APPENDIX A

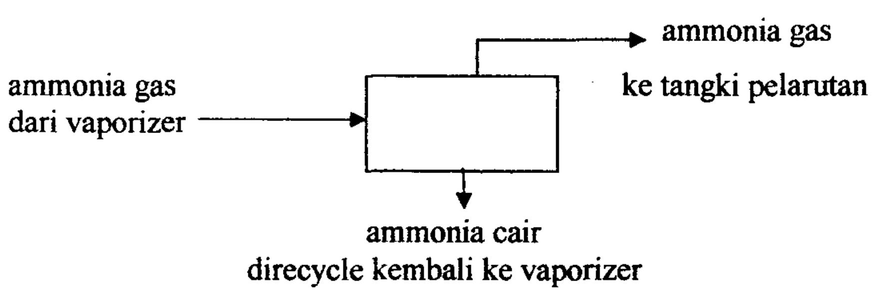
PERHITUNGAN NERACA MASSA

Tabel A.1 Data kelarutan masing-masing zat (dalam g per 100 g H_2O)

Zat	T = 5°C	T = 35°C
$K_2SO_4.Na_2SO_4$	6,4067	11,11
K_2SO_4	6,4067	11,11
$CaCl_2$	62,25	74,5
NaCl	35,79	36
KCl.2NaCl	35,79	36
$CaSO_4.2H_2O$	0,1844	0,2009

(Sumber: Perry, 1984)

1. Drum Separator (H-111)



Masuk drum separator:

NH_3 gas dari *vaporizer (V-112)* = 108.664,7845 kg

Keluar dari drum separator:

Direcycle sebanyak 20 % dikembalikan ke vaporizer (V-112).

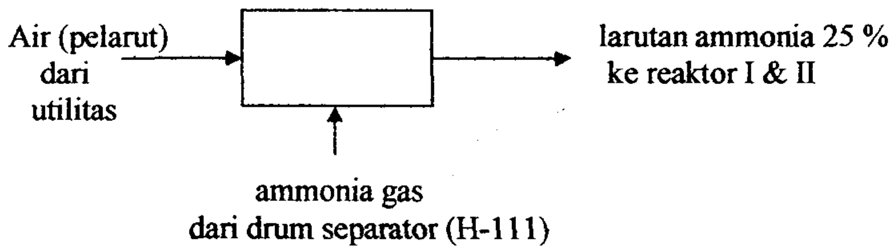
NH_3 gas menuju *tangki pelarut (D-110)* = (100-20)% × 108.664,7845 kg

= 86.931,8276 kg

NH_3 cair yang direcycle ke *vaporizer (V-112)* = 20% × 108.664,7845 kg

= 21.732,9569 kg

2. Tangki Pelarut NH_3 (D-110)



Konsentrasi NH_3 dalam larutan = 25% berat

Konsentrasi H_2O dalam larutan = 75% berat

<u>Masuk tangki pelarut NH_3:</u>

NH_3 dari *drum separator (H-111)* = 86.931,8276 kg

Air (pelarut) dari *utilitas* = $\frac{75\%}{25\%} \times 86.931{,}8276\,\text{kg} = 260.795{,}4827\,\text{kg}$

<u>Keluar tangki pelarut:</u>

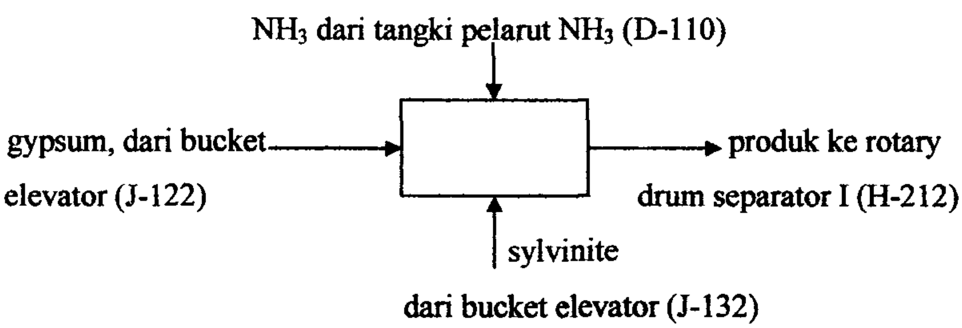
Larutan NH_3 menuju *reaktor I (R-210)* = 277.998,6120 kg

- NH_3 (25%) = 69.499,6530 kg
- H_2O (75%) = 208.498,9590 kg

Larutan NH_3 menuju *reaktor II (R-220)* = 69.728,6983 kg

- NH_3 (25%) = 17.432,1746 kg
- H_2O (75%) = 52.296,5237 kg

3. Reaktor I (R-210)



Konversi = 99,8 % (Fernandez-Lozano, 1997)

$2\ CaSO_4.2H_2O$	$+ 2\ KCl.2NaCl \leftrightarrow$	$K_2SO_4.Na_2SO_4 \downarrow$	$+ 2\ CaCl_2$	$+ 2\ NaCl$	$+ 4\ H_2O$
161,6271 kgmol	161,6271	-	-	-	-
161,3038	161,3038	80,6519	161,3038	161,3038	322,6076
0,3233	0,3233	80,6519	161,3038	161,3038	322,6076

Masuk ke reaktor I:

Dari bucket elevator (J-122):

- $CaSO_4.2H_2O$ = 161,6271 kgmol ×172 kg/kgmol = 27.799,8612 kg

Dari bucket elevator (J-132):

- KCl.2NaCl = 161,6271 kgmol × 191,5 kg/kgmol = 30.951,5897 kg

Dari tangki pelarut NH_3 (D-110):

- Larutan ammonia

  Perbandingan massa larutan ammonia 25 % (berat) : $CaSO_4.2H_2O$ = 10 : 1

  $$\text{Larutan ammonia } 25\ \% = \frac{10}{1} \times 27.799{,}8612 \text{ kg} = 277.998{,}6120 \text{ kg}$$

  $$\text{- Ammonia } (25\ \%) = \frac{25\%}{100\%} \times 277.998{,}6120 \text{ kg} = 69.499{,}6530 \text{ kg}$$

  $$\text{- } H_2O\ (75\ \%) = \frac{75\%}{100\%} \times 277.998{,}6120 \text{ kg} = 208.498{,}9590 \text{ kg}$$

Keluar dari reaktor I:

- $K_2SO_4.Na_2SO_4$ = 80,6519 kgmol × 316 kg/kgmol

  = 25.486,0004 kg

- $CaSO_4.2H_2O$ = 0,3233 kgmol × 172 kg/kgmol

  = 55,6076 kg

- $CaCl_2$ = 161,3038 kgmol × 111 kg/kgmol = 17.904,7218 kg
- NaCl = 161,3038 kgmol · 58,5 kg/kgmol = 9.436,2723 kg
- KCl.2NaCl = 0,3233 kgmol · 191,5 kg/kgmol = 61,9120 kg
- Ammonia = 69.499,6530 kg
- H_2O = (322,6076 kgmol × 18 kg/kgmol) + 208.498,9590 kg

= 5.806,9368 kg + 208.498,9590 kg = 214.305,8958 kg

Total padatan yang terlarut dalam H_2O

= (11,11+36+36+0,2009+74,5) g / 100 g H_2O

= 157,8109 g / 100 g H_2O

Batas maksimum yang terlarut dalam H_2O:

$$K_2SO_4.Na_2SO_4 = \frac{11{,}11}{157{,}8109} \times \frac{11{,}11}{100} \times 214.305{,}8958 \text{ kg} = 1.676{,}1977 \text{ kg}$$

$$NaCl = \frac{36}{157{,}8109} \times \frac{36}{100} \times 214.305{,}8958 \text{ kg} = 17.599{,}5727 \text{ kg}$$

$$CaSO_4.2H_2O = \frac{0{,}2009}{157{,}8109} \times \frac{0{,}2009}{100} \times 214.305{,}8958 \text{ kg} = 0{,}5481 \text{ kg}$$

$$KCl.2NaCl = \frac{36}{157{,}8109} \times \frac{36}{100} \times 214.305{,}8958 \text{ kg} = 17.599{,}5727 \text{ kg}$$

$$CaCl_2 = \frac{74{,}5}{157{,}8109} \times \frac{74{,}5}{100} \times 214.305{,}8958 \text{ kg} = 75.371{,}9355 \text{ kg}$$

Jadi, keluar dari reaktor I dan masuk ke *rotary drum separator I (H-212)*:

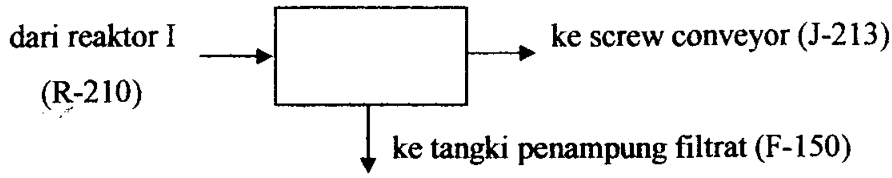
Padatan:

- $K_2SO_4.Na_2SO_4$ = 25.486,0004 kg – 1.676,1977 kg = 23.809,8027 kg
- $CaSO_4.2H_2O$ = 55,6076 kg – 0,5481 kg = 55,0595 kg

Yang terlarut dalam H_2O:

- $K_2SO_4.Na_2SO_4$ = 1.676,1977 kg
- $CaCl_2$ = 17.904,7218 kg
- NaCl = 9.436,2723 kg
- $CaSO_4.2H_2O$ = 0,5481 kg
- KCl.2NaCl = 61,9120 kg
- Ammonia = 69.499,6530 kg
- H_2O = 214.305,8958 kg

4. Rotary Drum Separator I (H-212)



Asumsi: retention liquid = 8 % dari dry solid (Foust, 1980)

<u>Masuk ke rotary drum separator I dari *reaktor I (R-210)*:</u>

Padatan:

- $K_2SO_4.Na_2SO_4$ = 23.809,8027 kg
- $CaSO_4.2H_2O$ = 55,0595 kg

Yang terlarut dalam H_2O:

- $K_2SO_4.Na_2SO_4$ = 1.676,1977 kg
- $CaCl_2$ = 17.904,7218 kg
- NaCl = 9.436,2723 kg
- $CaSO_4.2H_2O$ = 0,5481 kg
- KCl.2NaCl = 61,9120 kg
- Ammonia = 69.499,6530 kg
- H_2O = 214.305,8958 kg

Komponen	Massa, kg	Fraksi Massa
$K_2SO_4.Na_2SO_4$	1.676,1977	0,0054
NaCl	9.436,2723	0,0302
$CaSO_4.2H_2O$	0,5481	$1,75.10^{-6}$
KCl.2NaCl	61,9120	$1,98.10^{-4}$
$CaCl_2$	17.904,7218	0,0572
Ammonia	69.499,6530	0,2221
H_2O	214.305,8958	0,6849
Total Massa	312.885,2007	1,0000

Keluar dari rotary drum separator I:

Cake: (*menuju ke screw conveyor (J-213)*)

- $K_2SO_4.Na_2SO_4$ = 23.809,8027 kg
- $CaSO_4.2H_2O$ = 55,0595 kg
- Retention liquid = 8 % dari dry solid = 8 % × (23.809,8027 + 55,0595) kg

  = 8 % × 23.864,8622 kg = 1.909,1890 kg, terdiri dari:

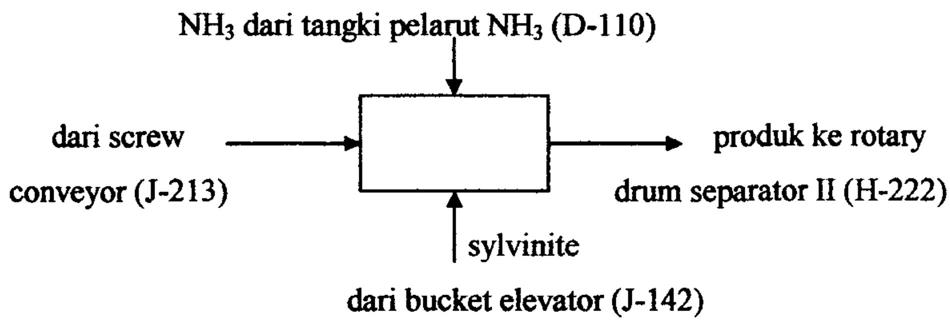
  - $K_2SO_4.Na_2SO_4$ = 0,0054 × 1.909,1890 kg = 10,3082 kg
  - $CaCl_2$ = 0,0572 × 1.909,1890 kg = 109,2056 kg
  - NaCl = 0,0302 × 1.909,1890 kg = 57,6576 kg
  - $CaSO_4.2H_2O$ = $1,75.10^{-6}$ × 1.909,1890 kg = 0,0033 kg
  - KCl.2NaCl = $1,99.10^{-4}$ × 1.909,1890 kg = 0,3799 kg
  - Ammonia = 0,2221 × 1.909,1890 kg = 424,0309 kg
  - H_2O = 0,6849 × 1.909,1890 kg = 1307,6035 kg

Filtrat: (*ke tangki penampung filtrat (F-150)*)

- $K_2SO_4.Na_2SO_4$ = 25.486,0004 kg – (23.809,8027 kg + 10,3082 kg)

  = 1.665, 8895 kg
- $CaCl_2$ = 17.904,7218 kg – 109,2056 kg = 17.795,5162 kg
- NaCl = 9.436,2723 kg – 57,6576 kg = 9.378,6147 kg
- $CaSO_4.2H_2O$ = 55,6076 kg – (55,0595 kg + 0,0033 kg) = 0,5448 kg
- KCl.2NaCl = 61,9120 kg - 0,3799 kg = 61,5321 kg
- Ammonia = 69.499,6530 kg - 424,0309 kg = 69.075,6221 kg
- H_2O = 214.305,8958 kg - 1307,6035 kg = 212.998,2923 kg

5.Reaktor II (R-220)



Konversi = 99,7 % (Fernandez-Lozano, 1997)

$K_2SO_4.Na_2SO_4$ +	2 $KCl.2NaCl$ ↔	2 K_2SO_4 ↓ +	6 $NaCl$
75,3801 kgmol	151,2000	-	-
75,3732	150,7464	150,7464	452,2392
0,0069	0,4536	150,7464	452,2392

<u>Masuk ke reaktor II:</u>

Dari screw conveyor (J-213):

- $K_2SO_4.Na_2SO_4$ = 23.809,8027 kg + 10,3082 kg = 23.820,1109 kg
- $CaSO_4.2H_2O$ = 55,0595 kg + 0,0033 kg = 55,0628 kg
- $CaCl_2$ = 109,2056 kg
- NaCl = 57,6576 kg
- KCl.2NaCl = 0,3799 kg
- Ammonia = 424,0309 kg
- H_2O = 1307,6035 kg

Dari bucket elevator (J-142):

KCl.2NaCl = (151,2000 kgmol × 191,5 kg/kgmol) – 0,3799 kg

= 28.954,8000 kg – 0,3799 kg = 28.954,4201 kg

Dari tangki pelarut NH_3 (D-110):

Larutan ammonia:

Perbandingan massa larutan ammonia 25 % (berat): $K_2SO_4.Na_2SO_4$ = 3 : 1

$$\text{Larutan ammonia 25 \%} = \frac{3}{1} \times 23.820{,}1109 \text{ kg} = 71.460{,}3327 \text{ kg}$$

$$NH_3\ (25\%) = \frac{25\%}{100\%} \times (71.460{,}3327 \text{ kg} - 424{,}0309 \text{ kg} - 1307{,}6035 \text{ kg})$$

$$= 17.432{,}1746 \text{ kg}$$

$$H_2O\,(75\%) = \frac{75\%}{100\%} \times (71.460{,}3327 \text{ kg} - 424{,}0309 \text{ kg} - 1307{,}6035 \text{ kg})$$

$$= 52.296{,}5237 \text{ kg}$$

Keluar dari reaktor II menuju *rotary drum separator II (H-222)*:

K_2SO_4 = 150,7464 kgmol × 174 kg/kgmol = 26.229,8736 kg

NaCl = (452,2392 kgmol × 58,5 kg/kgmol) + 57,6576 kg

= 26.455,9927 kg + 57,6576 kg = 26.513,6503 kg

$K_2SO_4.Na_2SO_4$ yang tidak bereaksi = 0,0069 kgmol × 316 kg/kgmol

= 2,1804 kg

KCl.2NaCl yang tidak bereaksi = 0,4536 kgmol × 191,5 kg/kgmol

= 86,8642 kg

$CaCl_2$ = 109,2056 kg

$CaSO_4.2H_2O$ = 55,0628 kg

Ammonia = 424,0309 kg + 17.432,1746 kg = 17.856,2055 kg

H_2O = 1307,6035 kg + 52.296,5237 kg = 53.604,1272 kg

Total padatan yang terlarut dalam H_2O

= (11,11+36+11,11+36+0,2009+74,5) g / 100 g H_2O

= 168,9209 g / 100 g H_2O

Batas maksimum yang terlarut dalam H_2O:

$$K_2SO_4 = \frac{11,11}{168,9209} \times \frac{11,11}{100} \times 53.604,1272 \text{ kg} = 391,6904 \text{ kg}$$

$$NaCl = \frac{36}{168,9209} \times \frac{36}{100} \times 53.604,1272 \text{ kg} = 4.112,6319 \text{ kg}$$

$$CaSO_4.2H_2O = \frac{0,2009}{168,9209} \times \frac{0,2009}{100} \times 53.604,1272 \text{ kg} = 0,1281 \text{ kg}$$

$$K_2SO_4.Na_2SO_4 = \frac{11,11}{168,9209} \times \frac{11,11}{100} \times 53.604,1272 \text{ kg} = 391,6904 \text{ kg}$$

$$KCl.2NaCl = \frac{36}{168,9209} \times \frac{36}{100} \times 53.604,1272 \text{ kg} = 4.112,6319 \text{ kg}$$

$$CaCl_2 = \frac{74,5}{168,9209} \times \frac{74,5}{100} \times 53.604,1272 \text{ kg} = 17.612,7588 \text{ kg}$$

Jadi, <u>keluar dari reaktor II menuju ke *rotary drum separator II (H-222)*:</u>

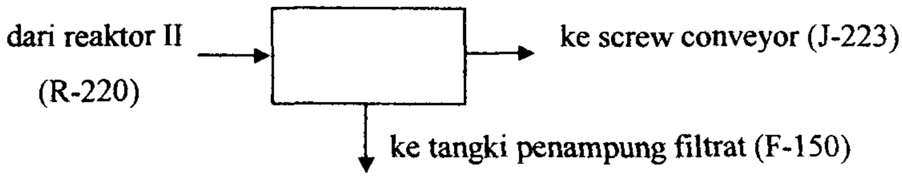
Padatan:

- K_2SO_4 = 26.229,8736 kg – 391,6904 kg = 25.838,1832 kg
- NaCl = 26.513,6503 kg – 4.112,6319 kg = 22.401,0184 kg
- $CaSO_4.2H_2O$ = 55,0628 kg – 0,1281 kg = 54,9347 kg

Terlarut dalam H_2O:

- K_2SO_4 = 391,6904 kg
- NaCl = 4.112,6319 kg
- $CaSO_4.2H_2O$ = 0,1281 kg
- $K_2SO_4.Na_2SO_4$ = 2,1804 kg
- KCl.2NaCl = 86,8642 kg
- $CaCl_2$ = 109,2056 kg
- Ammonia = 17.856,2055 kg
- H_2O = 53.604,1272 kg

6. Rotary Drum Separator II (H-222)



Asumsi: retention liquid = 8 % dari dry solid (Foust, 1980)

<u>Masuk ke rotary drum separator II dari *reaktor II (R-220)*:</u>

Padatan:

- K_2SO_4 = 25.838,1832 kg
- NaCl = 22.401,0184 kg
- $CaSO_4.2H_2O$ = 54,9347 kg

Terlarut dalam H_2O:

- K_2SO_4 = 391,6904 kg
- NaCl = 4.112,6319 kg
- $CaSO_4.2H_2O$ = 0,1281 kg

- $K_2SO_4.Na_2SO_4$ = 2,1804 kg
- KCl.2NaCl = 86,8642 kg
- $CaCl_2$ = 109,2056 kg
- Ammonia = 17.856,2055 kg
- H_2O = 53.604,1272 kg

Komponen	Massa, kg	Fraksi Massa
K_2SO_4	391,6904	0,0051
NaCl	4.112,6319	0,0540
$CaSO_4.2H_2O$	0,1281	$1{,}7.10^{-6}$
$K_2SO_4.Na_2SO_4$	2,1804	$2{,}82.10^{-5}$
KCl.2NaCl	86,8642	0,0012
$CaCl_2$	109,2056	0,0014
Ammonia	17.856,2055	0,2346
H_2O	53.604,1272	0,7037
Total Massa	76.163,0333	1,0000

<u>Keluar dari rotary drum separator II:</u>

Cake: (*menuju ke screw conveyor (J-223)*)

- K_2SO_4 = 25.838,1832 kg
- NaCl = 22.401,0184 kg
- $CaSO_4.2H_2O$ = 54,9347 kg
- Retention liquid = 8 % × 48.294,1363 kg = 3.863,5309 kg, terdiri dari:

  K_2SO_4 = 0,0051 × 3.863,5309 kg = 19,8164 kg

  NaCl = 0,0540 × 3.863,5309 kg = 208,6305 kg

  $CaSO_4.2H_2O$ = $1{,}7.10^{-6}$ × 3.863,5309 kg = 0,0507 kg

  $K_2SO_4.Na_2SO_4$ = $2{,}8.10^{-5}$ × 3.863,5309 kg = 0,1082 kg

  KCl.2NaCl = 0,0012 × 3.863,5309 kg = 4,4256 kg

  $CaCl_2$ = 0,0014 × 3.863,5309 kg = 5,5397 kg

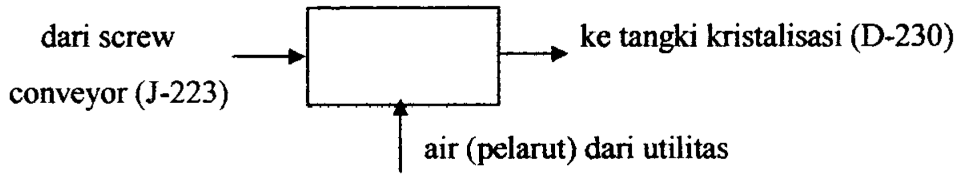
  Ammonia = 0,2346 × 3.863,5309 kg = 906,2399 kg

H_2O = 0,7037 × 3.863,5309 kg = 2.718,7199 kg

Filtrat: (*ke tangki penampung filtrat (F-150)*)

- K_2SO_4 = 26.229,8736 kg – (25.838,1832 + 19,8164) kg = 371,8740 kg
- NaCl = 26.513,6503 kg – (22.401,0184 + 208,6305) kg = 3.904,0014 kg
- $CaSO_4.2H_2O$ = 55,0628 kg – (54,9347 + 0,0507) kg = 0,0774 kg
- $K_2SO_4.Na_2SO_4$ = 2,1804 kg – 0,1082 kg = 2,0722 kg
- KCl.2NaCl = 86,8642 kg – 4,4256 kg = 82,4386 kg
- $CaCl_2$ = 109,2056 kg – 5,5397 kg = 103,6659 kg
- Ammonia = 17.856,2055 kg – 906,2399 kg = 16.949,9656 kg
- H_2O = 53.604,1272 kg – 2.718,7199 kg = 50.885,4073 kg

7. Tangki Pelarut (F-224)



<u>Masuk ke tangki pelarut:</u>

Dari screw conveyor (J-223):

- K_2SO_4 = 25.838,1832 kg
- NaCl = 22.401,0184 kg
- $CaSO_4.2H_2O$ = 54,9347 kg
- Retention liquid = 3.863,5309 kg, terdiri dari:

  K_2SO_4 = 19,8164 kg

  NaCl = 208,6305 kg

  $CaSO_4.2H_2O$ = 0,0507 kg

  $K_2SO_4.Na_2SO_4$ = 0,1082 kg

  KCl.2NaCl = 4,4256 kg

  $CaCl_2$ = 5,5397 kg

  Ammonia = 906,2399 kg

  H_2O = 2.718,7199 kg

Dari Utilitas:

- H_2O (pelarut) = 256.840,0000 kg

<u>Keluar dari tangki pelarut menuju ke *tangki kristalisasi (D-230)*:</u>

- K_2SO_4 = 25.838,1832 kg + 19,8164 kg = 25.857,9996 kg
- NaCl = 22.401,0184 kg + 208,6305 kg = 22.609,6489 kg
- $CaSO_4.2H_2O$ = 54,9347 kg + 0,0507 kg = 54,9854 kg
- $K_2SO_4.Na_2SO_4$ = 0,1082 kg
- KCl.2NaCl = 4,4256 kg
- $CaCl_2$ = 5,5397 kg
- Ammonia = 906,2399 kg
- H_2O = 2.718,7199 kg + 256.840,0000 kg = 259.558,7199 kg

8. Tangki Kristalisasi (D-230)

Kondisi operasi: T = 5°C (Fernandez-Lozano, 1997)

<u>Masuk ke tangki kristalisasi dari *tangki pelarut (F-224)*:</u>

- K_2SO_4 = 25.857,9996 kg
- NaCl = 22.609,6489 kg
- $CaSO_4.2H_2O$ = 54,9854 kg
- $K_2SO_4.Na_2SO_4$ = 0,1082 kg
- KCl.2NaCl = 4,4256 kg
- $CaCl_2$ = 5,5397 kg
- Ammonia = 906,2399 kg
- H_2O = 259.558,7199 kg

Total padatan yang dapat terlarut dalam H_2O

= (6,4067+0,1844+6,4067+35,79+ 35,79+62,25) g / 100 g H_2O

= 146,8278 g / 100 g H_2O

Batas maksimum yang terlarut dalam H_2O:

$$K_2SO_4 = \frac{6,4067}{146,8278} \times \frac{6,4067}{100} \times 259.558,7199 \text{ kg} = 725,5981 \text{ kg}$$

$$NaCl = \frac{35,79}{146,8278} \times \frac{35,79}{100} \times 259.558,7199 \text{ kg} = 22.643,8740 \text{ kg}$$

$$CaSO_4.2H_2O = \frac{0,1844}{146,8278} \times \frac{0,1844}{100} \times 259.558,7199 \text{ kg} = 0,6011 \text{ kg}$$

$$K_2SO_4.Na_2SO_4 = \frac{6,4067}{146,8278} \times \frac{6,4067}{100} \times 259.558,7199 \text{ kg} = 725,5981 \text{ kg}$$

$$KCl.2NaCl = \frac{35,79}{146,8278} \times \frac{35,79}{100} \times 259.558,7199 \text{ kg} = 22.643,8740 \text{ kg}$$

$$CaCl_2 = \frac{62,25}{146,8278} \times \frac{62,25}{100} \times 259.558,7199 \text{ kg} = 68.502,4404 \text{ kg}$$

Pada suhu 5°C terbentuk kristal:

- K_2SO_4 = 25.857,9996 kg – 725,5981 kg = 25.132,4015 kg
- $CaSO_4.2H_2O$ = 54,9854 kg – 0,6011 kg = 54,3843 kg

Keluar dari tangki kristalisasi menuju ke *rotary drum separator III (H-232):*

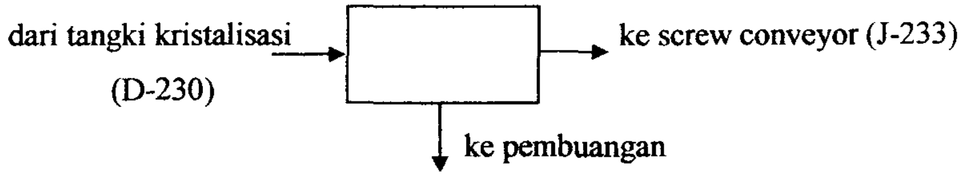
Kristal:

- K_2SO_4 = 25.132,4015 kg
- $CaSO_4.2H_2O$ = 54,3843 kg

Mother Liquor:

- K_2SO_4 = 725,5981 kg
- NaCl = 22.609,6489 kg
- $CaSO_4.2H_2O$ = 0,6011 kg
- $K_2SO_4.Na_2SO_4$ = 0,1082 kg
- KCl.2NaCl = 4,4256 kg
- $CaCl_2$ = 5,5397 kg
- Ammonia = 906,2399 kg
- H_2O = 259.558,7199 kg

9. Rotary Drum Separator III (H-232)



Asumsi: retention liquid = 8 % dari dry solid (Foust, 1980)

<u>Masuk ke rotary drum separator III dari *tangki kristalisasi (D-230)*:</u>

Kristal:

- K_2SO_4 = 25.132,4015 kg
- $CaSO_4.2H_2O$ = 54,3843 kg

Mother Liquor:

- K_2SO_4 = 725,5981 kg
- NaCl = 22.609,6489 kg
- $CaSO_4.2H_2O$ = 0,6011 kg
- $K_2SO_4.Na_2SO_4$ = 0,1082 kg
- KCl.2NaCl = 4,4256 kg
- $CaCl_2$ = 5,5397 kg
- Ammonia = 906,2399 kg
- H_2O = 259.558,7199 kg

Komponen	Massa, kg	Fraksi Massa
K_2SO_4	725,5981	$2,6.10^{-3}$
NaCl	22.609,6489	0,0798
$CaSO_4.2H_2O$	0,6011	$2,12.10^{-6}$
$K_2SO_4.Na_2SO_4$	0,1082	$3,8.10^{-7}$
KCl.2NaCl	4,4256	$1,5.10^{-5}$
$CaCl_2$	5,5397	$1,9.10^{-5}$
Ammonia	906,2399	$3,2.10^{-3}$
H_2O	259.558,7199	0,9144
Total Massa	283.810,8814	1,0000

Keluar dari rotary drum separator III:

Cake: (*menuju ke screw conveyor (J-233)*)

- K_2SO_4 = 25.132,4015 kg
- $CaSO_4.2H_2O$ = 54,3843 kg
- Retention liquid = 8 % × 25.186,7858 kg = 2.014,9429 kg, terdiri dari:

$K_2SO_4 = 2{,}6.10^{-3} \times 2.014{,}9429$ kg = 5,1515 kg

$NaCl = 0{,}0798 \times 2.014{,}9429$ kg = 160,5194 kg

$CaSO_4.2H_2O = 2{,}2.10^{-6} \times 2.014{,}9429$ kg = 0,0043 kg

$K_2SO_4.Na_2SO_4 = 2{,}7.10^{-6} \times 2.014{,}9429$ kg = $7{,}68.10^{-4}$ kg

$KCl.2NaCl = 1{,}5.10^{-5} \times 2.014{,}9429$ kg = 0,0314 kg

$CaCl_2 = 1{,}9.10^{-5} \times 2.014{,}9429$ kg = 0,0393 kg

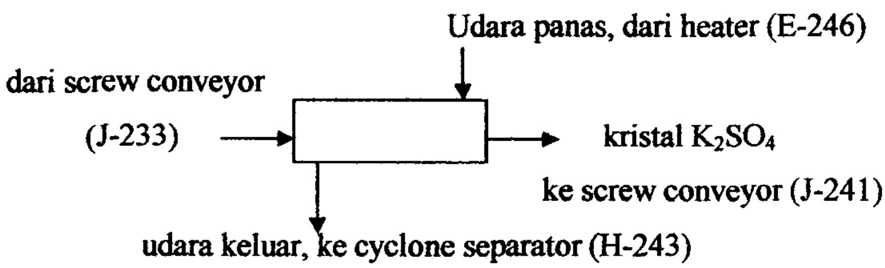
Ammonia = $3{,}2.10^{-3} \times 2.014{,}9429$ kg = 6,4339 kg

$H_2O = 0{,}9144 \times 2.014{,}9429$ kg = 1.842,7623 kg

Filtrat: (*ke pembuangan*)

- K_2SO_4 = (25.132,4015 + 725,5981) kg – (25.132,4015 + 5,1515) kg
  = 720,4466 kg
- NaCl = 22.609,6489 kg – 160,5194 kg = 22.449,1295 kg
- $CaSO_4.2H_2O$ = (54,3843 + 0,6011) kg – (54,3843 + 0,0043) kg
  = 0,5968 kg
- $K_2SO_4.Na_2SO_4$ = 0,1082 kg – $7{,}68.10^{-4}$ kg = 0,1074 kg
- KCl.2NaCl = 4,4256 kg – 0,0314 kg = 4,3942 kg
- $CaCl_2$ = 5,5397 kg – 0,0393 kg = 5,5004 kg
- Ammonia = 906,2399 kg – 6,4339 kg = 899,8060 kg
- H_2O = 259.558,7199 kg – 1.842,7623 kg = 257.715,9576 kg

10. Rotary Dryer (B-240)



Masuk rotary dryer dari *screw conveyor (J-233):*

- K_2SO_4 = 25.132,4015 kg + 5,1515 kg = 25.137,5530 kg
- $CaSO_4.2H_2O$ = 54,3843 kg + 0,0043 kg = 54,3886 kg
- NaCl = 160,5194 kg
- $K_2SO_4.Na_2SO_4$ = 7,68.10^{-4} kg
- KCl.2NaCl = 0,0314 kg
- $CaCl_2$ = 0,0393 kg
- Ammonia = 6,4339 kg
- H_2O = 1.842,7623 kg

Komponen dry solid	Massa, kg	Fraksi Massa
K_2SO_4	25.137,5530	0,9915
NaCl	160,5194	6,33.10^{-3}
$CaSO_4.2H_2O$	54,3886	2,15.10^{-3}
$K_2SO_4.Na_2SO_4$	7,68.10^{-4}	3,00.10^{-8}
KCl.2NaCl	0,0314	1,24.10^{-6}
$CaCl_2$	0,0393	1,54.10^{-6}
Total Massa	25.352,5325	1,0000

$$\text{Kadar liquid masuk} = \frac{\text{massa } H_2O + \text{amonia masuk rotary dryer}}{\text{total massa bahan masuk rotary dryer}} \times 100\ \%$$

$$= \frac{1.849{,}1962}{25.352{,}5325} \times 100\ \% = 7{,}29\ \%$$

Kadar liquid keluar diharapkan = 0,1 %

$$\text{Liquid yang terdapat dalam bahan keluar} = \frac{0{,}1\ \%}{99{,}9\ \%}\ x\ 25.352{,}5325\ \text{kg}$$

$$= 25{,}3779\ \text{kg}$$

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

= (6,4339 + 1.842,7623) kg – 25,3779 kg

= 1.849,1962 kg – 25,3779 kg

= 1.823,8183 kg

Padatan yang terikut keluar (ke cyclone) = 0,5 % dari dry solid

= 0,5 % × 25.352,5325 kg

= 126,7267 kg

Terdiri dari:

- K_2SO_4 = 0,9915 × 126,7267 kg = 125,6520 kg
- $CaSO_4.2H_2O$ = $2,15.10^{-3}$ ×126,7267 kg = 0,2719 kg
- NaCl = $6,33.10^{-3}$ ×126,7267 kg = 0,8024 kg
- $K_2SO_4.Na_2SO_4$ = $3,00.10^{-8}$ ×126,7267 kg = $3,84.10^{-6}$ kg
- KCl.2NaCl = $1,24.10^{-6}$ × 126,7267 kg = $1,57.10^{-4}$ kg
- $CaCl_2$ = $1,54.10^{-6}$ × 126,7267 kg = $1,96.10^{-4}$ kg

<u>Keluar rotary dryer:</u>

Ke screw conveyor (J-241):

- K_2SO_4 = 25.137,5530 kg – 125,6520 kg = 25.011,9010 kg
- $CaSO_4.2H_2O$ = 54,3886 kg – 0,2719 kg = 54,1167 kg
- NaCl = 160,5194 kg – 0,8024 kg = 159,7170 kg
- $K_2SO_4.Na_2SO_4$ = $7,68.10^{-4}$ kg – $3,84.10^{-6}$ kg = $7,64.10^{-4}$ kg
- KCl.2NaCl = 0,0314 kg – $1,57.10^{-4}$ kg = 0,0312 kg
- $CaCl_2$ = 0,0393 kg – $1,96.10^{-4}$ kg = 0,0391 kg
- Liquid dalam bahan keluar = 25,3779 kg

Ke cyclone separator (H-243):

- Liquid yang menguap = 1.823,8183 kg
- Padatan yang terikut keluar (debu) = 126,7267 kg, terdiri dari:

  K_2SO_4 = 125,6520 kg

  $CaSO_4.2H_2O$ = 0,2719 kg

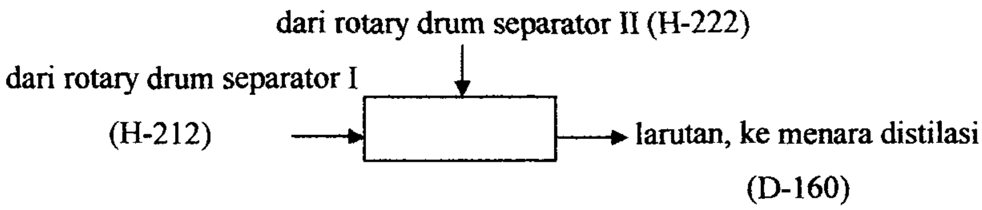
  NaCl = 0,8024 kg

  $K_2SO_4.Na_2SO_4$ = $3,84.10^{-6}$ kg

  KCl.2NaCl = $1,57.10^{-4}$ kg

  $CaCl_2$ = $1,96.10^{-4}$ kg

11. Tangki Penampung Filtrat (F-150)



<u>Masuk tangki penampung:</u>

Filtrat dari rotary drum separator I (H-212):

- $K_2SO_4.Na_2SO_4$ = 1.665, 8895 kg
- $CaCl_2$ = 17.795,5162 kg
- NaCl = 9.378,6147 kg
- $CaSO_4.2H_2O$ = 0,5448 kg
- KCl.2NaCl = 61,5321 kg
- Ammonia = 69.075,6221 kg
- H_2O = 212.998,2923 kg

Filtrat dari rotary drum separator II (H-222):

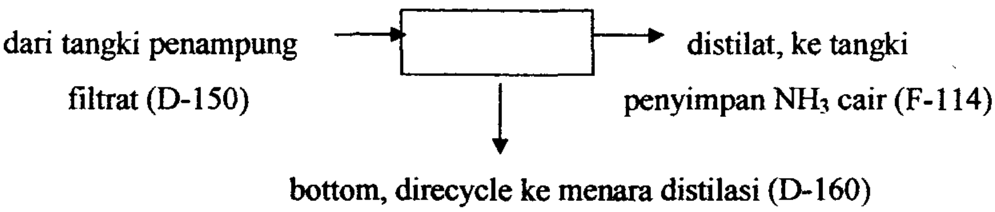
- K_2SO_4 = 371,8740 kg
- NaCl = 3.904,0014 kg
- $CaSO_4.2H_2O$ = 0,0774 kg
- $K_2SO_4.Na_2SO_4$ = 2,0722 kg
- KCl.2NaCl = 82,4386 kg
- $CaCl_2$ = 103,6659 kg
- Ammonia = 16.949,9656 kg
- H_2O = 50.885,4073 kg

<u>Keluar tangki penampung menuju ke *menara distilasi (D-160)*:</u>

- K_2SO_4 = 371,8740 kg
- NaCl = 9.378,6147 kg + 3.904,0014 kg = 13.282,6161 kg
- $CaSO_4.2H_2O$ = 0,5448 kg + 0,0774 kg = 0,6222 kg
- $K_2SO_4.Na_2SO_4$ = 1.665,8895 kg + 2,0722 kg = 1.667,9617 kg
- KCl.2NaCl = 61,5321 kg + 82,4386 kg = 143,9707 kg

- $CaCl_2$ = 17.795,5162 kg + 103,6659 kg = 17.899,1821 kg
- Ammonia = 69.075,6221 kg + 16.949,9656 kg = 86.025,5877 kg
- H_2O = 212.998,2923 kg + 50.885,4073 kg = 263.883,6996 kg

12. Menara Distilasi (D-160)



<u>Masuk menara distilasi dari *tangki penampung filtrat (F-150)*:</u>

Komposisi feed masuk menara distilasi:

- K_2SO_4 = 371,8740 kg / 174 kg/kmol = 2,1372 kmol
- NaCl = 13.282,6161 kg / 58,5 kg/kmol = 227,0533 kmol
- $CaSO_4.2H_2O$ = 0,6222 kg / 172 kg/kmol = $3,62.10^{-3}$ kmol
- $K_2SO_4.Na_2SO_4$ = 1.667,9617 kg / 316 kg/kmol = 5,2784 kmol
- KCl.2NaCl = 143,9707 kg / 191,5 kg/kmol = 0,7518 kgmol
- $CaCl_2$ = 17.899,1821 kg / 111 kg/kmol = 161,2540 kgmol
- Amonia = 86.025,5877 kg / 17 kg/kmol = 5.060,3287 kgmol
- H_2O = 263.883,6996 kg / 18 kg/kmol = 14.660,2055 kgmol

<u>Produk keluar menara distilasi:</u>

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

Komposisi distilat – menuju ke tangki penyimpan NH_3 (F-114):

- Ammonia = 99,5% mol dari NH_3 masuk = 5060 kmol = 86.020 kg
- H_2O = 0,1734% mol dari H_2O masuk = 25,4271 kmol = 457,6878 kg

Komposisi bottom – direcycle ke menara distilasi (D-160):

- K_2SO_4 = 2,1372 kmol = 371,8740 kg
- NaCl = 227,0533 kmol = 13.282,6161 kg

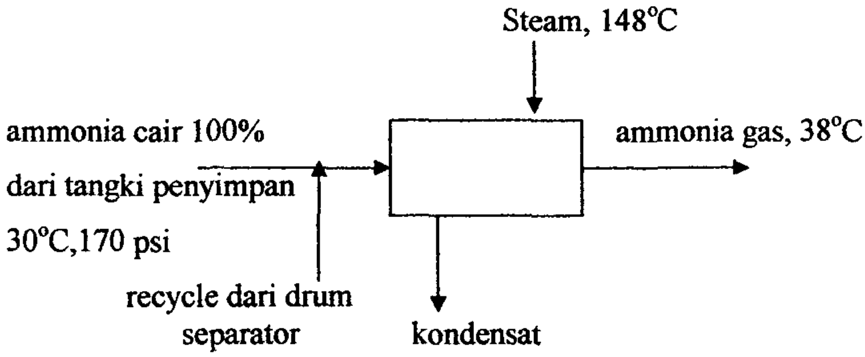
- $CaSO_4.2H_2O$ = 3,62.10^{-3} kmol = 0,6222 kg
- $K_2SO_4.Na_2SO_4$ = 5,2784 kmol = 1.667,9617 kg
- KCl.2NaCl = 0,7518 kmol = 143,9707 kg
- $CaCl_2$ = 161,2540 kmol = 17.899,1821 kg
- Amonia = 5.060,3287 – 5060 kmol = 0,3287 kmol = 5,5877 kg
- H_2O = 14.660,2055 – 25,4271 kmol = 14.634,7784 kmol = 263.426,0118 kg

APPENDIX B

PERHITUNGAN NERACA PANAS

APPENDIX B
PERHITUNGAN NERACA PANAS

1. Vaporizer (V-112)



<u>Panas masuk vaporizer:</u>

Ammonia cair 100 % masuk vaporizer pada suhu 30°C, tekanan 170 psi dari tangki penyimpan NH_3 sebanyak 86.931,8276 kg,dan recycle dari drum separator sebanyak 21.732,9569 kg.

$$\int Cp\ NH_3\ \text{cair, } 30°C\ dT = R. \int_{298}^{303} \frac{Cp}{R} dT = 405{,}97\ \text{J/mol}$$

Dari tangki penyimpan NH_3 cair (F-114):

$$H_1 = m. \int_{298}^{303} Cp\, dT = m.\ R. \int_{298}^{303} \frac{Cp}{R} dT$$

$$= \frac{86.931{,}8276\ \text{kg}}{17\ \text{kg/kgmol}} \times 405{,}97\ \text{kJ/kmol}$$

$$= 2.075.983{,}1795\ \text{kJ}$$

Recycle dari drum separator (H-111):

$$H_{Re} = m. \int_{298}^{303} Cp\, dT = m.\ R. \int_{298}^{303} \frac{Cp}{R} dT$$

$$= \frac{21.732{,}9569\ \text{kg}}{17\ \text{kg/kgmol}} \times 405{,}97\ \text{J/mol}$$

$$= 518.995.794{,}9\ \text{J} = 518.995{,}7949\ \text{kJ}$$

Total entalpi masuk $= H_1 + H_{Re} = H_{masuk}$

$= 2.075.983,1795$ kJ + $518.995,7949$ kJ

$= 2.594.978,9744$ kJ

Panas keluar vaporizer:

Ammonia gas keluar vaporizer pada suhu 38°C menuju ke drum separator sebanyak 108.664,7845 kg.

