APPENDIKS C
SPESIFIKASI ALAT

1. Storage Dimetil Formamide (F-111)

Fungsi : Untuk menyimpan Dimetil Formamide (C_3H_7NO) selama 1 jam

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

Dasar perancangan

Suhu operasi = 20 °C

Tekanan operasi = 1 atm = 14,7 psia

ρ campuran = 944 kg/m^3 = 58,9337 lb/ft^3

Rate aliran = 75465,9349 kg/jam = 166402,3864 lb/jam

Bahan kontruksi = Carbon steel SA 240 Grade M type 316

Allowable stress = 18750 (Brownell & Young, hal 342)

Tipe pengelasan = Double welded butt joint

E = 0,8 (Brownell & Young, hal 254)

Faktor korosi = 1/16

Waktu tinggal = 1 hari = 24 jam

Jumlah tangki = 5 buah

a. Menghitung volume tangki

Rate volumetrik = $\frac{\text{rate}}{\rho}$ = $\frac{166402,3864 \text{ lb/jam}}{58,9337 \text{ lb/ft}^3}$

= 2823,5524 ft^3/jam

Volume liquid = Q × waktu tinggal

= 2823,5524 ft^3/jam × 24 jam

= 67765,257 ft^3

Direncanakan 1 buah storage DMF

Asumsi = Vrk = 20% × Vtotal

Vtotal = $\frac{\text{Vliquid}}{0,8} = \frac{67765,2566}{0,8}$ ft^3

= 84706,5707 ft^3

b. Menghitung dimensi tangki

Asumsi Ls = 1,5 di (Ulrich, hal 248)

Vtotal = Vshell + Vtutup atas

84706,571 = ∏/4.di^2.Ls + 0,0847 di^3

84706,571 = 0,7850 di^2 . 1,5 di + 0,0847 di^3

84706,571 = 1,1775 di^3 + 0,0847 di^3

84706,571 = 1,2622 di^3

di^3 = 67110,26 ft^3

di = 34,4304 ft

di = 413,1648 in

c. Menghitung liquid dalam tangki

Vliquid = $\pi/4 \times di^2 \times Lls$

67765 = 0,7850 × 353,8857 × Lls

67765 = 277,8003 × Lls

Lls = 243,9352 ft

Lls = 20,3279 in

d. Menghitung tekanan desain

P_{desain} = Poperasi + Phidrostatik

$$P_{hidrostatik} = \frac{\varrho\ (Lls - 1)}{144}$$

$$P_{hidrostatik} = \frac{59,2301 \times (37,0469 - 1)}{144}$$

$P_{hidrostatik}$ = 14,8268 lb/ft²

P_{desain} = 14,7 + 14,8268

P_{desain} = 29,5268 psia

= 14,8268 psig

e. Menghitung tebal tangki

$$ts = \frac{Pi \times di}{2\ (f \times E - 0,6 \times 13,2121)} + C$$

$$ts = \frac{14,8268 \times 413,1648}{18750 \times 0,8 - 0,6 \times 13,21} + 1/16$$

$$ts = \frac{6125,9184}{29984,145} + 0,0625$$

= 0,2668 in

$$= \frac{2,1492}{16} \text{ in} \approx \frac{3}{16} \text{ in}$$

menghitung do

do = di + 2ts

= 413,1648 + 2 (3/16)

= 413,1648 + 0,375

= 413,5398 in

Berdasarkan tabel 5.7 Brownell & Young, hal 90 diperoleh:

do baru = 228 in

di baru = do - 2ts

= 228 - 2(3/16)

= 228 - 0,375

= 227,625 in

= 18,969 ft

f. Menghitung tinggi silinder

Ls = 1,5 di
= 1,5 × 413,1648
= 619,7472 in
= 51,6456 ft

g. Menghitung tebal tutup atas

r = 0,5 di
= 0,5 × 413,1648
= 206,5824 in

$$t_{ha} = \frac{0,885 \times Pi \times r}{(f \times E - 0,1\ Pi)} + C$$

$$= \frac{0,885 \times 14,8268 \times 113,8125}{(18750 \times 0,8 - 0,1 \times 13,2121)} + 1/16$$

$$= \frac{1493,4171}{14998,679} + 0,0625$$

= 0,1621 in

$$= \frac{2,0252}{16} \text{ in} \approx \frac{3}{16} \text{ in}$$

h. Menghitung tinggi tutup atas

ha = 0,169 × di
= 0,169 × 413,1648
= 69,8249 in
= 5,8187 ft

i. Menghitung tinggi tangki

Tinggi tangki = Tinggi silinder + tinggi tutup atas
= Ls + ha
= 619,7472 + 69,8249
= 689,5721 in
= 57,4643 ft
= 17,5266 m

Spesifikasi alat:

Nama	=	Tangki penyimpanan Dimetil Formamide (DMF)
Fungsi	=	Untuk menyimpan Dimetil Formamide selama 1 jam
Tipe	=	Silinder tegak dengan tutup atas berbentuk standard dish dan tutup bawah berbentuk silinder
Bahan kontruksi	=	Carbon steel SA 240 Grade M type 316
Volume tangki	=	84706,5707 ft^3
Tebal tangki (ts)	=	3/16 in
Diameter dalam (di)	=	227,6250 in
Diameter luar (do)	=	228 in

Tinggi silinder (Ls) = 619,7472 in
Tebal tutup atas (t ha) = 3/16 in
Tinggi tutup atas (ha) = 69,8249 in
Tinggi tangki = 689,5721 in
Jumlah = 5 buah

2. Pompa (L-113)

Fungsi = Mengalirkan solvent DMF menuju menara absorber
Tipe = Pompa sentrifugal
Dasar perancangan
Bahan konstruksi = Carbon steel
Suhu operasi = 30 °C
Tekanan operasi = 1 atm = 14,7 psia
Rate aliran = 75465,9349 kg/jam = 166402,39 lb/det
ρ campuran = 1898,4 kg/m^3 = 118,5133 lb/ft^3
Viskositas (μ) = 0,8172 cP = 1,9776 lb/ft.jam

a. Menghitung rate volumetrik

$$\text{Rate volumetrik (Q)} = \frac{\text{rate bahan masuk}}{\text{p bahan masuk}}$$

$$= \frac{166402,3864 \text{ lb/det}}{118,5133 \text{ lb/ft}^3}$$

$$= 1404,0824 \text{ ft}^3\text{/det} = 5054696,5 \text{ ft}^3\text{/jam}$$

$$Di_{optimum} = 3,9\, Q^{0,45} \times p^{0,13}$$ (Pers.15 "Peter and Timmerhaus",

$$= 3,9 \times 0,398^{0,45} \times 118,5133^{0,13}$$
$$= 3,9 \times 0,6606 \times 1,8603$$
$$= 4,7929 \text{ in}$$
$$= 0,3994 \text{ ft}$$

Standarisasi = 5 in sch 40 (Geankoplis, App A.5, hal 996)
Sehingga diperoleh:
OD = 5,563 in = 0,4636 ft
ID = 5,047 in = 0,4206 ft
A = 0,139 ft² = 20,02 in²

b. Menentukan kecepatan aliran fluida

$$\text{Kecepatan aliran (v)} = \frac{Q}{A}$$

$$= \frac{1400,4875 \text{ ft}^3\text{/jam}}{0,139 \text{ ft}^2}$$

$$= 10075,450 \text{ ft/jam}$$
$$= 2,7987 \text{ ft/det}$$

c. Menentukan bilangan Reynold

$$Nre = \frac{D \times v \times p}{}$$

$$= \frac{0{,}4206 \times 10075{,}45 \times 118{,}51327}{1{,}9776}$$

$$= \frac{502227{,}7080}{1{,}9776}$$

= 253958,1857 (aliran turbulen)

Dari fig 2.10-3 Geankoplis, hal 88 didapatkan

ε = 0,000046 m

ε/D = 0,0004

f = 0,0045

d. Menentukan panjang pipa

Asumsi :

- Panjang pipa lurus = 70 ft = 21,34 m
- elbow 90° = 3 buah
- Le/D = 35 (Geankoplis, tabel 2.10-1, hal 93)
- L elbow = 35 ID
  = 35 × 3 × 5,047
  = 529,94 in
  = 44,161 ft

- Gate valve = 1 buah
- Le/D = 225 (Geankoplis, tabel 2.10-1, hal 93)
- L elbow = 225 ID
  = 225 × 1 × 5,047
  = 1135,6 in
  = 94,631 ft

Panjang pipa total = Pipa lurus + elbow 90° + gate valve
= 70 + 44,161 + 94,63125
= 208,79 ft
= 2505,5 in

e. Menentukan Friction Loss

1. Friksi pada pipa lurus

$$F_f = 4f \frac{\Delta L}{D} \times \frac{v^2}{2gc}$$

$$F_f = 4 \times 0{,}0045 \frac{208{,}79}{0{,}4206} \times \frac{7{,}8329}{2 \times 32{,}174}$$

F_f = 1,0877 lb.ft/lbm

2. Kontraksi

$K_c = 0{,}55 \times \left(1 - \frac{A_1}{A_2}\right)^2$

$= 0{,}55 \times (1-0)^2$

$= 0{,}55$

$h_c = K_c \frac{v^2}{2gc}$

$= 0{,}55 \times \frac{7{,}8329}{64{,}348}$

$= 0{,}0669$ lbf.ft/lbm

3. Ekspansi

$K_{ex} = \left(1 - \frac{A_1}{A_2}\right)^2$

$= (1-0)^2$

$= 1$

$h_{ex} = Kex \frac{v^2}{2gc}$

$= 1 \frac{7{,}8329}{2 \times 32{,}174}$

$= 0{,}1217$ lbf.ft/lbm

4. Elbow 90 °C, 3 buah

$K_f = 0{,}75$ (Geankoplis, tabel 2.10-1, hal 93)

$h_f = 3Kf \frac{v^2}{2gc}$

$h_f = 2{,}25 \frac{7{,}8329}{64{,}348}$

$h_f = 0{,}2739$ lbf.ft/lbm

5. Gate valve half open, 1 buah

$K_f = 4{,}5$ (Geankoplis, tabel 2.10-1, hal 93)

$h_f = Kf \frac{v^2}{2gc}$

$h_f = 4{,}5 \frac{7{,}8329}{64{,}348}$

$h_f = 0{,}5478$ lbf.ft/lbm

Sehingga:

$\Sigma F = F_f + h_c + h_{ex} + h_f$

$= 1,0877 + 0,0669 + 0,1217 + 0,5478$

$= 1,8241$ lbf.ft/lbm

f. Menentukan kesetimbangan mekanik

Direncanakan :

$\Delta z = 50$ ft

$\Delta p = 0$ atm $= 0$ lb/ft²

$\Delta v = 2,799$ ft/s

$\alpha = 1$

Sehingga kesetimbangan mekanik:

$$\frac{\Delta v^2}{2\alpha\, gc} + \frac{g.\Delta z}{gc} + \frac{\Delta p}{p} + \Sigma F = -W_s$$

(Geankoplis, tabel 2.7-28, hal 64)

$$\frac{7,8329}{2 \times 32,174} + \frac{32,174 \times 50}{32,174} + \frac{0}{59,2301} + 1,8241 = -W_s$$

$0,1217 + 50 + 0 + 1,8241 = -W_s$

$51,9459 = -W_s$

Efisiensi pompa (η) = 83% (Petter & Timmerhause, Fig.1437, hal 52

$$Wp = \frac{-W_s}{\eta}$$

$$Wp = \frac{51,9459}{0,83}$$

$Wp = 62,5854$ ft.lbf/lbm

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

$= 1400,4870 \times 51,9459$

$= 72749,513$ lbm/jam

$= 20,2082$ lbm/det

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

$= 62,5854 \times 20,2082 \times \frac{1 \text{ Hp}}{550 \text{ ft.lbf/s}}$

$= 2,2995$ Hp

Broke horsepower $= \frac{\text{Pump horsepower}}{\eta}$

$= \frac{2,2995}{0,83}$

$= 2,7705$ Hp

Efisiensi motor (η) = 84% (Petter & Timmerhause, Fig.1438, hal 52

Daya motor $= \frac{\text{Pump horsepower}}{\eta}$

$$= \frac{2,2995}{0,84}$$

$$= 2,7375 \text{ Hp} \approx 3 \text{ Hp}$$

Spesifikasi Alat

Tipe = Pompa sentrifugal
Bahan = Carbon s ft^3/jam
Daya = 3 Hp
Rate = 0,8300 ft^3/jam
L pipa = 2505,5100 in
Jumlah = 1 buah

3. Storage Butane (F-112)

Fungsi : Untuk menyimpan n-Butane (C_4H_{10})
Tipe : Silinder horizontal dengan tutup atas dan bawah hemispherical
Dasar perancangan
Suhu operasi = 51 °C
Tekanan operasi = 5 atm = 73,5 psia
p campuran = 540,8 kg/m^3 = 33,7610 lb/ft^3
Rate aliran = 46150,2403 kg/jam = 101761,28 lb/jam
Bahan konstruksi = Carbon steel SA 240 Grade M type 316
Allowable stress = 18750 (Brownell & Young, hal 342)
Tipe pengelasan = Double welded butt joint
E = 1 (Brownell & Young, hal 254)
Faktor korosi = 1/16
Waktu tinggal = 2 hari = 48 jam
Jumlah tangki = 6 buah

a. Menghitung volume tangki

Rate volumetril = $\frac{101761,28}{33,761048}$

= 3014,1623 ft^3/jam

Volume liquid = $\frac{3014,1623 \times 48}{6}$

= 24113,299 ft^3

= 682,80614 m^3

Volume gas maksimum untuk cylindrical tank adalah 1600 m^3
(Ullrich, tabel 4-27, hal.248)

b. Menghitung dimensi tangki

Asumsi V_{rk} = 0,2 V_T

V_T = V_{liq} + 0 V_T

$24113,299 = V_{liq} + 0,2\ V_T$

$0,8\ V_T = 24113,299\ ft^3$

$V_T = 30141,623\ ft^3$

$L/D = 2$ (Ullrich, tabel 4-27, hal.249)

