LAMPIRAN A
PERHITUNGAN NERACA MASSA

Kapasitas: 5.000 ton/tahun

Basis perhitungan: 1 hari

Data komposisi susu sapi segar:

Komponen	% massa
Air	87,1
Protein	3,4
Lemak	3,9
Karbohidrat (laktosa)	4,9
Mineral	0,7

(*Sumber: Minard, R.,2000*)

Protein dalam susu terdiri dari casein (80% brt) dalam bentuk Ca^{2+}caseinate, dan protein whey (20% brt). Protein whey terdiri dari laktalbumin (75% brt), dan laktoglobulin (25% brt). (Indrawati,1993)

Data berat molekul:

BM Ca^{2+}caseinate = 250.000 (Walstra- Jenness,1984).

BM Asam asetat = 60

BM Kalsium asetat = 158

BM Casein = 249.962

Susu segar yang masuk centrifuge (H-114) = 212.500 liter

S.g susu pada 15,5°C = 1,0320 (Eckles, 1957)

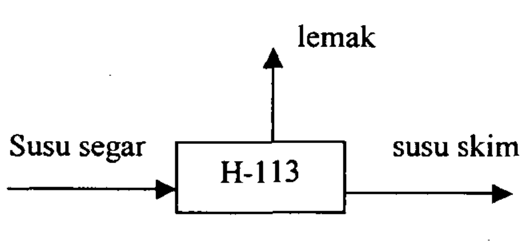
ρ air pada 15,5°C = 0,9989 gr/cm^3 (Geankoplis, 1997)

ρ susu = 1,0320 × 0,9989 gr/cm^3 = 1,0309 gr/cm^3 = 1,0309 kg/liter

Massa susu segar masuk tangki penampung F-111= 212.500 liter × 1,0309 kg/liter

= 219.059,8665 kg

1. Centrifuge (H-113)



Susu sapi segar masuk dari tangki penampung susu pada suhu 4°C, pH= 6,5 – 6,7

Susu sapi segar masuk terdiri dari:

Air = 0,871 × 219.059,8665 kg = 190.801,1437 kg

Ca^{2+}caseinate = 0,8 × 0,034 × 219.059,8665 kg = 5.958,4284 kg

Protein whey = 0,2 × 0,034 × 219.059,8665 kg = 1.489,6071 kg

Lemak = 0,039 × 219.059,8665 kg = 8.543,3348 kg

Laktosa = 0,049 × 219.059,8665 kg = 10.733,9335 kg

Mineral = 0,007 × 219.059,8665 kg = 1.533,4191 kg

Asumsi: lemak yang terpisah 99,98% = 0,9998 × 8.543,3348 kg = 8.541,6261 kg

Filtrat yg terikut padatan dalam centrifuge = 60-80% (Ulrich table 4.23 hal 220, 1984).

Diasumsi filtrat yang terikut lemak = 60%

Komponen filtrat	Massa	fraksi massa
Air	190.801,1437	0,9063
Ca2+caseinate	5.958,4284	0,0283
Protein whey	1.489,6071	0,0071
Lemak	1,7087	0,0000
Laktosa	10.733,9335	0,0510
Mineral	1.533,4191	0,0073
Total	210.518,2404	1,0000

Filtrat yg terikut lemak = 0,6/0,4 × 8.541,6261 kg = 12.812,4392 kg, terdiri dari:

Air = 0,9063 × 12.812,4392 kg = 11.612,4287 kg

Ca^{2+} caseinate = 0,0283 × 12.812,4392 kg = 362,6384 kg

Protein Whey = 0,0071 × 12.812,4392 kg = 90,6596 kg

Laktosa = 0,0510 × 12.812,4392 kg = 653,2824 kg

Mineral = 0,0073 × 12.812,4392 kg = 93,3261 kg

Jadi lemak yang keluar menuju tangki penampung lemak, terdiri dari:

Lemak = 8.541,6261 kg

Filtrat yang terikut lemak = 12.812,4392 kg

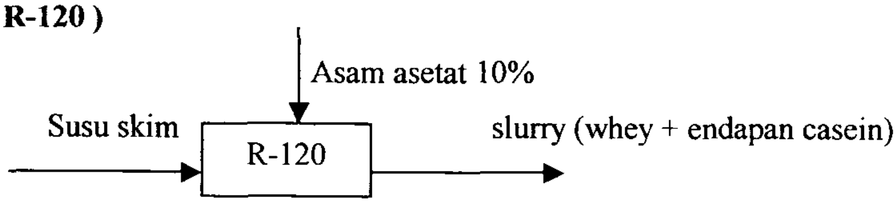
Sedangkan skim milk yang keluar menuju R–120 terdiri dari :

Air = (190.801,1437 – 11.612,4287) kg = 179.188,7150 kg

Ca^{2+} caseinate = (5.958,4284 – 362,6384) kg = 5.595,7900 kg

Protein Whey	= (1.489,6071 kg – 90,6596) kg	=	1.398,9475 kg
Lemak	= (8.543,3348 – 8.541,6261) kg	=	1,7087 kg
Laktosa	= (10.733,9335 – 653,2824) kg	=	10.080,6510 kg
Mineral	= (1.533,4191 - 93,3261) kg	=	1.440,0930 kg

2. Reaktor (R-120)



Susu skim masuk dari H-113 terdiri dari:

Air	=	179.188,7150 kg
Ca^{2+} caseinate	=	5.595,7900 kg
Protein Whey	=	1.398,9475 kg
Lemak	=	1,7087 kg
Laktosa	=	10.080,6510 kg
Mineral	=	1.440,0930 kg

Kondisi operasi sebagai berikut:

Harga pH 4,6; dan suhu operasi 45° C

Pada reaktor R-120 terjadi reaksi :

	Ca^{2+}caseinate	+	$2CH_3COOH$	$\rightarrow$	Casein↓	+	$Ca(CH_3COO)_2$
Mula	$\frac{5.595,7900}{250.000}$		$2\times\frac{5.595,7900}{250.000}\times 110\%$		-		-
Reaksi	$\frac{5.595,7900}{250.000}$	~	$\frac{2\times 5.595,7900}{250.000}$	~	$\frac{5.595,7900}{250.000}$	~	$\frac{5.595,7900}{250.000}$
Sisa	0,0000		$\frac{0,1\times 2\times 5.595,7900}{250.000}$		$\frac{5.595,7900}{250.000}$		$\frac{5.595,7900}{250.000}$

Asam asetat yang dibutuhkan = $\frac{2\times 5.595,7900}{250.000}$ kmol

Asam asetat dimasukan ke R-120 berlebih 10% mol dari yang dibutuhkan

$$= \frac{2\times 5.595,7900}{250.000}\times 110\%\ \text{kmol}\times 60\ \text{kg/kmol} = 2,9546\ \text{kg}$$

Larutan asam asetat 10% berat masuk dari M-123 terdiri dari:

Asam asetat = 2,9546 kg

$$\text{Air} = \frac{90}{10} \times 2{,}9546\ \text{kg} = 26{,}5912\ \text{kg}$$

Slurry yang keluar menuju H-125 terdiri dari:

$$\text{Casein yang mengendap} = \frac{5.595{,}7900}{250.000}\ \text{kmol} \times 249.962\ \text{kg/kmol}$$

$$= 5.594{,}9394\ \text{kg}$$

$$\text{Kalsium asetat} = \frac{5.595{,}7900}{250.000}\ \text{kmol} \times 158\ \text{kg/kmol} = 3{,}5365\ \text{kg}$$

$$\text{Asam asetat sisa} = \frac{0{,}1 \times 2 \times 5.595{,}7900}{250.000}\ \text{kmol} \times 60\ \text{kg/kmol} = 0{,}2686\ \text{kg}$$

Air = (179.188,7150 + 26,5912) kg = 179.215,3062 kg

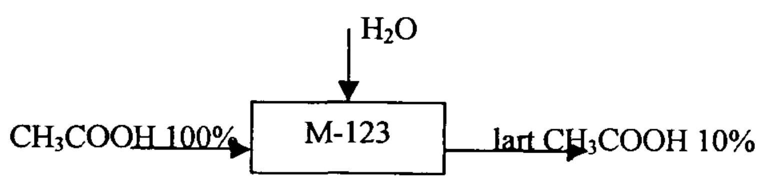
Protein Whey = 1.398,9475 kg

Lemak = 1,7087 kg

Laktosa = 10.080,6510 kg

Mineral = 1.440,0930 kg

3. Tanki pengencer (M-123)



Konsentrasi Asam asetat glasial masuk 100% kemudian diencerkan menjadi larutan asam asetat 10% berat.

Asam asetat glasial masuk = 2,9546 kg

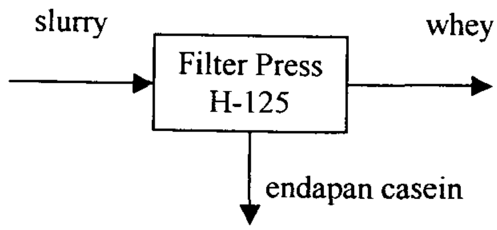
$$\text{Air dari utilitas} = \frac{90}{10} \times 2{,}9546\ \text{kg} = 26{,}5912\ \text{kg}$$

Larutan asam asetat keluar menuju R-120 terdiri dari:

Asam asetat = 2,9546 kg

Air = 26,5912 kg

4. Filter Press (H-125)



Slurry masuk dari R-120 terdiri dari:

Air	=	179.215,3062 kg
Casein	=	5.594,9394 kg
Protein Whey	=	1.398,9475 kg
Lemak	=	1,7087 kg
Laktosa	=	10.080,6510 kg
Mineral	=	1.440,0930 kg
Asam asetat	=	0,2686 kg
Kalsium asetat	=	3,5365 kg

Filtrat yg terikut padatan dalam Filter Press = 20 - 40% (Ulrich table 4.23b hal 223, 1984)

Komponen filtrat	Massa	fraksi massa
Air	179.215,3062	0,9327
Protein whey	1.398,9475	0,0073
Lemak	1,7087	0,0000
Laktosa	10.080,6510	0,0525
Mineral	1.440,0930	0,0075
Asam asetat	0,2686	0,0000
Kalsium asetat	3,5365	0,0000
Total	192.140,5116	1,0000

Diasumsi Filtrat yang terikut endapan casein = 20 %

Filtrat yang terikut endapan casein $= \frac{0.20}{0.80} \times 5.594{,}9394 = 1.398{,}7348$ kg , terdiri dari:

Air	$= 0{,}9327 \times 1.398{,}7348$ kg =	1.304,6426 kg
Protein whey	$= 0{,}0073 \times 1.398{,}7348$ kg =	10,1840 kg
Laktosa	$= 0{,}0525 \times 1.398{,}7348$ kg =	73,3846 kg
Mineral	$= 0{,}0075 \times 1.398{,}7348$ kg =	10,4835 kg

Jadi endapan casein yang keluar menuju M-210 terdiri dari:

Casein = 5.594,9394 kg

Filtrat yang terikut endapan = 1.398,7348 kg

Sedangkan larutan whey (filtrat) yang keluar menuju R-130 terdiri dari:

Air = (179.215,3062 – 1.304,6426) = 177.910,6637 kg

Protein Whey = (1.398,9475 – 10,1840) = 1.388,7635 kg

Lemak = 1,7087 kg

Laktosa = (10.080,6510 – 73,3846) = 10.007,2664 kg

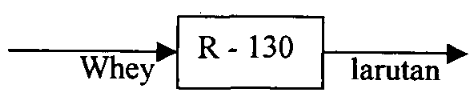
Mineral = (1.440,0930 – 10,4835) = 1.429,6095 kg

Asam asetat = 0,2686 kg

Kalsium asetat = 3,5365 kg

Pembuatan Edible Laktosa

5. Tanki Demineraliser (R – 130)



Larutan whey yang masuk dari H – 125 terdiri dari:

Air = 177.910,6637 kg

Protein Whey = 1.388,7635 kg

Lemak = 1,7087 kg

Laktosa = 10.007,2664 kg

Mineral = 1.429,6095 kg

Asam asetat = 0,2686 kg

Kalsium asetat = 3,5365 kg

Asumsi mineral yang terserap 99% = 1.429,6095 kg × 0,99

= 1.415,3134 kg

Mineral yang masih terlarut = (1.429,6095 – 1.415,3134) kg = 14,2961 kg

Larutan yang keluar menuju R-140 terdiri dari :

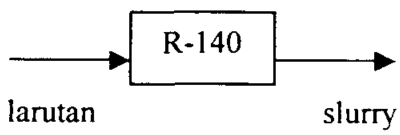
Air = 177.910,6637 kg

Protein Whey = 1.388,7635 kg

Lemak = 1,7087 kg

Laktosa	=	10.007,2664 kg
Mineral	=	14,2961 kg
Asam asetat	=	0,2686 kg
Kalsium asetat	=	3,5365 kg

6. Tangki Deproteinaser (R-140)



Larutan masuk dari R – 130 terdiri dari :

Air	=	177.910,6637 kg
Protein Whey	=	1.388,7635 kg
Lemak	=	1,7087 kg
Laktosa	=	10.007,2664 kg
Mineral	=	14,2961 kg
Asam asetat	=	0,2686 kg
Kalsium asetat	=	3,5365 kg

Protein whey mulai mengalami denaturasi pada suhu 70°C.

Ditetapkan : Suhu operasi 90°C

Asumsi : Protein whey yang mengendap 99% = 1.388,7635 kg × 0,99
= 1.374,8759 kg

Protein whey yang masih terlarut = (1.388,7635-1.374,8759) kg
= 13,8876 kg

Slurry yang keluar menuju H – 143 terdiri dari :

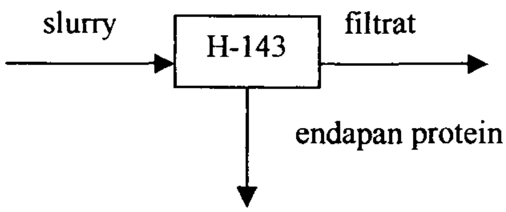
Air	=	177.910,6637 kg
Protein Whey	=	13,8876 kg
Lemak	=	1,7087 kg
Laktosa	=	10.007,2664 kg
Mineral	=	14,2961 kg

Asam asetat = 0,2686 kg

Kalsium asetat = 3,5365 kg

Endapan protein = 1.374,8759 kg

7. Filter Press (H – 143)



Slurry masuk dari R-140 terdiri dari :

Air = 177.910,6637 kg

Protein Whey = 13,8876 kg

Lemak = 1,7087 kg

Laktosa = 10.007,2664 kg

Mineral = 14,2961 kg

Asam asetat = 0,2686 kg

Kalsium asetat = 3,5365 kg

Endapan protein = 1.374,8759 kg

Filtrat yang terikut padatan dalam filter press = 20 – 40 % (Ulrich tabel 4.23 b hal 223, 1984)

Komponen filtrat	Massa	Fraksi massa
Air	177.910,6637	0,9466
Protein whey	13,8876	0,0001
Lemak	1,7087	0,0000
Laktosa	10.007,2664	0,0532
Mineral	14,2961	0,0001
Asam asetat	0,2686	0,0000
Kalsium asetat	3,5365	0,0000
Total	187.951,6276	1,0000

Asumsi filtrat yang terikut endapan protein = 20%

Filtrat yang terikut endapan = $\frac{0,2}{0,8} \times 1.374,8759 = 343,7190$ kg , terdiri dari:

Air = $0,9466 \times 343,7190$ kg = 325,3564 kg

Protein whey	= 0,0001 × 343,7190 kg =	0,0254 kg
Laktosa	= 0,0532 × 343,7190 kg =	18,3009 kg
Mineral	= 0,0001 × 343,7190 kg =	0,0261 kg

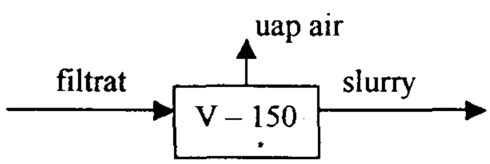
Jadi endapan yang keluar menuju penampung endapan terdiri dari:

Endapan	= 1.374,8759 kg
Filtrat yang terikut	= 343,7190 kg

Sedangkan filtrat yang keluar menuju V – 150 terdiri dari :

Air	= (177.910,6637 – 325,3564) kg	= 177.585,3072 kg
Protein whey	= (13,8876 – 0,0254) kg	= 13,8622 kg
Lemak		= 1,7087 kg
Laktosa	= (10.007,2664 – 18,3009) kg	= 9.988,9655 kg
Mineral	= (14,2961 – 0,0261) kg	= 14,2700 kg
Asam asetat		= 0,2686 kg
Kalsium asetat		= 3,5365 kg

8. Evaporator (V - 150)



Filtrat yang masuk dari H – 143 terdiri dari :

Air	= 177.585,3072 kg
Protein whey	= 13,8622 kg
Lemak	= 1,7087 kg
Laktosa	= 9.988,9655 kg
Mineral	= 14,2700 kg
Asam asetat	= 0,2686 kg
Kalsium asetat	= 3,5365 kg

Larutan filtrat diuapkan sampai mengandung total solid sebesar 55 – 65 %

(Ullman A15,1990)

Asumsi total solid dalam larutan 65 %

Berat komponen selain air = protein whey + lemak + laktosa + mineral + asam asetat + kalsium asetat = (13,8622 + 1,7087 + 9.988,9655 + 14,2700 + 0,2686 + 3,5365) kg = 10.022,6115 kg

$$\text{Massa air dalam larutan keluar} = \left(\frac{0.35}{0.65}\right) \times 10.022{,}6115 \text{ kg}$$

$$= 5.396{,}7908 \text{ kg}$$

Massa air yang menguap = (177.585,3072 – 5.396,7908) kg = 172.188,5164 kg

Jadi slurry yang menuju X – 160 terdiri dari:

Air	=	5.396,7908 kg
Protein whey	=	13,8622 kg
Lemak	=	1,7087 kg
Laktosa	=	9.988,9655 kg
Mineral	=	14,2700 kg
Asam asetat	=	0,2686 kg
Kalsium asetat	=	3,5365 kg

9. Kristaliser X – 160

$$\xrightarrow{\text{slurry}} \boxed{X - 160} \xrightarrow{\text{slurry}}$$

Slurry masuk dari V - 150 terdiri dari:

Air	=	5.396,7908 kg
Protein whey	=	13,8622 kg
Lemak	=	1,7087 kg
Laktosa	=	9.988,9655 kg
Mineral	=	14,2700 kg
Asam asetat	=	0,2686 kg
Kalsium asetat	=	3,5365 kg

Pada 5°C kelarutan laktosa = 15 gram per 100 gram air (Ullman A15, 1990)

Laktosa yang masih terlarut sebanyak = $\frac{15}{100} \times 5396{,}7908$ kg = 809,5186 kg

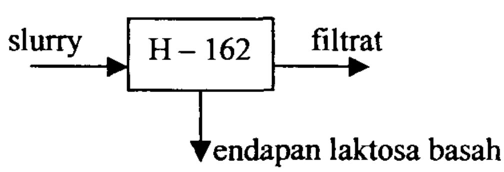
Kristal laktosa yang terbentuk sebanyak = (9.988,9655 – 809,5186) kg

= 9.179,4469 kg

Jadi Slurry yang menuju H – 162 terdiri dari :

Air	=	5.396,7908 kg
Protein whey	=	13,8622 kg
Lemak	=	1,7087 kg
Laktosa terlarut	=	809,5186 kg
Mineral	=	14,2700 kg
Asam asetat	=	0,2686 kg
Kalsium asetat	=	3,5365 kg
Kristal laktosa	=	9.179,4469 kg

10. Filter Press H – 162



Slurry keluar dari X – 160 terdiri dari :

Air	=	5.396,7908 kg
Protein whey	=	13,8622 kg
Lemak	=	1,7087 kg
Laktosa terlarut	=	809,5186 kg
Mineral	=	14,2700 kg
Asam asetat	=	0,2686 kg
Kalsium asetat	=	3,5365 kg
Kristal laktosa	=	9.179,4469 kg

Filtrat yang terikut padatan dalam filter press = 20 – 40 % (Ulrich tabel 4.23 b hal 223, 1984)

Komponen filtrat	Massa	Fraksi massa
Air	5.396,7908	0,8649
Protein whey	13,8622	0,0022
Lemak	1,7087	0,0003
laktosa terlarut	809,5186	0,1297
Mineral	14,2700	0,0023
Asam asetat	0,2686	0,0000
Kalsium asetat	3,5365	0,0006
Total	6.239,9554	1,0000

Asumsi filtrat yang terikut kristal laktosa = 20%

Filtrat yang terikut kristal laktosa = $\frac{0.2}{0.8} \times 9.179{,}4469$ kg = 2294,8617 kg, terdiri dari:

Air = 0,8649 × 2.294,8617 kg = 1.984,7720 kg

Protein whey = 0,0022 × 2.294,8617 kg = 5,0981 kg

Lemak = 0,0003 × 2.294,8617 kg = 0,6284 kg

Laktosa terlarut = 0,1297 × 2.294,8617 kg = 297,7158 kg

Mineral = 0,0023 × 2.294,8617 kg = 5,2480 kg

Kalsium asetat = 0,0006 × 2.294,8617 kg = 1,3006 kg

Jadi endapan laktosa basah yang keluar menuju B – 170 terdiri dari:

Kristal laktosa = 9.179,4469 kg

Filtrat yang terikut = 2.294,8617 kg

Sedangkan filtrat yang keluar menuju penampung filtrat terdiri dari :

Air = (5.396,7908 – 1.984,7720) kg = 3.412,0188 kg

Protein whey = (13,8622 - 5,0981) kg = 8,7641 kg

Lemak = (1,7087 - 0,6284) kg = 1,0803 kg

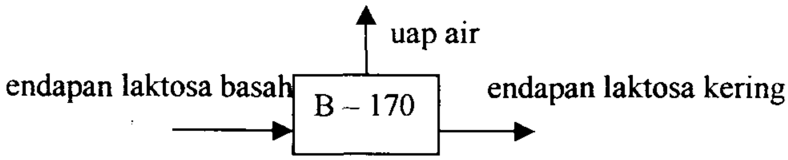
Laktosa terlarut = (809,5186 - 297,7158) kg = 511,8028 kg

Mineral = (14,2700 - 5,2480) kg = 9,0219 kg

Asam asetat = 0,2686 kg

Kalsium asetat = (3,5365 - 1,3006) kg = 2,2359 kg

11. Rotary Dryer (B – 170)



Endapan laktosa basah masuk dari H – 162 terdiri dari :

Air	=	1.984,7720 kg
Protein whey	=	5,0981 kg
Lemak	=	0,6284 kg
Laktosa terlarut	=	297,7158 kg
Mineral	=	5,2480 kg
Kalsium asetat	=	1,3006 kg
Kristal laktosa	=	9.179,4469 kg

Final produk mengandung 98 – 99,5 % laktosa (Ullman A6, 1990)

Asumsi: Kandungan air pada laktosa = 1,5%

Padatan yang terikut aliran gas keluar menuju cyclone = 1,5%

Padatan yang keluar menuju cyclone (H-173) terdiri dari:

Protein whey	= 1,5% × 5,0981 kg	=	0,0765 kg
Lemak	= 1,5% × 0,6284 kg	=	0,0094 kg
Laktosa terlarut	= 1,5% × 297,7158 kg	=	4,4657 kg
Mineral	= 1,5% × 5,2480 kg	=	0,0787 kg
Kalsium asetat	= 1,5% × 1,3006 kg	=	0,0195 kg
Kristal laktosa	= 1,5% × 9.179,4469 kg	=	137,6917 kg +
Berat komponen selain air		=	142,3416 kg

Kandungan air dalam padatan = $\frac{0.015}{0.985} \times 142{,}3416$ kg = 2,1676 kg

Endapan laktosa kering yang keluar menuju J-181:

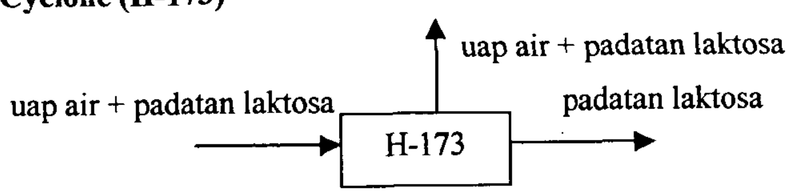
Protein whey	= (5,0981 - 0,0765) kg	=	5,0216 kg
Lemak	= (0,6284 - 0,0094) kg	=	0,6190 kg
Laktosa terlarut	= (297,7158 - 4,4657) kg	=	293,2501 kg
Mineral	= (5,2480 - 0,0787) kg	=	5,1693 kg
Kalsium asetat	= (1,3006 - 0,0195) kg	=	1,2811 kg
Kristal laktosa	= (9.179,4469 - 137,6917) kg	=	9.041,7552 kg +
Berat padatan selain air		=	9.347,0963 kg

Kandungan air dalam padatan = $\frac{0.015}{0.985} \times 9.347,0963$ kg = 142,3416 kg

Air yang menguap menuju H-173 = (1.984,7720 - 2,1676 - 142,3416) kg

= 1.840,2628 kg

12. Cyclone (H-173)



Uap air dan padatan laktosa masuk dari B-170 terdiri dari:

Uap air	=	1.840,2628 kg
Air	=	2,1676 kg
Protein whey	=	0,0765 kg
Lemak	=	0,0094 kg
Laktosa terlarut	=	4,4657 kg
Mineral	=	0,0787 kg
Kalsium asetat	=	0,0195 kg
Kristal laktosa	=	137,6917 kg

Efisiensi cyclone = 80%

Padatan laktosa keluar menuju J-181 terdiri dari:

Air	= 0,8 × 2,1676 kg	=	1,7341 kg
Protein whey	= 0,8 × 0,0765 kg	=	0,0612 kg
Lemak	= 0,8 × 0,0094 kg	=	0,0075 kg
Laktosa terlarut	= 0,8 × 4,4657 kg	=	3,5726 kg
Mineral	= 0,8 × 0,0787 kg	=	0,0630 kg
Kalsium asetat	= 0,8 × 0,0195 kg	=	0,0156 kg
Kristal laktosa	= 0,8 × 137,6917 kg	=	110,1534 kg

Uap air dan padatan laktosa yang keluar menuju stack terdiri dari:

Uap air		=	1.840,2628 kg
Air	= (2,1676 - 1,7341) kg	=	0,4335 kg
Protein whey	= (0,0765 - 0,0612) kg	=	0,0153 kg
Lemak	= (0,0094 - 0,0075) kg	=	0,0019 kg
Laktosa terlarut	= (4,4657 - 3,5726) kg	=	0,8931 kg
Mineral	= (0,0787 - 0,0630) kg	=	0,0157 kg
Kalsium asetat	= (0,0195 - 0,0156) kg	=	0,0039 kg
Kristal laktosa	= (137,6917 - 110,1534) kg	=	27,5383 kg

13. Screw conveyor (J-181)

Padatan laktosa yang masuk dari B-170 terdiri dari:

Air	=	142,3416 kg
Protein whey	=	5,0216 kg
Lemak	=	0,6190 kg
Laktosa terlarut	=	293,2501 kg
Mineral	=	5,1693 kg
Kalsium asetat	=	1,2811 kg
Kristal laktosa	=	9.041,7552 kg

Padatan laktosa yang masuk dari H-173 terdiri dari:

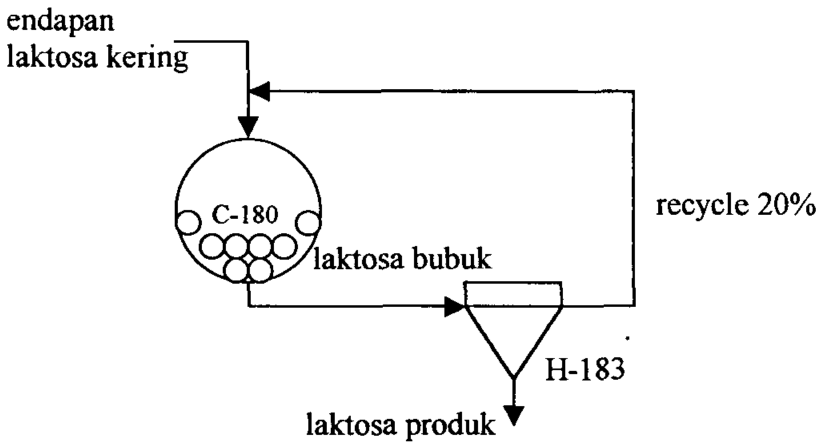
Air	=	1,7341 kg
Protein whey	=	0,0612 kg
Lemak	=	0,0075 kg
Laktosa terlarut	=	3,5726 kg

Mineral	=	0,0630 kg
Kalsium asetat	=	0,0156 kg
Kristal laktosa	=	110,1534 kg

Padatan laktosa keluar menuju C-180 terdiri dari:

Air	= (142,3416 + 1,7341) kg	= 144,0757 kg
Protein whey	= (5,0216 + 0,0612) kg	= 5,0828 kg
Lemak	= (0,6190 + 0,0075) kg	= 0,6265 kg
Laktosa terlarut	= (293,2501 + 3,5726) kg	= 296,8226 kg
Mineral	= (5,1693 + 0,0630) kg	= 5,2323 kg
Kalsium asetat	= (1,2811 + 0,0156) kg	= 1,2967 kg
Kristal laktosa	= (9.041,7552 + 110,1534) kg	= 9151,9085 kg

14. Ball mill (C-180)



Untuk pertama kali tidak ada recycle:

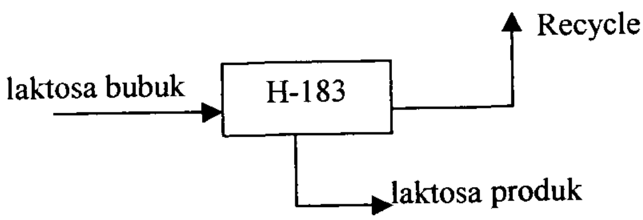
Laktosa padatan masuk dari J-181 terdiri dari:

Air	=	144,0757 kg
Protein whey	=	5,0828 kg
Lemak	=	0,6265 kg
Laktosa terlarut	=	296,8226 kg
Mineral	=	5,2323 kg
Kalsium asetat	=	1,2967 kg
Kristal laktosa	=	9151,9085 kg

Laktosa bubuk yang keluar menuju H-183 terdiri dari:

Air	=	144,0757 kg
Protein whey	=	5,0828 kg
Lemak	=	0,6265 kg
Laktosa terlarut	=	296,8226 kg
Mineral	=	5,2323 kg
Kalsium asetat	=	1,2967 kg
Kristal laktosa	=	9151,9085 kg

Screen (H-183)



Laktosa bubuk masuk dari C-180 terdiri dari:

Air	=	144,0757 kg
Protein whey	=	5,0828 kg
Lemak	=	0,6265 kg
Laktosa terlarut	=	296,8226 kg
Mineral	=	5,2323 kg
Kalsium asetat	=	1,2967 kg
Kristal laktosa	=	9151,9085 kg

Asumsi laktosa yang direcycle menuju C-180 = 20%

Laktosa yang direcycle menuju C-180 terdiri dari:

Air	= 0,2 × 144,0757 kg	=	28,8151 kg
Protein whey	= 0,2 × 5,0828 kg	=	1,0166 kg
Lemak	= 0,2 × 0,6265 kg	=	0,1253 kg
Laktosa terlarut	= 0,2 × 296,8226 kg	=	59,3645 kg
Mineral	= 0,2 × 5,2323 kg	=	1,0465 kg
Kalsium asetat	= 0,2 × 1,2967 kg	=	0,2593 kg
Kristal laktosa	= 0,2 × 9151,9085 kg	=	1830,3817 kg

Laktosa produk yang keluar menuju unit packing terdiri dari:

Air	= (144,0757 - 28,8151) kg	= 115,2605 kg
Protein whey	= (5,0828 - 1,0166) kg	= 4,0662 kg
Lemak	= (0,6265 - 0,1253) kg	= 0,5012 kg
Laktosa terlarut	= (296,8226 - 59,3645) kg	= 237,4581 kg
Mineral	= (5,2323 - 1,0465) kg	= 4,1858 kg
Kalsium asetat	= (1,2967 - 0,2593) kg	= 1,0374 kg
Kristal laktosa	= (9151,9085 - 1830,3817) kg	= 7321,5268 kg

Dihitung ulang dengan memakai recycle:

Pada C-180 laktosa masuk berasal dari B-170 dan recycle dari H-183, sehingga Neraca Massa pada C-180 dan H-183 berubah,

Dilakukan perhitungan ulang dengan cara yang sama sehingga diperoleh harga recycle yang konstan, Diperoleh hasil sebagai berikut:

C-180:

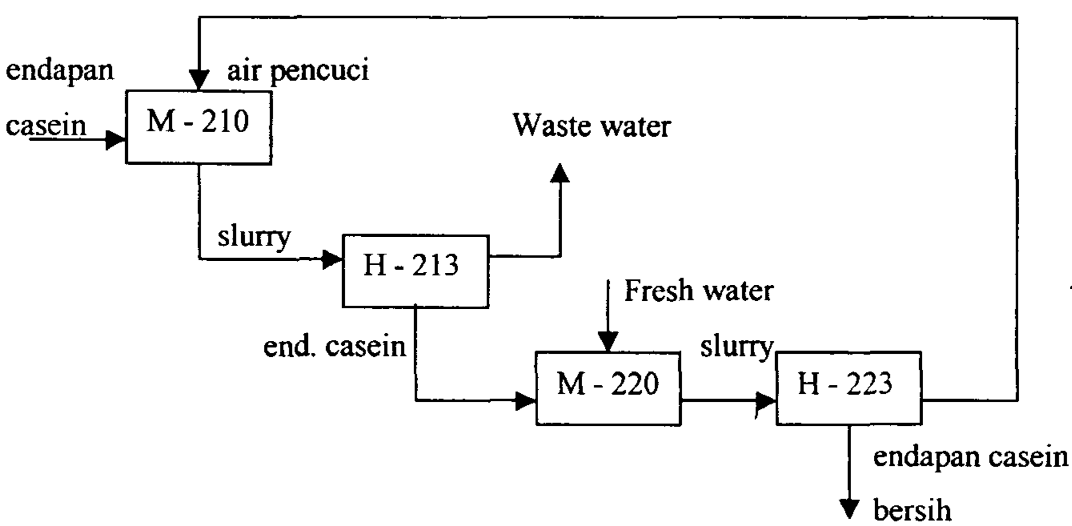
Massa masuk	kg	Massa keluar	kg
Dari J-181		**Menuju H-183**	
- Air	144,0757	- Air	180,0946
- Protein whey	5,0828	- Protein whey	6,3535
- Lemak	0,6265	- Lemak	0,7831
- Laktosa terlarut	296,8226	- Laktosa terlarut	371,0283
- Mineral	5,2323	- Mineral	6,5404
- Kalsium asetat	1,2967	- Kalsium asetat	1,6209
- Kristal laktosa	9151,9085	- Kristal laktosa	11439,8857
Dari recycle H-183			
- Air	36,0189		
- Protein whey	1,2707		
- Lemak	0,1566		
- Laktosa terlarut	74,2057		
- Mineral	1,3081		
- Kalsium asetat	0,3242		
- Kristal laktosa	2287,9771		
Total	12006,3065	Total	12006,3065

H-183:

Massa masuk	kg	Massa keluar	kg
Dari C-180		**Ke bin laktosa F-184**	
- Air	180,0946	- Air	144,0757
- Protein whey	6,3535	- Protein whey	5,0828
- Lemak	0,7831	- Lemak	0,6265
- Laktosa terlarut	371,0283	- Laktosa terlarut	296,8226
- Mineral	6,5404	- Mineral	5,2323
- Kalsium asetat	1,6209	- Kalsium asetat	1,2967
- Kristal laktosa	11439,8857	- Kristal laktosa	9151,9085
		Recycle ke-C180	
		- Air	36,0189
		- Protein whey	1,2707
		- Lemak	0,1566
		- Laktosa terlarut	74,2057
		- Mineral	1,3081
		- Kalsium asetat	0,3242
		- Kristal laktosa	2287,9771
Total	12006,3065	Total	12006,3065

Pembuatan Casein

15. Tangki pencuci (M – 210)



Endapan casein masuk dari H-128 terdiri dari:

Casein	= 5.594,9394 kg
Air	= 1.304,6426 kg
Protein whey	= 10,1840 kg
Laktosa	= 73,3846 kg
Mineral	= 10,4835 kg
Total	= 6.993,6341 kg

Untuk pertama kali tidak ada recycle, air pencucinya dipakai fresh water.

Berat endapan basah = 6.993,6341 kg

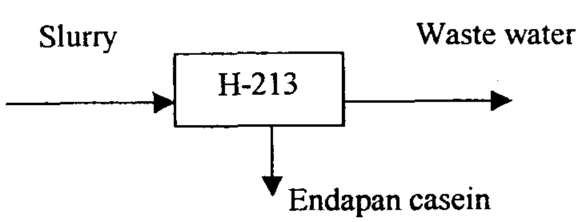
Asumsi: fresh water mula-mula = 3 × berat endapan basah

Air dari utilitas = 3 × 6.993,6341 kg = 20.980,9023 kg

Slurry yang keluar menuju H-213 terdiri dari:

Casein	= 5.594,9394 kg
Air = (1304,6426 + 20980,9023) kg	= 22.285,5449 kg
Protein whey	= 10,1840 kg
Laktosa	= 73,3846 kg
Mineral	= 10,4835 kg

Filter Press (H-213)



Slurry masuk dari M-210 terdiri dari:

Casein	= 5.594,9394 kg
Air	= 22.285,5449 kg
Protein whey	= 10,1840 kg
Laktosa	= 73,3846 kg
Mineral	= 10,4835 kg

Filtrat yg terikut padatan dalam Filter Press = 20 - 40% (Ulrich table 4.23b hal 223,1984)

Komponen filtrat	massa	fraksi massa
Air	22.285,5449	0,9958
Protein whey	10,1840	0,0005
Laktosa	73,3846	0,0033
Mineral	10,4835	0,0005
Total	22.379,5970	1,0000

Diasumsi Filtrat yang terikut endapan casein = 20 %

Filtrat yang terikut endapan casein $= \frac{0.20}{0.80} \times 5.594{,}9394 = 1.398{,}7348$ kg, terdiri

dari:

Air $= 0{,}9958 \times 1.398{,}7348$ kg $= 1.392{,}8565$ kg

Protein whey $= 0{,}0005 \times 1.398{,}7348$ kg $= 0{,}6365$ kg

Laktosa $= 0{,}0033 \times 1.398{,}7348$ kg $= 4{,}5866$ kg

Mineral $= 0{,}0005 \times 1.398{,}7348$ kg $= 0{,}6552$ kg

Jadi endapan casein yang keluar menuju M-220 terdiri dari:

Casein = 5.594,9394 kg

Filtrat yang terikut endapan = 1.398,7348 kg

Sedangkan filtrat yang keluar menuju penampung filtrat terdiri dari:

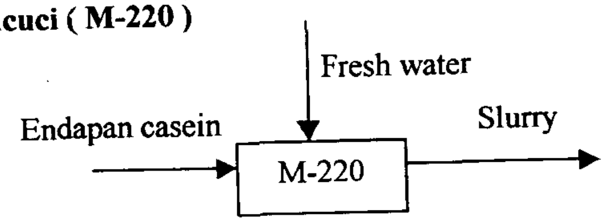
Air $= (22285{,}5449 - 1392{,}8565)$ kg $= 20.892{,}6883$ kg

Protein whey $= (10{,}1840 - 0{,}6365)$ kg $= 9{,}5475$ kg

Laktosa $= (73{,}3846 - 4{,}5866)$ kg $= 68{,}7980$ kg

Mineral $= (10{,}4835 - 0{,}6552)$ kg $= 9{,}8283$ kg

Tangki pencuci (M-220)



Endapan casein masuk dari H-213 terdiri dari:

Casein = 5.594,9394 kg

Air = 1.392,8565 kg

Protein whey = 0,6365 kg

Laktosa = 4,5866 kg

Mineral = 0,6552 kg

Total = 6.933,6742 kg

Berat endapan basah = 6.933,6742 kg

Ditetapkan: fresh water yang digunakan = 3 × berat endapan basah

Air dari utilitas = 3 × 6.933,6742 kg = 20.981,0227 kg

Slurry yang keluar menuju H-223 terdiri dari:

Casein = 5.594,9394 kg

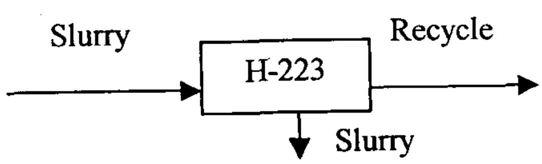
Air = (1.392,8565 + 20.981,0227) kg = 22.373,8793 kg

Protein whey = 0,6365 kg

Laktosa = 4,5866 kg

Mineral = 0,6552 kg

Filter press (H-223)



Slurry masuk dari M-220 terdiri dari:

Casein = 5.594,9394 kg

Air = 22.373,8793 kg

Protein whey = 0,6365 kg

Laktosa = 4,5866 kg

Mineral = 0,6552 kg

Filtrat yg terikut padatan dalam Filter Press = 20 - 40% (Ulrich table 4.23b hal 223,1984)

Komponen filtrat	massa	Fraksi massa
Air	22.373,8793	0,9998
Protein whey	0,6365	0,0000
Laktosa	4,5866	0,0002
Mineral	0,6552	0,0000
Total	22.379,7576	1,0000

Diasumsi Filtrat yang terikut endapan casein = 20 %

Filtrat yang terikut endapan casein $= \frac{0.20}{0.80} \times 5.594{,}9394 = 1.398{,}7348 \text{ kg}$, terdiri dari:

Air = 0,9998 × 1.398,7348 kg = 1.398,3675 kg

Laktosa = 0,0002 × 1.398,7348 kg = 0,2867 kg

Jadi endapan casein yang keluar menuju B-230 terdiri dari:

Casein = 5.594,9394 kg

Filtrat yang terikut endapan = 1.398,7348 kg

Sedangkan filtrat yang direcycle menuju M-210 terdiri dari:

Air = (22373,8793 – 1398,3675) kg = 20.975,5118 kg

Protein Whey = 0,6365 kg

Laktosa = (4,5866 – 0,2867) kg = 4,2999 kg

Mineral = 0,6552 kg

Dihitung ulang dengan memakai recycle:

Pada M-210 air pencuci yang digunakan berasal dari filtrat H-223, sehingga Neraca Massa pada M-210, H-213, M-220, H-223 berubah.

