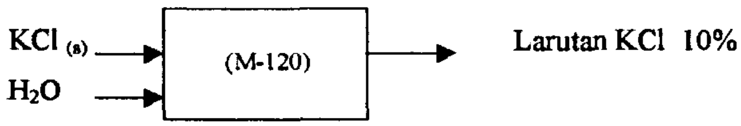
APPENDIX A
NERACA MASSA

Kapasitas produksi K_2SO_4 = 7000 ton/tahun

Operasi pabrik = 330 hari/tahun ; 24 jam/hari

Basis perhitungan = 1 hari

1. Tangki Pelarutan KCl (M-120) :



KCl_{keluar} Tangki Pelarutan KCl = KCl_{masuk} Reaktor (R-210)

= 275,8058 kmol = 20.561,5985 kg

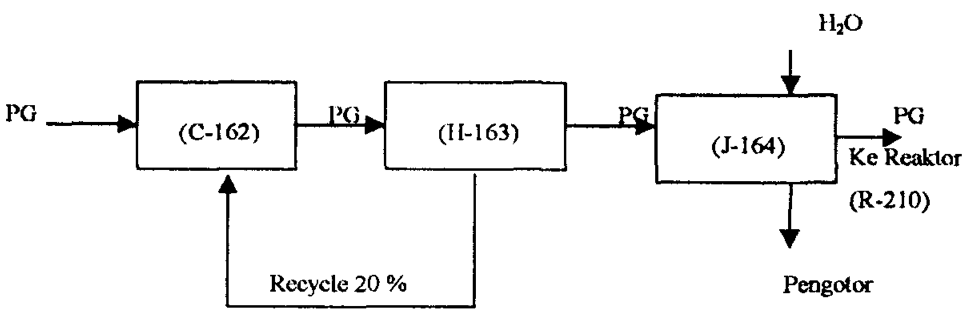
Komposisi KCl masuk : KCl = 99,5 %

Pengotor = 0,5 %

Komposisi larutan KCl 10% yang digunakan :

- KCl = 20.561,5985 kg
- Pengotor = 103,3246 kg
- H_2O = 185.984,3079 kg

Untuk menghitung Phosphogypsum (PG) masuk Reaktor (R-210) :



2. Hammer Mill (C-162) :

Phosphogypsum masuk Hammer Mill = 37.009,0100 kg

Komposisi Phosphogypsum : - $CaSO_4.2H_2O$ = 94,6623 %

- Pengotor = 5,3377 % (Abu-Eishah, 2000).

Asumsi : Phosphogypsum yang direcycle dari ayakan = 20 %

trial 1 : recycle = 20 % x 37.009,0100 kg = 7.401,8020 kg

Phosphogypsum masuk = (37.009,0100 + 7.401,8020) kg

= 44.410,8120 kg

Phosphogypsum yang direcycle = 20 % x 44.410,8120 kg = 8.882,1624 kg

trial 2 : recycle = 8.882,1624 kg

Dengan cara yang sama dicari sampai harga recycle konstan, dan didapatkan harga recycle = 9.252,2525 kg.

- Phosphogypsum masuk :

$CaSO_4.2H_2O$ = 94,6623 % x 37.009,0100 kg = 35.033,5801 kg

Pengotor = 5,3377 % x 37.009,0100 kg = 1.975,4299 kg

- Recycle :

$CaSO_4.2H_2O$ = 94,6623 % x 9.252,2525 kg = 8.758,3950 kg

Pengotor = 5,3377 % x 9.252,2525 kg = 493,8575 kg

- Phosphogypsum yang keluar :

$CaSO_4.2H_2O$ = 94,6623 % x 46.261,2625 kg = 43.791,9751 kg

Pengotor = 5,3377 % x 46.261,2625 kg = 2.469,2874 kg

3. Screen (H-163) :

- Phosphogypsum yang masuk screen :

$CaSO_4.2H_2O$ = 43.791,9751 kg

Pengotor = 2.469,2874 kg

- Phosphogypsum yang direcycle :

$CaSO_4.2H_2O$ = 8.758,3950 kg

Pengotor = 493,8575 kg

- Phosphogypsum yang keluar dari screen :

$CaSO_4.2H_2O$ = 35.033,5801 kg

Pengotor = 1.975,4299 kg

4. Belt Conveyor (J-164) :

- Phosphogypsum :

$CaSO_4.2H_2O$ = 35.033,5801 kg

Pengotor = 1.975,4299 kg

- Air pencuci :

Untuk mencuci 1 kg Phosphogypsum dibutuhkan air pencuci sebanyak 6 L (Abu-Eishah, 2000), **Jadi,** air pencuci yang dibutuhkan :

$$\frac{6L}{1\ kg} \times 37.009{,}0100\ kg = 222.054{,}0606\ L$$

$T_{H_2O} = 30^0C$; ρ_{air} = 0,99568 kg/L (Geankoplis, 1983) :

Massa H_2O = 222.054,0606 L x 0,99568 kg/L = 221.094,7868 kg

Phosphogypsum yang terlarut dengan air pencuci = 1,98 g/L (Abu-Eishah, 2000).

$=1{,}98 \cdot 10^{-3}$ kg /L x 222.054,0606 L = 439,6670 kg

Phosphogypsum yang keluar = phosphogypsum yang masuk - yang terlarut

= (37.009,0100 - 439,6670) kg = 36.569,3430 kg

Phosphogypsum keluar :

- $CaSO_4.2H_2O$ = 94,6623 % x 36.569,3430 kg = 34.617,3812 kg
- Pengotor = 5,3377 % x 36.569,3430 kg = 1.951,9618 kg
- H_2O = $\frac{35\%}{65\%}$ x (34.617,3812 + 1.951,9618) kg = 19.691,1847 kg

Larutan pencuci keluar: - $CaSO_4.2H_2O$ = 94,6623 % x 439,6670 kg = 416,1989 kg

- Pengotor = 5,3377 % x 439,6670 kg = 23,4681 kg
- H_2O = (221.094,7868 – 19.691,1847) kg

= 201.403,6021 kg

5. Reaktor (R-210) :

Phosphogypsum masuk Reaktor :

- $CaSO_4.2\ H_2O$ = 34.617,3812 kg
- Pengotor = 1.951,9618 kg
- H_2O = 19.691,1847 kg

$CaSO_4$ yang digunakan berlebih 50 % dan konversi reaksi = 97,2 % (Abu-Eishah, 2000).

$$CaSO_4.2\ H_2O = \frac{34.617,3812\ \text{kg}}{172,1723\ \text{kg/kmol}} = 201,0624\ \text{kmol}$$

$CaSO_4.2\ H_2O$ yang bereaksi = $\frac{97,2}{150} \times 201,0624$ kmol = 134,0416 kmol

KCl = 2 x mol $CaSO_4.2\ H_2O$ yang bereaksi

= 2 x 134,0416 kmol = 268,0832 kmol.

KCl masuk reaktor = $\frac{100}{97,2} \times 268,0832$ kmol = 275,8058 kmol = 20.561,5985 kg

$$2\ KCl + CaSO_4.2\ H_2O \longrightarrow CaCl_2 + K_2SO_4 + 2\ H_2O$$

	2 KCl	$CaSO_4.2\ H_2O$	$CaCl_2$	K_2SO_4	2 H_2O
m :	275,8058	201,0624			
r :	268,0832	134,0416	134,0416	134,0416	268,0832
s :	7,7226	67,0208	134,0416	134,0416	268,0832

Larutan KCl 10 % masuk reaktor :

- KCl = 20.561,5985 kg
- Pengotor = $\frac{0,5\%}{99,5\%}$ x 20.561,5985 kg = 103,3246 kg
- H_2O = $\frac{90\%}{10\%}$ x (20.561,5985 + 103,3246) kg = 185.984,3079 kg

$$\boxed{\frac{\text{larutan amonia}}{\textit{phosphogypsum}} = 4,32}$$ (Abu-Eishah, 2000)

Komposisi larutan amonia yang digunakan :

- NH_3 = 33 %
- Isopropanol = 7 %
- H_2O = 60 % (Abu-Eishah, 2000)

Massa larutan NH_3 = 4,32 x (34.617,3812 + 1.951,9618) kg

= 157.979,5618 kg

terdiri dari :

NH_3 = 33 % x 157.979,5618 kg = 52.133,2554 kg

Isopropanol = 7 % x 157.979,5618 kg = 11.058,5693 kg

H_2O = 60 % x 157.979,5618 kg = 94.787,7371 kg

Campuran keluar reaktor :

- KCl = 7,7226 kmol x 74,551 kg / kmol = 575,7248 kg
- $CaSO_4.2\ H_2O$ = 67,0208 kmol x 172,1723 kg / kmol = 11.539,1270 kg
- $CaCl_2$ = 134,0416 kmol x 110,986 kg / kmol = 14.876,7433 kg
- K_2SO_4 = 134,0416 kmol x 174,2577 kg / kmol = 23.357,7846 kg
- NH_3 = 52.133,2554 kg
- Isopropanol = 11.058,5693 kg
- H_2O = ((268,0832 kmol x 18,015 kg / kmol) + 19.691,1847+ 185.984,3079 + 94.787,7371) kg

  = 305.292,8297 kg
- Pengotor = (1.951,9618 + 103,3246) kg = 2.055,2864 kg

Solubility KCl pada T = 30^{0}C adalah = 37 gr / 100 gr H_2O

Solubility $CaSO_4.2\ H_2O$ pada T = 30^{0}C adalah = 0,2009 gr / 100 gr H_2O

Solubility $CaCl_2$ pada T = 30^{0}C adalah = 74,5 gr / 100 gr H_2O

Solubility K_2SO_4 pada T = 30^{0}C adalah = 11,11 gr / 100 gr H_2O (Perry,7th ed)

Total padatan yang larut dalam air :

= (37 + 0,2009 + 74,5 + 11,11) gr / 100 gr H_2O = 122,8109 gr / 100 gr H_2O

Batas maksimum yang terlarut dalam air pada suhu 30^{0}C :

- KCl = $\frac{37}{122,8109} x \frac{37}{100} x 305.292,8297$ kg = 34.031,6604 kg

- $CaSO_4.2\ H_2O$ = $\frac{0,2009}{122,8109} x \frac{0,2009}{100} x 305.292,8297$ kg = 1,0033 kg

- $CaCl_2$ = $\frac{74,5}{122,8109} x \frac{74,5}{100} x 305.292,8297$ kg = 137.972,4054 kg

- K_2SO_4 = $\frac{11,11}{122,8109} x \frac{11,11}{100} x$ 305.292,8297 kg = 3.068,3706 kg

Jadi, keluar dari reaktor dan masuk ke Rotary Drum Separator I (H-220) :

Padatan:

- $CaSO_4.2H_2O$ = 11.539,1270 kg – 1,0033 kg = 11.538,1237 kg
- K_2SO_4 = 23.357,7846 kg – 3.068,3706 kg = 20.289,4140 kg

Yang terlarut dalam H_2O:

- KCl = 575,7248 kg = 0,15 %
- $CaSO_4.2H_2O$ = 1,0033 kg = 2,58.10^{-4} %
- $CaCl_2$ = 14.876,7433 kg = 3,82 %
- K_2SO_4 = 3.068,3706 kg = 0,79 %
- NH_3 = 52.133,2554 kg = 13,40 %
- Isopropanol = 11.058,5693 kg = 2,84 %
- H_2O = 305.292,8297 kg = 78,47 %
- Pengotor = 2.055,2864 kg = 0,53 %

6. Rotary Drum Separator I (H-220) :

Asumsi : kandungan retention liquid dalam cake adalah sebesar 9 % (Foust, 1980).

Cake keluar (ke M-222) :

Padatan :

- $CaSO_4.2\ H_2O$ = 11.538,1237 kg
- K_2SO_4 = 20.289,4140 kg

Retention liquid : $\frac{9\%}{91\%}$ x (11.538,1237 + 20.289,4140) kg = 3.147,7784 kg

- KCl = 0,15 % x 3.147,7784 kg = 4,6580 kg
- $CaSO_4.2\ H_2O$ = $2{,}58.10^{-4}$ % x 3.147,7784 kg = 0,0081 kg
- $CaCl_2$ = 3,82 % x 3.147,7784 kg = 120,3631 kg
- K_2SO_4 = 0,79 % x 3.147,7784 kg = 24,8252 kg
- NH_3 = 13,40 % x 3.147,7784 kg = 421,7940 kg
- Isopropanol = 2,84 % x 3.147,7784 kg = 89,4715 kg
- H_2O = 78,47 % x 3.147,7784 kg = 2.470,0298 kg
- Pengotor = 0,53 % x 3.147,7784 kg = 16,6287 kg

Filtrat keluar (ke F-225) :

- KCl = (575,7248 – 4,6580) kg = 571,0668 kg
- $CaSO_4.2\ H_2O$ = (1,0033 – 0,0081) kg = 0,9952 kg
- $CaCl_2$ = (14.876,7433 – 120,3631) kg = 14.756,3802 kg
- K_2SO_4 = (3.068,3706 – 24,8252) kg = 3.043,5453 kg
- NH_3 = (52.133,2554 – 421,7940) kg = 51.711,4614 kg
- Isopropanol = (11.058,5693 – 89,4715) kg = 10.969,0979 kg
- H_2O = (305.292,8297 – 2.470,0298) kg = 302.822,7999 kg
- Pengotor = (2.055,2864 – 16,6287) kg = 2.038,6578 kg

7. Tangki Pelarutan K_2SO_4 (M-222) :

Padatan yang larut dalam air = (11,11 + 0,2009) gr / 100 gr H_2O

= 11,3109 gr / 100 gr H_2O

Massa H_2O yang digunakan untuk melarutkan $CaSO_4.2\ H_2O$ dan K_2SO_4 pada suhu 30^0C :

- H_2O (untuk $CaSO_4.2\ H_2O$) = $\frac{11{,}3109}{0{,}2009} \times \frac{100}{0{,}2009}$ x (11.538,1237 + 0,0081) kg

= 323.349.941,8758 kg

- H_2O (untuk K_2SO_4) $= \frac{11,3109}{11,11} x \frac{100}{11,11} x (20.289,4140 + 24,8252)$ kg

$= 186.152,8145$ kg

Jadi, Untuk melarutkan K_2SO_4 dibutuhkan H_2O sebanyak 186.152,8145 kg.

Sedangkan H_2O pada retention liquid (H-220) = 2.470,0298 kg

maka :

H_2O yang ditambahkan untuk melarutkan K_2SO_4 sebanyak :

= (186.152,8145 - 2.470,0298) kg

= 183.682,7847 kg

Batas maksimum yang terlarut dalam air pada suhu 30^0C :

- $CaSO_4.2\ H_2O = \frac{0,2009}{122,8109} x \frac{0,2009}{100} x$ 186.152,8145 kg = 6,6424 kg

- $K_2SO_4 = \frac{11,11}{122,8109} x \frac{11,11}{100} x$ 186.152,8145 kg = 20.314,2392 kg

Jadi, keluar dari Tangki Pelarutan K_2SO_4 (M-222) dan masuk ke (H-230) :

Padatan:

- $CaSO_4.2H_2O$ = (11.538,1237 + 0,0081) kg – 6,6424 kg

= 11.531,4894 kg

Yang terlarut dalam H_2O:

- KCl = 4,6580 kg = $2,25.10^{-3}$ %
- $CaSO_4.2H_2O$ = 6,6424 kg = $3,21.10^{-3}$ %
- $CaCl_2$ = 120,3631 kg = $5,81.10^{-2}$ %
- K_2SO_4 = 20.314,2392 kg = 9,81 %
- NH_3 = 421,7940 kg = 0,20 %
- Isopropanol = 89,4715 kg = $4,32.10^{-2}$ %
- H_2O = 186.152,8145 kg = 89,87 %
- Pengotor = 16,6287 kg = $8,03.10^{-3}$ %

8. Rotary Drum Separator II (H-230) :

Asumsi : kandungan retention liquid dalam cake adalah sebesar 9 % (Foust, 1980).

Cake keluar (ke Pembuangan) :

Padatan :

- $CaSO_4.2\ H_2O$ = 11.531,4894 kg

Retention liquid : $\frac{9\%}{91\%}$ x 11.531,4894 kg = 1.140,4770 kg

- KCl = $2{,}25.10^{-3}$ % x 1.140,4770 kg = 0,0256 kg
- $CaSO_4.2H_2O$ = $3{,}21.10^{-3}$ % x 1.140,4770 kg = 0,0366 kg
- $CaCl_2$ = $5{,}81.10^{-2}$ % x 1.140,4770 kg = 0,6627 kg
- K_2SO_4 = 9,81 % x 1.140,4770 kg = 111,8539 kg
- NH_3 = 0,20 % x 1.140,4770 kg = 2,3224 kg
- Isopropanol = $4{,}32.10^{-2}$ % x 1.140,4770 kg = 0,4926 kg
- H_2O = 89,87 % x 1.140,4770 kg = 1.024,9914 kg
- Pengotor = $8{,}03.10^{-3}$ % x 1.140,4770 kg = 0,0916 kg

Filtrat keluar (ke F-225) :

- KCl = (4,6580 – 0,0256) kg = 4,6324 kg
- $CaSO_4.2\ H_2O$ = (6,6424 – 0,0366) kg = 6,6058 kg
- $CaCl_2$ = (120,3631– 0,6627) kg = 119,7004 kg
- K_2SO_4 = (20.314,2392 – 111,8539) kg = 20.202,3853 kg
- NH_3 = (421,7940 – 2,3224) kg = 419,4716 kg
- Isopropanol = (89,4715 – 0,4926) kg = 88,9789 kg
- H_2O = (186.152,8145 – 1.024,9914) kg =185.127,8231 kg
- Pengotor = (16,6287 – 0,0916) kg = 16,5371 kg

9. Tangki penampung filtrat (F-225) :

Filtrat masuk : (dari (H-220) dan (H-230))

- KCl = (571,0668 + 4,6324) kg = 575,6992 kg
- $CaSO_4.2\ H_2O$ = (0,9952 + 6,6058) kg = 7,6010 kg
- $CaCl_2$ = (14.756,3802 + 119,7004) kg = 14.876,0806 kg

- K_2SO_4 = (3.043,5454 + 20.202,3853) kg = 23.245,9307 kg
- NH_3 = (51.711,4614 + 419,4716) kg = 52.130,9330 kg
- Isopropanol = (10.969,0978 + 88,9789) kg = 11.058,0767 kg
- H_2O = (302.822,7999 + 185.127,8231) kg = 487.950,6230 kg
- Pengotor = (2.038,6577 + 16,5371) kg = 2.055,1948 kg

Filtrat keluar : (ke X-240)

- KCl = 575,6992 kg
- $CaSO_4.2\,H_2O$ = 7,6010 kg
- $CaCl_2$ = 14.876,0806 kg
- K_2SO_4 = 23.245,9307 kg
- NH_3 = 52.130,9330 kg
- Isopropanol = 11.058,0767 kg
- H_2O = 487.950,6230 kg
- Pengotor = 2.055,1948 kg

10. Kristaliser (X-240) :

Filtrat masuk : (dari F-225)

- KCl = 575,6992 kg
- $CaSO_4.2\,H_2O$ = 7,6010 kg
- $CaCl_2$ = 14.876,0806 kg
- K_2SO_4 = 23.245,9307 kg
- NH_3 = 52.130,9330 kg
- Isopropanol = 11.058,0767 kg
- H_2O = 487.950,6230 kg
- Pengotor = 2.055,1948 kg

Solubility KCl pada T = 5^0C adalah = 29,3 gr / 100 gr H_2O

Solubility $CaSO_4.2\,H_2O$ pada T = 5^0C adalah = 0,1844 gr / 100 gr H_2O

Solubility $CaCl_2$ pada T = 5^0C adalah = 62,25 gr / 100 gr H_2O

Solubility K_2SO_4 pada T = 5^0C adalah = 6,4067 gr / 100 gr H_2O (Perry,7^{th} ed)

Padatan yang larut dalam air :

= (29,3 + 0,1844 + 62,25 + 6,4067) gr / 100 gr H_2O

= 98,1411 gr / 100 gr H_2O

Batas maksimum yang terlarut dalam air pada suhu 5^0C :

- KCl = $\frac{29,3}{98,1411} x \frac{29,3}{100} x\, 487.950,6230$ kg = 42.683,5169 kg
- $CaSO_4.2\,H_2O$ = $\frac{0,1844}{98,1411} x \frac{0,1844}{100} x\, 487.950,6230$ kg = 1,6906 kg
- $CaCl_2$ = $\frac{62,25}{98,1411} x \frac{62,25}{100} x\, 487.950,6230$ kg = 192.665,3727 kg
- K_2SO_4 = $\frac{6,4067}{98,1411} x \frac{6,4067}{100} x\, 487.950,6230$ kg = 2.040,7685 kg

Jadi, keluar dari kristaliser (X-240) dan masuk menuju (H-250) :

Kristal :

- $CaSO_4.2\,H_2O$ = (7,6010 - 1,6906) kg = 5,9104 kg
- K_2SO_4 = (23.245,9307 - 2.040,7685) kg = 21.205,1622 kg
- Pengotor = 0,5 % x 2.055,1948 kg = 10,2760 kg

Mother liquor :

- KCl = 575,6992 kg = 0,10 %
- $CaSO_4.2\,H_2O$ = 1,6906 kg = $2,96.10^{-4}$ %
- $CaCl_2$ = 14.876,0806 kg = 2,61 %
- K_2SO_4 = 2.040,7685 kg = 0,36 %
- NH_3 = 52.130,9330 kg = 9,13 %
- Isopropanol = 11.058,0767 kg = 1,94 %
- H_2O = 487.950,6230 kg = 85,50 %
- Pengotor = (2.055,1948 – 10,2760) kg = 2.044,9188 kg = 0,36 %

11. Rotary Drum Separator III (H-250) :

Asumsi : kandungan retention liquid dalam cake adalah sebesar 9 % (Foust, 1980).

Cake keluar (ke B-260) :

Padatan :

- $CaSO_4.2\ H_2O$ = 5,9104 kg
- K_2SO_4 = 21.205,1622 kg
- Pengotor = 10,2760 kg

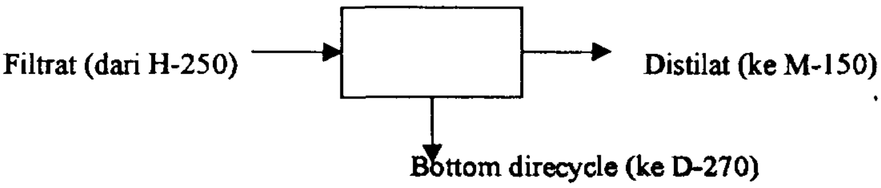
Retention liquid : $\frac{9\%}{91\%}$ x (5,9104 + 21.205,1622 +10,2760) kg = 2.098,8147 kg

- KCl = 0,10 % x 2.098,8147 kg = 2,1173 kg
- $CaSO_4.2\ H_2O$ = 2,96.10^{-4} % x 2.098,8147 kg = 0,0062 kg
- $CaCl_2$ = 2,61 % x 2.098,8147 kg = 54,7105 kg
- K_2SO_4 = 0,36 % x 2.098,8147 kg = 7,5054 kg
- NH_3 = 9,13 % x 2.098,8147 kg = 191,7246 kg
- Isopropanol = 1,94 % x 2.098,8147 kg = 40,6689 kg
- H_2O = 85,50 % x 2.098,8147 kg = 1.794,5611 kg
- Pengotor = 0,36 % x 2.098,8147 kg = 7,5207 kg

Filtrat keluar (ke D-270) :

- KCl = (575,6992 – 2,1173) kg = 573,5819 kg
- $CaSO_4.2\ H_2O$ = (1,6906 – 0,0062) kg = 1,6844 kg
- $CaCl_2$ = (14.876,0806 – 54,7105) kg = 14.821,3701 kg
- K_2SO_4 = (2.040,7685 – 7,5054) kg = 2.033,2631 kg
- NH_3 = (52.130,9330 – 191,7246) kg = 51.939,2084 kg
- Isopropanol = (11.058,0767 – 40,6689) kg = 11.017,4078 kg
- H_2O = (487.950,6230 – 1.794,5611) kg = 486.156,0619 kg
- Pengotor = (2.044,9188 – 7,5207) kg = 2.037,3981 kg

12. Menara Distilasi (D-270) :



Filtrat masuk (dari H-250) :

- KCl = 573,5819 kg / 74,551 kg/kmol = 7,6938 kmol
- $CaSO_4.2\ H_2O$ = 1,6844 kg / 172,1723 kg/kmol = 0,0098 kmol
- $CaCl_2$ = 14.821,3701 kg / 110,986 kg/kmol = 133,5427 kmol
- K_2SO_4 = 2.033,2631 kg / 174,2577 kg/kmol = 11,6681 kmol
- NH_3 = 51.939,2084 kg / 17,031 kg/kmol = 3.049,6864 kmol
- Isopropanol = 11.017,4078 kg / 60,096 kg/kmol = 183,3301 kmol
- H_2O = 486.156,0619 kg / 18,015 kg/kmol = 26.986,1816 kmol
- Pengotor = 2.037,3981 kg / 89,587 kg/kmol = 22,7421 kmol

Distilat keluar (ke M-150) :

Diinginkan fraksi mol NH_3 pada produk keluar di bagian distilat sebesar 99,5 % mol dan sisanya adalah H_2O.

- NH_3 = 3.049 kmol = 51.927,5190 kg
- $H_2O = \frac{0,005}{0,995} \times 3.049$ kmol = 15,3216 kmol = 276,0186 kg

Bottom keluar (direcycle ke D-270) :

- KCl = 573,5819 kg
- $CaSO_4.2\ H_2O$ = 1,6844 kg
- $CaCl_2$ = 14.821,3701 kg
- K_2SO_4 = 2.033,2631 kg
- NH_3 = (51.939,2084 - 51.927,5190) kg = 11,6894 kg
- Isopropanol = 11.017,4078 kg
- H_2O = (486.156,0619 - 276,0186) kg = 485.880,0433 kg
- Pengotor = 2.037,3981 kg

13. Tangki Pelarutan NH_3 (M-150) :

Larutan NH_3 keluar (ke R-210) :

- NH_3 = 52.133,2554 kg
- Isopropanol = 11.058,5693 kg
- H_2O = 94.787,7371 kg

Larutan NH_3 masuk (ke M-150) :

- NH_3 (dari F-140) = (52.133,2554 - 51.927,5190) kg = 205,7364 kg
- NH_3 (dari D-270) = 51.927,5190 kg
- Isopropanol (dari F-130) = 11.058,5693 kg
- H_2O (dari utilitas) = (94.787,7371 - 276,0186) kg = 94.511,7185 kg
- H_2O (dari D-270) = 276,0186 kg

14. Rotary Dryer (B-260) :

Cake masuk (dari H-250) :

- KCl = 2,1173 kg
- $CaSO_4.2\,H_2O$ = (5,9104 + 0,0062) kg = 5,9166 kg
- $CaCl_2$ = 54,7105 kg
- K_2SO_4 = (21.205,1622 + 7,5054) kg = 21.212,6676 kg
- NH_3 = 191,7246 kg
- Isopropanol = 40,6689 kg
- H_2O = 1.794,5611 kg
- Pengotor = (10,2760 + 7,5207) kg = 17,7967 kg

Komponen dry solid	Massa, kg	% berat
KCl	2,1173	$9,94.10^{-3}$
$CaSO_4.2\,H_2O$	5,9166	$2,78.10^{-2}$
$CaCl_2$	54,7105	0,26
K_2SO_4	21.212,6676	99,62
Pengotor	17,7967	$8,36.10^{-2}$
Total	21.293,2087	100,00

Kadar liquid masuk rotary dryer :

$$= \frac{\text{massa } H_2O + \text{amonia} + \text{isopropanol} \quad \text{masuk rotary dryer}}{\text{total massa bahan masuk rotary dryer}} \times 100\,\%$$

$$= \frac{1.794{,}5611 + 191{,}7246 + 40{,}6689}{21.293{,}2087} \times 100\% = 9{,}52\,\%$$

Kadar H_2O yang keluar diharapkan = 0,1 %

$$H_2O \text{ dalam bahan keluar} = \frac{0{,}1\,\%}{99{,}9\,\%} \, x \; 21.293{,}2087 \text{ kg}$$

$$= 21{,}3146 \text{ kg}$$

Liquid yang menguap = jml liquid dlm bahan masuk – jml H_2O dlm bhn keluar

= (1.794,5611 + 191,7246 + 40,6689) kg – 21,3146 kg

= 2.005,6400 kg

Padatan (dry solid) yang terikut keluar = 0,5 % x dry solid yang masuk

= 0,5 % x 21.293,2087 kg = 106,4660 kg

terdiri dari :

- KCl = $9{,}94.10^{-3}$ % x 106,4660 kg = 0,0106 kg
- $CaSO_4.2\,H_2O$ = $2{,}78.10^{-2}$ % x 106,4660 kg = 0,0296 kg
- $CaCl_2$ = 0,26 % x 106,4660 kg = 0,2736 kg
- K_2SO_4 = 99,62 % x 106,4660 kg = 106,0633 kg
- Pengotor = $8{,}36.10^{-2}$ % x 106,4660 kg = 0,0890 kg

Kristal K_2SO_4 Keluar (ke H-262) :

- KCl = 0,0106 kg
- $CaSO_4.2\,H_2O$ = 0,0296 kg
- $CaCl_2$ = 0,2736 kg
- K_2SO_4 = 106,0633 kg
- Pengotor = 0,0890 kg
- Liquid yang menguap = 2.005,6400 kg

Kristal K_2SO_4 Keluar (ke J-266) :

- KCl = (2,1173 - 0,0106) kg = 2,1067 kg
- $CaSO_4.2\ H_2O$ = (5,9166 - 0,0296) kg = 5,8870 kg
- $CaCl_2$ = (54,7105 - 0,2736) kg = 54,4369 kg
- K_2SO_4 = (21.212,6676 -106,0633) kg = 21.106,6043 kg
- H_2O = 21,3146 kg
- Pengotor = (17,7967 - 0,0890) kg = 17,7077 kg

15. Cyclone (H-262) :

Asumsi : 0,5 % dari dry solid keluar ke udara

Kristal K_2SO_4 Keluar (ke Udara) :

- KCl = 0,5 % x 0,0106 kg = $5,2932.10^{-5}$ kg
- $CaSO_4.2\ H_2O$ = 0,5 % x 0,0296 kg = $1,4792.10^{-4}$ kg
- $CaCl_2$ = 0,5 % x 0,2736 kg = 0,0014 kg
- K_2SO_4 = 0,5 % x 106,0633 kg = 0,5303 kg
- Pengotor = 0,5 % x 0,0890 kg = $4,4492.10^{-4}$ kg

Kristal K_2SO_4 Keluar (ke J-266) :

- KCl = (0,0106 - $5,2932.10^{-5}$) kg = 0,0106 kg
- $CaSO_4.2\ H_2O$ = (0,0296 - $1,4792.10^{-4}$) kg = 0,0295 kg
- $CaCl_2$ = (0,2736 - 0,0014) kg = 0,2722 kg
- K_2SO_4 = (106,0633 - 0,5303) kg = 105,5330 kg
- Pengotor = (0,0890 - $4,4492.10^{-4}$) kg = 0,0886 kg

16. Screw Conveyor (J-266) :

Kristal K_2SO_4 Masuk (dari B-260 dan H-262) :

- KCl = (2,1067 + 0,0106) kg = 2,1173 kg
- $CaSO_4.2\ H_2O$ = (5,8870 + 0,0295) kg = 5,9165 kg
- $CaCl_2$ = (54,4369 + 0,2722) kg = 54,7091 kg
- K_2SO_4 = (21.106,6043 + 105,5330) kg = 21.212,1373 kg
- H_2O = 21,3146 kg
- Pengotor = (17,7077 + 0,0886) kg = 17,7963 kg

Kristal K_2SO_4 Keluar (ke F-267) :

- KCl = 2,1173 kg
- $CaSO_4.2\ H_2O$ = 5,9165 kg
- $CaCl_2$ = 54,7091 kg
- K_2SO_4 = 21.212,1373 kg
- H_2O = 21,3146 kg
- Pengotor = 17,7963 kg

17. Menara Absorber (D-265) :

Dari Neraca Panas didapatkan :

massa udara kering = 23.909,4082 kg

Berdasarkan Humidity chart (Geankoplis, 2nd ed) pada suhu = 30°C dengan percentage humidity (H_p) = 80 % diperoleh :

Humidity (H) = 0,023 kg H_2O/kg udara kering

Kandungan H_2O dalam udara yang harus dihilangkan :

= 0,023 kg H_2O/kg udara kering x 23.909,4082 kg = 549,9164 kg

Jadi, massa udara yang masuk ke dalam menara absorber (D-265) sebesar :

= (23.909,4082 + 549,9164) kg = 24.459,3246 kg

Volume silika gel = 0,3-0,45 cm^3/gr (Ullman, p. 9-7)

Diambil : volume silika gel = 0,4 cm^3/gr

ρ air pada 30°C = 995,68 kg/m^3 (Geankoplis, 1997)

$$\text{Volume } H_2O \text{ dalam udara masuk} = \frac{549{,}9164 \text{ kg}}{995{,}68 \text{ kg/m}^3}$$

$$= 0{,}5523 \text{ m}^3 = 0{,}5523.10^6 \text{ cm}^3$$

$$\text{Massa silika gel} = \frac{0{,}5523.10^6 \text{ cm}^3}{0{,}4 \text{ cm}^3/\text{gr}} = 1.380.750 \text{ gr} = 1.380{,}75 \text{ kg}$$

APPENDIX B
NERACA PANAS

APPENDIX B
NERACA PANAS

Operasi pabrik= 24 jam/hari; 330 hari/tahun

Suhu basis = 25 ^{0}C

Basis perhitungan = 1 hari

Satuan panas : kiloJoule

Persamaan empiris hubungan antara suhu dengan kapasitas panas (Cp) dari Himmelblau edisi empat, Appendix E :

(1) Cp (J/mol ^{0}K) = a + b (T) + c (T^2) + d (T^3) untuk cairan / gas

Komponen	Rumus	Suhu	a	b.10^2	c.10^5	d.10^9
$H_2O_{(l)}$	1	K	18,2964	47,212	-133,88	1.314,2

Data kapasitas panas (*Perry, 7th ed)* :

- KCl = 51,7160 kJ/kmol.K
- $CaSO_4.2H_2O$ = 136,3984 kJ/kmol.K
- $CaCl_2$ = 74,3605 kJ/kmol.K
- K_2SO_4 = 131,1986 kJ/kmol.K
- Isopropanol = 141,8965 kJ/kmol.K
- Pengotor = 0,5 kJ/kg.K (asumsi)
- Ethylene glycol ($C_2H_6O_2$) = 92,8538 kJ/kmol.K

Data panas pembentukan :

- $KCl_{(c)}$ = -104,348 kkal/kmol = -436,952 kJ/kmol
- $CaSO_4.2H_2O_{(c)}$ = -479,33 kkal/kmol = - 2005,5167 kJ/kmol
- $CaCl_{2(c)}$ = -209,15 kkal/kmol = -875,0836 kJ/kmol
- $K_2SO_{4(c)}$ = -342,65 kkal/kmol = -1433,6476 kJ/kmol
- $H_2O_{(l)}$ = -68,3174 kkal/kmol = -285,84 kJ/kmol

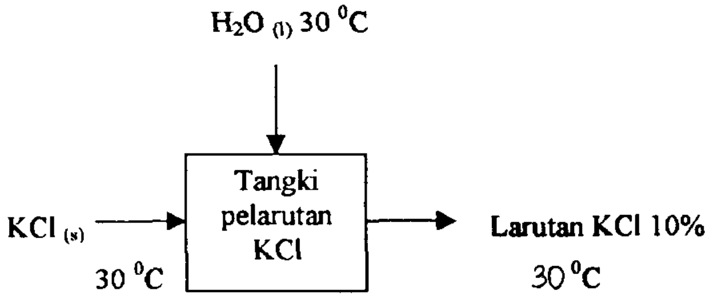
Data panas pelarutan :

- KCl = -18,4263 kJ/kg
- $CaSO_4.2H_2O$ = -0,7531 kJ/kg
- $CaCl_2$ = 20,5016 kJ/kg
- K_2SO_4 = -26,4429 kJ/kg
- Amonia = -226,15 kJ/kg
- Isopropanol = -51,0427 kJ/kg

Panas laten (*Kern, 1965*) :

- amonia = 246,556 kJ/kg
- isopropanol = 293,408 kJ/kg
- H_2O = 216,961 kJ/kg

1. Tangki pelarutan KCl (M-120)



$$\int_{298}^{303} Cp\ H_2O_{(l)}\ dT = 374{,}6764\ J / mol = 374{,}6764\ kJ/kmol$$

Entalpi bahan masuk :

1. Entalpi $KCl_{(s)}$ = m . Cp . ($T_{in} - T_{ref}$)

$$= \frac{20.561{,}5985}{74{,}551} \times 51{,}7160 \times (303\text{-}298)$$

$$= 71.317{,}8648\ kJ$$

2. Entalpi pengotor = m . Cp . ($T_{in} - T_{ref}$)

$$= 103{,}3246 \times 0{,}5 \times (303\text{-}298) = 258{,}3115\ kJ$$

3. Entalpi $H_2O_{(l)}$ $= m \cdot \int_{298}^{303} Cp\, dT$

$$= \frac{185.984,3079}{18,015} \times 374,6764 = 3.868.106,0750 \text{ kJ}$$

Total entalpi bahan masuk = 71.317,8648 + 258,3115 + 3.868.106,0750

= 3.939.682,2513 kJ

Panas pelarutan KCl = 20.561,5985 kg x (-18,4263) kJ/kg

= - 378.874,1824 kJ

Asumsi : panas yang hilang = 10 % dari entalpi bahan masuk

Panas yang hilang = 10 % x 3.939.682,2513 kJ

= 393.968,2251 kJ

Entalpi bahan masuk + panas pelarutan = Entalpi bahan keluar + Q loss

Entalpi bahan keluar = entalpi bahan masuk + panas pelarutan – Q loss

= 3.939.682,2513 + 378.874,1824 - 393.968, 2251

= 3.924.588,2086 kJ

Trial :

$$3.924.588,2086 = \left[\frac{20.561,5985}{74,551} \times 51,7160 \times (T-298) \right] + \left[103,3246 \times 0,5 \times (T-298) \right] + \left[\frac{185.984,3079}{18,015} \times \int_{298}^{T} Cp\, H_2O_{(l)}\, dT \right]$$

T = 302,98 K = 29,98 ^{0}C ≈ 30 °C

Entalpi bahan keluar :

1. Entalpi KCl = m . Cp . ($T_{out} - T_{ref}$)

$$= \frac{20.561,5985}{74,551} \times 51,7160 \times (302,98-298)$$

$$= 71.044,8357 \text{ kJ}$$

2. Entalpi pengotor = m . Cp . ($T_{out} - T_{ref}$)

= 103,3246 x 0,5 x (302,98-298) = 257,3226 kJ

3. Entalpi $H_2O = m \, . \int_{298}^{302,98} Cp \, dT$

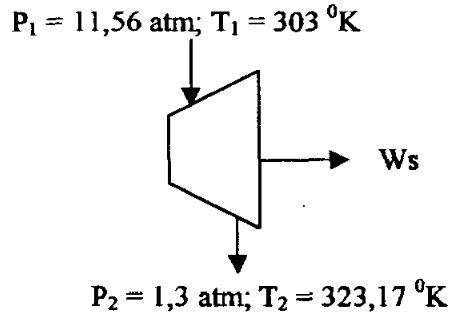
$$= \frac{185.984{,}3079}{18{,}015} \times 373{,}2409$$

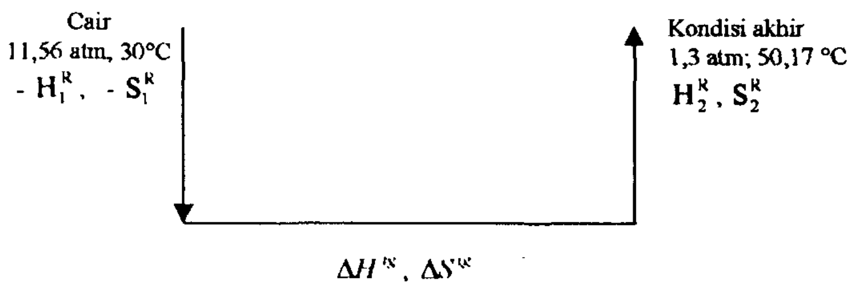
$$= 3.853.286{,}0503 \text{ kJ}$$

Total entalpi bahan keluar = 71.044,8357 + 257,3226 + 3.853.286,0503

= 3.924.588,2086 kJ

2. Expander (G-141)





Menghitung suhu keluar expander :

Sebagai langkah awal perhitungan, amonia dianggap sebagai gas ideal.

$$\frac{(Cp^{ig})_S}{R} = A + \left[B.T_0 + \left(C.T_0^2 + \frac{D}{\gamma^2 T_0^2} \right) \left(\frac{\gamma + 1}{2} \right) \right] \left(\frac{\gamma - 1}{\ln \gamma} \right) \quad \ldots\ldots\ldots\ldots (5.17)$$

$$\frac{(Cp^{ig})_H}{R} = A + \frac{B}{2} T_0 (\gamma+1) + \frac{C}{3} T_0^2 (\gamma^2 + \gamma + 1) + \frac{D}{\gamma . T_0^2} \quad \ldots\ldots\ldots\ldots (4.8)$$

Dari Smith Van Ness Appendix C, untuk amonia didapat :

$A = 22{,}626$; $B = -100{,}75.10^{-3}$; $C = 192{,}71.10^{-6}$; $D = 0$

Dimana : $\gamma = \dfrac{T_2}{T_1}$ (Smith Van Ness, hal 121)

$$\frac{(Cp^{ig})_S}{R} = \left[-0{,}10075(303) + \left(192{,}71.10^{-6}(303)^2\right)\left(\frac{(T_2/303)+1}{2}\right)\right]\left(\frac{(T_2/303)-1}{\ln(T_2/303)}\right) +$$

22,626

$$\frac{(Cp^{ig})_H}{R} = 22{,}626 - \{(0{,}10075/2)(303)((T_2/303)+1)\} + \{(192{,}71.10^{-6}/3)(303)^2$$

$$((T_2/303)^2 + (T_2/303) + 1)\}$$

$\Delta H = (Cp^{ig})_H (T_2 - T_1) + H_2^R - H_1^R$ ....(6.68)

$\Delta S = (Cp^{ig})_S \ln (T_2 / T_1) - R (\ln (P_2 / P_1) + S_2^R - S_1^R$ ....(6.69)

Dengan asumsi perhitungan awal, amonia dianggap sebagai gas ideal maka harga H_2^R, $- H_1^R$ dan S_2^R ,- S_1^R dianggap = 0, sehingga persamaan diatas menjadi :

$\Delta H = (Cp^{ig})_H (T_2 - T_1)$

$\Delta S = (Cp^{ig})_S \ln (T_2 / T_1) - R (\ln (P_2 / P_1))$

Untuk proses isentropis $\Delta S = 0$, maka :

$(Cp^{ig})_S \ln (T_2 / T_1) = R (\ln (P_2 / P_1))$

$$\frac{(Cp^{ig})_S}{R} \ln (T_2 / T_1) = \ln (P_2 / P_1) = \ln (1{,}3172/11{,}7132) = -2{,}1852$$

$$T_2 = \exp\left(\frac{-2{,}1852}{(Cp^{ig})_S / R} + \ln 303\right)$$

Dengan mengambil nilai awal untuk harga T_2 kemudian diiterasi , dengan

iterasi 1 = 200 ^{0}K didapat T_2 = 241,58 ^{0}K

iterasi 2 = 250 ^{0}K didapat T_2 = 241,01 ^{0}K

setelah beberapa kali iterasi maka didapatkan harga T_2 yang baru = 240,98 ^{0}K.