Pada P =167 psia Tb NH_3 = 30°C

$$\int Cp\ NH_3\ \text{gas, } 38°C\ dT = R. \int_{303}^{311} \frac{Cp}{R} dT = 464{,}1573\ \text{J/mol}$$

$$\int Cp\ NH_3\ \text{cair, } 30°C\ dT = R. \int_{298}^{303} \frac{Cp}{R} dT = 405{,}97\ \text{J/mol}$$

λ ammonia gas pada 30°C = 8.543,92/17 BTU/lb.2,326(Hougen II, 1943, p. 278)

= 1.169,0092 kJ/kg

$$H^{id} = m. \int_{298}^{303} Cp\,dT + m. \int_{303}^{311} Cp\,dT + m\,.\,\lambda$$

$$= m.\ R. \int_{298}^{303} \frac{Cp}{R} dT + m.\ R. \int_{303}^{311} \frac{Cp}{R} dT + m\,.\,\lambda$$

$$= 108.664{,}7845 \times \left(\frac{405{,}97\ \text{kJ/kmol}}{17\text{kg / kgmol}} + \frac{464{,}1573\ \text{kJ/kmol}}{17\text{kg / kgmol}} + 1.169{,}0092\ \text{kJ/kg} \right)$$

$= 132.592.026,6519$ kJ

$\omega = 0{,}253$

$T_R = T/T_c = 311/405{,}7 = 0{,}7666$

$P_R = P/P_c = 11{,}5137/112{,}8 = 0{,}1021$ (Smith Van Ness, 1996, p.636)

$$\frac{H^R}{R.Tc} = \left(\frac{H^R}{R.Tc}\right)^0 + \omega.\left(\frac{H^R}{R.Tc}\right)^1$$ (Smith Van Ness, 1996, eq. 6.60)

Dari Smith Van Ness, 1996, tabel E.5 didapat :

$$\left(\frac{H^R}{R.Tc}\right)^0 = -0{,}1754$$

$$\left(\frac{H^R}{R.Tc}\right)^1 = -0{,}2820$$

$$\frac{H^R}{R.Tc} = -0{,}1754 + 0{,}253.\ -0{,}2820 = -0{,}2467$$

$H^R = 8{,}31451\ \text{kJ/kmol.K} \times 405{,}7\ \text{K} \times -0{,}2467 = -832{,}2717\ \text{kJ/kmol}$

$= -832{,}2717\ \text{kJ/kmol} \times 6.392{,}0465\ \text{kmol} = -5.319.919{,}3766\ \text{kJ}$

$H_{keluar} = H^{id} + H^R$

$= 132.592.026{,}6519\ \text{kJ} + -5.319.919{,}3766\ \text{kJ} = 127.272.107{,}2753\ \text{kJ}$

Panas masuk = Panas keluar

$$Q_{suplai} + H_{masuk} = H_{keluar} + Q_{loss}$$

$$Q_{suplai} + 2.594.978{,}9744\ \text{kJ} = 127.272.107{,}2753\ \text{kJ} + Q_{loss}$$

$$Q_{suplai} + 2.594.978{,}9744\ \text{kJ} = 127.272.107{,}2753\ \text{kJ} + 10\ \%.Q_{suplai}$$

$$0{,}90.Q_{suplai} = 124.677.128{,}3011\ \text{kJ}$$

$$Q_{suplai} = 138.530.142{,}5565\ \text{kJ}$$

$Q_{loss} = 10\ \%.\ Q_{suplai}$

$= 0{,}1 \times 138.530.142{,}5565\ \text{kJ} = 13.853.014{,}2556\ \text{kJ}$

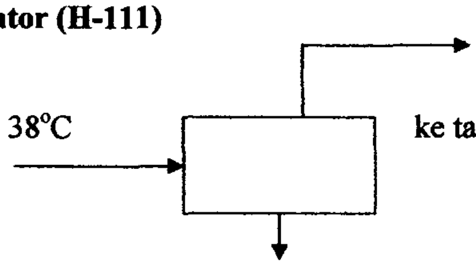
Digunakan steam 4,5 bar; 148°C:

$\lambda_{steam} = 2.119{,}5$ kJ/kg (Smith, 1996, p.671)

$$\text{Jadi, kebutuhan steam} = \frac{Q_{suplai}}{\lambda} = \frac{138.530.142{,}5560\ \text{kJ}}{2.119{,}5\ \text{kJ/kg}}$$

$= 65.359{,}8219$ kg/hari

2. Drum Separator (H-111)



Panas masuk drum separator:

Ammonia gas masuk drum separator bersuhu 38°C dari vaporizer (V-112) sebanyak 127.272.107,2753 kJ.

H_{masuk} = 127.272.107,2753 kJ

Panas keluar drum separator:

Ammonia keluar drum separator bersuhu 30°C berupa ammonia gas sebanyak 86.931,8276 kg menuju ke tangki pelarut NH_3 (D-110) dan ammonia cair sebanyak 21.732,9569 kg direcycle kembali ke vaporizer (V-112).

$\int Cp\ NH_3\ cair, 30°C\ dT = R.\int_{298}^{303} \frac{Cp}{R} dT = 405{,}97$ J/mol

λ ammonia gas pada 30°C = 8.543,92/17 BTU/lb.2,326(Hougen II,1943, p. 278)

= 1.169,0092 kJ/kg

Ammonia gas ke tangki pelarut NH_3 (D-110):

$$H^{id} = m.\int_{298}^{303} Cp\, dT + m.\lambda = m.R.\int_{298}^{303} \frac{Cp}{R} dT + m.\lambda$$

$$= 86.931{,}8276\text{ kg} \times \left(\frac{405{,}97\text{ kJ/kmol}}{17\text{ kg/kgmol}} + 1.169{,}0092\text{ kJ/kg} \right)$$

$$= 103.700.089{,}4167\text{ kJ}$$

$\omega = 0{,}253$

$T_R = T/T_c = 303/405{,}7 = 0{,}7469$

$P_R = P/P_c = 11{,}2384/112{,}8 = 0{,}0996$ (Smith,Van Ness, 1996, p.636)

$$\frac{H^R}{R.Tc} = \left(\frac{H^R}{R.Tc}\right)^0 + \omega.\left(\frac{H^R}{R.Tc}\right)^1$$ (Smith,Van Ness, 1996, eq. 6.60)

Dari Smith Van Ness, 1996, tabel E.5 didapat :

$$\left(\frac{H^R}{R.Tc}\right)^0 = -0{,}183$$

$$\left(\frac{H^R}{R.Tc}\right)^1 = -0{,}306$$

$$\frac{H^R}{R.Tc} = -0{,}183 + 0{,}253.\ -0{,}306 = -0{,}2604$$

H^R = 8,31451 kJ/kmol.K × 405,7 K × -0,2604 = -878,3873 kJ/kmol

= -878,3873 kJ/kmol × 5.113,6367 kmol = -4.491.753,5092 kJ

$H_l = H^{id} + H^R$

= 910.982,1442 kJ + -4.491.753,5092 kJ = 99.208.335,9075 kJ

Ammonia cair direcycle kembali ke vaporizer (V-112):

$$H_{Re} = m. \int_{298}^{303} Cp\, dT = m.\ R. \int_{298}^{303} \frac{Cp}{R} dT$$

$$= \frac{21.732{,}9569\ kg}{17\ kg/kgmol} \times 405{,}97\ J/mol$$

= 518.995.794,7 J = 518.995,7947 kJ

Total entalpi keluar = $H_l + H_{Re} = H_{keluar}$

= 99.208.335,9075 kJ + 518.995,7947 kJ

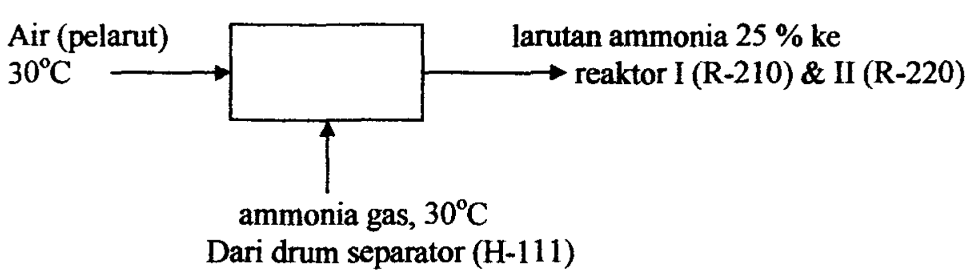
= 99.727.331,7022 kJ

Q_{loss} = $H_{masuk} - H_{keluar}$

= 127.272.107,2753 kJ – 99.727.331,7022 kJ

= 27.544.775,5731 kJ

3. Tangki Pelarut NH_3 (D-110)



<u>Panas masuk tangki pelarut NH_3:</u>

Ammonia gas masuk tangki pelarut NH_3 bersuhu 30°C dari drum separator (H-111) sebanyak 86.931,8276 kg, hendak dilarutkan dengan air bersuhu 30°C sebanyak 260.795,4827 kg.

$\int Cp$ air, 30°C dT = R. $\int_{298}^{303} \frac{Cp}{R} dT$ = 377,5873 J/mol

Dari drum separator (H-111):

$H_{ammonia\ masuk}$ = 99.727.331,7022 kJ

Dari utilitas:

$$H_{air} = m. \int_{298}^{303} Cp\, dT = m. R. \int_{298}^{303} \frac{Cp}{R} dT$$

$$= \frac{260.795{,}4827\ kg}{18\ kg/kgmol} \times 377{,}5873\ J/mol$$

= 5.470.725.677,1 J = 5.470.725,6771 kJ

Heat of solution of NH_3 = -8.200 kkal/kgmol (Hougen I, 1954)

$$Q_{solution} = -8.200\ kkal/kgmol \cdot \frac{86.931{,}8276}{17} kgmol \cdot 4{,}184\ J/kal$$

= - 175.442.746,2787 kJ

Total panas masuk = $H_{ammonia\ masuk} + H_{air} + Q_{solution}$

= (99.727.331,7022 + 5.470.725,6771 +175.442.746,2787) kJ

= 280.640.803,6580 kJ

<u>Panas keluar tangki pelarut NH_3:</u>

Larutan ammonia 25 % keluar tangki pelarut pada suhu 35°C sebanyak 347.727,3103 kg, dimana 277.998,6120 kg menuju ke reaktor I (R-210) dan 69.728,6983 kg menuju ke reaktor II (R-220).

$$\int_{298}^{308} Cp_{larutan\ ammonia} \cdot dT = 0{,}2609. \int_{298}^{308} Cp_{ammonia\ cair} \cdot dT + 0{,}7391. \int_{298}^{308} Cp_{air} \cdot dT$$

dimana:

$\int Cp$ NH_3 cair, 35°C dT = R. $\int_{298}^{308} \frac{Cp}{R} dT$ = 814,1791 J/mol

$\int Cp$ air, 35°dT = R. $\int_{298}^{308} \frac{Cp}{R} dT$ = 754,4309 J/mol

$$\int_{298}^{308} Cp_{larutan\ ammonia} \cdot dT = 0{,}2609.\ 814{,}1791\ J/mol + 0{,}7391.\ 754{,}4309\ J/mol$$

= 770,0192 J/mol = 770,0192 kJ/kgmol

$$H_{larutan\ ammonia} = m.\int_{298}^{308} Cp_{larutan\ ammonia}\ .\ dT$$

$$= \frac{347.727,3103\ kg}{(0,2609.17)+(0,7391.18)\ kg/kgmol}\ .\ 770,0192\ kJ/kgmol$$

$$= \frac{347.727,3103\ kg}{17,7391\ kg/kgmol}\ .\ 770,0192\ kJ/kgmol$$

$$= 15.094.153,8914\ kJ$$

Panas masuk = Panas keluar

$$H_{ammonia\ masuk} + H_{air} + Q_{solution} = H_{larutan\ ammonia} + Q_{loss} + Q_{yang\ diserap\ air\ pendingin}$$

$$280.640.803,6580\ kJ = H_{larutan\ ammonia} + 5\ \%.\ Q_{masuk} + Q_{yang\ diserap\ air\ pendingin}$$

$$280.640.803,6580 = 15.094.153,814 + 0,05.\ 280.640.803,6580 + Q_{yang\ diserap\ air\ pendingin}$$

$$280.640.803,6580\ kJ = 15.094.153,8914\ kJ + 14.032.040,1829\ kJ + Q_{yang\ diserap\ air\ pendingin}$$

$$Q_{yang\ diserap\ air\ pendingin} = 280.640.803,6580\ kJ - 15.094.153,8914\ kJ - 14.032.040,1829\ kJ$$

$$Q_{yang\ diserap\ air\ pendingin} = 251.514.609,5837\ kJ$$

$$\int_{303}^{322} Cp_{air\ pendingin}\ .\ dT = R.\int_{303}^{322} \frac{Cp}{R}\ dT = 1435,1277\ J/mol = 1435,1277\ kJ/kgmol$$

$$Q_{yang\ diserap\ air\ pendingin} = m_{air\ pendingin}\ .\ \int_{303}^{322} Cp_{air\ pendingin}\ .\ dT$$

$$251.514.609,5837\ kJ = m_{air\ pendingin}\ .\ 1435,1277\ kJ/kgmol$$

$$m_{air\ pendingin} = \frac{251.514.609,5837\ kJ}{1435,1277\ kJ/kgmol} = 175.255,9090\ kgmol$$

$$= 175.255,9090\ kgmol\ .\ 18\ kg/kgmol$$

$$= 3.154.606,3620\ kg/hari$$

$$= 131.441,9318\ kg/jam$$

Panas keluar tangki pelarut menuju ke reaktor I (R-210):

$$H_{larutan\ ammonia\ I} = m.\int_{298}^{308} Cp_{larutan\ ammonia}\ .\ dT$$

$$= \frac{277.998,6120\ kg}{17,7391\ kg/kgmol}\ .\ 770,0192\ kJ/kgmol$$

$$= 12.067.369,1908\ kJ$$

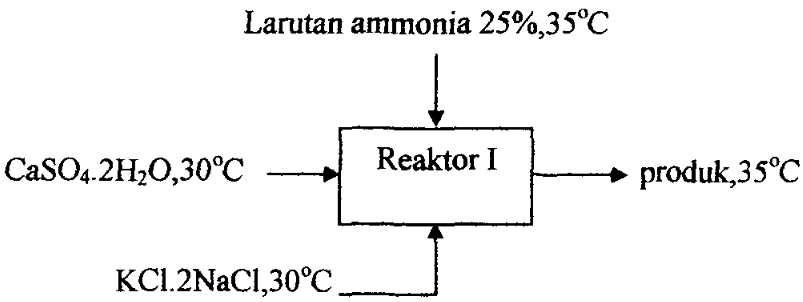
Panas keluar tangki pelarut menuju ke reaktor II (R-220):

$$H_{\text{larutan ammonia2}} = m.\int_{298}^{308} Cp_{\text{larutan ammonia}}\,.\,dT$$

$$= \frac{69.728,6983\ \text{kg}}{17,7391\ \text{kg/kgmol}}\,.\,770,0192\ \text{kJ/kgmol}$$

$$= 3.026.784,7006\ \text{kJ}$$

4. Reaktor I (R-210)



<u>Panas masuk reaktor I:</u>

Dari bucket elevator (J-122):

$CaSO_4.2H_2O$ masuk reaktor I pada suhu 30°C sebanyak 27.799,8612 kg.

Cp $CaSO_4.2H_2O$ = 46,8 kkal/kmol.K = 195,8112 kJ/kgmol.K

$$HCaSO_4.2H_2O = \frac{27.799,8612\ \text{kg}}{172\ \text{kg/kgmol}}.195,8112\ \text{kJ/kgmol.K}.(303\text{-}298)\text{K}$$

$$= 158.241,9820\ \text{kJ}$$

Dari bucket elevator (J-132):

KCl.2NaCl masuk reaktor I pada suhu 30°C sebanyak 30.951,5897 kg.

$$\int Cp\ \text{KCl.2NaCl,30°C}\ dT = R.\int_{298}^{303}\frac{Cp}{R}\,dT = 60,69\ \text{kkal/kmol} = 253,9270\ \text{kJ/kmol}$$

$$\text{HKCl.2NaCl} = \frac{30.951,5897\ \text{kg}}{191,5\ \text{kg/kgmol}}.253,9270\ \text{kJ/kgmol}$$

$$= 41.041,4847\ \text{kJ}$$

Dari tangki pelarut NH_3 (D-110):

Larutan ammonia masuk reaktor I pada suhu 35°C sebanyak 277.998,6120 kg.

$$H_{\text{larutan ammonia1}} = 12.067.369,1908\ \text{kJ}$$

Total entalpi masuk = $HCaSO_4.2H_2O + HKCl.2NaCl + H_{larutan\ ammonia\ I}$

= 158.241,9820 kJ + 41.041,4847 kJ + 12.067.369,1908 kJ

= 12.266.652,6575 kJ

Yang bereaksi:

$2\ CaSO_4.2H_2O + 2\ KCl.2NaCl \leftrightarrow K_2SO_4.Na_2SO_4 \downarrow + 2\ CaCl_2 + 2\ NaCl + 4\ H_2O$

161,3038 161,3038 80,6519 161,3038 161,3038 322,6076

H_{reaksi} = $(HK_2SO_4.Na_2SO_4 + HCaCl_2 + HNaCl + HH_2O) - (HCaSO_4.2H_2O + HKCl.2NaCl)$

= $[(-673{,}15.10^3.80{,}6519 + -190{,}6.10^3.161{,}3038 + -98{,}321.10^3.161{,}3038 + -68{,}3174.10^3.322{,}6076) - (-479{,}33.10^3.161{,}3038 + -202{,}669.10^3.161{,}3038)]$ kkal . 4,184 kJ/kkal

= (-122.889.594,1370 + 110.009.030,2960) kkal . 4,184 kJ/kkal

= -12.880.563,8410 kkal. 4,184 kJ/kkal

= -53.892.279,1107 kJ

Produk keluar reaktor I pada suhu 35°C:

$$HK_2SO_4.Na_2SO_4 = \frac{25.486{,}0004}{316}.137{,}2352.(308-298) = 110.682{,}7963\ kJ$$

$$HCaSO_4.2H_2O = \frac{55{,}6076}{172}.195{,}8112.(308-298) = 633{,}0576\ kJ$$

$$HCaCl_2 = \frac{17.904{,}7218}{111}.756{,}0312 = 121.950{,}7055\ kJ$$

$$HNaCl = \frac{9.436{,}2723}{58{,}5}.504{,}6992 = 81.409{,}8988\ kJ$$

$$HKCl.2NaCl = \frac{61{,}9120}{191{,}5}.504{,}9787 = 163{,}2598\ kJ$$

$$HNH_3 = \frac{69.499{,}6530}{17}.814{,}1791 = 3.328.538{,}9950\ kJ$$

$$HH_2O = \frac{214.305{,}8958}{18}.754{,}4309 = 8.982.165{,}9863\ kJ$$

$\Sigma Hproduk = HK_2SO_4.Na_2SO_4 + HCaSO_4.2H_2O + HCaCl_2 + HNaCl + HKCl.2NaCl + HNH_3 + HH_2O$

= 12.625.544,6993 kJ

Panas masuk = Panas keluar

$$Q_{masuk} = \Sigma H_{produk} + Q_{loss} + Q_{yang\ diserap\ air\ pendingin}$$

$$H_{masuk} + H_{reaksi} = \Sigma H_{produk} + 5\%.\ Q_{masuk} + Q_{yang\ diserap\ air\ pendingin}$$

$$12.266.652,6575 + 53.892.279,1107 = 12.625.544,6993 + 5\%.(12.266.652,6575 + 53.892.279,1107) + Q_{yang\ diserap\ air\ pendingin}$$

$Q_{yang\ diserap\ air\ pendingin}$ = 50.225.440,4805 kJ

$$\int_{303}^{306} Cp_{air\ pendingin}\,.\,dT = R.\int_{303}^{306} \frac{Cp}{R}\,dT = 226{,}3720\ \text{J/mol} = 226{,}3720\ \text{kJ/kgmol}$$

$$Q_{yang\ diserap\ air\ pendingin} = m_{air\ pendingin}\,.\int_{303}^{306} Cp_{air\ pendingin}\,.\,dT$$

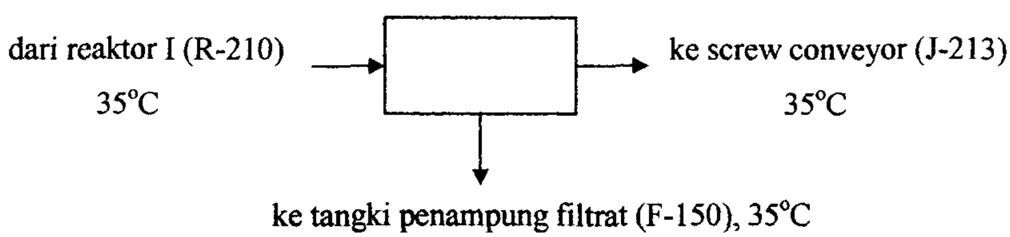
$$m_{air\ pendingin} = \frac{50.225.440{,}4805\ \text{kJ}}{226{,}3720\ \text{kJ/kgmol}} = 221.871{,}2583\ \text{kgmol}$$

= 221.871,2583 kgmol . 18 kg/kgmol

= 3.993.682,6491 kg/hari

= 166.403,4437 kg/jam

5. Rotary Drum Separator I (H-212)



Panas masuk rotary drum separator I:

Dari reaktor I (R-210) pada suhu 35°C:

$HK_2SO_4.Na_2SO_4$ = 110.682,7963 kJ

$HCaSO_4.2H_2O$ = 633,0576 kJ

$HCaCl_2$ = 121.950,7055 kJ

$HNaCl$ = 81.409,8988 kJ

$HKCl.2NaCl$ = 163,2598 kJ

HNH_3 = 3.328.538,9950 kJ

$HH_2O = 8.982.165,9863$ kJ

ΣHmasuk = $HK_2SO_4.Na_2SO_4 + HCaSO_4.2H_2O + HCaCl_2 + HNaCl + HKCl.2NaCl + HNH_3$

$+ HH_2O = 12.625.544,6993$ kJ

<u>Panas keluar rotary drum separator I pada suhu 35°C:</u>

Ke screw conveyor (J-213):

$$HK_2SO_4.Na_2SO_4 = \frac{23.820,1109}{316}.137,2352.(308-298) = 103.448,0280 \text{ kJ}$$

$$HCaSO_4.2H_2O = \frac{55,0628}{172}.195,8112.(308-298) = 626,8554 \text{ kJ}$$

$$HCaCl_2 = \frac{109,2056}{111}.756,0312 = 743,8094 \text{ kJ}$$

$$HNaCl = \frac{57,6576}{58,5}.504,6992 = 497,4315 \text{ kJ}$$

$$HKCl.2NaCl = \frac{0,3799}{191,5}.504,9787 = 1,0018 \text{ kJ}$$

$$HNH_3 = \frac{424,0309}{17}.814,1791 = 20.308,0645 \text{ kJ}$$

$$HH_2O = \frac{1.307,6035}{18}.754,4309 = 54.805,3603 \text{ kJ}$$

Total Hkeluar I ke screw conveyor = 180.430,5509 kJ

Ke tangki penampung filtrat (F-150):

$$HK_2SO_4.Na_2SO_4 = \frac{1.665,8895}{316}.137,2352.(308-298) = 7.234,7683 \text{ kJ}$$

$$HCaSO_4.2H_2O = \frac{0,5448}{172}.195,8112.(308-298) = 6,2022 \text{ kJ}$$

$$HCaCl_2 = \frac{17.795,5162}{111}.756,0312 = 121.206,8961 \text{ kJ}$$

$$HNaCl = \frac{9.378,6147}{58,5}.504,6992 = 80.912,2327 \text{ kJ}$$

$$HKCl.2NaCl = \frac{61,5321}{191,5}.504,9787 = 162,2580 \text{ kJ}$$

$$H_{NH_3} = \frac{69.075{,}6221}{17} . 814{,}1791 = 3.308.231{,}0490 \text{ kJ}$$

$$H_{H_2O} = \frac{212.998{,}2923}{18} . 754{,}4309 = 8.927.360{,}7421 \text{ kJ}$$

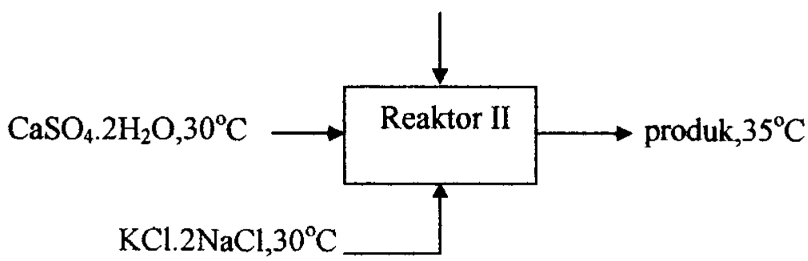
Total Hkeluar II ke tangki penampung filtrat = 12.445.114,1484 kJ

Total Hkeluar = ΣHkeluar ke screw conveyor + ΣHkeluar ke tangki penampung filtrat

= 180.430,2839 kJ + 12.445.114, 4154 kJ

= 12.625.544,6993 kJ

6. Reaktor II (R-220)



<u>Panas masuk reaktor II:</u>

Dari bucket elevator (J-142):

KCl.2NaCl masuk reaktor II pada suhu 30°C sebanyak 28.954,4201 kg.

$\int Cp_{KCl.2NaCl,30°C}\, dT = R. \int_{298}^{303} \frac{Cp}{R} dT$ = 60,69 kkal/kmol = 253,9270 kJ/kmol

$$H_{KCl.2NaCl} = \frac{28.954{,}4201 \text{ kg}}{191{,}5 \text{ kg/kgmol}} . 253{,}9270 \text{ kJ/kgmol} = 38.393{,}2587 \text{ kJ}$$

Dari tangki pelarut NH_3 (D-110):

Larutan ammonia masuk reaktor II pada suhu 35°C sebanyak 69.728,6983 kg.

$H_{larutan\ ammonia2}$ = 3.026.784,7006 kJ

Dari screw conveyor (J-213) masuk pada suhu 35°C:

$HK_2SO_4.Na_2SO_4$ = 103.448,0280 kJ

$HCaSO_4.2H_2O$ = 626,8554 kJ

$HCaCl_2$ = 743,8094 kJ

$HNaCl$ = 497,4315 kJ

$H_{KCl.2NaCl}$ = 1,0018 kJ

H_{NH_3} = 20.308,0645 kJ

H_{H_2O} = 54.805,3603 kJ

Total $H_{\text{masuk dari screw conveyor}}$ = 180.430,5509 kJ

Total panas masuk = $H_{KCl.2NaCl}$ + $H_{\text{larutan ammonia2}}$ + $H_{\text{dari screw conveyor}}$

= 38.393,2587 kJ + 3.026.784,7006 kJ + 180.430,5509 kJ

= 3.245.608,5102 kJ

Yang bereaksi:

$$K_2SO_4.Na_2SO_4 + 2\ KCl.2NaCl \leftrightarrow 2\ K_2SO_4 \downarrow + 6\ NaCl$$

75,3732 150,7464 150,7464 452,2392

H_{reaksi} = ($H_{K_2SO_4}$ + H_{NaCl}) – ($H_{K_2SO_4.Na_2SO_4}$ + $H_{KCl.2NaCl}$)

= [(-342,64.10^3.150,7464 + -98,321.10^3.452,2392) – (-673,15.10^3.75,3732 -202,669.10^3. 150,7464)] kkal . 4,184 kJ/kkal

= (-96.116.356,8792 + 40.640.927,9472) kkal . 4,184 kJ/kkal

= -62.189.489,8286 kJ

Produk keluar pada suhu 35°C menuju ke *rotary drum separator II (H-222)*:

$$H_{K_2SO_4} = \frac{26.229,8736}{174}.33,1.4,184.(308-298) = 208.769,2923 \text{ kJ}$$

$$H_{CaSO_4.2H_2O} = \frac{55,0628}{172}.195,8112.(308-298) = 626,8554 \text{ kJ}$$

$$H_{CaCl_2} = \frac{109,2056}{111}.756,0312 = 743,8094 \text{ kJ}$$

$$H_{NaCl} = \frac{26.513,6503}{58,5}.504,6992 = 228.742,1897 \text{ kJ}$$

$$H_{K_2SO_4.Na_2SO_4} = \frac{2,1804}{316}.137,2352.(308-298) = 9,4692 \text{ kJ}$$

$$H_{KCl.2NaCl} = \frac{86,8642}{191,5}.504,9787 = 229,0578 \text{ kJ}$$

$$H_{NH_3} = \frac{17.856,2055}{17}.814,1791 = 855.185,2239 \text{ kJ}$$

$$HH_2O = \frac{53.604,1272}{18}.754,4309 = 2.246.700,5225 \text{ kJ}$$

ΣHproduk = $HK_2SO_4 + HCaSO_4.2H_2O + HCaCl_2 + HNaCl + HK_2SO_4.Na_2SO_4 +$

$HKCl.2NaCl + HNH_3 + HH_2O$

= 3.541.006,4202 kJ

Panas masuk = Panas keluar

$$Q_{masuk} = \Sigma H_{produk} + Q_{loss} + Q_{yang\ diserap\ air\ pendingin}$$

$$H_{masuk} + H_{reaksi} = H_{produk} + 5\%.\ Q_{masuk} + Q_{yang\ diserap\ air\ pendingin}$$

$$3.245.608,5102 + 62.189.489,8286 = 3.541.006,4202 + 5\%.(3.245.608,5102 + 62.189.489,8286) + Q_{yang\ diserap\ air\ pendingin}$$

$$Q_{yang\ diserap\ air\ pendingin} = 58.622.337,0017 \text{ kJ}$$

$$\int_{303}^{306} Cp_{air\ pendingin}.\,dT = R.\int_{303}^{306}\frac{Cp}{R}\,dT = 226,3720 \text{ J/mol} = 226,3720 \text{ kJ/kgmol}$$

$$Q_{yang\ diserap\ air\ pendingin} = m_{air\ pendingin}.\int_{303}^{306} Cp_{air\ pendingin}.\,dT$$

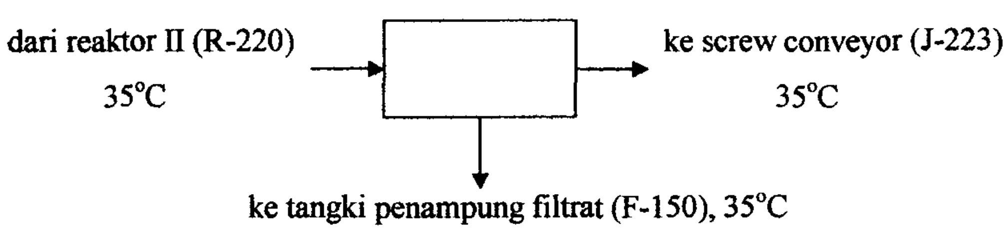
$$m_{air\ pendingin} = \frac{58.622.337,0017 \text{ kJ}}{226,3720 \text{ kJ/kgmol}} = 258.964,6114 \text{ kgmol}$$

= 258.964,6114 kgmol . 18 kg/kgmol

= 4.661.363,0044 kg/hari

= 194.223,4585 kg/jam

7. Rotary Drum Separator II (H-222)



<u>Panas masuk rotary drum separator II:</u>

Dari reaktor II (R-220) pada suhu 35°C:

$HK_2SO_4 = 208.769,2923$ kJ

$HCaSO_4.2H_2O = 626,8554$ kJ

$HCaCl_2 = 743,8094$ kJ

$HNaCl = 228.742,1897$ kJ

$HK_2SO_4.Na_2SO_4 = 9,4692$ kJ

$HKCl.2NaCl = 229,0578$ kJ

$HNH_3 = 855.185,2239$ kJ

$HH_2O = 2.246.700,5225$ kJ

$\Sigma Hmasuk = HK_2SO_4 + HCaSO_4.2H_2O + HCaCl_2 + HNaCl + HK_2SO_4.Na_2SO_4 +$

$HKCl.2NaCl + HNH_3 + HH_2O = 3.541.006,4202$ kJ

Panas keluar rotary drum separator II pada suhu 35°C:

Ke screw conveyor (J-223):

$$HK_2SO_4 = \frac{25.857,9996}{174}.33,1.4,184.(308-298) = 205.809,4660 \text{ kJ}$$

$$HCaSO_4.2H_2O = \frac{54,9854}{172}.195,8112.(308-298) = 625,9743 \text{ kJ}$$

$$HCaCl_2 = \frac{5,5397}{111}.756,0312 = 37,7314 \text{ kJ}$$

$$HNaCl = \frac{22.609,6489}{58,5}.504,6992 = 195.061,0549 \text{ kJ}$$

$$HK_2SO_4.Na_2SO_4 = \frac{0,1082}{316}.137,2352.(308-298) = 0,4699 \text{ kJ}$$

$$HKCl.2NaCl = \frac{4,4256}{191,5}.504,9787 = 11,6702 \text{ kJ}$$

$$HNH_3 = \frac{906,2399}{17}.814,1791 = 43.402,4462 \text{ kJ}$$

$$HH_2O = \frac{2.718,7199}{18}.754,4309 = 113.949,2389 \text{ kJ}$$

$\Sigma Hkeluar$ I ke screw conveyor = 558.898,0519 kJ

Ke tangki penampung filtrat (F-150):

$$HK_2SO_4 = \frac{371,8740}{174}.33,1.4,184.(308-298) = 2.959,8264 \text{ kJ}$$

$$HCaSO_4.2H_2O = \frac{0,0774}{172}.195,8112.(308-298) = 0,8812 \text{ kJ}$$

$$HCaCl_2 = \frac{103,6659}{111}.756,0312 = 706,0780 \text{ kJ}$$

$$HNaCl = \frac{3.904,0014}{58,5}.504,6992 = 33.681,0752 \text{ kJ}$$

$$HK_2SO_4.Na_2SO_4 = \frac{2,0722}{316}.137,2352.(308-298) = 8,9993 \text{ kJ}$$

$$HKCl.2NaCl = \frac{82,4386}{191,5}.504,9787 = 217,3877 \text{ kJ}$$

$$HNH_3 = \frac{16.949,9656}{17}.814,1791 = 811.782,8081 \text{ kJ}$$

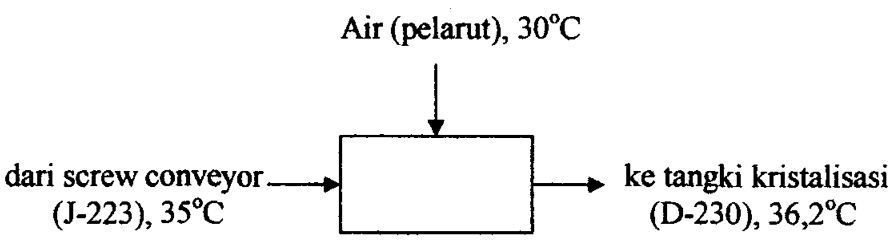
$$HH_2O = \frac{50.885,4073}{18}.754,4309 = 2.132.751,3126 \text{ kJ}$$

ΣHkeluar II ke tangki penampung filtrat = 2.982.108,3683 kJ

ΣHkeluar = ΣHkeluar ke screw conveyor + ΣHkeluar ke tangki penampung filtrat

= 558.898,0519 kJ + 2.982.108,3683 kJ = 3.541.006,4202 kJ

8. Tangki Pelarut (F-224)



Panas masuk tangki pelarut:

Dari screw conveyor (J-223) pada suhu 35°C:

HK_2SO_4 = 205.809,4660 kJ

$HCaSO_4.2H_2O$ = 625,9743 kJ

$HCaCl_2$ = 37,7314 kJ

H_{NaCl} = 195.061,0549 kJ

$H_{K_2SO_4.Na_2SO_4}$ = 0,4699 kJ

$H_{KCl.2NaCl}$ = 11,6702 kJ

H_{NH_3} = 43.402,4462 kJ

H_{H_2O} = 113.949,2389 kJ

Total Hmasuk dari rotary drum separator II = 558.898,0519 kJ

Dari utilitas:

Air (pelarut) masuk pada suhu 30°C:

$$\int Cp_{air,\ 30^\circ C}\, dT = R.\int_{298}^{303} \frac{Cp}{R}\, dT = 377{,}5873 \text{ J/mol} = 377{,}5873 \text{ kJ/kgmol}$$

$$H_{air} = m.\int_{298}^{303} Cp\, dT = m.\ R.\int_{298}^{303} \frac{Cp}{R}\, dT$$

$$= \frac{256.840{,}0000 \text{ kg}}{18 \text{ kg/kgmol}} \times 377{,}5873 \text{ kJ/kgmol} = 5.387.751{,}2296 \text{ kJ}$$

Total Hmasuk tangki pelarut = 558.898,0519 kJ + 5.387.751,2296 kJ

= 5.946.649,2815 kJ

<u>Panas pelarutan:</u>

$$Q_{K_2SO_4} = -6{,}32 \text{ kkal/gmol}.\ \frac{25.857{,}9996 \text{ kg}}{174 \text{ g/gmol}}.10^3 \frac{gr}{kg}.4{,}184 \text{ kJ/kkal}$$

= -3.929.655,0601 kJ

$$Q_{CaSO_4.2H_2O} = -0{,}18.\frac{54{,}9854}{172}.10^3.4{,}184 = -240{,}7593 \text{ kJ}$$

$$Q_{CaCl_2} = 4{,}9.\frac{5{,}5397}{111}.10^3.4{,}184 = 1023{,}1776 \text{ kJ}$$

$$Q_{NaCl} = -1{,}164.\frac{22.609{,}6489}{58{,}5}.10^3.4{,}184 = -1.882.272{,}9819 \text{ kJ}$$

$$Q_{K_2SO_4.Na_2SO_4} = -6{,}04.\frac{0{,}1082}{316}.10^3.4{,}184 = -8{,}6530 \text{ kJ}$$

$$Q_{KCl.2NaCl} = -5{,}568.\frac{4{,}4256}{191{,}5}.10^3.4{,}184 = -538{,}3867 \text{ kJ}$$

$$Q_{NH_3} = -8{,}4.\frac{906{,}2399}{17}.10^3.4{,}184 = -1.873.549{,}7076 \text{ kJ}$$

Total $Q_{solution}$ = - 7.685.242,4310 kJ

<u>Keluar dari tangki pelarut pada suhu T_2 menuju ke *tangki kristalisasi (D-230)*:</u>

$$H_{K_2SO_4} = \frac{25.857{,}9996}{174}.33{,}1.4{,}184.(T_2 - 298) \text{ kJ}$$

$$H_{CaSO_4.2H_2O} = \frac{54{,}9854}{172}.195{,}8112.(T_2 - 298) \text{ kJ}$$

$$H_{CaCl_2} = \frac{5{,}5397}{111}.4{,}184.\int_{298}^{T_2} 16{,}9 + 0{,}00386\,T\,dT \text{ kJ}$$

$$H_{NaCl} = \frac{22.609{,}6489}{58{,}5}.4{,}184.\int_{298}^{T_2} 10{,}79 + 0{,}0042\,T\,dT \text{ kJ}$$

$$H_{K_2SO_4.Na_2SO_4} = \frac{0{,}1082}{316}.137{,}2352.(T_2 - 298) \text{ kJ}$$

$$H_{KCl.2NaCl} = \frac{4{,}4256}{191{,}5}.4{,}184.\int_{298}^{T_2} 10{,}93 + 0{,}00376\,T\,dT \text{ kJ}$$

$$H_{NH_3} = \frac{906{,}2399}{17}.8{,}314.\int_{298}^{T_2} 22{,}626 - 100{,}75.10^{-3}\,T + 192{,}71.10^{-6}\,T^2\,dT \text{ kJ}$$

$$H_{H_2O} = \frac{259.558{,}7199}{18}.8{,}314.\int_{298}^{T_2} 8{,}712 + 1{,}25.10^{-3}\,T - 0{,}18.10^{-6}\,T^2\,dT \text{ kJ}$$

Panas masuk = Panas keluar

$H_{masuk} + Q_{solution} = H_{keluar} + Q_{loss}$

5.946.649,2815 kJ + 7.685.242,4310 kJ = H_{keluar} + 10% 7.685.242,4310 kJ

H_{keluar} = 12.863.367,4694 kJ

Trial T_2 = 36,2°C :

$H_{K_2SO_4}$ = 20.580,9466 × (309,2 – 298) = 230.506,601882 kJ

$H_{CaSO_4.2H_2O}$ = 62,5974 × (309,2 – 298) = 701,0911637 kJ

H_{CaCl_2} = 0,0499 × 846,8635 = 42,2645922 kJ

H_{NaCl} = 386,4897 × 565,3812 = 218.514,024387 kJ

$HK_2SO_4.Na_2SO_4 = 0,0470 \times (309,2 - 298) = 0,5262883$ kJ

$HKCl.2NaCl = 0,02311 \times 565,6818 = 13,0730098$ kJ

$HNH_3 = 443,2046 \times 109,7932 = 48.660,859853$ kJ

$HH_2O = 119.887,2887 \times 101,6390 = 12.185.219,3444$ kJ

$\Sigma H_{keluar} = 12.683.657,7855$ kJ → trial dianggap cocok

$$\text{Panas masuk} = \text{Panas keluar}$$

$$\Sigma H_{masuk} + Q_{solution} = \Sigma H_{keluar} + Q_{loss}$$

$$5.946.649,2815 \text{ kJ} + 7.685.242,4310 \text{ kJ} = 12.683.657,7855 \text{ kJ} + Q_{loss}$$

$$Q_{loss} = 948.233,9270 \text{ kJ}$$

9. Tangki Kristalisasi (D-230)

dari tangki pelarut (F-224), 36,2°C → [D-230] → ke rotary drum separator III (H-232)

<u>Panas masuk tangki kristalisasi:</u>

Dari tangki pelarut (F-224) pada suhu 36,2°C:

$HK_2SO_4 = 20.580,9466 \times (309,2 - 298) = 230.506,601882$ kJ

$HCaSO_4.2H_2O = 62,5974 \times (309,2 - 298) = 701,0911637$ kJ

$HCaCl_2 = 0,0499 \times 846,8635 = 42,2645922$ kJ

$HNaCl = 386,4897 \times 565,3812 = 218.514,024387$ kJ

$HK_2SO_4.Na_2SO_4 = 0,0470 \times (309,2 - 298) = 0,5262883$ kJ

$HKCl.2NaCl = 0,02311 \times 565,6818 = 13,0730098$ kJ

$HNH_3 = 443,2046 \times 109,7932 = 48.660,859853$ kJ

$HH_2O = 119.887,2887 \times 101,6390 = 12.185.219,3444$ kJ

$\Sigma Hmasuk = 12.683.657,7855$ kJ

<u>Panas kristalisasi:</u>

Panas kristalisasi = - Panas pelarutan:

$$QK_2SO_4 = -(-6{,}32\ \text{kkal/gmol}.\ \frac{25.857{,}9996\ \text{kg}}{174\ \text{g/gmol}}.10^3\ \frac{\text{gr}}{\text{kg}}.4{,}184\ \text{kJ/kkal}\ )$$

$$= 3.929.655{,}0601\ \text{kJ}$$

$$QCaSO_4.2H_2O = -(-0{,}18.\frac{54{,}9854}{172}.10^3.4{,}184\ ) = 240{,}7593\ \text{kJ}$$

$$QCaCl_2 \quad = -(4{,}9.\frac{5{,}5397}{111}.10^3.4{,}184\ ) = -1023{,}1776\ \text{kJ}$$

$$QNaCl = -(-1{,}164.\frac{22.609{,}6489}{58{,}5}.10^3.4{,}184\ ) = 1.882.272{,}9819\ \text{kJ}$$

$$QK_2SO_4.Na_2SO_4 \quad = -(-6{,}04.\frac{0{,}1082}{316}.10^3.4{,}184\ ) = 8{,}6530\ \text{kJ}$$

$$QKCl.2NaCl = -(-5{,}568.\frac{4{,}4256}{191{,}5}.10^3.4{,}184\ ) = 538{,}3867\ \text{kJ}$$

$$QNH_3 = -(-8{,}4.\frac{906{,}2399}{17}.10^3.4{,}184\ ) = 1.873.549{,}7076\ \text{kJ}$$