$Vtotal = Vshell + Vtutup\ atas + Vtutup\ bawah$

$30141,623 = \pi/4.di^2.Ls + 2/3\pi.0,5di^3$

$30141,623 = 0,7850\ di^2.\ 2\ di + 1,0467\ di^3$

$30141,623 = 1,5700\ di^3 + 1,0467\ di^3$

$30141,623 = 2,6167\ di^3$

$di^3 = 11518,945\ ft^3$

$di = 26,6070\ ft$

$di = 319,2840\ in$

c. Menghitung liquid dalam tangki

$Vliquid = \pi/4.di2.L_{ls}$

$24113,299 = 0,7850 \times 322,1378 \times L_{ls}$

$24113,299 = 252,8782\ L_{ls}$

$L_{ls} = 95,3554\ ft$

$L_{ls} = 1144,2648\ in$

d. Menghitung tekanan desain

$P_{desain} = Poperasi + Phidrostatik$

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

$$P_{hidrostatik} = \frac{33,7610 \times (47,6984 - 1)}{144}$$

$P_{hidrostatik} = 10,8735\ lb/ft^2$

$P_{desain} = 73,5 + 10,8735$

$P_{desain} = 84,3735\ psia$

$= 69,6735\ psig$

e. Menghitung tebal tangki

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

$$t_s = \frac{69,6735 \times 319,284}{(18750 \times 0,8 - 0,6 \times 69,1} + 1/16$$

$$t_s = \frac{22245,622}{29917,056} + 0,0625$$

$= 0,8061\ in$

$$= \frac{9,0300}{16}\ in \approx \frac{5}{8}\ in$$

menghitung do

do = di + 2ts

= 319,2840 + 2 (3/16)

= 319,2840 + 0,3750

= 319,6590 in

berdasarkan tabel 5.7 Brownell & Young, hal 90 diperoleh:

do baru = 228 in

di baru = do - 2ts

= 228 - 2(3/16)

= 228 - 0,375

= 227,63 in

= 18,969 ft

f. Menghitung tinggi silinder

Ls = 2 di

= 2,0 × 228

= 455,2500 in

= 37,9375 ft

g. Menghitung tebal tutup atas

r = 0,5 di Asumsi: $t_{ha} = t_{hb}$

= 0,5 × 228

= 113,8125 in

$$t\,ha = \frac{Pi \times di}{(4f \times E - 0{,}4\,Pi)} + C$$

$$= \frac{69{,}6735 \times 227{,}6250}{(4 \times 18750 - 0{,}4 \times 69{,}6735)} + 1/16$$

$$= \frac{15859{,}422}{74972{,}131} + 0{,}0625$$

= 0,2740 in

$$= \frac{5{,}2172}{16}\ \text{in} \approx \frac{3}{8}\ \text{in}$$

h. Menghitung tinggi tutup atas

Tutup atas = tutup bawah Asumsi: $h_a = h_b$

Direncanakan sf = 2 in

Lh_a, Lh_b = Sf + id + ts

= 115,200 in

= 9,6000 ft

i. Menghitung tinggi tangki

Tinggi tangki = Tinggi silinder + tinggi tutup atas

= $L_s + h_a + h_b$

= 455,2500 + 230,3750
= 685,6250 in
= 57,1354 ft

Spesifikasi alat:

Nama	=	Tangki penyimpanan n-Butane
Fungsi	=	Untuk menyimpan n-Butane (C_4H_{10}) selama 1 hari
Tipe	=	Silinder horizontal dengan tutup atas dan bawah hemispherical
Bahan konstruksi	=	Carbon steel SA 240 Grade M type 316
Volume tangki	=	30141,623 ft^3
Tebal tangki (ts)	=	5/8 in
Diameter dalam (di)	=	227,625 in
Diameter luar (do)	=	319,659 in
Panjang silinder (Ls)	=	455,25 in
Tebal tutup (tha)	=	0,2740 in
Tebal tutup (thb)	=	0,2740 in
Tinggi tutup (ha)	=	115,2 in
Tinggi tutup (hb)	=	115,2 in
Panjang tangki	=	685,6250 in
Jumlah	=	6 buah

4. Storage Fuel (F-116)

Fungsi : Untuk menampung fuel oil sebagai bahan bakar
Tipe : Tangki silinder dengan tutup atas standar dished dan tutup bawah berbentuk datar

Dasar perancangan

Suhu operasi	=	30 °C
Tekanan operasi	=	1 atm = 14,7 psia
ρ fuel oil	=	54,0002 lb/ft^3
Rate aliran	=	40979,1412 kg/jam = 90359,006 lb/jam
Bahan konstruksi	=	Carbon steel SA 240 Grade M type 316
Allowable stress	=	18750 (Brownell & Young, hal 342)
Tipe pengelasan	=	Double welded butt joint
E	=	0,8 (Brownell & Young, hal 254)
Faktor korosi	=	1/16
Waktu tinggal	=	1 hari = 24 jam
Jumlah tangki	=	2 buah

a. Menghitung volume tangki

Rate volumetril $= \frac{\text{rate}}{\rho} = \frac{90359,006 \text{ lb/jam}}{54,0002 \text{ lb/ft}^3}$

$= 1673,3087 \text{ ft}^3/\text{jam}$

Volume liquid = Q × waktu tinggal

$= 1673{,}3087\ ft^3/jam \times 24\ jam : 2$

$= 80318{,}819\ ft^3$

Direncanakan 1 buah storage DMF

Asumsi = Vrk = 20% × Vtangki

$$Vtangki = \frac{Vliquid}{0{,}8} = \frac{80318{,}819\ ft^3}{0{,}8}$$

$= 100398{,}52\ ft^3$

b. Menghitung dimensi tangki

Asumsi Ls = 1,5 di

Vtotal = Vshell + Vtutup atas

$100398{,}52 = \pi/4.di^2.Ls + 0{,}0847 di^3$

$100398{,}52 = 0{,}7850\ di^2.\ 2\ di + 0{,}0847\ di^3$

$100398{,}52 = 1{,}1775\ di^3 + 0{,}0847\ di^3$

$100398{,}52 = 1{,}2622\ di^3$

$di^3 = 79542\ ft^3$

$di = 43{,}006\ ft$

$di = 516{,}08\ in$

c. Menghitung liquid dalam tangki

$Vliquid = \pi/4.di2.L_{ls}$

$80318{,}819 = 0{,}7850 \times 276{,}9080 \times L_{ls}$

$80318{,}819 = 217{,}3728\ L_{ls}$

$L_{ls} = 369{,}4981\ ft$

$L_{ls} = 4433{,}9766\ in$

d. Menghitung tekanan desain

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

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

$$P_{hidrostatik} = \frac{54{,}0002 \times (24{,}4205 - 1)}{144}$$

$P_{hidrostatik} = 8{,}7827\ b/ft^2$

$P_{desain} = 14{,}7 + 8{,}7827$

$P_{desain} = 23{,}4827\ psia$

$= 8{,}7827\ psig$

e. Menghitung tebal tangki

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

$$t = \frac{8{,}7827 \times 516{,}0756}{} + 1/16$$

t_s = $\frac{}{(18750 \times 0,8 - 0,6 \times 8,945}$

$t_s = \frac{4532,5475}{29989,265} + 0,06$

$= 0,2136$ in

$= \frac{1,8152}{16}$ in $\approx \frac{3}{16}$ in

menghitung do

do = di + 2ts

= 516,0756 + 2 (3/16)

= 516,0756 + 0,3750

= 516,4506 in

berdasarkan tabel 5.7 Brownell & Young, hal 90 diperoleh:

do baru = 204 in

di baru = do - 2ts

= 204 - 2(3/16)

= 204 - 0,375

= 203,625 in

= 16,9688 ft

f. Menghitung tinggi silinder

Ls = 1,5 di

= 1,5 × 203,6250

= 305,4375 in

= 25,4531 ft

g. Menghitung tebal tutup atas

r = 0,5 di

= 0,5 × 203,6250

= 101,8125 in

t ha = $\frac{0,885 \times Pi \times di}{(f \times E - 0,1 Pi)} + C$

= $\frac{0,8850 \times 7,65 \times 101,8125}{(18750 \times 0,8 - 0,1 \times 7,62)} + 1/16$

= $\frac{689,2961}{14999,238} + 0,06$

= 0,1085 in

= $\frac{1,7355}{16}$ in $\approx \frac{3}{16}$ in

h. Menghitung tinggi tutup atas

ha = 0,169 × di

= 0,169 × 203,6250

= 34,4126 in

= 2,8677 ft

i. Menghitung tinggi tangki

Tinggi tangki = Tinggi silinder + tinggi tutup atas
= L_s + h_a
= 305,4375 + 34,4126
= 339,8501 in
= 28,3208 ft

Spesifikasi alat:

Nama	=	Storage fuel oil
Fungsi	=	Untuk menampung fuel oil sebagai bahan bakar
Tipe	=	Silinder tegak dengan tutup atas berbentuk *standar dishe* dan bawah berbentuk datar
Bahan konstruksi	=	Carbon steel SA 240 Grade M type 316
Volume tangki	=	100398,52 ft^3
Tebal tangki (ts)	=	3/16 in
Diameter dalam (di)	=	203,625 in
Diameter luar (do)	=	516,4506 in
Panjang silinder (Ls)	=	305,4375 in
Tebal tutup atas (tha)	=	3/16 in
Tinggi tutup atas (ha)	=	34,4126 in
Tinggi tangki	=	339,8501 in
Jumlah	=	2 buah

5. Pompa Fuel Oil (L-117)

Fungsi	=	Mengalirkan fuel oil menuju fire preheater
Tipe	=	Pompa sentrifugal
Dasar perancangan		
Bahan konstruksi	=	Carbon steel
Suhu operasi	=	30 °C
Tekanan operasi	=	1 atm = 14,7 psia
Rate aliran	=	40979,141 kg/jam = 90359,006 lb/jam
p campuran	=	54,0002 lb/ft³
Viskositas (μ)	=	65,372 lb/ft.jam

a. Menghitung rate volumetrik

Rate volumetrik (Q) = $\frac{\text{rate bahan masuk}}{\rho \text{ bahan masuk}}$

= $\frac{90359,006 \text{ lb/det}}{54,0002 \text{ lb/ft}^3}$

= 1673,3087 ft³/det = 0,4648 ft³/jam

$Di_{optimum}$ = $3,9\ Q^{0,45} \times p^{0,13}$ (Pers.15 "Peter and Timmerhaus",

= 3,9 × $0,8^{0,45}$ × $)002^{0,13}$

= 3,9 × 0,9045 × 1,6796

= 5,9247 in

Standarisasi = 6 in sch 40 (Geankoplis, App A.5, hal 996)

Sehingga diperoleh:

OD = 6,625 in = 0,5521 ft

ID = 6,065 in = 0,5054 ft

A = 0,2006 ft = 28,886 in^2

b. Menentukan kecepatan aliran fluida

Kecepatan aliran (v) = $\frac{Q}{A}$

$= \frac{1673,3087 \ ft^3/jam}{0,2006 \ ft^2}$

= 8341,5191 ft/jam

= 2,3171 ft/det

c. Menentukan bilangan Reynold

$Nre = \frac{D \times v \times p}{\mu}$

$= \frac{0,5054 \times 8341,52 \times 54,0002}{65,372}$

$= \frac{227661,75}{65,372}$

= 3482,5576 (aliran transisi)

Dari fig 2.10-3 Geankoplis, hal 88 didapatkan

ε = 0,000046 m

ε/D = 0,0006

f = 0,008

d. Menentukan panjang pipa

Asumsi :

- Panjang pipa lurus = 40 ft
- elbow 90° = 1 buah
- Le/D = 35 (Geankoplis, tabel 2.10-1, hal 99)
- L elbow = 35 ID
  = 35 × 1 × 2
  = 86,4150 in
  = 7,2013 ft

- Gate valve = 1 buah
- Le/D = 225 (Geankoplis, tabel 2.10-1, hal 99)
- L elbow = 225 ID
  = 225 × 1 × 2
  = 555,53 in

= 46,294 ft

Panjang pipa total = Pipa lurus + elbow 90° + gate valve
= 40 + 7,2013 + 46,2938
= 93,495 ft
= 1121,9 in

e. Menentukan Friction Loss

1. Friksi pada pipa lurus

$$F_f = 4f \frac{\Delta L}{D} \times \frac{v^2}{2gc}$$

$$F_f = 4 \times 0{,}008 \frac{93{,}495}{54} \times \frac{10{,}5122}{2 \times 32{,}174}$$

F_f = 0,0091 lb.ft/lbm

2. Kontraksi

$$K_c = 0{,}55 \times \left(1 - \frac{A_1}{A_2}\right)^2$$

$= 0{,}55 \times (1-0)^2$
$= 0{,}55$

$$h_c = K_c \frac{v^2}{2gc}$$

$$= 1 \times \frac{10{,}512}{32{,}174}$$

= 0,1797 lbf.ft/lbm

3. Ekspansi

$$K_{ex} = \left(1 - \frac{A_1}{A_2}\right)^2$$

$= (1-0)^2$
$= 1$

$$h_{ex} = Kex \frac{v^2}{2gc}$$

$$= 1 \frac{10{,}5122}{2 \times 32{,}174}$$

= 0,1634 lbf.ft/lbm

4. Elbow 90 °C, 3 buah

K_f = 1 (Geankoplis, tabel 2.10-1, hal 99)

$$h_f = 3Kf \frac{v^2}{}$$

$$h_f = 2{,}25 \frac{\overline{2gc}}{64{,}348} \quad 10{,}5122$$

$h_f = 0{,}3676$ lbf.ft/lbm

5. Gate valve half open, 1 buah

$K_f = 4{,}5$ (Geankoplis, tabel 2.10-1, hal 99)

$$h_f = Kf \frac{v^2}{2gc}$$

$$h_f = 4{,}5 \frac{10{,}5122}{64{,}3480}$$

$h_f = 0{,}7351$ lbf.ft/lbm

Sehingga:

$\Sigma F = F_f + h_c + h_{ex} + h_f$

$= 0{,}0091 + 0{,}1797 + 0{,}1634 + 0{,}7351$

$= 1{,}0873$ lbf.ft/lbm

f. Menentukan kesetimbangan mekanik

Direncanakan :

$\Delta z = 10$ ft

$\Delta p = 0$ atm $= 0$ lb/ft²

$\Delta v = 3{,}242$ ft/s

$\alpha = 0{,}5$

Sehingga kesetimbangan mekanik:

$$\frac{\Delta v^2}{2\alpha\, gc} + \frac{g.\Delta z}{gc} + \frac{\Delta p}{p} + \Sigma F = -W_s$$