Dari App. B (Smith Van Ness) didapat :

Tc = 405,7 ^{0}K ; Pc = 112,8 bar ; ω = 0,253

$Tr_1 = T_1 / Tc$ = 303 / 405,7 = 0,7469

$Pr_1 = P_1 / Pc$ = 11,56 / 112,8 = 0,1038

$$S_1^R = \text{-Pr.R}\left(\frac{0,675}{(T/Tc)^{2,6}} + \omega\frac{0,722}{(T/Tc)^{5,2}}\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots(6.63)$$

$$= -0,1038 \times 8,314\left(\frac{0,675}{(303/405,7)^{2,6}} + 0,253\frac{0,722}{(303/405,7)^{5,2}}\right)$$

$$= -1,9638 \text{ J/mol } ^0\text{K}$$

$$H_1^R = \text{Pr. R. Tc}\left[B^0 - Tr\frac{dB^0}{dTr} + \omega\left(B^1 - Tr\frac{dB^1}{dTr}\right)\right] \qquad \ldots\ldots\ldots\ldots(6.62)$$

$$= 0,1038 \times 8,314 \times 405,7 \times$$

$$\left(0,083 - \frac{0,422}{(303/405,7)^{1,6}}\right) - \left(\frac{303}{405,7}\right)\left(\frac{0,675}{(303/405,7)^{2,6}}\right) +$$

$$0,253\left(0,139 - \frac{0,172}{(303/405,7)^{4,2}}\right) - \left(\frac{303}{405,7}\right)\left(\frac{0,722}{(303/405,7)^{5,2}}\right)$$

$$= -584,3630 \text{ J/mol}$$

Untuk menghitung S_2^R dan H_2^R diambil hasil trial $T_2 = 240,98\ ^0K$, maka :

$Tr_2 = T_2 / Tc = 240,98 / 450,7 = 0,5940$

$Pr_2 = P_2 / Pc = 1,3 / 112,8 = 0,0117$

Dengan persamaan (6.63) didapat :

$S_2^R = -4,6229$ J/mol ^0K

Proses yang terjadi isentropik maka :

$0 = (Cp^{ig})_S \ln (T_2 / 303) - 8,314 (\ln (11,7132 / 1,3172)) - 4,6229 + 1,9638$

$\ln (T_2 / 303) = 20,8269 / (Cp^{ig})_S$

$$T_2 = \exp\left(\frac{20,8269}{(Cp^{ig})_S / R} + \ln 303\right)$$

Dengan iterasi 1 = 300 ^0K didapat $T_2 = 324,78\ ^0K$

iterasi 2 = 350 ^0K didapat $T_2 = 321,58\ ^0K$

setelah beberapa kali iterasi maka didapat harga $T_2 = 323,17\ ^0K$

Menghitung harga S_2^R dan H_2^R yang baru dengan $T_2 = 323,17\ ^0K$.

$Tr_2 = T_2 / Tc = 323,17 / 450,7 = 0,7966$

$Pr_2 = P_2 / Pc = 1,3 / 112,8 = 0,0117$

Dari persamaan (6.62) dan (6.63) didapat :

S_2^R = -1,5666 J/mol ^{0}K dan H_2^R = -524,1522 J/mol

Harga $(Cp^{ig})_H$ untuk T_2 = 323,17 ^{0}K sebesar 9,9791 J/mol ^{0}K dan

$(Cp^{ig})_S$ = -26,7846 J/mol ^{0}K

$\Delta H = (Cp^{ig})_H (T_2 - T_1) + H_2^R - H_1^R$

= 9,9791 (323,17-303) – 524,1522 + 584,3630

= 261,4889 J/mol

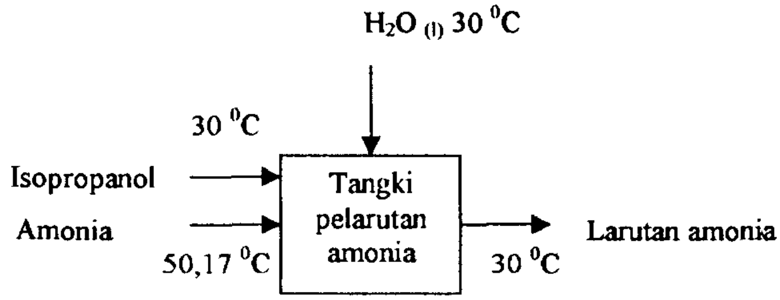
Ws isentropik = ΔH = 261,4889 J/mol

$\Delta S = (Cp^{ig})_S \ln (T_2 / T_1) - R (\ln (P_2 / P_1) + S_2^R - S_1^R$

= -26,7846 ln (323,17/303) – 8,314 (ln (11,7132/1,3172)) -1,5666 + 1,9638

= -19,4972 J/mol ^{0}K

3. Tangki pelarutan amonia (M-150)



$$\int_{298}^{323,17} Cp\ NH_{3\,(l)}\, dT = R \int_{298}^{323,17} \frac{Cp}{R} dT = 2.078,8492 \text{ J/mol} = 2.078,8492 \text{ kJ/kmol}$$

Entalpi bahan masuk :

1. Entalpi amonia $= m \cdot \int_{298}^{323,17} Cp\, dT$

$$= \frac{52.133,2554}{17,031} \times 2.078,8492$$

= 6.363.523,9435 kJ

2. Entalpi isopropanol $= m \cdot Cp \cdot (T_{in} - T_{ref})$

$$= \frac{11.058,5693}{60,096} \times 141,8965 \times (303\text{-}298)$$

$$= 130.555,4678 \text{ kJ}$$

3. Entalpi $H_2O_{(l)}$ $= m \cdot \int_{298}^{303} Cp\, dT$

$$= \frac{94.787,7371}{18,015} \times 374,6764$$

$$= 1.971.397,6187 \text{ kJ}$$

Total entalpi bahan masuk = 6.363.523,9435 + 130.555,4678 + 1.971.397,6187

= 8.465.477,0300 kJ

Panas pelarutan amonia = 52.133,2554 kg x (-226,15) kJ/kg

= -11.789.935,7087 kJ

Panas pelarutan isopropanol = 11.058,5693 kg x (-51,0427) kJ/kg

= - 564.459,2352 kJ

Total panas pelarutan = -11.789.935,7087 - 564.459,2352

= -12.354.394,9439 kJ

Entalpi bahan keluar :

1. Entalpi amonia $= m \cdot \int_{298}^{303} Cp\, dT$

$$= \frac{52.133,2554}{17,031} \times 405,4234 = 1.241.033,5070 \text{ kJ}$$

2. Entalpi isopropanol $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{11.058,5693}{60,096} \times 141,8965 \times (303\text{-}298)$$

$$= 130.555,4678 \text{ kJ}$$

3. Entalpi $H_2O_{(l)} = m \cdot \int_{298}^{303} Cp\ dT$

$$= \frac{94.787,7371}{18,015} \times 374,6764$$

$$= 1.971.397,6187 \text{ kJ}$$

Total entalpi bahan keluar = 1.241.033,5070 + 130.555,4678 + 1.971.397,6187

= 3.342.986,5935 kJ

Entalpi bahan masuk + panas pelarutan = entalpi bahan keluar + Q serap

Q serap = 8.465.477,0300 + 12.354.394,9439 - 3.342.986,5935

Q serap = 17.476.885,3804 kJ

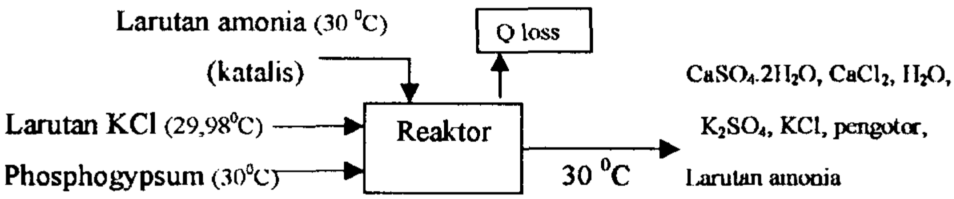
Kebutuhan air pendingin :

$$Q \text{ serap} = m \cdot \int_{302}^{314} Cp\ dT$$

$$17.476.885,3804 \text{ kJ} = \frac{m}{18,015} \times 905,8857$$

Massa air pendingin = 347.556,0881 kg

4. Reaktor (R-210)



Entalpi bahan masuk :

a. Entalpi larutan KCl = 3.924.588,2086 kJ

b. Entalpi phosphogypsum = (137.122,9695 + 409.537,7294 + 4.879,9045) kJ

= 551.540,6034 kJ

1. Entalpi $CaSO_4.2H_2O$ = m . Cp . ($T_{in} - T_{ref}$)

$$= \frac{34.617,3812}{172,1723} \times 136,3984 \times (303\text{-}298)$$

= 137.122,9695 kJ

2. Entalpi H_2O = m . $\int_{298}^{303} Cp\, dT$

$$= \frac{19.691,1847}{18,015} \times 374,6764$$

= 409.537,7294 kJ

3. Entalpi pengotor = m . Cp . ($T_{in} - T_{ref}$)

= 1.951,9618 x 0,5 x (303-298)

= 4.879,9045 kJ

c. Entalpi larutan amonia = 3.342.986,5935 kJ

Total entalpi bahan masuk = (3.924.588,2086 + 551.540,6034 + 3.342.986,5935) kJ

= 7.819.115,4055 kJ

Reaksi : **2 KCl + $CaSO_4.2H_2O$ ⟶ K_2SO4 + $CaCl_2$ + 2 H_2O**

ΔH^0_R = (ΔH^0_f K_2SO_4 + ΔH^0_f $CaCl_2$ + 2 ΔH^0_f H_2O) – (2 ΔH^0_f KCl + ΔH^0_f $CaSO_4.2H_2O$)

= ((-1.433,6476).134,0416)+((-875,0836).134,0416)+(2.(-285,84).268,0832)) - ((2.(-436,952).268,0832)+((-2.005,5167).134,0416))

= 40.377,8203 kJ

Asumsi : panas yang hilang = 10 % dari entalpi bahan masuk

Panas yang hilang = 10 % x 7.819.115,4055 kJ

= 781.911,5405 kJ

Entalpi bahan masuk = entalpi bahan keluar + panas reaksi + Q loss

entalpi bahan keluar = entalpi bahan masuk – panas reaksi – Q loss

= 7.819.115,4055 – 40.377,8203 – 781.911,5405

= 6.996.826,0447 kJ

$$6.996.826,0447 = \left[\frac{575,7248}{74,551} \times 51,716 \times (T-298)\right] + \left[\frac{11.539,1270}{172,1723} \times 136,3984 \times (T-298)\right] + \left[\frac{14.876,7433}{110,986} \times 74,3605 \times (T-298)\right] + \left[\frac{23.357,7846}{174,2577} \times 131,1986 \times (T-298)\right] + \left[\frac{52.133,2554}{17,031} \times \int_{298}^{T} Cp\, dT\right] + \left[\frac{11.058,5693}{60,096} \times 141,8965 \times (T-298)\right] + \left[\frac{305.292,8297}{18,015} \times \int_{298}^{T} Cp\, dT\right] + \left[2.055,2864 \times 0,5 \times (T-298)\right]$$

T = 302,42 K = 29,42 ^{0}C

Entalpi bahan keluar :

a. Entalpi KCl $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{575,7248}{74,551} \times 51,716 \times (302,42-298)$$

$= 1.776,2437$ kJ

b. Entalpi $CaSO_4.2\,H_2O$ $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{11.539,1270}{172,1723} \times 136,3984 \times (302,42-298)$$

$= 40.428,0873$ kJ

c. Entalpi $CaCl_2$ $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{14.876,7433}{110,986} \times 74,3605 \times (302,42-298)$$

$= 44.080,4701$ kJ

d. Entalpi K_2SO_4 $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{23.357,7846}{174,2577} \times 131,1986 \times (302,42-298)$$

$= 77.773,7642$ kJ

e. Entalpi amonia $= m \cdot \int_{298}^{302,42} Cp\, dT$

$$= \frac{52.133,2554}{17,031} \times 358,4314$$

$$= 1.097.187,2264 \text{ kJ}$$

f. Entalpi isopropanol $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{11.058,5693}{60,096} \times 141,8965 \times (302,42-298)$$

$$= 115.475,3554 \text{ kJ}$$

g. Entalpi $H_2O_{(l)}$ $= m \cdot \int_{298}^{302,42} Cp\, dT$

$$= \frac{305.292,8297}{18,015} \times 331,3687$$

$$= 5.615.570,1831 \text{ kJ}$$

h. Entalpi pengotor $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= 2.055,2864 \times 0,5 \times (302,42-298)$$

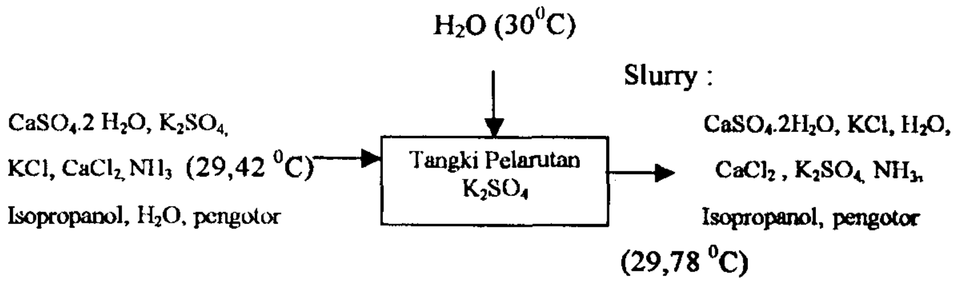
$$= 4.544,7145 \text{ kJ}$$

Total entalpi bahan keluar

= (1.776,2437 + 40.428,0873 + 44.080,4701 + 77.773,7642 + 1.097.187,2264 + 115.475,3554 + 5.615.570,1831 + 4.544,7145) kJ

= 6.996.826,0447 kJ

5. Tangki pelarutan K_2SO_4 (M-222)



Entalpi bahan masuk :

1. Entalpi KCl $= m \cdot Cp \cdot (T_{in} - T_{ref})$

$$= \frac{4{,}6580}{74{,}551} \times 51{,}716 \times (302{,}42\text{-}298)$$

$$= 14{,}2901 \text{ kJ}$$

2. Entalpi $CaSO_4.2H_2O$ $= m \cdot Cp \cdot (T_{in} - T_{ref})$

$$= \frac{11.538{,}1318}{172{,}1723} \times 136{,}3984 \times (302{,}42\text{-}298)$$

$$= 40.424{,}6005 \text{ kJ}$$

3. Entalpi $CaCl_2$ $= m \cdot Cp \cdot (T_{in} - T_{ref})$

$$= \frac{120{,}3631}{110{,}986} \times 74{,}3605 \times (302{,}42\text{-}298)$$

$$= 356{,}6414 \text{ kJ}$$

4. Entalpi K_2SO_4 $= m \cdot Cp \cdot (T_{in} - T_{ref})$

$$= \frac{20.314{,}2392}{174{,}2577} \times 131{,}1986 \times (302{,}42\text{-}298)$$

$$= 67.639{,}7559 \text{ kJ}$$

5. Entalpi amonia $= m \cdot \int_{298}^{302,42} Cp\, dT$

$$= \frac{421{,}7940}{17{,}031} \times 358{,}4314$$

$$= 8.877{,}0015 \text{ kJ}$$

6. Entalpi isopropanol $= m \cdot Cp \cdot (T_{in} - T_{ref})$

$$= \frac{89{,}4715}{60{,}096} \times 141{,}8965 \times (302{,}42\text{-}298)$$

$$= 934{,}2758 \text{ kJ}$$

7. Entalpi $H_2O_{(l)}$ $= m \cdot \int_{298}^{302,42} Cp\, dT$

$$= \frac{186.152{,}8145}{18{,}015} \times 331{,}3687 = 3.424.103{,}3294 \text{ kJ}$$

8. Entalpi pengotor $= m \cdot Cp \cdot (T_{in} - T_{ref})$

$= 16,6287 \times 0,5 \times (302,42-298)$

$= 36,7699$ kJ

Total entalpi bahan masuk

= (14,2901 + 40.424,6005 + 356,6414 + 67.639,7559 + 8.877,0015 + 934,2758 + 3.424.103,3294 + 36,7699) kJ

= 3.542.386,6645 kJ

Panas pelarutan :

1. KCl = 4,6580 kg x (-18,4263) kJ/kg

   = - 85,8297 kJ

2. $CaSO_4.2H_2O$ = 11.538,1319 kg x (-0,7531) kJ/kg

   = - 8.689,3671 kJ

3. $CaCl_2$ = 120,3631 kg x 20,5016 kJ/kg

   = 2.467,6361 kJ

4. K_2SO_4 = 20.314,2392 kg x (-26,4429) kJ/kg

   = - 537.167,3957 kJ

5. Amonia = 421,7940 kg x (-226,15) kJ/kg

   = - 95.388,7131 kJ

6. Isopropanol = 89,4715 kg x (-51,0427) kJ/kg

   = - 4.566,8669 kJ

Total panas pelarutan

= (-85,8297)+(-8.689,3671)+2.467,63+(-537.167,3957)+(-95.388,7131)+(-4.566,8669)

= -643.430,5364 kJ

Asumsi : panas yang hilang = 10 % dari entalpi bahan masuk

Panas yang hilang = 10 % x 3.542.386,6645 kJ

= 354.238,6665 kJ

Entalpi bahan masuk + panas pelarutan = entalpi bahan keluar + Q loss

Entalpi bahan keluar = entalpi bahan masuk + panas pelarutan – Q loss

= 3.542.386,6645 + 643.430,5364 - 354.238,6665

= 3.831.578,5344 kJ

$$3.831.578,5344 = \left[\frac{4,6580}{74,551} \times 51,716 \times (T-298)\right] + \left[\frac{11.538,1318}{172,1723} \times 136,3984 \times (T-298)\right] + \left[\frac{120,3631}{110,986} \times 74,3605 \times (T-298)\right] +$$

$$\left[\frac{20.314,2392}{174,2577} \times 131,1986 \times (T-298)\right] + \left[\frac{421,7940}{17,031} \times \int_{298}^{T} Cp\, dT\right] + \left[\frac{89,4715}{60,096} \times 141,8965 \times (T-298)\right] +$$

$$\left[\frac{186.152,8145}{18,015} \times \int_{298}^{T} Cp\, dT\right] + \left[16,6287 \times 0,5 \times (T-298)\right]$$

T = 302,78 K = 29,78 ^{0}C

Entalpi bahan keluar :

1. Entalpi KCl $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{4,6580}{74,551} \times 51,716 \times (302,78 - 298)$$

$= 15,4559$ kJ

2. Entalpi $CaSO_4.2H_2O$ $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{11.538,1318}{172,1723} \times 136,3984 \times (302,78 - 298)$$

$= 43.722,3603$ kJ

3. Entalpi $CaCl_2$ $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{120,3631}{110,986} \times 74,3605 \times (302,78 - 298)$$

$= 385,7355$ kJ

4. Entalpi K_2SO_4 $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{20.314,2392}{174,2577} \times 131,1986 \times (302,78 - 298)$$

$= 73.157,6748$ kJ

5. Entalpi amonia $= m \cdot \int_{298}^{302,78} Cp\, dT$

$$= \frac{421,7940}{17,031} \times 387,7812$$

$= 9.603,8861$ kJ

6. Entalpi isopropanol $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{89,4715}{60,096} \times 141,8965 \times (302,78 - 298)$$

$= 1.010,4921$ kJ

7. Entalpi $H_2O_{(l)}$ $= m \cdot \int_{298}^{302,78} Cp\, dT$

$$= \frac{186.152,8145}{18,015} \times 358,4213$$

$= 3.703.643,1602$ kJ

8. Entalpi pengotor $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$= 16,6287 \times 0,5 \times (302,78 - 298)$

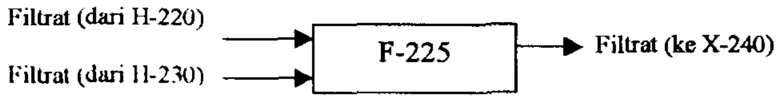
$= 39,7695$ kJ

Total entalpi bahan keluar

= (15,4559+43.722,3603+385,7355+73.157,6748+9.603,8861+1.010,4921+
3.703.643,1602+39,7695) kJ

= 3.831.578,5344 kJ

6. Tangki penampung filtrat (F-225)



Entalpi bahan masuk :

Filtrat (dari H-220) :

1. Entalpi KCl = m . Cp . ($T_{in} - T_{ref}$)

$$= \frac{571{,}0668}{74{,}551} \times 51{,}716 \times (302{,}42-298)$$

$$= 1.751{,}9537 \text{ kJ}$$

2. Entalpi $CaSO_4.2H_2O$ = m . Cp . ($T_{in} - T_{ref}$)

$$= \frac{0{,}9952}{172{,}1723} \times 136{,}3984 \times (302{,}42-298)$$

$$= 3{,}4867 \text{ kJ}$$

3. Entalpi $CaCl_2$ = m . Cp . ($T_{in} - T_{ref}$)

$$= \frac{14.756{,}3802}{110{,}986} \times 74{,}3605 \times (302{,}42-298)$$

$$= 43.723{,}8288 \text{ kJ}$$

4. Entalpi K_2SO_4 = m . Cp . ($T_{in} - T_{ref}$)

$$= \frac{3.043{,}5454}{174{,}2577} \times 131{,}1986 \times (302{,}42-298)$$

$$= 10.134{,}0083 \text{ kJ}$$

5. Entalpi amonia = $m. \int_{298}^{302,42} Cp\ NH_{3\,(l)}\, dT$

$$= \frac{51.711{,}4614}{17{,}031} \times 358{,}4314$$

$$= 1.088.310{,}2249 \text{ kJ}$$

6. Entalpi isopropanol = m . Cp . ($T_{in} - T_{ref}$)

$$= \frac{10.969,0978}{60,096} \times 141,8965 \times (302,42 - 298)$$

= 114.541,0796 kJ

7. Entalpi H_2O = m. $\int_{298}^{302,42} Cp\ H_2O_{(l)}\, dT$

$$= \frac{302.822,7999}{18,015} \times 331,3687$$

= 5.570.136,3427 kJ

8. Entalpi pengotor = m . Cp . ($T_{in} - T_{ref}$)

= 2.038,6577 x 0,5 x (302,42-298)

= 4.507,9445 kJ

Filtrat (dari H-230) :

1. Entalpi KCl = m . Cp . ($T_{in} - T_{ref}$)

$$= \frac{4,6324}{74,551} \times 51,716 \times (302,78\text{-}298)$$

= 15,3709 kJ

2. Entalpi $CaSO_4.2H_2O$ = m . Cp . ($T_{in} - T_{ref}$)

$$= \frac{6,6058}{172,1723} \times 136,3984 \times (302,78\text{-}298)$$

= 25,0319 kJ

3. Entalpi $CaCl_2$ = m . Cp . ($T_{in} - T_{ref}$)

$$= \frac{119,7004}{110,986} \times 74,3605 \times (302,78\text{-}298)$$

= 383,6117 kJ

4. Entalpi K_2SO_4 = m . Cp . ($T_{in} - T_{ref}$)

$$= \frac{20.202,3853}{174,2577} \times 131,1986 \times (302,78\text{-}298)$$

= 72.754,8553 kJ

5. Entalpi amonia = m. $\int_{298}^{302,78}$ Cp $NH_{3\,(l)}$ dT

$= \frac{419,4716}{17,031} x\ 387,7812$

= 9.551,0070 kJ

6. Entalpi isopropanol = m . Cp . ($T_{in} - T_{ref}$)

$= \frac{88,9789}{60,096}$ x 141,8965 x (302,78 - 298)

= 1.004,9287 kJ

7. Entalpi H_2O = m. $\int_{298}^{302,78}$ Cp $H_2O_{\,(l)}$ dT

$= \frac{185.127,8231}{18,015} x\ 358,4213$

= 3.683.250,2245 kJ

8. Entalpi pengotor = m . Cp . ($T_{in} - T_{ref}$)

= 16,5371 x 0,5 x (302,78-298)

= 39,5505 kJ

Total entalpi bahan masuk

= (1.751,9537+3,4867+43.723,8288+10.134,0083+1.088.310,2249+114.541,0796+ 5.570.136,3427+4.507,9445+15,3709+25,0319+383,6117+72.754,8553+9.551,0070+ 1.004,9287+3.683.250,2245+39,5505) kJ

=10.600.133,4497 kJ

Entalpi bahan keluar = entalpi bahan masuk

= 10.600.133,4497 kJ

Entalpi bahan keluar :

1. Entalpi KCl = (1.751,9537 + 15,3709) kJ = 1.767,3426 kJ
2. Entalpi $CaSO_4.2H_2O$ = (3,4867 + 25,0319) kJ = 28,5186 kJ
3. Entalpi $CaCl_2$ = (43.723,8288 + 383,6117) kJ = 44.107,4405 kJ

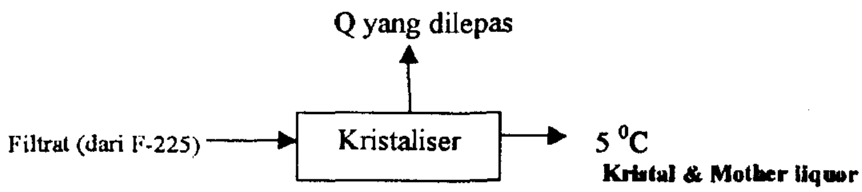
4. Entalpi K_2SO_4 = (10.134,0083 + 72.754,8553) kJ = 82.888,8636 kJ
5. Entalpi amonia = (1.088.310,2249 + 9.551,0070) kJ = 1.097.861,2319 kJ
6. Entalpi isopropanol = (114.541,0796 + 1.004,9287) kJ = 115.546,0083 kJ
7. Entalpi H_2O = (5.570.136,3427 + 3.683.250,2245) kJ = 9.253.386,5672 kJ
8. Entalpi pengotor = (4.507,9445 + 39,5505) kJ = 4.547,4950 kJ

Total entalpi bahan keluar

= (1.767,3426)+(28,5186)+(44.107,4405)+(82.888,8636)+(1.097.861,2319)+ (115.546,0083)+(9.253.386,5672)+(4.547,4950)

= 10.600.133,4497 kJ

7. Kristaliser (X-240)



Suhu operasi kristalisasi berlangsung pada 5 ^{0}C.

Entalpi bahan masuk :

Filtrat (dari F-225) :

1. Entalpi KCl = 1.767,3426 kJ
2. Entalpi $CaSO_4.2H_2O$ = 28,5186 kJ
3. Entalpi $CaCl_2$ = 44.107,4405 kJ
4. Entalpi K_2SO_4 = 82.888,8636 kJ
5. Entalpi amonia = 1.097.861,2319 kJ
6. Entalpi isopropanol = 115.546,0083 kJ
7. Entalpi H_2O = 9.253.386,5672 kJ
8. Entalpi pengotor = 4.547,4950 kJ

Total entalpi bahan masuk = 10.600.133,4497 kJ

Entalpi bahan keluar :

Kristal :

1. Entalpi $CaSO_4.2H_2O$ $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{5,9104}{172,1723} \times 136,3984 \times (278\text{-}298)$$

$= -93,6468$ kJ

2. Entalpi K_2SO_4 $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{21.205,1622}{174,2577} \times 131,1986 \times (278\text{-}298)$$

$= -319.307,2781$ kJ

3. Entalpi pengotor $= m.\ Cp.\ (T_{out} - T_{ref})$

$= 10,2760 \times 0,5 \times (278 - 298)$

$= -102,7600$ kJ

Mother liquor :

1. Entalpi KCl $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{575,6992}{74,551} \times 51,716 \times (278\text{-}298)$$

$= -7.987,2463$ kJ

2. Entalpi $CaSO_4.2H_2O$ $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{1,6906}{172,1723} \times 136,1984 \times (5\text{-}25)$$

$= -26,7866$ kJ

3. Entalpi $CaCl_2$ $= m \cdot Cp \cdot (T_{out} - T_{ref})$

$$= \frac{14.876,0806}{110,986} \times 74,3605 \times (278\text{-}298)$$

$= -199.339,1584$ kJ

4. Entalpi K_2SO_4 $m \cdot Cp \cdot (T_{out}\ \ T_{ref})$

$$= \frac{2040,7685}{174,2577} \times 131,1986 \times (278\text{-}298)$$

$= -31.118,6268$ kJ

5. Entalpi amonia = m. $\int_{298}^{278}$ Cp $NH_{3\,(l)}$ dT

$$= \frac{52.130,9330}{17,031} \times (-1.596,3814)$$

= -4.886.433,6684 kJ

6. Entalpi isopropanol = m . Cp . ($T_{out} - T_{ref}$)

$$= \frac{11.058,0767}{60,096} \times 141,8965 \times (278\text{-}298)$$

= -522.198,6090 kJ

7. Entalpi H_2O = m. $\int_{298}^{278}$ Cp $H_2O_{\,(l)}$ dT

$$= \frac{487.950,6230}{18,015} \times (-\ 1492,1639)$$

= -40.416.448,4610 kJ

8. Entalpi pengotor = m. Cp. ($T_{out} - T_{ref}$)

= 2.044,9188 x 0,5 x (278-298)

= -20.449,1880 kJ

Total entalpi bahan keluar

=(-93,6468)+(-319.307,2781)+(-102,7600)+(-7.987,2463)+(-26,7866)+

(-199.339,1584)+(-31.118,6268)+(-4.886.433,6684)+(-522.198,6090)+

(-40.416.448,4610)+(-20.449,1880)

= - 46.403.568,4294 kJ

ΔH kristalisasi = - panas pelarutan

ΔH kristalisasi :

1. KCl = 575,6992 kg x -(-18,4263) kJ/kg

= 10.608,0062 kJ

2. $CaSO_4.2H_2O$ = 7,6010 kg x -(-0,7531) kJ/kg

= 5,7243 kJ

3. $CaCl_2$ = 14.876,0806 kg x -(20,5016) kJ/kg = -304.983,4540 kJ

4. K_2SO_4 = 23.245,9307 kg x -(-26,4429) kJ/kg

   = 614.689,8209 kJ

5. Amonia = 52.130,9330 kg x -(-226,15) kJ/kg

   = 11.789.410,4980 kJ

6. Isopropanol = 11.058,0767 kg x -(-51,0427) kJ/kg

   = 564.434,0916 kJ

Total ΔH kristalisasi

= (10.608,0062+5,7243+(-304.983,4540)+ 614.689,8209+11.789.410,4980+ 564.434,0916) kJ

= 12.674.164,6870 kJ

Entalpi bahan masuk = ΔH kristalisasi + entalpi bahan keluar + Q yang dilepas

Q yang dilepas = entalpi bahan masuk - ΔH kristalisasi – entalpi bahan keluar

= 10.600.133,4497 – 12.674.164,6870 – (-46.403.568,4294)

= 44.329.537,1921 kJ

90% berat air pendingin ditambah dengan 10% berat ethylene glycol masuk pada suhu -10 °C dan keluar pada suhu 0 °C :

$$\text{Cp air pendingin} = \int_{263}^{273} \text{Cp } H_2O_{(l)}\, dT = 739{,}6105 \text{ J/mol} = 739{,}6105 \text{ kJ/kmol}$$

Cp campuran . ΔT = (0,9688 x 739,6105) + (0,0312 x 92,8538 x (273-263)) = 745,5051 kJ/kmol

BM campuran = (0,9688 x 18,015) + (0,0312 x 62,068) = 19,3895 kg/kmol

Kebutuhan air pendingin :

Q yang dilepas bahan = Q yang diserap air pendingin

$$44.329.537{,}1921 = \frac{m}{19{,}3895} \cdot Cp \cdot \Delta T$$

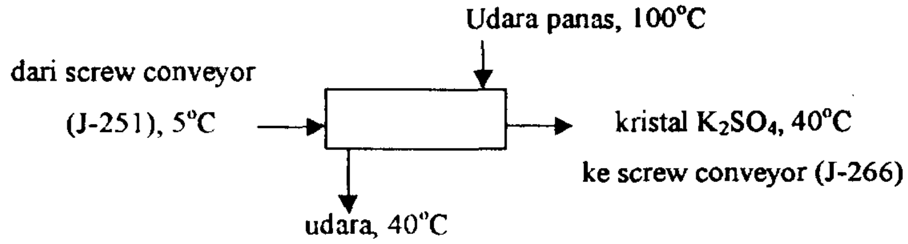
44.329.537,1921 x 19,3895 = m x 745,5051

massa air pendingin = 1.152.946,5880 kg

Massa air = 90 % x 1.152.946,5880 kg = 1.037.651,9292 kg

Massa ethylene glycol = 10 % x 1.152.946,5880 kg = 115.294,6588 kg

7. Rotary Dryer (B-260)



Entalpi bahan masuk :

1. Entalpi KCl = m. Cp. ($T_{in} - T_{ref}$)

$$= \frac{2{,}1173}{74{,}551} \times 51{,}716 \times (278\text{-}298)$$

$$= -\ 29{,}3754 \text{ kJ}$$

2. Entalpi $CaSO_4.2H_2O$ = m. Cp. ($T_{in} - T_{ref}$)

$$= \frac{5{,}9166}{172{,}1723} \times 136{,}3984 \times (278\text{-}298) = -\ 93{,}7450 \text{ kJ}$$

3. Entalpi $CaCl_2$ = m. Cp. ($T_{in} - T_{ref}$)

$$= \frac{54{,}7105}{110{,}986} \times 74{,}3605 \times (278\text{-}298)$$

$$= -\ 733{,}1195 \text{ kJ}$$

4. Entalpi K_2SO_4 = m. Cp. ($T_{in} - T_{ref}$)

$$= \frac{21.212{,}6676}{174{,}2577} \times 131{,}1986 \times (278\text{-}298)$$

$$= -\ 319.420{,}2944 \text{ kJ}$$

5. Entalpi amonia = m. $\int_{298}^{278} Cp\ NH_{3\ (l)}\, dT$

$$= \frac{191{,}7246}{17{,}031} \times (-1.596{,}3814)$$

$$= -17.971{,}0872 \text{ kJ}$$

6. Entalpi isopropanol = m. Cp. ($T_{in} - T_{ref}$)

$$= \frac{40{,}6689}{60{,}096} \times 141{,}8965 \times (278\text{-}298) = -\ 1.920{,}5187 \text{ kJ}$$

7. Entalpi H_2O = m. $\int_{298}^{278}$ Cp $H_2O_{(l)}$ dT

$$= \frac{1.794,5611}{18,015} x (- 1.492,1639)$$

= -148.641,6510 kJ

8. Entalpi pengotor = m. Cp. ($T_{in} - T_{ref}$)

= 17,7967 x 0,5 x (278-298)

= - 177,9670 kJ

Total entalpi bahan masuk

= (-29,3754)+(-93,7450)+(-733,1195)+(-319.420,2944)+(-17.971,0872)+

(- 1920,5187)+(-148.641,6510)+(-177,9670)

= -488.987,7582 kJ

Entalpi bahan keluar :

