}$$

$= 12{,}2067 \text{ ft.lbf / lbm}$

Asumsi:

$z_1 = 29{,}4899 \text{ ft}$

$z_2 = 4{,}9215 \text{ ft}$

$$\Delta z \frac{g}{g_C} = (29{,}5 \text{ ft} - 4{,}9 \text{ ft}) \times 1 \text{ lbf/lbm}$$

$= 24{,}5684 \text{ ft.lbf / lbm}$

$$\frac{\Delta V^2}{2 \times \alpha \times g_C} = \frac{(2{,}7401 \text{ ft/sec})^2}{2 \times 1{,}0 \times 32{,}2 \text{ ft.lbm/lbf}}$$

$= 0{,}1167 \text{ ft.lbf / lbm}$

$$-W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

$= 12{,}21 + 24{,}57 + 0{,}12 + 0{,}53$

$= 37{,}4267 \text{ ft.lbf / lbm}$

Perhitungan Brake Horsepower (BHp)

Untuk Flowrate tersebut, diperoleh efisiensi pompa sebesar:

$\eta_{\text{Pompa}} = 63\%$ ***(Peters 4th; hal. 520; Fig. 14-37)***

$W_S = -\eta \times W_P$ ***(Geankoplis 3rd; hal. 65; eq. 2.7-30)***

$$W_P = \frac{-W_S}{\eta}$$

$$= \frac{37{,}4 \text{ ft.lbf / lbm}}{63\%}$$

$= 59{,}4075 \text{ ft.lbf / lbm}$

$$BHp = \frac{W_P \times \text{Flowrate}}{550}$$ ***(Geankoplis 3rd; hal. 66)***

$$= \frac{59{,}4 \ \text{ft.lbf / lbm} \times 21{,}6 \ \text{lb/sec}}{550}$$

$= 2{,}332$

≈ 3 hp

Perhitungan Power Motor

Untuk BHp tersebut, diperoleh efisiensi motor sebesar:

$\eta_{Motor} = 82\%$ ***(Peters 4th; hal. 521; Fig. 14-38)***

$$hp = \frac{BHp}{\eta_{Motor}}$$

$$= \frac{3 \ \text{hp}}{82\%}$$

$= 3{,}6585$

≈ 4 hp

Spesifikasi Pompa 6

Fungsi	:	Memindahkan Campuran dari Tangki Netralisasi menuju Evaporator Efek Pertama
Tipe	:	Centrifugal Pump
Kecepatan Aliran	:	2,7401 ft/sec = 0,8351 ft/sec
Flowrate	:	0,1880 cuft/s = 84,4008 gal/min
Size Pipa, IPS	:	3 1/2 in
ID Pipa	:	3,5480 in
Schedule	:	No. 40
Efisiensi Pompa	:	63%
Power Pompa	:	3 hp
Efisiensi Motor	:	82%
Power Motor	:	4 hp
Jumlah	:	1 Pompa

24. EVAPORATOR EFEK PERTAMA

Kode Alat	:	V - 310
Fungsi	:	Memekatkan Larutan Pentaeritritol dengan menguapkan Kandungan Air (H_2O)
Tipe	:	Standard Vertical Short-Tube (Calandria) Evaporator

		dengan Tutup Atas dan Bawah Torispherical Dished
Material Konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*
Dasar Pemilihan	:	Umum digunakan untuk pemekatan larutan
Tekanan	:	1 atm
Temperatur	:	100 °C
Waktu Operasi	:	Kontinyu

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4\ (aq)}$	22,36%	5.253,7253	1,0734	1.073,4411	67,015
$Ca(HCOO)_{2(aq)}$	21,36%	5.020,6552	2,0200	2.020,0000	126,11
$H_2O_{(g)}$	53,22%	12.505,7402	1,0229	1.022,8753	63,858
CH_2O	2,47%	579,3182	0,7261	726,0991	45,330
CH_3OH	0,60%	140,9152	0,7827	782,6686	48,862
Total	100%	23.500,3542			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

= 1,199 x 63,8581 lb/cuft

= 76,5430 lb/cuft

Rate Massa = 23.500,3542 kg/jam

= 51.813,5810 lb/jam

$$\text{Rate Volumetrik} = \frac{\text{Rate Massa}}{\rho\ \text{Air}}$$

$$= \frac{51.813,5810\ \text{lb / Jam}}{63,8581\ \text{lb / cuft}}$$

= 811,3862 cuft / Jam

$$\text{sg Bahan} = \frac{\rho\ \text{Bahan}}{\rho\ \text{Reference (Udara)}}$$

$$= \frac{76,5\ \text{lb/cuft}}{63,9\ \text{lb/cuft}}$$

= 1,1986

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi
= 0,9960

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s
= 0,2780 Cps
= 0,0003 Pa.s

(Kern; hal. 823; Fig. 14)

μ Viskositas Bahan = $\dfrac{1{,}1986 \times 0{,}0003 \text{ Pa.s}}{0{,}9960}$
= 0,0003 lb/ft.s
= 0,0005 Ns/m^2
= 0,4979 Cps

Cp Campuran = 0,647 Btu/lb

Heat Balance

Panas yang dibutuhkan : 11.369.138,7590 kJ/Jam
10.776.434,8426 Btu/Jam

Steam yang digunakan : 5.230,5570 kg/Jam
11.533,3782 lb/Jam

Log Mean Temperature Difference (LMTD)

Suhu bahan masuk, t_1 = 70 °C = 158 °F
Suhu bahan keluar, t_2 = 105 °C = 222 °F
Suhu steam masuk, T_1 = 130 °C = 266 °F
Suhu steam kondensat, T_2 = 130 °C = 266 °F

$\Delta T_1 = T_2 - t_1$

$\Delta T_2 = T_1 - t_2$ ***(Kern; hal. 90)***

$\Delta T_1 = 266\ °F - 158\ °F$
$= 108\ °F$

$\Delta T_2 = 266\ °F - 222\ °F$
$= 44\ °F$

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln \dfrac{\Delta T_2}{\Delta T_1}}$$ ***(Kern; hal. 89; eq. 5.14)***

$= 71{,}3812\ °F$

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$ ***(Kern; hal. 142)***

$= \dfrac{266\ °F - 266\ °F}{}$

222 °F - 158 °F

= 0,0000 °F

S = $\frac{t_2 - t_1}{T_1 - t_1}$ ***(Kern; hal. 142)***

= $\frac{222\ °F - 158\ °F}{266\ °F - 158\ °F}$

= 0,5912 °F

F_T = 1,0 ***(Kern; hal. 828; Fig. 18)***

Δt = F_T x LMTD ***(Kern; hal. 149; eq. 7.42)***

= 1 x 71,38 °F

= 71,38 °F

Perhitungan T_C dan t_C dipakai Temperature rata-tata

T_C = $T_{Average}$ Steam ***(Kern; hal. 113)***

= $\frac{158\ °F + 222\ °F}{2}$

= 190 °F

t_C = $t_{Average}$ Bahan ***(Kern; hal. 113)***

= $\frac{266\ °F + 266\ °F}{2}$

= 266 °F

Trial

Asumsi U_D untuk Aqueous Solution (Less than 2.0 Cps)

U_D = 200 - 700 Btu/jam.ft^2.°F

= 700 Btu/jam.ft^2.°F ***(Kern; hal. 840; Tabel. 8)***

A = $\frac{Q}{\Delta t \times U_D}$ ***(Kern; hal. 107; eq. 6.11)***

= $\frac{10.776.434,8426\ \text{Btu/Jam}}{71,4\ °F \times 700\ \text{Btu/jam.ft}^2.°F}$

= 215,6717 ft^2

= 20,0364 m^2

= 31.056,7311 in^2

Digunakan OD pipa 1 1/2 in, sehingga diperoleh:

a" = 0,3925 ft^2/lin ft ***(Kern; hal. 843; Tabel. 10)***

Digunakan panjang pipa:

L = 20 ft = 240 in ***(Kern; hal. 103)***

Number of tubes

$$N_t = \frac{A}{L \times a''}$$

$$= \frac{215{,}6717 \ ft^2}{20 \ ft \times 0{,}3925 \ ft^2/lin \ ft}$$

$$= 27{,}4741 \approx 28$$

Dipilih:

Tube		Shell	
OD	= 1 1/2 in	Pitch	= 1 7/8 in
BWG	= 8	Shell ID	= 29 in
a't	= 1,075 in^2	Passes	= 1
a"	= 0,3925 Surface / lin ft, ft^2	N_t	= 160
Passes	= 2	B Space	= 2 in
ID	= 1,170 in	OD	= 1 1/2 in
Wall Thicness	= 0,165 in		

(Kern; hal. 843; Tabel. 10) ***(Kern; hal. 842; Tabel. 9)***

A baru $= N_t \times L \times a''$ ***(Kern; hal. 308)***

$= 160 \times 20 \ ft \times 0{,}3925$ Surface / lin ft, ft^2

$= 1.256{,}00 \ ft^2$

$= 116{,}69 \ m^2$

Memenuhi untuk Short-Tube Calandria (30 - 300 m^2)

(Ulrich; hal. 94; Tabel 4-7)

$$U_D \text{ baru} = \frac{Q}{A \text{ baru} \times \Delta T_{LMTD}}$$

$$= \frac{10.776.434{,}8426 \ Btu/Jam}{1.256 \ ft^2 \times 71{,}38 \ °F}$$

$$= 120{,}1992 \ Btu/jam.ft^2.°F$$

Hot Fluid (Tube)	**Cold Fluid (Shell)**
Steam	**Larutan Pentaeritritol**
(4) Flow Area Tube (a_t)	(4') Flow Area Shell (a_s)
$a_t = \frac{Nt \times a't}{144 \times n}$	C" = Pitch - OD
	= 2 in - 1 1/2 in
$= \frac{160 \times 1{,}1}{144 \times 2}$	= 3/8 in
	B = ID = 29

$= 0,5972\ ft^2$

$= \frac{\dots}{5}$

$= 6$ in

$a_s = \frac{ID \times C'' \times B}{144\ Pr}$

$= \frac{29\ in \times 3/8\ in \times 6\ in}{144 \times 2\ in}$

$= 0,2336\ ft^2$

(5) Mass Velocity Tube (Gt)

$G_t = \frac{W_{steam}}{a_t}$

$= \frac{51.813,6\ lb/Jam}{0,5972\ ft^2}$

$= 86.757,62\ lb/Jam.ft^2$

(6) Pada $t_C = 266,0$ °F

$\mu = 0,0141$ cps

$= 0,0341$ lbm/Jam.ft

(Kern; hal. 825; Fig. 15)

$D_i = 1,17$ in

$= 0,0975$ ft

$Re_t = \frac{D \times G_t}{\mu}$

$= \frac{0,10\ ft \times 86.758\ lb/Jam.ft^2}{0,0341\ lbm/Jam.ft}$

$= 247.900,7191$

(7) Heat Transfer Factor

$j_H = 500$

(Kern; hal. 834; Fig. 24)

(8) Konduktivitas Thermal pada t_C

$k = 0,0133$ Btu/Jam.ft^2.°F

(Yaws; hal.551; Tabel 24-2)

$Cp = 0,45$ Btu/lb°F

(Kern; hal. 805; Fig. 3)

(5) Mass Velocity Shell (Gs)

$G_s = \frac{W_{bahan}}{a_s}$

$= \frac{11.533,4\ lb/Jam}{0,2336\ ft^2}$

$= 49.369,9901\ lb/Jam.ft^2$

(6') Pada $T_C = 189,9$ °F

$\mu = 0,4979$ cps

$= 1,2049$ lbm/Jam.ft

$D_e = 0,73$ in

$= 0,0608$ ft

$Re_s = \frac{D_e \times G_s}{\mu}$

$= \frac{0,06\ ft \times 49.370\ lb/Jam.ft^2}{1,2049\ lbm/Jam.ft}$

$= 2.492,6638$

(7') Heat Transfer Factor

$j_H = 30$

(Kern; hal. 838; Fig. 28)

(8') Konduktivitas Thermal pada t_C

$k = 0,9892$ Btu/Jam.ft^2.°F

(Yaws; Tabel 24)

$Cp = 0,65$ Btu/lb°F

$\left(\frac{Cp \times \mu}{k}\right)^{1/3} = 1{,}0489$	$\left(\frac{Cp \times \mu}{k}\right)^{1/3} = 0{,}9239$
(9) Condensation of Steam $h_{io} = 1500$ Btu/Jam.ft^2.°F ***(Kern; hal. 164)***	(9') Condensation of Steam $h_o = j_H \frac{k}{D_e} \left(\frac{Cp \times \mu}{k}\right)^{1/3} \varphi_s$ ***(Kern; hal. 112; eq. 6.15b)*** $= 475{,}1321$ Btu/Jam.ft^2.°F
(10) Pada $t_w = 208{,}2234$ °F $\mu_w = 0{,}4979$ Cps $= 1{,}2049$ lbm/Jam.ft $\varphi_t = \left(\frac{\mu}{\mu_w}\right)^{0,14}$ $= \left(\frac{0{,}0341 \text{ °F}}{1{,}2049 \text{ °F}}\right)^{0,14}$ $= 0{,}6071$ Btu/Jam.ft^2.°F	(10') Tube Wall Temperature $t_w = t_c + \frac{h_{io}}{h_{io} + h_o} (T_c - t_c)$ $= 208{,}2234$ °F
(12) Corrected Coefficient $h_{io} = \frac{h_{io}}{\varphi_t} \times \varphi_t$ ***(Kern; hal. 121; eq. 6.37)*** $= 1500{,}0000$ Btu/Jam.ft^2.°F	

(13) Clean Overall Coefficient

$$U_C = \frac{h_{io} \times h_o}{h_{io} + h_o}$$ ***(Kern; hal. 121; eq. 6.38)***

$$= \frac{1.500{,}0 \text{ Btu/jam.ft}^2\text{.°F} \times 475{,}1321}{1.500{,}0 \text{ Btu/jam.ft}^2\text{.°F} + 475{,}1321}$$

$$= 360{,}8357 \text{ Btu/jam.ft}^2\text{.°F}$$

(14) Dirt Factor, Rd

$$R_d = \frac{U_C - U_D}{U_C \times U_D}$$ ***(Kern; hal. 108; eq. 6.13)***

$$= \frac{360{,}8 \text{ Btu/jam.ft}^2\text{.°F} - 120{,}2 \text{ Btu/jam.ft}^2\text{.°F}}{360{,}8 \text{ Btu/jam.ft}^2\text{.°F} \times 120{,}2 \text{ Btu/jam.ft}^2\text{.°F}}$$

= 0,0055

Untuk R_d data, digunakan "Brackish Water" atau Air Payau dengan R_d

R_d data = 0,002 - 0,001 ***(Kern; hal. 845; Tabel 12)***

R_d perhitungan > R_d data

0,006 > 0,002

Maka, desain dapat digunakan

Hot Fluid	**Cold Fluid**
Steam	**Larutan Pentaeritritol**
Pressure Drop	
(a) Untuk Re_t = 247.900,7191	(a') Untuk Re_s = 2.492,6638
f = 0,0001	f = 0,0025
(Kern; hal. 836; Fig. 26)	***(Kern; hal. 839; Fig. 29)***
s = 1,0000	s = 1,1986
(Kern; hal. 808; Tabel. 6)	
	(b') Number of times fluid crosses
	$N+1 = \frac{\text{Tube Length}}{\text{Baffle Space}} = \frac{12 \times L}{B}$
	(Kern; hal. 147; eq. 7.43)
	$= \frac{240 \text{ in}}{6 \text{ in}}$
	= 240
(c) Pressure drop in Tube or Pipes	(c') Pressure drop in Shell side
$\Delta P_t = \frac{1}{2} \times \frac{f \times G_t^2 \times L \times n}{5.22 \times 10^{10} \times D_i \times s}$	$\Delta P_s = \frac{1}{2} \times \frac{f \times G_s^2 \times D_s (N+1)}{5.22 \times 10^{10} \times D_e \times s}$
(Kern; hal. 273; eq. 12.48)	***(Kern; hal. 273; eq. 12.47)***
$= \frac{33.870.983,9}{5.089.500.000}$	$= \frac{88.964.951}{3.806.286.443}$
= 0,0033 Psi	= 0,0117 Psi
ΔP_t < 10 psi	ΔP_s < 10 psi
(memenuhi)	(memenuhi)

Perhitungan Dimensi Evaporator

Tinggi (H) = 3 Diameter (D) ***(Ulrich; hal. 94; Tabel 4-7)***

$V_S = \frac{1}{4} \pi D^2 H$

$V_S = \frac{3{,}14}{4} \times 2 \times Ds^3$

$V_S = 1{,}57\ Ds^3$

V tutup torispherical dish = $0{,}000049\ Ds^3$

(Brownell; hal. 88; eq. 5.11)

Volume Tangki = $V_S + 2\ V_{tutup}$

1.014,2327 cuft = $1{,}57\ Ds^3 + 0{,}000098\ Ds^3$

1.014,2327 cuft = $1{,}57\ Ds^3$

Ds^3 = 645,9678 cuft

Ds = 8,6444 ft = 103,7333 in = 2,6348 m

Hs = 25,9333 ft = 311,1999 in = 7,9045 m

Perhitungan Tinggi Komponen

Volume Bahan = $\frac{1}{4} \pi\ Ds^2\ H_{liq}$

811,3862 cuft = $\frac{3{,}14}{4} \times 8{,}6444^2 \times H_{liq}$

H_{liq} = 13,8320 ft = 165,9836 in = 4,2160 m

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

P = 1 atm = 14,6959 Psi

P_{Inside} = 14,6959 Psi

$P_{Outside}$ = 14,6959 Psi

$P_{Design} = P_{Inside} - P_{Outside} + P_{Hidrostatis}$

= 14,7 Psi - 14,7 Psi + $P_{Hidrostatis}$

$P_{Design} = P_{Hidrostatis}$

$P_{Hidrostatis} = \rho\ \text{Campuran} \times \frac{g}{gc} \times H_{liq}$

= 76,5430 lbm/cuft x 1 lbf/lbm x 13,8320 ft

= 1.058,7402 lb/ft^2

= 7,3582 Psi

P_{Design} dibuat berlebih 10% (faktor keamanan)

P_{Design} = 1,1 x 7,3582 Psi

= 8,0941 Psi

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

t_{min} = Tebal Shell Minimum (in)

P = Tekanan Tangki (Psi)

ri = Jari - jari Tangki (in) (1/2 D)

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, bahan konstruksi *Carbon Steel SA - 283 Grade C*

= 12.650 ***(Brownell; hal. 342; App. D, Item 4)***

$$t_{min} = \frac{8{,}0941 \text{ Psi} \times 51{,}8667 \text{ in}}{10.120 \text{ Psi} - 4{,}8564 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{419{,}8122}{10.115{,}1436} + 0{,}125 \text{ in}$$

= 0,1665 in

= (Digunakan t_S = $\frac{3}{8}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Shell

$$\frac{3}{8} \text{ in} = \frac{8{,}0941 \text{ Psi} \times 51{,}8667 \text{ in}}{f \times 0{,}80 - 4{,}8564 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 2.105,1317 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tebal tutup

Tutup atas berbentuk Torispherical Dished Head

OD = ID + (2 t_S)

= 103,7333 in + 2 x 0,38

= 104,4833 in = 8,7069 ft

= (Digunakan OD = 108 in)

(Brownell; hal.91; Tabel 5.7)

Diperoleh:

icr = 6,50 in = 0,5415 ft

r_C = 102 in = 8,4966 ft

Cek nilai icr dengan 6% rc:

icr = 6,50 in

6% rc = 6,12 in

karena nilai icr > 6% rc, maka menggunakan persamaan

$$t = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$ ***(Brownell; hal.138; eq. 7.77)***

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

(Brownell; hal.138; eq. 7.76)

Keterangan:

W = Faktor Stress

Pd = Tekanan design (P_{Design})

r_C = Radius Crown

r_1 or icr = Inside Crown Radius

E = Faktor Pengelasan = 0,80

t = Tebal dinding minimal

f = Stress Allowable, bahan konstruksi *Carbon Steel SA - 283 Grade C*

= 12.650 Psi ***(Brownell; hal. 251; Tabel 13-1)***

C = Faktor Korosi (in) = 0,125 in

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

$$= \frac{1}{4}\left(3 + \sqrt[2]{(102\ \text{in} / 7\ \text{in})}\right)$$

$$= 1{,}7403$$

$$t_{Head} = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$

$$= \frac{8{,}0941\ \text{Psi} \times 102\ \text{in} \times 1{,}7403}{25.300\ \text{Psi} \times 0{,}8 - 1{,}6188\ \text{Psi}} + 0{,}125\ \text{in}$$

$$= 0{,}1960\ \text{in}$$

$$= (\text{Digunakan } t = \frac{3}{8}\ \text{in})$$

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Head

$$\frac{3}{8}\ \text{in} = \frac{8{,}0941\ \text{Psi} \times 177{,}5145\ \text{in}}{2\ f \times 0{,}80 - 1{,}6188\ \text{Psi}} + 0{,}125\ \text{in}$$

$$f = 3.593{,}0476\ \text{Psi} < f_{Allowable}\ \text{(memenuhi)}$$

Perhitungan tinggi tutup atas:

Di = 103,7333 in

$a = \dfrac{Di}{2}$

$= \dfrac{103{,}7333 \text{ in}}{2}$

$= 51{,}8667$ in

icr = 6,50 in

r_C = 102 in **(Brownell; hal. 91; Tabel 5.7)**

$AB = \dfrac{Di}{2} - icr$

$= \dfrac{103{,}7333 \text{ in}}{2} - 6{,}5000 \text{ in}$

$= 45{,}3667$ in

BC $= r_C - icr$

= 102 in - 6,50 in

= 95,5000 in

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

= √ (9.120,2500 in - 2.058,1329 in)

= 84,0364 in

b $= r_C - AC$

= 102 in - 84,0364 in

= 17,9636 in

sf = 3 in **(Brownell; hal. 93; Tabel 5.8)**

t_{Head} = 0,3750 in

OA $= t_{Head} + b + sf$

= 0,3750 in + 17,9636 in + 3 in

= 21,3386 in

Maka, tinggi tutup atas = 21,3386 in

= 0,5420 m

Spesifikasi Evaporator Efek Pertama

Fungsi	:	Memekatkan Larutan Pentaeritritol dengan menguapkan Kandungan Air (H2O)
Tipe	:	Standard Vertical Short-Tube (Calandria) Evaporator dengan Tutup Atas dan Bawah Torispherical Dished

