APPENDIKS C
SPESIFIKASI ALAT

1. Storage Asam asetat (F-111)

Fungsi : Untuk menyimpan bahan baku Asam asetat

Tipe : Silinder tegak dengan tutup atas standard dished dan tutup bawah berbentuk datar

Direncanakan:

Bahan Konstruksi : Stainlees steel, SA 240 Grade M type 316

F allowable : 18750

Jenis pengelasan : Doubel welded

Faktor Korosi (C) : 1/16 in = 0.0625

E : 0.8

Suhu Bahan : 30 ℃ = 303.1500 K

Dasar Perencanaan

Kondisi operasi : Suhu = 30 ℃ = 303.15 K

: Tekanan = 1 atm = 14.6959 psia

Komponen	A	B	T	n	Tc	ρ g/ml
CH_3COOH	0.3518	0.2695	303.15	0.2684	592.710	1.0378
H_2O	0.3471	0.2740	303.15	0.2857	647.130	1.0229
Total						**2.0606**

Komponen	Massa (Kg/jam)	xi (massa)	ρ (g/mL)	xi.ρi
C_3H_8O	11635.9469	0.9800	1.0378	1.0170
H_2O	237.4682	0.0200	1.0229	0.0205
Total	**11873.4151**	**1**	**2.0606**	**1.0375**

$\rho = A \times B^{-(1-T/Tc)^{\wedge}n}$

$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$

$\rho \text{ campuran} = \frac{1.0375}{1}$

ρ campuran = 1.0375 g/ml

= 64.7664 lb/ft^3

Perhitungan

1. Menghitung Volume

Rate Volumetrik Asam asetat $= \frac{m}{\rho}$

$= \frac{26176.131 \text{ lb/jam}}{64.766 \text{ lb/ft}^3}$

= 404.162 ft^3/jam

Direncanakan akan menyimpan bahan baku selama 48 jam = 2 hari

Volume Liquid (V) = 404.1620 × 48

= 19399.776 ft^3

Liquid mengisi 80% Volume total

Volume Total (VT) = $\frac{100}{80}$ × 19399.776

= 24249.720 ft^3

2. Menghitung Diameter Tanki

Perbandingan tinggi silinder (Ls) dan diameter tanki (D) adalah 1,5

V dished = 0.00847 di^3 Ls = 1,5 di

V silinder = $\pi/4\ di^2\ Ls$

Volume Total (VT) = $\pi/4\ di^2\ Ls$ + 0.00847 di^3

24249.720 ft^3 = $\pi/4 x\ 1,5\ di^3$ + 0.00847 di^3

24249.720 ft^3 = 1.18 di^3 + 0.00847 di^3

24249.720 ft^3 = 1.1860 di^3

di = 27.345 ft

di = 328.14 in

3. Menentukan tinggi liqiuida dalam tangi (Li)

Tinggi Liquida (Li) = $\frac{\text{Volume Liquida}}{\pi/4\ di^2}$

= $\frac{19399.7759}{3.14/4 \times 747.7482}$

= $\frac{19399.7759}{586.9822985}$

Li = 33.0500 ft

Li = 396.600 in

4. Menghitung tebal silinder

Dalam merancang tebal silinder didasarkan oleh kondisi operasi seperti tekanan operasi pada liquid sendiri, maka dasar perancangan

P_{Design} (P = $P_{hidrostatis}$ + $P_{Operasi}$

$P_{Operasi}$ = 1 atm = 14.6959 psia

$P_{hidrostatis}$ = $\frac{\rho \times (Li-1)}{144}$

= $\frac{64.7664 \times (33.0500 - 1)}{144}$

= $\frac{2075.7654}{144}$

= 14.4150 psia

P_{Design} (Pi) = $P_{hidrostatis}$ + $P_{Operasi}$

= 14.4150 + 14.6959

= 29.1109 psia

Pi = 14.4150 psig

Tebal silinder (ts) $= \dfrac{Pi \times di}{2(fE - 0,6\ Pi)} + C$

$= \dfrac{14.4150 \times 328.1398}{18750 \times 0.8 - 0.6 \times 14.4 \times 2} + 0.06$

$= \dfrac{4730.1476}{29982.702} + 0.06$

$= 0.1577626 + 0.06$

$= 0.2203\ \text{in} \times \dfrac{16}{16}\ \text{in}$

$= \dfrac{3.52}{16}\ \text{in} \approx \dfrac{5}{16}\ \text{in}$

do = di + 2 ts

do = $328.140 + 2 \times \dfrac{5}{16}$ in

do = 328.765 in

do = 27.3971 ft

Standarisasi diameter tangki (Brownell and young tabel 5-7 hal 90)[12]

do baru = 240 in

di baru = do - 2 ts

= $240 - \dfrac{5}{16} \times 2$

= 239.375 in

r = di = 239.375 in

icr = 6% × di

icr = 6% × 239.375

icr = 14.3625 in

5. Menentukan tinggi tangki

H = ha + Ls

dimana :

ha = 0.17 × di

ha = 0.17 × 239.375

ha = 40.4544 in

Ls = 1,5 di

Ls = 1.5 × 239.375

Ls = 359.063 in

H = ha + Ls

H = 40.4544 + 359.063

H = 399.517 in

6. Menentukan tebal tutup atas /Standart dished head (tha)

tha $= \dfrac{0,885 \times Pi \times di}{(fE - 0,1\ Pi)} + C$

$$tha = \frac{0.89 \times 14.42 \times 239.375}{18750 \times 1 - 0.1 \times 14.42} + 0.06$$

$$tha = \frac{3053.78}{14998.6} + 0.06$$

$$tha = 0.2036 + 0.06$$

$$tha = 0.2661 \text{ in} \times \frac{16}{16} \text{ in}$$

$$tha = \frac{4}{16} \approx \frac{5}{16} \text{ in}$$

7. Kebutuhan Tangki 1 Bulan

Volume tangki untuk kapasitas bahan 2 hari = 24249.720 ft^3

1 bulan = 30 hari

maka kebutuhan tangki dalam 1 bulan :

$$\frac{30 \text{ hari}}{1 \text{ bulan}} \times 0.5 = 15 \text{ tangki}$$

Spesifikasi Asam Asetat (F-111)

Fungsi	:	Untuk menyimpan bahan baku Asam asetat				
Kode alat	:	F-111				
Tipe	:	Silinder tegak dengan tutup atas standard dished dan tutup bawah berbentu datar				
Suhu operasi	:	30	°C			
Tekanan operasi	:	1	atm			
Bahan Konstruksi	:	Stainlees steel, SA 240 Grade M type 316				
Volume Tangki	:	24249.720	ft^3	=	686.7521	m^3
Diamter Tangki (di	:	239.4	in	=	6.0801	m
Tinggi Tangki (H)	:	399.5169	in	=	10.1477	m
Diameter Luar (Do	:	240.0000	in	=	6.0960	m
Tebal silinder (ts)	:	5/16	in			
Tinggi silinder (Ls)	:	359.0625	in	=	9.1202	m
Tebal tutup atas (th	:	5/16	in			
Tinggi tutup atas (h	:	40.4544	in	=	1.0275	m
Kebutuhan Tangki	:	15	buah			

2. Pompa Asam Asetat (L-112)

Fungsi : Untuk mengalirkan liquid dari storage menuju Vaporiz

Tipe : Pompa sentrifugal

Dasar Perancangan

Suhu	:	30 °C	=	303.150	K	
Tekanan	:	1 atm	=	14.6959	psia	
Rate aliran	:	11873.4151	Kg/Ja	=	26176.131	lb/Jam
ρ campuran	:	64.3205	lb/ft^3			

Komponen	A	B	C	D	T	μ (cP)
CH_3COOH	-3.8937	784.82	0.0067	0.0000076	303.15	26.5906
H_2O	-10.216	1792.50	0.01773	-0.0000126	303.15	0.8150
Total						**27.4056**

(Yaws and Carl Viscosity of Liquid)[20]

Komponen	Massa (Kg/jam)	xi (massa)	μ (cP)	xi.ρi
CH_3COOH	11635.9469	0.9800	26.5906	26.0588
H_2O	237.4682	0.0200	0.8150	0.0163
Total	11873.4151	**1**	**27.4056**	**26.0751**

$$\mu \text{ campuran} = \frac{\sum xi.\mu i}{\sum xi}$$

$$\mu \text{ campuran} = \frac{26.0751}{1}$$

μ campuran = 26.1 cP = 0.01752 lb/ft.s = 63.1 lb/ft.jam

Q = Rate Volumetrik = 404.162 ft^3/jam

= 0.1123 ft^3/s = 50.3895 gpm

Perhitungan

1. Menentukan dimensi pipa

$Di_{optimum}$ = $3{,}9\ Q^{0,45} \times \rho^{0,13}$ (Pers.15 "Petters&Timmerhaus",hal 496)[23]

$Di_{optimum}$ = $4 \times 0.11^{0,4} \times 64.3^{0,13}$

$Di_{optimum}$ = 2.50475 ≈ 3 in

Standarisasi 3 in sch 40 (Kern, Table 11 hal 844)[24]

OD	=	3.50	in	=	0.29	ft
ID	=	3.07	in	=	0.26	ft
A	=	0.92	ft^2	=	132	in^2

2. Menentukan kecepatan aliran fluida

Kecepatan aliran = $\frac{Q}{A}$

$$= \frac{404.162\ ft^3/jam}{0.9170\ ft^2}$$

= 440.7437 ft/Jam

= 0.1224 ft/s

3. Menentukan bilangan Reynold

Bilangan Reynold = $\frac{D \times v \times \rho}{\mu}$

$$= \frac{0.26 \times 0.12 \times 64.3205}{0.017522}$$

= 114.8981 < 2100 maka jenis aliran yaitu aliran laminar

Dari gambar 2.10-3 Geankoplis[21] halaman 94 didapatkan:

ε = 4.6 x 10^{-5} m = 0.00015 (Geankoplis, fig. 2.10-3 hal. 88)[21]

$$\frac{\varepsilon}{D} = \frac{0.0001509}{0.2557} = 0.00059$$

f = 0.012 (Geankoplis, fig. 2.10-3 hal. 88)[21]

α = 1/2

4. Menentukan Panjang Pipa

Asumsi :

- Panjang pipa lurus = 100 ft
- elbow 90° = 2 buah
  - Le/D = 35
  - L elbow = 35 ID (Geankoplis,Tabel 2-10.1 Hal 93)[21]
  - = 35 x 0.26 x 2
  - = 17.9 ft
- Gate Valve = 1
  - Le/D = 9 (wide open)
  - L elbow = 9 ID
  - = 9 x 1 x 0.26
  - = 2.3010 ft

Panjang pipa total (L) = elbow 90 + Panjang pipa + Gate Valve
= 17.8967 + 100 + 2.301
= 120.198 ft
= 1442.37 in

5. Menentukan friksion Loss

1. Friksi pada pipa lurus

$$F_f = 4f \frac{\Delta L}{D} \times \frac{v^2}{2g_c}$$ (Geankoplis, Pers.2-10.6 Hal 86)[21]

$$= 4 \times 0.0120 \frac{120.1977}{0.2556667} \times \frac{0.1224^2}{2 \times 32.2}$$

= 0.0053 lbf.ft/lbm

2. Kontraksi pada keluaran tangki

$$hc = Kc \frac{v^2}{2g_c}$$ (Geankoplis, Pers.2-10.16 Hal 93)[21]

$$= 0.55 \frac{0.1224^2}{2 \times 32.174}$$

= 0.0001 lbf.ft/lbm

3. Elbow 90°, 2 buah

K_f = 0.75 (Geankoplis, Tabel 2.10-1 Hal. 93)[21]

$$hf = Kf \frac{v^2}{2g_c}$$ (Geankoplis, Pers.2-10.17 Hal 94)[21]

$= 2 \times 0.75 \dfrac{0.1224^2}{2 \times 32.174}$

$= 0.00035$ lbf.ft/lbm

4. Ekspansi

$K_{eks} = 1 - \dfrac{A_1}{A_2}^2$

$K_{eks} = (1-0)^2$

$K_{eks} = 1$

$h_{eks} = K_{eks} \dfrac{v^2}{2g_c}$

$= 1 \times \dfrac{0.1224^2}{2 \times 32.174}$

$= 0.0002$ lbf.ft/lbm

5. Gate Valve wide open 1 buah

$K_f = 0.17$ (Geankoplis, Tabel 2.10-1 Hal. 93)[21]

$hf = Kf \dfrac{v^2}{2g_c}$ (Geankoplis, Pers.2-10.17 Hal 94)[21]

$= 1 \times 0.17 \dfrac{0.1224^2}{2 \times 32.174}$

$= 0.0000396$ lbf.ft/lbm

Total friksi (= Ff + hc + he: + hf + hf

= 0.00526 + 0.00013 + 0.00023 + 0.00035 + 0.00004

= 0.00601 lbf.ft/lbm

6. Menentukan Kesetimbangan Mekanik

Direncanakan:

ΔZ = 50 ft

ΔP = 0 lb/ft^2

V_1 = 0 ft/s (karena fluida diam dalam tangki penampungan)

V_2 = 0.12 ft/s

α = 1 (aliran turbulen)

Sehingga Mechanical energy balance :

$$\frac{V_2 - V_1}{2.\alpha.gc} + \Delta Z \frac{g}{gc} + \frac{\Delta P}{\rho} + \sum F = -Ws$$

$$\frac{0.0150 - 0}{2 \times 1 \times 32.2} + 50 \frac{32.17}{32.17} + \text{lbf.ft/lbm} = -Ws$$

-Ws = 10.0062 lbf.ft/lbm

Dengan: Capacity = 50.3895 gal/menit

μ campuran = 26.0751 Centipoise

Dari Fig.14.36 Hal.520, Petters &Timmerhause, didapatkan:

Efisiensi pompa (η) = 78%

$Ws = -\ \eta\ Wp$

$10.0062 = -\ 78\%\ Wp$

$Wp = 12.8285$ ft.lbf/lbm

mass flow rate (m) $= Q \times \rho$

$= 404.1620 \times 64.3205$

$= 25995.921$ lbm/jam

$= 7.2211$ lbm/s

$WHp = Wp \times m \times \frac{1 \text{ hp}}{550 \text{ ft.lbf/s}}$

$WHp = 12.8285 \times 7.2211 \times \frac{1 \text{ hp}}{550 \text{ ft.lbf/s}}$

$WHp = 0.1684$ hp

$BHp = \frac{WHp}{\eta}$

$= \frac{0.1684}{78\%}$

$= 0.2159$ Hp

Dari Fig.14.38 Hal.521, Petters &Timmerhause[23], didapatkan:

Efisiensi motor = 85%

$\text{Daya} = \frac{\text{pump horsepower}}{\text{efisiensi motor}}$

$= \frac{0.2159}{85\%}$

$= 0.2540$ Hp ≈ 1 Hp

Spesifikasi Pompa Sentrifugal (L-112)

Fungsi	:	Untuk mengalirkan Asam asetat dari storage (F-111) menuju Vaporizer (V-113)
Kode alat	:	L-112
Tipe	:	Centrifugal pump
Kapasitas	:	50.3895 gpm
Suhu operasi	:	303.15 K
Tekanan operasi	:	1 atm
Efisiensi Pompa	:	78%
ΔP	:	0 lb/ft^2
Bahan Konstruksi	:	Carbon steel SA 213
Daya	:	1 Hp
L pipa	:	120.198 ft
Jumlah	:	1 buah

3. Vaporizer (V-113)

Fungsi : Untuk menguapkan Asam asetat liquid menjadi vapor
Tipe : Shell and Tube Heat Exchanger

Direncanakan :

- faktor kekotoran gabungan minumum (Rd) = 0.001 jam.ft^2.^{o}F/Btu
- Δp maksimum aliran = 10 psi
- Δp maksimum steam = 2.5 psi

Dasar perencanaan :

Dari Appendix B didapatkan data sebagai berikut:

- Massa bahan masuk = 11,873.4151 kg/jam
  = 26,176.131 Ib/jam
- Suhu bahan masuk (t_1) = 30 ^{o}C = 86.00 ^{o}F = 303.15 K
- Suhu bahan keluar (t_2) = 120 ^{o}C = 248 ^{o}F = 393.15 K
- Kebutuhan steam (m) = 611.1337 kg/jam
  = 1,347.3054 Ib/jam
- Panas yang dibawa steam = 472.9398 kkal/jam
  = 1,875.5543 btu/jam
- Steam masuk pada suhu(T_1) = 190 ^{o}C = 374 ^{o}F = 463.15 K
- Steam keluar pada suhu (T_2) = 95 ^{o}C = 203 ^{o}F = 368.15 K
- Digunakan pipa ukuran 3/4 in OD, BWG 16, L = 12 ft, P_T = 1 in
- Shell side : Asam Asetat
- Tube side : Steam
- Susunan tube segitiga (triangular pitch)

Perhitungan :

A. Menghitung ΔT_{LMTD}

Δt_1 = $T_1 - t_2$ = 374 ^{o}F - 248 ^{o}F = 126 ^{o}F

Δt_2 = $T_2 - t_1$ = 203 ^{o}F - 86.00 ^{o}F = 117 ^{o}F

$$\Delta T_{LMTD} = \frac{\Delta t_1 - \Delta t_2}{\ln \Delta t_1/\Delta t_2}$$ (Kern, Pers.5.14 Hal.89)[24]

$$= \frac{126 - 117.00}{\ln(126 / 117.00)}$$

= 121.4 ^{o}F

B. Menghitung Suhu Kalorik (Tc dan tc)

Tc = $(T_1 + T_2) / 2$ = 289 ^{o}F = 143 ^{o}C = 415.65 K

tc = $(t_1 + t_2) / 2$ = 167 ^{o}F = 75 ^{o}C = 348.15 K

C. Trial U_D

Dari Kern hal 840 tabel 8[24] diperoleh:

Range U_D = 100-200 Btu/jam ft^2. ^{o}F

Dicoba U_D = 100 Btu/jam $ft^2.\,^oF$

Dari App.B didapatkan Q = 472.940 kkal/jam

= 18767.7 Btu/jam

$$A = \frac{Q}{U_D \cdot \Delta t} = \frac{18767.7491}{100 \times 121.4444} = 254.538 \text{ ft}^2$$

dengan,

do_{tube} = 3/4 in

BWG = 16

Dari Kern, tabel 10, hal. 843[24], diperoleh harga a" 0.1963 ft^2/ft

$$Nt = \frac{A}{a'' \cdot L} = \frac{254.5378}{0.1963 \times 12} = 108 \text{ buah}$$

Dari Kern, tabel 9, hal. 842[24], diperoleh :

IDs = 13 1/4 in

n = 4

Nt = 127

$$U_D \text{ koreksi} = \frac{Nt}{Nt\ standar} \times U_D \text{ trial}$$

$$= \frac{109}{127} \times 100 = 85.8 \text{ Btu/jam ft}^2.\,^oF$$

Dari Kern, tabel 28, hal. 838[24], diperoleh :

de = 0.73 in

Viskositas aliran pada shell (bahan):

Dari Perry 8th Edition tabel 2-313 Hal. 2-427[7] didapatkan tabel berikut:

Komponen	C1	C2	C3	C4	C5
CH_3COOH	53.27000	-6304.500	-4.299	8.89E-18	6
H_2O	73.6490	-7258.200	-7.3037	4.2.E-06	2

dimana μ dalam Pa.s

$$\mu = \exp(C1 + C2/T + C3 \ln T + C4T^{C5}$$

Komponen	Massa (Kg/jam)	xi (massa)	μ (Pa.s)	μ (lb/ft.s)	xi.μi
CH_3COOH	11635.9469	0.9800	2745.32300	1844.7719	1807.8765
H_2O	237.4682	0.0200	4247.91259	2854.4655	57.0893
Total	11873.4151	1.0000	6993.23559	4699.2374	1864.9658

$$\mu \text{ campuran} = \frac{\sum xi.\mu i}{\sum xi}$$

$$= \frac{1864.9658}{1.0000} = 1864.9658 \text{ lb/ft.s} = 6713877 \text{ lb/ft.jam}$$

Viskositas aliran pada tube(steam):

Dari Perry 8th Edition tabel 2-313 Hal. 2-427[7] didapatkan tabel berikut:

Komponen	C1	C2	C3	C4	C5
H_2O	73.64900	-7258.200	-7.30370	4.17E-06	2

dimana μ dalam Pa.s

$$\mu = \exp(C1 + C2/T + C3 \ln T + C4T^{C5}$$

Komponen	Massa (Kg/jam)	xi (massa)	μ (Pa.s)	μ (lb/ft.s)	xi.μi
H_2O (steam)	611.1337	1.0000	1252467.52	841619.319	841619.319

Kesimpulan sementara hasil perancangan :

Type HE : 2-4

Bagian *Tube*

do = 3/4 in, 16 BWG

L = 12 ft Nt = 127

Susunan segitiga, n = 4

di = 0.6200 in = 0.052 ft

a' = 0.3020 in^2 = 0.025 ft^2

a" = 0.1963 ft^2/ft

Pt = 1 in

Bagian *Shell*

IDs = 13.25 in = 1.1 ft

n' = 2

B = 4 in = 0.33 ft

de = 0.73 in = 0.06 ft

C' = 1 - 3/4 = 1/4

Evaluasi Perpindahan Panas

Hot fluid: tube, Steam	Cold fluid: shell, Asam asetat
	Preheating:
1. Menghitung NRe	1'. Menghitung NRe
$a_t = \dfrac{Nt \times a'}{n \times 144}$	$a_s = \dfrac{IDs \times C' \times B}{n' \times Pt \times 144}$
$= \dfrac{127 \times 0.025}{4 \times 144}$	$= \dfrac{13.3 \times 0.25 \times 4}{2 \times 1 \times 144}$
$= 0.0055\ ft^2$	$= 0.04601\ ft^2$
$G_t = \dfrac{m}{a_t}$	$G_s = \dfrac{M}{a_s}$
$= \dfrac{1347.3054\ lb/jam}{0.0055\ ft^2}$	$= \dfrac{26176.1309\ lb/jam}{0.0460\ ft^2}$
$= 242805.8\ lb/jam.ft^2$	$= 568960.4308\ lb/jam.ft^2$
pada Tc = 289 ^oF	pada tc = 167 ^oF
μ = 841619.32 lb/ft.s	μ = 1864.96576 lb/ft.s
= 3029829549 lb/ft.jam	= 6713876.74 lb/ft.jam
di = 0.62 in	de = 0.73 in
= 0.052 ft	= 0.06 ft
$N_{re} = \dfrac{G_t \times di}{\mu}$	$Nre_s = \dfrac{G_{an} \times de}{\mu}$

$$= \frac{242805.8 \times 0.62}{3029829548.916380}$$

$= 0.00005$

2. J_H = - (*steam*)

3. Menghitung harga koefisien film perpindahan panas
   untuk steam didapatkan:
   h_{io} = 1500 Btu/ft^2.jam^{0}F

$$= \frac{568960.4308 \times 0.06}{6713876.7372}$$

$= 0.0052$

2'. Menghitung faktor panas (J_H)
   Dari Kern, Fig. 28Hal.838 didapatkan:
   J_H = 90

3'. Menghitung harga koefisien film
   Dari Kern, Tabel 4[24] hal.800 didapatkan:
   k = 0.093 Btu/jam.ft^2.^{o}F/ft
   Dari Kern, Fig.2 hal.804[24] didapatkan
   Cp = 0.239 Btu/lb.^{o}F
   maka,
   k (Cp.μ /k)$^{1/3}$ = 24.0213
   ho/φs = 35538.42
   tw = 760 ^{o}F
   dimana μ Pada suhu tw didapatkan:
   μw = 9850.09 lb/ft.jam
   μ /μw = 682

Dari Kern, Fig. 24 Hal.834[24] didapatkan:
φs = 2.49
sehingga,
ho = 88591.6 Btu/jam.ft^{2o}F

Clean overall coefficient untuk preheating U_p :

$$U_p = \frac{hio\ .\ ho}{hio + ho} = \frac{1500 \times 88591.6}{1500 + 88591.6} = 177183 \text{ Btu/ft}^2\text{.jam}^0\text{F}$$

Clean surface yang dibutuhkan untuk preheating A_p :

Dari App.B didapatkan q_p = 416956.73 kkal/jam = 16546165 Btu/jam

$$A_p = \frac{q_p}{U_p\ \Delta T_{LMTD}} = \frac{16546164.54}{177183 \times 121.444} = 23.0684 \text{ ft}^2$$

Vaporization:

1'. Menghitung NRe
   Pada suhu 248 ^{o}F
   Dari Kern, Fig. 15 Hal.825[24] didapatkan:
   μ = 0.18000 cp
   = 0.43544 lb/ft.jam
   de = 1 in

$= 0.061$ ft

$Nre_s = \frac{G_s \times de}{\mu}$

$= \frac{568960.4308 \times 0.06}{0.4354}$

$= 79487.6120$

2'. Menghitung faktor panas (J_H)

Dari Kern, Fig. 24 Hal.834[24] didapatkan:

J_H = #

3'. Menghitung harga koefisien film

Dari Kern,Tabel 4 hal.800[24] didapatkan:

k = 0.093 Btu/jam.ft^2.^{o}F/ft

Dari Kern,Fig.2 hal.804[24] didapatkan:

Cp = 0.2186 Btu/lb.^{o}F

maka,

$k (Cp.\mu / k)^{1/3}$ = 0.0937

$ho/\varphi s$ = 149.44

tw = 760 ^{o}F

dimana μ Pada suhu tw didapatkan:

μw = 9850.09 lb/ft.jam

μ /μw = 0.00004421

Dari Kern, Fig. 24 Hal.834[24] didapatkan:

φs = 0.24568

sehingga,

ho = 36.7151 Btu/jam.ft^{2o}F

Clean overall coefficient untuk Vaporization U_v :

$$U_v = \frac{hio \cdot ho}{hio + ho} = \frac{1500 \times 36.715}{1500 + 36.715} = 73.43 \text{ Btu/ft}^2.\text{jam}^0\text{F}$$

Clean surface yang dibutuhkan untuk preheating A_v:

Dari App.B didapatkan q_v = 24869.126 kkal/jam = 986885.74 Btu/jam

$$A_v = \frac{q_p}{U_v \Delta T_{LMTD}} = \frac{986885.7442}{73.4302 \times 121.444} = 110.666 \text{ ft}^2$$

Total clean surface A_c :

$$Ac = A_p + A_v = 23.0684 + 110.666 = 133.735 \text{ ft}^2$$

Weighted clean overall coefficient Uc :

$$Uc = \frac{\sum UA}{Ac} = \frac{4087342 + 8126.23}{133.73} = 30623.9$$

Menghitung overall coefficient :

surface per lin ft tube (a") = 0.1963 ft^2/ft

Total surface = Nt x L x a"

= 127 × 12 × 0.1963

= 299.161 ft^2

$$U_D = \frac{Q}{A\ .\Delta t} = \frac{18767.7491}{299.161 \times 121.444} = 0.5165702$$

Check maksimum fluks :

Total surface area yang dibutuhkan = 133.735 ft^2

Surface area yang dibutuhkan untuk vaporisasi = 110.666 ft^2

Total surface area yang tersedia = 299.161 ft^2

Sehingga dapat diasumsikan bahwa,

surface area yang tersedia untuk vaporisasi $= \frac{110.666}{133.735} \times 299.161\ ft^2$

= 247.558 ft^2

Dirt factor :

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

$$= \frac{30623.864 - 0.52}{30623.864 \times 0.52} = 1.9358 \quad \text{jam.ft}^2.°F/Btu$$

Karena harga Rd hitung > Rd tetapan, maka rancangan HE memenuhi.