(Geankoplis, pers 2.7-28, hal 68)

$$\frac{10{,}5122}{2 \times 32{,}174} + \frac{32{,}174 \times 10}{32{,}174} + \frac{0}{54{,}0002} + 1{,}0873 = -W_s$$

$0{,}1634 + 10 + 0 + 1{,}0873 = -W_s$

$11{,}2506 = -W_s$

Efisiensi pompa (η) = 84% (Petter & Timmerhause, Fig.1437, hal 52

$$Wp = \frac{-W_s}{\eta}$$

$$Wp = \frac{11{,}2506}{1}$$

$Wp = 13{,}3936$ ft.lbf/lbm

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

$= 8341{,}5191 \times 54$

$= 450442{,}03$ lbm/jam

= 125,12279 lbm/det

Pump horsepower = Wp × m

= 13,3936 × 125,12

= 1675,8445 ft.lbf/det

= 3,0470 Hp

$B_{hp} = \frac{Whp}{\eta}$

$= \frac{3,0470}{0,84}$

= 3,6274 Hp

Efisiensi motor (η) = 85% (Petter & Timmerhause, Fig.1438, hal 52

Daya motor $= \frac{B_{hp}}{\eta}$

$= \frac{3,6274}{0,85}$

= 4,2675 hp

Spesifikasi Alat

Fungsi = Mengalirkan fuel menuju fire preheater
Tipe = Pompa sentrifugal
Bahan = Carbon steel
Daya = 5 hp
Rate = 8341,5191 ft^3/jam
L pipa = 1121,9400 in
Jumlah = 1 buah

6. Filter Udara (H-118)

Fungsi : Untuk menyaring debu yang tersuspensi dalam udara
Tipe : Dry Filter
Bahan : Cellulosa pulp
Dasar Perhitungan:

Udara yang dibutuhkan = Fire Preheater O_2

= 2354533,948 kg/jam

= 5203520,025 lb/jam

Suhu udara masuk = 30°C

ρ udara pada 30°C = 1,1676 kg/m^3

= 0,0729 lb/ft^3

Rate volume udara $= \frac{5203520,025 \text{ lb/jam}}{0,0729 \text{ lb/ft}^3}$

= 71387784,67 ft^3/jam

= 1185037,226 ft^3/menit

Kadar debu dalam udara pada lingkungan industri (0,1 - 2 gram/1000ft^3)

$$= \frac{1 \text{ gram}}{1000 \text{ ft}^3}$$

Kadar debu di udara panas $= \frac{1 \text{ gram}}{1000 \text{ ft}^3} \times 1185037{,}226 \text{ ft}^3\text{/menit}$

$= 1185{,}0372$ gr/menit

$= 2{,}6070819$ lb/menit

Ukuran dry filter $= 24 \times 24 \times 11\ 1/2$ in

Kapasitas 1 filter $= 2000$ ft^3/menit

Filter yang dibutuhkan $= \frac{1185037{,}226}{2000}$

$= 93{,}0179$ buah ≈ 93 buah

Spesifikasi

Fungsi = Menyaring debu yang tersuspensi dalam udara proses

Tipe = air filter

Kapasitas = 1185037,226 ft^3/menit

Jumlah filte = 93 buah

Bahan = Cellolose pulp

7. Expansion Valve (K-114)

Fungsi : Menurunkan tekanan n-butane dari 5 atm menjadi 1 atm

Tipe : Globe valve

Dasar perancangan

Bahan konstruksi = Carbon steel

Rate aliran = 46150,24 kg/jam = 101761,28 lb/det

ρ campuran = 33,53 lb/ft^3

Viskositas (μ) = 0,1311 cP = 0,3173 lb/ft.jam

Kondisi operasi:

Tekanan keluar (P_1) = 5 atm = 73,5 psia

Tekanan keluar (P_2) = 1 atm = 14,7 psia

Suhu masuk (T_1) = 51°C

Suhu keluar (T_2) = 30°C

a. Menghitung rate volumetrik

Rate volumetrik (Q) $= \frac{\text{rate bahan masuk}}{\text{p bahan masuk}}$

$= \frac{101761{,}28 \text{ lb/det}}{46150{,}24 \text{ lb/ft}^3}$

$= 2{,}205$ ft^3/det $= 7938{,}0000$ ft^3/jam

$Di_{optimum}$ = $3,9Q^{0,45} \times \rho^{0,13}$ (Pers.15 "Petter and Timmerhaus", ha

= $3,90 \times 0,4160^{0,45} \times 33,53^{0,13}$

= $3,90 \times 0,6739 \times 1,5787$

= 4,1492 in

= 0,3458 ft

Standarisasi = 5 in sch 40 (Geankoplis, App A.5, hal.892)

Sehingga diperoleh:

OD = 5,563 in = 0,4636 ft

ID = 5,047 in = 0,421 ft = 0,0779 m

A = 0,139 ft^2 = 20,02 in^2

b. Menentukan kecepatan aliran fluida

Kecepatan aliran (V) = $\frac{Q}{A}$

= $\frac{7938}{0,139}$ ft^3/jam

= 57107,914 ft/jam

= 11,4216 ft/det

c. Menentukan bilangan Reynold

NR_e = $\frac{D \times v \times p}{\mu}$

= $\frac{0,421 \times 57107,91367 \times 33,53}{0,3173}$

= 2540632,63 (aliran turbulen)

Dari fig 2.10-3 Geankoplis, hal 94 didapatkan

ε = 0,000046 m

ε/D = 0,0006

f = 0,0045

d.Menentukan Fraction Loss

Friction loss karena valve

Globe valve half open, 1 buah

K^f = 9,5

$h_f = K_f \frac{v^2}{2}$

$h_f = 9,5 \frac{9,1411}{2}$

h_f = 43,4202 lb.ft/lbm

e. Menentukan Pressure Head

Pressure head (-F) $= \frac{\Delta P}{\rho}$

$= \frac{14,7 - 73,5 \text{ lb/ft}^2}{33,53 \text{ lb/ft}^3}$

$= \frac{58,8 \text{ lb/ft}^2}{33,53 \text{ lb/ft}^3}$

$= 1,7537 \text{ ft}$

Spesifikasi alat:

Fungsi = Menurunkan tekanan n-butane dari 5 atm menjadi 1 atm
Tipe = Globe valve
Bahan = Carbon steel
Pressure head = 1,7537 ft
Jumlah = 1 buah
P_1 = 5 atm
P_2 = 1 atm

8. Blower (G-119)

Fungsi : Menghembuskan udara menuju fire preheater
Tipe : Sentrifugal blower
Dasar perancangan
Bahan kosntruksi = Carbon steel
Suhu operasi = 30°C
ρ udara = 0,0724 lb/ft^3
Rate udara masuk = 2354533,9 kg/jam = 1441,8457 lb/det
Untuk 4 blower = 360,4614 lb/det

a. Menghitung rate volumetrik

Rate volumetrik (Q) $= \frac{\text{rate udara}}{\rho \text{ udara masuk}}$

$= \frac{14,1255 \text{ lb/det}}{0,0724 \text{ lb/ft}^3}$

$= 195,1036 \text{ ft}^3\text{/det} = 6894,1198 \text{ ft}^3\text{/menit}$

b. Menentukan daya blower

$P_1 - P_2$ = ΔP dalam blower = 0,5 lb/ft^2

$Hp = \frac{144 \times Q \times (P_1 - P_2)}{33000}$

$= \frac{144 \times 6894,1198 \times 0,5}{33000}$

$= 15,0417 \text{ Hp}$

Didapatkan (Peter & Timmerhause,Fig. 1438, hal 52

η_{motor} = 86%

Daya = $\frac{15,0417}{0,86}$

= 17,4904 ≈ 18 Hp

Spesifikasi alat:

Fungsi = Menghembuskan udara menuju fire preheater
Tipe = Centrifugal blower
Bahan = Carbon steel
Daya motor = 18 Hp
Jumlah = 4 buah

9. Fire Preheater (Q-115)

Fungsi : Memanaskan n-butane dari suhu 30°C menjadi 600°C
Tipe : Box type furnace with tube
Dasar perancangan
Bahan konstruksi = Dinding brick dengan tube HAS SA 167 Grade 11 tipe 3
Rate feed = 46150,2 kg/jam
= 43704,278 btu/jam
Q feed = 356095,25 kkal/jam
= 1412273,8 btu/jam
T keluar = 600°C = 1112 F
T masuk = 30°C = 86 F
Diasumsi suhu rata-rata dinding tube = 750°C = 1382 F

LMTD = $\frac{1296 - 135}{\ln \frac{1296}{135}}$

= $\frac{1161}{2,2617}$

= 513,3307 RR

Luas perpindahan panas

$Q = \sigma \times A' \times \varepsilon \times (t_2^4 - t_1^4)$

Maka, $A' = \frac{Q}{\sigma \times \varepsilon \times (t_2^4 - t_1^4)}$

= $\frac{1412273,779}{14523,85829}$

= 12,8836 ft^2

Direncanakan
Dimensi furnace = 45 × 30 × 15
Ukuran tube = 5 in
Baris = 1 row

Jarak antar pusat = 8 in

Luas dinding keseluruhan = 7000 ft^2

Menentukan beban panas total bagian radiasi

$Q = Q_F + Q_A + Q_R + Q_S + -Q_W - Q_G$

$Q_F = \frac{132535,5648 \text{ btu/jam}}{0,75}$

$= 176714,0864 \text{ btu/jam}$

Dianggap flue gas keluar pada suh = 700 °C = 1292 F = 973,15 K

Q_G = 207424,51 lb/jam × 2,654 Btu/lb/F × 1232 F

= 678221728 btu/jam

Q_A = 805320,1 lb/jam × 0,246 × 1232

= 244069973 btu/jam

Q_R = 0 (tidak ada rceycle)

Q_S = 0 (tidak ada rceycle)

Asumsi Q loss 5%

Q_W = 0,05 × 176714,0864 btu/jam

= 8835,70432 btu/jam

Maka Q

= 176714,0864 + 244069973,3 - 8835,70432 - 678221728,2

= 175943934,5 btu/jam

Menentukan luas permukaan perpindahan panas

Rasio dimensi = 45 : 30 : 15 ft = 3 : 2 : 1 ft

L = 0,667 × 27,2568

= 18,1803 ft

Seksi tube

Acp = 0,417 × 45 ft

= 18,765 ft^2

Rasio tengah/OD = 2

Dari buku Kern Fig. 19.11 hal 688 didapatkan nilai αAcp = 0,98

αAcp = 0,98 - 18,765

= 17,785 ft^2

Surface/tube = 58,8750

Jumlah tube = $\frac{175943934,5}{14000 \times 58,9}$

= 213,4413 ≈ 214 tube

Spesifikasi alat

Nama = Fire Preheater

Fungsi = Memanaskan feed sampai suhu 600°C

Tipe = Box furnace dengan tube
Dimensi furnace
Panjang = 45 ft
Lebar = 30 ft
Tinggi = 15 ft
Jumlah tube = 214 tube
Jumlah = 1

10. Reaktor (R-110)

Reaktor (R-110) tugas alat utama dirancang oleh
NIM.

11. Quencher Tower

Fungsi : Untuk mendinginkan gas dari furnace sampai suhu 30°C
Tipe : Tangko silinder tegak dengan tutup atas dan bawah standar dished dilengkapi dengan pipa tegak lurus (spray)
Bahan : HAS SA 167 grade 11 type 316
Dasar perhitungan:
Massa bahan = 46150,2403 kg/jam = 101743,7428 lb/jam
Massa pendingin = 286,0544 kg/jam = 630,6413 lb/jam
Suhu air masuk = 25°C
Suhu bahan masuk = 600°C = 873 K
Tekanan operasi = 1 atm = 14,7 psia
ρ air = 972 kg/m3
= 60,7 lb/ft^3
Perhitungan:
Kecepatan volumetrik air (C = $\frac{m}{\rho}$

$$= \frac{286,054 \text{ kg/jam}}{972,200 \text{ kg/m}^3}$$

= 0,2942 m^3/jam
= 1,29448 gpm

Beban liquid = 1-4 gpm/ft^2 (Mc. Cabe, hal 601)
Diambil beban liquid = 4 gpm/ft^2
Luas menara (A) = $\frac{1,29448 \text{ gpm}}{4 \text{ gpm/ft}^2}$
= 0,32362 ft^2

Diameter menara (d) = $\sqrt{\frac{A \times 4}{\pi}}$

$$= \sqrt{\frac{0{,}32362 \times 4}{\pi}}$$

$$= 1{,}1377 \text{ ft}$$
$$= 13{,}652 \text{ in}$$

Air pendingin

$t_1 = 27°C = 80{,}6$ F

$t_2 = 60°C = 140$ F

Bahan masuk

$T_1 = 600°C = 1112$ F

$T_2 = 30°C = 86$ F

$\Delta t_1 = 1112 - 140 = 972$ F

$\Delta t_2 = 86 - 80{,}6 = 5{,}4$ F

$$\Delta T_{LMTD} = \frac{\Delta t_1 - \Delta t_2}{\text{In}\frac{\Delta t_1}{\Delta t_2}}$$

$$= \frac{972 - 5{,}4}{4{,}6821}$$

$$= 206{,}4458 \text{ F}$$

$\Delta t = t_2 - t_1$

$= 140 - 80{,}6$

$= 59{,}4$ F

Number of diffusion unit $= \frac{haV}{L(Le)C} = \int \frac{dt}{LMTD}$ (Kern, Eq.17.89, hal 619)

$$= \frac{59{,}4}{206{,}4458}$$

$$= 0{,}2877$$

Diketahui:

Cp gas $= 0{,}4746$ BTU/lb.F

Le $= 0{,}89$

Maka:

$$nd = \frac{L \times av}{L \times Cp}$$

$$= \frac{0{,}2877}{}$$

$$= \frac{}{0,89 \times 0,4746}$$

$= 0,6812$

nd $= Kx \times a \times v/L$

Dimana: $Kx \times a$ = koefisien overall of mass transfer (lb/jam.ft^2)

$Kx \times a = C_1 \times G^{\Upsilon}$ (Kern, hal 600)

$$L = \frac{\text{Rate air}}{A}$$

$$= \frac{630,64 \text{ lb/jam}}{56,499 \text{ ft}^2}$$

$= 11,162$ lb/jam.ft^2

$$G = \frac{\text{Rate bahan}}{A}$$

$$= \frac{101743,74 \text{ lb/jam}}{56,4991 \text{ ft}^2}$$

$= 1800,8029$ lb/jam.ft^2

Dipilih packing dengan ukuran 1 Rashcing ring
didapat:

$\Upsilon = 0,5$

$C_1 = 40,2$

Maka:

$Kx \times a = C_1 \times G^{\Upsilon}$

$= 40,2 \times 29,9639$

$= 1204,5488$

Tinggi menara

$\frac{lw}{d} = 4$ (Ulrich, Tabel. 4.10, hal 133)

$lw = 4 \times 8$

$= 33,9348$ ft

$= 475,09$ in

$= 12,067$ m

Bahan konstruksi = Hihg alloy steel SA 240 grade M Type 316

F = 5300

Pengelasan = Double welded butt joint

E = 0,8

Faktor korosi = 0,063

L/D = 4 - 5 (Ulrich, Tabel. 4.10, hal 133)

L = 4×8

= 33,936 ft

= 407,23 in

Densitas gas (p) = 0,386 lb/ft^3

Menghitung tekanan desain

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

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

$$P_{hidrostatik} = \frac{0{,}3863 \times (33{,}8 - 1)}{144}$$

$P_{hidrostatik} = 0{,}0880\ lb/ft^2$

$P_{desain} = 14{,}7 + 0{,}0880$

$P_{desain} = 14{,}7880$ psia

$= 0{,}0880$ psig

Menghitung tebal tangki

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

$$t_s = \frac{0{,}0879906 \times 13{,}6524}{2(5300 \times 0{,}8 - 0{,}6 \times 0{,}088)} + 0{,}0625$$

$$t_s = \frac{1{,}2013}{8479{,}9904} + 0{,}0625$$

$= 0{,}0626$ in

$$= \frac{1{,}0198}{16}\ \text{in} \approx \frac{3}{16}\ \text{in}$$

Menghitung d_o

$d_o = di + 2ts$

$= 118{,}7719 + 2(3/16)$

$= 118{,}7719 + 0{,}375$

$= 119{,}1469$ in

Berdasarkan tabel 5.7 Brownell & Young, hal 90 diperoleh:

d_o baru = 120 in

d_i baru $= d_o - 2ts$

$= 120 - 2(3/16)$

$= 120 - 0{,}375$

$= 119{,}6250$ in

$= 9{,}9688$ ft

Menghitung tebal tutup atas

$r = 0{,}5\ d_i$

$= 59{,}8125$ in

$$t_{ha} = \frac{0{,}885 \times Pi \times r}{} + C$$

$$= \frac{0,885 \times 0,088 \times 59,8125}{(5300 \times 0,8 - 0,1 \times 0,071)} + 0,0625$$

$$= \frac{4,6582}{4239,9290} + 0,0625$$

$$= 0,0636 \text{ in}$$

$$= \frac{1,0176}{16} \text{ in} \approx \frac{3}{16} \text{ in}$$

Menghitung tinggi tutup atas

Karena tutup atas dan bawah standard dished maka ha = hb

ha = tha + b + sf

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

$$= \frac{59,8125}{2}$$

$$= 29,9063 \text{ in}$$

AB = a - icr

= 29,9063 - 4

= 26,3173 in

BC = r - icr

= 59,8125 - 4

= 56,2235 in

B = r - AC

$$= 59,8125 - \sqrt{26,3173^2 - 56,2235^2}$$

= 59,8125 - 49,66

= 10,1525

Maka:

ha = 0,1875 + 10,1525 + 2

= 11,8400 in

hb = 11,8400 in

Spesifikasi alat:

Nama	=	Quencher tower
Fungsi	=	Untuk mendingingkan gas dari furnace sampai 30°C
Tipe	=	Tangki silindef tegak dengan tutup atas dan bawah standar dished dilengkapi dengan pipa tegak lurus (spray)
Konstruksi	=	HAS SA 167 grade 11 type 316
Dimensi		
do	=	120 in
di	=	119,6250 in
ts	=	3/16 in
icr	=	3,5890 in
tha	=	3/16 in

thb = 3/16 in
ha = 11,8400 in
hb = 11,8400 in

12. Absorber (D-120)

Absorber (D-120) tugas alat utama dirancang oleh Inaz Auliannisa NIM. 2214901

13. Pompa (L-122)

Fungsi : Mengalirkan output dari absorber menuju stripping
Tipe : Pompa sentrifugal
Dasar perancangan
Bahan konstruksi = Carbon steel
Suhu operasi = 30°C
Tekanan operasi = 1 atm = 14,7 psia
Rate aliran = 90761,3538 kg/jam = 55,5795 lb/det
ρ campuran = 793,5 kg/m^3 = 49,54 lb/ft^3
Viskositas (μ) = 0,303 cP = 0,7333 lb/ft.jam

a. Menghitung rate volumetrik

$$\text{Rate volumetrik (Q)} = \frac{\text{rate bahan masuk}}{\rho \text{ bahan masuk}} = \frac{55,5795}{49,54} = 1,1219 \text{ ft}^3\text{/det} = 4038,8831 \text{ ft}^3\text{/jam}$$

$Di_{optimum} = 3,9\ Q^{0,45} \times \rho^{0,13}$ (Pers. 15 "Peter and Timmerhaus", ha

$= 3,9 \times 1,1219^{0,45} \times 1,890^{0,13}$
$= 3,9 \times 1,0531 \times 1,0863$
$= 4,4616$ in
$= 0,3718$ ft

Standarisasi = 6 in sch 40 (Ludwig, hal 858)
Sehingga diperoleh:
OD = 6,625 in = 0,5521 ft
ID = 6,0625 in = 0,5052 ft = 0,1540 m
A = 0,2006 ft^2 = 28,89 in^2

b. Menentukan kecepatan aliran fluida

$$\text{Kecepatan aliran (v)} = \frac{Q}{A} = \frac{4038,8831 \text{ ft}^3\text{/jam}}{0,2006 \text{ ft}^2} = 20134,013 \text{ ft/jam} = 5,5928 \text{ ft/det}$$

c. Menentukan bilangan Reynold

$$NR_e = \frac{D \times V \times \rho}{\mu}$$

$$= \frac{0{,}5052 \times 20134{,}013 \times 49{,}5400}{0{,}7333}$$

$$= \frac{503906{,}19}{0{,}7333}$$

$$= 687176{,}04 \text{ (aliran turbulen)}$$

Dari fig 2.10-3 Geankoplis, hal 88 didapatkan:

$\varepsilon = 0{,}000046$ m

$\varepsilon/D = 0{,}0003$

$f = 0{,}005$

d. Menentukan panjang pipa

Asumsi :

- Panjang pipa lurus = 40 ft
- elbow 90° = 2 buah
- Le/D = 35 (Geankoplis, tabel 2.10-1, hal 99)
- L elbow = 35 ID
  = 35 × 2 × 6,0630
  = 424,4100 in
  = 35,3675 ft

- Gate valve = 1 buah
- Le/D = 225 (Geankoplis, tabel 2.10-1, hal 99)
- L elbow = 225 ID
  = 225 × 1 × 6,0630
  = 1364,1750 in
  = 113,6813 ft
- Panjang pipa total = Pipa lurus + elbow 90° + gate valve
  = 40 + 35,368 + 113,6813
  = 189,0488 in
  = 2268,5850 ft

e. Menentukan Friction Loss

1. Friksi pada pipa lurus

$$Ff = 4 \frac{\Delta L}{D} \times \frac{v^2}{2gc}$$

$$Ff = 4 \times 0{,}0050 \frac{189{,}0488}{49{,}5400} \times \frac{31{,}2792}{2 \times 32{,}1740}$$

$Ff = 0{,}0371$ lbf.ft/lbm

2. Kontraksi

$$K_c = 0{,}55 \times \left(1 - \frac{A_1}{A_2}\right)^2$$

$$= 0{,}55 \times (1-0)^2$$

$$= 0{,}55$$

$$h_c = K_c \frac{v^2}{2gc}$$

$$= 0{,}55 \times \frac{31{,}2792}{32{,}1740}$$

$$= 0{,}5347 \text{ lbf.ft/lbm}$$

3. Ekspansi

$$K_{ex} = \left(1 - \frac{A_1}{A_2}\right)^2$$

$$= (1-0)^2$$

$$= 1$$

$$h_{ex} = Kex \frac{v^2}{2gc}$$

$$= 1 \frac{31{,}2792}{2 \times 32{,}174}$$

$$= 0{,}4861 \text{ lbf.ft/lbm}$$

4. Elbow 90 °C, 3 buah

$K_f = 0{,}75$ (Geankoplis, tabel 2.10-1, hal 99)

$$h_f = 3Kf \frac{v^2}{2gc}$$

$$h_f = 2{,}25 \frac{31{,}2792}{64{,}3480}$$

$$h_f = 1{,}0937 \text{ lbf.ft/lbm}$$

5. Gate valve half open, 1 buah

$K_f = 5$ (Geankoplis, tabel 2.10-1, hal 99)

$$h_f = Kf \frac{v^2}{2gc}$$

$$h_f = 5 \frac{31{,}2792}{64{,}3480}$$

$$h_f = 2{,}1874 \text{ lbf.ft/lbm}$$

Sehingga:

$\Sigma F = F_f + h_c + h_{ex} + h_f$

$= 0{,}0371 + 0{,}5347 + 0{,}4861 + 2{,}1874$

$= 3{,}2453$ lbf.ft/lbm

f. Menentukan kesetimbangan mekanik

Direncanakan :

$\Delta z = 10$ ft

$\Delta p = 4{,}35$ atm $= 64$ lb/ft²

$\Delta v = 2{,}780$ ft/s

$\alpha = 1$

Sehingga kesetimbangan mekanik:

$$\frac{\Delta v^2}{2\alpha\, gc} + \frac{g.\Delta z}{gc} + \frac{\Delta p}{p} + \Sigma F = -W_s$$

(Geankoplis, pers 2.7-28, hal 68)

$$\frac{31{,}2792}{2 \times 32{,}174} + \frac{32{,}174 \times 10}{32{,}174} + \frac{64}{54{,}0002} + 3{,}2453 = -W_s$$

$0{,}4861 + 10 + 1 + 3{,}2453 = -W_s$

$14{,}9166 = -W_s$

Efisiensi pompa (η) = 82% (Petter & Timmerhause, Fig.1437, hal 52

$$Wp = \frac{-W_s}{\eta}$$

$$Wp = \frac{14{,}9166}{0{,}82}$$

$Wp = 18{,}1910$ ft.lbf/lbm

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

$= 4038{,}88 \times 49{,}54$

$= 27{,}6226$ lbm/det

Pump horsepower $= Wp \times m$

$= 18{,}1910 \times 27{,}6226$

$= 502{,}4820$ ft.lbf/det

$= 0{,}7696$ hp

$$B_{hp} = \frac{Whp}{\eta}$$

$$= \frac{0{,}7696}{0{,}82}$$

$= 0{,}9385$ hp

Efisiensi motor (η) = 81% (Petter & Timmerhause, Fig.1438, hal 52

Daya motor $= \frac{B_{hp}}{\eta}$

$= \frac{0{,}9385}{}$

$$= \frac{0,81}{1,1587} \text{ Hp} \approx 2 \text{ Hp}$$

Spesifikasi alat

Fungsi	=	Mengalirkan output absorber menuju stripper
Tipe	=	Pompa sentrifugal
Bahan	=	Carbon steel
Daya	=	2 Hp
Rate	=	4038,8831 ft^3/jam
Panjang pipa	=	2268,5850
Jumlah	=	1 buah

14. Heater (E-123)

Fungsi	:	Untuk menaikkan suhu feed menjadi 110 °C
Tipe	:	Shell and tube
Bahan kosntruksi	:	Carbon steel SA-240 grade M type 316

Dasar perancangan

T feed masuk (t1)	=	27 °C
T feed keluar (t2)	=	110 °C
T steam masuk (T1)	=	800 °C
T steam keluar (T2)	=	800 °C
Foulinng factor (Rd)	=	0,003 jam.ft^2.F/btu
ΔP shell	=	10 psi
ΔP tube	=	2 psi
Arah aliran	=	Counter current

Perhitungan

a. Neraca massa dan panas

Massa liquid masuk	=	90761,354	kg/jam
	=	200128,79	lb/jam
Massa steam masuk	=		kg/jam
	=		lb/jam
Q steam masuk	=		kkal/jam
	=		btu/jam
Q bahan masuk	=		btu/jam

b. Menghitung ΔT (LMTD)

T feed masuk (t_1)	=	27	°C	=	80,6	°F
T feed keluar (t_2)	=	110	°C	=	230	°F
T steam masuk (T_1)	=	800	°C	=	1472	°F
T steam keluar (T_2)	=	800	°C	=	1472	°F

$\Delta t_1 = T_1 - t_2 = 1472 - 230 = 1242$ °F

$\Delta t_2 = T_2 - t_1 = 1472 - 80,6 = 1391$ °F

Maka,

$$\Delta T_{LMTD} = \frac{\Delta t_1 - \Delta t_2}{\ln \frac{\Delta t_1}{\Delta t_2}}$$

$$= \frac{1242 - 1391}{\ln \frac{1242}{1391}}$$

$$= 1315 \ °F$$

Untuk F_T diperoleh dari Kern hal 828

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{1472 - 1472}{230 - 80,6} = 0,0000$$

$$S = \frac{t_2 - t_1}{T_1 - T_2} = \frac{230 - 80,6}{1472 - 80,6} = 0,1074$$

Maka diperoleh nilai F_T sebesar = 0,9 dengan tipe HE 1-2

Karena pemanas menggunakan steam dan nilai R = 0

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

$\Delta t = 1315 \ °F$

c. Menghitung suhu caloric (Tc dan tc)