Material Konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*				
Tube						
Inside Diameter	:	1,17	in	=	0,0297	m
Outside Diameter	:	1 1/2	in	=	0,0381	m
Panjang	:	20	ft	=	6,0957	m
Jumlah Tube	:	160	buah			
Shell						
DI Evaporator	:	8,6444	ft	=	2,6347	m
DO Evaporator	:	8,7069	ft	=	2,6537	m
Tinggi Shell	:	25,9333	ft	=	7,9041	m
Tebal Shell	:	3/8	in	=	0,0095	m
Tutup						
Tebal Tutup Atas	:	3/8	in	=	0,0095	m
Tebal Tutup Bawa	:	3/8	in	=	0,0095	m
Tinggi Tutup Atas	:	21,3386	in	=	0,5420	m
Tinggi Tutup Bawah	:	21,3386	in	=	0,5420	m
Jumlah	:	1	Unit			

25. EVAPORATOR EFEK KEDUA

Kode Alat	:	V - 320
Fungsi	:	Memekatkan Larutan Pentaeritritol dengan menguapkan Kandungan Air (H_2O)
Tipe	:	Standard Vertical Short-Tube (Calandria) Evaporator dengan Tutup Atas dan Bawah Torispherical Dished
Material Konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*
Dasar Pemilihan	:	Umum digunakan untuk pemekatan larutan
Tekanan	:	0,3 atm
Temperatur	:	79 °C
Waktu Operasi	:	Kontinyu

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4\ (aq)}$	27,56%	5.253,7253	1,0734	1.073,4411	67,015
$Ca(HCOO)_{2(aq)}$	26,34%	5.020,6552	2,0200	2.020,0000	126,11
$H_2O_{(g)}$	43,65%	8.321,2659	1,0229	1.022,8753	63,858

CH2O	1,98%	376,5569	0,7261	726,0991	45,330
CH3OH	0,48%	91,5949	0,7827	782,6686	48,862
Total	100%	19.063,7982			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

= 1,229 x 63,8581 lb/cuft

= 78,4649 lb/cuft

Rate Massa = 19.063,7982 kg/jam

= 42.031,8622 lb/jam

$$\text{Rate Volumetrik} = \frac{\text{Rate Massa}}{\rho \text{ Air}}$$

$$= \frac{42.031,8622 \text{ lb / Jam}}{63,8581 \text{ lb / cuft}}$$

= 658,2072 cuft / Jam

$$\text{sg Bahan} = \frac{\rho \text{ Bahan}}{\rho \text{ Reference (Udara)}}$$

$$= \frac{78,5 \text{ lb/cuft}}{63,9 \text{ lb/cuft}}$$

= 1,2287

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi

= 0,9960

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s

= 0,2780 Cps

= 0,0003 Pa.s

(Kern; hal. 823; Fig. 14)

$$\mu \text{ Viskositas Bahan} = \frac{1,2287 \times 0,0003 \text{ Pa.s}}{0,9960}$$

= 0,0003 lb/ft.s

= 0,0005 Ns/m^2

= 0,5104 Cps

Cp Campuran = 0,578 Btu/lb

Heat Balance

Panas yang dibutuhkan : 11.355.275,9653 kJ/Jam

10.763.294,7539 Btu/Jam

Steam yang digunakan : 5.043,2030 kg/Jam
11.120,2627 lb/Jam

Log Mean Temperature Difference (LMTD)

Suhu bahan masuk, t_1 = 105 °C = 222 °F
Suhu bahan keluar, t_2 = 79 °C = 175 °F
Suhu steam masuk, T_1 = 104 °C = 219 °F
Suhu steam kondensat, T_2 = 104 °C = 219 °F

$\Delta T_1 = T_2 - t_2$

$\Delta T_2 = T_1 - t_1$ ***(Kern; hal. 90)***

ΔT_1 = 219 °F - 175 °F
= 44 °F

ΔT_2 = 219 °F - 222 °F
= 3 °F

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}$$ ***(Kern; hal. 89; eq. 5.14)***

= 15,0454 °F

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$ ***(Kern; hal. 142)***

$$= \frac{219\ °F - 219\ °F}{175\ °F - 222\ °F}$$

= 0,0000 °F

$$S = \frac{t_2 - t_1}{T_1 - t_1}$$ ***(Kern; hal. 142)***

$$= \frac{175\ °F - 222\ °F}{219\ °F - 222\ °F}$$

= 16,5883 °F

F_T = 1,0 ***(Kern; hal. 828; Fig. 18)***

Δt = F_T x LMTD ***(Kern; hal. 149; eq. 7.42)***
= 1 x 15,05 °F
= 15,05 °F

Perhitungan T_C dan t_C dipakai Temperature rata-tata

T_C = $T_{Average}$ Steam ***(Kern; hal. 113)***

$$= \frac{222\ °F + 175\ °F}{2}$$

= 198 °F

t_C = $t_{Average}$ Bahan *(Kern; hal. 113)*

$$= \frac{219\ °F + 219\ °F}{2}$$

= 219 °F

Trial

Asumsi U_D untuk Aqueous Solution (Less than 2.0 Cps)

U_D = 200 - 700 Btu/jam.ft^2.°F

= 700 Btu/jam.ft^2.°F *(Kern; hal. 840; Tabel. 8)*

$$A = \frac{Q}{\Delta t \times U_D}$$ *(Kern; hal. 107; eq. 6.11)*

$$= \frac{10.763.294,7539\ \text{Btu/Jam}}{15,0\ °F \times 700\ \text{Btu/jam.ft}^2.°F}$$

= 1.021,9796 ft^2

= 94,9442 m^2

= 147.165,0637 in^2

Digunakan OD pipa 1 1/2 in, sehingga diperoleh:

a" = 0,3925 ft^2/lin ft *(Kern; hal. 843; Tabel. 10)*

Digunakan panjang pipa:

L = 40 ft = 480 in *(Kern; hal. 103)*

Number of tubes

$$N_t = \frac{A}{L \times a''}$$

$$= \frac{1.021,9796\ ft^2}{40\ ft \times 0,3925\ ft^2/\text{lin ft}}$$

= 65,0942 ≈ 66

Dipilih:

Tube		Shell	
OD	= 1 1/2 in	Pitch	= 1 7/8 in
BWG	= 8	Shell ID	= 37 in
a't	= 1,075 in^2	Passes	= 1
a"	= 0,3925 Surface / lin ft, ft^2	N_t	= 275
		B Space	= 2 in
Passes	= 2	OD	= 1 1/2 in
ID	= 1,170 in		

Wall Thicness = 0,165 in	
(Kern; hal. 843; Tabel. 10)	***(Kern; hal. 842; Tabel. 9)***

A baru = N_t x L x a" ***(Kern; hal. 308)***
= 275 x 40 ft x 0,3925 Surface / lin ft, ft^2
= 4.317,50 ft^2
= 401,1055 m^2

Memenuhi untuk Short-Tube Calandria (30 - 300 m^2)
(Ulrich; hal. 94; Tabel 4-7)

$$U_D \text{ baru} = \frac{Q}{A \text{ baru} \times \Delta T_{LMTD}}$$
$$= \frac{10.763.294,7539 \text{ Btu/Jam}}{4.318 \text{ ft}^2 \times 15,05 \text{ °F}}$$
$$= 165,6944 \text{ Btu/jam.ft}^2.\text{°F}$$

Hot Fluid (Tube)	Cold Fluid (Shell)
Steam	**Larutan Pentaeritritol**
(4) Flow Area Tube (a_t)	(4') Flow Area Shell (a_s)
$a_t = \frac{Nt \times a't}{144 \times n}$	C" = Pitch - OD
$= \frac{275 \times 1,1}{144 \times 2}$	= 2 in - 1 1/2 in
= 1,0265 ft^2	= 3/8 in
	B = ID = $\frac{37}{5}$
	= 7 in
	$a_s = \frac{ID \times C" \times B}{144 \ Pr}$
	$= \frac{37 \text{ in} \times 3/8 \text{ in} \times 7 \text{ in}}{144 \times 2 \text{ in}}$
	= 0,3803 ft^2
(5) Mass Velocity Tube (Gt)	(5) Mass Velocity Shell (Gs)
$G_t = \frac{W_{steam}}{a_t}$	$G_s = \frac{W_{bahan}}{a_s}$
$= \frac{42.031,9 \text{ lb/Jam}}{1,0265 \text{ ft}^2}$	$= \frac{11.120,3 \text{ lb/Jam}}{0,3803 \text{ ft}^2}$
= 40.947,74 lb/Jam.ft^2	= 29.242,4731 lb/Jam.ft^2

(6) Pada t_C = 219,0 °F

μ = 0,0141 cps
= 0,0341 lbm/Jam.ft

(Kern; hal. 825; Fig. 15)

D_i = 1,17 in
= 0,0975 ft

$$Re_t = \frac{D \times G_t}{\mu}$$

$$= \frac{0{,}10 \text{ ftx } 40.948 \text{ lb/Jam.ft}^2}{0{,}0341 \text{ lbm/Jam.ft}}$$

= 117.003,8356

(7) Heat Transfer Factor

j_H = 250

(Kern; hal. 834; Fig. 24)

(8) Konduktivitas Thermal pada t_C

k = 0,0133 Btu/Jam.ft^2.°F

(Yaws; hal.551; Tabel 24-2)

Cp = 0,45 Btu/lb°F

(Kern; hal. 805; Fig. 3)

$$\left(\frac{Cp \times \mu}{k}\right)^{1/3} = 1{,}0489$$

(9) Condensation of Steam

h_{io} = 1500 Btu/Jam.ft^2.°F

(Kern; hal. 164)

(10) Pada t_w = 201,9242 °F

μ_w = 0,5104 Cps
= 1,2351 lbm/Jam.ft

$$\varphi = \left(\frac{\mu}{\ }\right)^{0,14}$$

(6') Pada T_C = 198,4 °F

μ = 0,5104 cps
= 1,2351 lbm/Jam.ft

D_e = 0,73 in
= 0,0608 ft

$$Re_s = \frac{D_e \times G_s}{\mu}$$

$$= \frac{0{,}06 \text{ ft x } 29.242 \text{ lb/Jam.ft}^2}{1{,}2351 \text{ lbm/Jam.ft}}$$

= 1.440,2718

(7') Heat Transfer Factor

j_H = 20

(Kern; hal. 838; Fig. 28)

(8') Konduktivitas Thermal pada t_C

k = 0,9892 Btu/Jam.ft^2.°F

(Yaws; Tabel 24)

Cp = 0,58 Btu/lb°F

$$\left(\frac{Cp \times \mu}{k}\right)^{1/3} = 0{,}8971$$

(9') Condensation of Steam

$$h_o = j_H \frac{k}{D_e} \left(\frac{Cp \times \mu}{k}\right)^{1/3} \varphi_s$$

(Kern; hal. 112; eq. 6.15b)

= 313,6657 Btu/Jam.ft^2.°F

(10') Tube Wall Temperature

$$t_w = t_c + \frac{h_{io}}{h_{io} + h_o} (T_c - t_c)$$

= 201,9242 °F

$\varphi_t = (\frac{\mu}{\mu_w})$

$= (\frac{0{,}0341 \ °F}{1{,}2351 \ °F})^{0,14}$

$= 0{,}6050$ Btu/Jam.ft^2.°F

(12) Corrected Coefficient

$h_{io} = \frac{h_{io}}{\varphi_t} \times \varphi_t$

(Kern; hal. 121; eq. 6.37)

$= 1500{,}0000$ Btu/Jam.ft^2.°F

(13) Clean Overall Coefficient

$U_C = \frac{h_{io} \times h_o}{h_{io} + h_o}$ ***(Kern; hal. 121; eq. 6.38)***

$= \frac{1.500{,}0 \text{ Btu/jam.ft}^2\text{.°F} \times 313{,}6657}{1.500{,}0 \text{ Btu/jam.ft}^2\text{.°F} + 313{,}6657}$

$= 259{,}4185$ Btu/jam.ft^2.°F

(14) Dirt Factor, Rd

$R_d = \frac{U_C - U_D}{U_C \times U_D}$ ***(Kern; hal. 108; eq. 6.13)***

$= \frac{259{,}4 \text{ Btu/jam.ft}^2\text{.°F} - 165{,}7 \text{ Btu/jam.ft}^2\text{.°F}}{259{,}4 \text{ Btu/jam.ft}^2\text{.°F} \times 165{,}7 \text{ Btu/jam.ft}^2\text{.°F}}$

$= 0{,}0022$

Untuk R_d data, digunakan "Brackish Water" atau Air Payau dengan R_d

R_d data = 0,002 - 0,001 ***(Kern; hal. 845; Tabel 12)***

R_d perhitungan > R_d data

0,0022 > 0,0020

Maka, desain dapat digunakan

Hot Fluid	Cold Fluid
Steam	**Larutan Pentaeritritol**
Pressure Drop	
(a) Untuk Re_t = 117.003,8356 f = 0,0001 ***(Kern; hal. 836; Fig. 26)*** s = 1,0000	(a') Untuk Re_s = 1.440,2718 f = 0,0035 ***(Kern; hal. 839; Fig. 29)*** s = 1,2287

(Kern; hal. 808; Tabel. 6)	(b') Number of times fluid crosses $N+1 = \frac{\text{Tube Length}}{\text{Baffle Space}} = \frac{12 \times L}{B}$ ***(Kern; hal. 147; eq. 7.43)*** $= \frac{480 \text{ in}}{7 \text{ in}}$ $= 240$
(c) Pressure drop in Tube or Pipes $\Delta P_t = \frac{1}{2} \times \frac{f \times G_t^2 \times L \times n}{5.22 \times 10^{10} \times D_i \times s}$ ***(Kern; hal. 273; eq. 12.48)*** $= \frac{15.090.458,4}{5.089.500.000}$ $= 0,0015$ Psi $\Delta P_t < 10$ psi (memenuhi)	(c') Pressure drop in Shell side $\Delta P_s = \frac{1}{2} \times \frac{f \times G_s^2 \times D_s (N+1)}{5.22 \times 10^{10} \times D_e \times s}$ ***(Kern; hal. 273; eq. 12.47)*** $= \frac{43.696.746}{3.901.860.896}$ $= 0,0056$ Psi $\Delta P_s < 10$ psi (memenuhi)

Perhitungan Dimensi Evaporator

Tinggi (H) = 3 Diameter (D) ***(Ulrich; hal. 94; Tabel 4-7)***

$V_S = \frac{1}{4} \pi D^2 H$

$V_S = \frac{3,14}{4} \times 2 \times Ds^3$

$V_S = 1,57 \ Ds^3$

V tutup torispherical dish = $0,000049 \ Ds^3$

(Brownell; hal. 88; eq. 5.11)

Volume Tangki = $V_S + 2 V_{tutup}$

822,7590 cuft = $1,57 \ Ds^3 + 0,000098 \ Ds^3$

822,7590 cuft = $1,57 \ Ds^3$

Ds^3 = 524,0176 cuft

Ds = 8,0621 ft = 96,7453 in = 2,4573 m

Hs = 24,1863 ft = 290,2359 in = 7,3720 m

Perhitungan Tinggi Komponen

Volume Bahan = $\frac{1}{} \pi \ Ds^2 \ H$

$$658{,}2072 \text{ cuft} = \frac{3{,}14}{4} \times 8{,}0621^2 \times H_{liq}$$

H_{liq} = 12,9002 ft = 154,8021 in = 3,9320 m

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

P = 1 atm = 14,6959 Psi

P_{Inside} = 14,6959 Psi

$P_{Outside}$ = 14,6959 Psi

P_{Design} = P_{Inside} - $P_{Outside}$ + $P_{Hidrostatis}$

= 14,7 Psi - 14,7 Psi + $P_{Hidrostatis}$

P_{Design} = $P_{Hidrostatis}$

$$P_{Hidrostatis} = \rho \text{ Campuran} \times \frac{g}{gc} \times H_{liq}$$

= 78,4649 lbm/cuft x 1 lbf/lbm x 12,9002 ft

= 1.012,2118 lb/ft^2

= 7,0349 Psi

P_{Design} dibuat berlebih 10% (faktor keamanan)

P_{Design} = 1,1 x 7,0349 Psi

= 7,7384 Psi

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

t_{min} = Tebal Shell Minimum (in)

P = Tekanan Tangki (Psi)

ri = Jari - jari Tangki (in) (1/2 D)

E = Faktor Pengelasan (digunakan double) = 0,80

C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in

f = Stress Allowable, bahan konstruksi *Carbon Steel SA - 283 Grade C*

= 12.650 ***(Brownell; hal. 342; App. D, Item 4)***

$$t_{min} = \frac{7{,}7384 \text{ Psi} \times 48{,}3726 \text{ in}}{10.120 \text{ Psi} - 4{,}6430 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{374{,}3249}{\quad} + 0{,}125 \text{ in}$$

10.115,3570 ... 0,125 in

= 0,1620 in

= (Digunakan t_S = $\frac{5}{16}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Shell

$$\frac{5}{16} \text{ in} = \frac{7{,}7384 \text{ Psi} \times 48{,}3726 \text{ in}}{f \times 0{,}80 - 4{,}6430 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 2.501,3033 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tebal tutup

Tutup atas berbentuk Torispherical Dished Head

OD = ID + (2 t_S)

= 96,7453 in + 2 x 0,31

= 97,3703 in = 8,1142 ft

= (Digunakan OD = 102 in)

(Brownell; hal.91; Tabel 5.7)

Diperoleh:

icr = 6,13 in = 0,5102 ft

r_C = 96 in = 7,9968 ft

Cek nilai icr dengan 6% rc:

icr = 6,13 in

6% rc = 5,76 in

karena nilai icr > 6% rc, maka menggunakan persamaan

$$t = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$

(Brownell; hal.138; eq. 7.77)

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)} \right)$$

(Brownell; hal.138; eq. 7.76)

Keterangan:

W = Faktor Stress

Pd = Tekanan design (P_{Design})

r_C = Radius Crown

r_1 or icr = Inside Crown Radius

E = Faktor Pengelasan = 0,80

t = Tebal dinding minimal

f = Stress Allowable, bahan konstruksi *Carbon Steel SA - 283 Grade C*

= 12.650 Psi ***(Brownell; hal. 251; Tabel 13-1)***

C = Faktor Korosi (in) = 0,125 in

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

$$= \frac{1}{4}\left(3 + \sqrt[2]{(96 \text{ in} / 6 \text{ in})}\right)$$

$$= 1{,}7397$$

$$t_{Head} = \frac{Pd \times r_C \times W}{2f\,E - 0{,}2\,Pd} + C$$

$$= \frac{7{,}7384 \text{ Psi} \times 96 \text{ in} \times 1{,}7397}{25.300 \text{ Psi} \times 0{,}8 - 1{,}5477 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= 0{,}1889 \text{ in}$$

= (Digunakan t = $\frac{5}{16}$ in)

(Brownell; hal. 89; Tabel 5.7)

Perhitungan Koreksi Stress Allowable Head

$$\frac{5}{16} \text{ in} = \frac{7{,}7384 \text{ Psi} \times 167{,}0154 \text{ in}}{2\,f \times 0{,}80 - 1{,}5477 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 4.309,0501 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tinggi tutup atas:

Di = 96,7453 in

$$a = \frac{Di}{2}$$

$$= \frac{96{,}7453 \text{ in}}{2}$$

$$= 48{,}3726 \text{ in}$$

icr = 6,13 in

r_C = 96 in ***(Brownell; hal. 91; Tabel 5.7)***

$$AB = \frac{Di}{2} - icr$$

$$= \frac{96{,}7453 \text{ in}}{2} - 6{,}1250 \text{ in}$$

$$= 42{,}2476 \text{ in}$$

BC = r_C - icr
= 96 in - 6,13 in
= 89,8750 in
AC = $\sqrt{(BC^2) - (AB^2)}$
= √ (8.077,5156 in - 1.784,8639 in)
= 79,3262 in
b = r_C - AC
= 96 in - 79,3262 in
= 16,6738 in
sf = 3 in **(*Brownell; hal. 93; Tabel 5.8*)**
t_{Head} = 0,3125 in
OA = t_{Head} + b + sf
= 0,3125 in + 16,6738 in + 3 in
= 19,9863 in
Maka, tinggi tutup atas = 19,9863 in
= 0,5077 m

Spesifikasi Evaporator Efek Kedua

Fungsi	:	Memekatkan Larutan Pentaeritritol dengan menguapkan Kandungan Air (H_2O)
Tipe	:	Standard Vertical Short-Tube (Calandria) Evaporator dengan Tutup Atas dan Bawah Torispherical Dished
Material Konstruksi	:	*Stainless Steel 316 SA-167, Grade 11*

Tube

Inside Diameter	:	1,17	in	=	0,0297	m
Outside Diameter	:	1 1/2	in	=	0,0381	m
Panjang	:	40	ft	=	12,1914	m
Jumlah Tube	:	275	buah			

Shell

DI Evaporator	:	8,0621	ft	=	2,4572	m
DO Evaporator	:	8,1142	ft	=	2,4731	m
Tinggi Shell	:	24,1863	ft	=	7,3716	m
Tebal Shell	:	1/3	in	=	0,0079	m

Tutup

Tebal Tutup Atas	:	1/3	in	=	0,0079	m

Tebal Tutup Bawa : 1/3 in = 0,0079 m
Tinggi Tutup Atas : 19,9863 in = 0,5077 m
Tinggi Tutup Bawah : 19,9863 in = 0,5077 m
Jumlah : 1 Unit

26. KONDENSOR

Kode Alat : E - 321
Fungsi : Merubah Fase Uap Air menjadi cair dengan Menurunkan Suhu
Tipe : Barometric Kondensor
Dasar Pemilihan : Umum digunakan untuk proses perpindahan panas
Tekanan : 0,3 atm
Temperatur : 45 °C
Waktu Operasi : Kontinyu

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m³)	ρ (lb/ft³)
$H_2O_{(g)}$	94%	4.184,4743	1,0229	1.022,8753	63,858
CH_2O	5%	202,7614	0,7261	726,0991	45,330
CH_3OH	1%	49,3203	0,7827	782,6686	48,862
Total	100%	4.436,5560			

$V_{Spesifik}$ Steam = 62,06 cuft/lb pada 170°F
= 0,0161 lb/cuft

(Badger; hal. 733, App. 9)

Rate Massa = 4.436,5560 kg/jam
= 9.781,7187 lb/jam

Rate Volumetrik = $\frac{\text{Rate Massa}}{\rho \text{ Air}}$

= $\frac{9.781,7187 \text{ lb / Jam}}{0,0161 \text{ lb / cuft}}$

= 607.053,4653 cuft / Jam

sg Bahan = $\frac{\rho \text{ Bahan}}{\rho \text{ Reference (Udara)}}$

= $\frac{62,1 \text{ lb/cuft}}{62,1 \text{ lb/cuft}}$

= 1,0000

Viskositas Uap Air = 0,0110 Cps

(Kern; hal. 825; Fig. 15)

Heat Balance

Panas yang diserap	:	40.142,3712	kJ/Jam
		38.049,6409	Btu/Jam
Pendingin yang digunaka	:	640,2292	kg/Jam
		1.411,7054	lb/Jam

Log Mean Temperature Difference (LMTD)