Evaluasi ΔP

Hot fluid: tube, Steam	Cold fluid: shell, Asam Asetat
	Preheating:
1. Pada NRe_t = 0.0000	1'. Pada Nres = 0.0052
Dari Kern,fig. 26 hal.836[24],	Dari Kern,fig. 29 hal.839[24], diperoleh
diperoleh: f = 0.00013	f = 0.003
Dari steam tabel, untuk kondisi :	2'. Panjang area preheating
saturated steam	$L_p = \frac{L.A_p}{A_c}$
T = 374 °F	$= \frac{12 \times 23.0684}{133.7345465}$
P = 45.4 psia	= 2.0699 ft
didapatkan,	
specific vol. = 9.31965 ft^3/lb	
$sg = \frac{1}{9.31965 \times 62.5}$	3'. No. of crosess
= 0.002	$(N+1) = \frac{12Lp}{B} = \frac{12 \times 2.0699}{4}$

2. ΔP karena panjang pipa :

$$\Delta Pl = \frac{1}{2} \cdot \frac{f.Gt^2.L.n}{5{,}22\times10^{10}.di.sg.\phi}$$

$$= \frac{0.00013 \times 242806^2 \times 12 \times 4}{2 \times 5{,}22.10^{10} \times 0.052 \times 0.002 \times 1}$$

= 1.5674 psi

ΔP karena tube passes

Dari Kern,fig. 27 hal.837[24], diperoleh

$$\left[\frac{v^2}{2gc}\right]\frac{\rho}{144} = 0.00007$$, sehingga

$$\Delta Pn = \frac{4n}{sg}\left[\frac{v^2}{2gc}\right]\frac{\rho}{144}$$

$$= \frac{4 \times 4}{0.0017} \times 0.0000700$$

= 0.65238 psi

sehingga,

ΔPt total = 1.5674 + 0.65238

= 2.2 psi < 2.5 psi

desain memenuhi

= 6.21

Dari Kern,Tabel 6 hal.808[24], diperoleh

sg = 1.26

4'. $$\Delta Ps = \frac{f.Gs^2.IDs.(N+1)}{5{,}22\times10^{10}.de.sg.\phi}$$

$$= \frac{0.003 \times 568960.43^2 \times 1 \times 6}{5{,}22\times10^{10} \times 0.061 \times 1.26 \times 0.97}$$

= 0.98694 psi

Vaporization:

1'. Pada Nres = 79487.6120

Dari Kern,fig. 29 hal.839[24], diperoleh

f = 0.002

2'. Panjang area vaporization

$$L_v = \frac{L.A_v}{A_c}$$

$$= \frac{12 \times 110.666}{133.7345465}$$

= 9.9301 ft

3'. No. of crosess

$$(N+1) = \frac{12Lv}{B} = \frac{12 \times 9.9301}{4}$$

= 29.8

Dari Kern,Tabel 6 hal.808[24], diperoleh

sg = 1.26

4'. $$\Delta Ps = \frac{f.Gs^2.IDs.(N+1)}{5{,}22\times10^{10}.de.sg.\phi}$$

$$= \frac{0.002 \times 568960.43^2 \times 1 \times 30}{5{,}22\times10^{10} \times 0.061 \times 1.26 \times 0.97}$$

= 8.5421 psi

sehingga,

ΔPs total = 0.98694 + 8.5421

= 9.52904 psi < 10 psi

desain memenuhi

Spesifikasi Vaporizer (V-113)

Fungsi	:	Untuk menguapkan Asam asetat liquid menjadi vapor
Kode alat	:	V-113
Tipe	:	Shell and Tube Heat Exchanger 2-4
Bahan Konstruksi	:	Carbon Steel SA 312 Grade M Type 317
Media pemanas	:	Saturated steam 190 ^oC ,
Kapasitas	:	11,873.415 kg/jam = 26,176.131 lb/jam
Rate steam	:	611.1337 kg/jam = 1,347.3054 lb/jam
Dimensi		*Tube side* , steam / *Shell side* , Asam Asetat

Tube side				Shell side			
do	=	3/4	in 16 BWG	IDs	=	13 1/4	in = 1.1
di	=	0.62	in	B	=	4	in
L	=	12	ft	de	=	0.73	in
Nt	=	127		C'	=	0.25	in
Pt	=	1	in	ΔPs	=	9.53	psi
Tringular Pitch							
ΔPt	=	2.22	psi				

4. Heater (E-114)

Fungsi : Untuk menaikkan suhu asam asetat sebelum masuk reaktor

Tipe : *Double Pipe Heat Exchanger*

Direncanakan :

- Faktor kekotoran gabungan minimum (Rd = 0.001 jam.ft^2.°F/Btu
- Penurunan tekanan aliran maksimal (Δp) = 10 psi
- Δp maksimum steam = 2.5 psi

Kondisi operasi :

- Massa bahan masuk (W) = 11873.4152 kg/jam
  = 26176.3687 lb/jam
- Suhu bahan masuk (t_1) = 120 °C = 248 °F
- Suhu bahan keluar (t_2) = 180 °C = 356 °F
- Kebutuhan steam (m) = 497.5799 kg/jam
  = 1096.9745 lb/jam
- Panas yang diserap (Q) = 235325.3 Kkal/jam
  = 933222.49 Btu/jam
- Suhu steam masuk (T_1) = 190 °C = 374 °F
- Suhu steam kondensat (T; = 190 °C = 374 °F

Perhitungan *density* berdasarkan pers. *Carl and Yaws*

Density = $A \times B^{-(1-T/Tc)^n}$ T = 120 °C = 393.15 K

Komponen	A	B	n	Tc	$(1-T/Tc)^n$
CH_3COOH	0.35182	0.26954	0.26843	592.71	0.7466
H_2O	0.3471	0.27400	0.28571	647.13	0.7655

(Pers. *Carls and Yaws Density of Liquid*)[20]

Komponen	Massa (Kg/jam)	xi (massa)	ρ (Kg/m³)	ρ (lb/ft³)	ρixi
CH_3COOH	11649.062	0.9800	936.3189	58.4525	57.2835
H_2O	237.73595	0.0200	935.1004	58.3764	1.1675
Total	**11886.7976**	**1.0000**	**1871.4192**	**116.8290**	**58.4510**

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{58.4510}{1.0000} = 58.4510 \quad lb/ft^3 = 936.2645 \quad kg/m^3$$

$$\log 10\ \mu = A+B/T+CT+DT^2$$

Komponen	μ (*Centripoise*)			
	A	B	C	D
CH_3COOH	-3.8937	784.8200	0.0067	-0.0000076
H_2O	-10.2158	1792.5000	0.0177	-0.0000126
$C_4H_6O_2$	-9.0671	1186.3000	0.0227	-0.0000232

(Yaws and Carl Viscosity of Liquid)[20]

Komponen	Massa (Kg/jam)	xi (massa)	μ (Cp)	μ (lb/ft.s)	xi.μi
CH_3COOH	11649.0616	0.9800	0.3583	0.0002	0.000236
H_2O	237.7360	0.0200	0.2300	0.0002	3.091E-06
Total	**11886.7976**	**1.0000**	**0.5883**	**0.0004**	**0.0002**

$$\mu \text{ campuran} = \frac{\sum xi.\mu i}{\sum xi}$$

$$= \frac{0.0002}{1.0000} = 0.0002 \quad lb/ft.s = 0.8606 \quad lb/ft.jam$$

Menentukan C_p

$$C_p = A + B\,T + C\,T^2 + DT^3$$

Komponen	A	B	C	D
CH_3COOH	-18.944	1.09710	-0.00289	2.9257E-06
H_2O	92.053	-0.03995	-0.000211	5.347.E-07

(Yaws and Carl Heat Capacity of Liquid)[20]

Komponen	Massa (Kg/jam)	xi (massa)	Cp (Joule/kg.	Cp (Btu/lb.°F)	Cp .xi
CH_3COOH	11649.0616	0.9800	143.147	0.034	0.0335
H_2O	237.7360	0.0200	76.219	0.018	0.0004
Total	**11886.7976**	**1.0000**	**219.366**	**0.052**	**0.0339**

$$Cp \text{ campuran} = \frac{\sum xi.Cp}{\sum xi}$$

$$= \frac{0.0339}{1.0000} = 0.0339 \quad Btu/lb.°F$$

$\log_{10} k_{liq}$ = A + B (1-T/C)^(2/7) (untuk CH_3COOH dan $C_4H_6O_2$)

k = A+ B T+ C T^2 (untuk H_2O)

Komponen	**A**	**B**	**C**	**$(1-T/C)^{2/7}$**
CH_3COOH	-1.2836	0.5893	6.E+02	0.1122
H_2O	-0.2758	0.0046	-5.54E-06	-

(Yaws and Carl Thermal Conductivity of Liquid)[20]

Komponen	Massa (Kg/jam)	xi (massa)	k (W/mK)	k (Btu/jam.ft^2	k.xi
CH_3COOH	11649.0616	0.9800	0.0606	0.0350	0.03432
H_2O	237.7360	0.0200	0.6812	0.3936	0.00787
Total	**11886.7976**	**1.0000**	**0.7419**	**0.4286**	**0.0422**

$$k\ campuran = \frac{\sum xi.k}{\sum xi} = \frac{0.0422}{1.0000} = 0.0422 \quad Btu/jam/ft^2.°F/ft$$

Perhitungan :

A. Menghitung Δt

$\Delta_{t1} = T_1 - t_2 = 374 - 356 = 18$ °F

$\Delta_{t2} = T_2 - t_1 = 374 - 248 = 126$ °F

maka,

$$\Delta T_{LMTD} = \frac{\Delta_{t1} - \Delta_{t2}}{\ln \frac{\Delta_{t1}}{\Delta_{t2}}} = \frac{18 - 126}{\ln \frac{18}{126}} = \frac{-108.0}{-1.9459} °F$$

$= 55.501$ °F

B. Menghitung suhu kalorik (Tc dan tc)

$Tc = (T_1+T_2)/2 = 374$ °F

$tc = (t_1+t_2)/2 = 302$ °F

C. Trial ukuran DPHE

Dicoba ukuran DPHE : 3 × 2" IPS sch 40 dengan aliran steam dibagian pipa.

Dari tabel 6.2. "Kern" hal.110[24], didapatkan:

a_{an} = 2.93 in^2 = 0.0203 ft^2

a_p = 3.35 in^2 = 0.0233 ft^2

de = 1.57 in = 0.1308 ft

de' = 0.69 in = 0.0575 ft

dari tabel 11 "Kern" hal.844[24], didapatkan:

do_p = 2.38 in = 0.1983 ft

di_p = 2.067 in = 0.1723 ft

a" = 0.622 ft^2/ft

Evaluasi Perpindahan Panas	
Bagian *Anulus* (Bahan)	Bagian Pipa (Steam)
1. Menghitung N_{Re} $G_{an} = \frac{W}{a_{an}}$ $= \frac{26176.3687}{0.0203}$ $= 1286483.6508$ lb/jam.ft^2 $\mu = 0.8606$ lb/ft.jam $NRe_{an} = \frac{G_{an} \times de}{\mu}$ $= 195582.5519$	1'. Menghitung N_{Re} $G_p = \frac{m}{a_p}$ $= \frac{1096.9745}{0.0233}$ $= 47153.5308$ lb/jam.ft^2 $\mu = 0.1434$ Cp $= 0.3470$ ft.jam $NRe_p = \frac{G_p \times di}{\mu}$ $= 23409.9898$
Mencari faktor panas (J_H) 2. (Fig. 24, hal 834, Kern)[24] $J_H = 1000$	2'. Mencari faktor panas (J_H) J_H tidak perlu dicari karena steam
3. Menghitung harga koefisien film Cp = 0.0339 Btu/lb.^{o}F k = 0.0422 Btu/jam.ft^2.^{o}F/ft $k(Cp.\mu/k)^{1/3} = 0.8840$ $\left(\frac{\mu}{\mu_w}\right)^{0.14} = 0.9743$ $ho = J_H \times \frac{k}{De} \times (Cp.\mu/k) \times \left(\frac{\mu}{\mu_w}\right)^{0.14}$ $= 1000 \times 0.32 \times 0.88 \times 0.97$ $ho = 277.7245$ Btu/jam.ft^2.^{o}F	3'. Menghitung harga koefisien film untuk steam $h_{i0} = 1500$ Btu/jam.ft^2.^{o}F

D. Mencari tahanan panas pipa bersih

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

$$Uc = \frac{277.7245 \times 1500}{277.7245 + 1500}$$

$$= 234.3371 \text{ Btu/jam.ft}^2.^o\text{F}$$

E. Mencari dirty faktor (faktor kekotoran) pipa terpakai

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

$$\frac{1}{U_D} = \frac{1}{U_C} + Rd$$

$$\frac{1}{U_D} = \frac{1}{234.337} + 0.0010$$

U_D = 189.8485 Btu/jam.ft^2.^{o}F

$$A = \frac{Q}{U_D \times \Delta T}$$

$$= \frac{933222.494}{189.849 \times 55.501}$$

= 88.568 ft^2

$$L = \frac{A}{a''}$$

$$= \frac{88.5680 \ ft^2}{0.622 \ ft^2/ft}$$

= 142.3923 ft

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

$$= \frac{234.337 - 189.849}{234.337 \times 189.849}$$

= 0.001

Rd ketetapar = 0.001

Rd hitung > Rd ketetapan jadi Ok

Hasil		
1500	h outside	277.724
U_C		234.3371
U_D		189.8485
Rd terhitung		0.0010
Rd tetapan		0.0010

F. Mencari panjang ekonomis

L(ft)	Hairpin	N_{pakai}	L_{baru}	A_{baru}	UD_{baru}	Rd_{baru}	Rd $_{over\ desain}$
12	5.9330	6	144	89.6	187.729	0.0011	0.0595
15	4.7464	5	150	93.3	180.220	0.0013	0.2814
20	3.5598	4	160	99.5	168.956	0.0017	0.6513

Jadi diambil over desain terkecil, yaitu = 0.0595

L = 12 ft

n = 6 buah

Evaluasi Δp	
Bagian *Anulus* (Bahan)	Bagian Pipa (Steam)
1. Menghitung N_{re} dan friksi	1'. Menghitung N_{re} dan friksi
NRe_{an} = 195582.55	NRe_p = 23409.99
Kern fig.29, hal.839[24]	Kern fig.26, hal.836[24]
f = 0.0008	f = 0.00020

2. Mencari ΔP karena panjang pipa

$\rho = 58.451 \ lb/ft^3$

$\Delta F_a = \dfrac{4 \times f \times G_{an}^2 \times L}{2 \times g \times \rho^2 \times de'}$

$\Delta F_a = 0.0387 \ ft$

$V = \dfrac{G}{3600 \times \rho}$

$= \dfrac{1286483.6508}{3600 \times 58.4510}$

$= 6.1138 \ fps$

$FI = 3 \times \dfrac{V^2}{2 g}$

$= 3 \times \dfrac{6.1138^2}{2 \times 32.174}$

$= 1.7426 \ ft$

$\Delta pa = 0.7231$

Hasil ΔP karena panjang pipa

ΔP allow = 10 psi

$\Delta P_a < \Delta P_{allow}$

$0.72306 < 10$ psi

(memenuhi syarat)

2'. Menghitung ΔP pipa

$\rho = 53.50 \ Ib/ft^3$

$\Delta Pp = \dfrac{4 . f . Gt^2 . L}{2 . g . \rho^2 . Di}$

$= 0.00518 \ ft$

$\Delta P_p < \Delta p_{tetapan}$

$0.0052 < 2.5$

(memenuhi syarat)

Spesifikasi Alat Heater (E-114) :

Fungsi	:	Menaikkan suhu larutan dari 120°C menjadi 180°C sebelum masuk reaktor
Type	:	*Double Pipe Heat Exchanger*
Bahan konstruksi	:	Stainlees Steel SA 312 Grade M Type 317
Kapasitas	:	11873.4152 kg/jam = 26176.3687 lb/jam
Rate steam	:	497.5799 kg/jam = 1973.2375 Btu/jam
Jumlah hairpin	:	5.9330 buah
Diameter luar pipa	:	2.3800 in = 0.1983 ft
Diameter dalam pipa	:	2.0670 in = 0.1723 ft
Panjang	:	12 ft
Jumlah	:	1 buah

5. Kompresor (G-115)

Fungsi : Menaikan tekanan aliran asam asetat dari 1 atm menjadi 5 atm

Type : Single stage reciprocating compressor

P_1 = 1 atm = 1.01 bar

P_2 = 5 atm = 5.07 bar

T_1 = 180 °C = 453.15 K

Dari Coulson and Richardson's, App. C Hal.938[22] didapatkan :

Komponen	Konstanta C_P = a+bT+cT2+dT3+eT4			
	a	b	c	d
CH_3COOH	-18.944	1.097.E+00	-2.8900.E-03	2.9250.E-06
H_2O	92.053	-3.995.E-02	-2.1100.E-04	5.3470.E-07

Komponen	Cp (J/gmol K)
CH_3COOH	1.569.E+02
H_2O	8.038.E+01

R = 8.314 J/gmol K

$$\gamma = \frac{Cp}{Cp - R}$$

$$= \frac{118.6571}{118.6571 - 8.314}$$

= 1.0753

Dari App.A didapatkan :

$$\text{Jumlah gas masuk} = \frac{11886.798 \text{ kg/jam}}{3600 \text{ detik}}$$

= 3.30189 kg/detik

Dari Perry 8th Edition tabel 2-32 Hal. 2-98[7] didapatkan tabel berikut:

Komponen	berat molekul	C1	C2	C3	C4
CH_3COOH	60	53.27000	-6304.500	-4.29850	8.89E-18
H_2O	18	73.64900	-7258.200	-7.30370	4.17E-06

Komponen	Massa (Kg/jam)	xi (massa)	ρ (kg/m^3)	xi.ρi
CH_3COOH	11649.062	0.9800	3739506.1	3664715.9
H_2O	237.73595	0.0200	4788369.4	95767.4
Total	11886.798	1.0000	8527875.4	3760483.3

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{3760483.32}{1.0000} = 3760483.3 \text{ kg/m}^3 = 234654.2 \text{ lb/ft}^3$$

$$Q = \frac{\text{Rate bahan masuk}}{\rho \text{ bahan masuk}}$$

$$= \frac{3.30189 \text{ kg/detik}}{3760483 \text{ kg/m}^3}$$

= 0.0000009 m^3/detik

Dari Coulson and Richardson's,Fig. 3.6 Hal.83 didapatkan Ep 0.65

$m = \frac{\gamma - 1}{\gamma . Ep} = \frac{1.0753 - 1}{1.0753 \times 0.65} = 0.1078$ (Coulsons, pers. 3.36a Hal.85)[22]

$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^m = 453.15 \left(\frac{5.07}{1.01}\right)^{0.1078} = 538.999 \text{ K} = 265.849\ ^oC$

(Coulsons, pers. 3.35 Hal.85)[22]

Dari Coulson and Richardson's, App. C Hal.938[22] didapatkan :

Komponen	Tc (K)	Pc (bar)
CH_3COOH	594.4	57.9
H_2O	647.3	220.5
Total	1241.7	278.4

$T_{r\ mean} = \frac{453.15 + 538.999}{2 \times 1241.7} = 0.39951$

$P_{r\ mean} = \frac{5.07 + 1.01}{2 \times 278.4} = 0.01092$

pada Tr mean,

Komponen	Cp (J/gmol K)
CH_3COOH	-18.5062
H_2O	92.0370
Total	73.5308

Dari Coulson and Richardson's, Fig. 3.2 Hal.70[22] didapatkan 2 kJ/mol K

$Cp = 73.531 + 2 = 75.531$ kJ/mol K

Dari Coulson and Richardson's, Fig. 3.8; 3,9; 3,10 Hal.87,88,89[22] didapatkan :

X = 0.3

Y = 1.15

Z = 0.95

$m = \frac{ZR}{Cp}\left(\frac{1}{Ep} + X\right)$ (Coulsons, pers. 3.36 Hal.85)[22]

$= \frac{0.95 \times 8.314}{75.5308} \times \left(\frac{1}{0.65} + 0.3\right)$

$= 0.19225$

$n = \frac{1}{Y - m(1+X)}$ (Coulsons, pers. 3.38 Hal.85)[22]

$= \frac{1}{1.15 - 0.19\ (1 + 0.3)}$

$= 1.111$

$$-W = Z \cdot \frac{RT_1}{M} \cdot \frac{n}{n-1} \cdot \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$= 0.95 \times \frac{8.314 \times 453.2}{59.16} \times \frac{1.111}{1.111 - 1}\left(\left(\frac{5.07}{1.01}\right)^{\frac{1.111-1}{1.111}} - 1\right)$$

= 650.58887 kJ/kmol

Actual work yang dibutuhkan $= \frac{\text{W polytropic}}{\text{Ep}}$

$= \frac{650.58887}{0.65}$

= 1000.906 kJ/kg

Daya $= \frac{1000.906}{2684.5195} \times 11886.798$

= 0.44 hp ≈ 1 hp

Spesifikasi Kompresor (G-115)

Fungsi	:	Menaikan tekanan asam asetat dari 1 atm menjadi 5 atm
Kode alat	:	G-115
Tipe	:	Radial
Kapasitas	:	3.3019 kg/detik
Daya	:	1 hp

6. Storage Etilena (F-116)

Fungsi : Untuk menyimpan bahan baku Etilena

tipe : Tangi silindertegak dengan jaket

Direncanakan:

Bahan konstruksi : Stainless steel SA 240 Grade M type 316

F allowable : 18750 psi

tipe pengelasan : single welding butt joint (E = 0.85)

Faktor korosi (C) : 1/16 in

Waktu tinggal : 2 hari

Volume ruang kosong : 20% Volume total

Jumlah Tangki Penampur : 3 buah

Dasar Perencanaan

Kondisi operasi :

Massa bahan masuk = 4344.0869 kg/jam

= 9576.974 lb/jam

Suhu operasi = -120.00 ^{o}C = 153.15 K

Tekanan operasi = 1 atm = 14.7 psia

Dari Perry 8th Edition tabel 2-32 Hal. 2-98[7] didapatkan tabel berikut:

Komponen	berat molekul	C1	C2	C3	C4
C_2H_4	28	2.09610	0.27657	282.340	0.2915
CH_4	16	2.92140	0.28976	190.560	0.2888
C_2H_6	30	1.91220	0.27937	305.320	0.2919

dimana, ρ dalam mol/m^3

$$\rho = \frac{C_1}{C_2^{(1+(1-\frac{T}{C_3})^{C_4}}}$$

Komponen	Massa (Kg/jam)	xi (massa)	ρ (kg/m^3)	xi.ρi
C_2H_4	4344.414	0.9950	101.3240	100.8174
CH_4	13.099	0.0030	71.7102	0.2151
C_2H_6	8.732	0.0020	100.1983	0.2004
Total	4366.245	1.0000	273.2325	101.2329

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{0.2004}{0.0020} = 100.1983 \text{ kg/m}^3 = 6.2524 \text{ lb/ft}^3$$

Dari Perry 8th Edition tabel 2-312 Hal. 2-421[7] didapatkan tabel berikut:

Komponen	C1	C2	C3	C4
C_2H_4	53.9630	-2443.0	-55643	1.908E-05
CH_4	39.2050	-1324.4	-3.4366	3.102E-05
C_2H_6	51.8570	-2598.7	-5.1283	1.491E-05

dimana μ dalam Pa.s

$$\mu = \frac{C_1 T^{C2}}{1 + C_3/T + C_4/T^2}$$

Komponen	Massa (Kg/jam)	xi (massa)	μ (Pa.s)	μ (lb/ft.s)	xi.μi
C_2H_4	28	0.0064	125.42	84.2751	0.540442
CH_4	16	0.0037	2.87	1.9265	0.007060
C_2H_6	30	0.0069	5.62	3.7778	0.025957
Total	74	0.0169	133.90406	89.9794	0.573458

$$\mu \text{ campuran} = \frac{\sum xi.\mu i}{\sum xi}$$

$$= \frac{0.573458}{0.0169} = 33.835945 \text{ lb/ft.s} = 121809 \text{ lb/ft.jam}$$

$$\text{Rate liquid} = \frac{9576.974 \text{ lb/jam}}{6.2524 \text{ lb/ft3}}$$

$$= 1531.7338 \text{ ft}^3\text{/jam}$$

Menghitung Volume Tangki

Untuk menentukan volume tangki, maka diasumsikan

- Waktu tinggal = 2 hari = 48 jam
- Tinggi silinder = 1.5 di

- Volume ruang kosong = 20% V_T
- Jumlah = 3 buah

Sehingga

Volume *Liquid* $= \dfrac{\textit{Rate Volumetrik}}{\text{jumlah}} \times$ waktu tinggal