Ke screw conveyor (J-266):

1. Entalpi KCl = m. Cp. ($T_{out} - T_{ref}$)

$$= \frac{2,1067}{74,551} x 51,716 x (313-298)$$

= 21,9213 kJ

2. Entalpi $CaSO_4.2H_2O$ = m. Cp. ($T_{out} - T_{ref}$)

$$= \frac{5,8870}{172,1723} x 136,3984 x (313-298)$$

= 69,9570 kJ

3. Entalpi $CaCl_2$ = m. Cp. ($T_{out} - T_{ref}$)

$$= \frac{54,4369}{110,986} x 74,3605 x (313-298) = 547,0900 \text{ kJ}$$

4. Entalpi K_2SO_4 = m. Cp. ($T_{out} - T_{ref}$)

$$= \frac{21.106,6043}{174,2577} x 131,1986 x (313-298)$$

= 238.367,3951 kJ

5. Entalpi H_2O = $m. \int_{298}^{313} Cp\ H_2O_{(l)}\ dT$

$$= \frac{21{,}3146}{18{,}015} x\ 1.125{,}7048$$

= 1.331,8872 kJ

8. Entalpi pengotor = m. Cp. $(T_{out} - T_{ref})$

= 17,7077 x 0,5 x (313-298)

= 132,8078 kJ

Total entalpi bahan keluar menuju screw conveyor

= 21,9213 + 69,9570 + 574,0900 + 238.367,3951 + 1.331,8872 + 132,8078

= 240.471,0584 kJ

Ke cyclone separator (H-262):

1. Entalpi KCl = m. Cp. $(T_{out} - T_{ref})$

$$= \frac{0{,}0106}{74{,}551} x\ 51{,}716\ x\ (313\text{-}298)$$

= 0,1103 kJ

2. Entalpi $CaSO_4.2H_2O$ = m. Cp. $(T_{out} - T_{ref})$

$$= \frac{0{,}0296}{172{,}1723} x\ 136{,}3984\ x\ (313\text{-}298)$$

= 0,3517 kJ

3. Entalpi $CaCl_2$ = m. Cp. $(T_{out} - T_{ref})$

$$= \frac{0{,}2736}{110{,}986} x\ 74{,}3605\ x\ (313\text{-}298)$$

= 2,7497 kJ

4. Entalpi K_2SO_4 = m. Cp. $(T_{out} - T_{ref})$

$$= \frac{106{,}0633}{174{,}2577} x\ 131{,}1986\ x\ (313\text{-}298)$$

= 1.197,8257 kJ

5. Entalpi pengotor = m. Cp. $(T_{out} - T_{ref})$

= 0,0890 x 0,5 x (313-298) = 0,6675 kJ

6. Entalpi liquid yang menguap :

$$= \left[m. \int_{298}^{313} Cp\ NH_{3\,(l)}\,dT + m.\lambda \right] + \left[m.\ Cp.\ (T_{out} - T_{ref}) + m.\lambda \right] +$$

$$\left[m. \int_{298}^{313} Cp\ H_2O_{(l)}\,dT + m.\lambda \right]$$

$$= (191{,}7246.(\frac{1226{,}6676}{17{,}031} + 246{,}556)) + (40{,}6689.\{(\frac{141{,}8965}{60{,}096} \times (313\text{-}298)) +$$

$$293{,}408\}) + (1773{,}2465.(\frac{1.125{,}7048}{18{,}015} + 216{,}961))$$

= 570.001,7195 kJ

Total entalpi bahan keluar menuju cyclone

= (0,1103 + 0,3517 + 2,7497 + 1.197,8257 + 0,6674 + 570.001,7195) kJ

= 571.203,4244 kJ

Total bahan keluar rotary dryer = 240.471,0584 + 571.203,4244

= 811.674,4828 kJ

Asumsi : panas yang hilang = 10 % dari panas yang disuplai

Q loss = 0,1 Q suplai

Entalpi bahan masuk + Q suplai = entalpi bahan keluar + Q loss

-488.987,7582 + Q suplai = 811.674,4828 + 0,1 Q suplai

0,9 Q suplai = 811.674,4828 + 488.987,7582

Q suplai = 1.445.180,2678 kJ

Q loss = 0,1 x 1.445.180,2678 kJ = 144.518,0268 kJ

Udara panas masuk pada suhu 100°C dan keluar pada suhu 40°C:

$Cp_{udara,\ 100°C}$ = 1,0100 kJ/kg.K

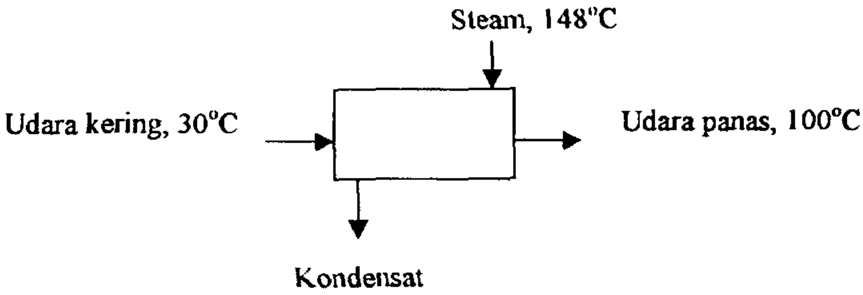
$Cp_{udara,\ 40°C}$ = 1,0048 kJ/kg.K (Geankoplis, 1993, tabel A.3-3)

$Q_{suplai} = \Delta H_{udara} = m_{udara}.\ (Cp_{udara}).\ \Delta T$

1.445.180,2678 kJ = m. (1,0100 + 1,0048)/2 kJ/kg.K . (100-40)K

m_{udara} = 23.909,4082 kg

8. Heater (E-263)



Entalpi masuk :

Entalpi udara = m_{udara}. Cp_{udara}. ΔT

= 23.909,4082 kg . 1,0048 kJ/kg.K . (30-25)K

= 120.120,8667 kJ

Entalpi keluar :

Entalpi udara = m_{udara}. Cp_{udara}. ΔT

= 23.909,4082 kg. (1,0048+ 1,0100)/2 kJ/kg.K . (100-25)K

= 1.806.475,3346 kJ

Asumsi : panas yang hilang = 10 % dari panas yang disuplai

Q loss = 0,1 Q suplai

Entalpi udara masuk + Q suplai = entalpi udara keluar + Q loss

120.120,8667 + Q suplai = 1.806.475,3346 + 0,1 Q suplai

0,9.Q suplai = 1.806.475,3346 - 120.120,8667

Q suplai = 1.873.727,1865 kJ

Q loss = 0,1 x 1.873.727,1865 kJ = 187.372,7186 kJ

Digunakan steam 4,5 bar; 298,4°F = 148°C:

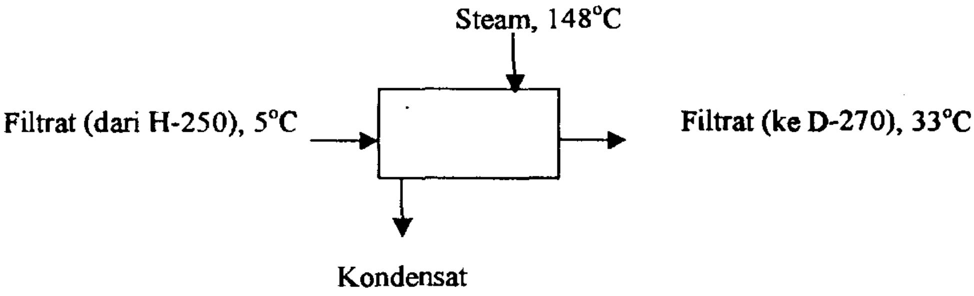
λ_{steam} = 911,22 Btu/lbm (Kern, 1965, p.816)

= 2.119,5171 kJ/kg

$$\text{Jadi, kebutuhan steam} = \frac{Q_{suplai}}{\lambda} = \frac{1.873.727,1865\ kJ}{2.119,5171\ kJ/kg}$$

= 884,0349 kg

9. Heater (E-254)



Entalpi bahan masuk :

1. Entalpi KCl = m. Cp. ($T_{in} - T_{ref}$)

$$= \frac{573{,}5819}{74{,}551} \times 51{,}716 \times (278\text{-}298)$$

$$= -\ 7.957{,}8709 \text{ kJ}$$

2. Entalpi $CaSO_4.2H_2O$ = m. Cp. ($T_{in} - T_{ref}$)

$$= \frac{1{,}6844}{172{,}1723} \times 136{,}3984 \times (278\text{-}298) = -\ 26{,}6883 \text{ kJ}$$

3. Entalpi $CaCl_2$ = m. Cp. ($T_{in} - T_{ref}$)

$$= \frac{14.821{,}3701}{110{,}986} \times 74{,}3605 \times (278\text{-}298)$$

$$= -\ 198.606{,}0388 \text{ kJ}$$

4. Entalpi K_2SO_4 = m. Cp. ($T_{in} - T_{ref}$)

$$= \frac{2.033{,}2631}{174{,}2577} \times 131{,}1986 \times (278\text{-}298)$$

$$= -\ 30.616{,}8705 \text{ kJ}$$

5. Entalpi amonia = $m. \int_{298}^{278} Cp\ NH_{3\,(l)}\, dT$

$$= \frac{51.939{,}2084}{17{,}031} \times (-1.596{,}3814)$$

$$= -\ 4.868.462{,}5812 \text{ kJ}$$

6. Entalpi isopropanol = m. Cp. ($T_{in} - T_{ref}$)

$$= \frac{11.017,4078}{60,096} \times 141,8965 \times (278\text{-}298) = -520.278,0904 \text{ kJ}$$

7. Entalpi H_2O = m. $\int_{298}^{278} Cp\ H_2O_{(l)}\, dT$

$$= \frac{486.156,0619}{18,015} \times (-1.492,1639)$$

$= -40.267.806,0135$ kJ

8. Entalpi pengotor = m. Cp. $(T_{in} - T_{ref})$

$= 2.037,3981 \times 0,5 \times (278\text{-}298)$

$= -20.373,9810$ kJ

Total entalpi bahan masuk

= (-7.957,8709)+(-26,6883)+(-198.606,0388)+(-30.616,8705)+(-4.868.462,5812)+

(-520.278,0904)+(-40.267.806,0135)+(-20.373,9810)

= - 45.914.128,1346 kJ

Entalpi bahan keluar :

1. Entalpi KCl = m. Cp. $(T_{out} - T_{ref})$

$$= \frac{573,5819}{74,551} \times 51,716 \times (306\text{-}298)$$

$= 3.183,1483$ kJ

2. Entalpi $CaSO_4.2H_2O$ = m. Cp. $(T_{out} - T_{ref})$

$$= \frac{1,6844}{172,1723} \times 136,3984 \times (306\text{-}298)$$

$= 10,6753$ kJ

3. Entalpi $CaCl_2$ = m. Cp. $(T_{out} - T_{ref})$

$$= \frac{14.821,3701}{110,986} \times 74,3605 \times (306\text{-}298) = 79.442,4155 \text{ kJ}$$

4. Entalpi K_2SO_4 = m. Cp. $(T_{out} - T_{ref})$

$$= \frac{2.033,2631}{174,2577} \times 131,1986 \times (306\text{-}298)$$

$= 12.246,7482$ kJ

5. Entalpi amonia = m. $\int_{298}^{306}$ Cp $NH_{3\,(l)}$ dT

$= \frac{51.939,2084}{17,031} \times 650,2513$

= 1.983.062,4717 kJ

6. Entalpi isopropanol = m. Cp. ($T_{out} - T_{ref}$)

$= \frac{11.017,4078}{60,096} \times 141,8965 \times (306\text{-}298) = 208.111,2361$ kJ

7. Entalpi H_2O = m. $\int_{298}^{306}$ Cp $H_2O_{(l)}$ dT

$= \frac{486.156,0619}{18,015} \times 599,7580$

= 16.185.177,1036 kJ

8. Entalpi pengotor = m. Cp. ($T_{out} - T_{ref}$)

= 2.037,3981 x 0,5 x (306-298)

= 8.149,5924 kJ

Total entalpi bahan keluar

= 3.183,1483 + 10,6753 + 79.442,4155 + 12.246,7482 + 1.983.062,4717 + 208.111,2361
+ 16.185.177,1036 + 8.149,5924

= 18.479.383,3911 kJ

Asumsi : panas yang hilang = 10 % dari panas yang disuplai

Q loss = 0,1 Q suplai

Entalpi bahan masuk + Q suplai = entalpi bahan keluar + Q loss

- 45.914.128,1346 + Q suplai = 18.479.383,3911 + 0,1 Q suplai

0,9.Q suplai = 18.479.383,3911 + 45.914.128,1346

Q suplai = 71.548.346,1397 kJ

Q loss = 0,1 x 71.548.346,1397 kJ = 7.154.834,6140 kJ

Digunakan steam 4,5 bar; 298,4°F = 148°C:

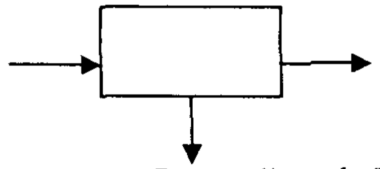
λ_{steam} = 911,22 Btu/lbm (Kern, 1965, p.816)

= 2.119,5171 kJ/kg

$$\text{Jadi, kebutuhan steam} = \frac{Q_{suplai}}{\lambda} = \frac{71.548.346{,}1397\ \text{kJ}}{2.119{,}5171\ \text{kJ/kg}}$$

= 33.756,9091 kg

10. Menara Distilasi (D-270)



Komponen	F (kmol)	Xf	D (kmol)	Xd	B (kmol)	Xb
KCl	7,6938	0,0003	0	0	7,6938	0,0003
$CaSO_4.2H_2O$	0,0098	$3{,}22.10^{-7}$	0	0	0,0098	$3{,}58.10^{-7}$
$CaCl_2$	133,5427	0,0044	0	0	133,5427	0,0049
K_2SO_4	11,6681	0,0004	0	0	11,6681	0,0004
NH_3	3.049,6864	0,1003	3.049	0,9950	0,6864	$2{,}51.10^{-5}$
Isopropanol	183,3301	0,0060	0	0	183,3301	0,0068
H_2O	26.986,1816	0,8879	15,3216	0,0050	26.970,8600	0,9868
Pengotor	22,7421	0,0007	0	0	22,7421	0,0008
Total	30.394,8547	1,0000	3.064,3216	1,0000	27.330,5331	1,0000

Perhitungan Tekanan dan Suhu:

P operasi = 3,5 atm = 51,45 psia

ΔP = P bottom – P puncak = 5 psia ......(1)

$$\text{P operasi} = \frac{\text{P puncak} + \text{P bottom}}{2} = 51{,}45 \text{ psia} \ldots\ldots.(2)$$

Dari substitusi persamaan (1) dan (2) dapat diketahui:

P puncak = 48,95 psia = 3,33 atm

P bottom = 53,95 psia = 3,67 atm

P distilat = P puncak – 5 psia = 48,95 psia – 5 psia = 43,95 psia = 3 atm

Mencari P^{sat}:

- untuk air

$\ln(Pvp/Pc) = (1\text{-}x)^{-1}[(VPA)x + (VPB)x^{1,5} + (VPC)x^3 + (VPD)x^6]$

$\ln(Pvp/Pc) = (1\text{-}x)^{-1}[(-7{,}76451)x + (1{,}45838)x^{1,5} + (-2{,}77580)x^3 + (-1{,}23303)x^6]$

dimana: $x = 1 - T/Tc$ **(Prausnitz, 1988, eq.1, p.657)**

$Pc = 221{,}2$ bar dan $Tc = 647{,}3$ K

- untuk ammonia

$\ln PVP = VPA - VPB/T + VPC \times \ln T + VPD \times PVP/T^2$

$\ln PVP = 45{,}327 - 4.104{,}67/T + (-5{,}146) \times \ln T + 615 \times PVP/T^2$

(Prausnitz, 1988, eq.2, p.657)

Mencari γ dengan metode Margules:

$\ln \gamma_1 = x_2^2 [A_{12} + 2 (A_{21} - A_{12}) x_1]$ **(Smith, 1996, eq. 11.8a, p.377)**

$\ln \gamma_2 = x_1^2 [A_{21} + 2 (A_{12} - A_{21}) x_2]$ **(Smith, 1996, eq. 11.8b, p.377)**

Dengan harga A_{12} = 1,35 dan A_{21} = 0,7 diperoleh:

$\gamma_1 = 2{,}6734$ dan $\gamma_2 = 1{,}0194$

<u>Suhu bubble point feed</u>

Suhu bubble point feed ditrial pada tekanan 3,5 atm.

Komponen	**Xi = Xf**	**Trial, T = 33 °C (306 K)**			
		P^{sat}, atm	γ	**Ki = $\gamma . P^{sat}$ / P**	**Yi = Xi . Ki**
NH_3	0,1015	12,7179	2,6734	9,7143	0,9860
Air	0,8985	0,0493	1,0194	0,0144	0,0129
Total	1,0000				0,9989 ≈ 1,0000

Karena feed masuk pada suhu bubble pointnya maka feed berupa saturated liquid dan harga q = 1.

Suhu bubble point distilat

Suhu bubble point distilat ditrial pada tekanan 3 atm.

Komponen	Xi = Xd	Trial, T = 6 °C (279 K)		
		P^{sat}, atm	Ki = P^{sat} / P	Yi = Xi . Ki
NH_3	0,9950	3,0404	1,0135	1,0084
Air	0,0050	0,0030	0,0010	$5{,}0383.10^{-6}$
Total	1,0000			1,0084 ≈ 1,0000

Suhu dew point distilat

Suhu dew point distilat ditrial pada tekanan 3 atm.

Komponen	Yi = Xd	Trial, T = 25 °C (298 K)			
		P^{sat}, atm	Ki = P^{sat} / P	Xi = Yi / Ki	αi = Ki / Kc
NH_3	0,9950	8,5777	2,8592	0,3480	376,2105
Air	0,0050	0,0229	0,0076	0,6550	1
Total	1,0000			1,0030 ≈ 1,0000	

Suhu bubble point bottom

Suhu bubble point bottom ditrial pada tekanan 3,67 atm.

Komponen	Xi = Xb	Trial, T = 142 °C (415 K)			
		P^{sat}, atm	Ki = P^{sat} / P	Yi = Xi . Ki	αi = Ki / Kc
NH_3	$2{,}55.10^{-5}$	132,8203	36,1908	0,0009	35,3253
Air	0,9999	3,7599	1,0245	1,0244	1
Total	1,0000			1,0253 ≈ 1,0000	

Perhitungan Jumlah Stage Minimum:

$$\alpha_{LK,avg} = \sqrt{\alpha_{LK,D} \cdot \alpha_{LK,B}}$$ (Geankoplis, 1997, eq.11.7-13, p. 683)

$$\alpha_{LK,avg} = \sqrt{376{,}2105 . 35{,}3253} = 115{,}2812$$

$$N_{min} = \frac{\log\left[\left(\frac{d_i}{d_j}\right)\left(\frac{b_j}{b_i}\right)\right]}{\log \alpha_m}$$

$$N_{min} = \frac{\log\left[\left(\frac{3049}{15,3216}\right)\left(\frac{26.970,8600}{0,6864}\right)\right]}{\log 115,2812} = 3,3433 \text{ stage}$$

Perhitungan Reflux Ratio:

$$1-q = \sum \frac{\alpha_i . X_{iF}}{\alpha_i - \theta}$$ (Geankoplis, 1997, eq.11.7-19, p. 686)

Suhu untuk menentukan αi adalah rata-rata suhu dew point distilat dan suhu bubble point bottom.

$$T = \frac{25+142}{2} = 83,5\ ^\circ C = 182,3\ ^\circ F$$

$$Ki = \frac{\gamma . P^{sat}}{P}$$

$$\alpha_i = \frac{Ki}{Kc}$$

Komponen	X_{iF}	X_{iD}	γ	P^{sat}	Ki (83,5°C)	αi (83,5°C)	$\alpha i.X_{iF}$	$\alpha i.X_{iD}$
NH_3	0,1015	0,9950	2,6734	26,8949	20,5431	336,7721	34,1824	335,0882
Air	0,8985	0,0050	1,0194	0,2094	0,0610	1	0,8985	0,0050
Total	1,0000	1,0000						

$$1-1 = \frac{34,1824}{336,7721-\theta} + \frac{0,8985}{1-\theta}$$

Dengan trial dan error didapat θ = 9,5998

$$R_m + 1 = \sum \frac{\alpha_i . X_{iD}}{\alpha_i - \theta}$$ (Geankoplis, 1997, eq.11.7-20, p. 687)

$$= \frac{335,0882}{336,7721-9,5998} + \frac{0,0050}{1-9,5998} = 1,0236$$

Rm = 0,0236

R = 1,2 .Rm = 1,2. 0,0236 = 0,0283 (Walas, 1990, p. 382)

Perhitungan Stage Aktual:

Dengan menggunakan *rules of thumb* dari Walas, 1990, p.382, yaitu jumlah stage aktual = 2. jumlah stage minimum, diperoleh:

$N = 2.\ N_m = 2.\ 3{,}3433 = 6{,}6866 \approx 7$ stage

Perhitungan Letak Feed Tray:

$$\log \frac{N_e}{N_s} = 0{,}206.\log\left[\left(\frac{x_{HK,F}}{x_{LK,F}}\right).\frac{B}{D}.\left(\frac{x_{LK,B}}{x_{HK,D}}\right)^2\right]$$ (Geankoplis,1997,eq.11.7-21,p.687)

$$\log \frac{N_e}{N_S} = 0{,}206.\log\left[\left(\frac{0{,}8985}{0{,}1015}\right).\frac{26.971{,}5464}{3.064{,}3216}.\left(\frac{2{,}55.10^{-5}}{0{,}0050}\right)^2\right]$$

$$\log \frac{N_e}{N_S} = -0{,}5576$$

$$\frac{N_e}{N_S} = 0{,}2769 \ldots (1)$$

$N_e + N_s = 7 \rightarrow N_e = 7 - N_s \ldots (2)$

Dari substitusi persamaan 1 dan 2 didapat :

$N_e = 2$

$N_s = 5$

Jadi, feed tray berada stage ke-3 dari puncak atau stage ke-6 dari reboiler.

Perhitungan Beban Kondenser:

V = D (1 + R) = 3.064,3216. (1 + 0,0283) = 3.151,0419 kmol

Reflux = V – D = 3.151,0419 – 3.064,3216 = 86,7203 kmol

Komposisi Reflux = Komposisi Distilat, terdiri dari :

NH_3 = 0,9950. 86,7203 = 86,2867 kmol = 1.469,5488 kg

Air = 0,0050. 86,7203 = 0,4336 kmol = 7,8113 kg

Beban kondenser: $Q_C = \lambda$ distilat + λ reflux

λ distilat = $\lambda\ NH_3 + \lambda$ Air

= ((1,1630.212) x 51.927,5190) kJ +((276,0186 x (1,0234.212)) kJ

= 12.803.041,37 kJ + 59.885,2163 kJ = 12.862.926,5863 kJ

λ reflux = R. λ distilat = 0,0283 . 12.862.926,5863 kJ = 364.020,8222 kJ

Q_C = 12.862.926,5863 kJ + 364.020,8222 kJ = 13.226.947,4085 kJ

Perhitungan Entalpi Masuk:

Untuk NH_3:

$$H^{id} = n.\ R.\int_{298}^{306}\frac{Cp}{R}\,dT$$ (Smith, 1996, eq. 6.70, p. 210)

= 3.049,6864 kmol. 650,2513 kJ/kmol

= 1.983.062,4717 kJ

H_{NH_3} = H^{id} = 1.983.062,4717 kJ

Dengan cara yang sama dapat memperoleh entalpi masuk untuk komponen lain:

Komponen	Masuk (kJ)
KCl	3.183,1483
$CaSO_4.2H_2O$	10,6753
$CaCl_2$	79.442,4155
K_2SO_4	12.246,7482
NH_3	1.983.062,4717
Isopropanol	208.111,2361
H_2O	16.185.177,1036
Pengotor	8.149,5924
Total	18.479.383,3911

Perhitungan Entalpi Distilat:

Untuk NH_3:

$$H^{id} = n.\ R.\int_{298}^{279}\frac{Cp}{R}\,dT$$ (Smith, 1996, eq. 6.70, p. 210)

= 3.049 kmol. –1.517,2807 kJ/kmol

= -4.626.188,8543 kJ

H_{NH_3} = H^{id} = -4.626.188,8543 kJ

Dengan cara yang sama dapat memperoleh entalpi distilat untuk komponen lain:

Komponen	Keluar (kJ)
NH_3	-4.626.188,8543
H_2O	-12.773,8286
Total	-4.638.962,6829

Perhitungan Entalpi Bottom:

Untuk NH_3:

$$H^{id} = n.\ R.\ \int_{298}^{415} \frac{Cp}{R}\, dT \qquad \text{(Smith, 1996, eq. 6.70, p. 210)}$$

$= 0{,}6864$ kmol. 11.109,0633 kJ/kmol

$= 7.625{,}2611$ kJ

$H_{NH_3} = H^{id} = 7.625{,}2611$ kJ

Dengan cara yang sama dapat memperoleh entalpi bottom untuk zat lain:

Komponen	Keluar (kJ)
KCl	46.553,4296
$CaSO_4.2H_2O$	179.108,0910
$CaCl_2$	1.161.845,3274
K_2SO_4	156,3944
NH_3	7.625,2611
Isopropanol	3.043.626,2456
H_2O	144.957.858,5193
Pengotor	119.187,7889
Total	149.515.961,0573

Perhitungan Beban Reboiler:

$H_F + Q_R = H_D + H_B + Q_C$

$Q_R = H_D + H_B + Q_C - H_F$

$= (-4.638.962{,}6829) + 149.515.961{,}0573 + 13.226.947{,}4085 - (18.479.383{,}3911)$

$= 139.624.562{,}3918$ kJ

APPENDIX C
SPESIFIKASI PERALATAN

APPENDIX C
SPESIFIKASI PERALATAN

1. Tempat Penyimpan KCl (F-110)

Fungsi : Menampung kalium klorida

Tipe : Gedung dengan konstruksi beton

Dasar pemilihan : Cocok untuk menampung padatan dengan kapasitas besar

Kondisi operasi : T = 30°C, P = 1 atm

Kapasitas : 20.664,9231 kg/hari = 45.566,1554 lb/hari

Perhitungan :

Densitas padatan = 1.984,8634 kg/m^3 = 123,9150 lb/ ft^3

Waktu tinggal = 15 hari

$$\text{Volume KCl} = \frac{45.566{,}1554 \text{ lb/hari} \times 15 \text{ hari}}{123{,}9150 \text{ lb/ ft}^3} = 5.515{,}8150 \text{ ft}^3$$

Asumsi = storage berisi 60 % dari volume storage

$$\text{Volume storage} = \frac{5.515{,}8150 \text{ ft}^3}{0{,}6} = 9.193{,}0250 \text{ ft}^3$$

Volume storage = p x l x t

9.193,0250 ft^3 = (2 x l) x l x 11,4835 ft

l = 20,0094 ft

p = (2 x l) = 40,0187 ft

t = 3,5 m = 11,4835 ft

Luas = p x l

= 40,0187 ft x 20,0094 ft

= 800,7484 ft^2

Spesifikasi :

1. Kapasitas : 20.664,9231 kg/hari
2. Panjang bangunan : 40,0187 ft
3. Lebar bangunan : 20,0094 ft
4. Tinggi bangunan : 11,4835 ft

5. Luas bangunan : 800,7484 ft^2
6. Bahan konstruksi : concrete
7. Jumlah : 1 buah

2. Belt Conveyor (J-111)

Fungsi : Mengangkut KCl $_{(s)}$ ke tangki pelarutan KCl (M-120)

Tipe : Troughed belt on 45° idlers with rolls of equal length

Dasar pemilihan : Ekonomis dan cocok untuk kapasitas besar

Kapasitas : 20.664,9231 kg/hari = 0,8610 ton/jam

Perhitungan :

Panjang belt conveyor = 25 ft

Berdasarkan Perry edisi 7 (Tabel 21-7) didapatkan :

Lebar belt = 14 in

Belt plies = 3-5

Kecepatan belt = 100 ft/mnt

Kapasitas = 32 ton/jam

Spesifikasi diatas berdasarkan material dengan density 100 lb/ft^3. Untuk material dengan density 123,9150 lb/ft^3 dan kapasitas 0,8610 ton/jam, diperoleh :

$$\text{Kecepatan screw belt} = \frac{0{,}8610 \text{ ton/jam}}{32 \text{ ton/jam}} \times \frac{100 \text{ lb/ft}^3}{123{,}9150 \text{ lb/ft}^3} \times 100 \text{ ft/mnt}$$

$$= 2{,}1713 \text{ ft/mnt}$$

Tenaga untuk menggerakkan belt :

Sesuai dengan Perry, 3rd ed, hal 1355 :

$$HP = TPH \times (H \times 0{,}002 + 0{,}001 \times V)\, C$$

Dimana : HP = Horse Power, Hp

TPH = Kapasitas, ton/jam

H = Jarak horizontal, ft

V = Jarak vertikal, ft

V = H x Sin 30° = 25 ft x Sin 30° = 12,5 ft

C = Faktor bahan yang diangkut diambil 2,5 (Perry, 3rd ed, hal 1356)

HP = 0,8610 ton/jam (25 ft x 0,002 + 0,001 x 12,5 ft) 2,5

= 0,1345 Hp

Effisiensi motor = 80 % (Peters & Timmerhaus, 1991, Fig. 14-38)

Tenaga motor penggerak belt = $\dfrac{0{,}1345\ \text{Hp}}{0{,}8}$ = 0,1681 Hp ≈ 0,5 Hp

Spesifikasi :

1. Tipe : Troughed belt on 45° idlers with rolls of equal length
2. Kapasitas : 0,8610 ton/jam
3. Lebar belt : 14 in
4. Belt plies : 3-5
5. Panjang belt conveyor : 25 ft
6. Tenaga motor : 0,5 Hp
7. Bahan : Rubber dan Steel
8. Jumlah : 1 buah

3. Tangki Pelarutan KCl (M-120)

Fungsi : Melarutkan $KCl_{(s)}$ menjadi larutan KCl

Tipe : Silinder tegak berpengaduk dengan tutup atas dan bawah berbentuk torispherical dished head

Dasar pemilihan : Cocok untuk melarutkan padatan

Kondisi operasi : P = 1 atm

Kapasitas : 206.649,2310 kg/hari = 8.610,3846 kg/jam = 18.985,8981 lb/jam

Perhitungan :

➢ *Perhitungan Dimensi Tangki*

$\rho_{larutan}$ = 1.047,9037 kg/m³ = 65,4206 lb/ft³

Volume larutan = $\dfrac{18.985{,}8981\ \text{lb/jam}}{65{,}4206\ \text{lb/ft}^3}$ = 290,2127 ft³

Asumsi: Volume ruang kosong = 20 % Volume larutan

Volume tangki = 1,2 x volume larutan

= 1,2 x 290,2127 ft³

= 348,2553 ft³

$\frac{H}{D} = 1{,}5$ (Ulrich, 1984, p. 433)

Volume tangki = (2 x volume torisperical dished head) + volume shell

$$348{,}2553\ ft^3 = (2 \times 0{,}000049 \times D^3) + \left(\frac{\pi}{4} \times 1{,}5 \times \left(\frac{D}{12}\right)^3\right)$$

$$= 7{,}7977.10^{-4} \times D^3$$

$$D = 76{,}4382\ in = 6{,}3696\ ft$$

$$H = 114{,}6573\ in = 9{,}5544\ ft$$

➢ *Perhitungan Tebal Shell*

Volume larutan (Vliq) = V tutup bawah + V shell

$$Vliq = 0{,}000049 * D^3 + \frac{\pi}{4} * \frac{D^2}{12^2} * Hliq$$

$$290{,}2127\ ft^3 = 0{,}000049 * (76{,}4382)^3 + \frac{\pi}{4} * \frac{(76{,}4382)^2}{12^2} * Hliq$$

$$Hliq = 8{,}4201\ ft$$

$$P_{hidrostatik} = \frac{\rho . H}{144} = \frac{65{,}4206\ lb/ft^3 \times 8{,}4201\ ft}{144} = 3{,}8253\ psi$$

$P_{operasi} = 3{,}8253 + 14{,}7 = 18{,}5253$ psi

$P_{design} = 1{,}2 \cdot P_{operasi} = 22{,}2304$ psi

Bahan konstruksi yang digunakan : SA-167 grade 3 Tipe 304

$f_{allow} = 18750$ psi (B & Y, App. D)

Tipe sambungan double-welded butt joint :

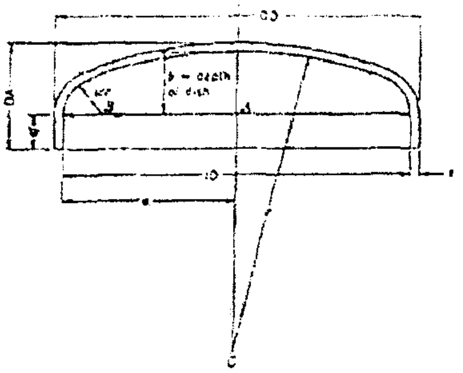
E = 0,8 (B & Y, Tabel 13.2)

faktor korosi (C) = $\frac{1}{8}$ in

$$t_{shell} = \frac{P.ID}{2(f.E - 0{,}6.P)} + C \quad \text{(B \& Y, pers. 13.1)}$$

$$t_{shell} = \frac{22{,}2304 \times 76{,}4382}{2((18750 \times 0{,}8) - (0{,}6 \times 22{,}2304))} + 0{,}125 = 0{,}1817\ in \approx \frac{3}{16}\ in$$

➢ *Perhitungan Tebal dish*



OD = ID + (2 x t_{shell}) = 76,4382 + (2 x $\frac{3}{16}$) = 76,8132 in

rc (radius of dish) = ID = 76,4382 in

icr (inside-corner radius) = 6 % x rc = 0,06 x 76,4382 in = 4,5863 in

$$W = \frac{1}{4}\left(3+\sqrt{\frac{rc}{icr}}\right) = \frac{1}{4}\left(3+\sqrt{\frac{76,4382}{4,5863}}\right) = 1,7706 \qquad \text{(B \& Y, pers. 7.76)}$$

$$a \text{ (inside radius)} = \frac{ID}{2} = \frac{76,4382}{2} = 38,2191 \text{ in}$$

BC = rc – icr = (76,4382 - 4,5863) in = 71,8519 in

AB = a – icr = (38,2191 – 4,5863) in = 33,6328 in

$$b \text{ (depth of dish (inside))} = rc - \sqrt{(BC)^2 - (AB)^2}$$

$$= 76,4382 - \sqrt{(71,8519)^2 - (33,6328)^2} = 12,9439 \text{ in}$$

$$t_{dish} = \frac{P.rc.W}{2.f.E - 0,2.P} + C \qquad \text{(B \& Y, pers 7.77)}$$

$$t_{dish} = \frac{22,2304 \times 76,4382 \times 1,7706}{(2 \times 18750 \times 0,8) - (0,2 \times 22,2304)} + 0,125 = 0,2253 \text{ in} \approx \frac{1}{4} \text{ in}$$

Maka dipakai tebal tutup atas dan bawah = $\frac{1}{4}$ in

Dipilih *straight-flange* (sf) = 2 in **(B & Y, Tabel 5.8)**

Tinggi dish = OA = t + b + sf = $\frac{1}{4}$ + 12,9439 + 2

= 15,1939 in = 1,2661 ft

Tinggi tangki keseluruhan = tinggi shell + (2 x tinggi dish)

= 9,5544 + (2 x 1,2661) = 12,0866 ft

➤ *Perhitungan pengaduk*

Dipilih jenis pengaduk = flat six-blade turbine

Jumlah impeller $= \dfrac{sg.H}{Dt} = \dfrac{1{,}0525 \times 8{,}4201}{6{,}3696} = 1{,}3913 \approx 2$ buah

$\left(\dfrac{Da}{Dt}\right) = \dfrac{1}{3}$ $\qquad Da = \dfrac{6{,}3696}{3} = 2{,}1232$ ft

$\left(\dfrac{J}{Dt}\right) = \dfrac{1}{12}$ $\qquad J = \dfrac{6{,}3696}{12} = 0{,}5308$ ft

$\left(\dfrac{E}{Dt}\right) = \dfrac{1}{3}$ $\qquad E = \dfrac{6{,}3696}{3} = 2{,}1232$ ft

$\left(\dfrac{W}{Da}\right) = \dfrac{1}{5}$ $\qquad W = \dfrac{2{,}1232}{5} = 0{,}4246$ ft

$\left(\dfrac{L}{Da}\right) = \dfrac{1}{4}$ $\qquad L = \dfrac{2{,}1232}{4} = 0{,}5308$ ft (McCabe, 5th ed, p.243)

dimana : Da = diameter pengaduk

Dt = diameter tangki

L = panjang blade

W = lebar blade

E = jarak dari dasar tangki ke pusat pengaduk

J = lebar baffle

Kecepatan agitator antara 20-150 rpm (McCabe, 5th ed, p.238), diambil 100 rpm

Kecepatan keliling putaran (periperal) pengaduk turbin = 200-250 m/mnt

(MV. Joshi, p. 389)

$= \pi \,.\, Da \,.\, 100 = \pi \,.\, 0{,}6472 \,.\, 100$ (Geankoplis, 2nd ed, p. 158)

$= 203{,}3085$ m/mnt (memenuhi)

$$N_{Re} = \frac{N.Da^2.\rho}{\mu}$$ (Geankoplis, 2nd ed, pers. 3.4-1)

dimana : Da = diameter impeller, ft

N = kecepatan putaran pengaduk, rps

ρ = densitas campuran, lb/ft^3

μ = viskositas campuran, lb/ft.s

$\mu_{campuran}$ = 10,4883 cps = 7,0478.10^{-3} lb/ft.s (Perry, 1950, p. 3-240)

Np = 5 (Geankoplis, 2nd ed, fig. 3.4-4, p.155)

$N_{Re} > 10^4$ berarti aliran turbulen

$$N_{Re} = \frac{\left(\frac{100}{60}\right) rps \times (2{,}1232)^2 \, ft^2 \times 65{,}4206 \, lb/ft^3}{7{,}0478.10^{-3} \, lb/ft.s} = 69.741{,}1634 \qquad \textbf{(turbulen)}$$

Power untuk 1 buah pengaduk :

$$P = \frac{Np.\rho.N^3.Da^5}{gc} \qquad \text{(Geankoplis, 2nd ed, pers. 3.4-2)}$$

$$= \frac{5 \times 65{,}4206 \times \left(\frac{100}{60}\right)^3 \times (2{,}1232)^5}{32{,}174} = \frac{2.030{,}8562 \, lb.ft/s}{550 \, Hp/\,lb.ft/s} = 3{,}6925 \, Hp$$

Total Power yang dibutuhkan = 2 x 3,6925 Hp = 7,3849 Hp

Transmission system losses dan gland losses = 20 % dan 10 %.