$Tc = 0,5 (T_1 + T_2) = 1 (1472 + 1472) = 1472 \ °F$

$tc = 0,5 (t_1 + t_2) = 1 (80,6 + 230) = 155 \ °F$

d. Trial U_D

Dari Kern hal. 840, tabel 8 didapat U_D = 50 - 100 btu/jam.ft^2.°F

Trial U_D = 75 btu/jam.ft^2.°F

Maka,

$$A = \frac{Q}{U_D - \Delta t} \quad \text{(Trial)}$$

$$= \frac{0}{50 \times 1315}$$

$$= 0 \ ft^2 \quad \text{(Digunakan HE tupe shell and tube)}$$

e. Trial ukuran

Shell side			Tube side		
ID_S	=	17,25 in	Nt, L	=	203 , 3,5 ft
Baffle space	=	half circle	ID	=	0,62 in
Passes	=	1	OD	=	0,75 in
a"	=	0,196 ft^2/ft	BWG	=	16
			Pitch	=	Tri, 1 in
			Passes	=	1

f. Evaluasi Perpindahan Panas

Shell side (feed)	Tube side (steam)
a_s = (area of shell - area of tube)	a'_t = 0,302 in
= 1 / 369,2160 ft^2 / in^2	$a_t = \frac{Nt \times a'_t}{144 \times n}$
$G_s = \frac{m}{a_s}$	= 0,426 ft^2
= 200128,79 lb/jam.ft^2	$G_t = \frac{m}{a_t}$
μ = 0,397 cP	= 21765,914
= 0,9607 lb/ft.jam	μ = 0,03 lb/ft.jam
D_c = 0,1004 ft	D_e = 0,62 in
1,2049 in	= 0,0517 ft
$Re_s = \frac{D_e \times G_s}{\mu}$	$Re_t = \frac{D_e \times G_t}{\mu}$
= 10392,192	= 38724,939
in = 50	h_{io} = 1500 btu/jam.ft^2.F
Tc = 155 °F	
= 341 K	
cP = 0,506 btu/lb.F	
k = 0,077 btu/jam.ft.F	
h_o = 80,664	

$$Uc = \frac{h_{io} \times h_o}{h_{io} + h_o}$$

$$= 76,54748$$

$$A = 139,47115 \ ft^2 \quad \text{(sesuai)}$$

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

$$= 75 \ BTU/jam.ft^2.F$$

Maka didapatkan fouling factor (R_d) :

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

$$= 0,0002695$$

g. Evaluasi Pressure Drop

Bagian shell (feed)	Bagian tube (steam)
Re_s = 10392,192	Re_t = 38724,939
f = 0,0015 ft^2/in^2	f = 0,0001 ft^2/in^2
$s_g = \frac{53,26 \ lb/ft^3}{62,5 \ lb/ft^3}$	$s_g = \frac{0,036 \ lb/ft^3}{62,5 \ lb/ft^3}$

	=	0,8522		=	0,0006
ΔP_s	=	$\frac{f \times G_s^2 \times n}{5,22 \times 1010 \times De_s \times s_g}$	ΔP_s	=	$\frac{f \times G_s^2 \times n}{5,22 \times 10^{10} \times Des \times sg}$
	=	0,0002 psi (OK)		=	0,0534 psi (OK)

Spesifikasi Alat

Nama = Heater
Fungsi = Untuk menaikkan suhu dari 30°C menjadi 110°C
Tipe = Shell and Tube
Bahan = Carboon steel SA 240 Grade M type 316
Dimensi
ODs = 17,25 in
Jumlah tube = 203 in
Baffle space = half circle
Passes = 1 - 2
ODt = 1 in
IDt = 0,62 in
Pitch = Tringular

16. STRIPPING (D-130)

Fungsi : Untuk memisahkan butadiena dari DMF
Tipe : Plate tower (sieve tray)
Bahan kosntruksi : High Alloy Steel SA-240 grade M tipe 316
Dasar perhitungan
Dari data neraca massa Appendiks A dan neraca panas Appendiks B diketahui:

1. Feed masuk
Rate = 90761,354 kg/jam
Suhu = 110 °C = 383,15 K
2. Destilat
Rate = 15086,095 kg/jam
Suhu = 52 °C = 325,15 K
3. Bottom
Rate = 75675,259 kg/jam
Suhu = 217 °C = 489,96 K

a. Menentukan refluks dan refluks minimum

Dari appendiks A didapatkan :

$R = 0,0602$

$\frac{R}{R+1} = \frac{0,0602}{0,0602 + 1}$

$= 0,0568$

$R_m = 0,0402$

$$\frac{R_m}{R_m + 1} = \frac{0,0402}{0,0402 + 1}$$

$$= 0,0386$$

b. Menentukan jumlah plate minimum

Dari figure 11.11 Coulson didapatkan

$$\frac{Nm}{N} = 0,28$$

$$Nm = \frac{\log\left[\left(\frac{x_{LK}}{X_{HK}}\right)_D \times \left(\frac{x_{LK}}{X_{HK}}\right)_B\right]}{\log \alpha_{ave.LK}}$$

Dari appendiks diketahui

$X_{LD} = 0,986$

$X_{HD} = 0,014$

$X_{LB} = 0,04$

$X_{HB} = 0,925$

$\alpha_{ave} = 2,458 = \log \alpha_{ave} = 0,391$

Maka didapatkan:

$N_m = 1605,396$

$= 8,2072$

c. Menentukan jumlah plate teoritis

$$\frac{N_m}{N} = 0,28$$

$$N = \frac{N_m}{0,28}$$

$$= \frac{8,2072}{0,28}$$

$= 29,3114$

$= 29$ tray tanpa reboiler

d. Menentukan plate aktual

$$E_0 = \frac{N}{N_{akt}}$$

E_0 didapatkan dari gafik 8.16 di Chopey

Diketahui

$m_B = 0,1735$

$m_D = 0,1091$

$m_{av} = 0,1376$

$m_{av} \times a_{ave} = 0{,}1376 \times 2{,}458$
$= 0{,}3382$
Didapatkan $E_0 = 90$
$= 0{,}9$
Maka,

$$N_{akt} = \frac{29{,}3114}{0{,}9}$$
$= 32{,}568$
$= 33$ tray tanpa reboiler

e. Menentukan letak plate feed

Menentukan letak plate feed dengan persamaan Kirkbride

$$\log \left(\frac{N_e}{N_S}\right) = 0{,}206 \times \log \left[\frac{B}{D}\left(\frac{x_{HK,F}}{x_{LK,F}}\right)\left(\frac{x_{HK,B}}{x_{LK,D}}\right)^2\right]$$

Diketahui
B = 1065,5 kmol/jam
D = 281,12 kmol/jam
$x_{LK,F} = 0{,}179$
$x_{HK,F} = 0{,}789$

$$\log \frac{N_e}{N_S} = 193{,}5948$$
$= 0{,}4711$
$N_e/N_s = 2{,}9587$
$N_e = 2{,}9587\ N_s$

Jumlah plate dengan reboiler 34 Tray. Sedangkan jumlah plate tanpa reboiler tanpa tray 33 Buah

$$N_S = \frac{33}{1 + 2{,}9587}$$
$N_S = 8{,}3361$
$= 9$ (tidak termasuk reboiler)
$N_e = 24$ feed masuk dari plate ke-9 dari bawah

f. Penentuan beban massa pada kolom stripping

Diketahui dari neraca massa Appendiks A didapatkan

- Aliran uap masuk kondensor (V)
  V = 15957,442 kgmol/jam
  = 35179,546 lbmol/jam
- Aliran liquid keluar kondensor (L)
  L = 910,6446 kgmol/jam
  = 2007,5938 lbmol/jam

- Aliran liquid keluar reboiler (L')
  L' = 101092,33 kgmol/jam
  = 222866,68 lbmol/jam
- Aliran uap keluar reboiler (V')
  V' = 25407,617 kgmol/jam
  = 56013,264 lbmol/jam
- Enriching
  L = 910,6446 kgmol/jam
  V = 2007,5938 lbmol/jam
- Exhausting
  L' = 101092,33 kgmol/jam
  V' = 222866,68 lbmol/jam

g. Penentuan dimensi kolom stripping

1. Menentukan diameter menara
   Dari neraca massa appendiks A diketahui
   - Laju alir massa bagian atas
     F = 90761,3538 kg/jam
     D = 15086,0950 kg/jam
     V = 15957,4421 kg/jam
     L = 910,6446 kg/jam
   - Laju alir massa bagian bawah
     B = 75675,2587 kg/jam
     V' = 25407,6167 kg/jam
     L' = 101092,3274 kg/jam
     L'-V' = 75684,7107 kg/jam
     L'/V' = 3,9788

   liquid-vapor flow factor top

   $F_{LV} = \frac{L_W}{V_W}$

   Diketahui :

   r_L = 587,8 kg/m^3

   r_V = 11,79 kg/m^3

   $F_{LV} = \frac{380,24}{15957,442} Ö \frac{11,8}{588}$

   = 0,0034

   K_1 = 0,04 (Coulson, fig. 11-27, hal, 568)

   liquid-vapor flow factor bottom

   $F_{LV} = \frac{L_W}{V_W}$

   Diketahui :

r_L = 673,5 kg/m^3

r_V = 9,99 kg/m^3

$F_{LV} = \frac{101092,3274}{25407,6167} \text{ Ö } \frac{9,99}{674}$

= 0,4845

K_1 = 0,044 (Coulson, fig. 11-27, hal, 568)

- Menentukan tegangan permukaan
  Tegangan permukaan dihitung dengan persamaan Sudgen

$$s = \left[\frac{P_{ch}\,(r_i - r_v)}{M} \right]^4 \times 10^{-12}$$

Komponen	BM	x_D	Pch	s	$x_D \times s$
n-C_4H_{10}	58,12	0,0009	113,8	4,443	0,0039
i-C_4H_{10}	58,12	0,00002	113,8	4,443	0,0001
C_4H_8	56,11	0,0005	118,7	6,4876	0,0034
C_4H_6	54,09	0,9866	121,2	6,502	6,4148
H_2O	18,02	0,0120	166,6	17,86	0,2137
C_3H_7NO	73,10	0	48,4	52,25	0
Total	1				6,636

s mix top = 6,6360 dyne/cm

= 0,0066 N/m

Komponen	BM	x_B	Pch	s	$x_B \times s$
n-C_4H_{10}	58,12	0,0027	113,8	4,443	0,0119
i-C_4H_{10}	58,12	0,0001	113,8	4,443	0,0003
C_4H_8	56,11	0,0016	118,7	6,4876	0,0105
C_4H_6	54,09	0,0000	121,2	6,502	0
H_2O	18,02	0,0363	166,6	17,86	0,6485
C_3H_7NO	73,10	0,9593	48,4	52,25	50,125
Total	1				50,796

s mix bott = 50,7958 dyne/cm

= 0,0508 N/m

Koreksi nilai K_1

$$K_{1\,top} = K_1 \left[\frac{s\ top}{0,02} \right]^{0.2}$$

= 0,013

$$K_{1\ bott} = K_1 \left[\frac{s\ bottom}{0,02} \right]^{0.2}$$

$$= 0,016$$

- Menentukan kecepatan flooding

$$u_f = K_i \sqrt{\frac{r_L - r_v}{r_v}}$$ (Coulson, pers. 11.81, hal 568)

Kecepatan flooding bagian atas (top)

$$u_f = 0,01 \sqrt{\frac{587,8 - 11,79}{11,79}}$$

$$= 0,0908 \text{ m/s}$$

Kecepatan flooding bagian atas (bottom)

$$u_f = 0,02 \sqrt{\frac{673,5 - 9,99}{9,99}}$$

$$= 0,1304 \text{ m/s}$$

Kecepatan umum flooding 70% - 90%. Untuk desain digunakan 80% - 85% kecepatan flooding (Coulson, hal. 568)

Kecepatan uap diambil = 70%

u_v, top = 0,7 × 0,0908

= 0,06356 m/s

u_v, bott = 0,7 × 0,1304

= 0,091273 m/s

- Menentukan laju alir volumetrik maksimum

$$Q_v = \frac{V_w}{r_v}$$

Laju alir volumetrik bagian atas (top)

$$Q_{v,}\ top = \frac{15957,442 \text{ kg/jam}}{11,79 \text{ kg/m}^3}$$

$$= 1353,5 \text{ m}^3\text{/jam}$$

$$= 0,376 \text{ m}^3\text{/det}$$

Laju alir volumetrik bagian bawah (bottom)

$$Q_{v,}\ bott = \frac{25407,62 \text{ kg/jam}}{9,99 \text{ kg/m}^3}$$

$$= 2543,3 \text{ m}^3\text{/jam}$$

$$= 0,7065 \text{ m}^3\text{/det}$$

- Menentukan luas area *Netto* untuk kontak uap-cair

$$A_n = \frac{Q_v}{}$$

u_v

Luas area *Netto* bagian atas (top)

$$A_{n,}\,top = \frac{0{,}376\ m/s}{0{,}0636\ m^3/s} = 5{,}9151\ m^2$$

Luas area *Netto* bagian bawah (bottom)

$$A_{n,}\,bott = \frac{0{,}7065\ m/s}{0{,}0913\ m^3/s} = 7{,}7402\ m^2$$

- Menentukan luas penampang area

$$A_c = \frac{A_n}{1 - A_d}$$ Asumsi A_d = 20%

Luas penampang area bagian atas (top)

$$A_{c,}\,top = \frac{5{,}9151135}{1 - 0{,}2} = 7{,}3939\ m^2$$

Luas penampang area bagian bawah (bottom)

$$A_{c,}\,bott = \frac{7{,}7402255}{1 - 0{,}2} = 9{,}6753\ m^2$$

- Menentukan diameter menara

$$D_c = \sqrt{\frac{4 \times A_c}{p}}$$

Menentukan diameter menara bagian atas (top)

$$D_{c,}\,top = \sqrt{\frac{4 \text{ x } 7{,}3939}{p}} = 1{,}732\ m$$

Menentukan diameter menara bagian atas (bottom)

$$D_{c,}\,bott = \sqrt{\frac{4 \text{ x } 9{,}6753}{p}} = 1{,}9812\ m$$

2. Pengecekan terhadap entraiment

Entrainment dapat dihitung dari % flooding , dengan persamaan :

$$\%\ flooding = \frac{u_v}{u_f} \times 100\% = 69{,}6\ \%$$

Menara bagian atas :

F_{LV} = 0,0034

Maka dari figure 11.29 diperoleh nilai y 0.02 maka tidak terjadi entrainmen karena < 0.1

Menara bagian bawah :

F_{LV} = 0,4845

Maka dari figure 11.29 diperoleh nilai y 0.003 maka tidak terjadi entrainme karena < 0.1

3. Menentukan tebal menara strpping

Menentukan tekanan desain

Diketahui tekanan opera = 5,2 atm = 76,419 psia

P_{desain} = 1,2 × $P_{operasi}$

= 1,2 × 76,419

= 91,702 psia

= 77,006 psig

Dasar perancangan

Suhu operasi = 110 °C = 27 °F

Bahan konstruksi = High Alloy steel SA 240 Grade M type 316

Allowable stress = 18750 (Brownell & Young, hal. 342)

Tipe pengelasan = Double welded joint

E = 0,8 (Brownell & Young, hal. 254)