$= \dfrac{1531.73 \text{ ft}^3/\text{jam}}{3 \text{ buah}} \times 48$ jam

$= 24507.741 \text{ ft}^3$

Volume ruang kosong = 20% volume total

$= 20\% \times V_T$

Volume total = Volume *Liquid* + Volume ruang kosong

Volume total = 24507.7410 + 20% Volume total

80% Volume total = 24507.7410

Volume total $= 30634.676 \text{ ft}^3$

- **Menghitung diameter tangki**

  Asumsi : Ls = 1.5 di

  $V_{total} = V_{tutup\ atas} + V_{silider}$

  $30634.676 = 0.0847\ di^3 + \left(\dfrac{\pi}{4} \times di^2 \times Ls\right)$

  $30634.676 = 0.0847\ di^3 + \left(\dfrac{\pi}{4} \times di^2 \times 1.5\ di\right)$

  $30634.676 = 0.085\ di^3 + 1.1775\ di^3$

  $30634.676 = 1.262\ di^3$

  $di^3 = 4270.857$

  $di = 16.2245$ ft

  $= 194.6942$ in

  $= 4.9452$ m

- **Menghitung tinggi *Liquid***

  V *Liquid* = V *Liquid* dalam silinder

  V *Liquid* $= \left(\dfrac{\pi}{4} \times di^2 \times Lls\right)$

  $24507.741 = \dfrac{\pi}{4} \times 16.22^2 \times Lls$

  $Lls = \dfrac{24507.74103}{263.23 \times 0.785}$

  $= 118.6015$ ft

  $= 1423.2182$ in

  $= 36.149742$ m

- **Menentukan tekanan desain**

  Tekanan hidrostatik (ρh) $= \dfrac{\rho \times (H-1)}{144}$ (*Brownell & Young*, Pers.3.17,p.46[12])

$$= \frac{6.2524 \ \text{lb/ft}^3 \times 118.602 \ \text{ft} - 1}{144}$$

Tekanan hidrostatik (ρh) = 5.1062 psia

Pi = $P_{atm} + P_{hidrostatik}$
= 14.6959 + 5.1062
= 19.8021 psia
= 5.1061 psig

- **Menentukan tebal silinder (ts)**

$$ts = \frac{Pi.di}{2(f.E - 0,6Pi)} + C$$

$$= \frac{5.1061 \times 194.6942}{2 \times [(18750 \times 0.85) - (0.6 \times 5.106)]} + \frac{1}{16}$$

= 0.03 + 0.0625

$$= 0.09 \times \frac{16}{16}$$

$$= \frac{1.49911}{16} \approx \frac{3}{16}$$

Standarisasi do
do = di + 2 ts

$$= 194.6942 + \left(2 \times \frac{3}{16}\right)$$

= 195.0692 in
= 16.2558 ft

Standarisasi dengan Tabel 5.7, *Brownell and Young* , hal 89 [12]
do = 204 in
icr = 12 1/4
r = 170
ts = 1 1/4
maka :
di_{baru} = do - 2 ts
= 204 - 2 × 0.01563
= 203.9688 in

- **Menghitung tinggi silinder (Ls)**

Ls = 1.5 di
= 1.5 × 203.9688
= 305.9531 in

- **Menghitung dimensi tutup atas**

Bentuk tutup atas dan bawah adalah *Standar Dish,* sehingga
r = di baru = 203.9688 in
Tebal tutup atas (tha)

$$tha/b = \frac{0,885 \ Pi.di}{(fE - 0,1 \ Pi)} + C$$ (*Brownell & Young* , pers. 13.12, p. 258 [12])

$$= \frac{0.885 \times 5.1061 \times 203.9688}{[(18750 \times 0.85)-(0.1 \times 5.106)]} + \frac{1}{16}$$

$$= 0.0578 + \frac{1}{16}$$

$$= \frac{1.925}{16} \approx \frac{3}{16}$$

Tinggi tutup (ha/hb)

ha/b = 0.169 × di

= 0.169 × 203.9688

= 34.4707 in

= 2.8726 ft

- **Menghitung tinggi tangki (H)**

Tinggi tangki (H) = Tingi silinder + Tinggi tutup atas + Tinggi tutup bawah

= 305.9531 in + 34.4707 in + 34.4707 in

= 374.8946 in

= 9.5223 m

5. Perhitungan Jaket Pendingin

- **Menentukan ΔT_{LMTD}**

Diketahui :

Suhu bahan masuk (t_1)	=	30.0	^oC	=	86	°F
Suhu bahan keluar (t_2)	=	-110.00	^oC	=	-166	°F
Suhu *Refrigerant* masuk (T_1)	=	-120	^oC	=	-184	°F
Suhu *Refrigerant* keluar (T_2)	=	-90	^oC	=	-130	°F

$\Delta t_1 = t_1 - t_2 = 86 - -130 = 216$ °F

$\Delta t_2 = t_1 - T_1 = 86 - -184 = 270$ °F

$$\Delta T_{LMTD} = \frac{\Delta t_1 - \Delta t_2}{\ln \frac{\Delta t_1}{\Delta t_2}} = \frac{216 - 270}{\ln \frac{216}{270}} = \frac{-54}{-0.22314} = 241.997 \ °F$$

$\Delta t = \Delta T_{LMTD} \times Ft$

$\Delta t = 241.997 \times 1$

$\Delta t = 241.997$ °F

- **Menentukan Luas Perpindahan Panas**

Nilai UD Berdasarkan *Kern* halaman 840 [7] bagian *Coolers* yaitu 5-75

$$A = \frac{Q}{UD . \Delta t}$$

$$= \frac{4906.7206}{50 \times 241.997}$$

$= 0.4055 \ ft^2$ (nilai A<120 ft^2, maka menggunakan Jaket)

Rate massa *Refrigerant* total = 108.8399 kg/jam
= 239.9484 lb/jam

Densitas *Refrigerant* = 0.0156 g/mL
= 15.5542 kg/m^3
= 0.9710 lb/ft^3

Laju alir air $= \frac{239.9484}{0.9710}$
= 247.1098 ft^3/jam

Volume *Refrigerant* yang dibutuhkan = 247.1098 × 48
= 11861.2684 ft^3

Volume *Refrigerant* total = Volume *Refrigerant* yang dibutuhkan + 10% *Excess*
= 11861.268 + 1186.1268
= 13047.395 ft^3/jam

Tekanan dalam tangki = 1.0000 atm

Diameter dalam tangki (di) = 204 in = 17.0000 ft

Diameter luar tangki (do) = 203.969 in = 16.9974 ft

Volume total tangki = 24507.7410 ft^3

Volume *Liquid* dalam jaket = volume *Refrigerant* total
= 13047.3953 ft^3

Asumsi nilai Ls = 1,5 di

Volume jaket = Volume *Refrigerant* dalam silinder jaket

$$13047.3953 = \frac{\pi\ di^2\ Lls}{4}$$

$$13047.3953 = \frac{\pi\ di^2 .\ 1,5\ di}{4}$$

$$13047.3953 = 1.1775\ di^3$$

di^3 = 11080.5905

di = 22.2940 ft

di = 267.5278 in
= 6.7952 m

Tinggi jaket (H)

H = Ls
= 1,5 di
= 33.4410 ft
= 401.2917 in
= 10.1928 m

Menentukan P *Design* = P operasi
= 5.1061 psig

- **Menentukan tebal dinding jaket**

$$ts = \frac{Pi \times di}{2(fE - 0,6\ Pi)} + C$$

$$= \frac{5.1061 \times 267.5278}{18750 \times 0.9 - 0.6 \times 5.1 \times 2} + 0.0625$$

$$= \frac{1366.0161}{31868.8727} + 0.0625$$

$= 0.0429 + 0.0625$

$= 0.1054$ in

$$= \frac{1.6858}{16} \text{ in} \approx \frac{3}{16} \text{ in}$$

do = di + 2 ts

$$= 267.5278 + 2\ \frac{3}{16} \text{ in}$$

$= 267.9028$ in

$= 22.2359$ ft

Standarisasi do baru pada *Brownell and Young* halaman 92 [12]

do = 240 ft

di = do - 2 ts

= 239.6250 in

= 19.9688 ft

Volume jaket = Volume *Liquid* dalam Silinder jaket

$$13047.3953 = \frac{\pi\, di^2\, Ls}{4}$$

$13047.3953 = 313.3043\ Ls$

Ls = 37.6445 ft

Ls = 451.7337

$$\frac{Ls}{di} = \frac{37.6445}{19.9688} = 1.8852 < 2 \quad \text{memenuhi}$$

Spesifikasi Storage Tank Etilen

Fungsi	:	Untuk menyimpan bahan baku etilena
Kode alat	:	F-116
Tipe	:	Tangi silindertegak dengan jaket
Kapasitas	:	30634.676 ft^3
Suhu operasi	:	153.15 K
Tekanan operasi	:	1 atm
Dimensi		
Diameter tangki	:	204 in
Tinggi tangki	:	203.969 in
Tebal tangki	:	3/16 in
Tipe pengelasan	:	Single welding butt joint
Bahan Konstruksi	:	Stainless steel SA 240 Grade M type 316
Jumlah	:	3 buah

6. Heater (E-117)

Fungsi : Untuk memanaskan Etilena

Tipe : Shell and Tube Heat Exchanger

Direncanakan :

- faktor kekotoran gabungan minumum (Rd) = 0.001 jam.ft^2.°F/Btu
- Δp maksimum aliran = 10 psi
- Δp maksimum steam = 2.5 psi

Dasar perencangan :

Dari Appendix B didapatkan data sebagai berikut:

- Massa bahan masuk = 4,366.2450 kg/jam
  = 9,625.824 Ib/jam
- Suhu bahan masuk (t_1) = -110 °C = -166.00 °F
- Suhu bahan keluar (t_2) = 180 °C = 356 °F
- Kebutuhan steam (m) = 241.7471 kg/jam
  = 532.9557 Ib/jam
- Panas yang dibawa steam = 114,329.2618 kkal/jam
  = 453,399.6740 btu/jam
- Steam masuk pada suhu(T_1) = 190 °C = 374 °F = 463.15 K
- Steam keluar pada suhu (T_2) = 190 °C = 374 °F = 463.15 K
- Digunakan pipa ukuran 3/4 in OD, BWG 16, L = 12 ft, P_T = 1 in
- Shell side : Etilen
- Tube side : Steam
- Susunan tube segitiga (triangular pitch)

Perhitungan :

A. Menghitung ΔT_{LMTD}

$\Delta t_1 = T_1 - t_2 = 463\ °F - 356\ °F = 107\ °F$

$\Delta t_2 = T_2 - t_1 = 463\ °F - (-166.00)\ °F = 629\ °F$

$$\Delta T_{LMTD} = \frac{\Delta t_1 - \Delta t_2}{\ln \Delta t_1/\Delta t_2}$$ (Kern, Pers.5.14 Hal.89)[24]

$$= \frac{107 - 629.15}{\ln(107 / 629.15)}$$

$$= 294.89\ °F$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{463 - 463}{356 - -166} = 0.00$$ (Kern, pers. 5.14 hal 149)[24]

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{356 - -166}{463 - -166} = 0.83$$

Jadi,

Ft = 1 (Isotermal) *(Kern, hal 167)* [24]

Sehingga Tipe HE; 2-4

$\Delta t = \Delta T_{LMTD} \times Ft = 294.8919 = 294.89\ °F$

B. Menghitung suhu kalorik

Tc = $(T_1 + T_2) / 2$ = 374 ^oF = 190 ^oC = 463.15 K

tc = $(t_1 + t_2) / 2$ = 95 ^oF = 35 ^oC = 308.15 K

C. Trial U_D

Dari Kern hal 840 tabel 8[24] diperoleh:

Range U_D = 2-200 Btu/jam $ft^2.\,^oF$

Dicoba U_D = 200 Btu/jam $ft^2.\,^oF$

Dari App.B didapatkan Q = 114,329.26 kkal/jam

= 4536947.5 Btu/jam

$$A = \frac{Q}{U_D \cdot \Delta t} = \frac{4536947.4833}{200 \times 294.8919} = 76.9256 \ ft^2$$

dengan,

do_{tube} = 3/4 in

BWG = 16

Dari Kern, tabel 10, hal. 843[24], diperoleh harga a" 0.1963 ft^2/ft

$$Nt = \frac{A}{a'' \cdot L} = \frac{76.9256}{0.1963 \times 12} = 33 \ \text{buah}$$

Dari Kern, tabel 9, hal. 842[24], diperoleh :

IDs = 17 1/4 in

n = 4

Nt = 178

$$U_D \text{ koreksi} = \frac{Nt}{Nt \text{ standar}} \times U_D \text{ trial}$$

$$= \frac{33}{178} \times 200 = 36.69 \ \text{Btu/jam ft}^2.\,^oF$$

Dari Kern, tabel 28, hal. 838[24], diperoleh :

de = 0.72 in

Viskositas aliran pada shell (bahan):

Dari Perry 8th Edition tabel 2-312 Hal. 2-421[7] didapatkan tabel berikut:

Komponen	C1	C2	C3	C4
C_2H_4	53.9630	-2443.0	-55643	1.908E-05
CH_4	39.2050	-1324.4	-3.4366	3.102E-05
C_2H_6	51.8570	-2598.7	-5.1283	1.491E-05

dimana μ dalam Pa.s

$$\mu = \frac{C_1 T^{C2}}{1 + C_3 / T + C_4 / T^2}$$

Komponen	Massa (Kg/jam)	xi (massa)	μ (Pa.s)	μ (lb/ft.s)	xi.μi
C_2H_4	4344.414	0.9950	125.42	84.2751	83.853681

CH_4	13.099	0.0030	2.87	1.9265	0.005780
C_2H_6	8.732	0.0020	5.62	3.7778	0.007555
Total	4366.245	1.0000	133.90406	89.9794	83.867016

$$\mu \text{ campuran} = \frac{\sum xi.\mu i}{\sum xi}$$

$$= \frac{83.867016}{1.0000} = 83.867016 \text{ lb/ft.s} = 301921 \text{ lb/ft.jam}$$

Viskositas aliran pada pipe (steam):

Dari Perry 8th Edition tabel 2-312 Hal. 2-421[7] didapatkan tabel berikut:

Komponen	C1	C2	C3	C4
H_2O	7.365.E+01	-7258.20	-7.3037	4.165.E-06

dimana μ dalam Pa.s

Komponen	Massa (Kg/jam)	xi (massa)	μ (Pa.s)	μ (lb/ft.s)	xi.μi
H_2O (steam)	241.7471	1.0000	1252467.52	841619.319	841619.319

Kesimpulan sementara hasil perancangan :

Type HE : 2-4

Bagian *Tube*

do = 3/4 in, 16 BWG
L = 10 ft Nt = 178
Susunan segitiga, n = 4
di = 0.6200 in = 0.052 ft
a' = 0.3020 in^2 = 0.025 ft^2
a" = 0.1963 ft^2/ft
Pt = 1 in

Bagian *Shell*

IDs = 17 1/4 in = 1.44 ft
n' = 2
B = 4 in = 0.33 ft
de = 0.72 in = 0.06 ft
C' = 1 1/4 - 1 = 0.25

Evaluasi Perpindahan Panas

Hot fluid: tube, Steam

1. Menghitung NRe

$$a_t = \frac{Nt \times a'}{n \times 144} = \frac{178 \times 0.025}{178 \times 144} = 0.0002 \text{ ft}^2$$

$$G_t = \frac{m}{a_t} = \frac{532.9557 \text{ lb/jam}}{0.0002 \text{ ft}^2} = 3049494.62 \text{ lb/jam.ft}^2$$

pada Tc = 374 °F

μ = 841619.32 lb/ft.s

Cold fluid: shell, gas etilena

1'. Menghitung NRe

$$a_s = \frac{IDs \times C' \times B}{n' \times Pt \times 144} = \frac{1.44 \times 0.25 \times 4}{2 \times 1 \times 144} = 0.00499 \text{ ft}^2$$

$$G_s = \frac{M}{a_s} = \frac{9625.824 \text{ lb/jam}}{0.0050 \text{ ft}^2} = 1928512.8580 \text{ lb/jam.ft}^2$$

pada tc = 95 °F

μ = 83.867016 lb/ft.s

= 3029829549 lb/ft.jam

di = 0.62 in

= 0.052 ft

$N_{re} = \frac{G_t \times di}{\mu}$

$= \frac{3049494.62 \times 0.052}{3029829548.916380}$

= 0.00005

2. J_H = - (*steam*)

3. Menghitung harga koefisien film perpindahan panas

= 1500 Btu/ft^2.jam^{0}F

= 301921.26 lb/ft.jam

de = 0.72 in

= 0.06 ft

$Nre_s = \frac{G_{an} \times de}{\mu}$

$= \frac{1928512.8580 \times 0.06}{301921.25611}$

= 0.3832

2'. Menghitung faktor panas (J_H)

Dari Kern, Fig. 24 Hal.834[24] didapatkan:

J_H = 1100

3'. Menghitung harga koefisien film

Dari Kern, Tabel 4 hal.800[24] didapatkan:

k = 0.043 Btu/jam.ft^2.^{o}F/ft

Dari Kern, Fig.3 hal.805[24] didapatkan:

Cp = 0.131 Btu/lb.^{o}F

maka,

$k\,(Cp.\mu/k)^{1/3}$ = 4.1797 in

ho/φs = 76628.010

tw = 221 ^{o}F

dimana μ Pada suhu tw didapatkan:

μw = 66724598 lb/ft.jam

μ /μw = 4.52E-03

Dari Kern, Fig. 24 Hal.834[24] didapatkan:

φs = 0.47

sehingga,

ho = 35989.24 Btu/jam.ft^{2o}F

Clean overall coefficient Uc :

$Uc = \frac{hio \cdot ho}{hio + ho} = \frac{1500 \times 35989.24}{1500 + 35989.24} = 71978.5$ Btu/ft^2.jam^{0}F

Dirt factor (faktor kekotoran) pipa terpakai

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

$= \frac{71978.47268 - 37}{71978.473 \times 37} = 0.02724$ jam.ft^2.°F/Btu

Karena harga Rd hitung > Rd tetapan, maka rancangan HE memenuhi.

Evaluasi ΔP

Hot fluid: tube, Steam

1. NRe_t = 0.0001

Dari Kern,fig. 26 hal.836[24], diperoleh :

Pada f = 0.00019

Dari steam tabel, untuk kondisi : saturated steam

T = 374 °F

P = 45.4 psia

didapatkan,

specific vol. = 9.31965 ft^3/lb

$$sg = \frac{1}{9.31965 \times 62.5}$$

= 0.0017168

2. ΔP karena panjang pipa :

$$\Delta Pl = \frac{1}{2} \cdot \frac{f.Gt^2.L.n}{5{,}22 \times 10^{10}.di.sg.\phi}$$

$$= \frac{0.00019 \times 3049494.6^2 \times 10 \times 4}{2 \times 5{,}22.10^{10} \times 0.052 \times 0.002 \times 1}$$

= 1.8528 psi

s

ΔP karena tube passes

Dari Kern,fig. 27 hal.837[24],diperoleh:

$$\left[\frac{v^2}{2gc}\right]\frac{\rho}{144} = 0.55$$, sehingga

$$= \frac{4n}{sg}\left[\frac{v^2}{2gc}\right]\frac{\rho}{144}$$

$$\Delta Pn = \frac{4 \times 4}{0.0017} \times 0.55$$

= 0.51258 psi

sehingga,

ΔPt total = 1.8528 + 0.51258

= 2.37 psi < 2.5 psi

desain memenuhi

Cold fluid: shell, gas Etilena

1'. Pada Nres = 0.3832

Dari Kern,fig. 29 hal.839[24], diperoleh

f = 0.0008

2'. No. of crosess

$$(N+1) = \frac{12L}{B} = \frac{12 \times 10}{4}$$

= 30

Dari Kern,Tabel 6 hal.808[24], diperoleh

sg = 1.29

3'. $$\Delta Ps = \frac{f.Gs^2.IDs.(N+1)}{5{,}22 \times 10^{10}.de.sg.\phi}$$

$$= \frac{0.001 \times 1928512.9^2 \times 1.44 \times 30}{5{,}22 \times 10^{10} \times 0.06 \times 1.29 \times 0.97}$$

= 3.51303 psi < 10.0 psi

desain memenuhi

Spesifikasi Heater (E-117)

Fungsi	:	Untuk memanaskan Etilen
Kode alat	:	E-117
Tipe	:	Shell and Tube Heat Exchanger 2-4

Bahan Konstruksi : Stainless steel SA 240 Grade M Type 316
Media pemanas : Saturated steam 190 °C ,
Kapasitas : 4,366.2450 kg/jam = 9,625.824 lb/jam
Rate steam : 241.7471 kg/jam = 532.9557 lb/jam
Dimensi

Tube side , steam		*Shell side* , Etilena	
do	= 3/4 in 16 BWG	IDs	= 17 1/4 in = 1.44
di	= 0.62 in	B	= 4 in
L	= 10 ft	de	= 0.72 in
Nt	= 178	C'	= 0.25 in
Pt	= 1 in	ΔPs	= 3.51 psi
Tringular Pitch			
ΔPt	= 2.37 psi		

8. Kompresor (G-115a)

Fungsi : Menaikan tekanan aliran etilena dari 1 atm menjadi 5 atm
Type : Single stage reciprocating compressor

P_1 = 1 atm = 1.01 bar

P_2 = 5 atm = 5.07 bar

T_1 = 180 °C = 453.15 K

Komponen	Konstanta C_P = a+bT+cT2+dT3+eT4			
	a	b	c	d
C_2H_4	32.083	-0.014831	2.4774E-04	-2.3766.E-07
CH_4	34.942	0.039957	1.9184E-04	-1.5303.E-07
C_2H_6	28.146	0.043447	1.8946.E-04	-1.9082.E-07

(Yaws and Carl Heat Capacity of Gas)[20]

Komponen	Cp (J/gmol K)
C_2H_4	54.1197
CH_4	78.2021
C_2H_6	68.9825

R = 8.314 J/gmol K

$$\gamma = \frac{Cp}{Cp - R}$$

$$= \frac{67.1014}{67.1014 - 8.314}$$

$$= 1.1414$$

Dari App.A didapatkan :

$$\text{Jumlah gas masuk} = \frac{4{,}366.2450 \text{ kg/jam}}{3600 \text{ detik}}$$

$$= 1.21285 \text{ kg/detik}$$

Dari Perry 8th Edition tabel 2-32 Hal. 2-98[7] didapatkan tabel berikut:

Komponen	berat molekul	C1	C2	C3	C4
C_2H_4	28	2.09610	0.27657	282.34000	0.29147
CH_4	16	2.92140	0.28976	190.56000	0.28881
C_2H_6	30	1.91220	0.27937	305.32000	0.29187

Komponen	Massa (Kg/jam)	xi (massa)	ρ (kg/m^3)	xi.ρi
C_2H_4	4344.414	0.9950	68.0516	67.7114
CH_4	13.099	0.0030	40.8303	0.1225
C_2H_6	8.732	0.0020	69.5078	0.1390
Total	4366.245	1.0000	178.3898	67.9729

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{67.9729}{1.0000} = 67.9729 \text{ kg/m}^3 = 4.24151 \text{ lb/ft}^3$$

$$Q = \frac{\text{Rate bahan masuk}}{\rho \text{ bahan masuk}}$$

$$= \frac{1.21285 \text{ kg/detik}}{67.9729 \text{ kg/m}^3}$$

$$= 0.0178431 \text{ m}^3\text{/detik}$$

Dari Coulson and Richardson's,Fig. 3.6 Hal.83[22] didapatkan Ep 0.65

$$m = \frac{\gamma - 1}{\gamma.Ep} = \frac{1.1414 - 1}{1.1414 \times 0.65} = 0.19062$$ (Coulsons, pers. 3.36a Hal.85)[22]

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^m = 453.15\left(\frac{453}{5.07}\right)^{0.1906} = 1067.2 \text{ K} = 794.046\ ^oC$$

(Coulsons, pers. 3.35 Hal.85)[22]

Dari Coulson and Richardson's, App. C Hal.938[22] didapatkan :

Komponen	Tc (K)	Pc (bar)
C_2H_4	594.4	57.9
CH_4	282.4	50.4
C_2H_6	305.4	48.8
Total	1182.2	157.1

$$T_{r\ mean} = \frac{453.15 + 1067.2}{2 \times 1182.2} = 0.64302$$

$$P_{r\ mean} = \frac{5.07 + 453.15}{2 \times 157.1} = 1.45836$$

pada Tr mean,

Komponen	Cp (J/gmol K)
C_2H_4	32.0736

CH_4	34.9678
C_2H_6	28.1740
Total	95.2154

Dari Coulson and Richardson's, Fig. 3.2 Hal.70[22] didapatkan 2 kJ/mol K

Cp = 95.215 + 2 = 97.215 kJ/mol K

Dari Coulson and Richardson's, Fig. 3.8; 3,9; 3,10 Hal.87,88,89[22] didapatkan :

X = 0.3

Y = 1.15

Z = 0.95

$$m = \frac{ZR}{Cp}\left(\frac{1}{Ep} + X\right)$$ (Coulsons, pers. 3.36 Hal.85)[22]

$$= \frac{0.95 \times 8.314}{97.2154} \times \left(\frac{1}{0.65} + 0.3\right)$$

= 0.14937

$$n = \frac{1}{Y-m(1+X)}$$ (Coulsons, pers. 3.38 Hal.85)[22]

$$= \frac{1}{1.15 - 0.15\,(1 + 0.3)}$$

= 1.046

$$-W = Z \cdot \frac{RT_1}{M} \cdot \frac{n}{n-1} \cdot \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$

$$= 0.95 \times \frac{8.314 \times 453.2}{27.89199965} \times \frac{1.046}{1.046 - 1}\left(\left(\frac{453}{5.07}\right)^{\frac{1.046-1}{1.046}} - 1\right)$$

= 3414.2422 kJ/kmol

Actual work yang dibutuhkan $= \frac{\text{W polytropic}}{\text{Ep}}$

$= \frac{3414.2422}{0.65}$

= 5252.6804 kJ/kg

$$\text{Daya} = \frac{5252.6804}{2684.5195} \times 4366.245$$

= 0.85 hp ≈ 1 hp

Spesifikasi Kompresor (G-115A)