Dilakukan perhitungan ulang dengan cara yang sama sehingga diperoleh harga recycle yang konstan. Diperoleh hasil sebagai berikut:

M-210:

Masuk	Kg	Keluar	Kg
Dari H-128		**Menuju H-213**	
Air	1.304,6426	Air	22.278,5043
Casein	5.594,9394	Casein	5.594,9394
Protein whey	10,1840	Protein whey	10,1840
Laktosa	73,3846	Laktosa	73,3846
Mineral	10,4835	Mineral	10,4835
Dari H-223			
Air	20.973,8617		
Protein whey	0,6365		
Laktosa	4,2999		
Mineral	0,6552		
Total	27.967,4958	Total	27.967,4958

H-213:

Masuk	Kg	Keluar	Kg
Dari M-210		**Menuju M-220**	
Air	22.278,5043	Air	1.392,4165
Casein	5.594,9394	Casein	5.594,9394
Protein whey	10,1840	Protein whey	0,6365
Laktosa	73,3846	Laktosa	4,5866
Mineral	10,4835	Mineral	0,6552
		Menuju TP limbah	
		Air	20.886,0878
		Protein whey	9,5475
		Laktosa	68,7980
		Mineral	9,8283
Total	27.967,4958	Total	27.967,4958

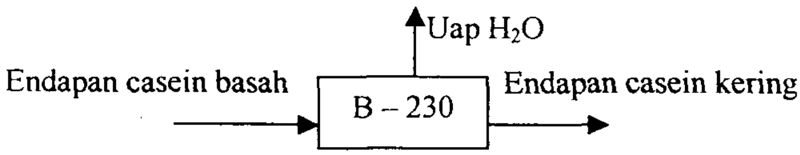
M-220:

Masuk	Kg	Keluar	Kg
Dari H-213		**Menuju H-223**	
Air	1.392,4165	Air	22.372,1191
Casein	5.594,9394	Casein	5.594,9394
Protein whey	0,6365	Protein whey	0,6365
Laktosa	4,5866	Laktosa	4,5866
Mineral	0,6552	Mineral	0,6552
Dari utilitas			
Air	20.979,7026		
Total	27.972,9368	Total	27.972,9368

H-223:

Masuk	Kg	Keluar	Kg
Dari M-220		**Menuju B-230**	
Air	22.372,1191	Air	1.398,2574
Casein	5.594,9394	Casein	5.594,9394
Protein whey	0,6365	Laktosa	0,2867
Laktosa	4,5866	**Menuju M-210**	
Mineral	0,6552	Air	20.973,8617
		Protein whey	0,6365
		Laktosa	4,2999
		Mineral	0,6552
Total	27.972,9368	Total	27.972,9368

16. Rotary dryer (B-230)



Endapan casein basah masuk dari H-223 terdiri dari:

Air = 1.398,2574 kg

Casein = 5.594,9394 kg

Laktosa = 0,2867 kg

Kandungan air pada edible casein maksimum 12% (Ullman A16, 1990)

Asumsi: Kandungan air yang terdapat pada produk casein = 0,5%

Padatan yang terikut aliran gas keluar menuju cyclone = 1,5%

Padatan yang keluar menuju cyclone (H-233) terdiri dari:

Casein = 1,5% × 5.594,9394 kg = 83,9241 kg

Laktosa = 1,5% × 0,2867 kg = 0,0043 kg +

Berat komponen selain air = 83,9284 kg

Kandungan air dalam padatan = $\frac{0.005}{0.995} \times 83{,}9284$ kg = 0,4218 kg

Endapan casein kering yang keluar menuju J-241:

Casein = (5.594,9394 – 83,9241) kg = 5.511,0153 kg

Laktosa = (0,2867 – 0,0043) kg = 0,2824 kg +

Berat padatan selain air = 5.511,2977 kg

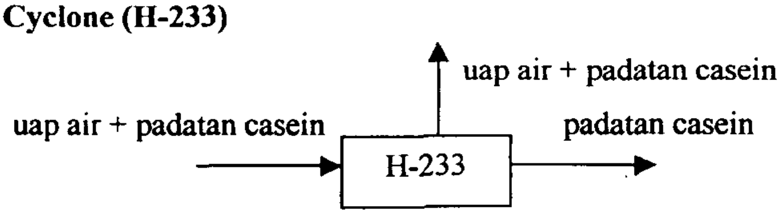
Kandungan air dalam padatan = $\frac{0{,}005}{0{,}995} \times 5.511{,}2977$ kg = 27,6950 kg

Air yang menguap menuju H-233 = (1.398,2574 - 0,4218 - 27,6950) kg

= 1.370,1407 kg

Air yang terkandung dalam padatan = $\frac{0{,}005}{0{,}995} \times 5.595{,}2261$ kg = 28,1167 kg

17. Cyclone (H-233)



Uap air dan padatan casein masuk dari B-230 terdiri dari:

Uap air	=	1.370,1407 kg
Air	=	0,4218 kg
Casein	=	83,9241 kg
Laktosa	=	0,0043 kg

Efisiensi cyclone = 80%

Padatan casein keluar menuju J-241 terdiri dari:

Air	= 0,8 × 0,4218 kg	= 0,3374 kg
Casein	= 0,8 × 83,9241 kg	= 67,1393 kg
Laktosa	= 0,8 × 0,0043 kg	= 0,0034 kg

Uap air dan padatan casein yang keluar menuju stack terdiri dari:

Uap air		= 1.370,1407 kg
Air	= (0,4218 – 0,3374) kg	= 0,0844 kg
Casein	= (83,9241 – 67,1393) kg	= 16,7848 kg
Laktosa	= (0,0043 – 0,0034) kg	= 0,0009 kg

18. Screw conveyor (J-241)

Padatan laktosa yang masuk dari B-230 terdiri dari:

Air	=	27,6950 kg
Casein	=	5.511,0153 kg
Laktosa	=	0,2824 kg

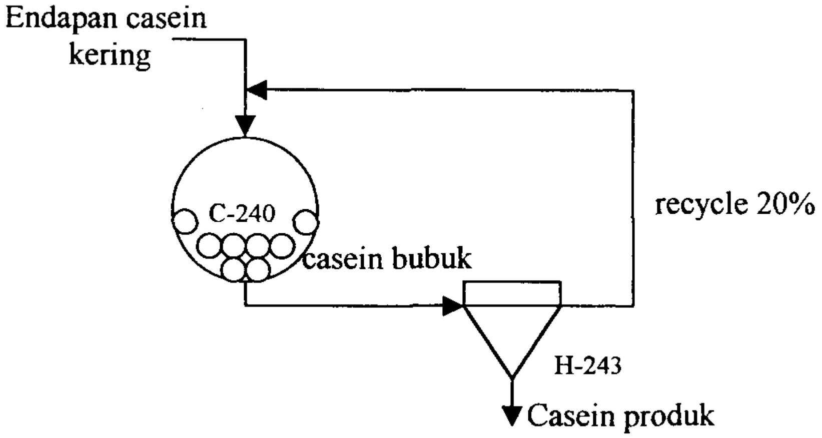
Padatan laktosa yang masuk dari H-233 terdiri dari:

Air	= 0,8 × 0,4218 kg	= 0,3374 kg
Casein	= 0,8 × 83,9241 kg	= 67,1393 kg
Laktosa	= 0,8 × 0,0043 kg	= 0,0034 kg

Padatan laktosa keluar menuju C-240 terdiri dari:

Air	= (27,6950 + 0,3374) kg	= 28,0324 kg
Casein	= (5.511,0153 + 67,1393) kg	= 5.578,1546 kg
Laktosa	= (0,2824 + 0,0034) kg	= 0,2858 kg

19. Ball mill (C-240)



Untuk pertama kali tidak ada recycle:

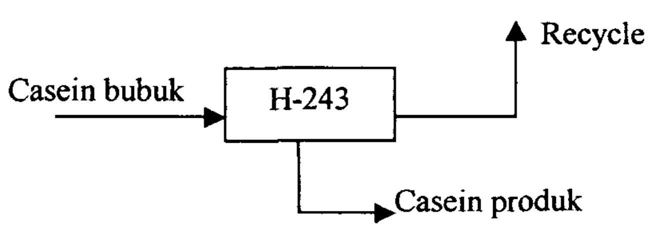
Endapan casein kering masuk dari J-241 terdiri dari:

Air	=	28,0324 kg
Casein	=	5.578,1546 kg
Laktosa	=	0,2858 kg

Casein bubuk yang keluar menuju H-243 terdiri dari:

Air	=	28,0324 kg
Casein	=	5.578,1546 kg
Laktosa	=	0,2858 kg

Screen (H-243)



Casein bubuk masuk dari C-240 terdiri dari:

Air	=	28,0324 kg
Casein	=	5.578,1546 kg
Laktosa	=	0,2858 kg

Asumsi casein yang direcycle menuju C-240 = 20%

Casein yang direcycle menuju C-240 terdiri dari:

Air	= 0,2 × 28,0324 kg	=	5,6065 kg
Casein	= 0,2 × 5578,1546 kg	=	1.115,6309 kg

Laktosa = 0,2 × 0,2858 kg = 0,0572 kg

Casein produk yang keluar menuju unit packing terdiri dari:

Air = (28,0324 – 5,6065) kg = 22,4259 kg

Casein = (5.578,1546 – 1.115,6309) kg = 4.462,5237 kg

Laktosa = (0,2858 – 0,0572) kg = 0,2286 kg

Dihitung ulang dengan memakai recycle:

Pada C-240 casein masuk berasal dari B-230 dan recycle dari H-243, sehingga Neraca Massa pada C-240 dan H-243 berubah.

Dilakukan perhitungan ulang dengan cara yang sama sehingga diperoleh harga recycle yang konstan. Diperoleh hasil sebagai berikut:

C-240:

Massa masuk	kg	Massa keluar	kg
Dari B-230		**Ke H-243**	
- Air	28,0324	- Air	35,0405
- Casein	5578,1546	- Casein	6972,6932
- Laktosa	0,2858	- Laktosa	0,3573
Dari H-243			
- Air	7,0081		
- Casein	1394,5386		
- Laktosa	0,0715		
Total	7008,0909	Total	7008,0909

H-243:

Massa masuk	kg	Massa keluar	kg
Dari C-240		**Ke bin casein F-244**	
- Air	35,0405	- Air	28,0324
- Casein	6972,6932	- Casein	5578,1546
- Laktosa	0,3573	- Laktosa	0,2858
		Recycle ke C-240	
		- Air	7,0081
		- Casein	1394,5386
		- Laktosa	0,0715
Total	7008,0909	Total	7008,0909

LAMPIRAN B
PERHITUNGAN NERACA PANAS

LAMPIRAN B
PERHITUNGAN NERACA PANAS

Kapasitas : 5000 ton / tahun

Proses : Kontinyu

Basis perhitungan : 1 hari

Suhu referensi : 25°C

Data-data kapasitas panas:

Cp protein = $(2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2)$ kJ/kg.°K (Heldman,1992)

Cp lemak = $(1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2)$ kJ/kg.°K (Heldman,1992)

Cp mineral = $(1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2)$ kJ/kg.°K (Heldman, 1992)

Cp air = $18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3$ kJ/kmol.°K (Himmelblau, 1996)

Cp laktosa = 0,287 kkal/kg.°K (Perry 7th ed, 1997)

Cp etilen glikol = (0,366 + 0,0011. T) kkal/kg.°K (Perry 7th ed, 1997)

Cp casein ≈ Cp protein

Cp ca^{2+}caseinate ≈ Cp protein

Cp asam asetat = (-0,0598 + 0,0073947.T) kJ/kg.°K (Geankoplis, 1997)

Cp ca asetat = $(8 + 4 \times 2{,}8 + 6 \times 4{,}3 + 4 \times 6)$ kkal/kmol.°K = 69 kkal/kmol.°K

(Kopp's rule, Himmelblau 5th ed)

Data-data $\Delta H°_{298}$:

$\Delta H°_{298}$ asam asetat = -116,4 kkal/mol (Hougen, 1954)

$\Delta H°_{298}$ kalsium asetat = -364,1 kkal/mol (Perry 7th ed, 1997)

$\Delta H°_{298}$ casein ≈ $\Delta H°_{298}$ ca^{2+}caseinate ≈ $\Delta H°_{298}$ protein = $-\Delta H$ denaturasi protein

= -89 kJ/mol = -21271,5105 kkal/kkmol (www.cbi.nlm.nih.Gov/entrez /quey.fcg)

Data ΔH denaturasi:

ΔH denaturasi α Laktalbumin = 253 kJ/mol (Heldman, 1992)

ΔH denaturasi β Laktoglobulin = 311 kJ/mol (Heldman, 1992)

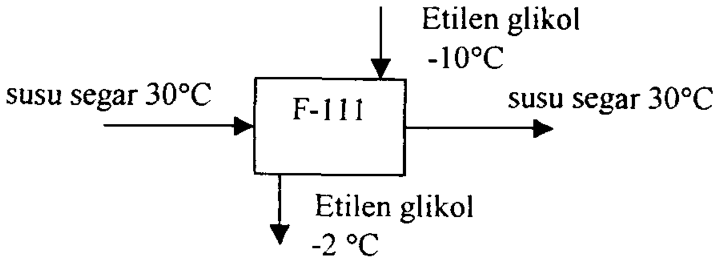
Data Berat Molekul:

BM α Laktalbumin = 14200 gr/mol (Ullman, 1990)

BM β Laktoglobulin = 18400 gr/mol (Ullman,1990)

BM Laktosa = 342 gr/mol

1. Tangki penampung susu segar (F-111)



Feed masuk : 212.500 liter susu = 219.059,8665 kg terdiri dari:

- Air : 190801,1437 kg
- Ca^{2+}caseinate : 5958,4284 kg
- Protein whey : 1489,6071 kg
- Lemak : 8543,3348 kg
- Laktosa : 10733,9335 kg
- Mineral : 1533,4191 kg

Entalpi masuk:

- Air

$$\int Cp\, dT = \int_{298}^{303} (18,2964 + 47,212.10^{-2}.T - 133,88.10^{-5}.T^2 + 1314,2.10^{-9}.T^3).dT$$

$$\int Cp\, dT = \left[18,2964.(303-298) + \frac{47,212.10^{-2}}{2}.(303^2 - 298^2) - \frac{133,88.10^{-5}}{3}\right.$$

$$\left..(303^3 - 298^3) + \frac{1314,2.10^{-9}}{4}.(303^4 - 298^4)\right] \Big/ 18$$

$$= 20,8154 \text{ kJ/kg} = 4,9750 \text{ kkal/kg}$$

$\Delta H1 = m.\ Cp.\ dT$

$= 190801,1437 \text{ kg} \times 4,9750 \text{ kkal/kg} = 949233,6281 \text{ kkal}$

- Ca^{2+}caseinate

$$\int Cp\ dT = \int_{298}^{303} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(303 - 298) + \frac{1{,}2089.10^{-3}}{2}.(303^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}.(303^3 - 298^3)$$

$$= 11{,}2646\ kJ/kg = 2{,}6923\ kkal/kg$$

$\Delta H2$ = m. Cp. dT

= 5958,4284 kg × 2,6923 kkal/kg = 16041,8758 kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{303} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(303 - 298) + \frac{1{,}2089.10^{-3}}{2}.(303^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}.(303^3 - 298^3)$$

$$= 11{,}2646\ kJ/kg = 2{,}6923\ kkal/kg$$

$\Delta H3$ = m. Cp. dT

= 1489,6071 kg × 2,6923 kkal/kg = 4010,4690 kkal

- Lemak

$$\int Cp\ dT = \int_{298}^{303} (1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}9842.(303 - 298) + \frac{1{,}4733.10^{-3}}{2}.(303^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3}.(303^3 - 298^3)$$

$$= 9{,}9670\ kJ/kg = 2{,}3822\ kkal/kg$$

$\Delta H4$ = m. Cp. dT

= 8543,3348 kg × 2,3822 kkal/kg = 20351,7101 kkal

- Laktosa

$\Delta H5$ = m. Cp. ΔT

= 10733,9335 kg × 0,287 kkal/kg.°K × (303 – 298)°K

= 15403,1945 kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{303} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}0926.(303 - 298) + \frac{1{,}8896.10^{-3}}{2}.(303^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}.(303^3 - 298^3)$$

$$= 6{,}6398\ kJ/kg = 1{,}5869\ kkal/kg$$

ΔH6 = m. Cp. dT

= 8543,3348 kg × 1,5869 kkal/kg = 2433,4574 kkal

Entalpi masuk = ΔH1 + ΔH2 + ΔH3 + ΔH4 + ΔH5 + ΔH6 = 1007474,3349 kkal

Entalpi keluar:

- Air

$$\int Cp\ dT = \int_{298}^{277} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(277 - 298) + \frac{47{,}212.10^{-2}}{2}.(277^2 - 298^2) - \frac{133{,}88.10^{-5}}{3}.(277^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(277^4 - 298^4)\right] / 18$$

$$= -87{,}0256\ kJ/kmol = -20{,}7996\ kkal/kg$$

ΔH7 = m. Cp. dT

= 190801,1437 kg × -20,7996 kkal/kg = -3968591,5586 kkal

- Ca^{2+}caseinate

$$\int Cp\ dT = \int_{298}^{277} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(277 - 298) + \frac{1{,}2089.10^{-3}}{2}.(277^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}.(277^3 - 298^3)$$

$$= -47{,}1910\ kJ/kg = -11{,}2789\ kkal/kg$$

ΔH8 = m. Cp. dT

= 5958,4284 kg × -11,2789 kkal/kg = -67204,6540 kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{277} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(277 - 298) + \frac{1{,}2089.10^{-3}}{2}.(277^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}.(277^3 - 298^3)$$

$$= -47{,}1910\ kJ/kg = -11{,}2789\ kkal/kg$$

$\Delta H9$ = m. Cp. dT

= 1489,6071 kg × -11,2789 kkal/kg = -16801,1635 kkal

- Lemak

$$\int Cp\ dT = \int_{298}^{277} (1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}9842.(277 - 298) + \frac{1{,}4733.10^{-3}}{2}.(277^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3}.(277^3 - 298^3)$$

$$= -42{,}2264\ kJ/kg = -10{,}0924\ kkal/kg$$

$\Delta H10$ = m. Cp. dT

= 8543,3348 kg × -10,0924 kkal/kg = -86222,3509 kkal

- Laktosa

$\Delta H11$ = m. Cp. ΔT

= 10733,9335 kg × 0,287 kkal/kg.°K × (277 – 298)°K

= -64693,4170 kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{277} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}0926.(277 - 298) + \frac{1{,}8896.10^{-3}}{2}.(277^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}.(277^3 - 298^3)$$

$$= -27{,}9596\ kJ/kg = -6{,}6825\ kkal/kg$$

$\Delta H12$ = m. Cp. dT

= 8543,3348 kg × -6,6825 kkal/kg = -10247,0776 kkal

Entalpi keluar menuju E-110 = $\Delta H7 + \Delta H8 + \Delta H9 + \Delta H10 + \Delta H11 + \Delta H12$

= -4213760,2215 kkal

Entalpi masuk = Entalpi keluar + Panas yang diserap pendingin + Q loss

Entalpi masuk = Entalpi keluar + Q + 5% × Entalpi masuk

$Q = 0,95 \times 1007474,3349 - (-4213760,2215)$ kkal

= 5170860,8397 kkal

Pendingin yang digunakan adalah etilen glikol

Q etilen glikol = m. Cp. dT

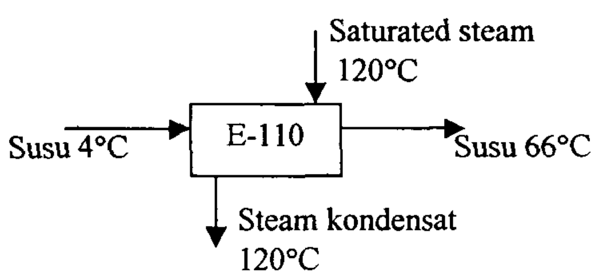
$$\int Cp\ dT = \int_{263}^{271} (0,366 + 0,0011.T).dT$$

$$\int Cp\ dT = 0,366.(271 - 263) + \frac{0,0011}{2}.(271^2 - 263^2)$$

$$= 5,2776\ \text{kkal/kg}$$

$$\text{m etilen glikol} = \frac{\text{Q etilen glikol}}{\int Cp.dT} = \frac{5170860,8397\ \text{kkal}}{5,2776\ \text{kkal/kg}} = 979775,0568\ \text{kg}$$

2. Heat Exchanger (E-110)



Entalpi masuk:

Entalpi masuk HE (E-110) = Entalpi keluar tangki penampung (F-111)

= -4213760,2215 kkal

Entalpi keluar:

- Air

$$\int Cp\ dT = \int_{298}^{339} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(339 - 298) + \frac{47{,}212.10^{-2}}{2}.(339^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} \right.$$

$$\left. .(339^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(339^4 - 298^4) \right] \Big/ 18$$

$$= 171{,}5282\ kJ/kg = 40{,}9962\ kkal/kg$$

$\Delta H1$ = m. Cp. dT

= 190801,1437 kg × 40,9962 kkal/kg = 7822125,3720 kkal

- Ca^{2+}caseinate

$$\int Cp\ dT = \int_{298}^{339} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(339 - 298) + \frac{1{,}2089.10^{-3}}{2}.(339^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}$$

$$.(339^3 - 298^3)$$

$$= 92{,}6546\ kJ/kg = 22{,}1450\ kkal/kg$$

$\Delta H2$ = m. Cp. dT

= 5958,4284 kg × 22,1450 kkal/kg = 131949,2188 kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{339} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(339 - 298) + \frac{1{,}2089.10^{-3}}{2}.(339^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}$$

$$.(339^3 - 298^3)$$

$$= 92{,}6546\ kJ/kg = 22{,}1450\ kkal/kg$$

$\Delta H3$ = m. Cp. dT

= 1489,6071 kg × 22,1450 kkal/kg = 32987,3047 kkal

- Lemak

$$\int Cp\ dT = \int_{298}^{339}(1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}9842.(339 - 298) + \frac{1{,}4733.10^{-3}}{2}.(339^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3}.(339^3 - 298^3)$$

$$= 80{,}5966\ kJ/kg = 19{,}2630\ kkal/kg$$

ΔH4 = m. Cp. dT

= 8543,3348 kg × 19,2630 kkal/kg = 164570,5868 kkal

- Laktosa

ΔH5 = m. Cp. ΔT

= 10733,9335 kg × 0,287 kkal/kg.°K × (339 – 298)°K

= 126306,1950 kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{339}(1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}0926.(339 - 298) + \frac{1{,}8896.10^{-3}}{2}.(339^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}.(339^3 - 298^3)$$

$$= 54{,}1381\ kJ/kg = 12{,}9393\ kkal/kg$$

ΔH6 = m. Cp. dT

= 8543,3348 kg × 12,9393 kkal/kg = 19841,4014 kkal

Entalpi keluar menuju R-120 = ΔH1 + ΔH2 + ΔH3 + ΔH4 + ΔH5 + ΔH6

= 8297780,0786 kkal

Entalpi masuk + Q suplai = Entalpi keluar + Qloss

Entalpi masuk + Q = Entalpi keluar + 5% × Q

$$Q = \frac{8297780{,}0786 - (-4213760{,}2215)}{0{,}95}$$

= 13170042,4212 kkal

Steam yang digunakan adalah saturated steam pada suhu 120°C, P = 198,53 kPa.

Dari steam tabel Geankoplis hal 857:

Hv = 2706,3 kJ/kg

Hl = 503,71 kJ/kg

$\lambda = Hv - Hl$

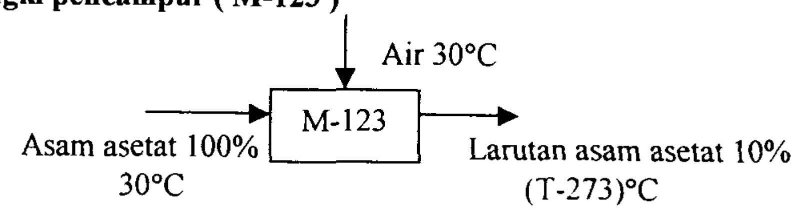
$= (2706{,}3 - 503{,}71)$ kJ/kg

$= 2202{,}59$ kJ/kg $= 526{,}4316$ kkal/kg

Q yang disuplai steam = m . λ

$$\text{Massa steam} = \frac{Q\,\text{suplai}}{\lambda} = \frac{13170042{,}4212\ \text{kkal}}{526{,}4316\ \text{kkal/kg}} = 25017{,}5736\ \text{kg}$$

3. Tangki pencampur (M-123)



Entalpi masuk dari tangki penampung:

- Air

$$\int Cp\,dT = \int_{298}^{303} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\,dT = \left[18{,}2964.(303-298) + \frac{47{,}212.10^{-2}}{2}.(303^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(303^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(303^4 - 298^4) \right] \Big/ 18$$

$$= 20{,}8154\ \text{kJ/kg} = 4{,}9750\ \text{kkal/kg}$$

$\Delta H1 = m.\ Cp.\ dT$

$= 26{,}5912$ kg × $4{,}9750$ kkal/kg $= 132{,}2909$ kkal

- Asam asetat

$$\int Cp\,dT = \int_{298}^{339} (-0{,}0598 + 0{,}0073947.T).dT$$

$$\int Cp\,dT = -0{,}0598.(339 - 298) + \frac{0{,}0073947}{2}(339^2 - 298^2)$$

$$= 10{,}8115\ \text{kJ/kg} = 2{,}5840\ \text{kkal/kg}$$

$\Delta H2 = m.\ Cp.\ dT$

$= 2{,}9546 \times 2{,}5840$ kkal/kg $= 7{,}6347$ kkal

Entalpi masuk = ΔH1 + ΔH2 = 139,9256 kkal

Entalpi keluar:

- Air

$$\int Cp\ dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(T - 298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4) \right] \Big/ 18 \text{ kkal/kg}$$

$\Delta H3 = m.\ Cp.\ dT$

$= 26{,}5912 \times [1{,}0165.(T\text{-}298) + 1{,}3114.10^{-2}.(T^2\text{-}298^2) - 2{,}4793.10^{-5}.(T^3\text{-}298^3) + 18{,}2528.10^{-9}.(T^4\text{-}298^4)]$ kkal

- Asam asetat

$$\int Cp\ dT = \int_{298}^{T} (\text{-}0{,}0598 + 0{,}0073947.T).dT$$

$$\int Cp\ dT = \left[-0{,}0598.(T - 298) + \frac{0{,}0073947}{2}(T^2 - 298^2) \right] \text{kJ/kg} \Big/ 4{,}184 \text{ kJ/kkal}$$

$\Delta H4 = m.\ Cp.\ dT$

$= 2{,}9546 \times [\text{-}0{,}0143.(T\text{-}298) + 8{,}8369.10^{-4}]$ kkal

Entalpi keluar $= \Delta H3 + \Delta H4$

$= f(T)$ kkal

Panas kelarutan asam asetat = -2,251 kkal/kmol (Perry 7[th]ed, 1997)

= -2,251 kkal/kmol × 2,9546 kg / 60 kg/kmol

= -0,1108 kkal (mengeluarkan panas)

Entalpi masuk + panas kelarutan = Entalpi keluar + Q loss

Entalpi masuk + panas kelarutan = Entalpi keluar + 5% × Entalpi masuk

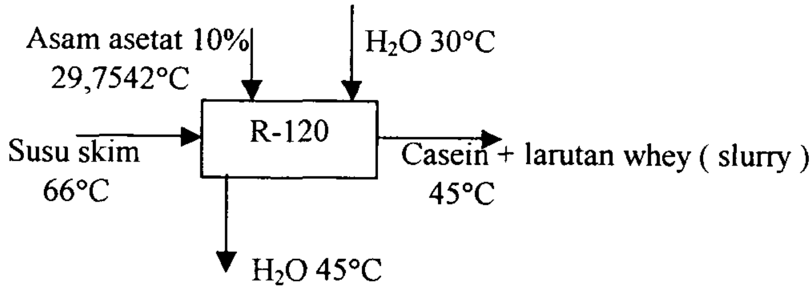
139,9256 + 0,1108 = f (T) + 0,05 × 139,9256

f (T) = 133,0402 kkal

Trial T = 302,7542 K = 29,7542°C, f (T) = 133,0402 kkal

Entalpi keluar menuju R-120 = 133,0402 kkal

4. Reaktor (R-120)



Entalpi masuk R-120 = Entalpi bahan keluar E-110 + Entalpi keluar M-123

= (8297780,0786 + 133,0402) kkal

= 8297913,1189 kkal

Entalpi keluar:

- Air

$$\int Cp\, dT = \int_{298}^{318} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\, dT = \left[18{,}2964.(318-298) + \frac{47{,}212.10^{-2}}{2}.(318^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(318^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(318^4 - 298^4) \right] \Big/ 18$$

$$= 83{,}4441 \text{ kJ/kg} = 19{,}9436 \text{ kkal/kg}$$

$\Delta H1$ = m. Cp. dT

= 179215,3062 × 19,9436 kkal/kg = 3574203,6226 kkal

- Casein

$$\int Cp\, dT = \int_{298}^{318} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\, dT = 2{,}0082.(318-298) + \frac{1{,}2089.10^{-3}}{2}.(318^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} .(318^3 - 298^3)$$

$$= 45{,}1190 \text{ kJ/kg} = 10{,}7837 \text{ kkal/kg}$$

$\Delta H2$ = m. Cp. dT

= 5594,9394 kg × 10,7837 kkal/kg = 60334,1600 kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{318} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(318-298) + \frac{1{,}2089.10^{-3}}{2}.(318^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}$$

$$.(318^3 - 298^3)$$

$$= 45{,}1190\ kJ/kg = 10{,}7837\ kkal/kg$$

ΔH3 = m. Cp. dT

= 1398,9475 kg × 10,7837 kkal/kg = 15085,8330 kkal

- Lemak

$$\int Cp\ dT = \int_{298}^{318} (1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}9842.(318-298) + \frac{1{,}4733.10^{-3}}{2}.(318^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3}$$

$$.(318^3 - 298^3)$$

$$= 39{,}6479\ kJ/kg = 9{,}4761\ kkal/kg$$

ΔH4 = m. Cp. dT

= 1,7087 kg × 9,4761 kkal/kg = 16,1914 kkal

- Laktosa

ΔH5 = m. Cp. ΔT

= 10080,6510 kg × 0,287 kkal/kg.°K × (318 – 298)°K

= 57862,9368 kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{318} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}0926.(318-298) + \frac{1{,}8896.10^{-3}}{2}.(318^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}$$

$$.(318^3 - 298^3)$$

$$= 26{,}5043\ kJ/kg = 6{,}3347\ kkal/kg$$

ΔH6 = m. Cp. dT

= 1440,0930 kg × 6,3347 kkal/kg = 9122,5162 kkal

- Asam asetat

$$\int Cp\ dT = \int_{298}^{318} (-0{,}0598 + 0{,}0073947.T).dT$$

$$\int Cp\ dT = -0{,}0598.(318 - 298) + \frac{0{,}0073947}{2}(318^2 - 298^2)$$

$$= 44{,}3554\ kJ/kg = 10{,}6012\ kkal/kg$$

ΔH7 = m. Cp. dT

= 2,9546 × 10,6012 kkal/kg = 2,8475 kkal

- Kalsium asetat

ΔH8 = m. Cp. ΔT

= 3,5365 kg × 69 kkal/kmol.°K / 158 kg/kmol × (318 – 298)°K

= 30,8888 kkal

Entalpi keluar menuju H-125 = ΔH1 + ΔH2 + ΔH3 + ΔH4 + ΔH5 + ΔH6 + ΔH7 + ΔH8

= 3716658,9963 kkal

Reaksi yang terjadi:

$$Ca^{2+}caseinate + 2CH_3COOH \rightarrow Casein\downarrow + Ca(CH_3COO)_2$$

$$\frac{5.595{,}7900}{250.000} \sim \frac{2\times 5.595{,}7900}{250.000} \sim \frac{5.595{,}7900}{250.000} \sim \frac{5.595{,}7900}{250.000}$$

Panas reaksi = ΔH°$_{298}$ casein + ΔH°$_{298}$ kalsium asetat - ΔH°$_{298}$ ca^{2+}caseinate - ΔH°$_{298}$ asam asetat

$$= \left(\frac{5.595{,}7900}{250.000} kmol \times -21271{,}5105\ kkal/kmol\right) + \left(\frac{5.595{,}7900}{250.000} kmol \times -364100\ kkal/kmol\right) - \left(\frac{5.595{,}7900}{250.000} kmol \times -21271{,}5105\ kkal/kmol\right) - \left(\frac{2\times 5.595{,}7900}{250.000} kmol \times -116400\ kkal/kmol\right)$$

= -2938,9089 kkal (mengeluarkan panas)

Entalpi masuk + panas reaksi = Entalpi keluar + Q yang diserap pendingin + Qloss

Entalpi masuk + panas reaksi = Entalpi keluar + Q yang diserap pendingin + 5% × (Entalpi masuk + panas reaksi)

8297913,1189 + 2938,9089 = 3716658,9963 + Q + 0,05 × (8297913,1189 + 2938,9089)

Q = 4169150,4301 kkal

Pendingin yang digunakan adalah H_2O

Suhu H_2O masuk = 30°C = 303 K

Suhu H_2O keluar = 45°C = 318 K

Q yang diserap H_2O = m. Cp. dT

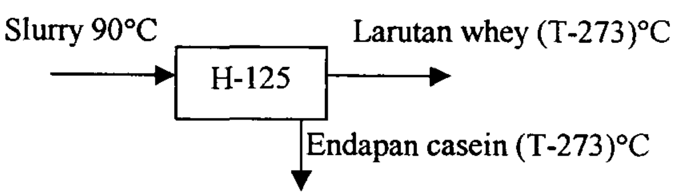
$$\int Cp\ dT = \int_{303}^{318} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(318-303) + \frac{47{,}212.10^{-2}}{2}.(318^2 - 303^2) - \frac{133{,}88.10^{-5}}{3}.(318^3 - 303^3) + \frac{1314{,}2.10^{-9}}{4}.(318^4 - 303^4)\right] \Big/ 18$$

$$= 62{,}6288\ kJ/kg = 14{,}9686\ kkal/kg$$

$$m\ H_2O = \frac{Q\ \text{yang diserap}\ H_2O}{\int Cp.dT} = \frac{4169150{,}4301\ kkal}{14{,}9686\ kkal/kg} = 278525{,}6654\ kg$$

5. Filter press (H-125)



Entalpi slurry masuk H-125 = Entalpi slurry keluar R-120

= 3716658,9963 kkal

Entalpi larutan whey keluar menuju R-130:

- Air

$$\int Cp\, dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\, dT = \left[18{,}2964.(T-298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4) \right] \Big/ 18\, kkal/kg$$

$\Delta H1 = m.\ Cp.\ dT$

$= 177910{,}6637 \times [1{,}0165.(T\text{-}298) + 1{,}3114.10^{-2}.(T^2\text{-}298^2) - 2{,}4793.10^{-5}.(T^3\text{-}298^3) + 18{,}2528.10^{-9}.(T^4\text{-}298^4)]$ kkal

- Protein whey

$$\int Cp\, dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \left[2{,}0082.(T-298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} .(T^3 - 298^3) \right] kJ.kg \Big/ 4{,}184\ kJ/kkal$$

$\Delta H2 = m.\ Cp.\ dT$

$= 1388{,}7635 \times [0{,}48.(T\text{-}298) + 0{,}1445.10^{-3}.(T^2\text{-}298^2) - 0{,}1046.10^{-6}.(T^3\text{-}298^3)]$ kkal

- Lemak

$$\int Cp\, dT = \int_{298}^{T} (1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \left[1{,}9842.(T-298) + \frac{1{,}4733.10^{-3}}{2}.(T^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3} .(T^3 - 298^3) \right] kJ/kg \Big/ 4{,}184\ kJ/kkal$$

$\Delta H3 = m.\ Cp.\ dT$

$= 1{,}7087 \times [0{,}4742.(T\text{-}298) + 0{,}1761.10^{-3}.(T^2\text{-}298^2) - 0{,}3825.10^{-6}.(T^3\text{-}298^3)$ kkal

- Laktosa

$\Delta H4 = m.\ Cp.\ \Delta T$

$= 10007{,}2664 \text{ kg} \times 0{,}287 \text{ kkal/kg.°K} \times (T - 298)\text{°K}$

$= 2872{,}0855.(T\text{-}298) \text{ kkal}$

- Mineral

$$\int Cp\, dT = \int_{298}^{T} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \left[1{,}0926.(T - 298) + \frac{1{,}8896.10^{-3}}{2}.(T^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}.(T^3 - 298^3)\right] kJ/kg \big/ 4{,}184\ kJ/kkal$$

$\Delta H5 = m.\ Cp.\ dT$

$= 1429{,}6095 \times [0{,}2611.(T\text{-}298) + 0{,}2258.10^{-3}.(T^2\text{-}298^2) - 0{,}2933.10^{-6} .(T^3\text{-}298^3) \text{ kkal}$

- Asam asetat

$$\int Cp\, dT = \int_{298}^{T} (-0{,}0598 + 0{,}0073947.T).dT$$

$$\int Cp\, dT = \left[-0{,}0598.(T - 298) + \frac{0{,}0073947}{2}(T^2 - 298^2)\right] kJ/kg \big/ 4{,}184\ kJ/kkal$$

$\Delta H6 = m.\ Cp.\ dT$

$= 0{,}2686 \times [-0{,}0143.(T\text{-}298) + 8{,}8369.10^{-4}] \text{ kkal}$

- Kalsium asetat

$\Delta H7 = m.\ Cp.\ \Delta T$

$= 3{,}5365 \text{ kg} \times 69 \text{ kkal/kmol.°K} / 158 \text{ kg/kmol} \times (T - 298)\text{°K}$

$= 1{,}5444.(T\text{-}298) \text{ kkal}$

Entalpi keluar menuju R-130 $= \Delta H1 + \Delta H2 + \Delta H3 + \Delta H4 + \Delta H5 + \Delta H6 + \Delta H7$

$= f(T)_1 \text{ kkal}$

Entalpi endapan casein keluar menuju M-210:

- Air

$$\int Cp\, dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\, dT = \left[18{,}2964.(T - 298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4) \right] \Big/ 18\,\text{kkal/kg}$$

$\Delta H8$ = m. Cp. dT

$= 1304{,}6426 \times [1{,}0165.(T\text{-}298) + 1{,}3114.10^{-2}.(T^2\text{-}298^2) - 2{,}4793.10^{-5}.(T^3\text{-}298^3) + 18{,}2528.10^{-9}.(T^4\text{-}298^4)]$ kkal

- Casein

$$\int Cp\, dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \left[2{,}0082.(T - 298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} .(T^3 - 298^3) \right] \text{kJ.kg} / 4{,}184\ \text{kJ/kkal}$$

$\Delta H9$ = m. Cp. dT

$= 5594{,}9394 \times [0{,}48.(T\text{-}298) + 0{,}1445.10^{-3}.(T^2\text{-}298^2) - 0{,}1046.10^{-6}.(T^3\text{-}298^3)]$ kkal

- Protein whey

$$\int Cp\, dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \left[2{,}0082.(T - 298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} .(T^3 - 298^3) \right] \text{kJ.kg} / 4{,}184\ \text{kJ/kkal}$$

$\Delta H10$ = m. Cp. dT

$= 10{,}1840 \times [0{,}48.(T\text{-}298) + 0{,}1445.10^{-3}.(T^2\text{-}298^2) - 0{,}1046.10^{-6}.(T^3\text{-}298^3)]$ kkal

- Laktosa

$\Delta H11$ = m. Cp. ΔT

$= 73,3864 \text{ kg} \times 0,287 \text{ kkal/kg.°K} \times (T - 298)\text{°K}$

$= 21,0619.(T\text{-}298) \text{ kkal}$

- Mineral

$$\int Cp\, dT = \int_{298}^{T} (1,0926 + 1,8896.10^{-3}.T - 3,6817.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \left[1,0926.(T - 298) + \frac{1,8896.10^{-3}}{2}.(T^2 - 298^2) - \frac{3,6817.10^{-6}}{3} .(T^3 - 298^3)\right] kJ/kg / 4,184\ kJ/kkal$$

$\Delta H12 = m.\ Cp.\ dT$

$= 10,4835 \times [0,2611.(T\text{-}298) + 0,2258.10^{-3}.(T^2\text{-}298^2) - 0,2933.10^{-6}.(T^3\text{-}298^3)$ kkal

Entalpi keluar menuju M-210 $= \Delta H8 + \Delta H9 + \Delta H10 + \Delta H11 + \Delta H12$

$= f(T)_2$ kkal

Entalpi keluar total $= f(T)_1 + f(T)_2 = f(T)$ kkal

Entalpi masuk = Entalpi keluar total + Q loss

Entalpi masuk = Entalpi keluar total + 10% × Entalpi masuk

$3716658,9963 = f(T) + 0,1 \times 3716658,9963$

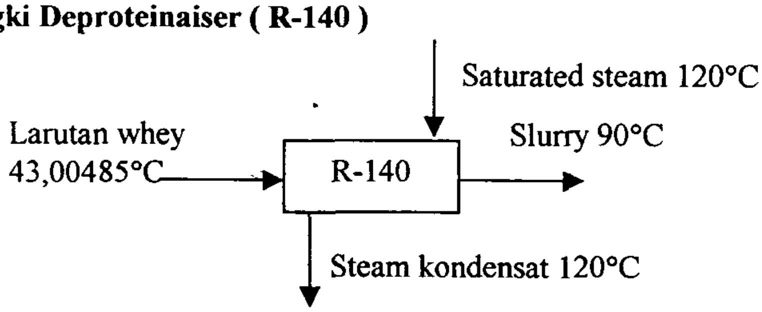
$f(T) = 3344993,097$ kkal

Trial T = 316,00485 K = 43,00485°C, f (T) = 3344993,097 kkal

Entalpi keluar menuju R-130 = 3266732,1093 kkal

Entalpi keluar menuju M-210 = 78260,9877 kkal

6. Tangki Deproteinaiser (R-140)



Entalpi masuk tangki deproteinaiser (R-140) =

Entalpi larutan whey keluar H-125 – Entalpi mineral yang terserap pada demineraliser

Entalpi mineral yang terserap demineraliser:

$$\int Cp\ dT = \int_{298}^{316,00485} (1,0926 + 1,8896.10^{-3}.T - 3,6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[1,0926.(316,00485 - 298) + \frac{1,8896.10^{-3}}{2}.(316,00485^2 - 298^2) - \frac{3,6817.10^{-6}}{3}.(316,00485^3 - 298^3)\right] kJ/kg \Big/ 4,184\ kJ/kkal$$

$$= 5,7044\ kkal/kg$$

ΔH mineral = m. Cp. dT

= 1415,3134 kg × 5,7044 kkal/kg = 8073,5835

Entalpi masuk Reaktor (R-140) = (3266732,1093 – 8073,5835) kkal

= 3258658,5258 kkal

Entalpi keluar:

- Air

$$\int Cp\ dT = \int_{298}^{363} (18,2964 + 47,212.10^{-2}.T - 133,88.10^{-5}.T^2 + 1314,2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18,2964.(363 - 298) + \frac{47,212.10^{-2}}{2}.(363^2 - 298^2) - \frac{133,88.10^{-5}}{3}.(363^3 - 298^3) + \frac{1314,2.10^{-9}}{4}.(363^4 - 298^4)\right] \Big/ 18$$

$$= 272,7307\ kJ/kg = 65,1842\ kkal/kg$$

$\Delta H1$ = m. Cp. dT

= 177910,6637 kg × 65,1842 kkal/kg = 11596962,7169 kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{363} (2,0082 + 1,2089.10^{-3}.T - 1,3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2,0082.(363 - 298) + \frac{1,2089.10^{-3}}{2}.(363^2 - 298^2) - \frac{1,3129.10^{-6}}{3}.(363^3 - 298^3)$$

$$= 147,1516\ kJ/kg = 35,1701\ kkal/kg$$

$\Delta H2$ = m. Cp. dT

= 13,8876 kg × 35,1701 kkal/kg = 488,4292 kkal

- Lemak

$$\int Cp\ dT = \int_{298}^{363} (1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}9842.(363 - 298) + \frac{1{,}4733.10^{-3}}{2}.(363^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3}.(363^3 - 298^3)$$

$$= 126{,}4278\ kJ/kg = 30{,}2170\ kkal/kg$$

$\Delta H3$ = m. Cp. dT

= 1,7087 kg × 30,2170 kkal/kg = 51,6307 kkal

- Laktosa

$\Delta H4$ = m. Cp. ΔT

= 10007,2664 kg × 0,287 kkal/kg.°K × (363 – 298)°K

= 186685,5547 kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{363} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}0926.(363 - 298) + \frac{1{,}8896.10^{-3}}{2}.(363^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}.(363^3 - 298^3)$$

$$= 85{,}3881\ kJ/kg = 20{,}4083\ kkal/kg$$

$\Delta H5$ = m. Cp. dT

= 14,2961 kg × 20,4083 kkal/kg = 291,7583 kkal

- Asam asetat

$$\int Cp\ dT = \int_{298}^{363} (-0{,}0598 + 0{,}0073947.T).dT$$

$$\int Cp\ dT = -0{,}0598.(363 - 298) + \frac{0{,}0073947}{2}(363^2 - 298^2)$$

$$= 154{,}9696\ kJ/kg = 37{,}0386\ kkal/kg$$

$\Delta H6$ = m. Cp. dT

= 0,2686 kg × 37,0386 kkal/kg = 9,9485 kkal

- Kalsium asetat

ΔH7 = m. Cp. ΔT

= 3,5365 kg × 69 kkal/kmol.°K / 158 kg/kmol × (363 – 298)°K

= 100,3885 kkal

- Endapan protein

$$\int Cp\ dT = \int_{298}^{363} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(363 - 298) + \frac{1{,}2089.10^{-3}}{2}.(363^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}.(363^3 - 298^3)$$

$$= 147{,}1516\ kJ/kg = 35{,}1701\ kkal/kg$$

ΔH8 = m. Cp. dT

= 1374,8759 kg × 35,1701 kkal/kg = 48354,4901 kkal

Entalpi keluar menuju H-143 = ΔH1 + ΔH2 + ΔH3 + ΔH4 + ΔH5 + ΔH6 + ΔH7 + ΔH8

= 11832944,9170 kkal

Protein whey terdiri dari α laktalbumin (75% brt), dan β laktoglobulin (25% brt)

ΔH denaturasi α laktalbumin= 253 kJ/mol × 1000 mol/kmol / 4,184 kJ/kkal

$$= 60468{,}4512\ kkal/kmol \times \frac{0{,}75 \times 1374{,}8559\ kg}{14200\ kg/kmol}$$

= 4391,0184 kkal

ΔH denaturasi β laktoglobulin = 311 kJ/mol × 1000 mol/kmol / 4,184 kJ/kkal

$$= 74330{,}7839\ kkal/kmol \times \frac{0{,}25 \times 1374{,}8559\ kg}{18400\ kg/kmol}$$

= 1388,5272 kkal

ΔH denaturasi protein whey = (4391,0184 + 1388,5272) kkal

= 5779,5456 kkal

Entalpi masuk + Q suplai = Entalpi keluar + ΔH denaturasi + Q loss

3258658,5258 + Q = 11832944,9170 + 5779,5456 + 5% × Q

Q = 9031648,3545 kkal

Steam yang digunakan adalah saturated steam pada T = 120°C, P = 198,53 kPa

Dari steam tabel Geankoplis hal 857 didapat:

Hv = 2706,3 kJ/kg

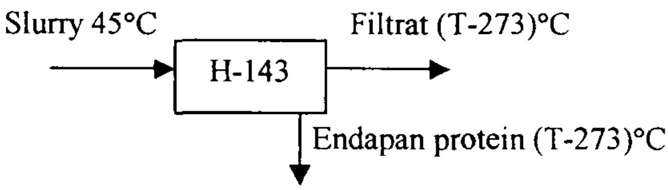
Hl = 503,71 kJ/kg

λ = 2202,59 kJ/kg = 526,4316 kkal/kg

Q yang disuplai steam = m . λ

$$\text{Massa steam} = \frac{\text{Q suplai}}{\lambda} = \frac{9031648{,}3545\ \text{kkal}}{526{,}4316\ \text{kkal/kg}} = 17156{,}3553\ \text{kg}$$

7. **Filter press (H-143)**



Entalpi slurry masuk H-143 = Entalpi slurry keluar R-140

= 11832944,9170 kkal

Entalpi filtrat keluar menuju V-150:

- Air

$$\int Cp\ dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(T-298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3}.(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4)\right] \Big/ 18\ \text{kkal/kg}$$

$\Delta H1$ = m. Cp. dT

= 177585,3072 × [1,0165.(T-298) + 1,3114.10^{-2}.(T^2-298^2) – 2,4793.10^{-5}.(T^3-298^3) + 18,2528.10^{-9}.(T^4-298^4)] kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[2{,}0082.(T - 298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} .(T^3 - 298^3)\right] kJ.kg / 4{,}184\ kJ/kkal$$

$\Delta H2$ = m. Cp. dT

= 13,8622 × [0,48.(T-298) + 0,1445.10^{-3}.(T^2-298^2) – 0,1046.10^{-6}. (T^3-298^3)] kkal

- Lemak

$$\int Cp\ dT = \int_{298}^{T} (1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[1{,}9842.(T - 298) + \frac{1{,}4733.10^{-3}}{2}.(T^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3} .(T^3 - 298^3)\right] kJ/kg / 4{,}184\ kJ/kkal$$

$\Delta H3$ = m. Cp. dT

= 1,7087 × [0,4742.(T-298) + 0,1761.10^{-3}.(T^2-298^2) – 0,3825.10^{-6}. (T^3-298^3) kkal

- Laktosa

$\Delta H4$ = m. Cp. ΔT

= 9988,9655 kg × 0,287 kkal/kg.°K × (T – 298)°K

= 2866,8331.(T-298) kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{T} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[1{,}0926.(T - 298) + \frac{1{,}8896.10^{-3}}{2}.(T^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3} .(T^3 - 298^3)\right] kJ/kg / 4{,}184\ kJ/kkal$$

$\Delta H5$ = m. Cp. dT

= 14,2700 × [0,2611.(T-298) + 0,2258.10^{-3}.(T^2-298^2) – 0,2933.10^{-6} .(T^3-298^3) kkal

- Asam asetat

$$\int Cp\ dT = \int_{298}^{T} (-0{,}0598 + 0{,}0073947.T).dT$$

$$\int Cp\ dT = \left[-0{,}0598.(T-298) + \frac{0{,}0073947}{2}(T^2 - 298^2)\right] kJ/kg \Big/ 4{,}184\ kJ/kkal$$

$\Delta H6 = m.\ Cp.\ dT$

$= 0{,}2686 \times [-0{,}0143.(T\text{-}298) + 8{,}8369.10^{-4}]$ kkal

- Kalsium asetat

$\Delta H7 = m.\ Cp.\ \Delta T$

$= 3{,}5365 \times 69$ kkal/kmol.°K / 158 kg/kmol $\times$ (T – 298)°K

$= 1{,}5444.(T\text{-}298)$ kkal

Entalpi keluar menuju V-150 $= \Delta H1 + \Delta H2 + \Delta H3 + \Delta H4 + \Delta H5 + \Delta H6 + \Delta H7$

$= f(T)_1$ kkal

Entalpi endapan protein keluar menuju penampung endapan:

- Air

$$\int Cp\ dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(T-298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4)\right] \Big/ 18\,kkal/kg$$

$\Delta H8 = m.\ Cp.\ dT$

$= 325{,}3564 \times [1{,}0165.(T\text{-}298) + 1{,}3114.10^{-2}.(T^2\text{-}298^2) - 2{,}4793.10^{-5}.$
$(T^3\text{-}298^3) + 18{,}2528.10^{-9}.(T^4\text{-}298^4)]$ kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \Big[2{,}0082.(T-298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}$$

$$.(T^3 - 298^3)\Big] kJ.kg/4{,}184\ kJ/kkal$$

$\Delta H9$ = m. Cp. dT

= 0,0254 × [0,48.(T-298) + 0,1445.10^{-3}.(T^2-298^2) – 0,1046.10^{-6}. (T^3-298^3)] kkal

- Laktosa

$\Delta H10$ = m. Cp. ΔT

= 18,3009 kg × 0,287 kkal/kg.°K × (T – 298)°K

= 5,2524.(T-298) kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{T} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \Big[1{,}0926.(T-298) + \frac{1{,}8896.10^{-3}}{2}.(T^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}$$

$$.(T^3 - 298^3)\Big] kJ/kg/4{,}184\ kJ/kkal$$

$\Delta H11$ = m. Cp. dT

= 0,0261 × [0,2611.(T-298) + 0,2258.10^{-3}.(T^2-298^2) – 0,2933.10^{-6} .(T^3-298^3) kkal

- Endapan protein

$$\int Cp\ dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \Big[2{,}0082.(T-298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}$$

$$.(T^3 - 298^3)\Big] kJ.kg/4{,}184\ kJ/kkal$$

$\Delta H12$ = m. Cp. dT

= 1374,8759 × [0,48.(T-298) + 0,1445.10^{-3}.(T^2-298^2) – 0,1046.10^{-6} .(T^3-298^3)] kkal

Entalpi keluar menuju M-210 $= \Delta H8 + \Delta H9 + \Delta H10 + \Delta H11 + \Delta H12$

$= f(T)_2$ kkal

Entalpi keluar total $= f(T)_1 + f(T)_2 = f(T)$ kkal

Entalpi masuk = Entalpi keluar total + Q loss

Entalpi masuk = Entalpi keluar total + 10% × Entalpi masuk

11832944,9170 $= f(T) + 0{,}1 \times 11832944{,}9170$

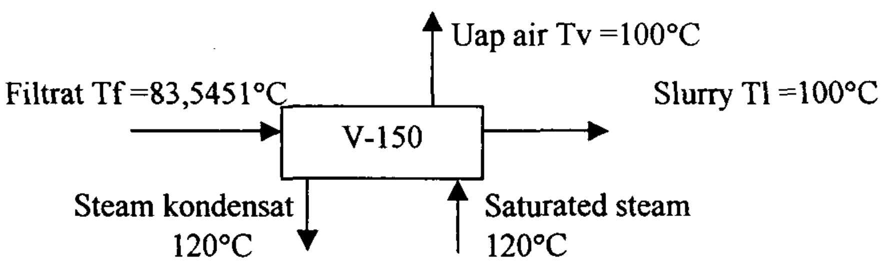
$f(T)$ = 10649650,4253 kkal

Trial T = 356,5451 K = 83,5451°C, $f(T)$ = 10649650,4253 kkal

Entalpi keluar menuju V-150 = 10586722,5996 kkal

Entalpi keluar menuju penampung endapan = 62927,8257 kkal

8. Evaporator (V-150)



P operasi = P_1 = 1 atm

Tl = Tv = T_1 = Td H_2O = 100°C = 373 K

Entalpi feed masuk V-150 = Entalpi keluar H-143 = 10586722,5996 kkal

Entalpi slurry keluar menuju X-160:

- Air

$$\int Cp\, dT = \int_{298}^{373} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\, dT = \left[18{,}2964.(373-298) + \frac{47{,}212.10^{-2}}{2}.(373^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(373^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(373^4 - 298^4)\right] / 18$$

$= 315{,}0786$ kJ / kg = 75,3056 kkal / kg

$\Delta H1$ = m. Cp. dT

= 5396,7908 kg × 75,3056 kkal/kg = 406408,5704 kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{373} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(373 - 298) + \frac{1{,}2089.10^{-3}}{2}.(373^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}.(373^3 - 298^3)$$

$$= 169{,}9043\ kJ/kg = 40{,}6081\ kkal/kg$$

$\Delta H2 = m.\ Cp.\ dT$

$= 13{,}8622\ kg \times 40{,}6081\ kkal/kg = 562{,}9190\ kkal$

- Lemak

$$\int Cp\ dT = \int_{298}^{373} (1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}9842.(373 - 298) + \frac{1{,}4733.10^{-3}}{2}.(373^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3}.(373^3 - 298^3)$$

$$= 145{,}1897\ kJ/kg = 34{,}7012\ kkal/kg$$

$\Delta H3 = m.\ Cp.\ dT$

$= 1{,}7087\ kg \times 34{,}7012\ kkal/kg = 59{,}2927\ kkal$

- Laktosa

$\Delta H4 = m.\ Cp.\ \Delta T$

$= 9988{,}9655\ kg \times 0{,}287\ kkal/kg.°K \times (373 - 298)°K$

$= 215012{,}4820\ kkal$

- Mineral

$$\int Cp\ dT = \int_{298}^{373} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}0926.(373 - 298) + \frac{1{,}8896.10^{-3}}{2}.(373^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}.(373^3 - 298^3)$$

$$= 98{,}2816\ kJ/kg = 23{,}4899\ kkal/kg$$

$\Delta H5 = m.\ Cp.\ dT$

$= 14{,}2700\ kg \times 23{,}4899\ kkal/kg = 335{,}1994\ kkal$

- Asam asetat

$$\int Cp\ dT = \int_{298}^{373} (-0{,}0598 + 0{,}0073947.T).dT$$

$$\int Cp\ dT = -0{,}0598.(373-298) + \frac{0{,}0073947}{2}(373^2 - 298^2)$$

$$= 181{,}5841\ kJ/kg = 43{,}3997\ kkal/kg$$

$\Delta H6$ = m. Cp. dT

= 0,2686 kg × 43,3997 kkal/kg = 11,6571 kkal

- Kalsium asetat

$\Delta H7$ = m. Cp. ΔT

= 3,5365 kg × 69 kkal/kmol.°K / 158 kg/kmol × (373 – 298)°K

= 115,8329 kkal

Entalpi keluar menuju X-160 = $\Delta H1 + \Delta H2 + \Delta H3 + \Delta H4 + \Delta H5 + \Delta H6 + \Delta H7$

= 11832944,9170 kkal

Entalpi uap air keluar:

Dari steam tabel Geankoplis hal 857 pada T = 373 K, P = 1 atm = 101,35 kPa:

Hv = 2676,1 kJ/kg

Hl = 419,04 kJ/kg

λv = 2257,06 kJ/kg = 539,4503 kkal/kg

Entalpi uap air = m air yang menguap × λv

= 172188,5164 kg × 539,4503 kkal/kg

= 92887144,5746 kkal

Entalpi feed masuk + Q yang disuplai steam = Entalpi slurry keluar + Entalpi uap air + Q loss

Entalpi feed masuk + Q = Entalpi slurry keluar + Entalpi uap air + 5% × Q

10586722,5996 + Q = 11832944,9170 + 92887144,5746 + 0,05 × Q

Q = 87287292,5564 kkal

Steam yang digunakan adalah saturated steam pada T = 120°C, P = 198,53 kPa

Hv = 2706,3 kJ/kg

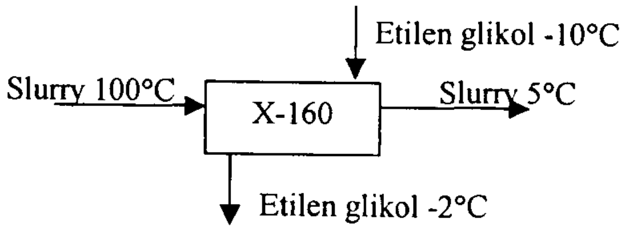
Hl = 503,71 kJ/kg

λ = 2202,59 kJ/kg = 526,4316 kkal/kg

Q yang disuplai steam = m . λ

$$\text{Massa steam} = \frac{\text{Q suplai}}{\lambda} = \frac{87287292{,}5564 \text{ kkal}}{526{,}4316 \text{ kkal/kg}} = 165809{,}3572 \text{ kg}$$

9. Kristaliser (X-160)



Entalpi slurry masuk kristaliser (X-160) = Entalpi keluar evaporator (V-150)

= 11832944,9170 kkal

Entalpi slurry keluar:

- Air

$$\int Cp\, dT = \int_{298}^{278} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\, dT = \left[18{,}2964.(278-298) + \frac{47{,}212.10^{-2}}{2}.(278^2 - 298^2) - \frac{133{,}88.10^{-5}}{3}.(278^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(278^4 - 298^4)\right] \Big/ 18$$

$$= -82{,}8980 \text{ kJ/kg} = -19{,}8131 \text{ kkal/kg}$$

$\Delta H1 = m.\ Cp.\ dT$

$= 5396{,}7908 \text{ kg} \times -19{,}8131 \text{ kkal/kg} = -106927{,}1372 \text{ kkal}$

- Protein whey

$$\int Cp\, dT = \int_{298}^{278} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\, dT = 2{,}0082.(278-298) + \frac{1{,}2089.10^{-3}}{2}.(278^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}.(278^3 - 298^3)$$

$$= -44{,}9484 \text{ kJ/kg} = -10{,}7429 \text{ kkal/kg}$$

$\Delta H2 = m.\ Cp.\ dT$

$= 13{,}8622 \text{ kg} \times -10{,}7429 \text{ kkal/kg} = -148{,}9211 \text{ kkal}$

- Lemak

$$\int Cp\, dT = \int_{298}^{278} (1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\, dT = 1{,}9842.(278 - 298) + \frac{1{,}4733.10^{-3}}{2}.(278^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3}$$

$$.(278^3 - 298^3)$$

$$= -40{,}2031 \text{ kJ / kg} = -9{,}6088 \text{ kkal / kg}$$

ΔH3 = m. Cp. dT

= 1,7087 kg × -9,6088 kkal/kg = -16,4182 kkal

- Laktosa

ΔH4 = m. Cp. ΔT

= 809,5186 kg × 0,287 kkal/kg.°K × (278 – 298)°K

= -4646,6369 kkal

- Mineral

$$\int Cp\, dT = \int_{298}^{278} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\, dT = 1{,}0926.(278 - 298) + \frac{1{,}8896.10^{-3}}{2}.(278^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}$$

$$.(278^3 - 298^3)$$

$$= -26{,}6261 \text{ kJ / kg} = -6{,}3638 \text{ kkal / kg}$$

ΔH5 = m. Cp. dT

= 14,2700 kg × -6,3638 kkal/kg = -90,8111 kkal

- Asam asetat

$$\int Cp\, dT = \int_{298}^{278} (-0{,}0598 + 0{,}0073947.T).dT$$

$$\int Cp\, dT = -0{,}0598.(278 - 298) + \frac{0{,}0073947}{2}(278^2 - 298^2)$$

$$= -41{,}3975 \text{ kJ / kg} = -9{,}8942 \text{ kkal / kg}$$

ΔH6 = m. Cp. dT

= 0,2686 kg × -9,8942 kkal/kg = -2,6576 kkal

- Kalsium asetat

$\Delta H7$ = m. Cp. ΔT

= 3,5365 kg × 69 kkal/kmol.°K / 158 kg/kmol × (278 – 298)°K

= -30,8888 kkal

- Kristal laktosa

$\Delta H8$ = m. Cp. ΔT

= 9179,4469 kg × 0,287 kkal/kg.°K × (278 – 298)°K

= -52690,0250 kkal

Entalpi keluar menuju H-162 = $\Delta H1 + \Delta H2 + \Delta H3 + \Delta H4 + \Delta H5 + \Delta H6 + \Delta H7 + \Delta H8$

= -164553,4959 kkal

Panas kelarutan laktosa = -3,705 kkal/kmol

Panas kristalisasi laktosa = - panas kelarutan = 3,705 kkal/kmol

= 3,705 kkal/kmol × 9179,4469 kg / 342 kg/kmol

= 99,4440 kkal

Entalpi masuk = Entalpi keluar + panas kristalisasi + panas yang diserap pendingin + Q loss

Entalpi masuk = Entalpi keluar + panas kristalisasi + Q + 5% × Entalpi masuk

11832944,9170 = -164553,4959 + 99,4440 + Q + 0,05 × 11832944,9170

Q = 755834,7077 kkal

Pendingin yang digunakan adalah etilen glikol

Q etilen glikol = m. Cp. dT

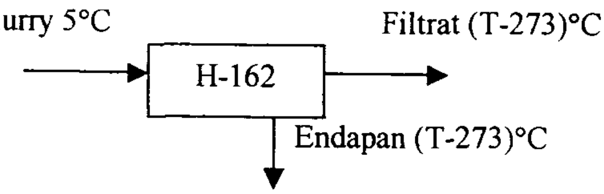
$$\int Cp\ dT = \int_{263}^{271} (0{,}366 + 0{,}0011.T).dT$$

$$\int Cp\ dT = 0{,}366.(271 - 263) + \frac{0{,}0011}{2}.(271^2 - 263^2)$$

$$= 5{,}2776\ kkal/kg$$

$$m\ etilen\ glikol = \frac{Q\ etilen\ glikol}{\int Cp.dT} = \frac{755834{,}7077\ kkal}{5{,}2776\ kkal/kg} = 143215{,}6108\ kg$$

10. Filter Press (H-162)



Entalpi slurry masuk H-162 = Entalpi slurry keluar X-160

= -164553,4959 kkal

Entalpi endapan keluar menuju B-170:

- Air

$$\int Cp\ dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(T-298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4) \right] \Big/ 18\ kkal/kg$$

$\Delta H1 = m.\ Cp.\ dT$

$= 1984{,}7720 \times [1{,}0165.(T\text{-}298) + 1{,}3114.10^{-2}.(T^2\text{-}298^2) - 2{,}4793.10^{-5}.(T^3\text{-}298^3) + 18{,}2528.10^{-9}.(T^4\text{-}298^4)]$ kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[2{,}0082.(T-298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} .(T^3 - 298^3) \right] kJ.kg \Big/ 4{,}184\ kJ/kkal$$

$\Delta H2 = m.\ Cp.\ dT$

$= 5{,}0981 \times [0{,}48.(T\text{-}298) + 0{,}1445.10^{-3}.(T^2\text{-}298^2) - 0{,}1046.10^{-6}.(T^3\text{-}298^3)]$ kkal

- Lemak

$$\int Cp\ dT = \int_{298}^{T} (1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[1{,}9842.(T - 298) + \frac{1{,}4733.10^{-3}}{2}.(T^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3} .(T^3 - 298^3)\right] kJ/kg / 4{,}184\ kJ/kkal$$

$\Delta H3$ = m. Cp. dT

= 0,6284 × [0,4742.(T-298) + 0,1761.10^{-3}.(T^2-298^2) – 0,3825.10^{-6}. (T^3-298^3) kkal

- Laktosa

$\Delta H4$ = m. Cp. ΔT

= 297,7158 kg × 0,287 kkal/kg.°K × (T – 298)°K

= 85,4444.(T-298) kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{T} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[1{,}0926.(T - 298) + \frac{1{,}8896.10^{-3}}{2}.(T^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3} .(T^3 - 298^3)\right] kJ/kg / 4{,}184\ kJ/kkal$$

$\Delta H5$ = m. Cp. dT

= 5,2480 × [0,2611.(T-298) + 0,2258.10^{-3}.(T^2-298^2) – 0,2933.10^{-6}.(T^3-298^3) kkal

- Kalsium asetat

$\Delta H6$ = m. Cp. ΔT

= 1,3006 kg × 69 kkal/kmol.°K / 158 kg/kmol × (T – 298)°K

= 0,5680.(T-298) kkal

- Kristal laktosa

$\Delta H7$ = m. Cp. ΔT

= 9179,4469 kg × 0,287 kkal/kg.°K × (T – 298)°K

= 2634,5013.(T-298) kkal

Entalpi keluar menuju B-170 $= \Delta H1 + \Delta H2 + \Delta H3 + \Delta H4 + \Delta H5 + \Delta H6 + \Delta H7$

$= f(T)_1$ kkal

Entalpi filtrat keluar menuju penampung filtrat:

- Air

$$\int Cp\, dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\, dT = \left[18{,}2964.(T-298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} \right.$$

$$\left. .(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4) \right] \Big/ 18\, kkal/kg$$

$\Delta H8 = m.\ Cp.\ dT$

$= 3412{,}0188 \times [1{,}0165.(T\text{-}298) + 1{,}3114.10^{-2}.(T^2\text{-}298^2) - 2{,}4793.10^{-5}.$
$(T^3\text{-}298^3) + 18{,}2528.10^{-9}.(T^4\text{-}298^4)]$ kkal

- Protein whey

$$\int Cp\, dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \left[2{,}0082.(T-298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} \right.$$

$$\left. .(T^3 - 298^3) \right] kJ.kg \big/ 4{,}184\ kJ/kkal$$

$\Delta H9 = m.\ Cp.\ dT$

$= 8{,}7641 \times [0{,}48.(T\text{-}298) + 0{,}1445.10^{-3}.(T^2\text{-}298^2) - 0{,}1046.10^{-6}.(T^3\text{-}$
$298^3)]$ kkal

- Lemak

$$\int Cp\, dT = \int_{298}^{T} (1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \left[1{,}9842.(T-298) + \frac{1{,}4733.10^{-3}}{2}.(T^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3} \right.$$

$$\left. .(T^3 - 298^3) \right] kJ/kg \big/ 4{,}184\ kJ/kkal$$

$\Delta H10 = m.\ Cp.\ dT$

$= 1{,}0803 \times [0{,}4742.(T\text{-}298) + 0{,}1761.10^{-3}.(T^2\text{-}298^2) - 0{,}3825.10^{-6}.(T^3\text{-}$
$298^3)$ kkal

- Laktosa

ΔH11 = m. Cp. ΔT

= 511,8028 kg × 0,287 kkal/kg.°K × (T – 298)°K

= 146,8874.(T-298) kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{T} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[1{,}0926.(T-298) + \frac{1{,}8896.10^{-3}}{2}.(T^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3} .(T^3 - 298^3)\right] kJ/kg \Big/ 4{,}184\ kJ/kkal$$

ΔH12 = m. Cp. dT

$= 9{,}0219 \times [0{,}2611.(T\text{-}298) + 0{,}2258.10^{-3}.(T^2\text{-}298^2) – 0{,}2933.10^{-6}.(T^3\text{-}298^3)$ kkal

- Asam asetat

$$\int Cp\ dT = \int_{298}^{T} (-0{,}0598 + 0{,}0073947.T).dT$$

$$\int Cp\ dT = \left[-0{,}0598.(T-298) + \frac{0{,}0073947}{2}(T^2 - 298^2)\right] kJ/kg \Big/ 4{,}184\ kJ/kkal$$

ΔH13 = m. Cp. dT

$= 0{,}2686 \times [-0{,}0143.(T\text{-}298) + 8{,}8369.10^{-4}]$ kkal

- Kalsium asetat

ΔH14 = m. Cp. ΔT

= 2,2359 kg × 69 kkal/kmol.°K / 158 kg/kmol × (T – 298)°K

= 0,9764.(T-298) kkal

Entalpi keluar menuju B-170 = ΔH8 + ΔH9 + ΔH10 + ΔH11 + ΔH12 + ΔH13 + ΔH14

$= f(T)_2$ kkal

Entalpi keluar total = $f(T)_1 + f(T)_2 = f(T)$ kkal

Entalpi masuk = Entalpi keluar total + Q loss

Entalpi masuk + Q dari lingkungan = Entalpi keluar total

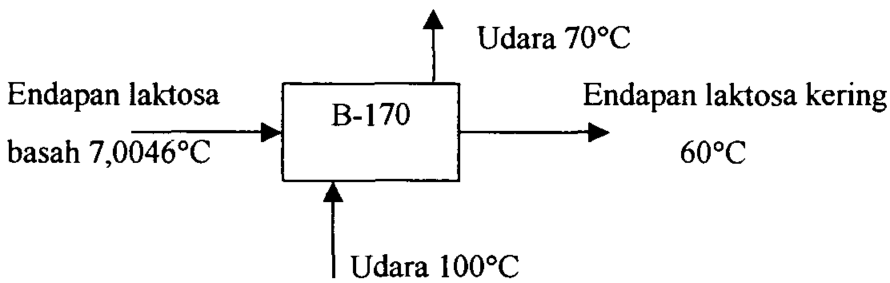
-164553,4959 + 10% × 164553,4959 = f (T) f (T) = -148098,1463 kkal

Trial T = 280,0046 K = 7,0046°C, f (T) = -148098,1463 kkal

Entalpi keluar menuju B-170 = -84438,4207 kkal

Entalpi keluar menuju penampung filtrat = -63659,7256 kkal

11. Rotary Dryer (B-170)



Entalpi endapan basah masuk B-170 = Entalpi keluar H-162

= -84438,4207 kkal

Entalpi keluar menuju J-181:

- Air

$$\int Cp\, dT = \int_{298}^{333} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\, dT = \left[18{,}2964.(333 - 298) + \frac{47{,}212.10^{-2}}{2}.(333^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(333^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(333^4 - 298^4) \right] \Big/ 18$$

$$= 146{,}3165 \text{ kJ / kg} = 34{,}9705 \text{ kkal / kg}$$

$\Delta H1 = m.\ Cp.\ dT$

$= 142{,}3416 \text{ kg} \times 34{,}9705 \text{ kkal/kg} = 4977{,}7522 \text{ kkal}$

- Protein whey

$$\int Cp\, dT = \int_{298}^{333} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\, dT = 2{,}0082.(333 - 298) + \frac{1{,}2089.10^{-3}}{2}.(333^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} .(333^3 - 298^3)$$

$$= 79{,}0576 \text{ kJ / kg} = 18{,}8952 \text{ kkal / kg}$$

$\Delta H2 = m.\ Cp.\ dT$

$= 5{,}0216 \text{ kg} \times 18{,}8952 \text{ kkal/kg} = 94{,}8847 \text{ kkal}$

- Lemak

$$\int Cp\ dT = \int_{298}^{333} (1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}9842.(333 - 298) + \frac{1{,}4733.10^{-3}}{2}.(333^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3}.(333^3 - 298^3)$$

$$= 68{,}9732 \text{ kJ / kg} = 16{,}4850 \text{ kkal / kg}$$

$\Delta H3 = m.\ Cp.\ dT$

$= 0{,}6190 \text{ kg} \times 16{,}4850 \text{ kkal/kg} = 10{,}2037 \text{ kkal}$

- Laktosa

$\Delta H4 = m.\ Cp.\ \Delta T$

$= 293{,}2501 \text{ kg} \times 0{,}287 \text{ kkal/kg.°K} \times (333 - 298)\text{°K}$

$= 2945{,}6968 \text{ kkal}$

- Mineral

$$\int Cp\ dT = \int_{298}^{333} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}0926.(333 - 298) + \frac{1{,}8896.10^{-3}}{2}.(333^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}.(333^3 - 298^3)$$

$$= 46{,}2670 \text{ kJ / kg} = 11{,}0581 \text{ kkal / kg}$$

$\Delta H5 = m.\ Cp.\ dT$

$= 5{,}1693 \text{ kg} \times 11{,}0581 \text{ kkal/kg} = 57{,}1628 \text{ kkal}$

- Kalsium asetat

$\Delta H6 = m.\ Cp.\ \Delta T$

$= 1{,}2811 \text{ kg} \times 69 \text{ kkal/kmol.°K} / 158 \text{ kg/kmol} \times (333 - 298)\text{°K}$

$= 19{,}5817 \text{ kkal}$

- Kristal laktosa

$\Delta H7 = m.\ Cp.\ \Delta T$

$= 9041{,}7552 \text{ kg} \times 0{,}287 \text{ kkal/kg.°K} \times (333 - 298)\text{°K}$

= 90824,4306 kkal

Entalpi keluar menuju J-181 = ΔH1 + ΔH2 + ΔH3 + ΔH4 + ΔH5 + ΔH6 + ΔH7

= 98929,7126 kkal

Entalpi keluar menuju H-173:

- Air

$$\int Cp\ dT = \int_{298}^{333} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(333-298) + \frac{47{,}212.10^{-2}}{2}.(333^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(333^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(333^4 - 298^4)\right] / 18$$

$$= 146{,}3165\ kJ/kg = 34{,}9705\ kkal/kg$$

ΔH8 = m. Cp. dT

= 2,1676 kg × 34,9705 kkal/kg = 75,8033 kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{333} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(333-298) + \frac{1{,}2089.10^{-3}}{2}.(333^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} .(333^3 - 298^3)$$

$$= 79{,}0576\ kJ/kg = 18{,}8952\ kkal/kg$$

ΔH9 = m. Cp. dT

= 0,0765 kg × 18,8952 kkal/kg = 1,4449 kkal

- Lemak

$$\int Cp\ dT = \int_{298}^{333} (1{,}9842 + 1{,}4733.10^{-3}.T - 4{,}8008.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}9842.(333-298) + \frac{1{,}4733.10^{-3}}{2}.(333^2 - 298^2) - \frac{4{,}8008.10^{-6}}{3} .(333^3 - 298^3)$$

$$= 68{,}9732\ kJ/kg = 16{,}4850\ kkal/kg$$

ΔH10 = m. Cp. dT

= 0,0094 kg × 16,4850 kkal/kg = 0,1554 kkal

- Laktosa

ΔH11 = m. Cp. ΔT

= 4,4657 kg × 0,287 kkal/kg.°K × (333 – 298)°K

= 44,8583 kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{333} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}0926.(333 - 298) + \frac{1{,}8896.10^{-3}}{2}.(333^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}.(333^3 - 298^3)$$

$$= 46{,}2670\ kJ/kg = 11{,}0581\ kkal/kg$$

ΔH12 = m. Cp. dT

= 0,0787 kg × 11,0581 kkal/kg = 0,8705 kkal

- Kalsium asetat

ΔH13 = m. Cp. ΔT

= 0,0195 kg × 69 kkal/kmol.°K / 158 kg/kmol × (333 – 298)°K

= 0,2982 kkal

- Kristal laktosa

ΔH14 = m. Cp. ΔT

= 137,6917 kg × 0,287 kkal/kg.°K × (333 – 298)°K

= 1383,1132 kkal

Entalpi keluar menuju H-173 = ΔH8 + ΔH9 + ΔH10 + ΔH11 + ΔH12 + ΔH13 + ΔH14

= 1506,5438 kkal

Asumsi: udara yang digunakan untuk mengeringkan bahan adalah udara panas T = 100°C

Udara berasal dari udara dengan T = 30°C, P = 1 atm , kelembaban = 70%

Dari Geankoplis grafik hal 529 didapat:

Humidity udara masuk = H_2 = 0,02 kg H_2O / kg udara kering

Entalpi udara masuk :

$Hg_2 = Cs. (T - To) + H_2 . \lambda o$

$Cs = 1{,}005 + 1{,}88 . H$

$\lambda o = 2501{,}4$ kJ/kg (Geankoplis, hal 857)

$Hg_2 = (1{,}005 + 1{,}88 . H_2). (T - To) + H_2 . \lambda o$

$= (1{,}005 + 1{,}88. 0{,}02) . (373\text{-}273) + 0{,}02 . 2501{,}4$

$= 154{,}288$ kJ/kg udara kering = 36,8757 kkal/kg udara kering

Entalpi udara keluar:

$Hg_1 = (1{,}005 + 1{,}88 . H_1). (T - To) + H_1 . \lambda o$

$= (1{,}005 + 1{,}88 . H_1) . (343\text{-}273) + H_1 . 2501{,}4$

$= (70{,}35 + 2633. H_1)$ kJ/kg udara kering

$= (16{,}8141 + 629{,}3021 . H_1)$ kkal/kg udara kering

Neraca massa moisture:

$G . H_2$ + air dari bahan masuk = $G . H_1$ + air dari bahan keluar

$G . 0{,}02 + 1984{,}7720 = G . H_1 + 144{,}5092$

$G = \dfrac{1840{,}2628}{(H_1 - 0{,}02)}$ kg udara kering .... (1)

Neraca panas total:

Entalpi udara masuk + Entalpi bahan masuk = Entalpi udara keluar + Entalpi bahan keluar + Q loss

$G. Hg_2$ + Entalpi bahan masuk = $G. Hg_1$ + Entalpi bahan keluar + 5% × $(G.Hg_2)$

$G. 36{,}8757 - 84438{,}4217 = G .(16{,}8141 + 629{,}3021.H_1) + 100436{,}2564 + (0{,}05 \times G. 36{,}8757)$

$18{,}2178. G - 629{,}3021. G. H_1 = 184874{,}6781$

$G . (18{,}2178 - 629{,}3021.H_1) = 184874{,}6781$ .... (2)

Substitusi persamaan (1) ke persamaan (2):

$$\frac{1840{,}2628}{(H_1 - 0{,}02)} . (18{,}2178 - 629{,}3021.H_1) = 184874{,}6781$$

$1840{,}2628 .(18{,}2178 - 629{,}3021.H_1) = 184874{,}6781. (H_1 - 0{,}02)$

$33525{,}5970 - 1158081{,}2446 . H_1 = 184874{,}6781. H_1 - 3697{,}4936$

$H_1 = 0{,}0277$ kg H_2O/kg udara kering

G = 238459,9073 kg udara kering

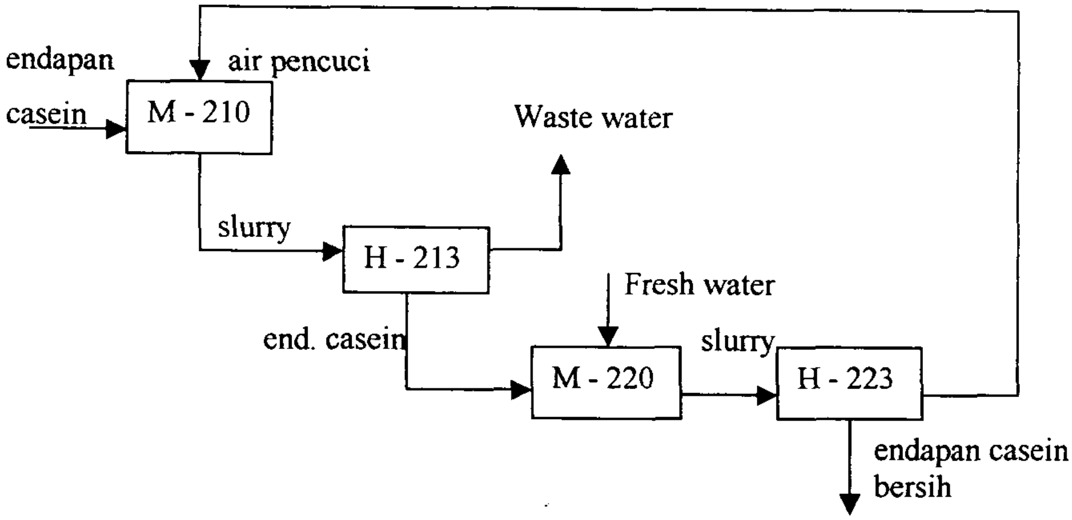
Entalpi udara masuk = G. Hg_1 = 8793380,0625 kkal

Entalpi udara keluar = G. Hg_2 = 8168836,3813 kkal

Massa udara masuk = $(1 + H_2) \times G$ = 243229,1055 kg

Massa udara keluar = $(1 + H_1) \times G$ = 245069,3683 kg

12. Tangki pencuci (M – 210)



Suhu endapan casein masuk = 43,00485°C

Suhu slurry keluar = T K = (T-273)°C

Asumsi: suhu air pencuci mula-mula = 30°C

Entalpi masuk M-210 = Entalpi keluar H-125 + Entalpi keluar H-223

= 78260,9877 kkal + Entalpi keluar H-223

Entalpi keluar H-223:

- Air

$$\int Cp\, dT = \int_{298}^{303} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\, dT = \left[18{,}2964.(303 - 298) + \frac{47{,}212.10^{-2}}{2}.(303^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(303^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(303^4 - 298^4) \right] \Big/ 18$$

$$= 20{,}8154 \text{ kJ/kg} = 4{,}9750 \text{ kkal/kg}$$

$\Delta H1$ = m. Cp. dT

$= 20973{,}8617 \times 4{,}9750$ kkal/kg = 104344,7354 kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{303} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(303 - 298) + \frac{1{,}2089.10^{-3}}{2}.(303^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}$$

$$.(303^3 - 298^3)$$

$$= 11{,}2646\ kJ/kg = 2{,}6923\ kkal/kg$$

$\Delta H2$ = m. Cp. dT

$= 0{,}6365$ kg $\times$ 2,6923 kkal/kg = 1,7137 kkal

- Laktosa

$\Delta H3$ = m. Cp. ΔT

$= 4{,}2999$ kg $\times$ 0,287 kkal/kg.°K $\times$ (303 – 298)°K

= 6,1704 kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{303} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 1{,}0926.(303 - 298) + \frac{1{,}8896.10^{-3}}{2}.(303^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}$$

$$.(303^3 - 298^3)$$

$$= 6{,}6398\ kJ/kg = 1{,}5869\ kkal/kg$$

$\Delta H4$ = m. Cp. dT

$= 0{,}6552$ kg $\times$ 1,5869 kkal/kg = 1,0398 kkal

Entalpi keluar H-223 = $\Delta H1 + \Delta H2 + \Delta H3 + \Delta H4$

= 104353,6592 kkal

Entalpi masuk M-120 = 78260,9877 + 104353,6592 = 182614,6469 kkal

Entalpi keluar menuju H-213:

- Air

$$\int Cp\ dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(T-298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3}.(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4)\right] \Big/ 18\ \text{kkal/kg}$$

$\Delta H5$ = m. Cp. dT

$= 22278{,}5043 \times [1{,}0165.(T\text{-}298) + 1{,}3114.10^{-2}.(T^2\text{-}298^2) - 2{,}4793.10^{-5}.(T^3\text{-}298^3) + 18{,}2528.10^{-9}.(T^4\text{-}298^4)]$ kkal

- Casein

$$\int Cp\ dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[2{,}0082.(T-298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}.(T^3 - 298^3)\right] \text{kJ.kg} / 4{,}184\ \text{kJ/kkal}$$

$\Delta H6$ = m. Cp. dT

$= 5594{,}9394 \times [0{,}48.(T\text{-}298) + 0{,}1445.10^{-3}.(T^2\text{-}298^2) - 0{,}1046.10^{-6}.(T^3\text{-}298^3)]$ kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[2{,}0082.(T-298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}.(T^3 - 298^3)\right] \text{kJ.kg} / 4{,}184\ \text{kJ/kkal}$$

$\Delta H7$ = m. Cp. dT

$= 10{,}1840 \times [0{,}48.(T\text{-}298) + 0{,}1445.10^{-3}.(T^2\text{-}298^2) - 0{,}1046.10^{-6}.(T^3\text{-}298^3)]$ kkal

- Laktosa

$\Delta H8$ = m. Cp. ΔT

$= 73{,}3846 \text{ kg} \times 0{,}287 \text{ kkal/kg.°K} \times (T - 298)\text{°K}$

$= 21{,}0614.(T\text{-}298) \text{ kkal}$

- Mineral

$$\int Cp\, dT = \int_{298}^{T} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \left[1{,}0926.(T - 298) + \frac{1{,}8896.10^{-3}}{2}.(T^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3} .(T^3 - 298^3)\right] \text{kJ/kg} \big/ 4{,}184 \text{ kJ/kkal}$$

$\Delta H9 = m.\ Cp.\ dT$

$= 10{,}4835 \times [0{,}2611.(T\text{-}298) + 0{,}2258.10^{-3}.(T^2\text{-}298^2) - 0{,}2933.10^{-6}.(T^3\text{-}298^3) \text{ kkal}$

Entalpi keluar menuju H-213 $= \Delta H5 + \Delta H6 + \Delta H7 + \Delta H8 + \Delta H9$