Suhu Air Pendingin $_{in}$, T_1	=	30	°C	=	86	°F
Suhu Air Pendingin $_{Out}$, T_2	=	45	°C	=	113	°F
Suhu bahan masuk, t_1	=	77	°C	=	171	°F
Suhu banah keluar, t_2	=	46	°C	=	115	°F

$\Delta T_1 = T_2 - t_2$

$\Delta T_2 = T_1 - t_1$ ***(Kern; hal. 90)***

$\Delta T_1 = 115\ °F - 113\ °F$

$= 2\ °F$

$\Delta T_2 = 171\ °F - 86\ °F$

$= 85\ °F$

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}$$ ***(Kern; hal. 89; eq. 5.14)***

$= 21,5057\ °F$

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$ ***(Kern; hal. 142)***

$$= \frac{171\ °F - 115\ °F}{113\ °F - 86\ °F}$$

$= 2,0667\ °F$

$$S = \frac{t_2 - t_1}{T_1 - t_1}$$ ***(Kern; hal. 142)***

$$= \frac{113\ °F - 86\ °F}{171\ °F - 86\ °F}$$

$= 0,3191\ °F$

$F_T = 1$ ***(Kern; hal. 828; Fig. 18)***

$\Delta t = F_T \times LMTD$ ***(Kern; hal. 149; eq. 7.42)***

$= 1 \times 21,51\ °F$

= 21,51 °F

Perhitungan T_C dan t_C dipakai Temperature rata-tata

T_C = $T_{Average}$ Fluid ***(Kern; hal. 113)***

$$= \frac{86\ °F + 113\ °F}{2}$$

= 100 °F

t_C = $t_{Average}$ Air Pendingin ***(Kern; hal. 113)***

$$= \frac{171\ °F + 115\ °F}{2}$$

= 143 °F

Trial

Asumsi U_D untuk Uap Air (Gases)

U_D = 2 - 50 Btu/jam.ft^2.°F

= 50 Btu/jam.ft^2.°F ***(Kern; hal. 840; Tabel. 8)***

$$A = \frac{Q}{\Delta t \times U_D}$$ ***(Kern; hal. 107; eq. 6.11)***

$$= \frac{38.049,6409\ \text{Btu/Jam}}{21,5\ °F \times 50\ \text{Btu/jam.ft}^2.°F}$$

= 35,3857 ft^2

= 5.095,5386 in^2

Digunakan OD pipa 3/4 in, sehingga diperoleh:

a" = 0,1963 ft^2/lin ft ***(Kern; hal. 843; Tabel. 10)***

Digunakan panjang pipa:

L = 20 ft = 240 in ***(Kern; hal. 103)***

Number of tubes

$$N_t = \frac{A}{L \times a''}$$

$$= \frac{35,3857\ \text{ft}^2}{20\ \text{ft} \times 0,1963\ \text{ft}^2/\text{lin ft}}$$

= 9,0132 ≈ 10

Dipilih:

Tube		Shell	
OD	= 3/4 in	Pitch	= 1 in
BWG	= 16	Shell ID	= 8 in

a't = 0,302 in^2	Passes = 1
a" = 0,1963 Surface / lin ft, ft^2	N_t = 37
Passes = 2	B Space = 2 in
ID = 0,620 in	OD = 3/4 in
Wall Thicness = 0,065 in	

(Kern; hal. 843; Tabel. 10) ***(Kern; hal. 842; Tabel. 9)***

A baru = N_t x L x a" ***(Kern; hal. 308)***
= 10 x 20 ft x 0,1963 Surface / lin ft, ft^2
= 39,26 ft^2

$$U_D \text{ baru} = \frac{Q}{A \text{ baru} \times \Delta T_{LMTD}}$$
$$= \frac{38.049,6409 \text{ Btu/Jam}}{39,26 \text{ ft}^2 \times 21,51 \text{ °F}}$$
= 45,0658 Btu/jam.ft^2.°F

Hot Fluid (Tube)	Cold Fluid (Shell)
Uap Air	**Air Pendingin**
(4) Flow Area Tube (a_t)	(4') Flow Area Shell (a_s)
$a_t = \frac{Nt \times a't}{144 \times n}$	C" = Pitch - OD
$= \frac{37 \times 0,3}{144 \times 2}$	= 1 in - 3/4 in
= 0,0388 ft^2	= 1/4 in
	$B = ID = \frac{8}{5}$
	= 2 in
	$a_s = \frac{ID \times C'' \times B}{144 \text{ Pr}}$
	$= \frac{8 \text{ in} \times 1/4 \text{ in} \times 2 \text{ in}}{144 \times 1 \text{ in}}$
	= 0,0222 ft^2
(5) Mass Velocity Tube (Gt)	(5) Mass Velocity Shell (Gs)
$G_t = \frac{W_{bahan}}{a_t}$	$G_s = \frac{W_{pendingin}}{a_s}$
$= \frac{9.781,7 \text{ lb/Jam}}{0,0388 \text{ ft}^2}$	$= \frac{1.411,7 \text{ lb/Jam}}{0,0222 \text{ ft}^2}$
= 252.115,1780 lb/Jam.ft^2	= 63.526,7429 lb/Jam.ft^2

(6) Pada t_C = 142,7 °F

μ = 0,0110 cps

= 0,0266 lbm/Jam.ft

D_i = 0,62 in

= 0,0517 ft

$$Re_t = \frac{D \times G_t}{\mu}$$

$$= \frac{0{,}05 \text{ ft} \times 252.115 \text{ lb/Jam.ft}^2}{0{,}0266 \text{ lbm/Jam.ft}}$$

= 489.329,4839

(7) Heat Transfer Factor

j_H = 800

(Kern; hal. 834; Fig. 24)

(8) Konduktivitas Thermal pada t_C

k = 0,0133 $Btu/Jam.ft^2.°F$

(Yaws; hal.551; Tabel 24-2)

Cp = 0,45 Btu/lb°F

(Kern; hal. 805; Fig. 3)

$$\left(\frac{Cp \times \mu}{k}\right)^{1/3} = 0{,}9656$$

(9) Condensation of Steam

$$h_i = j_H \frac{k}{D_i} \left(\frac{Cp \times \mu}{k}\right)^{1/3} \varphi_t$$

(Kern; hal. 111; eq. 6.15a)

= 204,1072 $Btu/Jam.ft^2.°F$

$$h_{io} = h_i \frac{ID}{OD}$$

(Kern; hal. 105; eq. 6.5)

= 168,7287 $Btu/Jam.ft^2.°F$

(10) Pada t_w = 123,5368 °F

(6') Pada T_C = 99,5 °F

μ = 0,9500 cps

(Kern; hal. 825; Fig. 15)

= 2,2990 lbm/Jam.ft

D_e = 0,73 in

= 0,0608 ft

$$Re_s = \frac{D_e \times G_s}{\mu}$$

$$= \frac{0{,}06 \text{ ft} \times 63.527 \text{ lb/Jam.ft}^2}{2{,}2990 \text{ lbm/Jam.ft}}$$

= 1.680,9672

(7') Heat Transfer Factor

j_H = 18

(Kern; hal. 838; Fig. 28)

(8') Konduktivitas Thermal pada t_C

k = 0,3600 $Btu/Jam.ft^2.°F$

(Kern; hal. 800; Tabel 4)

Cp = 75,55 Btu/lb°F

(Yaws; hal. 79; Tabel 3-2)

$$\left(\frac{Cp \times \mu}{k}\right)^{1/3} = 7{,}8431$$

(9') Condensation of Steam

$$h_o = j_H \frac{k}{D_e} \left(\frac{Cp \times \mu}{k}\right)^{1/3} \varphi_s$$

(Kern; hal. 112; eq. 6.15b)

= 211,6396 $Btu/Jam.ft^2.°F$

(10') Tube Wall Temperature

μ_w = 0,0110 Cps
= 0,0266 lbm/Jam.ft

$\varphi_t = \left(\dfrac{\mu}{\mu_w} \right)^{0,14}$

$= \left(\dfrac{0,0266 \text{ °F}}{0,0266 \text{ °F}} \right)^{0,14}$

= 1,0000 Btu/Jam.ft^2.°F

(12) Corrected Coefficient

$h_{io} = \dfrac{h_{io}}{\varphi_t} \times \varphi_t$

(Kern; hal. 121; eq. 6.37)

= 168,7287 Btu/Jam.ft^2.°F

$t_w = t_c + \dfrac{h_{io}}{h_{io} + h_o} (T_c - t_c)$

= 123,5368 °F

(13) Clean Overall Coefficient

$U_C = \dfrac{h_{io} \times h_o}{h_{io} + h_o}$ ***(Kern; hal. 121; eq. 6.38)***

$= \dfrac{168,7 \text{ Btu/jam.ft}^2\text{.°F} \times 211,6396}{168,7 \text{ Btu/jam.ft}^2\text{.°F} + 211,6396}$

= 93,8818 Btu/jam.ft^2.°F

(14) Dirt Factor, Rd

$R_d = \dfrac{U_C - U_D}{U_C \times U_D}$ ***(Kern; hal. 108; eq. 6.13)***

$= \dfrac{93,9 \text{ Btu/jam.ft}^2\text{.°F} - 45,1 \text{ Btu/jam.ft}^2\text{.°F}}{93,9 \text{ Btu/jam.ft}^2\text{.°F} \times 45,1 \text{ Btu/jam.ft}^2\text{.°F}}$

= 0,0115

Untuk R_d data, digunakan "Brackish Water" atau Air Payau dengan R_d

R_d data = 0,002 - 0,001 ***(Kern; hal. 845; Tabel 12)***

R_d perhitungan > R_d data

0,012 > 0,002

Maka, desain dapat digunakan

Hot Fluid	Cold Fluid
Uap Air	**Air Pendingin**

Pressure Drop	
(a) Untuk Re_t = 489.329,4839	(a') Untuk Re_s = 1.680,9672
f = 0,0001	f = 0,0035
(Kern; hal. 836; Fig. 26)	***(Kern; hal. 839; Fig. 29)***
s = 1,0000	s = 1,0000
	(Kern; hal. 808; Tabel. 6)
	(b') Number of times fluid crosses
	$N+1 = \frac{\text{Tube Lengtl}}{\text{Baffle Space}} = \frac{12 \times L}{B}$
	(Kern; hal. 147; eq. 7.43)
	$= \frac{240 \text{ in}}{2 \text{ in}}$
	= 240
(c) Pressure drop in Tube or Pipes	(c') Pressure drop in Shell side
$\Delta P_t = \frac{1}{2} \times \frac{f \times G_t^2 \times L \times n}{5.22 \times 10^{10} \times D_i \times s}$	$\Delta P_s = \frac{1}{2} \times \frac{f \times G_s^2 \times D_s (N+1)}{5.22 \times 10^{10} \times D_e \times s}$
(Kern; hal. 273; eq. 12.48)	***(Kern; hal. 273; eq. 12.47)***
$= \frac{152.548.951,1}{2.697.000.000}$	$= \frac{206.221.565}{3.175.500.000}$
= 0,0283 Psi	= 0,0325 Psi
$\Delta P_t < 10$ psi	$\Delta P_s < 10$ psi
(memenuhi)	(memenuhi)

Perhitungan Dimensi Kondensor

A = 39,2600 ft^2

D = $\sqrt{(4 \times A) / \pi}$

= 7,0720 ft = 2,1554 m

r = 3,5360 ft = 1,0777 m

Asumsi:

H = 3 D

= 3 x 7,0720 ft

= 21,2159 ft = 6,4663 m

Penentuan P_{Design}

P_{Design} = $P_{Outside}$ - P_{Inside}
= 14,7 Psi - 0,3 Atm
= 14,7 Psi - 4,8 Psi
= 9,9 Psi

P_{Design} dibuat berlebih 10% (faktor keamanan)

P_{Design} = 1,1 x 9,9483 Psi
= 10,9431 Psi

Perhitungan tebal Shell

Asumsi tebal shell (ts) = 1/2 in

f = Stress Allowable, Material Konstruksi *Steel A-283-54 Grade C*
= 18.750 Psi ***(Brownell; hal. 79; Tabel 5.1)***

ID = 7,0720 ft = 84,8636 in

OD = ID + (2 t_S)
= 84,86 in + 2 x 0,50
= 85,8636 in = 7,1553 ft

H = 21,2159 ft = 254,5909 in

Penentuan B Factor Shell

Untuk Silinder digunakan H/OD

$$\frac{H}{OD} = 2,9651$$

$$\frac{OD}{ts} = 171,7272$$

B Factor untuk terhadap OD/ts dan H/OD, diperoleh:

B_{Factor} = 2.600 ***(Brownell; hal. 147; Fig. 8.8)***

Perhitungan $P_{Allowabe}$ Shell

$$P_{Allowable} = \frac{B}{OD / ts}$$ ***(Brownell; hal. 149; eq. 8.33)***

$$= \frac{2600}{85,9 \text{ in} / 0,50 \text{ in}}$$

= 15,1403 Psi

Karena $P_{Allowable}$ > P_{Design} , maka desain dapat digunakan

Perhitungan Tebal Tutup Atas dan Bawah

OD = 85,8636 in

Tutup atas dan bawah berbentuk Torispherical Dished Head

Asumsi Tebal Tutup Ata: = $\frac{5}{8}$ in

Radius of Curvature = OD

= 85,8636 in

$$r = \frac{r_C}{100 \times t_{Head}}$$

$$= \frac{85{,}9 \text{ in}}{100 \times 0{,}6250 \text{ in}}$$

= 1,3738

Penentuan B Factor Tutup

Untuk Sphere digunakan $H/(100 \times t_{Head})$

$$\frac{H}{100 \times t_{Head}} = 4{,}0735$$

$$\frac{OD}{t_{Head}} = 137{,}3818$$

B Factor untuk terhadap OD/t_{Head} dan $H/(100 \times t_{Head})$, diperoleh:

B_{Factor} = 3.000 ***(Brownell; hal. 147; Fig. 8.8)***

Perhitungan $P_{Allowable}$ Tutup

$$P_{Allowable} = \frac{B}{r / t_{Head}}$$ ***(Brownell; hal. 152; eq. 8.56)***

$$= \frac{B}{r \times 100}$$

$$= \frac{3000}{1{,}3738 \text{ in} \times 100}$$

= 21,8370 Psi

Karena $P_{Allowable} > P_{Design}$, maka desain dapat digunakan

Perhitungan Tinggi Tutup Atas dan Bawah

Perhitungan tinggi Torispherical

$$H_{Head} = r_C - \left(r_C^2 - \frac{D^2}{4}\right)^{0,5}$$ ***(Hesse; hal. 92; eq. 4-14)***

$$= 85{,}9 \text{ in} \left(7.372{,}56 \text{ in} - \frac{7.201{,}83 \text{ in}}{4}\right)^{0,5}$$

= 11,2171 in = 0,9344 ft = 0,2848 m

Spesifikasi Kondensor

Fungsi	:	Merubah Fase Uap Air menjadi cair dengan Menurunkan Suhu
Tipe	:	Barometric Kondensor
Material Konstruksi	:	*Steel A-283-54 Grade C*
Tube		
Inside Diameter	:	0,62 in = 0,0157 m
Outside Diameter	:	3/4 in = 0,0191 m
Panjang	:	20 ft = 6,0957 m
Jumlah Tube	:	37 buah
Shell		
DI Kondensor	:	7,0720 ft = 2,1554 m
DO Kondensor	:	7,1553 ft = 2,1808 m
Tinggi Kondensor	:	21,2159 ft = 6,4663 m
Tebal Kondensor	:	1/2 in = 0,0127 m
Tutup		
Tebal Tutup Atas	:	5/8 in = 0,0159 m
Tebal Tutup Bawa	:	5/8 in = 0,0159 m
Tinggi Tutup Atas	:	11,2171 in = 0,2849 m
Tinggi Tutup Bawah	:	11,2171 in = 0,2849 m
Jumlah Kondensor	:	1 buah

27. STEAM JET EJECTOR

Kode Alat	:	G - 322
Fungsi	:	Menciptakan Kondisi Vakum pada Evaporator, serta Menghilangkan Uap Air yang tidak Terkondensasi
Tipe	:	*Single Stage Steam Jet Ejector*
Dasar Pemilihan	:	Ekonomis untuk menciptakan keadaan Vakum
Tekanan	:	0,3 atm
Temperatur	:	45 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)

$H_2O_{(g)}$	94%	37,6603	1,0229	1.022,8753	63,8581
CH_2O	5%	1,8249	0,7261	726,0991	45,3304
CH_3OH	1%	0,4439	0,7827	782,6686	48,8620
Total	100%	39,9290			

$V_{Spesifik}$ Steam = 62,06 lb/cuft pada 170°C

(Badger; hal. 733, App. 9)

Rate Massa = 39,9290 kg/jam

= 88,0355 lb/jam

Rate Volumetrik = $\frac{\text{Rate Massa}}{\rho \text{ Air}}$

= $\frac{88,0355 \text{ lb / Jam}}{62,0600 \text{ lb / cuft}}$

= 1,4186 cuft / Jam

Steam yang digunakan adalah Saturated Steam, diperoleh:

Suhu (T) = 130 °C = 403,15 K

Tekanan (P) = 270,13 kPa ***(Smith 9th; hal. 700, App. E)***

= 2,67 atm = 79,77 inHg = 39,18 Psig

Pemilihan Ukuran Steam Jet Ejector

$P_{Suction}$ = 0,3 atm = 30,40 kPa = 8,98 inHg

Ukuran Steam Jet Ejector = 2 Inch M untuk 20 Psig

Kebutuhan Steam pada 90 Psig = 225 lb/Jam

(Ludwig 3rd; hal. 373, Fig. 6-26A)

Perhitungan Kebutuhan Steam Aktual

P_{Steam} = 2,7 atm = 39,18 Psig

Faktor (F) = 1,3 ***(Ludwig 3rd; hal. 373, Fig. 6-26B)***

$W_S = W_{S90} \times F$ ***(Ludwig 3rd; hal. 371, eq. 6-20)***

Keterangan:

W_S = Kebutuhan Steam Aktual, lb/Jam

W_{S90} = Kebutuhan Steam pada 90 Psig, lb/Jam

F = Faktor Tekanan Steam

W_S = 225 lb/Jam x 1,3

= 293 lb/Jam

Perhitungan Waktu Evakuasi

$W'_m = E \times \frac{V_S}{t}$ ***(Ludwig 3rd; hal. 371, eq. 6-21)***

Keterangan:

W'_m = Massa Uap Air, lb/Jam

E = Faktor Evakuasi terhadap $P_{Suction}$

= 2 ***(Ludwig 3rd; hal. 374, Tabel 6-9)***

V_S = Volume Sistem, cuft

t = Waktu Evakuasi Volume terhadap Ukuran Ejector, menit

Volume Spesifik Uap Air = 62,06 cuft/lb pada 170.6°F

(Badger; hal. 733, App. 9)

V_S = Volume Spesifik Uap Air x Rate Mass Air

= 62,06 cuft/lb x 88,04 lb/Jam

= 5.463,4812 cuft/Jam

$$W'_m = E \times \frac{V_S}{t}$$

$$88{,}04 \text{ lb/Jam} = 2 \times \frac{5.463{,}5 \text{ cuft/Jam}}{t}$$

$$t = \frac{E \times V_S}{W'_m}$$

$$= \frac{2 \times 5.463{,}5 \text{ cuft/Jam}}{88{,}04 \text{ lb/Jam}}$$

$$= 117{,}914 \text{ menit}$$

$$\approx 118 \text{ menit}$$

Untuk mengevakuasi volume dengan 2 Inch M Steam Jet Ejector

Spesifikasi Steam Jet Ejector

Fungsi	:	Menciptakan Kondisi Vakum pada Evaporator, serta Menghilangkan Uap Air yang tidak Terkondensasi
Tipe	:	*Single Stage Steam Jet Ejector*
Tekanan	:	0,3 atm
Kapasitas / Volume	:	1,4186 cuft
Size	:	2 Inch M
Waktu Evakuasi	:	118 menit
Jumlah	:	1 Unit

28. HOT WELL

Kode Alat	:	F - 323
Fungsi	:	Menampung Uap Air yang telah di Kondensasi

Bentuk : Balok Beton tanpa Tutup Atas, dan lantai rata
Dasar Pemilihan : Ekonomis untuk penampungan Air bertekanan Atmosfer
Tekanan : 1 atm
Temperatur : 45 °C
Waktu Operasi : 30 menit

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$H_2O_{(l)}$	94%	4.184,4743	1,0229	1.022,8753	63,8581
CH_2O	5%	202,7614	0,7261	726,0991	45,3304
CH_3OH	1%	49,3203	0,7827	782,6686	48,8620
Total	100%	4.436,5560			

ρ Air pada 113°F = 61,85 lb/cuft

(Badger; hal. 733, App. 9)

Rate Massa = 4.436,5560 kg/jam
= 9.781,7187 lb/jam

Rate Volumetrik $= \dfrac{\text{Rate Massa}}{\rho\ \text{Air}}$

$= \dfrac{9.781,7187\ \text{lb / Jam}}{61,8500\ \text{lb / cuft}}$

= 158,1523 cuft / Jam

Waktu tinggal = 30 menit

Ditetapkan pengisian bahan sebanyak 80% Kapasitas Volume (faktor keamanan)

Volume Bahan = 80% dari Kapasitas Kristallizer

Volume Kristalizer $= \dfrac{79,0761\ \text{cuft}}{80\%}$

= 98,8452 cuft

Perhitungan Dimensi Hot Well

Panjang (P) = 2 Tinggi (H)
Tinggi (H) = Lebar (L)
V = P x L x H
= 2 L x L x L

Keterangan:

V = Volume Hot Well (Balok), cuft
P = Panjang Balok, ft

L = Lebar Balok, ft

H = Tinggi Balok, ft

98,8452 cuft = 2 L x L x L

Lebar (L)	=	3,6698	ft	=	1,1185	m
Tinggi (H)	=	3,6698	ft	=	1,1185	m
Panjang (P)	=	7,3396	ft	=	2,2370	m

Spesifikasi Hot Well

Fungsi	:	Menampung Uap Air yang telah di Kondensasi		
Bentuk	:	Balok Beton tanpa Tutup Atas, dan lantai rata		
Bahan Konstruksi	:	Concrete (beton)		
Tekanan	:	1 atm		
Kapasitas / Volume	:	98,8452 cuft	=	2,7973 m^3
Lebar Hot Well	:	3,6698 ft	=	1,1185 m
Tinggi Hot Well	:	3,6698 ft	=	1,1185 m
Panjang Hot Well	:	7,3396 ft	=	0,1864 m
Jumlah	:	1 Unit		

29. POMPA 7

Kode Alat	:	L - 324
Fungsi	:	Memindahkan Larutan Pentaeritrito dari Evaporator menuju Kristallizer
Tipe	:	Centrifugal Pump
Dasar Pemilihan	:	Sesuai untuk Fluida Liquid dengan Viskositas <10 Cp
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4(aq)}$	28%	4.136,7916	1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$	36%	5.253,7253	2,0200	2.020,0000	126,11
$H_2O_{(l)}$	34%	5.020,6552	1,0229	1.022,8753	63,8581
CH_2O	1%	173,7955	0,7261	726,0991	45,3304
CH_3OH	0%	42,2746	0,7827	782,6686	48,8620
Total	100%	14.627,2422			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