Fungsi	:	Menaikan tekanan Etilena dari 1 atm menjadi 5 atm
Kode alat	:	G-115a
Tipe	:	Radial
Kapasitas	:	1.2128 kg/detik
Daya	:	1 hp

9. Filter Udara (H-118)

Fungsi : Untuk menyaring debu yang tersuspensi dalam udara
Tipe : Automatic dry air filter

Dasar Perhitungan :

Udara yang dibutuhkan = O_2 + N_2
= 2482.34 + 9339.31
= 11821.6444 Kg/jam
= 26061.9972 lb/jam

Suhu = 30 °C = 86 °F = 303 K

ρ Udara pada suhu 30°C = 1.17 Kg/m^3
= 0.073 lb/ft^3

Rate Volume udara (v) = 357653.539 ft^3/Jam
= 5960.8923 ft^3/menit

kadar debu dalam udara
di industri (0,1-2 gram/1000ft^3)

$= \dfrac{1 \text{ gram}}{1000 \text{ ft}^3} \times 5960.9$ (Perry, ed 8, table 17-8, hal 17-52)[7]

= 5.9609 gr/menit
= 0.0131 lb/menit

Ukuran dry filter = 24 x 24 x 11 1/2 (in)

Kapasitas 1 Filter = 1000 ft^3/menit (Perry, ed 7, table 17-9, hal 17-50)[7]

Filter yang dibutuh $= \dfrac{5960.8923}{1000}$
= 5.9609 ≈ 6 buah

Spesifikasi Filter Udara (H-118)

Fungsi	:	Untuk menyaring debu yang tersuspensi dalam udara
Tipe	:	Automatic dry air filter
Kode alat	:	H-118
Kapasitas	:	357653.539 ft^3/Jam
Jumlah Filter	:	6 buah

10. Blower (G-119)

Fungsi : Mengalirkan udara menuju heater
Tipe : Centrifugal Multiblade Forward Curved Blower

Direncanakan :

A. Menentukan jumlah gas masuk (G_G)

Dari App.A didapatkan :

$G_G = \dfrac{11821.6444 \text{ kg/jam}}{60 \text{ menit}}$
= 197.02741 kg/menit
= 89.370128 lb/menit

B. Menentukan densitas gas

T masuk = 30 ^oC = 303.15 K

Dari Perry 8th Edition tabel 2-32 Hal. 2-98[7] didapatkan tabel berikut:

Komponen	berat molekul	C1	C2	C3	C4
O_2	32	51.24500	-1200.20	-6.4361	0.02841
N_2	28	58.28200	-1084.10	-8.3144	0.04413

dimana, ρ dalam mol/m^3

$$\rho = \frac{C_1}{C_2^{\left(1+\left(1-\frac{T}{C_3}\right)^{C_4}\right)}}$$

Komponen	Massa (Kg/jam)	xi (massa)	ρ (kg/m^3)	xi.ρi
O_2	2482.3352	0.2100	1096.1477	230.1715
N_2	9339.3092	0.7900	1631.8960	1289.2268
Total	11821.644	1.0000	2728.0437	1519.3984

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{1519.3984}{1.0000} = 1519.3984 \text{ kg/m}^3 = 94.81046 \text{ lb/ft}^3$$

C. Menentukan laju alir volumetrik gas (Q)

$$Q = \frac{G_G}{\rho}$$

$$= \frac{89.37013 \text{ lb/menit}}{94.81046 \text{ lb/ft}^3}$$

$$= 0.94262 \text{ ft}^3\text{/menit}$$

D. Menentukan Daya Blower

$P_{operasi}$ = 1 atm

= 407.184 in

Daya(P)teoritis = $1{,}57 \times 10^4 Q.P_{operasi}$ (Perry 8th Edition, pers.10-84 Hal.10-51)[7]

= $1.57 \times 10^{-4} \times 0.94262 \times 407.184$

= 0.602597 ≈ 1 hp

Dari Perry 8th Edition, Hal.10-51[7] didapatkan efisiensi blower 40-80%

Nilai efisiensi diambil 80% , maka daya aktual blower adalah :

$$\text{Daya(P) aktual} = \frac{P_{teoritis}}{\eta}$$

$$= \frac{0.6026}{80\%}$$

= 0.75325 ≈ 1 hp

Spesifikasi Blower (G-119)

Fungsi	:	Mengalirkan udara menuju kompresor
Kode alat	:	G-119
Tipe	:	Centrifugal Multiblade Forward Curved Blower
Kapasitas	:	197.0274 kg/menit
Daya	:	1 hp

8. Kompresor (G-115b)

Fungsi : Menaikan tekanan aliran udara dari 1 atm menjadi 5 atm

Type : Single stage reciprocating compressor

P_1 = 1 atm = 1.01 bar

P_2 = 5 atm = 5.07 bar

T_1 = 180 ^oC = 453.15 K

Komponen	Konstanta C_P = a+bT+cT2+dT3+eT4			
	a	b	c	d
O_2	29.526	-0.0088999	3.8083E-05	-3.2629.E-08
N_2	29.342	-0.0035354	1.0076E-05	-4.3116.E-08

(Yaws and Carl Heat Capacity of Gas)[20]

Komponen	Cp (J/gmol K)
O_2	30.2770
N_2	25.7970

R = 8.314 J/gmol K

$$\gamma = \frac{Cp}{Cp - R}$$

$$= \frac{18.6913}{18.6913 - 8.314}$$

$$= 1.8012$$

Dari App.A didapatkan :

$$\text{Jumlah gas masuk} = \frac{0.6026 \text{ kg/jam}}{3600 \text{ detik}}$$

$$= 0.00017 \text{ kg/detik}$$

Dari Perry 8th Edition tabel 2-32 Hal. 2-98[7] didapatkan tabel berikut:

Komponen	berat molekul	C1	C2	C3	C4
O_2	32	51.24500	-1200.2000	-6.43610	0.02841
N_2	28	58.28200	-1084.1000	-8.31440	0.04413

Komponen	Massa (Kg/jam)	xi (massa)	ρ (kg/m^3)	xi.ρi
O_2	2482.3352	0.2100	1.4290	0.3001

N_2	9339.3092	0.7900	1.2510	0.9883
Total	11821.644	1.0000	2.6800	1.2884

ρ campuran $= \dfrac{\sum xi.\rho i}{\sum xi}$

$= \dfrac{1.2884}{1.0000} = 1.2884$ kg/m^3 = 0.08039 lb/ft^3

Q = $\dfrac{\text{Rate bahan masuk}}{\rho \text{ bahan masuk}}$

$= \dfrac{0.00017 \text{ kg/detik}}{1.2884 \text{ kg/m}^3}$

= 0.0001299 m^3/detik

Dari Coulson and Richardson's,Fig. 3.6 Hal.83[22] didapatkan 0.65

$m = \dfrac{\gamma - 1}{\gamma.Ep} = \dfrac{1.8012 - 1}{1.8012 \times 0.65} = 0.68432$ (Coulsons, pers. 3.36a Hal.85)[22]

$T_2 = T_1\left(\dfrac{P_2}{P_1}\right)^m = 453.15\left(\dfrac{453}{5.07}\right)^{0.6843} = 514.359 \text{ K} = 241.209\ ^{o}C$

(Coulsons, pers. 3.35 Hal.85)[22]

Dari Coulson and Richardson's, App. C Hal.938[22] didapatkan :

Komponen	Tc (K)	Pc (bar)
O_2	154.6	50.5
N_2	309.6	72.4
Total	464.2	122.9

$T_{r\ mean} = \dfrac{453.15 + 514.359}{2 \times 464.2} = 1.04212$

$P_{r\ mean} = \dfrac{5.07 + 453.15}{2 \times 122.9} = 1.86418$

pada Tr mean,

Komponen	Cp (J/gmol K)
O_2	29.5168
N_2	29.3383
Total	58.8551

Dari Coulson and Richardson's, Fig. 3.2 Hal.70[22] didapatkan 4 kJ/mol K

Cp = 58.855 + 4 = 62.855 kJ/mol K

Dari Coulson and Richardson's, Fig. 3.8; 3,9; 3,10 Hal.87,88,89[22] didapatkan :

X = 0.3

Y = 1.15

Z = 0.95

$m = \dfrac{ZR}{Cp}\left(\dfrac{1}{Ep} + X\right)$ (Coulsons, pers. 3.36 Hal.85)[22]

$$= \frac{0.95 \times 8.314}{62.8551} \times \left(\frac{1}{0.65} + 0.3 \right)$$

$= 0.23102$

$$n = \frac{1}{Y - m(1+X)}$$ (Coulsons, pers. 3.38 Hal.85)[22]

$$= \frac{1}{1.15 - 0.23\,(1 + 0.3)}$$

$= 1.177$

$$-W = Z \cdot \frac{RT_1}{M} \cdot \frac{n}{n-1} \cdot \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$= 0.95 \times \frac{8.314 \times 453.2}{39.67319604} \times \frac{1.177}{1.177 - 1} \left(\left(\frac{453}{5.07} \right)^{\frac{1.177-1}{1.177}} - 1 \right)$$

$= 1089.06$ kJ/kmol

Actual work yang dibutuhkan $= \frac{\text{W polytropic}}{\text{Ep}}$

$= \frac{1089.06}{0.65}$

$= 1675.4769$ kJ/kg

Daya $= \frac{1675.4769}{2684.5195} \times 0.603$

$= 0.38$ hp $\approx$ 1 hp

Spesifikasi Kompresor (G-115b)

Fungsi	:	Menaikan tekanan udara dari 1 atm menjadi 5 atm
Kode alat	:	G-115b
Tipe	:	Radial
Kapasitas	:	0.0002 kg/detik
Daya	:	1 hp

12. Heater (E-111A)

Fungsi : untuk menaikkan suhu udara sebelum masuk kedalam reaktor R-110

Tipe : Shell and Tube Heat Exchanger

Direncanakan :

- faktor kekotoran gabungan minumum (Rd = 0.001 jam.ft^2.^{o}F/Btu
- Δp maksimum aliran = 10 psi
- Δp maksimum steam = 2.5 psi

Dasar perencangan :

Dari Appendix B didapatkan data sebagai berikut:

- Massa bahan masuk = 11,821.644 kg/jam
  = 26,061.997 Ib/jam
- Suhu bahan masuk (t_1) = 30.0 ^{o}C = 86.00 ^{o}F

- Suhu bahan keluar (t_2) = 180 °C = 356 °F
- Kebutuhan steam (m) = 915.9261 kg/jam
  = 2,019.2507 Ib/jam
- Panas yang dibawa steam = 433,177.8798 kkal/jam
  = 1,717,869.1299 btu/jam
- Steam masuk pada suhu(T_1) = 190 °C = 374 °F = 463.15 K
- Steam keluar pada suhu (T_2) = 95 °C = 203 °F = 368.15 K
- Digunakan pipa ukuran 3/4 in OD, BWG 16, L = 12 ft, P_T = 1 in
- Shell side : Udara
- Tube side : Steam
- Susunan tube segitiga (triangular pitch)

Perhitungan :

A. Menghitung ΔT_{LMTD}

$\Delta t_1 = T_1 - t_2 = 463\ °F - 356\ °F = 107\ °F$

$\Delta t_2 = T_2 - t_1 = 368\ °F - 86.00\ °F = 282\ °F$

$$\Delta T_{LMTD} = \frac{\Delta t_1 - \Delta t_2}{\ln \Delta t_1 / \Delta t_2}$$ (Kern, Pers.5.14 Hal.89)[24]

$$= \frac{107 - 282.15}{\ln(107 / 282.15)}$$

$= 180.75\ °F$

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{463 - 368}{356 - 86.0} = 0.35$$ (Kern, pers. 5.14 hal 149)[24]

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{356 - 86.0}{463 - 86.0} = 0.72$$

Jadi,

Ft = 1 (Isotermal) *(Kern, hal 167)* [24]

Sehingga Tipe HE; 2-4

$\Delta t = \Delta T_{LMTD} \times Ft = 180.7461 = 180.75\ °F$

B. Menghitung suhu kalorik

$Tc = (T_1 + T_2)/2 = 289\ °F = 143\ °C = 415.65\ K$

$tc = (t_1 + t_2)/2 = 221\ °F = 105\ °C = 378.15\ K$

C. Trial U_D

Dari Kern hal 840 tabel 8[24] diperoleh:

Range U_D = 200-700 Btu/jam ft^2. °F

Dicoba U_D = 200 Btu/jam ft^2. °F

Dari App.B didapatkan Q = 433,177.88 kkal/jam
= 17189871 Btu/jam

$$A = \frac{Q}{U_D \cdot \Delta t} = \frac{17189871.2599}{200 \times 180.7461} = 475.5254 \ ft^2$$

dengan,

do_{tube} = 3/4 in

BWG = 16

Dari Kern, tabel 10, hal. 843[24], diperoleh harga a" 0.1963 ft^2/ft

$$Nt = \frac{A}{a'' \cdot L} = \frac{475.5254}{0.1963 \times 12} = 202 \ \text{buah}$$

Dari Kern, tabel 9, hal. 842[24], diperoleh :

IDs = 17 1/4 in

n = 4

Nt = 165

$$U_D \ \text{koreksi} = \frac{Nt}{Nt \ standar} \times U_D \ \text{trial}$$

$$= \frac{202}{165} \times 200 = 244.69 \ \text{Btu/jam ft}^2 . {}^oF$$

Dari Kern, tabel 28, hal. 838[24], diperoleh :

de = 0.72 in

Viskositas aliran pada shell (bahan):

Dari Perry 8th Edition tabel 2-312 Hal. 2-421[7] didapatkan tabel berikut:

Komponen	C1	C2	C3	C4
O_2	53.9630	-2443.0	-55643	1.908E-05
N_2	39.2050	-1324.4	-3.4366	3.102E-05

dimana μ dalam Pa.s

$$\mu = \frac{C_1 T^{C2}}{1 + C_3/T + C_4/T^2}$$

Komponen	Massa (Kg/jam)	xi (massa)	μ (Pa.s)	μ (lb/ft.s)	xi.μi
O_2	2482.3352	0.2100	0.0230	0.0155	0.003245
N_2	9339.3092	0.7900	0.0230	0.0155	0.012210
Total	11821.644	1.0000	0.04600	0.0309	0.015455

$$\mu \ \text{campuran} = \frac{\sum xi.\mu i}{\sum xi}$$

$$= \frac{0.015455}{1.0000} = 0.015455 \ \text{lb/ft.s} = 55.639 \ \text{lb/ft.jam}$$

Viskositas aliran pada pipe (steam):

Dari Perry 8th Edition tabel 2-312 Hal. 2-421[7] didapatkan tabel berikut:

Komponen	C1	C2	C3	C4
H_2O	7.36.E+01	-7.26.E+03	-7.30.E+00	4.17.E-06

dimana μ dalam Pa.s

Komponen	Massa (Kg/jam)	xi (massa)	μ (Pa.s)	μ (lb/ft.s)	xi.μi
H_2O (steam)	915.9261	1.0000	1252467.52	841619.32	841619.32

Kesimpulan sementara hasil perancangan :

Type HE : 2-4

Bagian *Tube*

- do = 3/4 in, 16 BWG
- L = 12 ft Nt = 165
- Susunan segitiga, n = 4
- di = 0.6200 in = 0.052 ft
- a' = 0.3020 in^2 = 0.025 ft^2
- a" = 0.1963 ft^2/ft
- Pt = 1 in

Bagian *Shell*

- IDs = 17 1/4 in = 1.44 ft
- n' = 2
- B = 4 in = 0.33 ft
- de = 0.72 in = 0.06 ft
- C' = 1 1/4 - 1 = 0.25

Evaluasi Perpindahan Panas

Hot fluid: tube, Steam

1. Menghitung NRe

$$a_t = \frac{Nt \times a'}{n \times 144} = \frac{165 \times 0.025}{165 \times 144} = 0.0002 \ ft^2$$

$$G_t = \frac{m}{a_t} = \frac{2019.2507 \ lb/jam}{0.0002 \ ft^2} = 11553858 \ lb/jam.ft^2$$

pada Tc = 289 ^oF

μ = 0.015455 lb/ft.s
= 55.639032 lb/ft.jam

di = 0.62 in
= 0.052 ft

$$N_{re} = \frac{G_t \times di}{\mu} = \frac{11553858.2 \times 0.052}{55.639032} = 10729.0$$

2. J_H = - (*steam*)

Cold fluid: shell, Udara

1'. Menghitung NRe

$$a_s = \frac{IDs \times C' \times B}{n' \times Pt \times 144} = \frac{1.44 \times 0.25 \times 4}{2 \times 1 \times 144} = 0.00499 \ ft^2$$

$$G_s = \frac{M}{a_s} = \frac{26061.997 \ lb/jam}{0.0050 \ ft^2} = 5221464.4914 \ lb/jam.ft^2$$

pada tc = 221 ^oF

μ = 0.015455 lb/ft.s
= 55.63903 lb/ft.jam

de = 0.72 in
= 0.06 ft

$$Nre_s = \frac{G_{an} \times de}{\mu} = \frac{5221464.4914 \times 0.06}{55.63903} = 5630.7211$$

2'. Menghitung faktor panas (J_H)

Dari Kern, Fig. 24 Hal.834[24] didapatkan:

	J_H = 1100
3. Menghitung harga koefisien film perpindahan panas = 1500 Btu/ft^2.jam^{0}F	3'. Menghitung harga koefisien film Dari Kern, Tabel 4 hal.800[24] didapatkan: k = 0.043 Btu/jam.ft^2.^{o}F/ft Dari Kern, Fig.3 hal.805[24] didapatkan Cp = 0.131 Btu/lb.^{o}F maka, k (Cp.μ /k)$^{1/3}$ = 0.2379 ho/φs = 4360.63 tw = 221.00 ^{o}F dimana μ Pada suhu tw didapatkan: μw = 12296 lb/ft.jam μ /μw = 4.52E-03 Dari Kern, Fig. 24 Hal.834[24] didapatkan: φs = 0.47 sehingga, ho = 2048.02 Btu/jam.ft^{2o}F

Clean overall coefficient Uc :

$$Uc = \frac{hio \cdot ho}{hio + ho} = \frac{1500 \times 2048.02}{1500 + 2048.02} = 4096.04 \text{ Btu/ft}^2\text{.jam}^0\text{F}$$

Dirt factor (faktor kekotoran) pipa terpakai

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

$$= \frac{4096.04373 - 245}{4096.0437 \times 245} = 0.00384 \text{ jam.ft}^2\text{.°F/Btu}$$

Karena harga Rd hitung > Rd tetapan, maka rancangan HE memenuhi.

Evaluasi ΔP

Hot fluid: tube, Steam	Cold fluid: shell, gas Etilena
1. NRe_t = 10728.9671 Dari Kern,fig. 26 hal.836[24], diperoleh : Pada *f* = 0.00019	1'. Pada Nres = 5630.7211 Dari Kern,fig. 29 hal.839[24], diperoleh *f* = 0.0008
Dari steam tabel, untuk kondisi : saturated steam T = 203 °F P = 45.4 psia didapatkan, specific vol. = 9.31965 ft^3/lb sg = $\frac{1}{9.31965 \times 62.5}$	2'. No. of crosess (N+1) = $\frac{12L}{B} = \frac{12 \times 12}{4}$ = 36 Dari Kern,Tabel 6 hal.808[24], diperolel sg = 1.29

$= 0.0017168$

2. ΔP karena panjang pipa :

$$\Delta Pl = \frac{1}{2} \cdot \frac{f.Gt^2.L.n}{5{,}22\times10^{10}.di.sg.\phi}$$

$$= \frac{0.00019 \times 11553858^2 \times 12 \times 4}{2 \times 5{,}22.10^{10} \times 0.052 \times 0.002 \times 1}$$

$= 0.52587$ psi

s

ΔP karena tube passes

Dari Kern,fig. 27 hal.837[24],diperoleh:

$$\left[\frac{v^2}{2gc}\right]\frac{\rho}{144} = 0.55 \text{ , sehingga}$$

$$= \frac{4n}{sg}\left[\frac{v^2}{2gc}\right]\frac{\rho}{144}$$

$$\Delta Pn = \frac{4 \times 4}{0.0017} \times 0.55$$

$= 0.51258$ psi

sehingga,

ΔPt total $= 0.52587 + 0.51258$

$= 1.04$ psi < 2.5 psi

desain memenuhi

3'. $$\Delta Ps \; \frac{f.Gs^2.IDs.(N+1)}{5{,}22\times10^{10}.de.sg.\phi}$$

$$= \frac{0.001 \times 5221464.5^2 \times 1.44 \times 36}{5{,}22\times10^{10} \times 0.06 \times 1 \times 0.97}$$

$= 9.60021$ psi < 10.0 psi

desain memenuhi

Spesifikasi Heater (E-111A)

Fungsi	:	Untuk memanaskan udara
Kode alat	:	E-111A
Tipe	:	Shell and Tube Heat Exchanger 2-4
Bahan Konstruksi	:	Stainless steel SA 240 Grade M Type 316
Media pemanas	:	Saturated steam 190 °C ,
Kapasitas	:	11,821.644 kg/jam = 26,061.997 lb/jam
Rate steam	:	915.9261 kg/jam = 2,019.2507 lb/jam

Dimensi

Tube side , steam			*Shell side* , Etilena		
do	=	3/4 in 16 BWG	IDs	=	17 1/4 in = 1.44
di	=	0.62 in	B	=	4 in
L	=	12 ft	de	=	0.72 in
Nt	=	165	C'	=	0.25 in
Pt	=	1 in	ΔPs	=	9.6 psi
Tringular Pitch					
ΔPt	=	1.04 psi			

13. Reaktor (R-110)

Fungsi : Tempat terjadinya reaksi antara Asam Asetat, Etilena dan Oksigen dengan bantuan katalis Palladium Klorida

Tipe : Fixed-Bed Multitubular Reactor
Reaktor (R-110) dirancang oleh Bela Ariska (1914035), lihat Bab VI Perancangan alat utama.

14.Expander (G-121)

Fungsi : Menurunkan tekanan dari 5 atm pada keluaran reaktor menjadi 2 atm menuju flash tank

Type : Radial

Direncanakan :

Massa = 25685.2932 kg/jam = 56625.7973 lb/jam

P_1 = 5 atm = 5.0663 bar

P_2 = 2 atm = 2.0265 bar

T_1 = 180 °C = 453.15 K

Komponen	Konstanta C_P = a+bT+cT2+dT3+eT4				
	A	B	C	D	E
$C_4H_6O_2$	27.664	2.3366E-01	6.2106E-05	-1.697E-07	5.792E-11
C_2H_4	32.083	-1.4831E-12	2.4774E-07	-2.377E-07	6.827E-11
C_2H_6	28.146	4.3447E-02	1.8946E-07	-1.908E-07	5.335E-11
CH_4	34.942	-3.9957E-02	1.9184E-04	-1.530E-07	3.932E-11
CH_3COOH	34.850	3.7626E-02	2.8311E-04	-3.077E-07	9.265E-11
H_2O	33.933	-8.4186E-03	2.9906E-05	-1.783E-08	3.693E-12
O_2	29.526	-8.8999E-03	3.8083E-05	-3.263E-08	8.861E-12
N_2	29.342	-3.540E-03	1.0076E-05	-4.312E-09	2.594E-13

(Carl L.yaws hal 32)[20]

Komponen	Massa (gmol/jam)	xi (massa)	Cp (J/gmol.K)	Cp .xi
$C_4H_6O_2$	0.1476	0.2292	132.950	30.4702
C_2H_4	0.0044	0.0069	12.898	0.0889
C_2H_6	0.3116	0.4840	32.366	15.6662
CH_4	0.0136	0.0211	43.647	0.9214
CH_3COOH	0.0078	0.0121	85.313	1.0291
H_2O	0.1581	0.2456	34.756	8.5361
O_2	0.0004	0.0006	30.651	0.0195
N_2	0.0003	0.0005	29.417	0.0143
Total	**0.6438**	**1.0000**	**401.997**	**56.7456**

$$\text{Cp campuran} = \frac{\sum xi.cp}{\sum xi}$$

$$= \frac{56.7456}{1.0000} = 56.7456 \text{ J/gmol.K}$$

R = 8.314 J/gmol K

$$\gamma = \frac{Cp}{Cp - R} = \frac{56.7456}{56.7456 - 8.314} = 1.1717$$

Dari App.A didapatkan :

Jumlah gas masuk $= \frac{25714.243 \text{ kg/jam}}{3600 \text{ detik}}$

$= 7.14285$ kg/detik

ρ bahan fase gas $= 5.021$ kg/m^3 (hysys, 2023)

$= 0.3135$ lb/ft^3

$$Q = \frac{\text{Rate bahan masuk}}{\rho \text{ bahan masuk}} = \frac{7.14285 \text{ kg/detik}}{5.0210 \text{ kg/m}^3} = 1.42259 \text{ m}^3\text{/detik}$$

Dari Coulson and Richardson's,Fig. 3.6 Hal.83[22] didapatkan Ep 0.68

$$m = \frac{\gamma - 1}{\gamma . Ep} = \frac{1.1717 - 1}{1.1717 \times 0.68} = 0.2155$$

(Coulsons, pers. 3.36a Hal.85)[22]

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^m = 453.15 \left(\frac{2.027}{5.066}\right)^{0.2155} = 371.964 \text{ K} = 98.8145 \ ^oC$$

(Coulsons, pers. 3.35 Hal.85)[22]

Dari Coulson and Richardson's, App. C Hal.938[22] didapatkan :

Komponen	Tc (K)	Pc (bar)
CH_3COOH	594.4	57.9
H_2O	647.3	220.5
C_2H_4	282.4	50.4
C_2H_6	305.4	48.8
CH_4	190.6	46
O_2	154.6	50.5
N_2	126.2	33.9
$C_4H_6O_2$	525	43.6
Total	353.238	68.95

$$T_{r\ mean} = \frac{453.15 + 371.964}{2 \times 353.238} = 1.1679$$

$$P_{r\ mean} = \frac{5.07 + 2.03}{2 \times 68.95} = 0.0514$$

Komponen	**Massa (gmol/jam)**	**xi (massa)**	**Cp (J/gmol.K)**	**Cp .xi**
$C_4H_6O_2$	0.1476	0.2292	27.937	6.4028
C_2H_4	0.0044	0.0069	32.083	0.2211