$= f(T) \text{ kkal}$

Entalpi keluar total = f (T) kkal

Entalpi masuk = Entalpi keluar total + Q loss

Entalpi masuk = Entalpi keluar total + 5% × Entalpi masuk

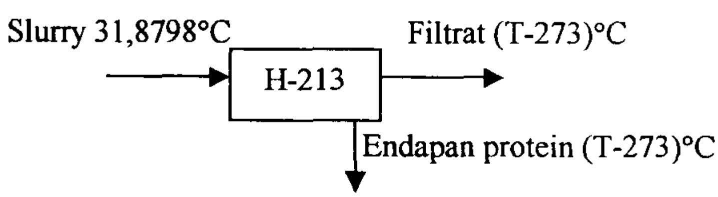
182614,6469 = f (T) + 0,05 × 182614,6469

f (T) = 173483,9146 kkal

Trial T = 304,8798 K = 31,8798°C, f (T) = 173483,9146 kkal

Entalpi keluar menuju H-213 = 173483,9146 kkal

Filter Press (H-213):



Entalpi slurry masuk H-213 = Entalpi slurry keluar M-210

= 173483,9146 kkal

Entalpi endapan keluar menuju M-220:

- Air

$$\int Cp\, dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\, dT = \left[18{,}2964.(T - 298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4) \right] / 18\, kkal/kg$$

$\Delta H1$ = m. Cp. dT

= 1392,4165 × [1,0165.(T-298) + 1,3114.10^{-2}.(T^2-298^2) – 2,4793.10^{-5}.(T^3-298^3) + 18,2528.10^{-9}.(T^4-298^4)] kkal

- Casein

$$\int Cp\, dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \left[2{,}0082.(T - 298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} .(T^3 - 298^3) \right] kJ.kg / 4{,}184\, kJ/kkal$$

$\Delta H2$ = m. Cp. dT

= 5594,9394 × [0,48.(T-298) + 0,1445.10^{-3}.(T^2-298^2) – 0,1046.10^{-6}.(T^3-298^3)] kkal

- Protein whey

$$\int Cp\, dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \left[2{,}0082.(T - 298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} .(T^3 - 298^3) \right] kJ.kg / 4{,}184\, kJ/kkal$$

$\Delta H3$ = m. Cp. dT

= 0,6365 × [0,48.(T-298) + 0,1445.10^{-3}.(T^2-298^2) – 0,1046.10^{-6}. (T^3-298^3)] kkal

- Laktosa

$\Delta H4$ = m. Cp. ΔT

$= 4{,}5866 \text{ kg} \times 0{,}287 \text{ kkal/kg.°K} \times (T - 298)\text{°K}$

$= 1{,}3164.(T\text{-}298) \text{ kkal}$

- Mineral

$$\int Cp\, dT = \int_{298}^{T} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \Big[1{,}0926.(T - 298) + \frac{1{,}8896.10^{-3}}{2}.(T^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3} .(T^3 - 298^3)\Big] kJ/kg \Big/ 4{,}184\ kJ/kkal$$

$\Delta H5 = m.\ Cp.\ dT$

$= 0{,}6552 \times [0{,}2611.(T\text{-}298) + 0{,}2258.10^{-3}.(T^2\text{-}298^2) - 0{,}2933.10^{-6}.(T^3\text{-}298^3)]$ kkal

Entalpi keluar menuju M-220 $= \Delta H1 + \Delta H2 + \Delta H3 + \Delta H4 + \Delta H5$

$= f(T)_1$ kkal

Entalpi filtrat keluar menuju penampung filtrat:

- Air

$$\int Cp\, dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\, dT = \left[18{,}2964.(T - 298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4)\right] \Big/ 18\ kkal/kg$$

$\Delta H6 = m.\ Cp.\ dT$

$= 20886{,}0878 \times [1{,}0165.(T\text{-}298) + 1{,}3114.10^{-2}.(T^2\text{-}298^2) - 2{,}4793.10^{-5}.(T^3\text{-}298^3) + 18{,}2528.10^{-9}.(T^4\text{-}298^4)]$ kkal

- Protein whey

$$\int Cp\, dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \Big[2{,}0082.(T - 298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} .(T^3 - 298^3)\Big] kJ.kg \Big/ 4{,}184\ kJ/kkal$$

$\Delta H7 = m.\ Cp.\ dT$

$= 9{,}5475 \times [0{,}48.(T\text{-}298) + 0{,}1445.10^{-3}.(T^2\text{-}298^2) - 0{,}1046.10^{-6}.\ (T^3\text{-}298^3)]$ kkal

- Laktosa

$\Delta H8 = m.\ Cp.\ \Delta T$

$= 68{,}7980\ kg \times 0{,}287\ kkal/kg.°K \times (T - 298)°K$

$= 19{,}7450.(T\text{-}298)$ kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{T} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[1{,}0926.(T - 298) + \frac{1{,}8896.10^{-3}}{2}.(T^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3}.(T^3 - 298^3)\right] kJ/kg / 4{,}184\ kJ/kkal$$

$\Delta H9 = m.\ Cp.\ dT$

$= 9{,}8283 \times [0{,}2611.(T\text{-}298) + 0{,}2258.10^{-3}.(T^2\text{-}298^2) - 0{,}2933.10^{-6}.(T^3\text{-}298^3)$ kkal

Entalpi keluar menuju M-210 $= \Delta H6 + \Delta H7 + \Delta H8 + \Delta H9$

$= f(T)_2$ kkal

Entalpi keluar total $= f(T)_1 + f(T)_2 = f(T)$ kkal

Entalpi masuk = Entalpi keluar total + Q loss

Entalpi masuk = Entalpi keluar total + 10% × Entalpi masuk

$173483{,}9146 = f(T) + 0{,}1 \times 173483{,}9146$

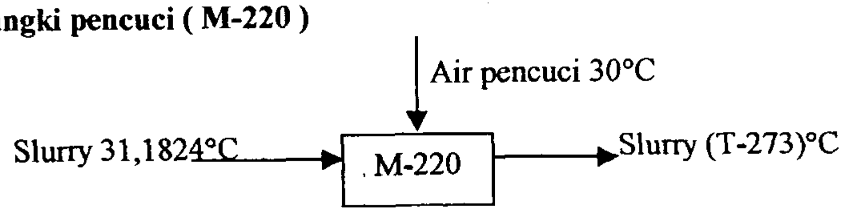
$f(T) = 156135{,}5231$ kkal

Trial T = 304,1924 K = 31,1924°C, f (T) = 156135,5231 kkal

Entalpi keluar menuju M-220 = 27250,0657 kkal

Entalpi keluar menuju penampung filtrat = 128885,4574 kkal

Tangki pencuci (M-220)



Entalpi masuk M-220 = Entalpi keluar H-213 + Entalpi air pencuci

Entalpi air pencuci:

$$\int Cp\ dT = \int_{298}^{303} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(303-298) + \frac{47{,}212.10^{-2}}{2}.(303^2 - 298^2) - \frac{133{,}88.10^{-5}}{3}\right.$$

$$\left. .(303^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(303^4 - 298^4)\right] \Big/ 18$$

$$= 20{,}8154\ kJ/kg = 4{,}9750\ kkal/kg$$

ΔH = m. Cp. dT

= 20979,7026 × 4,9750 kkal/kg = 104373,7937 kkal

Entalpi masuk M-120 = 27250,0657 + 104373,7937 = 131623,8594 kkal

Entalpi keluar menuju H-223:

- Air

$$\int Cp\ dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(T-298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3}\right.$$

$$\left. .(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4)\right] \Big/ 18\ kkal/kg$$

$\Delta H1$ = m. Cp. dT

= 22372,1191 × [1,0165.(T-298) + 1,3114.10^{-2}.(T^2-298^2) – 2,4793.10^{-5}.(T^3-298^3) + 18,2528.10^{-9}.(T^4-298^4)] kkal

- Casein

$$\int Cp\ dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[2{,}0082.(T-298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}\right.$$

$$\left. .(T^3 - 298^3)\right] kJ.kg \Big/ 4{,}184\ kJ/kkal$$

$\Delta H2$ = m. Cp. dT

$= 5594{,}9394 \times [0{,}48.(T-298) + 0{,}1445.10^{-3}.(T^2-298^2) - 0{,}1046.10^{-6}.$
$(T^3-298^3)]$ kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \Big[2{,}0082.(T-298) + \frac{1{,}2089.10^{-3}}{2}.(T^2-298^2) - \frac{1{,}3129.10^{-6}}{3}$$
$$.(T^3-298^3)\Big] kJ.kg / 4{,}184\ kJ/kkal$$

$\Delta H3 = m.\ Cp.\ dT$

$= 0{,}6365 \times [0{,}48.(T-298) + 0{,}1445.10^{-3}.(T^2-298^2) - 0{,}1046.10^{-6}.(T^3-$
$298^3)]$ kkal

- Laktosa

$\Delta H4 = m.\ Cp.\ \Delta T$

$= 4{,}5866$ kg $\times$ 0,287 kkal/kg.°K $\times$ (T – 298)°K

$= 21{,}0614.(T-298)$ kkal

- Mineral

$$\int Cp\ dT = \int_{298}^{T} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \Big[1{,}0926.(T-298) + \frac{1{,}8896.10^{-3}}{2}.(T^2-298^2) - \frac{3{,}6817.10^{-6}}{3}$$
$$.(T^3-298^3)\Big] kJ/kg / 4{,}184\ kJ/kkal$$

$\Delta H5 = m.\ Cp.\ dT$

$= 0{,}6552 \times [0{,}2611.(T-298) + 0{,}2258.10^{-3}.(T^2-298^2) - 0{,}2933.10^{-6}.(T^3-$
$298^3)$ kkal

Entalpi keluar menuju H-223 $= \Delta H1 + \Delta H2 + \Delta H3 + \Delta H4 + \Delta H5$

$= f(T)$ kkal

Entalpi keluar total = f (T) kkal

Entalpi masuk = Entalpi keluar total + Q loss

Entalpi masuk = Entalpi keluar total + 5% × Entalpi masuk

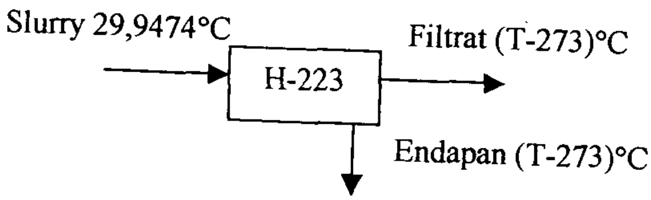
131623,8594 = f (T) + 0,05 × 131623,8594

f (T) = 125042,6664 kkal

Trial T = 302,9474 K = 29,9474°C, f (T) = 125042,6664 kkal

Entalpi keluar menuju H-223 = 125042,6664 kkal

Filter Press (H-223):



Entalpi slurry masuk H-223 = Entalpi slurry keluar M-220

= 125042,6664 kkal

Entalpi endapan keluar menuju B-230:

- Air

$$\int Cp\ dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(T-298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4) \right] \Big/ 18\ kkal/kg$$

$\Delta H1$ = m. Cp. dT

= 1398,2574 × [1,0165.(T-298) + 1,3114.10^{-2}.(T^2-298^2) – 2,4793.10^{-5}.(T^3-298^3) + 18,2528.10^{-9}.(T^4-298^4)] kkal

- Casein

$$\int Cp\ dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[2{,}0082.(T-298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3} .(T^3 - 298^3) \right] kJ.kg \Big/ 4{,}184\ kJ/kkal$$

$\Delta H2$ = m. Cp. dT

= 5594,9394 × [0,48.(T-298) + 0,1445.10^{-3}.(T^2-298^2) – 0,1046.10^{-6}.(T^3-298^3)] kkal

- Laktosa

$\Delta H3$ = m. Cp. ΔT

= 0,2867 kg × 0,287 kkal/kg.°K × (T – 298)°K

= 0,0823.(T-298) kkal

Entalpi keluar menuju B-230 = $\Delta H1 + \Delta H2 + \Delta H3$

= f (T)$_1$ kkal

Entalpi filtrat keluar menuju M-210:

- Air

$$\int Cp\ dT = \int_{298}^{T} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(T-298) + \frac{47{,}212.10^{-2}}{2}.(T^2 - 298^2) - \frac{133{,}88.10^{-5}}{3}\right.$$

$$\left..(T^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(T^4 - 298^4)\right] \Big/ 18\,kkal/kg$$

$\Delta H4$ = m. Cp. dT

= 20973,8617 × [1,0165.(T-298) + 1,3114.10^{-2}.(T^2-298^2) – 2,4793.10^{-5}.(T^3-298^3) + 18,2528.10^{-9}.(T^4-298^4)] kkal

- Protein whey

$$\int Cp\ dT = \int_{298}^{T} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = \left[2{,}0082.(T-298) + \frac{1{,}2089.10^{-3}}{2}.(T^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}\right.$$

$$\left..(T^3 - 298^3)\right] kJ.kg \Big/ 4{,}184\ kJ/kkal$$

$\Delta H5$ = m. Cp. dT

= 0,6365 × [0,48.(T-298) + 0,1445.10^{-3}.(T^2-298^2) – 0,1046.10^{-6}. (T^3-298^3)] kkal

- Laktosa

$\Delta H6$ = m. Cp. ΔT

= 4,2999 kg × 0,287 kkal/kg.°K × (T – 298)°K

= 1,2341.(T-298) kkal

- Mineral

$$\int Cp\, dT = \int_{298}^{T} (1{,}0926 + 1{,}8896.10^{-3}.T - 3{,}6817.10^{-6}.T^2).dT$$

$$\int Cp\, dT = \left[1{,}0926.(T - 298) + \frac{1{,}8896.10^{-3}}{2}.(T^2 - 298^2) - \frac{3{,}6817.10^{-6}}{3} .(T^3 - 298^3)\right] kJ/kg \big/ 4{,}184\ kJ/kkal$$

$\Delta H7$ = m. Cp. dT

= 0,6552 × [0,2611.(T-298) + 0,2258.10^{-3}.(T^2-298^2) – 0,2933.10^{-6}.(T^3-298^3) kkal

Entalpi keluar menuju M-210 = $\Delta H4 + \Delta H5 + \Delta H6 + \Delta H7$

= $f(T)_2$ kkal

Entalpi keluar total = $f(T)_1 + f(T)_2 = f(T)$ kkal

Entalpi masuk = Entalpi keluar total + Q loss

Entalpi masuk = Entalpi keluar total + 10% × Entalpi masuk

125042,6664 = f (T) + 0,1 × 125042,6664

f (T) = 112538,3998 kkal

Trial T = 302,4530 K = 29,4530°C, f (T) = 112538,3998 kkal

Entalpi keluar menuju B-230 = 19609,6400 kkal

Entalpi keluar menuju M-210 = 92928,7598 kkal

Suhu keluar filter press H-223 yang diperoleh tidak sama dengan suhu air pencuci pada tangki pencuci M-210, sehingga dilakukan perhitungan ulang dengan memakai suhu keluar H-223 sebagai suhu air pencuci pada M-210. Perhitungan ulang dilakukan sampai suhu keluar H-223 sama dengan suhu air pencuci pada M-210.

Diperoleh hasil sebagai berikut:

T air pencuci pada M-210 = T keluar H-223 = 302,3886 K = 29,3886°C

M-210:

Masuk	ΔH, kkal	Keluar	ΔH, kkal
Dari H-125		**Menuju H-213**	
Air	23417.1937	Air	141.880,4033
Casein	54305.9358	Casein	19.280,8170
Protein whey	98.8484	Protein whey	35,0952
Laktosa	379.2071	Laktosa	134,7744
Mineral	59.8027	Mineral	21,2885
Dari H-223		**Q loss**	8.492,2304
Air	91.575,7885		
Protein whey	1,5040		
Laktosa	5,4158		
Mineral	0,9127		
Total	169.844,6088		169.844,6088

H-213:

Masuk	ΔH, kkal	Keluar	ΔH, kkal
Dari M-210		**Menuju M-220**	
Air	141.880,4033	Air	7.980,7915
Casein	19.280,8170	Casein	17.353,3348
Protein whey	35,0952	Protein whey	1,9742
Laktosa	134,7744	Laktosa	7,5818
Mineral	21,2885	Mineral	1,1977
		Menuju penampung filtrat	
		Air	119.710,9562
		Protein whey	29,6126
		Laktosa	113,7265
		Mineral	17,9653
		Q loss	16.135,2378
Total	161.352,3783		161.352,3783

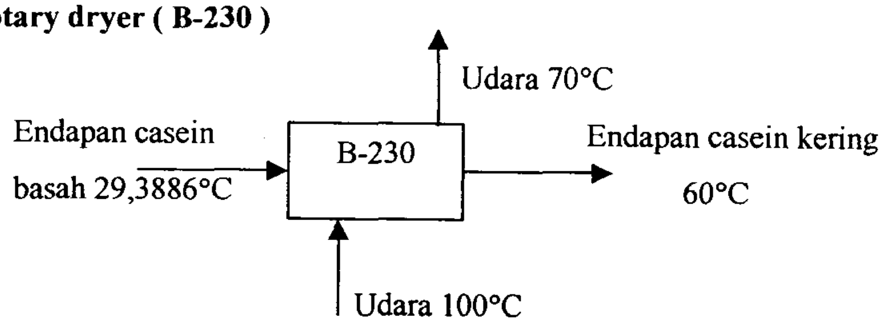
M-220:

Masuk	ΔH, kkal	Keluar	ΔH, kkal
Dari H-213		**Menuju H-223**	
Air	7.980,7915	Air	108.534,6648
Casein	17.353,3348	Casein	14.688,9718
Protein whey	1,9742	Protein whey	1,6711
Laktosa	7,5818	Laktosa	6,4183
Mineral	1,1977	Mineral	1,0140
Air Pencuci	104.373,7937	**Q loss**	6.485,9337
Total	129.718,6737		129.718,6737

H-223:

Masuk	ΔH, kkal	Keluar	ΔH, kkal
Dari M-220:		**Menuju B-230**	
Air	108.534,6648	Air	6.105,0525
Casein	14.688,9718	Casein	13.220,4316
Protein whey	1,6711	Laktosa	0,3611
Laktosa	6,4183	**Menuju M-210**	
Mineral	1,0140	Air	91.575,7882
		Protein whey	1,5040
		Laktosa	5,4158
		Mineral	0,9127
		Q loss	12.323,2740
Total	123.232,7400		123.232,7400

13. Rotary dryer (B-230)



Entalpi endapan basah masuk B-230 = Entalpi keluar H-223

= 19235,8452 kkal

Entalpi endapan keluar menuju J-241:

- Air

$$\int Cp\, dT = \int_{298}^{333} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\, dT = \left[18{,}2964.(333-298) + \frac{47{,}212.10^{-2}}{2}.(333^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} .(333^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(333^4 - 298^4) \right] \Big/ 18$$

$$= 146{,}3165\ kJ/kg = 34{,}9705\ kkal/kg$$

$\Delta H1 = m.\ Cp.\ dT$

$= 27{,}6950\ kg \times 34{,}9705\ kkal/kg = 968{,}5060\ kkal$

- Casein

$$\int Cp\ dT = \int_{298}^{333} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(333 - 298) + \frac{1{,}2089.10^{-3}}{2}.(333^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}$$

$$.(333^3 - 298^3)$$

$$= 79{,}0576\ kJ/kg = 18{,}8952\ kkal/kg$$

$\Delta H2$ = m. Cp. dT

= 5511,0153 kg × 18,8952 kkal/kg = 104131,7979 kkal

- Laktosa

$\Delta H3$ = m. Cp. ΔT

= 0,2824 kg × 0,287 kkal/kg.°K × (333 – 298)°K

= 2,8363 kkal

Entalpi keluar menuju J-241 = $\Delta H1 + \Delta H2 + \Delta H3$

= 105103,1403 kkal

Entalpi endapan keluar menuju H-233:

- Air

$$\int Cp\ dT = \int_{298}^{333} (18{,}2964 + 47{,}212.10^{-2}.T - 133{,}88.10^{-5}.T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$\int Cp\ dT = \left[18{,}2964.(333 - 298) + \frac{47{,}212.10^{-2}}{2}.(333^2 - 298^2) - \frac{133{,}88.10^{-5}}{3} \right.$$

$$\left. .(333^3 - 298^3) + \frac{1314{,}2.10^{-9}}{4}.(333^4 - 298^4) \right] \Big/ 18$$

$$= 146{,}3165\ kJ/kg = 34{,}9705\ kkal/kg$$

$\Delta H4$ = m. Cp. dT

= 0,4218 kg × 34,9705 kkal/kg = 14,7488 kkal

- Casein

$$\int Cp\ dT = \int_{298}^{333} (2{,}0082 + 1{,}2089.10^{-3}.T - 1{,}3129.10^{-6}.T^2).dT$$

$$\int Cp\ dT = 2{,}0082.(333-298) + \frac{1{,}2089.10^{-3}}{2}.(333^2 - 298^2) - \frac{1{,}3129.10^{-6}}{3}.(333^3 - 298^3)$$

$$= 79{,}0576\ kJ/kg = 18{,}8952\ kkal/kg$$

$\Delta H5$ = m. Cp. dT

= 83,9241 kg × 18,8952 kkal/kg = 1585,7634 kkal

- Laktosa

$\Delta H6$ = m. Cp. ΔT

= 0,0043 kg × 0,287 kkal/kg.°K × (333 – 298)°K

= 0,0432 kkal

Entalpi keluar menuju H-233 = $\Delta H4 + \Delta H5 + \Delta H6$

= 1600,5554 kkal

Asumsi: udara yang digunakan untuk mengeringkan bahan adalah udara panas T = 100°C

Udara berasal dari udara dengan T = 30°C, P = 1 atm , kelembaban = 70%

Dari Geankoplis grafik hal 529 didapat:

Humidity udara masuk = H_2 = 0,02 kg H_2O / kg udara kering

Entalpi udara masuk :

$Hg_2 = Cs. (T - To) + H_2 . \lambda o$

$Cs = 1{,}005 + 1{,}88 . H$

λo = 2501,4 kJ/kg (Geankoplis, hal 857)

$Hg_2 = (1{,}005 + 1{,}88 . H_2). (T - To) + H_2 . \lambda o$

$= (1{,}005 + 1{,}88. 0{,}02) . (373\text{-}273) + 0{,}02 . 2501{,}4$

= 154,288 kJ/kg udara kering = 36,8757 kkal/kg udara kering

Entalpi udara keluar:

$Hg_1 = (1{,}005 + 1{,}88 . H_1). (T - To) + H_1 . \lambda o$

$= (1{,}005 + 1{,}88 . H_1) . (343\text{-}273) + H_1 . 2501{,}4$

$= (70{,}35 + 2633. H_1)$ kJ/kg udara kering

$= (16{,}8141 + 629{,}3021 \,.\, H_1)$ kkal/kg udara kering

Neraca massa moisture:

$G \,.\, H_2$ + air dari bahan masuk = $G \,.\, H_1$ + air dari bahan keluar

$G \,.\, 0{,}02 + 1398{,}2574 = G \,.\, H_1 + 28{,}1167$

$$G = \frac{1370{,}1407}{(H_1 - 0{,}02)} \text{ kg udara kering} \quad \ldots\ldots\ldots\ldots \quad (1)$$

Neraca panas total:

Entalpi udara masuk + Entalpi bahan masuk = Entalpi udara keluar + Entalpi bahan keluar + Q loss

$G.\, Hg_2$ + Entalpi bahan masuk = $G.\, Hg_1$ + Entalpi bahan keluar + 5% × $(G.Hg_2)$

$G.\, 36{,}8757 + 19235{,}8452 = G\,.(16{,}8141 + 629{,}3021.H_1) + 106703{,}6957 + (0{,}05 \times G.\, 36{,}8757)$

$18{,}2178.\, G - 629{,}3021.\, G.\, H_1 = 87377{,}8505$

$G\,.\,(18{,}2178 - 629{,}3021.H_1) = 87377{,}8505 \quad \ldots\ldots\ldots\ldots \quad (2)$

Substitusi persamaan (1) ke persamaan (2):

$$\frac{1370{,}1407}{(H_1 - 0{,}02)}\,.\,(18{,}2178 - 629{,}3021.H_1) = 87377{,}8505$$

$1370{,}1407\,.(18{,}2178 - 629{,}3021.H_1) = 87377{,}8505\,.\,(H_1 - 0{,}02)$

$24960{,}9925 - 862232{,}4386\,.\,H_1 = 87377{,}8505\,.\,H_1 - 1747{,}5570$

$H_1 = 0{,}0281$ kg H_2O/kg udara kering

$G = 168616{,}0936$ kg udara kering

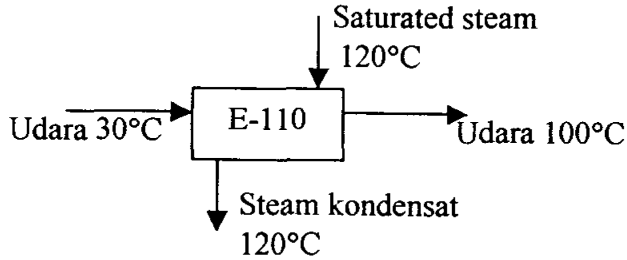
Entalpi udara masuk = $G.\, Hg_1$ = 6217839,3517 kkal

Entalpi udara keluar = $G.\, Hg_2$ = 5819569,5336 kkal

Massa udara masuk = $(1 + H_2) \times G$ = 171988,4155 kg

Massa udara keluar = $(1 + H_1) \times G$ = 173358,5562 kg

14. Heat Exchanger (E-236)



Udara berasal dari udara dengan T = 30°C, P = 1 atm , kelembaban = 70%

Dari Geankoplis grafik hal 529 didapat:

Humidity udara masuk = H_1 = 0,02 kg H_2O / kg udara kering

Humidity udara keluar = H_2 = H_1 = 0,02 kg H_2O / kg udara kering

Massa udara masuk = massa udara keluar = massa udara masuk rotary dryer B-170 + massa udara masuk rotary dyer B-230 = (243229,1055 + 171988,4155) kg = 415217,5209 kg

$$\text{Massa udara kering masuk HE} = \frac{\text{massa udara masuk}}{(1+H_1)} = \frac{415217.5209}{(1+0{,}02)}$$

$$= 407076{,}0009 \text{ kg udara kering}$$

Entalpi udara masuk :

$Hg_1 = Cs. (T - To) + H_1 . \lambda o$

$Cs = 1{,}005 + 1{,}88 . H$

λo = 2501,4 kJ/kg (Geankoplis, hal 857)

$Hg_1 = (1{,}005 + 1{,}88 . H_1). (T - To) + H_1 . \lambda o$

$= (1{,}005 + 1{,}88. 0{,}02) . (303-273) + 0{,}02 . 2501{,}4$

$= 81{,}3060$ kJ/kg udara kering

Entalpi udara masuk = m udara kering × Hg_1

= 407076,0009 kg ud kering × 81,3060 kJ/kg ud kering

= 33.097.721,3304 kJ = 7.910.545,2510 kkal

Entalpi udara keluar:

$Hg_2 = (1{,}005 + 1{,}88 . H_2). (T - To) + H_2 . \lambda o$

$= (1{,}005 + 1{,}88. 0{,}02) . (373-273) + 0{,}02 . 2501{,}4$

$= 154{,}2880$ kJ/kg udara kering

Entalpi udara keluar = m udara kering × Hg_2

= 407076,0009 kg ud kering × 154,2880 kJ/kg ud kering

= 62.806.942,0291 kJ = 15.011.219,4142 kkal

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

Entalpi udara masuk + Q suplai = Entalpi udara keluar + 5% × Q suplai

7.910.545,2510 + Q suplai = 15.011.219,4142 + 0,05 × Q suplai

Q suplai = 7.474.393,8560 kkal

Steam yang digunakan adalah saturated steam pada suhu 120°C, P = 198,53 kPa.

Dari steam tabel Geankoplis hal 857:

Hv = 2706,3 kJ/kg

Hl = 503,71 kJ/kg

λ = Hv – Hl

= (2706,3 – 503,71) kJ/kg

= 2202,59 kJ/kg = 526,4316 kkal/kg

Q yang disuplai steam = m . λ

$$\text{Massa steam} = \frac{\text{Q suplai}}{\lambda} = \frac{7.474.393{,}8560\ \text{kkal}}{526{,}4316\ \text{kkal/kg}} = 14198{,}2230\ \text{kg}$$

LAMPIRAN C

SPESIFIKASI ALAT

LAMPIRAN C

SPESIFIKASI ALAT

Data – data konduktivitas thermal (W/m.K)

K protein = $1,7881.10^{-1} + 1,1958.10^{-3}.T - 2,7178.10^{-6}T^2$

K lemak = $1,8071.10^{-1} - 2,7604\ 10^{-3}.T - 1,7749.10^{-6}T^2$

K laktosa = $2,0141.10^{-1} + 1,3874\ 10^{-3}.T - 4,3312.10^{-6}T^2$

K mineral = $3,2962.10^{-1} + 1,4011\ 10^{-3}.T - 2,9069.10^{-6}T^2$ (Heldman, 1992)

K air = 0,6020

K asam asetat = -0.0035 (%berat) +0.5209

K susu = 0,5830

K ethylene Glycol = 0,265 (Geankoplis,1993)

Data – data densitas (Kg/m^3)

ρ protein = $1,3299.10^3 - 5,1840.10^{-1}T$

ρ lemak = $9,2559.10^2 - 4,1757.10^{-1}T$

ρ laktosa = $1,5994.10^3 - 3,1046.10^{-1}T$

ρ mineral = $2,4238.10^3 - 2,8063.10^{-1}T$ (Heldman, 1992)

ρ susu = 1030,9

ρ air = -0,2324.T+1001.6 (Geankoplis, 1993)

ρ asam asetat 10% = 1.0090 kg/lt

ρ asam asetat 100% = 1.0380 kg/lt (Perry ed 6.Table 3-107 p.3-88,3-89)

Data – data viskositas (cp)

μ susu = 2,12

μ asam asetat = -0.0217.(x %)+3,0667 (Geankoplis, 1993)

Tangki Penyimpan Susu (F – 111)

Fungsi = menyimpan susu segar

Tipe = silinder tegak dengan tutup atas dan bawah berbentuk dished head dilengkapi dengan pengaduk dan jaket pendingin

Dasar pemilihan = beroperasi pada tekanan atmosfer

Tangki dirancang untuk menyimpan susu selama satu hari, disimpan dalam 3 tangki

Volume liquid = 70.833,333 liter = 2.501,1770 ft^3

Massa umpan masuk = 73.019,9555 kg = 160.979,7939 lb

Q pendingin = 5.170.860,8397 kal/hari = 20.505.830,7140 btu/hari

= 284.803,2044 btu/jam.tangki

Ditetapkan :

- volume liquid = 80% volume tangki
- Diameter nozzle (Dn) = 1 ft
- Hs = D
- Plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).
- F_M = 0,92 (standard)
- F_S = 0,25 (T_{op} < 650°F)
- Tanpa dikenai radiograf → F_a = 1
- Tanpa stress relieve → F_N = 1

- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$
- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

$$\text{Volume tangki} = \frac{2.501{,}1770\, ft^3}{80\%} = 3.126{,}4713\, ft^3$$

Dengan perhitungan awal D = H

Volume dished head = 0,000049 Di^3 = 0,000049 H^3

Volume total tangki = volume shell + 2×volume dished head

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

$$3.126{,}4713\ ft^3 = \frac{\pi}{4} \times H^3 + 2 \times 0{,}000049\, H^3$$

Hs = 14,8519ft → Hs = 16 ft

D = 14,4350 ft

Volume liquid dalam head = 0,000049 $(Di\ (in))^3$

= 254,6772 ft^3

Volume liquid dalam shell = volume liquid – volume liquid dalam head

$$\frac{\pi}{4} \times D^2 \times H_l = 2.501{,}1770\ ft^3 - 254{,}6772\ ft^3$$

$$\frac{\pi}{4} \times 14{,}4350^2 \times H_l = 2.246{,}4998\ ft^3$$

$$H_l = 13{,}7342\ ft$$

$$\text{P operasi} = \text{P hidrostatik} = \frac{\rho_{campuran} \times Hliquid}{144}$$

(Brownell & Young, p.46, eq. 3.17)

$$= \frac{64{,}3568 \, {}^{lb}\!/_{ft^3} \times 13{,}7342 \, ft}{144 \, {}^{in^2}\!/_{ft^2}} = 6{,}1381 \, psi$$

P design diambil 1,2 × P operasi = 7,3657 psi

Tebal shell

$$f_{allow} = f_a \times F_M \times F_S \times F_a \times F_N$$

F_{allow} = 75.000 × 0,92 × 0,25 ×1 × 1 = 17.250 psi

$$t_s = \frac{P_{design} \times Di}{2 \times f_{allow} \times E} + C = \frac{6{,}1381 \, psi \times 14{,}4350 \, ft \times 12 \, {}^{in}\!/_{ft}}{2 \times 17{,}250 \, psi \times 0{,}8} + 0{,}125 in = 0{,}1712 in \rightarrow {}^{3}\!/_{16} \, in$$

Tebal dished head

OD = 14,4350 × 12 + 2 × $^3/_{16}$ = 173,5950 in =14,4662 ft

rc = 170

icr = 11 (Table 5.7 Brownell p.89)

$$W = {}^{1}\!/_{4}\left(3 + \sqrt{\frac{rc}{icr}}\right) \ldots$$ (pers 7.76,Brownell,1959)

$$W = {}^{1}\!/_{4}\left(3 + \sqrt{\frac{170}{11}}\right) = 1{,}7328$$

$$t_h = \frac{P.rc.W}{2.F.E - 0{,}2.P} + c \ldots$$ (pers 7.77,Brownell,1959)

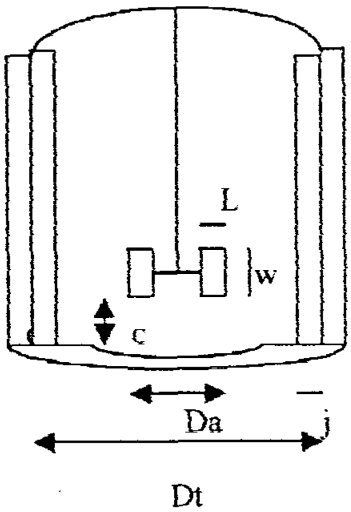
$$t_h = \frac{7{,}3657.170.1{,}7328}{2.17250.0{,}8 - 0{,}2.7{,}3657} + 0{,}125 = 0{,}2036 \rightarrow {}^{1}\!/_{4} \, in$$

Perhitungan pengaduk

Dipilih jenis pengaduk = six blade turbin with disk

Dari tabel 3.4-1 hal 145 Geankoplis diperoleh:

$$\frac{Da}{Dt}=\frac{1}{3},\frac{j}{Dt}=\frac{1}{12},\frac{W}{Da}=\frac{1}{5},\frac{L}{Da}=\frac{1}{4},\frac{C}{Dt}=\frac{1}{3}$$



Da = 1/3 Dt = 1/3 × 14,435 ft = 4,8117 ft

J = 1/12 Dt = 1/12 × 14,435 ft = 1,2029 ft

W = 1/5 Da = 1/5 × 4,8117 ft = 0,9623 ft

C = 1/3 Dt = 1/3 × 14,435 ft = 4,8117 ft

Dimana : Da = diameter pengaduk

Dt = diameter tangki

L = panjang blade

W = lebar blade

C = jarak dari dasar tangki ke pusat pengaduk

J = lebar baffle

Kecepatan pengaduk diambil 30 rpm = 0,5 rps μ susu = 2,12 cp = 5,1304 lb/ft.h = 0,0014 lb/ft.s

$$N_{Re} = \frac{Da^2.N.\rho}{\mu} \qquad (Geankoplis, pers3.4-1)$$

$$= \left(\frac{(4{,}8117)^2.0{,}5.64{,}3568}{0{,}0014}\right) = 555.339{,}1385$$

dari gambar 3.4-4, Geankoplis ed 3[rd], hal 145, untuk flat six-blade turbine with disk diperoleh Np= 4,9

$$Np = \frac{P \times gc}{\rho..N^3.Da^5} \qquad (Geankoplis, pers3.4-2)$$

$$P = \frac{Np \times \rho \times N^3 \times Da^5}{gc} = \frac{4{,}9 \times 64{,}3568\, lb/ft^3 \times 0{,}5/s^3 \times (4{,}8117\,ft)^5}{32{,}174\, lb.ft/lbf.s^2}$$

$$P = 3.159{,}8969\, lb.ft/s = 5{,}7453 Hp$$

Jumlah pengaduk (n)= tinggi liquid dalam shell . sg / diameter tangki

ρ susu = 64,3568 lb/ ft^3

ρ air pada 4°C = 62,43 lb/ ft^3

sg = ρ camp / ρ air = 1,0309

$$n = \frac{13{,}7324 ft \times 1.0309}{14{,}4350 ft} = 0.9809 buah \approx 1 buah$$

Effisiensi pengaduk = 85%

Jadi Power yang dibutuhkan untuk pengaduk = 5,7453/ 0,85 = 6,7591 Hp

Perhitungan jaket pendingin

Diambil spasi jaket = 1,4 in

ID jacket = OD shell + jaket spacing

= (14,4350×12)+(3/16)×2 + 2 . 1,4 in = 176,3950 in

μ ethilen glikol = 60 cp = 0,0403 lb/ft.s

Outside

$$NRe = \frac{De.G}{\mu}$$

$$De = \frac{4.\text{flow area}}{\text{wetted perimeter}} = \text{Djaket-Dshell} \quad \text{(Geankoplis, pers 2.10-23,p.99)}$$

= 2,8 in= 0,2333 ft

a = flow area = ¼ . π (ID_{jaket}^2 - OD_{shell}^2) = 769,2779 in^2 = 5,3422 ft^2

Dari neraca panas refrigerant yang dipakai sebanyak = 326.591,6856 kg/hari

= 30.000,1679 lb/jam

$$G = \frac{30.000{,}1679 \text{lb/jam}}{5{,}3422 \text{ft}^2} = 5.615{,}6871 \text{ lb/ft}^2\text{jam}$$

$$NRe = \frac{0{,}2333\,\text{ft}.5.615{,}6871 \frac{\text{lb}}{\text{ft}^2\text{hr}}.\frac{1\text{h}}{3600\text{s}}}{0.0403 \frac{\text{lb}}{\text{ft.s}}} = 48{,}2096$$

Jh= 10 (Kern fig 20.2)

k= 0,153 Btu/(hr.ft^2°F/ft)

c = 0,55 Btu/lbm°F

$$ho = \frac{Jh.k}{De}\left(\frac{c.\mu}{k}\right)^{1/3}\left(\frac{\mu}{\mu w}\right)^{0,14}$$

$$ho = \frac{10.0{,}153 \frac{\text{Btu}}{\text{hr.ft}^2\,°\text{F/ft}}}{0{,}2333\text{ft}}\left(\frac{0{,}5500\frac{\text{Btu}}{\text{lb°F}}.0{,}0403\frac{\text{lb}}{\text{ft.s}}}{0{,}153\frac{\text{Btu}}{\text{hr.ft}^2\,°\text{F/ft}}.\frac{\text{hr}}{3600\text{s}}}\right)^{1/3}.1$$

= 52,8149 Btu/hr.ft^2°F

Inside

NRe = 554.339,1385

Jc = 3000 (fig 20.2, Kern)

$$hi = j \times \frac{k}{D}\left(\frac{Cp \times \mu}{k}\right)^{1/3}\left(\mu/\mu_w\right)^{1/4} \qquad Kern.1957$$

$$hi = 3000 \times \frac{0.3176\,Btu/h.ft.F}{14{,}4350\,ft} \times \left(\frac{8{,}2070\,Btu/lb \times 5{,}1304\,lb/ft.h}{0{,}3176\,Btu/h.ft.F}\right)^{-1/3} \times 1 =$$

$$hi = 330{,}0778\,Btu/hour.ft^2\,°F$$

$$hio = hi \times ID/OD = 329{,}3648\,Btu/hour.ft^2\,°F$$

$$Uc = \frac{hio.ho}{hio + ho} = \frac{329{,}3648.52{,}8149}{329{,}3648 + 52{,}8149} = 45{,}5162$$

$$Rd = \frac{Uc - Ud}{Uc \times Ud} \qquad (Kern, pers 6.13)$$

$$= 0{,}001$$

Ud = 43,5347

$$A = \frac{Q}{U_D.\Delta T} \qquad \text{(Rule of Thumb Ulrich)}$$

$$\Delta T_{LMTD} = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln\frac{(T_1 - t_1)}{(T_2 - t_2)}}$$

Suhu susu segar masuk= 30 C = 86 F = T1

Suhu susu segar keluar= 4 C = 39,2 F = T2

Suhu etilen glikol masuk= -10 C = 14 F = t1

Suhu etilen glikol keluar= -2 C = 28,4 K = t2

Luas jaket = 2.398,8490 ft^2

Luas jaket = luas jaket pada shell + luas jaket pada tutup bawah

$2.398,8490\ ft^2 = \pi \cdot OD_{shell} \cdot H_{jaket} + ¼ \cdot \pi \cdot OD_{shell}{}^{\wedge 2}$

$2.398,8490\ ft^2 = \pi \cdot 14,4662 \cdot Hj + ¼\ \pi\ 14,4662^{\wedge}2$

H jaket = 13,6023 ft < tinggi liquid (13,7342 ft) memenuhi syarat

Spesifikasi alat :

Tangki Penyimpan Susu (F – 111)

Dimensi:

ID_s = Diameter dalam tangki = 14,4350 ft

OD_s = Diameter luar tangki = 14,4662 ft

Hs = Tinggi shell = 16 ft ,

Ts = Tebal shell = $^3/_{16}$ in

Th = Tebal head = ¼ in

Pengaduk turbin flat six blade dengan baffle

P = 6,7591Hp

Jumlah = 1 buah pengaduk

Bahan konstruksi = plate steel SA-240 grade C

Tinggi jaket = 13,6023 ft

Spasi jaket = 1,4 in

Jumlah tangki = 3 buah

Heat Exchanger (E – 110)

Fungsi = untuk memanaskan dan mempasteurisasikan susu segar sebelum masuk ke centrifuge

Type = shell and tube heat exchanger

Dasar pemilihan = luas perpindahan panas besar

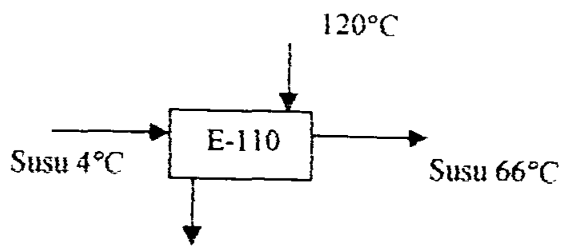
Perhitungan :

Dari neraca massa : susu masuk = 219.059,8665 kg/hari = 44.362,0067 lb/jam

Steam = 25.017,5736 kg/hari = 2.298,0726l/lb/jam

Dari neraca panas : Q = 13.170.042,4212 kkal/hari = 2.177.620,9446 Btu/jam

Saturated steam



Steam kondensat

120°C

$$\Delta T_{LMTD} = \frac{(120-66)-(120-4)}{\ln\left(\frac{120-66}{120-4}\right)} = 81{,}0857\ °C = 177{,}9575°F$$