= 1,287 x 63,858 lb/cuft

= 82,2026 lb/cuft

= 1.316,7626 kg/m^3

Rate Massa = 14.627,2422 kg/jam

= 32.250,1435 lb/jam

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

$$= \frac{32.250,1435 \text{ lb / Jam}}{82,2026 \text{ lb / cuft}}$$

= 392,3250 cuft / Jam

= 6,5388 cuft / menit

= 0,1090 cuft / sec

= 48,9164 gal / min

$$\text{Viskositas Bahan} = \frac{\text{sg Bahan} \times \mu \text{ Reference } (H_2O)}{\text{sg Reference}}$$

μ Reference (H_2O) = Viskositas Air pada suhu operasi, Pa.s

= 0,5065 Cps

= 0,0005 Pa.s

sg Reference (H_2O) = Specific Gravity Air pada suhu operasi

= 0,9960

$$\text{sg Bahan} = \frac{\rho \text{ Bahan}}{\rho \text{ Reference } (H_2O)}$$

$$= \frac{97,8 \text{ lb/cuft}}{63,9 \text{ lb/cuft}}$$

= 1,5319

$$\text{Viskositas Bahan} = \frac{1,5319 \times 0,0005 \text{ Pa.s}}{0,9960}$$

= 0,0008 lb/ft.s

= 0,0012 Ns/m^2

= 1,1593 Cps

Perhitungan ID Optimum

Asumsi Aliran Turbulen, dengan $N_{Re} > 2100$, digunakan rumus:

$ID_{Optimum} = 3{,}9 \; qf^{0,45} \; \rho^{0,13}$

(Peters 4th; hal. 496; eq. 15)

Keterangan:

ID = Optimum Pipe Inside Diameter, in

qf = Fluid Flow Rate, cuft/sec

ρ = Fluid Density, lb/cuft

$ID_{Optimum}$ = 3,9 x 0,3688 cuft/sec x 1,77 lb/cuft

= 2,5516 in

Perhitungan Pipa

Dipilih pipa:

IPS, Size = 3 in

OD = 3,5000 in

Schedule = No. 40

ID = 3,0680 in ***(McCabe7th; hal. 1090; App. 3)***

= 0,2557 ft

= 0,0779 m

$A_1 = \frac{1}{4} \pi \times ID_{Tangki}^2$

$= \frac{3{,}14}{4} \times (96{,}75 \text{ in})^2$

$= 7.347{,}3275 \text{ in}^2$

$= 51{,}0231 \text{ ft}^2$

$A_2 = \frac{1}{4} \pi \times ID^2$

$= \frac{3{,}14}{4} \times (3{,}07 \text{ in})^2$

$= 7{,}3889 \text{ in}^2$

$= 0{,}0513 \text{ ft}^2$

$A_2 / A_1 = 0{,}0010057 < 0.715$

$V = \frac{\text{Rate Volumetrik}}{A}$

$= \frac{0{,}1090 \text{ ft}^3 / \text{sec}}{0{,}05 \text{ ft}^2}$

= 2,1239 ft / sec

= 0,6473 m / sec

$N_{Re} = \dfrac{D \times V \times \rho}{\mu}$ ***(Peters 4th; hal. 481; eq. 6)***

$= \dfrac{0{,}08 \text{ in} \times 0{,}65 \text{ m/s} \times 1316{,}8 \text{ kg/m}^3}{0{,}0012 \text{ Pa.s}}$

$= 57.294{,}2464 \quad > 2{,}100$ (Airan Turbulen)

Equivalent Roughness for Pipe (ε) untuk material Commercial Steel

ε = 0,00015 ft ***(Peters 4th; hal. 482; Fig. 14-1)***

= 0,000046 m ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

= 0,001800 in

$\dfrac{\varepsilon}{D}$ = 0,000587

f = 0,0055 ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

Perhitungan Equivalent Suction (L_e)

Sambungan / Fitting	L_e / D
90° Elbow Standard	35
Gate Valve, Open	9

(Peters 4th; hal. 484; Tabel 1)
(Peters 4th; hal. 485; Tabel 1)

3 Elbow std 90° = 3 x (L_e / D) x DI
= 35 x 0,2557 ft
= 26,8450 ft
= 8,1820 m

1 Gate Valve $_{\text{Wide Open}}$ = 1 x (L_e / D) x DI
= 9 x 0,2557 ft
= 2,3010 ft
= 0,7013 m

Perhitungan Panjang Pipa

Pipa A ke B	=	1,50	m	=	4,9215 ft
Elbow 1 ke Elbow 2 (Asumsi jarak ke Kristallizer)	=	2,50	m	=	8,2025 ft
Elbow 2 ke Elbow 3	=	1,00	m	=	3,2810 ft
Elbow 3 ke Elbow Reaktor	=	1,00	m	=	3,2810 ft
Panjang Total Pipa Lurus	=	6,0000	m	=	19,6860 ft
Panjang Total Pipa Keseluruhan	=	14,8833	m	=	48,8320 ft

Perhitungan Friksi

Friksi karena Gesekan :

$F_1 = \dfrac{2 f \times V^2 \times L_e}{}$

$g_C \times D$ ***(Peters 4th; hal. 484; Tabel 1)***

$F_2 = \dfrac{K \times V^2}{2 \times \alpha \times g_C}$ ***(Peters 4th; hal. 484; Tabel 1)***

$F_3 = \dfrac{(V_2 - V_1)^2}{2 \times \alpha \times g_C}$ ***(Peters 4th; hal. 484; Tabel 1)***

$F_4 = n \times Kf \times \dfrac{V_1^2}{2 \times g_C}$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

$F_5 = n \times Kf \times \dfrac{V_1^2}{2 \times g_C}$ ***(Geankoplis 3rd; hal. 94; eq. 2.10-17)***

Keterangan

F_1 = Flow Through long straight pipe

F_2 = Sudden Contraction

F_3 = Sudden Enlargement

F_4 = Losses Fitting - Elbow 90º

F_5 = Losses Fitting - Gate Valve Open

V = Linear Velocity, ft/sec

= 2,1239 ft/sec

α = Correction Coefficient, Viscous (0.5), Turbulen (1.0)

= 1,0 Turbulen (>2100) ***(Peters 4th; hal. 480)***

L = Length of Pipe

= 48,8320 ft

D = Diameter of Pipe

= 3,0680 in = 0,2557 ft

f = Fanning Friction Factor

= 0,0055 ***(Geankoplis 3rd; hal. 88; Fig. 2.10-3)***

g_C = Newton's Law Conversion Factor, ft.lbm / lbf

= 32,17 ft.lbm/lbf

A_1 = Luas Penampang Evaporator Efek Kedua, ft^2

= 51,0231 ft^2

A_2 = Luas Penampang Pipa, ft2

= 0,0513 ft^2

K_C = Coefficient Friction Loss, (untuk $A_2/A_1 < 0.715$)

$= 0{,}40 \times \left(1{,}25 - \dfrac{A_2}{A_1}\right)$

= 0,4996 ***(Peters 4th; hal. 484; Tabel 1)***

Kf = Number of Velocity Heads
= Elbow 90° = 0,7500
= Gate Valve Open = 0,1700

(Geankoplis 3rd; hal. 93; Tabel 2.10-1)

$$F_1 = \frac{2 \times 0{,}0055 \times (2{,}1 \text{ ft/sec})^2 \times 48{,}8 \text{ ft}}{32{,}17 \text{ ft.lbm/lbf} \times 3{,}0680 \text{ in}}$$

= 0,0245 ft .lbf / lbm

$$F_2 = \frac{0{,}50 \times (2{,}1 \text{ ft/sec})^2}{2 \times 1{,}0 \times 32{,}17 \text{ ft.lbm/lbf}}$$

= 0,0350 ft .lbf / lbm

F_3 = Karena A_1 (Tangki) > A_2 (Pipa), Maka $V_1 = 0$

$$= \frac{(2{,}1 \text{ ft/sec})^2}{2 \times 1{,}0 \times 32{,}17 \text{ ft.lbm/lbf}}$$

= 0,0701 ft .lbf / lbm

$$F_4 = 3 \times 0{,}75 \times \frac{(2{,}1 \text{ ft/sec})^2}{2 \times 32{,}2 \text{ ft.lbm/lbf}}$$

= 0,1577 ft.lbf / lbm

$$F_5 = 1 \times 0{,}41 \times \frac{(2{,}1 \text{ ft/sec})^2}{2 \times 32{,}2 \text{ ft.lbm/lbf}}$$

= 0,0284 ft.lbf / lbm

$\sum F$ = $F_1 + F_2 + F_3 + F_4 + F_5$ ***(Geankoplis 3rd; hal. 95)***
= 0,3158 ft .lbf / lbm

Persamaan Bernoulli

$$z_1 \frac{g}{g_C} + \frac{V_1^2}{2\alpha g_C} + \frac{P_1 - P_2}{\rho_1 - \rho_2} - W_f = z_2 \frac{g}{g_C} + \frac{V_2^2}{2\alpha g_C} + \sum F$$

(Geankoplis 3rd; hal. 95; eq. 2.10-20)

$$- W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

Keterangan :

W_S = Work done by Fluid ***(Geankoplis 3rd; hal. 62)***
z = Vertical Distance, ft
V = Linear Velocity, ft/sec
g = g_C = Gravity Constants
g / g_C = 1 lbf/lbm ***(Peters 4th; hal. 487; ex. 1)***
$\sum F$ = Total Friction Loss, ft.lbf/lbm

= 0,3158 ft .lbf / lbm

ρ = Densitas Campuran, lb/cuft

= 82,2026 lb/cuft

P = Tekanan, Psi

P_1 = $P_1 + P_{\text{Hidrostatis}}$

= 14,7 Psi + 7,0 Psi = 21,73 Psi

P_2 = 14,7 Psi

ΔP = $P_1 - P_2$

= 21,7 Psi - 14,7 Psi

= 7,0 Psi

= 1013,0 lbf / ft^2

$$\frac{\Delta P}{\rho} = \frac{1013{,}02 \ \text{lbf / ft}^2}{82{,}20 \ \text{lb/cuft}}$$

= 12,3235 ft.lbf / lbm

Asumsi:

z_1 = 8,2025 ft

z_2 = 4,9215 ft

$$\Delta z \frac{g}{g_C} = (8{,}2 \ \text{ft} - 4{,}9 \ \text{ft}) \ x \ 1 \ \text{lbf/lbm}$$

= 3,2810 ft.lbf / lbm

$$\frac{\Delta V^2}{2 \ x \ \alpha \ x \ g_C} = \frac{(2{,}1239 \ \text{ft/sec})^2}{2 \ x \ 1{,}0 \ x \ 32{,}2 \ \text{ft.lbm/lbf}}$$

= 0,0701 ft.lbf / lbm

$$- W_S = \frac{\Delta P}{\rho} + \Delta z \frac{g}{g_C} + \frac{\Delta V^2}{2\alpha g_C} + \sum F$$

= 12,32 + 3,28 + 0,07 + 0,32

= 15,9904 ft.lbf / lbm

Perhitungan Brake Horsepower (BHp)

Untuk Flowrate tersebut, diperoleh efisiensi pompa sebesar:

η_{Pompa} = 63% ***(Peters 4th; hal. 520; Fig. 14-37)***

W_S = $- \eta \ x \ W_P$ ***(Geankoplis 3rd; hal. 65; eq. 2.7-30)***

$$W_P = \frac{- W_S}{\eta}$$

$$= \frac{16{,}0 \ \text{ft.lbf / lbm}}{63\%}$$

= 25,3816 ft.lbf / lbm

$$BHp = \frac{W_P \times Flowrate}{550}$$ ***(Geankoplis 3rd; hal. 66)***

$$= \frac{25{,}4 \text{ ft.lbf / lbm} \times 12{,}5 \text{ lb/sec}}{550}$$

= 0,577

≈ 1 hp

Perhitungan Power Motor

Untuk BHp tersebut, diperoleh efisiensi motor sebesar:

η_{Motor} = 82% ***(Peters 4th; hal. 521; Fig. 14-38)***

$$hp = \frac{BHp}{\eta_{Motor}}$$

$$= \frac{1 \text{ hp}}{82\%}$$

= 1,2195

≈ 2 hp

Spesifikasi Pompa 7

Fungsi	:	Memindahkan Larutan Pentaeritrito dari Evaporator menuju Kristallizer
Tipe	:	Centrifugal Pump
Kecepatan Aliran	:	2,1239 ft/sec = 0,6473 ft/sec
Flowrate	:	0,1090 cuft/s = 48,9164 gal/min
Size Pipa, IPS	:	3 in
ID Pipa	:	3,0680 in
Schedule	:	No. 40
Efisiensi Pompa	:	63%
Power Pompa	:	1 hp
Efisiensi Motor	:	82%
Power Motor	:	2 hp
Jumlah	:	1 Pompa

30. KRISTALLIZER

Kode Alat	:	S -330
Fungsi	:	Membentuk Kristal Pentaeritritol
Tipe	:	*Swenson-Walker Crystallizer*

Dasar Pemilihan : Efektif untuk kristalisasi dingin
Tekanan : 1 atm
Temperatur : 30 °C
Waktu Operasi : 1 Jam

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4\,(aq)}$	28,28%	4.136,7916	1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$	35,92%	5.253,7253	2,0200	2.020,0000	126,11
$H_2O_{(l)}$	34,32%	5.020,6552	1,0229	1.022,8753	63,8581
CH_2O	1,19%	173,7955	0,7261	726,0991	45,3304
CH_3OH	0,29%	42,2746	0,7827	782,6686	48,8620
Total	100%	14.627,2422			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

$= 1,287 \times 63,8581$ lb/cuft
$= 82,2026$ lb/cuft

Rate Massa = 14.627,2422 kg/jam
= 32.250,1435 lb/jam

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

$$= \frac{32.250,1435 \text{ lb / Jam}}{82,2026 \text{ lb / cuft}}$$

= 392,3250 cuft / Jam

Ditetapkan pengisian bahan sebanyak 80% Kapasitas Volume (faktor keamanan)

Volume Bahan = 80% dari Kapasitas Kristallizer

$$\text{Volume Kristalizer} = \frac{392,3250 \text{ cuft}}{80\%}$$

= 490,4063 cuft

Perhitungan Dimensi Kristallizer

Panjang (L) = 3 - 3,5 D ***(Hugot 1st; hal. 541)***

$$\text{Rasio (L/D)} = \frac{3,33}{D}$$

$$m = \frac{L}{D} = 3{,}33$$ ***(Hugot 3rd; hal. 732)***

$$V = \frac{m\ D^3}{2}\left(1 + \frac{\pi}{4}\right)$$

(Hugot 3rd; hal. 733, eq. 34.7)

Keterangan:

m = Rasio panjang terhadap diameter
L = Panjang Kristallizer, ft
D = Diameter Kristallizer, ft
V = Volume Kristallizer, cuft

$$490{,}4063\ ft^3 = \frac{3{,}33 \times D^3}{2}\left(1 + \frac{3{,}14}{4}\right)$$

$$490{,}4063\ ft^3 = 1{,}6650\ D^3 \times 1{,}7850$$

Diameter (D) = 5,4849 ft = 1,6717 m
Panjang (L) = 18,2647 ft = 5,5668 m

Perhitungan Cooling Area Kristallizer

$$\frac{S}{V} = \frac{2\ (1 + 2\ m)}{m\ D}$$ ***(Hugot 3rd; hal. 733, eq. 34.8)***

Keterangan:

m = Rasio panjang terhadap diameter
L = Panjang Kristallizer, ft
D = Diameter Kristallizer, ft
V = Volume Kristallizer, cuft
S = Cooling Area Kristallizer, ft^2/ft^3

$$S = 490{,}4063\ ft^3 \times \frac{2\ (1 + (2 \times 3{,}33))}{3{,}33 \times 5{,}48\ ft}$$

$$= 411{,}3417\ ft^2/ft^3$$

Perhitungan Power Kristallizer

Penentuan Power menggunakan kelipatan 1 Hp untuk setiap 1000 cuft Feed

(Hugot 3rd; hal. 729)

$$Power = 1\ Hp \times \frac{Volume\ Feed}{1.000}$$

$$= 1\ Hp \times \frac{392{,}3}{1.000}\ cuft$$

$$= 0{,}3923$$

≈ 1 Hp

Spesifikasi Kristallizer

Fungsi	:	Membentuk Kristal Pentaeritritol		
Tipe	:	*Swenson-Walker Crystallizer*		
Tekanan	:	1 atm		
Kapasitas / Volume	:	490,4063 cuft	=	13,8785 m^3
Diameter Kristallizer	:	5,4849 ft	=	1,6717 m
Panjang Kristallizer	:	18,2647 ft	=	5,5668 m
Luas Cooling Area	:	411,3417 ft^2/ft^3		
Power	:	1 Hp		
Jumlah	:	1 Unit		

31. SENTRIFUGE

Kode Alat	:	H - 340
Fungsi	:	Memisahkan padatan Kristal dengan Mother Liquor
Tipe	:	*Sedimenting Centrifuges (Disc Stack Centrifuge)*
Dasar Pemilihan	:	Efektif di operasi Kontinyu, sesuai kapasitas volumetrik
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4\,(s)}$	35,90%	5.251,4087	1,0734	1.073,4411	67,0149
$C_5H_{12}O_{4\,(aq)}$	0,02%	2,3166	1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$	34,32%	5.020,6552	2,0200	2.020,0000	126,11
$H_2O_{(l)}$	28,28%	4.136,7916	1,0229	1.022,8753	63,8581
$CH_2O_{(aq)}$	1,19%	173,7955	0,7261	726,0991	45,3304
$CH_3OH_{(aq)}$	0,29%	42,2746	0,7827	782,6686	48,8620
Total	100%	14.627,2422			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

= 1,280 x 63,8581 lb/cuft

= 81,7634 lb/cuft

Rate Massa = 14.627,2422 kg/jam

= 32.250,1435 lb/jam

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

= $\frac{32.250,1435 \text{ lb / Jam}}{81,7634 \text{ lb / cuft}}$

= 394,4325 cuft / Jam

= 6,5739 cuft / menit

= 49,1760 galons / menit

Pemilihan jenis Sentrifuge didasari oleh Rate Volumetrik Feed dari Kristalizer yang mengacu pada ***(Perry 8th; hal. 18-121, Tabel 18.12)*** dan diperkuat oleh pertimbangan berdasarkan ***(Walas 2nd; hal. 331, Tabel 11.3)*** , sehingga dipilih Sentrifuge jenis *"Disc"*

Spesifikasi Sentrifuge

Fungsi	:	Memisahkan padatan Kristal dengan Mother Liquor
Tipe	:	*Sedimenting Centrifuges (Disc Stack Centrifuge)*
Tekanan	:	1 atm
Kapasitas / Volume	:	49,1760 galons/menit
Kapasitas Maksimum	:	20 - 200 galons/menit
Diameter Sentrifuge	:	24 in
Kecepatan Putaran	:	4.000 rpm
Sentrifugal Force	:	5.500
Power	:	7,5 Hp
Jumlah	:	1 Unit

32. TANGKI PENAMPUNGAN MOTHER LIQUOR

Kode Alat	:	F - 341
Fungsi	:	Menampung Mother Liquor yang telah dipisahkan oleh Centrifuge
Tipe	:	Tangki Silinder Tegak dengan Tutup Atas Torispherical Dish Head dan Tutup Bawah Datar
Material Konstruksi	:	*Carbon Steel SA-283, Grade C*
Dasar Pemilihan	:	Ekonomis dan umum digunakan untuk Fluida
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Penyimpanan	:	3 hari

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4\,(aq)}$	0,02%	2,2008	1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$	53,55%	4.769,6224	2,0200	2.020,0000	126,11
$H_2O_{(l)}$	44,12%	3.929,9520	1,0229	1.022,8753	63,8581
$CH_2O_{(aq)}$	1,85%	165,1057	0,7261	726,0991	45,3304
$CH_3OH_{(aq)}$	0,45%	40,1608	0,7827	782,6686	48,8620
Total	100%	8.907,0418			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

= 1,435 x 63,8581 lb/cuft

= 91,6613 lb/cuft

Rate Massa = 8.907,0418 kg/jam

= 19.638,2457 lb/jam

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

$$= \frac{19.638,2457 \text{ lb / Jam}}{91,6613 \text{ lb / cuft}}$$

= 214,2481 cuft / Jam

Volume Komponen = Rate Volumetrik x Waktu Penyimpanan

= 214,25 cuft / Jam x 3 hari

= 15.425,8602 cuft

= 436,8076 m^3

= 436.810,9978 Liter

Direncanakan untuk penyimpanan dengan 5 buah tangki
(mempermudah pengeluaran dan pengisian), sehingga volume bahan:

$$\text{Volume Komponen} = \frac{15.425,8602 \text{ cuft}}{5 \text{ Tangki}}$$

= 3.085,1720 cuft

Dilakukan pengisian bahan sebanyak 80% volume (faktor keamanan)

Volume Bahan = 80% dari volume Tangki Penampungan

$$\text{Volume Tangki } (V_S) = \frac{3.085,1720 \text{ cuft}}{80\%}$$

= 3.856,4650 cuft

Perhitungan Dimensi Tangki

Tinggi (H) = 2 Diameter (D) ***(Ulrich; hal. 248; Tabel 4-27)***

$$V_S = \frac{1}{4}\ \pi\ D^2\ H$$

$$V_S = \frac{3,14}{4} \times 2 \times Ds^3$$

$$V_S = 1,57\ Ds^3$$

V tutup atas torispherical dish = 0,000049 Ds^3

(Brownell; hal. 88; eq. 5.11)

Volume Tangki = V_S + V tutup atas

3.856,4650 cuft = 1,57 Ds^3 + 0,000049 Ds^3

3.856,4650 cuft = 1,57 Ds^3

Ds^3 = 2.456,2705 cuft

Ds = 13,4925 ft = 161,9099 in = 4,1125 m

Hs = 26,9850 ft = 323,8197 in = 8,2250 m

Perhitungan Tinggi Komponen

$$\text{Volume Bahan} = \frac{1}{4}\ \pi\ Ds^2\ H_{liq}$$

$$3.085,1720 \text{ cuft} = \frac{3,14}{4} \times 13,4925^2 \times H_{liq}$$

H_{liq} = 21,5887 ft = 259,0639 in = 6,5802 m

Penentuan P_{Design}

Apabila didalam bejana terdapat liquid, maka:

P = 1 atm = 14,6959 Psi

P_{Inside} = 14,6959 Psi

$P_{Outside}$ = 14,6959 Psi

P_{Design} = P_{Inside} - $P_{Outside}$ + $P_{Hidrostatis}$

= 14,7 Psi - 14,7 Psi + $P_{Hidrostatis}$

P_{Design} = $P_{Hidrostatis}$

$$P_{Hidrostatis} = \rho\ \text{Campuran} \times \frac{g}{gc} \times H_{liq}$$

= 91,6613 lbm/cuft x 1 lbf/lbm x 21,5887 ft

= 1.978,8433 lb/ft^2

= 13,7530 Psi

P_{Design} dibuat berlebih 10% (faktor keamanan)

P_{Design} = 1,1 x 13,7530 Psi
= 15,1283 Psi

Perhitungan tebal Shell Minimum

Tebal Shell berdasarkan ASME code untuk Cylincrical Tank

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

Keterangan:

t_{min} = Tebal Shell Minimum (in)
P = Tekanan Tangki (Psi)
ri = Jari - jari Tangki (in) (1/2 D)
E = Faktor Pengelasan (digunakan double) = 0,80
C = Faktor Korosi (in) (digunakan 1/8 in) = 0,125 in
f = Stress Allowable, Material Konstruksi *Carbon Steel SA-283 Grade C*
= 12.650 Psi **(*Brownell; hal. 251; Tabel 13.1*)**

$$t_{min} = \frac{15{,}1283 \text{ Psi} \times 80{,}9549 \text{ in}}{10.120 \text{ Psi} - 9{,}0770 \text{ Psi}} + 0{,}125 \text{ in}$$

$$= \frac{1.224{,}7070}{10.110{,}9230} + 0{,}125 \text{ in}$$

= 0,2461 in

= (Digunakan t_S = $\frac{1}{2}$ in)

(*Brownell; hal. 89; Tabel 5.7*)

Perhitungan Koreksi Stress Allowable Shell

$$\frac{1}{2} \text{ in} = \frac{15{,}1283 \text{ Psi} \times 80{,}9549 \text{ in}}{f \times 0{,}80 - 9{,}0770 \text{ Psi}} + 0{,}125 \text{ in}$$

f = 4.093,7029 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tebal tutup atas

Tutup atas berbentuk Torispherical Dished Head

OD = ID + (2 t_S)
= 161,9099 in + 2 x 0,50
= 162,9099 in
= (Digunakan OD = 168 in)

(*Brownell; hal.91; Tabel 5.7*)

Diperoleh:

icr = 10,1250 in = 0,8434 ft

r_C = 144 in = 11,9952 ft

Cek nilai icr dengan 6% rc:

icr = 10,13 in

6% rc = 8,64 in

karena nilai icr > 6% rc, maka menggunakan persamaan

$$t = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$

(Brownell; hal.138; eq. 7.77)

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

(Brownell; hal.138; eq. 7.76)

Keterangan:

W = Faktor Stress

Pd = Tekanan design (P_{Design})

r_C = Radius Crown

r_1 or icr = Inside Crown Radius

E = Faktor Pengelasan = 0,80

t = Tebal dinding minimal

f = Stress Allowable, bahan konstruksi *Carbon Steel SA - 283 Grade C*

= 12.650 Psi ***(Brownell; hal. 251; Tabel 13-1)***

C = Faktor Korosi (in) = 0,125 in

$$W = \frac{1}{4}\left(3 + \sqrt[2]{(r_C/r_1)}\right)$$

$$= \frac{1}{4}\left(3 + \sqrt[2]{(144\ \text{in} / 10{,}13\ \text{in})}\right)$$

$$= 1{,}6928$$

$$t_{Head} = \frac{Pd \times r_C \times W}{2f\ E - 0{,}2\ Pd} + C$$

$$= \frac{15{,}1283\ \text{Psi} \times 144\ \text{in} \times 1{,}6928}{25.300\ \text{Psi} \times 0{,}8 - 3{,}0257\ \text{Psi}} + 0{,}125\ \text{in}$$

$$= 0{,}3072\ \text{in}$$

= (Digunakan $t = \frac{1}{2}$ in)

(Brownell; hal. 89; Tabel 5.7)

Untuk Tebal Tutup Bawah, karena ditopang oleh permukaan semen, digunakan:

$t_{Bottom} = \frac{5}{16}$ in *(Brownell; hal. 58)*

Perhitungan Koreksi Stress Allowable Head

$\frac{1}{2}$ in $= \frac{15{,}1283 \text{ Psi} \times 243{,}7645 \text{ in}}{2\ f \times 0{,}80 - 3{,}0257 \text{ Psi}} + 0{,}125$ in

f = 6.148,1110 Psi < $f_{Allowable}$ (memenuhi)

Perhitungan tinggi tutup atas:

Di = 161,9099 in

a $= \frac{Di}{2}$

$= \frac{161{,}9099 \text{ in}}{2}$

= 80,9549 in

icr = 10,13 in

r_C = 144 in *(Brownell; hal. 91; Tabel 5.7)*

AB $= \frac{Di}{2} - icr$

$= \frac{161{,}9099 \text{ in}}{2} - 10{,}125$ in

= 70,8299 in

BC = r_C - icr

= 144 in - 10,13 in

= 133,8750 in

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

= √ (17.922,5156 in - 5.016,8793 in)

= 113,6030 in

b = r_C - AC

= 144 in - 113,6030 in

= 30,3970 in

sf = 3 in *(Brownell; hal. 93; Tabel 5.8)*

t_{Head} = 0,5000 in

OA = t_{Head} + b + sf

= 0,5000 in + 30,3970 in + 3 in

= 33,8970 in

Maka, tinggi tutup atas	=	33,8970 in		
	=	0,8610 m		

Spesifikasi Tangki Penampungan Mother Liquor

Fungsi	:	Menampung Mother Liquor yang telah dipisahkan oleh Centrifuge		
Tipe	:	Tangki Silinder Tegak dengan Tutup Atas Torispherical Dish Head dan Tutup Bawah Datar		
Tekanan	:	1 atm		
Kapasitas / Volume	:	3.856,4650 cuft	=	109,1380 m^3
Diameter	:	13,4925 ft	=	4,1123 m
Tinggi Shell	:	26,9850 ft	=	8,2246 m
Tebal Shell	:	0,5000 in	=	0,0127 m
Tinggi tutup atas	:	33,8970 in	=	0,8610 m
Tebal tutup atas	:	0,5000 in	=	0,0127 m
Tebal tutup bawah	:	0,3125 in	=	0,0079 m
Bahan konstruksi	:	*Carbon Steel SA-283, Grade C*		
Waktu Penyimpanan	:	3 hari		
Jumlah	:	5 tangki		

33. SCREW CONVEYOR 1

Kode Alat	:	J - 342
Fungsi	:	Memindahkan produk berupa kristal basah dari Sentrifuge menuju *Rotary Dryer*
Tipe	:	*Plain spouts or chutes* , dengan *Discharge trough end*
Dasar Pemilihan	:	Umum digunakan untuk pemindahan komponen padatan halus, tidak lengket
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4\,(s)}$	91,80%	5.251,4087	1,0734	1.073,4411	67,0149
$C_5H_{12}O_{4\,(aq)}$	0,00%	0,1158	1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$	4,39%	251,0328	2,0200	2.020,0000	126,11
$H_2O_{(l)}$	3,62%	206,8396	1,0229	1.022,8753	63,8581
$CH_2O_{(aq)}$	0,15%	8,6898	0,7261	726,0991	45,3304
$CH_3OH_{(aq)}$	0,04%	2,1137	0,7827	782,6686	48,8620
Total	100%	5.720,2004			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \frac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

$$= 1{,}096 \times 63{,}8581\ \text{lb/cuft}$$

$$= 69{,}9944\ \text{lb/cuft}$$

Rate Massa = 5.720,2004 kg/jam

= 12.611,8978 lb/jam

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

$$= \frac{12.611{,}8978\ \text{lb / Jam}}{69{,}9944\ \text{lb / cuft}}$$

$$= 180{,}1844\ \text{cuft / Jam}$$

Untuk densitas 69,9944 lb/cuft, digunakan kelas c

diperoleh F = 2,0 - 2,5 ***(Badger; hal. 711, Tabel 16-6)***

= 2,0 (dipilih)

Perhitugnan Power Motor

$$hp = \frac{C\,L\,W\,F}{33000}$$ ***(Badger; hal. 713, eq. 16-4)***

Keterangan:

C = Kapasitas (cuft/m)

L = Panjang (ft)

W = Berat Meterial (lb/cuft)

F = Faktor Konstanta (Tabel 16-6)

Asumsi panjang = 30 ft

$$hp = \frac{3{,}0031\ \text{cuft/m} \times 30\ \text{ft} \times 69{,}9944\ \text{lb/cuft} \times 2{,}0}{33.000}$$

= 0,3822

Untuk power (hp) dibawah 2, maka dikalikan 2 ***(Badger; hal. 713)***

= 0,3822 x 2

= 0,7644

Berdasarkan kapasitas yang dimiliki, untuk kelas "c" diperoleh:

Diameter	=	6	in
Kecepatan putaran	=	100	rpm

(Badger; hal. 712, Fig. 16-20)

Spesifikasi Screw Conveyor 1

Fungsi	:	Memindahkan produk berupa kristal basah dari Sentrifuge menuju Rotary Dryer				
Tipe	:	Plain spouts or chutes, dengan Discharge trough end				
Tekanan	:	1	atm			
Kapasitas / Volume	:	180,1844	cuft			
Diameter	:	6,0000	in			
Panjang Conveyor	:	30,0000	ft	=	9,1436	m
Kecepatan putaran	:	100	rpm			
Power	:	0,7644	hp			
Jumlah	:	1	Unit			

34. ROTARY DRYER

Kode Alat	:	B - 350
Fungsi	:	Mengeringkan Kristal Basah menggunakan udara Kering Panas
Tipe	:	*Single Shell direct Rotary Dryer*
Dasar Pemilihan	:	Cocok untuk Kristal dengan operasi Kontinyu
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4\,(s)}$	91,80%	5.251,4087	1,0734	1.073,4411	67,0149
$C_5H_{12}O_{4\,(aq)}$	0,00%	0,1158	1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$	4,39%	251,0328	2,0200	2.020,0000	126,11
$H_2O_{(l)}$	3,62%	206,8396	1,0229	1.022,8753	63,8581
$CH_2O_{(aq)}$	0,15%	8,6898	0,7261	726,0991	45,3304
$CH_3OH_{(aq)}$	0,04%	2,1137	0,7827	782,6686	48,8620
Total	100%	5.720,2004			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

$= 1,096 \times 63,8581$ lb/cuft

$= 69,9944$ lb/cuft

Rate Massa $= 5.720,2004$ kg/jam

$= 12.611,8978$ lb/jam

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

$$= \frac{12.611,8978 \text{ lb / Jam}}{69,9944 \text{ lb / cuft}}$$

$= 180,1844$ cuft / Jam

***Log Mean Temperature Difference* (LMTD)**

Suhu Bahan Masuk = 30,00 °C = 303,15 K = 86,00 °F

Suhu Bahan Keluar = 47,27 °C = 320,42 K = 117,09 °F

Suhu Udara Masuk = 90,00 °C = 363,15 K = 194,00 °F

Suhu Udara Keluar = 35,00 °C = 308,15 K = 95,00 °F

ΔT_1 = Suhu Bahan Masuk - Suhu Udara Keluar

= 117 °F - 194 °F

= 76,91 °F

ΔT_2 = Suhu Bahan Keluar - Suhu Udara Masuk

= 86 °F - 95 °F

= 9,00 °F

$$\Delta T \text{ LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln \dfrac{\Delta T_2}{\Delta T_1}}$$

$$= \frac{76{,}91 \ °F - 9{,}00 \ °F}{\ln \dfrac{76{,}91 \ °F}{9{,}00 \ °F}}$$

$= 31{,}6536$ °F

Perhitungan Area of Drum (A)

A = π x D x L

= 3,14 x 1,0 m x 4 m

= 12,5600 m^2

= 135,1946 ft^2

$$A_S = \frac{m_S}{\rho_S \quad u_S}$$ ***(Ulrich; hal. 143, dari eq. 4-51)***

Keterangan:

A_S = Luas Penampang yang ditempati komponen solid, m^2

m_S = Mass Flow Rate, kg/detik

ρ_S = Densitas Komponen, kg/m^3

u_S = Kecepatan Aliran, m/detik

= 0,02 - 0,06 m/s

= 0,02 m/s (dipilih)

$$A_S = \frac{1{,}5889 \ kg/s}{1.121{,}2 \ kg/m^3 \times 0{,}02 \ m/s}$$

= 0,0709 m^2

= 0,7627 ft^2

Presentase penampang yang ditempati oleh komponen solid ialah 10% - 15%

Dipilih 15% ***(Ulrich; hal. 132, Tabel 4-10)***

$$\frac{A_S}{15\%} = \frac{1}{4} \pi D^2$$

$$\frac{0{,}0709 \ m^2}{15\%} = \frac{3{,}14}{4} \times D^2$$

D^2 = 0,3708 m^2

D = 0,6090 m ≈ 1,0000 m

= 3,2808 ft

Perhitungan Dimensi Rotary Dryer

Diameter (D) = 1 - 3 m

= 1 m (hasil perhitungan)

Panjang (L) = 4 - 20 m

Rasio (L/D) = 4 - 5
= 4 (dipilih)

Panjang (L) = 4 D
= 4 m *(Ulrich; hal. 132, Tabel 4-10)*
= 13,1240 ft

Perhitungan Putaran Rotary Dryer

$$N = \frac{V}{\pi \times D}$$

Keterangan:

N = Putaran Rotary Dryer, rpm

V = Kecepatan Peripheral, ft/menit
= 0,5 - 0,25 m/s ***(Perry 7th; hal. 12-56)***
= 0,5 m/s (dipilih)
= 98,4250 ft/menit

D = Diameter Rotary Dryer, ft
= 3,2808 ft

$$N = \frac{98{,}4250 \text{ m/s}}{3{,}14 \times 3{,}2808 \text{ ft}}$$

= 9,5541 rpm ≈ 10 rpm

Perhitungan Time of Passes

$$\theta = \frac{0{,}23\ L}{SN^{0.9}\ D} \pm 0{,}6\ \frac{BLG}{F}$$

(Perry 7th; hal. 12-55, eq. 12-55)

$$B = 5\ (D_P)^{-0.5}$$

(Perry 7th; hal. 12-55, eq. 12-56)

Keterangan:

θ = Time of Passes, menit

L = Panjang Drum, m

S = Slope Drum, ft/ft
= 0 - 8 cm/m ***(Perry 7th; hal. 12-56)***
= 8 x 0,01
= 0,08 ft/ft

N = Kecepatan Putaran, rpm

D = Diameter Drum, ft

B = Konstanta Material

G = Rate Massa Udara, $lb/Jam.ft^2$

= 5 - 0,5 $kg/s.m^2$ ***(Perry 7th; hal. 12-55)***

= 1 x 737,3381

= 737,3381 $lb/Jam.ft^2$

F = Rate Solid / Feed, $lb/Jam.ft^2$

$= \dfrac{\text{Rate Massa}}{A_S}$

$= \dfrac{12.611,90 \text{ lb/Jam}}{0,7627 \text{ ft}^2}$

= 16.535,4903 $lb/Jam.ft^2$

= 275,5915 $lb/menit.ft^2$

D_P = Diameter Partikel, µm

= 50 mesh (asumsi)

= 297 µm ***(KM Coating Inc.)***

B = $5\ (D_P)^{-0.5}$

= $5\ (297\ \mu m)^{-0,5}$

= 0,2901

$\theta = \dfrac{0,23\ L}{SN^{0.9}\ D} \pm 0,6\ \dfrac{BLG}{F}$

$= \dfrac{0,23 \times 13,12 \text{ ft}}{0.08 \text{ ft/ft} \times 10 \text{ rpm}^{0.9} \times 1 \text{ m}} \pm 0,6\ \dfrac{0,3 \times 13 \text{ ft} \times 737,3}{16.535,4903 \text{ lb/Jam.ft}^2}$

$= \dfrac{3,0185}{0,6355} + 0,6\ \dfrac{2.807,5318}{16.535,4903}$

= 4,8520 menit

= 0,0809 Jam

Perhitungan Sudut Rotary Dryer

Slope menggunakan nilai yang sama untuk perhitungan Time of Passes

Slope = 0 - 8 cm/m ***(Perry 7th; hal. 12-56)***

$= \dfrac{8}{100}$

= 0,08 m/m

Slope Actual = Slope x Panjang Drum

= 0,08 m/m x 4,00 m

= 0,32 m

tg α = 0,32 m

= 17,74 °

Perhitungan Flight Rotary Dryer

Offset Flight = 0,6 m - 2 m
= 1 m (dipilih) ***(Perry 7th; hal. 12-53)***

Jumlah Flight tiap 1 circle = 2,4 - 3 D
(Perry 7th; hal. 12-54)
= 2,4 D (dipilih)
= 2,4 x 1 m
= 2,4 buah ≈ 3 buah

Jumlah Circle $= \frac{\text{Panjang Drum}}{\text{Offset Flight}}$
$= \frac{4 \text{ m}}{1 \text{ m}}$
= 4 Circle

Total Jumlah Flight = Jumlah Flight tiap Circle x Jumlah Circle
= 3 buah x 4 Circle
= 12 buah

Perhitungan Tebal Shell Drum

Material menggunakan *Carbon Steel SA-283 Grade C*

Stress Allowable (F) = 12.650 psi
(Brownell; hal. 251, Tabel 13.1)

Faktor Korosi (C) = 1/8 in = 0,125

Faktor Pengelasan (E) = 80%
= 0,8 ***(Brownell; hal. 254, Tabel 13.2)***

Tebal Shell digunakan ASME Code

$$ts_{min} = \frac{P \times ri}{F\ E - 0{,}6\ P} + C$$ ***(Brownell; hal. 254, eq. 13-1)***

Keterangan:

ts_{min} = Tebal Shell, in
P = Tekanan Tangki, psi
= 14,6959 psi
ri = Jari-jari tangki, in
= 0,5 D
= 19,6851 in
F = Stress Allowable, psi

= 12.650 psi

E = Faktor Pengelasan

= 0,8

C = Faktor Korosi

= 0,125

$$ts_{min} = \frac{P \times ri}{F\ E - 0{,}6\ P} + C$$

$$= \frac{14{,}70 \text{ psi} \times 19{,}69 \text{ in}}{12.650 \text{ psi} \times 0{,}8 - 0{,}6 \times 14{,}70 \text{ psi}} + 0{,}125$$

= 0,1536 in

$$= \frac{3}{16} \text{ in}$$

Perhitungan Tebal Isolasi

Batu isolasi = 4 cm

= 0,1312 ft

ID Rotary Dryer = 1,0000 m

= 3,2808 ft

OD Rotary Dryer = ID + (2 ts_{min})

= 3,2808 ft + (2 x 0,1536 ft)

= 3,5881 ft

= 43,0567 in

= (digunakan OD = 48 in)

(Brownell; hal. 90, Tabel 5.7)

Diameter Rotary Dryer Terisolasi

= OD + (2 Batu Isolasi)

= 3,5881 ft + (2 x 0,1312 ft)

= 3,8505 ft

Perhitungan Berat Drum

$$W = \frac{\pi}{4} \times (OD^2 - ID^2) \times (L \times \rho)$$

Keterangan:

W = Berat, lb

OD = Diameter Luar, ft

ID = Diameter Dalam, ft

L = Panjang Rotary Dryer, ft

ρ = Densitas Material, lb/cuft

ρ Steel = 0,2790 lb/in^3 ***(Brownell; hal. 341, App. D, Item 3)***

= 482,11 lb/ft^3

ρ alumina = 165,00 lb/ft^3 ***(Perry 7th; hal. 2-119, Tabel 2-118)***

Perhitungan Berat Drum

$$W_S = \frac{3{,}14}{4} \times (3{,}59^2 \text{ ft} - 3{,}28^2 \text{ ft}) \times (13{,}1 \times 482)$$

= 10.481,4896 lb

= 4.753,5100 kg

Perhitungan Berat Isolasi

$$W_i = \frac{3{,}14}{4} \times (3{,}85^2 \text{ ft} - 3{,}59^2 \text{ ft}) \times (13 \times 165)$$

= 3.318,8338 lb

= 1.505,1400 kg

Perhitungan Berat Produk

W_P = Rate Massa x Time of Passes

= 12.611,90 lb/Jam x 0,0809 Jam

= 1.019,8795 lb

= 462,5304 kg

Perhitungan Berat Flight

W_F = n x L x h x t x ρ

Keterangan:

n = Jumlah Flight, buah

= 12 buah

L = Panjang Flight, ft

= 1,00 m

= 3,28 ft

h = Tinggi Flight, ft

= 1/12 - 1/8 ID

= 1/12 (dipilih)

= 0,0833 x 3,2808 ft

= 0,2734 ft

t = Tebal Flight, in

= 3/16 in

ρ = Densitas Flight (Steel), lb/cuft

= 482,11 lb/cuft

W_F = 12 x 3,28 x 0,2734 x 0,188 x 482,11

= 973,0145 lb

= 441,2764 kg

Perhitungan Berat Total Rotary Dryer

W = W_S + W_i + W_P + W_F

= 10.481,5 lb + 3.318,8 lb + 1.019,9 lb + 973,0 lb

= 15.793,2174 lb

= 7.162,4569 kg

= 7,1625 ton

Perhitungan Kebutuhan Power Penggerak

$$bhp = \frac{N\ (4.75\ dw + 0.1925\ DW + 0.33W)}{10.000}$$

Keterangan: ***(Perry 8th; hal. 12-60, eq. 12-60)***

bhp = brake horsepower

= 1 bhp = 0,75 kW

N = Kecepatan putaran, rpm

= 10 rpm

W = Berat Total Rotary Dryer, lb

= 15.793,2174 lb

w = Berat Material (Produk), lb

= 1.019,8795 lb

D = Diameter ring, ft

= OD + 2 ft

= 3,5881 ft + 2 ft

= 5,5881 ft

d = Outside Diameter Drum, ft

= 3,5881 ft

$$bhp = \frac{N\ (4.75\ dw + 0.1925\ DW + 0.33W)}{10.000}$$

$$= \frac{10\ (4.75 \times 3.5 \times 1,041.9)+(0.1925 \times 5.5 \times 15,815)+(0.33 \times 15,815.3)}{10.000}$$

= 39,5827 Hp

= 29,6870 kW

Efisiensi Motor = 80%

$$\text{Power} = \frac{100\%}{80\%} \times 39{,}5827$$

= 49,4783 Hp ≈ 50 Hp

= 37,5000 kW

Spesifikasi Rotary Dryer

Fungsi	:	Mengeringkan Kristal Basah menggunakan udara Kering Panas
Tipe	:	*Single Shell direct Rotary Dryer*
Tekanan	:	1 atm
Kapasitas / Volume	:	180,1844 cuft
Surface Area (A_S)		12,5600 m^2 = 135,1946 ft^2
Time of Passes	:	4,8520 menit
Diameter Drum	:	3,2808 ft
Panjang Drum	:	13,1240 ft
Kecepatan putaran	:	10 rpm
Sudut Kemiringan	:	17,74 ^{o}
Tebal Drum	:	0,1875 in
Bahan Konstruksi	:	*Carbon Steel SA-283, Grade C*
Jumlah Flight	:	12 buah
Berat Rotary Dryer	:	15.793,2174 lb
Power	:	50 Hp
Jumlah	:	1 Unit