Power motor = 1,3 x 7,3849 Hp = 9,6004 Hp ≈ 10 Hp

Spesifikasi :

1. Kapasitas : 348,2553 ft^3
2. Dimensi Bejana :
   - Diameter : 6,3696 ft
   - Tinggi : 9,5544 ft
   - Tebal Shell : $\frac{3}{16}$ in
   - Tebal Tutup atas : $\frac{1}{4}$ in
   - Tebal Tutup bawah : $\frac{1}{4}$ in
3. Pengaduk :
   - Jenis : flat six-blade turbine
   - Kecepatan : 100 rpm
   - Power : 10 Hp
   - Jumlah : 2
   - Panjang blade : 0,5308 ft
   - Lebar blade : 0,4246 ft

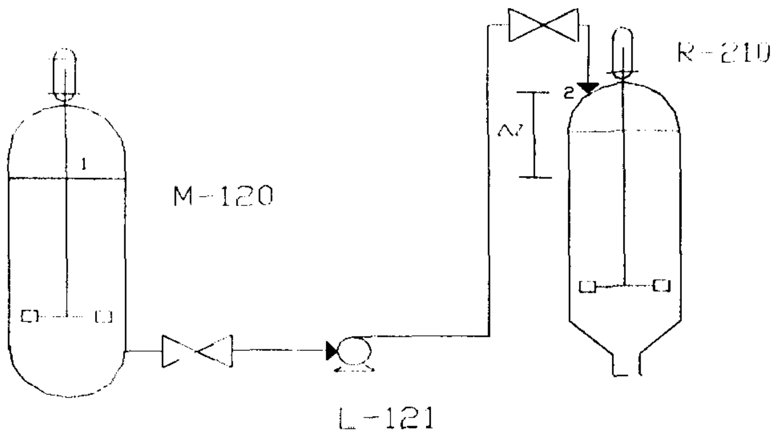
4. Baffle :

   Jumlah : 4

   Lebar : 0,5308 ft

5. Jumlah : 1 buah

4. Pompa (L-121)



Fungsi : Memompa larutan KCl menuju reaktor (R-210)

Tipe : Centrifugal pump

Dasar pemilihan : 1. Cocok untuk liquida dengan viskositas rendah.

2. Cocok untuk rate massa besar

Kapasitas : 206.649,2310 kg/hari = 8.610,3846 kg/jam = 18.985,8981 lb/jam

Perhitungan :

$\rho_{larutan}$ = 1.047,9037 kg/m^3 = 65,4206 lb/ft^3

$\mu_{larutan}$ = 10,4883 cp = 7,0478.10^{-3} lb/ft.s

$$\text{Laju alir massa (m)} = \frac{18.985{,}8981\ \text{lb}}{1\ \text{jam}} \times \frac{1\ \text{jam}}{3600\ \text{detik}} = 5{,}2739\ \text{lb/s}$$

$$\text{Laju alir volumetrik (qf)} = \frac{\text{Laju alir massa}}{\rho\ \text{liquid}}$$

$$= \frac{5{,}2739\ \text{lb/s}}{65{,}4206\ \text{lb/ft}^3} = 0{,}0806\ \text{ft}^3\text{/s} = 36{,}1847\ \text{gpm}$$

➢ *Perhitungan Diameter Pipa*

Diameter optimum (Di,op) = 3,9 $(qf)^{0,45}(\rho)^{0,13}$

(Peters & Timmerhaus, 1991 , eq.15, p. 496)

$= 3,9\ (0,0806)^{0,45}\ (65,4206)^{0,13}$

$= 2,1627$ in

Dipilih pipa $2\frac{1}{2}$ in Sch 40 : (McCabe, 5th ed, App. 5)

ID	=	2,469 in = 0,2058 ft
OD	=	2,875 in
A	=	0,03322 ft^2

$$\text{Kecepatan linear (v)} = \frac{qf}{A} = \frac{0,0806}{0,03322} = 2,4267 \text{ ft/s}$$

Check Aliran :

$$N_{Re} = \frac{\rho \times v \times ID}{\mu} = 4.634,6109 \qquad \{> 2100 \longrightarrow \text{Turbulen } (\alpha = 1)\}$$

Untuk aliran turbulen (steel pipe) digunakan:

$$f = \frac{0,04}{(N_{Re})^{0,16}} = \frac{0,04}{(4.634,6109)^{0,16}} = 0,0104$$

(Peters & Timmerhaus, 1991, eq.8, p.483)

Panjang pipa lurus = 30 ft

➢ *Perhitungan Panjang ekivalen*

- 1 buah gate valve, Le/D = 7 (Peters & Timmerhaus, 1991 , tab.1, p.485)

  Le = 1 × 7 × 0,2058 ft = 1,4406 ft

- 1 buah globe valve, Le/D = 300 (Peters & Timmerhaus, 1991 , tab.1, p.485)

  Le = 1 × 300 × 0,2058 ft = 61,7250 ft

- 3 buah elbow 90°, Le/D = 32 (Peters & Timmerhaus, 1991, tab.1, p.484)

  Le = 3 × 32 × 0,2058 ft = 19,7568 ft

Panjang total pipa = (30 + 1,4406 + 61,7250 + 19,7568) ft = 112,9174 ft

➢ *Friksi yang melalui pipa dan fitting*

$$F_1 = \frac{2.f.\Delta L.v^2}{D.gc} = \frac{2 * 0,0104 * 112,9174 * (2,4267)^2}{0,2058 * 32,174} = 2,0820 \text{ ft.lbf/lbm}$$

(Peters & Timmerhaus,1991, eq.9, p.483)

➤ *Friksi karena sudden contraction dan sudden enlargement*

Untuk aliran turbulen $\alpha = 1$,

$$\frac{A_2}{A_1} = \frac{\pi/4.D_2^2}{\pi/4.D_1^2} = \frac{(0,2058)^2}{(6,3696)^2} = 0,0093$$

$$Kc = 0,4\left(1,25 - \frac{A_2}{A_1}\right) = 0,4996 \approx 0,5$$

Kex = 1 (Brown, 1950)

$$F_2 = \frac{Kc.v^2}{2.\alpha.gc} + \frac{Kex.v^2}{2.\alpha.gc} = \frac{0,5*(2,4267)^2}{2*1*32,174} + \frac{1*(2,4267)^2}{2*1*32,174} = 0,1373 \text{ ft.lbf/lbm}$$

(Peters & Timmerhaus, 1991, tab.1, p.484)

ΣF = (2,0820 + 0,1373) ft.lbf/lbm = 2,2193 ft.lbf/lbm

➤ *Persamaan Bernoulli*

$$Ws = -\frac{1}{2.\alpha.g_c}(v_2^2 - v_1^2) - \frac{g}{g_c}(z_2 - z_1) - \frac{P_2 - P_1}{\rho} - \sum F$$

(Geankoplis, 2nd ed, p.75)

dimana : $\Delta z = (z_2 - z_1) = 10$ ft

$P_1 = P_2 = 14,7$ psi = 2.116,8 lb/ft^2

$v_1 = 0$

$v_2 = 2,4267$ ft/s

$$Ws = -\frac{1}{2.\alpha.g_c}(v_2^2 - v_1^2) - \frac{g}{g_c}(z_2 - z_1) - \frac{P_2 - P_1}{\rho} - \sum F$$

$$= -12,3107 \text{ ft.lbf/lbm}$$

Effisiensi pompa (η) = 25 % (Peter & Timmerhaus, fig 14-37, p.520)

$$\text{Brake Hp} = \frac{-Ws.m}{\eta.550} = \frac{12,3107 \times 5,2739}{0,25 \times 550} = 0,4722 \text{ Hp}$$

Effisiensi motor = 80 % (Peter & Timmerhaus, fig. 1-38, p.521)

$$\text{Sehingga dipakai power pompa} = \frac{0,4722}{0,80} = 0,5902 \text{ Hp} \approx 1 \text{ Hp}$$

Spesifikasi :

1. Tipe : Centrifugal pump
2. Kapasitas : 36,1847 gpm

3. Pipa ($2\frac{1}{2}$ in Sch 40) :

ID : 2,469 in

OD : 2,875 in

A : 0,03322 ft^2

4. Efisiensi : 80 %
5. Power : 1 Hp
6. Jumlah : 1 buah

5. Tangki Penyimpan Isopropanol (F-130)

Fungsi : Menyimpan isopropanol

Tipe : Silinder tegak dengan tutup atas dan bawah berbentuk torispherical dished head

Dasar pemilihan : Cocok untuk menyimpan liquid dalam kapasitas besar

Kondisi operasi : P = 1 atm

Kapasitas : 11.058,5693 kg/hari = 24.384,1453 lb/hari

Perhitungan :

➢ *Perhitungan Dimensi Tangki*

ρ_{liquid} = 784,9 kg/m^3 = 49,0013 lb/ft^3

$$\text{Volume larutan} = \frac{24.384,1453 \text{ lb/hari} \times 7 \text{ hari}}{49,0013 \text{ lb/ft}^3} = 3.483,3564 \text{ ft}^3$$

Asumsi: Volume ruang kosong = 20 % Volume larutan

Volume tangki = 1,2 x volume larutan

= 1,2 x 3.483,3564 ft^3

= 4.180,0277 ft^3

$$\frac{H}{D} = 2$$ (B & Y, tabel 4-27)

Volume tangki = (2 x volume torisperical dished head) + volume shell

$$4.180,0277 \text{ ft}^3 = (2 \times 0,000049 \times D^3) + \left(\frac{\pi}{4} \times 2 \times \left(\frac{D}{12}\right)^3\right)$$

$$= 1,0070.10^{-3} \times D^3$$

D = 160,7112 in = 13,3926 ft

H = 321,4224 in = 26,7852 ft

- *Perhitungan Tebal Shell*

Volume larutan (Vliq) = V tutup bawah + V shell

$$Vliq = 0{,}000049 * D^3 + \frac{\pi}{4} * \frac{D^2}{12^2} * Hliq$$

$$3.483{,}3564\ ft^3 = 0{,}000049 * (160{,}7112)^3 + \frac{\pi}{4} * \frac{(160{,}7112)^2}{12^2} * Hliq$$

$$Hliq = 23{,}2836\ ft$$

$$P_{hidrostatik} = \frac{\rho . H}{144} = \frac{49{,}0013 lb/ft^3 \times 23{,}2836 ft}{144} = 7{,}9231\ psi$$

$P_{operasi}$ = 7,9231 + 14,7 = 22,6231 psi

P_{design} = 1,2 . $P_{operasi}$ = 27,1477 psi

Bahan konstruksi yang digunakan : SA-167 grade 3 Tipe 304

f_{allow} = 18750 psi (B & Y, App. D)

Tipe sambungan double-welded butt joint :

E = 0,8 (B & Y, Tabel 13.2)

faktor korosi (C) = $\frac{1}{8}$ in

$$t_{shell} = \frac{P . ID}{2(f . E - 0{,}6 . P)} + C \qquad \text{(B \& Y, pers. 13.1)}$$

$$t_{shell} = \frac{27{,}1477 \times 160{,}7112}{2((18750 \times 0{,}8) - (0{,}6 \times 27{,}1477))} + 0{,}125 = 0{,}2706\ in \approx \frac{5}{16}\ in$$

- *Perhitungan Tebal dish*

OD = ID + (2 x t_{shell}) = 160,7112 + (2 x $\frac{5}{16}$) = 161,3362 in

rc (radius of dish) = ID = 160,7112 in

icr (inside-corner radius) = 6 % x rc = 0,06 x 160,7112 in = 9,6427 in

$$W = \frac{1}{4}\left(3 + \sqrt{\frac{rc}{icr}}\right) = \frac{1}{4}\left(3 + \sqrt{\frac{160{,}7112}{9{,}6427}}\right) = 1{,}7706 \qquad \text{(B \& Y, pers. 7.76)}$$

$$a = \frac{ID}{2} = \frac{160{,}7112}{2} = 80{,}3556\ in$$

BC = rc – icr = (160,7112 - 9,6427) in = 151,0686 in

AB = a – icr = (80,3556 – 9,6427) in = 70,7129 in

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

$$= 160{,}7112 - \sqrt{(151{,}0686)^2 - (70{,}7129)^2} = 27{,}2145 \text{ in}$$

$$t_{dish} = \frac{P \cdot rc \cdot W}{2 \cdot f \cdot E - 0{,}2 \cdot P} + C$$ (B & Y, pers 7.77)

$$t_{dish} = \frac{27{,}1477 \times 160{,}7112 \times 1{,}7706}{(2 \times 18750 \times 0{,}8) - (0{,}2 \times 27{,}1477)} + 0{,}125 = 0{,}3826 \text{ in} \approx \tfrac{7}{16} \text{ in}$$

Maka dipakai tebal tutup atas dan bawah = $\tfrac{7}{16}$ in

Dipilih *straight-flange* (sf) = 2 ½ in (B & Y, Tabel 5.8)

Tinggi dish = OA = t + b + sf = $\tfrac{7}{16}$ + 27,2145 + 2 ½

= 30,1520 in = 2,5127 ft

Tinggi tangki keseluruhan = tinggi shell + (2 x tinggi dish)

= 26,7852 + (2 x 2,5127)

= 31,8106 ft

Spesifikasi :

1. Kapasitas : 4.180,0277 ft^3
2. Dimensi bejana :

   Diameter : 13,3926 ft → 0,9 cm

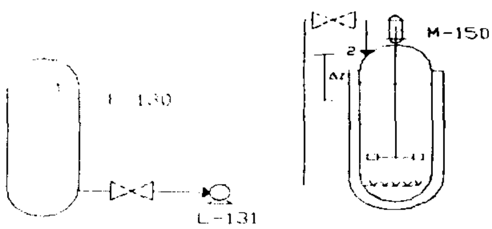
   Tinggi : 26,7852 ft

   Tebal Shell : $\tfrac{7}{16}$ in

   Tebal Tutup atas : $\tfrac{7}{16}$ in

   Tebal Tutup bawah : $\tfrac{7}{16}$ in
3. Jumlah : 1 buah

6. Pompa (L-131)



Fungsi : Memompa isopropanol ke tangki pelarutan amonia (M-150)

Tipe : Centrifugal pump

Dasar pemilihan : 1. Cocok untuk liquida dengan viskositas rendah

2. Cocok untuk rate massa besar

Spesifikasi :

1. Tipe : Centrifugal pump
2. Kapasitas : 2,5852 gpm
3. Pipa ($\frac{3}{4}$ in Sch 40) :

   ID : 0,824 in

   OD : 1,050 in

   A : 0,00371 ft^2
4. Efisiensi : 80 %
5. Power : 0,5 Hp
6. Jumlah : 1 buah

7. Tangki Penyimpan Ammonia (F-140)

Fungsi : Menyimpan ammonia

Tipe : Silinder tegak dengan tutup atas dan tutup bawah berbentuk torispherical dished head

Dasar pemilihan : Cocok untuk bertekanan tinggi

Kondisi operasi : P = 170 psi

Kapasitas : 52.133,2554 kg/hari = 114.953,8282 lb/hari

Perhitungan :

➤ *Perhitungan Dimensi Tangki*

ρ_{liquid} = 594,5205 kg/m^3 = 37,1159 lb/ft^3

$$\text{Volume larutan} = \frac{114.953{,}8282 \text{ lb/hari} \times 7 \text{ hari}}{37{,}1159 \text{ lb/ft}^3} = 21.680{,}1014 \text{ ft}^3$$

Asumsi: Volume ruang kosong = 20 % Volume larutan

Volume tangki = 1,2 x volume larutan

= 1,2 x 21.680,1014 ft^3

= 26.016,1217 ft^3

$\frac{H}{D} = 2$ (B & Y, tabel 4-27)

Volume tangki = (2 x volume torisperical dished head) + volume shell

$26.016,1217\ ft^3 = (2 \times 0,000049 \times D^3) + \left(\frac{\pi}{4} \times 2 \times \left(\frac{D}{12}\right)^3\right)$

$= 1,0070.10^{-3} \times D^3$

$D = 295,6201\ in = 24,6350\ ft$

$H = 591,2403\ in = 49,2700\ ft$

➤ *Perhitungan Tebal Shell*

Volume larutan (Vliq) = V tutup bawah + V shell

$Vliq = 0,000049 * D^3 + \frac{\pi}{4} * \frac{D^2}{12^2} * Hliq$

$21.680,1014\ ft^3 = 0,000049 * (295,6201)^3 + \frac{\pi}{4} * \frac{(295,6201)^2}{12^2} * Hliq$

$Hliq = 42,8289\ ft$

$P_{hidrostatik} = \frac{\rho.H}{144} = \frac{37,1159 lb/ft^3 \times 42,8289\ ft}{144} = 11,0391\ psi$

$P_{operasi} = 11,0391\ psi + 170\ psi = 181,0391\ psi$

$P_{design} = 1,2\ .\ P_{operasi} = 217,2470\ psi$

Bahan konstruksi yang digunakan : SA-167 grade 3 Tipe 304

$f_{allow} = 18750\ psi$ (B & Y, App. D)

Tipe sambungan double-welded butt joint :

$E = 0,8$ (B & Y, Tabel 13.2)

faktor korosi (C) = $\frac{1}{8}$ in

$t_{shell} = \frac{P.ID}{2(f.E - 0,6.P)} + C$ (B & Y, pers. 13.1)

$t_{shell} = \frac{217,2470 \times 295,6201}{2((18750 \times 0,8) - (0,6 \times 247,2470))} + 0,125 = 2,2845\ in \approx 2\frac{1}{2}\ in$

➤ *Perhitungan Tebal dish*

$OD = ID + (2 \times t_{shell}) = 295,6201 + (2 \times 2\frac{1}{2}) = 300,6201\ in$

rc (radius of dish) = ID = 295,6201 in

icr (inside-corner radius) = 6 % x rc = 0,06 x 295,6201 in = 17,7372 in

$$W = \frac{1}{4}\left(3+\sqrt{\frac{rc}{icr}}\right) = \frac{1}{4}\left(3+\sqrt{\frac{295,6201}{17,7372}}\right) = 1,7706 \qquad \text{(B \& Y, pers. 7.76)}$$

$$a = \frac{ID}{2} = \frac{295,6201}{2} = 147,8101 \text{ in}$$

BC = rc – icr = (295,6201 - 17,7372) in = 277,8829 in

AB = a – icr = (147,8101 - 17,7372) in = 130,0729 in

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

$$= 295,6201 - \sqrt{(277,8829)^2 - (130,0729)^2} = 50,0596 \text{ in}$$

$$t_{dish} = \frac{P.rc.W}{2.f.E - 0,2.P} + C \qquad \text{(B \& Y, pers 7.77)}$$

$$t_{dish} = \frac{217,2470 \times 295,6201 \times 1,7706}{(2 \times 18750 \times 0,8) - (0,2 \times 217,2470)} + 0,125 = 3,9210 \text{ in} \approx 4 \text{ in}$$

Maka dipakai tebal tutup atas dan bawah = 4 in

Dipilih *straight-flange* (sf) = 3 in (B & Y, Tabel 5.8)

Tinggi dish = OA = t + b + sf = 4 + 50,0596 + 3

= 57,0596 in = 4,7550 ft

Tinggi tangki keseluruhan = tinggi shell + (2 x tinggi dish)

= 49,2700 + (2 x 4,7550)

= 58,7800 ft

Spesifikasi :

1. Kapasitas : 26.016,1217 ft^3
2. Dimensi bejana :
   - Diameter : 24,6350 ft
   - Tinggi : 49,2700 ft
   - Tebal Shell : 2 ½ in
   - Tebal Tutup atas : 4 in
   - Tebal Tutup bawah : 4 in
3. Jumlah : 1 buah

8. Expander (G-141)

Fungsi : Menurunkan tekanan ammonia larutan menjadi 1,3 atm

Tipe : Radial

Dasar pemilihan : Cocok untuk menurunkan tekanan yang tinggi

Kapasitas : 52.133,2554 kg/hari = 2.172,2190 kg/jam = 0,6034 kg/s

Perhitungan :

P_1 = 170 psia = 11,7259 bar

P_2 = 19,11 psia = 1,3181 bar

η = 75 %

$\rho_{ammonia}$ = 37,1159 lb/ft^3 = 594,5205 kg/m^3

Dari pers. 4-19 (Ulrich, pp. 93), didapat :

$$Ws = \frac{\eta * m * (P_1 - P_2)}{\rho}$$

$$= \frac{0{,}75 * 0{,}6034\ \text{kg/s} * (11{,}7259 - 1{,}3181)\ \text{bar} * \left(1 \times 10^5\ \text{J/bar.m}^3\right)}{594{,}5205\ \text{kg/m}^3}$$

= 792,2435 W = 0,7922 kW

= 0,5908 Hp

Effisiensi motor = 80 % (Peter & Timmerhaus, fig. 14-38, p.521)

$$\text{Power motor} = \frac{Ws}{\eta}$$

$$\text{Power motor} = \frac{0{,}5908}{0{,}80} = 0{,}7385\ \text{Hp} \approx 1\ \text{Hp}$$

Spesifikasi :

1. Tipe : Radial
2. Kapasitas : 0,6034 kg/s
3. Effisiensi motor : 80 %
4. Power motor : 1 Hp
5. Jumlah : 1 buah

9. Tangki Pelarutan NH_3 (M-150)

Fungsi : Melarutkan ammonia dan isopropanol

Tipe : Silinder tegak berpengaduk dengan tutup atas dan bawah berbentuk torispherical dished head yang dilengkapi dengan sparger dan jaket pendingin

Dasar pemilihan : cocok untuk melarutkan gas

Kondisi operasi : T = 30 °C, P = 1 atm

Kapasitas : 157.979,5618 kg/hari = 6.582,4817 kg/jam = 14.514,3722 lb/jam

Perhitungan :

➤ *Perhitungan Dimensi Tangki*

$$\frac{1}{\rho_{larutan}} = \frac{x_{H_2O}}{\rho_{H_2O}} + \frac{x_{NH_3}}{\rho_{NH_3}} + \frac{x_{isopropanol}}{\rho_{isopropanol}}$$

$$\frac{1}{\rho_{larutan}} = \frac{0,6}{995,68} + \frac{0,33}{594,5205} + \frac{0,07}{784,9}$$

$$\rho_{larutan} = 802,0174 \text{ kg/m}^3 = 50,0699 \text{ lb/ft}^3$$

$$\text{Volume larutan} = \frac{14.514,3722 \text{ lb/jam}}{50,0699 \text{ lb/ft}^3}$$

$$= 289,8819 \text{ ft}^3$$

Asumsi: Volume ruang kosong = 20 % Volume larutan

Volume tangki = 1,2 x volume larutan

= 1,2 x 289,8819 ft^3

= 347,8583 ft^3

$$\frac{H}{D} = 1,5$$ (Ulrich, 1984, p. 433)

Volume tangki = (2 x volume torisperical dished head) + volume shell

$$347,8583 \text{ ft}^3 = (2 \times 0,000049 \times D^3) + \left(\frac{\pi}{4} \times 1,5 \times D^3 \times \left(\frac{1}{12}\right)^3\right)$$

$$= 7,7977.10^{-4} \times D^3$$

D = 76,4092 in = 6,3674 ft

H = 114,6137 in = 9,5511 ft

➢ *Perhitungan Tebal Shell*

Volume larutan (Vliq) = V tutup bawah + V shell

$$Vliq = 0.000049 * D^3 + \frac{\pi}{4} * \frac{D^2}{12^2} * Hliq$$

$$289,8819\ ft^3 = 0.000049 * (76,4092)^3 + \frac{\pi}{4} * \frac{(76,4092)^2}{12^2} * Hliq$$

$$Hliq = 8,4169\ ft$$

$$P_{hidrostatik} = \frac{\rho.H}{144} = \frac{50,0699\ lb/ft^3 \times 8,4169\ ft}{144} = 2,9266\ psi$$

$P_{operasi} = 2,9266 + 14,7 = 17,6266$ psi

$P_{design} = 1,2 \cdot P_{operasi} = 21,1520$ psi

Bahan konstruksi yang digunakan : SA-167 grade 3 Tipe 304

f_{allow} = 18750 psi (B & Y, App. D)

Tipe sambungan double-welded butt joint :

E = 0,8 (B & Y, Tabel 13.2)

faktor korosi (C) = $\frac{1}{8}$ in

$$t_{shell} = \frac{P.ID}{2(f.E - 0,6.P)} + C \qquad \text{(B \& Y, pers. 13.1)}$$

$$t_{shell} = \frac{P.ID}{2(f.E - 0,6.P)} + C \qquad \text{(B \& Y, pers. 13.1)}$$

$$t_{shell} = \frac{21,1520 \times 76,4092}{2((18750 \times 0,8) - (0,6 \times 21,1520))} + 0,125 = 0,1789\ in \approx \frac{3}{16}\ in$$

➢ *Perhitungan Tebal dish*

OD = ID + (2 x t_{shell}) = 76,4092 + (2 x $\frac{3}{16}$) = 76,7842 in

rc (radius of dish) = ID = 76,4092 in

icr (inside-corner radius) = 6 % x rc = 0,06 x 76,4092 in = 4,5845 in

$$W = \frac{1}{4}\left(3 + \sqrt{\frac{rc}{icr}}\right) = \frac{1}{4}\left(3 + \sqrt{\frac{76,4092}{4,5845}}\right) = 1,7706 \qquad \text{(B \& Y, pers. 7.76)}$$

$$a\ (\text{inside radius}) = \frac{ID}{2} = \frac{76,4092}{2} = 38,2046\ in$$

BC = rc – icr = (76,4092 – 4,5845) in = 71,8246 in

AB = a – icr = (38,2046 – 4,5845) in = 33,6200 in

b (depth of dish (inside)) = rc - $\sqrt{(BC)^2 - (AB)^2}$

$= 76{,}4092 - \sqrt{(71{,}8246)^2 - (33{,}6200)^2} = 12{,}9389$ in

$t_{dish} = \dfrac{P \cdot rc \cdot W}{2 \cdot f \cdot E - 0{,}2 \cdot P} + C$ (B & Y, pers 7.77)

$t_{dish} = \dfrac{21{,}1520 \times 76{,}4092 \times 1{,}7706}{(2 \times 18750 \times 0{,}8) - (0{,}2 \times 21{,}1520)} + 0{,}125 = 0{,}2204 \text{ in} \approx \frac{1}{4} \text{ in}$

Maka dipakai tebal tutup atas dan bawah = $\frac{1}{4}$ in

Dipilih *straight-flange* (sf) = 2 in (B & Y, Tabel 5.8)

Tinggi dish = OA = t + b + sf = $\frac{1}{4}$ + 12,9389 + 2

= 15,1889 in = 1,2657 ft

Tinggi tangki keseluruhan = tinggi shell + (2 x tinggi dish)

= 9,5511 + (2 x 1,2657)

= 12,0826 ft

➢ *Perhitungan pengaduk*

Dipilih jenis pengaduk = flat six-blade turbine

Jumlah impeller $= \dfrac{sg \cdot H}{Dt} = \dfrac{0{,}8055 \times 8{,}4169}{6{,}3674} = 1{,}0648 \approx 2$ buah

$\left(\dfrac{Da}{Dt}\right) = \dfrac{1}{3}$ $Da = \dfrac{6{,}3674}{3} = 2{,}1225$ ft

$\left(\dfrac{J}{Dt}\right) = \dfrac{1}{12}$ $J = \dfrac{6{,}3674}{12} = 0{,}5306$ ft

$\left(\dfrac{E}{Dt}\right) = \dfrac{1}{3}$ $E = \dfrac{6{,}3674}{3} = 2{,}1225$ ft

$\left(\dfrac{W}{Da}\right) = \dfrac{1}{5}$ $W = \dfrac{2{,}1225}{5} = 0{,}4245$ ft

$\left(\dfrac{L}{Da}\right) = \dfrac{1}{4}$ $L = \dfrac{2{,}1225}{4} = 0{,}5306$ ft

(McCabe, 5th ed, p.243)

dimana : Da = diameter pengaduk

Dt = diameter tangki

L = panjang blade

W = lebar blade

E = jarak dari dasar tangki ke pusat pengaduk

J = lebar baffle

Kecepatan agitator antara 20-150 rpm (McCabe, 5th ed, p.238), diambil 100 rpm

Kecepatan keliling putaran (periperal) pengaduk turbin = 200-250 m/mnt

(MV. Joshi, p. 389)

$= \pi \cdot Da \cdot 100 = \pi \cdot 0{,}6469 \cdot 100$ (Geankoplis, 2nd ed, p. 158)

= 203,2393 m/mnt (memenuhi)

$$N_{Re} = \frac{N . Da^2 . \rho}{\mu}$$ (Geankoplis, 2nd ed, pers. 3.4-1)

dimana : Da = diameter impeller, ft

N = kecepatan putaran pengaduk, rps

ρ = densitas campuran, lb/ft^3

μ = viskositas campuran, lb/ft.s

$\mu_{campuran} = 9{,}1757$ cps $= 6{,}1658.10^{-3}$ lb/ft.s (Perry, 1950, p. 3-240)

Np = 5 (Geankoplis, 2nd ed, fig. 3.4-4, p.155)

$N_{Re} > 10^4$ berarti aliran turbulen

$$N_{Re} = \frac{\left(\frac{100}{60}\right) rps \times (2{,}1225)^2 ft^2 \times 50{,}0699 \, lb/ft^3}{6{,}1658.10^{-3} \, lb/ft.s} = 60.971{,}2272$$ (turbulen)

Power untuk 1 buah pengaduk :

$$P = \frac{Np . \rho . N^3 . Da^5}{gc}$$ (Geankoplis, 2nd ed, pers. 3.4-2)

$$= \frac{5 \times 50{,}0699 \times \left(100/60\right)^3 \times (2{,}1225)^5}{32{,}174} = \frac{1.551{,}6828 \text{ lb.ft/s}}{550 \text{ Hp/ lb.ft/s}} = 2{,}8212 \text{ Hp}$$

Total Power yang dibutuhkan = 2 x 2,8212 Hp = 5,6425 Hp

Transmission system losses dan gland losses = 20 % dan 10 %.

Power motor = 1,3 x 5,6425 Hp = 7,3352 Hp ≈ 7,5 Hp

➢ *Perhitungan Sparger*

Digunakan sparger berbentuk cincin (ring)

Ukuran gas-bubble = 2 – 6 mm (Ulrich, 1984, p.172)

do = 3 – 6,5 mm (Treybal, 1981, p.153)

Ditetapkan do = 3 mm = 0,0098 ft

μ_G = 1,1 cps = $0{,}74.10^{-3}$ lb/ft.s (Geankoplis, 1993, fig.A.3-5, p.879)

$$\text{Reo} = \frac{4 * \text{wo}}{\pi * \text{do} * \mu_G}$$ (Treybal, 1981, p.141)

$$= \frac{4 \times \frac{1{,}3305}{50}\ \text{lb/s}}{\pi \times 0{,}0098\ \text{ft} \times 0{,}74.10^{-3}\ \text{lb/ft.s}} = 41.201{,}8082$$

$\text{dp} = 0{,}0071.\text{Reo}^{-0,05} = 0{,}0071.\ 41.201{,}8082^{-0,05}$ (Treybal, 1981, eq.6.5, p.141)

= 0,0042 m = 0,0137 ft = 4,2 mm (memenuhi)

σ = 0,025 – 0,076 N/m (Treybal, 1981, p.143)

Ditetapkan 0,05 N/m = 0,11 lb/s^2

$$\text{vt} = \sqrt{\frac{2.\text{gc}.\sigma}{\text{dp}.\rho} + \frac{\text{gc}.\text{dp}}{2}} = \sqrt{\frac{2 * 32{,}174 * 0{,}11}{0{,}0137 * 50{,}0699} + \frac{32{,}174 * 0{,}0137}{2}} = 3{,}2464\ \text{ft/s}$$

D sparger ≤ D pengaduk (Treybal, 1981, p.153)

Diambil : D sparger = 2,1225 ft = 646,938 mm

Jarak antar lubang = π.(646,938)/50 = 40,65 mm

Panjang pipa (L) ≈ keliling lingkaran

L = π . D = π . 2,1225 ft = 6,6680 ft

➢ *Perhitungan Jaket Pendingin*

Diambil : spasi jaket = 5 in

OD shell = ID shell + (2. tebal shell) = 76,7842 in

ID jaket = OD shell + spasi jaket

= 76,7842 + (2 . 5) = 86,7842 in = 7,2320 ft

Diambil : tebal jaket = tebal dish = $\frac{1}{4}$ in

OD jaket = ID jaket + 2 (tebal jaket)

= (86,7842 + (2. $\frac{1}{4}$)) in = 87,2842 in

L = 2,1225 ft

N = 100 rpm × 60 = 6000 rev/hr

ρ = 50,0699 lb/ft^3

μ = 6,1658.10^{-3} lb/ft.s = 22,1967 lb/ft.hr

k = 0,356 Btu/hr.ft^2.(°F/ft) (Kern,1965, tab.4, p.800)

c = 1,1 Btu/lb.°F (Kern,1965, fig.2, p.804)

$$R_{ej} = \frac{L^2.N.\rho}{\mu} = \frac{(2,1225\,ft)^2.6000\,rev/hr.50,0699\,lb/ft^3}{22,1967\,lb/ft.hr} = 60.971,2272$$

$$j = \frac{h_j.D_j}{k}\left(\frac{c.\mu}{k}\right)^{-1/2}\left(\frac{\mu}{\mu_w}\right)^{-0,14} = 600$$ (Kern,1965, fig.20.2, p.718)

$$600 = \frac{h_j.6,3674}{0,356}.\left(\frac{1,1.22,1967}{0,356}\right)^{-1/2}.(1)^{0,14}$$

h_j = 277,8133 Btu/hr.ft^2.°F

$$hoi = \frac{h_j.ID}{OD} = \frac{277,8133.6,3674}{6,3984} = 276,4676 \text{ Btu/hr.ft}^2.°F$$

$$Uc = \frac{hj.hoi}{hj + hoi} = \frac{277,8133 * 276,4676}{277,8133 + 276,4676} = 138,5694 \text{ Btu/hr.ft}^2.°F$$

Rd = 0,005 (Kern, 1965)

hd = 1/Rd = 1/0,005 = 200

$$Ud = \frac{Uc.hd}{Uc + hd} = \frac{138,5694 * 200}{138,5694 + 200} = 81,8558 \text{ Btu/hr.ft}^2.°F$$

Q yang diserap air pendingin = 17.476.885,3804 kJ/hari = 690.377,4283 Btu/jam

$$A' = \frac{Q}{Ud.\Delta T} = \frac{690.377,4283}{81,8558.50} = 168,6814 \text{ ft}^2$$

Ditetapkan : tinggi jaket = tinggi liquida = 8,4169 ft

A = π × Dj × z + π/4 × Dj^2 = π × 7,2320 × 8,4169 + π/4 × (7,2320)^2

= 246,8729 ft^2

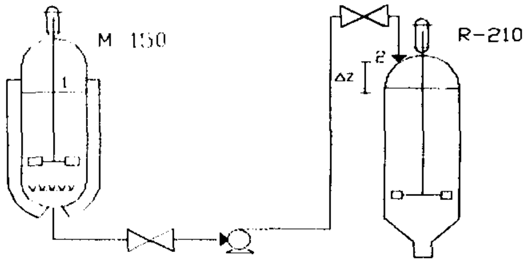
Karena A' ≤ A, maka asumsi tinggi jaket diatas sudah benar.

Jadi, tinggi jaket = 8,4169 ft

Spesifikasi :

1. Kapasitas : 347,8583 ft^3
2. Dimensi Bejana :
   - Diameter : 6,3674 ft
   - Tinggi : 9,5511 ft
   - Tebal Shell : $\frac{3}{16}$ in
   - Tebal Tutup atas : $\frac{1}{4}$ in
   - Tebal Tutup bawah : $\frac{1}{4}$ in
3. Pengaduk :
   - Jenis : flat six-blade turbine
   - Kecepatan : 100 rpm
   - Power : 7,5 Hp
   - Jumlah : 2
   - Panjang blade : 0,5306 ft
   - Lebar blade : 0,4245 ft
4. Sparger :
   - Kecepatan : 3,1638 ft/s
   - Diameter lubang : 1 mm
   - Panjang : 6,6680 ft
5. Baffle :
   - Jumlah : 4
   - Lebar : 0,5306 ft
6. Jaket Pendingin :
   - Tinggi : 8,4169 ft
   - Tebal : $\frac{1}{4}$ in
   - Luas : 246,8729 ft^2
7. Jumlah : 1 buah

10. Pompa (L-151)



Fungsi : Memompa larutan NH_3 menuju reaktor (R-210)

Tipe : Centrifugal pump

Dasar pemilihan : 1. Cocok untuk larutan dengan viskositas rendah

2. Cocok untuk rate massa besar

Spesifikasi :

1. Tipe : Centrifugal pump
2. Kapasitas : 36,1434 gpm
3. Pipa ($2\frac{1}{2}$ in Sch 40) :

   ID : 0,8240 in

   OD : 2,875 in

   A : 0,03322 ft^2
4. Efisiensi : 80 %
5. Power : 1 Hp
6. Jumlah : 1 buah

11. Tempat Penyimpan Phosphogypsum (F-160)

Fungsi : Menyimpan phosphogypsum

Tipe : Gedung dengan konstruksi beton

Dasar pemilihan : Cocok untuk menampung padatan dengan kapasitas besar

Kondisi operasi : T = 30°C, P = 1 atm

Kapasitas : 46.261,2625 kg/hari = 102.006,0840 lb/hari

Perhitungan :

Densitas padatan = 2.260,1935 kg/m^3 = 144,1039 lb/ ft^3

Waktu tinggal = 7 hari

$$\text{Volume phosphogypsum} = \frac{102.006{,}0840 \text{ lb/hari x 7 hari}}{144{,}1039 \text{ lb/ ft}^3} = 5.060{,}4036 \text{ ft}^3$$

Asumsi = storage berisi 60 % dari volume storage

$$\text{Volume storage} = \frac{5.060{,}4036 \text{ ft}^3}{0{,}6} = 8.434{,}0060 \text{ ft}^3$$

Volume storage = p x l x t

8.434,0060 ft^3 = (2 x l) x l x 11,4835 ft

l = 19,1631 ft

p = (2 x l) = 38,3261 ft

t = 11,4835 ft

Luas = p x l

= 38,3261 ft x 19,1631 ft = 734,4469 ft^2

Spesifikasi :

1. Kapasitas : 46.261,2625 kg/hari
2. Panjang bangunan : 38,3261 ft
3. Lebar bangunan : 19,1631 ft
4. Tinggi bangunan : 11,4835 ft
5. Luas bangunan : 734,4469 ft^2
6. Bahan konstruksi : concrete
7. Jumlah : 1 buah

12. Bucket Elevator (J-161)

Fungsi : Memindahkan phosphogypsum secara vertikal dari tangki penyimpan phosphogypsum ke hammer mill (C-162)

Tipe : Centrifugal discharge bucket

Dasar pemilihan : Cocok untuk transportasi bahan padat secara vertikal

Kondisi operasi : T = 30°C

Perhitungan :

Rate phosphogypsum = 46.261,2625 kg/hari = 1927,5526 kg/jam = 1,9276 ton/jam

$\rho_{\text{bulk phosphogypsum}}$ = 2.260,1935 kg/m^3 = 144,1039 lb/ ft^3

Sudut elevasi = 90°C

Jarak vertikal = 25 ft

Dari Perry, 1984, table 7-8, p.7-13, untuk kapasitas 14 ton/jam diperoleh data-data sebagai berikut :

Ukuran bucket	= (6 × 4 × 4,5) in
Jarak bucket	= 12 in
Kecepatan bucket	= 225 ft/min
Head shaft	= 43 rpm
Shaft diameter	= Head : $1\frac{15}{16}$ in
	Tail : $1\frac{11}{16}$ in
Diameter of pulleys	= Head : 20 in
	Tail : 14 in
Lebar belt	= 7 in

Data-data diatas didasarkan pada padatan dengan bulk density 100 lb/ft^3, jadi untuk padatan dengan bulk density 144,1039 lb/ft^3 dengan kapasitas 1.927,5526 kg/jam diperoleh spesifikasi sebagai berikut :

$$\text{Kecepatan bucket} = \frac{1.927{,}5526\,\text{kg/jam}}{14.000\ \text{kg/jam}} \times \frac{100\,\text{lb/ft}^3}{144{,}1039\,\text{lb/ft}^3} \times 225\ \text{ft/min}$$

$$= 21{,}4974\ \text{ft/min}$$

➤ *Tenaga bucket elevator*

$$HP = \frac{TPH \times 2 \times L}{1000} \qquad \text{(Perry, 3}^{rd}\text{, p.1349)}$$

dimana : TPH = kapasitas feed, ton/jam

L = tinggi elevasi bucket, ft

$$HP = \frac{1{,}9276 \times 2 \times 25}{1000} = 0{,}0964\ \text{Hp}$$

Effisiensi motor = 80 % (Peter & Timmerhaus, fig. 14-38, p. 521)

$$\text{Power} = \frac{0{,}0964}{0{,}80} = 0{,}1205 \text{ Hp} \approx 0{,}5 \text{ Hp}$$

Spesifikasi :

1. Tipe : Centrifugal discharge bucket
2. Sudut elevasi : 90°C
3. Jarak vertikal : 25 ft
4. Ukuran bucket : 6 x 4 x 4 $\frac{1}{2}$ in
5. Jarak bucket : 12 in
6. Kecepatan bucket : 225 ft/mnt
7. Lebar belt : 7 in
8. Jumlah : 1 buah

13. Hammer Mill (C-162)

Fungsi : Menghancurkan batuan phospogypsum

Tipe : Hinged-hammer pulverizer jenis limestone $\frac{1}{8}$ in slots

Dasar pemilihan : Cocok untuk menghancurkan padatan dengan kekerasan mohs $\leq$ 1,5

Perhitungan :

Range hammer mill = 0,1 – 5 ton/jam (Wallas, 1988)

Range produk = 10 – 100 μm

$$\text{Kapasitas phosphogypsum masuk} = \frac{46.261{,}2625 \text{ kg/hari}}{24 \text{ hari/jam}}$$

$$= 1.927{,}5526 \text{ kg/jam} = 1{,}9276 \text{ ton/jam}$$

(memenuhi range Wallas)

Wi = 8,16 (Wallas, 1988, Tabel 12.2, p.342)

Range power consumption (W) = 1-100 kWh (Wallas, 1988)

$$W = 10 \cdot Wi \cdot \left(\frac{1}{\sqrt{d}} - \frac{1}{\sqrt{di}}\right)$$

dimana : W = power consumption, kWh/ton

d = diameter setelah penghancuran, μm

di = diameter mula-mula, μm

$$W = 10 \times 8{,}16 \times \left(\frac{1}{\sqrt{50}} - \frac{1}{\sqrt{10000}} \right)$$

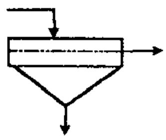
$= 24{,}9882$ kW/(ton/h) = 33,5 Hp/(ton/h) (memenuhi range Wallas)

Dari Wallas, Tabel 12-9, p.350, didapatkan untuk kapasitas 1,9276 ton/jam.