Total $Q_{kristalisasi}$ = 7.685.242,4310 kJ

<u>Produk keluar pada suhu 5°C ke *rotary drum separator III (H-232)*:</u>

$$HK_2SO_4 = \frac{25.857{,}9996}{174}.33{,}1.4{,}184.(278-298) \ = -\ 411.618{,}9319\ \text{kJ}$$

$$HCaSO_4.2H_2O = \frac{54{,}9854}{172}.195{,}8112.(278-298) \ = -\ 1.238{,}2622\ \text{kJ}$$

$$HCaCl_2 = \frac{5{,}5397}{111}.(-1507{,}2174) \ = -\ 75{,}2210\ \text{kJ}$$

$$HNaCl = \frac{22.609{,}6489}{58{,}5}.(-1004{,}1265) \ = -\ 388.084{,}5746\ \text{kJ}$$

$$HK_2SO_4.Na_2SO_4 = \frac{0{,}1082}{316}.137{,}2352.(278-298) \ = -\ 0{,}9389\ \text{kJ}$$

$$HKCl.2NaCl = \frac{4{,}4256}{191{,}5}.(-1005{,}2378) \ = -\ 23{,}2312\ \text{kJ}$$

$$HNH_3 = \frac{906{,}2399}{17}.(-1.596{,}3814) \ = -\ 85.100{,}2677\ \text{kJ}$$

$$HH_2O = \frac{259.558{,}71\ 99}{18}.(-1.506{,}0086) = -\ 21.716.537{,}1292 \text{ kJ}$$

$$\Sigma Hkeluar = HK_2SO_4 + HCaSO_4.2H_2O + HCaCl_2 + HNaCl + HK_2SO_4.Na_2SO_4 +$$

$$HKCl.2NaCl + HNH_3 + HH_2O = -\ 22.602.678{,}5567 \text{ kJ}$$

Panas masuk = Panas keluar

$$\Sigma H_{masuk} = \Sigma H_{keluar} + Q_{kristalisasi} + Q_{yang\ diserap\ air\ pendingin}$$

$$12.683.657{,}7855 \text{ kJ} = -\ 22.602.678{,}5567 \text{ kJ} + 7.685.242{,}4310 \text{ kJ} + Q_{yang\ diserap\ air\ pendingin}$$

$$Q_{yang\ diserap\ air\ pendingin} = 27.601.093{,}9112 \text{ kJ}$$

90% berat air pendingin ditambah dengan 10% berat ethylene glycol masuk pada suhu -5 °C dan keluar pada suhu 4°C:

$$\int Cp_{air\ pendingin} = R \int_{268}^{277} \frac{Cp}{R}\, dT = 699{,}8995 \text{ J/mol} = 699{,}8995 \text{ kJ/kgmol}$$

$$Cp_{ethylene\ glycol} \cdot \Delta T = 92{,}8538 \text{ kJ/kgmol.K} \times (277\text{-}268)\text{K} = 853{,}6842 \text{ kJ/kgmol}$$

$$Q_{suplai} = \Delta H_{air\ pendingin} = m.\ Cp.\ \Delta T$$

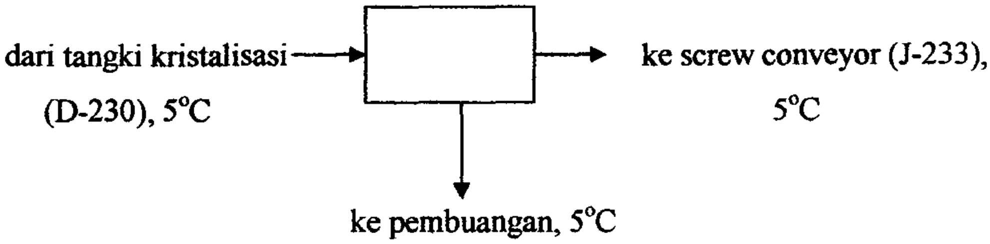
$$27.601.093{,}9112 = \frac{m}{(0{,}973.18 + 0{,}027.62)} \times (0{,}973.699{,}8995 + 0{,}027.853{,}6842)$$

$$m = 752.231{,}4055 \text{ kg}$$

$$m_{air} = 90\%\ 752.231{,}4055 \text{ kg} = 677.008{,}2649 \text{ kg}$$

$$m_{ethylene\ glycol} = 10\%\ 752.231{,}4055 \text{ kg} = 75.223{,}1406 \text{ kg}$$

10. Rotary Drum Separator III (H-232)



Panas masuk rotary drum separator III:

Dari tangki kristalisasi (D-230) pada suhu 5°C:

$$HK_2SO_4 = \frac{25.857,9996}{174}.33,1.4,184.(278-298) = -411.618,9319 \text{ kJ}$$

$$HCaSO_4.2H_2O = \frac{54,9854}{172}.195,8112.(278-298) = -1.238,2622 \text{ kJ}$$

$$HCaCl_2 = \frac{5,5397}{111}.(-1507,2174) = -75,2210 \text{ kJ}$$

$$HNaCl = \frac{22.609,6489}{58,5}.(-1004,1265) = -388.084,5746 \text{ kJ}$$

$$HK_2SO_4.Na_2SO_4 = \frac{0,1082}{316}.137,2352.(278-298) = -0,9389 \text{ kJ}$$

$$HKCl.2NaCl = \frac{4,4256}{191,5}.(-1005,2378) = -23,2312 \text{ kJ}$$

$$HNH_3 = \frac{906,2399}{17}.(-1.596,3814) = -85.100,2677 \text{ kJ}$$

$$HH_2O = \frac{259.558,71\,99}{18}.(-1.506,0086) = -21.716.537,1292 \text{ kJ}$$

ΣHmasuk = HK_2SO_4 + $HCaSO_4.2H_2O$ + $HCaCl_2$ + HNaCl + $HK_2SO_4.Na_2SO_4$ + HKCl.2NaCl + HNH_3 + HH_2O = - 22.602.678,5567 kJ

Panas keluar rotary drum separator III:

Ke screw conveyor (J-233) pada suhu 5°C:

$$HK_2SO_4 = \frac{25.137,5530}{174}.33,1.4,184.(278-298) = -400.150,5483 \text{ kJ}$$

$$HCaSO_4.2H_2O = \frac{54,3886}{172}.195,8112.(278-298) = -1.238,3601 \text{ kJ}$$

$$HCaCl_2 = \frac{0,0393}{111}.(-1507,2174) = -0,5336 \text{ kJ}$$

$$HNaCl = \frac{160,5194}{58,5}.(-1004,1265) = -2.755,2442 \text{ kJ}$$

$$HK_2SO_4.Na_2SO_4 = \frac{7,68.10^{-4}}{316}.137,2352.(278-298) = -6,67.10^{-3} \text{ kJ}$$

$$HKCl.2NaCl = \frac{0,0314}{191,5}.(-1005,2378) = -0,1648 \text{ kJ}$$

$$HNH_3 = \frac{6{,}4339}{17}.(-1.596{,}3814) = -\ 604{,}1740\ kJ$$

$$HH_2O = \frac{1.824{,}7623}{18}.(-1.506{,}0086) = -\ 152.672{,}6509\ kJ$$

ΣHkeluar I = HK_2SO_4 + $HCaSO_4.2H_2O$ + $HCaCl_2$ + HNaCl + $HK_2SO_4.Na_2SO_4$ +

HKCl.2NaCl + HNH_3 + HH_2O = - 557.421,6826 kJ

Ke pembuangan pada suhu 5°C:

$$HK_2SO_4 = \frac{720{,}4466}{174}.33{,}1.4{,}184.(278-298) = -12.214{,}6551\ kJ$$

$$HCaSO_4.2H_2O = \frac{0{,}5968}{172}.195{,}8112.(278-298) = -\ 13{,}5884\ kJ$$

$$HCaCl_2 = \frac{5{,}5004}{111}.(-1507{,}2174) = -\ 74{,}6874\ kJ$$

$$HNaCl = \frac{22.449{,}1295}{58{,}5}.(-1004{,}1265) = -386.075{,}6019\ kJ$$

$$HK_2SO_4.Na_2SO_4 = \frac{0{,}1074}{316}.137{,}2352.(278-298) = -\ 0{,}9329\ kJ$$

$$HKCl.2NaCl = \frac{4{,}3942}{191{,}5}.(-1005{,}2378) = -\ 23{,}0664\ kJ$$

$$HNH_3 = \frac{899{,}8060}{17}.(-1.596{,}3814) = -\ 84.496{,}0919\ kJ$$

$$HH_2O = \frac{257.715{,}9576}{18}.(-1.506{,}0086) = -\ 21.562.358{,}2502\ kJ$$

ΣHkeluar II = HK_2SO_4 + $HCaSO_4.2H_2O$ + $HCaCl_2$ + HNaCl + $HK_2SO_4.Na_2SO_4$ +

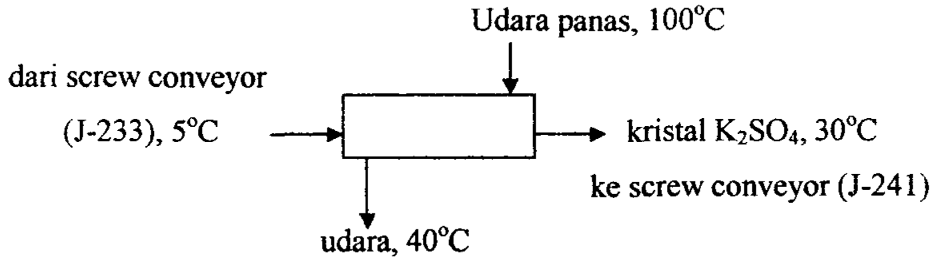
HKCl.2NaCl + HNH_3 + HH_2O = -22.045.256,8741 kJ

Total Hkeluar = ΣHkeluar I + ΣHkeluar II

= - 557.421,6826 kJ + (-22.045.256,8741 kJ)

= - 22.602.678,5567 kJ

11. Rotary Dryer (B-240)



<u>Panas masuk rotary dryer:</u>

Dari srew conveyor (J-233) pada suhu 5°C:

$$HK_2SO_4 = \frac{25.137{,}5530}{174}.33{,}1.4{,}184.(278-298) = -\ 400.150{,}5483 \text{ kJ}$$

$$HCaSO_4.2H_2O = \frac{54{,}3886}{172}.195{,}8112.(278-298) = -\ 1.238{,}3601 \text{ kJ}$$

$$HCaCl_2 = \frac{0{,}0393}{111}.(-1507{,}2174) = -\ 0{,}5336 \text{ kJ}$$

$$HNaCl = \frac{160{,}5194}{58{,}5}.(-1004{,}1265) = -\ 2.755{,}2442 \text{ kJ}$$

$$HK_2SO_4.Na_2SO_4 = \frac{7{,}68.10^{-4}}{316}.137{,}2352.(278-298) = -\ 6{,}67.10^{-3} \text{ kJ}$$

$$HKCl.2NaCl = \frac{0{,}0314}{191{,}5}.(-1005{,}2378) = -\ 0{,}1648 \text{ kJ}$$

$$HNH_3 = \frac{6{,}4339}{17}.(-1.596{,}3814) = -\ 604{,}1740 \text{ kJ}$$

$$HH_2O = \frac{1.824{,}7623}{18}.(-1.506{,}0086) = -\ 152.672{,}6509 \text{ kJ}$$

$$\Sigma H\text{masuk} = HK_2SO_4 + HCaSO_4.2H_2O + HCaCl_2 + HNaCl + HK_2SO_4.Na_2SO_4 + HKCl.2NaCl + HNH_3 + HH_2O$$

$$= -\ 557.421{,}6826 \text{ kJ}$$

Produk keluar dari rotary dryer pada suhu 30°C:

Ke screw conveyor (J-241):

$$HK_2SO_4 = \frac{25.011,9010}{174}.33,1.4,184.(303-298) = 99.537,5912 \text{ kJ}$$

$$HCaSO_4.2H_2O = \frac{54,1167}{172}.195,8112.(303-298) = 308,0423 \text{ kJ}$$

$$HCaCl_2 = \frac{0,0391}{111}.377,8137 = 0,1331 \text{ kJ}$$

$$HNaCl = \frac{159,7170}{58,5}.252,1299 = 688,3663 \text{ kJ}$$

$$HK_2SO_4.Na_2SO_4 = \frac{7,64.10^{-4}}{316}.137,2352.(303-298) = 1,66.10^{-3} \text{ kJ}$$

$$HKCl.2NaCl = \frac{0,0312}{191,5}.252,2927 = 0,0411 \text{ kJ}$$

$$HNH_3 = \frac{0,0883}{17}.405,4234 = 2,1058 \text{ kJ}$$

$$HH_2O = \frac{25,2896}{18}.377,0969 = 529,8128 \text{ kJ}$$

$$\Sigma Hkeluar\ I = HK_2SO_4 + HCaSO_4.2H_2O + HCaCl_2 + HNaCl + HK_2SO_4.Na_2SO_4 + HKCl.2NaCl + HNH_3 + HH_2O$$

$$= 101.066,0943 \text{ kJ}$$

Ke cyclone separator (H-243):

$$HK_2SO_4 = \frac{125,6520}{174}.33,1.4,184.(313-298) = 1500,1376 \text{ kJ}$$

$$HCaSO_4.2H_2O = \frac{0,2719}{172}.195,8112.(313-298) = 4,6431 \text{ kJ}$$

$$HCaCl_2 = \frac{0,0002}{111}.1208,679 = 2,18.10^{-3} \text{ kJ}$$

$$HNaCl = \frac{0,8024}{58,5}.838,2327 = 11,4974 \text{ kJ}$$

$$HK_2SO_4.Na_2SO_4 = \frac{0,04.10^{-4}}{316}.137,2352.(313-298) = 2,6.10^{-5} \text{ kJ}$$

$$HKCl.2NaCl = \frac{0,0002}{191,5}.830,4525 = 8,7.10^{-4} \text{ kJ}$$

$$HNH_3 = m.\ R. \int_{298}^{303} \frac{Cp}{R} dT + m\ .\ \lambda = \frac{0{,}0883}{17}.(536{,}4032 + 14.200 \times 2{,}326)$$

$$= 2.174{,}3437 \text{ kJ}$$

$$HH_2O = m.\ R. \int_{298}^{303} \frac{Cp}{R} dT + m\ .\ \lambda = 25{,}2896.(\frac{487{,}9871}{18} + 2.405{,}8981)$$

$$= 61.570{,}1417 \text{ kJ}$$

ΣHkeluar II = $HK_2SO_4 + HCaSO_4.2H_2O + HCaCl_2 + HNaCl + HK_2SO_4.Na_2SO_4 +$

$HKCl.2NaCl + HNH_3 + HH_2O$

= 63.260,7766 kJ

Panas masuk = Panas keluar

$$\Sigma H_{masuk} + Q_{suplai} = \Sigma H_{keluar\ I} + \Sigma H_{keluar\ II} + Q_{loss}$$

$$\Sigma H_{masuk} + Q_{suplai} = \Sigma H_{keluar\ I} + \Sigma H_{keluar\ II} + 10\%\ .\ Q_{suplai}$$

$$-\ 557.421{,}6826 \text{ kJ} + Q_{suplai} = 101.066{,}0943 \text{ kJ} + 63.260{,}7666 \text{ kJ} + 10\%\ .\ Q_{suplai}$$

$$Q_{suplai} = 801.942{,}8261 \text{ kJ}$$

Q_{loss} =10% . 801.942,8261 kJ = 80.194,2826 kJ

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

$Cp_{udara,\ 100°C}$ = 1,0100 kJ/kg.K

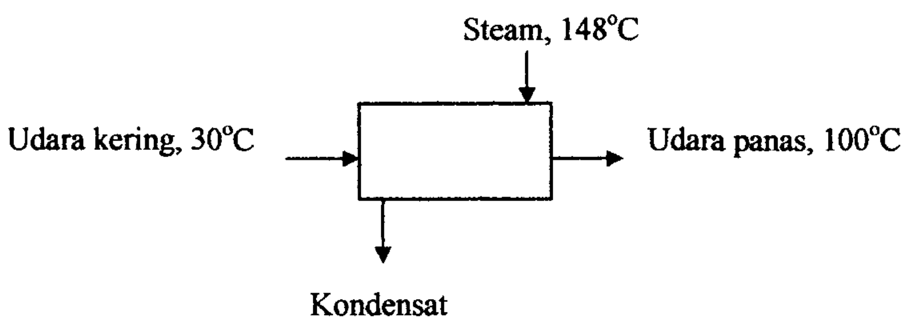
$Cp_{udara,\ 40°C}$ = 1,0048 kJ/kg.K (Geankoplis, 1993, tabel A.3-3)

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

801.942,8261 kJ = m. (1,0100 + 1,0048)/2 kJ/kg.K . (100-40)K

m_{udara} = 13.267,5340 kg

12. Heater (E-246)



<u>Panas masuk:</u>

$\Delta H_{udara\ I}$ $= m_{udara} \cdot Cp_{udara} \cdot \Delta T$

$= 13.267{,}5340$ kg $1{,}0048$ kJ/kg.K . (30-25)K

$= 66.656{,}0909$ kJ

<u>Panas keluar:</u>

$\Delta H_{udara\ II}$ $= m_{udara} \cdot Cp_{udara} \cdot \Delta T$

$= 13.267{,}5340$ kJ $(1{,}0048 + 1{,}0100)/2$ kJ/kg.K . (100-25)K

$= 1.002.428{,}5314$ kJ

Panas masuk = Panas keluar

$$\Delta H_{udara\ I} + Q_{suplai} = \Delta H_{udara\ II} + Q_{loss}$$

$$66.656{,}0909 \text{ kJ} + Q_{suplai} = 1.002.428{,}5314 \text{ kJ} + 10\% \cdot Q_{suplai}$$

$$Q_{suplai} = 935.772{,}4405 \text{ kJ} + 10\% \cdot Q_{suplai}$$

$$Q_{suplai} = 1.039.747{,}1561 \text{ kJ}$$

$Q_{loss} = 10\% \cdot Q_{suplai} = 10\% \cdot 1.039.747{,}1561$ kJ $= 103.974{,}7156$ kJ

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

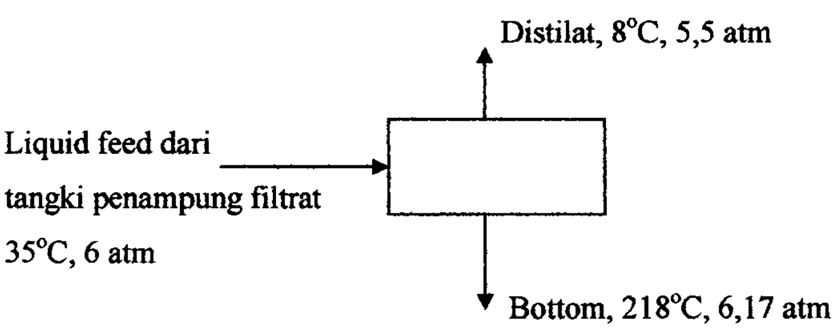
λ_{steam} = 911,22 Btu/lbm (Kern, 1965, p.816)

= 2.119,5 kJ/kg

$$\text{Jadi, kebutuhan steam} = \frac{Q_{suplai}}{\lambda} = \frac{1.039.747{,}1561 \text{ kJ}}{2.119{,}5 \text{ kJ/kg}}$$

$$= 490{,}5625 \text{ kg/hari}$$

13. Menara Distilasi (D-160)



Kondisi Operasi :

P inlet = 6 atm = 88,2 psia

T inlet = 35 °C

Komposisi Menara Distilasi:

Masuk	kmol	Keluar	kmol
K_2SO_4	2,1372	**Distilat :**	
NaCl	227,0533	Ammonia	5060
$CaSO_4.2H_2O$	$3{,}62.10^{-3}$	H_2O	25,4271
$K_2SO_4.Na_2SO_4$	5,2784		5085,4271
KCl.2NaCl	0,7518	**Bottom :**	
$CaCl_2$	161,2540	K_2SO_4	2,1372
Ammonia	5.060,3287	NaCl	227,0533
H_2O	14.660,2055	$CaSO_4.2H_2O$	$3{,}62.10^{-3}$
		$K_2SO_4.Na_2SO_4$	5,2784
		KCl.2NaCl	0,7518
		$CaCl_2$	161,2540
		Ammonia	0,3287
		H_2O	14634,7784
			15031,5854

Perhitungan Tekanan dan Suhu:

Asumsi: P operasi = 6 atm = 88,2 psia

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

$$\text{P operasi} = \frac{\text{P puncak} + \text{P bottom}}{2} = 88{,}2 \text{ psia} \;\ldots\ldots(2)$$

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

P puncak = 85,7 psia = 5,83 atm

P bottom = 90,7 psia = 6,17 tm

P distilat = P puncak – 5 psia = 85,7 psia – 5 psia = 80,7 psia = 5,5 atm

Suhu Bubble Point Feed = 35°C = 308 K; P = 6 atm

Mencari P^{sat}:

- untuk air

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

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

  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:

γ_1 = 1,7537 dan γ_2 = 1,1160

Zat	Zi = Xi	P^{sat}, atm	γ	Ki = $\gamma.P^{sat}/P$	Yi = Ki. Xi
NH_3	0,2566	13,2248	1,7537	3,8654	0,9919
Air	0,7434	0,0700	1,1160	0,0130=Kc	0,0097
	$\sum$Xi = 1				$\sum$Yi = 0,9972≈1

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

Suhu Bubble Point Distilat = 8°C = 281 K

P = 5,5 atm

Zat	Zi = Xi	P^{sat}, atm	Ki = P^{sat}/P	Yi = Ki. Xi
NH_3	0,995	5,6250	1,0227	1,0176
Air	0,005	0,0326	0,0059	$2,96.10^{-5}$
	$\sum$Xi = 1			$\sum$Yi = 1,0176 ≈ 1

Suhu Dew Point Distilat = 27°C

P = 5,5 atm

Zat	Zi = Yi	P^{sat}, atm	Ki = P^{sat}/ P	Xi = Yi/Ki	$\alpha i = {}^{Ki}/_{Kc}$
NH_3	0,995	10,3267	1,88413	0,5281	184,7168
Air	0,005	0,0561	0,0102=Kc	0,4905	1
	$\sum Yi = 1$			$\sum Xi = 1{,}0186 \approx 1$	

Suhu Bubble Point Bottom = 218°C

P = 6,17 atm

Zat	Zi = Xi	P^{sat}, atm	Ki = P^{sat}/ P	Yi = Ki. Xi	$\alpha i = {}^{Ki}/_{Kc}$
NH_3	$2{,}25.10^{-5}$	422,220	68,4311	$1{,}54.10^{-3}$	68,7197
Air	0,9999	6,1438	0,9958=Kc	0,9957	1
	$\sum Xi = 1$			$\sum Yi = 0{,}9972 \approx 1$	

<u>Perhitungan Jumlah Stage Minimum:</u>

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

$$\alpha_{LK,avg} = \sqrt{184{,}7186.68{,}7197} = 112{,}6668$$

$$N_m = \frac{\log\left[\left(\frac{x_{LK,D}.D}{x_{HK,D}.D}\right)\cdot\left(\frac{x_{HK,B}.B}{x_{LK,B}.B}\right)\right]}{\log \alpha_{LK,avg}}$$ (Geankoplis, 1997, eq.11.7-12, p. 683)

$$N_m = \frac{\log\left[\left(\frac{0{,}995}{0{,}005}\right)\left(\frac{0{,}9999}{2{,}25.10^{-5}}\right)\right]}{\log 112{,}6668} = 3{,}3856 \text{ stage}$$

<u>Perhitungan Reflux Ratio:</u>

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

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

$$T = \frac{27+218}{2} = 122{,}5°C = 252{,}5°F$$

$$Ki = \frac{\gamma.Psat}{P}$$

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

Zat	Xi_F	Xi_D	γ	Psat	Ki (122,5°C)	α_i (122,5°C)	$\alpha i.Xi_F$	$\alpha i.Xi_D$
NH_3	0,2566	0,995	1,7537	92,7708	27,1154	217,6196	55,8412	216,5315
Air	0,7434	0,005	1,1160	0,6700	0,1246=Kc	1,0000	0,7434	0,005
	$\Sigma = 1$	$\Sigma = 1$						

$$1\text{-}1 = \frac{55{,}8412}{217{,}6196-\theta} + \frac{0{,}7434}{1-\theta}$$

Dengan trial dan error didapat $\theta = 3{,}8460$

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

$$= \frac{216{,}5315}{217{,}6196-3{,}8460} + \frac{0{,}005}{1-3{,}8460} = 1{,}0111$$

Rm = 0,0111

R = 1,2 .Rm = 1,2. 0,0111 = 0,0134 (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:

$N = 2.\ N_m = 2.\ 3{,}3856 = 6{,}7712 \approx 7$ 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)

$$\log\frac{N_e}{N_S} = 0{,}206.\log\left[\left(\frac{0{,}7434}{0{,}2566}\right).\frac{14.635{,}1071}{5.085{,}4271}.\left(\frac{2.25.10^{-5}}{0{,}005}\right)^2\right]$$

$$\log\frac{N_e}{N_S} = -0{,}7771$$

$$\frac{N_e}{N_S} = 0{,}1671\ldots(1)$$

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

Dari substitusi persamaan 1 dan 2 didapat :

$N_e = 1$

$N_s = 7$

Jadi feed tray berada 1 stage dari puncak

Perhitungan Beban Kondenser:

V = D (1 + R) = 5085,4271. (1 + 0,0134) = 5153,5718 kmol

Reflux = V – D = 5153,5718 – 5085,4271 = 68,1447 kmol

Komposisi Reflux = Komposisi Distilat, terdiri dari :

NH_3 = 0,995. 68,1447 = 67,8040 kmol = 1.152,6680 kg

Air = 0,005. 68,1447 = 0,3407 kmol = 6,1326 kg

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

λ distilat = λ NH_3 + λ Air (pada 27°C)

= 19334670,4214 J/kmol.5060 kmol + 43450783,9478 J/kmol.25,4271 kmol

= 97833432,3323 kJ + 1104827,4285 kJ

= 98938259,7608 kJ

λ reflux = R. λ distilat = 0,0134. 98938259,7608 kJ = 1325772,6808 kJ

Q_C = 98938259,7608 kJ + 1325772,6808 kJ = 100264032,4416 kJ

Perhitungan Entalpi Masuk:

Untuk NH_3:

$$H^{id} = n.\,R.\int_{308}^{298}\frac{Cp}{R}\,dT \qquad \text{(Smith, 1996, eq. 6.70, p. 210)}$$

= 5060,3287 kmol. -814,1791 kJ/kmol

= - 4120013,8667 kJ

H_{NH_3} = H^{id} = - 4120013,8667 kJ

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

Zat	Hin, kJ
$K_2SO_4.Na_2SO_4$	- 7243,8228
$CaCl_2$	- 121913,0551
NaCl	- 114593,6189
$CaSO_4.2H_2O$	- 7,0884
KCl.2NaCl	- 379,6429
K_2SO_4	- 2959,8168
NH_3	- 4120013,8667
Air	- 11060112,0295
Total	- 15427222,9411

Perhitungan Entalpi Distilat:

Untuk NH_3:

$$H^{id} = n.\ R. \int_{298}^{281} \frac{Cp}{R}\, dT$$ (Smith, 1996, eq. 6.70, p. 210)

= 5060 kmol. -1357,7974 kJ/kmol

= - 6870454,8440 kJ

H_{NH_3} = H^{id} = - 6870454,8440 kJ

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

Zat	Hout, kJ
NH_3	- 6870454,8440
Air	- 32528,8287
Total	- 6902983,6727

Perhitungan Entalpi Bottom:

Untuk NH_3:

$$H^{id} = n.\ R. \int_{298}^{491} \frac{Cp}{R}\, dT$$ (Smith, 1996, eq. 6.70, p. 210)

= 0,3287 kmol. 21613,6795 kJ/kmol

= 7104,4224 kJ

H_{NH_3} = H^{id} = 7104,4224 kJ

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

Zat	Hout, kJ
$K_2SO_4.Na_2SO_4$	139805,7800
$CaCl_2$	2398912,3940
NaCl	271913,2895
$CaSO_4.2H_2O$	136,8055
KCl.2NaCl	7535,9718
K_2SO_4	57124,4648
NH_3	7104,4224
Air	215492941,1460
Total	218375474,2740

Perhitungan Beban Reboiler:

$H_F + Q_R = H_D + H_B + Q_C$

$Q_R = H_D + H_B + Q_C - H_F$

$= (-6902983,6727) + 218375474,2740 + 100264032,4416 - (15427222,9411)$

$= 296309300,1018$ kJ

APPENDIX C

PERHITUNGAN SPESIFIKASI PERALATAN

APPENDIX C
PERHITUNGAN SPESIFIKASI PERALATAN

1. Tangki Penyimpan NH_3 Cair (F-114)

Fungsi : Untuk meyimpan NH_3 cair sebelum masuk ke vaporizer (V-112)

Tipe : Silinder tegak tertutup dengan tutup atas elipsoidal (ea) dan tutup bawah elipsoidal (eb)

Dasar pemilihan : Cocok untuk bertekanan tinggi

Kondisi operasi : T = 30°C = 303 K

Kapasitas : 86.931,8276 kg/hari × 2,2 lb/kg = 191.250,0207 lb/hari

Jumlah : 1 buah

Perhitungan :

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

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

$\ln PVP = 45{,}327 - 4.104{,}67/303 + (-5{,}146) \times \ln 303 + 615 \times PVP/303^2$

$\ln PVP - 0{,}0067\ PVP = 2{,}3774$

trial PVP = 11 bar → $\ln PVP - 2{,}0297\ PVP = 2{,}324$

PVP = 11,65 bar → $\ln PVP - 2{,}0297\ PVP = 2{,}3773$ (cocok)

Tangki beroperasi pada 11,65 bara = 11,5 atm = 169,05 psia ≈ 170 psia

$\rho_{NH_3,\,30°C} = sg.\ \rho H_2O,\ 30°C$ (Perry, 1984, tab.3-1, p.3-7)

$= 0{,}5971 \times 995{,}68\ kg/m^3 = 594{,}5205\ kg/m^3 = 37{,}1146\ lb/ft^3$

$$\text{Volume larutan total} = \frac{191.250{,}0207\ lb/hari \times 7\ hari}{37{,}1146\ lb/ft^3} = 36.070{,}7146\ ft^3$$

Dari Ulrich,1984, p. 433:

$h = (1\text{-}1{,}5) \times D$

Diambil tinggi liquida (h) = 1,25.diameter tangki (D)

Volume larutan = volume silinder + volume elipsoidal

$= \pi/4 \times D^2 \times h + 0{,}000076 \times D^3$

$36.070{,}7146\ ft^3 = \pi/4 \times D^2 \times 1{,}25.D + 0{,}000076 \times D^3$

$D = 33{,}2435\ ft \approx 33{,}5\ ft$

$h = 41{,}875$ ft

Asumsi : Volume ruang kosong = 25% Volume larutan

Volume total = $1{,}25 \times (\pi/4 \times 33{,}5^2 \times 41{,}875 + 0{,}000076 \times 33{,}5^3)$

$= 46.140{,}0379\ ft^3$

Volume tangki = volume silinder + volume ea + volume eb

$46.140{,}0379\ ft^3 = \pi/4 \times D^2 \times H + 0{,}000076 \times D^3 + 0{,}000076 \times D^3$

$= \pi/4 \times 6{,}5^2 \times H + 0{,}000076 \times 6{,}5^3 + 0{,}000076 \times 6{,}5^3$

$H = 52{,}3413$ ft $\approx$ 54 ft (memenuhi)

H/D = 1,61 (Dari Ulrich,1984, p. 433 H = (1,5-2,0) × D)

Bahan konstruksi yang digunakan : stainlees steel 18-8 tipe 304

Dari Brownell & Young, 1959, App. D, p. 342 diperoleh:

$f_{allowable} = 18.750\ lb/in^2$

$E = 0{,}85$

$c = {}^1/_2$ in

$$P = \frac{\rho \times h}{144} = \frac{37{,}1146\ lb/ft^3 \times 41{,}875\ ft}{144} = 10{,}7929\ psi$$

$P_{op} = 170 + 10{,}7929 = 180{,}7929$ psia

$P_{desain} = 1{,}2 \times P_{op} = 1{,}2 \times 180{,}7929 = 216{,}9514$ psia

<u>Perhitungan tebal tutup atas:</u>

$k = a/b = 2/1 = 2$

$V = 1/6 \times (2 + k^2) = 1/6 \times (2 + 2^2) = 1$ (Brownell & Young, 1959, eq.7.56, p.133)

$$t_{ea} = \frac{P \times D \times V}{(2 \times f \times E - 0{,}2 \times P)} + c$$ (Brownell & Young, 1959, eq. 7.57, p.133)

$$= \frac{216{,}9514\ lb/in^2 \times 33{,}5.12\ in \times 1}{(2 \times 18.750\ lb/in^2 \times 0{,}85 - 0{,}2 \times 216{,}9514\ lb/in^2} + 1/2\ in = 3{,}2399\ in \approx 3\ {}^1/_2\ in$$

<u>Perhitungan tebal shell:</u>

$$t_{shell} = \frac{P \times D}{2 \times f \times E} + c = \frac{216{,}9514\ lb/in^2 \times 33{,}5.12\ in}{2 \times 18.750\ lb/in^2 \times 0{,}85} + 1/2\ in = 3{,}2361\ in \approx 3\ {}^1/_2\ in$$

Perhitungan tebal tutup bawah:

$k = a/b = 2/1 = 2$

$V = 1/6 \times (2 + k^2) = 1/6 \times (2 + 2^2) = 1$ (Brownell & Young, 1959, eq.7.56, p.133)

$t_{eb} = \dfrac{P \times D \times V}{(2 \times f \times E - 0{,}2 \times P)} + c$ (Brownell & Young, 1959, eq.7.57, p.133)

$= \dfrac{216{,}9514 \text{ lb/in}^2 \times 33{,}5.12 \text{ in} \times 1}{(2 \times 18.750 \text{ lb/in}^2 \times 0{,}85 - 0{,}2 \times 216{,}9514 \text{ lb/in}^2} + 1/2 \text{ in} = 3{,}2399 \text{ in} \approx 3\ ^1/_2 \text{ in}$

2. Vaporizer (V-112)

Fungsi : Menguapkan ammonia cair dari tangki penyimpan NH_3 (F-114)

Tipe : Submerged Coil

Dasar pemilihan: Mempunyai luas perpindahan panas lebih besar daripada jaket pemanas

Perhitungan:

Pada 38°C, ρ ammonia cair = 592,8994 kg/m³ (Perry, 1984)

$\text{Volume liquid} = \dfrac{(86.931{,}8276 + 21.732{,}9569) \text{ kg/hari}}{592{,}8994 \text{kg/m}^3 \times 24 \text{jam/hari}} = 7{,}6365 \text{m}^3 = 269{,}6720 \text{ft}^3$

Volume liquid = 80 % Volume tangki

Volume tangki = 323,6064 ft³

Jenis tangki: tangki silinder vertikal dengan tutup atas dan bawah jenis *flanged and dished head*

Diambil: H = 2 D

Volume tangki = volume silinder + volume tutup atas + volume tutup bawah

$V = \left(\dfrac{\pi . Di^2 . Hs}{4}\right) + \left(2.0{,}000049.Di^3\right)$ (Brownell & Young, 1959)

$323{,}6064 \text{ ft}^3 = 1{,}5708 \, Di^3 + 9{,}8.10^{-5} \, Di^3$

$Di = 5{,}9060 \text{ ft} \approx 6 \text{ ft} = 1{,}8288 \text{ m}$

$Hs = 12 \text{ ft} = 3{,}6576 \text{ m}$

$r = 3 \text{ ft}$

Berdasarkan Ulrich, 1984, tab.4-7, p.94 : $D_{max} = 4$ m dan $H_{max} = 16$ m

Perhitungan tebal dinding shell:

P design = P operasi + 2,5 bar (Ulrich, 1984)

= 11,36.1,013 + 2,5 bar = 14,0077 bar = 203,2704 psia

c = 0,5 (Brownell & Young, 1959)

f = falllow = 13.300 psia untuk jenis Nickel tipe SB-162 (Brownell & Young, 1959)

$$t_{shell} = \frac{P.r}{0{,}9.f - 0{,}6.P} + c$$ (Ulrich, 1984, eq. 4-113)

$$t_{shell} = \frac{203{,}2704.3.12}{0{,}9.13.300 - 0{,}6.203{,}2704} + 0{,}5$$

$= 0{,}7059$ in $\approx {}^{7}/_{8}$ in

Perhitungan tebal tutup:

Do = Di + 2. t_{shell} = 5,9060.12 + 2. ${}^{5}/_{16}$ = 71,497 in ≈ 72 in

E = 0,8 (Double Welded Butt Joint) (tabel 13.2, Brownell & Young, 1959)

icr/rc = 0,025 – 0,19 (Brownell & Young, 1959) ditetapkan icr/rc = 0,1

$$W = \frac{1}{4}.\left(3 + \sqrt{\frac{rc}{icr}}\right)$$ (Brownell & Young, 1959, eq. 7.76)

$$W = \frac{1}{4}.\left(3 + \sqrt{10}\right) = 1{,}5406$$

$$t_h = \frac{P.rc.W}{2.f.E - 0{,}2.P} + c$$ (Brownell & Young,1959, eq. 7.77)

$$t_h = \frac{203{,}2704 \times (4{,}375/0{,}1) \times 1{,}5406}{2 \times 13.300 \times 0{,}8 - 0{,}2 \times 203{,}2704} + 0{,}5$$

t_h = 1,145 in ≈ $1^{1}/_{4}$ in

Perhitungan tinggi tutup:

Do = 72 in

Dari Brownell & Young tabel 5.7 diketahui untuk t = ${}^{1}/_{4}$ in, icr = 4,375 in, r = 43,75 in dan sf = 2 in

Di = Do – 2.t = 71,5 in

$$AB = \frac{Di}{2} - icr = 31{,}625 \text{ in}$$

BC = r – icr = 39,375 in

Kedalaman dish (b) = r - $\sqrt{(BC)^2 - (AB)^2}$ = 20,2926 in

Tinggi tutup = t + b + sf = 23,5426 in

Perhitungan tinggi keseluruhan tangki:

Tinggi tangki = tinggi shell + 2. tinggi tutup

= 12.12 + 2. 23,5426 = 191,0852 in = 15,9238 ft

Perhitungan panjang koil:

Dari neraca panas, Q pemanas = 138.530.142,5560 kJ/hari

= 5.470.863,5274 BTU/jam

Tsteam = 298,4°F = 148°C

Dari Kern,1965,tab.7, p.816 didapat λ_{steam} = 2.119,5kJ/kg = 911,2210BTU/lb

Feed masuk vaporizer pada suhu 30°C

Feed keluar vaporizer pada suhu 38°C

T_{avg} = 148°C = 298,4°F

$$t_{avg} = \frac{(86 + 100{,}4)}{2} = 93{,}2°F$$

Δt_1 = 298,4 – 86 = 212,4°F

Δt_2 = 298,4 – 100,4 = 198°F

$$\Delta t_{LMTD} = \frac{\Delta t_1 - \Delta t_2}{\ln\left(\frac{\Delta t_1}{\Delta t_2}\right)} = \frac{212{,}4 - 198}{\ln\left(\frac{212{,}4}{198}\right)} = 205{,}1158°F$$

Digunakan pipa 3 in sch. 40, 24 ft

Fluida Panas: Steam (Bagian Tube)	Fluida Dingin: NH_3 cair (Bagian tangki)
Hio = 1500 Btu/jam.ft^2.°F	Trial ho = 80 Btu/jam.ft^2.°F $t_w = t_{avg} + \dfrac{hio}{hio + ho}(T_{avg} - t_{avg})$ $t_w = 93{,}2 + \dfrac{1500}{1500+80}(298{,}4 - 93{,}2)$ $= 288{,}0101°F$ $t_f = \dfrac{(t_w + t_{avg})}{2} = \dfrac{(288{,}0101 + 93{,}2)}{2}$ $= 190{,}6051°F$ Dari Kern,1965, fig.10.4, p.216 diperoleh: $\Delta t = t_w - t_{av} = 194{,}8101°F$ do = 3,5 in (Kern,1965,tab.11,p.844) $\dfrac{\Delta t}{do} = 55{,}6600$ ho = 80 Btu/jam.ft^2.°F (trial benar)

$$U_c = \frac{ho\,.\,hio}{ho + hio} = \frac{80.1500}{80 + 1500} = 75{,}9494 \text{ Btu/jam.ft}^2.°F$$

Rd = 0,01 (Kern, 1965, p.724)

h_d = 1/Rd = 100

$$U_d = \frac{Uc\,.\,hd}{Uc + hd} = 43{,}1655$$

$$A = \frac{Q}{Ud.\Delta t_{LMTD}} = \frac{5.470.863{,}5274}{43{,}1655.205{,}1158} = 617{,}9026 \text{ ft}^2$$

Luas permukaan/lin ft = 0,917 ft^2/ft (Kern,1965, tab.11, p.844)

Banyak coil yang dibutuhkan = $\frac{617{,}9026}{0{,}917.24} = 28{,}0763 \approx 29$

3. Drum Separator (H-111)

Fungsi : Memisahkan liquid yang terdapat dalam kesetimbangan uap NH_3

Tipe : Vertikal drum separator dengan tutup berbentuk hemi-spherical

Dasar pemilihan : Dapat dioperasikan pada tekanan tinggi, pengoperasian mudah

Kondisi operasi : T = 30°C = 303 K

Kapasitas : 108.664,7845 kg/hari

Laju NH_3 gas (W_v) = 86.931,8276 kg/hari = 2,2135 lb/sec

Laju NH_3 liqiud (W_l) = 21.732,9569 kg/hari = 0,5534 lb/sec

Drum beroperasi pada = 11,09 atm = 11,23 bara = 163 psia

Perhitungan:

$\omega = 0,253$

$T_R = T/T_c = 303/405,7 = 0,75$

$P_R = P/P_c = 11,23/112,8 = 0,0996 \approx 0,1$ (Smith & Van Ness, 1996, p.636)

$Z^0 = 0,9165$ dan $Z^1 = -0,0744$ (Smith & Van Ness, 1996, p.650)

$Z = Z^0 + \omega . Z^1$ (Smith & Van Ness, 1996, eq.3.46, p.650)

$= 0,9165 + 0,253.-0,0744 = 0,8977$

$$P.V = z.n.R.T \rightarrow \frac{P.m}{\rho} = z.n.R.T \rightarrow \frac{P}{z.R.T}.\frac{m}{n} = \rho \rightarrow \frac{P.BM}{z.R.T} = \rho$$

$$\rho_v = \frac{11,09\ \text{atm}.17\ \text{kg/kgmol}}{0,8977.0,082057\text{m}^3.\text{atm/kgmol.K}\ (30 + 273)\ \text{K}} = 8,4468\ \text{kg/m}^3 = 0,5273\ \text{lb/ft}^3$$

$\rho_l = 594,5205\ \text{kg/m}^3 = 37,1146\ \text{lb/ft}^3$ (Perry, 1984, tab.3.1, p.3-7)

$$\frac{W_l}{W_v}.\sqrt{\frac{\rho_v}{\rho_l}} = \frac{0,5534\ \text{lb/sec}}{2,2135\ \text{lb/sec}}.\sqrt{\frac{0,5273\ \text{lb/ft}^3}{37,1146\ \text{lb/ft}^3}}$$ (Evans, 1980, vol.2, eq.5-1, p.154)

$= 0,0298$

Dari Evans, 1980, vol.2, fig 5-1, p.154 diperoleh:

K_v = faktor desain kecepatan uap = 0,4

$(U_v)_{max} = K_v . \sqrt{(\rho_l - \rho_v)/\rho_v}$ (Evans, 1980, vol.2, p.154)

$= 0,4 . \sqrt{(37,1146 - 0,5273)/0,5273} = 3,3319$ ft/sec

$$Q_v = \frac{W_v}{\rho_v} = \frac{2,2135\ \text{lb/sec}}{0,5273\ \text{lb/ft}^3} = 4,1978\ \text{ft}^3/\text{sec}$$