Faktor korosi = 1/16

Maka tebal menara :

$$t_s = \frac{Pi \times di}{2 (f \times E - 0.6 \times P_i)} + C$$

$$= \frac{77,006 \times 91,557}{2 (18750 \text{ x } 0.8 - 0.6 \text{ x } 77.006)} + 1/16$$

$$= \frac{7050,4229}{29907,593} + 0,06$$

= 0,2982402 in

= $\frac{5}{16}$ in

4. Menentukan diameter menara

d_0 = di + 2ts

= 91,5568 + 2(5/16)

= 91,5568 + 0,625

= 92,1533

Berdasarkan tabel 5.7 Brownell & Young, hal. 90 diperoleh:

d_0, baru = 96 in

d_i, baru = d0 - 2ts

= 96 - 2(5/16)

= 96 - 0,625
= 95,375 in
= 7,9161 ft = 2,4128 m

5. Menentukan tebal tutup atas dan bawah

$$t_{ha} = \frac{0,885 \times Pi \times r}{(f \times E - 0.1 \times P_i)} + C$$

$$= \frac{0,885 \times 77,006 \times 47,813}{(18750 \text{ x } 0.8 - 0.1 * 77.006)} + 1/16$$

$$= \frac{3258,4367}{14992,299} + 0,0625$$

= 0,2798 in

$$= \frac{4,5980}{16} = \frac{5}{\#} \text{ in}$$

6. Menentukan tinggi tutup
Karena tutup atas dan bawah standard dished maka ha=hb
ha = tha + b + sf

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

$$= \frac{95,4}{2}$$

= 47,7
AB = a - icr
= 47,7 - 5,74
= 41,95
BC = r - icr
= 92,153 - 5,74
= 86,415
B = r - AC
= 92,153 - Ö 86,415 ^2 - 41,95 ^2
= 92,153 - 75,550249
= 16,603031
Maka :
ha = 0,313 + 16,603 + 3
= 19,916 in = 0,5059 m
hb = 19,916 in

7. Menentukan liquid dalam menara
Doketahui

Rate volumetrik bottom (Q) $= \frac{L}{r_L}$

$$= \frac{101092,33}{}$$

$$= \frac{673,5}{150,1}$$
$$= 2,5017$$

Waktu tinggal cairan di bottom adalah 5 - 10 menit (Ulrich, hal. 195)

Diambil waktu 5 menit

Maka V liquid = 2,5017 × 5

= 12,508 m3

Tinggi cairan dalam menara

$V_{liquid} = \frac{p \quad D_c^2 \; H_L}{4}$

$H_L = \frac{12,50833053}{0,785 \times 3,9252}$

= 4,0594 m

8. Menentukan tinggi kolom

Diketahui :

Jumlah tray = 34 m

Tray spacing = 0,3

H liquid = 4,0594

Tinggi tutup atas = 0,5059

Tinggi tutup bawa = 0,5059

Tinggi total = (34 × 0,3) + 4,06 + 0,51 + 0,51

= 15,3 m

= 50,1 ft

Spesifikasi alat :

Nama	=	Strpping
Fungsi	=	Untuk memisahkan butadiena dari DMF
Tipe	=	Plate tower (sieve tray)
Bahan konstruksi	=	High Alloy Steel SA-240 grade M tipe 316
Jumlah tray	=	34 buah (dengan reboiler)
Feed tray	=	9 (dari bawah)
Tebal kolom (ts)	=	5/16
Diameter dalam (di)	=	95,4
Diameter luar (do)	=	96
Tinggi kolom (L)	=	15,3
Jumlah	=	1 buah

17. Kondensor (E-131)

Fungsi	:	Untuk mengubah fasa destilat dan menurunkan suhu
Tipe	:	Shell and Tube (subcooler condensor)
Bahan konstruksi	:	Carbon Steel SA-240 grade M type 316

Dasar perancangan

T feed masuk (t_1) = 116 °C = 241 °F

T feed keluar (t_2) = 33 °C = 91,4 °F
T air (T_1) = 30 °C = 86 °F
T air (T_2) = 60 °C = 140 °F
Foulling factor (R_c = 0,003 jam.ft2.F/btu
DP shell = 10 psi
DP tube = 10 psi
Arah aliran = Counter current
Perhitungan =

a. Neraca massa dan panas

Massa liquid masuk = 13316,7049
= 29358,0077
Massa air masuk = 7264,2440
= 16014,7523
Q air masuk = 77693,6399
= 308132,9759
Q bahan masuk = 538729,1053
= 2136599,6316

b. Menghitung DT (LMTD)

T air masuk (t_1) = 30 °C = 86 °F
T air keluar (t_2) = 60 °C = 140 °F
T feed in = 116 °C = 241 °F
T condensate = 52,2 °C = 126 °F
T feed out = 33 °C = 91,4 °F
Heat balance
Condensing range = 241 - 126
Enthalpy vapor = 910,5 btu/lb
Enthalpy liquid = 689,6 btu/lb
q_c = 433153,79 btu/jam

Kondensasi

Hot fluid	Cold fluid	Diff
240,8	140	101
125,79	112,95	12,8

Subcooling

Hot fluid	Cold fluid	Diff
125,79	112,95	12,8
91,4	86	5,4

Subcooling range = 125.79 - 91.4
q_s = 247634,02
Q = Sq = 680787,82
Air, Q = 979814,58
Dt_{air} = 27,1

$$DT_{LMTD} = \frac{Dt2 - Dt1}{\ln \frac{Dt2}{Dt1}}$$

$$DT_{LMTD} = \frac{Dt2 - Dt1}{\ln \frac{Dt2}{Dt1}}$$

$$= \frac{101 - 12,8}{\ln \frac{101}{12,8}}$$

$= 42,7$ F

Dt_c = LMTD

$= 42,693$

$$= \frac{12,8 - 5,4}{\ln \frac{12,8}{5,4}}$$

$= 8,59$ F

Dt_s = LMTD

$= 8,5915$

Maka,

$Dt_c = 42,693$ btu/jam.F

$Dt_s = 8,5915$ btu/jam.F

$Dt = 34,101$ F

c. Menghitung suhu caloric (Tc dan tc)

$Tc = 0,5 \quad (T_1 + T_2) = 1 (\quad 241 + 126) = 183$

$tc = 0,5 \quad (t_1 + t_2) = 1 (\quad 86 + 140) = 113$

d. Trial U_D

Kern hal. 840, tabel 8 didapat U_D = 75 - 150 btu/jam.ft2.F

Trial U_D = 150

Maka,

$$A = \frac{Q}{U_D \times Dt}$$ (Trial)

$$= \frac{586678,7095}{150 \times 34,1}$$

$= 114,69344$ (Digunakan HE tipe Shell n Tube)

e. Trial Ukuran

Sheel side			Tube side		
ID_S	= 17 in =	1,44 ft	Nt	= 178	
Baffle space	= 12 in		ID	= 0,62	
Passes	= 1		OD	= 0,75	0,06
a"	= 0,2		BWG	= 16	
			Pitch	= Tri 1	5 ft
			Passes	= 4	

f. Evaluasi Perpindahan Panas

Condensate

Shell side (feed)	Tube side (steam)
$a_s = \frac{ID_S \times C^n \times B}{144 \times P_T}$	$a'_t = 0,302$ in $a_t = \frac{Nt \times a'_t}{}$

= 1,438	a_t = 144 x n
$G_s = \frac{m}{a_s}$	= 0,093 ft^2
= 48410,1887 $lb/jam.ft^2$	$G_t = \frac{m}{a_t}$
G^n = $W/3.14N_tD_o$	= 171599,3998
= 398,4241 $lb/jam.ft^2$	μ = 1,81 lb/ft.jam
Asumsi h = h_o	D_e = 0,62 in
= 125	= 0,052 ft
t_c = 110,3 F	$Re_t = \frac{D_e \times G_t}{\mu}$
T_v = 178,96 F	= 4895,2746
$t_w = t_c + \frac{h_o}{h_o + h_{io}} (T_v - t_c)$	$v = \frac{G_t}{3600 \times \rho}$
= 132,33 F	= 0,7626 ft/detik
t_f = (Tv + tw)/2	h_i = 320 (Kern, hal. 835)
= 156 F	$h_{io} = h_i \times \frac{ID}{OD}$
k_f = 0,05 $Btu/jam.ft^2.F$	= 264,53
s_f = 0,5893	
m_f = 0,1125 cP	
Dari fig 12.9	
h = h_o = 70 $Btu/jam.ft^2.F$	

$$U_C = \frac{h_{io} \times h_o}{h_{io} + h_o}$$

= 55,353

A_C = 257,9611 ft^2

Subcooling

Shell side	Tube side
$a_s = \frac{ID_S \times C^n \times B}{144 \times P_T}$	Re_t = 4895,275
= 0,3594	h_{io} = 264,5
$G_s = \frac{m}{a_s}$	
= 38728,151 $lb/jam.ft^2$	
T_C = 101,56 F	
μ = 0,1205 cP	
D_e = 0,95 in	
= 0,0792 ft	
$Re_t = \frac{D_e \times G_t}$	

$\frac{}{m}$	
= 10513,969	
c = 0,5712 btu/lb.F	
Jh = 250	
k = 0,052 jam.ft2.F	
h_o = 241,97002 btu/jam.ft2.F	

$$U_C = \frac{h_{io} \times h_o}{h_{io} + h_o}$$

=

A_S = 411,8305

SA = 669,7916

$$U_C = \frac{SUA_c}{SA_c}$$

= 99,0214

a" = 0,1963

A = 174,707

$$U_D = \frac{Q}{A \times Dt}$$

= 138,0884

Maka didapatkan foulling factor (R_d)

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

= 0,0028 (SESUAI)

Evaluasi Pressure Drop

Bagian shell (feed)	Bagian tube (air pendingin)
L_s = LA_c/A_c	Re_t = 4895,2746
= 1,93 FT	f = 0,0002 ft2/in2
T_C = 178,96	s_g = 62,5 lb/ft3 = 1
m = 0,0086 Cp	62,5 lb/ft3
= 0,0208 lb/ft.jam	DPt = 0,0436
Re_t = $\frac{D_e \times G_t}{m}$	G_t = 171599,4
= 147317,8272	$\frac{V^2}{2g'}$ = 0,005
f = 0,001 ft2/in2	$DP_r = \frac{4n}{s_g} \times \frac{V^2}{2g'}$ = 0,072
r_v = 0,7219 lb/ft3	DP_T = DPt + DPr
s_g = 0,0116	= 0,116 psi (OK)
$N + 1 = \frac{12L}{B}$	
$DP_S = \frac{1 \times f \times G_s^2 \times D_S \times (N+1)}{}$	

$\sqrt{\frac{2 \times 5.22 \times 10^{10}}{De_s \times s_g}}$ = 0,0435 (OK)	

Spesifikasi Alat

Nama = Kondensor
Fungsi = Untuk mengubah fasa hasil destilat
Tipe = Shell and Tube (subcooler)
Bahan = Carbon steel SA 240 Grade M type 316
Dimensi
ID_s = 17,25 in
Jumlah tube = 178 in
Baffle space = 12 in
Passes = 1 - 4 in
OD_t = 0,75 in
ID_t = 0,62 in
Pitch = Tringular

18. Akumulator (F-142)

Fungsi : Untuk menampung kondensat dari kondensor destilasi
Tipe : Tangki horizontal dengan hemispherical head
Bahan konstruksi : Carbon steel SA-240 grade M type 316
Dasar perancangan
Suhu operasi = 30^oC
Tekanan operasi = 5,2 atm = 76,4 psi
r campuran = 610 kg/m3 = 38,0640 lb/ft3
Rate aliran = 12626,263 kg/jam = 27904,04035 lb/jam
Bahan konstruksi = Carbon steel SA-240 grade M type 316
Allowable stress = 18750 *(Brownell & Young, hal 342)*
Tipe pengelasan = Double welded butt joint
E = 0,8 *(Brownell & Young, hal 342)*
Faktor korosi = 1/16
Waktu tinggal = 1 jam

a. Menghitung volume tangki

$$\text{Rate volumetrik} = \frac{\text{rate}}{\rho} = \frac{27904,04 \text{ lb/jam}}{38,0640 \text{ lb/ft3}}$$
$$= 733,08219$$

Volume liquid = Q x Waktu tinggal
= 733,08219 ft3/jam x 1 jam
= 733,08219 ft3

Direncanakan 1 buah storage DMF
Asumsi = Vrk = 20% x V total

$$\text{V total} = \frac{\text{V liquid}}{0,8} = \frac{733,08219 \text{ ft3}}{0,8}$$

$$= 916,3527 \text{ ft3}$$

b. Menghitung dimensi tangki

Asumsi $L_S = 1,5\ di$ (Ulrich, hal. 248)

V total = V shell + V tutup atas

$916,3527 = p/4.di^2.L_S + 0,5 \times (2 \times 1/6p \times di^3)$

$916,3527 = 0,785\ di^2 .\ 1,5\ di + 0,5 \times 1,0467\ di^3$

$916,3527 = 1,1775\ di^3 + 0,5234\ di^3$

$916,3527 = 1,7009\ di^3$

$di^3 = 538,76$ ft3

$di = 23,211$ ft

$di = 278,53$ in

c. Menghitung tebal tangki

$P_{desain} = 97,8$ psi $= 83,14$ psig

$$t_s = \frac{Pi \times di}{2\,(f \times E - 0.6 \times P_i)} + C$$

$$= \frac{83,14 \times 278,53}{2(18750 \times 0,8 - 0,6 \times 83,14)} + 1/16$$

$$= \frac{23157,389}{29900,232} + 0,0625$$

$= 0,8370$ in

$$= \frac{4,45 \text{ in}}{16} \approx \frac{5}{16}$$

Menghitung d_o

$d_o = di + 2ts$

$= 278,53 + 2(5/16)$

$= 278,53 + 0,0625$

$= 278,6$ in

Berdasarkan tabel 5.7 Brownell & Young, hal. 90 diperoleh :

do baru = 78 in

di baru = do - 2ts

$= 78 - 2(5/16)$

$= 78 - 0,0625$

$= 77,938$ in

$= 6,4688$ ft

$= 1,9717$ m

d. Menghitung tinggi silinder

Ls = 1,5 di

$= 1,5 \times 77,938$

= 116,9063 in
= 9,7422 ft

e. Menghitung tebal tutup atas

$$t_{ha} = \frac{Pi \times d}{4\,(f \times E - 0.4 \times P_i)} + C$$

$$= \frac{83,143 \times 77,938}{(4 \times 18750 - 0,4 \times 83,1432)} + 1/16$$

$$= \frac{6479,9576}{74866,971} + 0,0625$$

= 0,1491 in

$$= \frac{2,722}{16} = \frac{3}{16} \text{ in}$$

f. Menghitung tinggi tutup atas

Tutup atas = tutup bawah
Direncanakan sf = 2,5 in
Lha, Lhb = sf + id + ts
= 41,5 in
= 3,4538 ft

g. Menghitung tinggi tangki

L total = Ls + Lha + Lhb
= 16,6198 ft

Spesifikasi Alat

Nama	=	Akkumulator	
Fungsi	=	Untuk menampung kondensat dari kondensor destilasi	
Tipe	=	Tangki horizontal dengan hemishpherical head	
Bahan konstruksi	=	Carbon steel SA 240 Grade M type 316	
Volume tangki	=	916,3527	ft3
Tebal tangki	=	3/16	in
Diameter dalam	=	77,938	in
Diameter luar	=	78	in
Tinggi silinder	=	116,9063	in
Tebal tutup atas	=	3/16	in
Tinggi tutup atas	=	3/16	in
Panjang tangki	=	16,6198	ft
Jumlah	=	1 buah	