Spesifikasi :

1. Tipe : Hinged-hammer pulverizer jenis limestone $\frac{1}{8}$ in slots
2. Ukuran : 2,42 ft x 3 ft
3. Power : 33,5 Hp
4. Feed opening : 12 x 12 in
5. Jumlah : 1 buah

14. Screen (H-163)



Fungsi : Mengayak phosphogypsum sehingga diperoleh produk yang lolos ayakan 100 mesh

Tipe : Vibrating screen

Dasar pemilihan : - Dapat memisahkan partikel dari 4-325 mesh
- Efisiensi tinggi
- Biaya pemeliharaan rendah

Kapasitas : 46.261,2625 kg/hari = 1.927,5526 kg/jam = 1,9276 ton/jam

Perhitungan :

Standarisasi ukuran screen : (Brown, p.10)

Lebar = 3-4 ft

Panjang = 8-10 ft

Diambil ukuran screen = 3 x 8 ft

$$\text{Kapasitas} = \frac{100 \text{ ton/ft}^2}{24 \text{ jam}} = 4{,}1667 \text{ ton/jam.ft}^2$$

Luas screen yang dibutuhkan = $\frac{1,9276 \text{ ton/jam}}{4,1667 \text{ ton/jam. ft}^2}$ = 0,4626 ft^2

Dari McCabe, 4th ed, p.216 :

$$P = T \times 0,1362 \times W \times \left(\frac{1}{\sqrt{DP_B}} - \frac{1}{\sqrt{DP_A}} \right)$$

dimana : P = tenaga motor, kW

T = kapasitas, ton/jam

DP_A = ukuran umpan yang masuk, ft

DP_B = ukuran umpan yang lolos, ft

W = work index, diambil = 12,74 (McCabe, Tabel 4-4)

DP_A = 0,177 mm = $5,8074.10^{-4}$ ft

DP_B = 0,149 mm = $4,8887.10^{-4}$ ft

$$P = 1,9276 \times 0,1362 \times 12,74 \times \left(\frac{1}{\sqrt{4,8887.10^{-4}}} - \frac{1}{\sqrt{5,8074.10^{-4}}} \right)$$

= 12,4803 kW = 16,7360 Hp

Effisiensi motor = 87 % (Peter & Timmerhaus, fig. 14-38, p. 521)

Power = $\frac{16,7360}{0,87}$ = 19,2368 Hp ≈ 20 Hp

Spesifikasi :

1. Kapasitas : 4,1667 ton/jam.ft^2
2. Ukuran screen : 3 x 8 ft
3. Sieve designation : Standard 149 mikron, Alternative No.100
4. Sieve opening : 0,149 mm
5. Nominal wire diameter : 0,110 mm
6. Power : 20 Hp
7. Jumlah : 1 buah

15. Belt Conveyor (J-164)

Fungsi : mengangkut dan mencuci phosphogypsum

Tipe : Troughed belt on 45° idlers with rolls of equal length

Dasar pemilihan : Ekonomis dan cocok untuk kapasitas besar

Kapasitas : 37.009,0100 kg/hari = 1,5420 ton/jam

Perhitungan :

Panjang belt conveyor = 25 ft

Berdasarkan Perry edisi 7 (Tabel 21-7) didapatkan :

Lebar belt = 14 in

Belt plies = 3-5

Kecepatan belt = 100 ft/mnt

Kapasitas = 32 ton/jam

Spesifikasi diatas berdasarkan material dengan density 100 lb/ft^3. Untuk material dengan density 144,1039 lb/ft^3 dan kapasitas 1,5420 ton/jam, diperoleh:

$$\text{Kecepatan screw belt} = \frac{1{,}5420\ \text{ton/jam}}{32\ \text{ton/jam}} \times \frac{100\ \text{lb/ft}^3}{144{,}1039\ \text{lb/ft}^3} \times 100\ \text{ft/mnt}$$

$$= 3{,}3439\ \text{ft/mnt}$$

Tenaga untuk menggerakkan belt :

Sesuai dengan Perry edisi 3 hal 1355 :

HP = TPH x (H x 0,002 + 0,001 x V) C

dimana : HP = Horse Power, Hp

TPH = Kapasitas, ton/jam

H = Jarak horizontal, ft

V = Jarak vertikal, ft

C = Faktor bahan yang diangkut diambil 2,5 (Perry, 3rd ed, hal 1356)

HP = 1,5420 ton/jam (25 ft x 0,002 + 0,001 x 0 ft) 2,5

= 0,1928 Hp

Effisiensi motor = 80 % (Peter and Timmerhaus, fig 14-38, hal 521)

$$\text{Tenaga motor penggerak belt} = \frac{0{,}1928\ \text{Hp}}{0{,}8} = 0{,}2409\ \text{Hp} \approx 0{,}5\ \text{Hp}$$

Spesifikasi :

1. Tipe : Troughed belt on 45° idlers with rolls of equal length
2. Kapasitas : 1,5420 ton/jam

3. Lebar belt : 14 in
4. Belt plies : 3-5
5. Panjang belt conveyor: 25 ft
6. Tenaga motor : 0,5 Hp
7. Bahan : Rubber dan Steel
8. Jumlah : 1 buah

16. Screw Conveyor (J-165)

Fungsi : Mengangkut phosphogypsum dari belt conveyor (J-164) menuju reaktor (R-210)

Tipe : Standard pitch screw conveyor

Dasar pemilihan : Membutuhkan ruangan sedikit, harga murah, pemeliharaan mudah, cocok untuk memindahkan padatan

Kapasitas : 56.260,5277 kg/hari = 2.344,1887 kg/jam = 5.168,9360 lb/jam

Perhitungan :

Densitas = 1.564,6892 kg/m^3 = 97,6835 lb/ft^3

Sudut elevasi = 30°

$$\text{Rate volumetrik} = \frac{5.168{,}9360\,\text{lb/jam}}{97{,}6835\,\text{lb/ft}^3} = 52{,}9151\ \text{ft}^3\text{/jam} = 0{,}8819\ \text{ft}^3\text{/mnt}$$

Dari Perry, 1984, tab. 7-6, p. 7-7 didapat :

Diameter lubang feed = 6 in

Panjang screw = 10 ft

Kecepatan screw = 40 rpm

Power : $$\text{Hp} = \frac{C.L.W.F}{33000}$$ (Badger, 1957, p. 711)

dimana : C = kapasitas, ft^3/menit

L = panjang srew conveyor,ft

W = berat material, lb/ft^3

F = faktor material (F = 3, Badger, 1957, tabel 16-6, hal 711)

$$\text{Hp} = \frac{0{,}8819 \times 10 \times 97{,}6835 \times 3}{33000} = 0{,}0783\ \text{Hp}$$

Efisiensi motor = 80% (Peters & Timmerhaus, 1991, grafik 14-38, p. 521)

$$\text{Power} = \frac{0{,}0783}{0{,}8}\ \text{Hp} = 0{,}0979\ \text{Hp}$$

Dari Badger, 1957, hal 713: jika power < 2 Hp, maka power dikalikan dua.

Power = 0,0979 x 2 = 0,1958 Hp ≈ 0,5 Hp

Spesifikasi :

1. Kapasitas : 5.168,9360 lb/jam
2. Tipe : Standard pitch screw conveyor
3. Kecepatan screw : 40 rpm
4. Panjang screw : 10 ft
5. Diameter lubang feed : 6 in
6. Power : 0,5 Hp
7. Jumlah : 1 buah

17. Reaktor (R-210)

Fungsi : Mereaksikan larutan KCl, phosphogypsum dan larutan ammonia

Tipe : Silinder tegak berpengaduk dengan tutup atas berbentuk torispherical dished head dan tutup bawah berbentuk konikal α = 45

Dasar pemilihan : Cocok untuk larutan yang banyak mengandung padatan

Kondisi operasi : P = 1 atm

Kapasitas : 420.889,3205 kg/hari = 928 060,9518 lb/hari

Perhitungan :

➢ *Perhitungan Dimensi Tangki*

$$\frac{1}{\rho_{larutan}} = \frac{x_{KCl}}{\rho_{KCl}} + \frac{x_{H_2O}}{\rho_{H_2O}} + \frac{x_{NH_3}}{\rho_{NH_3}} + \frac{x_{Ca_2SO_4\cdot 2H_2O}}{\rho_{Ca_2SO_4\cdot 2H_2O}} + \frac{x_{isopropanol}}{\rho_{isopropanol}} + \frac{x_{pengotor}}{\rho_{pengotor}}$$

$\rho_{larutan}$ = 978,5016 kg/m^3 = 61,0879 lb/ft^3

$$\text{Volume larutan} = \frac{928.060{,}9518\ \text{lb/hari}}{24\ \text{jam/hari} \times 61{,}0879\ \text{lb/ft}^3} = 633{,}0098\ \text{ft}^3$$

Asumsi: Volume ruang kosong = 20 % Volume larutan

Volume tangki = 1,2 x volume larutan

= 1,2 x 633,0098 ft^3 = 759,6117 ft^3

$\frac{H}{D} = 2$ (Ulrich,1984, p. 433)

Volume tangki = volume konis + volume tutup atas + volume shell

$$759{,}6117\ ft^3 = \left(\frac{\pi}{24} x \frac{\left(\frac{D}{12}\right)^3}{tg\ 45^\circ} \right) + (0{,}000049\ x\ D^3) + \left(\frac{\pi}{4} x\ 2\ x \left(\frac{D}{12}\right)^3 \right)$$

$= 1{,}0338.10^{-3}\ x\ D^3$

D = 90,2377 in = 7,5198 ft

H = 180,4755 in = 15,0396 ft

➤ *Perhitungan Tebal Shell*

Volume larutan (Vliq) = V konis + V shell

$$Vliq = \left(\frac{\pi}{24} x \frac{\left(\frac{D}{12}\right)^3}{tg\ 45^\circ} \right) + \frac{\pi}{4} * \frac{D^2}{12^2} * Hliq$$

$$633{,}0098\ ft^3 = \left(\frac{\pi}{24} x \frac{\left(\frac{90{,}2377}{12}\right)^3}{tg\ 45^\circ} \right) + \frac{\pi}{4} * \frac{(90{,}2377)^2}{12^2} * Hliq$$

Hliq = 12,9997 ft

$$P_{hidrostatik} = \frac{\rho.H}{144} = \frac{61{,}0879\ lb/ft^3\ x\ 12{,}9997\ ft}{144} = 5{,}5148\ psi$$

$P_{operasi}$ = 5,5148 psi + 14,7 psi = 20,2148 psi

P_{design} = 1,2 . $P_{operasi}$ = 24,2577 psi

Bahan konstruksi yang digunakan : SA-167 grade 3 Tipe 304

f_{allow} = 18750 psi (B & Y, App. D)

Tipe sambungan double-welded butt joint :

E = 0,8 (B & Y, Tabel 13.2)

faktor korosi (C) = $\frac{1}{8}$ in

$$t_{shell} = \frac{P \cdot ID}{2(f \cdot E - 0{,}6 \cdot P)} + C \qquad \text{(B \& Y, pers. 13.1)}$$

$$t_{shell} = \frac{24{,}2577 \times 90{,}2377}{2((18750 \times 0{,}8) - (0{,}6 \times 24{,}2577))} + 0{,}125 = 0{,}1980 \text{ in} \approx \frac{1}{4} \text{ in}$$

➤ *Perhitungan Tebal Tutup atas*

OD = ID + (2 x t_{shell}) = 90,2377 + (2 x $\frac{1}{4}$) = 90,7377 in

rc (radius of dish) = ID = 90,2377 in

icr (inside-corner radius) = 6 % x rc = 0,06 x 90,2377 in = 5,4143 in

$$W = \frac{1}{4}\left(3 + \sqrt{\frac{rc}{icr}}\right) = \frac{1}{4}\left(3 + \sqrt{\frac{90{,}2377}{5{,}4143}}\right) = 1{,}7706 \qquad \text{(B \& Y, pers. 7.76)}$$

$$a \text{ (inside radius)} = \frac{ID}{2} = \frac{90{,}2377}{2} = 45{,}1189 \text{ in}$$

BC = rc – icr = (90,2377 – 5,4143) in = 84,8235 in

AB = a – icr = (45,1189 – 5,4143) in = 39,7046 in

$$b \text{ (depth of dish (inside))} = rc - \sqrt{(BC)^2 - (AB)^2}$$

$$= 90{,}2377 - \sqrt{(84{,}8235)^2 - (39{,}7046)^2} = 15{,}2806 \text{ in}$$

$$t_{dish} = \frac{P \cdot rc \cdot W}{2 \cdot f \cdot E - 0{,}2 \cdot P} + C \qquad \text{(B \& Y, pers 7.77)}$$

$$t_{dish} = \frac{24{,}2577 \times 90{,}2377 \times 1{,}7706}{(2 \times 18750 \times 0{,}8) - (0{,}2 \times 24{,}2577)} + 0{,}125 = 0{,}2542 \text{ in} \approx \frac{5}{16} \text{ in}$$

Maka dipakai tebal tutup atas = $\frac{5}{16}$ in

Dipilih *straight-flange* (sf) = 2 in (B & Y, Tabel 5.8)

Tinggi dish = OA = t + b + sf = $\frac{5}{16}$ + 15,2806 + 2

= 17,5931 in = 1,4661 ft

➤ *Perhitungan Tebal Tutup bawah (Konical)*

$$t_{konis} = \frac{P \cdot ID}{2 \cdot \cos\alpha\,(f \cdot E - 0{,}6 \cdot P)} + C \qquad \text{(B \& Y, pers. 6.154)}$$

$$= \frac{24{,}2577 \times 90{,}2377}{2 \times \cos 45° \times (18.750 \times 0{,}8 - 0{,}6 \times 24{,}2577)} + 0{,}125 \text{ in}$$

$= 0{,}2283 \text{ in} \approx \frac{1}{4} \text{ in}$

$$\text{Tinggi konis} = \frac{0{,}5.D}{tg\,45^\circ} = \frac{0{,}5 * 7{,}5198 \text{ ft}}{tg\,45^\circ} = 3{,}7599 \text{ ft}$$

Tinggi tangki keseluruhan = tinggi shell + tinggi konis + tinggi tutup atas

= 15,0396 + 3,7599 + 1,4661 = 20,2656 ft

➢ *Perhitungan pengaduk*

Dipilih jenis pengaduk = flat six-blade turbine

$$\text{Jumlah impeller} = \frac{sg.H}{Dt} = \frac{0{,}9827 \times 12{,}9997}{7{,}5198} = 1{,}6989 \approx 2 \text{ buah}$$

$$\left(\frac{Da}{Dt}\right) = \frac{1}{3} \qquad Da = \frac{7{,}5198}{3} = 2{,}5066 \text{ ft}$$

$$\left(\frac{J}{Dt}\right) = \frac{1}{12} \qquad J = \frac{7{,}5198}{12} = 0{,}6267 \text{ ft}$$

$$\left(\frac{E}{Dt}\right) = \frac{1}{3} \qquad E = \frac{7{,}5198}{3} = 2{,}5066 \text{ ft}$$

$$\left(\frac{W}{Da}\right) = \frac{1}{5} \qquad W = \frac{2{,}5066}{5} = 0{,}5013 \text{ ft}$$

$$\left(\frac{L}{Da}\right) = \frac{1}{4} \qquad L = \frac{2{,}5066}{4} = 0{,}6267 \text{ ft}$$

(McCabe, 5th ed, p.243)

dimana : Da = diameter pengaduk

Dt = diameter tangki

L = panjang blade

W = lebar blade

E = jarak dari dasar tangki ke pusat pengaduk

J = lebar baffle

Kecepatan agitator antara 20-150 rpm (McCabe, 5th ed, p.238), diambil 100 rpm

Kecepatan keliling putaran (periperal) pengaduk turbin = 200-250 m/mnt

(MV. Joshi, p. 389)

$= \pi . Da . 100 = \pi . 0{,}7640 . 100$ (Geankoplis, 2nd ed, p. 158)

= 240,0217 m/mnt (memenuhi)

$$N_{Re} = \frac{N.Da^2.\rho}{\mu}$$ (Geankoplis, 2nd ed, pers. 3.4-1)

dimana : Da = diameter impeller, ft

N = kecepatan putaran pengaduk, rps

ρ = densitas campuran, lb/ft^3

μ = viskositas campuran, lb/ft.s

$\mu_{campuran}$ = 10,1350 cps = $6,8104.10^{-3}$ lb/ft.s (Perry, 1950, p. 3-240)

Np = 5 (Geankoplis, 2nd ed, fig. 3.4-4, p.155)

$N_{Re} > 10^4$ berarti aliran turbulen

$$N_{Re} = \frac{\left(\frac{100}{60}\right) rps \times (2,5066)^2 ft^2 \times 61,0879 lb/ft^3}{6,8104.10^{-3}\ lb/ft.s} = 93.928,9029$$ (turbulen)

Power untuk 1 buah pengaduk :

$$P = \frac{Np.\rho.N^3.Da^5}{gc}$$ (Geankoplis, 2nd ed, pers. 3.4-2)

$$= \frac{5 \times 61,0879 \times \left(100/60\right)^3 \times (2,5066)^5}{32,174} = \frac{4.349,0490 lb.ft/s}{550\ Hp/lb.ft/s} = 7,9074\ Hp$$

Total Power yang dibutuhkan = 2 x 7,9074 Hp = 15,8147 Hp

Kehilangan transmisi dan gland losses = 10 % dan 20 %.

Power motor = 1,3 x 15,8147 Hp = 20,5591 Hp ≈ 21 Hp

Spesifikasi :

1. Kapasitas : 759,6117 ft^3
2. Dimensi Bejana :

   Diameter : 7,5198 ft

   Tinggi : 15,0396 ft

   Tebal Shell : $\frac{1}{4}$ in

   Tebal Tutup atas : $\frac{5}{16}$ in

   Tebal Tutup bawah : $\frac{1}{4}$ in
3. Pengaduk :

   Jenis : flat six-blade turbine

Kecepatan : 100 rpm

Power : 21 Hp

Jumlah : 2

Panjang blade : 0,6267 ft

Lebar blade : 0,5013 ft

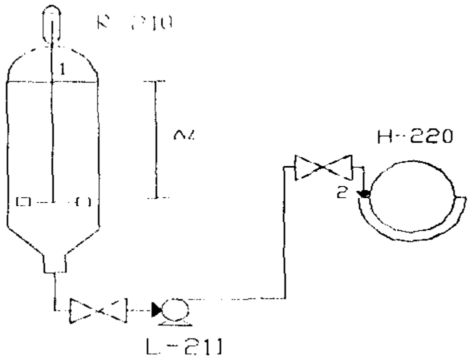
4. Baffle :

 Jumlah : 4

 Lebar : 0,6267 ft

5. Jumlah : 1 buah

18. Pompa (L-211)



Fungsi : Memompa larutan yang keluar dari reaktor (R-210) ke dalam rotary drum separator I (H-220)

Tipe : Centrifugal pump

Dasar pemilihan : 1. Cocok untuk liquida dengan viskositas rendah

2. Cocok untuk rate massa besar

Spesifikasi :

1. Tipe : Centrifugal pump
2. Kapasitas : 82,2971 gpm
3. Pipa ($3\frac{1}{2}$ in Sch 40) :

 ID : 3,5480 in

 OD : 4,0000 in

 A : 0,06870 ft^2

4. Efisiensi : 80 %
5. Power : 1,5 Hp
6. Jumlah : 1 buah

19. Rotary Drum Separator I (H-220)

Fungsi : Menyaring endapan sebagai hasil reaksi dari reaktor I (R-210)

Tipe : Continuous Rotary Drum Filter

Dasar pemilihan : Retention larutan pada cake rendah

Pengoperasian sederhana

Kondisi operasi : T = 30°C, P = 1 atm = $1{,}01.10^5$ Pa

Kapasitas : 420.889,3205 kg/hari = 17.537,0550 kg/jam

Perhitungan :

$$C_x = \text{konsentrasi padatan} = \frac{52.404{,}6661}{420.889{,}3205} = 0{,}1245\ \frac{\text{kg solid}}{\text{kg slurry}}$$

$$m = \frac{\text{berat cake basah}}{\text{berat cake kering}} = \frac{34.975{,}3162}{52.404{,}6661} = 0{,}6674$$

Pada T = 30°C :

$\rho = 931{,}2215$ kg/m^3

$\mu = 9{,}887.10^{-3}$ kg/m.s

$\alpha = 4{,}37.10^9 \cdot \Delta P^{0,3} = 4{,}37.10^9 \cdot (50.10^3)^{0,3} = 1{,}1225.10^{11}$ m/kg

f = fraksi drum yang tercelup dalam slurry = 33 %

Dari pers. 13.2 – 10, Geankoplis, 2nd ed, mendapatkan :

$$Cs = \frac{\rho.C_x}{1 - m.C_x} = \frac{931{,}2215 \times 0{,}1245}{1 - (0{,}6674 \times 0{,}1245)} = 126{,}4539\ \frac{\text{kg solid}}{\text{m}^3\ \text{filtrat}}$$

Filter cycle time (t_c) = 250 detik

Slurry rate = 17.537,0550 kg slurry/jam = 4,8714 kg slurry/s

$$\frac{V}{t_C} = 4{,}8714 \frac{C_X}{C_S}$$

$$= 4{,}8714\,\frac{\text{kg slurry}}{\text{s}} \times \left(\frac{0{,}1245\,\dfrac{\text{kg solid}}{\text{kg slurry}}}{126{,}4539\,\dfrac{\text{kg solid}}{\text{m}^3\ \text{filtrat}}} \right) = 4{,}7965.10^{-3}\ \text{m}^3\ \text{filtrat/s}$$

$$\frac{V}{A.t_c} = \left(\frac{2.f.(-\Delta P)}{t_c.\mu.\alpha.C_s} \right)^{1/2}$$ (Geankoplis, 2nd ed, pers. 13.2 –24)

$$\frac{4{,}7965.10^{-3}}{A} = \left(\frac{2 * 0.33 * 50.10^3}{250 * 9{,}887.10^{-3} * 1{,}1225.10^{11} * 126{,}4539} \right)^{1/2}$$

A = 156,3983 m^2

Spesifikasi :

1. Tipe : Continuous Rotary Drum Filter
2. Kapasitas : 420.889,3205 kg/hari
3. Filter surface area : 156,3983 m^2
4. Jumlah : 1 buah

20. Screw Conveyor (J-221)

Fungsi : Mengangkut cake dari rotary drum separator I (H-220) ke tangki pelarutan K_2SO_4 (M-222)

Tipe : Standard pitch screw conveyor

Dasar pemilihan : Membutuhkan ruangan sedikit, harga murah, pemeliharaan mudah, cocok untuk memindahkan padatan

Kapasitas : 34.975,3161 kg/hari = 1.457,3048 kg/jam = 3.213,3572 lb/jam

Perhitungan :

Densitas = 1.090,6907 kg/m^3 = 68,0918 lb/ft^3

Sudut elevasi = 30°

$$\text{Rate volumetrik} = \frac{3.213{,}3572\ \text{lb/jam}}{68{,}0918\ \text{lb/ft}^3} = 47{,}1915\ \text{ft}^3/\text{jam} = 0{,}7865\ \text{ft}^3/\text{mnt}$$

Dari Perry, 1984, tab. 7-6, p. 7-7 didapat :

Diameter lubang feed = 6 in

Panjang screw = 10 ft

Kecepatan screw = 40 rpm

Power : $Hp = \frac{C.L.W.F}{33000}$ (Badger, 1957, p. 711)

dimana : C = kapasitas, ft^3/menit

L = panjang srew conveyor,ft

W= berat material, lb/ft^3

F = faktor material (F = 3, Badger, 1957, tabel 16-6, hal 711)

$$Hp = \frac{0,7865 \times 10 \times 68,0918 \times 3}{33000} = 0,0487 \text{ Hp}$$

Efisiensi motor = 80% (Peters & Timmerhaus, 1991, grafik 14-38, p. 521)

$$Power = \frac{0,0487}{0,8} \text{ Hp} = 0,0609 \text{ Hp}$$

Dari Badger, 1957, hal 713: jika power < 2 Hp, maka power dikalikan dua.

Power = 0,0609 x 2 = 0,1217 Hp ≈ 0,5 Hp

Spesifikasi :

1. Kapasitas : 3.213,3572 lb/jam
2. Tipe : Standard pitch screw conveyor
3. Kecepatan screw : 40 rpm
4. Panjang screw : 10 ft
5. Diameter lubang feed : 6 in
6. Power : 0,5 Hp
7. Jumlah : 1 buah

21. Tangki Pelarutan K_2SO_4 (M-222)

Fungsi : Melarutkan K_2SO_4

Tipe : Silinder tegak berpengaduk dengan tutup atas dan bawah berbentuk torispherical dished head

Dasar pemilihan : Cocok untuk melarutkan padatan

Kondisi operasi : P = 1 atm

Kapasitas : 218.658,1008 kg/hari = 482.141,1123 lb/hari

Perhitungan :

➢ *Perhitungan Dimensi Tangki*

$\rho_{larutan}$ = 1.090,6907 kg/m^3 = 68,0918 lb/ft^3

$$\text{Volume larutan} = \frac{482.141,1123 \text{ lb/hari}}{24 \text{ jam/hari} \times 68,0918 \text{ lb/ft}^3}$$

$$= 295,0312 \text{ ft}^3$$

Asumsi: Volume ruang kosong = 20 % Volume larutan

Volume tangki = 1,2 x volume larutan

= 1,2 x 295,0312 ft^3

= 354,0375 ft^3

$$\frac{H}{D} = 1,5$$ (Ulrich,1984, p. 433)

Volume tangki = (2 x volume torisperical dished head) + volume shell

$$354,0375 \text{ ft}^3 = (2 \times 0,000049 \times D^3) + \left(\frac{\pi}{4} \times 1,5 \times D^3 \times \left(\frac{1}{12}\right)^3\right)$$

$$= 7,7977.10^{-4} \times D^3$$

D = 76,8589 in = 6,4049 ft

H = 115,2884 in = 9,6074 ft

➢ *Perhitungan Tebal Shell*

Volume larutan (Vliq) = V tutup bawah + V shell

$$\text{Vliq} = 0,000049 * Ds^3 + \frac{\pi}{4} * \frac{Ds^2}{12^2} * \text{Hliq}$$

$$295,0312 \text{ ft}^3 = 0,000049 * (76,8589)^3 + \frac{\pi}{4} * \frac{(76,8589)^2}{12^2} * \text{Hliq}$$

Hliq = 8,4665 ft

$$P_{hidrostatik} = \frac{\rho.H}{144} = \frac{68,0918 \text{ lb/ft}^3 \times 8,4665 \text{ ft}}{144} = 4,0035 \text{ psi}$$

$P_{operasi}$ = 4,0035 psi + 14,7 psi = 18,7035 psi

P_{design} = 1,2 . $P_{operasi}$ = 22,4441 psi

Bahan konstruksi yang digunakan : SA-167 grade 3 Tipe 304

f_{allow} = 18750 psi (B & Y, App. D)

Tipe sambungan double-welded butt joint :

E = 0,8 (B & Y, Tabel 13.2)

faktor korosi (C) = $\frac{1}{8}$ in

$$t_{shell} = \frac{P \cdot ID}{2(f \cdot E - 0{,}6 \cdot P)} + C \qquad \text{(B \& Y, pers. 13.1)}$$

$$t_{shell} = \frac{22{,}4441 \times 76{,}8589}{2((18750 \times 0{,}8) - (0{,}6 \times 22{,}4441))} + 0{,}125 = 0{,}1826 \text{ in} \approx \frac{3}{16} \text{ in}$$

➢ *Perhitungan Tebal dish*

OD = ID + (2 x t_{shell}) = 76,8589 + (2 x $\frac{3}{16}$) = 77,2339 in

rc (radius of dish) = ID = 76,8589 in

icr (inside-corner radius) = 6 % x rc = 0,06 x 76,8589 in = 4,6115 in

$$W = \frac{1}{4}\left(3 + \sqrt{\frac{rc}{icr}}\right) = \frac{1}{4}\left(3 + \sqrt{\frac{76{,}8589}{4{,}6115}}\right) = 1{,}7706 \qquad \text{(B \& Y, pers. 7.76)}$$

$$a \text{ (inside radius)} = \frac{ID}{2} = \frac{76{,}8589}{2} = 38{,}4295 \text{ in}$$

BC = rc – icr = (76,8589 - 4,6115) in = 72,2474 in

AB = a – icr = (76,8589 – 4,6115) in = 33,8179 in

$$b \text{ (depth of dish (inside))} = rc - \sqrt{(BC)^2 - (AB)^2}$$

$$= 76{,}8589 - \sqrt{(72{,}2474)^2 - (33{,}8179)^2} = 13{,}0151 \text{ in}$$

$$t_{dish} = \frac{P \cdot rc \cdot W}{2 \cdot f \cdot E - 0{,}2 \cdot P} + C \qquad \text{(B \& Y, pers 7.77)}$$

$$t_{dish} = \frac{22{,}4441 \times 76{,}8589 \times 1{,}7706}{(2 \times 18750 \times 0{,}8) - (0{,}2 \times 22{,}4441)} + 0{,}125 = 0{,}2268 \text{ in} \approx \frac{1}{4} \text{ in}$$

Maka dipakai tebal tutup atas dan bawah = $\frac{1}{4}$ in

Dipilih *straight-flange* (sf) = 2 in (B & Y, Tabel 5.8)

Tinggi dish = OA = t + b + sf = $\frac{1}{4}$ + 13,0151 + 2

= 15,2651 in = 1,2721 ft

Tinggi tangki keseluruhan = tinggi shell + (2 x tinggi dish)

= 9,6074 + (2 x 1,2721)

= 12,1516 ft

➢ *Perhitungan pengaduk*

Dipilih jenis pengaduk = flat six-blade turbine

Jumlah impeller $= \dfrac{sg.H}{Dt} = \dfrac{1{,}0954 \times 8{,}4665}{6{,}4049} = 1{,}4480 \approx 2$ buah

$\left(\dfrac{Da}{Dt}\right) = \dfrac{1}{3}$ $\qquad Da = \dfrac{6{,}4049}{3} = 2{,}1350$ ft

$\left(\dfrac{J}{Dt}\right) = \dfrac{1}{12}$ $\qquad J = \dfrac{6{,}4049}{12} = 0{,}5337$ ft

$\left(\dfrac{E}{Dt}\right) = \dfrac{1}{3}$ $\qquad E = \dfrac{6{,}4049}{3} = 2{,}1350$ ft

$\left(\dfrac{W}{Da}\right) = \dfrac{1}{5}$ $\qquad W = \dfrac{2{,}1350}{5} = 0{,}4270$ ft

$\left(\dfrac{L}{Da}\right) = \dfrac{1}{4}$ $\qquad L = \dfrac{2{,}1350}{4} = 0{,}5337$ ft

(McCabe, 5th ed, p.243)

dimana : Da = diameter pengaduk

Dt = diameter tangki

L = panjang blade

W = lebar blade

E = jarak dari dasar tangki ke pusat pengaduk

J = lebar baffle

Kecepatan agitator antara 20-150 rpm (McCabe, 5th ed, p.238), diambil 100 rpm

Kecepatan keliling putaran (periperal) pengaduk turbin = 200-250 m/mnt

(MV. Joshi, p. 389)

$= \pi \,.\, Da \,.\, 100 = \pi \,.\, 0{,}6507 \,.\, 100$ (Geankoplis, 2nd ed, p. 158)

= 204,4357 m/mnt (memenuhi)

$N_{Re} = \dfrac{N.Da^2.\rho}{\mu}$ (Geankoplis, 2nd ed, pers. 3.4-1)

dimana : Da = diameter impeller, ft

N = kecepatan putaran pengaduk, rps

ρ = densitas campuran, lb/ft^3

μ = viskositas campuran, lb/ft.s

$\mu_{campuran}$ = 10,7003 cps = $7,1903.10^{-3}$ lb/ft.s (Perry, 1950, p. 3-240)

Np = 5 (Geankoplis, 2nd ed, fig. 3.4-4, p.155)

$N_{Re} > 10^4$ berarti aliran turbulen

$$N_{Re} = \frac{\left(\frac{100}{60}\right) rps \times (2{,}1350)^2 ft^2 \times 68{,}0918 lb/ft^3}{7{,}1903.10^{-3}\ lb/ft.s} = 71.941{,}8740 \quad \text{(turbulen)}$$

Power untuk 1 buah pengaduk :

$$P = \frac{Np.\rho.N^3.Da^5}{gc} \quad \text{(Geankoplis, 2nd ed, pers. 3.4-2)}$$

$$= \frac{5 \times 68{,}0918 \times \left(100/60\right)^3 \times (2{,}1350)^5}{32{,}174} = \frac{2.173{,}0290 lb.ft/s}{550\ Hp/\ lb.ft/s} = 3{,}9510\ Hp$$

Total Power yang dibutuhkan = 2 x 3,9510 Hp = 7,9019 Hp

Transmission system losses dan gland losses = 20 % dan 10 %.