35. CYCLONE

Kode Alat	:	H - 351
Fungsi	:	Memisahkan Padatan Kristal yang terbawa Udara Keluar dari *Rotary Dryer*
Tipe	:	*Cyclone-Separator*
Dasar Pemilihan	:	Umum digunakan sebagai pemilah padatan halus
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4\,(s)}$	10,16%	52,5141	1,0734	1.073,4411	67,0149
$C_5H_{12}O_{4\,(aq)}$	0,02%	0,1147	1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$	48,11%	248,5224	2,0200	2.020,0000	126,11
$H_2O_{(l)}$	39,64%	204,7712	1,0229	1.022,8753	63,8581
$CH_2O_{(aq)}$	1,67%	8,6029	0,7261	726,0991	45,3304
$CH_3OH_{(aq)}$	0,41%	2,0926	0,7827	782,6686	48,8620
Total	100%	516,6178			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

= 1,388 x 63,8581 lb/cuft

= 88,6237 lb/cuft

Rate Massa = 516,6178 kg/jam

= 1.139,0390 lb/jam

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

$$= \frac{1.139,0390\ \text{lb / Jam}}{88,6237\ \text{lb / cuft}}$$

= 12,8525 cuft / Jam

= 0,2142 cuft / menit

Komposisi Gas

Komponen	Presentase	m (kg/jam)	ρ (lb/cuft)	V (cuft/Jam)
Udara	100%	3.088,7305	0,0725	223,8750
Total	100%	3.088,7305		

(Haynes 95th; hal. 6-17)

Time of Passes = 30 detik (asumsi)

Volume Cyclone = $(V_S + V_G)$ x Time of Passes

Keterangan:

V_S = Volume Solid, cuft/detik

$$= \frac{12,85\ \text{cuft/Jam}}{3.600}$$

= 0,0036 cuft/detik

V_G = Volume Gas, cuft/detik

= 223,87 cuft/Jam

3.600

= 0,0622 cuft/detik

Volume Cyclone = (0,0036 + 0,0622) x 30 detik

= 1,9727 cuft

Ditetapkan pengisian bahan sebanyak 80% Kapasitas Volume (faktor keamanan)

Volume Bahan = 80% dari Kapasitas Cyclone

$$\text{Volume Cyclone} = \frac{1{,}9727 \text{ cuft}}{80\%}$$

= 2,4659 cuft

Perhitungan Dimensi Cyclone

$H = 4\ D_C$ ***(Perry 8th; hal. 17-29, Fig. 17-36)***

$$V_C = \frac{\pi}{4} \times D_C^2 \times L_C$$

$$2{,}4659 \text{ cuft} = \frac{3{,}14}{4} \times D_C^2 \times 4\ D_C$$

$$= 3{,}14 \times D_C^3$$

D_C^3 = 0,7853

D_C = 0,9226 ft

= 0,2812 m

= 11,0713 in

B_C	=	Diameter Lubang Inlet	=	$D_C / 4$	=	0,0703 m
D_e	=	Diameter Gas Outlet	=	$D_C / 2$	=	0,1406 m
H_C	=	Tinggi Lubang Inlet	=	$D_C / 2$	=	0,1406 m
L_C	=	Panjang Silinder Cyclone	=	$2\ D_C$	=	0,5624 m
S_C	=	Tinggi Gas Outlet	=	$D_C / 8$	=	0,0351 m
Z_C	=	Panjang Conis Cyclone	=	$2\ D_C$	=	0,5624 m
J_C	=	Diameter Dust Outlet	=	$D_C / 4$	=	0,0703 m

(Perry 8th; hal. 17-29, Fig. 17-36)

$$\text{Area Cyclone} = \frac{3{,}14}{4} \times D_C^2$$

$$= \frac{3{,}14}{4} \times 0{,}9226^2 \text{ ft}$$

= 0,6682 ft^2

Perhitungan Kecepatan Bahan

Kecepatan Gas = $\dfrac{\text{Rate Volumetrik Udara}}{}$

$$= \frac{0{,}0622 \text{ cuft/detik}}{0{,}6682 \text{ ft}^2}$$

$= 0{,}0931$ ft/detik

$= 0{,}0284$ m/detik

$$\text{Kecepatan Bahan} = \frac{\text{Total Rate Volumetrik}}{\text{Area Cyclone}}$$

$$= \frac{0{,}0658 \text{ cuft/detik}}{0{,}6682 \text{ ft}^2}$$

$= 0{,}0984$ ft/detik

$= 0{,}0300$ m/detik

Perhitungan Size Partikel Teoritis

$$D_{pth} = \left(\frac{9\ \mu_G\ B_C}{\pi\ N_S\ V_{in}\ (\rho_S - \rho_G)} \right)^{0,5}$$

(Perry 8th; hal. 17-30)

Keterangan:

D_{pth} = Ukuran Partike Teoritis, ft

μ_G = Viskositas Udara, lb/ft.s

= 18,5 μPa.s ***(Haynes 95th; hal. 6-229)***

= 0,1850 cP

= 0,0001243 lb/ft.s

B_C = Diameter Lubang Inlet, ft

= 0,2307 ft

N_S = Velocity Maksimal (belokan udara)

= 0,1 digunakan Velocity lebih besar

≈ 1 ***(Perry 8th; hal. 17-30, Fig. 17-38)***

V_{in} = Kecepatan Komponen Masuk Cyclone, ft/s

= 0,0984 ft/detik

= 0,0300 m/detik

ρ_S = Densitas Padatan, lb/cuft

= 88,6237 lb/cuft

ρ_G = Densitas Udara, lb/cuft

= 0,0725 lb/cuft

$$D_{pth} = \left(\frac{9 \times 0{,}00012 \times 0{,}2}{3{,}1 \times 1 \times 0{,}0984 \times (88{,}62 - 0{,}07)} \right)^{0,5}$$

= 0,0031 ft

= 936,0311 μm

Perhitungan Tebal Shell

Material menggunakan *Carbon Steel SA-283 Grade C*

Stress Allowable (F) = 12.650 psi

(*Brownell; hal. 251, Tabel 13.1)*

Faktor Korosi (C) = 1/8 in = 0,125

Faktor Pengelasan (E) = 80%

= 0,8 **(*Brownell; hal. 254, Tabel 13.2)***

Tebal Shell digunakan ASME Code

$$ts_{min} = \frac{P \times ri}{F\ E - 0{,}6\ P} + C$$

(*Brownell; hal. 254, eq. 13-1)*

Keterangan:

ts_{min} = Tebal Shell, in

P = Tekanan Tangki, psi

= 14,6959 psi

ri = Jari-jari tangki, in

= 0,5 D_C

= 5,5356 in

F = Stress Allowable, psi

= 12.650 psi

E = Faktor Pengelasan

= 0,8

C = Faktor Korosi

= 0,125

$$ts_{min} = \frac{P \times ri}{F\ E - 0{,}6\ P} + C$$

$$= \frac{14{,}70\ \text{psi} \times 5{,}54\ \text{in}}{12.650\ \text{psi} \times 0{,}8 - 0{,}6 \times 14{,}70\ \text{psi}} + 0{,}125$$

= 0,1330 in

= $\frac{3}{16}$ in (Untuk OD = 16 in)

OD = ID + (2 x ts_{min})

= 0,9226 ft + (2 x 0,0111 ft)

= 0,9448 ft

$= \quad 11{,}3374 \text{ in}$

Perhitungan Koreksi Stress Allowable Shell

$$\frac{3}{16} \text{ in} = \frac{14{,}6959 \text{ Psi} \times 5{,}5356 \text{ in}}{f \times 0{,}80 - 8{,}8175 \text{ Psi}} + 0{,}125 \text{ in}$$

$f = 1.638{,}0438 \text{ Psi} < f_{Allowable}$ (memenuhi)

Perhitungan Tebal Tutup

Material menggunakan *Carbon Steel SA-283 Grade C*

Stress Allowable (F) = 12.650 psi

(Brownell; hal. 251, Tabel 13.1)

Faktor Korosi (C) = 1/8 in = 0,125

Faktor Pengelasan (E) = 80%

= 0,8 ***(Brownell; hal. 254, Tabel 13.2)***

Tebal Conical

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

(Brownell; hal. 118, eq. 6-154)

Keterangan:

tc_{min} = Tebal Conical, in

P = Tekanan Tangki, psi

= 14,6959 psi

D = Diameter tangki (D_C), in

= 11,0713 in

α = Sudut Conis, 30 °

F = Stress Allowable, psi

= 12.650 psi

E = Faktor Pengelasan

= 0,8

C = Faktor Korosi

= 0,125

$$tc_{min} = \frac{14{,}6959 \times 11{,}0713}{2 \cos 30 \,(12.650 \times 0{,}8 - 0{,}6 \times 14{,}6959)} + 0{,}13$$

$= 0{,}1772 \text{ in}$

$= \frac{3}{16} \text{ in}$

Perhitungan Koreksi tebal tutup bawah Minimum

$$\frac{3}{16} = \frac{14{,}6959 \text{ Psi} \times 11{,}0713 \text{ in}}{2 \cos 30^{o} \;(f \times 0{,}80 - 8{,}8175 \text{ Psi})} + 0{,}125 \text{ in}$$

$$0{,}2 = \frac{162{,}7022 \text{ Psi}}{1{,}7321 \;(f \times 0{,}80 - 8{,}8175 \text{ Psi})} + 0{,}125 \text{ in}$$

f = 1.889,7449 Psi > $f_{Allowable}$ **(Memenuhi)**

Perhitungan Tinggi Conical

$$h_C = \frac{\tan \alpha \,(D - m)}{2}$$ ***(Hesse; hal. 92, eq.4-17)***

Keterangan:

α = Sudut Conis, 30 ^{o}

D = Diameter Tangki (D_C), ft

m = Flat Spot Diameter = 0,5 ft

$$h_C = \frac{\tan 30^{o} \times (0{,}9226 \text{ ft} - 0{,}5 \text{ ft})}{2}$$

$$= \frac{0{,}5774 \times (0{,}9226 \text{ ft})}{2}$$

= 0,2663 ft

= 0,0812 m

Spesifikasi Cyclone Separator

Fungsi	:	Memisahkan Padatan Kristal yang terbawa Udara Keluar dari Rotary Dryer			
Tipe	:	*Cyclone-Separator*			
Tekanan	:	1 atm			
Kapasitas / Volume	:	236,7275 cuft			
Time of Passes	:	2 detik			
Diameter Silinder Cyclone	=	D_C	=	0,2812	m
Diameter Lubang Inlet	=	B_C	=	0,0703	m
Diameter Gas Outlet	=	D_e	=	0,1406	m
Tinggi Lubang Inlet	=	H_C	=	0,1406	m
Panjang Silinder Cyclone	=	L_C	=	0,5624	m
Tinggi Gas Outlet	=	S_C	=	0,0351	m
Panjang Conis Cyclone	=	Z_C	=	0,5624	m
Diameter Dust Outlet	=	J_C	=	0,0703	m
Tebal Shell	:	3/16 in			
Tebal Conical	:	3/16 in			

Bahan Konstruksi : *Carbon Steel SA-283 Grade C*
Jumlah : 1 Unit

36. BLOWER UDARA

Kode Alat : G - 352
Fungsi : Mengalirkan udara untuk proses pengeringan menuju *Rotary Dryer*
Tipe : *Centrifugal Blower*
Tekanan : 1 atm
Temperatur : 30 °C
Waktu Operasi : Kontinyu

Komposisi

Komponen	Presentase	m (kg/jam)	BM (kg/kmol)	n (kmol)
Udara	100%	3.088,7305	28,96	89.449,6342
Total	100%	3.088,7305		

(Perry 8th; hal. 2-176, Tabel 2-156)

Rate Massa = 3.088,7305 kg/jam
= 6.810,6507 lb/jam
Rate Mol = 89.449,6342 kmol
= 434.906,3575 lbmol
ρ Udara pada 30°C = 1,1610 kg/m^3
= 0,0725 lb/cuft

(Haynes 95th; hal. 6-17)

$$\text{Rate Volumetrik} = \frac{\text{m Udara}}{\rho \text{ Udara}}$$

$$= \frac{6.810,6507 \text{ lb/jam}}{0,0725 \text{ lb/cuft}}$$

= 93.964,3362 cuft/jam
= 1.566,0723 cuft/menit

Jenis Blade = *Radial Straight Blade*

(Perry 8th; hal. 10-49)

Perhitungan Power

Untuk Blower, rentang tekanan 0.5 lb/in^2 - 1.5 lb/in^2

(Perry 8th; hal. 10-49)

Asumsi, digunakan:

Tekanan = 1,5 lb/in2
= 1,5 Psi
= 41,5620 InWC
Hp = 1,57 x 10^{-4} Qp

(Perry 8th; hal. 10-51, eq. 10-84)

Keterangan:
Q = Volume fan, cuft/min
p = Tekanan Operasi fan, InWC
Hp = 1,57 x 10^{-4} x 1.566,0723 cuft/menit x 41,56 InWC
= 10,2190 Hp ≈ 11 Hp

Perhitungan Efisiensi Operasi

Untuk Blower, rentang efisiensi 40% hingga 80%

(Perry 8th; hal. 10-51)

Asumsi, digunakan:
Efisiensi = 80%

$$\text{Efisiensi} = \frac{\text{Power Udara Masuk}}{\text{Power Shaft Masuk}}$$

(Perry 8th; hal. 10-51, eq. 10-85)

$$80\% = \frac{10{,}2190 \text{ Hp}}{\text{Power Shaft Masuk}}$$

Power Shaft = 12,7737 Hp ≈ 13 Hp

Spesifikasi Blower Udara

Fungsi	:	Mengalirkan udara untuk proses pengeringan menuju *Rotary Dryer*
Tipe	:	*Centrifugal Blower*
Tipe Blade	:	*Radial Straight Blade*
Tekanan	:	1 atm
Rate Volumetrik	:	1.566,0723 cuft/menit
Efisiensi	:	80%
Power Udara Masuk	:	11 hp
Power Shaft	:	13 hp
Jumlah	:	1 Unit

37. MOLECULAR SIEVE TRAY

Kode Alat	:	D - 353
Fungsi	:	Mengurangi kelembaban udara yang dialirkan dari *Blower* menuju *Rotary Dryer*
Tipe	:	*Zeolite 4A,* dalam tangki silinder tegak dengan tutup atas dan bawah Torishperical Dish Head
Dasar Pemilihan	:	Umum dengan Fungsi Zeolit untuk menurunkan kadar kelembapan udara
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Kelembapan Udara di Subang, Jawa Barat, Indonesia

Jumat, 21 Februari 2025 = 66% ***(The Weather Channel)***

Rate Humidity = Humidity x Rate Volume Udara
= 66% x 3.088,7305 kg/jam
= 2.038,5621 kg/jam

Diperoleh Zeolite 4A:

Fungsi = Dehidrasi
Bentuk Partikel = Pellet
Densitas = 0,61 - 0,67 kg/L
= 0,61 kg/L (dipilih)
Diameter Pori = 0,40 - 0,40 nm
Luas Permukaan = 0,70 km^2/kg
Kapasitas Penyerapan = 0,22 - 0,26 kg/kg
= 0,26 = 26% ***(Perry 8th; hal. 16-10, Tabel 16-5)***

Perhitungan MS 4A yang diperlukan

$$\text{Kebutuhan per Jam} = \frac{100\%}{\text{Kapasitas Penyerapan}} \times \text{Rate Humidity}$$

$$= \frac{100\%}{26\%} \times 2.038,5621 \text{ kg/jam}$$

$$= 7.840,6235 \text{ kg/jam}$$

Waktu Regenerasi = 3 - 6 jam ***(Chem Enviro)***
= 3 jam (dipilih)

Kebutuhan batch = Kebutuhan per jam x Waktu Regenerasi

= 7.840,6235 kg/jam x 3 Jam
= 23.521,8704 kg

Digunakan sistem bergantian, dimana saat MS 4A sedang beregenerasi, digunakan MS 4A yang lain untuk melanjutkan operasi, Sehingga

Kebutuhan Total = 2 x Kebutuhan Batch
= 2 x 23.521,8704 kg
= 47.043,7409 kg

Perhitungan Volume Tangki

Volume MS 4A = Kebutuhan Batch x Densitas MS 4A
= 23.521,8704 kg x 0,61 kg/L
= 14.348,3410 L
= 506,7041 cuft

Asumsi, Molecular Sieve terisi 80%

Volume Tangki = $\frac{100\%}{80\%}$ x Volume MS 4A
= 633,3802 cuft
= 17,9352 m^3

Perhitungan dimensi Tangki

Asumsi H = 2 D *(Ulrich; hal. 248; Tabel 4-27)*

$V_S = \frac{1}{4} \pi \ Ds^2 \ H_S$

$V_S = \frac{3,14}{4} \times 2 \times Ds^3$

$V_S = 1,57 \ Ds^3$

V tutup atas torispherical dish = 0,000049 Ds^3

(Brownell; hal. 88; eq. 5.11)

V tutup atas = V tutup bawah

Volume Tangki = V_S + 2 V tutup atas
633,3802 cuft = 1,57 Ds^3 + 0,000098 Ds^3
633,3802 cuft = 1,57 Ds^3
Ds^3 = 403,4017 cuft
Ds = 7,3889 ft = 88,6667 in = 2,2521 m
Hs = 14,7778 ft = 177,3334 in = 4,5043 m

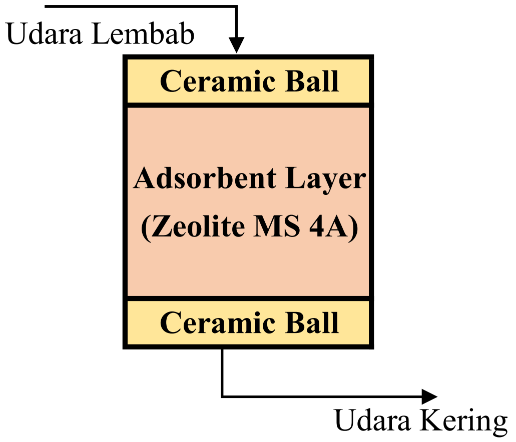
Perhitungan Tinggi Komponen

Volume Bahan = $\frac{1}{\ }$ π Ds^2 $H_{..}$

$$\frac{\pi}{4} \quad Ds^2 \quad H_{liq}$$

$$506{,}7041 \text{ cuft} = \frac{3{,}14}{4} \times 7{,}3889^2 \times H_{liq}$$

$$H_{liq} = 11{,}8230 \text{ ft} = 141{,}8756 \text{ in} = 3{,}6036 \text{ m}$$



Tebal Lapisan Ceramic Ball

Tebal per layer = 2 in
= 0,0508 m
Tebal total = 2 x 0,0508 m
= 0,1016 m

Tinggi Tangki Akhir = Hs + Tebal Total Lapisan Ceramic Ball
= 4,5043 m + 0,1016 m
= 4,6059 m
= 181,3330 in

Spesifikasi Molecular Sieve Tray

Fungsi	:	Mengurangi kelembaban udara yang dialirkan dari *Blower* menuju *Rotary Dryer*
Tipe	:	*Zeolite 4A,* dalam tangki silinder tegak dengan tutup atas dan bawah Torishperical Dish Head
Wujud Zeolite	:	Pellet
Tekanan	:	1 atm
Kapasitas / Volume	:	506,7041 cuft
Diameter Tangki	:	88,6667 in
Tinggi Tangki	:	181,3330 in
Jumlah	:	1 Unit

38. HEATER UDARA

Kode Alat : E - 354
Fungsi : Memanaskan Udara Kering sebelum memasuki Rotary Dryer
Tipe : Shell and Tube Heat Exchanger
Dasar Pemilihan : Umum digunakan untuk proses perpindahan panas
Tekanan : 1 atm
Temperatur : 55 °C
Waktu Operasi : Kontinyu

Komposisi Masuk

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
Udara	100%	3.088,7305	0,0012	1,1610	0,0725
Total	100%	3.088,7305			

ρ Udara pada 30°C = 1,1610 kg/m^3
= 0,0725 lb/cuft
(Haynes 95th; hal. 6-17)

Rate Massa = 3.088,7305 kg/jam
= 6.810,0329 lb/jam

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

= $\frac{6.810,0329 \text{ lb / Jam}}{0,0725 \text{ lb / cuft}}$

= 93.955,8134 cuft / Jam

sg Bahan = $\frac{\rho \text{ Bahan}}{\rho \text{ Reference (Udara)}}$

= $\frac{0,1 \text{ lb/cuft}}{0,1 \text{ lb/cuft}}$

= 1,0000

Viskositas Udara = 0,0180 Cps
(Kern; hal. 825; Fig. 15)

Heat Balance

Panas yang dibutuhkan : 205.276,8444 kJ/Jam
194.575,2079 Btu/Jam
Steam yang digunakan : 94,4409 kg/Jam
208,2423 lb/Jam

Log Mean Temperature Difference (LMTD)

Suhu bahan masuk, t_1 = 30 °C = 86 °F
Suhu banah keluar, t_2 = 90 °C = 194 °F
Suhu steam masuk, T_1 = 130 °C = 266 °F
Suhu steam kondensat, T_2 = 130 °C = 266 °F

$\Delta T_1 = T_2 - t_2$

$\Delta T_2 = T_1 - t_1$ ***(Kern; hal. 90)***

$\Delta T_1 = 266\ °F - 194\ °F$
$= 72\ °F$

$\Delta T_2 = 266\ °F - 86\ °F$
$= 180\ °F$

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}$$ ***(Kern; hal. 89; eq. 5.14)***

$= 117{,}8665\ °F$

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$ ***(Kern; hal. 142)***

$$= \frac{266\ °F - 266\ °F}{194\ °F - 86\ °F}$$

$= 0{,}0000\ °F$

$$S = \frac{t_2 - t_1}{T_1 - t_1}$$ ***(Kern; hal. 142)***

$$= \frac{194\ °F - 86\ °F}{266\ °F - 86\ °F}$$

$= 0{,}6000\ °F$

$F_T = 1$ ***(Kern; hal. 828; Fig. 18)***

$\Delta t = F_T \times LMTD$ ***(Kern; hal. 149; eq. 7.42)***
$= 1 \times 117{,}87\ °F$
$= 117{,}87\ °F$

Perhitungan T_C dan t_C dipakai Temperature rata-tata

T_C = $T_{Average}$ Steam ***(Kern; hal. 113)***

$$= \frac{266\ °F + 266\ °F}{2}$$

$= 266\ °F$

t_C = $t_{Average}$ Bahan ***(Kern; hal. 113)***

$$= \frac{86\ °F + 194\ °F}{2}$$

$= 140\ °F$

Trial

Asumsi U_D untuk Udara (Gases)