$A_{min} = \dfrac{Q_v}{(U_v)_{max}} = \dfrac{4,1978\,ft^3/sec}{3,3319\,ft/sec} = 1,2599\ ft^2$ (Evans, 1980, vol.2, eq.5-2, p.154)

$D_{min} = \sqrt{(4.Amin/\pi)} = \sqrt{(4.1,2599ft^2/\pi)}$ (Evans, 1980, vol.2, eq.5-3, p.154)

$= 1,2665$ ft

$D = D_{min} - (D_{min} + 6\ in)$ (Evans, 1980, vol.2, p.154)

Diambil $D = D_{min} + 6\ in = 1,7665\ ft = 0,5384\ m \approx 0,6\ m$ (memenuhi)

Berdasarkan Ulrich, 1984, tab.4-18, p.188 : D = 0,3 – 4 m

Berdasarkan Ulrich, 1984, tab.4-18, p.188 untuk tekanan < 18 barg ditentukan:

$L/D = 3 \rightarrow L = 3.D = 3.\ 1,7665\ ft = 5,2995\ ft$

$P_{desain} = 1,2 \times P_{op} = 1,2 \times 163\ psia = 195,6\ psia$

Bahan konstruksi yang digunakan : stainlees steel 18-8 tipe 304

Dari Brownell & Young, 1959, App. D, p. 342 diperoleh:

$f_{allowable} = 18.750\ lb/in^2$

$E = 0,85$

$c = {}^1/_2$ in

Perhitungan tebal tutup atas:

$t = \dfrac{P \times D}{4 \times f \times E - 0,4 \times P} + c$ (Brownell & Young, 1959, eq.7.88, p.140)

$= \dfrac{195,6 lb/in^2 \times 1,7665 \times 12\,in}{4 \times 18.750\,lb/in^2 \times 0,85 - 0,4 \times 195,6 lb/in^2} + 1/2\,in = 0,5651\ in \approx {}^5/_8\ in$

Perhitungan tebal shell:

$t_{shell} = \dfrac{P \times R}{f \times E - 0,2 \times P} + c$ (Evans, 1980, vol.2, p.156)

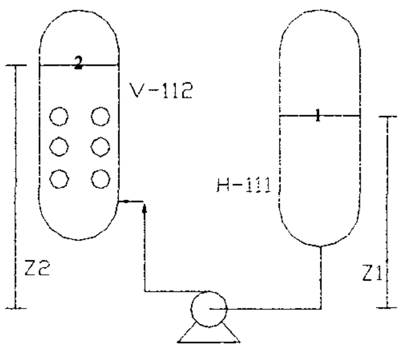
$= \dfrac{195,6 lb/in^2 \times 57}{18.750\,lb/in^2 \times 0,85 - 0,2 \times 195,6 lb/in^2} + 1/2in = 1,2013\ in \approx 1\,{}^1/_2\ in$

Perhitungan tebal tutup bawah:

$$t = \frac{P \times D}{4 \times f \times E - 0{,}4 \times P} + c$$ (Brownell & Young, 1959, eq.7.88, p.140)

$$= \frac{195{,}6\,\text{lb/in}^2 \times 1{,}7665 \times 12\,\text{in}}{4 \times 18.750\,\text{lb/in}^2 \times 0{,}85 - 0{,}4 \times 195{,}6\,\text{lb/in}^2} + 1/2\,\text{in} = 0{,}5651\ \text{in} \approx {}^5/_8\ \text{in}$$

4. Pompa (L-113)



Fungsi : Untuk memompa larutan dari drum separator (H-111) menuju vaporizer (V-112)

Tipe : Centrifugal

Dasar pemilihan :

1. Cocok untuk liquida dengan viskositas rendah
2. Cocok untuk rate massa besar

Jumlah : 1 buah

Perhitungan:

ρ_l = 594,5205 kg/m^3 = 37,1146 lb/ft^3 (Perry, 1984, tab.3.1, p.3-7)

μ = 0,85 cps = 0,85.10^{-3} kg/m.s (Geankoplis, 1997, tab.A.3-4, p.876)

= 0,5712.10^{-3} lb/ft.s

Kapasitas = 21.732,9569 kg/hari = 33,2031 lb/menit

$$\text{Rate volumetrik} = \frac{33{,}2031\,\text{lb/menit}}{37{,}1146\,\text{lb/ft}^3} = 0{,}8946\ \text{ft}^3/\text{menit}$$

= 0,0149 ft^3/s = 6,6925 gal/min

Dianggap $N_{Re} > 2100$

$Di_{opt} = 3{,}9.q_f^{0,45}.\rho^{0,13}$ in (Peters & Timmerhaus, 1991 , eq.15, p. 496)

$= 3{,}9.\ 0{,}0149^{0,45}.\ (37{,}1146)^{0,13} = 0{,}9398 \text{ in} \approx 0{,}957 \text{ in}$

Dari Kern, 1965, p. 844 diperoleh:

Ukuran pipa IPS : 1 in ; sch. 80

ID = 0,957 in

OD = 1,315 in

$A_p = 0{,}7193 \text{ in}^2$

Kecepatan aliran:

$$v = \frac{Q}{A} = \frac{0{,}0149 \text{ ft}^3/\text{s}}{0{,}7193/144 \text{ ft}^2} = 2{,}9829 \text{ ft}^3/\text{s}$$

$$N_{Re} = \frac{D.v.\rho}{\mu} = \frac{0{,}957/12 \times 2{,}9829 \times 37{,}1146}{0{,}5712.10^{-3}} = 15.457{,}0272$$

Untuk aliran turbulen (steel pipe) digunakan:

$$f = \frac{0{,}04}{\left(N_{Re}\right)^{0,16}} = \frac{0{,}04}{(15.457{,}0272)^{0,16}} = 0{,}0085$$

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

Panjang pipa lurus = 30 ft

<u>Panjang pipa ekivalen:</u>

- 1 buah gate valve, Le/D = 7 (Peters & Timmerhaus, 1991 , tab.1, p.485)
  Le = 1 × 7 × 0,957/12 ft = 0,5583 ft
- 1 buah globe valve, Le/D = 300 (Peters & Timmerhaus, 1991 , tab.1, p.485)
  Le = 1 × 300 × 0,957/12 ft = 23,925 ft
- 3 buah elbow 90°, Le/D = 32 (Peters & Timmerhaus, 1991, tab.1, p.484)
  Le = 3 × 32 × 0,957/12 ft = 7,656 ft

Panjang total pipa = (30 + 0,5583 + 23,925 + 7,656) ft = 62,1393 ft

<u>Friksi yang melalui pipa dan fitting:</u>

$$F_1 = \frac{2.f.\Delta L.v^2}{D.gc} = \frac{2.0{,}0085.62{,}1393.2{,}9829^2}{0{,}957/12.32{,}17} = 3{,}6636 \text{ ft.lbf/lbm}$$

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

<u>Friksi karena contraction dan expansion:</u>

Untuk aliran turbulen $\alpha = 1$,

$$\frac{A_2}{A_1} = \frac{\pi/4.D_2^2}{\pi/4.D_1^2} = \frac{(0{,}987/12)^2}{1{,}7665^2} = 0{,}0022$$

$$Kc = 0{,}4\left(1{,}25 - \frac{A_2}{A_1}\right) = 0{,}4991 = 0{,}5$$

Kex = 1 (Brown, 1950)

$$F_2 = \frac{Kc.v^2}{2.\alpha.gc} + \frac{Kex.v^2}{2.\alpha.gc} = \frac{0{,}5.2{,}9829^2}{2.1.32{,}17} + \frac{1.2{,}9829^2}{2.1.32{,}17} = 0{,}2074 \text{ ft.lbf/lbm}$$

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

$\Sigma F = (3{,}6636 + 0{,}2074)$ ft.lbf/lbm = 3,8710 ft.lbf/lbm

Persamaan Bernoulli:

P_1 = 163 psi = 23.472 lb/ft^2

P_2 = 166,992 psi = 24.046,848 lb/ft^2

$v_1 = v_2 \approx 0$

$\Delta z = z_2 - z_1 = (18 - 12) = 6$ ft

$$-Ws = \frac{P_2 - P_1}{\rho} + \frac{v_2^2 - v_1^2}{2.\alpha.gc} + \frac{g}{gc}.\Delta z + \Sigma F$$

$$= \frac{24.046{,}848 - 23.472 \text{ lb/ft}^2}{37{,}1146 \text{ lb/ft}^3} + 0 + 6 + 3{,}8710$$

$$= 25{,}3595 \text{ ft.lbf/lbm}$$

Effisiensi pompa = 20 % (Peters & Timmerhaus, 1991, fig. 14-37, p.520)

$$\text{Brake hp} = \frac{-Ws.m}{\eta.550}$$ (Geankoplis, 1997, eq. 3.3-2, p. 134)

$$= \frac{25{,}3595 \text{ ft lbf/lbm}.33{,}2031/60 \text{ lbm/s}}{0{,}2.550\frac{\text{ft.lbf/s}}{\text{hp}}} = 0{,}1276 \text{ Hp}$$

Effisiensi motor = 80% (Peters & Timmerhaus, 1991, fig.14.38, p. 521)

Sehingga dipakai pompa dengan power motor = $\frac{0{,}1276}{0{,}8}$ = 0,1595 Hp ≈ 0,5 Hp

5. Tangki Pelarut NH_3 (F-110)

Fungsi : Untuk melarutkan gas NH_3 sebelum masuk ke reaktor I (R-210) dan reaktor II (R-220)

Tipe : Silinder tegak tertutup dengan tutup atas berbentuk *flange & dished* (fdha) dan tutup bawah juga berbentuk *flange & dished* (fdhb) serta dilengkapi sparger

Dasar pemilihan : Cocok untuk melarutkan gas

Kondisi operasi : P = 156 psia, T = 35°C

Kapasitas : 347.727,3212 kg/hari × 2,2 lb/kg = 765.000,1066 lb/hari

Jumlah : 1 buah

Perhitungan :

$$\frac{1}{\rho_{campuran}} = \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 845,7170 kg/m^3 × 0,0624 (lb/ft^3)/(kg/m^3) = 52,7981 lb/ft^3

$$\text{Volume larutan total} = \frac{765.000{,}1066 \text{ lb/hari}}{52{,}7981 \text{lb/ft}^3 \times 24 \text{ jam/hari}} = 603{,}7150 \text{ ft}^3$$

Dari Ulrich, 1984, p. 433: h = (1-1,5) × D

Diambil tinggi liquida (h) = 1,2.diameter tangki (D)

Volume larutan = volume silinder + volume fdh

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

603,7150 ft^3 $= \pi/4 \times D^2 \times 1{,}2.D + 0{,}000049 \times D^3$

D = 8,500 ft ≈ 8,5 ft = 2,6 m

h = 1,25.8,5 = 10,625 ft

Asumsi : Volume ruang kosong = 25% Volume larutan

Volume total = $1{,}25 \times (\pi/4 \times 8{,}5^2 \times 10{,}625 + 0{,}000049 \times 8{,}5^3)$

= 753,6824 ft^3

Volume tangki = volume silinder + volume fdha + volume fdhb

753,6824 ft^3 $= \pi/4 \times D^2 \times H + 0{,}000049 \times D^3 + 0{,}000049 \times D^3$

$= \pi/4 \times 8{,}5^2 \times H + 0{,}000049 \times 8{,}5^3 + 0{,}000049 \times 8{,}5^3$

H = 13,2809 ft ≈ 16 ft = 4,9 m (memenuhi)

Dari Ulrich,1984, tab.4-16, p.168: D = 0,01 – 5 m dan H = 0,03 – 5 m

Bahan konstruksi yang digunakan : stainless steel 18-8 tipe 304

Dari Brownell & Young, 1959, App. D, p. 342 diperoleh:

$f_{allowable} = 18.750\ lb/in^2$

$E = 0,85$

$c = {}^1/_2$ in

$$P = \frac{\rho \times h}{144} = \frac{52,7981 lb/ft^3 \times 10,625 ft}{144} = 3,8957 \text{ psi}$$

$P_{op} = 156 + 3,8957$ psi $= 159,8957$ psia (Ulrich,1984, p. 172)

$P_{desain} = 1,2 \times P_{op} = 1,2 \times 159,8957 = 191,8748$ psia

Perhitungan tebal tutup atas:

Radius = icr = 6% × D = 6% × 8,5 ft = 0,51 ft ≈ 5 $^7/_8$ in

Dari Brownell & Young, 1959, tabel 5.7, p. 90 diperoleh:

$t_{fdh} = {}^3/_8$ in

Perhitungan tinggi tutup atas:

Di = 8,5 ft = 102 in

Dari Brownell & Young tabel 5.7 diketahui untuk t = $^3/_8$ in, icr = 6 $^1/_8$ in, r = 96 in dan sf = 2,5 in

$$AB = \frac{Di}{2} - icr = 44,875 \text{ in}$$

BC = r – icr = 89,875 in

Kedalaman dish (b) = r - $\sqrt{(BC)^2 - (AB)^2}$ = 18,1299 in

Tinggi tutup atas = t + b + sf = 21,0049 in = 1,7504 ft

Perhitungan tebal shell:

$$t_{shell} = \frac{P \times D}{2 \times f \times E} + c = \frac{191,8748 lb/in^2 \times 8,5.12 in}{2 \times 18.750 lb/in^2 \times 0,85} + 1/2 \text{ in} = 1,1140 \text{ in} \approx 1\ {}^1/_8 \text{ in}$$

Perhitungan tebal tutup bawah:

Radius = icr = 6% × D = 6% × 8,5 ft = 0,51 ft ≈ 5 $^7/_8$ in

Dari Brownell & Young, 1959, tabel 5.7, p. 90 diperoleh:

$t_{fdh} = {}^3/_8$ in

Perhitungan tinggi tutup bawah:

Di = 8,5 ft = 102 in

Dari Brownell & Young tabel 5.7 diketahui untuk t = $^3/_8$ in, icr = 6 $^1/_8$ in, r = 96 in dan sf = 2,5 in

$$AB = \frac{Di}{2} - icr = 44{,}875 \text{ in}$$

BC = r – icr = 89,875 in

Kedalaman dish (b) = r - $\sqrt{(BC)^2 - (AB)^2}$ = 18,1299 in

Tinggi tutup atas = t + b + sf = 21,0049 in = 1,7504 ft

Tinggi total tangki pelarut = $H_{\text{tutup atas}} + H_{\text{shell}} + H_{\text{tutup bawah}}$

= 1,7504 ft + 16 ft + 1,7504 ft = 19,5008 ft

Perancangan sparger:

Berdasarkan Ulrich, 1984, p.172: ukuran bubble = 2 – 6 mm

do = 0,4 – 1,6 mm (Treybal, 1981, p.141) ditetapkan do = 1 mm = 0,0033 ft

μ_G = 1,1 cps = $0{,}74.10^{-3}$ lb/ft.s (Geankoplis, 1993, fig.A.3-5, p.879)

Reo = $4.wo/\pi.do.\mu_G$ (Treybal, 1981, p.141)

= (4.8,8542/200 lb/s)/(π. 0,0033 ft. $0{,}74.10^{-3}$ lb/ft.s) = 23.082,5503

dp = $0{,}0071.Reo^{-0,05}$ = 0,0071. $23.082{,}5503^{-0,05}$ (Treybal, 1981, eq.6.5, p.141)

= 0,0043 m = 0,0141 ft = 4,3 mm (memenuhi)

σ = 0,025 – 0,076 N/m (Treybal, 1981, p.143) ditetapkan 0,05 N/m = 0,11lb/s^2

$$vt = \sqrt{\frac{2.gc.\sigma}{dp.\rho} + \frac{gc.dp}{2}} = \sqrt{\frac{2.32{,}17.0{,}11}{0{,}0141.52{,}7981} + \frac{32{,}17.0{,}0141}{2}} = 1{,}0851 \text{ ft/s}$$

Perancangan jaket pendingin:

ρ = 855,6680 kg/m^3 × 0,0624 (lb/ft^3)/(kg/m^3) = 52,7981 lb/ft^3

μ = 0,9 cps = $0{,}9.10^{-3}$ kg/m.s = 2,1772 lb/ft.hr

k = 0,31 BTU/hr.ft^2.(°F/ft) (Kern,1965, tab.4, p.800)

c = 1,1 BTU/lb.°F (Kern,1965, fig.2, p.804)

L = 4 ft (Treybal, 1981, p.143)

N = (1,0851 ft/s)/4 ft = 0,2713 /s = 976,59 /hr

$$R_e = \frac{L^2.N.\rho}{\mu} = \frac{(4\text{ ft})^2.0{,}2713/\text{s}.52{,}7981\text{ lb/ft}^3}{0{,}0006\text{ lb/ft.s}} = 381.976{,}6541$$

$$j = \frac{h_j.D_j}{k}.\left(\frac{c.\mu}{k}\right)^{-1/2}.\left(\frac{\mu}{\mu_w}\right)^{-0{,}14} = 2.000$$ (Kern,1965, fig.20.2, p.718)

$$2.000 = \frac{h_j.8{,}5}{0{,}31}.\left(\frac{1{,}1.2{,}1772}{0{,}31}\right)^{-1/2}.(1)^{-0{,}14}$$

h_j = 202,7391 BTU/hr.ft^2.°F

$$hio = \frac{h_j.ID}{OD} = \frac{202{,}7391.8{,}5}{10{,}75} = 160{,}3053\text{ BTU/hr.ft}^2.°F$$

$$Uc = \frac{hj.hio}{hj + hio} = \frac{202{,}7391.160{,}3053}{202{,}7391 + 160{,}3053} = 89{,}5212\text{ BTU/hr.ft}^2.°F$$

Rd = 0,005 hd = 1/Rd = 1/0,005 = 200 (Kern, 1965)

$$Ud = \frac{Uc.hd}{Uc + hd} = \frac{89{,}5212.200}{89{,}5212 + 200} = 61{,}8408\text{ BTU/hr.ft}^2.°F$$

A = $\pi \times Dj \times z + \pi/4 \times Dj^2 = \pi \times 8{,}5 \times 10{,}625 + \pi/4 \times (8{,}5)^2$

= 340,4701 ft^2

6. Silo Gypsum (F-120)

Fungsi : Menyimpan gypsum untuk kebutuhan produksi

Tipe : Tangki vertikal dengan tutup atas berbentuk *flange only* dan tutup bawah berbentuk konis

Dasar pemilihan : Cocok untuk menampung padatan dengan kapasitas besar

Kondisi operasi : T = 30°C

P = 1 atm

Jumlah : 1 buah

Perhitungan:

Rate masuk = 27.799,8612 kg/hari

Waktu tinggal = 7 hari

Kapasitas $= 27.799,8612$ kg/hari x 7 hari

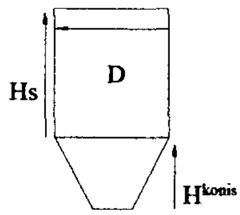
$= 194.599,0284$ kg

ρ_{bulk} gypsum $= 144,2021\ lb/ft^3 = 65,4034\ kg/ft^3$

$$\text{Volume gypsum} = \frac{194.599,0284\ kg}{65,4034\ kg/ft^3} = 2.975,3656\ ft^3$$

Storage berbentuk silinder dengan tutup bawah berbentuk konis:

H = 1,5 D ; gypsum mengisi $^3/_4$ bagian shell



F-120

V_{gypsum} $= {}^3/_4 \cdot V_{shell} + V_{konis}$

$$= \frac{3}{4}\left(\frac{\pi.D^2.H}{4}\right) + \left(\frac{1}{3}.\frac{\pi}{4}.D^2.\frac{D}{2.tg\,60^\circ}\right)$$

$$= \frac{3}{4}\left(\frac{\pi.D^2.1,5.D}{4}\right) + \left(\frac{1}{3}.\frac{\pi}{4}.D^2.\frac{D}{2.tg\,60^\circ}\right)$$

$2.975,3656\ ft^3 = 0,8831\ D^3 + 0,0756\ D^3$

$D_{shell} = 14,5865\ ft \approx 15\ ft$

$H_{shell} = 1,5.\ D_{shell} = 1,5.\ 14,5865\ ft = 21,8798\ ft \approx 24\ ft$

$$H_{konis} = \frac{0,5.D}{tg\,60^\circ} = 4,2108\ ft$$

Perhitungan tebal shell:

$$t_{shell} = \frac{P.D}{2.f.E} + c \text{ ; dimana:}$$

- P = 1 atm = 14,7 psia
- D = 14,5865 ft
- f_u = 75.000 psia (untuk material SA-240 grade S tipe 304)

  f_m = 0,92 (untuk bahan kualitas B – *flange grade quality*)

$f_a = 1$ (untuk bahan yang tidak dikenakan radiograph)

$f_r = 1$ (untuk bahan yang tidak dikenakan *stress relief*)

$f_s = 0{,}25$ (untuk suhu operasi < 650°F)

$f_{allow} = f_u \cdot f_m \cdot f_a \cdot f_r \cdot f_s = 17250$

- E = 0,8 (untuk pengelasan tipe *doble welded butt joint*)

- c = 0,1 in

$$t_{shell} = \frac{14{,}7\ \text{psia}.14{,}5865\ \text{ft}.12\ \text{in/ft}}{2.17250.0{,}8} + 0{,}1$$

$= 0{,}1932$ in $\approx$ $^1/_4$ in (Brownell & Young, 1959, App. F item 2)

<u>Perhitungan tebal tutup atas (*flange only*):</u>

$t_{flange\ only} = t_{shell} = {}^1/_4$ in

sf = tinggi = 1,5 – 2,5 in; diambil 2 in (Brownell & Young, 1959, tabel 5.4)

$H_{flange\ only} = 0{,}1667$ ft

<u>Perhitungan tebal tutup bawah (*konis*):</u>

$\alpha = 60° \rightarrow z = 3{,}2$ (Bhattacharyya, 1991, p. 49)

Daerah yang jauh dari knuckle:

$$t_{konis} = \frac{P.D.z}{2.f.E} + c$$ (Bhattacharyya, 1991, eq. 4.2.17, p. 49)

$$t_{konis} = \frac{14{,}7\ \text{psia}.14{,}5865\ \text{ft}.12\ \text{in/ft}.3{,}2}{2.17250.0{,}8} + 0{,}1\ \text{in}$$

$= 0{,}3983$ in $\approx$ $^7/_{16}$ in (Brownell & Young, 1959, App. F item 2)

Daerah di sekitar knuckle:

$$t_{konis} = \frac{P.D}{2.f.E - P} \cdot \frac{1}{\cos 60°} + c$$ (Bhattacharyya, 1991, eq. 4.2.16, p. 47)

$$t_{konis} = \frac{14{,}7\ \text{psia}.14{,}5865\ \text{ft}.12\ \text{in/ft}}{2.17250.0{,}8 - 14{,}7} \cdot \frac{1}{\cos 60°} + 0{,}1\ \text{in}$$

$= 0{,}2866$ in $\approx$ $^5/_{16}$ in (Brownell & Young, 1959, App. F item 2)

maka untuk tebal konis dipilih nilai yang terbesar yaitu $^7/_{16}$ in.

<u>Tinggi silo keseluruhan:</u>

$H_{tangki} = H_{shell} + H_{flanged\ only} + H_{konis}$

$= 24\ ft + 0,1667\ ft + 4,2108\ ft$

$= 28,3775\ ft \approx 29\ ft$

7. Belt Conveyor (J-121)

Fungsi : Mengangkut gypsum dari silo gypsum (F-120) ke reaktor I (R- 210)

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

Dasar pemilihan : Ekonomis dan cocok untuk kapasitas besar

Kapasitas : 27.799,8612 kg/hari = 1.158,3276 kg/jam = 1,1583 ton/jam

Suhu operasi : 30°C

Bahan : Steel & rubber

Jumlah : 1 buah

Perhitungan:

Panjang belt conveyor : 25 ft

Sudut elevasi : 0°

Dari Perry, 1984, tabel 7-7 diperoleh:

Lebar belt = 14 in

Belt plies = 3 – 5

Belt speed = 100 ft/min

Kapasitas = 32 ton/jam

Spesifikasi diatas untuk material dengan densitas 100 lb/ft³. Untuk material dengan densitas 144,2021 lb/ft³ dan kapasitas 1,1583 ton/jam, diperoleh:

$$\text{Speed Belt} = \frac{1,1583}{32} \times \frac{100}{144,2021} \times 100\ \text{Fpm} = 2,5102\ \text{ft/min}$$

Tenaga untuk menggerakkan belt:

Berdasarkan Perry, 1950, fig. 14 diperoleh:

$Hp = TPH \times H \times 0,002 \times C$

$= 1,1583\ ton/jam \times 25\ ft \times 0,002 \times 1,5$

$= 0,0869\ Hp$

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

$$\text{Power yang dibutuhkan} = \frac{0{,}0869}{0{,}8} = 0{,}1086 \text{ Hp} \approx 0{,}5 \text{ Hp}$$

8. Bucket Elevator (J-122)

Fungsi : Memindahkan gypsum secara vertikal dari belt conveyor (J-121) ke reaktor I (R-210)

Tipe : *Centrifugal discharge bucket*

Dasar pemilihan : Cocok untuk transportasi bahan padat secara vertikal

Suhu operasi : 30°C

Jumlah : 1 buah

Perhitungan:

$$\text{Rate gypsum} = \frac{27.799{,}8612 \text{ kg/hari}}{24 \text{ jam/hari}} = 1.158{,}3276 \text{ kg/jam}$$

ρ_{bulk} gypsum = 144,2 lb/ft^3

Jarak vertikal = 25 ft

Sudut elevasi = 90°

Dari Perry, 1984, tabel 7-8, p.7-13, untuk kapasitas 14 ton/jam diperoleh data-data sebagai berikut :

Size of bucket = (6 × 4 × 4,5) in

Bucket spacing = 12 in

Bucket speed = 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

Belt width = 7 in

Data-data diatas didasarkan pada padatan dengan bulk density 100 lb/ft^3, jadi untuk padatan dengan bulk density 144,2 lb/ft^3 dengan kapasitas 1.158,3276 kg/jam diperoleh spesifikasi sebagai berikut :

$$\text{Kecepatan bucket} = \frac{1.158{,}3276 \text{ kg/jam}}{14.000 \text{ kg/jam}} \times \frac{100 \text{ lb/ft}^3}{144{,}2 \text{ lb/ft}^3} \times 225 \text{ ft/min}$$

$$= 12{,}9098 \text{ ft /min}$$

Tenaga bucket elevator:

$$Hp = \frac{TPH \cdot L}{500} \qquad \text{(Perry, 1984, p.7-13)}$$

dimana: TPH = kapasitas dalam ton / jam

L = tinggi elevasi bucket

$$Hp = \frac{1{,}1583 \text{ ton/jam} \times 25 \text{ ft}}{500} = 0{,}0579 \text{ Hp}$$

Effisiensi motor = 80% (Peters & Timmerhaus, 1991, Fig. 14-38, p.521), sehingga

dipakai motor dengan power = $\frac{0{,}0579}{0{,}8} = 0{,}0724$ Hp ≈ 0,5 Hp

9. Silo Sylvinite I (F-130)

Fungsi	: Menyimpan sylvinite untuk kebutuhan produksi di reaktor I (R-210)
Tipe	: Tangki vertikal dengan tutup atas berbentuk *flange only* dan tutup bawah berbentuk konis
Dasar pemilihan	: Cocok untuk menampung padatan dengan kapasitas besar
Kondisi operasi	: T = 30°C P = 1 atm
Jumlah	: 1 buah

Perhitungan:

Rate masuk = 30.951,5897 kg/hari

Waktu tinggal = 30 hari

Kapasitas = 30.951,5897 kg/hari x 30 hari

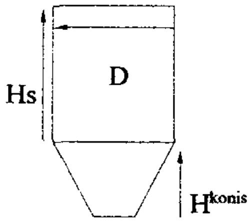
= 928.547,6910 kg

ρ_{bulk} sylvinite = 123,5663 lb/ft^3 = 56,0439 kg/ft^3

Volume sylvinite = $\dfrac{928.547,6910 \text{ kg}}{56,0439 \text{ kg/ft}^3}$ = 16.568,2205 ft^3

Storage berbentuk silinder dengan tutup bawah berbentuk konis:

H = 1,5 D ; sylvinite mengisi $^3/_4$ bagian shell



F-130

$V_{sylvinite}$ = $^3/_4$. V_{shell} + V_{konis}

$$= \frac{3}{4}\left(\frac{\pi.D^2.H}{4}\right) + \left(\frac{1}{3}.\frac{\pi}{4}.D^2.\frac{D}{2.tg\,60°}\right)$$

$$= \frac{3}{4}\left(\frac{\pi.D^2.1{,}5.D}{4}\right) + \left(\frac{1}{3}.\frac{\pi}{4}.D^2.\frac{D}{2.tg\,60°}\right)$$

16.568,2205 ft^3 = 0,8831 D^3 + 0,0756 D^3

D_{shell} = 25,8542 ft ≈ 26 ft

H_{shell} = 1,5. D_{shell} = 1,5. 25,8542 ft = 38,7813 ft ≈ 40 ft

$H_{konis} = \dfrac{0{,}5.D}{tg\,60°}$ = 7,4635 ft

Perhitungan tebal shell:

$$t_{shell} = \frac{P.D}{2.f.E} + c$$

dimana:

- P = 1 atm = 14,7 psia
- D = 25,8542 ft
- f_u = 75.000 psia (untuk material SA-240 grade M tipe 316)
  f_m = 0,92 (untuk bahan kualitas B – *flange grade quality*)
  f_a = 1 (untuk bahan yang tidak dikenakan radiograph)

$f_r = 1$ (untuk bahan yang tidak dikenakan *stress relief*)

$f_s = 0{,}25$ (untuk suhu operasi < 650°F)

$f_{allow} = f_u.\ f_m.\ f_a.\ f_r.\ f_s = 17.250$

- $E = 0{,}8$ (untuk pengelasan tipe *doble welded butt joint*)

- $c = 0{,}1$ in

$$t_{shell} = \frac{14{,}7\ \text{psia}.25{,}8542\ \text{ft}.12\ \text{in/ft}}{2.17250.0{,}8} + 0{,}1$$

$= 0{,}2652$ in $\approx {}^5/_{16}$ in (Brownell & Young, 1959, App. F item 2)

<u>Perhitungan tebal tutup atas (*flange only*):</u>

$t_{flange\ only} = t_{shell} = {}^5/_{16}$ in

sf = tinggi = 1,5 – 3 in; diambil 2,25 in (Brownell & Young, 1959, tabel 5.4)

$H_{flange\ only} = 0{,}1875$ ft

<u>Perhitungan tebal tutup bawah (*konis*):</u>

$\alpha = 60^\circ \rightarrow z = 3{,}2$ (Bhattacharyya, 1991, p. 49)

Daerah yang jauh dari knuckle:

$$t_{konis} = \frac{P.D.z}{2.f.E} + c$$ (Bhattacharyya, 1991, pers. 4.2.17, p. 49)

$$t_{konis} = \frac{14{,}7\ \text{psia}.25{,}8542\ \text{ft}.12\ \text{in/ft}.3{,}2}{2.17250.0{,}8} + 0{,}1\ \text{in}$$

$= 0{,}6288$ in $\approx {}^{11}/_{16}$ in (Brownell & Young, 1959, App. F item 2)

Daerah di sekitar knuckle:

$$t_{konis} = \frac{P.D}{2.f.E - P}.\frac{1}{\cos 60^\circ} + c$$ (Bhattacharyya, 1991, eq. 4.2.16, p. 47)

$$t_{konis} = \frac{14{,}7\ \text{psia}.25{,}8542\ \text{ft}.12\ \text{in/ft}}{2.12650.0{,}8 - 14{,}7}.\frac{1}{\cos 60^\circ} + 0{,}1\ \text{in}$$

$= 0{,}4307$ in $\approx {}^7/_{16}$ in (Brownell & Young, 1959, App. F item 2)

maka untuk tebal konis dipilih nilai yang terbesar yaitu ${}^{11}/_{16}$ in.

Tinggi silo keseluruhan:

$H_{tangki} = H_{shell} + H_{flanged\ only} + H_{konis}$

$= 40\ ft + 0{,}1875\ ft + 7{,}4635\ ft$

$= 47{,}6510\ ft \approx 48\ ft$

10. Belt Conveyor (J-131)

Fungsi : Mengangkut sylvinite dari silo sylvinite I (F-130) ke reaktor I (R- 210)

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

Dasar pemilihan : Ekonomis dan cocok untuk kapasitas besar

Kapasitas : 30.951,5897 kg/hari = 1.289,6496 kg/jam = 1,2896 ton/jam

Suhu operasi : 30°C

Bahan : Steel & rubber

Jumlah : 1 buah

Perhitungan:

Panjang belt conveyor : 25 ft

Sudut elevasi : 0°

Dari Perry, 1984, tabel 7-7 diperoleh:

Lebar belt = 14 in

Belt plies = 3 – 5

Belt speed = 100 ft/min

Kapasitas = 32 ton/jam

Spesifikasi diatas untuk material dengan densitas 100 lb/ft^3. Untuk material dengan densitas 123,5663 lb/ft^3 dan kapasitas 1,2896 ton/jam, diperoleh:

$$\text{Speed Belt} = \frac{1{,}2896}{32} \times \frac{100}{123{,}5663} \times 100\ \text{Fpm} = 3{,}2614\ \text{ft/min}$$

Tenaga untuk menggerakkan belt:

Berdasarkan Perry, 1950, fig. 14 diperoleh:

$Hp = TPH \times H \times 0{,}002 \times C$

$= 1{,}2896\ ton/jam \times 25\ ft \times 0{,}002 \times 1{,}5$

$= 0{,}0967\ Hp$

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

Power yang dibutuhkan = $\dfrac{0,0967}{0,8}$ = 0,1209 Hp ≈ 0,5 Hp

11. Bucket Elevator (J-132)

Fungsi : Memindahkan sylvinite secara vertikal dari belt conveyor (J-131) ke reaktor I (R-210)

Tipe : *Centrifugal discharge bucket*

Dasar pemilihan : Cocok untuk transportasi bahan padat secara vertikal

Suhu operasi : 30°C

Jumlah : 1 buah

Perhitungan:

Rate sylvinite $= \dfrac{30.951,5897 \text{ kg/hari}}{24 \text{ jam/hari}} = 1.289,6496 \text{ kg/jam}$

ρ_{bulk} sylvinite = 123,5663 lb/ft^3

Jarak vertikal = 25 ft

Sudut elevasi = 90°

Dari Perry, 1984, table 7-8, p.7-13, untuk kapasitas 14 ton/jam diperoleh data-data sebagai berikut :

Size of bucket = (6 × 4 × 4,5) in

Bucket spacing = 12 in

Bucket speed = 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

Belt width = 7 in

Data-data diatas didasarkan pada padatan dengan bulk density 100 lb/ft^3, jadi untuk padatan dengan bulk density 123,5663 lb/ft^3 dengan kapasitas 1.289,6496 kg/jam diperoleh spesifikasi sebagai berikut :

$$\text{Kecepatan bucket} = \frac{1.289{,}6496\ \text{kg/jam}}{14.000\ \text{kg/jam}} \times \frac{100\ \text{lb/ft}^3}{123{,}5663\ \text{lb/ft}^3} \times 225\ \text{ft/min}$$

$$= 16{,}7736\ \text{ft/min}$$

Tenaga bucket elevator:

$$Hp = \frac{TPH \cdot L}{500} \qquad \text{(Perry, 1984, p.7-13)}$$

dimana: TPH = kapasitas dalam ton / jam

L = tinggi elevasi bucket

$$Hp = \frac{1{,}2896\ \text{ton/jam} \times 25\ \text{ft}}{500} = 0{,}0645\ Hp$$

Effisiensi motor = 80% (Peters & Timmerhaus, 1991, Fig. 14-38, p.521), sehingga dipakai motor dengan power = $\frac{0{,}0645}{0{,}8}$ = 0,0806 Hp ≈ 0,5 Hp

12. Reaktor I (R-210)

Fungsi : Sebagai tempat mereaksikan sylvinite dan gypsum

Tipe : Silinder tegak tertutup dengan tutup atas berbentuk *flange & standard dished* (fdh) dan tutup bawah berbentuk konis dilengkapi dengan pengaduk dan jaket pendingin

Dasar pemilihan : Cocok untuk larutan yang banyak mengandung padatan

Kondisi operasi : T = 35°C

Kapasitas : 336.750,0629 kg/hari × 2,2 lb/kg = 740.850,1384 lb/hari

Jumlah : 1 buah

Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} + \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 855,6680 kg/m^3 × 0,0624 $(lb/ft^3)/(kg/m^3)$ = 53,4194 lb/ft^3

$$\text{Volume larutan total} = \frac{740.850{,}1384\ \text{lb/hari}}{53{,}4194\ \text{lb/ft}^3 \times 24\ \text{jam/hari}} = 577{,}8567\ \text{ft}^3$$

Dari Ulrich, 1984, p. 433:

$h = (1\text{-}1{,}5) \times D$

Diambil tinggi liquida (h) = 1,25.diameter tangki (D)

Asumsi : $^1/_2$ Sudut konis = α = 45°

Volume larutan = volume silinder + volume konis

$= \pi/4 \times D^2 \times h + (0{,}131 \times D^3)/\text{tg}\ \alpha$

$577{,}8567\ \text{ft}^3 = \pi/4 \times D^2 \times 1{,}25.D + (0{,}131 \times D^3)/\text{tg}\ 45°$

$D = 8{,}0379\ \text{ft} \approx 9\ \text{ft}$

$h = 1{,}25.9 = 11{,}25\ \text{ft}$

Asumsi: Volume ruang kosong = 25% Volume larutan

Volume total = $1{,}25 \times (\pi/4 \times 9^2 \times 11{,}25 + (0{,}131 \times 9^3)/\text{tg}\ 45°)$

$= 1.013{,}9913\ \text{ft}^3$

Volume tangki = volume silinder + volume fdh + volume konis

$1.013{,}9913\ \text{ft}^3 = \pi/4 \times D^2 \times H + 0{,}000049 \times D^3 + (0{,}131 \times D^3)/\text{tg}\ \alpha$

$= \pi/4 \times 9^2 \times H + 0{,}000049 \times 9^3 + (0{,}131 \times 9^3)/\text{tg}\ 45°$

$H = 14{,}4372\ \text{ft} \approx 18\ \text{ft}$ (memenuhi)

H/D = 2 (Dari Ulrich,1984, p. 433 H = (1,5-2,0) × D)

Bahan konstruksi yang digunakan : stainless steel 18-8 tipe 304

Dari Brownell & Young, 1959, App. D, p. 342 diperoleh:

$f_{allowable} = 18.750\ \text{lb/in}^2$

E = 0,85

c = $^1/_4$ in

$$P = \frac{\rho \times h}{144} = \frac{53{,}4194\ \text{lb/ft}^3 \times 11{,}25\ \text{ft}}{144} = 4{,}1734\ \text{psi}$$

$P_{tot} = 14{,}7 + 4{,}1734 = 18{,}8734$ psia

$P_{desain} = 1{,}2 \times P_{tot} = 1{,}2 \times 18{,}8734 = 22{,}6481$ psia

Perhitungan tebal shell:

$$t_{shell} = \frac{P \times D}{2 \times f \times E} + c = \frac{22{,}6481\,\text{lb/in}^2 \times 9/12\,\text{in}}{2 \times 18.750\,\text{lb/in}^2 \times 0{,}85} + 1/4\,\text{in} = 0{,}2505\ \text{in} \approx {}^5/_{16}\ \text{in}$$

Perhitungan tebal tutup atas:

Radius = icr = 6% × D = 6% × 9 ft = 0,54 ft ≈ 6 $^1/_2$ in

Dari Brownell & Young, 1959, tabel 5.7, p. 90 diperoleh:

$t_{fdh} = {}^3/_8$ in

Perhitungan tinggi tutup atas:

Di = 9 ft = 108 in

Dari Brownell & Young tabel 5.7 diketahui untuk t = $^3/_8$ in, icr = 6 $^1/_2$ in, r = 102 in dan sf = 2 in

$$AB = \frac{Di}{2} - icr = 47{,}5\ \text{in}$$

BC = r – icr = 95,5 in

Kedalaman dish (b) = r - $\sqrt{(BC)^2 - (AB)^2}$ = 19,1507 in

Tinggi tutup atas = t + b + sf = 21,5257 in = 1,7938 ft

Perhitungan tebal tutup bawah:

$$t_{konis} = \frac{P \times D}{2 \times \cos\alpha \times (f \times E - 0{,}6 \times P)} + c$$

$$= \frac{22{,}6481\,\text{lb/in}^2 \times 9/12\,\text{in}}{2 \times \cos 45° \times (18.750\,\text{lb/in}^2 \times 0{,}85 - 0{,}6 \times 22{,}6481\,\text{lb/in}^2)} + 1/4\,\text{in}$$

=0,2507 in ≈ $^5/_{16}$ in

Perhitungan tinggi tutup bawah:

$$H_{konis} = \frac{0{,}5.D}{tg\,45°} = \frac{0{,}5.9\,\text{ft}}{tg\,45°} = 4{,}5\ \text{ft}$$

Perhitungan tinggi keseluruhan tangki:

Tinggi tangki = tinggi shell + tinggi tutup atas + tinggi tutup bawah

= 18 ft + 1,7938 ft + 4,5 ft = 24,2938 ft ≈ 25 ft

Perhitungan pengaduk:

Jenis pengaduk: *flat six blade turbine*

Dari Geankoplis, 1993 diperoleh:

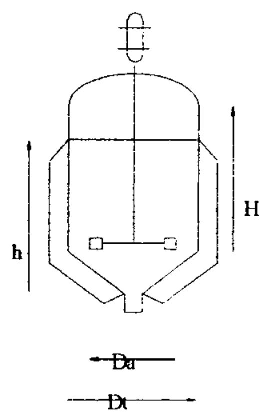
$C/D_t = {}^1/_3$ (tabel 3.4-1, p. 144) $\rightarrow C = {}^1/_3 \cdot 9$ ft = 3 ft = 0,9146 m

D_a/D_t = 0,25-0,5 (p. 146) diambil 0,3 $\rightarrow D_a = 0,3 \cdot 9$ ft = 2,7 ft = 0,8232 m

Dimana: C = jarak pengaduk

D_a = diameter impeller

D_t = diameter tangki



Kecepatan putar impeller diambil 125 rpm

$\mu_{campuran}$ = 4 cps = 4.10^{-3} kg/m.s

$$sg_{campuran} = \frac{\rho_{camp}}{\rho_{air}} = 0,8613$$

$$N_{Re}' = \frac{D_a^2.N.\rho}{\mu} = \frac{(0,8232\,m)^2 \times 125/60\,rps \times 855,6680\,kg/m^3}{4.10^{-3}\,kg/m.s} = 294.639,4669$$

Dari Geankoplis, 1993, fig.3.4-4, p.145 dengan memotongkan kurva 1 dengan N_{Re}' diperoleh N_p = 5

$$\text{Jumlah impeller} = \frac{sg \times H}{D} = \frac{0,8613 \times 18}{9} = 1,7226 \approx 2$$

Power = $N_p \times \rho \times N^3 \times D_a^5$ = 5 × 855,6680 × $(125/60)^3$ × $0,8232^5$

= 14.624,4113 J/s

Power 2 impeller = 2 × 14.624,4113 J/s = 21,8108 Hp

Power input = 1,1 × 21,8108 Hp = 23,9919 Hp

Transmission system losses = 0,2 × Power input = 0,2 × 21,8108 Hp = 4,3622 Hp

Power motor = Power input + Transmission system losses

= (23,9919 + 4,3622) Hp = 28,3541 Hp ≈ 30 Hp

Perancangan jaket pendingin:

L = 2,7 ft

N = 125 rpm × 60 = 7500 rev/hr

ρ = 855,6680 kg/m^3 × 0,0624 (lb/ft^3)/(kg/m^3) = 53,4194 lb/ft^3

μ = 4 cps = 4.10^{-3} kg/m.s = 9,6764 lb/ft.hr

k = 0,34 BTU/hr.ft^2.(°F/ft) (Kern,1965, tab.4, p.800)

c = 0,85 BTU/lb.°F (Kern,1965, fig.2, p.804)

$$R_{ej} = \frac{L^2.N.\rho}{\mu} = \frac{(2,7\ \text{ft})^2.7500\ \text{rev/hr}.53,4194\ \text{lb/ft}^3}{9,6764\ \text{lb/ft.hr}} = 301.838,0486$$

$$j = \frac{h_j.D_j}{k}.\left(\frac{c.\mu}{k}\right)^{-1/2}.\left(\frac{\mu}{\mu_w}\right)^{-0,14} = 1.700$$ (Kern,1965, fig.20.2, p.718)

$$1700 = \frac{h_j.9}{0,34}.\left(\frac{0,85.9,6764}{0,34}\right)^{-1/2}.(1)^{-0,14}$$

h_j = 315,8724 BTU/hr.ft^2.°F

$$hio = \frac{h_j.ID}{OD} = \frac{315,8724.9}{9,0521} = 314,0544\ \text{BTU/hr.ft}^2.°\text{F}$$

$$Uc = \frac{hj.hio}{hj + hio} = \frac{315,8724.314,0544}{315,8724 + 314,0544} = 156,5740\ \text{BTU/hr.ft}^2.°\text{F}$$

Rd = 0,005 (Kern, 1965)

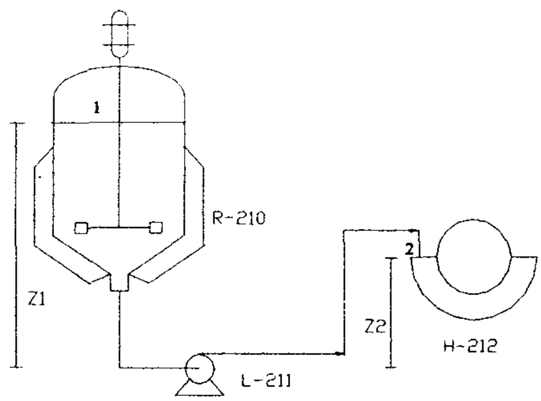
hd = 1/Rd = 1/0,005 = 200

$$Ud = \frac{Uc.hd}{Uc + hd} = \frac{156,5740.200}{156,5740 + 200} = 87,8213\ \text{BTU/hr.ft}^2.°\text{F}$$

A = π × Dj × z + π/4 × Dj^2 = π × 9 × 11,25 + π/4 × (9)^2

= 381,7035 ft^2

13. Pompa (L-211)



Fungsi : Untuk memompa larutan dari reaktor I (R-210) menuju rotary drum separator I (H-212)

Tipe : Centrifugal

Dasar pemilihan : 1. Cocok untuk liquida dengan viskositas rendah

2. Cocok untuk rate massa besar

Jumlah : 1 buah

Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} + \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 855,6680 kg/m^3 × 0,0624 (lb/ft^3)/(kg/m^3) = 53,4194 lb/ft^3

$\mu_{campuran}$ = 4 cps = 4.10^{-3} kg/m.s = 2,6879.10^{-3} lb/ft.s

Kapasitas = 336.750,0629 kg/hari = 233,8542 kg/menit = 514,4793 lb/menit

$$\text{Rate volumetrik} = \frac{514{,}4793\ \text{lb/menit}}{53{,}4194\ \text{lb/ft}^3} = 9{,}6309\ \text{ft}^3/\text{menit}$$

= 0,1605 ft^3/detik = 72,0420 gal/min

Dianggap $N_{Re} > 2100$

$Di_{opt} = 3{,}9.q_f^{0,45}.\rho^{0,13}$ in (Peters & Timmerhaus, 1991 , eq.15, p. 496)

$= 3{,}9.\ 0{,}1605^{0,45}.\ (53{,}4194)^{0,13} = 2{,}8716$ in ≈ 3,068 in

Dari Brown, 1950, tab. 23, p.123 diperoleh:

Ukuran pipa 3 in sch. 40

ID = 3,068 in

OD = 3,5 in

A_p = 7,393 in^2

Kecepatan aliran:

$$v = \frac{Q}{A} = \frac{0,1605\ ft^3/detik}{7,393/144\ ft^2} = 3,1262\ ft/detik$$

$$N_{Re} = \frac{D.v.\rho}{\mu} = \frac{3,068/12 \times 3,1262 \times 53,4194}{2,6879.10^{-3}} = 15.884,6177$$

Untuk aliran turbulen (steel pipe) digunakan:

$f = 0,04/(N_{Re}^{0,16})$ (Peters & Timmerhaus, 1991, eq.8, p.483)

$= 0,04/(15.884,6177^{0,16}) = 0,0085$

Panjang pipa lurus = 39,36 ft

Panjang pipa ekivalen:

- 1 buah gate valve, Le/D = 7 (Peters & Timmerhaus, 1991, tab.1, p.484)

  Le = 1 × 7 × 3,068/12 ft = 1,7897 ft
- 1 buah globe valve, Le/D = 300 (Peters & Timmerhaus, 1991, tab.1, p.484)

  Le = 1 × 300 × 3,068/12 ft = 76,7 ft
- 4 buah elbow 90°, Le/D = 32 (Peters & Timmerhaus, 1991, tab.1, p.484)

  Le = 4 × 32 × 3,068/12 ft = 32,7253 ft

Panjang total pipa = (39,36 + 1,7897 + 76,7 + 32,7253) ft = 183,3003 ft

Friksi yang melalui pipa dan fitting:

$$F_1 = \frac{2.f.\Delta L.v^2}{D.gc} = \frac{2.0,0085.183,3003.3,1262^2}{3,068/12.32,17} = 3,7027\ ft.lbf/lbm$$

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

Friksi karena contraction:

Untuk aliran turbulen α = 1, tangki konis Kc = 0,05

$$F_2 = \frac{Kc.v^2}{2.\alpha.gc} = \frac{0,05.3,1262^2}{2.1.32,17} = 0,0024\ ft.lbf/lbm$$

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

ΣF = (3,7027 + 0,0024) ft.lbf/lbm = 3,7051 ft.lbf/lbm

Persamaan Bernoulli:

$\Delta z = z_2 - z_1 = 29 - 15{,}75 = 13{,}25$ ft

$$-Ws = \frac{P_2 - P_1}{\rho} + \frac{v_2^2 - v_1^2}{2.\alpha.gc} + \frac{g}{gc}.\Delta z + \Sigma F$$

$$= 0 + \frac{3{,}1262^2 - 0}{2.1.32{,}17} + 13{,}25 + 3{,}7051$$

$$= 17{,}1070 \text{ ft.lbf/lbm}$$

Effisiensi pompa = 38% (Peters & Timmerhaus, 1991, fig. 14-37, p.520)

$$\text{Brake hp} = \frac{-Ws.m}{\eta.550}$$ (Geankoplis, 1997, eq. 3.3-2, p.134)

$$= \frac{17{,}1070 \text{ft lbf/lbm} .514{,}4793\ /60 \text{ lbm/s}}{0{,}38.550\frac{\text{ft.lbf/s}}{\text{hp}}} = 0{,}7018 \text{ HP}$$

Effisiensi motor = 80% (Peters & Timmerhaus, 1991, fig.14.38, p. 521)

Sehingga dipakai pompa dengan power motor = $\frac{0{,}7018}{0{,}8} = 0{,}8773$ HP ≈ 1 HP

14. Rotary Drum Separator I (H-212)

Fungsi : Untuk menyaring endapan sebagai hasil reaksi dari reaktor I (R-210)

Tipe : *Continuous Rotary Drum Filter*

Kondisi operasi : T = 35°C

Dasar pemilihan : Retention liquid pada cake rendah

Pengoperasian sederhana

Perhitungan:

$P = 1 \text{ atm} = 1{,}01.10^5$ Pa

C_x = konsentrasi padatan = 52.994,5141/336.750,0629 = 0,1572 kg solid/kg slurry

$$m = \frac{\text{berat cake basah}}{\text{berat cake kering}} = \frac{25.774{,}0512}{52.994{,}5141} = 0{,}4864$$

Pada T = 35°C :

$\rho = 993{,}965 \text{ kg/m}^3$

$\mu = 0{,}7228$ cps $= 0{,}7228.10^{-3}$ kg/m.s

$\alpha = 4{,}37.10^{9} . \Delta P^{0,3} = 4{,}37.10^{9} . (0{,}5.10^{5})^{0,3} = 1{,}1225.10^{11}$ m/kg

f = fraksi drum yang tercelup dalam slurry = 33%

$$C_s = \frac{\rho.C_x}{1 - m.C_x} = \frac{993{,}965.0{,}1572}{1 - 0{,}4864.0{,}1572}$$ (Geankoplis, 1993, eq.14.2-10)

$= 169{,}1877$ kg solid/m^3 filtrat

Filter cycle time = 250 detik

kg slurry/detik = 336.750,0629 kg/hari = 3,8976 kg/detik

$$\frac{V}{tc} = \frac{3{,}8976.C_x}{C_s} = \frac{3{,}8976.0{,}1572}{169{,}1877} = 3{,}6214.10^{-3} \text{ m}^3 \text{ filtrat / detik}$$

$$\frac{V}{A.tc} = \left(\frac{2.f\Delta P}{tc.\mu c.\mu._s}\right)^{1/2}$$

(Geankoplis,1993,eq.14.2-24)

$$\frac{3{,}6214.10^{-3}}{A} = \left(\frac{2.0{,}33.0{,}5.10^{5}}{250.0{,}7228.10^{-3}.1{,}1225.10^{11}.169{,}1877}\right)^{1/2}$$

$A = 36{,}9297$ m^2

15. Screw Conveyor (J-213)

Fungsi : Mengangkut cake yang keluar dari rotary drum separator I (H-212) menuju ke reaktor II (R-220)

Tipe : *Standard pitch screw conveyor*

Dasar pemilihan : Membutuhkan ruangan sedikit, harga murah, pemeliharaan mudah, cocok untuk memindahkan padatan berbentuk kristal basah

Data : Kapasitas = 25.774,0512 kg/hari = 1.073,9188 kg/jam

Densitas = 1.214,8540 kg/m^3 = 75,8345 lb/ft^3

Elevasi = Horizontal

Perhitungan:

$$\text{Rate volumetric} = \frac{1.073{,}9188 \text{ kg/jam}}{1.214{,}8540 \text{ kg/m}^3} = 0{,}8840 \text{ m}^3\text{/jam} = 0{,}5203 \text{ ft}^3\text{/min}$$

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)

$$Hp = \frac{0{,}5203\ ft^3/min.10\ ft.75{,}8345\ lb/ft^3.3}{33000} = 0{,}0359\ Hp$$

Efisiensi motor = 80% (Peters & Timmerhaus, 1991, grafik 14-38, p. 521)

$$Power = \frac{100}{80}.0{,}0359\ Hp = 0{,}0449\ Hp$$

Dari Badger, 1957, hal 713: jika power < 2 Hp, maka power dikalikan dua.

Power = 0,0449 x 2 = 0,0898 Hp ≈ 0,5 Hp

16. Silo Sylvinite II (F-140)

Fungsi : Menyimpan sylvinite untuk kebutuhan produksi di reaktor II (R-220)

Tipe : Tangki vertikal dengan tutup atas berbentuk *flange only* dan tutup bawah berbentuk konis

Dasar pemilihan : Cocok untuk menampung padatan dengan kapasitas besar

Kondisi operasi : T = 30°C

P = 1 atm

Jumlah : 1 buah

Perhitungan:

Rate masuk = 28.954,4201 kg/hari

Waktu tinggal = 30 hari

Kapasitas = 28.954,4201 kg/hari x 30 hari

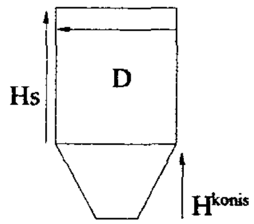
= 868.632,6030 kg

ρ_{bulk} sylvinite = 123,5663 lb/ft^3 = 56,0439 kg/ft^3

$$\text{Volume sylvinite} = \frac{868.632{,}6030\ \text{kg}}{56{,}0439\ \text{kg/ft}^3} = 15.499{,}1463\ \text{ft}^3$$

Storage berbentuk silinder dengan tutup bawah berbentuk konis:

H = 1,5 D ; sylvinite mengisi $^3/_4$ bagian shell



F-140

$$V_{sylvinite} = {}^3/_4 \,.\, V_{shell} + V_{konis}$$

$$= \frac{3}{4}\left(\frac{\pi.D^2.H}{4}\right) + \left(\frac{1}{3}.\frac{\pi}{4}.D^2.\frac{D}{2.tg60}\right)$$

$$= \frac{3}{4}\left(\frac{\pi.D^2.1{,}5.D}{4}\right) + \left(\frac{1}{3}.\frac{\pi}{4}.D^2.\frac{D}{2.tg60}\right)$$

$15.499{,}1463\ \text{ft}^3 = 0{,}8831\ D^3 + 0{,}0756\ D^3$

$D_{shell} = 25{,}2857\ \text{ft} \approx 26\ \text{ft}$

$H_{shell} = 1{,}5.\ D_{shell} = 1{,}5.\ 25{,}2857\ \text{ft} = 37{,}9286\ \text{ft} \approx 40\ \text{ft}$

$$H_{konis} = \frac{0{,}5.D}{tg\ 60°} = 7{,}2994\ \text{ft}$$

<u>Perhitungan tebal shell:</u>

$$t_{\,shell} = \frac{P.D}{2.f.E} + c$$

dimana:

- P = 1 atm = 14,7 psia
- D = 25,2857 ft
- f_u = 75.000 psia (untuk material SA-240 grade M tipe 316)

  f_m = 0,92 (untuk bahan kualitas B – *flange grade quality*)

  f_a = 1 (untuk bahan yang tidak dikenakan radiograph)

  f_r = 1 (untuk bahan yang tidak dikenakan *stress relief*)

$f_s = 0{,}25$ (untuk suhu operasi < 650°F)

$f_{allow} = f_u . f_m . f_a . f_r . f_s = 17.250$

- $E = 0{,}8$ (untuk pengelasan tipe *doble welded butt joint*)

- $c = 0{,}1$ in

$$t_{shell} = \frac{14{,}7\ \text{psia}.\ 25{,}2857\ \text{ft}.\ 12\ \text{in/ft}}{2.17250.0{,}8} + 0{,}1$$

$= 0{,}2616$ in $\approx {}^5/_{16}$ in (Brownell & Young, 1959, App. F item 2)

<u>Perhitungan tebal tutup atas (*flange only*):</u>

$t_{flange\ only} = t_{shell} = {}^5/_{16}$ in

sf = tinggi = 1,5 – 3 in; diambil 2,25 in (Brownell & Young, 1959, tabel 5.4)

$H_{flange\ only} = 0{,}1875$ ft

<u>Perhitungan tebal tutup bawah (*konis*):</u>

$\alpha = 60° \rightarrow z = 3{,}2$ (Bhattacharyya, 1991, p. 49)

Daerah yang jauh dari knuckle:

$$t_{konis} = \frac{P.D.z}{2.f.E} + c$$ (Bhattacharyya, 1991, pers. 4.2.17, p. 49)

$$t_{konis} = \frac{14{,}7\ \text{psia}.\ 25{,}2857\ \text{ft}.\ 12\ \text{in/ft}.\ 3{,}2}{2.17250.\ 0{,}8} + 0{,}1\ \text{in}$$

$= 0{,}6171$ in $\approx {}^5/_8$ in (Brownell & Young, 1959, App. F item 2)

Daerah di sekitar knuckle:

$$t_{konis} = \frac{P.D}{2.f.E - P} . \frac{1}{\cos 60°} + c$$ (Bhattacharyya, 1991, pers. 4.2.16, p. 47)

$$t_{konis} = \frac{14{,}7\ \text{psia}.\ 25{,}2857\ \text{ft}.\ 12\ \text{in/ft}}{2.17250.0{,}8 - 14{,}7} . \frac{1}{\cos 60°} + 0{,}1\ \text{in}$$

$= 0{,}4234$ in $\approx {}^7/_{16}$ in (Brownell & Young, 1959, App. F item 2)

maka untuk tebal konis dipilih nilai yang terbesar yaitu ${}^5/_8$ in.

<u>Tinggi silo keseluruhan:</u>

$H_{tangki} = H_{shell} + H_{flanged\ only} + H_{konis}$

$= 40 \text{ ft} + 0{,}1875 \text{ ft} + 7{,}2994 \text{ ft}$

$= 47{,}4869 \text{ ft} \approx 48 \text{ ft}$

17. Belt Conveyor (J-141)

Fungsi : Mengangkut sylvinite dari silo sylvinite II (F-140) ke reaktor II (R- 220)

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

Dasar pemilihan : Ekonomis dan cocok untuk kapasitas besar

Kapasitas : 28.954,4201 kg/hari = 1.206,4342 kg/jam = 1,2064 ton/jam

Suhu operasi : 30°C

Bahan : Steel & rubber

Jumlah : 1 buah

Perhitungan:

Panjang belt conveyor : 33 ft

Sudut elevasi : 0°

Dari Perry, 1984, tabel 7-7 diperoleh:

Lebar belt = 14 in

Belt plies = 3 – 5

Belt speed = 100 ft/min

Kapasitas = 32 ton/jam

Spesifikasi diatas untuk material dengan densitas 100 lb/ft^3. Untuk material dengan densitas 123,5663 lb/ft^3 dan kapasitas 1,2064 ton/jam, diperoleh:

$$\text{Speed Belt} = \frac{1{,}2064}{32} \times \frac{100}{123{,}5663} \times 100 \text{ Fpm } = 3{,}0510 \text{ ft/min}$$

Tenaga untuk menggerakkan belt:

Berdasarkan Perry, 1950, fig. 14 diperoleh:

$$\text{Hp} = \text{TPH} \times \text{H} \times 0{,}002 \times \text{C}$$

$$= 1{,}2064 \text{ ton/jam} \times 33 \text{ ft} \times 0{,}002 \times 1{,}5 = 0{,}1194 \text{ Hp}$$

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

$$\text{Power yang dibutuhkan} = \frac{0{,}1194}{0{,}8} = 0{,}1493 \text{ Hp} \approx 0{,}5 \text{ Hp}$$

18. Bucket Elevator (J-142)

Fungsi : Memindahkan sylvinite secara vertikal dari belt conveyor (J-141) ke reaktor II (R-220)

Tipe : *Centrifugal discharge bucket*

Dasar pemilihan : Cocok untuk transportasi bahan padat secara vertikal

Suhu operasi : 30°C

Jumlah : 1 buah

Perhitungan:

Rate sylvinite $= \dfrac{28.954,4201\ \text{kg/hari}}{24\ \text{jam/hari}} = 1.206,4342\ \text{kg/jam}$

ρ_{bulk} sylvinite $= 123,5663\ \text{lb/ft}^3$

Jarak vertikal = 20 ft

Sudut elevasi = 90°

Dari Perry, 1984, table 7-8, p.7-13, untuk kapasitas 14 ton/jam diperoleh data-data sebagai berikut :

Size of bucket = (6 × 4 × 4,5) in

Bucket spacing = 12 in

Bucket speed = 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

Belt width = 7 in

Data-data diatas didasarkan pada padatan dengan bulk density 100 lb/ft^3, jadi untuk padatan dengan bulk density 123,5663 lb/ft^3 dengan kapasitas 1.206,4342 kg/jam diperoleh spesifikasi sebagai berikut :

$$\text{Kecepatan bucket} = \frac{1.206,4342\ \text{kg/jam}}{14.000\ \text{kg/jam}} \times \frac{100\ \text{lb/ft}^3}{123,5663\ \text{lb/ft}^3} \times 225\ \text{ft/min}$$

$$= 15,6913\ \text{ft/min}$$

Tenaga bucket elevator:

$$Hp = \frac{TPH \cdot L}{500}$$ (Perry, 1984, p.7-13)

dimana: TPH = kapasitas dalam ton / jam

L = tinggi elevasi bucket

$$Hp = \frac{1{,}2064 \text{ ton/jam} \times 20 \text{ ft}}{500} = 0{,}0483 \text{ Hp}$$

Effisiensi motor = 80% (Peters & Timmerhaus, 1991, Fig. 14-38, p.521), sehingga

dipakai motor dengan power = $\frac{0{,}0483}{0{,}8}$ = 0,0604 Hp ≈ 0,5 Hp

19. Reaktor II (R-220)

Fungsi : Sebagai tempat mereaksikan sylvinite dan glaserit

Tipe : Silinder tegak tertutup dengan tutup atas berbentuk *flange & dished* (fdh) dan tutup bawah berbentuk konis dilengkapi dengan pengaduk dan jaket pendingin

Dasar pemilihan : Cocok untuk larutan yang banyak mengandung padatan

Kondisi operasi : P = 1 atm, T = 35°C

Kapasitas : 124.457,1696 kg/hari × 2,2 lb/kg = 273.805,7731 lb/hari

Jumlah : 1 buah

Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} + \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 873,4480 kg/m^3 × 0,0624 (lb/ft^3)/(kg/m^3) = 54,5294 lb/ft^3

$$\text{Volume larutan total} = \frac{273.805{,}7731 \text{ lb/hari}}{54{,}5294 \text{ lb/ft}^3 \times 24 \text{ jam/hari}} = 209{,}2188 \text{ ft}^3$$

Dari Ulrich, 1984, p. 433:

h = (1-1,5) × D

Diambil tinggi liquida (h) = 1,25.diameter tangki (D)

Asumsi: ½ Sudut konis = α = 45°

Volume larutan = volume silinder + volume konis

$= \pi/4 \times D^2 \times h + (0{,}131 \times D^3)/\text{tg}\ \alpha$

$209{,}2188\ ft^3 = \pi/4 \times D^2 \times 1{,}25.D + (0{,}131 \times D^3)/\text{tg}\ 45°$

$D = 5{,}7289\ ft \approx 6\ ft$

$h = 1{,}25.6 = 7{,}5\ ft$

Asumsi : Volume ruang kosong = 25% Volume larutan

Volume total $= 1{,}25 \times (\pi/4 \times 6^2 \times 7{,}5 + 0{,}000049 \times 6^3 + (0{,}131 \times 6^3)/\text{tg}\ 45°)$

$= 300{,}4551\ ft^3$

Volume tangki = volume silinder + volume fdh + volume konis

$300{,}4551\ ft^3 = \pi/4 \times D^2 \times H + 0{,}000049 \times D^3 + (0{,}131 \times D^3)/\text{tg}\ \alpha$

$= \pi/4 \times 6^2 \times H + 0{,}000049 \times 6^3 + (0{,}131 \times 6^3)/\text{tg}\ 45°$

$H = 9{,}6253\ ft \approx 12\ ft$ (memenuhi)

H/D = 2 (Dari Ulrich,1984, p. 433 H = (1,5-2,0) × D)

Bahan konstruksi yang digunakan : stainless steel 18-8 tipe 304

Dari Brownell & Young, 1959, App. D, p. 342 diperoleh:

$f_{allowable} = 18.750\ lb/in^2$

E = 0,85

c = 1/4 in

$$P = \frac{\rho \times h}{144} = \frac{54{,}5294\ lb/ft^3 \times 7{,}5\ ft}{144} = 2{,}84\ psi$$

$P_{tot} = 14{,}7 + 2{,}84 = 15{,}54$ psia

$P_{desain} = 1{,}2 \times P_{tot} = 1{,}2 \times 15{,}54 = 18{,}648$ psia

Perhitungan tebal shell:

$$t_{shell} = \frac{P \times D}{2 \times f \times E} + c = \frac{18{,}648\ lb/in^2 \times 6.12\ in}{2 \times 18.750\ lb/in^2 \times 0{,}85} + 1/4\ in = 0{,}2921\ in \approx {}^5/_{16}\ in$$

Perhitungan tebal tutup atas:

Radius = icr = 6% × D = 6% × 6 ft = 0,36 ft ≈ 4 $^3/_8$ in

Dari Brownell & Young, 1959, tabel 5.7, p. 90 diperoleh:

$t_{fdh} = {}^5/_{16}$ in

Perhitungan tinggi tutup atas:

Di = 6 ft = 72 in

Dari Brownell & Young tabel 5.7 diketahui untuk t = $^5/_{16}$ in, icr = 4 $^3/_8$ in, r = 72 in dan sf = 2 in

$$AB = \frac{Di}{2} - icr = 31{,}625 \text{ in}$$

BC = r – icr = 67,625 in

Kedalaman dish (b) = r - $\sqrt{(BC)^2 - (AB)^2}$ = 12,2254 in

Tinggi tutup atas = t + b + sf = 14,5379 in = 1,2115 ft

Perhitungan tebal tutup bawah:

$$t_{konis} = \frac{P \times D}{2 \times \cos\alpha \times (f \times E - 0{,}6 \times P)} + c$$

$$= \frac{18{,}648\,\text{lb/in}^2 \times 6.12\,\text{in}}{2 \times \cos 45° \times (18.750\,\text{lb/in}^2 \times 0{,}85 - 0{,}6 \times 18{,}648\,\text{lb/in}^2)} + 1/4\,\text{in}$$

$= 0{,}4499$ in $\approx$ $^1/_2$ in

Perhitungan tinggi tutup bawah:

$$H_{konis} = \frac{0{,}5.D}{tg\ 45°} = \frac{0{,}5.6\ \text{ft}}{tg\ 45°} = 3\ \text{ft}$$

Perhitungan tinggi keseluruhan tangki:

Tinggi tangki = tinggi shell + tinggi tutup atas + tinggi tutup bawah

= 12 ft + 1,2115 ft + 3 ft = 16,2115 ft

Perhitungan pengaduk:

Jenis pengaduk: *flat six blade turbine*

Dari Geankoplis, 1993 diperoleh:

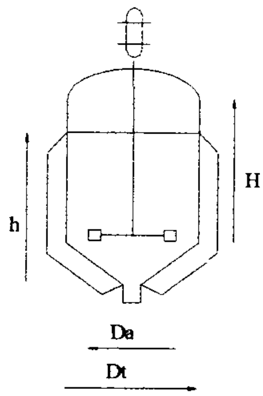
C/D_t = $^1/_3$ (tabel 3.4-1, p. 144)→ C = $^1/_3$. 6 ft = 2 ft = 0,6098 m

D_a/D_t = 0,25-0,5 (p. 146) diambil 0,3 → D_a = 0,3 . 6 ft = 1,8 ft = 0,5488 m

Dimana: C = jarak pengaduk

D_a = diameter impeller

D_t = diameter tangki



Kecepatan putar impeller diambil 125 rpm

$\mu_{campuran}$ = 4,35 cps = $4{,}35.10^{-3}$ kg/m.s

$$sg_{campuran} = \frac{\rho_{camp}}{\rho_{air}}$$

= 0,8788

$$N_{Re}' = \frac{D_a^2.N.\rho}{\mu} = \frac{(0{,}5488\,m)^2 \times 125/60\,rps \times 873{,}4480\,kg/m^3}{4{,}35.10^{-3}\,kg/m.s} = 125.989{,}6199$$

Dari Geankoplis, 1993, fig.3.4-4, p.145 dengan memotongkan kurva 1 dengan N_{Re}' diperoleh N_p = 5

$$\text{Jumlah impeller} = \frac{sg \times H}{D} = \frac{0{,}8788 \times 12}{6} = 1{,}7576 \approx 2$$

Power = $N_p \times \rho \times N^3 \times D_a^5$ = 5 × 873,4480 × $(125/60)^3$ × $0{,}5488^5$

= 1.965,8658 J/s

Power 2 impeller = 2 × 1.965,8658 J/s = 2,9319 Hp

Power input = 1,1 × 2,9319 Hp = 3,2251 Hp

Transmission system losses = 0,2 × Power input = 0,2 × 2,9319 Hp = 0,5864 Hp

Power motor = Power input + Transmission system losses

= (3,2251 + 0,5864) Hp = 3,8115 Hp ≈ 4 Hp

Perancangan jaket pendingin:

L = 1,8 ft

N = 125 rpm × 60 = 7500 rev/hr

ρ = 873,4480 kg/m^3 × 0,0624 (lb/ft^3)/(kg/m^3) = 54,5294 lb/ft^3

μ = 4,35 cps = 4,35.10^{-3} kg/m.s = 10,5321 lb/ft.hr

k = 0,34 BTU/hr.ft^2.(°F/ft) (Kern,1965, tab.4, p.800)

c = 0,85 BTU/lb.°F (Kern,1965, fig.2, p.804)

$$R_{ej} = \frac{L^2.N.\rho}{\mu} = \frac{(1{,}8\,ft)^2.7500\,rev/hr.54{,}5294\,lb/ft^3}{10{,}5321\,lb/ft.hr} = 125.811{,}9862$$

$$j = \frac{h_j.D_j}{k}\left(\frac{c.\mu}{k}\right)^{-1/2}.\left(\frac{\mu}{\mu_w}\right)^{-0{,}14} = 800$$ (Kern,1965, fig.20.2, p.718)

$$800 = \frac{h_j.6}{0{,}34}\left(\frac{0{,}85.10{,}5321}{0{,}34}\right)^{-1/2}.(1)^{-0{,}14}$$

h_j = 232,6190 BTU/hr.ft^2.°F

$$hio = \frac{h_j.ID}{OD} = \frac{232{,}6190.6}{6{,}625} = 210{,}6738\ BTU/hr.ft^2.°F$$

$$Uc = \frac{hj.hio}{hj+hio} = \frac{232{,}6190.210{,}6738}{232{,}6190+210{,}6738} = 110{,}5516\ BTU/hr.ft^2.°F$$

Rd = 0,005 (Kern, 1965)

hd = 1/Rd = 1/0,005 = 200

$$Ud = \frac{Uc.hd}{Uc+hd} = \frac{110{,}5516.200}{110{,}5516+200} = 71{,}1969\ BTU/hr.ft^2.°F$$

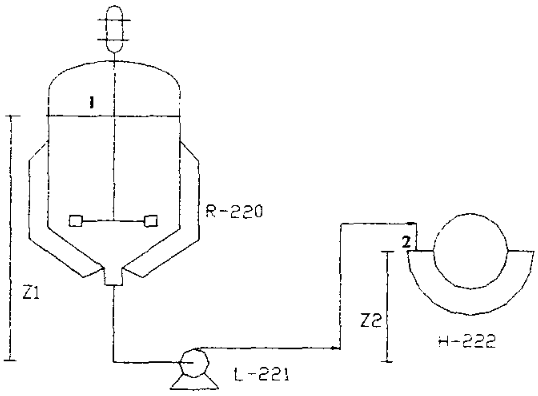
A = π × Dj × z + π/4 × Dj^2 = π × 6 × 7,5 + π/4 × (6)^2

= 169,6460 ft^2

20. Pompa (L-221)

Fungsi : Untuk memompa larutan dari reaktor II (R-220) menuju rotary drum separator II (H-222)

Tipe : Centrifugal



Dasar pemilihan : 1. Cocok untuk liquida dengan viskositas rendah

2. Cocok untuk rate massa besar

Jumlah : 1 buah

Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} + \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 873,4480 kg/m^3 × 0,0624 (lb/ft^3)/(kg/m^3) = 54,5294 lb/ft^3

$\mu_{campuran}$ = 4,35 cps = 4,35.10^{-3} kg/m.s = 2,9231.10^{-3} lb/ft.s

Kapasitas = 124.457,1696 kg/hari = 86,4286 kg/menit = 190,1429 lb/menit

$$\text{Rate volumetrik} = \frac{190{,}1429\ \text{lb/menit}}{54{,}5294\ \text{lb/ft}^3} = 3{,}4870\ \text{ft}^3/\text{menit}$$

= 0,0581 ft^3/detik = 26,0788 gal/min

Dianggap $N_{Re} > 2100$

$Di_{opt} = 3{,}9.q_f^{0,45}.\rho^{0,13}$ in (Peters & Timmerhaus, 1991 , eq.15, p. 496)

= 3,9. 0,0581^{0,45}. (54,5294)^{0,13} = 1,8227 in ≈ 2,067 in

Dari Brown, 1950, tab. 23, p.123 diperoleh:

Ukuran pipa 2 in sch. 40

ID = 2,067 in

OD = 2,375 in

A_p = 3,356 in^2

Kecepatan aliran:

$$v = \frac{Q}{A} = \frac{0,0581\,ft^3/detik}{3,356/144\,ft^2} = 2,4930 \text{ ft/detik}$$

$$N_{Re} = \frac{D.v.\rho}{\mu} = \frac{2,067/12 \times 2,4930 \times 54,5294}{2,9231.10^{-3}} = 8.010,6647$$

Untuk aliran turbulen (steel pipe) digunakan:

$f = 0,04/(N_{Re}^{0,16})$ (Peters & Timmerhaus,1991,eq.8, p.483)

$= 0,04/(8.010,6647^{0,16}) = 0,0095$

Panjang pipa lurus = 32 ft

Panjang pipa ekivalen:

- 1 buah gate valve, Le/D = 7 (Peters & Timmerhaus,1991,tab.1, p.484)
  Le = 1 × 7 × 2,067/12 ft = 1,2058 ft
- 1 buah globe valve, Le/D = 300 (Peters & Timmerhaus,1991,tab.1, p.484)
  Le = 1 × 300 × 2,067/12 ft = 51,675 ft
- 4 buah elbow 90°, Le/D = 32 (Peters & Timmerhaus,1991,tab.1, p.484)
  Le = 4 × 32 × 2,067/12 ft = 22,048 ft

Panjang total pipa = (32 + 1,2058 + 51,675 + 22,048) ft = 106,9288 ft

Friksi yang melalui pipa dan fitting:

$$F_1 = \frac{2.f\Delta L.v^2}{D.gc} = \frac{2.0,0095.106,9288.2,4930^2}{2,067/12.32,17} = 2,2787 \text{ ft.lbf/lbm}$$

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

Friksi karena contraction:

Untuk aliran turbulen α =1, tangki konis Kc = 0,05

$$F_2 = \frac{Kc.v^2}{2.\alpha.gc} = \frac{0,05.2,493^2}{2.1.32,17} = 0,0048 \text{ ft.lbf/lbm}$$

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

$\Sigma F = (2,2787 + 0,0048)$ ft.lbf/lbm = 2,2835 ft.lbf/lbm

Persamaan Bernoulli:

$\Delta z = z_2 - z_1 = (20 - 15)$ ft = 5 ft

$$- Ws = \frac{P_2 - P_1}{\rho} + \frac{v_2^2 - v_1^2}{2.\alpha.\alpha.} + \frac{g}{gc}.\Delta z + \Sigma F$$

$$= 0 + \frac{2{,}4930^2 - 0}{2.1.32{,}17} + 5 + 2{,}2835$$

$$= 7{,}3801 \text{ ft.lbf/lbm}$$

Effisiensi pompa = 20% (Peters & Timmerhaus, 1991, fig. 14-37, p.520)

$$\text{Brake hp} = \frac{-Ws.m}{\eta.550}$$ (Geankoplis, 1997, eq. 3.3-2, p. 134)

$$= \frac{7{,}3801 \text{ ft lbf/lbm } 190{,}1429/60 \text{ lbm/s}}{0{,}2.550 \frac{\text{ft.lbf/s}}{\text{hp}}} = 0{,}2126 \text{ HP}$$

Effisiensi motor = 80 % (Peters & Timmerhaus, 1991, fig.14.38, p. 521)

Sehingga dipakai pompa dengan power motor = $\frac{0{,}2126}{0{,}80} = 0{,}2658\text{HP} \approx 0{,}5\text{HP}$

21. Rotary Drum Separator II (H-222)

Fungsi : Untuk menyaring endapan sebagai hasil reaksi dari reaktor II (R-220)

Tipe : *Continuous Rotary Drum Filter*

Kondisi operasi : T = 35°C

Dasar pemilihan : Retention liquid pada cake rendah

Pengoperasian sederhana

Perhitungan:

P = 1 atm = $1{,}01.10^5$ Pa

C_x = konsentrasi padatan = 52.996,8369/124.457,1696 = 0,4258 kg solid/kg slurry

$$m = \frac{\text{berat cake basah}}{\text{berat cake kering}} = \frac{52.157{,}6672}{52.996{,}8369} = 0{,}9842$$

Pada T = 35°C :

ρ = 993,965 kg/m^3

μ = 0,7228 cps = $0{,}7228.10^{-3}$ kg/m.s

$\alpha = 4{,}37.10^9 . \Delta P^{0,3} = 4{,}37.10^9 . (0{,}5.10^5)^{0,3} = 1{,}1225.10^{11}$ m/kg f = fraksi drum yang tercelup dalam slurry = 33%

$$C_s = \frac{\rho.C_x}{1-m.C_x} = \frac{993{,}965.0{,}4258}{1-0{,}9842.0{,}4258}$$ (Geankoplis, 1993, eq.14.2-10)

= 728,5422 kg solid/m^3 filtrat

Filter cycle time = 250 detik

kg slurry/detik = 124.457,1696 kg/hari = 1,4405 kg/detik

$$\frac{V}{tc} = \frac{1{,}4405.C_x}{C_s} = \frac{1{,}4405.0{,}4258}{728{,}5422} = 8{,}4189.10^{-4}\ m^3\ \text{filtrat / detik}$$

$$\frac{V}{A.tc} = \left(\frac{2.f\Delta P}{tc.\mu c.\mu._s}\right)^{1/2}$$

(Geankoplis,1993,eq.14.2-24)

$$\frac{8{,}4189.10^{-4}}{A.} = \left(\frac{2.0{,}33.0{,}5.10^5}{250.0{,}7228.10^{-3}.1{,}1225.10^{11}.728{,}5422}\right)^{1/2}$$

A = 17,8155 m^2

22. Screw Conveyor (J-223)

Fungsi : Mengangkut cake yang keluar dari rotary drum separator II (H-222) menuju ke tangki pelarut (F-224)

Tipe : *Standard pitch screw conveyor*

Dasar pemilihan : Membutuhkan ruangan sedikit, harga murah, pemeliharaan mudah, cocok untuk memindahkan padatan berbentuk kristal basah

Data : Kapasitas = 52.157,6672 kg/hari = 2.173,2361 kg/jam

Densitas = 1.547,9274 kg/m^3 = 96,6320 lb/ft^3

Elevasi = Horizontal

Perhitungan:

$$\text{Rate volumetric} = \frac{2.173{,}2361\ kg/jam}{1.547{,}9274\ kg/m^3} = 1{,}4040\ m^3/jam = 0{,}8264\ ft^3/min$$

Dari Perry, 1984, table 7-6 hal 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, hal 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)

$$Hp = \frac{0{,}8264\ ft^3/min.10\ ft.96{,}6320\ lb/ft^3.3}{33000} = 0{,}0726\ Hp$$

Efisiensi motor = 80% (Peters & Timmerhaus, 1991, grafik 14-38, hal 521)

$$Power = \frac{100}{80}.0{,}0726\ Hp = 0{,}0907\ Hp$$

Dari Badger, 1957, hal 713: jika power < 2 Hp, maka power dikalikan dua.

Power = 0,0907 × 2 = 0,1814 Hp ≈ 0,5 Hp

23. Tangki Pelarut (F-224)

Fungsi : Untuk tempat melarutkan produk reaktor II (R-220) sebelum masuk ke tangki kristalisasi (D-230)

Tipe : Silinder tegak tertutup dengan tutup atas berbentuk *flange & dished* (fdh) dan tutup bawah berbentuk konis dilengkapi dengan pengaduk

Dasar pemilihan : Cocok untuk larutan yang banyak mengandung padatan.