Power motor = 1,3 x 7,9019 Hp = 10,2725 Hp ≈ 10,5 Hp

Spesifikasi :

1. Kapasitas : 354,0375 ft^3
2. Dimensi Bejana :
   - Diameter : 6,4049 ft
   - Tinggi : 9,6074 ft
   - Tebal Shell : 3/16 in
   - Tebal Tutup atas : 1/4 in
   - Tebal Tutup bawah : 1/4 in
3. Pengaduk :
   - Jenis : flat six-blade turbine
   - Kecepatan : 100 rpm
   - Power : 10,5 Hp
   - Jumlah : 2
   - Panjang blade : 0,5337 ft

Lebar blade : 0,4270 ft

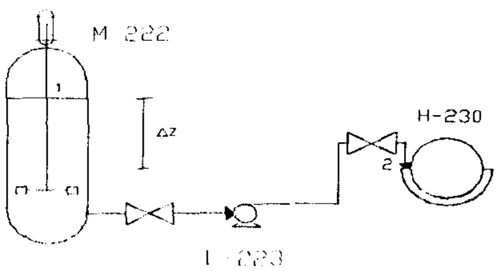
4. Baffle :

Jumlah : 4

Lebar : 0,5337 ft

5. Jumlah : 1 buah

22. Pompa (L-223)



Fungsi : Memompa larutan yang keluar dari tangki pelarutan K_2SO_4 (M-222) ke dalam rotary drum separator II (H-230)

Tipe : Centrifugal pump

Dasar pemilihan : 1. Cocok untuk larutan dengan viskositas rendah

2. Cocok untuk rate massa besar

Spesifikasi :

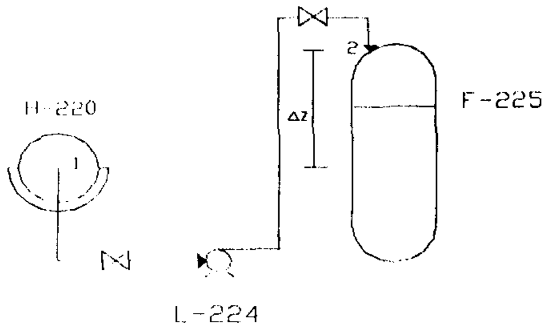
1. Tipe : Centrifugal pump
2. Kapasitas : 36,7855 gpm
3. Pipa ($2\frac{1}{2}$ in Sch 40) :

   ID : 0,8240 in

   OD : 2,875 in

   A : 0,03322 ft^2
4. Efisiensi : 80 %
5. Power : 0,5 Hp
6. Jumlah : 1 buah

23. Pompa (L-224)



Fungsi : Memompa larutan yang keluar dari rotary drum separator I (H-220) ke dalam tangki penampung filtrat (F-225)

Tipe : Centrifugal pump

Dasar pemilihan : 1. Cocok untuk larutan dengan viskositas rendah

2. Cocok untuk rate massa besar

Spesifikasi :

1. **Tipe** : **Centrifugal pump**
2. **Kapasitas** : 76,0414 gpm
3. Pipa (3 in Sch 40) :

   ID : 3,068 in

   OD : 3,5000 in

   A : 0,05130 ft^2
4. Efisiensi : 80 %
5. Power : 1,5 Hp
6. Jumlah : 1 buah

24. Tangki Penampung Filtrat (F-225)

Fungsi : Menampung filtrat yang keluar dari rotary drum separator I (H-220) dan rotary drum separator II (H-230)

Tipe : Silinder tegak dengan tutup atas dan bawah berbentuk torispherical dished head

Dasar pemilihan : Cocok untuk menyimpan liquid dalam kapasitas besar

Kondisi operasi : P = 1 atm

Kapasitas : 591.900,1390 kg/hari = 1.305.139,8065 lb/hari

Perhitungan :

- *Perhitungan Dimensi Tangki*

ρ_{liquid} = 972,2002 kg/m^3 = 60,6945 lb/ft^3

$$\text{Volume larutan} = \frac{1.305.139{,}8065\ \text{lb/hari}}{24\ \text{jam/hari} \,.\, 60{,}6945\ \text{lb/ft}^3} = 895{,}9768\ \text{ft}^3$$

Asumsi: Volume ruang kosong = 20 % Volume larutan

Volume tangki = 1,2 x volume larutan

= 1,2 x 895,9768 ft^3

= 1.075,1721 ft^3

$$\frac{H}{D} = 2$$ (B & Y, tabel 4-27)

Volume tangki = (2 x volume torisperical dished head) + volume shell

$$1.075{,}1721\ \text{ft}^3 = (2 \times 0{,}000049 \times D^3) + \left(\frac{\pi}{4} \times 2 \times \left(\frac{D}{12}\right)^3\right)$$

$$= 1{,}0070.10^{-3} \times D^3$$

D = 102,2067 in = 8,5172 ft

H = 204,4133 in = 17,0344 ft

- *Perhitungan Tebal Shell*

Volume larutan (Vliq) = V tutup bawah + V shell

$$\text{Vliq} = 0{,}000049 * D^3 + \frac{\pi}{4} * \frac{D^2}{12^2} * \text{Hliq}$$

$$895{,}9768\ \text{ft}^3 = 0{,}000049 * (8{,}5172)^3 + \frac{\pi}{4} * \frac{(8{,}5172)^2}{12^2} * \text{Hliq}$$

Hliq = 14,8075 ft

$$P_{hidrostatik} = \frac{\rho.H}{144} = \frac{60{,}6945\ \text{lb/ft}^3 \times 14{,}8075\ \text{ft}}{144} = 6{,}2412\ \text{psi}$$

$P_{operasi}$ = 6,2412 + 14,7 = 20,9412 psi

P_{design} = 1,2 . $P_{operasi}$ = 25,1295 psi

Bahan konstruksi yang digunakan : SA-167 grade 3 Tipe 304

f_{allow} = 18750 psi (B & Y, App. D)

Tipe sambungan double-welded butt joint :

E = 0,8 (B & Y, Tabel 13.2)

faktor korosi (C) = $\frac{1}{8}$ in

$$t_{shell} = \frac{P \,.\, ID}{2(f \,.\, E - 0{,}6 \,.\, P)} + C \qquad \text{(B \& Y, pers. 13.1)}$$

$$t_{shell} = \frac{25{,}1295 \times 102{,}2067}{2((18750 \times 0{,}8) - (0{,}6 \times 25{,}1295))} + 0{,}125 = 0{,}2107 \text{ in} \approx \tfrac{1}{4} \text{ in}$$

➢ *Perhitungan Tebal dish*

OD = ID + (2 x t_{shell}) = 102,2067 + (2 x $\frac{1}{4}$) = 102,7067 in

rc (radius of dish) = ID = 102,2067 in

icr (inside-corner radius) = 6 % x rc = 0,06 x 102,2067 in = 6,1324 in

$$W = \frac{1}{4}\left(3 + \sqrt{\frac{rc}{icr}}\right) = \frac{1}{4}\left(3 + \sqrt{\frac{102{,}2067}{6{,}1324}}\right) = 1{,}7706 \qquad \text{(B \& Y, pers. 7.76)}$$

$$a = \frac{ID}{2} = \frac{102{,}2067}{2} = 51{,}1033 \text{ in}$$

BC = rc – icr = (102,2067 - 6,1324) in = 96,0743 in

AB = a – icr = (80,3556 – 6,1324) in = 44,9709 in

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

$$= 102{,}2067 - \sqrt{(96{,}0743)^2 - (44{,}9709)^2} = 17{,}3074 \text{ in}$$

$$t_{dish} = \frac{P \,.\, rc \,.\, W}{2 \,.\, f \,.\, E - 0{,}2 \,.\, P} + C \qquad \text{(B \& Y, pers 7.77)}$$

$$t_{dish} = \frac{25{,}1295 \times 102{,}2067 \times 1{,}7706}{(2 \times 18750 \times 0{,}8) - (0{,}2 \times 25{,}1295)} + 0{,}125 = 0{,}2766 \text{ in} \approx \tfrac{5}{16} \text{ in}$$

Maka dipakai tebal tutup atas dan bawah = $\frac{5}{16}$ in

Dipilih *straight-flange* (sf) = 2 $\frac{1}{2}$ in (B & Y, Tabel 5.8)

Tinggi dish = OA = t + b + sf = $\frac{5}{16}$ + 17,3074 + 2 $\frac{1}{2}$

= 20,1199 in = 1,6767 ft

Tinggi tangki keseluruhan = tinggi shell + (2 x tinggi dish)

= 17,0344 + (2 x 1,6767)

= 20,3878 ft

Spesifikasi :

1. Kapasitas : 1.075,1721 ft^3
2. Dimensi bejana :

   Diameter : 8,5172 ft

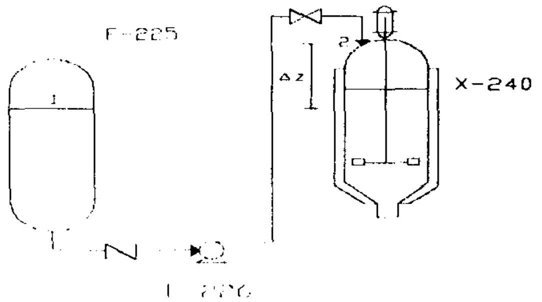
   Tinggi : 17,0344 ft

   Tebal Shell : $\frac{1}{4}$ in

   Tebal Tutup atas : $\frac{5}{16}$ in

   Tebal Tutup bawah : $\frac{5}{16}$ in
3. Jumlah : 1 buah

25. Pompa (L-226)



Fungsi : Memompa larutan yang keluar dari tangki penampung filtrat (F-225) ke dalam kristaliser (X-240)

Tipe : Centrifugal pump

Dasar pemilihan : 1. Cocok untuk larutan dengan viskositas rendah

2. Cocok untuk rate massa besar

Spesifikasi :

1. Tipe : Centrifugal pump
2. Kapasitas : 111,7134 gpm
3. Pipa (4 in Sch 40) :

   ID : 4,0260 in

OD : 4,5000 in

A : 0,08840 ft^2

4. Efisiensi : 80 %
5. Power : 1 Hp
6. Jumlah : 1 buah

26. Rotary drum separator II (H-230)

Fungsi : Menyaring endapan dari tangki pelarutan K_2SO_4 (M-222)

Tipe : Continuous Rotary Drum Filter

Dasar pemilihan : Retention larutan pada cake rendah

Pengoperasian sederhana

Kondisi operasi : T = 30°C, P = 1 atm = $1,01.10^5$ Pa

Kapasitas : 218.658,1008 kg/hari = 9.110,7542 kg/jam

Perhitungan :

$$C_x = \text{konsentrasi padatan} = \frac{31.994,0209}{218.658,1008} = 0,1463\ \frac{\text{kg solid}}{\text{kg slurry}}$$

$$m = \frac{\text{berat cake basah}}{\text{berat cake kering}} = \frac{12.671,9663}{31.994,0209} = 0,3961$$

Pada T = 29,78°C :

$\rho = 1.059,5138\ kg/m^3$

$\mu = 1,0546.10^{-2}$ kg/m.s

$\alpha = 4,37.10^9 . \Delta P^{0,3} = 4,37.10^9 . (50.10^3)^{0,3} = 1,1225.10^{11}$ m/kg

f = fraksi drum yang tercelup dalam slurry = 33 %

Dari pers. 13.2 – 10, Geankoplis, 2nd ed, mendapatkan :

$$Cs = \frac{\rho.C_x}{1 - m.C_x} = \frac{1.059,5538 \times 0,1463}{1-(0,3961 \times 0,1463)} = 164,5712\ \frac{\text{kg solid}}{m^3\ \text{filtrat}}$$

Filter cycle time (t_c) = 250 detik

Slurry rate = 9.110,7542 kg slurry/jam

= 2,5308 kg slurry/s

$$\frac{V}{t_C} = 2,5308 \frac{C_X}{C_S}$$

$$= 2{,}5308\,\frac{\text{kg slurry}}{\text{s}} \times \left(\frac{0{,}1463\,\frac{\text{kg solid}}{\text{kg slurry}}}{164{,}5712\,\frac{\text{kg solid}}{\text{m}^3\text{ filtrat}}} \right) = 2{,}2501.10^{-3}\ \text{m}^3\ \text{filtrat/s}$$

$$\frac{V}{A.t_c} = \left(\frac{2.f.(-\Delta P)}{t_c.\mu.\alpha.C_s} \right)^{1/2}$$ (Geankoplis, 2nd ed, pers. 13.2 –24)

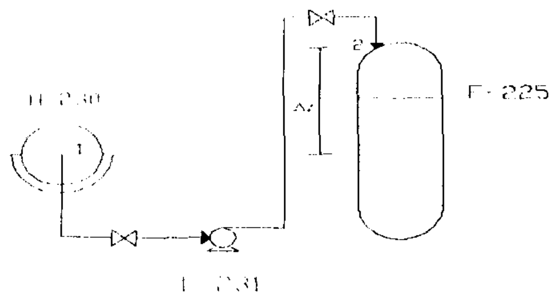
$$\frac{2{,}2501.10^{-3}}{A} = \left(\frac{2 * 0.33 * 50.10^3}{250 * 1{,}0546.10^{-2} * 1{,}1225.10^{11} * 164{,}5712} \right)^{1/2}$$

$A = 86{,}4446\ m^2$

Spesifikasi :

1. Tipe : Continuous Rotary Drum Filter
2. Kapasitas : 218.658,1008 kg/hari
3. Filter surface area : 86,4446 m^2
4. Jumlah : 1 buah

27. Pompa (L-231)



Fungsi : Memompa larutan yang keluar dari rotary drum separator II (H-230) ke dalam kristaliser (X-240)

Tipe : Centrifugal pump

Dasar pemilihan : 1. Cocok untuk larutan dengan viskositas rendah
2. Cocok untuk rate massa besar

Spesifikasi :

1. Tipe : Centrifugal pump
2. Kapasitas : 35,6720 gpm

3. Pipa ($2\frac{1}{2}$ in Sch 40) :

   ID : 0,8240 in

   OD : 2,875 in

   A : 0,03322 ft^2

4. Efisiensi : 80 %
5. Power : 1 Hp
6. Jumlah : 1 buah

28. Kristaliser (X-240)

Fungsi : Mengkristalkan K_2SO_4 sebelum masuk rotary dryer (B-260)

Tipe : Silinder tegak berpengaduk dengan tutup atas berbentuk torispherical dished head dan tutup bawah berbentuk konikal α = 45 yang dilengkapi dengan koil pendingin

Dasar pemilihan : Cocok untuk membentuk padatan kristal dari larutan cair

Kondisi operasi : P = 1 atm, T = 5 °C

Kapasitas : 591.900,1390 kg/hari = 1.305.139,8063 lb/hari

Perhitungan :

➢ *Perhitungan Dimensi Tangki*

$$\frac{1}{\rho_{larutan}} = \frac{x_{KCl}}{\rho_{KCl}} + \frac{x_{H_2O}}{\rho_{H_2O}} + \frac{x_{NH_3}}{\rho_{NH_3}} + \frac{x_{Ca_2SO_4.2H_2O}}{\rho_{Ca_2SO_4.2H_2O}} + \frac{x_{isopropanol}}{\rho_{isopropanol}} + \frac{x_{K_2SO_4}}{\rho_{K_2SO_4}} + \frac{x_{CaCl_2}}{\rho_{CaCl_2}} + \frac{x_{pengotor}}{\rho_{pengotor}}$$

$\rho_{larutan}$ = 972,2002 kg/m^3 = 60,6945 lb/ft^3

$$\text{Volume larutan} = \frac{1.305.139{,}8063 \text{ lb/hari}}{24 \text{ jam/hari} \times 60{,}6945 \text{ lb/ft}^3}$$

= 895,9768 ft^3

Volume tangki = 1,2 x volume larutan

= 1,2 x 895,9768 ft^3 = 1.075,1722 ft^3

$$\frac{H}{D} = 2$$ (Ulrich,1984, p. 433)

Volume tangki = volume konis + volume tutup atas + volume shell

$$1.075,1722\ ft^3 = \left(\frac{\pi}{24} x \frac{\left(\frac{D}{12}\right)^3}{tg\ 45^\circ} \right) + (0,000049\ x\ D^3) + \left(\frac{\pi}{4} x\ 2\ x \left(\frac{D}{12}\right)^3 \right)$$

$$= 1,0338.10^{-3}\ x\ D^3$$

$$D = 101,3173\ in = 8,4431\ ft$$

$$H = 202,6346\ in = 16,8862\ ft$$

➢ *Perhitungan Tebal Shell*

Volume larutan (Vliq) = V konis + V shell

$$Vliq = \left(\frac{\pi}{24} x \frac{\left(\frac{D}{12}\right)^3}{tg\ 45^\circ} \right) + \frac{\pi}{4} * \frac{D^2}{12^2} * Hliq$$

$$895,9768\ ft^3 = \left(\frac{\pi}{24} x \frac{\left(\frac{101,3173}{12}\right)^3}{tg\ 45^\circ} \right) + \frac{\pi}{4} * \frac{(101,3173)^2}{12^2} * Hliq$$

$$Hliq = 14,5958\ ft$$

$$P_{hidrostatik} = \frac{\rho.H}{144} = \frac{60,6945\ lb/ft^3\ x\ 14,5958\ ft}{144} = 6,1520\ psi$$

$P_{operasi}$ = 6,1520 psi + 14,7 psi = 20,8520 psi

P_{design} = 1,2 . $P_{operasi}$ = 25,0224 psi

Bahan konstruksi yang digunakan : SA-167 grade 3 Tipe 304

f_{allow} = 18750 psi (B & Y, App. D)

Tipe sambungan double-welded butt joint :

E = 0,8 (B & Y, Tabel 13.2)

faktor korosi (C) = $\frac{1}{8}$ in

$$t_{shell} = \frac{P . ID}{2(f . E - 0,6 . P)} + C \quad \text{(B \& Y, pers. 13.1)}$$

$$t_{shell} = \frac{25,0224 \times 101,3173}{2((18750 \times 0,8) - (0,6 \times 25,0224))} + 0,125 = 0,2096 \text{ in} \approx \frac{1}{4} \text{ in}$$

➤ *Perhitungan Tebal Tutup atas*

$OD = ID + (2 \times t_{shell}) = 101,3173 + (2 \times \frac{1}{4}) = 101,8173$ in

rc (radius of dish) = ID = 101,3173 in

icr (inside-corner radius) = 6 % x rc = 0,06 x 101,3173 in = 6,0790 in

$$W = \frac{1}{4}\left(3 + \sqrt{\frac{rc}{icr}}\right) = \frac{1}{4}\left(3 + \sqrt{\frac{101,3173}{6,0790}}\right) = 1,7706 \qquad \text{(B \& Y, pers. 7.76)}$$

$$a \text{ (inside radius)} = \frac{ID}{2} = \frac{101,3173}{2} = 50,6586 \text{ in}$$

BC = rc – icr = (101,3173 – 6,0790) in = 95,2383 in

AB = a - icr = (50,6586 – 6,0790) in = 44,5796 in

$$b \text{ (depth of dish (inside))} = rc - \sqrt{(BC)^2 - (AB)^2}$$

$$= 101,3173 - \sqrt{(95,2383)^2 - (44,5796)^2} = 17,1568 \text{ in}$$

$$t_{dish} = \frac{P.rc.W}{2.f.E - 0,2.P} + C \qquad \text{(B \& Y, pers 7.77)}$$

$$t_{dish} = \frac{25,0224 \times 101,3173 \times 1,7706}{(2 \times 18750 \times 0,8) - (0,2 \times 25,0224)} + 0,125 = 0,2747 \text{ in} \approx \frac{5}{16} \text{ in}$$

Maka dipakai tebal tutup atas = $\frac{5}{16}$ in

Dipilih *straight-flange* (sf) = 2 in (B & Y, Tabel 5.8)

Tinggi dish = OA = t + b + sf = $\frac{5}{16}$ + 17,1568 + 2

= 19,4693 in = 1,6224 ft

➤ *Perhitungan Tebal Tutup bawah (Konical)*

$$t_{konis} = \frac{P.ID}{2.\cos\alpha(f.E - 0,6.P)} + C$$

$$= \frac{25,0224 \times 101,3173}{2 \times \cos 45° \times (18.750 \times 0,8 - 0,6 \times 25,0224)} + 0,125 \text{ in}$$

$= 0,2446$ in $\approx \frac{1}{4}$ in

$$\text{Tinggi konis} = \frac{0,5.D}{tg\,45°} = \frac{0,5 * 8,4431 \text{ ft}}{tg\,45°} = 4,2216 \text{ ft}$$

Tinggi tangki keseluruhan = tinggi shell + tinggi konis + tinggi tutup atas

= 16,8862 + 4,2216 + 1,6224

= 22,7302 ft

➤ *Perhitungan pengaduk*

Dipilih jenis pengaduk = flat six-blade turbine

$$\text{Jumlah impeller} = \frac{sg.H}{Dt} = \frac{0{,}9764 \times 14{,}5958}{8{,}4431} = 1{,}6880 \approx 2 \text{ buah}$$

$$\left(\frac{Da}{Dt}\right) = \frac{1}{3} \qquad Da = \frac{8{,}4431}{3} = 2{,}8144 \text{ ft}$$

$$\left(\frac{E}{Dt}\right) = \frac{1}{3} \qquad E = \frac{8{,}4431}{3} = 2{,}8144 \text{ ft}$$

$$\left(\frac{W}{Da}\right) = \frac{1}{5} \qquad W = \frac{2{,}8144}{5} = 0{,}5629 \text{ ft}$$

$$\left(\frac{L}{Da}\right) = \frac{1}{4} \qquad L = \frac{2{,}8144}{4} = 0{,}7036 \text{ ft}$$ (McCabe, 5th ed, p.243)

dimana : Da = diameter pengaduk

Dt = diameter tangki

L = panjang blade

W = lebar blade

E = jarak dari dasar tangki ke pusat pengaduk

Kecepatan agitator antara 20-150 rpm (McCabe, 5th ed, p.238), diambil 20 rpm.

$$N_{Re} = \frac{N.Da^2.\rho}{\mu}$$ (Geankoplis, 2nd ed, pers. 3.4-1)

dimana : Da = diameter impeller, ft

N = kecepatan putaran pengaduk, rps

ρ = densitas campuran, lb/ft^3

μ = viskositas campuran, lb/ft.s

$\mu_{campuran}$ = 10,1024 cps = 6,7885.10^{-3} lb/ft.s (Perry, 1950, p. 3-240)

Np = 5 (Geankoplis, 2nd ed, fig. 3.4-4, p.151)

$N_{Re} > 10^4$ berarti aliran turbulen

$$N_{Re} = \frac{\left(\frac{20}{60}\right) rps \times (2,8144)^2 ft^2 \times 60,6945 lb/ft^3}{6,7885.10^{-3} lb/ft.s} = 23.605,7194 \quad \text{(turbulen)}$$

Power untuk 1 buah pengaduk :

$$P = \frac{Np.\rho.N^3.Da^5}{gc} \quad \text{(Geankoplis, 2}^{nd}\text{ ed, pers. 3.4-2)}$$

$$= \frac{5 \times 60,6945 \times \left(20/60\right)^3 \times (2,8144)^5}{32,174} = \frac{61,6816 \text{ lb.ft/s}}{550 \text{ Hp/ lb.ft/s}} = 0,1121 \text{ Hp}$$

Total Power yang dibutuhkan = 2 x 0,1121 Hp = 0,2243 Hp

Kehilangan transmisi dan gland losses = 10 % dan 20 %.

Power motor = 0,2916 Hp ≈ 0,5 Hp

- *Perhitungan jaket pendingin*

Diambil : spasi jaket = 5 in

OD shell = ID shell + (2. tebal shell) = 101,8173 in

ID jaket = OD shell + spasi jaket

= 101,8173 + (2 . 5) = 111,8173 in = 9,3181 ft

Diambil : tebal jaket = tebal konis = $\frac{1}{4}$ in

OD jaket = ID jaket + 2 (tebal jaket)

= (111,8173 + (2. $\frac{1}{4}$) in = 112,3173 in

L = 2,8144 ft

N = 80 rpm × 60 = 4800 rev/hr

ρ = 60,6945 lb/ft^3

μ = 6,7885.10^{-3} lb/ft.s = 24,4385 lb/ft.hr

k = 0,327 Btu/hr.ft^2.(°F/ft) (Kern,1965, tab.4, p.800)

c = 1,35 Btu/lb.°F (Kern,1965, fig.2, p.804)

$$R_{ej} = \frac{L^2.N.\rho}{\mu} = \frac{(2,8144 ft)^2.4800 \text{ rev/hr}.60,6945 \text{ lb/ft}^3}{24,4385 \text{ lb/ft.hr}} = 94.422,8775$$

$$j = \frac{h_j.D_j}{k}\left(\frac{c.\mu}{k}\right)^{-1/2}\left(\frac{\mu}{\mu_w}\right)^{-0,14} = 800 \quad \text{(Kern,1965, fig.20.2, p.718)}$$

$$800 = \frac{h_j.8,4431}{0,327}.\left(\frac{1,35.24,4385}{0,327}\right)^{1/2}.(1)^{-0,14}$$

h_j = 311,2190 Btu/hr.ft^2.°F

$$hoi = \frac{h_j.ID}{OD} = \frac{311,2190.8,4431}{8,4848} = 309,6895 \text{ Btu/hr.ft}^2.°F$$

$$Uc = \frac{hj.hoi}{hj + hoi} = \frac{311,2190.309,6895}{311,2190 + 309,6895} = 155,2262 \text{ Btu/hr.ft}^2.°F$$

Rd = 0,005 (Kern, 1965)

hd = 1/Rd = 1/0,005 = 200

$$Ud = \frac{Uc.hd}{Uc + hd} = \frac{155,2262.200}{155,2262 + 200} = 87,3957 \text{ Btu/hr.ft}^2.°F$$

$A = \pi \times Dj \times z + \pi/4 \times Dj^2 = \pi \times 9,3181 \times 14,5958 + \pi/4 \times (9,3181)^2$

$= 495,4665$ ft^2

Spesifikasi :

1. Kapasitas : 791,8447 ft^3
2. Dimensi Bejana :

   Diameter : 7,4927 ft

   Tinggi : 11,2391 ft

   Tebal Shell : $\frac{1}{4}$ in

   Tebal Tutup atas : $\frac{5}{16}$ in

   Tebal Tutup bawah : $\frac{1}{4}$ in
3. Pengaduk :

   Jenis : flat six-blade turbine

   Kecepatan : 20 rpm

   Power : 0,5 Hp

   Jumlah : 2

   Panjang blade : 0,6244 ft

   Lebar blade : 0,4995 ft
4. Jaket Pendingin :

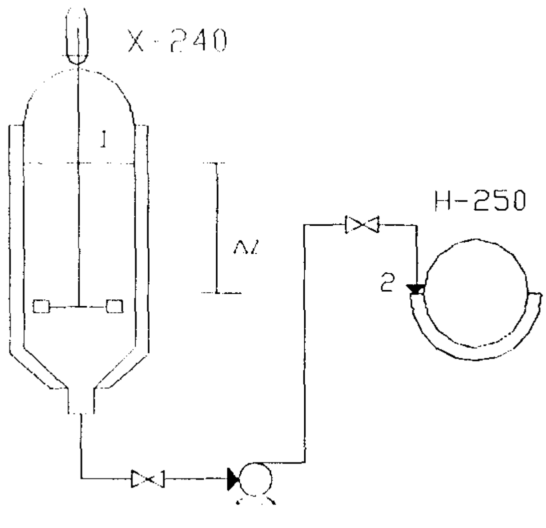
   Tinggi : 14,5958 ft

Tebal : ¼ in

Luas : 495,4665 ft^2

5. Jumlah : 1 buah

29. Pompa (L-241)



Fungsi : Memompa larutan yang keluar dari kristaliser (X-240) ke dalam rotary drum separator (H-250)

Tipe : Centrifugal pump

Dasar pemilihan : 1. Cocok untuk larutan dengan viskositas rendah

2. Cocok untuk rate massa besar

Spesifikasi :

1. Tipe : Centrifugal pump
2. Kapasitas : 36,1847 gpm
3. Pipa ($2\frac{1}{2}$ in Sch 40) :

   ID : 0,8240 in

   OD : 2,875 in

   A : 0,03322 ft^2
4. Efisiensi : 80 %

5. Power : 1,5 Hp
6. Jumlah : 1 buah

30. Rotary drum separator III (H-250)

Fungsi : untuk menyaring endapan dari kristaliser (X-240)

Tipe : Continuous Rotary Drum Filter

Dasar pemilihan : Retention larutan pada cake rendah

Pengoperasian sederhana

Kondisi operasi : T = 30°C, P = 1 atm = $1{,}01.10^5$ Pa

Kapasitas : 591.900,1390 kg/hari = 24.662,5058 kg/jam

Perhitungan :

$$C_x = \text{konsentrasi padatan} = \frac{40.760{,}5063}{591.900{,}1389} = 0{,}0689 \frac{\text{kg solid}}{\text{kg slurry}}$$

$$m = \frac{\text{berat cake basah}}{\text{berat cake kering}} = \frac{23.320{,}1634}{40.760{,}5063} = 0{,}5721$$

Pada T = 30°C :

$\rho = 949{,}7847\ \text{kg/m}^3$

$\mu = 9{,}9852.10^{-3}\ \text{kg/m.s}$

$\alpha = 4{,}37.10^9 . \Delta P^{0,3} = 4{,}37.10^9 . (50.10^3)^{0,3} = 1{,}1225.10^{11}\ \text{m/kg}$

f = fraksi drum yang tercelup dalam slurry = 33 %

Dari pers. 13.2 – 10, Geankoplis, 2nd ed, mendapatkan :

$$Cs = \frac{\rho.C_x}{1 - m.C_x} = \frac{949{,}7847 \times 0{,}0689}{1 - (0{,}5721 \times 0{,}0689)} = 68{,}0884 \frac{\text{kg solid}}{\text{m}^3\ \text{filtrat}}$$

Filter cycle time (t_c) = 250 detik

Slurry rate = 24.662,5058 kg slurry/jam

= 6,8507 kg slurry/s

$$\frac{V}{t_C} = 6{,}8507 \frac{C_X}{C_S}$$

$$= 6{,}8507\,\frac{\text{kg slurry}}{\text{s}} \times \left(\frac{0{,}0689\ \frac{\text{kg solid}}{\text{kg slurry}}}{68{,}0884\ \frac{\text{kg solid}}{\text{m}^3\ \text{filtrat}}} \right) = 6{,}9287.10^{-3}\ \text{m}^3\ \text{filtrat/s}$$

$$\frac{V}{A.t_c} = \left(\frac{2.f.(-\Delta P)}{t_c.\mu.\alpha.C_s} \right)^{1/2}$$ **(Geankoplis, 2nd ed, pers. 13.2 –24)**

$$\frac{6{,}9287.10^{-3}}{A} = \left(\frac{2 * 0.33 * 50.10^3}{250 * 9{,}9852.10^{-3} * 1{,}1225.10^{11} * 68{,}0884} \right)^{1/2}$$

A = 166,5997 m^2

Spesifikasi :

1. Tipe : Continuous Rotary Drum Filter
2. Kapasitas : 591.900,1390 kg/hari
3. Filter surface area : 166,5997 m^2
4. Jumlah : 1 buah

31. Screw Conveyor (J-251)

Fungsi : Mengangkut cake(padatan) dari rotary drum separator III (H-250) menuju rotary dryer (B-260)

Tipe : Standard pitch screw conveyor

Dasar pemilihan : Membutuhkan ruangan sedikit, harga murah, pemeliharaan mudah, cocok untuk memindahkan padatan berbentuk kristal basah

Kapasitas : 56.260,5277 kg/hari = 2.344,1887 kg/jam = 5.168,9360 lb/jam

Perhitungan :

ρ_{campuran} = 2.289,7703 kg/m^3 = 142,9504 lb/ft^3

Sudut elevasi = 30°

$$\text{Rate volumetrik} = \frac{5.168{,}9360\ \text{lb/jam}}{142{,}9504\ \text{lb/ft}^3} = 36{,}1589\ \text{ft}^3/\text{jam} = 0{,}6026\ \text{ft}^3/\text{mnt}$$

Dari Perry, 1984, tab. 7-6, p. 7-7 didapat :

Diameter lubang feed = 6 in

Panjang screw = 10 ft

Kecepatan screw = 40 rpm

Power : $Hp = \dfrac{C.L.W.F}{33000}$ (Badger, 1957, p. 711)

dimana : C = kapasitas, ft^3/menit

L = panjang srew conveyor,ft

W = berat material, lb/ft^3

F = faktor material (F = 3, Badger, 1957, tabel 16-6, hal 711)

$$Hp = \frac{0{,}6026 \times 10 \times 142{,}9504 \times 3}{33000} = 0{,}0078 \text{ Hp}$$

Efisiensi motor = 80% (Peters & Timmerhaus, 1991, grafik 14-38, p. 521)

$$Power = \frac{0{,}0078}{0{,}8} \text{ Hp} = 0{,}0098 \text{ Hp}$$

Dari Badger, 1957, hal 713: jika power < 2 Hp, maka power dikalikan dua.

Power = 0,0098 x 2 = 0,0196 Hp ≈ 0,5 Hp

Spesifikasi :

1. Kapasitas : 5.168,9360 lb/jam
2. Tipe : Standard pitch screw conveyor
3. Kecepatan screw : 40 rpm
4. Panjang screw : 10 ft
5. Diameter lubang feed : 6 in
6. Power : 0,5 Hp
7. Jumlah : 1 buah

32. Tangki Penampung Filtrat (F-252)

Fungsi : Menampung filtrat yang keluar dari rotary drum separator III (H-250)

Tipe : Silinder tegak dengan tutup atas dan bawah berbentuk torispherical dished head

Dasar pemilihan : Cocok untuk menyimpan liquid dalam kapasitas besar

Kondisi operasi : P = 1 atm

Kapasitas : 568.579,9757 kg/hari = 1.253.718,8461 lb/hari

Perhitungan :

➢ *Perhitungan Dimensi Tangki*

ρ_{liquid} = 949,7847 kg/m^3 = 59,2951 lb/ft^3

$$\text{Volume larutan} = \frac{1.253.718{,}8461\ \text{lb/hari}}{24\ \text{jam/hari} \cdot 59{,}2951\ \text{lb/ft}^3} = 880{,}9888\ \text{ft}^3$$

Asumsi: Volume ruang kosong = 20 % Volume larutan

Volume tangki = 1,2 x volume larutan

= 1,2 x 880,9888 ft^3

= 1.057,1866 ft^3

$$\frac{H}{D} = 2$$ (B & Y, tabel 4-27)

Volume tangki = (2 x volume torisperical dished head) + volume shell

$$1.057{,}1866\ \text{ft}^3 = (2 \times 0{,}000049 \times D^3) + \left(\frac{\pi}{4} \times 2 \times \left(\frac{D}{12}\right)^3\right)$$

= 1,0070.10^{-3} x D^3

D = 101,6335 in = 8,4695 ft

H = 203,2671 in = 16,9389 ft

➢ *Perhitungan Tebal Shell*

Volume larutan (Vliq) = V tutup bawah + V shell

$$\text{Vliq} = 0{,}000049 * D^3 + \frac{\pi}{4} * \frac{D^2}{12^2} * \text{Hliq}$$

$$880{,}9888\ \text{ft}^3 = 0{,}000049 * (8{,}4695)^3 + \frac{\pi}{4} * \frac{(8{,}4695)^2}{12^2} * \text{Hliq}$$

Hliq = 14,7245 ft

$$P_{hidrostatik} = \frac{\rho . H}{144} = \frac{59{,}2951\ \text{lb/ft}^3 \times 14{,}7245\ \text{ft}}{144} = 6{,}0631\ \text{psi}$$

$P_{operasi}$ = 6,0631 + 14,7 = 20,7631 psi

P_{design} = 1,2 . $P_{operasi}$ = 24,9157 psi

Bahan konstruksi yang digunakan : SA-167 grade 3 Tipe 304

f_{allow} = 18750 psi (B & Y, App. D)

Tipe sambungan double-welded butt joint :

E $= 0{,}8$ (B & Y, Tabel 13.2)

faktor korosi (C) = $\frac{1}{8}$ in

$$t_{shell} = \frac{P \cdot ID}{2(f \cdot E - 0{,}6 \cdot P)} + C \qquad \text{(B \& Y, pers. 13.1)}$$

$$t_{shell} = \frac{24{,}9157 \times 101{,}6335}{2((18750 \times 0{,}8) - (0{,}6 \times 24{,}9157))} + 0{,}125 = 0{,}2095 \text{ in} \approx \tfrac{1}{4} \text{ in}$$

➢ *Perhitungan Tebal dish*

$OD = ID + (2 \times t_{shell}) = 101{,}6335 + (2 \times \frac{1}{4}) = 102{,}1335$ in

rc (radius of dish) = ID = 101,6335 in

icr (inside-corner radius) = 6 % x rc = 0,06 x 101,6335 in = 6,0980 in

$$W = \frac{1}{4}\left(3 + \sqrt{\frac{rc}{icr}}\right) = \frac{1}{4}\left(3 + \sqrt{\frac{101{,}6335}{6{,}0980}}\right) = 1{,}7706 \qquad \text{(B \& Y, pers. 7.76)}$$

$$a = \frac{ID}{2} = \frac{101{,}6335}{2} = 50{,}8168 \text{ in}$$

BC = rc – icr = (101,6335 - 6,0980) in = 95,5355 in

AB = a – icr = (50,8168 – 6,0980) in = 44,7188 in

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

$$= 101{,}6335 - \sqrt{(95{,}5355)^2 - (44{,}7188)^2} = 17{,}2104 \text{ in}$$

$$t_{dish} = \frac{P \cdot rc \cdot W}{2 \cdot f \cdot E - 0{,}2 \cdot P} + C \qquad \text{(B \& Y, pers 7.77)}$$

$$t_{dish} = \frac{24{,}9157 \times 101{,}6335 \times 1{,}7706}{(2 \times 18750 \times 0{,}8) - (0{,}2 \times 24{,}9157)} + 0{,}125 = 0{,}2745 \text{ in} \approx \tfrac{5}{16} \text{ in}$$

Maka dipakai tebal tutup atas dan bawah = $\frac{5}{16}$ in

Dipilih *straight-flange* (sf) = 2 $\frac{1}{2}$ in (B & Y, Tabel 5.8)

Tinggi dish = OA = t + b + sf = $\frac{5}{16}$ + 17,2104 + 2 $\frac{1}{2}$

= 20,0229 in = 1,6686 ft

Tinggi tangki keseluruhan = tinggi shell + (2 x tinggi dish)

= 16,9389 + (2 x 1,6686)

= 20,2761 ft

Spesifikasi :

1. Kapasitas : 1.057,1866 ft^3
2. Dimensi bejana :

   Diameter : 8,4695 ft → 0,6 cm

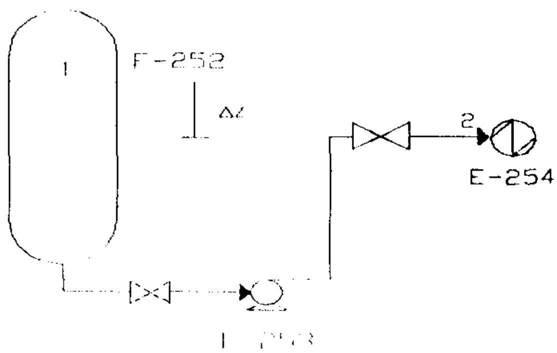
   Tinggi : 16,9389 ft

   Tebal Shell : $\frac{1}{4}$ in

   Tebal Tutup atas : $\frac{5}{16}$ in

   Tebal Tutup bawah : $\frac{5}{16}$ in
3. Jumlah : 1 buah

33. Pompa (L-253)



Fungsi : Memompa larutan yang keluar dari tangki penampung filtrat (F-252) ke dalam heater (E-254)

Tipe : Centrifugal pump

Dasar pemilihan : 1. Cocok untuk larutan dengan viskositas rendah

2. Cocok untuk rate massa besar

Spesifikasi :

1. Tipe : Centrifugal pump
2. Kapasitas : 36,1847 gpm
3. Pipa ($2\frac{1}{2}$ in Sch 40) :

   ID : 2,4690 in

   OD : 2,8750 in

   A : 0,03322 ft^2

4. Efisiensi : 83 %
5. Power : 3,5 Hp
6. Jumlah : 1 buah

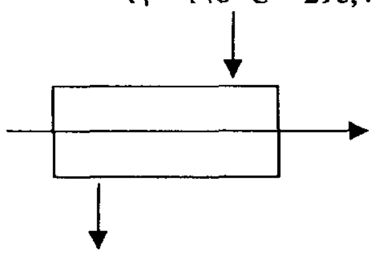
34. Heater (E-254)

Steam masuk tube :

T_1 = 148 °C = 298,4 °F

Filtrat masuk shell :

t_1 = 5°C = 41°F



t_2 = 33°C = 91,4°F

Kondensat keluar tube :

T_2 = 148 °C = 298,4 °F

Fungsi : Memanaskan filtrat dari rotary drum separator III hingga suhu 33°C sebelum masuk ke menara distilasi

Tipe : Shell and Tube

Dasar Pemilihan : Pressure drop yang dihasilkan kecil

Kondisi operasi : Suhu filtrat masuk (t_1) = 5°C (41°F)

Suhu filtrat keluar (t_2) = 33°C (91,4°F)

Suhu steam (T_1) = 148°C (298,4°F)

Suhu kondensat (T_2) = 148°C (298,4°F)

Perhitungan :

Berdasarkan neraca panas:

$m_{filtrat}$ = 568.579,9757 kg/hari = 52.238,2853 lb/jam

m_{steam} = 33.756,9091 kg/hari = 3.101,4160 lb/jam

Beban panas = Q = 71.548.346,1397 kJ/hari = 2.825.593,2481 Btu/jam

1. $$\Delta T_{LMTD} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}} = \frac{(298,4 - 91,4) - (298,4 - 41)}{\ln \frac{(298,4 - 91,4)}{(298,4 - 41)}} = 231,2855°F$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{(298{,}4 - 298{,}4)}{(91{,}4 - 41)} = 0$$

Dipakai HE 3-6 exchanger: (Kern,1965, fig.20 hal 830)

Ft = 1

$\Delta t = Ft \times \Delta T_{LMTD} = 1 \times 231{,}2855^{o}F = 231{,}2855^{o}F$