$U_D = 5 - 50$ Btu/jam.ft^2.°F

$= 50$ Btu/jam.ft^2.°F ***(Kern; hal. 840; Tabel. 8)***

$$A = \frac{Q}{\Delta t \times U_D}$$ ***(Kern; hal. 107; eq. 6.11)***

$$= \frac{194.575,2079 \text{ Btu/Jam}}{117,9\ °F \times 50 \text{ Btu/jam.ft}^2.°F}$$

$= 33,0162$ ft^2

$= 4.754,3323$ in^2

Digunakan OD pipa 3/4 in, sehingga diperoleh:

a" = 0,1963 ft^2/lin ft ***(Kern; hal. 843; Tabel. 10)***

Digunakan panjang pipa:

L = 40 ft = 480 in ***(Kern; hal. 103)***

Number of tubes

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

$$= \frac{33,0162 \text{ ft}^2}{40 \text{ ft} \times 0,1963 \text{ ft}^2\text{/lin ft}}$$

$= 4,2048 \approx 5$

Dipilih:

Tube		Shell	
OD	= 3/4 in	Pitch	= 1 in
BWG	= 16	Shell ID	= 8 in
a't	= 0,302 in^2	Passes	= 1
a"	= 0,1963 Surface / lin ft, ft^2	Nt	= 37
		B Space	= 2 in
Passes	= 2	OD	= 3/4 in
ID	= 0,620 in		
Wall Thicness	= 0,065 in		

(Kern; hal. 843; Tabel. 10) ***(Kern; hal. 842; Tabel. 9)***

A baru = Nt x L x a" ***(Kern; hal. 150)***

$= 37 \times 40 \text{ ft} \times 0{,}1963$ Surface / lin ft, ft^2

$= 290{,}52 \ ft^2$

$$U_D \text{ baru} = \frac{Q}{A \text{ baru} \times \Delta T_{LMTD}}$$

$$= \frac{194.575{,}2079 \text{ Btu/Jam}}{290{,}52 \ ft^2 \times 117{,}87 \ °F}$$

$= 5{,}6822$ Btu/jam.ft^2.°F

Cold Fluid (Tube)	**Hot Fluid (Shell)**
Asetaldehid	**Steam**
(4) Flow Area Tube (a_t)	(4') Flow Area Shell (a_s)
$a_t = \frac{Nt \times a't}{144 \times n}$	$C'' = \text{Pitch} - \text{OD}$
$= \frac{37 \times 0{,}3}{144 \times 2}$	$= 1 \text{ in} - 3/4 \text{ in}$
$= 0{,}0388 \ ft^2$	$= 1/4 \text{ in}$
	$B = ID = \frac{8}{5}$
	$= 2 \text{ in}$
	$a_s = \frac{ID \times C'' \times B}{144 \ Pr}$
	$= \frac{8 \text{ in} \times 1/4 \text{ in} \times 2 \text{ in}}{144 \times 1 \text{ in}}$
	$= 0{,}0222 \ ft^2$
(5) Mass Velocity Tube (Gt)	(5) Mass Velocity Shell (Gs)
$G_t = \frac{W_{bahan}}{a_t}$	$G_s = \frac{W_{steam}}{a_s}$
$= \frac{6.810{,}0 \text{ lb/Jam}}{0{,}0388 \ ft^2}$	$= \frac{208{,}2 \text{ lb/Jam}}{0{,}0222 \ ft^2}$
$= 175.522{,}5954$ lb/Jam.ft^2	$= 9.370{,}9031$ lb/Jam.ft^2
(6) Pada t_C = 140,0 °F	(6') Pada T_C = 266,0 °F
μ = 0,0180 cps	μ = 0,0135 cps
= 0,0436 lbm/Jam.ft	***(Kern; hal. 825; Fig. 15)***
D_i = 0,62 in	= 0,0327 lbm/Jam.ft

$= 0{,}0517$ ft

$Re_t = \dfrac{D \times G_t}{\mu}$

$= \dfrac{0{,}05 \text{ ft} \times 175.523 \text{ lb/Jam.ft}^2}{0{,}0436 \text{ lbm/Jam.ft}}$

$= 208.187{,}9575$

(7) Heat Transfer Factor

$j_H = 550$

(Kern; hal. 834; Fig. 24)

(8) Konduktivitas Thermal pada t_C

$k = 0{,}0264$ W/(m K)

$= 0{,}0457$ Btu/Jam.ft^2.°F

(Perry 8th; hal. 2-213 Tabel 2-187)

$Cp = 0{,}25$ Btu/lb°F

(Kern; hal. 805; Fig. 3)

$\left(\dfrac{Cp \times \mu}{k}\right)^{1/3} = 0{,}6210$

(9) Condensation of Steam

$h_i = j_H \dfrac{k}{D_i} \left(\dfrac{Cp \times \mu}{k}\right)^{1/3} \varphi_t$

(Kern; hal. 111; eq. 6.15a)

$= 414{,}7157$ Btu/Jam.ft^2.°F

$h_{io} = h_i \dfrac{ID}{OD}$

(Kern; hal. 105; eq. 6.5)

$= 342{,}8316$ Btu/Jam.ft^2.°F

(10) Pada $t_w = 260{,}1668$ °F

$\mu_w = 0{,}0180$ Cps

$= 0{,}0436$ lbm/Jam.ft

$D_e = 0{,}73$ in

$= 0{,}0608$ ft

$Re_s = \dfrac{D_e \times G_s}{\mu}$

$= \dfrac{0{,}06 \text{ ft} \times 9.371 \text{ lb/Jam.ft}^2}{0{,}0327 \text{ lbm/Jam.ft}}$

$= 17.449{,}1359$

(7') Heat Transfer Factor

$j_H = 75$

(Kern; hal. 838; Fig. 28)

(8') Konduktivitas Thermal pada t_C

$k = 0{,}0133$ Btu/Jam.ft^2.°F

(Yaws; hal. 551; Tabel 24-2)

$Cp = 0{,}46$ Btu/lb°F

(Kern; hal. 805; Fig. 3)

$\left(\dfrac{Cp \times \mu}{k}\right)^{1/3} = 1{,}0368$

(9') Condensation of Steam

$h_o = j_H \dfrac{k}{D_e} \left(\dfrac{Cp \times \mu}{k}\right)^{1/3} \varphi_s$

(Kern; hal. 112; eq. 6.15b)

$= 16{,}6421$ Btu/Jam.ft^2.°F

(10') Tube Wall Temperature

$t_w = t_c + \dfrac{h_{io}}{h_{io} + h_o} (T_c - t_c)$

$\varphi_t = \left(\frac{\mu}{\mu_w}\right)^{0,14}$ $= \left(\frac{0,0436 \text{ °F}}{0,0436 \text{ °F}}\right)^{0,14}$ $=$ 1,0000 Btu/Jam.ft^2.°F (12) Corrected Coefficient $h_{io} = \frac{h_{io}}{\varphi_t} \times \varphi_t$ ***(Kern; hal. 121; eq. 6.37)*** $=$ 342,8316 Btu/Jam.ft^2.°F	$=$ 260,1668 °F

(13) Clean Overall Coefficient

$$U_C = \frac{h_{io} \times h_o}{h_{io} + h_o}$$

(Kern; hal. 121; eq. 6.38)

$$= \frac{342{,}8 \text{ Btu/jam.ft}^2.°\text{F} \times 16{,}6421}{342{,}8 \text{ Btu/jam.ft}^2.°\text{F} + 16{,}6421}$$

$=$ 15,8716 Btu/jam.ft^2.°F

(14) Dirt Factor, Rd

$$R_d = \frac{U_C - U_D}{U_C \times U_D}$$

(Kern; hal. 108; eq. 6.13)

$$= \frac{15{,}9 \text{ Btu/jam.ft}^2.°\text{F} - 5{,}7 \text{ Btu/jam.ft}^2.°\text{F}}{15{,}9 \text{ Btu/jam.ft}^2.°\text{F} \times 5{,}7 \text{ Btu/jam.ft}^2.°\text{F}}$$

$=$ 0,1130

Untuk R_d data, digunakan "Brackish Water" atau Air Payau dengan R_d

R_d data $=$ 0,002 - 0,001 ***(Kern; hal. 845; Tabel 12)***

R_d perhitungan $> R_d$ data

0,113 $>$ 0,002

Maka, desain dapat digunakan

Cold Fluid	**Hot Fluid**
Asetaldehid	**Steam**
Pressure Drop	

(a) Untuk Re_t = 208.187,9575	(a') Untuk Re_s = 17.449,1359
f = 0,0001	f = 0,0018
(Kern; hal. 836; Fig. 26)	***(Kern; hal. 839; Fig. 29)***
s = 1,0000	s = 1,0000
	(Kern; hal. 808; Tabel. 6)
	(b') Number of times fluid crosses
	$N+1 = \frac{\text{Tube Length}}{\text{Baffle Space}} = \frac{12 \times L}{B}$
	(Kern; hal. 147; eq. 7.43)
	$= \frac{480 \text{ in}}{2 \text{ in}}$
	= 240
(c) Pressure drop in Tube or Pipes	(c') Pressure drop in Shell side
$\Delta P_t = \frac{f \times G_t^2 \times L \times n}{5.22 \times 10^{10} \times D_i \times s \times \varphi_t}$	$\Delta P_s = \frac{f \times G_s^2 \times D_s (N+1)}{5.22 \times 10^{10} \times D_e \times s \times \varphi_s}$
(Kern; hal. 148; eq. 7.45)	***(Kern; hal. 147; eq. 7.44)***
$= \frac{147.879.271,2}{2.697.000.000}$	$= \frac{2.307.747}{3.175.500.000}$
= 0,0548 Psi	= 0,0007 Psi
ΔP_t < 10 psi	ΔP_s < 10 psi
(memenuhi)	(memenuhi)

Spesifikasi Heater Udara

Fungsi	:	Memanaskan Udara Kering sebelum memasuki Rotary Dryer			
Tipe	:	Shell and Tube Heat Exchanger			
Tube					
Inside Diameter	:	0,62	in =	0,0157	m
Outside Diameter	:	3/4	in =	0,0191	m
Panjang	:	40	ft =	12,1914	m
Jumlah Tube	:	5 buah			
Shell					
Pitch	:	1	in =	0,0254	m

Inside Diameter	:	8	in =	0,2032 m
OD Shell	:	3/4	in =	0,0191 m
Jumlah Heater	:	1 buah		

39. COOLING SCREW CONVEYOR

Kode Alat	:	J - 355
Fungsi	:	Memindahkan produk berupa kristal kering dari *Rotary Dryer* dan *Cyclone* menuju *Ball Mill*
Tipe	:	Plain spouts or chutes, dengan Discharge trough end
Dasar Pemilihan	:	Umum digunakan untuk pemindahan komponen padatan halus, tidak lengket
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4\,(s)}$	99,47%	5.248,7830	1,0734	1.073,4411	67,0149
$C_5H_{12}O_{4\,(aq)}$	0,0001%	0,0069	1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$	0,28%	14,9364	2,0200	2.020,0000	126,11
$H_2O_{(l)}$	0,23%	12,3070	1,0229	1.022,8753	63,8581
$CH_2O_{(aq)}$	0,01%	0,5170	0,7261	726,0991	45,3304
$CH_3OH_{(aq)}$	0,00%	0,1258	0,7827	782,6686	48,8620
Total	100,00%	5.276,6761			

$$\rho \text{ Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho \text{ Komponen (g/ml)}}} \times \frac{\rho \text{ Pelarut}}{\text{(lb/cuft)}}$$

$$= 1{,}075 \times 63{,}8581 \text{ lb/cuft}$$

$$= 68{,}6394 \text{ lb/cuft}$$

$$\text{Rate Massa} = 5.276{,}6761 \text{ kg/jam}$$

$$= 11.634{,}0155 \text{ lb/jam}$$

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

$$= \frac{11.634{,}0155 \text{ lb / Jam}}{68{,}6394 \text{ lb / cuft}}$$

= 169,4947 cuft / Jam

Untuk densitas 68,6394 lb/cuft, digunakan kelas c

diperoleh F = 2,0 - 2,5 ***(Badger; hal. 711, Tabel 16-6)***

= 2,0 (dipilih)

Perhitugnan Power Motor

$$hp = \frac{C\,L\,W\,F}{33.000}$$ ***(Badger; hal. 713, eq. 16-4)***

Keterangan:

C = Kapasitas (cuft/m)

L = Panjang (ft)

W = Berat Meterial (lb/cuft)

F = Faktor Konstanta (Tabel 16-6)

Asumsi panjang = 30 ft

$$hp = \frac{2{,}8249 \text{ cuft/m} \times 30 \text{ ft} \times 68{,}6394 \text{ lb/cuft} \times 2{,}0}{33.000}$$

= 0,3525

Untuk power (hp) dibawah 2, maka dikalikan 2 ***(Badger; hal. 713)***

= 0,3525 x 2

= 0,7051

Berdasarkan kapasitas yang dimiliki, untuk kelas "a" diperoleh:

Diameter = 6 in

Kecepatan putaran = 100 rpm

(Badger; hal. 712, Fig. 16-20)

Spesifikasi Cooling Screw Conveyor

Fungsi	:	Memindahkan produk berupa kristal kering dari Rotary Dryer dan Cyclone menuju Ball Mill
Tipe	:	Plain spouts or chutes, dengan Discharge trough end
Tekanan	:	1 atm
Kapasitas / Volume	:	169,4947 cuft
Diameter	:	6,00 in
Panjang Conveyor	:	30,00 ft
Kecepatan putaran	:	100,00 rpm
Power	:	0,7051 hp
Jumlah	:	1 Unit

40. BUCKET ELEVATOR 2

Kode Alat	:	J - 356
Fungsi	:	Memindahkan Produk dari *Ball Mill* menuju Gudang Penyimpanan Pentaeritritol
Tipe	:	*Continous Bucket Elevator*
Dasar Pemilihan	:	Umum dan cocok untuk transportasi vertikal komponen padatan
Tekanan	:	1 atm
Temperatur	:	30 °C
Waktu Operasi	:	Kontinyu

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4\,(s)}$	99,47%	5.248,7830	1,0734	1.073,4411	67,0149
$C_5H_{12}O_{4\,(aq)}$	0,00%	0,0069	1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$	0,28%	14,9364	2,0200	2.020,0000	126,11
$H_2O_{(l)}$	0,23%	12,3070	1,0229	1.022,8753	63,8581
$CH_2O_{(aq)}$	0,01%	0,5170	0,7261	726,0991	45,3304
$CH_3OH_{(aq)}$	0,00%	0,1258	0,7827	782,6686	48,8620
Total	100%	5.276,6761			

Digunakan Bucket Elevator :

Ukuran Bucket	=	Lebar x Proyeksi x Kedalaman
	=	6 x 4 x 4 1/4 in
Jarak antar Bucket	=	12 in
Tinggi Elevator	=	25 ft
Kapasitas Maksimum	=	14 ton/jam
	=	14.000 kg/jam
Kecepatan Bucket	=	225 ft/min
	=	68,6 m/min
Putaran Head Shaft	=	43 r/min
Lebar Belt	=	7 in
Power yang dibutuhkan	=	1 hp untuk head shaft
Power tambahan	=	0,02 hp/ft ***(Perry 7th; hal. 21-15; Tabel 21-8)***
	=	0,02 x 25 ft
	=	0,5 hp
Total Power	=	Power Head Shaft + Power Tambahan

	=	1 hp + 0,5 hp
	=	1,5 hp
Efisiensi Motor	=	80%

$$\text{Power yang dibutuhkan} = \frac{\text{Total Power}}{\text{Efisiensi Motor}} = \frac{1{,}5 \text{ hp}}{80\%} = 1{,}875 \text{ hp}$$

Perhitungan Kecepatan Bucket Elevator

$$\text{Kecepatan Bucket} = \frac{\text{Rate Massa}}{\text{Kapasitas maksimum}} \times \text{Kecepatan Bucket}$$

$$= \frac{5.276{,}6761 \text{ kg/jam}}{14.000{,}0000 \text{ kg/jam}} \times 225 \text{ ft/mir}$$

$$= 84{,}80 \text{ ft/min}$$

Spesifikasi Bucket Elevator 2

Fungsi	=	Memindahkan Produk dari Ball Mill menuju Gudang Penyimpanan Pentaeritritol
Tipe	=	*Continous Bucket Elevator*
Tekanan	=	1 atm
Kapasitas / Volume	=	14 ton/jam
Ukuran Bucket	=	6 x 4 x 4 1/4 in
Tinggi Elevator	=	25 ft
Kecepatan Bucket	=	84,80 ft/min
Putaran Head Shaft	=	43 r/min
Power yang dibutuhkan	=	1,8750 hp
Jumlah	=	1 Unit

41. GUDANG PENAMPUNGAN PENTAERITRITOL

Kode Alat	:	J-357
Fungsi	:	Menampung Pentaeritritol hasil Produksi sebelum Didistribusikan kepada Pembeli
Tipe	:	Bangunan Persegi empat, dengan atap Limas segi 4, dan lantai rata
Dasar Pemilihan	:	Ekonomis dan umum digunakan untuk Padatan
Tekanan	:	1 atm

Temperatur : 30 °C

Waktu Penyimpanan : 7 hari

Komposisi

Komponen	Fraksi	m (kg/jam)	ρ (g/ml)	ρ (kg/m^3)	ρ (lb/ft^3)
$C_5H_{12}O_{4\,(s)}$	99,47%	5.248,7830	1,0734	1.073,4411	67,0149
$C_5H_{12}O_{4\,(aq)}$	0,0001%	0,0069	1,0734	1.073,4411	67,0149
$Ca(HCOO)_{2(aq)}$	0,28%	14,9364	2,0200	2.020,0000	126,11
$H_2O_{(l)}$	0,23%	12,3070	1,0229	1.022,8753	63,8581
$CH_2O_{(aq)}$	0,01%	0,5170	0,7261	726,0991	45,3304
$CH_3OH_{(aq)}$	0,00%	0,1258	0,7827	782,6686	48,8620
Total	100%	5.276,6761			

$$\rho\ \text{Campuran} = \frac{1}{\Sigma \dfrac{\text{Fraksi Massa}}{\rho\ \text{Komponen (g/ml)}}} \times \frac{\rho\ \text{Pelarut}}{\text{(lb/cuft)}}$$

= 1,075 x 63,8581 lb/cuft

= 68,6394 lb/cuft

Rate Massa = 5.276,6761 kg/jam

= 11.634,0155 lb/jam

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

$$= \frac{11.634{,}0155\ \text{lb / Jam}}{68{,}6394\ \text{lb / cuft}}$$

= 169,4947 cuft / Jam

Volume Komponen = Rate Volumetrik x Waktu Penyimpanan

= 169,49 cuft / Jam x 7 hari

= 28.475,1087 cuft

= 806,3177 m^3

= 806.323,9579 Liter

Dilakukan pengisian bahan sebanyak 80% volume (faktor keamanan)

Volume Bahan = 80% dari volume Gudang

$$\text{Volume Gudang (V)} = \frac{28.475{,}1087\ \text{cuft}}{80\%}$$

= 35.593,8859 cuft

Perhitungan Dimensi Gudang

Dipilih rasio:

Panjang (P)	=	3 H				
Lebar (L)	=	3 H				
Tinggi (H)	=	H				
V	=	3 H x	3 H	x H		
35.594 cuft	=	$9\ X^3$				
H^3	=	3.954,9	ft^3			
Tinggi (H)	=	15,8141	ft	=	4,8199	m
Panjang (P)	=	47,4423	ft	=	14,4597	m
Lebar (L)	=	47,4423	ft	=	14,4597	m

Atap dari Asbes dengan kemiringan 30º

$$\text{Tinggi Atap} = \tan 30 \times \frac{L}{2}$$

$$= 0{,}1263 \text{ m}$$

Spesifikasi Gudang Penampungan Pentaeritritol

Fungsi	:	Menampung Pentaeritritol hasil Produksi sebelum Didistribusikan kepada Pembeli
Tipe	:	Bangunan Persegi empat, dengan atap Limas segi 4, dan lantai rata
Tekanan	:	1 atm
Waktu Penyimpanan	:	7 hari
Kapasitas / Volume	:	35.593,8859 cuft
Panjang	:	14,4597 m
Lebar	:	14,4597 m
Tinggi	:	4,8199 m
Tinggi Atap	:	0,1263 m
Bahan konstruksi	:	Concrete (beton) dengan atap Asbes
Jumlah	:	1 Gudang

APPENDIX D
PERHITUNGAN ANALISA EKONOMI

Kapasitas Produksi	=	42.000 ton/tahun			
Waktu Operasi	=	1 tahun	=	331	hari
	=	1 hari	=	24	jam

Kapasitas Produksi	=	42.000	ton/tahun
	=	5,2870	ton / jam
	=	5.287,0091	kg / jam
Basis Asetaldehid (99%)	=	1.717,0000	kg / jam

Komponen	Rate Volumetrik	
	kg/Jam	kg/hari
Bahan Baku		
Formaldehid(37%)	14.091,5248	338.196,5942
Asetaldehid (99%)	1.717,0000	41.208,0000
Kalsium Hidroksida (99%)	3.009,8463	72.236,3115
Asam Format (99%)	1.973,1214	47.354,9143
Produk Utama		
Pentaeritritol (99%)	5.276,0333	126.624,7996
Produk Samping		
Kalsium Format	4.769,6224	114.470,9381
Methanol	140,9152	3.381,9659

Analisa Ekonomi digunakan untuk pertimbangan kelayakan pendirian Pabrik, dalam artian Feasible (memenuhi) :

1. Laju Pengembalian Modal (Rate of Return, **ROR**)
2. Laju Investasi yang Sehat (Rate of Investment, **ROI**)
3. Lama Pengembalian Modal (Pay-Out Period)
4. Titik Impas (Break Even Point, **BEP**)

Diperlukan penaksiran / perhitungan terhadap beberapa faktor antara lain :

1. Penaksiran Modal Industri (Total Capital Investment, **TCI**)
   a. Modal Tetap (Fixed Capital Investment, **FCI**)
   b. Modal Kerja (Working Capital Investment, **WCI**)

2. Penentuan biaya Produksi (Production Cost)
    a. Biaya Pembuatan (Manufacturing Cost)
    b. Biaya Pengeluaran Umum (General Expenses)
3. Total Pendapatan

I. PERHITUNGAN PERALATAN

Harga peralatan berubah menurut waktu resmi sesuai dengan kondisi perekonomian dunia. Untuk memperkirakan harga peralatan, digunakan persamaan :

$$C_p = \frac{I_p}{I_o} \times C_o$$

Keterangan :

C_p = Harga Alat pada Tahun 2028

I_p = Cost Index pada Tahun 2028

C_o = Harga Alat pada Tahun 2024

I_o = Cost Index pada Tahun 2024

Cost Index diperoleh dari Data *Chemical Engineering Plant Cost Index* (CEPCI)