Dari tabel 8 Kern U_D = 100-500

Diambil : U_D = 200

$$A = \frac{Q}{U_D \cdot LMTD}$$

$$= \frac{2.298{,}0726}{200 \times 177{,}9575} = 61{,}1837\ ft^2$$

Digunakan tube ¾ in OD, 16 BWG, panjang 16 ft, square pitch, Pt = 1 in,

a' = 0,1963 ft^2/ linft (Kern, tab.10)

$$\text{Jumlah tube} = \frac{A}{a'' \times L} = \frac{61{,}1837\ ft^2}{0{,}1963\ ft^2/linft\ .16\ ft} = 19{,}4803$$

Dari Kern, tab.9, p.841, didapatkan : Nt = 32 tube

ID = 8 in

Tube side	Shell side
Number tube 32, Length 16"	ID = 8 in
$\frac{3}{4}$ OD, 16 BWG 1in pitch	Baffle space = 5 in
Passes = 2	

Steam (dalam tube)	Susu (dalam shell)
$a't = 0{,}302\ in^2$	$C' = P_t - OD = 1 - \frac{3}{4} = \frac{1}{4}$ in
$at = \dfrac{Nt\ .\ at'}{144\ .\ n}$	$A_s = ID \times C' \times B / 144 \times P_t$
$= \dfrac{32 \times 0{,}302}{144 \times 2} = 0{,}0336\ ft^2$	$= 8 \times \frac{1}{4} \times 5/(144 \times 1) = 0{,}0694 ft^2$
$Gt = \dfrac{w}{at} = \dfrac{2.298{,}0726}{0{,}0336}$	$Gs = \dfrac{W}{as} = \dfrac{482.939{,}3817}{0{,}1671\ ft^2}$
$= 34.242{,}8039\ lb/ft^2$	$= 638.812{,}8965 lb/.ft^2$
	$\mu_{susu} = 5{,}1304\ lb/ft$
	De = 0,95 in = 0,0792 ft
Di = 0,62 in = 0,0517 ft	(Kern, fig 28)
(Kern, tab.10)	$Re_s = \dfrac{De \times Gs}{\mu} = \dfrac{0{,}95/12\ ft \times 638.812{,}8965}{5{,}1304}$
hio = 1500 Btu/hr.ft²	$= 9.857{,}4551$
	jH = 42 (Kern, fig.28)
	$k = 0{,}3109\ Btu/.ft^2.(°F/ft)$
	Cp = 0,9196 Btu/lb.°F
	$\left(\dfrac{Cp\ .\ \mu}{k}\right)^{1/3} = \left(\dfrac{0{,}9196\ .\ 5{,}1304}{0{,}3109}\right)^{1/3}$

	$= 2{,}4759$ $ho = jH \cdot \frac{k}{De} \cdot \left(\frac{Cp \cdot \mu}{k}\right)^{1/3} \cdot \left(\frac{\mu}{\mu_w}\right)^{0,14}$ $= 42\left(\frac{0{,}3109}{0{,}0792}\right)2{,}4759$ $= 408{,}3546 \text{ Btu/hr.ft}^2$

$$Uc = \frac{hio \cdot ho}{hio + ho} = \frac{1500 \times 408{,}3546}{1500 + 408{,}3546} = 320{,}9739 \text{ Btu/hr.ft}^2 . ^\circ F$$

$$A = Nt \times L \times a'' = 32 \times 16 ft \times 0{,}1963 \text{ ft} = 100{,}5056 ft^2$$

$$\text{Ud terkoreksi} = \frac{Q}{A.Tlmtd} = \frac{548.751{,}7676}{100{,}5056 \times 177{,}9575} = 121{,}7519 \text{ Btu/hr.ft}^2 . ^\circ F$$

$$Rd = \frac{U_C - U_D}{U_C \cdot U_D} = \frac{320{,}9739 - 121{,}7519}{324{,}9739 \times 121{,}7519} = 0{,}0051$$

Pressue drop

Steam (dalam tube)	Susu (dalam shell)
Ret = 53.129,4755 $\rightarrow$ f = 0,00020 ft/in^2 (Kern, fig.26) Dari Geankoplis hal 859 ρ 0,0333 lbm/ft^3 $sg = \frac{\rho}{62{,}5} = 0{,}0005$	$Res = \frac{De.Gs}{\mu}$ $= 9.857{,}4551$ $\rightarrow f = 0{,}0022 \ ft^2/in^2$ (Kern, fig.26) ρ = 64,3568 lb/cuft $sg = \frac{\rho}{62{,}5} = 1{,}0297$

$\Delta P_t = \dfrac{f \cdot Gt^2 \cdot L \cdot n}{5{,}22 \times 10^{10} \cdot D \cdot s}$ $= \dfrac{0{,}0002 \times 34.242{,}8039^2 .16.1}{5{,}22 \times 10^{10} .0{,}0517}$ $= 2{,}3475$ psi ΔP_r diabaikan	Ds = 8 in/12= 0,6667 ft number of crosses = 12 ×L/B = 38,4≅38 (pers 7.43 Kern) $\Delta P_s = \dfrac{f \cdot Gs^2 \cdot Ds(N+1)}{5{,}22 \times 10^{10} \cdot De \cdot s}$ $= \dfrac{0{,}0022.(638.812{,}8965)^2 .0{,}6667(38)}{5{,}22 \times 10^{10} .0{,}0792 \times 1{,}0297}$ $= 5{,}3448$ psi

1500	H outside	408,3546
U_C	320,9739	
U_D	121,7519	
R_D Calculated = 0,0051		
R_D Reguired = 0,001		
2,3475	Calculated ΔP	5,3448
10	Allowable ΔP	10

Spesifikasi :

Nama : Heat Exchanger (E – 110)

Type : Shell and tube heat exchanger

Ukuran :

- Untuk tube : diameter luar = ¾ in, 16 BWG

  jumlah = 32 buah

panjang = 16 ft

passes = 2

pengaturan = square pitch, Pt = 1 in

- Untuk shell : diameter = 8 in

passes = 1

Bahan : stainless steel

Jumlah : 1 unit

Centrifuges (H-113)

Fungsi : untuk memisahkan lemak dari susu

Tipe : Disk Centrifuge

Dasar pemilihan : alat ini biasa digunakan dalam industri susu

Densitas campuran = ρ susu = 1,0309 kg/liter

Rate umpan masuk = 219059.8665 kg/ hari

$$kecepatan.umpan.masuk = \frac{219059{,}8665\ {}^{kg}/_{hari}}{1{,}0309\ {}^{kg}/_{liter}} = 38{,}9849\ {}^{gal}/_{menit}$$

Dirancang kecepatan susu masuk = 39 gpm

Dari tabel 19-14, Perry 6 ed p.19-91 untuk kecepatan liquid masuk 5-50 gpm didapatkan :

N = 7500 rpm

D_i = 13 in

Power motor = 6 hp

Spesifikasi alat :

Kapasitas = 212.493,8078 liter/hari = 38,9849 gal/menit

Jenis = Disk Centrifuges

Diameter = 13 in

Kecepatan putaran = 7500 rpm

Power motor = 6 hp

Bahan = stainless stell

Jumlah =1 buah

Tangki Penyimpan Asam Asetat Glasial (F-121)

Fungsi : untuk menyimpan asam asetat glacial

Type : silinder tegak dengan tutup atas berbentuk standard dished head dan tutup bawah berbentuk flat

Dasar pemilihan : beroperasi pada tekanan atmosfer.

Perhitungan

Asam asetat glacial = 2,9546 kg/hari

Suhu penyimpanan 30°C

Tangki dirancang untuk menyimpan asam asetat glacial selama 60 hari

$$volume.laru\tan = \frac{2{,}9546\,{}^{kg}/_{hari} \times 60 hari}{1{,}0380\,{}^{kg}/_{lt}} = 170{,}7861 liter = 6{,}0306\, ft^3$$

Jumlah tangki = 1 buah

Asumsi : tangki berisi 80% cairan, maka:

$$volume.\tan gki = \frac{100}{80} \times 6{,}0306\, ft^3 = 7{,}5382\, ft^3$$

asumsi $H/D_i = 1$; $H = D_i$

$$volume.tutup.dished.head = 0{,}000049 d_i^{\,3} \qquad (Brownell\ \&\ Young, pers5.11)$$

$$.volume.\tan gki = \left[\left(\frac{\pi \times D^2}{4}\right) \times H + (0{,}000049 Di^3)\right] = \left[\left(\frac{\pi \times H^3}{4}\right) + \left(0{,}000049 H^3\right)\right]$$

$$7{,}5382 ft^3 = \left[\left(\frac{\pi \times H^3}{4}\right) + \left(0{,}000049 H^3\right)\right]$$

$$Hshell = 2{,}1255 ft$$

$$dipakai.tinggi.shell = 2\ ft$$

Diameter shell = 2,19ft

Tinggi cairan dalam tangki

Volume liquid = volume asam asetat glacial dalam shell

$$6{,}0306 ft^3 = \left[\left(\frac{\pi \times D_t^{\,3}}{4}\right) \times H_l\right]$$

$$6{,}0306 ft^3 = \left[\left(\frac{\pi \times 2{,}19^3}{4}\right) \times H_l\right]$$

$$H_l = 1{,}6001 ft$$

Dipilih plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).

$$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_N$$

F_M = 0,92 (standard)

F_S = 0,25 (T_{op} < 650°F)

Ditetapkan

- Tanpa dikenai radiograf → F_a = 1
- Tanpa stress relieve → F_N = 1
- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$
- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

P operasi = P hidrostatik = $\dfrac{\rho_{campuran} \times Htot}{144}$

(Brownell & Young, p.46, eq. 3.17)

$$= \frac{64{,}8001 \, {}^{lb}/_{ft^3} \times 1{,}6001 ft}{144 \, {}^{in^2}/_{ft^2}} = 0{,}7201 psi$$

P design diambil 1,2 × P operasi = 0,8641 psi

Tebal shell

$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_N$

F_{allow} = 75.000 × 0,92 × 0,25 ×1 × 1 = 17.250 psi

$$t_s = \frac{P_{desain} \times Di}{2 \times f_{allow} \times E} + C = \frac{0{,}8641 psi \times 2{,}19 ft \times 12 \, {}^{in}/_{ft}}{2 \times 17.250 psi \times 0{,}8} + 0{,}125 in = 0{,}1258 in \rightarrow {}^{3}/_{16} in$$

OD = 2,1911 ft ×12 + 2 × ($^3/_{16}$)/12 = 26,2936 in

Tebal tutup flat bawah

Diambil 3/16 in

Tebal dished head

OD = 26,2936 in = 28 in

rc = 26

icr = 1¾ in (Table 5.7 B&Y p.89)

$W = \frac{1}{4}\left(3 + \sqrt{\frac{rc}{icr}}\right)\ldots$ (pers 7.76,Brownell,1959)

$$W = \frac{1}{4}\left(3 + \sqrt{\frac{26}{1\frac{3}{4}}}\right) = 4{,}0881$$

$$t_h = \frac{P.rc.W}{2.F.E - 0{,}2.P} + c \ldots \qquad \text{(pers 7.77,Brownell,1959)}$$

$$t_h = \frac{0{,}8641.26.4{,}0881}{2.17250.0{,}8 - 0{,}2.0{,}8641} + 0{,}125 = 0{,}1283 \rightarrow \frac{3}{16} in$$

Spesifikasi tangki penyimpan asam asetat

Tangki Penyimpan Asam Asetat Glasial (F-121)

Kapasitas maksimum : 7,5382 ft^3

Kapasitas operasi : 6,0306 ft^3

Diameter : 2,19ft

Tinggi shell : 2 ft

Tebal shell : $^3/_{16}$ in

Tebal tutup atas : $^3/_{16}$ in

Tebal plat : $^3/_{16}$ in

Bahan konstruksi : plate steel SA-240 grade C

Jumlah tangki : 1 buah

Tangki Pengencer asam asetat (M-123)

Fungsi = Mengencerkan asam asetat glacial menjadi asam asetat 10 % berat

Tipe = silinder tegak dengan tutup atas dan bawah berbentuk standard dished head, berpengaduk.

Dasar pemilihan = bekerja pada tekanan atmosfer

Perhitungan :

Masa Asam asetat 10% = 29,54580 kg

Suhu keluar 29,7463°C = 302,7463 °K

Tangki dirancang untuk pengenceran asam asetat glacial selama 7 hari

$$volume.laru\tan = \frac{29{,}54580\,^{kg}/_{hari} \times 7hari}{1{,}0090\,^{kg}/_{lt}} = 204{,}97801 liter = 7{,}2379\,ft^3$$

Jumlah tangki = 1 buah

Ditetapkan : tangki berisi 80% cairan, maka:

$$volume.\tan gki = \frac{100}{80} \times 7{,}2379\,ft^3 = 9{,}0474\,ft^3$$

$$volume.tutup.dished.head = 0{,}000049 d_i^3 \qquad (Brownell \,\&\, Young, pers 5.11)$$

$$volume.\tan gki = \left[\left(\frac{\pi \times D^2}{4}\right) \times H + (0{,}000049 Di^3) \times 2\right] = \left[\left(\frac{\pi \times H^3}{4}\right) + \left(0{,}000049 H^3\right) \times 2\right]$$

$$7{,}2379\,ft^3 = \left[\left(\frac{\pi \times H^3}{4}\right) + \left(0{,}000049 H^3\right) \times 2\right]$$

$$Hshell = 2{,}2589\,ft$$

$$dipakai.tinggi.shell = 2\,ft$$

$$Diameter \tan gki = 2{,}40\,ft$$

Tinggi cairan dalam shell

Volume liquid dalam shell= volume liquid – volume liquid dalam tutup bawah

$$\left(\frac{\pi \times D_i^3}{4}\right) \times H_l = 7{,}2379\,ft^3 - 0{,}000049 Di^3$$

$$\left(\frac{\pi \times 2{,}4004^3}{4}\right) \times H_l = 7{,}2379\,ft^3 - 0{,}000049(2{,}40 * 12)^3$$

$$H_l = 1{,}3413\,ft$$

Tebal shell

Dipilih plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).

$$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_N$$

F_M = 0,92 (standard)

F_S = 0,25 (T_{op} < 650°F)

Ditetapkan

- Tanpa dikenai radiograf → F_a = 1
- Tanpa stress relieve → F_N = 1
- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$
- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

$$P\ operasi = P\ hidrostatik = \frac{\rho_{campuran} \times Htot}{144}$$

(Brownell & Young, p.46, eq. 3.17)

$$= \frac{62{,}9889\ lb/ft^3 \times 2{,}40\ ft}{144\ in^2/ft^2} = 0{,}5867\ psi$$

P design diambil 1,2 × P operasi = 0,7041 psi

Tebal shell

$$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_N$$

F_{allow} = 75.000 × 0,92 × 0,25 ×1 × 1 = 17.250 psi

$$t_s = \frac{P_{design} \times Di}{2 \times f_{allow} \times E} + C = \frac{0{,}7041 psi \times 2{,}4004 ft \times 12\ in/ft}{2 \times 17.250 psi \times E} + 0{,}125 in = 0{,}1257 in \rightarrow 3/16\ in$$

Tebal dished head

OD = 2,4004 × 12 + 2 × $^3/_{16}$ = 29,1796

rc = 30

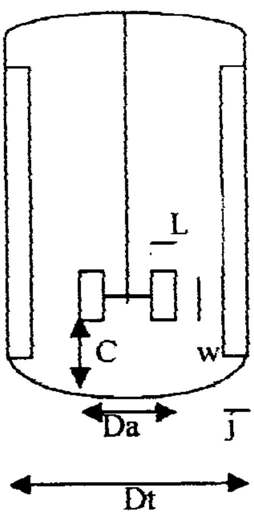
icr = $1\,^7/_{16}$ (Table 5.7 Brownell p.89)

$$W = \tfrac{1}{4}\left(3 + \sqrt{\frac{rc}{icr}}\right)\ldots \qquad \text{(pers 7.76,Brownell,1959)}$$

$$W = \tfrac{1}{4}\left(3 + \sqrt{\frac{30}{1\tfrac{7}{8}}}\right) = 1{,}75$$

$$t_h = \frac{P.rc.W}{2.F.E - 0{,}2.P} + c\ldots \qquad \text{(pers 7.77,Brownell,1959)}$$

$$t_h = \frac{0{,}7041.30.1{,}75}{2.17250.0{,}8 - 0{,}2.0{,}7041} + 0{,}125 = 0{,}1263 \rightarrow \tfrac{3}{16}\,in$$



Da = 1/3 Dt = 1/3 × 2,4004 ft = 0,8001 ft

J = 1/12 Dt = 1/12 × 2,4004 ft = 0,2000 ft

W = 1/5 Da = 1/5 × 0,8001 ft = 0,1600 ft

C = 1/3 Dt = 1/3 × 2,4004 ft = 0,8001 ft

Dimana : Da = diameter pengaduk

Dt = diameter tangki

L = panjang blade

W = lebar blade

C = jarak dari dasar tangki ke pusat pengaduk

J = lebar baffle

Jumlah pengaduk (n)= tinggi liquid dalam shell . sg / diameter tangki

ρ campuran = 62,9889 lb/ ft³

ρ air pada 4°C = 62,43 lb/ ft³

sg = ρ camp / ρ air = 1,009

$$n = \frac{1{,}341\,ft \times 1{,}009}{2{,}4004\,ft} = 0{,}5638 buah \approx 1 buah$$

Perhitungan power pengaduk

Kecepatan pengaduk diambil 120 *rpm* = 2 rps

Diambil μ air karena komponen terbesar

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

$$= \left(\frac{(0{,}8001)^2.2.62{,}9889}{0{,}0005}\right) = 152.847{,}3583$$

dari gambar 3.4-4, Geankoplis ed 3rd, hal 145, untuk flat six-blade turbine with disk diperoleh Np= 4.9

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

$$P = \frac{Np \times \rho \times N^3 \times Da^5}{gc} = \frac{4{,}9 \times 62{,}9889\,{}^{lb}\!/\!{}_{ft^3} \times 2/s^3 \times (0{,}8001\,ft)^5}{32{,}174\,{}^{lb.ft}\!/\!{}_{lbf.s^2}}$$

$$P = 25{,}1674\,{}^{lb.ft}\!/\!{}_{s} = 0.0458 Hp$$

Effisiensi pengaduk = 85%

Jadi Power yang dibutuhkan untuk 4 pengaduk = 0,0458/ 0,85

= 0,0538 Hp ≈0,25Hp

Spesifikasi :

Tangki Pengencer asam asetat (M-123)

Kapasitas maksimum	: 1,2925 ft^3
Kapasitas operasi	: 1,0340 ft^3
Diameter	: 2,4004 ft
Tinggi shell	: 2 ft
Tebal shell	: $^3/_{16}$ in
Tebal tutup atas	: $^3/_{16}$ in
Tebal tutup bawah	: $^3/_{16}$ in
Power pengaduk	: 0,25 hp
Bahan konstruksi	: plate steel SA-240 grade C
Jumlah tangki	: 1 buah

Reactor (R – 120)

Fungsi = memisahkan casein dengan mereaksikan susu dan asam asetat 10 %

Tipe = silinder tegak dengan tutup atas berbentuk dished head dan bawah berbentuk konis dilengkapi dengan jaket pendingin, pengaduk

Dasar pemilihan = beroperasi pada tekanan atmosfer

Bahan masuk = 197.735,4509 kg/ hari = 18.163,6490 lb/jam

$$\frac{1}{\rho_{campuran}} = \frac{x_{larutan\ susu}}{\rho_{larutan\ susu}} + \frac{x_{asamasetat}}{\rho_{asamasetat}}$$

ρ campuran = 957,4269kg/m^3 = 59,7701 lb/ft^3

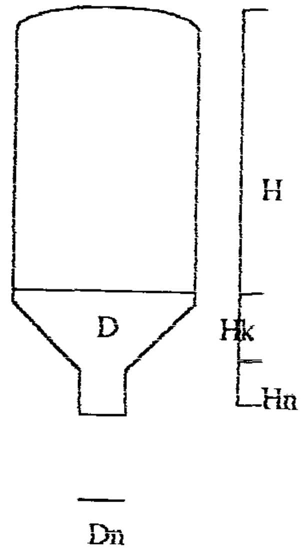
Q pendingin = 4169150,4301 kKal/hari = 688.891,5243 Btu/jam

Ditetapkan :

- volume liquid = 80% volume tangki
- Diameter nozzle (Dn) = 0,5 ft
- $\alpha = 45°$
- Hs = D
- Plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).
- F_M = 0,92 (standard)
- F_S = 0,25 (T_{op} < 650°F)
- Tanpa dikenai radiograf → F_a = 1
- Tanpa stress relieve → F_N = 1
- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$
- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

$$\text{Volume liquid} = \frac{umpan.masuk}{\rho_{campuran}} = \frac{8.238,9771 kg}{957,4269 \, kg/m^3} = 8,6053 m^3 = 303,8928 \ ft^3$$

$$\text{Volume tangki} = \frac{303,8928 \, ft^3}{80\%} = 379,8660 \, ft^3$$



Keterangan:

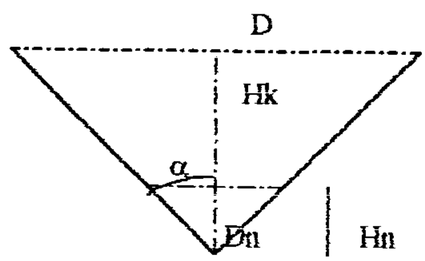
D = diameter shell

H = tinggi shell

Hk = tinggi konis

Hn = tinggi nozzle

Dn = diameter nozzle



Dari gambar dapat dicari persamaan untuk menghitung Hn dan Hk

$$Hn = \frac{Dn}{2 * tg\alpha}$$

$$Hk = \frac{D}{2 * tg\alpha} - Hn = \frac{D - Dn}{2 * tg\alpha}$$

Volume Shell $= \frac{\pi}{4} \times D^2 \times H$ (dengan $\frac{H}{D} = 1$)

$= \frac{\pi}{4} \times H^3$

Volume Konis $= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times Hk - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times Hn$

$= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times \frac{D}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$

$= \frac{1}{3} \times \frac{\pi}{4} \times H^2 \times \frac{H}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$

$= \frac{\pi}{24.tg\alpha} \times \left(H^3 - Dn^3\right)$

Volume dished head = 0,000049 Di^3 = 0,000049 H^3

Volume total tangki = volume shell + volume konis + volume dished head

$= \frac{\pi}{4} \times H^3 + \frac{\pi}{24.tg\alpha} \times \left(H^3 - Dn^3\right) + 0,000049\ H^3$

379,8660 ft^3 $= \frac{\pi}{4} \times H^3 + \frac{\pi}{24.tg45^\circ} \times \left(H^3 - 1^3\right) + 0,000049\ H^3$

H = 7,5988 ft → H = 8 ft

D = 7,3425 ft

Volume liquid dalam konis $= \frac{\pi}{24.tg45^\circ} \times \left(D^3 - 1^3\right)$

= 31,9634 ft^3

Tinggi liquid dalam konis $= \frac{D - Dn}{2 \times tg\alpha} = \frac{7,3425 - 1}{2 \times tg45^\circ} = 2,1122\ ft$

Volume liquid dalam shell = volume liquid – volume liquid dalam konis

$\frac{\pi}{4} \times D^2 \times H_l$ = 303,8928 ft^3 - 31,9634 ft^3

$$\frac{\pi}{4} \times 7{,}3425^2 \times H_l = 271{,}9295 \text{ ft}^3$$

$$H_l = 6{,}4254 \text{ ft}$$

Tinggi total liquid dalam tangki = tinggi liquid dalam shell + tinggi liquid dalam konis

= 6,4254 ft + 2,1122 ft

= 8,5375 ft

$$\text{P operasi} = \text{P hidrostatik} = \frac{\rho_{campuran} \times Htot}{144}$$

(Brownell & Young, p.46, eq. 3.17)

$$= \frac{59{,}7701 \, {}^{lb}/_{ft^3} \times 8{,}5376 \, ft}{144 \, {}^{in^2}/_{ft^2}} = 3{,}5437 \, psi$$

P design diambil 1,2 × P operasi = 4,2524 psi

<u>Tebal shell</u>

$$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_N$$

F_{allow} = 75.000 × 0,92 × 0,25 ×1 × 1 = 17.250 psi

$$t_s = \frac{p_{design} \times Di}{2 \times f_{allow} \times E} + C = \frac{4{,}2524 \, psi \times 7{,}3425 \, ft \times 12 \, {}^{in}/_{ft}}{2 \times 17.250 \, psi \times 0{,}8} + 0{,}125 in = 0{,}1386 in \rightarrow {}^{3}/_{16} \, in$$

OD shell = 88,4846 in

<u>Tebal dished head</u>

rc = 90

icr = $5^1/_8$ (Table 5.7 Brownell p.89)

$$W = \frac{1}{4}\left(3 + \sqrt{\frac{rc}{icr}}\right) \ldots$$ (pers 7.76,Brownell,1959)

$$W = \frac{1}{4}\left(3 + \sqrt{\frac{90}{5\frac{1}{8}}}\right) = 1{,}7613$$

$$t_h = \frac{P.rc.W}{2.F.E - 0{,}2.P} + c \ldots$$ (pers 7.77,Brownell,1959)

$$t_h = \frac{4{,}2524.90.1{,}7613}{2.17250.0{,}8 - 0{,}2.04{,}2524} + 0{,}125 = 0{,}1494 \rightarrow \frac{3}{16} in$$

Tebal konis

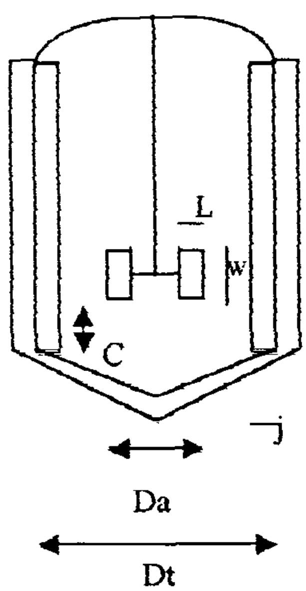
Untuk sudut puncak ≥45° tebal konis = tebal shell = $^{3}/_{16}$ in

Perhitungan pengaduk

Dipilih jenis pengaduk = six blade turbin with disk

Dari tabel 3.4-1 hal 145 Geankoplis diperoleh:

$$\frac{Da}{Dt} = \frac{1}{3}, \frac{j}{Dt} = \frac{1}{12}, \frac{W}{Da} = \frac{1}{5}, \frac{L}{Da} = \frac{1}{4}, \frac{C}{Dt} = \frac{1}{3}$$



Da = 1/3 Dt = 1/3 × 7,3425 ft = 2,4475 ft

J = 1/12 Dt = 1/12 × 7,3425 ft = 0,6119 ft

W = 1/5 Da = 1/5 × 2,4475 ft = 0,4895 ft

C = 1/3 Dt = 1/3 × 7,3425 ft = 2,4475 ft

Dimana : Da = diameter pengaduk

Dt = diameter tangki

L = panjang blade

W = lebar blade

C = jarak dari dasar tangki ke pusat pengaduk

J = lebar baffle

Kecepatan pengaduk diambil 30 rpm = 0,5 rps

Diambil μ susu skim karena komponen terbesar

$$N\,\mathrm{Re} = \frac{Da^2.N.\rho}{\mu} \qquad (Geankoplis, pers3.4-1)$$

$$= \left(\frac{(2{,}4475)^2.0{,}5.59{,}7701}{0{,}0009}\right) = 190.290{,}5594$$

dari gambar 3.4-4, Geankoplis ed 3rd, hal 145, untuk flat six-blade turbine with disk

diperoleh Np= 4,9

$$Np = \frac{P \times gc}{\rho..N^3.Da^5} \qquad (Geankoplis, pers3.4-2)$$

$$P = \frac{Np \times \rho \times N^3 \times Da^5}{gc} = \frac{4{,}9 \times 59{,}7701\, lb/ft^3 \times 0{,}5/s^3 \times (2{,}4475ft)^5}{32{,}174\, lb.ft/lbf.s^2}$$

$$P = 99{,}9282\, lb.ft/s = 0{,}1817 Hp$$

Effisiensi pengaduk = 85%

Jumlah pengaduk (n)= tinggi liquid dalam shell . sg / diameter tangki

ρ campuran = 59,7701 lb/ ft^3

ρ air pada 4°C = 62,43 lb/ ft^3

sg = ρ camp / ρ air = 0,9574

$$n = \frac{8{,}5376\ ft \times 0{,}9574}{7\ {,}3425\,ft} = 1{,}1132 buah \approx 2 buah$$

Jadi Power yang dibutuhkan untuk 2 pengaduk = 0,1817×2/ 0,85 = 0,4275 Hp

Perhitungan jaket pendingin

Diambil spasi jaket = 1 in

ID jacket = OD shell + jaket spacing

= (7,3425×12)+(3/16)×2 + 1 . 2in = 90,4846 in

ρ air pada suhu 30°C = 62,1581 lb/ft^3

μ air = 0,8007cp = 0,0005lb/ft.s = 1.9377lb/ft h

Dalam jaket

$$NRe = \frac{De.G}{\mu}$$

$$De = \frac{4.\text{flow area}}{\text{wetted perimeter}} = \text{IDjaket} - \text{ODshell} = 90{,}4846 - 88{,}4846$$

= 2 in = 0,1667 ft

a = flow area = ¼ . π (ID_{jaket}^2- OD_{shell}^2) = 280,9816 in^2 = 1,9513 ft^2

dari neraca panas air pendingin yang dipakai sebanyak = 278.525,6654 kg/hari = 25.584,9034 lb/jam

$$G = \frac{25{,}584.9034\ \text{lb/jam}}{1{,}9513 ft^2} = 13.111{,}9826\ \text{lb/ft}^2\text{jam}$$

$$NRe = \frac{0,1667\ ft . 13.111,9826 \frac{lb}{ft^2 hr} . \frac{1h}{3600s}}{0,0005 \frac{lb}{ft.s}} = 1.128,2229$$

Jh = 40 (Kern fig 20.2)

K air = 0.3716 Btu/(hr.ft^2°F/ft)

c = 4,1810 kj/kg°K = 0,9986 Btu/lbm°F

$$ho = \frac{Jh.k}{De}\left(\frac{c.\mu}{k}\right)^{1/3}\left(\frac{\mu}{\mu w}\right)^{0,14}$$

$$ho = \frac{40.0,3716 \frac{Btu}{hr.ft^2 °F/ft}}{0,1667ft}\left(\frac{0,9986 \frac{Btu}{lb°F} . 0,0005 \frac{lb}{ft.s}}{0,3716 \frac{Btu}{hr.ft^2 °F/ft} . \frac{hr}{3600s}}\right)^{1/3} .1$$

= 154,5617 /hr.ft^2°F

Dalam tangki

NRe = 190.290,5594

Jc = 1250 (fig 20.2, Kern)

k campuran = 0,5784k w/m.k 0,3342Btu/h.ft°F

cp camp = 18,5181Cp(kkal/kg) 33,3329 cp(Btu/lb)

Dipakai viskositas susu skim (Geankoplis p.891) = 1,4 cp = 3,3880lb/ft.h

$$hi = j \times \frac{kcamp}{Dt}\left(\frac{Cp \times \mu}{k}\right)^{1/3}\left(\frac{\mu}{\mu_w}\right)^{1/4} \qquad Kern.1957$$

$$hi = 1250 \times \frac{0.332 \,btu/h.ft.F}{7,3425\,ft} \times \left(\frac{33,3329\,btu/lb \times 3,3880\,lb/ft.h}{0,332\,btu/ft.h}\right)^{1/3} \times 1 =$$

$$hi = 396,2715\,btu/hour.ft^2 °F$$

$$hio = hi \times (ID/OD)shell = 394,5921\,btu/hour.ft^2 °F$$

$$Uc = \frac{hio.ho}{hio + ho} = \frac{394{,}5921.154{,}5617}{394{,}5921 + 154{,}5617} = 111{,}0596$$

$$Rd = \frac{Uc - Ud}{Uc \times Ud} \qquad (Kern, pers6.13)$$

$$= 0{,}001$$

$$Ud = 99{,}9583$$

$$A = \frac{Q}{U_D.\Delta T} \qquad \text{(Rule of Thumb Ulrich)}$$

$$\Delta T_{LMTD} = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln \frac{(T_1 - t_1)}{(T_2 - t_2)}}$$

Suhu susu segar masuk=	66C =	150,80F
Suhu susu segar keluar=	45C =	113F = T_2
Suhu air masuk=	30C =	86F = t_1
Suhu air keluar=	50C =	122F = t_2
suhu asam asetat masuk =	29.7542C	85,5576F
suhu asam asetat keluar =	45C	113F

Suhu rata-rata bahan masuk =(29,7542+66)°C/2 =118,1788 F = T_1

A jaket = 1.062,8249 ft^2

Luas jaket = luas jaket pada shell + luas jaket pada tutup bawah

$$1.062{,}8249\ ft^2 = \pi \times Do_{shell} \times Hj + (\pi \times Rs \times S - \pi \times Rn \times s)$$

$$1.062{,}8249\ ft^2 = \pi \times 7{,}3737\ ft \times Hj + \pi \times (Rs \times \frac{Rs}{\sin\alpha} - Rn * \frac{Rn}{\sin\alpha})$$

$$1.062{,}8249\ ft^2 = \pi \times 7{,}3737\ ft \times Hj + \frac{\pi}{\sin\alpha} \times (\frac{Ds^2}{4} - \frac{Dn^2}{4})$$

$$1.062,8249\ ft^2 = \pi \times 7,3737\ ft \times Hj + \frac{\pi}{\sin 45} \times \left(\frac{7,3737^2}{4} - \frac{0,5^2}{4}\right)$$

H jaket = 5,9859 ft < tinggi liquid dalam shell (6,4254 ft) memenuhi syarat

Spesifikasi alat :

Reactor (R – 120)

Dimensi:

ID_s = Diameter dalam tangki = 7,3425 ft

OD_s = Diameter luar tangki = 7,3737 ft

Hs = Tinggi shell = 8 ft

Ts = Tebal shell = $^3/_{16}$ in

Th = Tebal head = $^3/_{16}$ in

Tk = Tebal konis = $^3/_{16}$ in

Pengaduk turbin flat six blade dengan 4 baffle

P = 0,4245 Hp

Jumlah = 2 buah pengaduk

Bahan konstruksi = plate steel SA-240 grade C

Tinggi jaket = 5,9859 ft

Spasi jaket = 1 in

Jumlah tangki = 1 buah

Filter Press (H – 125)

Fungsi = untuk memisahkan endapan casein yang terbentuk dan larutan whey

Tipe = plate and filter press

Dasar pemilihan = cara pengoperasian sederhana, biaya murah

Perhitungan :

Komponen	Massa (kg/hari)	Densitas
Air	177,910.6637	928.1605
Protein whey	1,388.7635	1,166.0831
Lemak	1.7087	793.6359
Laktosa	10,007.2664	1,500.9931
Mineral	1,429.6095	2,335.1196
Asam asetat	0.2686	1,023.8919
Kalsium asetat	3.5365	2,335.1196

Rate filtrat = 200,1551 m^3/hari = 2.203,1243 gal/ jam

Rate filtrasi 60-120 gal / ft^2. hr (Perry's ed 5, tabel 19-18)

Diambil rate filtrasi 60 gal/ft^2.hr

Diambil ukuran plate and frame = 18"×18" (Perry's ed 5, table 19-17)

Luas efektif = 3,9 ft^2

$$\text{Luas frame total} = \frac{2.203{,}1243\, gal/hr}{60\, gal/sqrft.hr} = 36{,}7187\, ft^2$$

$$\Sigma plate = \frac{luas.total}{luas.efektif} = \frac{36{,}7187\, ft^2}{3{,}9\, ft^2} = 9{,}4151 \approx 10$$

Panjang alat berkisar antara 0,5 – 20 m (Ulrich p223)

Jumlah plate dan frame = (10×2)+1 = 21 buah

Tebal frame berkisar antara 0,125 – 8 in (Perry, 5 ed,p 19-66)

Diambil 4 in

Tebal plate dan frame seluruhnya = 21 × 4 in = 84 in = 7 ft ≅ 2,1336 m

Spesifikasi alat :

Filter Press (H – 128)

Jumlah alat yang dibutuhkan : 2 buah

Tebal plate dan frame total : 2,1336 m

Bahan : metal (Perry ed 5 tab.19-17)

Tangki Penampung Filtrat (F-126)

Fungsi = untuk menampung filtrat sebelum masuk ke Tangki Demineralisasi(R – 130)

Tipe = silinder tegak dengan tutup atas dan bawah flat head.

Larutan filtrat masuk = 190.741,8168 kg/hari

Komponen	Massa	Densitas	Fraksi
Air	177.910,6637	928,1605	0,9327
Protein whey	1.388,7635	1.166,0831	0,0073
Lemak	1,7087	793,6359	0,0000
Laktosa	10.007,2664	1.500,8931	0,0525
Mineral	1.429,6095	2.335,1196	0,0075
Asam asetat	0,2686	1.023,8919	0,0000
Kalsium asetat	3,5365	2.335,1196	0,0000
	190.741,8168		1,0000

$$\frac{1}{\rho_{campuran}} = \sum \frac{x_i}{\rho_{1i}}$$

ρ campuran = 952,9699 kg/m^3 = 59,4917 lb/ft^3

Kapasitas bahan masuk = 7.947,5757 kg/jam

Ditetapkan :

- volume liquid = 80% volume tangki
- Plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).
- F_M = 0,92 (standard)
- F_S = 0,25 (T_{op} < 650°F)
- Tanpa dikenai radiograf → F_a = 1
- Tanpa stress relieve → F_N = 1
- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$
- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

$$\text{volume liquid} = \frac{umpan.msuk}{\rho_{campuran}} = \frac{7.947,5757 kg}{952,9677 \, kg/m^3} = 8,3398 \text{ m}^3 = 294,5039 \text{ ft}^3$$

$$\text{volume tangki} = \frac{294,5039 ft^3}{80\%} = 368,1299 ft^3$$

Volume total tangki = volume shell

$$= \frac{\pi}{4} \times H^3$$

$$368,1299 \text{ ft}^3 = \frac{\pi}{4} \times H^3$$

Hs = 7,7692 ft → Hs = 8 ft

$D = 7,6563 \text{ ft}$

Volume liquid dalam shell = volume liquid

$$\frac{\pi}{4} \times D^2 \times H_l = 294,5039 \text{ ft}^3$$

$$\frac{\pi}{4} \times 7,6563^2 \times H_l = 294,5039 \text{ ft}^3$$

$$H_l = 6,4 \text{ ft}$$

$$P \text{ operasi} = P \text{ hidrostatik} = \frac{\rho_{campuran} \times Hliquid}{144}$$

(Brownell & Young, p.46, eq. 3.17)

$$= \frac{59.4917 \, lb/ft^3 \times 6,4 \, ft}{144 \, in^2/ft^2} = 2,6441 psi$$

P design diambil 1,2 × P operasi = 3,1729 psi

Tebal shell

$$f_{allow} = f_u \times F_M \times F_S \times F_z \times F_N$$

F_{allow} = 75.000 × 0,92 × 0,25 × 1 × 1 = 17.250 psi

$$t_s = \frac{p_{design} \times Di}{2 \times f_{allow} \times E} + C = \frac{2.6441 psi \times 7,6563 ft \times 12 \, in/ft}{2 \times 17,250 psi \times 0,8} + 0,125 in = 0,1356 in \rightarrow 3/16 \, in$$

Tebal head = tebal shell = $^3/_{16}$ in

Spesifikasi alat

Tangki Penampung Filtrat (F – 126)

Dimensi tangki :

Kapasitas maksimum : 368,1299 ft^3

Kapasitas operasi : 294,5039 ft^3

Diameter : 7,6563 ft

Tinggi shell : 8 ft

Tebal shell : $^{3}/_{16}$ in

Tebal plat atas dan bawah : $^{3}/_{16}$ in

Bahan konstruksi : plate steel SA-240 grade C

Jumlah tangki : 1 buah

Tangki Demineralisasi (R – 130)

Fungsi = untuk mengurangi mineral-mineral yang terkandung dalam larutan filtrat dari filter press (H - 128)

Tipe = silinder tegak dengan tutup atas dan bawah berbentuk flat, fixed bed ion exchanger

Data dari neraca massa larutan filtrat masuk = 190.741,8168 kg/hari

Komponen	Massa	Densitas	Fraksi
Air	177.910.6637	928,1605	0,9327
Protein whey	1.388,7635	1.166,0831	0,0073
Lemak	1.7087	793.6359	0,0000
Laktosa	10.007,2664	1.500,8931	0,0525
Mineral	1.429,6095	2.335,1196	0,0075
Asam asetat	0.2686	1.023,8919	0,0000
Kalsium asetat	3,5365	2.335,1196	0,0000
	190.741,8168		1,0000

$$\frac{1}{\rho_{campuran}} = \Sigma \frac{x_i}{\rho_i}$$

ρ campuran = 952,9677 kg/m^3 = 59,4917 lb/ft^3

Kapasitas bahan masuk = 7.947,5757 kg/jam

Rate larutan filtrat = 8,3398 m^3/jam = 0,1390 m^3/menit = 36,7188 gpm

Resin yang digunakan = *Mixed cation and strong-base anion*

Kapasitas maksimum 16 Gpm/ft^2, (Perry ed.7, tabel 16-19)

Diambil kapasitas aliran 2 Gpm/ft^2.

$$A = \frac{36,7188}{2} = 18,3594\ ft^2$$

Tinggi bed minimum = 1,2 m = 47 in ....(Perry ed.7, tabel 16-19)

Dirancang tinggi resin = 1,5 m = 4,92 ft

Volume resin = $A.H_r$ = 18,3594 ft^2 x 4,92 ft = 90,3283 ft^2

$$\text{Diameter shell} = \sqrt{\frac{90,3283}{\pi/4}} = 10,7270\ ft$$

Ditambahkan tinggi 1 ft untuk ruang distribusi air masing-masing tutup

Tinggi tangki = 4,92 ft + 1 ft + 1ft = 6,92 ft

Spesifikasi alat

Tangki Demineralisasi (R – 130)

Dimensi tangki :

D = 10,7270 ft

H_s = 6,92 ft

Tebal shell : $^3/_{16}$ in

Tebal head : $^3/_{16}$ in

Volume resin : 117,5002 ft^3

Rate : 36,7188 gpm

Bahan konstruksi : steel

Jumlah : 1 buah

Tangki Deproteinaser (R – 140)

Fungsi = memisahkan protein whey dengan cara denaturasi

Tipe = silinder tegak dengan tutup atas berbentuk dished head dan bawah berbentuk konis dilengkapi dengan jaket pemanas, berpengaduk