Kondisi operasi : P = 1 atm, T = 36,2°C

Kapasitas : 308.997,6672 kg/hari × 2,2 lb/kg = 679.794,8678 lb/hari

Jumlah : 1 buah

Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} + \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 1.013,0365 kg/m^3 × 0,0624 (lb/ft^3)/(kg/m^3) = 63,2439 lb/ft^3

$$\text{Volume larutan total} = \frac{679.794{,}8678\ \text{lb/hari}}{63{,}2439\ \text{lb/ft}^3 \times 24\ \text{jam/hari}} = 447{,}8661\ \text{ft}^3$$

Dari Ulrich, 1984, p. 433:

$h = (1\text{-}1{,}5) \times D$

Diambil tinggi liquida (h) = 1,25.diameter tangki (D)

Asumsi : $^1/_2$ Sudut konis = α = 45°

Volume larutan = volume silinder + volume konis

$= \pi/4 \times D^2 \times h + (0{,}131 \times D^3)/\text{tg}\ \alpha$

$447{,}8661\ \text{ft}^3 = \pi/4 \times D^2 \times 1{,}25.D + (0{,}131 \times D^3)/\text{tg}\ 45°$

$D = 7{,}5446\ \text{ft} \approx 8\ \text{ft}$

$h = 1{,}25.8 = 10\ \text{ft}$

Asumsi : Volume ruang kosong = 25% Volume larutan

Volume total = $1{,}25 \times (\pi/4 \times 8^2 \times 10 + (0{,}131 \times 8^3)/\text{tg}\ 45°)$

$= 712{,}1334\ \text{ft}^3$

Volume tangki = volume silinder + volume fdh + volume konis

$712{,}1334\ \text{ft}^3 = \pi/4 \times D^2 \times H + 0{,}000049 \times D^3 + (0{,}131 \times D^3)/\text{tg}\ \alpha$

$= \pi/4 \times 8^2 \times H + 0{,}000049 \times 8^3 + (0{,}131 \times 8^3)/\text{tg}\ 45°$

$H = 12{,}8326\ \text{ft} \approx 16\ \text{ft}$ (memenuhi)

H/D = 2 (Dari Ulrich, 1984, p. 433 H = (1,5-2,0) × D)

Bahan konstruksi yang digunakan : stainless steel 18-8 tipe 304

Dari Brownell & Young, 1959, App. D, p. 342 diperoleh:

$f_{allowable} = 18.750\ \text{lb/in}^2$

$E = 0{,}85$

$c = 1/4\ \text{in}$

$$P = \frac{\rho \times h}{144} = \frac{63{,}2439\ \text{lb/ft}^3 \times 10\ \text{ft}}{144} = 4{,}3919\ \text{psi}$$

$P_{op} = 14{,}7 + 4{,}3919 = 19{,}0919$ psia

$P_{desain} = 1{,}2 \times P_{op} = 1{,}2 \times 19{,}0919 = 22{,}9103$ psia

Perhitungan tebal shell:

$$t_{shell} = \frac{P \times D}{2 \times f \times E} + c = \frac{22{,}9103\,lb/in^2 \times 8/12\,in}{2 \times 18.750\,lb/in^2 \times 0{,}85} + 1/4\,in = 0{,}2504\ in \approx {}^5/_{16}\ in$$

Perhitungan tebal tutup atas:

Radius = icr = 6% × D = 6% × 8 ft = 0,48 ft ≈ 5 $^7/_8$ in

Dari Brownell & Young, 1959, tabel 5.7, p. 90 diperoleh:

$t_{fdh} = {}^3/_8$ in

Perhitungan tinggi tutup atas:

Do = 8 ft = 96 in

Dari Brownell & Young, 1959, tabel 5.7 diketahui untuk t = $^3/_8$ in, icr = 5 $^7/_8$ in, r = 96 in dan sf = 2 in

Di = Do – 2.t = 96 in – 2.0,375 in = 95,25 in

$$AB = \frac{Di}{2} - icr = 41{,}75\ in$$

BC = r – icr = 90,125 in

Kedalaman dish (b) = r - $\sqrt{(BC)^2 - (AB)^2}$ = 16,1285 in

Tinggi tutup atas = t + b + sf = 18,5035 in = 1,5420 ft

Perhitungan tebal tutup bawah:

$$t_{konis} = \frac{P \times D}{2 \times \cos\alpha \times (f \times E - 0{,}6 \times P)} + c$$

$$= \frac{22{,}9103\,lb/in^2 \times 8/12\,in}{2 \times \cos 45° \times (18.750\,lb/in^2 \times 0{,}85 - 0{,}6 \times 22{,}9103\,lb/in^2)} + 1/4\,in$$

= 0,2505 in ≈ 5/16 in

Perhitungan tinggi tutup bawah:

$$H_{konis} = \frac{0{,}5.D}{tg45} = \frac{0{,}5.8\,ft}{tg45} = 4\ ft$$

Perhitungan tinggi keseluruhan tangki:

Tinggi tangki = tinggi shell + tinggi tutup atas + tinggi tutup bawah

= 16 ft + 1,5420 ft + 4 ft = 21,5420 ft ≈ 22 ft

Perhitungan pengaduk:

Jenis pengaduk: *flat six blade turbine*

Dari Geankoplis, 1993 diperoleh:

$C/D_t = {}^1/_3$ (tabel 3.4-1, p. 144) → $C = {}^1/_3 \,.\, 8$ ft = 2,6667 ft = 0,8130 m

D_a/D_t = 0,25-0,5 (p. 146) diambil 0,3 → D_a = 0,3 . 8 ft = 2,4 ft = 0,7317 m

Dimana: C = jarak pengaduk

D_a = diameter impeller

D_t = diameter tangki

Kecepatan putar impeller diambil 125 rpm

$\mu_{campuran}$ = 4,675 cps = $4{,}675.10^{-3}$ kg/m.s

$$sg_{campuran} = \frac{\rho_{camp}}{\rho_{air}}$$

= 1,0192

$$N_{Re}' = \frac{D_a^2.N.\rho}{\mu} = \frac{(0{,}7317\ \text{m})^2 \times 125/60\ \text{rps} \times 1.013{,}0365\ \text{kg/m}^3}{4{,}675.10^{-3}\ \text{kg/m.s}} = 241.695{,}3811$$

Dari Geankoplis, 1993, fig.3.4-4, p.145 dengan memotongkan kurva 1 dengan N_{Re}' diperoleh N_p = 5

$$\text{Jumlah impeller} = \frac{sg \times H}{D} = \frac{1{,}0192 \times 16}{8} = 2{,}0384 \approx 3$$

Power = $N_p \times \rho \times N^3 \times D_a^5$ = 5 × 1.013,0365 × $(125/60)^3$ × $0{,}7317^5$

= 9.605,8690 J/s

Power 3 impeller = 3 × 9.605,8690 J/s = 21,4893 Hp

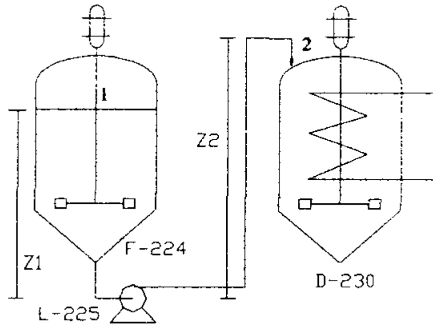
Power input = 1,1 × 21,4893 Hp = 23,6382 Hp

Transmission system losses = 0,2 × Power input = 0,2 × 21,4893 Hp = 4,2979 Hp

Power motor = Power input + Transmission system losses

= (21,4893 + 4,2979) Hp = 25,7872 Hp ≈ 30 Hp

24. Pompa (L-225)



Fungsi : Untuk memompa larutan dari tangki pelarut (F-224) menuju tangki kristalisasi (D-230)

Tipe : Centrifugal

Dasar pemilihan : 1. Cocok untuk liquida dengan viskositas rendah

2. Cocok untuk rate massa besar

Jumlah : 1 buah

Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} + \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 1.013,0365 kg/m^3 × 0,0624 (lb/ft^3)/(kg/m^3) = 63,2439 lb/ft^3

$\mu_{campuran}$ = 4,675 cps = 4,675.10^{-3} kg/m.s = 3,1415.10^{-3} lb/ft.s

Kapasitas = 308.997,6672 kg/hari = 214,5817 kg/menit = 472,0798 lb/menit

Rate volumetrik = $\dfrac{472{,}0798 \text{ lb/menit}}{63{,}2439 \text{ lb/ft}^3}$ = 7,4644 ft^3/menit

= 0,1244 ft^3/detik = 55,8382 gal/min

Dianggap $N_{Re} > 2100$

$Di_{opt} = 3{,}9.q_f^{0,45}.\rho^{0,13}$ in (Peters & Timmerhaus, 1991 , eq.15, p. 496)

= 3,9. 0,1244^{0,45}. (63,2439)^{0,13} = 2,6174 in ≈ 3,068 in

Dari Brown, 1950, tab. 23, p.123 diperoleh:

Ukuran pipa 3 in sch. 40

ID = 3,068 in

OD = 3,5 in

A_p = 7,393 in^2

Kecepatan aliran:

$$v = \frac{Q}{A} = \frac{0{,}1244\ ft^3/detik}{7{,}393/144\ ft^2} = 2{,}423\ ft/s$$

$$N_{Re} = \frac{D.v.\rho}{\mu} = \frac{3{,}068/12 \times 2{,}423 \times 63{,}2469}{3{,}1415.10^{-3}} = 12.471{,}8162$$

Untuk aliran turbulen (steel pipe) digunakan:

$f = 0{,}04/(N_{Re}^{0,16})$ (Peters & Timmerhaus,1991,eq.8, p.483)

$= 0{,}04/(12.471{,}8162^{0,16}) = 0{,}0088$

Panjang pipa lurus = 39,36 ft

Panjang pipa ekivalen:

- 1 buah gate valve, Le/D = 7 (Peters & Timmerhaus,1991,tab.1, p.484)

  Le = 1 × 7 × 3,068/12 ft = 1,7897 ft
- 1 buah globe valve, Le/D = 300 (Peters & Timmerhaus,1991,tab.1, p.484)

  Le = 1 × 300 × 3,068/12 ft = 76,7 ft
- 4 buah elbow 90°, Le/D = 32 (Peters & Timmerhaus,1991,tab.1, p.484)

  Le = 4 × 32 × 3,068/12 ft = 32,7253 ft

Panjang total pipa = (39,36 + 1,7897 + 76,7 + 32,7253) ft = 183,3003 ft

Friksi yang melalui pipa dan fitting:

$$F_1 = \frac{2.f.\Delta L.v^2}{D.gc} = \frac{2.0{,}0088.183{,}3003\ .2{,}423^2}{3{,}068/12.32{,}17} = 2{,}3028\ ft.lbf/lbm$$

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

Friksi karena contraction:

Untuk aliran turbulen $\alpha = 1$, tangki konis Kc = 0,05

$$F_2 = \frac{Kc.v^2}{2.\alpha.gc} = \frac{0{,}05.2{,}423^2}{2.1.32{,}17} = 0{,}0046\ ft.lbf/lbm$$

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

ΣF = (2,3028 + 0,0046) ft.lbf/lbm = 2,3074 ft.lbf/lbm

Persamaan Bernoulli:

$\Delta z = z_2 - z_1 = (26 - 18)\text{ ft} = 8\text{ ft}$

$$-Ws = \frac{P_2 - P_1}{\rho} + \frac{v_2^2 - v_1^2}{2.\alpha.\alpha.} + \frac{g}{gc}.\Delta z + \Sigma F$$

$$= 0 + \frac{2{,}423^2 - 0}{2.1.32{,}17} + 8 + 2{,}3074 = 10{,}3986\text{ ft.lbf/lbm}$$

Effisiensi pompa = 34% (Peters & Timmerhaus, 1991, fig. 14-37, p.520)

$$\text{Brake hp} = \frac{-Ws.m}{\eta.550}$$ (Geankoplis, 1997, eq. 3.3-2, p. 134)

$$= \frac{10{,}3986\text{ft lbf/lbm}.472{,}0798/60\text{ lbm/s}}{0{,}34.550\frac{\text{ft.lbf/s}}{\text{hp}}} = 0{,}4375\text{ HP}$$

Effisiensi motor = 80% (Peters & Timmerhaus, 1991, fig.14.38, p. 521)

Sehingga dipakai pompa dengan power motor = $\frac{0{,}4375}{0{,}8} = 0{,}5469\text{ HP} \approx 1\text{ HP}$

25. Tangki Kristalisasi (D-230)

Fungsi : Untuk membentuk kristal K_2SO_4 sebelum masuk ke rotary dryer (B-240)

Tipe : Silinder tegak tertutup dengan tutup atas berbentuk *flange & dished* (fdh) dan tutup bawah berbentuk konis dilengkapi dengan pengaduk dan koil pendingin

Dasar pemilihan : Cocok untuk larutan yang banyak mengandung padatan.

Kondisi operasi : P = 1 atm, T = 5°C

Kapasitas : 308.997,6672 kg/hari × 2,2 lb/kg = 679.794,8678 lb/hari

Jumlah : 1 buah

Perhitungan :

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} + \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran} = 1.013{,}0365\text{ kg/m}^3 \times 0{,}0624\ (\text{lb/ft}^3)/(\text{kg/m}^3) = 63{,}2439\text{ lb/ft}^3$

$$\text{Volume larutan total} = \frac{679.794{,}8678\ \text{lb/hari}}{63{,}2439\ \text{lb/ft}^3 \times 24\ \text{jam/hari}} = 447{,}8661\ \text{ft}^3$$

Dari Ulrich, 1984, p. 433:

$h = (1\text{-}1{,}5) \times D$

Diambil tinggi liquida (h) = 1,25.diameter tangki (D)

Asumsi : $^1/_2$ Sudut konis = α = 45°

Volume larutan = volume silinder + volume konis

$= \pi/4 \times D^2 \times h + (0{,}131 \times D^3)/\text{tg}\ \alpha$

$447{,}8661\ \text{ft}^3 = \pi/4 \times D^2 \times 1{,}25.D + (0{,}131 \times D^3)/\text{tg}\ 45°$

$D = 7{,}5446\ \text{ft} \approx 8\ \text{ft}$

$h = 1{,}25.8 = 10\ \text{ft}$

Asumsi : Volume ruang kosong = 25% Volume larutan

Volume total = $1{,}25 \times (\pi/4 \times 8^2 \times 10 + (0{,}131 \times 8^3)/\text{tg}\ 45°)$

$= 712{,}1334\ \text{ft}^3$

Volume tangki = volume silinder + volume fdh + volume konis

$712{,}1334\ \text{ft}^3 = \pi/4 \times D^2 \times H + 0{,}000049 \times D^3 + (0{,}131 \times D^3)/\text{tg}\ \alpha$

$= \pi/4 \times 8^2 \times H + 0{,}000049 \times 8^3 + (0{,}131 \times 8^3)/\text{tg}\ 45°$

$H = 12{,}8326\ \text{ft} \approx 16\ \text{ft}$ (memenuhi)

H/D = 2 (Dari Ulrich, 1984, p. 433 H = (1,5-2,0) × D)

Bahan konstruksi yang digunakan : stainless steel 18-8 tipe 304

Dari Brownell & Young, 1959, App. D, p. 342 diperoleh:

$f_{\text{allowable}} = 18.750\ \text{lb/in}^2$

E = 0,85

c = $^1/_4$ in

$$P = \frac{\rho \times h}{144} = \frac{63{,}2439\ \text{lb/ft}^3 \times 10\ \text{ft}}{144} = 4{,}3919\ \text{psi}$$

$P_{op} = 14{,}7 + 4{,}3919 = 19{,}0919$ psia

$P_{desain} = 1{,}2 \times P_{op} = 1{,}2 \times 19{,}0919 = 22{,}9103$ psia

Perhitungan tebal shell:

$$t_{shell} = \frac{P \times D}{2 \times f \times E} + c = \frac{22{,}9103\,\text{lb/in}^2 \times 8/12\,\text{in}}{2 \times 18.750\,\text{lb/in}^2 \times 0{,}85} + 1/4\,\text{in} = 0{,}2504\ \text{in} \approx 5/16\ \text{in}$$

Perhitungan tebal tutup atas:

Radius = icr = 6% × D = 6% × 8 ft = 0,48 ft ≈ 5 $^7/_8$ in

Dari Brownell & Young, 1959, tabel 5.7, p. 90 diperoleh: $t_{fdh} = {}^3/_8$ in

Perhitungan tinggi tutup atas:

Do = 8 ft = 96 in

Dari Brownell & Young, 1959, tabel 5.7 diketahui untuk t = $^3/_8$ in, icr = 5 $^7/_8$ in, r = 96 in dan sf = 2 in

Di = Do – 2.t = 96 in – 2.0,375 in = 95,25 in

$$AB = \frac{Di}{2} - icr = 41{,}75\ \text{in}$$

BC = r – icr = 90,125 in

Kedalaman dish (b) = r - $\sqrt{(BC)^2 - (AB)^2}$ = 16,1285 in

Tinggi tutup atas = t + b + sf = 18,5035 in = 1,5420 ft

Perhitungan tebal tutup bawah:

$$t_{konis} = \frac{P \times D}{2 \times \cos\alpha \times (f \times E - 0{,}6 \times P)} + c$$

$$= \frac{22{,}9103\,\text{lb/in}^2 \times 8/12\,\text{in}}{2 \times \cos 45° \times (18.750\,\text{lb/in}^2 \times 0{,}85 - 0{,}6 \times 22{,}9103\,\text{lb/in}^2)} + 1/4\,\text{in}$$

= 0,2505 in ≈ 5/16 in

Perhitungan tinggi tutup bawah:

$$H_{konis} = \frac{0{,}5.D}{tg\ 45°} = \frac{0{,}5.8\ \text{ft}}{tg\ 45°} = 4\ \text{ft}$$

Perhitungan tinggi keseluruhan tangki:

Tinggi tangki = tinggi shell + tinggi tutup atas + tinggi tutup bawah

= 16 ft + 1,5420 ft + 4 ft = 21,5420 ft ≈ 22 ft

Perhitungan pengaduk:

Jenis pengaduk: *flat six blade turbine*

Dari Geankoplis, 1993 diperoleh:

$C/D_t = 1/3$ (tabel 3.4-1, p. 144)→ $C = 1/3 \cdot 8$ ft = 2,6667 ft = 0,8130 m

$D_a/D_t = 0{,}25\text{-}0{,}5$ (p. 146) diambil 0,3 → $D_a = 0{,}3 \cdot 8$ ft = 2,4 ft = 0,7317 m

Dimana: C = jarak pengaduk

D_a = diameter impeller

D_t = diameter tangki

Kecepatan putar impeller diambil 125 rpm.

$\mu_{campuran}$ = 4,675 cps = 4,675.10^{-3} kg/m.s

$$sg_{campuran} = \frac{\rho_{camp}}{\rho_{air}}$$

$$= 1{,}0192$$

$$N_{Re}' = \frac{D_a^2.N.\rho}{\mu} = \frac{(0{,}7317\,\text{m})^2 \times 125/60\,\text{rps} \times 1.013{,}0365\,\text{kg/m}^3}{4{,}675.10^{-3}\,\text{kg/m.s}} = 241.695{,}3811$$

Dari Geankoplis, 1993, fig.3.4-4, p.145 dengan memotongkan kurva 1 dengan N_{Re}' diperoleh $N_p = 5$

$$\text{Jumlah impeller} = \frac{sg \times H}{D} = \frac{1{,}0192 \times 16}{8} = 2{,}0384 \approx 3$$

Power = $N_p \times \rho \times N^3 \times D_a^5$ = 5 × 1.013,0365 × $(125/60)^3$ × $0{,}7317^5$

= 9.605,8690 J/s

Power 3 impeller = 3 × 9.605,8690 J/s = 21,4893 Hp

Power input = 1,1 × 21,4893 Hp = 23,6382 Hp

Transmission system losses = 0,2 × Power input = 0,2 × 21,4893 Hp = 4,2979 Hp

Power motor = Power input + Transmission system losses

= (21,4893 + 4,2979) Hp = 25,7872 Hp ≈ 30 Hp

Perhitungan koil pendingin:

Data untuk air pendingin pada 31,1°F:

$\mu_{ethylene\ glycol}$ = 50 cp (Geankoplis, 1993, Fig. A.3-4, p. 876)

μ_{air} = 1,7921 cp (Geankoplis, 1993, Fig. A.2-4, p. 855)

$\mu_{campuran}^{1/3} = \mu_{air\ pendingin}^{1/3} = x_{air} \cdot \mu_{air}^{1/3} + x_{ethylene\ glycol} \cdot \mu_{ethylene\ glycol}^{1/3}$

$= 0{,}973.1{,}2147 + 0{,}027.3{,}68 = 1{,}2813$ cp

$\mu_{campuran} = \mu_{air\ pendingin} = 2{,}1034$ cp $= 7{,}4840$ lb/h.ft

$k_{ethylene\ glycol} = 0{,}265$ W/m.K $= 0{,}153$ Btu/h.ft.°F

(Geankoplis, 1993, tab. A.3-12, p. 880)

$k_{air} = 0{,}569$ W/m.K $= 0{,}329$ Btu/h.ft.°F (Geankoplis, 1993, tab. A.2-6, p. 856)

$k_{campuran} = k_{air\ pendingin} = x_{air} \cdot k_{air} + x_{ethylene\ glycol} \cdot k_{ethylene\ glycol}$

$= 0{,}973.0{,}329 + 0{,}027.0{,}153 = 0{,}324$ Btu/h.ft.°F

$Cp_{ethylene\ glycol} = 0{,}55$ Btu/lb.°F (Geankoplis, 1993, Fig. A.3-5, p. 879)

$Cp_{air} = 0{,}995$ Btu/lb.°F (Geankoplis, 1993, Fig. A.3-5, p. 879)

$Cp_{campuran} = Cp_{air\ pendingin} = x_{air} \cdot Cp_{air} + x_{ethylene\ glycol} \cdot Cp_{ethylene\ glycol}$

$= 0{,}973.0{,}995 + 0{,}027.0{,}55 = 0{,}983$ Btu/lb.°F

Dari perhitungan neraca panas diperoleh data sebagai berikut:

Q = panas yang diserap air pendingin = 1.150.045,5796 kJ/jam

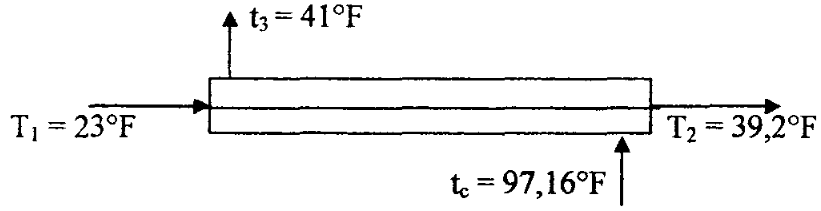
= 1.090.744,0093 Btu/jam

Suhu larutan masuk tangki = t_c = 36,2°C = 97,16°F

Suhu larutan keluar tangki = t_3 = 5°C = 41°F

$m_{air\ pendingin} = m_{air} + m_{ethylene\ glycol}$ = 752.231,4055 kg/hari

= 31.342,9752 kg/jam = 68.954,5455 lb/hr



a. Neraca panas dan neraca massa

Q = panas yang diserap = 1.150.045,5796 kJ/jam = 1.090.744,0093 Btu/jam

b. $\Delta T_{LMTD} = \dfrac{(T_1 - t_3) - (T_2 - t_c)}{\ln\left[\dfrac{(T_1 - t_3)}{(T_2 - t_c)}\right]} = \dfrac{(23-41)-(39{,}2-97{,}16)}{\ln\left[\dfrac{(23-41)}{(39{,}2-97{,}16)}\right]} = 34{,}1719$°F

c. $T_c = ½ (T_1 + T_2) = ½ (23 + 39{,}2)$°F = 31,1 °F

$t_c = \frac{1}{2}(t_c + t_3) = \frac{1}{2}(97,16 + 41)°F = 69,08\ °F$

d. Berdasarkan Kern, 1965, tabel 11 hal 844, trial ukuran pipa koil:

IPS = 2,5 in; sch. 40

do = 2,88 in   di = 2,469 in = 0,2058 ft

a' = 4,79 in^2 = 0,0333 ft^2 a" = 0,753 ft^2/ft

Evaluasi perpindahan panas:

Sisi bejana = fluida panas	Sisi pipa = fluida dingin
e. Nre = 241.695,3811 f. J_H = 1600 (Kern, Fig.20.2,hal 718) g. $ho = J_H \cdot \frac{k}{D_{shell}} \cdot \left(\frac{Cp.\mu}{k}\right)^{1/3} \cdot \left(\frac{\mu}{\mu_w}\right)^{1/4}$ Dimana: $\mu_{campuran}$ = 4,675 cps = 11,314 lb/h.ft k = 0,279 Btu/h.ft.°F Cp = 1,53 Btu/lb.°F Didapat ho = 234,2372 Btu/h.ft^2.°F	e. a'_t = 0,0882 ft^2 $G_t = \frac{W}{a_t} = \frac{68.954,5455\ lb/h}{0,0333\ ft^2}$ = 2.070.707,0721 lb/h.ft^2 $Nre = \frac{di.Gt}{\mu\ campuran}$ $= \frac{0,2058 . 2070707,0721}{7,4840}$ = 56.941,6776 f. Jc = 160 (Kern,1965,Fig.24,p.834) g. $hi = J_c \cdot \frac{k}{di_{coil}} \cdot \left(\frac{Cp.\mu}{k}\right)^{1/3} \left(\frac{\mu}{\mu_w}\right)^{1/4}$ Dimana: $\mu_{campuran}$ = 7,484 lb/h.ft k = 0,324 Btu/h.ft.°F Cp = 0,983 Btu/lb.°F Didapat hi = 713,2912 Btu/h.ft^2.°F hio = hi × (di/do) $= 713,2912 \times \frac{2,469}{2,88}$ hio = 611,4986 Btu/h.ft^2.°F

h. $U_c = \frac{hio.ho}{hio + ho} = \frac{611,4986 \times 234,2372}{611,4986 + 234,2372} = 169,3623$ Btu/jam.ft^2.°F

i. R_d larutan = 0,003

R_d air pendingin = 0,001

R_d gabungan = 0,004

$h_d = 1/\ r_{d\ gabungan} = 1/0{,}004 = 250$

$$U_d = \frac{Uc.hd}{Uc + hd} = \frac{169{,}3623.250}{169{,}3623 + 250} = 100{,}9642\ \text{Btu/jam.ft}^2.^\circ\text{F}$$

$$A_{koil} = \frac{Q}{Ud.\Delta T_{LMTD}} = \frac{1.090.744{,}0093\ \text{Btu/jam}}{100{,}9642\ \text{Btu/jam.ft}^2.^\circ\text{F}.\ 34{,}1719^\circ\text{F}}$$

$$= 316{,}1451\ \text{ft}^2$$

$$L = \frac{A_{koil}}{a''} = \frac{316{,}1451\ \text{ft}^2}{0{,}753\ \text{ft}^2/\text{ft}} = 419{,}8474\ \text{ft}$$

$d_c = d_{koil} = 0{,}6 \times D_{shell} = 0{,}6 \times 8\ \text{ft} = 4{,}8\ \text{ft}$

$$n_c = \frac{L}{\pi . d_c} = \frac{419{,}8474\ \text{ft}}{\pi . 4{,}8\ \text{ft}} = 27{,}8419 \approx 28\ \text{buah}$$

$h_c = \{(n_c - 1) \times (d_o + s_c)\} + d_o$

$= \{(28 - 1) \times (2{,}88\ \text{in} + 1\ \text{in})\} + 2{,}88\ \text{in}$

$= 107{,}64\ \text{in} = 8{,}97\ \text{ft}$

Pengecekan:

$H_{liquid} = 10\ \text{ft} = 120\ \text{in}$

Rancangan memadai karena $H_{liquid} > h_c$

Agar tinggi ruang kosong di atas koil dan di bawah koil sama, maka:

$$\text{Tinggi ruang kosong} = \frac{(120\ \text{in} - 107{,}64\ \text{in})}{2} = 6{,}18\ \text{in} = 0{,}515\ \text{ft}$$

26. Pompa (L-231)

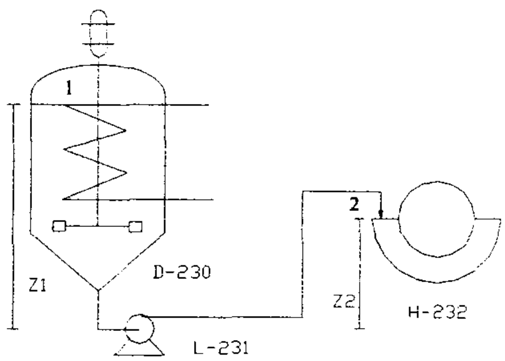
Fungsi : Untuk memompa larutan dari tangki kristalisasi (D-230) menuju rotary drum separator III (H-232)

Tipe : Centrifugal

Dasar pemilihan : 1. Cocok untuk liquida dengan viskositas rendah

2. Cocok untuk rate massa besar

Jumlah : 1 buah



Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} +$$

$$\frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 1.017,7999 kg/m^3 × 0,0624 (lb/ft^3)/(kg/m^3) = 63,5390 lb/ft^3

$\mu_{campuran}$ = 4,675 cps = 4,675.10^{-3} kg/m.s

= 3,1415.10^{-3} lb/ft.s

Kapasitas = 308.997,6672 kg/hari = 214,5817 kg/menit = 472,0798 lb/menit

$$\text{Rate volumetrik} = \frac{472{,}0798 \text{ lb/menit}}{63{,}5390 \text{ lb/ft}^3} = 7{,}4298 \text{ ft}^3\text{/menit} = 0{,}1238 \text{ ft}^3\text{/s}$$

Dianggap $N_{Re} > 2100$

$Di_{opt} = 3{,}9.q_f^{0,45}.\rho^{0,13}$ in (Peters & Timmerhaus, 1991 , eq.15, p. 496)

$= 3{,}9.\ 0{,}1238^{0,45}.\ (63{,}5390)^{0,13} = 2{,}6133$ in ≈ 3,068 in

Dari Kern, 1965, p. 844 diperoleh:

Ukuran pipa IPS : 3 in ; sch. 40

ID = 3,068 in

OD = 3,5 in

A_p = 7,38 in^2

Kecepatan aliran:

$$v = \frac{Q}{A} = \frac{0{,}1238 \text{ ft}^3\text{/s}}{7{,}38/144 \text{ ft}^2} = 2{,}4156 \text{ ft}^3\text{/s}$$

$$N_{Re} = \frac{D.v.\rho}{\mu} = \frac{3{,}068/12 \times 2{,}4156 \times 63{,}5390}{3{,}1415.10^{-3}} = 12.491{,}1505$$

Untuk aliran turbulen (steel pipe) digunakan:

$$f = \frac{0,04}{\left(N_{Re}\right)^{0,16}} = \frac{0,04}{(12.491,1505)^{0,16}} = 0,0088$$

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

Panjang pipa lurus = 12 m = 39,36 ft

Panjang pipa ekivalen:

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

  Le = 1 × 7 × 3,068/12 ft = 1,7897 ft

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

  Le = 1 × 300 × 3,068/12 ft = 76,70 ft

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

  Le = 4 × 32 × 3,068/12 ft = 32,7253 ft

Panjang total pipa = (39,36 + 1,7897 + 76,70 + 32,7253) ft = 150,5750 ft

Friksi yang melalui pipa dan fitting:

$$F_1 = \frac{2.f.\Delta L.v^2}{D.gc} = \frac{2.0,0088.150,575.2,4156^2}{3,068/12.32,17} = 1,8801 \text{ lbf.ft/lbm}$$

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

Friksi karena contraction:

Untuk aliran turbulen α = 1, tangki konis Kc = 0,05

$$F_2 = \frac{Kc.V^2}{2.\alpha.gc} = \frac{0,05.2,4156^2}{2.1.32,17} = 0,0045 \text{ lbf.ft/lbm}$$

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

ΣF = (1,8801 + 0,0045) lbf.ft/lbm = 1,8846 lbf.ft/lbm

Persamaan Bernoulli:

$\Delta z = z_2 - z_1 = (18 - 12) = 6$ ft

$$-Ws = \frac{P_2 - P_1}{\rho} + \frac{v_2^2 - v_1^2}{2.\alpha.gc} + \frac{g}{gc}.\Delta z + \Sigma F$$

$$= 0 + \frac{2,4156^2 - 0}{2.1.32,17} + 6 + 1,8846$$

$$= 7,9753 \text{ ft.lbf/lbm}$$

Effisiensi pompa = 36 % (Peters & Timmerhaus, 1991, fig. 14-37, p.520)

Brake hp = $\dfrac{-Ws.m}{\eta.550}$ (Geankoplis, 1997, eq. 3.3-2, p. 134)

$$= \frac{7{,}9753 \text{ ft lbf/lbm}.472{,}0798/60 \text{ lbm/s}}{0{,}36.550 \dfrac{\text{ft.lbf/s}}{\text{hp}}} = 0{,}3169 \text{ Hp}$$

Effisiensi motor = 80% (Peters & Timmerhaus, 1991, fig.14.38, p. 521)

Sehingga dipakai pompa dengan power motor = $\dfrac{0{,}3169}{0{,}8}$ = 0,3961 Hp ≈ 0,5 Hp

27. Rotary Drum Separator III (H-232)

Fungsi : Untuk menyaring endapan dari tangki kristalisasi (D-230)

Tipe : *Continous Rotary Drum Filter*

Kondisi operasi : T = 35°C

Dasar pemilihan : Retention liquid pada cake rendah

Pengoperasian sederhana

Perhitungan:

P = 1 atm = $1{,}01.10^5$ Pa

C_x = konsentrasi padatan = 48.532,7074/308.997,6672 = 0,1571kg solid/kg slurry

$$m = \frac{\text{berat cake basah}}{\text{berat cake kering}} = \frac{27.201{,}7287}{48.532{,}7074} = 0{,}5605$$

Pada T = 35°C :

ρ = 993,965 kg/m^3

μ = 0,7228 cps = $0{,}7228.10^{-3}$ kg/m.s

$\alpha = 4{,}37.10^9 . \Delta P^{0{,}3} = 4{,}37.10^9 . (0{,}5.10^5)^{0{,}3} = 1{,}1225.10^{11}$ m/kg

f = fraksi drum yang tercelup dalam slurry = 33%

$$C_s = \frac{\rho.C_x}{1 - m.C_x} = \frac{993{,}965.0{,}1571}{1 - 0{,}5605.0{,}1571}$$ (Geankoplis, 1993, eq.14.2-10)

= 171,2294 kg solid/m^3 filtrat

Filter cycle time = 250 detik

kg slurry/detik = 308.997,6672 kg/hari = 3,5764 kg/detik

$$\frac{V}{tc} = \frac{3,5764.C_x}{C_s} = \frac{3,5764.0,1571}{171,2294} = 3,2812.10^{-3}\ m^3\ \text{filtrat / detik}$$

$$\frac{V}{A.tc} = \left(\frac{2.f\Delta P}{tc.\mu c.\mu._s}\right)^{1/2}$$

(Geankoplis, 1993, eq. 14.2-24)

$$\frac{3,2812.10^{-3}}{A.} = \left(\frac{2.0,33.0,5.10^5}{250.0,7228.10^{-3}.1,1225.10^{11}.171,2294}\right)^{1/2}$$

$$A = 33,6618\ m^2$$

28. Screw Conveyor (J-233)

Fungsi : Mengangkut cake yang keluar dari rotary drum separator III (H-232) menuju ke rotary dryer (B-240)

Tipe : *Standard pitch screw conveyor*

Dasar pemilihan : Membutuhkan ruangan sedikit, harga murah, pemeliharaan mudah, cocok untuk memindahkan padatan berbentuk kristal basah

Data : Kapasitas = 27.201,7287 kg/hari = 1.133,4054 kg/jam

Densitas = 1.577,2590 kg/m^3 = 98,4648 lb/ft^3

Elevasi = Horizontal

Perhitungan:

$$\text{Rate volumetric} = \frac{1.133,4054\ kg/jam}{1.577,2590\ kg/m^3} = 0,7186\ m^3/jam = 0,4229\ ft^3/min$$

Dari Perry, 1984, table 7-6, hal 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, hal 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)

$$Hp = \frac{0,4229\ ft^3/min.10\ ft.98,4648\ lb/ft^3.3}{33000} = 0,0379\ Hp$$

Efisiensi motor = 80% (Peters & Timmerhaus, 1991, grafik 14-38, hal 521)

$$Power = \frac{100}{80}.0,0379\ Hp = 0,0474\ Hp$$

Dari Badger, 1957, hal 713: jika power < 2 Hp, maka power dikalikan dua.

Power = $0,0474 \times 2 = 0,0948$ Hp $\approx 0,5$ Hp

29. Rotary Dryer (B-240)

Fungsi : Untuk mengeringkan kristal K_2SO_4 dari rotary drum separator III (H-232)

Tipe : *Counter-current Direct Contact Rotary Dryer*

Dasar Pemilihan : Perpindahan panas yang dihasilkan besar sehingga mampu mengeringkan sampai kadar airnya 0,1%.

Kondisi operasi : P = 1 atm

Laju udara masuk : 15.956,4212 kg/hari = 1.462,6719 lb/jam

Laju material masuk : 27.201,7287 kg/hari = 2.493,4918 lb/jam

Suhu udara masuk : 100°C

Suhu udara keluar : 40°C

Suhu kristal masuk : 5°C

Suhu kristal keluar : 30°C

Perhitungan:

Perhitungan diameter rotary dryer:

$$D = \sqrt{\frac{M}{0,785.G}} = \sqrt{\frac{1.462,6719}{0,785 \times 200}}$$ (Perry, 1950, p.833)

$= 3,0523$ ft $= 0,9304$ m ≈ 1 m $= 3,2808$ ft

Dimana :

D = diameter rotary dryer, ft

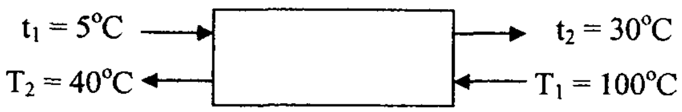
M = kecepatan udara masuk, lb/hr

G = Kecepatan udara pada rotary dryer, lb/hr.ft^2

$= 200 - 4000$ lb/hr.ft^2 (Perry, 1973, p.20-36)

Ditetapkan G = 200 lb/hr.ft^2

Perhitungan panjang rotary dryer:



$$\Delta T_{LMTD} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}} = \frac{(373 - 303) - (313 - 278)}{\ln \frac{(373 - 303)}{(313 - 278)}} = 50{,}4943 \text{ K}$$

$Q_t = 0{,}4 \,.\, D \,.\, G^{0,67} \,.\, L \,.\, \Delta T_{LMTD}$ (Perry, 1984, eq. 20-37, p.20-52)

Dimana:

Q_t = jumlah panas yang dipindahkan, BTU/jam

= 803.724,9354 kJ/hari = 9.302,3719 J/s = 31.741,1265 BTU/jam

L = panjang rotary dryer, ft

G = Kecepatan udara, lb/jam.ft^2

= 1.462,6719/(π/4.3,2808^2) = 173,0205 lb/jam.ft^2 ≈ 200 lb/jam.ft^2

D = diameter rotary dryer, ft

ΔT_{LMTD} = beda suhu, K

31.741,1265 = 0,4 . 3,2808 . 200^{0,67} . L . 50,4943

L = 14,5636 ft = 4,4390 m ≈ 4,5 m

L/D = 4,5 (memenuhi, berdasarkan Ulrich,1984, tab.4-10, p.132 L/D = 4-6)

Perhitungan 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 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

$$t_{shell} = \frac{P \times D}{2 \times f \times E} + c = \frac{17{,}64 \text{ lb/in}^2 \times 3{,}2808/12 \text{ in}}{2 \times 12.750 \text{ lb/in}^2 \times 0{,}6} + 1/4 \text{ in} = 0{,}2503 \text{ in} \approx 5/16 \text{ in}$$

Perhitungan putaran rotary dryer:

Kecepatan peripheral (v) rotary dryer = 0,25 – 0,5 m/s (Perry, 1984, p. 20-33)

Ditetapkan v = 0,35 m/s

$$N = \frac{V}{\pi.D} = \frac{0,35\ \text{m/s}}{\pi.3,2808/3,2808\ \text{m}} = 0,1114\ \text{rps} = 6,6845\ \text{rpm}$$

Perhitungan jumlah flight:

Jenis flight = 45° lip flight (Perry, 1984, p. 20-33)

Jumlah flight = (2,4 – 3).D (Perry, 1984, p. 20-31)

Ditetapkan 2,5.D = 2,5.3,2808 = 8,2020 ≈ 9

Tinggi flight antara D/12 - D/8 (Perry, 1984, p. 20-33)

Ditetapkan D/10 = 3,2808 ft/10 = 0,3281 ft

$$\text{Jarak antar flight} = \frac{\pi.D}{\text{jumlah flight}} = \frac{\pi.3,2808}{9} = 1,1452\ \text{ft} \approx 1,2\ \text{ft}$$

Perhitungan waktu dalam rotary dryer:

$$\theta = \frac{0,23.L}{S.N^{0,9}.D} \pm 0,6.\frac{B.L.G}{F}$$ (Perry, 1984, eq. 20-39 p. 20-33)

$B = 5\ .\ D_p^{-0,5}$ (Perry, 1984, eq. 20-40 p. 20-33)

Dimana:

B = konstanta

D_p = diameter partikel, μm = 5000 μm

F = feed rate, lb material kering/jam.ft^2

$$= \frac{2.493,4918\ \text{lb/jam}}{\pi/4.3,2808^2\ \text{ft}^2} = 294,9569\ \text{lb/jam.ft}^2$$

θ = time of passage, menit

S = slope, ft/ft = 0 – 8 cm/m (Perry, 1984, p. 20-33)

Ditetapkan S = 4 cm/m = 0,04 ft/ft

tg α = 0,04 → α = 2,2906°

N = kecepatan putaran, rpm

L = panjang rotary dryer, ft

G = kecepatan udara, lb/jam.ft^2

D = diameter rotary dryer, ft

$B = 5 \,.\, D_p^{-0,5} = 5.\ 3{,}2808^{-0,5} = 2{,}7605$

$$\theta = \frac{0{,}23.14{,}5636}{0{,}04.6{,}6845^{0,9}.3{,}2808} \pm 0{,}6.\frac{2{,}7605.14{,}5636.200}{294{,}9569}$$

θ_1 = -11,7387 menit (tidak mungkin)

θ_2 = 20,9734 menit

<u>Perhitungan tenaga untuk memutar rotary dryer:</u>

$HP = 0{,}5.D^2 - D^2$ (Perry, 1984, p. 20-33)

Ditetapkan $HP = 0{,}75.D^2 = 0{,}75.3{,}2808^2 = 8{,}0727$ HP

Efisiensi motor = 86 % (Peters & Timmerhaus, 1991, fig.14-38, p.521)

$$\text{Power} = \frac{8{,}0727\,\text{HP}}{0{,}86} = 9{,}3869\ \text{HP} \approx 9{,}5\ \text{HP}$$

30. Screw Conveyor (J-241)

Fungsi : Mengangkut kristal K_2SO_4 yang keluar dari rotary dryer (B-240) menuju ke tangki produk (F-242)

Tipe : *Standard pitch screw conveyor*

Dasar pemilihan : Membutuhkan ruangan sedikit, harga murah, pemeliharaan mudah, cocok untuk memindahkan padatan berbentuk kristal

Data : Kapasitas = 25.352,5651 kg/hari = 1.056,3569 kg/jam

Densitas = 2.641,2013 kg/m³ = 164,8844 lb/ft³

Elevasi = Horizontal

Perhitungan:

$$\text{Rate volumetric} = \frac{1.056{,}3569\ \text{kg/jam}}{2.641{,}2013\ \text{kg/m}^3} = 0{,}4\ \text{m}^3\text{/jam} = 0{,}2354\ \text{ft}^3\text{/min}$$

Dari Perry, 1984, table 7-6 hal 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, hal 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)

$$Hp = \frac{0{,}2354\ ft^3/min.10\ ft.164{,}8844\ lb/ft^3.3}{33000} = 0{,}0353\ Hp$$

Efisiensi motor = 80% (Peters & Timmerhaus, 1991, grafik 14-38, hal 521)

$$Power = \frac{100}{80}.0{,}0353\ Hp = 0{,}0441\ Hp$$

Dari Badger, 1957, hal 713: jika power < 2 Hp, maka power dikalikan dua.

Power = 0,0441 × 2 = 0,0882 Hp ≈ 0,5 Hp

31. Tangki Produk (F-242)

Fungsi : Menampung produk kristal K_2SO_4 sebelum dipacking

Tipe : Tangki vertikal dengan tutup atas berbentuk *flange only* dan tutup bawah berbentuk konis

Dasar pemilihan : Cocok untuk menampung padatan

Kondisi operasi : T = 30°C

P = 1 atm

Jumlah : 1 buah

Perhitungan:

Rate masuk = 25.352,5651 kg/hari = 1.056,3569 kg/jam

Waktu tinggal = 8 jam

Kapasitas = 1.056,3569 kg/jam x 8 jam

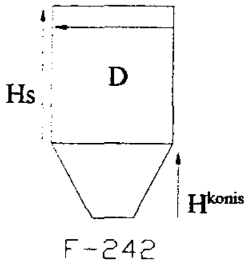
= 8.450,8552 kg

ρ_{bulk} K_2SO_4 = 2.641,2013 kg/m³

$$\text{Volume } K_2SO_4 = \frac{8.450{,}8552\ kg}{2.641{,}2013\ kg/m^3} = 3{,}1996\ m^3 = 112{,}9907\ ft^3$$

Storage berbentuk silinder dengan tutup bawah berbentuk konis:

H = 1,5 D ; gypsum mengisi $^3/_4$ bagian shell



$$V\ K_2SO_4 = {}^3/_4 \,.\, V_{shell} + V_{konis}$$

$$= \frac{3}{4}\cdot\left(\frac{\pi.D^2.H}{4}\right)+\left(\frac{1}{3}\cdot\frac{\pi}{4}.D^2.\frac{D}{2.tg60}\right)$$

$$= \frac{3}{4}\cdot\left(\frac{\pi.D^2.1{,}5.D}{4}\right)+\left(\frac{1}{3}\cdot\frac{\pi}{4}.D^2.\frac{D}{2.tg60}\right)$$

$112{,}9907\ ft^3 = 0{,}8831\ D^3 + 0{,}0756\ D^3$

$D_{shell} = 4{,}9031\ ft \approx 5\ ft$

$H_{shell} = 1{,}5.\ D_{shell} = 1{,}5.\ 4{,}9031\ ft = 7{,}3547\ ft \approx 8\ ft$

$$H_{konis} = \frac{0{,}5.D}{tg\ 60°} = \frac{0{,}5.4{,}9031\ ft}{tg\ 60°} = 1{,}4434\ ft$$

<u>Perhitungan tebal shell:</u>

$$t_{\ shell} = \frac{P.D}{2.f.E} + c$$

dimana:

- P = 1 atm = 14,7 psia
- D = 4,9031 ft
- f_u = 75.000 psia (untuk material SA-240 grade S tipe 304)
  - f_m = 0,92 (untuk bahan kualitas B – *flange grade quality*)
  - f_a = 1 (untuk bahan yang tidak dikenakan radiograph)
  - f_r = 1 (untuk bahan yang tidak dikenakan *stress relief*)
  - f_s = 0,25 (untuk suhu operasi < 650°F)
  - $f_{allow} = f_u.\ f_m.\ f_a.\ f_r.\ f_s = 17250$

- $E = 0{,}8$ (untuk pengelasan tipe *doble welded butt joint*)
- $c = 0{,}1$ in

$$t_{shell} = \frac{14{,}7 \text{ psia}.4{,}9031 \text{ ft}.12 \text{ in/ft}}{2.17250.0{,}8} + 0{,}1$$

$= 0{,}1313 \text{ in} \approx {}^3/_{16} \text{ in}$ (Brownell & Young, 1959, App. F item 2)

<u>Perhitungan tebal tutup atas (*flange only*):</u>

$t_{flange\ only} = t_{shell} = {}^3/_{16}$ in

sf = tinggi = 1,5 – 2 in; diambil 1,5 in (Brownell & Young, 1959, tabel 5.4)

$H_{flange\ only} = 0{,}125$ ft

<u>Perhitungan tebal tutup bawah (*konis*):</u>

$\alpha = 60^\circ \rightarrow z = 3{,}2$ (Bhattacharyya, 1991, hal 49)

Daerah yang jauh dari knuckle:

$$t_{konis} = \frac{P.D.z}{2.f.E} + c$$ (Bhattacharyya, 1991, pers. 4.2.17, hal 49)

$$t_{konis} = \frac{14{,}7 \text{ psia}.4{,}9031 \text{ ft}.12 \text{ in/ft}.3{,}2}{2.17250.0{,}8} + 0{,}1 \text{ in}$$

$= 0{,}2003 \text{ in} \approx {}^1/_4 \text{ in}$ (Brownell & Young, 1959, App. F item 2)

Daerah di sekitar knuckle:

$$t_{konis} = \frac{P.D}{2.f.E - P} \cdot \frac{1}{\cos 60^\circ} + c$$ (Bhattacharyya, 1991, pers. 4.2.16, hal 47)

$$t_{konis} = \frac{14{,}7 \text{ psia}.4{,}9031 \text{ ft}.12 \text{ in/ft}}{2.17250.0{,}8 - 14{,}7} \cdot \frac{1}{\cos 60^\circ} + 0{,}1 \text{ in}$$

$= 0{,}1627 \text{ in} \approx {}^3/_{16} \text{ in}$ (Brownell & Young, 1959, App. F item 2)

maka untuk tebal konis dipilih nilai yang terbesar yaitu ${}^1/_4$ in.