C_2H_6	0.3116	0.4840	28.197	13.6481
CH_4	0.0136	0.0211	34.896	0.7366
CH_3COOH	0.0078	0.0121	34.894	0.4209
H_2O	0.1581	0.2456	33.923	8.3315
O_2	0.0004	0.0006	29.516	0.0188
N_2	0.0003	0.0005	29.338	0.0142
Total	**0.6438**	**1.0000**	**250.783**	**29.7940**

Cp pada Tr mean $= \frac{\sum xi.cp}{\sum xi}$

$= \frac{29.7940}{1.0000} = 29.7940$ J/gmol.K

Dari Coulson and Richardson's, Fig. 3.2 Hal.70[22] didapatkan 0.9 kJ/mol K

Cp = 29.7940 + 0.9 = 30.6940 kJ/mol K

Dari Coulson and Richardson's, Fig. 3.8; 3,9; 3,10 Hal.87,88,89[22] didapatkan :

X = 0.5

Y = 1.15

Z = 0.9

$m = \frac{ZR}{Cp}\left(Ep + X\right)$ (Coulsons, pers. 3.37 Hal.85)[22]

$= \frac{0.9 \times 8.314}{30.6940} \times \left(0.68 + 0.5\right)$

$= 0.2877$

$n = \frac{1}{Y - m(1+X)}$ (Coulsons, pers. 3.38 Hal.85)[22]

$= \frac{1}{1.15 - 0.288\left(1 + 0.5\right)}$

$= 1.392$

$-W = Z\frac{RT_1}{M} \times \frac{n}{n-1}\left(\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right)$ (Coulsons, pers. 3.31 Hal.82)[22]

$= 0.9 \times \frac{8.314 \times 453.2}{648.8401} \times \frac{1.392}{1.392 - 1}\left(\left(\frac{2.027}{5.066}\right)^{\frac{1.392 - 1}{1.392}} - 1\right)$

$= 9.1183$ kJ/kmol

Actual work yang dibutuhkaı $= \frac{W\ polytropic}{Ep}$

$= \frac{9.1183}{0.68}$

$= 13.4093$ kJ/kg

Daya $= \frac{13.4093}{2684.5195} \times 25714.2427$

$= 6.4222$ hp ≈ 7 hp

Spesifikasi Alat Expander (G-121) :

Type	:	Radial
Bahan	:	Carbon Steels
Daya	:	7 Hp
Jumlah	:	1 buah

15. Kondensor (E-122)

Fungsi : Untuk menkondensasi produk keluaran expander

Tipe : Horizontal Shell and Tube Heat Exchanger

Direncanakan :

- faktor kekotoran gabungan minumum (Rd = 0.001 jam.ft^2.^{o}F/Btu
- Δp maksimum aliran shell = 10 psi
- Δp maksimum aliran tube = 2.5 psi

Dasar perencangan :

Dari Appendix B didapatkan data sebagai berikut:

- Massa bahan masuk = 25,497.237 kg/jam
  = 56,211.209 Ib/jam
- Suhu bahan masuk (T_1) = 180 ^{o}C = 356.00 ^{o}F
- Suhu bahan keluar (T_2) = 65 ^{o}C = 149 ^{o}F
- Kebutuhan pendingin (m) = 13,810.853 kg/jam
  = 30,447.407 Ib/jam
- Panas yang dibawa coolar = ############ kkal/jam
  = 48,442,348.2420 btu/jam
- H_2O masuk pada suhu (t_1) = 30 ^{o}C = 86 ^{o}F = 303.15 K
- H_2O keluar pada suhu (t_2) = 95 ^{o}C = 203 ^{o}F = 368.15 K
- Digunakan pipa ukuran 1 in OD, BWG 16, L = 20 ft, P_T = 1,25 in
- Shell side : Produk R-110
- Tube side : Cooling water
- Susunan tube segitiga (triangular pitch)

Perhitungan :

A. Menghitung ΔT_{LMTD}

Δt_1 = $T_1 - t_2$ = 303 ^{o}F - 149 ^{o}F = 154 ^{o}F

Δt_2 = $T_2 - t_1$ = 368 ^{o}F - 356.00 ^{o}F = 12 ^{o}F

$$\Delta T_{LMTD} = \frac{\Delta t_1 - \Delta t_2}{\ln \Delta t_1/\Delta t_2}$$ (Kern, Pers.5.14 Hal.89)[24]

$$= \frac{154 - 12.15}{\ln(154 / 12.15)}$$

$= 55.89$ ^{o}F

B. Menghitung suhu kalorik

Tc = $(T_1 + T_2) / 2$ = 145 ^{o}F = 63 ^{o}C = 335.65 K

tc = ($t_1 + t_2$) / 2 = 253 ^oF = 123 ^oC = 395.65 K

C. Trial U_D

Dari Kern hal 840 tabel 8[24] diperoleh:

Range U_D = 2-50 Btu/jam ft^2. ^oF

Dicoba U_D = 20 Btu/jam ft^2. ^oF

Dari App.B didapatkan Q = 1284260.4 kkal/jam

= 5096352.2 Btu/jam

$$A = \frac{Q}{U_D \cdot \Delta t} = \frac{5096352.2088}{20 \times 55.8924} = 4559.0764 \ ft^2$$

dengan,

do $_{tube}$ = 1 in

BWG = 16

Dari Kern, tabel 10, hal. 843[24], diperoleh harga a" 0.2618 ft^2/ft

$$Nt = \frac{A}{a'' \cdot L} = \frac{4559.0764}{0.2618 \times 150} = 116 \text{ buah}$$

Dari Kern, tabel 9, hal. 842[24], diperoleh :

IDs = 35 in

n = 4

Nt = 152

$$U_D \text{ koreksi} = \frac{Nt}{Nt \text{ standar}} \times U_D \text{ trial}$$

$$= \frac{116}{152} \times 20 = 15.28 \text{ Btu/jam ft}^2. ^oF$$

Dari Kern, tabel 28, hal. 838[24], diperoleh :

de = 0.72 in

Viskositas aliran pada shell (bahan):

Dari Perry 8th Edition tabel 2-312 Hal. 2-421[7]didapatkan tabel berikut:

Komponen	**C1**	**C2**	**C3**
CH_3COOH	2.74E-08	1.0123	7.4948
H_2O	1.71E-08	1.1146	
O_2	1.10E-06	0.5634	96.3
N_2	6.56E-07	0.6081	54.714
C_2H_4	2.08E-06	0.4163	352.7
CH_4	5.25E-07	0.59006	105.67
C_2H_6	2.59E-07	0.67988	98.902
$C_4H_6O_2$	1.39E-07	0.7599	98

dimana μ dalam Pa.s $\mu = \dfrac{C_1 T^{C2}}{1 + C_3/T + C_4/T^2}$

Komponen	**Massa (Kg/jam)**	**xi (massa)**	**μ (Pa.s)**	**μ (lb/ft.s)**	**xi.μi**
CH_3COOH	465.4729	0.0183	9.26E-06	6.22E-06	1.14E-07
H_2O	2654.1955	0.1041	1.73E-06	1.16E-06	1.21E-07
O_2	124.1261	0.0049	1.03E-02	6.91E-03	3.36E-05
N_2	9339.0117	0.3663	5.80E-03	3.90E-03	1.43E-03
C_2H_4	217.2207	0.0085	2.75E-02	1.85E-02	1.57E-04
CH_4	13.0987	0.0005	5.30E-03	3.56E-03	1.83E-06
C_2H_6	8.7325	0.0003	1.55E-03	1.04E-03	3.57E-07
$C_4H_6O_2$	12676.379	0.4971	4.64E-04	3.12E-04	1.55E-04
Total	**25498.237**	**1.0000**	**0.05088**	**0.0342**	**0.001775**

$$\mu \text{ campuran} = \frac{\sum xi.\mu i}{\sum xi}$$

$$= \frac{0.001775}{1.0000} = 0.001775 \text{ lb/ft.s} = 6.3902 \text{ lb/ft.jam}$$

Viskositas aliran pada tube (cooling water):

Dari Perry 8th Edition tabel 2-313Hal. 2-427[7] didapatkan tabel berikut:

Komponen	C1	C2	C3	C4	C5
H_2O	-52.84300	3703.6000	5.8660	-5.9.E-29	10

dimana μ dalam Pa.s

$$\mu = \exp(C1 + C2/T + C3\ln T + C4T^{C5}$$

Komponen	Massa (Kg/jam)	xi (massa)	μ (Pa.s)	μ (lb/ft.s)	xi.μi
H_2O	30.0000	1.0000	0.00022	0.000150	0.000150

Densitas aliran pada shell (bahan):

Perhitungan *density* berdasarkan pers. *Carl and Yaws* [20]

Density = A x B $^{-(1-T/Tc)^n}$ T = 180 °C = 453.15 K

Komponen	**A**	**B**	**n**	**Tc**	**$(1-T/Tc)^n$**
CH_3COOH	0.35182	0.26954	0.26843	592.71	0.6782724
H_2O	0.3471	0.27400	0.28571	647.13	0.7087722
C_2H_4	0.21428	0.28061	0.28571	282.36	0.000000
C_2H_6	0.20087	0.27330	0.2833	305.42	0.000000
CH_4	0.15998	0.2881	0.277	190.58	0.000000
O_2	0.43533	0.28772	0.2924	154.58	0.000000
N_2	0.31205	0.28479	0.2925	126.1	0.000000
$C_4H_6O_2$	0.31843	0.25803	0.2827	524	0.567984

(Pers. *Carls and Yaws Density of Liquid*)[20]

Komponen	**Massa (Kg/jam)**	**xi (massa)**	**ρ (kg/m³)**	**ρ (lb/ft³)**	**xi.ρi**
CH_3COOH	465.4729	0.0183	856.0775	53.4432	0.9756
H_2O	2653.1955	0.1041	868.8831	54.2426	5.6444
C_2H_4	217.2207	0.0085	214.2800	13.3771	0.1140
C_2H_6	8.7325	0.0003	200.8700	12.5399	0.0043
CH_4	13.0987	0.0005	159.9800	9.9872	0.0051
O_2	124.1261	0.0049	435.3300	27.1768	0.1323
N_2	9339.0117	0.3663	312.0500	19.4807	7.1353
$C_4H_6O_2$	12676.3785	0.4972	687.3468	42.9097	21.3333
Total	25497.2367	1.0000	3734.8174	233.1572	35.3443

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{35.3443}{1.0000} = 35.3443 \text{ lb/ft}^3 = 566.1427 \text{ kg/m}^3$$

Densitas aliran pada tube (cooling water):

Dari Perry 8th Edition tabel 2-32 Hal. 2-98[7] didapatkan tabel berikut:

Komponen	berat molekul	C1	C2	C3	C4
H_2O	18	-13.85100	0.64038	-0.0019	1.8.E-06

dimana, ρ dalam mol/m³ $\rho = C_1 + C_2T + C_3T^2 + C_4T^3$

Komponen	Massa (Kg/jam)	xi (massa)	ρ (kg/m³)	ρ (lb/ft³)	xi.ρi
H_2O	13,810.853	1.0000	998.7518	66.1601	66.1601
Total	13810.853	1.0000	998.7518	66.1601	66.1601

Kesimpulan sementara hasil perancangan :

Type HE : 2-4

Bagian *Tube*

do = 1 in, 16 BWG

L = 16 ft Nt = 152

Susunan segitiga, n = 4

di = 0.8700 in = 0.073 ft

a' = 0.5940 in² = 0.050 ft²

a" = 0.2618 ft²/ft

Pt = 1.25 in

Bagian *Shell*

IDs = 35 in = 2.92 ft

n' = 2

B = 8 in = 0.67 ft

de = 0.72 in = 0.06 ft

C' = 1 1/4 - 1 = 0.25

Evaluasi Perpindahan Panas

Cold fluid: tube, cooling water

1. Menghitung NRe

$a_t = \dfrac{Nt \times a'}{n \times 144}$

$= \dfrac{152 \times 0.050}{4 \times 144}$

$= 0.0131 \ ft^2$

$G_t = \dfrac{m}{a_t}$

$= \dfrac{30447.4072 \ lb/jam}{0.0131 \ ft^2}$

$= 2330901.99 \ lb/jam.ft^2$

pada Tc = 145 ^oF

μ = 0.000150 lb/ft.s

= 0.540753 lb/ft.jam

di = 0.87 in

= 0.073 ft

$N_{re\,p} = \dfrac{G_t \times di}{\mu}$

$= \dfrac{2330901.99 \times 0.073}{0.540753}$

= 312509.34

Velocity

$v = \dfrac{G_t}{3600\rho}$

$= \dfrac{2330901.99}{3600 \times 66.160}$

= 97.864524 fps

2. Menghitung harga koefisien film perpindahan panas

Dari Kern, Fig. 25 Hal.835[24] , didapatkan:

hi = 492 Btu/jam.ft^{2o}F

faktor koreksi = 0.94

sehingga,

$hic = hi \left(\dfrac{di}{do}\right)$

$= 462.48 \left(\dfrac{0.8700}{1.00}\right)$

= 402.358 Btu/jam.ft^{2o}F

Hot fluid: shell, produk R-110

1'. Menghitung NRe

$a_s = \dfrac{IDs \times C' \times B}{n' \times Pt \times 144}$

$= \dfrac{2.92 \times 0.25 \times 8}{2 \times 1 \times 144}$

$= 0.0162 \ ft^2$

$G_s = \dfrac{M}{a_s}$

$= \dfrac{56211.209 \ lb/jam}{0.0162 \ ft^2}$

$= 3469034.5935 \ lb/jam.ft^2$

pada tc = 253 ^oF

μ = 0.001775 lb/ft.s

= 6.39020 lb/ft.jam

de = 0.72 in

= 0.06 ft

$Nre_s = \dfrac{G_s \times de}{\mu}$

$= \dfrac{3469034.5935 \times 0.06}{6.39020}$

= 32572.0588

2'. Menghitung harga koefisien film

Untuk condensor horizontal,

ho berkisar 150-300 Btu/jam.ft^2 ^{o}F

Trial ho = 300 Btu/jam.ft^{2o}F

$tw = tc + \left(\dfrac{ho}{ho + hio}\right) tc\text{-}Tc$

$= 253 + \dfrac{300}{300 + 402}\ 252.5$

= 298.63 ^oF

$tf = \dfrac{Tc + tw}{2} = \dfrac{252.5 + 298.6}{2}$

$= 276\ ^oF$

sehingga,

Dari Kern,Tabel 4 hal.800[24] didapatkan:

$kf = 0.1111$ Btu/jam.ft^2.^{o}F/ft

Dari Kern,Tabel 6 hal.808[24] didapatkan:

$sf = 1.00262$ Btu/jam.ft^2.^{o}F/ft

Dari Kern, Fig.14hal.823[24] didapatkan:

$\mu f = 0.16709$ cp

$$G'' = \frac{M}{L\ Nt^{2/3}}$$

$$= \frac{56{,}211.209}{16 \times 152^{2/3}}$$

$= 123.3504$ lb/jam.ft

Dari Kern,Fig.12.9 hal.267[24] didapatkan:

$ho = 325$

$$\varepsilon = \frac{325 - 300}{300}$$

$= 8\% < 10\%$ *ho memenuhi*

Clean overall coefficient Uc :

$$U_c = \frac{hio \cdot ho}{hio + ho} = \frac{402.4 \times 325}{402.4 + 325} = 650.00 \text{ Btu/ft}^2\text{.jam}^0\text{F}$$

Dirt factor (faktor kekotoran) pipa terpakai

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

$$= \frac{650 - 15.3}{650 \times 15.3} = 0.06392 \text{ jam.ft}^2\text{.°F/Btu}$$

Karena harga Rd hitung > Rd tetapan, maka rancangan HE memenuhi.

Evaluasi ΔP

Cold fluid: tube, cooling water	Hot fluid: shell, produk R-110
1. Pada $NRe_t = 312509.3356$ Dari Kern,fig. 26 hal.836[24], diperoleh: $f = 0.00013$ $sg = 1$	1'. Pada Nres = 32572.0588 Dari Kern,fig. 29 hal.839[24], diperoleh $f = 0.0023$
2. ΔP karena panjang pipa : $\Delta Pl = \frac{1}{2} \cdot \frac{f.Gt^2.L.n}{5{,}22 \times 10^{10}.di.sg.\phi}$ $= \frac{0.00013 \times 2330902^2 \times 16 \times 4}{2 \times 5{,}22.10^{10} \times 0.073 \times 1 \times 1}$ $= 1.19444$ psi	2'. No. of crosess $(N+1) = \frac{12L}{B} = \frac{12 \times 16}{8}$ $= 24$ bahan = 56211.2087 lb/ft $sg = \frac{\rho}{62.5}$

ΔP karena tube passes

Dari Kern,fig. 27 hal.837[24],diperoleh:

$$\left[\frac{v^2}{2gc}\right]\frac{\rho}{144} = 0.55$$, sehingga

$$\Delta Pn = \frac{4n}{sg}\left[\frac{v^2}{2gc}\right]\frac{\rho}{144}$$

$$= \frac{4 \times 4}{1} \times 0.55$$

= 0.88 psi

sehingga,

ΔPt total = 1.19444 + 0.88

= 2.07 psi < 2.5 psi

desain memenuhi

$$= \frac{56211.2087}{62.5}$$

= 899.37934

4'. $$\Delta Ps = \frac{f.Gs^2.IDs.(N+1)}{5{,}22\times10^{10}.de.sg.\phi}$$

$$= \frac{0.0023 \times 3469035^2 \times 2.92 \times 24}{5{,}22\times10^{10} \times 0.06 \times 899.4 \times 0.97}$$

= 3.7091 psi < 10.0 psi

desain memenuhi

Spesifikasi Kondensor (E-122)

Fungsi	:	Untuk menkondensasi produk reaktor (R-110)
Kode alat	:	E-122
Tipe	:	Horizontal Shell and Tube Heat Exchanger
Bahan Konstruksi	:	Carbon steel SA-135 Grade B
Media pendingin	:	Cooling water
Kapasitas	:	25,497.237 kg/jam = 56,211.209 lb/jam
Rate pendingin	:	13810.8533 kg/jam = 30,447.407 lb/jam
Dimensi		*Tube side* , cooling water — *Shell side* , produk R-110

Tube side				Shell side				
do	=	1	in 16 BWG	IDs	=	35	in	= 2.92
di	=	0.87	in	B	=	8	in	
L	=	16	ft	de	=	0.72	in	
Nt	=	152		C'	=	0.25	in	
Pt	=	1.25	in	ΔPs	=	3.71	psi	
Tringular Pitch								
ΔPt	=	2.07	psi					

16.Flash Drum (H-120)

Fungsi : Untuk memisahkan fase gas dan fase liquid dari produk keluaran rea

Tipe : Silinder vertikal dengan tutup atas dan tutup bawah berbentuk standa dished

Direncanakan :

Bahan konstruksi : Carbon Steel SA-250 Grade T1

Allowable stress (f : 11700

Tipe pengelasan (E : 0.8

Faktor korosi (C) : 1/16 = 0.0625 in

Jumlah storage : 1 buah

Kondisi operasi :

Suhu = 65 ℃ = 149 ℉ = 338.15 K

Tekanan = 2 atm = 29.392 Psia
Waktu tinggal = 0.02 jam

Perhitungan :

A. Menentukan Volume Tangki

Rate feed masul = 25685.2932 kg/jam
= 56625.7973 lb/jam

ρ campuran = 42.2592 lb/ft^3

$$\text{Volume liquid} = \frac{\text{Rate feed masuk}}{\rho v} \times \text{waktu tinggal}$$

$$= \frac{56625.7973}{42.2592} \times 0.02$$

$$= 26.7993 \; ft^3$$

Volume fluida = 80% volume total

$$\text{Volume total} = \frac{\text{Volume fluida}}{80\%}$$

$$= \frac{26.7993}{80\%}$$

$$= 33.4991 \; ft^3$$

B. Menentukan Dimensi Tangki

Asumsi Ls = 1.5 di

V total = V_{Ls} + V_{tutup}

$$33.4991 = \frac{\pi}{4} Di^2 \, Ls + 2\left(0.0847 \; d^3\right)$$

$$33.4991 = 1.1775 \; di^3 + 0.1694 \; d^3$$

$$33.4991 = 1.3469 \; di^3$$

$$di^3 = 24.8713$$

$$di = 2.9190 \; ft$$

$$= 35.027881 \; in$$

C. Menghitung Tinggi Liquida

$$V_{fluida} = V_{LS} + 2 \; V_{tutup}$$

$$26.80 = \frac{\pi}{4} Di^2 \; L_{Ls} + 2\left(0.0847 \; Di^3\right)$$

$$26.80 = \frac{\pi}{4}\left(2.9190\right)^{\wedge 2} L_{Ls} + 2\left(0.0847\left(2.9190\right)^{\wedge 3}\right)$$

$$26.80 = 10.90 \; L_{Ls}$$

$$H = L_{Ls} = 2.4582 \; ft$$

D. Menentukan Tekanan Design (Pi)

$$P_{hidrostatik} = \frac{\rho \, (H-1)}{144}$$

$$= \frac{42.2592 \times 2.4582 - 1}{144}$$

$= 0.4279$ psia

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

$= 29.3920 + 0.4279$

$= 29.8199$ Psia $= 15.1199$ Psig

E. Menghitung Tebal Silinder (ts)

$$\text{Tebal silinder (ts)} = \frac{Pi.di}{2\,(f.E - 0.6Pi)} + C$$

$$= \frac{15.1199 \times 35.0279}{2\left(11700 \times 0.8 - 0.6 \times 15.1199\right)} + 0.063$$

$$= 0.0908 \times \frac{16}{16}$$

$$= \frac{1.45311}{16} \approx \frac{3}{16} \text{ in}$$

do = di + 2 ts

= 35.028 + 0.375

= 35.403 in

berdasarkan "Brownel and Young" tabel 5.7 hal 89[12], didapatkan :

do_s = 36 in

icr = 2 1/4

r = 36

ts = 0.19 in

di_{baru} = do_s - 2 ts

= 36 - 0.38

= 35.625 in

= 2.9688 ft

F. Menghitung Tinggi Silinder

Tinggi silinder (Ls) = 1.5 × di

= 1.5 × 2.9688

= 4.4531 ft = 53.4375 in

G. Menghitung Dimensi Tutup Atas Dan Tutup Bawah

Bentuk tutup atas dan tutup bawah adalah standart dished, sehingga :

r = di

$$\text{Tebal tutup (tha/thb)} = \frac{0.855 \times Pi.\,r}{(f.E - 0.1\,Pi)} + C$$

$$= \frac{0.855 \times 15.1199 \times 35.6250}{11700 \times 0.8 - 0.1 \times 15.1199} + 0.0625$$

$$= 0.1117 \times \frac{16}{16}$$

$= \frac{1.7874}{16} \approx \frac{3}{16}$ in

Tinggi tutup (ha/hb = 0.169 × di
= 0.169 × 35.6250
= 6.0206 in
= 0.5017 ft

H. Menghitung Tinggi Storage

Tinggi storage (H) = tinggi silinder + tinggi tutup atas + tinggi tutup bawah
= 53.4375 + 6.0206 + 6.0206
= 65.4788 in
= 5.4566 ft

Spesifikasi Alat Flash Tank (H-120) :

Fungsi	:	Untuk memisahkan gas dan liquid yang keluar dari reaktor bagian atas
Jumlah tangki	:	1 buah
Bahan konstruksi	:	Carbon Steel SA 250 Grade T1
Volume tangki	:	33.4991 ft^3
Diameter dalam (di)	:	35.6250 in
Diameter luar (do)	:	36 in
Tebal silinder (ts)	:	3/16 in
Tinggi silinder (L)	:	53.4375 in
Tinggi tangki (H)	:	65.4788 in
Tebal tutup atas (tha)	:	3/16 in
Tinggi tutup atas (ha)	:	6.0206 in
Tebal tutup bawah (thb)	:	3/16 in
Tinggi tutup bawah (hb)	:	6.0206 in

17. Pompa Centrifugal (L-123)

Fungsi : Untuk mengalirkan produk bawah flash drum menuju preheater dest

Type : Pompa centrifugal

Direncanakan :

Bahan konstruksi : Carbon Steel dengan pelapis polypropylene

Jumlah : 1 buah

Kondisi operasi :

Suhu = 65 ℃ = 338.15 K

Tekanan = 1 atm = 14.696 psia

Rate aliran = 15983.8333 kg/jam = 35237.9589 lb/jam

Perhitungan *density* berdasarkan pers. *Carl and Yaws* [20]

Density = $A \times B^{-(1-T/Tc)^n}$ T = 65 ℃ = 338.15 K

Komponen	A	B	n	Tc	$(1-T/Tc)^n$
CH_3COOH	0.35182	0.26954	0.26843	592.71	0.7970

H_2O	0.3471	0.27400	0.28571	647.13	0.8096
$C_4H_6O_2$	0.31843	0.25803	0.28270	524.00	0.7460

(Pers. *Carls and Yaws Density of Liquid*)[20]

Komponen	Massa (Kg/jam)	xi (massa)	ρ (kg/m³)	ρ (lb/ft³)	xi.ρi
CH_3COOH	465.9625	0.0291	1000.2955	62.4464	1.8184
H_2O	2846.1748	0.1779	990.0356	61.8059	10.9931
$C_4H_6O_2$	12689.7112	0.7930	874.7953	54.6117	43.3079
Total	**16001.8484**	**1.0000**	**2865.1265**	**178.8641**	**56.1195**

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{56.1195}{1.0000} = 56.1195 \text{ lb/ft}^3 = 898.9183 \text{ kg/m}^3$$

$$\log 10\ \mu = A+B/T+CT+DT^2$$

Komponen	μ (*Centripoise*)			
	A	B	C	D
CH_3COOH	-3.8937	784.8200	0.0067	-0.0000076
H_2O	-10.2158	1792.5000	0.0177	-0.0000126
$C_4H_6O_2$	-9.0671	1186.3000	0.0227	-0.0000232

(Yaws and Carl Viscosity of Liquid)[20]