Dasar pemilihan = beroperasi pada tekanan atmosfer

Umpan masuk dari R – 130 = 189,326,5035 kg/hari = 7.888,6043kg/jam

Massa steam = 17.156,3553 kg/hari = 1.575,9542 lb/jam

bahan masuk	Massa kg/hari	densitas
Air	177910,6637	928,1605
Protein whey	1388,7635	1.166,0831
Lemak	1,7087	793,6359
Laktosa	10007,2664	1.500,9931
Mineral	14,2961	2.335,1196
Asam asetat	0,2686	1.023,8919
Kalsium asetat	3,5365	2.335,1196
	189.326,5035	

$$\frac{1}{\rho_{campuran}} = \Sigma \frac{x_i}{\rho_{ii}}$$

ρ campuran = 948,7718 kg/m^3 = 59,2298 lb/ ft^3

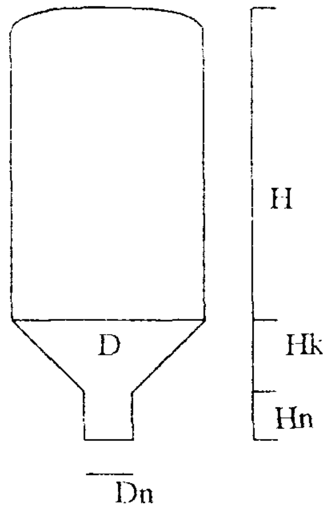
Q steam = 9031648,3548 kKal/hari =2.058.179,3739 Btu/jam

Ditetapkan :

- Volume liquid = 80% volume tangki
- Diameter nozzle (Dn) = 0,5 ft
- $\alpha = 45°$
- Hs = D
- Plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).
- F_M = 0,92 (standard)
- F_S = 0,25 (T_{op} < 650°F)
- Tanpa dikenai radiograf → F_a = 1
- Tanpa stress relieve → F_N = 1
- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$
- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

$$\text{volume liquid} = \frac{umpan.msuk}{\rho_{campuran}} = \frac{7.888,6043 kg}{948,7718 \, kg/m^3} = 8,3145 \text{ m}^3 = 293.6237 \text{ ft}^3$$

$$\text{volume tangki} = \frac{293,6237 \, ft^3}{80\%} = 367,0297 \, ft^3$$



Keterangan:

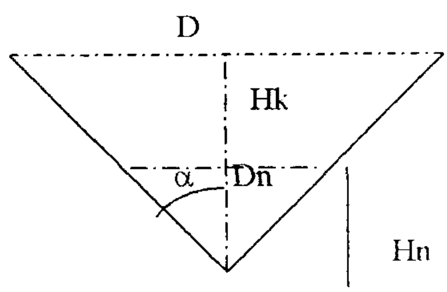
D = diameter shell

H = tinggi shell

Hk = tinggi konis

Hn = tinggi nozzle

Dn = diameter nozzle



Dari gambar dapat dicari persamaan untuk menghitung Hn dan Hk

Hn = $\dfrac{Dn}{2 * tg\alpha}$

Hk = $\dfrac{D}{2 * tg\alpha}$ - Hn = $\dfrac{D - Dn}{2 * tg\alpha}$

Volume Shell = $\dfrac{\pi}{4} \times D^2 \times H$ (dengan $\dfrac{H}{D} = 1$)

$$= \frac{\pi}{4} \times H^3$$

Volume Konis $= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times Hk - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times Hn$

$$= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times \frac{D}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$$

$$= \frac{1}{3} \times \frac{\pi}{4} \times H^2 \times \frac{H}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$$

$$= \frac{\pi}{24.tg\alpha} \times \left(H^3 - Dn^3\right)$$

Volume dished head = 0,000049 Di^3 = 0,000049 H^3

Volume total tangki = volume shell + volume konis + volume dished head

$$= \frac{\pi}{4} \times H^3 + \frac{\pi}{24.tg\alpha} \times \left(H^3 - Dn^3\right) + 0,000049\ H^3$$

367,0297 ft^3 $= \frac{\pi}{4} \times H^3 + \frac{\pi}{24.tg45^\circ} \times \left(H^3 - 1^3\right) + 0,000049\ H^3$

H = 7,5127 ft → H = 8 ft

D = 7,2012 ft

Volume liquid dalam konis $= \frac{\pi}{24.tg45^\circ} \times \left(D^3 - 1^3\right)$

= 30,1525 ft^3

Tinggi liquid dalam konis $= \frac{D - Dn}{2 \times tg\alpha} = \frac{7,2012 - 1}{2 \times tg45^\circ} = 2,0685\ ft$

Volume liquid dalam shell = volume liquid – volume liquid dalam konis

$\frac{\pi}{4} \times D^2 \times H_l$ = 293,6237 ft^3 – 30,1525 ft^3

$\frac{\pi}{4} \times 7,2012^2 \times H_l$ = 271,9295 ft^3

H_l = 6,4254 ft

Tinggi total liquid dalam tangki = tinggi liquid dalam shell + tinggi liquid dalam konis

= 6,4254 ft + 2,0685 ft

= 8,5409 ft

$$P \text{ operasi} = P \text{ hidrostatik} = \frac{\rho_{campuran} \times Htot}{144}$$

(Brownell & Young, p.46, eq. 3.17)

$$= \frac{59{,}2298\, {}^{lb}/_{ft^3} \times 8{,}5409\, ft}{144\, {}^{in^2}/_{ft^2}} = 3{,}5130\, psi$$

P design diambil 1,2 × P operasi = 4,2156 psi

Tebal shell

$$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_N$$

F_{allow} = 75.000 × 0,92 × 0,25 ×1 × 1 = 17.250 psi

$$t_s = \frac{P_{design} \times Di}{2 \times f_{allow} \times E} + C = \frac{4{,}2156\, psi \times 7{,}2010\, ft \times 12\, {}^{in}/_{ft}}{2 \times 17.250\, psi \times 0{,}8} + 0{,}125 in = 0{,}1382 in \rightarrow {}^{3}/_{16}\, in$$

OD shell = 7,2012 + (3/16)/12×2 = 7,2324 ft = 86,7888 in

Tebal dished head

rc = 90

icr = $5^1/_8$ (Table 5.7 Brownell p.89)

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

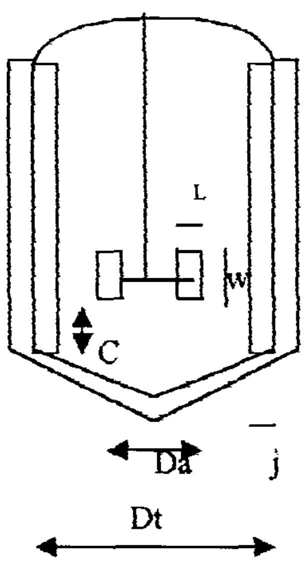
$$W = \frac{1}{4}\left(3+\sqrt{\frac{90}{5\frac{1}{8}}}\right) = 1{,}7613$$

$$t_h = \frac{P.rc.W}{2.F.E-0{,}2.P}+c$$ (pers 7.77,Brownell,1959)

$$t_h = \frac{4{,}2156.90.1{,}7613}{2.17250.0{,}8-0{,}2.4{,}2156}+0{,}125 = 0{,}1492 \rightarrow \frac{3}{16} in$$

Tebal konis

Untuk sudut puncak ≥45° tebal konis = tebal shell = $^3/_{16}$ in



Da = 1/3 Dt = 1/3 × 7,2012 ft = 2,4004 ft

J = 1/12 Dt = 1/12 × 7,2012 ft = 0,6001 ft

W = 1/5 Da = 1/5 × 2,4004 ft = 0,4801 ft

C = 1/3 Dt = 1/3 × 7,2012 ft = 2,4004 ft

Dimana : Da = diameter pengaduk

Dt = diameter tangki

L = panjang blade

W = lebar blade

C = jarak dari dasar tangki ke pusat pengaduk

J = lebar baffle

Jumlah pengaduk (n)= tinggi liquid dalam shell . sg / diameter tangki

ρ campuran = 59,2298 lb/ ft^3

ρ air pada 4°C = 62,43 lb/ ft^3

sg = ρ camp / ρ air = 0,9487

$$n = \frac{8{,}5409\,ft \times 0{,}9487}{7{,}2012\,ft} = 0{,}8527 buah \approx 1 buah$$

Perhitungan power pengaduk

Kecepatan pengaduk diambil 30 rpm = 0,5 rps

Diambil μ air karena komponen terbesar

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

$$= \left(\frac{(2{,}4004)^2.0{,}5.59{,}2298}{0{,}0004}\right) = 402.148{,}6254$$

dari gambar 3.4-4, Geankoplis ed 3rd, hal 145, untuk flat six-blade turbine with disk diperoleh Np= 5

$$Np = \frac{P \times gc}{\rho..N^3.Da^5} \qquad (Geankoplis, pers3.4-2)$$

$$P = \frac{Np \times \rho \times N^3 \times Da^5}{gc} = \frac{5 \times 59{,}2298^{lb}/_{ft^3} \times 0{,}5/s^3 \times (2{,}4004\,ft)^5}{32{,}174^{lb.ft}/_{lbf.s^2}}$$

$$P = 91{,}6891^{lb.ft}/_{s} = 0{,}1667\,Hp$$

Effisiensi pengaduk = 85%

Jadi Power yang dibutuhkan untuk pengaduk = 0,1667/ 0,85 = 0,1961 Hp

Perhitungan jaket Pemanas

Diambil spasi jaket = 2 in

Ho = 1500 Btu/hr.ft^2°F

Dalam tangki

N_{Re} = 402.148,6254

Jc = 2500 (fig 20.2, Kern)

cp campuran= 62.5002Kkal/kg

k campuran = 0.5781k w/m.k =0.3340Btu/h.ft F

$$hi = j \times \frac{k}{D}\left(\frac{Cp \times \mu}{k}\right)^{1/3}\left(\mu/\mu_w\right)^{1/4} \qquad Kern,1957$$

$$hi = 2500 \times \frac{0{,}3340^{Btu}/_{h.ft.F}}{7{,}2012\,ft} \times \left(\frac{62{,}5002^{Btu}/_{lb} \times 1{,}5281^{lb}/_{ft.h}}{0{,}3340^{Btu}/_{ft.h}}\right)^{-1/3} \times 1 =$$

$$hi = 763{,}9073^{Btu}/_{hour.ft^2\,°F}$$

$$hio = hi \times {}^{ID}/_{OD} = 760{,}6066^{Btu}/_{hour.ft^2\,°F}$$

$$Uc = \frac{hio.ho}{hio + ho} = \frac{760{,}6066.1500}{760{,}6066 + 1500} = 504{,}6919$$

$$Rd = \frac{Uc - Ud}{Uc \times Ud} \qquad (Kern, pers6.13)$$

$$= 0{,}001$$

Ud = 335,4121

Ud = 99,9583

$$A = \frac{Q}{U_D.\Delta T} \qquad \text{(Rule of Thumb Ulrich)}$$

$$\Delta T_{LMTD} = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln\frac{(T_1 - t_1)}{(T_2 - t_2)}}$$

Suhu whey masuk=	316,0049K	109.4087' F = T_1
Suhu whey keluar=	363K	194' F = T_2
Suhu steam masuk=	393K	248 'F = t_1
Suhu steam keluar =	393K	248 'F = t_2

A = 3.054,4622 ft^2

Luas jaket = luas jaket pada shell + luas jaket pada tutup bawah

$$3.054{,}4622\ ft^2 = \pi \times Do_{shell} \times Hj + (\pi \times Rs \times S - \pi \times Rn \times s)$$

$$3.054{,}4622\ ft^2 = \pi \times 7{,}2324\ ft \times Hj + \pi \times (Rs \times \frac{Rs}{\sin\alpha} - Rn * \frac{Rn}{\sin\alpha})$$

$$3.054{,}4622\ ft^2 = \pi \times 7{,}2324\ ft \times Hj + \frac{\pi}{\sin\alpha} \times (\frac{Ds^2}{4} - \frac{Dn^2}{4})$$

$$3.054{,}4622\ ft^2 = \pi \times 7{,}2324\ ft \times Hj + \frac{\pi}{\sin 45} \times (\frac{7{,}2324^2}{4} - \frac{0{,}5^2}{4})$$

H jaket = 6,3045 ft < tinggi liquid dalam shell (6,4723 ft) memenuhi syarat

Spesifikasi alat :

Tangki Deproteinaser (R – 140)

Dimensi:

ID_s = Diameter dalam tangki = 7,2012 ft

OD_s = Diameter luar tangki = 7,2324 ft

Hs = Tinggi shell = 8 ft

Ts = Tebal shell = $^3/_{16}$ in

Th = Tebal head = $^3/_{16}$ in

Pengaduk turbin flat six blade dengan baffle

P = 0,1961Hp ≈ 0,25 Hp

Jumlah = 1 buah pengaduk

Bahan konstruksi = plate steel SA-240 grade C

Tinggi jaket = 6,3045 ft

Spasi jaket = 2 in

Jumlah tangki = 1 buah

Filter Press (H – 143)

Fungsi = untuk memisahkan larutan laktosa dengan endapan denaturasi protein

Tipe = plate and filter press

Dasar pemilihan = cara pengoperasian sederhana

Perhitungan :

Suhu bahan keluar = 356,5451 K

Komponen	Massa,kg	densitas
Air	177.585,3072	918,7389
Protein whey	13,8622	1,145,0670
Lemak	1,7087	776,7075
Laktosa	9.988,9655	1,488,4070
Mineral	14,2700	2,323,7428
Asam asetat	0,2686	982,7354
Kalsium asetat	3,5365	2,323,7428
	187.607,9187	

$\dfrac{1}{\rho_{campuran}} = \Sigma \dfrac{x_{li}}{\rho_i}$ ρ filtrat = 937,9182 kg/m^3

Rate filtrat = 200,0259 m^3/hari = 2.201,7016 gal/ jam

Rate filtrasi 60-120 gal / ft^2. hr (Perry's ed 5, tabel 19-18)

Diambil rate filtrasi 60 gal/ft^2.hr

Diambil ukuran plate and frame = 18"×18" (Perry's ed 5, table 19-17)

Luas efektif = 3,9 ft^2

$$\text{Luas frame total} = \frac{2.201,7016\,{}^{gal}/_{hr}}{60\,{}^{gal}/_{sqrft.hr}} = 36,6950\,ft^2$$

$$\Sigma plate = \frac{luas.total}{luas.efektif} = \frac{36,6950\,ft^2}{3,9\,ft^2} = 9,4090 \approx 10$$

Panjang alat berkisar antara 0,5 – 20 m (Ulrich p223)

Jumlah plate dan frame = (10×2)+1 = 21 buah

Tebal frame berkisar antara 0,125 – 8 in (Perry, 5 ed,p 19-66)

Diambil 4 in

Tebal plate dan frame seluruhnya = 21 × 4 in = 84 in = 7 ft ≅ 2,1336 m

Spesifikasi alat :

Filter Press (H – 143)

Jumlah alat yang dibutuhkan : 2 buah

Tebal plate dan frame total : 2,1336 m

Bahan : metal (Perry ed 5 tab.19-17)

Tangki Penampung Filtrat (F-144)

Fungsi = untuk menampung filtrat sementara sebelum masuk ke Evaporator(V – 150)

Tipe = silinder tegak dengan tutup atas dan bawah flat head.

Komponen	Massa Kg/hari	Densitas	Fraksi
Air	177585,3072	918,.7389	0,9466
Protein whey	13,8622	1,145,0670	0,0001
Lemak	1,7087	776,7075	0,0000
Laktosa	9988,9655	1,488,3070	0,0532
Mineral	14,2700	2,323,7428	0,0001
Asam asetat	0,2686	982,7354	0,0000
kalsium asetat	3,5365	2,323,7428	0,0000
Total	187.607,9187		

$$\frac{1}{\rho_{campuran}} = \Sigma \frac{x_i}{\rho_{1i}}$$

ρ campuran = 937,9182 kg/m^3 = 58,5521 lb/ft^3

Ditetapkan :

- volume liquid = 80% volume tangki
- Hs = D
- Plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).
- F_M = 0,92 (standard)
- F_S = 0,25 (T_{op} < 650°F)
- Tanpa dikenai radiograf → F_a = 1
- Tanpa stress relieve → F_N = 1
- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$
- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

$$\text{volume liquid} = \frac{umpan.masuk}{\rho_{campuran}} = \frac{7.816,9966 kg}{937,9161 \,{}^{kg}\!/\!{}_{m^3}} = 8,3344 \text{ m}^3 = 294,3260 \text{ ft}^3$$

$$\text{volume tangki} = \frac{294,3260 ft^3}{80\%} = 367,9076 ft^3$$

Volume total tangki = volume shell

$$= \frac{\pi}{4} \times H^3$$

$$367,9076 \text{ ft}^3 = \frac{\pi}{4} \times H^3$$

Hs = 7,7650 ft → H = 8 ft

D = 7,6540 ft

Volume liquid dalam shell = volume liquid

$$\frac{\pi}{4} \times D^2 \times H_l = 294{,}3260 \text{ ft}^3$$

$$\frac{\pi}{4} \times 7{,}6540^2 \times H_l = 294{,}3260 \text{ ft}^3$$

$$H_l = 6{,}4 \text{ ft}$$

$$P \text{ operasi} = P \text{ hidrostatik} = \frac{\rho_{campuran} \times Hliquid}{144}$$

(Brownell & Young, p.46, eq. 3.17)

$$= \frac{58{,}5521 \, lb/ft^3 \times 6{,}4 \, ft}{144 \, in^2/ft^2} = 2{,}6023 \, psi$$

P design diambil 1,2 × P operasi = 3,1228 psi

Tebal shell

$$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_N$$

F_{allow} = 75.000 × 0,92 × 0,25 ×1 × 1 = 17.250 psi

$$t_s = \frac{P_{design} \times Di}{2 \times f_{allow} \times E} + C = \frac{2{,}6023 psi \times 7{,}6540 ft \times 12 \, in/ft}{2 \times 17{,}250 psi \times 0{,}8} + 0{,}125 in = 0{,}1259 in \rightarrow \frac{3}{16} in$$

Tebal head = tebal shell = $^3/_{16}$ in

Spesifikasi alat :

Tangki Penampung Filtrat (F-143)

Dimensi:

D =Diameter tangki = 7,6540 ft

H = Tinggi tangki = 8 ft

Ts = Tebal shell = $^3/_{16}$ in

Th = Tebal head = $^3/_{16}$in

Bahan konstruksi = plate steel SA-240 grade C

Jumlah tangki = 1 buah

Evaporator (V-150)

Fungsi : Menguapkan larutan laktosa sampai 65% TS

Tipe : Single efek once through long tube vertical evaporator

Kondisi operasi: Suhu bahan masuk: 83,5451°C = 182,3812°F

Suhu bahan keluar: 100°C = 212°F

Tekanan operasi: 1 atm = 14,696 psia

Suhu operasi: 100°C = 212°F

Suhu steam masuk (Ts): 120°C = 248°F

Tekanan steam = 198,53 kPa = 28,7944 psia

Rate bahan masuk = 187607,9187 kg/hari = 17233,3507 lb/jam

Rate steam masuk = 165809,3572 kg/hari = 15230,9712 lb/jam

Qs = 87287292,5564 kkal/hari = 14432422,7110 Btu/jam

ΔT = 36°C

Koefisien heat transfer (U_D) untuk long tube evaporator = 200 – 600

(Brown, 1955)

Trial: U_D = 500 Btu/j.ft^2.°F

$$A = \frac{Qs}{U_D.\Delta T} = \frac{14432422,7110}{500 \times 36} = 801,8013 \text{ ft}^2$$

Dipilih tube dengan OD ¾ in, 16 BWG, L = 20 ft

Dari Kern tabel 10 didapat a" = 0,1963 ft^2/ft

$$Nt = \frac{A}{a''.L} = \frac{801,8013}{0,1963 \times 20} = 204,2285$$

Untuk OD ¾ in, $^{15}/_{16}$ in pitch susunan segitiga didapat:

Nt = 239 buah

IDs = 17 ¼ in = 1,4375 ft

A = Nt × a" × L

A = 239 × 0,1963 × 20 = 938,3140 ft^2 = 87,2301 m^2

Dari Ulrich tabel 4-7: Untuk once through long tube vertical evaporator,

A = 100 – 10000 m^2

Jadi digunakan tipe single efek evaporator karena luasnya kecil.

$$U_D \text{ koreksi} = \frac{Qs}{A \times \Delta T} = \frac{14432422,7110}{938,3140 \times 36} = 427,2564 \text{ Btu / j.ft}^2.F$$

Tube (steam)	Shell (larutan whey)
a't = 0,302 in^2 (tabel 10, Kern) ID = 0,62 in = 0,05167 ft $at = \frac{Nt \times a't}{144 \times n} = \frac{239 \times 0,302}{144 \times 1} = 0,5012 \text{ ft}^2$ $Gt = \frac{W}{at} = \frac{15230,9712 \text{ lb/j}}{0,5809 \text{ ft}^2}$ = 30386,8194 lb/j.ft^2 Pada Ts, μ steam = 0,03267 lb/ft.j $Re_t = \frac{D \times Gt}{\mu} = \frac{0,05167 \times 30386,8194}{0,03267}$ = 48055,8822 hio untuk steam = 1500 Btu/j.ft^2.°F	Asumsi: $B = \frac{IDs}{5} = \frac{17,25}{5} = 3,45$ in C' = Pt – OD = $^{15}/_{16}$ – ¾ = 0,1875 in $as = \frac{ID \times C' \times B}{144 \times Pt} = \frac{17,25 \times 0,1875 \times 3,45}{144 \times 15/16}$ = 0,0827 ft^2 $Gs = \frac{w}{as} = \frac{17233,3507}{0,0827} = 208494,2244$ lb/j.ft^2 Pada Tav = 91,7725 °F ρ camp = 63,6160 lb/ft^3 μ camp = 0,7471 lb/ft.j

	De = 0,55 in = 0,0458 ft (fig. 28) $Re_s = \dfrac{De \times Gs}{\mu} = \dfrac{0{,}0458 \times 208494{,}2244}{0{,}7471}$ $= 12790{,}9123$ $j_H = 96$ (fig. 28) $\left(\dfrac{\mu}{\mu w}\right) = 1$ $ho = \dfrac{(j_H.k)}{D}.\left(\dfrac{cp.\mu}{k}\right)^{1/3}.\left(\dfrac{\mu}{\mu w}\right)^{0,14}$ $= 6345{,}5842$ Btu/j.ft^2.°F

$$U_C = \frac{hio \times ho}{hio + ho} = \frac{1500 \times 6345{,}5842}{1500 + 6345{,}5842} = 1213{,}2145 \text{ Btu/j.ft}^2.°F$$

$$Rd = \frac{U_C - U_D}{U_C \times U_D} = \frac{1213{,}2145 - 427{,}2564}{1213{,}2145 \times 427{,}2564} = 0{,}0015 > 0{,}001 \text{ (memenuhi syarat)}$$

Perhitungan Pressure Drop (ΔP):

Tube (steam)	Shell (larutan whey)
Untuk Re_t = 48055,8822 f = 0,00021 (fig. 26) $\phi t = 1$ spesific volume untuk steam pada P = 14,696 psia: vg = 26,80 ft^3/lb	Untuk Re_s = 12790,9123 f = 0,002 $\phi s = 1$ s = 1,0190 $(N+1) = \dfrac{L}{B} = \dfrac{12 \times 20}{3{,}45} = 70$

$s = \dfrac{1}{26{,}80 \times 62{,}5} = 0{,}000597$ $Pt = \dfrac{1}{2} \times \dfrac{f.Gt^2.L.n}{5{,}22 \times 10^{10} D.s.\phi t}$ $= \dfrac{1}{2} \times \dfrac{0{,}00021.(30386{,}8194)^2.20.1}{5{,}22 \times 10^{10}.0{,}05167.0{,}000597.1}$ $= 2{,}4085$ psi Pr diabaikan PT = Pt + Pr = 2,4085 psi < 10 psi (memenuhi syarat)	$Ps = \dfrac{f.Gs^2 Ds.(N+1)}{5{,}22 \times 10^{10} De.s.\phi s}$ $= \dfrac{0{,}002.(208494{,}2244)^2.1{,}4375.70}{5{,}22 \times 10^{10}.0{,}0458.1{,}0190.1}$ = 3,5883 psi < 10 psi (memenuhi syarat)

Spesifikasi evaporator:

Tube:

OD = ¾ in, 16 BWG, L = 20 ft

Nt = 239

Pitch = $^{15}/_{16}$ in susunan segitiga

Passes = 1

Shell:

ID = 17 ¼ in

Spasi baffle = 3,45 in

Passes = 1

Bahan konstruksi: Stainless steel

Jumlah: 1 buah

Kristaliser (X-160)

Fungsi = Mengkristalkan laktosa dari larutan yang keluar dari evaporator (V-150)

Tipe = silinder tegak dengan tutup atas berbentuk dished head dan tutup bawah berbentuk konis dilengkapi dengan pengaduk dan jaket pendingin

Dasar pemilihan = cocok untuk beroperasi pada tekanan atmosfer

Kapasitas tangki = 15.419,4023 kg/hari × 1/24 hari/jam = 3.854,8506 kg

Komponen	Massa kg/hari	Fraksi	Densitas
Air	5.396,7908	0,3500	914,9148
Protein whey	13,8622	0,0009	1.136,5368
Lemak	1,7087	0,0001	769,8364
Laktosa	9.988,9655	0,6478	1.483,1984
Mineral	14,2700	0,0009	2.319,1250
Asam asetat	0,2686	0,0000	966,0304
kalsium asetat	3,5365	0,0002	2.319,1250

$$\frac{1}{\rho_{campuran}} = \Sigma \frac{x_i}{\rho_{li}}$$

ρ campuran = 1.218,5132 kg/m^3 = 76,0691 lb/ft^3

Q pendingin = 755.834,7077 kKal/hari = 749.344,2120 Btu/6jam

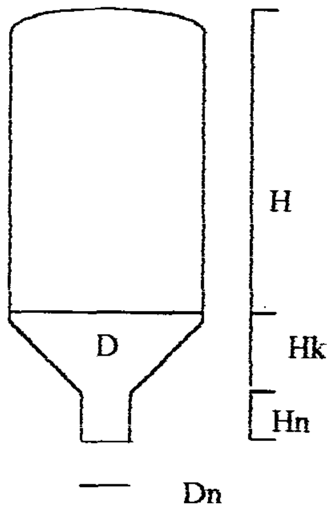
Ditetapkan :

- volume liquid = 80% volume tangki
- Diameter nozzle (Dn) = 1 ft
- $\alpha = 45°$
- Hs = D

- Plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).
- F_M = 0,92 (standard)
- F_S = 0,25 (T_{op} < 650°F)
- Tanpa dikenai radiograf → F_a = 1
- Tanpa stress relieve → F_N = 1
- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$
- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

$$\text{volume liquid} = \frac{umpan.msuk}{\rho_{campuran}} = \frac{3.854{,}8506\,kg}{1.218{,}5132\,kg/m^3} = 3{,}1636\ m^3 = 111{,}7198\ ft^3$$

$$\text{volume tangki} = \frac{111{,}7198\,ft^3}{80\%} = 139{,}6497\,ft^3$$



Keterangan:

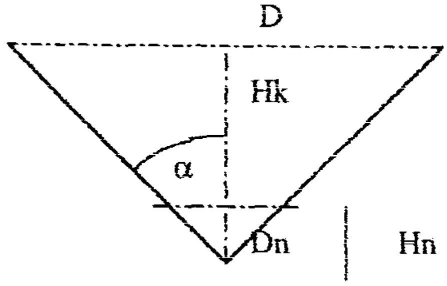
D = diameter shell

H = tinggi shell

Hk = tinggi konis

Hn = tinggi nozzle

Dn = diameter nozzle



Dari gambar dapat dicari persamaan untuk menghitung Hn dan Hk

$$\text{Hn} = \frac{Dn}{2 * tg\alpha}$$

$$\text{Hk} = \frac{D}{2 * tg\alpha} - \text{Hn} = \frac{D - Dn}{2 * tg\alpha}$$

Volume Shell $= \frac{\pi}{4} \times D^2 \times H$ (dengan $\frac{H}{D} = 1$)

$$= \frac{\pi}{4} \times H^3$$

Volume Konis $= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times Hk - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times Hn$

$$= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times \frac{D}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$$

$$= \frac{1}{3} \times \frac{\pi}{4} \times H^2 \times \frac{H}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$$

$$= \frac{\pi}{24.tg\alpha} \times \left(H^3 - Dn^3\right)$$

Volume dished head = 0,000049 Di^3 = 0,000049 H^3

Volume total tangki = volume shell + volume konis + volume dished head

$$= \frac{\pi}{4} \times H^3 + \frac{\pi}{24.tg\alpha} \times \left(H^3 - Dn^3\right) + 0{,}000049\ H^3$$

139,6497 ft³ $= \frac{\pi}{4} \times H^3 + \frac{\pi}{24.tg45°} \times \left(H^3 - 1^3\right) + 0{,}000049\ H^3$

H = 5,4444 ft → H = 6 ft

D = 5,0951 ft

Volume liquid dalam konis = $\frac{\pi}{24.tg45°} \times \left(D^3 - 1^3\right)$

= 10,6031 ft³

Tinggi liquid dalam konis = $\frac{D - Dn}{2 \times tg\alpha} = \frac{5{,}0951 - 1}{2 \times tg45°} = 1{,}2641\ ft$

Volume liquid dalam shell = volume liquid – volume liquid dalam konis

$\frac{\pi}{4} \times D^2 \times H_l$ = 111,7198 ft³ – 10,6031 ft³

$\frac{\pi}{4} \times 5{,}0951^2 \times H_l$ = 101,1167 ft³

H_l = 4,9618 ft

Tinggi total liquid dalam tangki = tinggi liquid dalam shell + tinggi liquid dalam konis

= 1,2641 ft + 4,9618 ft

= 6,2260 ft

P operasi = P hidrostatik = $\frac{\rho_{campuran} \times Htot}{144}$

(Brownell & Young, p.46, eq. 3.17)

$$= \frac{76{,}0691\, {}^{lb}\!/_{ft^3} \times 6{,}2260\, ft}{144\, {}^{in^2}\!/_{ft^2}} = 3{,}2889\, psi$$

P design diambil $1{,}2 \times$ P operasi = 3,9467 psi

Tebal shell

$$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_N$$

F_{allow} = 75.000 × 0,92 × 0,25 ×1 × 1 = 17.250 psi

$$t_s = \frac{P_{design} \times Di}{2 \times f_{allow} \times E} + C = \frac{3{,}9467\, psi \times 5{,}0951\, ft \times 12\, {}^{in}\!/_{ft}}{2 \times 17.250\, psi \times 0{,}8} + 0{,}125 in = 0{,}1337 in \rightarrow {}^{3}\!/_{16}\, in$$

OD = 5,0951×12 + 2 × 3/16 = 61,5165 in

Tebal dished head

rc = 66

icr = 4 (Table 5.7 Brownell p.89)

$$W = {}^{1}\!/_{4} \cdot \left(3 + \sqrt{\frac{rc}{icr}} \right) \ldots$$ (pers 7.76,Brownell,1959)

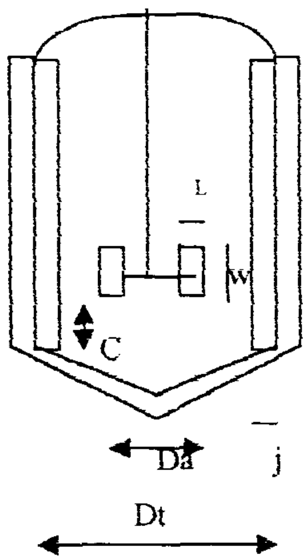
$$W = {}^{1}\!/_{4} \cdot \left(3 + \sqrt{\frac{66}{4}} \right) = 1{,}7655$$

$$t_h = \frac{P.rc.W}{2.F.E - 0{,}2.P} + c \ldots$$ (pers 7.77,Brownell,1959)

$$t_h = \frac{3{,}9467.66.1{,}7655}{2.17250.0{,}8 - 0{,}2.1{,}7655} + 0{,}125 = 0{,}1417 \rightarrow {}^{3}\!/_{16}\, in$$

Tebal konis

Untuk sudut puncak ≥45° tebal konis = tebal shell = $^{3}/_{16}$ in



Da = 1/3 Dt = 1/3 × 5,0951 ft = 1,6984 ft

J = 1/12 Dt = 1/12 × 5,9051 ft = 0,4246 ft

W = 1/5 Da = 1/5 × 1,6984 ft = 0,3397 ft

C = 1/3 Dt = 1/3 × 5,9051 ft = 1,6984 ft

Dimana : Da = diameter pengaduk

Dt = diameter tangki

L = panjang blade

W = lebar blade

C = jarak dari dasar tangki ke pusat pengaduk

J = lebar baffle

Jumlah pengaduk (n)= tinggi liquid dalam total . sg / diameter tangki

ρ campuran = 76,0691 lb/ ft^3

ρ air pada 4°C = 62,43 lb/ ft^3

sg = ρ camp / ρ air = 1,2185

$$n = \frac{6,2260 ft \times 1,2185}{5,0951 ft} = 1,4889 buah \approx 2 buah$$

Perhitungan power pengaduk

Kecepatan pengaduk diambil 50 rpm =0,8333 rps

Diambil μ laktosa karena komponen terbesar

$$N\,Re = \frac{Da^2.N.\rho}{\mu} \qquad (Geankoplis, pers3.4-1)$$

$$= \left(\frac{(1{,}6984)^2.0{,}833.76{,}0691}{0{,}0013}\right) = 141.723{,}9428$$

dari gambar 3.4-4, Geankoplis ed 3rd, hal 145, untuk flat six-blade turbine with disk diperoleh Np= 5

$$Np = \frac{P \times gc}{\rho..N^3.Da^5} \qquad (Geankoplis, pers3.4-2)$$

$$P = \frac{Np \times \rho \times N^3 \times Da^5}{gc} = \frac{5 \times 76{,}0691\,{}^{lb}/_{ft^3} \times 0{,}8333/s^3 \times (1{,}6984\,ft)^5}{32{,}174\,{}^{lb.ft}/_{lbf.s^2}}$$

$$P = 96{,}6713\,{}^{lb.ft}/_{s} = 0{,}1758Hp$$

Effisiensi pengaduk = 85%

Jadi Power yang dibutuhkan untuk 2 pengaduk = 0,0372×2/ 0,85 = 0,2068 Hp

Perhitungan jaket pendingin

Diambil spasi jaket = 2 in

ID jacket = OD shell + jaket spacing

= (5,0951×12)+(3/16)×2 + 2 . 2in = 65,5165 in

μ ethilen glikol = 60 cp = 0,0403 lb/ft.s

Outside

$$NRe = \frac{De.G}{\mu}$$

$$De = \frac{4.\text{flow area}}{\text{wetted perimeter}} = \text{Djaket-Dshell} \quad \text{(Geankoplis, pers 2.10-23,p.99)}$$

$= 4$ in$= 0,3333$ ft

a = flow area = $\frac{1}{4} . \pi (ID_{jaket}{}^2 - OD_{shell}{}^2) = 398,8836\ in^2 = 2,7700\ ft^2$

Dari neraca panas refrigerant yang dipakai sebanyak = 143215,6018 kg/hari

= 65.777,7366 lb/5 jam

$$G = \frac{65.777,7366 lb/jam}{2,7700 ft^2} = 23.746,2598\ lb/ft^2 jam$$

$$NRe = \frac{0,3333\ ft.23.746,2598 \frac{lb}{ft^2hr}.\frac{1h}{3600s}}{0.0403 \frac{lb}{ft.s}} = 328,9012$$

Jh= 18 (Kern fig 20.2)

k= 0,153 Btu/(hr.ft²°F/ft)

c = 0,55 Btu/lbm°F

$$ho = \frac{Jh.k}{De}\left(\frac{c.\mu}{k}\right)^{1/3}\left(\frac{\mu}{\mu w}\right)^{0,14}$$

$$ho = \frac{18.0,153 \frac{Btu}{hr.ft^2\,°F/ft}}{0,3333ft}\left(\frac{0,5500 \frac{Btu}{lb°F}.0,0403 \frac{lb}{ft.s}}{0,153 \frac{Btu}{hr.ft^2\,°F/ft}.\frac{hr}{3600s}}\right)^{1/3}.1$$

$= 66,5551$ Btu/hr.ft²°F

Inside

NRe = 85.034,3657

Jc = 700 (fig 20.2, Kern)

$$hi = j \times \frac{k}{D}\left(\frac{Cp \times \mu}{k}\right)^{1/3}\left(\frac{\mu}{\mu_w}\right)^{1/4} \qquad Kern.1957$$

$$hi = 700 \times \frac{0.3176\,btu/h.ft.F}{5{,}0951\,ft} \times \left(\frac{72{,}6696\,btu/lb \times 5{,}1304\,lb/ft.h}{0{,}3176\,btu/ft.h}\right)^{-1/3} \times 1 =$$

$$hi = 288{,}9163\,btu/hour.ft^2\,{}^\circ F$$

$$hio = hi \times ID/OD = 287{,}1551\,btu/hour.ft^2\,{}^\circ F$$

$$Uc = \frac{hio.ho}{hio + ho} = \frac{287{,}1551.66{,}5551}{287{,}1551 + 66{,}5551} = 54{,}0319$$

$$Rd = \frac{Uc - Ud}{Uc \times Ud} \qquad (Kern, pers 6.13)$$

$= 0{,}001$

Ud = 51,2621

$$A = \frac{Q}{U_D.\Delta T} \qquad \text{(Rule of Thumb Ulrich)}$$

$$\Delta T_{LMTD} = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln\frac{(T_1 - t_1)}{(T_2 - t_2)}}$$

Suhu bahan masuk = 100 C = 212 F = T_1

Suhu bahan keluar = 5 C = 41 F = T_2

T pendingin masuk= -10 C = 14 F = t_1

T pendingin keluar = -2 C = 28,4 F = t_2

A = 1022,5770 ft^2

Luas jaket = luas jaket pada shell + luas jaket pada tutup bawah

1.022,5770 ft^2 = $\pi \times Do_{shell} \times Hj + (\pi \times Rs \times S - \pi \times Rn \times s)$

$$1.022,5770\ ft^2 = \pi \times 5,1264\ ft \times Hj + \pi \times (Rs \times \frac{Rs}{\sin\alpha} - Rn * \frac{Rn}{\sin\alpha})$$

$$1.022,5770\ ft^2 = \pi \times 5,1264\ ft \times Hj + \frac{\pi}{\sin\alpha} \times (\frac{Ds^2}{4} - \frac{Dn^2}{4})$$

$$1.022,5770\ ft^2 = \pi \times 5,1264\ ft \times Hj + \frac{\pi}{\sin 45} \times (\frac{5,1264^2}{4} - \frac{1^2}{4})$$

H jaket = 4,9038 ft < tinggi liquid dalam shell (4,9168 ft) memenuhi syarat

Spesifikasi alat :

Kristaliser (X-160)

Dimensi:

D =Diameter tangki = 5,9051 ft

H = Tinggi tangki = 6 ft

Ts = Tebal shell = $^3/_{16}$ in

Th = Tebal head = $^3/_{16}$ in

Pengaduk turbin flat six blade dengan baffle

P = 0,2068 Hp ≈ 0,25 hp

Jumlah = 2 buah pengaduk

Bahan konstruksi = plate steel SA-240 grade C

Jumlah tangki = 1 buah

Filter Press (H – 162)

Fungsi = untuk memisahkan kristal laktosa dari larutan

Tipe = plate and filter press

Dasar pemilihan = cara pengoperasian sederhana

Perhitungan :

Suhu bahan keluar = 280,0046 K

Komponen	massa,kg	densitas
Air	1.984,7720	936,5269
Protein whey	5,0981	1.184,7456
Lemak	0,6284	808,6685
Laktosa	297,7158	1.512,1698
Mineral	5,2480	2.345,2223
Kalsium asetat	1,3006	2.345,2223
Kristal laktosa	9.179,4469	1.512,1698
Total	11.474,2098	

$$\frac{1}{\rho_{campuran}} = \Sigma \frac{x_{li}}{\rho_i}$$

ρ filtrat = 1.366,8848 kg/m^3

Rate filtrat = 8,3944 m^3/hari = 296,4447 ft^3/hari = 92,3981 gal /jam

Rate filtrasi 60-120 gal / ft^2. hr (Perry's ed 5, tabel 19-18)

Diambil rate filtrasi 60 gal/ft^2.hr

Diambil ukuran plate and frame = 7"×7" (Perry's ed 5, table 19-17)

Luas efektif = 0,5 ft^2

$$\text{Luas frame total} = \frac{92{,}3981\,gal/hr}{60\,gal/sqrft.hr} = 1{,}5400\,ft^2$$

$$\Sigma plate = \frac{luas.total}{luas.efektif} = \frac{1{,}54\,ft^2}{0{,}5\,ft^2} = 3{,}0799 \approx 4$$

Panjang alat berkisar antara 0,5 – 20 m (Ulrich p223)

Jumlah plate dan frame = $(4\times2)+1$ = 9 buah

Tebal frame berkisar antara 0,125 – 8 in (Perry, 5 ed,p 19-66)

Diambil 4 in

Tebal plate dan frame seluruhnya = 9 × 4 in = 36 in = 3 ft = 0,9144 m

Spesifikasi alat :

Filter Press (H – 143)

Jumlah alat yang dibutuhkan	: 2 buah
Tebal plate dan frame total	: 0,9144 m
Bahan	: metal (Perry ed 5 tab.19-17)

Conveyor (J – 171)

Fungsi = mengalirkan slurry kristal laktosa dari filter press(H-165) ke Rotary Dryer(B– 170)

Tipe = screw conveyor

Dasar pemilihan = cocok untuk industri makanan

Kondisi operasi = jumlah muatan masuk

Massa slurry kristal laktosa masuk = 11.474,2098 kg / hari

Komponen	massa,kg	densitas
Air	1.984,7720	936,5269
Protein whey	5,0981	1.184,7456
Lemak	0,6284	808,6685

Kondisi Operasi

Suhu operasi : 60 °C

Tekanan operasi : 1 atm

Material masuk : 11474,2098 kg/hari

Suhu udara masuk (T_2) : 100 °C (= 212 °F)

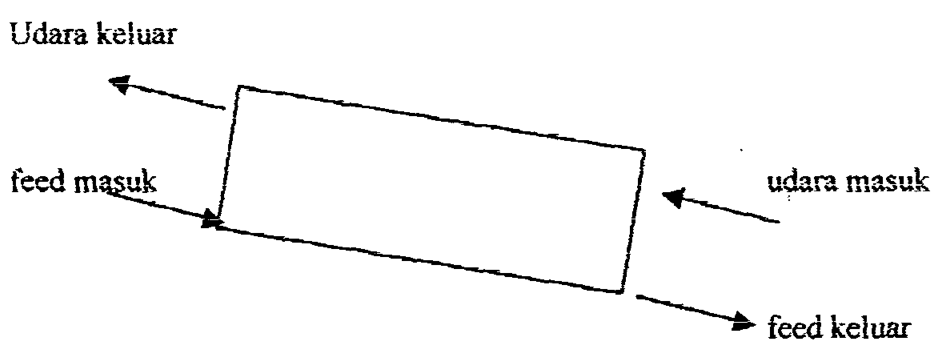
Suhu udara keluar (T_1) : 70 °C (= 158 °F)

Suhu bahan masuk (t_1) : 7,0046 °C (= 44,6083 °F)

Suhu bahan keluar (t_2) : 60 °C (= 140 °F)

Laju udara masuk : 243229,1055 kg/hari

Sketsa Alat



Perhitungan

a. Diameter Rotary Dryer

Kebutuhan udara panas = 243.229,1055 kg/hari = 22346,6741 lb/jam

Dari Perry 6th ed., p.20-33 :

Kecepatan massa udara dalam dryer selalu berkisar antara 400-4000 lb/ft²jam

Ditetapkan : kecepatan massa udara dalam dryer = G = 2500 lb/ft²jam

$$S = \text{cross sectional of dryer, } ft^2 = \frac{rate\ udara\ panas\ masuk}{G}$$

$$= \frac{22346{,}6741 \text{ lb/jam}}{2500 \text{ lb/ft}^2 \text{jam}} = 8{,}9387 \text{ ft}^2$$

$S = \frac{\pi}{4}.D^2$ jadi $D = \sqrt{\frac{4}{\pi}.8{,}9387} = 3{,}3744 \text{ ft} \sim 3{,}5 \text{ ft}$

$S \text{ koreksi} = \frac{\pi}{4}.(3{,}5)^2 = 9{,}6163 \text{ ft}^2$

$$G \text{ koreksi} = \frac{\textit{rate udara masuk}}{S \textit{ koreksi}} = \frac{22346{,}6741 \text{ lb/jam}}{9{,}6163 \text{ ft}^2}$$

$$= 2323{,}8450 \text{ lb/ft}^2\text{.jam}$$

b. Panjang Rotary Dryer

$Qt = 0{,}4 \times L \times D \times G^{0,67} \times \Delta tm$ (Perry 6th ed., pers. 20-37)

Dimana: Qt = Heat transfer total = (8793380,0625 – 8168836,3823) kkal/hari

= 624543,6803 kkal/hari

= 26022,6534 kkal/j = 103266,1367 Btu/jam

L = Panjang (ft)

D = Diameter rotary dryer (ft) = 3,5 ft

G = Kecepatan udara ($\text{lb/ft}^2\text{.jam}$) = $2323{,}8450 \text{ lb/ft}^2\text{.jam}$

Δtm = Beda temperatur antara gas panas dan material

Menentukan Δtm:

$Nt = \frac{T1 - T2}{\Delta tm}$ (Perry 6th ed., pers. 20-38)

Dimana: T1 = Temperatur gas masuk (°F) = 212°F

T2 = Temperatur gas keluar (°F) = 158°F

Range Nt = 1,5 – 2,5, diambil Nt = 2

Maka: $2 = \frac{212 - 158}{\Delta tm}$

$\Delta tm = 27°F$

$$L = \frac{Qt}{0{,}4 \times D \times G^{0,67} \times \Delta tm}$$

$$= \frac{103266{,}1367}{0{,}4 \times 3{,}5 \times 2323{,}8450^{0,67} \times 27} = 15{,}1743 \text{ ft}$$

Dari Perry 6th ed, p. 20-32: L/D = 4 –10

$$\frac{L}{D} = \frac{15{,}1743}{3{,}5} = 4{,}3355$$ (Jadi memenuhi syarat)

c. Kemiringan (slope) rotary dryer

Dari Perry 3th ed, p. 832: Slope (tg α) = 0 – 0,08 ft/ft

Diambil: slope (tg α)= 0,04 ft/ft

$\alpha = 2{,}2906°$

d. Putaran Rotary dryer (N)

Rotary dryer bekerja pada kecepatan peripheral (V) = 30-150 ft/menit (Perry, 3th ed, p.832)

Diambil V = 100 ft/menit

$$N = \frac{V}{\pi . D} = \frac{100}{\pi . 3{,}5} = 9{,}0992 \text{ rpm}$$

Dari Perry 3rd ed, p.832: N × D = 25-35

N x D = 9,0992 × 3,5 = 31,8471 (Jadi memenuhi syarat)

e. Waktu transportasi dalam rotary dryer (θ)

Time of passage , $\theta = \frac{0{,}23 \text{ x } L}{S \text{ x } N^{0,9} \text{ x } D} + 0{,}6 \frac{B \text{ x } L \text{ x } G}{F}$ (Perry, 6th ed, pers 20-39)

Dimana : θ = time of passage, menit

L = Panjang dryer, ft = 15,1743 ft

S = Slope dryer = 0,04 ft/ft

N = kecepatan putaran, rpm = 9,0992 rpm

D = diameter rotary dryer = 3,5 ft

G = kecepatan udara, lb/ft^2.jam = 2323,8450 lb/ft^2.jam

F = kecepatan umpan dalam dryer, lb/ft^2.jam

$$= \frac{1054,1930 \text{ lb/jam}}{9,6163 \text{ ft}^2} = 109,6262 \text{ lb/ft}^2.\text{jam}$$

B = konstanta (tergantung pada material yang dikeringkan)

$= 5 \times (Dp)^{-0,5}$ (Perry, 6th ed.,pers. 20-40)

Dp = diameter partikel, μm = 800 μm

B $= 5 \times (800)^{-0,5} = 0,1768$

$$\theta = \frac{0,23 \times 15,1743}{0,04 \times 9,0992^{0,9} \times 3,5} + 0,6 \times \frac{0,1768 \times 15,1743 \times 2323,8450}{109,6262}$$

= 37,5341 menit

f. Tebal dryer

Dari Perry 3rd ed., p.831, dryer beroperasi dengan isi 10 – 15% volume dryer.