<u>Tinggi tangki produk keseluruhan:</u>

$H_{tangki} = H_{shell} + H_{flanged\ only} + H_{konis}$

$= 8 \text{ ft} + 0{,}125 \text{ ft} + 1{,}4434 \text{ ft} = 9{,}5684 \text{ ft} \approx 10 \text{ ft}$

32. Cyclone Separator (H-243)

Fungsi : Memisahkan solid yang terikut dalam udara pemanas dari Rotary Dryer (B-320)

Tipe : *Cyclone Separator*

Dasar pemilihan : Untuk memisahkan gas dan solid yang berukuran kecil

Kondisi operasi : Suhu udara masuk = 40°C

Kapasitas : 1.950,5450 kg/hari

Jumlah : 1 buah

Perhitungan:

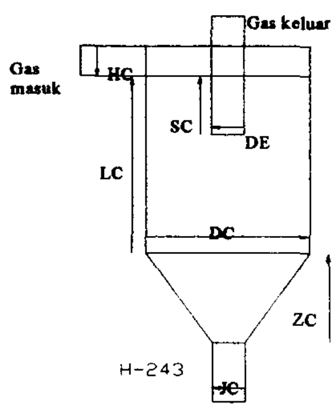
$$\rho_{udara} = \frac{BM\,.\,P_0\,.\,T_0}{V_0\,.\,P\,.\,T} 1\,\text{lbmol} = \frac{28{,}84\,.\,14{,}7\,.\,492}{395\,.\,14{,}7\,.\,564} 1\,\text{lbmol} = 0{,}0637\ \text{lb/ft}^3$$

$$\text{Laju gas} = \frac{1.950{,}5450\ \text{kg/hari}\,.\,2{,}2\ \text{lb/kg}}{24\ \text{jam/hari}\,.\,3600\ \text{s/jam}\,.\,0{,}0637\ \text{lb/ft}^3} = 0{,}7798\ \text{ft}^3/\text{s}$$

Kecepatan aliran gas = 50-75 ft/s (Perry 6th ed., 1991, p. 10-82)

Ditetapkan kecepatan aliran gas = 62 ft/s.

$$\text{Luas penampang masuk} = \frac{0{,}7798}{62} = 0{,}0126\ \text{ft}^2\,.\,144\ \text{in}^2/\text{ft}^2 = 1{,}8118\ \text{in}^2$$



Dari Perry, 1991, p. 20-84 diperoleh:

$AC = BC \times HC$

$HC = 2 \times BC$

sehingga $AC = 2 \times BC^2$

$1{,}8118\ \text{in}^2 = 2 \times BC^2 \rightarrow BC = 0{,}9518\ \text{in}$

$HC = 2 \times 0{,}9518\ \text{in} = 1{,}9036\ \text{in}$

DC = 2 × HC = 3,8072 in

De = HC = 1,9036 in

LC = 2 × DC = 7,6144 in

SC = DC/8 = 0,4759 in

ZC = 2 × DC = 7,6144 in

JC = DC/4 = 0,9518 in

33. Menara Absorber (D-244)

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

Feed: Udara bersuhu 30°C, tekanan 101,325 kpa

Dari neraca panas diperoleh:

Udara jenuh yang dibutuhkan = 13.267,5346 kg/hari

Densitas udara pada 30°C = ρ = 1,0562 kg/m^3

Viskositas udara pada 30°C = μ = 1,8652x10^{-5} kg/m.s (Geankoplis, 1997)

Volume udara masuk = 13.267,5346 kg/(1,0562 kg/m^3) = 12.561,5740 m^3

Bahan isian = silika gel → Dp = 1,2 cm

Void fraction = ε = 0,4

Trial diameter tower = 0,75 m

$$\text{Kecepatan udara} = G' = \frac{13.267{,}5346 \text{ kg/hari}}{24.3600 \text{ detik/hari}.\left(\pi/4.0{,}75^2\right)\text{m}^2} = 0{,}3476 \text{ kg/m}^2\text{.s}$$

Pressure drop = ΔP = 0,02.10^5 Pa

$$N_{Re} = \frac{G' \times Dp}{(1-\varepsilon).\mu} = \frac{0{,}3476 \times 0{,}012}{(1-0{,}4).1{,}8652.10^{-5}}$$ (Geankoplis, 1997, eq. 3.1-15)

= 372,7214 (turbulen karena N_{Re} >10)

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)

$$\frac{0{,}02.10^5.1{,}056}{(0{,}3476)^2}.\frac{0{,}012}{\Delta L}.\frac{(0{,}4)^3}{(1-0{,}4)} = \frac{150}{372{,}7214}+1{,}75$$

Tinggi tower = ΔL = 11,5513 m ≈ 11,6 m

Flow rate udara = v = $\dfrac{13.267{,}5346 \text{ kg/hari}}{24.3600 \text{ detik/hari}.28{,}84 \text{ kg/kgmol}}$ = 0,0053 kgmol/s

Diameter tower = D = $\left(\dfrac{4.v.BM}{\pi.G'}\right)^{1/2}$ (Ulrich, 1984, eq. 4-88, p.199)

$= \left(\dfrac{4.0{,}0053.28{,}84}{\pi.0{,}3476}\right)^{1/2}$ = 0,7482 m ≈ 0,75 m (memenuhi)

L/D = 15,67 (Ulrich, 1984, tab. 4-18, p.188, L/D = 5 – 30)

Bahan konstruksi : Carbon steel

Jumlah : 2 buah

34. Blower (G-245)

Fungsi : Mensuplai kebutuhan udara untuk media pemanas di dalam Rotary Dryer (B-320)

Tipe : Centrifugal

Dasar pemilihan: Sesuai untuk debit yang besar

Kondisi operasi : Suhu udara masuk = 30°C

Tekanan = 1 atm

Perhitungan:

Perhitungan efisiensi blower:

Rate udara = 13.267,5340 kg/hari

$= \dfrac{13.267{,}5340}{28{,}84 \times 24 \times 3600}$ = 0,0053 kmol/s

Rate volumetrik = $0{,}0053 \times 22{,}4 \times \dfrac{(30+273)}{273}$ = 0,1318 m^3/s

Efisiensi = 70 %

$m = \dfrac{\gamma - 1}{\gamma \times Ep}$ (Coulson & Richardson, 1983, eq. 3.36, p. 79)

$$n = \frac{1}{1-m}$$ (Coulson & Richardson, 1983, eq. 3.37, p. 79)

dimana: γ_{udara} = 1,4 (gas diatomik)

$$m = \frac{1,4-1}{1,4 \times 0,7} = 0,408$$

$$n = \frac{1}{1-0,408} = 1,689$$

Perhitungan power:

$$-W = z_1.R.T_1.\ \frac{n}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right]$$ (Coulson & Richardson, 1983, eq. 3.31, p. 73)

dimana: W = kerja per mol

z_1 = 1 (dianggap gas ideal)

R = konstanta gas ideal = 8,314 kJ/kgmol. K

T_1 = suhu masuk = 30°C

P_1 = tekanan mula-mula = 14,7 psia

P_2 = tekanan akhir = 15 psia

$$-W = 1.8,314.(30+273).\ \frac{1,689}{1,689-1}\left[\left(\frac{15}{14,7}\right)^{\frac{1,689-1}{1,689}} - 1\right]$$

$$= 51,1038 \text{ kJ/kgmol}$$

$$\text{Power} = \frac{-W.M}{Ep} = \frac{51,1038.0,00532}{0,7}$$

$$= 0,3869 \text{ kJ/s} . 1,314 = 0,5084 \text{ HP} \approx 1 \text{ HP}$$

35. Heater (E-246)

Fungsi : Menaikkan suhu udara sebelum masuk Rotary Dryer (B-240)

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)

Berdasarkan neraca panas:

m_{udara} = 13.267,5340 kg/hari = 1.216,1906 lb/jam

M_{steam} = 490,5625 kg/hari = 44,9682 lb/jam

Beban panas = Q = 1.039.747,1561 kJ/hari = 41.061,9284 BTU/jam

1. $\Delta T_{LMTD} = \dfrac{(T_1 - t_2) - (T_2 - t_1)}{\ln\dfrac{(T_1 - t_2)}{(T_2 - t_1)}} = \dfrac{(298{,}4 - 212) - (298{,}4 - 86)}{\ln\dfrac{(298{,}4 - 212)}{(298{,}4 - 86)}} = 57{,}5692°\text{F}$

$R = \dfrac{T_1 - T_2}{t_2 - t_1} = \dfrac{(298{,}4 - 298{,}4)}{(212 - 86)} = 0$

Dipakai HE 3-6 exchanger: Kern,1965, fig.20 hal 830

Ft = 1

$\Delta t = Ft \times \Delta T_{LMTD} = 1 \times 57{,}5692°\text{F} = 57{,}5692°\text{F}$

2. $t_c = (t_1+t_2)/2 = (86+212)/2 = 149°\text{F}$

$T_c = (T_1+T_2)/2 = 298{,}4°\text{F}$

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

$$A = \frac{Q}{U_D.\Delta t} = \frac{41.061{,}9284\ \text{BTU/jam}}{15\ \text{BTU/jam.ft}^2.°\text{F}.57{,}5692°\text{F}} = 55{,}9421\ \text{ft}^2$$

4. Dari Kern, 1965, tab. 10, p.843, untuk Do = $^3/_4$ in, 12 BWG diperoleh:

a" = 0,1309 ft^2/ft ; a' = 0,223 in^2

l = 12 ft (panjang pipa standar)

Di = 0,532 in

$$N_t\ (\text{jumlah tube}) = \frac{A}{a".\,l} = \frac{55{,}9421\,\text{ft}^2}{0{,}1309\,\text{ft}^2/\text{ft}.12\,\text{ft}} = 35{,}6133$$

Dari Kern, 1965, tabel 9 hal. 841:

untuk Do = ¾ in, P_t = 1 in squre pitch, di = 10 in, diperoleh:

Nt, std = 36 ; n = 6

$$U_{D\,koreksi} = \frac{Nt}{Nt, std}.U_D = \frac{35{,}6133}{36}.15 = 14{,}8391$$

Tube (steam)	Shell (udara)
5. $a_t = \frac{Nt, std . a'}{144.n} = \frac{36.0{,}233}{144.6} = {,}0097 ft^2$ 6. $G_t = \frac{M}{a_t} = \frac{44{,}9682}{0{,}0097}$ $= 4.635{,}8969\ lb/hr.ft^2$ 7. dari Kern, 1965, fig.15, p. 825 pada $T_c = 298{,}4°F$ diperoleh: $\mu = 0{,}0125$ $N_{Ret} = \frac{D.G_t}{\mu} = \frac{0{,}532 \times 4.635{,}8969}{12 \times 0{,}0125 \times 2{,}42}$ $= 6.794{,}2070$ 8. dari Kern, 1965, hal. 164 hio = 1500 $BTU/hr.ft^2.°F$	5. C' = Pt – do = 1 – 0,75 = 0,25 B = 2 in $a_s = \frac{di.C'.B}{144.P_t} = \frac{12.0{,}25.2}{144.1} = 0{,}0417 ft^2$ 6. $G_s = \frac{m}{a_s} = \frac{1.216{,}1906}{0{,}0417}$ $= 29.165{,}2422\ lb/hr.ft^2$ 7. dari Kern, 1965, fig.15, hal. 825 pada $t_c = 149°F$ diperoleh: $\mu = 0{,}0194$ $N_{Res} = \frac{D_e.G_{st}}{\mu} = \frac{0{,}95 \times 29.165{,}2422}{12 \times 0{,}0194 \times 2{,}42}$ $= 49.180{,}3634$ 8. dari Kern, 1965, fig.28, hal. 838 De = 0,95 jH = 140 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) $ho = jH.\frac{k.}{D_e}.(\frac{c.\mu}{k})^{1/3}.\varphi_s$ $\frac{ho}{\varphi_s} = 140.\frac{0{,}0162}{0{,}95/12}.(\frac{0{,}248.0{,}0194.2{,}42}{0{,}0162})^{1/3}$ $= 25{,}6617$ $ho = \frac{ho}{\varphi_s} = 25{,}6617$

9. Koefisien overall bersih, U_C:

$$U_C = \frac{hio.ho}{hio + ho} = \frac{1500.25,6617}{1500 + 25,6617} = 25,2301 \text{ BTU/hr.ft}^2.°F$$

10. Faktor kekotoran, R_D:

$$R_D = \frac{U_C - U_D}{U_C.U_D} = \frac{25,2301 - 14,8391}{25,2301.14,8391} = 0,0278$$

$R_{Dallowable} = 0,003$

Perhitungan Pressure Drop:

Tube (steam)	Shell (udara)
1. $N_{Re,t} = 7.746,9072$ Dari Kern, 1965, Fig. 26 : $f = 0,00030$ 2. $\Delta P_t = \frac{f.G_t^2.l.n}{5,22.10^{10}.di.s.\varphi_t}$ $= \frac{0,00030 \times 4.635,8696^2 \times 12 \times 6}{5,22.10^{10}.12/12.1.1}$ $= 8,89.10^{-6}$ 3. $\Delta P_r = \frac{4.n}{s}.\frac{V^2}{2.g'}.\frac{62,5}{144} = \frac{4.6}{1}.0,0001$ $= 2,4.10^{-3}$ 4. $\Delta P_T = \Delta P_t + \Delta P_r = 8,89.10^{-6} + 2,4.10^{-3}$ $= 2,4089.10^{-3}$psi <2psi,memenuhi)	1. $N_{Re,s} = 49.180,2634$ Dari Kern, 1965, Fig. 29 : $f = 0,0015$ 2. $N + 1 = \frac{12.1}{B} = \frac{12.12}{2} = 72$ 3. $\Delta P_s = \frac{f.G_s^2.(N+1)}{5,22.10^{10}.de.s.\varphi_s}$ $= \frac{0,0015 \times 49.180,2634^2 \times 72}{5,22.10^{10} \times 0,95/12 \times 1 \times 1}$ $= 0,0632$ psi (< 1 psi,memenuhi)

Spesifikasi alat:

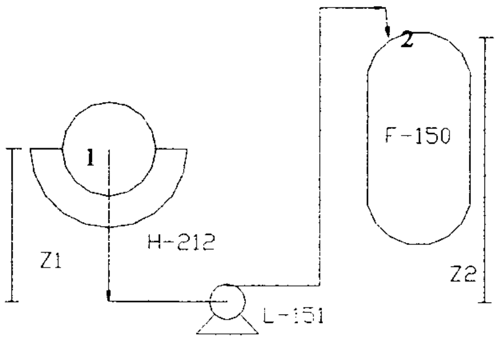
Tube

Media pemanas	: steam jenuh
Rate	: 44,9682 lb/jam
Bahan konstruksi	: carbon steel
Dimensi	: $^3/_4$ in OD, 12 BWG
	1 in square pitch
	6 passes

Shell

Media yang dipanaskan	: udara
Rate	: 1.216,1906 lb/jam
Bahan konstruksi	: carbon steel
Dimensi	: Diameter ekivalen = 0,95 in
	3 passes

36. Pompa (L-151)



Fungsi : Untuk memompa larutan dari rotary drum separator I (H-212) menuju tangki penampung filtrat (F-150)

Tipe : Centrifugal

Dasar pemilihan :

1. Cocok untuk liquida dengan viskositas rendah
2. Cocok untuk rate massa besar

Jumlah : 1 buah

Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} + \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 54,5618 lbm/ft^3

$\mu_{campuran}$ = 2,736 cps = 2,736.10^{-3} kg/m.s = 1,8385.10^{-3} lb/ft.s

Kapasitas = 310.976,0117 kg/hari = 215,9556 kg/menit = 475,1023 lb/menit

$$\text{Rate volumetrik} = \frac{475{,}1023\ \text{lb/menit}}{54{,}5618\ \text{lb/ft}^3} = 8{,}7076\ \text{ft}^3\text{/menit} = 0{,}1451\ \text{ft}^3\text{/s}$$

Dianggap $N_{Re} > 2100$

$Di_{opt} = 3{,}9.q_f^{0,45}.\rho^{0,13}$ in (Peters & Timmerhaus, 1991 , eq.15, p. 496)

$= 3{,}9.\ 0{,}1451^{0,45}.\ (54{,}5618)^{0,13} = 2{,}7518\ \text{in} \approx 3{,}068\ \text{in}$

Dari Kern, 1965, p. 844 diperoleh:

Ukuran pipa IPS : 3 in ; sch. 40

ID = 3,068 in

OD = 3,5 in

$A_p = 7{,}38\ \text{in}^2$

Kecepatan aliran:

$$v = \frac{Q}{A} = \frac{0{,}1451\ \text{ft}^3\text{/s}}{7{,}38/144\ \text{ft}^2} = 2{,}8312\ \text{ft}^3\text{/s}$$

$$N_{Re} = \frac{D.v.\rho}{\mu} = \frac{3{,}068/12 \times 2{,}8312 \times 54{,}5618}{1{,}8385.10^{-3}} = 21.481{,}7527$$

Untuk aliran turbulen (steel pipe) digunakan:

$$f = \frac{0{,}04}{(N_{Re})^{0,16}} = \frac{0{,}04}{(21.481{,}7527)^{0,16}} = 0{,}0081$$

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

Panjang pipa lurus = 12 m = 39,36 ft

Panjang pipa ekivalen:

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

  Le = 1 × 7 × 3,068/12 ft = 1,7897 ft

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

  Le = 1 × 300 × 3,068/12 ft = 76,70 ft

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

  Le = 4 × 32 × 3,068/12 ft = 32,7253 ft

Panjang total pipa = (39,36 + 1,7897 + 76,70 + 32,7253) ft = 150,5750 ft

Friksi yang melalui pipa dan fitting:

$$F_1 = \frac{2.f.\Delta L.v^2}{D.gc} = \frac{2.0,0081.150,575.2,8312^2}{3,068/12.32,17} = 2,3773 \text{ lbf.ft/lbm}$$

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

Friksi karena contraction:

Dari Peters & Timmerhaus, 1991, tabel 1, p.484 diperoleh:

A_1 = luas penampang rotary drum separator I = 36,9297 m^2

A_2 = luas penampang pipa = 7,38 in^2

$$\frac{A_2}{A_1} = \frac{7,38/144 \text{ ft}^2}{36,9297 \times 3,28^2 \text{ ft}^2} = 1,28.10^{-4}$$

Untuk $\frac{A_2}{A_1} < 0,715 \rightarrow Kc = 0,5$; untuk aliran turbulen $\rightarrow \alpha = 1$

$$F_2 = \frac{Kc.V^2}{2.\alpha.gc} = \frac{0,5.2,8312^2}{2.1.32,17} = 0,0623 \text{ lbf.ft/lbm}$$

ΣF = (2,3773 + 0,0623) ft.lbf/lbm = 2,4396 lbf.ft/lbm

Persamaan Bernoulli:

$\Delta z = z_2 - z_1 = (23 - 16) = 7$ ft

$\Delta P = P_2 - P_1 = 1 - 0,5$ atm = 0,5 atm = 1.058,1140 lbf/ft^2

$\rho_{campuran}$ = 54,5618 lbm/ft^3

$$- Ws = \frac{P_2 - P_1}{\rho} + \frac{v_2^2 - v_1^2}{2.\alpha.gc} + \frac{g}{gc}.\Delta z + \Sigma F$$

$$= \frac{1.058,1140}{54,5618} + \frac{2,8312^2 - 0}{2.1.32,17} + 7 + 2,4396$$

$$= 28,9571 \text{ lbf.ft/lbm}$$

Effisiensi pompa = 36 % (Peters & Timmerhaus, 1991, fig. 14-37, p.520)

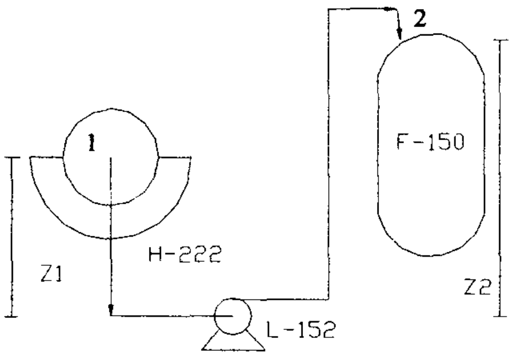
$$\text{Brake hp} = \frac{-Ws.m}{\eta.550}$$ (Geankoplis, 1997, eq. 3.3-2, p. 134)

$$= \frac{28,9571 \text{ lbf.ft/lbm}.475,1023/60 \text{ lbm/s}}{0,36.550 \frac{\text{lbf.ft/s}}{\text{hp}}} = 1,1580 \text{ Hp}$$

Effisiensi motor = 80% (Peters & Timmerhaus, 1991, fig.14.38, p. 521)

Sehingga dipakai pompa dengan power motor = $\frac{1,1580}{0,80}$ = 1,4476 Hp ≈ 1,5 Hp

37. Pompa (L-152)



Fungsi : Untuk memompa larutan dari rotary drum separator II (H-222) menuju tangki penampung filtrat (F-150)

Tipe : Centrifugal

Dasar pemilihan :

1. Cocok untuk liquida dengan viskositas rendah
2. Cocok untuk rate massa besar

Jumlah : 1 buah

Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} + \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 53,3215 lb/ft^3

$\mu_{campuran}$ = 2,653 cps = 2,653.10^{-3} kg/m.s = 1,7827.10^{-3} lb/ft.s

Kapasitas = 72.299,5024 kg/hari = 50,2080 kg/menit = 110,4576 lb/menit

Rate volumetrik = $\frac{110,4576 \text{ lb/menit}}{53,3215 \text{ lb/ft}^3}$ = 2,0715 ft^3/menit = 0,0345 ft^3/s

Dianggap $N_{Re} > 2100$

$Di_{opt} = 3,9.q_f^{0,45}.\rho^{0,13}$ in (Peters & Timmerhaus, 1991 , eq.15, p. 496)

$= 3{,}9.\ 0{,}0345^{0,45}.\ (53{,}3215)^{0,13} = 1{,}4374 \text{ in} \approx 1{,}610 \text{ in}$

Dari Kern, 1965, p. 844 diperoleh:

Ukuran pipa IPS : 1 ½ in ; sch. 40

ID = 1,610 in

OD = 1,90 in

$A_p = 2{,}04 \text{ in}^2$

Kecepatan aliran:

$$v = \frac{Q}{A} = \frac{0{,}0345 \text{ ft}^3/\text{s}}{2{,}04/144 \text{ ft}^2} = 2{,}4353 \text{ ft}^3/\text{s}$$

$$N_{Re} = \frac{D.v.\rho}{\mu} = \frac{1{,}610/12 \times 2{,}4353 \times 53{,}3215}{1{,}7827.10^{-3}} = 9.772{,}8490$$

Untuk aliran turbulen (steel pipe) digunakan:

$$f = \frac{0{,}04}{(N_{Re})^{0,16}} = \frac{0{,}04}{(9.772{,}8490)^{0,16}} = 0{,}0092$$

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

Panjang pipa lurus = 12 m =39,36 ft

<u>Panjang pipa ekivalen:</u>

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

  Le = 1 × 7 × 1,610/12 ft = 0,9392 ft

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

  Le = 1 × 300 × 1,610/12 ft = 40,25 ft

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

  Le = 4 × 32 × 1,610/12 ft = 17,1733 ft

Panjang total pipa = (39,36 + 0,9392 + 40,25 + 17,1733) ft = 97,7225 ft

<u>Friksi yang melalui pipa dan fitting:</u>

$$F_1 = \frac{2.f.\Delta L.v^2}{D.gc} = \frac{2.0{,}0092.97{,}7225.2{,}4353^2}{1{,}610/12.32{,}17} = 2{,}4707 \text{ lbf.ft/lbm}$$

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

<u>Friksi karena contraction:</u>

Dari Peters & Timmerhaus, 1991, tabel 1, p.484 diperoleh:

A_1 = luas penampang rotary drum separator II = 17,8155 m^2

A_2 = luas penampang pipa = 2,04 in^2

$$\frac{A_2}{A_1} = \frac{2{,}04/144\ ft^2}{17{,}8155 \times 3{,}28^2\ ft^2} = 7{,}39.10^{-5}$$

Untuk $\frac{A_2}{A_1} < 0{,}715 \rightarrow Kc = 0{,}5$; untuk aliran turbulen $\rightarrow \alpha = 1$

$$F_2 = \frac{Kc.V^2}{2.\alpha.gc} = \frac{0{,}5.2{,}4353^2}{2.1.32{,}17} = 0{,}0461\ lbf.ft/lbm$$

ΣF = (2,4707 + 0,0461) ft.lbf/lbm = 2,5168 lbf.ft/lbm

<u>Persamaan Bernoulli:</u>

$\Delta z = z_2 - z_1 = (23 - 12) = 11$ ft

$\Delta P = P_2 - P_1 = 1 - 0{,}5$ atm = 0,5 atm = 1.058,1140 lbf/ft^2

$\rho_{campuran}$ = 53,3215 lb/ft^3

$$-Ws = \frac{P_2 - P_1}{\rho} + \frac{v_2^2 - v_1^2}{2.\alpha.gc} + \frac{g}{gc}.\Delta z + \Sigma F$$

$$= \frac{1.058{,}1140}{53{,}3215} + \frac{2{,}4353^2 - 0}{2.1.32{,}17} + 11 + 2{,}5168$$

$$= 33{,}4530\ lbf.ft/lbm$$

Effisiensi pompa = 36 % (Peters & Timmerhaus, 1991, fig. 14-37, p.520)

$$\text{Brake hp} = \frac{-Ws.m}{\eta.550}$$ (Geankoplis, 1997, eq. 3.3-2, p. 134)

$$= \frac{33{,}4530\ lbf.ft/lbm.110{,}4576/60\ lbm/s}{0{,}36.550\frac{lbf.ft/s}{hp}} = 0{,}3110\ Hp$$

Effisiensi motor = 80% (Peters & Timmerhaus, 1991, fig.14.38, p. 521)

Sehingga dipakai pompa dengan power motor = $\frac{0{,}3110}{0{,}8}$ = 0,3888 Hp ≈ 0,5 Hp

38. Tangki Penampung Filtrat (F-150)

Fungsi : Sebagai tempat menampung filtrat dari rotary drum separator I (H-212) dan II (H-222) sebelum diproses dalam menara distilasi (D-160)

Tipe : Silinder tegak tertutup dengan tutup atas dan tutup bawah berbentuk *flange & standard dished*

Dasar pemilihan : Cocok untuk menampung larutan dengan kapasitas besar

Kondisi operasi : P = 1 atm, T = 35°C

Kapasitas : 383.275,5141 kg/hari × 2,2 lb/kg = 843.206,1310 lb/hari

Jumlah : 1 buah

Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} + \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran} = 54,1872 \text{ lb/ft}^3$

$$\text{Volume larutan total} = \frac{843.206,1310 \text{ lb/hari}}{54,1872 \text{ lb/ft}^3 \times 24 \text{ jam/hari}} = 648,3743 \text{ ft}^3$$

Dari Ulrich, 1984, p. 433:

$h = (1\text{-}1,5) \times D$

Diambil tinggi liquida (h) = 1,25.diameter tangki (D)

Volume larutan = volume silinder + volume fdh

$= \pi/4 \times D^2 \times h + 0,000049 \times D^3$

$648,3743 \text{ ft}^3 = \pi/4 \times D^2 \times 1,25.D + 0,000049 \times D^3$

$D = 8,7083 \text{ ft} \approx 9 \text{ ft}$

$h = 1,25.9 = 11,25 \text{ ft}$

Asumsi : Volume ruang kosong = 25% Volume larutan

Volume total $= 1,25 \times (\pi/4 \times 9^2 \times 11,25 + 2 \times 0,000049 \times 9^3)$

$= 715,7655 \text{ ft}^3$

Volume tangki = volume silinder + 2.volume fdh

$715,7655 \text{ ft}^3 = \pi/4 \times D^2 \times H + 2 \times 0,000049 \times D^3$

$= \pi/4 \times 9^2 \times H + 2 \times 0{,}000049 \times 9^3$

$H = 12{,}5003 \text{ ft} \approx 16 \text{ ft}$ (memenuhi)

H/D = 1,78 (Dari Ulrich, 1984, p. 433 H = (1,5-2,0) × D)

Bahan konstruksi yang digunakan : stainless steel 18-8 tipe 304

Dari Brownell & Young, 1959, App. D, p. 342 diperoleh:

$f_{allowable} = 18.750 \text{ lb/in}^2$

E = 0,85

c = 1/4 in

$$P = \frac{\rho \times h}{144} = \frac{79{,}0757 \text{ lb/ft}^3 \times 10 \text{ ft}}{144} = 5{,}49 \text{ psi}$$

$P_{tot} = 14{,}7 + 5{,}49 = 20{,}19$ psia

$P_{desain} = 1{,}2 \times P_{tot} = 1{,}2 \times 20{,}19 = 24{,}228$ psia

<u>Perhitungan tebal shell:</u>

$$t_{shell} = \frac{P \times D}{2 \times f \times E} + c = \frac{24{,}228 \text{ lb/in}^2 \times 9/12 \text{ in}}{2 \times 18.750 \text{ lb/in}^2 \times 0{,}85} + 1/4 \text{ in} = 0{,}2506 \text{ in} \approx {}^5/_{16} \text{ in}$$

<u>Perhitungan tebal tutup atas dan tutup bawah:</u>

Radius = icr = 6% × D = 6% × 9 ft = 0,54 ft ≈ 6 ½ in

Dari Brownell & Young, 1959, tabel 5.7, p. 90 diperoleh:

$t_{fdh} = {}^3/_8$ in

<u>Perhitungan tinggi tutup atas dan tutup bawah:</u>

Do = 9 ft = 108 in

Dari Brownell & Young, 1959, tabel 5.7 diketahui untuk t = $^3/_8$ in, icr = 6 ½ in, r = 102 in dan sf = 2 in

Di = Do – 2.t = 102 in – 2.0,375 in = 107,25 in

$$AB = \frac{Di}{2} - icr = 47{,}125 \text{ in}$$

BC = r – icr = 95,5 in

Kedalaman dish (b) = r - $\sqrt{(BC)^2 - (AB)^2}$ = 18,9369 in

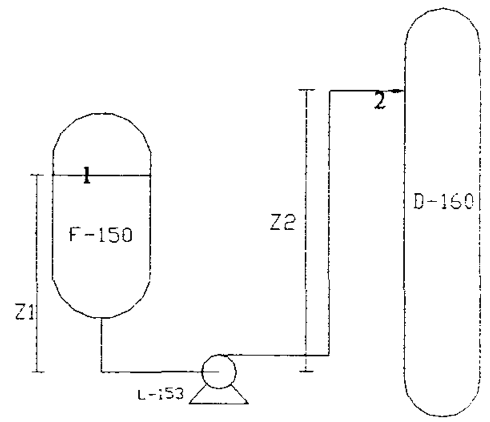
Tinggi tutup = t + b + sf = 21,3119 in = 1,7760 ft

Perhitungan tinggi keseluruhan tangki:

Tinggi tangki = tinggi shell + tinggi tutup atas + tinggi tutup bawah

= 16 ft + 2. 1,7760 ft = 19,5520 ft ≈ 20 ft

39. Pompa (L-153)



Fungsi : Untuk memompa larutan dari tangki penampung filtrat (F-150) menuju menara distilasi (D-160)

Tipe : *Centrifugal pump*

Dasar pemilihan :

1. Cocok untuk liquida dengan viskositas rendah
2. Cocok untuk rate massa besar

Jumlah : 1 buah

Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} + \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 54,1872 lb/ft^3

$\mu_{campuran}$ = 2,714 cps = 2,714.10^{-3} kg/m.s = 1,8237.10^{-3} lb/ft.s

Kapasitas = 383.275,5141 kg/hari = 266,1636 kg/menit = 585,5598 lb/menit

Rate volumetrik = $\dfrac{585{,}5598 \text{ lb/menit}}{54{,}1872 \text{ lb/ft}^3}$ = 10,8062 ft^3/menit = 0,1801 ft^3/s

Dianggap $N_{Re} > 2100$

$Di_{opt} = 3{,}9.q_f^{0,45}.\rho^{0,13}$ in (Peters & Timmerhaus, 1991 , eq.15, p. 496)

$= 3{,}9.\ 0{,}1801^{0,45}.\ (54{,}1872)^{0,13} = 3{,}03$ in $\approx$ 3,068 in

Dari Kern, 1965, p. 844 diperoleh:

Ukuran pipa IPS : 3 in ; sch. 40

ID = 3,068 in

OD = 3,5 in

$A_p = 7{,}38$ in^2

Kecepatan aliran:

$$v = \frac{Q}{A} = \frac{0{,}1801 \text{ ft}^3/\text{s}}{7{,}38/144 \text{ ft}^2} = 3{,}5141 \text{ ft}^3/\text{s}$$

$$N_{Re} = \frac{D.v.\rho}{\mu} = \frac{3{,}068/12 \times 3{,}5141 \times 54{,}1872}{1{,}8237.10^{-3}} = 26.695{,}0990$$

Untuk aliran turbulen (steel pipe) digunakan:

$$f = \frac{0{,}04}{(N_{Re})^{0,16}} = \frac{0{,}04}{(26.695{,}0990)^{0,16}} = 0{,}0078$$

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

Panjang pipa lurus = 40 ft

Panjang pipa ekivalen:

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

  Le = 1 × 7 × 3,068/12 ft = 1,7897 ft

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

  Le = 1 × 300 × 3,068/12 ft = 76,70 ft

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

  Le = 3 × 32 × 3,068/12 ft = 24,5440 ft

Panjang total pipa = (40 + 1,7897 + 76,70 + 24,5440) ft = 143,0337 ft

Friksi yang melalui pipa dan fitting:

$$F_1 = \frac{2.f.\Delta L.v^2}{D.gc} = \frac{2.0,0078.143,0337.3,5141^2}{3,068/12.32,17} = 3,3502 \text{ lbf.ft/lbm}$$

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

Friksi karena contraction dan expansion:

Dari Peters & Timmerhaus, 1991, tabel 1, p.484 diperoleh:

A_1 = luas penampang tangki penampung filtrat = 63,6173 ft^2

A_2 = luas penampang pipa = 7,38 in^2

$$\frac{A_2}{A_1} = \frac{7,38/144 \text{ ft}^2}{63,6173 \text{ ft}^2} = 8,06.10^{-4}$$

Untuk $\frac{A_2}{A_1} < 0,715 \rightarrow Kc = 0,5$; untuk aliran turbulen $\rightarrow \alpha = 1$

$$F_2 = \frac{Kc.v^2}{2.\alpha.gc} = \frac{0,5.3,5141^2}{2.1.32,17} = 0,0960 \text{ lbf.ft/lbm}$$

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

K_{ex} = 1 (Brown, 1950)

$$F_3 = \frac{K_{ex}.v^2}{2.\alpha.gc} = \frac{1.3,5141^2}{2.1.32,17} = 0,1919 \text{ lbf.ft/lbm}$$

ΣF = (3,3502 + 0,0960 + 0,1919) lbf.ft/lbm = 3,6381 lbf.ft/lbm

Persamaan Bernoulli:

$\Delta z = z_2 - z_1 = (28 - 13,25) = 14,75$ ft

$\Delta P = P_2 - P_1 = 6 - 1$ atm = 5 atm = 10584 lbf/ft^2

$\rho_{campuran}$ = 54,1872 lb/ft^3

$$- Ws = \frac{P_2 - P_1}{\rho} + \frac{v_2^2 - v_1^2}{2.\alpha.gc} + \frac{g}{gc}.\Delta z + \Sigma F$$

$$= \frac{10584}{54,1872} + \frac{3,5141^2 - 0}{2.1.32,17} + 14,75 + 3,6381$$

$$= 213,9029 \text{ lbf.ft/lbm}$$

Effisiensi pompa = 36 % (Peters & Timmerhaus, 1991, fig. 14-37, p.520)

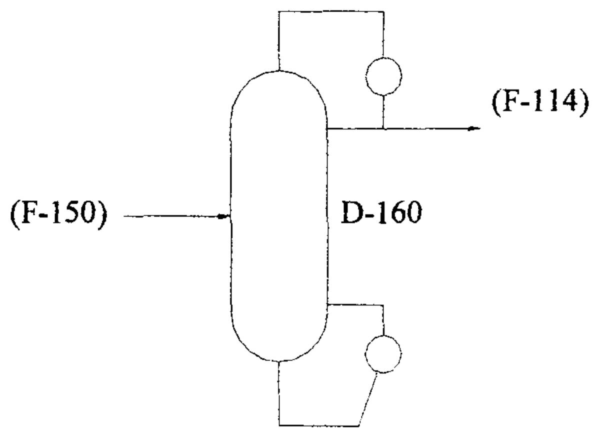
$$\text{Brake hp} = \frac{-\text{Ws. m}}{\eta.\ 550}$$ (Geankoplis, 1997, eq. 3.3-2, p. 134)

$$= \frac{213{,}9029\ \text{lbf.ft/lbm.}585{,}5598/60\ \text{lbm/s}}{0{,}36.550\dfrac{\text{lbf.ft/s}}{\text{hp}}} = 10{,}5432\ \text{Hp}$$

Effisiensi motor = 87% (Peters & Timmerhaus, 1991, fig.14.38, p. 521)

Dipakai pompa dengan power motor $= \dfrac{10{,}5432}{0{,}87} = 12{,}1186\ \text{Hp} \approx 13\ \text{Hp}$

40. Menara Distilasi (D-160)



Fungsi : Memisahkan ammonia 99,5 % berat

Tipe : Sieve Tray

Dasar Pemilihan :

1. Biaya pembuatan lebih murah daripada tipe bubble cap
2. Kapasitasnya besar

<u>Perhitungan Diameter Menara Distilasi:</u>

P operasi = 6 atm = 6,0795 bar

T operasi = T avg = 122,5°C = 395,5 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

$Pr = P/P_c$ = 6,0795/112,8 = 0,05

$Tr = T/T_c$ = 395,5/405,7 = 0,97

Dari Smith & Van Ness, 1996, Tabel E.1, hal 650, pada Pr dan Tr tersebut diperoleh: Z^0 = 0,9815 dan Z^1 = - 0,0050

Sehingga: $Z = Z^0 + \omega.Z^1$

= 0,9815 + 0,253.(-0,0050) = 0,9802

$$\rho NH_3 = \frac{P \times BM}{Z \times R \times T}$$

$$= \frac{6 \text{ atm} \times 17 \text{ g/mol}}{0,9802 \times 82,06 \text{ cm}^3\text{.atm/mol.K} \times 395,5 \text{ K}}$$

$= 0,0032 \text{ g/cm}^3 = 0,2003 \text{ lb/ft}^3 = 1,89.10^{-4} \text{ mol/cm}^3$

$\rho_{Lm} \approx \rho_{air} = 0,8993 \text{ g/ml} = 56,1433 \text{ lb/ft}^3 = 0,05 \text{ mol/cm}^3$

Perhitungan *surface tension* untuk campuran liquid menggunakan korelasi Macleod-Sugden:

$$\sigma_m^{1/4} = \sum_{i=1}^{n} P_i.(\rho_{Lm}.x_i - \rho_{Vm}.y_i) \quad ...(12\text{-}5.1)$$ (Prausnitz, 1988, p.642)

$\sigma_m = 58.(0,05.2,25.10^{-5} - 1,89.10^{-4}.\ 0,995) + 45,3.\ (0,05.0,9999 - 1,89.10^{-4}.\ 0,005)$

$\sigma_m = 2,2539$

Dari Ludwig fig.8.50 untuk σ_m = 2,2539 dan jarak antara tray 20 in, didapat harga konstanta empiris = C = 325 (Ludwig, 1974)

$W = C.[\rho_V.(\rho_L - \rho_V)]^{1/2}$

$W = 325.[0,2003.(56,1433 - 0,2003)]^{1/2} = 1087,9194 \text{ lb/ft}^2\text{.jam}$

$$D = \left[\frac{4}{\pi}.\frac{V'}{W}\right]^{1/2}$$ (Ludwig, 1974, p. 108)

dimana: V' = rate uap = 5153,5718 kmol/hari = 87.636,4888 kg/hari

= 3651,5204 kg/jam = 8.033,3449 lb/jam

$$D = \left[\frac{4}{\pi}.\frac{8033,3449}{1087,9194}\right]^{1/2} = 3,0662 \text{ ft} \approx 4 \text{ ft}$$

r = 2 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) + 2.9 ft

= 6 × (20/12) ft + 20 ft = 28 ft

Perhitungan Tebal Dinding Shell:

P design = P operasi + 2,5 bar (Ulrich, 1984)

= 6.1,013 + 2,5 = 8,5795 bar = 124,4354 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)

$$= \frac{124,4354.2.12}{0,8.18750 - 0,6.124,4354} + 0,12 \text{ in} = 0,3201 \text{ in}$$

Diambil $t_{menara} = {}^3/_8$ 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} = 4.12 + 2.0,375 = 48,75 in ≈ 54 in

E = 0,8 (Double Welded Butt Joint) (Brownell & Young,1959, tabel 13.2, p.254)

rc = Di + t = 4.12 + 0,375 = 48,375 in ≈ 49 in

$$W = \frac{1}{4}\cdot\left(3+\sqrt{\frac{rc}{icr}}\right)$$ (Brownell & Young, 1959, eq. 7.76, p.138)

$$W = \frac{1}{4}\cdot\left(3+\sqrt{\frac{49}{3{,}25}}\right) = 1{,}7207$$

$$t_h = \frac{P.rc.W}{2.f.E - 0{,}2.P} + c$$ (Brownell & Young, 1959, eq. 7.77, p.138)

$$t_h = \frac{124{,}4354.49.1{,}7207}{2.18750.0{,}8 - 0{,}2.124{,}4354} + 0{,}12\,\text{in} = 0{,}47\,\text{in}$$

Diambil tebal tutup = t_h = ½ in (Brownell & Young,1959, tabel 5.8, p.93)

Perhitungan Tinggi Tutup:

Do = 54 in

Dari Brownell & Young, 1959, tabel 5.7 dan 5.8 diketahui untuk t = ½ in, icr = 3,25 in, r = 48 in dan sf = 2,5 in

Di = Do – 2 . t = 53 in

$$AB = \frac{Di}{2} - icr = 23{,}25\text{ in}$$

BC = r – icr = 44,75 in

Kedalaman dish (b) = r - $\sqrt{(BC)^2 - (AB)^2}$ = 9,7639 in

Tinggi tutup = t + b + sf = 12,7639 in = 1,0637 ft

Perhitungan Tinggi Total Menara Distilasi:

Tinggi total menara = tinggi menara bagian shell + 2. tinggi tutup

= 28 + 2. 1,0637 = 30,1274 ft ≈ 31 ft

Perhitungan Isolasi:

Untuk isolasi digunakan isolator dari Kalsium Silikat dengan:

k = 0,372 Btu.in/ft^2.hr.°F dan tebal isolasi = 2 in

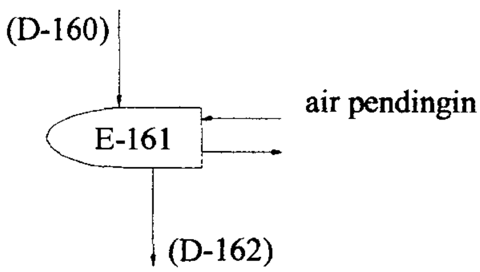
$$\text{Diameter luar isolasi} = OD + \left(\frac{2.\text{ tebal isolasi}}{12}\right)$$

$$= 54/12 + \left(\frac{2.2}{12}\right) = 4,83 \text{ ft}$$

Spesifikasi Menara Distilasi (D-160)

Fungsi	: Memisahkan ammonia 99,5% berat
Type	: Sieve tray
Dasar pemilihan	: Biaya pembuatan lebih murah daripada tipe bubble cap dan kapasitasnya lebih besar
Kapasitas	: 383.275,5141 kg/hari
Suhu operasi	: 122,5°C
Tekanan operasi	: 6 atm
Dimensi	:
~ Diameter	: 4 ft
~ Tinggi	: 31 ft
~ Tebal isolasi	: 2 in
Bahan isolasi	: Kalsium silikat
Bahan konstruksi	: Stainless steel 18-8 tipe 304
Jumlah	: 1 buah

41. Kondensor Distilasi (E-161)



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:

<u>Perhitungan Koefisien Transfer Panas:</u>

P operasi = 5,5 atm

T gas masuk = 27°C ; T liquid keluar = 8°C

Qc = 100264032,4416 kJ/hari = 4177668,0184 kJ/jam = 3959649,705 Btu/jam

Rate gas masuk = 1,0134.(5060.17 + 25,4271.18) = 87636,4888 kg/hari

= 3651,5204 kg/jam = 8033,3449 lb/jam

Air pendingin terdiri dari 90% berat air ditambah dengan 10% berat ethylene glycol.