Tabel D. 1. Cost Index

Tahun	Index
2013	567,3
2014	576,1
2015	556,8
2016	541,7
2017	567,5
2018	603,1
2019	607,5
2020	596,2
2021	708,8
2022	816,0
2023	800,8

(University of Manchester; Departement of Chemical Engineering; Chemical Engineering Plant Cost Index)

Digunakan metode *Least Square* dari data *Cost Index* pada Tabel D. 1. menggunakan persamaan :

Y = a + bX

Keterangan :

Y = Cost Index pada tahun ke-n

X = Tahun ke-n

n	X	Y	X^2	Y^2	XY
1	2014	576,1	4.056.196	331.891	1.160.265
2	2015	556,8	4.060.225	310.026	1.121.952
3	2016	541,7	4.064.256	293.439	1.092.067
4	2017	567,5	4.068.289	322.056	1.144.648
5	2018	603,1	4.072.324	363.730	1.217.056
6	2019	607,5	4.076.361	369.056	1.226.543
7	2020	596,2	4.080.400	355.454	1.204.324
8	2021	708,8	4.084.441	502.397	1.432.485
9	2022	816,0	4.088.484	665.856	1.649.952
10	2023	800,8	4.092.529	641.281	1.620.018
Total	20.185	6.375	40.743.505	4.155.187	12.869.310

Jumlah Data (n) = 10

Perhitungan Index Harga

Digunakan metode Least Square

$$\sum (\bar{x} - x)^2 = \sum x^2 - \frac{(\sum x)^2}{n}$$

(Peters 4th; hal. 760; eq. 17-21)

$$= 40.743.505,0 - \frac{407.434.225,0}{10}$$

$$= 82,5000$$

$$\sum (\bar{y} - y)^2 = \sum y^2 - \frac{(\sum y)^2}{n}$$

(Peters 4th; hal. 760; eq. 17-21)

$$= 4.155.187,0 - \frac{40.634.250,3}{10}$$

$$= 91.761,9450$$

$\sum (\bar{x} - x)(\bar{y} - y) = \sum xy - \dfrac{\sum x \sum y}{n}$ ***(Peters 4th; hal. 760; eq. 17-20)***

$= 12.869.309,6 - \dfrac{128.669.282,5}{10}$

$= 2.381,3500$

$b = \dfrac{\sum (\bar{x} - x)(\bar{y} - y)}{\sum (\bar{x} - x)^2}$ ***(Peters 4th; hal. 760)***

$= \dfrac{2.381,35}{82,5}$

$= 28,8648$

Rata - rata x (c) $= \dfrac{\sum x}{n} = 2.018,5000$

Rata - rata y (a) $= \dfrac{\sum y}{n} = 637,4500$

$y = a + b(X - c)$

$= 637,5 + 28,9 \times (X - 2.018,5)$

$= 637,5 + 28,9 X - 58.263,7$

$= -57.626,2 + 28,9 X$

Dimana X = tahun, maka

$X = 2028$

$y = -57.626,2 + 28,9 (2028)$

$= 911,7$

Maka, index untuk tahun 2028 = 911,7

$X = 2025$

$y = -57.626,2 + 28,9 (2025)$

$= 825,1$

Maka, index untuk tahun 2025 = 825,1

Pada Website Bank Indonesia, diperoleh nilai Kurs Beli USD ($)

Kurs = 1 $ = Rp 16.151,83 ***(Bank Indonesia, 30 Juni 2025)***

= 1 ¥ = Rp 2.253,51 ***(Bank Indonesia, 30 Juni 2025)***

Perhitungan Harga Peralatan

Index harga pada 2025 = $ 825,07

Index harga pada 2028 = $ 911,67

$$\text{Harga (2028), \$} = \frac{\text{Index 2028}}{\text{Index X}} \times \text{Harga Alat pada X}$$

Untuk Bak Beton, digunakan acuan harga milik Alit Mix, Cor-Ready K250

Harga = Rp 985.000,00 /m^3

= $ 60,98 /m^3

Tabel D. 1. Harga Peralatan Proses

No	Kode	Nama Alat	Harga Unit (USD)		Jml	Harga Unit
			2025	2028		(USD)
1	F-110	Tangki Penyimpanan Formaldehid	200.000	220.991	6	1.325.945
2	L-111	Pompa 1	4.117	4.549	1	4.549
3	E-112	Heater 1	1.850	2.044	1	2.044
4	F-120	Tangki Penyimpanan Asetaldehid	20.000	22.099	2	44.198
5	L-121	Pompa 2	3.824	4.225	1	4.225
6	E-122	Heater 2	1.850	2.044	1	2.044
7	F-130	Gudang Penyimpanan Kalsium Hidroksida	53.662	59.294	1	59.294
8	J-131	Bucket Elevator 1	1.800	1.989	1	1.989
9	F-132	Hopper	10.000	11.050	1	11.050
10	M-133	Tangki Pencampuran	10.000	11.050	1	11.050
11	L-134	Pompa 3	3.824	4.225	1	4.225
12	E-135	Heater 3	1.850	2.044	1	2.044
13	F-140	Tangki Penyimpanan Asam Format	200.000	220.991	2	441.982
14	L-141	Pompa 4	3.824	4.225	1	4.225
15	E-142	Heater 4	1.850	2.044	1	2.044

16	R-210	Reaktor Reaksi	50.000	55.248	1	55.248
17	L-211	Pompa 5	4.665	5.155	1	5.155
18	R-220	Reaktor Netralisasi	50.000	55.248	1	55.248
19	L-221	Pompa 6	3.824	4.225	1	4.225
20	V-310	Evaporator Efek Pertama	80.000	88.396	1	88.396
21	V-320	Evaporator Efek Kedua	80.000	88.396	1	88.396
22	E-321	Kondensor	2.000	2.210	1	2.210
23	G-322	Steam Jet Ejector	18.666	20.625	1	20.625
24	F-323	Hot Well	199	220	1	220
25	L-324	Pompa 8	3.824	4.225	1	4.225
26	S-330	Kristallizer	30.000	33.149	1	33.149
27	H-340	Sentrifuge	50.000	55.248	1	55.248
28	F-341	Tangki Penampungan Mother Liquor	200.000	220.991	5	1.104.954
29	J-342	Screw Conveyor 1	2.999	3.314	1	3.314
30	B-350	Rotary Dryer	130.000	143.644	1	143.644
31	H-351	Cyclone	10.000	11.050	1	11.050
32	G-352	Blower Udara	6.480	7.160	1	7.160
33	D-353	Molecular Sieve Tray	2.650	2.928	1	2.928
34	E-354	Heater 6	1.850	2.044	1	2.044
35	J-355	Cooling Screw Conveyor	3.500	3.867	1	3.867
36	J-362	Bucket Elevator 2	1.800	1.989	1	1.989
37	F-363	Gudang Penampungan Pentaeritritol	58.252	64.366	1	64.366
Total						3.678.568

Tabel D. 2. Harga Peralatan Utilitas

No	Kode	Nama Alat	Harga Unit (USD) 2014	Harga Unit (USD) 2028	Jmlh	Harga Unit (USD)
1	F-110	Bak Penampung Air Payau	916	1.012	2	2.025
2	L-111	Pompa 1	3.824	4.225	1	4.225
3	L-112	Pompa 2	3.824	4.225	1	4.225
4	M-210	Tangki Koagulasi	10.000	11.050	1	11.050
5	L-211	Pompa 3	3.824	4.225	1	4.225
6	M-220	Tangki Flokulasi	10.000	11.050	1	11.050
7	L-221	Pompa 4	3.824	4.225	1	4.225
8	H-310	Tangki Clarifier	10.700	11.823	1	11.823
9	F-311	Bak Penampung Flok	534	590	1	590
10	F-312	Bak Penampung Air Jernih	465	514	1	514
11	L-313	Pompa 5	3.824	4.225	1	4.225
12	H-320	Sand Filter	3.000	3.315	2	6.630
13	F-321	Bak Penampung Air Bersih	463	511	1	511
14	L-322	Pompa 6	3.824	4.225	1	4.225
15	F-323	Bak Penampung Air Sanitasi	313	346	6	2.077
16	L-324	Pompa 7	3.824	4.225	1	4.225
17	H-330	Tangki Kation Exchanger	10.000	11.050	1	11.050
18	L-331	Pompa 8	3.824	4.225	1	4.225
19	H-340	Tangki Anion Exchanger	10.000	11.050	1	11.050
20	F-341	Bak Penampung Air Demineralisasi	287	317	1	317
21	L-342	Pompa 9	3.824	4.225	1	4.225
22	L-343	Pompa 10	3.824	4.225	1	4.225
23	L-344	Pompa 11	3.824	4.225	1	4.225
24	V-410	Boiler	630.000	696.121	1	696.121

25	P-350	Cooling Tower	258.000	285.078	3	855.234
26	F-351	Bak Penampung Cooling Water	328	363	1	363
27	L-352	Pompa 12	3.824	4.225	2	8.451
28	F-353	Bak Penampung Cooling Water Return	328	363	1	363
29	L-354	Pompa 13	3.824	4.225	2	8.451
30	-	Tangki Penyimpanan Bahan Bakar	60.000	66.297	11	729.270
31	-	Generator Set	45.650	50.441	2	100.882
Total						2.514.298

Harga Total = Harga Peralatan Proses + Harga Peralatan Utilitas
= \$ 3.678.568,14 + \$ 2.514.297,75
= \$ 6.192.865,8871
= Rp 100.026.117.020,91

II. PERHITUNGAN BAHAN BAKU

1. Formaldehid (37%)
   Supplier = PT. Dover Chemical
   Harga Satuan = Rp 5.000,00 /kg
2. Asetaldehid (99%)
   Supplier = PT. Indo Aciditama
   Harga Satuan = Rp 15.791,00 /kg
3. Kalsium Hidroksida (99%)
   Supplier = PT. Darnait Esa Artha
   Harga Satuan = Rp 4.500,00 /kg
4. Asam Format (90%)
   Supplier = PT. Sintas Kurama Perdana
   Harga Satuan = Rp 14.000,00 /kg

Dirancamg Pabrik Ber-Operasi dalam 1 Tahun selama : 331 hari

Tabel D. 3. Harga Bahan Baku Produksi

Bahan Baku	Harga/kg (Rp)	Kebutuhan (kg/tahun)	Harga/tahun (Rp)
Formaldehid (37%)	5.000,00	111.943.072,6666	559.715.363.333,12
Asetaldehid (99%)	15.791,00	13.639.848,0000	215.386.814.095,08
Kalsium Hidroksida (99%)	4.500,00	23.910.219,1224	107.595.986.050,71
Asam Format (99%)	14.000,00	15.674.476,6396	219.442.672.954,77
Total			1.102.140.836.433,67

III. PERHITUNGAN PRODUK

1. Pentaeritritol (99%)

Referensi : Shouguang Puer Chemical Co., ltd (Alibaba)
Harga : $ 1.750,00 /1000 kg
= Rp 28.265.702,50 /1000 kg
Harga Satuan : Rp 28.265,70 /kg

2. Kalsium Format (98%)

Referensi : Shandong Hanying Co., ltd (Alibaba)
Harga : $ 1.300,00 /1000 kg
= Rp 20.997.379,00 /1000 kg
Harga Satuan : Rp 20.997,38 /kg

Tabel D. 4. Harga Produk

Bahan Baku	Harga/kg (Rp)	Produksi (kg/tahun)	Harga/tahun (Rp)
Pentaeritritol	28.265,70	41.912.808,7	1.184.694.981.066,59
Kalsium Format (98%)	20.997,38	37.889.880,5	795.588.181.261,13
Total			1.980.283.162.327,71

IV. PERHITUNGAN PENGEMASAN

1. Pentaeritritol

Wujud	:	Padatan Kristal
Jumlah Produk	:	41.912.809 kg/tahun
Kapasitas	:	25 kg
Harga Sak	:	Rp 1.200
Jumlah Sak	:	1.676.512 Sak ≈ 1.676.520 Sak
Supplier	:	PT Maharani Marga Sejahtera
Biaya Sak	:	Rp 2.011.824.000

2. Kalsium Format

Wujud	:	Liquid
Jumlah Produk	:	37.889.881 kg/tahur = 18.757.367 liter/tahun
Kemasan	:	20 liter
Harga Jirigen	:	Rp 20.000
Jumlah Jirigen	:	937.868 Buah ≈ 937.870 Buah
Supplier	:	CV Berlian Biru
Biaya Jirigen	:	Rp 18.757.400.000

Total Biaya = 2.011.824.000 + 18.757.400.000
Pengemasan = Rp 20.769.224.000

Total Biaya Penjualan = Total Harga Produk + Total Biaya Pengemasan
= Rp 1.980.283.162.327,71 + Rp 20.769.224.000,00
= Rp 2.001.052.386.327,71

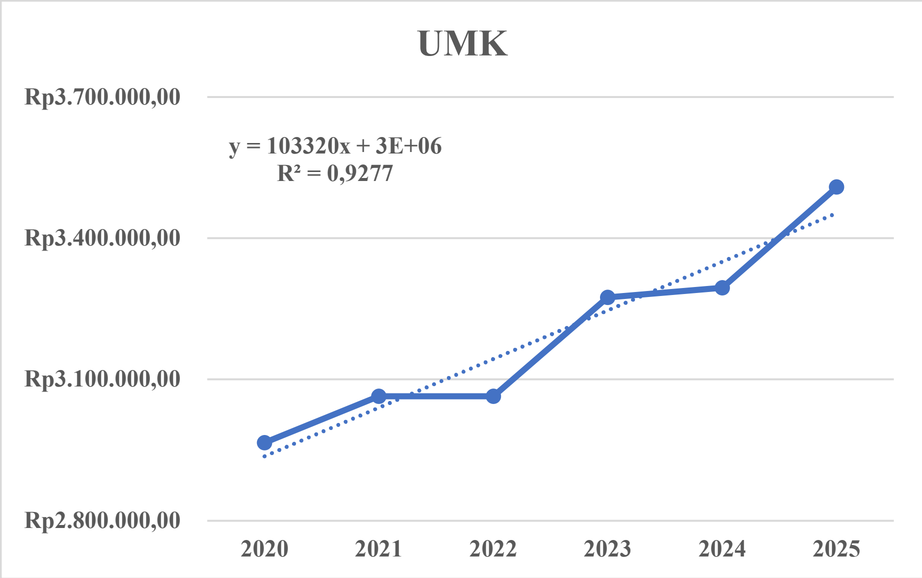
V. GAJI KARYAWAN

Diketahui Upah Minimum Kabupatan/Kota (UMK) pada Kabupaten Subang, Provinsi Jawa Barat pada 5 tahun terakhir sebesar :

Tabel D. 5. Upah Minimum Karyawan (UMK) Kabupaten Subang

No.	Tahun	UMK
1	2020	Rp 2.965.468,00
2	2021	Rp 3.064.218,00
3	2022	Rp 3.064.218,00
4	2023	Rp 3.273.810,00
5	2024	Rp 3.294.485,00
6	2025	Rp 3.508.626,00

(Badan Pusat Statistik)



Berdasarkan Grafik UMK yang ada, diperhitungkan UMK Kabupaten Subang pada tahun 2028 adalah :

X = Tahun ke-n sejak data pertama
= 2028 - 2020 + 1
= 9

y = 103.320 X + 3,00E+06
= 103.320 (9) + 3,00E+06
= Rp 3.929.880,00

Maka, diperkirakan UMK Kabupaten Subang, Jawa Barat adalah sebesar :
= Rp 3.929.880,00

Tabel D. 6. Harga Bahan Baku Produksi

No	Jabatan	Gaji per Orang (Rp)	Jml	Jumlah Gaji (Rp)
1	Direktur Utama	50.000.000	1	50.000.000
2	Dir. Produksi & Teknik	40.000.000	1	40.000.000
3	Dir. Keuangan & Sumber Daya Manusia	40.000.000	1	40.000.000
4	Sekretaris Direktur	20.000.000	3	60.000.000
5	Staff Ahli	20.000.000	3	60.000.000
6	Kepala Produksi & Teknik	15.000.000	1	15.000.000

7	Kep. Bagian Produksi	15.000.000	1	15.000.000
8	Kep. Bagian Teknik	15.000.000	1	15.000.000
9	Kep. Bagian Pemasaran	15.000.000	1	15.000.000
10	Kep. Bagian Umum	15.000.000	1	15.000.000
11	Kep. Bagian Keuangan	15.000.000	1	15.000.000
12	Kasi Proses	8.500.000	1	8.500.000
13	Kasi Riset & Pengembangan	8.500.000	1	8.500.000
14	Kasi Utillitas & Energi	8.500.000	1	8.500.000
15	Kasi Pemeliharaan & Perbaikan	8.500.000	1	8.500.000
16	Kasi Pembelian	8.500.000	1	8.500.000
17	Kasi Gudang	8.500.000	1	8.500.000
18	Kasi K3	8.500.000	1	8.500.000
19	Kasi Pemasaran & Penjualan	8.500.000	1	8.500.000
20	Kasi Administrasi	8.500.000	1	8.500.000
21	Kasi Personalia & Kesejahteraan	8.500.000	1	8.500.000
22	Kasi Keamanan	8.500.000	1	8.500.000
23	Karyawan Proses (Kepala)	8.000.000	4	32.000.000
24	Karyawan Proses (Anggota)	6.000.000	45	270.000.000
25	Karyawan Laboratorium	6.000.000	12	72.000.000
26	Karyawan Utilitas	6.000.000	15	90.000.000
27	Karyawan K3	6.000.000	3	18.000.000
28	Karyawan Personalia	6.000.000	3	18.000.000
29	Karyawan Pemasaran	6.000.000	6	36.000.000
30	Karyawan Administrasi	6.000.000	6	36.000.000
31	Karyawan Pembelian	5.500.000	6	33.000.000
32	Karyawan Pemeliharaan	4.500.000	9	40.500.000
33	Karyawan Gudang	4.500.000	6	27.000.000
34	Karyawan Keamanan	4.500.000	12	54.000.000
35	Karyawan Kebersihan	4.500.000	12	54.000.000

36	Dokter	12.000.000	3	36.000.000
37	Perawat	4.500.000	6	27.000.000
38	Supir	4.000.000	6	24.000.000
39	Satpam & Pesuruh	4.000.000	15	60.000.000
Total			195	1.361.000.000

Maka, pengeluaran untuk Gaji seluruh Tenaga Kerja Selama 1 bulan:

Gaji 1 Bulan = Rp 1.361.000.000,00

Dihitung untuk mencakup Tunjangan dan lainnya (diluar gaji pokok), maka:

Gaji 1 Tahun = Gaji 1 Bulan x 15
= Rp 20.415.000.000,00

VI. PERHITUNGAN UTILITAS

1. Kebutuhan Air Bersih

Diluar Air Sanitasi dari Water Treatment, dibutuhkan Air Bersih untuk keperluan dapur atau yang berhubungan dengan Food Grade yang berasal dari Perusahaan Daerah Air Minum (PDAM).

Kebutuhan per hari = 50.000,0000 liter/hari
= 50,0000 m^3/hari
= 13.210,0000 gal/hari

Berdasarkan ***Peraturan Bupati Subang No.76 tahun 2021*** , diperoleh tarif untuk Industri Besar lebih dari 30m^3 :

Tarif Air PDAM = Rp 22.250,00 /m^3

Biaya Air PDAM = Rp 22.250,00 /m^3 x 50,0000 m^3/hari
= Rp 1.112.500,00 /hari
= Rp 368.237.500,00 /tahun

2. Kebutuhan Pengolahan Air

A. Aluminium Sulfat

Supplier = PT. Timuraya Tunggal
Harga Satuan = Rp 5.000,00 /kg
Kebutuhan = 3.246,8188 kg/tahun
Biaya Total = Rp 16.234.094,10 /tahun

B. Poly Aluminium Chloride

Supplier = PT. Timuraya Tunggal
Harga Satuan = Rp 16.000,00 /kg

Kebutuhan = 324,6980 kg/tahun
Biaya Total = Rp 5.195.167,29 /tahun

C. Sodium Hypochloride

Supplier = PT. Asahimas Chemical
Harga Satuan = Rp 5.000,00 /kg
Kebutuhan = 23,7974 kg/tahun
Biaya Total = Rp 118.987,08 /tahun

D. Resin Kation

Supplier = PT. Darnait Esa Artha
Harga Satuan = Rp 7.672,12 /kg
Kebutuhan = 173.525,6447 kg/tahun
Biaya Total = Rp 1.331.309.439,34 /tahun

E. Resin Anion

Supplier = PT. Darnait Esa Artha
Harga Satuan = Rp 32.303,66 /kg
Kebutuhan = 101.408,8379 kg/tahun
Biaya Total = Rp 3.275.876.619,70 /tahun

3. Kebutuhan Bahan Bakar

Supplier = PT. Megah Anugerah Energi
Harga Satuan = Rp 21.050,00 /liter
Kebutuhan = 539.029,9325 liter/tahun
Biaya Total = Rp 11.346.580.080,04 /tahun

4. Kebutuhan Listrik

Supplier = PT. Megah Anugerah Energi

Berdasarkan ***Permen ESDM No. 28 Tahun 2016*** , diperoleh tarif untuk Industri Besar dari PT PLN senilai:

Harga Satuan = Rp 1.191,00 /kWh
Kebutuhan = 309.482,3520 kWh/tahun
Biaya Total = Rp 368.593.481,23 /tahun

Maka, pengeluaran untuk Biaya Utilitas selama 1 tahun:

= Kebutuhan Air Bersih + Kebutuhan Pengolahan Air
+ Kebutuhan Bahan Bakar + Kebutuhan Listrik
= Rp 368.237.500,00 + Rp 7.904.610.927,21 +
Rp 11.346.580.080,04 + Rp 368.593.481,23
= Rp 19.988.021.988,48

VII. PERHITUNGAN LAHAN TANAH DAN BANGUNAN

1. Luas Lahan Tanah Pabrik

Luas	=	13.000,0000	m^2
Harga satuan	=	Rp 1.950.000,00	$/m^2$
Biaya Total	=	Rp 25.350.000.000,00	
Sumber	=	OLX - Tanah Industri dijual di Subang	

2. Luas Bangunan Proses

Luas	=	2.308,0000	m^2
Harga satuan	=	Rp 4.500.000,00	$/m^2$
Biaya Total	=	Rp 10.386.000.000,00	
Sumber	=	99 Panduan Properti	

3. Luas Bangunan Gedung

Luas	=	1.150,0000	m^2
Harga satuan	=	Rp 5.500.000,00	$/m^2$
Biaya Total	=	Rp 6.325.000.000,00	
Sumber	=	99 Panduan Properti	

Total Biaya Bangunan	=	Rp 16.711.000.000,00
Total Biaya Tanah dan Bangunan	=	Rp 25.350.000.000,00