2. $t_c = (t_1+t_2)/2 = (41+91{,}4)/2 = 66{,}2^{o}F$

$T_c = (T_1+T_2)/2 = 298{,}4^{o}F$

3. Trial U_D

Dari tabel 8 hal.840, Kern, 1965, untuk steam dan gases adalah U_D = 5-50

Diambil U_D = 15 Btu/jam.ft^2.°F

$$A = \frac{Q}{U_D.\Delta t} = \frac{2.825.593{,}2481 \text{ Btu/jam}}{15 \text{ Btu/jam.ft}^2.^{o}F.231{,}2855^{o}F} = 814{,}4604 \text{ ft}^2$$

4. Asumsi $^3/_4$ inch OD, 12 BWG, 1 inch square pitch , L =12 ft.

a" = 0,1963 ft^2/ft ; a'= 0,223 in^2 (Tabel 10, p. 843, Kern, 1965)

A = Nt . a" . L = Nt . 0,1963 .12

Nt = 345,7550 tubes ≈ 356 tubes

Dari tabel 9 hal 842, Kern, 1965, diperoleh untuk 3-6 heat exchanger :

ID_{shell} = 25 in Nt = 356 tubes

U_D koreksi → A = Nt . a" . L = 356 . 0,1963 . 12 = 838,5936 ft^2

$$U_D = \frac{Q}{A.\Delta T} = \frac{2.825.593{,}2481}{838{,}5936.231{,}2855} = 14{,}5683 \text{ Btu/jam.ft}^2.^{o}F$$

Tube (steam)	Shell (filtrat)
5. $a_t = \frac{Nt.a'}{144.n} = \frac{356.0{,}233}{144.6} = 0{,}0960 \text{ ft}^2$ 6. $G_t = \frac{m}{a_t} = \frac{3.101{,}4160}{0{,}0960}$ = 32.304,8588 lb/hr.ft^2 7. dari Kern, 1965, fig.15, p. 825 pada T_c = 298,4 °F diperoleh: μ = 0,0125	5. C' = Pt – do = 1 – 0,75 = 0,25 B = 2 in $a_s = \frac{di.C'.B}{144.P_t.n} = \frac{25.0{,}25.2}{144.1.3} = 0{,}0289 \text{ ft}^2$ 6. $G_s = \frac{m}{a_s} = \frac{52.238{,}2853}{0{,}0289}$ = 1.807.553,1250 lb/hr.ft^2 7. dari Kern, 1965, fig.14, hal. 823

$N_{Ret} = \frac{D.G_t}{\mu} = \frac{0{,}532 \times 32.304{,}8588}{12 \times 0{,}0125 \times 2{,}42}$ $= 47.344{,}8619$ 8. dari Kern, 1965, hal. 164 hio = 1500 Btu/hr.ft^2.°F	pada t_c = 149°F diperoleh: $\mu = 1{,}6045$ $N_{Res} = \frac{D_e.G_s}{\mu} = \frac{0{,}95 \times 1.807.553{,}1250}{12 \times 1{,}6045 \times 2{,}42}$ $= 36.853{,}4663$ 8. dari Kern, 1965, fig.28, hal. 838 De = 0,95 jH = 99 pada tc = 149°F diperoleh: c = 0,997 Btu/lb.°F (Fig.2, Kern, 1965) k = 0,328 Btu/hr.ft^2.(°F/ft) (Tab. 4) $ho = jH.\frac{k.}{D_e}.(\frac{c.\mu}{k})^{1/3}.\varphi_s$ $\frac{ho}{\varphi_s} = 99.\frac{0{,}328}{0{,}95/12}.(\frac{0{,}997.1{,}6045.2{,}42}{0{,}328})^{1/3}$ $= 933{,}8823$ $ho = \frac{ho}{\varphi_s} = 933{,}8823$

9. Koefisien overall bersih, U_C:

$$U_C = \frac{hio.ho}{hio + ho} = \frac{1500.933{,}8823}{1500 + 933{,}8823} = 575{,}5510 \text{ Btu/hr.ft}^2.°F$$

10. Faktor kekotoran, R_D:

$$R_D = \frac{U_C - U_D}{U_C.U_D} = \frac{575{,}5510 - 14{,}5683}{575{,}5510.14{,}5683} = 0{,}0669$$

Perhitungan Pressure Drop :

Tube (steam)	Shell (filtrat)
1. $N_{Re,t} = 47.344{,}8619$ Dari Kern, 1965, Fig. 26 : f = 0,00019 2. $\Delta P_t = \frac{f.G_t^2.l.n}{5{,}22.10^{10}.di.s.\varphi_t}$	1. $N_{Re,s} = 36.853{,}4663$ Dari Kern, 1965, Fig. 29 : f = 0,00016 2. $N + 1 = \frac{12.l}{B} = \frac{12.12}{2} = 72$

$= \dfrac{0{,}00019 \times 32.304{,}8588^2 \times 12 \times 6}{5{,}22.10^{10}.0{,}0443.1.1}$ $= 6{,}1737.10^{-3}$ 3. $\Delta P_r = \dfrac{4.n}{s}.\dfrac{V^2}{2.g'}.\dfrac{62{,}5}{144} = \dfrac{4.6}{1}.0{,}001$ $= 0{,}024$ 4. $\Delta P_T = \Delta P_t + \Delta P_r = 6{,}1737.10^{-3} + 0{,}024$ $= 0{,}0302$ psi (<2psi,memenuhi)	3. $\Delta P_s = \dfrac{f.G_s^{\,2}.(N+1)}{5{,}22.10^{10}.de.s.\varphi_s}$ $= \dfrac{0{,}00016 \times 1.807.553{,}1250^2 \times 72}{5{,}22.10^{10} \times 0{,}95/12 \times 1 \times 1}$ $= 0{,}8945$ psi (< 1psi, memenuhi)

Spesifikasi :

1. Tipe : Shell and Tube
2. Tube :

   Media pemanas : steam jenuh
   Rate : 3.101,4160 lb/jam
   Bahan konstruksi : carbon steel
   Dimensi : $^3/_4$ in OD, 12 BWG
   1 in square pitch
   6 passes

3. Shell :

   Media yang dipanaskan : filtrat
   Rate : 52.238,2853 lb/jam
   Bahan konstruksi : carbon steel
   Dimensi : Diameter ekivalen = 0,95 in
   3 passes

4. Jumlah : 1 buah

35. Rotary Dryer (B-260)

Fungsi : Mengeringkan kristal kalium sulfat dari rotary drum separator III

Tipe : Counter-current direct contact rotary dryer

Dasar Pemilihan: Perpindahan panas yang dihasilkan besar sehingga mampu mengeringkan sampai kadar airnya 0,1%.

Kapasitas : 23.320,1633 kg/hari = 2.142,54 lb/jam

Perhitungan :

➢ *Mencari diameter rotary dryer*

Rate udara masuk = 23.909,4082 kg/hari = 2.196,6769 lb/jam

$$D = \sqrt{\frac{M}{0{,}785 . G}}$$ (Perry, 3rd ed, p. 883)

dimana : D = diameter rotary dryer, ft

M = kecepatan udara masuk, lb/jam

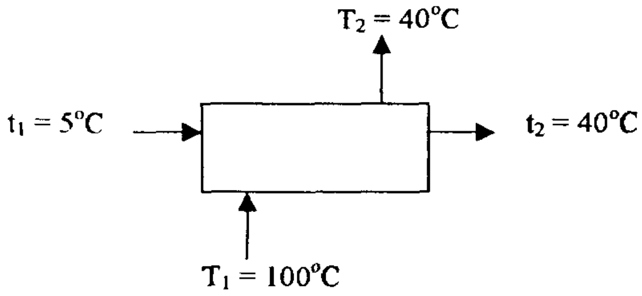
G = kecepatan udara pada rotary dryer, lb/jam.ft^2

= 200-4000 lb/jam.ft^2 **(Perry, 5th ed, p. 20-35)**

Ditetapkan : G = 200 lb/jam.ft^2

$$D = \sqrt{\frac{2.196{,}6769}{0{,}785 \times 300}} = 3{,}7405 \text{ ft} = 1{,}1401 \text{ m} \approx 1{,}5 \text{ m}$$

➢ *Menghitung panjang rotary dryer*



$$\Delta T_{LMTD} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}} = \frac{(373 - 313) - (313 - 278)}{\ln \frac{(373 - 313)}{(313 - 278)}} = 46{,}3825 \text{ K}$$

Panjang rotary dryer : (Perry, 5th ed, pers. 20-52)

$Qt = 0{,}4 \, . \, D \, . \, G^{0,67} \, . \, L \, . \, \Delta T_{LMTD}$

dimana : Qt = jumlah panas yang dipindahkan, Btu/jam

= 1.445.180,2678 kJ/hari = 57.073,1796 Btu/jam

L = panjang rotary dryer, ft

$$G = \text{kecepatan udara} = \frac{\text{rate udara panas}}{\left(\frac{\pi}{4} \times D^2\right)} = \frac{2.196{,}6769 \text{ lb/jam}}{\left(\frac{\pi}{4} \times (3{,}7405)^2\right)}$$

$= 199{,}9019 \text{ lb/jam.ft}^2 \approx 200 \text{ lb/jam.ft}^2$

D = diameter rotary dryer, ft

ΔT_{LMTD} = beda temperature, °K

$$\text{Panjang rotary dryer} = \frac{Qt}{0{,}4 \times D \times G^{0,67} \times \Delta T_{LMTD}}$$

$$= \frac{57.073{,}1796}{0{,}4 \times 3{,}7405 \times 200^{0,67} \times 46{,}3825}$$

$= 23{,}6264 \text{ ft} = 7{,}2013 \text{ m} \approx 7{,}5 \text{ m}$

L/D = 5 (memenuhi, berdasarkan Ulrich,1984, tab.4-10, p.132 L/D = 4-6)

➢ *Menghitung tebal shell*

Bahan konstruksi yang digunakan: carbon steel SA-53 grade B

Dari Brownell & Young, 1959, App. D, p. 335 diperoleh:

$f_{allowable} = 12.750 \text{ lb/in}^2$

E = 0,60 (butt welded)

$c = {}^1/_4$ in

$P_{desain} = 1{,}2 \times P_{op} = 1{,}2 \times 14{,}7 = 17{,}64$ psia

$$t_{shell} = \frac{P \times D}{2 \times f \times E} + c = \frac{17{,}64 \text{ lb/in}^2 \times (3{,}7405 \times 12) \text{ in}}{2 \times 12.750 \text{ lb/in}^2 \times 0{,}6} + \tfrac{1}{4} \text{in} = 0{,}3018 \text{ in} \approx \tfrac{5}{16} \text{ in}$$

➢ *Menghitung putaran rotary dryer*

Kecepatan peripheral (V) dryer = 0,25-0,5 m/s (Perry, 5th ed, p. 20-30)

Ditetapkan V = 0,35 m/s

$$N = \frac{V}{\pi \times D} = \frac{0{,}35}{\pi \times 1{,}1401} = 0{,}0977 \text{ rps} = 5{,}8631 \text{ rpm}$$

➢ *Menghitung jumlah flight*

Jenis flight = 45° lip flight (Perry, 6th ed, p. 20-30)

Jumlah flight = (2,4 – 3)D (Perry, 6th ed, p. 20-31)

Ditetapkan 2,5.D = 2,5 x 3,7405 = 9,3513 ≈ 10

Tinggi flight antara : $\frac{D}{12} - \frac{D}{8}$ (Perry , 6th ed, p. 20-33)

Ditetapkan : $\frac{D}{10} = \frac{3,7405}{10} = 0,3741$ ft

Jarak antar flight = $\frac{\pi \times D}{\text{jumlah flight}} = \frac{\pi \times 3,7405}{10} = 1,1751$ ft

➢ *Menghitung waktu perjalanan dalam rotary dryer*

Time of passage, $\theta = \frac{0,23 . L}{S . N^{0,9} . D} \pm 0,6 \frac{B . L . G}{F}$ (Perry, 6th ed, pers. 20-39)

$B = 5 \times (Dp)^{-0,5}$ (Perry, 6th ed, pers. 20-40)

dimana : B = konstanta

Dp = diameter partikel, μm = 100 μm = 0,1 mm

$F = \text{feed rate}, \frac{\text{lb material kering}}{\text{jam . ft}^2}$

$= \frac{2.142,54}{\frac{\pi}{4} \times (3,7405)^2} = 194,9754 \frac{\text{lb material kering}}{\text{jam . ft}^2}$

θ = time of passage, menit

S = slope, ft/ft = 0 – 8 cm/m (Perry, 5th ed, p. 20-30)

Ditetapkan : S = 4 cm/m = 0,04 ft/ft

$\text{tg } \alpha = 0,04 \longrightarrow \alpha = 2,2906°$

N = kecepatan putaran, rpm

L = panjang rotary dryer, ft

G = kecepatan udara, lb/jam.ft^2

D = diameter rotary dryer, ft

$B = 5 \times (100)^{-0,5} = 0,5$

$$\theta = \frac{0,23 \times 23,6264}{0,04 \times 5,8631^{0,9} \times 3,7405} \pm 0,6 \frac{0,5 \times 23,6264 \times 200}{194,9754}$$

θ = 7,3930 + 7,2706 = 14,6636 menit

➢ *Menghitung tenaga yang dibutuhkan untuk memutar rotary dryer*

$HP = 0,5.D^2 - D^2$ (Perry, 1984, p. 20-33)

Ditetapkan $HP = 0,75.D^2 = 0,75 \times 3,7405^2 = 10,4935$ Hp

Efisiensi motor = 88 % (Peters & Timmerhaus, 1991, fig.14-38, p.521)

$$\text{Power} = \frac{10{,}4935\,\text{Hp}}{0{,}88} = 11{,}9244\ \text{Hp} \approx 12\ \text{Hp}$$

Spesifikasi :

1. Tipe : Counter-current rotary dryer
2. Kapasitas : 2.142,54 lb/jam
3. Tebal shell : $\frac{5}{16}$ in
4. Diameter : 3,7405 ft
5. Panjang : 23,6264 ft
6. Putaran : 5,8631 rpm
7. Time of passage : 14,6636 menit
8. Jumlah flight : 10 buah
9. Power : 12 Hp
10. Jumlah : 1 buah

36. Blower (G-261)

Fungsi : Menghembuskan debu/partikel halus dari rotary dryer ke cyclone

Tipe : Centrifugal

Dasar pemilihan : Sesuai untuk debit yang besar

Kapasitas : 106,4661 kg/hari = $2{,}7171.10^{-3}$ lb/s

Perhitungan :

$\rho_{udara} = 0{,}0637\ \text{lb/ft}^3$

$$\text{Rate partikel} = \frac{2{,}7171.10^{-3}}{0{,}0637} = 0{,}0427\ \text{ft}^3/\text{s}$$

$$\text{Tenaga penggerak blower} = \frac{144 \times Q \times (P_2 - P_1)}{33000}$$ (Perry, 5th ed, pers. 6-34)

dimana : Q = rate volumetrik, ft^3/s

P_1 = Tekanan mula-mula = 14,7 psia

P_2 = Tekanan akhir = 16,17 psia

$$\text{Tenaga penggerak blower} = \frac{144 \times 0{,}0427 \times (16{,}17 - 14{,}7)}{33000} = 2{,}7361.10^{-4}\ \text{Hp}$$

Effisiensi = 80 % **(Perry, 5th ed, pers. 6-21)**

$$\text{Hp} = \frac{2{,}7361.10^{-4}}{0{,}80} = 3{,}4201.10^{-4}\ \text{Hp} \approx 0{,}5\ \text{Hp}$$

Spesifikasi :

1. Tipe : Centrifugal blower
2. Kapasitas : 106,4661 kg/hari
3. Power : 0,5 Hp
4. Jumlah : 1 buah

37. Cyclone (H-262)

Fungsi : Memisahkan solid yang terikut dalam udara pemanas dari rotary dryer (B-260)

Tipe : Cyclone Separator

Dasar pemilihan : Untuk memisahkan solid dan gas

Kondisi operasi : Suhu udara masuk = 40°C

Kapasitas : 106,4661 kg/hari = 234,7578 lb/hari

Perhitungan :

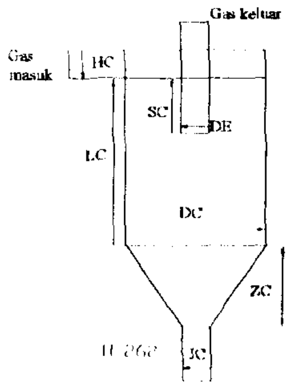
$$\rho_{udara} = \frac{BM \, . \, P_0 \, . \, T_0}{V_0 \, . \, P \, . \, T} 1\ \text{lbmol} = \frac{28{,}84 \, . \, 14{,}7 \, . \, 492}{395 \, . \, 16{,}17 \, . \, 564} 1\ \text{lbmol} = 0{,}0579\ \text{lb/ft}^3$$

$$\text{Laju gas} = \frac{234{,}7578\ \text{lb/hari}}{24\ \text{jam/hari} \, . \, 3600\ \text{s/jam} \, . \, 0{,}0579\ \text{lb/ft}^3} = 0{,}0469\ \text{ft}^3/\text{s}$$

Kecepatan aliran gas = 50-75 ft/s (Perry 6th ed., 1991, p. 10-82)

Ditetapkan kecepatan aliran gas = 62 ft/s

$$\text{Luas penampang masuk} = \frac{0{,}0469}{62} = 7{,}5687.10^{-4}\ \text{ft}^2 \, . \, 144\ \text{in}^2/\text{ft}^2 = 0{,}1090\ \text{in}^2$$



Dari Perry, 1991, p. 20-84 diperoleh:

$AC = BC \times HC$

$HC = 2 \times BC$

Sehingga : $AC = 2 \times BC^2$

$0,1090 \text{ in}^2 = 2 \times BC^2 \rightarrow BC = 0,2334 \text{ in}$

$HC = 2 \times 0,2334 \text{ in} = 0,4669 \text{ in}$

$DC = 2 \times HC = 0,9338 \text{ in}$

$De = HC = 0,4669 \text{ in}$

$LC = 2 \times DC = 1,8675 \text{ in}$

$SC = DC/8 = 0,1167 \text{ in}$

$ZC = 2 \times DC = 1,8675 \text{ in}$

$JC = DC/4 = 0,2334 \text{ in}$

Spesifikasi :

1. Kapasitas : 106,4661 kg/hari
2. Tipe : Cyclone separator
3. Ukuran : $AC = 0,1090 \text{ in}^2$

$HC = 0,4669$ in

$DC = 0,9338$ in

$De = 0,4669$ in

$LC = 1,8675$ in

$SC = 0,1167$ in

ZC = 1,8675 in

JC = 0,2334 in

4. Jumlah : 1 buah

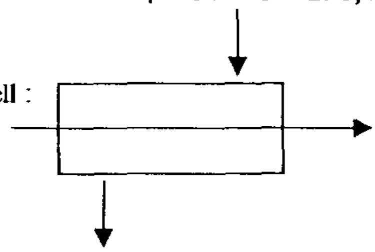
38. Heater (E-263)

Steam masuk tube :

T_1 = 148 °C = 298,4 °F

Udara kering masuk shell :

t_1 = 30 °C = 86 °F



t_2 = 100 °C = 212 °F

Kondensat keluar tube :

T_2 = 148 °C = 298,4 °F

Fungsi : memanaskan udara yang akan digunakan untuk rotary dryer

Tipe : Shell and Tube

Dasar Pemilihan: Pressure drop yang dihasilkan kecil

Kondisi operasi : Suhu udara masuk (t_1) = 30°C (86°F)

Suhu udara keluar (t_2) = 100°C (212°F)

Suhu steam (T_1) = 148°C (298,4°F)

Suhu kondensat (T_2) = 148°C (298,4°F)

Perhitungan :

Berdasarkan neraca panas:

m_{udara} = 23.909,4082 kg/hari = 2.196,6769 lb/jam

m_{steam} = 884,0349 kg/hari = 81,2207 lb/jam

Beban panas = Q = 1.873.727,1865 kJ/hari = 73.997,3902 Btu/jam

1. $$\Delta T_{LMTD} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln\frac{(T_1 - t_2)}{(T_2 - t_1)}} = \frac{(298,4 - 212) - (298,4 - 86)}{\ln\frac{(298,4 - 212)}{(298,4 - 86)}} = 57,5692°F$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{(298,4 - 298,4)}{(212 - 86)} = 0$$

Dipakai HE 3-6 exchanger: (Kern,1965, fig.20 hal 830)

$Ft = 1$

$\Delta t = Ft \times \Delta T_{LMTD} = 1 \times 57{,}5692°F = 57{,}5692°F$

2. $t_c = (t_1+t_2)/2 = (86+212)/2 = 149°F$

$T_c = (T_1+T_2)/2 = 298{,}4°F$

3. Trial U_D

Dari tabel 8 hal.840, Kern, 1965, untuk steam dan gases adalah U_D = 5-50

Diambil U_D = 16 Btu/jam.ft².°F

$$A = \frac{Q}{U_D.\Delta t} = \frac{73.997{,}3902 \text{ Btu/jam}}{16 \text{ Btu/jam.ft}^2.°F.57{,}5692°F} = 80{,}3353 \text{ ft}^2$$

4. Asumsi ³/₄ inch OD, 12 BWG, 1 inch square pitch , L =12 ft.

$a'' = 0{,}1963 \text{ ft}^2/\text{ft}$; $a' = 0{,}223 \text{ in}^2$ (Tabel 10, p. 843, Kern, 1965)

$A = Nt \cdot a'' \cdot L = Nt \cdot 0{,}1963 \cdot 12$

$Nt = 34{,}1039$ tubes ≈ 36 tubes

Dari tabel 9 hal 842, Kern, 1965, diperoleh untuk 3-6 heat exchanger :

$ID_{shell} = 10$ in $Nt = 36$ tubes

U_D koreksi → $A = Nt \cdot a'' \cdot L = 36 \cdot 0{,}1963 \cdot 12 = 84{,}8016 \text{ ft}^2$

$$U_D = \frac{Q}{A.\Delta T} = \frac{73.997{,}3902}{84{,}8016.57{,}5692} = 15{,}1573 \text{ Btu/jam.ft}^2.°F$$

Tube (steam)	Shell (udara)
5. $a_t = \frac{Nt.a'}{144.n} = \frac{36.0{,}233}{144.6} = 0{,}0097 \text{ ft}^2$ 6. $G_t = \frac{m}{a_t} = \frac{81{,}2207}{0{,}0097}$ $= 8.373{,}2680 \text{ lb/hr.ft}^2$ 7. dari Kern, 1965, fig.15, p. 825 pada T_c = 298,4 °F diperoleh: $\mu = 0{,}0125$ $N_{Ret} = \frac{D.G_t}{\mu} = \frac{0{,}532 \times 8.373{,}2680}{12 \times 0{,}0125 \times 2{,}42}$	5. $C' = Pt - do = 1 - 0{,}75 = 0{,}25$ $B = 2$ in $a_s = \frac{di.C'.B}{144.P_t.n} = \frac{10.0{,}252}{144.1.3} = 0{,}0116 \text{ ft}^2$ 6. $G_s = \frac{m}{a_s} = \frac{2.196{,}6769}{0{,}0116}$ $= 189.792{,}8842 \text{ lb/hr.ft}^2$ 7. dari Kern, 1965, fig.15, hal. 825 pada t_c = 149°F diperoleh: $\mu = 0{,}0194$

<table>
<tr><td>
$= 12.271,5663$
8. dari Kern, 1965, hal. 164
hio = 1500 Btu/hr.ft^2.°F
</td><td>
$N_{Res} = \dfrac{D_e.G_s}{\mu} = \dfrac{0,95 \times 189.792,8842}{12 \times 0,0194 \times 2,42}$
$= 320.040,6832$
8. dari Kern, 1965, fig.28, hal. 838
De = 0,95
jH = 390
pada tc = 149°F diperoleh:
c = 0,248 Btu/lb.°F (Fig.3, Kern, 1965)
k = 0,0162 Btu/hr.ft^2.(°F/ft) (Tab. 5)
$ho = jH.\dfrac{k.}{D_e}.(\dfrac{c.\mu}{k})^{1/3}.\varphi_s$
$\dfrac{ho}{\varphi_s} = 390.\dfrac{0,0162}{0,95/12}.(\dfrac{0,248.0,0194.2,42}{0,0162})^{1/3}$
$= 71,4861$
$ho = \dfrac{ho}{\varphi_s} = 71,4861$
</td></tr>
</table>

9. Koefisien overall bersih, U_C:

$$U_C = \frac{hio.ho}{hio + ho} = \frac{1500.\ 71,4861}{1500 + 71,4861} = 68,2342 \text{ Btu/hr.ft}^2.°F$$

10. Faktor kekotoran, R_D:

$$R_D = \frac{U_C - U_D}{U_C.U_D} = \frac{68,2342 - 15,1573}{68,2342.15,1573} = 0,0513$$

Perhitungan Pressure Drop :

<table>
<tr><th>Tube (steam)</th><th>Shell (udara)</th></tr>
<tr><td>
1. $N_{Re,t} = 12.271,5663$
Dari Kern, 1965, Fig. 26 :
f = 0,00026
2. $\Delta P_t = \dfrac{f.G_t^{\,2}.l.n}{5,22.10^{10}.di.s.\varphi_t}$
$= \dfrac{0,00026 \times 12.271,5663^2 \times 12 \times 6}{5,22.10^{10}.0,0443.1.1}$
</td><td>
1. $N_{Re,s} = 320.040,6832$
Dari Kern, 1965, Fig. 29 :
f = 0,0011
2. $N + 1 = \dfrac{12.1}{B} = \dfrac{12.12}{2} = 72$
3. $\Delta P_s = \dfrac{f.G_s^{\,2}.(N+1)}{5,22.10^{10}.de.s.\varphi_s}$
</td></tr>
</table>

$= 1,2191.10^{-3}$ 3. $\Delta P_r = \frac{4.n}{s}.\frac{V^2}{2.g'}.\frac{62,5}{144} = \frac{4.6}{1}.0,001$ $= 0,024$ 4. $\Delta P_T = \Delta P_t + \Delta P_r = 1,2191.10^{-3}+0,024$ $= 0,0252$ psi (<2psi,memenuhi)	$= \frac{0,0011 \times 189.792,8842^2 \times 72}{5,22.10^{10} \times 0,95/12 \times 1 \times 1}$ $= 0,6904$ psi(< 1psi, memenuhi)

Spesifikasi :

1. Tipe : Shell and Tube
2. Tube :

   Media pemanas : steam jenuh

   Rate : 81,2207 lb/jam

   Bahan konstruksi : carbon steel

   Dimensi : $^3/_4$ in OD, 12 BWG

   1 in square pitch

   6 passes
3. Shell :

   Media yang dipanaskan : udara

   Rate : 2.196,6769 lb/jam

   Bahan konstruksi : carbon steel

   Dimensi : Diameter ekivalen = 0,95 in

   3 passes
4. Jumlah : 1 buah

39. Blower (G-264)

Fungsi : Menghembuskan udara ke heater (E-263)

Tipe : Centrifugal

Dasar pemilihan : Sesuai untuk debit yang besar

Kondisi operasi : T = 30 °C, P = 1 atm

Kapasitas udara : 23.909,4082 kg/hari = 52.720,2451 lb/hari

Perhitungan :

$\rho_{udara} = 0,0658$ lb/ft^3

$$\text{Rate udara} = \frac{52.720{,}2451 \text{ lb/hari}}{24 \text{ jam/hari} \cdot 3600 \text{ s/jam} \cdot 0{,}0658 \text{ lb/ft}^3} = 9{,}2734 \text{ ft}^3/\text{s}$$

$$\text{Power blower} = \frac{144 \times Q \times (P_2 - P_1)}{33000}$$ (Perry, 5th ed, pers. 6-34)

dimana : Q = rate volumetrik, ft^3/s

P_1 = Tekanan mula-mula = 14,7 psia

P_2 = Tekanan akhir = 16,17 psia

$$\text{Power blower} = \frac{144 \times 9{,}2734 \times (16{,}17 - 14{,}7)}{33000} = 0{,}0595 \text{ Hp}$$

Effisiensi blower = 40-80 %, diambil 80 % (Perry, 5th ed, pers. 6-21)

$$\text{Hp} = \frac{0{,}0595}{0{,}80} = 0{,}0744 \text{ Hp} \approx 0{,}5 \text{ Hp}$$

Spesifikasi :

1. Tipe : Centrifugal blower
2. Kapasitas : 23.909,4082 kg/hari
3. Power : 0,5 Hp
4. Jumlah : 1 buah

40. Menara Absorber (D-265)

Fungsi : Menurunkan kadar air dalam udara

Tipe : Packed Tower

Dasar Pemilihan : Dapat menghasilkan udara kering pada suhu rendah

Kondisi operasi : T = 30°C, P = 1 atm

Perhitungan :

Dari neraca panas diperoleh :

Udara kering yang dibutuhkan = 23.909,4082 kg/hari

Densitas udara pada 30°C = ρ = 1,0562 kg/m^3

Viskositas udara pada 30°C = μ = $1{,}8652 \times 10^{-5}$ kg/m.s (Geankoplis, 1997)

Bahan isian = silika gel → Dp = 1,2 cm

Void fraction = ε = 0,4

Trial diameter tower = 0,6 m

Kecepatan udara = G' = $\dfrac{23.909,4082\ \text{kg/hari}}{24.3600\ \text{detik/hari}.\left(\pi/4.0,6^2\right)\text{m}^2}$ = 0,9787 kg/m^2.s

$N_{Re} = \dfrac{G' \times Dp}{(1-\varepsilon).\mu} = \dfrac{0,9787 \times 0,012}{(1-0,4).1,8652.10^{-5}}$ (Geankoplis, 1997, eq. 3.1-15)

= 1049 (turbulen karena $N_{Re} > 1000$)

Trial pressure drop (ΔP) = 0,034.10^5 Pa

P_1 = Tekanan masuk = 1,1 atm = 1,115.10^5 Pa

P_2 = Tekanan keluar = (1,115.10^5 - 0,034.10^5) = 1,081.10^5 Pa

P_{av} = Tekanan rata-rata = $\dfrac{(P_1 + P_2)}{2}$ = 1,098.10^5 Pa

$\rho_{av} = \dfrac{M}{R.T} P_{av} = \dfrac{28,84 * (1,098.10^5)}{8314,34 * (30 + 273)}$ = 1,256 kg/m^3 (Geankoplis, 1997, eq. 3.1-22)

Tinggi tower = ΔL = 3 m

Persamaan aliran turbulen dalam packed bed:

$$\frac{\Delta P.\rho}{(G')^2}.\frac{Dp}{\Delta L}.\frac{\varepsilon^3}{1-\varepsilon} = \frac{150}{N_{Re}} + 1,75$$ (Geankoplis, 1997, eq. 3.1-21)

$$\frac{\Delta P.1,256}{(0,9787)^2}.\frac{0,012}{3}.\frac{(0,4)^3}{(1-0,4)} = \frac{150}{1049} + 1,75$$

Pressure drop (ΔP) = 0,0338.10^5 Pa ≈ 0,034.10^5 Pa (Trial dianggap benar)

Flow rate udara = v = $\dfrac{23.909,4082\ \text{kg/hari}}{24.3600\ \text{detik/hari}.28,84\ \text{kg/kgmol}}$ = 0,0096 kgmol/s

Diameter tower = D = $\left(\dfrac{4.v.BM}{\pi.G'}\right)^{1/2}$ (Ulrich, 1984, eq. 4-88, p.199)

= $\left(\dfrac{4.0,0096\ 28,84}{\pi.0,9787}\right)^{1/2}$ = 0,6 m (memenuhi)

L/D = 5 (Ulrich, 1984, tab. 4-18, p.188, L/D = 5 – 30)

Spesifikasi :

1. Tipe : Packed tower
2. Bahan konstruksi : Carbon steel
3. Diameter : 0,6 m → 0,2 cm

4. Tinggi : 3 m
5. Jumlah : 2 buah

41. Screw Conveyor (J-266)

Fungsi : Mengangkut produk dari rotary dryer (B-260) dan cyclone (H-262) menuju tangki penyimpan K_2SO_4 (F-267)

Tipe : Standard pitch screw conveyor

Dasar pemilihan : Membutuhkan ruangan sedikit, harga murah, pemeliharaan mudah, cocok untuk memindahkan padatan

Kapasitas : 21.313,9911 kg/hari = 888,083 kg/jam = 1.958,2229 lb/jam

Perhitungan :

Densitas = 2.654,6065 kg/m^3 = 165,7271 lb/ft^3

Sudut elevasi = horizontal

$$\text{Rate volumetrik} = \frac{1.958{,}2229 \text{ lb/jam}}{165{,}7271 \text{ lb/ft}^3} = 11{,}8159 \text{ ft}^3\text{/jam} = 0{,}1969 \text{ ft}^3\text{/mnt}$$

Dari Perry, 1984, tab. 7-6, p. 7-7 didapat :

Diameter lubang feed = 6 in

Panjang screw = 10 ft

Kecepatan screw = 40 rpm

$$\text{Power : } Hp = \frac{C.L.W.F}{33000}$$ (Badger, 1957, p. 711)

dimana : C = kapasitas, ft^3/menit

L = panjang srew conveyor, ft

W = berat material, lb/ft^3

F = faktor material (F = 3, Badger, 1957, tabel 16-6, hal 711)

$$Hp = \frac{0{,}1969 \times 10 \times 165{,}7271 \times 3}{33000} = 0{,}0297 \text{ Hp}$$

Efisiensi motor = 80 % (Peters & Timmerhaus, 1991, grafik 14-38, p. 521)

$$\text{Power} = \frac{0{,}0297}{0{,}8} \text{ Hp} = 0{,}0371 \text{ Hp}$$

Dari Badger, 1957, hal 713: jika power < 2 Hp, maka power dikalikan dua.