19. Reboiler (E-144)

Fungsi	:	Untuk menguapkan kembali bottom produk dari destilas
Tipe	:	Shell and tube kattle reboiler
Bahan konstruksi	:	High Alloy steel SA-240 grade S

Dasar perancangan

T feed masuk (t_1)	=	110	°C	=	230 °F
T feed keluar (t_2)	=	187	°C	=	369 °F
T steam (T_1)	=	800	°C	=	1472 °F
T steam (T_2)	=	800	°C	=	1472 °F
Foulling factor (R_d	=	0,003	jam.ft2.F/btu		
DP shell	=	10	psi		
DP tube	=	2	psi		
Arah aliran	=	Counter current			

Perhitungan

a. Neraca massa dan panas

Massa liquid masuk	=	15086,0950	kg/jam
	=	33340,2700	lb/jam
Massa steam masuk	=	5412,14	kg/jam
	=	11931,6038	lb/jam
Q steam masuk	=	2713070,872	kkal/jam
	=	10765465,22	btu/jam
Q bahan masuk	=	2506080,635	kkal/jam
	=	9944127,958	btu/jam

b. Menghitung DT (LMTD)

T feed masuk (t_1)	=	110	°C	=	230	°F	
T feed keluar (t_2)	=	187	°C	=	369	°F	
T steam in	=	800	°C	=	1472	°F	
T steam out	=	800	°C	=	1472	°F	
Dt1 = T1 - t2	=	1472	-	369	=	1103,4	°F
Dt2 = T2 - t1	=	1472	-	230	=	1242	°F

Maka,

$$DT_{LMTD} = \frac{Dt2 - Dt1}{\ln \frac{Dt2}{Dt1}}$$

$$= \frac{1242 - 1103}{\ln \frac{1242}{1103}}$$

$$= 1171 \text{ °F}$$

Untuk FT diperoleh dari Kern hal 828

$$R = \frac{T1 - T2}{t2 - t1} = \frac{1472 - 1472}{368,6 - 230} = 0,000$$

$$S = \frac{t2 - t1}{T1 - t1} = \frac{368,6 - 230}{1472 - 230} = 0,1116$$

Maka diperoleh nilai FT sebesar = 0,9 dengan tipe HE 1-2

Karena pemanas menggunakan steam dan nilai R = 0

$$Dt = DT_{LMTD}$$

$$= 1171,33 \text{ F}$$

c. Menghitung suhu caloric (Tc dan tc)

Tc = 0,5 $(T_1 + T_2)$ = 1 (1472 + 1472) = 1472 F

tc = 0,5 $(t_1 + t_2)$ = 1 (230 + 369) = 299 F

d. Trial U_D

Kern hal. 840, tabel 8 didapat U_D = 50 - 100 btu/jam.ft2.F

Trial U_D = 50 btu/jam.ft2.F

Maka,

$$A = \frac{Q}{U_D \times Dt} \quad \text{(Trial)}$$

$$= \frac{9944127,958}{50 \times 1171}$$

= 169,7921 ft2 (Digunakan HE tipe Shell n Tube)

e. Trial Ukuran

Sheel side			Tube side		
ID_S	= 15,3 in =	ft	Nt	= 138	5 ft
Baffle space	= 12 in		ID	= 0,87 in	
Passes	= 1		OD	= 1 in	
a"	= 0,262 ft2/ft		BWG	= 16	
			Pitch	= Tringulai =	1,25 in
			Passes	= 2	

f. Evaluasi Perpindahan Panas

Shell side	Tube side
a_s = ID_S x C'B / 144 x P_T	a't = 0,594 in2
= 0,2542 ft2	$at = \frac{Nt \times a't}{144 \times n}$
$G_s = \frac{m}{a_s}$	= 0,285 ft2
= 391237,1575 lb/jam.ft2	$G_t = \frac{m}{a_t}$
m = 0,21 cP	= 41920,4351
= 0,5082 lb/ft.jam	m = 0,048 lb/ft.jam
D_e = 0,99 ft	D_e = 0,87 in
= 11,9 in	= 0,073 ft
$Re_t = \frac{D_e \times G_t}{m}$	$Re_t = \frac{D_e \times G_t}{m}$
= 762150,307	= 62794,0402
Jh = 700	h_{io} = 1500 btu/jam.ft2.F
T_C = 299,3 F	
cp = 0,425 btu/lb.F	
k = 0,076 btu/jam.ft.F	

h_o	=	50,9295	

$$U_C = \frac{h_{io} \times h_o}{h_{io} + h_o}$$

$= 49,257$

$A = 180,642$ ft2 (SESUAI)

$$U_D = \frac{Q}{A \times Dt}$$

$= 47,00$ btu/jam.ft2.F

Maka didapatkan foulling factor (R_d)

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

$= 0,0009764$ (memenuhi karena kurang dari 0,003)

f. Evaluasi Pressure Drop

Bagian shell (feed)	Bagian tube (air pendingin)
$Re_t = \frac{D_e \times G_t}{m}$	$Re_t = 62794,0402$
$f = 0,0009$ ft2/in2	$f = 0,0002$ ft2/in2
$s_g = \frac{42,5 \text{ lb/ft3}}{62,5 \text{ lb/ft3}}$	$s_g = \frac{0,07 \text{ lb/ft3}}{62.5 \text{ lb/ft3}}$
$= 0,6796$	$= 0,001$
$DP_S = \frac{1 \times f \times G_s^2 \times D_S \times (N+1)}{2 \times 5.22 \times 10^{10} \times De_s \times s_g}$	$DPt = 0,841$
$= 0,0007$ psi (OK)	$G_t = 49120,44$
	$\frac{V^2}{2g'} = 0,02$
	$DP_r = \frac{4n}{s_g} \times \frac{V^2}{2g'}$
	$= 0,003$
	$DP_T = 0,844$ psi (OK)

Spesifikasi Alat

Nama = Reboiler

Fungsi = Untuk menguapkan kembali bottom produk dari destilasi

Tipe = Shell and tube kettle reboiler

Bahan = High Alloy steel SA-240 grade S

Dimensi

$ID_s = 15$ in

Jumlah tube = 138

Baffle space = 12 in

Passes = 1 - 2

$OD_t = 1$ in

ID_t = 0,87 in
Pitch = Tringular

20. Pompa Reboiler (L-143)

Fungsi : Mengalirkan feed menuju reboiler
Tipe : Pompa sentrifugal
Dasar perancangan
Bahan konstruksi = Carbon steel
Suhu operasi = 110 ^oC
Tekanan operasi = 5 atm = 79,4 psia
Rate aliran = 15086,0950 kg/jam = 33258,805 lb/det
ρ campuran = 853,9 kg/m^3 = 53,31 lb/ft^3
Viskositas (μ) = 0,366 cP = 0,8857 lb/ft.jam

a. Menghitung rate volumetrik

Rate volumetrik (Q) = $\frac{\text{rate bahan masuk}}{\rho \text{ bahan masuk}}$

= $\frac{33258,8051}{53,31}$

= 623,88 ft^3/det = 2245951,9 ft^3/jam

$Di_{optimum}$ = $3,9\ Q^{0,45} \times \rho^{0,13}$ *(Pers. 15 "Peter and Timmerhaus", hal 496)*

= $3,9 \times 0,571^{0,45} \times 53,31^{0,13}$

= $3,9 \times 0,7771 \times 1,6768$

= 5,082 in

= 0,4235 ft

Standarisasi = 6 in sch 40 (Ludwig, hal 858)

Sehingga diperoleh:

OD = 6,625 in = 0,5521 ft
ID = 6,0625 in = 0,5052 ft = 0,1516 m
A = 0,2007 ft2 = 28,9 in2

b. Menentukan kecepatan aliran fluida

Kecepatan aliran (v) = $\frac{Q}{A}$

= $\frac{2245951,9 \ ft^3/jam}{0,200694 \ ft^2}$

= 11190927 ft/jam

= 2238,2 ft/det

c. Menentukan bilangan Reynold

NR_e = $\frac{D \times V \times \rho}{\mu}$

$$= \frac{0{,}5052 \times 9294{,}4252 \times 53{,}3100}{0{,}8857}$$

$$= \frac{250319{,}43}{0{,}8857}$$

= 282616,89 (aliran turbulen)

Dari fig 2.10-3 Geankoplis, hal 88 didapatkan:

ε = 0,000046 m

ε/D = 0,0003

f = 0,006

d. Menentukan panjang pipa

Asumsi :

- Panjang pipa lurus = 20 ft = 6,096 m
- elbow 90° = 2 buah
- Le/D = 35 *(Geankoplis, tabel 2.10-1, hal 99)*
- L elbow = 35 ID
  = 35 × 2 × 6,0630
  = 424,4100 in
  = 35,36 ft

- Gate valve = 1 buah
- Le/D = 225 *(Geankoplis, tabel 2.10-1, hal 99)*
- L elbow = 225 ID
  = 225 × 1 × 6,0630
  = 1364,1750 in
  = 113,6813 ft
- Panjang pipa total = Pipa lurus + elbow 90° + gate valve
  = 20 + 35,365 + 113,6719
  = 169,0369 in
  = 2028,4428 ft

e. Menentukan Friction Loss

1. Friksi pada pipa lurus

$$Ff = 4\frac{\Delta L}{D} \times \frac{v^2}{2gc}$$

$$Ff = 4 \times 0{,}0060 \frac{169{,}0360}{0{,}5052} \times \frac{6{,}6656}{2 \times 32{,}1740}$$

Ff = 0,8318 lbf.ft/lbm

2. Kontraksi

$$K_c = 0{,}55 \times \left(1 - \frac{A_1}{A_2}\right)^2$$

$$= 0{,}55 \times (1\text{-}0)^2$$

$= 0,55$

$$h_c = K_c \frac{v^2}{2gc}$$
$$= 0,55 \times \frac{6,6656}{32,1740}$$
$= 0,057$ lbf.ft/lbm

3. Ekspansi

$$K_{ex} = \left(1 - \frac{A_1}{A_2}\right)^2$$
$= (1-0)^2$
$= 1$

$$h_{ex} = Kex \frac{v^2}{2gc}$$
$$= 1 \frac{6,6656}{2 \times 32,174}$$
$= 0,1036$ lbf.ft/lbm

4. Elbow 90 °C, 3 buah

$K_f = 0,75$ (Geankoplis, tabel 2.10-1, hal 99)

$$h_f = 2Kf \frac{v^2}{2gc}$$
$$h_f = 1,5 \frac{6,6656}{64,3480}$$
$h_f = 0,1554$ lbf.ft/lbm

5. Gate valve half open, 1 buah

$K_f = 4,5$ *(Geankoplis, tabel 2.10-1, hal 99)*

$$h_f = Kf \frac{v^2}{2gc}$$
$$h_f = 4,5 \frac{6,6656}{64,3480}$$
$h_f = 0,4661$ lbf.ft/lbm

Sehingga:

$\Sigma F = F_f + h_c + h_{ex} + h_f$
$= 0,8318 + 0,06 + 0,1036 + 0,6215$
$= 1,6139$ lbf.ft/lbm

f. Menentukan kesetimbangan mekanik

Direncanakan :

Δz = 5 ft

Δp = 0 atm = 0 lb/ft²

Δv = 0,201 ft/s

α = 1

Sehingga kesetimbangan mekanik:

$$\frac{\Delta v^2}{2\alpha\, gc} + \frac{g.\Delta z}{gc} + \frac{\Delta p}{p} + \Sigma F = -W_s$$

(Geankoplis, pers 2.7-28, hal 68)

$$\frac{0,0403}{2 \times 32,174} + \frac{32,174 \times 5}{32,174} + \frac{0}{53,31} + 1,6139 = -W_s$$

$$0,0006 + 5 + 0 + 1,6139 = -W_s$$

$$= -W_s$$

Efisiensi pompa (η) = 83% *(Petter & Timmerhause, Fig.1437, hal 520)*

$$Wp = \frac{-W_s}{\eta}$$

$$Wp = \frac{6,6145}{0,83}$$

Wp = 7,9693 ft.lbf/lbm

Mass flow rate (m) = Q × ρ

= 2245951,9 × 53,31

= 119731698 lbm/det

Pump horsepower = Wp × m

= 7,9693 × 27,6226

= 220,1328 ft.lbf/det

= 0,4050 hp

$$B_{hp} = \frac{Whp}{\eta}$$

$$= \frac{0,4050}{0,83}$$

= 0,4880 hp

Efisiensi motor (η) = 80% (Petter & Timmerhause, Fig.1438, hal 52

$$\text{Daya motor} = \frac{B_{hp}}{\eta}$$

$$= \frac{0,4880}{0,8}$$

= 0,6100 Hp ≈ 1 Hp

Spesifikasi alat

Fungsi = Mengalirkan feed menuju reboiler

Tipe = Pompa sentrifugal
Bahan = Carbon steel
Daya = 1 hp
Rate = 2245951,9457 ft3/jam
Panjang pipa = 2,0284
Jumlah = 1 buah