Komponen	Massa (Kg/jam)	xi (massa)	μ (Cp)	μ (lb/ft.s)	xi.μi
CH_3COOH	465.9625	0.0291	0.6553	0.0004	1.282E-05
H_2O	2846.1748	0.1779	0.4327	0.0003	5.172E-05
$C_4H_6O_2$	12689.7112	0.7930	0.2824	0.0002	0.0002
Total	**16001.8484**	**1.0000**	**1.3705**	**0.0009**	**0.0002**

$$\mu \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{0.0002}{1.0000} = 0.0002 \text{ lb/ft.s} = 0.7741 \text{ lb/ft.jam}$$

Perhitungan :

$$Q = \frac{\text{rate bahan masuk}}{\rho \text{ bahan masuk}}$$

$$= \frac{35237.9589}{56.1195}$$

$$= 627.9097 \text{ ft}^3\text{/jam} = 0.1744 \text{ ft}^3\text{/s} = 65.1905 \text{ gal/menit}$$

A. Menentukan Dimensi Pipa

$Di_{optimum} = 3.9\ Q^{0.45} \times \rho^{0.13}$ (Pers. 15 "Petters & Timmerhaus", hal 496)[23]

$$= 3.9 \times 0.1744^{0.45} \times 56.1195^{0.13}$$

$$= 3.00 \approx 3 \text{ in}$$

Standarisasi 3 in sch 40 (Kern, Tabel 11 Hal 844)[24]

Sehingga diperoleh :

OD	=	3.5000	in	=	0.2917	ft
ID	=	3.0680	in	=	0.2557	ft
A	=	0.9170	ft^2	=	132.0480	in^2

B. Menentukan Kecepatan Aliran Fluida

Kecepatan aliran fluida (v $= \dfrac{Q}{A}$

$= \dfrac{627.9097}{0.9170}$

= 684.7434 ft/Jam

= 0.1902 ft/s

C. Menentukan Bilangan Reynold

$N_{re} = \dfrac{D \times v \times \rho}{\mu}$

$= \dfrac{0.2557 \times 0.1902 \times 56.1195}{0.0002}$

= 12691.5184 > 4000 (aliran turbulen)

Dari fig 2.10-3 Geankoplis Halaman 94[21], didapatkan :

$\varepsilon = 4.6 \times 10^{-5}$ m = 0.00015 (Geankoplis, fig. 2.10-3 hal. 88)[21]

$\dfrac{\varepsilon}{D} = \dfrac{0.00015}{0.2557} = 0.00059$

f = 0.007 (Geankoplis, fig. 2.10-3 hal. 88)[21]

α = 1

D. Menentukan Panjang Pipa

Asumsi :

- Panjang pipa lurus = 40 ft
- elbow 90^o = 3 buah
  Le/D = 35
  L elbow = 35 ID (Geankoplis, Tabel 2-10.1 Hal 93)[21]
  = 35 × 0.2557 × 3
  = 26.8450 ft
- Gate valave = 1 buah
  Le/D = 9 (wide open) (Geankoplis, Tabel 2-10.1 Hal 93)[21]
  L elbow = 9 ID
  = 9 × 0.2557 × 1
  = 2.3010 ft
- Globe valve = 1 buah
  Le/D = 300 (wide open) (Geankoplis, Table 2.10-1 Hal 93)[21]
  L elbow = 300 ID

$= 300 \times 1 \times 0.2557$ ft

$= 76.7000$ ft

Panjang pipa total (L) $=$ Pipa lurus + elbow 90^o + gate valve + globe valve

$= 40 + 26.8450 + 2.3010 + 76.7000$

$= 145.8460$ ft

$= 1750.152$ in

E. Menentukan Friksion Loss

1. Friksi pada pipa lurus

$$F_f = 4f \frac{\Delta L}{D} \times \frac{v^2}{2g_c}$$ (Geankoplis, Pers.2-10.6 Hal 89)[21]

$$= 4 \times 0.0070 \frac{145.8460}{0.2557} \times \frac{0.1902^2}{2 \times 32.174}$$

$= 0.0090$ lbf.ft/lbm

2. Kontraksi pada keluaran tangki

$$hc = Kc \frac{v^2}{2g_c}$$ (Geankoplis, Pers.2-10.16 Hal 93)[21]

$$= 0.55 \frac{0.1902^2}{2 \times 32.174}$$

$= 0.0003$ lbf.ft/lbm

3. Elbow 90°, 3 buah

$K_f = 0.75$ (Geankoplis, Tabel 2.10-1 Hal. 93)[21]

$$hf = Kf \frac{v^2}{2}$$ (Geankoplis, Pers.2-10.17 Hal 94)[21]

$$= 3 \times 0.75 \frac{0.1902^2}{2}$$

$= 0.0407$ lbf.ft/lbm

4. Ekspansi

$$K_{eks} = 1 - \frac{A_1}{A_2}^2$$

$= 1 - (0)^2$

$= 1$

$$h_{eks} = K_{eks} \frac{v^2}{2\alpha}$$

$$= 1 \times \frac{0.1902^2}{2 \times 1}$$

$= 0.0181$ lbf.ft/lbm

5. Gate valve wide open, 1 buah

$K_f = 0.17$ (Geankoplis, Tabel 2.10-1 Hal. 93)[21]

$$hf = 1Kf \frac{v^2}{2}$$ (Geankoplis, Pers.2-10.17 Hal 94)[21]

$= 1 \times 0.17 \dfrac{0.1902^{2}}{2}$

$= 0.0031$ lbf.ft/lbm

6. Globe valve wide open, 1 buah

$K_f = 6.0$ (Tabel 2.10-1, Geankoplis)[21]

$h_f = 1K_f \dfrac{v^{2}}{2}$ (Pers. 2.10-17, Geankoplis)[21]

$= 1 \times 6.0 \times \dfrac{0.1902^{2}}{2}$

$= 0.1085$ $ft.lb_f/lb_m$

Sehingga :

Total friksi (ΣF) $= F_f + h_c + \Sigma h_f + h_{ex}$

$= 0.0090 + 0.0003 + 0.1523 + 0.0181$

$= 0.1797$ $ft.lb_f/lb_m$

F. Menentukan Kesetimbangan Mekanik

Direncanakan :

$\Delta Z = 20$ ft

$\Delta P = 0$ lb/ft^2 (karena $P_1 = P_2$)

$v_1 = 0$ ft/s (karena fluida diam dalam tangki penampungan)

$v_2 = 0.1902$ ft/s

$\alpha = 1$ (aliran turbulen)

Sehingga kesetimbangan mekanik :

$$\frac{V_2^{2} - V_1^{2}}{2.\alpha.gc} + \Delta Z\frac{g}{gc} + \frac{\Delta P}{\rho} + \sum F = -Ws$$

$$\frac{0.0362 - 0}{2 \times 1 \times 32.174} + 20 \frac{32.174}{32.174} + \frac{0.0000}{56.1195} + 0.1797 = -Ws$$

$-Ws = 20.1803$ lbf.ft/lbm

Dari Fig. 14.37 "Petters & Timmerhause", hal 520[23], didapatkan :

Efisiensi pompa (η) $= 80\%$

$Ws = - \eta \; Wp$

$20.1803 = - 80\% \; Wp$

$Wp = 25.2253$ ft.lbf/lbm

Mass flow rate (m) $= Q \times \rho$

$= 627.9097 \times 56.1195$

$= 35237.9589$ lbm/jam

$= 9.7883$ lbm/s

Pump horsepower $= Wp \times m \times \dfrac{1 \text{ hp}}{550 \text{ ft.lbf/s}}$

$= 25.2253 \times 9.7883 \times \dfrac{1 \text{ hp}}{550 \text{ ft.lbf/s}}$

$= 0.4489$ hp

Dari Fig.14.38 Hal.521, Petters &Timmerhause[23], didapatkan :

Efisiensi motor = 80%

Broken horsepower $= \dfrac{\text{pump horsepower}}{\eta}$

$= \dfrac{0.4489}{80\%}$

$= 0.5612 \approx 1$ Hp

Daya $= \dfrac{\text{BHP}}{\text{Efisiensi Motor}}$

$= \dfrac{0.5612}{80\%}$

$= 0.7015$ Hp $\approx$ 1 Hp

Spesifikasi Alat Pompa Sentrifugal (L-123) :

Fungsi	:	Untuk mengalirkan liquid dari flash drum menuju heater
Tipe	:	*Centrifugal pump*
Kapasitas	:	65.1905 gpm
Suhu operasi	:	338.15 K
Tekanan operasi	:	1 atm
Efisiensi Pompa	:	80%
ΔP	:	0 lb/ft^2
Bahan Konstruksi	:	Carbon Steel dengan pelapis polypropylene
Daya	:	1 Hp
L pipa	:	145.846 ft
Jumlah	:	1 buah

18. Heater (E-131)

Fungsi : Untuk menaikkan suhu feed sebelum masuk ke kolom destilasi

Tipe : *Double Pipe Heat Exchanger*

Direncanakan :

- Faktor kekotoran gabungan minimum (Rd = 0.001 jam.ft^2.°F/Btu
- Penurunan tekanan aliran maksimal (Δp) = 10 psi
- Δp maksimum steam = 2.5 psi

Kondisi operasi :

- Massa bahan masuk (W) = 15983.8333 kg/jam
  = 35238.2786 lb/jam
- Suhu bahan masuk (t_1) = 65 °C = 149 °F
- Suhu bahan keluar (t_2) = 85 °C = 185 °F
- Kebutuhan steam (m) = 387.2583 kg/jam
  = 853.7575 lb/jam
- Panas yang diserap (Q) = 183149.87 Kkal/jam
  = 726311.96 Btu/jam

- Suhu steam masuk (T_1) = 190 °C = 374 °F
- Suhu steam kondensat (T_2 = 190 °C = 374 °F

Perhitungan *density* berdasarkan pers. *Carl and Yaws* [20]

Density = $A \times B^{-(1-T/Tc)^n}$ T = 65 °C = 338.15 K

Komponen	A	B	n	Tc	$(1-T/Tc)^n$
CH_3COOH	0.35182	0.26954	0.26843	592.71	0.7970
H_2O	0.3471	0.27400	0.28571	647.13	0.8096
$C_4H_6O_2$	0.31843	0.25803	0.28270	524.00	0.7460

(Pers. *Carls and Yaws Density of Liquid*)[20]

Komponen	Massa (Kg/jam)	xi (massa)	ρ (Kg/m^3)	ρ (lb/ft^3)	*ρ*ixi
CH_3COOH	465.96247	0.02912	1000.2955	62.4464	1.8184
H_2O	2846.1748	0.17787	990.0356	61.8059	10.9931
$C_4H_6O_2$	12689.7112	0.79302	874.7953	54.6117	43.3079
Total	**16001.8484**	**1.0000**	**2865.1265**	**178.8641**	**56.1195**

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{56.1195}{1.0000} = 56.1195 \quad lb/ft^3 = 898.9183 \quad kg/m^3$$

$$\log 10\ \mu = A + B/T + CT + DT^2$$

Komponen	μ (*Centripoise*)			
	A	B	C	D
CH_3COOH	-3.8937	784.8200	0.0067	-0.0000076
H_2O	-10.2158	1792.5000	0.0177	-0.0000126
$C_4H_6O_2$	-9.0671	1186.3000	0.0227	-0.0000232

(Yaws and Carl Viscosity of Liquid)[20]

Komponen	Massa (Kg/jam)	xi (massa)	μ (Cp)	μ (lb/ft.s)	xi.μi
CH_3COOH	465.9625	0.0291	0.6553	0.0004	1.282E-05
H_2O	2846.1748	0.1779	0.4327	0.0003	5.172E-05
$C_4H_6O_2$	12689.7112	0.7930	0.2824	0.0002	0.0002
Total	**16001.8484**	**1.0000**	**1.3705**	**0.0009**	**0.0002**

$$\mu \text{ campuran} = \frac{\sum xi.\mu i}{\sum xi}$$

$$= \frac{0.0002}{1.0000} = 0.0002 \quad lb/ft.s = 0.7741 \quad lb/ft.jam$$

Menentukan C_p

$$C_p = A + B\,T + C\,T^2 + DT^3$$

Komponen	A	B	C	D
CH_3COOH	-18.944	1.09710	-0.00289	2.9257E-06

H_2O	92.053	-0.03995	-0.000211	5.347.E-07
$C_4H_6O_2$	63.91	0.70656	-0.00228	3.1788E-06

(Yaws and Carl Heat Capacity of Liquid)[20]

Komponen	**Massa (Kg/jam)**	**xi (massa)**	**Cp (Joule/kg.**	**Cp (Btu/lb.^{o}F)**	**Cp .xi**
CH_3COOH	465.9625	0.02912	134.467	0.032	0.0009
H_2O	2846.1748	0.17787	75.087	0.018	0.0032
$C_4H_6O_2$	12689.7112	0.79302	164.671	0.039	0.0312
Total	**16001.848**	**1.0000**	**374.225**	**0.089**	**0.0353**

$$\text{Cp campuran} = \frac{\sum xi.Cp}{\sum xi}$$

$$= \frac{0.0353}{1.0000} = 0.0353 \quad \text{Btu/lb.°F}$$

$\log_{10} k_{liq} = A + B\,(1\text{-}T/C)^{\wedge(2/7)}$ (untuk CH_3COOH dan $C_4H_6O_2$)

$k = A + B\,T + C\,T^2$ (untuk H_2O)

Komponen	**A**	**B**	**C**	**$(1\text{-}T/C)^{2/7}$**
CH_3COOH	-1.2836	0.5893	6.E+02	0.1502
H_2O	-0.2758	0.0046	-5.54E-06	-
$C_4H_6O_2$	-1.7519	1.1895	524.00	0.1193

(Yaws and Carl Thermal Conductivity of Liquid)

Komponen	Massa (Kg/jam)	xi (massa)	k (W/mK)	k (Btu/jam.ft^2	k.xi
CH_3COOH	465.9625	0.0291	0.0638	0.0369	0.00107
H_2O	2846.1748	0.1779	0.6504	0.3758	0.06684
$C_4H_6O_2$	12689.7112	0.7930	0.0245	0.0142	0.01125
Total	**16001.8484**	**1.0000**	**0.7387**	**0.4268**	**0.0792**

$$\text{k campuran} = \frac{\sum xi.k}{\sum xi}$$

$$= \frac{0.0792}{1.0000} = 0.0792 \quad \text{Btu/jam/ft}^2\text{.°F/ft}$$

Perhitungan :

A. Menghitung Δt

$\Delta_{t1} = T_1 - t_2 = 374 - 185 = 189$ °F

$\Delta_{t2} = T_2 - t_1 = 374 - 149 = 225$ °F

maka,

$$\Delta T_{LMTD} = \frac{\Delta_{t1} - \Delta_{t2}}{\ln \frac{\Delta_{t1}}{\Delta_{t2}}} = \frac{189 - 225}{\ln \frac{189}{225}} = \frac{-36.0}{-0.1744} \text{ °F}$$

$$= 206.477 \text{ °F}$$

B. Menghitung suhu kalorik (Tc dan tc)

Tc = $(T_1+T_2)/2$ = 374 °F

tc = $(t_1+t_2)/2$ = 167 °F

C. Trial ukuran DPHE

Dicoba ukuran DPHE : 3 × 2" IPS sch 40 dengan aliran steam dibagian pipa.

Dari tabel 6.2. "Kern" hal.110[24], didapatkan:

a_{an} = 2.93 in^2 = 0.0203 ft^2

a_p = 3.35 in^2 = 0.0233 ft^2

de = 1.57 in = 0.1308 ft

de' = 0.69 in = 0.0575 ft

dari tabel 11 "Kern" hal.844[24], didapatkan:

do_p = 2.38 in = 0.1983 ft

di_p = 2.067 in = 0.1723 ft

a'' = 0.622 ft^2/ft

Evaluasi Perpindahan Panas	
Bagian *Anulus* (Bahan)	Bagian Pipa (Steam)
1. Menghitung N_{Re}	1'. Menghitung N_{Re}
$G_{an} = \frac{W}{a_{an}}$	$G_p = \frac{m}{a_p}$
$= \frac{35238.2786}{0.0203}$	$= \frac{853.7575}{0.0233}$
= 1731847.1376 lb/jam.ft^2	= 36698.8296 lb/jam.ft^2
μ = 0.7741 lb/ft.jam	μ = 0.1434 Cp = 0.3470 ft.jam
$NRe_{an} = \frac{G_{an} \times de}{\mu}$	$NRe_p = \frac{G_p \times di}{\mu}$
= 292702.2285	= 18219.6161
Mencari faktor panas (J_H)	
2. (Fig. 24, hal 834, Kern)[24]	2'. Mencari faktor panas (J_H)
J_H = 550	J_H tidak perlu dicari karena steam
3. Menghitung harga koefisien film	
Cp = 0.0353 Btu/lb.°F	3'. Menghitung harga koefisien film
k = 0.0792 Btu/jam.ft^2.°F/ft	untuk steam
$k(Cp.\mu/k)^{1/3}$ = 0.7016	h_{i0} = 1500 Btu/jam.ft^2.°F
$\left(\frac{\mu}{\mu_w}\right)^{0.14}$ = 0.9599	

$$ho = J_H \times \frac{k}{De} \times (Cp.\mu/k) \times \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

$$= 550 \times 0.61 \times 0.70 \times 0.96$$

$$ho = 224.0989 \text{ Btu/jam.ft}^2.^oF$$

D. Mencari tahanan panas pipa bersih

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

$$Uc = \frac{224.0989 \times 1500}{224.0989 + 1500}$$

$$= 194.9705 \text{ Btu/jam.ft}^2.^oF$$

E. Mencari dirty faktor (faktor kekotoran) pipa terpakai

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

$$\frac{1}{U_D} = \frac{1}{U_C} + Rd$$

$$\frac{1}{U_D} = \frac{1}{194.970} + 0.0010$$

$$U_D = 163.1592 \text{ Btu/jam.ft}^2.^oF$$

$$A = \frac{Q}{U_D \times \Delta T}$$

$$= \frac{726311.958}{163.159 \times 206.477}$$

$$= 21.560 \text{ ft}^2$$

$$L = \frac{A}{a''}$$

$$= \frac{21.5595 \text{ ft}^2}{0.622 \text{ ft}^2/\text{ft}}$$

$$= 34.6616 \text{ ft}$$

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

$$= \frac{194.970 - 163.159}{194.970 \times 163.159}$$

$$= 0.001$$

Rd ketetapar = 0.001

Rd hitung > Rd ketetapan jadi Ok

Hasil		
1500	h outside	224.099
U_C	194.9705	

U_D	163.1592
Rd terhitung	0.0010
Rd tetapan	0.0010

F. Mencari panjang ekonomis

L(ft)	Hairpin	N_{pakai}	L_{baru}	A_{baru}	UD_{baru}	Rd_{baru}	$Rd_{over\ desain}$
12	1.4442	2	48	29.9	117.820	0.0034	2.3585
15	1.1554	2	60	37.3	94.256	0.0055	4.4804
20	0.8665	1	40	24.9	141.384	0.0019	0.9439

Jadi diambil over desain terkecil, yaitu = 0.9439

L = 20 ft

n = 1 buah

Evaluasi Δp

Bagian *Anulus* (Bahan)

1. Menghitung N_{re} dan friksi

NRe_{an} = 292702.23

Kern fig.29, hal.839[24]

f = 0.0012

2. Mencari ΔP karena panjang pipa

ρ = 56.119 lb/ft^3

$$\Delta F_a = \frac{4 \times f \times G_{an}^2 \times L}{2 \times g \times \rho^2 \times de'}$$

ΔF_a = 0.19019 ft

$$V = \frac{G}{3600 \times \rho}$$

$$= \frac{1731847.1376}{3600 \times 56.1195}$$

= 8.5722 fps

$$FI = 3 \times \frac{V^2}{2\,g}$$

$$= 3 \times \frac{8.5722^2}{2 \times 32.174}$$

= 3.4259 ft

Δpa = 1.4093

Hasil ΔP karena panjang pipa

ΔP allow = 10 psi

ΔP_a < ΔP_{allow}

1.40925 < # psi

(memenuhi syarat)

Bagian Pipa (Steam)

1'. Menghitung N_{re} dan friksi

NRe_p = 18219.62

Kern fig.26, hal.836[24]

f = 0.0003

2'. Menghitung ΔP pipa

ρ = 53.50 Ib/ft^3

$$\Delta Pp = \frac{4 \,.\, f \,.\, Gt^2 \,.\, L}{2 \,.\, g \,.\, \rho^2 \,.\, Di}$$

= 0.00784 ft

ΔP_p < $\Delta p_{tetapan}$

0.0078 < 2.5

(memenuhi syarat)

Spesifikasi Alat Heater (E-131) :

Fungsi	:	Menaikkan suhu larutan dari 65°C menjadi 85°C sebelu masuk kolom distilasi
Type	:	*Double Pipe Heat Exchanger*
Bahan konstruksi	:	Stainlees Steel SA 312 Grade M Type 317
Kapasitas	:	15983.8333 kg/jam = 35238.2786 lb/jam
Rate steam	:	387.2583 kg/jam = 1535.7388 Btu/jam
Jumlah hairpin	:	0.8665 buah
Diameter luar pipa	:	2.3800 in = 0.1983 ft
Diameter dalam pipa	:	2.0670 in = 0.1723 ft
Panjang	:	20 ft
Jumlah	:	1 buah

19. Kolom Distilasi (D-130)

Fungsi : Untuk memisahkan produk utama dari impuritiesnya

Tipe : *Sieve Tray*

Kolom distilasi didesain sebagai alat utama oleh Dwi Nirmala Sari (1914034) dap dilihat di BAB VI Perancangan Alat Utama

20. Reboiler (E-132)

Fungsi : Untuk menguapkan dan memanaskan kembali *bottom product* distil

Tipe : *Double Pipe Heat Exchanger*

Direncanakan :

- Faktor kekotoran gabungan minimum (Rd = 0.001 jam.ft^2.°F/Btu
- Penurunan tekanan aliran maksimal (Δp) = 10 psi
- Δp maksimum steam = 2.5 psi

Kondisi operasi :

- Massa bahan masuk (W) = 3357.5707 kg/jam
  = 7402.1675 lb/jam
- Suhu bahan masuk (t_1) = 100 °C = 213 °F
- Suhu bahan keluar (t_2) = 101 °C = 214 °F
- Kebutuhan steam (m) = 696.0156 kg/jam
  = 1534.4499 lb/jam
- Panas yang diserap (Q) = 329173.46 Kkal/jam
  = 1305393.3 Btu/jam
- Suhu steam masuk (T_1) = 190 °C = 374 °F
- Suhu steam kondensat (T_2 = 190 °C = 374 °F

Perhitungan *density* berdasarkan pers. *Carl and Yaws* [20]

Density = $A \times B^{-(1-T/Tc)^n}$ T = 100 °C = 373.576 K

Komponen	A	B	n	Tc	$(1-T/Tc)^n$
CH_3COOH	0.35182	0.26954	0.26843	592.71	0.7656
H_2O	0.3471	0.274	0.28571	647.13	0.7819
$C_4H_6O_2$	0.31843	0.25803	0.28270	524	0.7027

(Pers. *Carls and Yaws Density of Liquid*)[20]

Komponen	Massa (Kg/jam)	xi (massa)	ρ (Kg/m³)	ρ (lb/ft³)	ρixi
CH_3COOH	465.96247	0.13862	959.9230	59.9261	8.30716
H_2O	2831.9439	0.8425	955.1811	59.6300	50.2384
$C_4H_6O_2$	63.4486	0.01888	824.9663	51.5010	0.97213
Total	**3361.3550**	**1.0000**	**2740.0705**	**171.0571**	**59.5176**

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{59.5176}{1.0000} = 59.5176 \text{ lb/ft}^3 = 953.3500 \text{ kg/m}^3$$

$$\log 10\ \mu = A+B/T+CT+DT^2$$

Komponen	μ (*Centripoise*)			
	A	B	C	D
CH_3COOH	-3.8937	784.8200	0.0067	-0.0000076
H_2O	-10.2158	1792.5000	0.0177	-0.0000126
$C_4H_6O_2$	-9.0671	1186.3000	0.0227	-0.0000232

(Yaws and Carl Viscosity of Liquid)[20]

Komponen	Massa (Kg/jam)	xi (massa)	μ (Cp)	μ (lb/ft.s)	xi.μi
CH_3COOH	465.9625	0.0291	0.4384	0.0003	8.578E-06
H_2O	2831.9439	0.1770	0.2774	0.0002	3.299E-05
$C_4H_6O_2$	63.4486	0.0040	0.2167	0.0001	0.00000
Total	**3361.3550**	**0.2101**	**0.9325**	**0.0006**	**0.00004**

$$\mu \text{ campuran} = \frac{\sum xi.\mu i}{\sum xi}$$

$$= \frac{0.00004}{0.2101} = 0.0002 \text{ lb/ft.s} = 0.7223 \text{ lb/ft.jam}$$

Menentukan C_p

$$C_p = A + B\,T + C\,T^2 + DT^3$$

Komponen	A	B	C	D
CH_3COOH	-18.944	1.09710	-0.00289	2.9257E-06
H_2O	92.053	-0.03995	-0.000211	5.347.E-07
$C_4H_6O_2$	63.91	0.70656	-0.00228	3.1788E-06

(Yaws and Carl Heat Capacity of Liquid)[2

Komponen	Massa (Kg/jam)	xi (massa)	Cp (Joule/kg.	Cp (Btu/lb.°F)	Cp .xi
CH_3COOH	465.9625	0.02912	139.821	0.033	0.0010
H_2O	2831.9439	0.17698	75.553	0.018	0.0032
$C_4H_6O_2$	63.4486	0.00397	174.952	0.042	0.0002
Total	**3361.355**	**0.2101**	**390.327**	**0.093**	**0.0043**

$$Cp\ campuran = \frac{\sum xi.Cp}{\sum xi}$$

$$= \frac{0.0043}{0.2101} = 0.0206 \quad Btu/lb.°F$$

$\log_{10} k_{liq}$ = A + B (1-T/C)$^{(2/7)}$ (untuk CH_3COOH dan $C_4H_6O_2$)

k = A+ B T+ C T^2 (untuk H_2O)

Komponen	**A**	**B**	**C**	**$(1-T/C)^{2/7}$**
CH_3COOH	-1.2836	0.5893	6.E+02	0.1253
H_2O	-0.2758	0.0046	-5.54E-06	-
$C_4H_6O_2$	-1.7519	1.1895	524.00	0.0935

(Yaws and Carl Thermal Conductivity of Liquid)

Komponen	Massa (Kg/jam)	xi (massa)	k (W/mK)	k (Btu/jam.ft^2	k.xi
CH_3COOH	465.9625	0.0291	0.0617	0.0356	0.00104
H_2O	2831.9439	0.1770	0.6504	0.3758	0.0665
$C_4H_6O_2$	63.4486	0.0040	0.0229	0.0132	5.2E-05
Total	**3361.3550**	**0.2101**	**0.7349**	**0.4246**	**0.0676**

$$k\ campuran = \frac{\sum xi.k}{\sum xi}$$

$$= \frac{0.0676}{0.2101} = 0.3218 \quad Btu/jam/ft^2.°F/ft$$

Perhitungan :

A. Menghitung Δt

Δ_{t1} = T_1 - t_2 = 374 - 214 = 160 °F

Δ_{t2} = T_2 - t_1 = 374 - 213 = 161 °F

maka,

$$\Delta T_{LMTD} = \frac{\Delta_{t1} - \Delta_{t2}}{\ln \frac{\Delta_{t1}}{\Delta_{t2}}} = \frac{160 - 161}{\ln \frac{160}{161}} = \frac{-0.9}{-0.0058}\ °F$$

$$= 160.766\ °F$$

B. Menghitung suhu kalorik (Tc dan tc)

Tc = $(T_1+T_2)/2$ = 374 °F

tc = $(t_1+t_2)/2$ = 213 °F

C. Trial ukuran DPHE

Dicoba ukuran DPHE : 3 × 2" IPS sch 40 dengan aliran steam dibagian pipa.