Suhu air pendingin masuk = -5°C = 268 K

Suhu air pendingin keluar = 6°C = 279 K

$$\int Cp_{\text{air pendingin}}\, dT = R \int_{268}^{279} \frac{Cp}{R}\, dT = 826{,}7815 \text{ kJ/kmol}$$

$$Cp_{\text{ethylene glycol}} \cdot \Delta T = 92{,}8538 \text{ kJ/kgmol.K} \times (279\text{-}268)\text{K} = 1021{,}3918 \text{ kJ/kmol}$$

$$Q_c = m_{\text{air pendingin}} \cdot Cp \cdot \Delta T$$

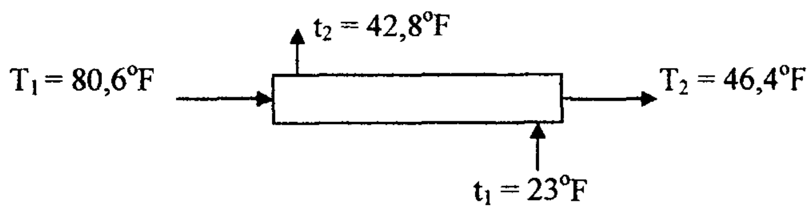
$$100264032{,}4416 = \frac{m \text{ kg}}{(0{,}973.18 + 0{,}027.62)} \cdot (0{,}973.826{,}7815 + 0{,}027.1021{,}3918)$$

$m_{\text{air pendingin}}$ = 2312239,1994 kg/hari = 211955,26 lb/jam

dimana:

m_{air} = 90% 2312239,1994 kg = 2081015,2795 kg/hari = 86708,9700 kg/jam

$m_{\text{ethylene glycol}}$ = 10%.2312239,1994 kg = 231223,9199 kg/hari = 9634,33 kg/jam



ΔT1 = T1 – t2 = 80,6 – 42,8 = 37,8°F

ΔT2 = T2 – t1 = 46,4 – 23 = 23,4 °F

$$\Delta T_{LMTD} = \frac{\Delta T1 - \Delta T2}{Ln\left(\frac{\Delta T1}{\Delta T2}\right)} = \frac{37,8 - 23,4}{Ln\left(\frac{37,8}{23,4}\right)} = 30,0267°F$$

$$R = \frac{T1 - T2}{t2 - t1} = \frac{80,6 - 46,4}{42,8 - 23} = 1,7273$$

$$S = \frac{t2 - t1}{T1 - t1} = \frac{42,8 - 23}{80,6 - 23} = 0,3438$$

Berdasarkan harga R dan S didapatkan: $F_T = 0,975$ (Kern, 1965, Fig. 19, p.829)

$\Delta T = \Delta T_{LMTD} \times F_T = 30,0267 \times 0,975 = 29,276$ °F

$$Tc = \frac{80,6 + 46,4}{2} = 63,5°F$$

$$tc = \frac{23 + 42,8}{2} = 32,9°F$$

Trial UD = 75 btu/jam.ft^2.°F

Asumsi: ¾ inch OD, 16 BWG, 1inch triangular pitch, L = 12 ft

a" = 0,1963 (Kern, 1965, tabel 10, p.843)

$Q = U_D \,.\, A \,.\, \Delta T$

$$A = \frac{Q}{U_D \times \Delta T} = \frac{3959649,7050}{12 \times 29,276} = 1803,3655 \text{ ft}^2$$

A = Nt . a" . L → 1803,3655 = Nt . 0,1963 . 8

Nt = 765,5652 tubes

Dari tabel 9 Kern, 1965, diperoleh untuk 2-4 heat exchanger:

ID_{shell} = 33 in Nt = 774 tubes

U_D koreksi → A = Nt . a" . L = 774 . 0,1963 . 8 = 1823,2344 ft^2

$$U_D = \frac{Q}{A \times \Delta T} = \frac{3959649,7050}{1823,2344 \times 29,276} = 74,1827 \text{ Btu/jam.ft}^2.°F$$

Shell Side

B = ID/5 = 33/5 = 6,6 in

$$as = \frac{ID \times C' \times B}{144 . P_T} \; ; C' = P_T - OD$$

$$= 1 - \tfrac{3}{4} = 0,25$$

$$= \frac{33 \times 1/4 \times 6,6}{144.1} = 0,3781 \text{ ft}^2$$

Gs = W/as

= 8033,3449 / 0,3781

= 21246,6144 lb/jam.ft^2

De = 0,06 ft (Figure 28, Kern, 1965)

$$G" = \frac{W}{L . Nt^{2/3}} = \frac{8033,3449}{12 . 774^{2/3}}$$

= 7,9412 lb/jam.lin ft

Asumsi ho = 105

$$tw = tc + \frac{ho}{hio + ho} . (Tc + tc)$$

$$= 32,9 + \frac{105}{347,2 + 105} .(63,5 + 32,9)$$

= 55,2839°F

tf = (Tc + tw)/2 = 59,3920°F

kf = ∑ki.xi =0,2903 Btu/jam.ft^2.(°F/ft)

sf = ∑ si . xi = 0,6120

µf = ∑ µi . xi = 0,3029 lb/ft.jam

Dari figure 12.9 Kern, 1965, diperoleh :

ho = 111 Btu/jam.ft^2.°F

Tube Side

a't = 0.302 in

$$at = \frac{Nt . a't}{144 . n} = \frac{774 . 0,302}{144 . 4} = 0,4058$$

Gt = W/at

= 211955,26/0,4058

= 522314,5885 lb/jam.ft^2

Pada tc = 32,9°F

µ = 2,8156.2,42 = 6,8138 lb/ft.hr

D = 0,62/12 = 0,0517 ft

$$Ret = \frac{D . Gt}{\mu} = 3963,1123$$

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

$$V = \frac{Gt}{3600 . \rho} \qquad \text{(figure 25, Kern)}$$

$$= \frac{522314,5885}{3600 . 62,5011} = 2,3214 \text{ ft/detik}$$

Dari figure 25, Kern, 1965, didapatkan

hi = 420 Btu/jam.ft^2.°F

hio = hi . ID/OD

= 420 . 0,62/0,75

= 347,2 Btu/jam.ft^2.°F

$$Uc = \frac{hio \times ho}{hio + ho} = \frac{347,2 \times 111}{347,2 + 111} = 84,11 \text{ Btu/jam.ft}^2.°F$$

$$Rd = \frac{U_C - U_D}{U_C \times U_D} = \frac{84,11 - 74,1827}{84,11 \times 74,1827} = 0,0016 \text{ jam.ft}^2.°\text{F/Btu}$$

Perhitungan Pressure Drop:

Shell Side

Pada Tc = 63,5°F

μ vapor = 0,0252 lb/jam.ft

De = 0,06 ft

Res = (De . Gs)/μ

$$= \frac{0,06.21246,6144}{0,0252} = 50587,1771$$

f = 0,0015 ft²/in² (Figure 29, Kern,1965)

$$N + 1 = 12.\frac{L}{B} = 12.\frac{12}{6,6} = 21,8$$

BM campuran = 17,005 g/gmol

$$\rho = \frac{P.BM}{Z.R.T} = \frac{5,5.17,005}{0,9384.82,06.290,5}$$

$= 0,0042$ g/cm³ $= 0,2610$ lb/ft³

s = 0,2610/62,5 = 0,0042

Ds = 33 /12 = 2,75 ft

$$\Delta Ps = \frac{1}{2}.\frac{f.Gs^2.Ds.(N+1)}{5,22.10^{10}.De.s}$$

$$= \frac{1}{2}.\frac{0,0015.21246,6144^2.2,75.21,8}{5,22.10^{10}.0,06.0,0042}$$

= 1,5430 psia < 2 psia

Tube Side

Untuk Ret = 3963,1123

f = 0,00038 (Figure 26, Kern, 1965)

$$\Delta Pt = \frac{f.Gt^2.L.n}{5,22.10^{10}.D.s.\varphi_t}$$

$$= \frac{0,0038.522314,5885^2.12.4}{5,22.10^{10}.0,0517.1.1}$$

= 1,8439 psia

Pada Gt = 522314,5885 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

$$\Delta P_T = \Delta P_t + \Delta P_r$$

= 1,8439 + 0,608

= 2,4519 psia < 10 psia

Spesifikasi Kondensor Distilasi (E-161)

Fungsi : Untuk mengkondensasi produk atas menara distilasi 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

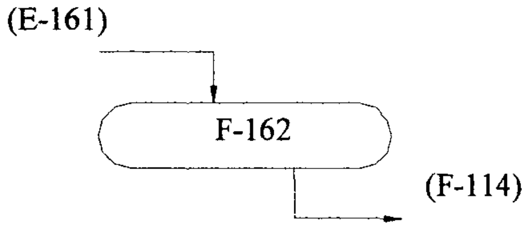
Dimensi :

~ Shell	ID	: 33 in
	Baffle space	: 6,6 in
~ Tube	ID	: 0,62 in
	OD	: ¾ in
	Jumlah	: 774
	Passes	: 4
	Pitch	: 1 in
	Susunan	: triangular
~ Panjang		: 12 ft
~ Luas perpindahan panas		: 1823,2344 ft^2

Bahan konstruksi : stainless steel 18-8 tipe 304

Jumlah : 1 buah

42. Drum Akumulator (F-162)



Fungsi : Menampung distilat dari kondensor distilasi (E-161)

Tipe : Tangki horisontal dengan tutup samping elipsoidal

Perhitungan:

Rate masuk = 87636,4888 kg/hari

= 3651,5204 kg/jam = 8033,3449 lb/jam

ρ = 598,2143 kg/m^3 = 37,3452 lb/ft^3

$$\text{Rate volumetrik} = \frac{8033{,}3449 \text{ lb/jam}}{37{,}3452 \text{ lb/ft}^3} = 215{,}1105 \text{ ft}^3\text{/jam}$$

Diambil: L = 2.D

Liquid mengisi ¾ bagian tangki

Volume liquid = ¾ (volume shell + 2.volume elipsoidal)

$$215{,}1105 = \tfrac{3}{4}\left(\left[\frac{\pi}{4}D^2.L\right] + 2.\left[0{,}131328.D^3\right]\right)$$

$$215{,}1105 = \tfrac{3}{4}\left(\left[\frac{\pi}{4}D^2.2.D\right] + 2.\left[0{,}131328.D^3\right]\right)$$

$$215{,}1105 = \tfrac{3}{4}.(1{,}8335\ D^3)$$

$$215{,}1105 = 1{,}3751\ .\ D^3$$

$$D^3 = 156{,}4326\ ft^3$$

$$D_{shell} = 5{,}3881\ ft \approx 6\ ft$$

$$L_{shell} = 2.D = 10{,}7762\ ft \approx 11\ ft$$

$$L_{elipsoidal} = 2.\ \frac{D}{4} = 2.\frac{5{,}3881}{4} = 2{,}6941\ ft$$

$$L_{tangki} = L_{shell} + L_{elipsoidal}$$

$$= 10{,}7762 + 2{,}6941\ ft = 13{,}4703\ ft \approx 16\ ft$$

Perhitungan Tebal Shell:

$$t_{shell} = \frac{P.D}{2.f\,E} + c$$

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

$$P = \frac{\rho.h}{144}$$

$\rho = 37{,}3452\ lb/ft^3$

h = 0,74. D = 0,74. 5,3881 = 3,9872 ft

$$P = \frac{37{,}3452.(3{,}9872)}{144} = 1{,}034\ psia$$

$P_{operasi}$ = 1,034 + 80,85 = 81,884 psia

Untuk safety, $P_{design} = 1{,}2 \,.\, 81{,}884 = 98{,}2608$ psia

$$t_{shell} = \frac{98{,}2608.5{,}3881.12}{2.18750.0{,}8} + 0{,}1$$

$$= 0{,}3118 \text{ in}$$

Diambil $t_{shell} = {}^{5}/_{16}$ in (Brownell & Young, 1959, App.F item 2, p.350)

<u>Perhitungan Tebal Elipsoidal:</u>

$$v = \frac{1}{6}.\left(2 + k^2\right)$$

$$= \frac{1}{6}.\left(2 + 2^2\right) = 1$$

$$t_{elipsoidal} = \frac{P.D.v}{2.f\,E - 0{,}2.P} + c$$

$$= \frac{98{,}2608.5{,}3881.12.1}{2.18750.0{,}8 - 0{,}2.98{,}2608} + 0{,}1 = 0{,}3120 \text{ in}$$

Diambil $t_{elipsoidal} = {}^{5}/_{16}$ in (Brownell & Young, 1959, App.F item 2, p.350)

Spesifikasi Drum Akumulator (F-162)

Fungsi : Menampung distilat dari kondensor distilasi (E-161)

Type : Tangki horisontal dengan tutup samping berbentuk elipsoidal

Dasar pemilihan : Tekanan tidak terlalu besar

Kapasitas : 12458,6615 ft^3/jam

Suhu operasi : 8°C

Tekanan operasi : 5,5 atm

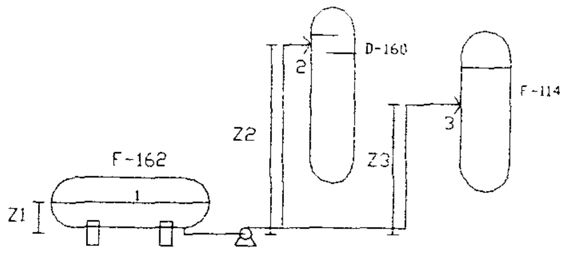
Dimensi :

- ~ diameter shell : 6 ft
- ~ tebal shell : ${}^{5}/_{16}$ in
- ~ tebal elipsoidal : ${}^{5}/_{16}$ in
- ~ panjang : 16 ft

Bahan konstruksi : Stainless steel 18-8 tipe 304

Jumlah : 1 buah

43. Pompa Reflux (L-165)



Fungsi : Memompa liquida dari drum akumulator (F-162) kembali ke menara distilasi (D-160) dan ke tangki penyimpan NH_3 (F-114)

Tipe : *Centrifugal Pump*

Dasar pemilihan:

1. Cocok untuk liquida dengan viskositas rendah
2. Cocok untuk rate massa besar

Jumlah: 1 buah

Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 598,2143 kg/m^3 = 37,5452 lb/ft^3 (Perry, 1984, tab.3-1, p.3-7)

$\mu_{campuran}$ = 0,1363 cps = 9,16.10^{-5} lb/ft.s (Geankoplis, 1997, fig.A.3-4, p.876)

Kapasitas 1 (m_1) = 87.636,4888 kg/hari = 2,2315 lb/sec

Kapasitas 2 (m_2) = 1.158,8006 kg/hari = 0,7082 lb/sec

Kapasitas 3 (m_3) = 86.477,6882 kg/hari = 2,2011 lb/sec

$$\text{Rate volumetric 1} = \frac{2{,}2315\ \text{lb/detik}}{37{,}5452\ \text{lb/ft}^3} = 0{,}0594\ \text{ft}^3\text{/detik} = 26{,}6780\ \text{gal/min}$$

$$\text{Rate volumetric 2} = \frac{0{,}7082\ \text{lb/detik}}{37{,}5452\ \text{lb/ft}^3} = 0{,}0189\ \text{ft}^3\text{/detik} = 8{,}4835\ \text{gal/min}$$

$$\text{Rate volumetric 3} = \frac{2{,}2011\ \text{lb/detik}}{37{,}5452\ \text{lb/ft}^3} = 0{,}0586\ \text{ft}^3\text{/detik} = 26{,}3032\ \text{gal/min}$$

Dianggap $N_{Re} > 2100$

$Di_{opt}\ 1 = 3{,}9.q_f^{0,45}.\rho^{0,13}$ in (Peters & Timmerhaus, 1991 , eq.15, p. 496)

$= 3{,}9.\ 0{,}0594^{0,45}.\ (37{,}5452)^{0,13} = 1{,}7537$ in $\approx 2{,}067$ in

Dari Brown, 1950, tab. 23, p.123 diperoleh:

Ukuran pipa 2 in sch. 40

ID = 2,067 in

OD = 2,375 in

$A_p = 3{,}356\ in^2$

$Di_{opt}\ 2 = 3{,}9.q_f^{0,45}.\rho^{0,13}$ in (Peters & Timmerhaus, 1991 , eq.15, p. 496)

$= 3{,}9.\ 0{,}0189^{0,45}.\ (37{,}5452)^{0,13} = 1{,}0475$ in $\approx 1{,}049$ in

Dari Brown, 1950, tab. 23, p.123 diperoleh:

Ukuran pipa 1 in sch. 40

ID = 1,049 in

OD = 1,315 in

$A_p = 0{,}864\ in^2$

$Di_{opt}\ 3 = 3{,}9.q_f^{0,45}.\rho^{0,13}$ in (Peters & Timmerhaus, 1991 , eq.15, p. 496)

$= 3{,}9.\ 0{,}0586^{0,45}.\ (37{,}5452)^{0,13} = 1{,}7431$ in $\approx 2{,}067$ in

Dari Brown, 1950, tab. 23, p.123 diperoleh:

Ukuran pipa 2 in sch. 40

ID = 2,067 in

OD = 2,375 in

$A_p = 3{,}356\ in^2$

<u>Kecepatan aliran:</u>

$$v_1 = \frac{Q}{A} = \frac{0{,}0594\ ft^3/detik}{3{,}356/144\ ft^2} = 2{,}5487\ ft/detik$$

$$N_{Re1} = \frac{D.v.\rho}{\mu} = \frac{2{,}067/12 \times 2{,}5487 \times 37{,}5452}{9{,}16.10^{-5}} = 179964{,}9307$$

$$v_2 = \frac{Q}{A} = \frac{0{,}0189\ ft^3/detik}{0{,}864/144\ ft^2} = 3{,}1504\ ft/detik$$

$$N_{Re2} = \frac{D.v.\rho}{\mu} = \frac{1{,}049/12 \times 3{,}1504 \times 37{,}5452}{9{,}16.10^{-5}} = 112893{,}4182$$

$$v_3 = \frac{Q}{A} = \frac{0{,}0586\ ft^3/detik}{3{,}356/144\ ft^2} = 2{,}5144\ ft/detik$$

$$N_{Re3} = \frac{D.v.\rho}{\mu} = \frac{2{,}067/12 \times 2{,}5144 \times 37{,}5452}{9{,}16.10^{-5}} = 177542{,}4793$$

Untuk aliran turbulen (steel pipe) digunakan:

$f1 = 0{,}04/(N_{Re}^{0,16})$ (Peters&Timmerhaus,1991,eq.8, p.483)

$= 0{,}04/(179964{,}9307^{0,16}) = 0{,}0058$

$f2 = 0{,}04/(N_{Re}^{0,16})$ (Peters&Timmerhaus,1991,eq.8, p.483)

$= 0{,}04/(112298{,}6434^{0,16}) = 0{,}0062$

$f3 = 0{,}04/(N_{Re}^{0,16})$ (Peters&Timmerhaus,1991,eq.8, p.483)

$= 0{,}04/(177542{,}4793^{0,16}) = 0{,}0058$

Titik 1:

Panjang pipa lurus = 40 ft

Panjang pipa ekivalen:

- 1 buah gate valve, Le/D = 7 (Peters & Timmerhaus,1991,tab.1, p.484)
  Le = 1 × 7 × 2,067/12 ft = 1,2058 ft
- 1 buah globe valve, Le/D = 300 (Peters & Timmerhaus,1991,tab.1, p.484)
  Le = 1 × 300 × 2,067/12 ft = 51,675 ft
- 1 buah tee, Le/D = 90 (Peters & Timmerhaus,1991,tab.1, p.484)
  Le = 1 × 90 × 2,067/12 ft = 15,5025 ft
- 3 buah elbow 90°, Le/D = 32 (Peters & Timmerhaus,1991,tab.1, p.484)
  Le = 3 × 32 × 2,067/12 ft = 16,536 ft

Panjang total pipa = (40 + 1,2058 + 51,675 + 15,5025 + 16,536) ft = 124,9193 ft

Friksi yang melalui pipa dan fitting:

$$F_{1a} = \frac{2.f.\Delta L.v^2}{D.gc} = \frac{2.0{,}0058.124{,}9193.2{,}5487^2}{2{,}067/12.32{,}17} = 1{,}6987 \text{ lbf.ft/lbm}$$

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

Friksi karena contraction:

Dari Peters & Timmerhaus, 1991, tabel 1, p.484 diperoleh:

A_1 = luas penampang drum akumulator = 301,5929 ft^2

A_2 = luas penampang pipa = 3,356 in^2

$$\frac{A_2}{A_1} = \frac{3{,}356/144 \text{ ft}^2}{301{,}5929 \text{ ft}^2} = 7{,}73.10^{-5}$$

Untuk $\frac{A_2}{A_1} < 0{,}715 \rightarrow Kc = 0{,}5$; untuk aliran turbulen $\rightarrow \alpha = 1$

$$F_{1b} = \frac{Kc.V^2}{2.\alpha.gc} = \frac{0{,}5.2{,}5487^2}{2.1.32{,}17} = 0{,}0505 \text{ lbf.ft/lbm}$$

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

$\Sigma F = (1{,}6987 + 0{,}0505)$ lbf.ft/lbm = 1,7492 lbf.ft/lbm

Titik 2:

Panjang pipa lurus = 20 ft

Panjang pipa ekivalen:

- 1 buah globe valve, Le/D = 300 (Peters & Timmerhaus,1991,tab.1, p.484)

  Le = 1 × 300 × 1,049/12 ft = 26,2250 ft

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

  Le = 3 × 32 × 1,049/12 ft = 8,392 ft

Panjang total pipa = (20 + 26,225 + 8,392) ft = 54,617 ft

Friksi yang melalui pipa dan fitting:

$$F_{2a} = \frac{2.f.\Delta L.v^2}{D.gc} = \frac{2.0{,}0062.54{,}617.3{,}1504^2}{1{,}049/12.32{,}17} = 2{,}3902 \text{ lbf.ft/lbm}$$

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

Friksi karena expansion:

K_{ex} = 1 (Brown, 1950)

$$F_{2b} = \frac{K_{ex}.v^2}{2.\alpha.gc} = \frac{1.3,1504^2}{2.1.32,17} = 0,1543 \text{ lbf.ft/lbm}$$

$\Sigma F_2 =$ 2,3902 + 0,1543 = 2,5445 lbf.ft/lbm

Titik 3:

Panjang pipa lurus = 20 ft

Panjang pipa ekivalen:

- 1 buah globe valve, Le/D = 300 (Peters & Timmerhaus,1991,tab.1, p.484)

  Le = 1 × 300 × 2,067/12 ft = 51,675 ft

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

  Le = 3 × 32 × 2,067/12 ft = 16,536 ft

Panjang total pipa = (20 + 51,675 + 16,536) ft = 88,2110 ft

Friksi yang melalui pipa dan fitting:

$$F_{3a} = \frac{2.f.\Delta L.v^2}{D.gc} = \frac{2.0,0058.88,2110.2,5144^2}{2,067/12.32,17} = 1,1675 \text{ lbf.ft/lbm}$$

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

Friksi karena expansion:

K_{ex} = 1 (Brown, 1950)

$$F_{3b} = \frac{K_{ex}.v^2}{2.\alpha.gc} = \frac{1.2,5144^2}{2.1.32,17} = 0,0983 \text{ lbf.ft/lbm}$$

$\Sigma F_3 =$ 1,1675 + 0,0983 = 1,2658 lbf.ft/lbm

Persamaan Bernoulli:

P_1 = 80,85 psia; z_1 = 15 ft

P_2 = 88,2 psia; z_2 = 27 ft

P_3 = 170 psia; z_3 = 10 ft

$$m_1 \times (-Ws) = m_3 \times (\frac{P_3}{\rho c} + \frac{v_3^2}{2.\alpha.gc} + \frac{g}{gc}.z_3) + m_2 \times (\frac{P_2}{\rho c} + \frac{v_2^2}{2.\alpha.gc} + \frac{g}{gc}.z_2) -$$

$$m_1 \times (\frac{P_1}{\rho} + \frac{v_1^2}{2.\alpha.gc} + \frac{g}{gc}.z_1) + m_1 \times \Sigma F_1 + m_2 \times \Sigma F_2 + m_3 \times \Sigma F_3$$

(Nevers, 1991)

$$2{,}2315 \times (\text{-Ws}) = 2{,}2011 \times (\frac{170.144}{37{,}5452} + \frac{2{,}5144^2}{2.1.32{,}17} + \frac{32{,}17}{32{,}17}.10) +$$

$$0{,}7082 \times (\frac{88{,}2.144}{37{,}5452} + \frac{3{,}1504^2}{2.1.32{,}17} + \frac{32{,}17}{32{,}17}.27) -$$

$$2{,}2315 \times (\frac{80{,}85.144}{37{,}5452} + \frac{2{,}5487^2}{2.1.32{,}17} + \frac{32{,}17}{32{,}17}.15) +$$

$$2{,}2315 \times 1{,}7492 + 0{,}7082 \times 2{,}5445 + 2{,}2011 \times 1{,}2658$$

$$\text{-Ws} = 447{,}6825 \text{ lbf.ft/lbm}$$

Effisiensi pompa = 28 % (Peters & Timmerhaus, 1991, fig. 14-37, p.520)

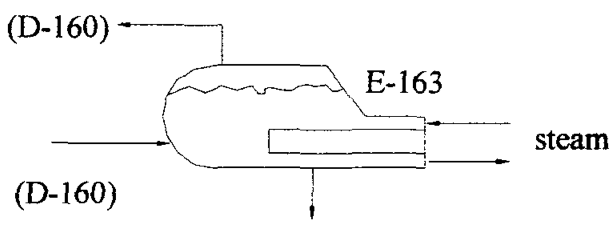
$$\text{Brake hp} = \frac{-\text{Ws. m}}{\eta.\ 550}$$ (Geankoplis, 1997, eq. 3.3-2, p. 134)

$$= \frac{447{,}6825 \text{ lbf.ft/lbm.}2{,}2315 \text{ lbm/s}}{0{,}28.550 \dfrac{\text{lbf.ft/s}}{\text{hp}}} = 6{,}4870 \text{ Hp}$$

Effisiensi motor = 86% (Peters & Timmerhaus, 1991, fig.14.38, p. 521)

Sehingga dipakai pompa dengan power motor $= \frac{6{,}4870}{0{,}86} = 7{,}5431$ Hp $\approx$ 8 Hp

44. Reboiler (E-163)



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 = 6,17 atm

T liquid masuk = 218°C ; T gas keluar = 228°C

Q_R = 296309300,1018 kJ/hari = 12346220,8375 kJ/jam= 11701913,47 Btu/jam

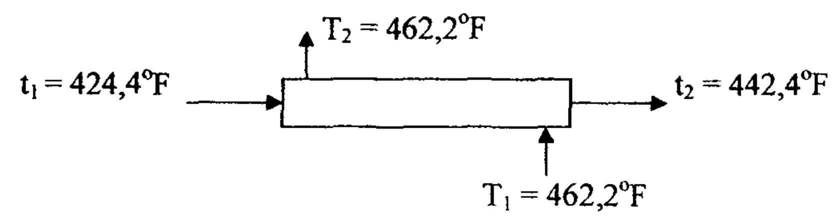
Steam yang digunakan : *saturated steam* dengan tekanan 33 bar, 239°C

λ steam, 239°C = 1769,155 kJ/kg (Smith, 1996, p. 672)

$$\text{Massa steam yang dibutuhkan} = \frac{296309300{,}1018\ \text{kJ/hari}}{1769{,}155\ \text{kJ/kg}}$$

= 167486,3424 kg/hari = 6978,5976 kg/jam

= 15352,9147 lb/jam



$\Delta T1 = T2 - t1 = 462{,}2 - 424{,}4 = 37{,}8$°F

$\Delta T2 = T1 - t2 = 462{,}2 - 442{,}4 = 19{,}8$°F

$$\Delta T_{LMTD} = \frac{\Delta T1 - \Delta T2}{\mathrm{Ln}\left(\dfrac{\Delta T1}{\Delta T2}\right)} = \frac{37{,}8 - 19{,}8}{\mathrm{Ln}\left(\dfrac{37{,}8}{19{,}8}\right)} = 27{,}8368$$

F_T = 1 karena salah satu fluida suhunya konstan (Figure 18, p.828, Kern, 1965)

$\Delta T = \Delta T_{LMTD} \times F_T = 27{,}8368 \times 1 = 27{,}8368$°F

Tc = 462,2 °F

$$tc = \frac{424{,}4 + 442{,}4}{2} = 433{,}4\text{°F}$$

Trial U_D = 182 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)

$Q = U_D \,.\, A \,.\, \Delta T$

$$A = \frac{Q}{UD \times \Delta T} = \frac{11701913{,}47}{182 \times 27{,}8368} = 2309{,}7564\ ft^2$$

$A = Nt \,.\, a" \,.\, L = Nt \,.\, 0{,}2618 \,.\, 12$

$Nt = 735{,}2166$ tubes

Dari tabel 9 hal 842, Kern, 1965, diperoleh untuk 1-2 heat exchanger:

$ID_{shell} = 39$ in   Nt = 736 tubes

UD koreksi → $A = Nt \,.\, a" \,.\, L = 736 \,.\, 0{,}2618 \,.\, 12 = 2312{,}2176\ ft^2$

$$UD = \frac{Q}{A.\Delta T} = \frac{11701913{,}47}{2312{,}2176.27{,}8368} = 181{,}8063\ Btu/jam.ft^2.°F$$

Tube Side

$a't = 0{,}479\ in^2$ (Tabel 10, p.843, Kern,1965)

$at = (Nt \,.\, a't)/144.n$

$= (736.0{,}479)/144.2 = 1{,}2241$

$Gt = W/at$

$= 15352{,}9147/\ 1{,}2241$

$= 12542{,}2063\ lb/jam.ft^2$

Pada tc = 462,2 °F

$\mu = 0{,}0175.2{,}42 = 0{,}0424\ lb/ft.hr$

$D = 0{,}782/12 = 0{,}0652$ ft

$$Ret = \frac{D.G}{\mu} = 19286{,}6003$$

$hio = 1500\ Btu/jam.ft^2.\ °F$

Shell Side

Asumsi ho = 160

$$tw = tc + \frac{ho}{hio + ho}.\ (Tc + tc)$$

$$= 433{,}4 + \frac{160}{1500 + 160}.(462{,}2 + 433{,}4)$$

$= 519{,}7229$ °F

$\Delta tw = tw - tc = 86{,}3229$ °F

Dari Fig. 15.11, p.474, Kern, 1965,

diperoleh : $ho = 300\ btu/jam.ft^2.°F$

$$Uc = \frac{hio \times ho}{hio + ho} = \frac{1500 \times 300}{1500 + 300} = 250$$

$$Rd = \frac{Uc - Ud}{Uc \times Ud} = \frac{250 - 181{,}8063}{250 \times 181{,}8063} = 0{,}0015\ \text{(memenuhi)}$$

Tube Side	Shell Side
Untuk Ret = 19286,6003	Diabaikan
f = 0,00023 (Fig.26, p.836, Kern 1965)	
$\Delta\ Pt = \dfrac{f\,.\,Gt^2\,.\,L\,.\,n}{5{,}22\,.\,10^{10}\,.\,D.\,s\,.\,\varphi_t}$	
$= \dfrac{0{,}00023\,.\,12542{,}2063^2\,.\,12\,.\,2}{5{,}22.\,10^{10}\,.\,0{,}0652.\,1.\,1}$	
= 0,00026 psia	

Spesifikasi Reboiler (F-163)

Fungsi : Menguapkan kembali bottom product dari menara distilasi (D-160)

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

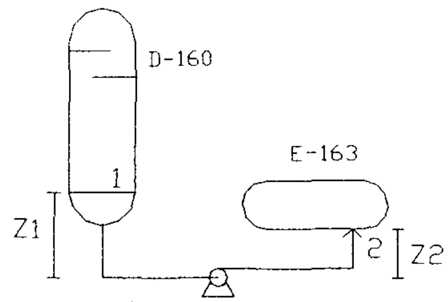
Dimensi :

~ Shell	ID	: 39 in
	Baffle space	: 5 in
~ Tube	ID	: 0,782 in
	OD	: 1 in
	Jumlah	: 736
	Passes	: 2
	Pitch	: 1 ¼ in
	Susunan	: triangular
~ Panjang		: 12 ft
~ Luas perpindahan panas		: 2312,2176 ft^2

Bahan konstruksi : Carbon steel

Jumlah : 1 buah

45. Pompa Reboiler (L-164)



Fungsi : Memompa liquida dari menara distilasi (D-160) ke reboiler (E-163)

Tipe : *Centrifugal Pump*

Dasar pemilihan:

1. Cocok untuk liquida dengan viskositas rendah
2. Cocok untuk rate massa besar

Jumlah : 1 buah

Perhitungan:

$$\frac{1}{\rho_{campuran}} = \frac{x_{K2SO4}}{\rho_{K2SO4}} + \frac{x_{NaCl}}{\rho_{NaCl}} + \frac{x_{CaSO4.2H2O}}{\rho_{CaSO4.2H2O}} + \frac{x_{K2SO4.Na2SO4}}{\rho_{K2SO4.Na2SO4}} + \frac{x_{KCl.2NaCl}}{\rho_{KCl.2NaCl}} + \frac{x_{CaCl2}}{\rho_{CaCl2}} +$$

$$\frac{x_{NH3}}{\rho_{NH3}} + \frac{x_{H2O}}{\rho_{H2O}}$$

$\rho_{campuran}$ = 54,1872 lb/ft^3

$\mu_{campuran}$ = 2,714 cps = 2,714.10^{-3} kg/m.s = 1,8237.10^{-3} lb/ft.s

Kapasitas = 383.275,5141 kg/hari = 266,1636 kg/menit = 585,5598 lb/menit

$$\text{Rate volumetrik} = \frac{585{,}5598 \text{ lb/menit}}{54{,}1872 \text{ lb/ft}^3} = 10{,}8062 \text{ ft}^3\text{/menit} = 0{,}1801 \text{ ft}^3\text{/s}$$

Dianggap N_{Re} > 2100

$Di_{opt} = 3{,}9.q_f^{0,45}.\rho^{0,13}$ in (Peters & Timmerhaus, 1991 , eq.15, p. 496)

$= 3{,}9.\ 0{,}1801^{0,45}.\ (54{,}1872)^{0,13} = 3{,}03$ in $\approx$ 3,068 in

Dari Kern, 1965, p. 844 diperoleh:

Ukuran pipa IPS : 3 in ; sch. 40

ID = 3,068 in

OD = 3,5 in

$A_p = 7{,}38\ in^2$

Kecepatan aliran:

$$v = \frac{Q}{A} = \frac{0{,}1801\ ft^3/s}{7{,}38/144\ ft^2} = 3{,}5141\ ft^3/s$$

$$N_{Re} = \frac{D.v.\rho}{\mu} = \frac{3{,}068/12 \times 3{,}5141 \times 54{,}1872}{1{,}8237.10^{-3}} = 26.695{,}0990$$

Untuk aliran turbulen (steel pipe) digunakan:

$$f = \frac{0{,}04}{\left(N_{Re}\right)^{0,16}} = \frac{0{,}04}{(26.695{,}0990)^{0,16}} = 0{,}0078$$

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

Panjang pipa lurus = 10 m = 32,81 ft

Panjang pipa ekivalen:

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

  $Le = 1 \times 7 \times 3{,}068/12\ ft = 1{,}7897\ ft$

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

  $Le = 1 \times 300 \times 3{,}068/12\ ft = 76{,}70\ ft$

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

  $Le = 2 \times 32 \times 3{,}068/12\ ft = 16{,}3627\ ft$

Panjang total pipa = (32,81 + 1,7897 + 76,70 + 16,3627) ft = 127,6624 ft

Friksi yang melalui pipa dan fitting:

$$F_1 = \frac{2.f.\Delta L.v^2}{D.gc} = \frac{2.0{,}0078.127{,}6624.3{,}5141^2}{3{,}068/12.32{,}17} = 2{,}9901\ lbf.ft/lbm$$

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

Friksi karena contraction dan expansion:

Dari Peters & Timmerhaus, 1991, tabel 1, p.484 diperoleh:

A_1 = luas penampang menara distilasi = 12,5663 m²

A_2 = luas penampang pipa = 7,38 in²

$$\frac{A_2}{A_1} = \frac{7{,}38/144\ ft^2}{12{,}5663\ ft^2} = 4{,}08.10^{-3}$$

Untuk $\frac{A_2}{A_1} < 0{,}715 \rightarrow Kc = 0{,}5$; untuk aliran turbulen $\rightarrow \alpha = 1$

$$F_2 = \frac{Kc.v^2}{2.\alpha.gc} = \frac{0{,}5.3{,}5141^2}{2.1.32{,}17} = 0{,}0960 \text{ lbf.ft/lbm}$$

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

K_{ex} = 1 (Brown, 1950)

$$F_3 = \frac{K_{ex}.v^2}{2.\alpha.gc} = \frac{1.3{,}5141^2}{2.1.32{,}17} = 0{,}1919 \text{ lbf.ft/lbm}$$

$\Sigma F = (2{,}9901 + 0{,}0960 + 0{,}1919)$ lbf.ft/lbm = 3,278 lbf.ft/lbm

Persamaan Bernoulli:

$\Delta z = z_2 - z_1 = 2 - 10$ ft = -8 ft

$\Delta P = P_2 - P_1 = 6{,}17 - 6$ atm = 0,17 atm = 359,7588 lbf/ft^2

$\rho_{campuran}$ = 54,1872 lb/ft^3

$$-Ws = \frac{P_2 - P_1}{\rho} + \frac{v_2^2 - v_1^2}{2.\alpha.gc} + \frac{g}{gc}.\Delta z + \Sigma F$$

$$= \frac{359{,}7588}{54{,}1872} + \frac{3{,}5141^2 - 0}{2.1.32{,}17} + (-8) + 3{,}278$$

$$= 2{,}1091 \text{ lbf.ft/lbm}$$

Effisiensi pompa = 36 % (Peters & Timmerhaus, 1991, fig. 14-37, p.520)

$$\text{Brake hp} = \frac{-Ws.m}{\eta.550}$$ (Geankoplis, 1997, eq. 3.3-2, p. 134)

$$= \frac{2{,}1091 \text{ lbf.ft/lbm. } 585{,}5598/60 \text{ lbm/s}}{0{,}36.550 \frac{\text{ft.lbf/s}}{\text{hp}}} = 0{,}1040 \text{ Hp}$$

Effisiensi motor = 80% (Peters & Timmerhaus, 1991, fig.14.38, p. 521)

Sehingga dipakai pompa dengan power motor = $\frac{0{,}1040}{0{,}8} = 0{,}13 \text{ Hp} \approx 0{,}5 \text{ Hp}$

APPENDIX D

PERHITUNGAN ANALISA EKONOMI

APPENDIX D
PERHITUNGAN ANALISA EKONOMI

Metode Perkiraan Harga

Harga peralatan sering mengalami perubahan karena kondisi ekonomi. Oleh karena itu, untuk memperkirakan harga peralatan sekarang diperlukan suatu indeks yang dapat mengkonversikan harga peralatan sebelumnya menjadi harga ekivalen sekarang. Metode yang digunakan untuk menentukan harga peralatan adalah metode Cost Index yang dihitung dengan persamaan :

$$\text{Harga alat saat ini} = \frac{\text{Cost index saat ini}}{\text{Cost index pd tahun A}}.\text{Harga alat pd tahun A}$$

Pada perencanaan pabrik Kalium Sulfat, harga peralatan yang digunakan didasarkan pada harga alat yang terdapat pada pustaka Peters & Timmerhaus, 1991 dan Ulrich, 1984. Cost index yang digunakan adalah dari Marshall & Swift Cost Index dan Chemical Engineering Plant Cost Index.

D.1. Perhitungan Harga Peralatan

- Cost Index Marshall & Swift pada tahun 1990 = 924 (Peters & Timmerhaus,1991)
- Cost Index Marshall & Swift pada tahun 2002 = 1094,9 (Chemical Engineering, Agustus, 2002)
- Cost Index Chemical Engineering Plant pada tahun 1982 = 315 (Ulrich,1984)
- Cost Index Chemical Engineering Plant pada tahun 2002 = 392,7 (Chemical Engineering, Agustus, 2002)

Contoh perhitungan :

Nama alat : Tangki Penyimpan NH_3 cair

Kapasitas : 3574650,3040 liter

Bahan konstruksi : Stainless Steel 18-8 tipe 304

Harga Tahun 1990 : US$ 6000

$$\text{Harga Tahun 2002} = \frac{1094{,}9}{924}.\text{US\$ } 6.000 = \text{US\$ } 7.110 \text{ (US\$1 = Rp 8.900,00)}$$

Biaya beban per tahun = $650 \times 35000 \times 12$ = Rp 273.000.000,00

Listrik yang terpakai = 620,4224 kW

Biaya listrik :

WBP (Waktu Beban Puncak, pk.18.00-22.00) = Rp 388/kWh

LWBP (Luar Waktu Beban Puncak, pk.22.00-18.00) = Rp 314/kWh

Dalam 1 hari terdapat 4 jam WBP dan 20 jam LWBP

Listrik terpakai = 634,6907 kW untuk 330 hari (full operation)

= $^1/_2$.32,4521 kW untuk 30 hari (of f operation)

Biaya listrik terpasang per tahun :

= (330. 634,6907 + 30. $^1/_2$. 32,4521).(388.4 + 314.20)

= Rp 2.593.343.400,00

Total biaya utilitas = Rp 8.171.105.500,00

D.5. Perhitungan Harga Tanah dan Bangunan

Luas tanah	= 9000 m^2
Luas bangunan pabrik	= 4500 m^2
Luas bangunan gedung	= 2032 m^2
Harga tanah per m^2	= Rp 95.000,00
Harga bangunan pabrik per m^2	= Rp 120.000,00
Harga bangunan gedung per m^2	= Rp 150.000,00

Harga tanah total	= Rp 855.000.000,00
Harga bangunan pabrik	= Rp 540.000.000,00
Harga bangunan gedung	= Rp 304.800.000,00
Total harga tanah dan bangunan	= Rp1.699.800.000,00

D. 6. Perhitungan Gaji Karyawan

Untuk karyawan bagian proses, pengemasan, dan keamanan dilakukan sistem 3 shift/hari yang terdiri atas 4 regu secara bergantian.

Shift pergantian kerja karyawan disajikan pada tabel D.3.

Tabel D.3. Shift Pergantian Kerja Karyawan

Regu	Hari								
	Senin	Selasa	Rabu	Kamis	Jumat	Sabtu	Minggu	Senin	Selasa
1	P	P	P	L	M	M	M	L	S
2	S	S	L	P	P	P	L	M	M
3	M	L	S	S	S	L	P	P	P
4	L	M	M	M	L	S	S	S	L

Keterangan tabel : P = pagi S = siang M = malam L = libur

Jam pergantian shift untuk karyawan bagian proses, pengemasan, dan bagian keamanan berbeda. Untuk karyawan proses dan pengemasan, pergantian yang diterapkan adalah :

Shift 1 : 06.00 – 14.00

Shift 2 : 14.00 – 22.00

Shift 3 : 22.00 – 06.00

Sedangkan untuk karyawan bagian keamanan, pergantian yang diterapkan adalah :

Shift 1 : 07.00 – 15.00

Shift 2 : 15.00 – 23.00

Shift 3 : 23.00 – 07.00

Untuk karyawan non shift memiliki jam kerja :

Senin-Jumat : 07.30 – 16.00, waktu istirahat 12.00 – 13.00

kecuali Jumat waktu istirahat 11.30 – 13.00

Sabtu : 07.30 – 12.00

Perincian gaji karyawan disajikan pada tabel D-4.

Tabel D.4 Perincian Gaji Karyawan

No	Jabatan	Jumlah	Gaji tiap orang/Bulan, Rupiah	Total
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 198.150.000,00

Total gaji karyawan per tahun = Rp 2.377.800.000,00