21. KOLOM DESTILASI (D-140)

Fungsi : Untuk memisahkan butadiene dari impuritisnya
Tipe : Plate tower (sieve tray)
Bahan kosntruksi : High Alloy Steel SA-240 grade M tipe 316
Dasar perhitungan
Dari data neraca massa Appendiks A dan neraca panas Appendiks B diketahui:
1. Feed masuk
Rate = 15086,095
Suhu = 30 ^{o}C = 303,15 K
2. Destilat
Rate = 2459,8324
Suhu = 30 ^{o}C = 303,15 K
3. Bottom
Rate = 12626,263
Suhu = 100 ^{o}C = 373,15 K

a. Menentukan refluks dan refluks minimum

Dari appendiks A didapatkan :

$R = 0,0602$

$\frac{R}{R+1} = \frac{0,0602}{0,0602 + 1}$

$= 0,0568$

$R_m = 0,0402$

$\frac{R_m}{R_m + 1} = \frac{0,0402}{0,0402 + 1}$

$= 0,0386$

b. Menentukan jumlah plate minimum

Dari figure 11.11 Coulson didapatkan

$\frac{Nm}{N} = 0,28$

$$Nm = \frac{\log\left[\left(\frac{x_{LK}}{X_{HK}}\right)_D \times \left(\frac{x_{LK}}{X_{HK}}\right)_B\right]}{\log \alpha_{ave.LK}}$$

Dari appendiks diketahui

X_{LD} = 0,986

X_{HD} = 0,014

X_{LB} = 0,04

X_{HB} = 0,925

α_{ave} = 2,458 = log α_{ave} = 0,391

Maka didapatkan:

N_m = 1605,3962

= 8,2072

c. Menentukan jumlah plate teoritis

$\frac{N_m}{N}$ = 0,28

$N = \frac{N_m}{0,28}$

$= \frac{8,2072}{0,28}$

= 29,311

= 29 tray tanpa reboiler

d. Menentukan plate aktual

$E_0 = \frac{N}{N_{akt}}$

E_0 didapatkan dari gafik 8.16 di Chopey

Diketahui

m_B = 0,1735

m_D = 0,1091

m_{av} = 0,1376

$m_{av} \times a_{ave}$ = 0,138 × 2,458

= 0,3392

Didapatkan E_0 = 90

= 0,9

Maka,

$N_{akt} = \frac{29,311}{0,9}$

= 32,568

= 33 tray (tanpa reboiler)

e. Menentukan letak plate feed

Menentukan letak plate feed dengan persamaan Kirkbride

$\log \left(\frac{N_e}{} \right) = 0,206 \times \log \left[\frac{B}{} \left(\frac{\text{HK, F}}{} \right) \left(\frac{\text{HK, B}}{} \right) 2 \right]$

N_S D $x_{LK, F}$ $x_{LK, D}$

Diketahui

B = 653,6

D = 117,88

$x_{LK, F}$ = 0,179

$x_{HK, F}$ = 0,789

$\log \frac{N_e}{N_S}$ = 193,59

N_e/N_S = 2,9587

N_e = 2,9587 N_s

Jumlah plate dengan reboiler 34 tray. Sedangkan jumlah plate tanpa reboiler tanpa tray 33 buah

$N_S = \frac{33}{1 + 2,9587}$

N_S = 8,3361

= 9 (tidak termasuk reboiler)

N_e = 24 feed masuk dari plate ke-9 dari bawah

f. Penentuan beban massa pada kolom distilasi

Diketahui dari neraca massa Appendiks A didapatkan

- Aliran uap masuk kondensor (V)
  V = 124,923 kgmol/jam
  = 275,4052 lbmol/jam
- Aliran liquid keluar kondensor (L)
  L = 7,097 kgmol/jam
  = 15,646 lbmol/jam
- Aliran liquid keluar reboiler (L')
  L' = 705,91 kgmol/jam
  = 1556,249 lbmol/jam
- Aliran uap keluar reboiler (V')
  V' = 154,97 kgmol/jam
  = 341,6469 lbmol/jam
- Enriching
  L = 7,097 kgmol/jam
  V = 124,923 lbmol/jam
- Exhausting
  L' = 705,91 kgmol/jam
  V' = 154,97 lbmol/jam

g. Penentuan dimensi kolom distilasi

1. Menentukan diameter menara
   Dari neraca massa appendiks A diketahui

- Laju alir massa bagian atas

F	=	15086,0950	kg/jam
D	=	12626,2626	kg/jam
V	=	13342,4419	kg/jam
L	=	716,1793	kg/jam

- Laju alir massa bagian bawah

B	=	2459,8324	kg/jam
V'	=	13426,4583	kg/jam
L'	=	15886,2907	kg/jam
L'-V'	=	2459,8324	kg/jam
L'/V'	=	1,1832	

liquid-vapor flow factor top

$$F_{LV} = \frac{L_W}{V_W}$$

Diketahui :

r_L = 587,8 kg/m^3

r_V = 11,79 kg/m^3

$$F_{LV} = \frac{716,1793}{13342,442} = 0,008$$

K_1 = 0,044 *(Coulson, fig. 11-27, hal, 568)*

liquid-vapor flow factor bottom

$$F_{LV} = \frac{L_W}{V_W}$$

Diketahui :

r_L = 673,5 kg/m^3

r_V = 9,99 kg/m^3

$$F_{LV} = \frac{15886,291}{13426,458} = 0,5548$$

K_1 = 0,044 *(Coulson, fig. 11-27, hal, 568)*

- Menentukan tegangan permukaan

Tegangan permukaan dihitung dengan persamaan Sudgen

$$s = \left[\frac{P_{ch} (r_i - r_v)}{M} \right]^4 \times 10^{-12}$$

Komponen	BM	x_D	Pch	s	$x_D \times s$
n-C_4H_{10}	58,12	0,0009	113,8	4,443	0,0040
i-C_4H_{10}	58,12	0,00002	113,8	4,443	0,0001
C_4H_8	56,11	0,0005	118,7	6,4876	0,0035

C_4H_6	54,09	0,9974	121,2	6,502	6,4850
H_2O	18,02	0,0012	166,6	17,86	0,0206
Total	1				6,5132

σ mix top = 6,5132 dyne/cm
= 0,0065132 N/m

Komponen	BM	xB	Pch	s	xB × s
n-C_4H_{10}	58,12	0,0008	113,8	4,443	0,0037
i-C_4H_{10}	58,12	0,00002	113,8	4,443	9E-05
C_4H_8	56,11	0,0005	118,7	6,4876	0,0033
C_4H_6	54,09	0,9335	121,2	6,502	6,0698
H_2O	18,02	0,0651	166,6	17,86	1,1628
Total	1				7,2397

s mix bott = 7,2397 dyne/cm
= 0,0072397 N/m

Koreksi nilai K_1

$$K_{1\ top} = K_1 \left[\frac{s\ top}{0,02} \right]^{0.2}$$
$$= 0,013$$
$$K_{1\ bott} = K_1 \left[\frac{s\ bottom}{0,02} \right]^{0.2}$$
$$= 0,016$$

- Menentukan kecepatan flooding

$$u_f = K_i \sqrt{\frac{r_L - r_v}{r_v}}$$ *(Coulson, pers. 11.81, hal 568)*

Kecepatan flooding bagian atas (top)

$$u_f = 0,01 \sqrt{\frac{587,8 - 11,79}{11,79}}$$
$$= 0,09 \text{ m/s}$$

Kecepatan flooding bagian atas (bottom)

$$u_f = 0,02 \sqrt{\frac{673,5 - 9,99}{9,99}}$$
$$= 0,128 \text{ m/s}$$

Kecepatan umum flooding 70% - 90%. Untuk desain digunakan 80% - 85% kecepatan flooding (Coulson, hal. 568)

Kecepatan uap diambil = 70%

u_v, top = 0,7 × 0,9

= 0,6300 m/s

u_v, bott = 0,7 × 0,13

= 0,0896 m/s

- Menentukan laju alir volumetrik maksimum

$$Q_v = \frac{V_w}{r_v}$$

Laju alir volumetrik bagian atas (top)

$$Q_{v,}\,top = \frac{13342,4 \text{ kg/jam}}{11,79 \text{ kg/m}^3}$$

= 1131,7 m^3/jam

= 0,3144 m^3/det

Laju alir volumetrik bagian bawah (bottom)

$$Q_{v,}\,bott = \frac{13426,5 \text{ kg/jam}}{9,99 \text{ kg/m}^3}$$

= 1344 m^3/jam

= 0,3733 m^3/det

- Menentukan luas area *Netto* untuk kontak uap-cair

$$A_n = \frac{Q_v}{u_v}$$

Luas area *Netto* bagian atas (top)

$$A_{n,}\,top = \frac{0,1577 \text{ m/s}}{0,0627 \text{ m}^3/\text{s}}$$

= 2,5164 m^2

Luas area *Netto* bagian bawah (bottom)

$$A_{n,}\,bott = \frac{0,3034 \text{ m/s}}{0,0893 \text{ m}^3/\text{s}}$$

= 3,3975 m^2

- Menentukan luas penampang area

$$A_c = \frac{A_n}{1 - A_d}$$

Asumsi A_d = 20%

Luas penampang area bagian atas (top)

$$A_{c,}\,top = \frac{2,5164}{1 - 0}$$

= 2,5164 m^2

Luas penampang area bagian bawah (bottom)

$A_{c,}$ bott = $\frac{3,3975}{1 - 0}$

= 3,3975 m^2

- Menentukan diameter menara

$D_c = \sqrt{\frac{4 \times A_c}{p}}$

Menentukan diameter menara bagian atas (top)

$D_{c,}$ top = $\sqrt{\frac{4 \text{ x } 1,7616}{\pi}}$

= 2,2441 m

Menentukan diameter menara bagian atas (bottom)

$D_{c,}$ bott = $\sqrt{\frac{4 \text{ x } 4,1934}{\pi}}$

= 5,3419 m

2. Pengecekan terhadap entraiment

Entrainment dapat dihitung dari % flooding , dengan persamaan :

% flooding = $\frac{u_v}{u_f} \times$ 100%

= 70 %

Menara bagian atas :

F_{LV} = 0,008

Maka dari figure 11.29 diperoleh nilai 0,02 maka tidak terjadi entrainment karena < 0.1

Menara bagian bawah :

F_{LV} = 0,5548

Maka dari figure 11.29 diperoleh nilai 0,003 maka tidak terjadi entrainment karena < 0.1

3. Menentukan tebal menara distilasi

Menentukan tekanan desain

Diketahui tekanan operasi = 5,35 atm = 78,65 psia

P_{desain} = 1,2 × $P_{operasi}$

= 1,2 × 78,65

= 94,38 psia

= 80,38 psig

Dasar perancangan

Suhu operasi = 110 °C = 27 °F

Bahan konstruksi = High Alloy steel SA 240 Grade M type 316

Allowable stress = 18750 *(Brownell & Young, hal. 342)*

Tipe pengelasan = Double welded joint
E = 0,8 *(Brownell & Young, hal. 254)*
Faktor korosi = 1/16
Maka tebal menara :

$$t_s = \frac{Pi \times di}{2\,(f \times E - 0.6 \times P_i)} + C$$

$$= \frac{79,674 \times 91,557}{18750x0,8-0,6x79,674} + 1/16$$

$$= \frac{7294,6965}{29904,391} + 0,0625$$

$$= 0,3064 \text{ in}$$

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

4. Menentukan diameter menara

d_0 = di + 2ts
= 91,5568 + 2(5/16)
= 91,5568 + 0,6250
= 92,1818 in

Berdasarkan tabel 5.7 Brownell & Young, hal. 90 diperoleh:

d_0, baru = 96 in
d_i, baru = do + 2ts
= 96 - 2(5/16)
= 96 - 0,6250
= 95,3750 in
= 7,9479 ft = 2,4224 m

5. Menentukan tebal tutup atas dan bawah

$$t_{ha} = \frac{0,89 \times Pi \times r}{2(f \times E - 0.1 \times P_i)} + C$$

$$= \frac{0,885 \times 79,67 \times 47,813}{(18750 \text{ x } 0,8 - 0,1 \text{ x } 79,674)} + 1/16$$

$$= \frac{3371,1614}{14992,033} + 1/16$$

$$= 0,2874 \text{ in}$$

$$= \frac{4,598}{16} = \frac{5}{16} \text{ in}$$

6. Menentukan tinggi tutup

Karena tutup atas dan bawah standard dished maka ha=hb
ha = tha + b + sf

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

$$= \frac{96,625}{2}$$

= 48,3125 in

AB = a - icr

= 47,813 - 5,738

= 42,075 in

BC = r - icr

= 92,17 - 5,738

= 86,432 in

B = r - AC

= 92,17 - Ö 86,4322^2 - 42,075^2

= 92,17 - 75,5

= 16,67 in

Maka :

ha = 0,313 + 16,6699 + 3

= 19,9829 in = 6,0905 m

hb = 19,9829 in

7. Menentukan liquid dalam menara

Doketahui

Rate volumetrik bottom (Q) $= \frac{L}{r_L}$

$= \frac{49703,9 \text{ kg/jam}}{673,5 \text{ kg/m}}$

= 73,7994 m3/jam

= 0,02050 m3/menit

Waktu tinggal cairan di bottom adalah 5 - 10 menit (Ulrich, hal. 195)

Diambil waktu 5 menit

Maka V liquid = 1,23 × 5

= 6,15 m3

Tinggi cairan dalam menara

$V_{liquid} = \frac{\pi \ D_c^2 \ H_L}{4}$

$H_L = \frac{6,15}{0,785 \times 5,8994}$

= 1,328 m

8. Menentukan tinggi kolom

Diketahui :

Jumlah tray = 34 buah

Tray spacing = 0,3 m *(Coulson hal 448)*

H liquid = 1,328 m

Tinggi tutup atas = 0,5076 m

Tinggi tutup bawa	=	0,507	m
Tinggi total	=	(34 × 0,3) + 1,33 + 0,51 + 0,51	
	=	12,543	m
	=	41,154	ft

Spesifikasi alat :

Nama	=	Kolom Destilasi	
Fungsi	=	Untuk memisahkan butadiene dari impuritisnya	
Tipe	=	Plate tower (sieve tray)	
Bahan konstruksi	=	HAS SA 240 Grade M type 316	
Jumlah tray	=	34	buah (dengan reboiler)
Feed tray	=	9	(dari bawah)
Tebal kolom (ts)	=	5/16	in
Diameter dalam (di)	=	95,626	in
Diameter luar (do)	=	96	in
Tinggi kolom (L)	=	12,543	in
Jumlah	=	1	buah