Power = 0,0371 x 2 = 0,0743 Hp ≈ 0,5 Hp

Spesifikasi :

1. Kapasitas : 1.958,2229 lb/jam
2. Tipe : Standard pitch screw conveyor
3. Kecepatan screw : 40 rpm
4. Panjang screw : 10 ft
5. Diameter lubang feed : 6 in
6. Power : 0,5 Hp
7. Jumlah : 1 buah

42. Tempat Penyimpan K_2SO_4 (F-267)

Fungsi : Menyimpan kalium sulfat

Tipe : Gedung dengan konstruksi beton

Dasar pemilihan : Cocok untuk menampung padatan dengan kapasitas besar

Kondisi operasi : P = 1 atm, T = 30°C

Kapasitas : 21.313,9911 kg/hari = 46.997,3501 lb/hari

Perhitungan :

Densitas padatan = 2.654,6065 kg/m^3 = 165,7271 lb/ ft^3

$$\text{Volume } K_2SO_4 = \frac{46.997{,}3501 \text{ lb/hari} \times 15 \text{ hari}}{165{,}7271 \text{ lb/ ft}^3} = 4.253{,}7416 \text{ ft}^3$$

Asumsi = storage berisi 60 % dari volume storage

$$\text{Volume storage} = \frac{4.253{,}7416 \text{ ft}^3}{0{,}6} = 7.089{,}5693 \text{ ft}^3$$

Volume storage = p x l x t

7.089,5693 ft^3 = (2 x l) x l x 11,4835 ft

l = 17,5694 ft

p = (2 x l) = 35,1389 ft

t = 3,5 m = 11,4835 ft

Luas = p x l

= 35,1389 ft x 17,5694 ft

= 617,3689 ft^2

Spesifikasi :

1. Kapasitas : 21.313,9911 kg/hari
2. Panjang bangunan : 35,1389 ft
3. Lebar bangunan : 17,5694 ft
4. Tinggi bangunan : 11,4835 ft
5. Luas bangunan : 617,3689 ft^2
6. Bahan konstruksi : concrete
7. Jumlah : 1 buah

43. Menara Distilasi (D-270)

Fungsi : untuk memisahkan ammonia 99,5 % berat

Tipe : Sieve Tray

Dasar pemilihan : 1. Biaya pembuatan lebih murah daripada tipe bubble cap

2. Kapasitasnya besar

Perhitungan :

➢ *Perhitungan Diameter menara distilasi*

P operasi = 3,5 atm = 3,5466 bar

T operasi = T avg = 83,5 °C = 356,5 K

$$\rho v_m \approx \rho NH_3 = \frac{P \times BM}{Z \times R \times T}$$

dimana: R = 82,06 cm^3.atm/mol.K (Smith & Van Ness, 1996, Tabel A.2, p.633)

Z = korelasi Pitzer untuk faktor kompresibilitas gas

$= Z^0 + \omega . Z^1$ ... (3.46) (Smith & Van Ness, 1996, p.87)

Dari Smith Van Ness, 1996, Tabel B.1, hal 636 diperoleh data untuk

ammonia: P_c = 112,8 bar

T_c = 405,7 K

ω = 0,253

$Pr = P/P_c$ = 3,5466/112,8 = 0,03

$Tr = T/T_c$ = 356,5/405,7 = 0,88

Dari Smith & Van Ness, 1996, Tabel E.1, hal 650, pada Pr dan Tr tersebut diperoleh: Z^0 = 0,9851 dan Z^1 = - 0,0072

Sehingga: $Z = Z^0 + \omega.Z^1$

$= 0{,}9851 + 0{,}253.(- 0{,}0072) = 0{,}9833$

$$\rho NH_3 = \frac{P \times BM}{Z \times R \times T}$$

$$= \frac{3{,}5\,\text{atm} \times 17{,}031\,\text{g/mol}}{0{,}9833 \times 82{,}06\,\text{cm}^3.\text{atm/mol.K} \times 356{,}5\,\text{K}}$$

$= 2{,}0722.10^{-3}$ g/cm^3 = 0,1294 lb/ft^3 = $1{,}2167.10^{-4}$mol/cm^3

$\rho_{Lm} \approx \rho_{air}$ = 0,9697 g/ml = 60,5384 lb/ft^3 = 0,0538 mol/cm^3

Perhitungan *surface tension* untuk campuran liquid menggunakan korelasi Macleod-Sugden:

$$\sigma_m^{1/4} = \sum_{i=1}^{n} P_i.\left(\rho_{Lm}.x_i - \rho_{Vm}.y_i\right) \quad ...(12\text{-}5.1)$$ (Prausnitz, 1988, p.642)

$\sigma_m = 58.(0{,}0538.2{,}55.10^{-5} - 1{,}2167.10^{-4}. 0{,}9950) + 45{,}3. (0{,}0538.0{,}9999 - 1{,}2167. 10^{-4}. 0{,}0050)$

$\sigma_m = 2{,}4299$

Dari Ludwig fig.8.50 untuk σ_m = 2,4299 dan jarak antara tray 20 in, didapat harga konstanta empiris = C = 325 (Ludwig,1974)

$W = C.[\rho_V.(\rho_L - \rho_V)]^{1/2}$

$W = 325.[0{,}1294.(60{,}5384 - 0{,}1294)]^{1/2} = 908{,}6598$ lb/ft^2.jam

$$D = \left[\frac{4}{\pi}.\frac{V'}{W}\right]^{1/2}$$ (Ludwig, 1974, p. 108)

dimana: V' = rate uap = 3.151,0419 kmol/hari = 53.680,8976 kg/hari

= 2.236,0581 kg/jam = 4.930,5081 lb/jam

$$D = \left[\frac{4}{\pi}.\frac{4.930{,}5081}{908{,}6598}\right]^{1/2} = 2{,}6285 \text{ ft} \approx 3 \text{ ft}$$

r = 1,5 ft

➢ *Perhitungan Tinggi menara distilasi bagian shell*

Jumlah tray = 7

Jarak antar tray = 20 in

Tinggi menara bagian shell = ((jumlah tray – 1) × jarak antar tray) + 0,5 ft

= 6 × (20/12) ft + 0,5 ft = 10,5 ft

➢ *Perhitungan Tebal dinding shell*

P design = P operasi + 2,5 bar (Ulrich, 1984)

= 3,5466 + 2,5 = 6,0466 bar = 87,6630 psia

c = faktor korosi maksimum = 3 mm = 0,01 ft (Ulrich, 1984)

f = f allow = 18750 psia

untuk jenis stainless steel 18-8 tipe 304 (Brownell & Young, 1959)

E = 0,8 (Double Welded Butt Joint) (Brownell & Young, 1959, tabel 13.2, p.254)

$$t_{shell} = \frac{P.r}{f.E - 0,6.P} + c$$ (Brownell & Young, 1959, eq. 13.1, p.254)

$$= \frac{87,6630.1,5.12}{0,8.18750 - 0,6.87,6630} + 0,12 \text{ in } = 0,2256 \text{ in}$$

Diambil t_{menara} = $\frac{1}{4}$ in (Brownell & Young, 1959, App.F item 2, p.350)

➢ *Perhitungan Tebal Tutup*

Digunakan tutup atas dan bawah jenis *flanged and dished* maka:

Do = Di + 2. t_{shell} = 3.12 + 2.0,25 = 36,5 in ≈ 38 in

E = 0,8 (Double Welded Butt Joint) (Brownell & Young, 1959, tabel 13.2, p.254)

rc = Di + t = 3.12 + 0,25 = 36,25 in ≈ 37 in

$$W = \frac{1}{4}\left(3 + \sqrt{\frac{rc}{icr}}\right)$$ (Brownell & Young, 1959, eq. 7.76, p.138)

$$W = \frac{1}{4}\left(3 + \sqrt{\frac{37}{2,375}}\right) = 1,7368$$

$$t_h = \frac{P.rc.W}{2.f.E - 0,2.P} + c$$ (Brownell & Young, 1959, eq. 7.77, p.138)

$$t_h = \frac{87,6630.37.1,7368}{2.18750.0,8 - 0,2.87,6630} + 0,12 \text{ in } = 0,3079 \text{ in}$$

Diambil tebal tutup = t_h = $\frac{5}{16}$ in (Brownell & Young, 1959, tabel 5.8, p.93)

➢ *Perhitungan Tinggi Tutup*

Do = 38 in

Dari Brownell & Young, 1959, tabel 5.7 dan 5.8 diketahui untuk t = $\frac{5}{16}$ in, icr = 2,375 in, r = 36 in dan sf = 2,5 in

$Di = Do - 2 \cdot t = 37{,}375$ in

$AB = \frac{Di}{2} - icr = 16{,}3125$ in

$BC = r - icr = 33{,}625$ in

Kedalaman dish (b) = $r - \sqrt{(BC)^2 - (AB)^2} = 6{,}5969$ in

Tinggi tutup = t + b + sf = 9,4094 in = 0,7841 ft

➢ *Perhitungan Tinggi Total Menara Distilasi*

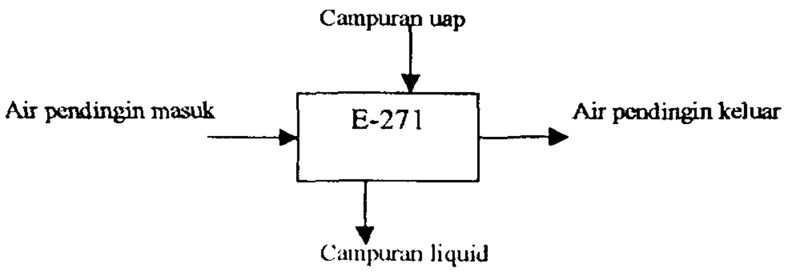
Tinggi total menara = tinggi menara bagian shell + 2. tinggi tutup

= 10,5 + 2. 0,7841 = 12,0682 ft ≈ 13 ft

Spesifikasi :

1. Kapasitas : 568.579,9757 kg/hari
2. Dimensi Bejana :
   - Diameter : 3 ft
   - Tinggi : 13 ft
   - Tebal Shell : $\frac{1}{4}$ in
   - Tebal Tutup atas : $\frac{3}{16}$ in
   - Tebal Tutup atas : $\frac{3}{16}$ in
3. Bahan konstruksi : Stainless steel 18-8 tipe 304
4. Jumlah : 1 buah

44. Kondensor Distilasi (E-271)



Fungsi : Mendinginkan distilat secara total

Tipe : *Shell and Tube*

Dasar Pemilihan : 1. Luas perpindahan panas besar

2. Dapat digunakan untuk tekanan tinggi

3. Mempunyai kapasitas aliran yang besar

Perhitungan :

➢ *Perhitungan Koefisien Transfer Panas*

P operasi = 3 atm

T gas masuk = 25°C ; T liquid keluar = 6°C

Qc = 13.226.947,4085 kJ/hari = 551.122,8083 kJ/jam = 522.495,0402 Btu/jam

Rate gas masuk = 1,0283.(3049.17,031 + 15,3216.18,015) kg/hari

= 53.680,8976 kg/hari

= 2.236,0581 kg/jam = 4.930,5081 lb/jam

90% berat air pendingin ditambah dengan 10% berat ethylene glycol masuk pada suhu -10 °C dan keluar pada suhu 0 °C :

$$\text{Cp air pendingin} = \int_{263}^{273} \text{Cp } H_2O_{(l)}\, dT = 739{,}6105 \text{ J/mol} = 739{,}6105 \text{ kJ/kmol}$$

Cp campuran . ΔT = (0,9688 x 739,6105) + (0,0312 x 92,8538 x (273-263)) = 745,5051 kJ/kmol

BM campuran = (0,9688 x 18,015) + (0,0312 x 62,068) = 19,3895 kg/kmol

Kebutuhan air pendingin :

Qc = Q yang diserap air pendingin

$$13.226.947{,}4085 = \frac{m}{19{,}3895} \cdot Cp \cdot \Delta T$$

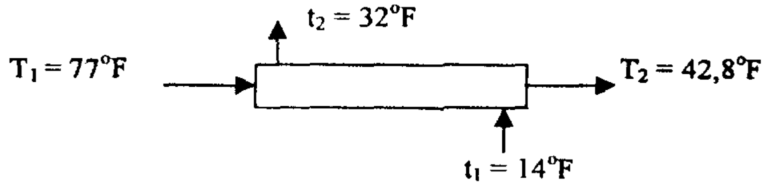
13.226.947,4085 x 19,3895 = m x 745,5051

massa air pendingin = 344.013,6045 kg/hari = 31.606,2499 lb/jam

Massa air = 90 % x 344.013,6045 kg = 309.612,2440 kg/hari = 12.900,5102 kg/jam

Massa ethylene glycol = 10 % x 344.013,6045 kg = 34.401,3605 kg/hari

= 1.433,3900 kg/jam



$\Delta T1 = T1 - t2 = 77 - 32 = 45°F$

$\Delta T2 = T2 - t1 = 42{,}8 - 14 = 28{,}8\ °F$

$$\Delta T_{LMTD} = \frac{\Delta T1 - \Delta T2}{Ln\left(\frac{\Delta T1}{\Delta T2}\right)} = \frac{45 - 28,8}{Ln\left(\frac{45}{28,8}\right)} = 36,2995^\circ F$$

$$R = \frac{T1 - T2}{t2 - t1} = \frac{77 - 42,8}{32 - 14} = 1,9$$

$$S = \frac{t2 - t1}{T1 - t1} = \frac{32 - 14}{77 - 14} = 0,2857$$

Berdasarkan harga R dan S didapatkan: $F_T = 0,975$ (Kern, 1965, Fig. 19, p.829)

$\Delta T = \Delta T_{LMTD} \times F_T = 36,2995 \times 0,975 = 35,392$ °F

$$Tc = \frac{77 + 42,8}{2} = 59,9^\circ F$$

$$tc = \frac{32 + 14}{2} = 23^\circ F$$

Trial : $U_D = 99$ btu/jam.ft^2.°F

Asumsi: ¾ inch OD, 16 BWG, 1 inch triangular pitch, L = 10 ft

a" = 0,1963 (Kern, 1965, tabel 10, p.843)

$Q = U_D \cdot A \cdot \Delta T$

$$A = \frac{Q}{U_D \times \Delta T} = \frac{522.495,0402}{99 \times 35,392} = 149,1221 \text{ ft}^2$$

A = Nt . a" . L → 149,1221 = Nt . 0,1963 . 10

Nt = 75,9664 tubes

Dari tabel 9 Kern, 1965, diperoleh untuk 2-4 heat exchanger:

ID_{shell} = 12 in Nt = 76 tubes

U_D koreksi → A = Nt . a" . L = 76 . 0,1963 . 10 = 149,1880 ft^2

$$U_D = \frac{Q}{A \times \Delta T} = \frac{522.495,0402}{149,1880 \times 35,392} = 98,9562 \text{ Btu/jam.ft}^2.^\circ F$$

Shell Side

B = ID/5 = 12/5 = 2,4 in

$$as = \frac{ID \times C' \times B}{144 . P_T} \; ; \; C' = P_T - OD$$

$$= 1 - \tfrac{3}{4} = 0,25$$

Tube Side

a't = 0,182 in

$$at = \frac{Nt . a't}{144 . n} = \frac{76 . 0,182}{144 . 4} = 0,0240$$

Gt = W/at

= 31.606,2499/0,0240

$$= \frac{12 \times 1/4 \times 2,4}{144.1} = 0,05 \text{ ft}^2$$

Gs = W/as

= 4.930,5081 / 0,05

= 95.924,0003 lb/jam.ft^2

De = 0,08 ft (Figure 28, Kern, 1965)

$$G" = \frac{W}{L.Nt^{2/3}} = \frac{4.930,5081}{10.76^{2/3}}$$

= 26,7314 lb/jam.lin ft

Asumsi : ho = 105

$$tw = tc + \frac{ho}{hio + ho}.(Tc + tc)$$

$$= 23 + \frac{105}{526,9 + 105}.(59,9 + 23)$$

= 36,7732°F

tf = (Tc + tw)/2 = 48,3366°F

kf = Σ ki.xi =0,2903 Btu/jam.ft^2.(°F/ft)

sf = Σ si . xi = 0,6120

μf = Σ μi . xi = 0,3029 lb/ft.jam

Dari figure 12.9 Kern, 1965, diperoleh :

ho = 151 Btu/jam.ft^2.°F

= 1.316.927,08 lb/jam.ft^2

Pada tc = 23°F

μ = 2,8156.2,42 = 6,8138 lb/ft.hr

D = 0,482/12 = 0,0402 ft

$$Ret = \frac{D.Gt}{\mu} = 7.763,1529$$

Dari Perry, 1984, tabel 3-117, p.3-93:

$\rho_{\text{ethylene glycol}}$ = 1,0013 g/ml = 62,5112 lb/ft^3

ρ_{air} = 62,5 lb/ft^3

$\rho_{\text{air pendingin}} = \rho_{\text{campuran}}$ = 62,5011 lb/ft^3

$$V = \frac{Gt}{3600.\rho}$$ (figure 25, Kern)

$$= \frac{1.316.927,08}{3600.62,5011} = 5,8529 \text{ ft/detik}$$

Dari figure 25, Kern, 1965, didapatkan

hi = 820 Btu/jam.ft^2.°F

hio = hi . ID/OD

= 820 . 0,482/0,75

= 526,9 Btu/jam.ft^2.°F

$$Uc = \frac{hio \times ho}{hio + ho} = \frac{526,9 \times 151}{526,9 + 151} = 117,37 \text{ Btu/jam.ft}^2.°F$$

$$Rd = \frac{U_C - U_D}{U_C \times U_D} = \frac{117,37 - 98,9562}{117,37 \times 98,9562} = 0,0016 \text{ jam.ft}^2.°F/Btu$$

➢ *Perhitungan Pressure Drop*

Shell Side

Pada Tc = 59,9°F

μ vapor = 0,0252 lb/jam.ft

De = 0,08 ft

Res = (De . Gs)/μ

$$= \frac{0,08.(95.924,0003)}{0,0252} = 304.520,6359$$

f = 0,0015 ft²/in² (Figure 29, Kern,1965)

$$N + 1 = 12.\frac{L}{B} = 12.\frac{10}{2,4} = 50$$

BM campuran = 17,0359 g/gmol

$$\rho = \frac{P.BM}{Z.R.T} = \frac{3.17,0359}{0,9833.82,06.288,5}$$

$$= 0,0022 \text{ g/cm}^3 = 0,1371 \text{ lb/ft}^3$$

s = 0,2610/62,5 = 0,0494

Ds = 12 /12 = 1 ft

$$\Delta Ps = \frac{1}{2}.\frac{f.Gs^2.Ds.(N+1)}{5,22.10^{10}.De.s}$$

$$= \frac{1}{2}.\frac{0,0015.(95.924,0003^2).1.50}{5,22.10^{10}.0,08.0,0494}$$

= 1,6723 psia < 2 psia

Tube Side

Untuk Ret = 7.763,1529

f = 0,0038 (Figure 26, Kern, 1965)

$$\Delta Pt = \frac{f.Gt^2.L.n}{5,22.10^{10}.D.s.\varphi_t}$$

$$= \frac{0,0038.(1.316.927,08^2).10.4}{5,22.10^{10}.0,0402.1.1}$$

= 1,5262 psia

Pada Gt = 1.316.927,08 lb/jam.ft², di-

dapat: $\frac{V^2}{2.g'} = 0,038$ (Fig.27, Kern, 1965)

$$\Delta P_r = \frac{4.n}{s}.\frac{V^2}{2.g'} = \frac{4.4}{1}.0,038$$

= 0,608 psia

$$\Delta P_T = \Delta P_t + \Delta P_r$$

= 1,5262 + 0,608

= 2,1342 psia < 10 psia

Spesifikasi :

1. Tipe : Shell and Tube
2. Dimensi Shell :
   - ID : 12 in
   - Baffle space : 2,4 in
3. Dimensi Tube :
   - ID : 0,482 in
   - OD : ¾ in

Passes : 4

Pitch : 1 in

Susunan : triangular

Jumlah : 76

4. Panjang : 10 ft
5. Luas perpindahan panas : 149,1880 ft^2
6. Bahan konstruksi : Stainless steel 18-8 tipe 304
7. Jumlah : 1 buah

45. Drum Akumulator Distilasi (F-272)

Fungsi : Menampung distilat dari kondensor distilasi (E-271)

Tipe : Tangki horisontal dengan tutup samping ellipsoidal

Dasar Pemilihan : dapat menampung kapasitas yang besar

Perhitungan :

➤ *Perhitungan Dimensi Tangki*

Rate masuk = 53.680,8976 kg/hari

= 2.236,0581 kg/jam = 4.930,5081 lb/jam

ρ = 598,2143 kg/m^3 = 37,3452 lb/ft^3

$$\text{Volume liquid} = \frac{4.930,5081\ \text{lb/jam}}{37,3452\ \text{lb/ft}^3} = 128,4288\ \text{ft}^3$$

Diambil: L = 2.D

Liquid mengisi ¾ bagian tangki

Volume liquid = ¾ (volume shell + 2.volume ellipsoidal)

$$128,4288 = \tfrac{3}{4}\left(\left[\frac{\pi}{4}D^2.L\right] + 2.\left[0,131328.D^3\right]\right)$$

$$128,4288 = \tfrac{3}{4}\left(\left[\frac{\pi}{4}D^2.2.D\right] + 2.\left[0,131328.D^3\right]\right)$$

$$128,4288 = \tfrac{3}{4}.(1,8335\ D^3)$$

$$128,4288 = 1,3751\ .\ D^3$$

$$D^3 = 93,3960\ \text{ft}^3$$

$$D_{shell} = 4,5371\ \text{ft} \approx 5\ \text{ft}$$

$$L_{shell} = 2.D = 9{,}0742 \text{ ft} \approx 10 \text{ ft}$$

$$L_{ellipsoidal} = 2.\frac{D}{4} = 2.\frac{4{,}5371}{4} = 2{,}2686 \text{ ft}$$

$$L_{tangki} = L_{shell} + L_{ellipsoidal}$$

$$= 9{,}0742 + 2{,}2686 \text{ ft} = 11{,}3428 \text{ ft} \approx 12 \text{ ft}$$

➢ *Perhitungan Tebal Shell*

$$t_{shell} = \frac{P.ID}{2.(f\,E - 0{,}6.P)} + c$$

dimana:

f_{allow} = 18750 psi (untuk stainless steel 18-8 tipe 304)

E = 0,8 (tipe pengelasan Double Welded Butt Joint)

c = faktor korosi = 0,1 in

$$P = \frac{\rho.h}{144}$$

$\rho = 37{,}3452 \text{ lb/ft}^3$

h = 0,75. D = 0,75. 4,5371 = 3,4028 ft

$$P = \frac{37{,}3452.(3{,}4028)}{144} = 0{,}8825 \text{ psia}$$

$P_{operasi}$ = 0,8825 + 44,10 = 44,9825 psia

Untuk safety, P_{design} = 1,2 . 44,9825 = 53,9790 psia

$$t_{shell} = \frac{53{,}9790.4{,}5371.12}{2.(18750.0{,}8 - 0{,}6.53{,}9790)} + 0{,}1$$

$$= 0{,}1982 \text{ in}$$

Diambil $t_{shell} = {}^{1}/_{4}$ in (Brownell & Young, 1959, App.F item 2, p.350)

➢ *Perhitungan Tebal Ellipsoidal*

$$v = \frac{1}{6}.\left(2 + k^2\right)$$

$$= \frac{1}{6}.\left(2 + 2^2\right) = 1$$

$$t_{ellipsoidal} = \frac{P.D.v}{2.f\,E - 0{,}2.P} + c$$

$$= \frac{53{,}9790.4{,}5371.12.1}{2.18750.0{,}8 - 0{,}2.53{,}9790} + 0{,}1 = 0{,}1980 \text{ in}$$

Diambil $t_{ellipsoidal}$ = $^1/_4$ in (Brownell & Young, 1959, App.F item 2, p.350)

Spesifikasi :

1. Tipe : Tangki horisontal dengan tutup samping berbentuk ellipsoidal
2. Kapasitas : 128,4288 ft^3/jam
3. Suhu operasi : 6 °C
4. Tekanan operasi : 3 atm
5. Dimensi :

   Diameter shell : 5 ft

   Tebal shell : $^1/_4$ in

   Tebal ellipsoidal : $^1/_4$ in

   Panjang : 12 ft
6. Bahan konstruksi : Stainless steel 18-8 tipe 304
7. Jumlah : 1 buah

46. Reboiler (E-273)

Fungsi : Menguapkan kembali bottom product dari menara distilasi

Tipe : Shell and Tube Kettle Reboiler

Dasar pemilihan :

1. Luas perpindahan panas besar
2. Dapat digunakan untuk tekanan tinggi
3. Mempunyai kapasitas aliran yang besar

Perhitungan :

➢ *Perhitungan Koefisien Transfer Panas*

P operasi = 3,67 atm

T liquid masuk = 142°C ; T gas keluar = 152°C

Q_R = 146.321.853,8394 kJ/hari = 12346220,8375 kJ/jam = 5.778.554,8453 Btu/jam

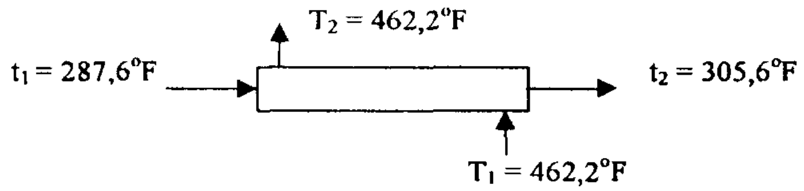
Steam yang digunakan : *saturated steam* dengan tekanan 33 bar, 239°C

λ steam, 239°C = 1769,155 kJ/kg (Smith, 1996, p. 672)

Massa steam yang dibutuhkan = $\dfrac{146.321.853,8394 \text{ kJ/hari}}{1769,155 \text{ kJ/kg}}$

= 82.707,1985 kg/hari = 3.446,1333 kg/jam

= 7.598,7239 lb/jam



$\Delta T1 = T2 - t1 = 462,2 - 287,6 = 174,6°F$

$\Delta T2 = T1 - t2 = 462,2 - 305,6 = 156,6°F$

$$\Delta T_{LMTD} = \frac{\Delta T1 - \Delta T2}{Ln\left(\dfrac{\Delta T1}{\Delta T2}\right)} = \frac{174,6 - 156,6}{Ln\left(\dfrac{174,6}{156,6}\right)} = 165,4368$$

F_T = 1 karena salah satu fluida suhunya konstan (Figure 18, p.828, Kern, 1965)

$\Delta T = \Delta T_{LMTD} \times F_T = 165,4368 \times 1 = 165,4368°F$

Tc = 462,2 °F

$$tc = \frac{287,6 + 305,6}{2} = 296,6°F$$

Trial U_D = 169 Btu/jam.ft^2.°F

Asumsi 1 inch OD, 12 BWG, 1 ¼ inch triangular pitch, L = 12 ft.

a" = 0,2618 (Tabel 10, p. 843, Kern, 1965)

$Q = U_D . A . \Delta T$

$$A = \frac{Q}{UD \times \Delta T} = \frac{5.778.554,8453}{169 \times 165,4368} = 206,6809 \text{ ft}^2$$

A = Nt . a" . L = Nt . 0,2618 . 12

Nt = 65,7884 tubes ≈ 66 tubes

Dari tabel 9 hal 842, Kern, 1965, diperoleh untuk 1-2 heat exchanger :

ID_{shell} = 13 ¼ in Nt = 66 tubes

U_D koreksi → A = Nt . a" . L = 66 . 0,2618 . 12 = 207,3456 ft^2

$$U_D = \frac{Q}{A.\Delta T} = \frac{5.778.554,8453}{207,3456.165,4368} = 168,4583 \text{ Btu/jam.ft}^2.°F$$

Tube Side

a't = 0,479 in^2 (Tabel 10,p.843,Kern,1965)

at = (Nt . a't)/144.n

= (66.0,479)/144.2 = 0,1098

Gt = W/at

= 7.598,7239/ 0,1098

= 69.205,1354 lb/jam.ft^2

Pada tc = 462,2 °F

μ = 0,0175.2,42 = 0,0424 lb/ft.hr

D = 0,782/12 = 0,0652 ft

$$Ret = \frac{D.G}{\mu} = 106.419,2176$$

hio = 1500 Btu/jam.ft^2. °F

Shell Side

Asumsi : ho = 160

$$tw = tc + \frac{ho}{hio + ho}.(Tc + tc)$$

$$= 296,6 + \frac{160}{1500+160}.(462,2+296,6)$$

= 369,7373°F

Δtw = tw - tc = 73,1373°F

Dari Fig. 15.11, p.474, Kern, 1965, diperoleh : ho = 300 btu/jam.ft^2.°F

$$Uc = \frac{hio \times ho}{hio + ho} = \frac{1500 \times 300}{1500 + 300} = 250$$

$$Rd = \frac{Uc - Ud}{Uc \times Ud} = \frac{250 - 168,4583}{250 \times 168,4583} = 0,0019 \text{ (memenuhi)}$$

Tube Side

Untuk Ret = 106.419,2176

f = 0,00023 (Fig.26, p.836, Kern 1965)

$$\Delta Pt = \frac{f.Gt^2.L.n}{5,22.10^{10}.D.s.\varphi_t}$$

$$= \frac{0,00023.69.205,1354^2.12.2}{5,22.10^{10}.0,0652.1.1}$$

= 0,0078 psia

Shell Side

Diabaikan

Spesifikasi :

1. Tipe : Shell and Tube Kettle Reboiler
2. Dimensi :

Shell	ID	: 13 ¼ in
	Baffle space	: 5 in
Tube	ID	: 0,782 in
	OD	: 1 in
	Jumlah	: 66
	Passes	: 2
	Pitch	: 1 ¼ in
	Susunan	: triangular
Panjang		: 12 ft
Luas perpindahan panas		: 207,3456 ft^2
Bahan konstruksi		: Carbon steel

3. Jumlah : 1 buah

APPENDIX D
ANALISA EKONOMI

APPENDIX D
ANALISA EKONOMI

Perhitungan harga setiap waktu akan berubah, tergantung pada perubahan kondisi ekonomi dan politik. Oleh karena itu membutuhkan suatu metode untuk mengkonversikan harga suatu alat beberapa tahun yang lalu, sehingga memperoleh harga yang ekivalen untuk waktu sekarang.

$$\text{Harga alat saat ini} = \frac{\text{Indeks harga saat ini}}{\text{Indeks harga tahun X}} \times \text{harga tahun X}$$

Harga alat yang digunakan dalam perencanaan didasarkan pada harga alat yang terdapat pada pustaka Peter and Timmerhaus dan Ulrich G.D.

Untuk perhitungan ini menggunakan indeks harga Marshall dan Swift Equipment Cost Index dan Chemical Engineering Plant Cost Index. Index harga tersebut adalah:

- Marshall dan Swift Equipment Cost Index

Tahun 1990 = 904 (Peters & Timmerhaus, 1991)

Tahun 2005 = 1142,6 (ekstrapolasi)

- Chemical Engineering Plant Cost Index

Tahun 1982 = 315 (Ulrich, 1984)

Tahun 2005 = 404,4 (ekstrapolasi)

Untuk memperkirakan harga alat-alat yang dapat dibeli di dalam negeri maka perlu ditanyakan langsung ke produsen peralatan di dalam negeri yang sudah bisa membuat peralatan-peralatan tersebut. Sebagai contoh, misal tangki dapat dipesan dari PT. Meco Inox Prima di Jl. Kalijaten 114, Sepanjang dan untuk conveyor dapat dipesan di PT. Piramid Mas Perdana yang berkantor di Jl. Kranggan 70, Surabaya.

D.1 Perhitungan Harga Peralatan

Harga peralatan dihitung berdasarkan persamaan umum, yaitu:

$$\text{Harga alat saat ini} = \frac{\text{Indeks harga saat ini}}{\text{Indeks harga tahun X}} \times \text{harga tahun X}$$

Contoh perhitungan :

Nama alat : Expander

Kapasitas : 52.133,2554 kg/hari

Jumlah : 1

Harga tahun 1990 : \$ 25.000

Harga tahun 2005 : (1142,6 / 904) x \$ 25.000 = \$ 31.598,45

Total : \$ 31.598,45 x Rp 8.000 / \$ = Rp 252.787.650,-

Dengan cara yang sama diperoleh harga peralatan seperti di bawah ini :

Tabel D.1 Harga Peralatan Proses

No	Nama Peralatan	Kode	Harga/unit (\$)	Jumlah	Total (Rp)
1	Belt Conveyor	J-111	-	1	65.000.000
2	Tangki Pelarutan KCl	M-120	-	1	71.700.000
3	Pompa	L-121	-	1	1.500.000
4	Tangki Penyimpan Isopropanol	F-130	-	1	429.445.000
5	Pompa	L-131	-	1	1.500.000
6	Tangki Penyimpan Amonia	F-140	-	1	786.801.500
7	Expander	G-141	31.598,45	1	252.787.650
8	Tangki Pelarutan Amonia	M-150	-	1	276.987.000
9	Pompa	L-151	-	1	1.500.000
10	Bucket Elevator	J-161	-	1	40.000.000
11	Hammer Mill	C-162	20.223,01	1	161.784.500
12	Screen	H-163	15.167,26	1	121.338.500
13	Belt Conveyor	J-164	-	1	115.400.000
14	Screw Conveyor	J-165	-	1	47.210.000
15	Reaktor	R-210	-	1	72.000.000
16	Pompa	L-211	-	1	2.500.000

17	Rotary drum separator I	H-220	189.590,71	1	1.516.725.700
18	Screw Conveyor	J-221	-	1	47.210.000
19	Tangki Pelarutan K_2SO_4	M-222	-	1	72.000.000
20	Pompa	L-223	-	1	1.500.000
21	Pompa	L-224	-	1	2.500.000
22	Tangki Penampung Filtrat	F-225	-	1	63.279.000
23	Pompa	L-226	-	1	1.500.000
24	Rotary drum separator II	H-230	126.393,81	1	1.011.150.450
25	Pompa	L-231	-	1	1.500.000
26	Kristaliser	X-240	-	1	269.187.000
27	Pompa	L-241	-	1	2.500.000
28	Rotary drum separator III	H-250	208.549,78	1	1.668.398.300
29	Screw conveyor	J-251	-	1	47.210.000
30	Pompa	L-252	-	1	3.000.000
31	Heater	E-253	-	1	53.000.000
32	Menara distilasi	D-270	69.516,59	1	556.133.000
33	Kondensor distilasi	E-271	6.193,30	1	49.546.500
34	Drum akumulator distilasi	F-272	18.959,07	1	151.673.000
35	Reboiler	E-273	5.687,72	1	45.502.000
36	Rotary Dryer	B-260	-	1	419.627.500
37	Blower	G-261	-	1	32.500.000
38	Cyclone	H-262	-	1	3.682.500
39	Heater	E-263	-	1	31.500.000
40	Blower	G-264	-	1	32.500.000
41	Menara absorber	D-265	-	2	123.790.500
42	Screw conveyor	J-266	-	1	47.210.000
Total :					8.765.058.600

Tabel D.2 Harga Peralatan Utilitas

No	Nama Peralatan	Kode	Harga / unit ($)	Jumlah	Total (Rp)
1	Pompa bak penampung	L-311	-	1	2.500.000
2	Tangki flokulator	M-320	-	1	72.000.000
3	Pompa tangki flokulator	L-321	-	1	2.500.000
4	Sand filter	H-340	-	2	23.100.000
5	Pompa	L-342	-	1	2.500.000
6	Tangki demineraliser	H-350	-	2	83.000.000
7	Pompa	L-351	-	1	2.500.000
8	Pompa bak air pendingin	L-382	-	1	1.500.000
9	Cooling tower	P-380	-	1	96.187.500
10	Chiller	P-390	-	1	63.279.000
11	Boiler I	E-353	-	1	333.680.000
12	Boiler II	E-354	-	1	960.593.000
13	Generator	-	-	1	535.350.000
14	Fuel oil storage	F-355	-	1	64.125.000
15	Pompa fuel oil	L-357	-	1	1.500.000
16	IDO storage	F-356	-	1	32.150.000
17	Pompa IDO	L-358	-	1	1.500.000
Total :					2.277.964.500

Tabel D.3 Luas Bak Penampung pada Utilitas

No	Nama Peralatan	Kode	Volume, m^3	Jumlah	Luas, m^2
1	Bak penampung air sungai	F-310	288	1	72
2	Bak sedimentasi	F-330	288	1	125
3	Bak penampung air bersih	F-341	145	1	25
4	Bak demineralized water	F-360	112	2	40
5	Bak penampung air sanitasi	F-370	8,1	1	6
6	Bak penampung air pendingin	F-381	9,5	1	6,25
Total :					274,25

Harga bak = Rp 200.000 /m^2

Harga bak total = Rp 200.000 x 274,25 = Rp 54.850.000,-

Harga alat total = Rp (11.043.023.100 + 54.850.000) = Rp 11.097.873.100,-

2. Perhitungan harga bahan baku

2.1. Phosphogypsum

Kebutuhan per tahun	= 46.261,2625 kg/hari . 330 hari/tahun
	= 15.266.216,6250 kg/tahun
Harga beli	= Rp 150.000 / 4 ton
Biaya pembelian per tahun	= Rp 572.483.150

2.2. KCl (China)

Kebutuhan per tahun	= 20.664,9231 kg/hari . 330 hari/tahun
	= 6.819.424,6230 kg/tahun
Harga beli	= US$ 415/metric ton
	= Rp 3.320/kg (kurs US$ 1 = Rp 8.000)
Biaya pembelian per tahun	= Rp 22.640.489.750

2.3. Ammonia (PT. Petrokimia, Gresik)

Kebutuhan per tahun	= 205,7364 kg/hari . 330 hari/tahun
	= 67.893,0120 kg/tahun
Harga beli	= Rp 1.500 / kg
Biaya pembelian per tahun	= Rp 101.839.550

2.4. Isopropanol

Kebutuhan per tahun	= 11.058,5693 kg/hari . 330 hari/tahun
	= 3.649.327,8690 kg/tahun
Harga beli	= Rp 2.800/kg
Biaya pembelian per tahun	= Rp 10.218.118.000

Total biaya bahan baku tiap tahun : Rp 33.532.930.450

3. Perhitungan harga packing

Biaya 1 kantong = Rp 600,-

Kebutuhan kantong per tahun = (21.313,9911/25) kg x 330 = 281.345 buah

Biaya tiap tahun = 281.345 x Rp 600 = Rp 168.806.850

4. Perhitungan harga jual produk

4.1. Potassium Sulfate (K_2SO_4)

Produk per hari = 21.313,9911 kg

Harga jual pasaran US$ 500/metric ton (www.clevelandpotash.com)

= Rp 4.000/kg (kurs US$ 1 = Rp 8.000)

Harga jual per tahun = Rp 28.134.468.300

5. Perhitungan biaya utilitas

5.1. Alum

Kebutuhan per hari = 128,8825 kg

Harga beli alum per kg = Rp 1.350

Biaya untuk alum per tahun = Rp 57.417.200

5.2. Zeolite

Kebutuhan per tahun = 2.068,15 kg

Harga beli zeolit per kg = Rp 2.500

Biaya untuk zeolit per tahun = Rp 5.170.400

5.3. IDO

Kebutuhan per bulan = 722,0474 liter

Harga beli diesel oil per liter = Rp 1.500

Biaya untuk diesel oil per tahun = Rp 12.996.900

5.4. Residu Fuel Oil

Kebutuhan per bulan = 233.256,8866 liter

Harga beli residu per liter = Rp 800

Biaya untuk residu per tahun = Rp 2.239.266.150

5.5. Listrik

Beban terpasang = 500 kW

Biaya beban per bulan = Rp 35.000 per kW

Biaya beban per tahun = Rp 210.000.000

Listrik yang terpakai = 439,7816 kW

Biaya listrik :

WBP (Waktu Beban Puncak, pk.18.00-22.00) = Rp 388/kW

LWBP (Luar Waktu Beban Puncak, pk.22.00-18.00) = Rp 314/kW

Dalam 1 hari terdapat 4 jam WBP dan 20 jam LWBP

Listrik terpakai = 439,7816 kW untuk 330 hari (full operation)

= 75,88 kW untuk 35 hari (off operation)

Biaya listrik terpasang per tahun :

= (330.439,7816 + 35.75,88).(388.4 + 314.20)

= Rp 1.157.442.200

Biaya listrik total = Rp (210.000.000 + 1.157.442.200) = Rp 1.367.442.200

6. Perhitungan harga tanah dan bangunan

Luas tanah	= 20.000 m^2
Luas bangunan pabrik	= 15.648 m^2
Luas bangunan gedung	= 829 m^2
Harga tanah per m^2	= Rp 100.000
Harga bangunan pabrik per m^2	= Rp 300.000
Harga bangunan gedung per m^2	= Rp 400.000

Harga tanah total	= Rp 2.000.000.000
Harga bangunan pabrik	= Rp 4.694.400.000
Harga bangunan gedung	= Rp 331.600.000
Total harga tanah dan bangunan	= Rp 7.026.000.000

7. Perhitungan gaji karyawan

Karyawan Non Shift :

- Tidak langsung menangani bagian proses produksi
- Bekerja 6 hari/minggu

- Minggu dan hari besar libur
- Jadwal Kerja :

  Senin – Kamis: masuk pukul 8.00 WIB

  istirahat pukul 11.30 – 12.30 WIB

  pulang pukul 16.00 WIB

  Jumat : masuk pukul 8.00 WIB

  istirahat pukul 11.00 - 13.00 WIB

  pulang pukul 16.00 WIB

  Sabtu : masuk pukul 8.00 WIB

  pulang pukul 12.00 WIB

Karyawan Shift :

- Langsung menangani proses produksi dan langsung mengatur bagian-bagian tertentu pabrik yang ada hubungannya dengan keamanan dan kelancaran produksi. Karyawan tersebut bekerja secara bergantian antara satu dengan lainnya dan biasanya juga masuk pada hari libur.
- Dibagi menjadi 4 kelompok, yaitu:

  3 shift bekerja

  1 shift istirahat (biasanya yang habis dinas malam hari)
- Jadwal Kerja

  Shift I : pukul 6.00 - 14.00 WIB

  Shift II : pukul 14.00 - 22.00 WIB

  Shift III: pukul 22.00 - 6.00 WIB

Tabel D.4 Jadwal Kerja Karyawan Shift

Regu	Hari ke-											
	1	2	3	4	5	6	7	8	9	10	11	12
I	P	P	P	L	S	S	S	L	M	M	M	L
II	M	M	L	P	P	P	L	S	S	S	L	M
III	S	L	M	M	M	L	P	P	P	L	S	S
IV	L	S	S	S	L	M	M	M	L	P	P	P

Keterangan tabel : P = pagi S = siang M = malam L = libur

Perincian gaji karyawan disajikan pada tabel D.5 dibawah ini :

Tabel D.5 Perhitungan Gaji Karyawan

No	Jabatan	Jumlah	Gaji tiap orang/Bulan (Rp)	Total (Rp)
1	Direktur	1	10.000.000	10.000.000
2	Manager produksi	1	4.500.000	4.500.000
3	Manager keuangan	1	4.500.000	4.500.000
4	Manager Adm/personalia & Humas	1	4.500.000	4.500.000
5	Manager lab., QC, dan R&D	1	4.500.000	4.500.000
6	Sekretaris	2	900.000	1.800.000
7	Supervisor bhn baku dan produk	1	3.250.000	3.250.000
8	Supervisor proses	1	3.250.000	3.250.000
9	Supervisor utilitas	1	3.250.000	3.250.000
10	Supervisor lab., QC, dan R&D	1	3.250.000	3.250.000
11	Supervisor maintenance	1	3.250.000	3.250.000
12	Supervisor keuangan	1	3.250.000	3.250.000
13	Supervisor controller	1	3.250.000	3.250.000
14	Supervisor Adm/personalia & Humas	1	3.250.000	3.250.000
15	Shift supervisor	4	2.500.000	10.000.000
16	Karyawan keamanan	13	850.000	11.050.000
17	Karyawan utilitas	32	750.000	24.000.000
18	Karyawan lab., QC, dan R&D	10	1.000.000	10.000.000
19	Karyawan pemeliharaan alat	5	750.000	3.750.000
20	Karyawan warehouse produk	8	700.000	5.600.000
21	Karyawan penyedia bahan baku	20	700.000	14.000.000
22	Karyawan proses	48	700.000	33.600.000
23	Karyawan pengemasan	8	700.000	5.600.000
24	Karyawan controller	2	700.000	1.400.000
25	Karyawan penjualan & pembelian	7	850.000	5.950.000
26	Karyawan pembukuan	6	800.000	4.800.000
27	Karyawan Adm/personalia & Humas	4	800.000	3.200.000
28	Dokter	1	2.000.000	2.000.000
29	Perawat	2	800.000	1.600.000
30	Sopir	3	600.000	1.800.000
31	Cleaning Service & Tukang Kebun	8	500.000	4.000.000
	Total	196		198.150.000

Total gaji karyawan per bulan = Rp. 198.150.000

Ditetapkan satu tahun produksi adalah 12 bulan, (termasuk tunjangan hari raya, 1 bulan gaji).

Jadi, gaji karyawan per tahun = 13 x Rp 198.150.000

= Rp 2.575.950.000