Dari tabel 6.2. "Kern" hal.110[24], didapatkan:

a_{an} = 2.93 in^2 = 0.0203 ft^2

a_p = 3.35 in^2 = 0.0233 ft^2

de = 1.57 in = 0.1308 ft

de' = 0.69 in = 0.0575 ft

dari tabel 11 "Kern" hal.844[24], didapatkan:

do_p = 2.38 in = 0.1983 ft

di_p = 2.067 in = 0.1723 ft

a" = 0.622 ft^2/ft

Evaluasi Perpindahan Panas	
Bagian *Anulus* (Bahan)	Bagian Pipa (Steam)
1. Menghitung N_{Re}	1'. Menghitung N_{Re}
$G_{an} = \frac{W}{a_{an}}$	$G_p = \frac{m}{a_p}$
$= \frac{7402.1675}{0.0203}$	$= \frac{1534.4499}{0.0233}$
= 363792.5329 $lb/jam.ft^2$	= 65958.4440 $lb/jam.ft^2$
μ = 0.7223 lb/ft.jam	μ = 0.1434 Cp = 0.3470 ft.jam
$NRe_{an} = \frac{G_{an} \times de}{\mu}$	$NRe_p = \frac{G_p \times di}{\mu}$
= 65891.89963	= 32745.9360
2. Mencari faktor panas (J_H) (Fig. 24, hal 834, Kern)[24]	2'. Mencari faktor panas (J_H)
J_H = 200	J_H tidak perlu dicari karena steam
3. Menghitung harga koefisien film	3'. Menghitung harga koefisien film untuk steam
Cp = 0.0206 $Btu/lb.^oF$	h_{i0} = 1500 $Btu/jam.ft^2.^oF$
k = 0.3218 $Btu/jam.ft^2.^oF/ft$	
$k(Cp.\mu/k)^{1/3}$ = 0.3590	
$\left(\frac{\mu}{\mu_w}\right)^{0.14}$ = 0.9507	
$ho = J_H \times \frac{k}{De} \times (Cp.\mu/k) \times \left(\frac{\mu}{\mu_w}\right)^{0.14}$	
= 200 × 2.46 × 0.36 × 0.95	
ho = 167.8967 $Btu/jam.ft^2.^oF$	

D. Mencari tahanan panas pipa bersih

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

$$Uc = \frac{167.8967 \times 1500}{167.8967 + 1500}$$

= 150.9956 $Btu/jam.ft^2.^oF$

E. Mencari dirty faktor (faktor kekotoran) pipa terpakai

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

$$\frac{1}{U_D} = \frac{1}{U_C} + Rd$$

$$\frac{1}{U_D} = \frac{1}{150.996} + 0.0010$$

U_D = 131.1869 Btu/jam.ft^2.^{o}F

$$A = \frac{Q}{U_D \times \Delta T}$$

$$= \frac{1305393.308}{131.187 \times 160.766}$$

= 61.895 ft^2

$$L = \frac{A}{a''}$$

$$= \frac{61.8950 \text{ ft}^2}{0.622 \text{ ft}^2/\text{ft}}$$

= 99.5097 ft

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

$$= \frac{150.996 - 131.187}{150.996 \times 131.187}$$

= 0.001

Rd ketetapar = 0.001

Rd hitung > Rd ketetapan jadi Ok

Hasil		
1500	h outside	167.897
U_C		150.9956
U_D		131.1869
Rd terhitung		0.0010
Rd tetapan		0.0010

F. Mencari panjang ekonomis

L(ft)	Hairpin	N_{pakai}	L_{baru}	A_{baru}	UD_{baru}	Rd_{baru}	$Rd_{over\ desain}$
12	4.1462	5	120	74.6	108.786	0.0026	1.5696
15	3.3170	4	120	74.6	108.786	0.0026	1.5696
20	2.4877	3	120	74.6	108.786	0.0026	1.5696

Jadi diambil over desain terkecil, yaitu = 1.5696

L = 12 ft

n = 5 buah

Evaluasi Δp

Bagian *Anulus* (Bahan)

1. Menghitung N_{re} dan friksi

NRe_{an} = 65891.9

Kern fig.29, hal.839[24]

f = 0.0012

2. Mencari ΔP karena panjang pipa

ρ = 59.518 lb/ft^3

$$\Delta F_a = \frac{4 \times f \times G_{an}^2 \times L}{2 \times g \times \rho^2 \times de'}$$

ΔF_a = 0.00448 ft

$$V = \frac{G}{3600 \times \rho}$$

$$= \frac{363792.5329}{3600 \times 59.5176}$$

= 1.6979 fps

$$FI = 3 \times \frac{V^2}{2\,g}$$

$$= 3 \times \frac{1.6979^2}{2 \times 32.174}$$

= 0.1344 ft

Δpa = 0.0574

Hasil ΔP karena panjang pipa

ΔP allow = 10 psi

ΔP_a < ΔP_{allow}

0.0574 < 10 psi

(memenuhi syarat)

Bagian Pipa (Steam)

1'. Menghitung N_{re} dan friksi

NRe_p = 32745.94

Kern fig.26, hal.836[24]

f = 0.0003

2'. Menghitung ΔP pipa

ρ = 53.5008 Ib/ft^3

$$\Delta Pp = \frac{4 \,.\, f \,.\, Gt^2 \,.\, L}{2 \,.\, g \,.\, \rho^2 \,.\, Di}$$

= 0.0152 ft

ΔP_p < $\Delta p_{tetapan}$

0.0152 < 2.5

(memenuhi syarat)

Spesifikasi Alat Reboiler (E-132) :

Fungsi	:	Untuk menguapkan dan memanaskan kembali produk distilasi
Type	:	*Double Pipe Heat Exchanger*
Bahan konstruksi	:	Stainlees Steel SA 312 Grade M Type 317
Kapasitas	:	3357.5707 kg/jam = 7402.1675 lb/jam
Rate steam	:	696.0156 kg/jam = 2760.1682 Btu/jam
Jumlah hairpin	:	2.4877 buah
Diameter luar pipa	:	2.3800 in = 0.1983 ft
Diameter dalam pipa	:	2.0670 in = 0.1723 ft
Panjang	:	12 ft
Jumlah	:	1 buah

21. Kondensor (E-133)

Fungsi : Mengembunkan uap produk atas yang keluar dari kolom distilasi

Tipe *Shell and Tube*

Direncanakan :

- faktor kekotoran gabungan minimum (Rd) = 0.001 jam.ft^2.°F/Btu
- penurunan tekanan aliran maksimum (Δp) = 10 psi
- Δp maksimum aliran air pendingin = 2.5 psi
- Digunakan pipa ukuran 1 in OD, BWG 12, L = 20 ft, P_T = 1,25 in
- susunan segitiga (triangular)

Kondisi operasi :

- Massa bahan masuk (W) = 12626.2626 kg/jam
  = 27836.1111 lb/jam
- Suhu bahan masuk (T_1) = 73.22 °C = 163.80 °F = 346.37 K
- Suhu bahan keluar (T_2) = 73.03 °C = 163.45 °F = 346.18 K
- Kebutuhan air pendingin = 53432.8596 kg/jam
  = 117799.151 lb/jam
- Panas yang diserap (Q) = 3515727.5 Kkal/jam
  = 13942215.0 Btu/jam
- Suhu pendingin masuk (t_1 = 30 °C = 86 °F
- Suhu pendingin keluar (t_2 = 60 °C = 140 °F

Density = $A \times B^{-(1-T/Tc)^n}$ T = 73.22 °C = 346.371 K

Komponen	A	B	n	Tc	$(1-T/Tc)^n$
H_2O	0.3471	0.27400	0.28571	647.13	0.8034
$C_4H_6O_2$	0.31843	0.25803	0.28270	524.00	0.7365

(Pers. *Carls and Yaws Density of Liquid*)[20]

Komponen	Massa (Kg/jam)	xi (massa)	ρ (Kg/m^3)	ρ (lb/ft^3)	*ρ*ixi
H_2O	13.2660	0.0011	982.1030	61.3107	0.0644
$C_4H_6O_2$	12612.9966	0.9989	863.6318	53.9148	53.8582
Total	**12626.2626**	**1.0000**	**1845.7349**	**115.2255**	**53.9226**

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{53.9226}{1.0000} = 53.9226 \text{ lb/ft}^3 = 863.7286 \text{ kg/m}^3$$

$$\log 10\ \mu = A + B/T + CT + DT^2$$

Komponen	μ (*Centripoise*)			
	A	**B**	**C**	**D**
H_2O	-10.2158	1792.5000	0.0177	-0.0000126
$C_4H_6O_2$	-9.0671	1186.3000	0.0227	-0.0000232

(Yaws and Carl Viscosity of Liquid)[20]

Komponen	Massa (Kg/jam)	xi (massa)	μ (Cp)	μ (lb/ft.s)	xi.μi
H_2O	13.2660	0.0011	0.3847	0.0003	2.716E-07
$C_4H_6O_2$	12612.9966	0.9989	0.2650	0.0002	0.0002
Total	**12626.2626**	**1.0000**	**0.6497**	**0.0004**	**0.0002**

$$\mu \text{ campuran} = \frac{\sum xi.\mu i}{\sum xi}$$

$$= \frac{0.0002}{1.0000} = 0.0002 \text{ lb/ft.s} = 0.6415 \text{ lb/ft.jam}$$

Menentukan C_p

$$C_p = A + B\,T + C\,T^2 + DT^3$$

Komponen	A	B	C	D
H_2O	92.053	-0.03995	-0.00021	5.347.E-07
$C_4H_6O_2$	63.910	0.70656	-0.00228	3.179.E-06

(Yaws and Carl Heat Capacity of Liquid)[2

Komponen	Massa (Kg/jam)	xi (massa)	Cp (Joule/kg.	Cp (Btu/lb.°F)	Cp .xi
H_2O	13.2660	0.0011	75.116	0.018	0.0000
$C_4H_6O_2$	12612.9966	0.9989	166.815	0.040	0.0398
Total	**12626.2626**	**1.0000**	**241.931**	**0.058**	**0.0398**

$$\text{Cp campuran} = \frac{\sum xi.Cp}{\sum xi}$$

$$= \frac{0.0398}{1.0000} = 0.0398 \text{ Btu/lb.°F}$$

$\log_{10} k_{liq} = A + B\,(1\text{-}T/C)^{\wedge(2/7)}$ (untuk $C_4H_6O_2$)

$k = A + B\,T + C\,T^2$ (untuk H_2O)

Komponen	A	B	C	$(1\text{-}T/C)^{2/7}$
H_2O	-0.2758	0.0046	-5.54E-06	-
$C_4H_6O_2$	-1.7519	1.1895	524.00	0.1131

(Yaws and Carl Thermal Conductivity of Liquid)

Komponen	Massa (Kg/jam)	xi (massa)	k (W/mK)	k (Btu/jam.ft^2	k.xi
H_2O	13.2660	0.0011	0.6571	0.3797	0.0004
$C_4H_6O_2$	12612.9966	0.9989	0.0241	0.0139	0.01393
Total	**12626.2626**	**1.0000**	**0.6813**	**0.3936**	**0.0143**

$$\text{k campuran} = \frac{\sum xi.k}{\sum xi}$$

$$= \frac{0.0143}{1.0000} = 0.0143 \text{ Btu/jam/ft}^2\text{.°F/ft}$$

Perhitungan :

A. Menghitung Δt

Δ_{t1} = T_1 - t_2 = 24 °F

Δ_{t2} = T_2 - t_1 = 77 °F

$$\Delta T_{LMTD} = \frac{\Delta_{t1} - \Delta_{t2}}{\ln \frac{\Delta_{t1}}{\Delta_{t2}}} = \frac{24 - 77}{\ln \frac{24}{77}} = \frac{-53.7}{-1.1801} \text{ °F}$$

$= 45.4675$ °F

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{164 - 163}{140 - 86} = 1.4 \text{ °F}$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{140 - 86.0}{164 - 86.0} = 0.216 \text{ °F}$$

Dari Kern fig.18, hal.828[24] didapatkan harga Ft yang cocok adalah :

Ft = 0.91 (dipilih tipe HE : 1-2)

Jadi :

Δt = Ft × ΔT_{LMTD}

= 0.91 × 45.5

= 41.375 °F

B. Menghitung suhu kalorik (Tc dan tc)

$$Tc = \frac{(T_1 + T_2)}{2} = \frac{163.798 + 163.45}{2} = 163.625 \text{ °F}$$

$$tc = \frac{(t_1 + t_2)}{2} = \frac{86.0 + 140.0}{2} = 113.000 \text{ °F}$$

C. Trial UD

Dari tabel 8 "Kern" hal. 840[24], range $U_{D\ (Gases)}$ = 2 - 50 Btu/jam.ft^2.°F

Dicoba UD = 25 Btu/jam.ft^2.°F

$$A = \frac{Q}{UD \times \Delta t}$$

$$= \frac{3515727.4828}{25 \times 41.3754}$$

= 3398.8547 ft^2

dengan

$d_{o\ tube}$ = 1.00

BWG = 12

L = 20 ft

Pt = 1.25 in

Dari Kern, tabel 10 hal 843[24], sehingga diperoleh harg 0.2618 ft^2

$$Nt = \frac{A}{a''\ L}$$

$= \dfrac{3398.8547}{0.2618 \times 20}$

= 649.132 buah

Dari Kern, tabel 9 Hal 842[24], diperoleh

IDs = 37.00 in

n = 2

Nt = 664 buah

$U_D \text{ koreksi} = \dfrac{Nt}{Nt \text{ standar}} \times U_D \text{ trial}$

$= \dfrac{649.1319}{664} \times 25$

= 24.4402 Btu/jam.ft^2.ºF

Dari Kern, tabel 28, hal. 838[24], diperoleh :

de = 0.72 in

D. Trial ukuran SHE

Type HE 1-2	
Bagian *Shell*	Bagian *Tube*
ID_S = 37.00 in	do = 1.00 in BWG = 12
n' = 1	L = 20 ft Nt = 664
B = 7.40 in	Susunan segitiga, n = 2
Pt = 1.25 in	a' = 0.4790 in^2
de = 0.72 in	a'' = 0.2618 ft^2/ft
= 0.06 ft	di = 0.7820 in
C'' = 0.25	= 0.0652 ft

Evaluasi Perpindahan Panas	
Bagian *Shell* (Bahan)	Bagian *Tube* (Air Pendingin)
1. Menghitung N_{Re}	1'. Menghitung N_{Re}
$a_s = \dfrac{IDs \times C \times B}{n \times Pt \times 144}$	$a_t = \dfrac{Nt \times a'}{n \times 144}$
$= \dfrac{37.00 \times 1/4 \times 7\ 2/5}{1 \times 1.25 \times 144}$	$= \dfrac{664.00 \times 0.48}{2 \times 144}$
= 0.3803	= 1.1044
$G_s = \dfrac{W}{a_s}$	$G_t = \dfrac{m}{at}$
$= \dfrac{27836.1111}{0.3803}$	$= \dfrac{117799.151}{1.1044}$
= 73199.4155 lb/jam.ft^2	= 106667.2393 lb/jam.ft^2
μ = 0.6497 cP	(fig.14 "Kern", hal.823)[24]
= 0.6415 lb/ft.jam	μ = 0.4500 Cp
	= 1.0886 ft.jam

$N_{re_s} = \dfrac{Gs \times de}{\mu \times 2.42}$

$= 6846.7592$

2. Mencari faktor panas (J_H)

J_H = -

3. Menghitung harga koefisien film trial ho maksimal 300 Btu/jam.ft^2 ^{o}F

Trial ho = 150 Btu/jam.ft^{2o}F

$tw = tc + \dfrac{ho}{ho + hio}\left(tc\text{-}Tc\right)$

$= 113 + \dfrac{150}{150 + 225} - \quad -51$

$= 92.7615\ ^oF$

Δt = tc-tw = 113.0 - 92.8

= 20.24 ^{o}F

Dari Kern, fig.15.11hal.474[24] didapatkan:

hs = 32 Btu/ft^2.jam^{0}F

hv = 85 Btu/ft^2.jam^{0}F

Dari App. B didapatkan:

Q1 = 4331744.8 kkal/jam

= 17178556 btu/jam

Q2 = 3515727.5 kkal/jam

= 13942447 btu/jam

$ho = \dfrac{Q}{\dfrac{Q1}{hs} + \dfrac{Q2}{hv}}$

$= \dfrac{31121003.53}{\dfrac{17{,}178{,}556}{32} + \dfrac{13{,}942{,}447}{85}}$

= 444.0411

$NRe_p = \dfrac{Gt \times di}{\mu \times 2.42}$

$= 6385.6951$

2'. Mencari faktor panas (J_H)

J_H = -

3'. Menghitung harga koefisien film untuk air

ρ = 61.98 lbm/ft^3

$v = \dfrac{Gt}{3600.\ \rho}$

$= \dfrac{106667.2393}{3600 \times 61.98}$

= 0.48 ft/s

("Kern", hal.835)[24]

faktor koreksi = 0.96

(fig.25 "Kern", hal.835)[24]

hi = 300 Btu/jam.ft^2.^{o}F

hi = 300 × 0.96

= 288.0 Btu/jam.ft^2.^{o}F

hio = hi x (di/do)

= 225.216 Btu/jam.ft^2.^{o}F

E. Mencari tahanan panas pipa bersih

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

$Uc = \dfrac{444.0411 \times 225}{444.0411 + 225}$

= 149.4271 Btu/jam.ft^2.^{o}F

F. Mencari dirty faktor (faktor kekotoran) pipa terpakai

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

$$= \frac{149.427 - 24.440}{149.427 \times 24.440}$$

$= 0.03422$

Karena harga Rd hitung > Rd tetapan, maka rancangan HE memenuhi

Evaluasi Δp

Bagian *Shell* (Bahan)	Bagian *Tube* (Air Pendingin)
1. Menghitung N_{re} dan friksi	1. Menghitung N_{re} dan friksi
Nre_s = 6846.7592	Nre_t = 6385.6951
Kern fig.29, hal.839 [24]	*Kern fig.26, hal.836* [24]
f = 0.0022	*f* = 0.00030
	sg = 1
2. Mencari ΔPs	2. Mencari ΔP karena panjang pipa
ρ = 53.923 lb/ft^3	$\Delta P_1 = \frac{1}{2} \cdot \frac{f.Gt^2.L.n}{5{,}22 \times 10^{10}.di.sg.\phi}$
BM = 104	
$S = \frac{144 \times \rho \times BM}{1545 \times (460+T) \times 62.5}$	$= \frac{0.00030 \times 106667.2^2 \times 20 \times 2}{2 \times 5{,}22.10^{10} \times 0.065 \times 1 \times 1}$
= 0.0134065	= 0.02146 psi
N+1 = (12 x L)/B	ΔP karena tube passes
= 4.44	Dari Kern,fig. 27 hal.837[24],diperoleh:
$\varphi s = \left[\frac{\mu}{\mu_w}\right]^{0,14}$	$\left[\frac{v^2}{2gc}\right]\frac{\rho}{144}$ = 0.0011 , sehingga
= 0.93	$\Delta Pn = \frac{4n}{sg}\left[\frac{v^2}{2gc}\right]\frac{\rho}{144}$
$\Delta P_1 = \frac{f \times Gs^2 \times ID \times (N+1)}{2 \times 5{,}22.10^{10} \times de \times sg \times \varphi}$	$= \frac{4 \times 2}{1} \times 0.001$
ΔP_1 = 0.33065 psi	= 0.00088 psi
ΔP_1 < ΔP_{allow}	sehingga,
0.3306 < 10 psi	ΔPt total = 0.02146 + 0.00088
(memenuhi syarat)	= 0.02 psi < 2.5 psi
	desain memenuhi

Spesifikasi Alat Kondensor (E-133) :

Fungsi	:	Mengembukan uap produk atas yang keluar dari distilasi
Tipe	:	*Shell and Tube*
Bahan konstruksi	:	Stainless Steel SA 167 Grade 3 Type 304
Media pemanas	:	Air pendingi 30 °C
Kapasitas	:	12626.2626 kg/jam
Rate pendingin	:	53432.8596 kg/jam
Dimensi	:	Bagian *Shell* — Bagian *Tube*
		ID_S = 37.00 in — do = 1.00 in BWG = 12

n'	=	1		L	=	20.00 ft	Nt	=	664
B	=	7.40	in	Susunan segitiga, n				=	2
Pt	=	1.25	in	a'	=	0.6390	in^2		
de	=	0.72	in	a"	=	0.2618	ft^2/ft		
	=	0.06	ft	di	=	0.7820	in		
C"	=	0.25			=	0.0652	ft		

Jumlah : 1 buah

22. Akumulator (F-134)

Fungsi : Untuk menampung liquid sebagai hasil kondensasi kolom distilasi

Tipe : Tangki berbentuk silinder horizontal dengan tutup samping berbentu standar dish

Bahan konstruksi : Stainless Steel SA 240 Grade M Type 316

Allowable stress (f : 18750

Tipe pengelasan (E : 0.8

Faktor korosi (C) : 1/16 = 0.0625 in

Jumlah storage : 1 buah

Kondisi operasi :

Suhu = 73.03 ℃ = 163 °F = 346.179 K

Tekanan = 1 atm = 14.696 Psia

Waktu tinggal = 1 jam

Density = A x B $^{-(1-T/Tc)^n}$ T = 73.03 ℃ = 346.179 K

Komponen	A	B	n	Tc	$(1-T/Tc)^n$
H_2O	0.3471	0.27400	0.28571	647.13	0.8035
$C_4H_6O_2$	0.31843	0.25803	0.28270	524.00	0.7367

(Pers. *Carls and Yaws Density of Liquid*)[20]

Komponen	Massa (Kg/jam)	xi (massa)	ρ (Kg/m^3)	ρ (lb/ft^3)	*ρ*ixi
H_2O	13.2660	0.0011	982.2892	61.3224	0.0644
$C_4H_6O_2$	12612.9966	0.9989	863.8949	53.9312	53.8746
Total	**12626.2626**	**1.0000**	**1846.1841**	**115.2536**	**53.9390**

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{53.9390}{1.0000} = 53.9390 \ lb/ft^3 = 863.9916 \ kg/m^3$$

Perhitungan :

A. Menghitung volume tangki

Rate feed masul = 12626.2626 kg/jam

= 27835.8585 lb/jam

ρ campuran = 53.9390 lb/ft^3

$$\text{Volume liquid} = \frac{\text{Rate feed masuk}}{\rho v} \times \text{waktu tinggal}$$

$$= \frac{27835.8585}{53.9390} \times 1$$

$= 516.0618 \ ft^3$

Volume fluida = 80% volume total

$$\text{Volume total} = \frac{\text{Volume fluida}}{80\%}$$

$$= \frac{516.0618}{80\%}$$

$= 645.0773 \ ft^3$

B. Menentukan Dimensi Tangki

Asumsi Ls = 1.5 di

V total = V_{Ls} + V_{tutup}

$$645.0773 = \frac{\pi}{4} Di^2 \ Ls + 2 \left(0.0847 \ d^3 \right)$$

$645.0773 = 1.1775 \ di^3 + 0.1694 \ d^3$

$645.0773 = 1.3469 \ di^3$

$di^3 = 478.9348$

$di = 7.8239$ ft

$= 93.887271$ in

C. Menghitung Tinggi Liquida

$V_{fluida} = V_{LS} + 2 \ V_{tutup}$

$$516.062 = \frac{\pi}{4} Di^2 \ L_{Ls} + 2 \left(0.0847 \ Di^3 \right)$$

$$516.062 = \frac{\pi}{4} \left(7.8239 \right)^{\wedge 2} L_{Ls} + 2 \left(0.0847 \left(7.8239 \right)^{\wedge 3} \right)$$

$516.062 = 129.185 \ L_{Ls}$

$H = L_{Ls} = 3.9948$ ft

D. Menentukan Tekanan Design (Pi)

$$P_{hidrostatik} = \frac{\rho \ (H-1)}{144}$$

$$= \frac{53.9390 \times 3.9948 - 1}{144}$$

$= 1.1218$ psia

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

$= 14.6960 + 1.1218$

$= 15.8178$ Psia $= 1.1178$ Psig

E. Menghitung Tebal Silinder (ts)

Tebal silinder (ts) $= \dfrac{Pi.di}{2\,(f.E - 0.6Pi)} + C$

$= \dfrac{1.1178 \times 93.8873}{2\,(18750 \times 0.8 - 0.6 \times 1.1178)} + 0.063$

$= 0.0660 \times \dfrac{16}{16}$

$= \dfrac{1.05597}{16} \approx \dfrac{3}{16}$ in

do = di + 2 ts

= 93.8873 + 0.3750

= 94.2623 in

berdasarkan "Brownel and Young" tabel 5.7 hal 89[12], didapatkan :

do_s = 96 in

icr = 5 7/8

r = 96

ts = 5/16 in

di_{baru} = do_s - 2 ts

= 96 - 0.3750

= 95.6250 in

= 7.9688 ft

Tinggi silinder (Ls) = 1.5 × di

= 1.5 × 7.9688

= 11.9531 ft = 143.438 in

G. Menghitung Dimensi Tutup Samping

Bentuk tutup atas dan tutup bawah adalah standart dished, sehingga :

r = di

Tebal tutup (tha/thb) $= \dfrac{0.855 \times Pi.\ r}{(f.E - 0.1\ Pi)} + C$

$= \dfrac{0.855 \times 1.1178 \times 95.6250}{18750 \times 0.8 - 0.1 \times 1.1178} + 0.0625$

$= 0.0686 \times \dfrac{16}{16}$

$= \dfrac{1.0975}{16} \approx \dfrac{3}{16}$ in

Tinggi tutup (ha/hb) = 0.169 × di

= 0.169 × 95.6250

= 16.1606 in

= 1.3467 ft

H. Menghitung Tinggi Storage

Tinggi storage (H) = tinggi silinder + tinggi tutup atas + tinggi tutup bawah

= 143.438 + 16.1606 + 16.1606
= 175.7588 in
= 14.6466 ft

Spesifikasi Alat Akumulator (F-134) :

Fungsi	:	Untuk menampung liquid sebagai hasil kondensasi kolom distilasi
Jumlah tangki	:	1 buah
Bahan konstruksi	:	Stainless Steel SA 240 Grade M Type 316
Volume tangki	:	645.077 ft^3
Diameter dalam (di)	:	95.6250 in
Diameter luar (do)	:	96 in
Tebal silinder (ts)	:	5/16 in
Tinggi silinder (L)	:	143.438 in
Tinggi tangki (H)	:	175.759 in
Tebal tutup atas (tha)	:	3/16 in
Tinggi tutup atas (ha)	:	16.1606 in
Tebal tutup bawah (thb)	:	3/16 in
Tinggi tutup bawah (hb)	:	16.1606 in

23. Cooler (E-135)

Fungsi : Mendinginkan produk Vinil Asetat yang keluar dari akumulator
Tipe : *Shell and Tube*

Direncanakan :

- faktor kekotoran gabungan minimum (Rd) = 0.001 jam.ft^2.°F/Btu
- penurunan tekanan aliran maksimum (Δp) = 10 psi
- Δp maksimum aliran air pendingin = 2.5 psi
- Digunakan pipa ukuran 1 in OD, BWG 12, L = 20 ft, P_T = 1,25 in
- susunan segitiga (triangular)

Kondisi operasi :

- Massa bahan masuk (W) = 12626.2626 kg/jam
  = 27836.1111 lb/jam
- Suhu bahan masuk (T_1) = 73.03 °C = 163.45 °F = 346.18 K
- Suhu bahan keluar (T_2) = 33.00 °C = 91.40 °F = 306.15 K
- Kebutuhan air pendingin = 1791.1116 kg/jam
  = 3948.720 lb/jam
- Panas yang diserap (Q) = 224976.89 Kkal/jam
  = 892184.1 Btu/jam
- Suhu pendingin masuk (t_1 = 30 °C = 86 °F
- Suhu pendingin keluar (t_2 = 60 °C = 140 °F

Density = $A \times B^{-(1-T/Tc)^{n}}$ T = 73.03 °C = 346.179 K

Komponen	A	B	n	Tc	$(1-T/Tc)^n$
H_2O	0.3471	0.27400	0.28571	647.13	0.8034
$C_4H_6O_2$	0.31843	0.25803	0.28270	524.00	0.7365

(Pers. *Carls and Yaws Density of Liquid*)[20]

Komponen	Massa (Kg/jam)	xi (massa)	ρ (Kg/m^3)	ρ (lb/ft^3)	*ρ*ixi
H_2O	13.2660	0.0011	982.1030	61.3107	0.0644
$C_4H_6O_2$	12612.9966	0.9989	863.6318	53.9148	53.8582
Total	**12626.2626**	**1.0000**	**1845.7349**	**115.2255**	**53.9226**

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{53.9226}{1.0000} = 53.9226 \quad lb/ft^3 = 863.7286 \quad kg/m^3$$

$$\log 10\ \mu = A + B/T + CT + DT^2$$

Komponen	μ (*Centripoise*)			
	A	B	C	D
H_2O	-10.2158	1792.5000	0.0177	-0.0000126
$C_4H_6O_2$	-9.0671	1186.3000	0.0227	-0.0000232

(Yaws and Carl Viscosity of Liquid)[20]

Komponen	Massa (Kg/jam)	xi (massa)	μ (Cp)	μ (lb/ft.s)	xi.μi
H_2O	13.2660	0.0011	0.3847	0.0003	2.716E-07
$C_4H_6O_2$	12612.9966	0.9989	0.2650	0.0002	0.0002
Total	**12626.2626**	**1.0000**	**0.6497**	**0.0004**	**0.0002**

$$\mu \text{ campuran} = \frac{\sum xi.\mu i}{\sum xi}$$

$$= \frac{0.0002}{1.0000} = 0.0002 \quad lb/ft.s = 0.6415 \quad lb/ft.jam$$

Menentukan C_p

$$C_p = A + B\,T + C\,T^2 + DT^3$$

Komponen	A	B	C	D
H_2O	92.053	-0.03995	-0.00021	5.347.E-07
$C_4H_6O_2$	63.910	0.70656	-0.00228	3.179.E-06

(Yaws and Carl Heat Capacity of Liquid)[2

Komponen	Massa (Kg/jam)	xi (massa)	Cp (Joule/kg.	Cp (Btu/lb.^{o}F)	Cp .xi
H_2O	13.2660	0.0011	75.116	0.018	0.0000
$C_4H_6O_2$	12612.9966	0.9989	166.815	0.040	0.0398
Total	**12626.2626**	**1.0000**	**241.931**	**0.058**	**0.0398**

$$\text{Cp campuran} = \frac{\sum xi.Cp}{\sum xi}$$

$$= \frac{0.0398}{1.0000} = 0.0398 \quad \text{Btu/lb.°F}$$

$\log_{10} k_{liq} = A + B\,(1\text{-}T/C)^{\wedge(2/7)}$ (untuk $C_4H_6O_2$)

$k = A + B\,T + C\,T^2$ (untuk H_2O)

Komponen	**A**	**B**	**C**	**$(1\text{-}T/C)^{2/7}$**
H_2O	-0.2758	0.0046	-5.54E-06	-
$C_4H_6O_2$	-1.7519	1.1895	524.00	0.1133

(Yaws and Carl Thermal Conductivity of Liquid)

Komponen	Massa (Kg/jam)	xi (massa)	k (W/mK)	k (Btu/jam.ft^2	k.xi
H_2O	13.2660	0.0011	0.6570	0.3796	0.0004
$C_4H_6O_2$	12612.9966	0.9989	0.0241	0.0140	0.01394
Total	**12626.2626**	**1.0000**	**0.6811**	**0.3935**	**0.0143**

$$\text{k campuran} = \frac{\sum xi.k}{\sum xi}$$

$$= \frac{0.0143}{1.0000} = 0.0143 \quad \text{Btu/jam/ft}^2\text{.°F/ft}$$

Perhitungan :

A. Menghitung Δt

$\Delta_{t1} = T_1 - t_2 = 23$ °F

$\Delta_{t2} = T_2 - t_1 = 5$ °F

$$\Delta T_{LMTD} = \frac{\Delta_{t1} - \Delta_{t2}}{\ln \frac{\Delta_{t1}}{\Delta_{t2}}} = \frac{23 - 5}{\ln \frac{23}{5}} = \frac{18.1}{1.46858} \text{ °F}$$

$$= 12.2925 \text{ °F}$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{163 - 91}{140 - 86} = 1.3 \text{ °F}$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{140 - 86.0}{163 - 86.0} = 0.7 \text{ °F}$$

Dari Kern fig.21, hal.831[24] didapatkan harga Ft yang cocok adalah :

Ft = 0.94 (dipilih tipe HE : 1-2)

Jadi :

$$\Delta t = Ft \times \Delta T_{LMTD}$$

$$= 0.94 \times 12.2925$$

$$= 11.5550 \text{ °F}$$

B. Menghitung suhu kalorik (Tc dan tc)

$$Tc = \frac{(T_1 + T_2)}{2} = \frac{163.453 + 91.40}{2} = 127.426\ °F$$

$$tc = \frac{(t_1 + t_2)}{2} = \frac{86.0 + 140.0}{2} = 113.000\ °F$$

C. Trial UD

Dari tabel 8 "Kern" hal. 840[24], range $U_{D\ (light\ organics)}$ = 75 - 150 Btu/jam.ft^2.°F

Dicoba UD = 100 Btu/jam.ft^2.°F

$$A = \frac{Q}{UD \times \Delta t}$$

$$= \frac{892184.1103}{100 \times 11.5550}$$

$$= 772.1205\ ft^2$$

dengan

$d_{o\ tube}$ = 1.00

BWG = 12

L = 20 ft

Pt = 1.25 in

Dari Kern, tabel 10 hal 843[24], sehingga diperoleh harg 0.2618 ft^2

$$Nt = \frac{A}{a''\ L}$$

$$= \frac{772.1205}{0.2618 \times 20}$$

$$= 147.464\ buah$$

Dari Kern, tabel 9 Hal 842[24], diperoleh

IDs = 19 1/4 in

n = 2

Nt = 152 buah

$$U_D\ koreksi = \frac{Nt}{Nt\ standar} \times U_D\ trial$$

$$= \frac{147.4638}{152} \times 100$$

$$= 97.0157\ Btu/jam.ft^2.°F$$

Dari Kern, tabel 28, hal. 838[24], diperoleh :

de = 0.72 in

D. Trial ukuran SHE

Type HE 1-2	
Bagian *Shell*	Bagian *Tube*
ID_S = 19.25 in	do = 1.00 in BWG = 12
n' = 1	L = 20 ft Nt = 152

B	=	3.85	in	Susunan segitiga, n	=	2	
Pt	=	1.25	in	a'	=	0.4790	in^2
de	=	0.72	in	a"	=	0.2618	ft^2/ft
	=	0.06	ft	di	=	0.7820	in
C"	=	0.25			=	0.0652	ft

Evaluasi Perpindahan Panas

Bagian *Shell* (Bahan)

1. Menghitung N_{Re}

$$a_s = \frac{IDs \times C \times B}{n \times Pt \times 144}$$

$$= \frac{19.25 \times 1/4 \times 3\ 6/7}{1 \times 1.25 \times 144}$$

$$= 0.1029$$

$$G_s = \frac{W}{a_s}$$

$$= \frac{27836.1111}{0.1029}$$

$$= 270426.7156 \text{ lb/jam.ft}^2$$

$$\mu = 0.6497 \text{ cP}$$

$$= 0.6415 \text{ lb/ft.jam}$$

$$Nre_s = \frac{Gs \times de}{\mu \times 2.42}$$

$$= 25294.5544$$

2. Mencari faktor panas (J_H)

J_H = -

3. Menghitung harga koefisien film trial ho maksimal 300 $Btu/jam.ft^2\,{}^oF$

Trial ho = 150 $Btu/jam.ft^{2o}F$

$$tw = tc + \frac{ho}{ho + hio}\left(tc\text{-}Tc\right)$$

$$= 113 + \frac{150}{150 + 225} - \ -14$$

$$= 107.233\ {}^oF$$

$$\Delta t = tc\text{-}tw = 5.77\ {}^oF$$

Dari Kern, fig.15.11hal.474[24] didapatkan:

hs = 30 $Btu/ft^2.jam^0F$

hv = 62 $Btu/ft^2.jam^0F$

Bagian *Tube* (Air Pendingin)

1'. Menghitung N_{Re}

$$a_t = \frac{Nt \times a'}{n \times 144}$$

$$= \frac{152.00 \times 0.48}{2 \times 144}$$

$$= 0.2528$$

$$G_t = \frac{m}{at}$$

$$= \frac{3948.720}{0.2528}$$

$$= 15619.5954 \text{ lb/jam.ft}^2$$

(fig.14 "Kern", hal.823)[24]

$$\mu = 0.4500 \text{ Cp}$$

$$= 1.0886 \text{ ft.jam}$$

$$NRe_p = \frac{Gt \times di}{\mu \times 2.42}$$

$$= 935.0760$$

2'. Mencari faktor panas (J_H)

J_H = -

3'. Menghitung harga koefisien film untuk air

$$\rho = 61.98 \text{ lbm/ft}^3$$

$$v = \frac{Gt}{3600.\ \rho}$$

$$= \frac{15619.5954}{3600 \times 61.98}$$

$$= 0.07 \text{ ft/s}$$

("Kern", hal.835)[24]

faktor koreksi = 0.96

(fig.25 "Kern", hal.835)[24]

hi = 300 $Btu/jam.ft^2.{}^oF$

hi = 300 × 0.96

Dari App. B didapatkan:	$= 288.0$ Btu/jam.ft^2.°F
Q1 = 4331744.8 kkal/jam	hio = hi x (di/do)
= 17178556 btu/jam	$= 225.216$ Btu/jam.ft^2.°F
Q2 = 3515727.5 kkal/jam	
= 13942447 btu/jam	
$ho = \dfrac{Q}{\dfrac{Q1}{hs} + \dfrac{Q2}{hv}}$	
$= \dfrac{31121003.53}{\dfrac{17,178,556}{30} + \dfrac{13,942,447}{62}}$	
= 390.2336	

E. Mencari tahanan panas pipa bersih

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

$$Uc = \frac{390.2336 \times 225}{390.2336 + 225}$$

$= 142.8011$ Btu/jam.ft^2.°F

F. Mencari dirty faktor (faktor kekotoran) pipa terpakai

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

$$= \frac{142.801 - 97.016}{142.801 \times 97.016}$$

$= 0.00330$

Karena harga Rd hitung > Rd tetapan, maka rancangan HE memenuhi

Evaluasi Δp	
Bagian *Shell* (Bahan)	Bagian *Tube* (Air Pendingin)
1. Menghitung N_{re} dan friksi	1. Menghitung N_{re} dan friksi
Nre_s = 25294.5544	Nre_t = 935.0760
Kern fig.29, hal.839 [24]	*Kern fig.26, hal.836* [24]
f = 0.0018	*f* = 0.00025
	sg = 1
2. Mencari ΔPs	2. Mencari ΔP karena panjang pipa
ρ = 53.923 lb/ft^3	$\Delta P_1 = \dfrac{1}{2} \cdot \dfrac{f.Gt^2.L.n}{5{,}22 \times 10^{10}.di.sg.\phi}$
BM = 104	
$S = \dfrac{144 \times \rho \times BM}{1545 \times (460+T) \times 62.5}$	$= \dfrac{0.00025 \times 15619.6^2 \times 20 \times 2}{2 \times 5{,}22.10^{10} \times 0.065 \times 1 \times 1}$
= 0.0134139	

N+1 = (12 x L)/B

= 2.31

$\varphi s = \left[\frac{\mu}{\mu_w}\right]^{0,14}$

= 0.93

$\Delta P_1 = \frac{f \times Gs^2 \times ID \times (N+1)}{2 \times 5{,}22.10^{10} \times de \times sg \times \varphi}$

ΔP_1 = 0.99944 psi

ΔP_1 < ΔP_{allow}

0.9994 < 10 psi

(memenuhi syarat)

= 0.00038 psi

ΔP karena tube passes

Dari Kern,fig. 27 hal.837[24],diperoleh:

$\left[\frac{v^2}{2gc}\right]\frac{\rho}{144}$ = 0.065 , sehingga

$\Delta Pn = \frac{4n}{sg}\left[\frac{v^2}{2gc}\right]\frac{\rho}{144}$

$= \frac{4 \times 2}{1} \times 0.065$

= 0.052 psi

sehingga,

ΔPt total = 0.00038 + 0.052

= 0.05 psi < 2.5 psi

desain memenuhi

Spesifikasi Alat Cooler (E-135) :

Fungsi	:	Menurunkan suhu produk dari 73°C menjadi 33°C
Tipe	:	*Shell and Tube*
Bahan konstruksi	:	Stainless Steel SA 167 Grade 3 Type 304
Media pemanas	:	Air pendingi 30 °C
Kapasitas	:	12626.2626 kg/jam
Rate pendingin	:	1791.1116 kg/jam
Dimensi	:	Bagian *Shell* / Bagian *Tube*

Bagian *Shell*				Bagian *Tube*						
ID_S	=	19.25	in	do =	1.00	in	BWG	=	12
n'	=	1		L =	20.00	ft	Nt	=	152
B	=	3.85	in	Susunan segitiga, n				=	2
Pt	=	1.25	in	a' =	0.6390	in^2			
de	=	0.72	in	a" =	0.2618	ft^2/ft			
	=	0.06	ft	di =	0.7820	in			
C"	=	0.25		=	0.0652	ft			

Jumlah : 1 buah

24. Tangki Penampung Produk (F-136)

Fungsi	:	Untuk menampung Vinil Asetat sementara
Tipe	:	Silinder tegak dengan tutup atas dan bawah standart dishec
Bahan konstruksi	:	Stainless Steel SA 240 Grade M Type 316
Allowable stress (f	:	18750
Tipe pengelasan (E	:	0.8
Faktor korosi (C)	:	1/16 = 0.0625 in
Jumlah storage	:	1 buah

Kondisi operasi :

Suhu = 33.00 °C = 91.4 °F = 306.15 K

Tekanan = 1 atm = 14.696 Psia

Waktu tinggal = 1 jam

Density = A x B $^{-(1-T/Tc)^n}$ T = 33.00 °C = 306.15 K

Komponen	A	B	n	Tc	$(1-T/Tc)^n$
H_2O	0.3471	0.27400	0.28571	647.13	0.8327
$C_4H_6O_2$	0.31843	0.25803	0.28270	524.00	0.7803

(Pers. *Carls and Yaws Density of Liquid*)[20]

Komponen	Massa (Kg/jam)	xi (massa)	ρ (Kg/m^3)	ρ (lb/ft^3)	*ρ*ixi
H_2O	13.2660	0.0011	1020.1157	63.6838	0.0669
$C_4H_6O_2$	12612.9966	0.9989	916.3623	57.2067	57.1466
Total	**12626.2626**	**1.0000**	**1936.4780**	**120.8904**	**57.2135**

$$\rho \text{ campuran} = \frac{\sum xi.\rho i}{\sum xi}$$

$$= \frac{57.2135}{1.0000} = 57.2135 \text{ lb/ft}^3 = 916.4419 \text{ kg/m}^3$$

Perhitungan :

A. Menghitung volume tangki

Rate feed masul = 12626.2626 kg/jam

= 27835.8585 lb/jam

ρ campuran = 57.2135 lb/ft^3

$$\text{Volume liquid} = \frac{\text{Rate feed masuk}}{\rho v} \times \text{waktu tinggal}$$

$$= \frac{27835.8585}{57.2135} \times 1$$

$$= 486.5263 \text{ ft}^3$$

Volume fluida = 80% volume total

$$\text{Volume total} = \frac{\text{Volume fluida}}{80\%}$$

$$= \frac{486.5263}{80\%}$$

$$= 608.1579 \text{ ft}^3$$

B. Menentukan Dimensi Tangki

Asumsi Ls = 1.5 di

V total = V_{Ls} + V_{tutup}

$$608.1579 = \frac{\pi}{4} Di^2 Ls + 0.0847 d^3$$

$$608.1579 = 1.1775 di^3 + 0.0847 d^3$$

$$608.1579 = 1.2622 di^3$$

$$di^3 = 481.8237$$

$d_i = 7.8396$ ft
$= 94.075667$ in

C. Menghitung Tinggi Liquida

$$\text{Tinggi liquid } (H_L) = \frac{V_{liquida}}{\frac{\pi}{4} \times d_i^2}$$

$$= \frac{486.5263 \text{ ft}^3}{0.7850 \times 61.4599}$$

$= 10.0843$ ft
$= 121.0113$ in

D. Menentukan Tekanan Design (Pi)

$$P_{hidrostatik} = \frac{\rho\,(H-1)}{144}$$

$$= \frac{57.2135 \times 10.0843 - 1}{144}$$

$= 3.6093$ psia

$P_{design} = P_{operasi} + P_{hidrostatik}$
$= 14.6960 + 3.6093$
$= 18.3053$ Psia $= 3.6053$ Psig

E. Menghitung Tebal Silinder (ts)

$$\text{Tebal silinder (ts)} = \frac{Pi.di}{2\,(f.E - 0.6Pi)} + C$$

$$= \frac{3.6053 \times 7.8396}{2\left(18750 \times 0.8 - 0.6 \times 3.6053\right)} + 0.063$$

$$= 0.0634 \times \frac{16}{16}$$

$$= \frac{1.01508}{16} \approx \frac{3}{16} \text{ in}$$

do = di + 2 ts
= 94.0757 + 0.3750
= 94.4507 in

berdasarkan "Brownel and Young" tabel 5.7 hal 89[12], didapatkan :

do_s = 96 in
icr = 5 7/8
r = 96
ts = 5/16 in
$di_{\ baru}$ = do_s - 2 ts
= 96 - 0.3750
= 95.6250 in
= 7.9688 ft

F. Menghitung Tinggi Silinder

Tinggi silinder (Ls) = 1.5 × di
= 1.5 × 7.9688
= 11.9531 ft = 143.438 in

G. Menghitung Dimensi Tutup Atas dan Bawah (tha/thb)

Bentuk tutup atas dan bawah adalah standart dished, sehingga :

r = di

$$\text{Tebal tutup (tha/thb)} = \frac{0.855 \times Pi.\ r}{(f.E - 0.1\ Pi)} + C$$

$$= \frac{0.855 \times 3.6053 \times 95.6250}{18750 \times 0.8 - 0.1 \times 3.6053} + 0.0625$$

$$= 0.0822 \times \frac{16}{16}$$

$$= \frac{1.3144}{16} \approx \frac{3}{16} \text{ in}$$

Tinggi tutup (ha/hb) = 0.169 × di
= 0.169 × 95.6250
= 16.1606 in
= 1.3467 ft

H. Menghitung Tinggi Storage

Tinggi storage (H) = tinggi silinder + tinggi tutup atas + tinggi tutup bawah
= 143.438 + 16.1606 + 16.1606
= 175.7588 in
= 14.6466 ft

Spesifikasi Alat Tangki Penampung Produk (F-136) :

Fungsi	:	Untuk menampung Vinil Asetat sementara
Jumlah tangki	:	1 buah
Bahan konstruksi	:	Stainless Steel SA 240 Grade M Type 316
Volume tangki	:	608.158 ft^3
Diameter dalam (di)	:	95.6250 in
Diameter luar (do)	:	96 in
Tebal silinder (ts)	:	5/16 in
Tinggi silinder (L)	:	143.438 in
Tinggi tangki (H)	:	175.759 in
Tebal tutup atas (tha)	:	3/16 in
Tinggi tutup atas (ha)	:	16.1606 in
Tebal tutup bawah (thb)	:	3/16 in
Tinggi tutup bawah (hb)	:	16.1606 in

25. ***Packing* Produk Vinil Asetat (P-137)**

Fungsi : Untuk pengemasan produk Vinil Asetat dari tangki penyimpanan

Direncanakan:

Kapasitas bahan = 12626.2626 kg/jam = 27840.9090 lb/jam

Kapasitas mesin = 27840.9090 lb/jam

ρ $C_4H_6O_2$ = 57.1466 lb/ft^3

Volume mesin = $\frac{\text{Kapasitas mesin}}{\text{Densitas bahan}}$

= $\frac{27840.9090 \text{ lb/jam}}{57.1466 \text{ lb/ft}^3}$

= 487.1844 ft^3/jam

= 13795.5020 L/jam

Asumsi : dalam 1 jam dapat mengemas 1 drum dengan uk 100 L

Kebutuhan drum = $\frac{13795.5020 \text{ L/jam}}{100.0000 \text{ L/jam}}$

= 138 drum/jam

Spesifikasi Alat *Packing* Produk Vinil Asetat (P-137) :

Bahan konstruksi	:	*Stainless Steel*
Kapasitas mesin	:	27840.9090 lb/jam
Volume mesin	:	487.1844 ft^3/jam
Jumlah	:	1

26. Gudang Vinil Asetat (F-138)

Fungsi : Untuk penyimpanan produk utama Vinil Asetat

Tipe : Bangunan gedung berbahan beton

Direncanakan :

Waktu tinggal (q) = 14 hari = 336 jam

Volume gudang = 80% storage

Jumlah gudang = 1 buah

Kondisi operasi :

Suhu operasi = 33.00 °C

Tekanan operasi = 1 atm

ρ bahan = 57.1466 lb/ft^3

Kapasitas bahan masuk = 12626.2626 Kg/jam = 27840.9090 lb/jam

Perhitungan :

A. Menghitung volume gudang

Volume gudang = $\frac{m}{\rho} \times q$

= $\frac{27840.9090}{57.1466} \times 336$

= 163693.9441 ft^3

= 4632.5386 m^3

Volume ruang kosong = 20% volume gudang

Volume gudang = volume gudang + 20% volume gudang

= 4632.5386 + 926.5077

= 5559.0463 m^3

B. Menentukan ukuran gudang

Ditetapkan :

Panjang = 4 × lebar bangunan

Tinggi I beam = 15 m

Maka :

$V = P \times l \times t$

$5559.0463\ m^3 = 4 \times l \times l \times 15$

$5559.0463\ m^3 = 60\ l^2$

l = 9.6255 m

P = 38.5021 m

t = 12 m

Spesifikasi Gudang Vinil Asetat (F-138) :

Bahan	:	Beton
Ukuran	:	Panjang = 39 m
		Lebar = 10 m
		Tinggi = 12 m
Kapasitas	:	5559.0463 m^3
Jumlah	:	1 buah