Diambil volume material dalam dryer = 10% volume dryer

Volume dryer = S × L = 9,6163 ft^2 × 15,1743 ft = 145,9194 ft^3

Volume material = 0,1 × 145,9194 cuft = 14,5919 cuft

Densitas material = 1409,6782 kg/m^3 = 88,0062 lb/cuft

Berat material dalam rotary dryer = 14,5919 cuft × 88,0062 lb/cuft

= 1284,1815 lb

Plate yang digunakan adalah stainless steel 18-8 tipe 304 dengan allowable stress

(f) = 19988, c = 0 (Perry 5th ed., p.23-33)

S = Slope dryer = 0,04 ft/ft

N = kecepatan putaran, rpm = 9,0992 rpm

D = diameter rotary dryer = 3,5 ft

G = kecepatan udara, lb/ft^2.jam = 2323,8450 lb/ft^2.jam

F = kecepatan umpan dalam dryer, lb/ft^2.jam

$$= \frac{1054{,}1930 \text{ lb/jam}}{9{,}6163 \text{ ft}^2} = 109{,}6262 \text{ lb/ft}^2\text{.jam}$$

B = konstanta (tergantung pada material yang dikeringkan)

= $5 \times (Dp)^{-0,5}$ (Perry, 6th ed.,pers. 20-40)

Dp = diameter partikel, μm = 800 μm

B = $5 \times (800)^{-0,5} = 0{,}1768$

$$\theta = \frac{0{,}23 \times 15{,}1743}{0{,}04 \times 9{,}0992^{0,9} \times 3{,}5} + 0{,}6 \times \frac{0{,}1768 \times 15{,}1743 \times 2323{,}8450}{109{,}6262}$$

= 37,5341 menit

f. Tebal dryer

Dari Perry 3rd ed., p.831, dryer beroperasi dengan isi 10 – 15% volume dryer.

Diambil volume material dalam dryer = 10% volume dryer

Volume dryer = S × L = 9,6163 ft^2 × 15,1743 ft = 145,9194 ft^3

Volume material = 0,1 × 145,9194 cuft = 14,5919 cuft

Densitas material = 1409,6782 kg/m^3 = 88,0062 lb/cuft

Berat material dalam rotary dryer = 14,5919 cuft × 88,0062 lb/cuft

= 1284,1815 lb

Plate yang digunakan adalah stainless steel 18-8 tipe 304 dengan allowable stress

(f) = 19988, c = 0 (Perry 5th ed., p.23-33)

$$P_{hidrostatis} = \frac{\rho \times h}{144} = \frac{88{,}0062 \text{ lb/ft}^3 \times 1{,}8010 \text{ ft}}{144 \text{ in}^2} = 1{,}1007 \text{ psia}$$

$$P_{operasi} = 14{,}7 + 1{,}1007 = 15{,}8007 \text{ psi}$$

$$P_{design} = 1{,}2 \times P_{operasi} = 1{,}2 \times 15{,}8007 \text{ psi} = 18{,}9608 \text{ psi}$$

$$tsm = \frac{P.D}{2.f.E - P} + C$$ (Brownell & Young, p.45)

$$= \frac{18{,}9608 \frac{\text{lb}}{\text{in}^2} \times 3{,}5 \frac{\text{ft}}{\text{in}} \times 12 \text{in}}{2 \times 19988 \frac{\text{lb}}{\text{in}^2} \times 0{,}8 - 18{,}9608} = 0{,}1499 \text{ in} \approx 3/16 \text{ in}$$

g. Power Rotary dryer

Power rotary dryer = $0{,}5\ D^2 - 1\ D^2$ Hp (Perry 5th ed., p.20-36)

Dimana D = diameter rotary dryer, ft

Effisiensi direct heat rotary dryer antara 55 – 75 % (Perry 6th ed.)

Diambil power rotary dryer = $0{,}75\ D^2$ dan effisiensi 75 %

Power rotary dryer = $0{,}75 \cdot 3{,}5^2 = 9{,}1875$ Hp

$$\text{Power motor} = \frac{power.rotary.dryer}{effisiensi} = \frac{9{,}1875 \text{ Hp}}{0{,}75} = 12{,}25 \text{ Hp}$$

Spesifikasi Alat :

Nama	: Rotary Dryer
Fungsi	: Mengeringkan produk laktosa sampai kandungan air mencapai 1,5 %
Type	: Direct Heat Counter current Rotary Dryer
Bahan	: Stainless steel
Diameter	: 3,5 ft

Panjang : 15,1743 ft

Sudut kemiringan : 2,2906 °

Putaran : 9,0992 rpm

Waktu transportasi : 37,5341 menit

Tebal : $\frac{3}{16}$ in

Power : 12,25 Hp

Jumlah : 1 buah

Separator (H-173)

Tipe : Cyclone separator

Fungsi : Memisahkan padatan laktosa yang terbawa udara panas yang keluar rotary dryer.

Dasar pemilihan : Cocok digunakan untuk memisahkan padatan dari aliran gas, memiliki efisiensi yang tinggi dan desainnya sederhana.

Dimensi cyclone :

(gambar diambil dari Perry, 6th edition, fig. 20-106, p.20-84)

Massa udara masuk dryer = 22515,7482 lb/jam

Suhu udara masuk = 70°C = 158°F

ρ pada 158°F = 0,0643 lb/ft^3 (Geankoplis, 3rd ed, p. 866)

$$\text{Rate udara} = \frac{22515{,}7482\ \text{lb/jam}}{0{,}0643\ \text{lb/ft}^3} = 350080{,}0456\ \text{ft}^3/\text{jam} = 97{,}2445\ \text{ft}^3/\text{detik}$$

Kecepatan gas = 20 -70 ft/s (Perry ed.6, p.20-87)

Ditetapkan kecepatan aliran gas masuk = 50 ft/s

Menentukan luas penampang cyclone (Ac)

$$Ac = \frac{V_1}{V_2}$$

Dimana : V_1 = rate volumetrik udara

V_2 = kecepatan aliran gas masuk

$$Ac = \frac{97{,}2445\ ft^3/detik}{50\ ft/detik}$$

$$= 1{,}9449\ ft^2$$

Keterangan :

$$Ac = Bc \times Hc$$

$$Bc = \frac{Dc}{4}$$

$$Hc = \frac{Dc}{2}$$

Sehingga:

$$Hc = 2 \times Bc$$

$$Ac = 2 \times Bc^2$$

$$Bc = \sqrt{\frac{Ac}{2}} = \sqrt{\frac{1{,}9449}{2}} = 0{,}9861\ ft$$

$$Hc = 2 \times 0{,}9861\ ft = 1{,}9723\ ft$$

$$Dc = 2 \times Hc = 2 \times 1{,}9723\ ft = 3{,}9445\ ft$$

$$De = \frac{Dc}{2} = \frac{3{,}9445\ ft}{2} = 1{,}9723\ ft$$

$$Lc = 2 \times Dc = 2 \times 3{,}9445\ ft = 7{,}8890\ ft$$

$$Sc = \frac{Dc}{8} = \frac{3{,}9445}{8} = 0{,}4931\ ft$$

$$Zc = 2 \times Dc = 2 \times 3{,}9445\ ft = 7{,}8890\ ft$$

$$Jc = \frac{Dc}{4} = \frac{3{,}9445}{4} = 0{,}9861 \text{ ft}$$

Frition loss (Fev) :

$$Fev = \frac{k \times Bc \times Hc}{De^2}$$

Dimana : k = 16 (Perry, 6th edition, p. 20-84)

Harga ini berlaku bila :

$$\frac{Bc}{Dc} = \tfrac{1}{2} - \tfrac{1}{4}$$

$$\frac{Hc}{Dc} = \tfrac{1}{4} - \tfrac{1}{2}$$

$$\frac{De}{Dc} = \tfrac{1}{4} - \tfrac{1}{2}$$

$$Fev = \frac{16 \times 0{,}9861 \times 1{,}9723}{1{,}9723^2}$$

$$= 8 \text{ ft}$$

Spesifikasi alat:

Type : effluent dust cyclone

Kapasitas : 22693,9816 lb/jam

Ukuran : $Ac = 1{,}9449 \text{ ft}^2$

$Bc = 0{,}9861$ ft

$Hc = 1{,}9723$ ft

$Dc = 3{,}9445$ ft

$De = 1{,}9723$ ft

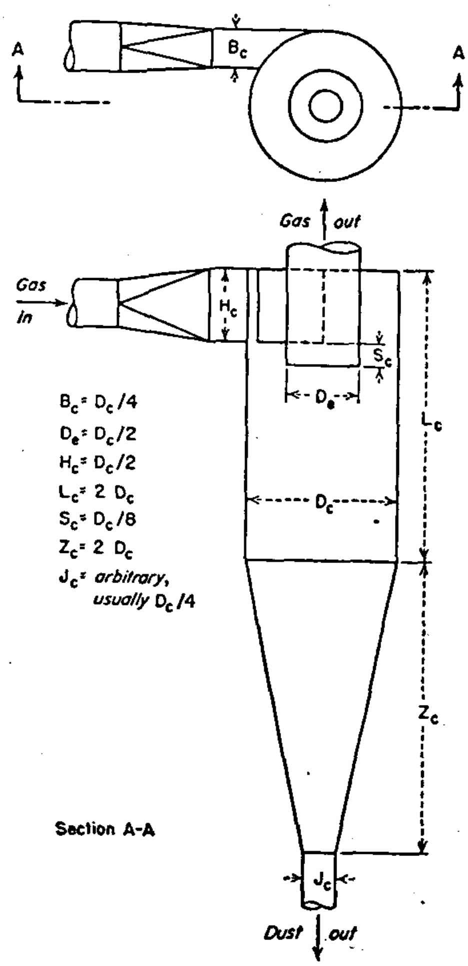
$Lc = 7{,}8890$ ft

$Sc = 0{,}4931$ ft

$Zc = 7{,}8890$ ft

$Jc = 0{,}9861$ ft

Jumlah : 1 buah



Blower (G – 172)

Fungsi : Menghembuskan udara masuk ke rotary dryer

Tipe : Turbo blower

Dasar pemilihan : cocok untuk kapasitas besar

Data : Kebutuhan udara = 243.229,1055 kg/hari = 22346,6741 lb/jam

= 2,8152 kg/s

Tudara = 100°C = 373 K

P masuk = 1 atm

P keluar = 2 atm

$$-Ws = \frac{\gamma}{\gamma - 1} \times \frac{R.T_1}{M} \times \left[\left(\frac{P_2}{P_1} \right)^{(\gamma-1)/\gamma} - 1 \right]$$ .... Geankoplis 3rd.ed, p.139, eq(3.3-14)

di mana : R = 8314,3 j/kmol

γ = 1,4 (untuk udara, Geankoplis, 3rd.ed, p.139)

T_1 = 30 °C

M= 28,84 kg udara/mol

$$-Ws = \frac{1,4}{1,4 - 1} \times \frac{8314,3 \times 373}{28,84} \times \left[\left(\frac{2}{1} \right)^{(1,4-1)/1,4} - 1 \right]$$

= 66.959,8371 j/kg

brake kw = $\frac{-Ws.m}{\eta.1000}$;

di mana : m = kapasitas = 2,8152 kg/s

η = 0,8

brake kw $= \frac{66.959,8371 \times 2,8152}{0,8 \times 1000} = 23,5628$ kw

$= 23,5628 \text{ kw} \times \frac{1 \text{Hp}}{0,7457 \text{kw}} = 31,5982$ Hp

bahan konstruksi = wrought iron

jumlah = 1 buah

Conveyor (J – 181)

Fungsi = mengalirkan kristal laktosa dari rotary dryer (B-170) ke Ball mill (C-175)

Tipe = screw conveyor

Dasar pemilihan = cocok untuk industri makanan

Kondisi operasi = jumlah muatan masuk

Massa campuran kristal laktosa masuk = 9.633,9470 kg / hari

Komponen	masa	densitas
Air	144,5092	924,2108
Protein whey	5,0981	1.157,2728
Lemak	0,6284	786,5392
laktosa terlarut	297,7158	1.495,7168
Mineral	5,2480	2.330,3502
Kalsium asetat	1,3006	2.330,3502
kristal laktosa	9.179,4469	1.495,7168
Total	9.633,9470	

.ρ campuran = 1.482,0146 kg/m^3

Diambil kapasitas 10 ton

Dari Perry edisi 6 hal 7-6 didapat :

- Diameter shaft = 2 in
- Diameter Flight = 10 in
- Feed section diameter = 9 in
- Panjang conveyor = 15 ft

Effisiensi motor = 0,85

Power yang dibutuhkan = 0,85×2/0,85 = 2 hp

bahan konstruksi = stainless stell

Jumlah = 2 buah

Ball Mill (C-180)

Fungsi = untuk menghaluskan produk laktosa

Type = Ball mill

Kapasitas = 12.042,4338 kg/hari

Diambil kapasitas = 15 ton /hari didapatkan dari tabel 8-18 Perry ed 6

Data untuk ball mill dilihat pada Perry,1984 (hal 8-28) tabel 8-18.

Spesifikasi :

1. Kapasitas : 12.042,4338 kg/hari
2. Ukuran : 3 x 2 ft
3. Ball charge : 0,85 ton
4. HP : 5 HP
5. Mill speed : 35 rpm
6. Jumlah : 1 buah

Conveyor (J-182)

Fungsi = mengalirkan bubuk laktosa dari Ball mill (C-175) ke Screen (J-177)

Tipe = screw conveyor

Dasar pemilihan = cocok untuk industri makanan

Kondisi operasi = jumlah muatan masuk

Massa campuran kristal laktosa masuk = 9.633,9470 kg / hari

Komponen	Masa	Densitas
Air	144,5092	924,2108
Protein whey	5,0981	1.157,2728
Lemak	0,6284	786,5392
laktosa terlarut	297,7158	1.495,7168
Mineral	5,2480	2.330,3502
Kalsium asetat	1,3006	2.330,3502
kristal laktosa	9.179,4469	1.495,7168
Total	9.633,9470	

ρ campuran = 1.482,0146 kg/m^3

Diambil kapasitas 10 ton

Dari Perry edisi 6 hal 7-6 didapat :

- Diameter shaft = 2 in
- Diameter Flight = 10 in
- Feed section diameter = 9 in
- Panjang conveyor = 15 ft

Effisiensi motor = 0,85

Power yang dibutuhkan = 0,85/0,85 = 1 hp

bahan konstruksi = stainless stell

Jumlah = 1 buah

Screen (H-183) .

Fungsi = untuk memisahkan ukuran produk laktosa yang tidak sama

Tipe = Vibrating screen

Jumlah = 1 buah

Kapasitas = 12042,4338 kg/hari = 501,7681 kg/jam = 0,5 ton/jam

Kapasitas actual screen = 0,2 – 0,8 ton/ft^2.h.mm mesh size

(Mc.Cabe, 1985.p859)

Pada vibrating screen, biasa dipakai 1800 – 3600 vibrasi per menit. (Mc.Cabe, 854)

Ditetapkan :

- Diameter partikel = 120 mesh = 0,074 mm
- Dipakai 3000 vibrasi per menit.
- Kapasitas actual screen 0,8 ton/ft^2.h.mm mesh size

(Mc.Cabe, 1985, 754)

Luas area yang dibutuhkan = $\frac{0{,}5 ton/h}{0{,}8 ton/ft^2.h.mm.mesh.size} = 0{,}625\, ft^2.mm.mesh/size$

Dipakai screen lebar 12 in dan panjang 24 in

Power = $\frac{1}{3}.hp$

Bin Laktosa (F – 184)

Fungsi : sebagai tempat penyimpanan laktosa

Tipe : silinder tegak dengan tutup atas flat dan tutup bawah berbentuk konis

Dasar pemilihan : cocok untuk penyimpanan material berbentuk granular

Densitas casein = 93,9745 lb/cuft

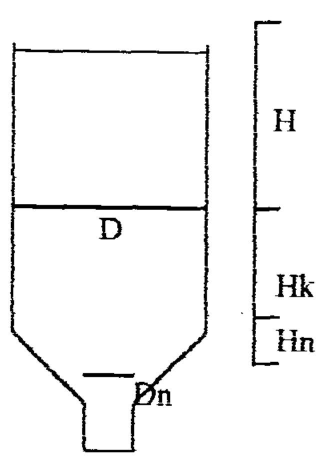
Rate produk : 9605,0452 kg/hari

Volume padatan = 6,3807 m^3 = 225,3212 ft^3

Ditetapkan :

- volume padatan = 80% volume tangki
- Diameter nozzle (Dn) = 1 ft
- $\alpha = 45°$
- Hs = D
- Plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).
- F_M = 0,92 (standard)
- F_S = 0,25 (T_{op} < 650°F)
- Tanpa dikenai radiograf → F_a = 1
- Tanpa stress relieve → F_N = 1
- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$
- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

Volume tangki = 281,2653 ft^3



Keterangan:

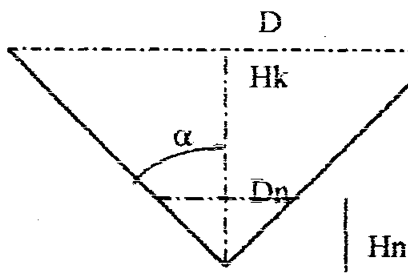
D = diameter shell

H = tinggi shell

Hk = tinggi konis

Hn = tinggi nozzle

Dn = diameter nozzle



Dari gambar dapat dicari persamaan untuk menghitung Hn dan Hk

$$Hn = \frac{Dn}{2 * tg\alpha}$$

$$Hk = \frac{D}{2 * tg\alpha} - Hn = \frac{D - Dn}{2 * tg\alpha}$$

Volume Shell $= \frac{\pi}{4} \times D^2 \times H$ (dengan $\frac{H}{D} = 1$)

$$= \frac{\pi}{4} \times H^3$$

Volume Konis $= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times Hk - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times Hn$

$$= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times \frac{D}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$$

$$= \frac{1}{3} \times \frac{\pi}{4} \times H^2 \times \frac{H}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$$

$$= \frac{\pi}{24.tg\alpha} \times \left(H^3 - Dn^3\right)$$

Volume total tangki = volume shell + volume konis

$$= \frac{\pi}{4} \times H^3 + \frac{\pi}{24.tg\alpha} \times \left(H^3 - Dn^3\right)$$

$$281{,}6515 \text{ ft}^3 = \frac{\pi}{4} \times H^3 + \frac{\pi}{24.tg45^\circ} \times \left(H^3 - 1^3\right)$$

H = 6,8751 ft → H = 8 ft

D = 5,6012 ft

$$\text{Volume padatan dalam konis} = \frac{\pi}{24.tg45^\circ} \times \left(D^3 - 1^3\right)$$

$$= 14{,}1132 \text{ ft}^3$$

$$\text{Tinggi padatan dalam konis} = \frac{D - Dn}{2 \times tg\alpha} = 1{,}4203 \text{ ft}$$

Volume padatan dalam shell = volume padatan – volume padatan dalam konis

$$\frac{\pi}{4} \times D^2 \times H_l = 225{,}3212 \text{ ft}^3 - 14{,}1132 \text{ ft}^3$$

$$H_l = 8{,}9962 \text{ ft}$$

Tinggi total padatan dalam tangki = tinggi padatan dalam shell + tinggi padatan dalam konis

$$= 7{,}5759 \text{ ft} + 1{,}4203 \text{ ft}$$

$$= 8{,}9962 \text{ ft}$$

$$\text{P operasi} = \frac{r.\rho_b.\left(g/gc\right)}{2 \times \mu' \times K'}\left(1 - e^{-2\mu' K' Zt / r}\right)$$

(Mc.Cabe, pers 26-24)

dimana r = jari –jari shell = 5,6012/2 = 2,8006 ft

ρ_b = densitas padatan, untuk laktosa = 93,9745 lb/cuft

g = gaya gravitasi = 32,174 ft/s^2

gc = factor konversi gravitasional = 32,174 lbm.ft/f.s^2

μ' = koefisien friksi, untuk granular material di permukaan metal yang licin 0,35 – 0,55; diambil 0,4

K' = konstanta rasio tekanan, untuk material yang dapat mengalir dengan mudah 0,35 – 0,6; diambil 0,4

Zt = tinggi total padatan; 8,9962 ft

P operasi = 475,9180 lb$_f$/ft^2 = 3,3050 lb$_f$/in^2 = 3,3050 psi

P design diambil 1,2 × P operasi = 3,9960 psi

Tebal shell

$$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_N$$

F$_{allow}$ = 75.000 × 0,92 × 0,25 ×1 × 1 = 17.250 psi

$$t_s = \frac{P_{design} \times Di}{2 \times f_{allow} \times E} + C = \frac{3{,}9960 psi \times 5{,}6012 ft \times 12 \, {}^{in}\!/_{ft}}{2 \times 17{,}250 psi \times 0{,}8} + 0{,}125 in = 0{,}1347 in \rightarrow {}^{3}\!/_{16}\, in$$

tebal tutup atas = tebal shell = 3/16 in

Spesifikasi alat :

Bin laktosa (F – 184)

Dimensi:

ID$_s$ = Diameter dalam tangki = 4,4860 ft

Hs = Tinggi shell = 8 ft ,

Ts = Tebal shell = $^{3}/_{16}$ in

Th = Tebal head = $^{3}/_{16}$ in

Conveyor (J – 211)

Fungsi = mengalirkan endapan casein dari filter press(H - 128) ke tangki pencuci (M –210)

Tipe = screw conveyor

Dasar pemilihan = cocok untuk industri makanan

Kondisi operasi = jumlah muatan masuk

Massa slurry casein masuk = 6993,6341 kg / hari

Komponen	Massa	Densitas
Air	1.304,6426	928,1605
Casein	5.594,9394	1,166,0831
Protein whey	10,1840	1,166,0831
Laktosa	73,3846	1,500,9931
Mineral	10,4835	2,335,1196
Total	6.993,6341	

.ρ campuran = 1.116,1602 kg/m^3

Diambil kapasitas 10 Ton

Diambil kapasitas 10 ton

Dari Perry edisi 6 hal 7-6 didapat :

- Diameter shaft = 2 in
- Diameter Flight = 10 in

- Feed section diameter = 9 in
- Panjang conveyor = 15 ft

Effisiensi motor = 0,85

Power yang dibutuhkan = 0,85×2/0,85 = 2 hp

Bahan konstruksi = Stainless stell

Jumlah = 1 buah

Tangki Pencuci I (M-210)

Fungsi = mencuci slurry casein dengan air pencuci

Tipe = silinder tegak dengan tutup atas berbentuk dished head dan bawah berbentuk konis dilengkapi dengan pengaduk

Dasar pemilihan = beroperasi pada tekanan atmosfer

Data dari neraca massa dan neraca panas

Slurry masuk =1.165,3123 kg/jam

Komponen	Massa kg/hari	Fraksi	Densitas
Air	22278,5043	0,7966	930,7459
Casein	5594,9394	0,2001	1.171,8503
Protein whey	10,1840	0,00036	1.171,8503
Laktosa	73,3846	0,0026	1.504,3470
Mineral	10,4835	0,00037	2.338,2416
	27967,4958		

$$\frac{1}{\rho_{campuran}} = \Sigma \frac{x_i}{\rho_i}$$

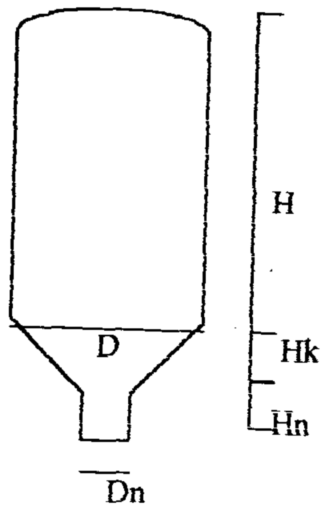
ρ campuran = 972,01883 kg/m³ = 60,6810 lb/ft³

Ditetapkan :

- volume liquid = 80% volume tangki
- Diameter nozzle (Dn) = 1 ft
- $\alpha = 45°$
- Hs = D
- Plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).
- F_M = 0,92 (standard)
- F_S = 0,25 (T_{op} < 650°F)
- Tanpa dikenai radiograf → F_a = 1
- Tanpa stress relieve → F_N = 1
- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$
- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

$$\text{volume liquid} = \frac{umpan.msuk}{\rho_{campuran}} = \frac{1.165,3123 kg}{972,01883 \, kg/m^3} = 1,1989 \text{ m}^3 = 42,3370 \text{ ft}^3$$

$$\text{volume tangki} = \frac{42,3370 \, ft^3}{80\%} = 52,9213 \, ft^3$$



Keterangan:

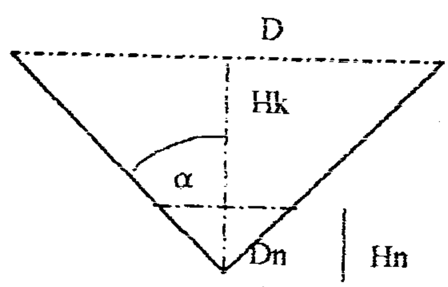
D = diameter shell

H = tinggi shell

Hk = tinggi konis

Hn = tinggi nozzle

Dn = diameter nozzle



Dari gambar dapat dicari persamaan untuk menghitung Hn dan Hk

$$Hn = \frac{Dn}{2 * tg\alpha}$$

$$Hk = \frac{D}{2 * tg\alpha} - Hn = \frac{D - Dn}{2 * tg\alpha}$$

Volume Shell $= \frac{\pi}{4} \times D^2 \times H$ (dengan $\frac{H}{D} = 1$)

$$= \frac{\pi}{4} \times H^3$$

Volume Konis $= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times Hk - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times Hn$

$$= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times \frac{D}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$$

$$= \frac{1}{3} \times \frac{\pi}{4} \times H^2 \times \frac{H}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$$

$$= \frac{\pi}{24.tg\alpha} \times \left(H^3 - Dn^3\right)$$

Volume dished head = 0,000049 Di^3 = 0,000049 H^3

Volume total tangki = volume shell + volume konis + volume dished head

$$= \frac{\pi}{4} \times H^3 + \frac{\pi}{24.tg\alpha} \times \left(H^3 - Dn^3\right) + 0,000049\ H^3$$

52,9213 ft^3 $= \frac{\pi}{4} \times H^3 + \frac{\pi}{24.tg45^\circ} \times \left(H^3 - 1^3\right) + 0,000049\ H^3$

H = 3,6222 ft

Dipakai H = 4 ft

D = 3,6753 ft

Volume liquid dalam konis $= \frac{\pi}{24.tg45^\circ} \times \left(D^3 - 1^3\right)$

$= 3,9291\ ft^3$

Tinggi liquid dalam konis $= \frac{D - Dn}{2 \times tg\alpha} = \frac{3,6753 - 1}{2 \times tg45^\circ} = 0,8258\ ft$

Volume liquid dalam shell = volume liquid – volume liquid dalam konis

$\frac{\pi}{4} \times D^2 \times H_l$ = 42,3370 ft^3 – 3,9291 ft^3

$$\frac{\pi}{4} \times 3{,}6753^2 \times H_l \qquad = 38{,}4080 \text{ ft}^3$$

$$H_l \qquad = 3{,}6222 \text{ ft}$$

Tinggi total liquid dalam tangki = tinggi liquid dalam shell + tinggi liquid dalam konis

$$= 3{,}6222 \text{ ft} + 0{,}8258 \text{ ft}$$

$$= 4{,}4480 \text{ ft}$$

$$\text{P operasi} = \text{P hidrostatik} = \frac{\rho_{campuran} \times Htot}{144}$$

(Brownell & Young, p.46, eq. 3.17)

$$= \frac{60.6810\, {}^{lb}/_{ft^3} \times 4{,}4480\, ft}{144\, {}^{in^2}/_{ft^2}} = 1{,}8744\, psi$$

P design diambil 1,2 × P operasi = 2,2493 psi

Tebal shell

$$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_N$$

F_{allow} = 75.000 × 0,92 × 0,25 ×1 × 1 = 17.250 psi

$$t_s = \frac{p_{design} \times Di}{4 \times f_{allow}} + C = \frac{2{,}2493 psi \times 3{,}6753\, ft \times 12\, {}^{in}/_{ft}}{4 \times 17.250\, psi} + 0{,}125 in = 0{,}1264 in \rightarrow {}^{3}/_{16}\, in$$

OD = 3,6753 ×12 + 2 × 3/16 = 123,0399 in

Tebal dished head

rc = 120

icr = $7\,{}^{5}/_{8}$

(Table 5.7 Brownell p.89)

$$W = {}^{1}/_{4}\left(3 + \sqrt{\frac{rc}{icr}}\right) \ldots$$

(pers 7.76,Brownell,1959)

$$W = \frac{1}{4}\left(3+\sqrt{\frac{120}{7\frac{5}{8}}}\right) = 1,7418$$

$$t_h = \frac{P.rc.W}{2.F.E - 0,2.P} + c \ldots \qquad \text{(pers 7.77,Brownell,1959)}$$

$$t_h = \frac{7,1722.120.1,7418}{2.17250.0,8 - 0,2.7,1722} + 0,125 = 0,1793 \rightarrow \frac{3}{16}in$$

Tebal konis

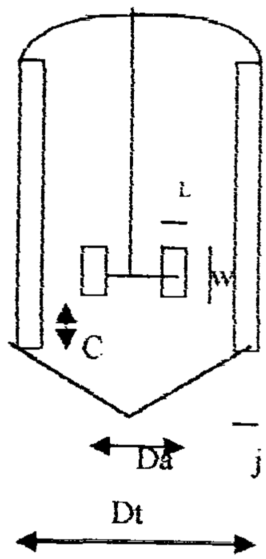
Untuk sudut puncak ≥45° tebal konis = tebal shell = $^3/_{16}$ in

Perhitungan pengaduk

Dipilih jenis pengaduk = six blade turbin with disk

Dari tabel 3.4-1 hal 145 Geankoplis diperoleh:

$$\frac{Da}{Dt} = \frac{1}{3}, \frac{j}{Dt} = \frac{1}{12}, \frac{W}{Da} = \frac{1}{5}, \frac{L}{Da} = \frac{1}{4}, \frac{C}{Dt} = \frac{1}{3}$$



Da = 1/3 Dt = 1/3 × 3,6753 ft = 1,2251 ft

J = 1/12 Dt = 1/12 × 3,6753 ft = 0,3063 ft

W = 1/5 Da = 1/5 × 1,2251 ft = 0,2450 ft

C = 1/3 Dt = 1/3 × 3,6753 ft = 1,2251 ft

Dimana : Da = diameter pengaduk

Dt = diameter tangki

L = panjang blade

W = lebar blade

C = jarak dari dasar tangki ke pusat pengaduk

J = lebar baffle

Kecepatan pengaduk diambil 30 rpm = 0,5 rps

Diambil μ air karena komponen terbesar

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

$$= \left(\frac{(1,2251)^2.0,5.60,6810}{0,0005}\right) = 82.157,6890$$

dari gambar 3.4-4, Geankoplis ed 3[rd], hal 145, untuk flat six-blade turbine with disk diperoleh Np= 4,9

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

$$P = \frac{Np \times \rho \times N^3 \times Da^5}{gc} = \frac{4,9 \times 60,6810\,{}^{lb}/_{ft^3} \times 0,5/s^3 \times (ft)^5}{32,174\,{}^{lb.ft}/_{lbf.s^2}}$$

$$P = 3,1878\,{}^{lb.ft}/_{s} = 0,0058\,Hp$$

Effisiensi pengaduk = 85%

Jumlah pengaduk (n)= tinggi liquid dalam total . sg / diameter tangki

ρ campuran = 60,6810 lb/ ft^3

ρ air pada 4°C = 62,43 lb/ ft^3

sg = ρ camp / ρ air = 0,9720

$$n = \frac{4,4480\,ft \times 0,9720}{3,6753\,ft} = 1,1764 buah \approx 2 buah$$

Power untuk 2 buah pengaduk = 0,0058 ×2/0,85 = 0,0136 Hp

Spesifikasi alat :

Tangki Pencuci I (M-210)

Dimensi:

D =Diameter tangki = 3,6753 ft

H = Tinggi tangki= 4 ft

Ts = Tebal shell = $^{3}/_{16}$ in

Th = Tebal head = $^{3}/_{16}$in

Pengaduk turbin flat six blade dengan baffle

P = 0,0136 Hp ≈0,25 /Hp

Jumlah = 2 buah pengaduk

Bahan konstruksi = plate steel SA-240 grade C

Jumlah tangki = 1 buah

Filter Press (H-213)

Fungsi = untuk memisahkan casein dari larutan pencuci dan impuritiesnya

Tipe = plate and filter frame

Dasar pemilihan = cara pengoperasian sederhana

Perhitungan :

Suhu bahan keluar = 303,75975 T

a. cake

Komponen	massa,kg	Densitas
Air	1.392,4165	931,0062
Casein	5.594,9394	1.172,4309
Protein whey	0,6365	798,7490
Laktosa	4,5866	1.504,7947
Mineral	0,6552	2.338,5559
	6.993,2342	

$$\frac{1}{\rho_{campuran}} = \Sigma \frac{x_{li}}{\rho_i}$$

ρ cake = 1.115,0259 kg/m^3

b. filtrat

Menuju pengolahan limbah	massa	densitas
Air	20.886,0878	931,0062
Protein whey	9,5475	798,7490
Laktosa	68,7980	1.504,7947
Mineral	9,8283	2.338,5559
	20.974,2616	

ρ filtrat = 932,3651 kg/m^3

Rate filtrat = 22,4958 m^3/hari = 247,6127gal/ jam

Rate filtrasi 60-120 gal / ft^2. hr (Perry's ed 5, tabel 19-18)

Diambil rate filtrasi 60 gal/ft^2.hr

Diambil ukuran plate and frame = 7"×7" (Perry's ed 5, table 19-17)

Luas efektif = 0,5 ft^2

$$\text{Luas frame total} = \frac{247{,}6127 \; {gal}/{hr}}{60 \; {gal}/{sqrft.hr}} = 4{,}1269 \; ft^2$$

$$\Sigma plate = \frac{luas.total}{luas.efektif} = \frac{4{,}1269 \; ft^2}{0{,}5 \; ft^2} = 8{,}2538 \approx 9$$

Panjang alat berkisar antara 0,5 – 20 m (Ulrich p223)

Jumlah plate dan frame = $(9\times2)+1$ = 19 buah

Tebal frame berkisar antara 0,125 – 8 in (Perry, 5 ed,p 19-66)

Diambil 4 in

Tebal plate dan frame seluruhnya = 19×4 in = 76 in = 6,333 ft = 1,9304 m

Spesifikasi alat :

Filter Press (H – 213)

Jumlah alat yang dibutuhkan	: 2 buah
Tebal plate dan frame total	: 6,33 ft
Bahan	: metal (Perry ed 5 tab.19-17)

Conveyor (J – 221)

Fungsi = mengalirkan slurry casein dari filter press(H-215) ke tangki pencuci (M-220)

Tipe = screw conveyor

Dasar pemilihan = cocok untuk industri makanan

Kondisi operasi = jumlah muatan masuk

Massa slurry casein masuk = 6993,2342 kg

Komponen	Massa,kg	Fraksi	Densitas
Air	1392,4165	0,1991	931,0062
Casein	5594,9394	0,8001	1.172,4309
Protein whey	0,6365	0,0001	1.172,4309
Laktosa	4,5866	0,0007	1.504,7947
Mineral	0,6552	0,0001	2.338,5559
	6993,2342	1,0000	

Densitas campuran = 1.115,0711 kg/m^3

Diambil kapasitas 10 ton

Dari Perry edisi 6 hal 7-6 didapat :

- Diameter shaft = 2 in
- Diameter Flight = 10 in
- Feed section diameter = 9 in
- Panjang conveyor = 15 ft

Effisiensi motor = 0,85

Power yang dibutuhkan = 0,85×2/0,85 = 2 hp

bahan konstruksi = stainless stell

Jumlah = 2 buah

Tangki Pencuci II (M-220)

Fungsi = mencuci slurry casein dengan air

Tipe = silinder tegak dengan tutup atas berbentuk dished head dan bawah berbentuk konis dilengkapi dengan pengaduk

Dasar pemilihan = beroperasi pada tekanan atmosfer

Data dari neraca massa dan neraca panas

Komponen	Massa, kg/hari	Densitas	Fraksi
Air	1.392,4165	931,0062	0,0498
Casein	5.594,9394	1.172,4309	0,2000
Protein whey	0,6365	1.172,4309	0,0000
Laktosa	4,5866	1.504,6947	0,0002
Mineral	0,6552	2.338,5559	0,0000
Air pencuci	20.979,7026	931,1828	0,7500
Total	27.972,9368		1,0000

Slurry masuk 1.165,5390 kg/jam

$$\frac{1}{\rho_{campuran}} = \Sigma \frac{x_i}{\rho_i}$$

ρ campuran = 971,2244 kg/m^3 = 60,6314 lb/cuft

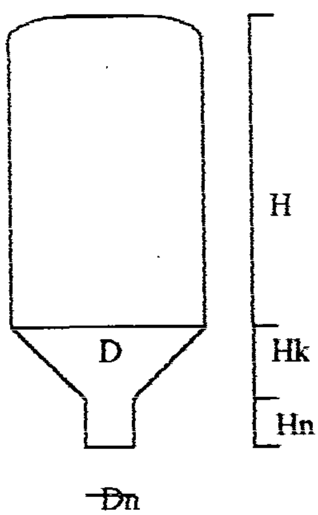
Ditetapkan :

- volume liquid = 80% volume tangki
- Diameter nozzle (Dn) = 1 ft
- α = 45°
- Hs = D
- Plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).
- F_M = 0,92 (standard)
- F_S = 0,25 (T_{op} < 650°F)

- Tanpa dikenai radiograf → $F_a = 1$
- Tanpa stress relieve → $F_N = 1$
- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$
- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

$$\text{volume liquid} = \frac{umpan\,masuk}{\rho_{campuran}} = \frac{1.165{,}53908\,kg}{971{,}2244\,{}^{kg}/{}_{m^3}} = 1{,}2001\ m^3 = 52{,}9749\ ft^3$$

$$\text{volume tangki} = \frac{42{,}3799\ ft^3}{80\%} = 52{,}9749\ ft^3$$



Keterangan:

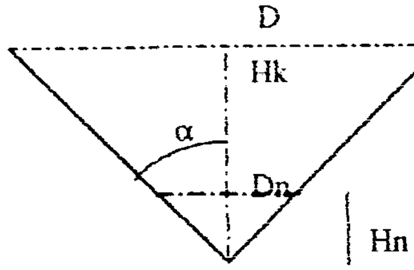
D = diameter shell

H = tinggi shell

Hk = tinggi konis

Hn = tinggi nozzle

Dn = diameter nozzle



Dari gambar dapat dicari persamaan untuk menghitung Hn dan Hk

$$Hn = \frac{Dn}{2 * tg\alpha}$$

$$Hk = \frac{D}{2 * tg\alpha} - Hn = \frac{D - Dn}{2 * tg\alpha}$$

Volume Shell $= \frac{\pi}{4} \times D^2 \times H$ (dengan $\frac{H}{D} = 1$)

$$= \frac{\pi}{4} \times H^3$$

Volume Konis $= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times Hk - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times Hn$

$$= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times \frac{D}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$$

$$= \frac{1}{3} \times \frac{\pi}{4} \times H^2 \times \frac{H}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$$

$$= \frac{\pi}{24.tg\alpha} \times \left(H^3 - Dn^3\right)$$

Volume dished head = 0,000049 Di^3 = 0,000049 H^3

Volume total tangki = volume shell + volume konis + volume dished head

$$= \frac{\pi}{4} \times H^3 + \frac{\pi}{24.tg\alpha} \times \left(H^3 - Dn^3\right) + 0{,}000049\ H^3$$

$$52{,}9749\ ft^3 = \frac{\pi}{4} \times H^3 + \frac{\pi}{24.tg45°} \times \left(H^3 - 1^3\right) + 0{,}000049\ H^3$$

H = 3,9425 ft

Dipakai H = 4 ft

D = 3.9050 ft

Volume liquid dalam konis = $\frac{\pi}{24\,tg45°} \times \left(D^3 - 1^3\right)$

$= 4{,}7292\ ft^3$

Tinggi liquid dalam konis = $\frac{D - Dn}{2 \times tg\alpha} = \frac{3{,}9050 - 1}{2 \times tg45°} = 0{,}8967\ ft$

Volume liquid dalam shell = volume liquid – volume liquid dalam konis

$\frac{\pi}{4} \times D^2 \times H_l \quad = 42{,}3799 ft^3 - 4{,}7292\ ft^3$

$\frac{\pi}{4} \times 3{,}9050^2 \times H_l \quad = 37{,}6507\ ft^3$

$H_l \quad = 3{,}1452\ ft$

Tinggi total liquid dalam tangki = tinggi liquid dalam shell + tinggi liquid dalam konis

= 3,1452 ft + 0,8967 ft

= 4,042 ft

P operasi = P hidrostatik = $\frac{\rho_{campuran} \times Htot}{144}$

(Brownell & Young, p.46, eq. 3.17)

$= \frac{60{,}6314\ {}^{lb}/_{ft^3} \times 4{,}0420\ ft}{144\ {}^{in^2}/_{ft^2}} = 1{,}7019\ psi$

P design diambil 1,2 × P operasi = 2,0423psi

Tebal shell

$$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_Y$$

F_{allow} = 75.000 × 0,92 × 0,25 ×1 × 1 = 17.250 psi

$$t_s = \frac{P_{design} \times Di}{2 \times f_{allow} \times E} + C = \frac{2{,}0423\,psi \times 3{,}9050\,ft \times 12\,\frac{in}{ft}}{2 \times 17.250\,psi \times 0{,}80} + 0{,}125 in = 0{,}1264 in \rightarrow \tfrac{3}{16} in$$

OD = 3,9050 ×12 + 2 × 3/16 = 131,9109 in

Tebal dished head

rc = 130

icr = 8 (Table 5.7 Brownell p.89)

$$W = \tfrac{1}{4}\left(3 + \sqrt{\frac{rc}{icr}}\right)\ldots$$ (pers 7.76,Brownell,1959)

$$W = \tfrac{1}{4}\left(3 + \sqrt{\frac{130}{8}}\right) = 1{,}7578$$

$$t_h = \frac{P.rc.W}{2.F.E - 0{,}2.P} + c \ldots$$ (pers 7.77,Brownell,1959)

$$t_h = \frac{6{,}4329.130.1{,}7578}{2.17250.0{,}8 - 0{,}2.6{,}4329} + 0{,}125 = 0{,}1783 \rightarrow \tfrac{3}{16} in$$

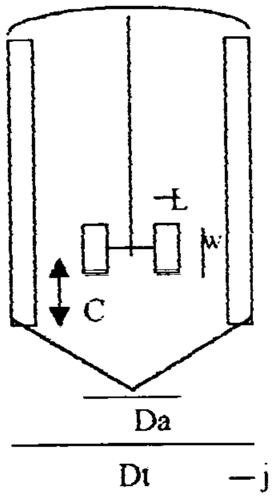
Tebal konis

Untuk sudut puncak ≥45° tebal konis = tebal shell = $^3/_{16}$ in

Perhitungan pengaduk

Dipilih jenis pengaduk = six blade turbin with disk

Dari tabel 3.4-1 hal 145 Geankoplis diperoleh:



Da = 1/3 Dt = 1/3 × 3,9050 ft = 1,3017 ft

J = 1/12 Dt = 1/12 × 3,9050 ft = 0,3254 ft

W = 1/5 Da = 1/5 × 1,3017 ft = 0,2603 ft

C = 1/3 Dt = 1/3 × 3,9050 ft = 1,3017 ft

Dimana : Da = diameter pengaduk

Dt = diameter tangki

L = panjang blade

W = lebar blade

C = jarak dari dasar tangki ke pusat pengaduk

J = lebar baffle

Kecepatan pengaduk diambil 30 rpm = 0,5 rps

Diambil μ air karena komponen terbesar

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

$$= \left(\frac{(1{,}3017)^2.0{,}5.60{,}6314}{0{,}0005}\right) = 743{,}056.7085$$

dari gambar 3.4-4, Geankoplis ed 3rd, hal 145, untuk flat six-blade turbine with disk diperoleh Np= 4,9

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

$$P = \frac{Np \times \rho \times N^3 \times Da^5}{gc} = \frac{4{,}9 \times 60{,}6314\ {}^{lb}/_{ft^3} \times 0{,}5 / s^3 \times (1{,}3017\,ft)^5}{32{,}174\ {}^{lb.ft}/_{lbf.s^2}}$$

$$P = 4{,}3134\ {}^{lb.ft}/_{s} = 0{,}0078\ Hp$$

Effisiensi pengaduk = 85%

Jumlah pengaduk (n)= tinggi liquid dalam total . sg / diameter tangki

ρ campuran = 60,6314 lb/ ft^3

ρ air pada 4°C = 62,43 lb/ ft^3

sg = ρ camp / ρ air = 0,9712

$$n = \frac{4{,}0420\ ft \times 0{,}9712}{3{,}9050\,ft} = 1{,}0052\,buah \approx 2\,buah$$

Power untuk 2 buah pengaduk = 0,0078×2 = 0,0185 Hp

Spesifikasi alat :

Tangki Pencuci II (M-220)

Dimensi:

D =Diameter tangki = 3,9050 ft

H = Tinggi tangki= 4 ft

Ts = Tebal shell = $^3/_{16}$ in

Th = Tebal head = $^3/_{16}$in

Pengaduk turbin flat six blade dengan baffle

P = 0,0185 Hp ≈ 0,25 Hp

Jumlah = 2 buah pengaduk

Bahan konstruksi = plate steel SA-240 grade C

Jumlah tangki = 1 buah

Filter Press (H-223)

Fungsi = untuk memisahkan casein dari larutan pencuci dan impuritiesnya

Tipe = plate and filter frame

Dasar pemilihan = cara pengoperasian sederhana

Perhitungan :

Suhu bahan keluar = 302,3886 T

a. cake

Komponen	massa,kg	Densitas
Air	1.398,2574	931,3249
Casein	5.594,9394	1.173,1418
Laktosa	0,2867	1.505,2204
	6.993,4835	

$$\frac{1}{\rho_{campuran}} = \Sigma \frac{x_{li}}{\rho_i}$$

ρ cake = 1.115,2552 kg/m^3

b. filtrat

Menuju M-210	Massa	Densitas
Air	20.973,8617	931,3249
Protein whey	0,6365	1.173,1418
Laktosa	4,2999	1.505,2204
Mineral	0,6552	2.338,9407
	20.979,4533	

ρ filtrat = 931,4210 kg/m^3

Rate filtrat = 22,5241 m^3/hari = 247,9250gal/ jam

Rate filtrasi 60-120 gal / ft^2. hr (Perry's ed 5, tabel 19-18)

Diambil rate filtrasi 60 gal/ft^2.hr

Diambil ukuran plate and frame = 7"×7" (Perry's ed 5, table 19-17)

Luas efektif = 0,5 ft^2

$$\text{Luas frame total} = \frac{247{,}9250\, {}^{gal}/_{hr}}{60\, {}^{gal}/_{sqrft.hr}} = 4{,}1321 ft^2$$

$$\Sigma plate = \frac{luas.total}{luas.efektif} = \frac{4{,}1321 ft^2}{0{,}5 ft^2} = 8{,}2642 \approx 9$$

Panjang alat berkisar antara 0,5 – 20 m (Ulrich p223)

Jumlah plate dan frame = (9×2)+1 = 19 buah

Tebal frame berkisar antara 0,125 – 8 in (Perry, 5 ed,p 19-66) diambil 4 in

Tebal plate dan frame seluruhnya = 19 × 4 in = 76 in = 6,333 ft = 1,9304 m

Spesifikasi alat :

Filter Press (H – 223)

Jumlah alat yang dibutuhkan	: 2 buah
Tebal plate dan frame total	: 6,33 ft
Bahan	: metal (Perry ed 5 tab.19-17)

Tangki Penampung Filtrat(F – 224)

Fungsi = untuk menampung filtrat sebelum masuk ke Tangki pencuci I (M – 210)

Tipe = silinder tegak dengan tutup atas dan bawah flat head.

Komponen	Massa kg/hari	Densitas
Air	20.973,8617	931,3249
Protein whey	0,6365	1,173,1418
Laktosa	4,2999	1,505,2204
Mineral	0,6552	2,338,9407
	20.979,4533	

$$\frac{1}{\rho_{campuran}} = \Sigma \frac{x_i}{\rho_{1i}}$$

ρ campuran = 931,4210 kg/m^3 = 58,1466 lb/ft^3

Kapasitas bahan masuk = 874,1439 kg/jam

Ditetapkan :

- volume liquid = 80% volume tangki
- Plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).
- F_M = 0,92 (standard)
- F_S = 0,25 (T_{op} < 650°F)
- Tanpa dikenai radiograf → F_a = 1
- Tanpa stress relieve → F_N = 1
- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$

- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

$$\text{volume liquid} = \frac{umpan.masuk}{\rho_{campuran}} = \frac{874,1439 kg}{931,4210 \, kg/m^3} = 0,9385 \text{ m}^3 = 33,1428 \text{ ft}^3$$

$$\text{volume tangki} = \frac{33,1428 ft^3}{80\%} = 41,4285 ft^3$$

Volume total tangki = volume shell

$$= \frac{\pi}{4} \times H^3$$

$$41,4285 \text{ ft}^3 = \frac{\pi}{4} \times H^3$$

Hs = 3,7152 ft

Dipakai jadi Hs = 4 ft

D = 3,6323 ft

Volume liquid dalam shell = volume liquid

$$\frac{\pi}{4} \times D^2 \times H_l = 33,1428 \text{ ft}^3$$

$$\frac{\pi}{4} \times 3,6323^2 \times H_l = 33,1428 \text{ ft}^3$$

$$H_l = 3,2 \text{ ft}$$

$$\text{P operasi} = \text{P hidrostatik} = \frac{\rho_{campuran} \times Hliquid}{144}$$

(Brownell & Young, p.46, eq. 3.17)

$$= \frac{58,1466 \, lb/ft^3 \times 63,2 ft}{144 \, in^2/ft^2} = 1,2921 psi$$

P design diambil 1,2 × P operasi = 1,5506 psi

Tebal shell

$$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_N$$

F_{allow} = 75.000 × 0,92 × 0,25 ×1 × 1 = 17.250 psi

$$t_s = \frac{p_{design} \times Di}{2 \times f_{allow} \times E} + C = \frac{1{,}5506 psi \times 3{,}6323 ft \times 12 \, in/ft}{2 \times 17{,}250 psi \times 0{,}8} + 0{,}125 in = 0{,}1252 in \rightarrow 3/16 \, in$$

Tebal head = tebal shell = $^3/_{16}$ in

Spesifikasi alat

Tangki Penampung Filtrat(F – 224)

Dimensi tangki :

Kapasitas maksimum : 41,4258 ft^3

Kapasitas operasi : 33,1428 ft^3

Diameter : 3,6323 ft

Tinggi shell : 4 ft

Tebal shell : $^3/_{16}$ in

Tebal plat atas dan bawah : $^3/_{16}$ in

Bahan konstruksi : plate steel SA-240 grade C

Jumlah tangki : 1 buah

Conveyor (J-231)

Fungsi = mengalirkan slurry casein dari filter press(H-223) ke rotary drier (B-230)

Tipe = screw conveyor

Dasar pemilihan = cocok untuk industri makanan

Kondisi operasi = jumlah muatan masuk

Massa slurry casein masuk = 6993,4835 kg

Komponen	massa,kg	fraksi	densitas
Air	1398.2574	0.1999	931.3099
Casein	5594.9394	0.8000	1,173.1084
Laktosa	0.2867	0.0000	1,505.2005
	6,993.4835	1.0000	

Densitas campuran = 1.115,2268 kg/m^3

Diambil kapasitas 10 ton

Dari Perry edisi 6 hal 7-6 didapat :

- Diameter shaft = 2 in
- Diameter Flight = 10 in
- Feed section diameter = 9 in
- Panjang conveyor = 15 ft

Effisiensi motor = 0,85

Power yang dibutuhkan = 0,85×2/0,85 = 2 hp

bahan konstruksi = stainless stell

Jumlah = 2 buah

Rotary dryer (B-230)

Fungsi : Mengeringkan produk casein sampai kandungan air mencapai 0,5 %

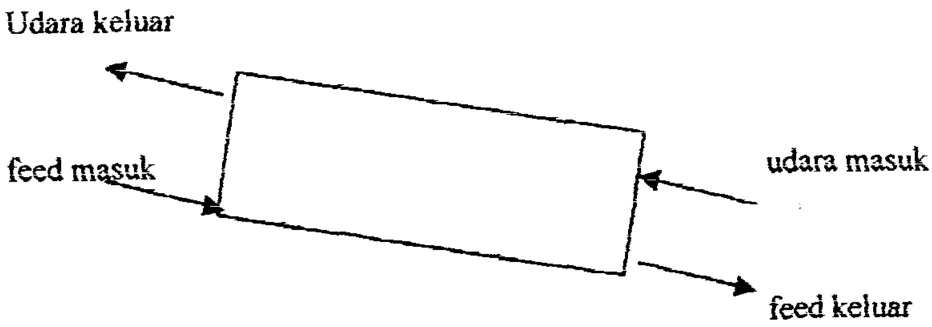
Type : Direct Heat Counter current Rotary Dryer

Dasar pemilihan : Perpindahan panas yang terjadi besar karena udara berkontak langsung dengan bahan

Kondisi Operasi

Suhu operasi	: 60 °C
Tekanan operasi	: 1 atm
Material masuk	: 6993,4835 kg/hari
Suhu udara masuk (T_2)	: 100 °C (= 212 °F)
Suhu udara keluar (T_1)	: 70 °C (= 158 °F)
Suhu bahan masuk (t_1)	: 29,3886 °C (= 84,8994 °F)
Suhu bahan keluar (t_2)	: 60 °C (= 140 °F)
Laju udara masuk	: 172036,4849 kg/hari

Sketsa Alat



Perhitungan

a. Diameter Rotary Dryer

Kebutuhan udara panas = 172036,4849 kg/hari = 15805,8520 lb/jam

Dari Perry ed.6, p.20-36 :

Kecepatan massa udara dalam dryer selalu berkisar antara 400-4000 lb/ft^{2}jam

Ditetapkan : kecepatan massa udara dalam dryer = G = 2500 lb/ft^{2}jam

$$S = \text{cross sectional of dryer, ft}^2 = \frac{\textit{rate udara panas masuk}}{G}$$

$$= \frac{15805{,}8520\ \text{lb/jam}}{2500\ \text{lb/ft}^2\text{jam}} = 6{,}3223\ \text{ft}^2$$

$S = \frac{\pi}{4}.D^2$ jadi $D = \sqrt{\frac{4}{\pi}.6{,}3223} = 2{,}8379\ \text{ft} \sim 3\ \text{ft}$

S koreksi $= \frac{\pi}{4}.(3)^2 = 7{,}0650\ \text{ft}^2$

G koreksi $= \frac{\textit{rate udara masuk}}{\textit{S koreksi}} = \frac{15805{,}8520\ \text{lb/jam}}{7{,}0650\ \text{ft}^2}$

$= 2237{,}2048\ \text{lb/ft}^2.\text{jam}$

b. Panjang Rotary Dryer

$Qt = 0{,}4 \times L \times D \times G^{0{,}67} \times \Delta tm$

Dimana: Qt = Heat transfer total = (6219577,1889 – 5821220,4789) kkal/hari

= 398356,7099 kkal/hari

= 16598,1962 kkal/j = 65866,9036 Btu/jam

L = Panjang (ft)

D = Diameter rotary dryer (ft) = 3 ft

G = Kecepatan udara (lb/ft^2.jam) = 2237,2048 lb/ft^2.jam

Δtm = Beda temperatur antara gas panas dan material

Menentukan Δtm:

$$Nt = \frac{T1 - T2}{\Delta tm}$$

Dimana: T1 = Temperatur gas masuk (°F) = 212°F

T2 = Temperatur gas keluar (°F) = 158°F

Range Nt = 1,5 – 2,5, diambil Nt = 2

Maka: $2 = \frac{212 - 158}{\Delta tm}$

$\Delta tm = 27°F$

$$L = \frac{Qt}{0{,}4 \times D \times G^{0,67} \times \Delta tm}$$

$$= \frac{65866{,}9036}{0{,}4 \times 3 \times 2237{,}2048^{0,67} \times 27} = 11{,}5830 \text{ ft}$$

Dari Perry 6th ed, pers. 20-32: L/D = 4 –10

$$\frac{L}{D} = \frac{11{,}5830}{3} = 3{,}8610 \approx 4$$ (Jadi memenuhi syarat)

c. Kemiringan (slope) rotary dryer

Dari Perry 6th ed, pers. 20-36: Slope ($tg\ \alpha$) = 0 – 1 in/ft

Diambil: slope ($tg\ \alpha$)= 0,5 in/ft = 0,0417 ft/ft

$\alpha = 2{,}3879°$

d. Putaran Rotary dryer (N)

Rotary dryer bekerja pada kecepatan peripheral (V) = 50-300 ft/menit (Perry, 6th ed)

Diambil V = 100 ft/menit

$$N = \frac{V}{\pi . D} = \frac{100}{\pi . 3} = 10{,}6157 \text{ rpm}$$

Dari Perry 3rd ed, p.832: N × D = 25-35

N x D = 10,6157 × 3 = 31,8471 (Jadi memenuhi syarat)

e. Waktu transportasi dalam rotary dryer (θ)

$$\text{Time of passage}, \theta = \frac{0{,}23 \text{ x } L}{S \text{ x } N^{0,9} \text{ x } D} + 0{,}6 \frac{B \text{ x } L \text{ x } G}{F}$$ (Perry, 6th ed, pers 20-54)

Dimana : θ = time of passage, menit

L = Panjang dryer, ft = 11,5830 ft

S = Slope dryer = 0,0417 ft/ft

N = kecepatan putaran, rpm = 10,6157 rpm

D = diameter rotary dryer = 3 ft

G = kecepatan udara, lb/jam ft^2 = 2237,2048 lb/ ft^2.jam

F = kecepatan umpan dalam dryer, lb/jam = 6993,4835 kg/hari

= 642,5263 lb/jam

B = konstanta (tergantung pada material yang dikeringkan)

$= 5 \times (Dp)^{-0,5}$

Dp = diameter partikel, μm = 212,2061 μm

$B = 5 \times (212,2061)^{-0,5} = 0,3432$

$$\theta = \frac{0,23 \times 11,5830}{0,0417 \times 10,6157^{0,9} \times 3} + 0,6 \times \frac{0,3432 \times 11,5830 \times 2237,2048}{642,5263}$$

= 6,3687 menit

f. Tebal dryer

Dari Perry 3rd ed., p.831, dryer beroperasi dengan isi 10 – 15% volume dryer.

Diambil volume material dalam dryer = 10% volume dryer

Volume dryer = S × L = 6,3223 ft^2 × 11,5830 ft = 81,8336 ft^3

Volume material = 0,1 × 81,8336 cuft = 8,1834 cuft

Densitas material = 1231,2011 kg/m^3 = 76,8639 lb/cuft

Berat material dalam rotary dryer = 8,1834 cuft × 76,8639 lb/cuft

= 629,0047 lb

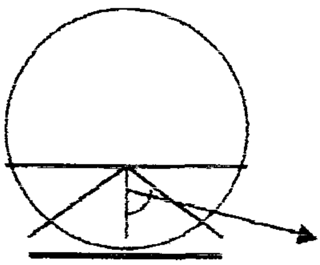
Plate yang digunakan adalah stainless steel 18-8 tipe 304 dengan allowable stress

(f) = 19988, c = 0 (Perry 5th ed., p.23-33)

Untuk las dipakai double welded butt joint, effisiensi (E) = 80%

Menentukan tinggi material untuk menentukan P hidrostatik

Luas penampang material = $\frac{V}{L} = \frac{8{,}1834\ ft^3}{11{,}5830\ ft} = 1{,}1583\ ft^2$



A segitiga = A juring – A material

A cairan = A juring – A segitiga

$= \frac{2\alpha}{360}.\pi.R^2 - 2.\frac{1}{2} \times \text{luas alas} \times \text{tinggi}$

$= \frac{2\alpha}{360}.\pi.R^2 - 2.\frac{1}{2}\text{y.x.}$

$1{,}1583\ ft^2 = \frac{2\alpha}{360}.\pi.R^2 - (2.\frac{1}{2}.R\sin\alpha \times R\cos\alpha)$

$= \frac{2\alpha}{360}.\pi.\left(\frac{3}{2}\right)^2 - (\left(\frac{3}{2}\right)^2 \sin\alpha.\cos\alpha)$

α = 26,7518°

h = tinggi cairan = R – x

= R - Rcosα = R (1-cosα) = $\frac{3}{2}$ [1-cos(26,7518°)]

= 1,5723 ft

$P_{hidrostatis} = \frac{\rho \times h}{144} = \frac{76{,}8639\ lb/ft^3 \times 1{,}5723\ ft}{144\ in^2} = 0{,}8393\ psia$

$P_{operasi}$ $= 14,7 + 0,8393 = 15,5393$ psi

P_{design} $= 1,2 \times P_{operasi} = 1,2 \times 15,5393$ psi $= 18,6471$ psi

tsm $= \dfrac{P.D}{2.f.E - P} + C$ (Brownell & Young, p.45)

$$= \frac{18,6471 \dfrac{lb}{in^2} \times 3 \dfrac{ft}{in} \times 12 \, in}{2 \times 19988 \dfrac{lb}{in^2} \times 0,8 - 18,6471} = 0,1460 \text{ in} \approx 3/16 \text{ in}$$

g. Power Rotary dryer

Power rotary dryer = 0,5 D^2 – 1 D^2 Hp (Perry ed.5, p.20-36)

Dimana D = diameter rotary dryer, ft

Effisiensi direct heat rotary dryer antara 55 – 75 % (Perry ed.6)

Diambil power rotary dryer = 0,75 D^2 dan effisiensi 75 %

Power rotary dryer = 0,75 . 3^2 = 6,75 Hp

$$\text{Power motor} = \frac{power.rotary.dryer}{effisiensi} = \frac{6,75 \text{ Hp}}{0,75} = 9 \text{ Hp}$$

Spesifikasi Alat :

Nama	: Rotary Dryer
Fungsi	: Mengeringkan produk casein sampai kandungan air mencapai 0,5 %
Type	: Direct Heat Counter current Rotary Dryer
Bahan	: Stainless steel
Diameter	: 3 ft
Panjang	: 11,5830 ft
Sudut kemiringan	: 26,7518°

Putaran : 10,6157 rpm

Waktu transportasi : 6,3687 menit

Tebal : $\frac{3}{16}$ in

Power : 9 Hp

Jumlah : 1 buah

Separator (H-233)

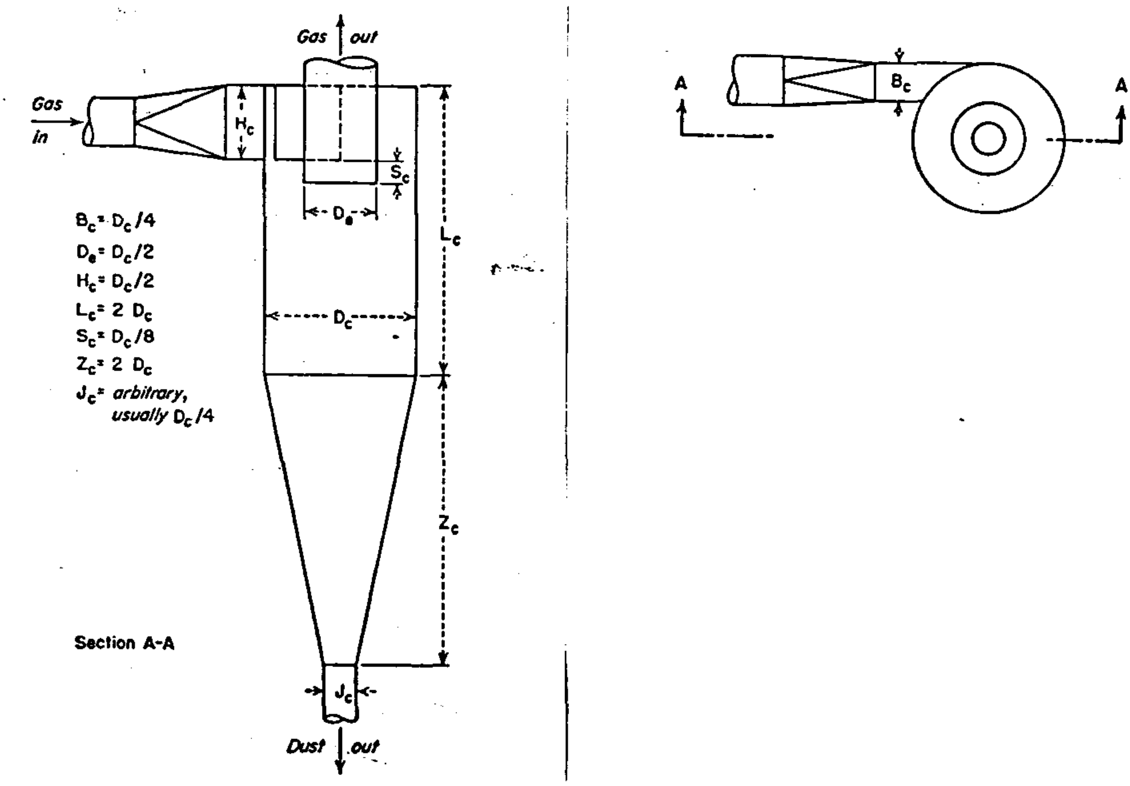
Tipe : Cyclone separator

Fungsi : Memisahkan padatan casein yang terbawa udara panas yang keluar rotary dryer.

Dasar pemilihan : Cocok digunakan untuk memisahkan padatan dari aliran gas, memiliki efisiensi yang tinggi dan desainnya sederhana.

Dimensi cyclone :

(gambar diambil dari Perry, 6th edition, fig. 20-106, p.20-84)



Massa udara masuk dryer = 15931,7725 lb/jam

Suhu udara masuk = 70°C = 158°F

ρ pada 158°F = 0,0643 lb/ft^3 (Geankoplis, 3rd ed, p. 866)

$$\text{Rate udara} = \frac{15931{,}7725\ \text{lb/jam}}{0{,}0643\ \text{lb/ft}^3} = 247710{,}8725\ \text{ft}^3/\text{jam} = 68{,}8086\ \text{ft}^3/\text{detik}$$

Kecepatan gas = 50 -75 ft/s (Perry ed.6, p.10-82)

Ditetapkan kecepatan aliran gas = 75 ft/s

Menentukan luas penampang cyclone (Ac)

$$Ac = \frac{V_1}{V_2}$$

Dimana : V_1 = rate volumetrik udara

V_2 = kecepatan bahan masuk

$$Ac = \frac{68{,}8086\ \text{ft}^3/\text{detik}}{75\ \text{ft/detik}}$$

$$= 0{,}9174\ \text{ft}^2$$

Keterangan :

$$Ac = Bc \times Hc$$

$$Bc = \frac{Dc}{4}$$

$$Hc = \frac{Dc}{2}$$

Sehingga:

$$Hc = 2 \times Bc$$

$$Ac = 2 \times Bc^2$$

$$Bc = \sqrt{\frac{Ac}{2}} = \sqrt{\frac{0{,}9174}{2}} = 0{,}6773\ \text{ft}$$

$Hc = 2 \times 0,6773 \text{ ft} = 1,3546 \text{ ft}$

$Dc = 2 \times Hc = 2 \times 1,3546 \text{ ft} = 2,7092 \text{ ft}$

$De = \dfrac{Dc}{2} = \dfrac{2,7092 \text{ ft}}{2} = 1,3546 \text{ ft}$

$Lc = 2 \times Dc = 2 \times 2,7092 \text{ ft} = 5,4183 \text{ ft}$

$Sc = \dfrac{Dc}{8} = \dfrac{2,7092}{8} = 0,3386 \text{ ft}$

$Zc = 2 \times Dc = 2 \times 2,7092 = 5,4183 \text{ ft}$

$Jc = \dfrac{Dc}{4} = \dfrac{2,7092}{4} = 0,6773 \text{ ft}$

Frition loss (Fev) :

$$Fev = \frac{k \times Bc \times Hc}{De^2}$$

Dimana : k = 16 (Perry, 6th edition, p. 20-84)

Harga ini berlaku bila :

$$\frac{Bc}{Dc} = \tfrac{1}{12} - \tfrac{1}{4}$$

$$\frac{Hc}{Dc} = \tfrac{1}{4} - \tfrac{1}{2}$$

$$\frac{De}{Dc} = \tfrac{1}{4} - \tfrac{1}{2}$$

$$Fev = \frac{16 \times 0,6773 \times 1,3546}{1,3546^2}$$

$= 8$ ft

Spesifikasi alat:

Type : effluent dust cyclone

Kapasitas : 16062,4895 lb/jam

Ukuran : Ac = 0,9174 ft^2

Bc = 0,6773 ft

Hc = 1,3546 ft

Dc = 2,7092 ft

De = 1,3546 ft

Lc = 5,4183 ft

Sc = 0,3386 ft

Zc = 5,4183 ft

Jc = 0,6773 ft

Jumlah : 1 buah

Blower (G – 232)

Fungsi : Menghembuskan udara masuk ke rotary dryer (B-230)

Tipe : Turbo blower

Dasar pemilihan :cocok untuk kapasitas besar

Data : Kebutuhan udara = 172036,4849 kg/hari = 15805,8520 lb/jam

= 1,9521 kg/second

Tudara = 100°C = 373 K

P masuk = 1 atm

P keluar = 2 atm

$$-Ws = \frac{\gamma}{\gamma-1} \times \frac{R.T_1}{M} \times \left[\left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma} - 1\right] \quad \text{......... Geankoplis 3}^{rd}\text{.ed, p.139, eq(3.3-14)}$$

di mana : R = 8314,3 j/kmol

γ = 1,4 (untuk udara, Geankoplis, 3[rd].ed, p.139)

T_1= 373 °C

M= 28,84 kg udara/mol

$$-Ws = \frac{1,4}{1,4-1} \times \frac{8314,3 \times 373}{28,84} \times \left[\left(\frac{2}{1} \right)^{(1.4-1)/1.4} - 1 \right]$$

$$= 82.429,1064 \text{ j/kg}$$

$$\text{brake kw} = \frac{-Ws.m}{\eta.1000};$$

di mana : m = kapasitas = 1,9521 kg/s

$\eta = 0,8$

brake kw = 20,5127 kw

$$= 20,5162 \text{ kw} \times \frac{1 \text{Hp}}{0,7457 \text{kw}} = 27,5127 \text{ Hp}$$

bahan konstruksi = wrought iron

jumlah = 1 buah

Conveyor (J-241)

Fungsi = mengalirkan produk casein dari rotary drier (B-230) ke ball mill (C-240)

Tipe = screw conveyor

Dasar pemilihan = cocok untuk industri makanan

Kondisi operasi = jumlah muatan masuk

Massa slurry casein masuk = 6993,4835 kg

Komponen	massa,kg	fraksi	densitas
Air	1398,2574	0.1999	924.2108
Casein	5594,9394	0.8000	1,157.2728
Laktosa	0,2867	0.0000	1,495.7168
	6,993,4835	1.0000	

Densitas campuran = 1.101,7347 kg/m^3

Diambil kapasitas 10 ton

Dari Perry edisi 6 hal 7-6 didapat :

- Diameter shaft = 2 in
- Diameter Flight = 10 in
- Feed section diameter = 9 in
- Panjang conveyor = 15 ft

Effisiensi motor = 0,85

Power yang dibutuhkan = 0,85×2/0,85 = 2 hp

bahan konstruksi = stainless stell

Jumlah = 2 buah

Ball Mill(C-240)

Fungsi = untuk menghaluskan produk casein yang keluar dari rotary dryer (B-230)

Type = Ball mill

Kapasitas = 7.029,1785 kg/hari

Diambil kapasitas = 8 ton /hari didapatkan dari tabel 8-18 Perry ed 6

Spesifikasi :

1. Ukuran : 3 x 2 ft
2. Ball charge : 0,85 ton

3. HP : 5 HP
4. Mill speed : 35 rpm
5. Jumlah : 1 buah

Conveyor (J-242)

Fungsi = mengalirkan produk casein dari ball mill (C-240) ke screen(H-243)

Tipe = screw conveyor

Dasar pemilihan = cocok untuk industri makanan

Kondisi operasi = jumlah muatan masuk

Massa slurry casein masuk = 6993,4835 kg

Komponen	massa,kg	fraksi	densitas
Air	1398,2574	0.1999	924.2108
Casein	5594,9394	0.8000	1,157.2728
Laktosa	0,2867	0.0000	1,495.7168
	6,993,4835	1.0000	

Densitas campuran = 1.101,7347 kg/m^3

Diambil kapasitas 10 ton

Dari Perry edisi 6 hal 7-6 didapat :

- Diameter shaft = 2 in
- Diameter Flight = 10 in
- Feed section diameter = 9 in
- Panjang conveyor = 15 ft

Effisiensi motor = 0,85

Power yang dibutuhkan = 0,85/0,85 = 1 hp

bahan konstruksi = stainless stell

Jumlah = 1 buah

Screen (H-243)

Fungsi = untuk memisahkan ukuran produk casein yang tidak sama

Tipe = Vibrating screen

Jumlah = 1 buah

Kapasitas = 7029,1785 kg/hari = 292,8824 kg/jam = 0,2 ton/ jam

Kapasitas actual screen = 0,2 – 0,8 ton/ft^2.h.mm mesh size

(Mc.Cabe, 1985.pp1001)

Pada vibrating screen, biasa dipakai 1800 – 3600 vibrasi per menit. (Mc.Cabe, 854)

Ditetapkan :

- Diameter partikel = 120 mesh = 0,074 mm
- Dipakai 3000 vibrasi per menit.
- Kapasitas actual screen 0,4 ton/ft^2.h.mm mesh size

(Mc.Cabe, 1985, 754)

Luas area yang dibutuhkan = $\dfrac{0{,}2 ton/h}{0{,}4 ton/ft^2.h.mm.mesh.size} = 0{,}5\, ft^2.mm.mesh/size$

Dipakai screen lebar 12 in dan panjang 24 in

Power = $\dfrac{1}{3}.hp$

Bin Produk Casein (F – 244)

Fungsi : sebagai tempat penyimpanan casein produk

Tipe : silinder tegak dengan tutup atas flat dan tutup bawah berbentuk konis

Dasar pemilihan : cocok untuk penyimpanan material berbentuk granular

Densitas casein = 73,2169 lb/cuft

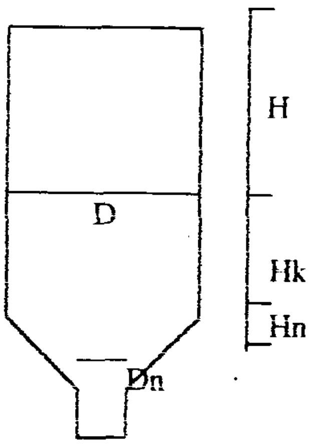
Rate produk : 5.606,4727 kg/hari

Volume padatan = 4,7803 m^3 = 168,8073 ft^3

Ditetapkan :

- volume padatan = 80% volume tangki
- Diameter nozzle (Dn) = 1 ft
- $\alpha = 45^\circ$
- Hs = D
- Plate steel SA-240 grade C dengan : $F_{ultimate}$ = 75.000 psi (Brownell & Young, hal 342).
- F_M = 0,92 (standard)
- F_S = 0,25 (T_{op} < 650°F)
- Tanpa dikenai radiograf → F_a = 1
- Tanpa stress relieve → F_N = 1
- Factor korosi = 0,125 in
- P design = 1,2 × $P_{operasi}$
- Effisiensi pengelasan diambil untuk double welded butt joint E = 80%

Volume tangki = 211,0091 ft^3



Keterangan:

D = diameter shell

H = tinggi shell

Hk = tinggi konis

Hn = tinggi nozzle

Dn = diameter nozzle

Dari gambar dapat dicari persamaan untuk menghitung Hn dan Hk

$$Hn = \frac{Dn}{2 * tg\alpha}$$

$$Hk = \frac{D}{2 * tg\alpha} - Hn = \frac{D - Dn}{2 * tg\alpha}$$

Volume Shell $= \frac{\pi}{4} \times D^2 \times H$ (dengan $\frac{H}{D} = 1$)

$= \frac{\pi}{4} \times H^3$

Volume Konis $= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times Hk - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times Hn$

$= \frac{1}{3} \times \frac{\pi}{4} \times D^2 \times \frac{D}{2.tg\alpha} - \frac{1}{3} \times \frac{\pi}{4} \times Dn^2 \times \frac{Dn}{2.tg\alpha}$

$$= \frac{1}{3}\times\frac{\pi}{4}\times H^2\times\frac{H}{2.tg\alpha}-\frac{1}{3}\times\frac{\pi}{4}\times Dn^2\times\frac{Dn}{2.tg\alpha}$$

$$= \frac{\pi}{24.tg\alpha}\times\left(H^3 - Dn^3\right)$$

Volume total tangki = volume shell + volume konis

$$= \frac{\pi}{4}\times H^3+\frac{\pi}{24.tg\alpha}\times\left(H^3 - Dn^3\right)$$

$$211{,}0091\ ft^3 = \frac{\pi}{4}\times H^3+\frac{\pi}{24.tg45^\circ}\times\left(H^3 - 1^3\right)$$

H = 6,0560 ft → H = 8 ft

D = 4,4860 ft

Volume padatan dalam konis = $\frac{\pi}{24.tg45^\circ}\times\left(D^3 - 1^3\right)$

= 7,2113 ft^3

Tinggi padatan dalam konis = $\frac{D - Dn}{2\times tg\alpha}$ = 1.0761 ft

Volume padatan dalam shell = volume padatan – volume padatan dalam konis

$\frac{\pi}{4}\times D^2\times H_l$ = 168,8073 ft^3 – 7,2113 ft^3

H_l = 6,7290 ft

Tinggi total padatan dalam tangki = tinggi padatan dalam shell + tinggi padatan dalam konis

= 6,7290 ft + 1,0761 ft

= 7,8051 ft

$$P\ operasi = \frac{r.\rho_b.\left(g/_{gc}\right)}{2 \times \mu' \times K'}\left(1 - e^{-2\mu' K' Zt / r}\right)$$

(Mc.Cabe, pers 26-24)

dimana r = jari –jari shell = 4,4860/2 =2,2403 ft

ρ_b = densitas padatan, untuk casein = 73,2169 lb/cuft

g = gaya gravitasi = 32,174 ft/s^2

gc = factor konversi gravitasional = 32,174 lbm.ftf.s^2

μ' = koefisien friksi, untuk granular material di permukaan metal yang licin 0,35 – 0,55; diambil 0,4

K' = konstanta rasio tekanan, untuk material yang dapat mengalir dengan mudah 0,35 – 0,6; diambil 0,4

Zt = tinggi total padatan; 7,8051ft

P operasi = 308,4987 lb$_f$/ft^2 = 2,1424 lb$_f$/in^2 = 2,1424 psi

P design diambil 1,2 × P operasi = 2,5708 psi

Tebal shell

$f_{allow} = f_u \times F_M \times F_S \times F_a \times F_N$

F_{allow} = 75.000 × 0,92 × 0,25 ×1 × 1 = 17.250 psi

$$t_s = \frac{p_{design} \times Di}{2 \times f_{allow} \times E} + C = \frac{2{,}5708 psi \times 4{,}4860 ft \times 12\ ^{in}/_{ft}}{2 \times 17{,}250 psi \times 0{,}8} + 0{,}125 in = 0{,}1300 in \rightarrow {}^3/_{16} in$$

tebal tutup atas = tebal shell = 3/16 in

Spesifikasi alat :

Bin casein produk (F – 184)

Dimensi:

ID_s = Diameter dalam tangki = 4,4860 ft

Hs = Tinggi shell = 8 ft ,

Ts = Tebal shell = $^3/_{16}$ in

Th = Tebal head = $^3/_{16}$ in

Filter Udara (H-234)

Fungsi : menyaring debu yang terbawa dalam udara

Tipe : Automatic Filter

Dasar pemilihan : cocok untuk operasi kontinu dan kapasitas besar

Perhitungan :

Jumlah udara yang dibutuhkan = 415.217,5209 kg/hari

= 915.388,5466 lb/hari

ρ udara pada suhu 30 °C = 0,0742 lb/ft³ (Geankoplis, 1983)

$$\text{Volume udara yang dibutuhkan} = \frac{915.388{,}5466}{0{,}0742}$$

= 12.343.427,0044 ft³/hari

= 514.309,4585 ft³/jam

Standar rate velocity untuk Automatic filter = 350 – 750 ft/ menit (Perry ed.6)

Diambil 500 ft/menit

$$\text{Luas permukaan filter} = \frac{514.309{,}4585\ {}^{ft^3}/_{jam} \times {}^{1}/_{60}\ {}^{jam}/_{menit}}{500\ {}^{ft}/_{menit}} = 17{,}1436\ ft^2$$

Blower (G – 235)

Fungsi : Menghembuskan udara masuk ke pemanas udara (HE)

Tipe : Turbo blower

Dasar pemilihan :cocok untuk kapasitas besar

Data : Kapasitas udara = 415.217,5209 kg/hari

= 4,8058 kg/second

Tudara = 30°C = 303 K

P masuk = 1 atm

P keluar = 2 atm

$$-Ws = \frac{\gamma}{\gamma - 1} \times \frac{R.T_1}{M} \times \left[\left(\frac{P_2}{P_1} \right)^{(\gamma-1)/\gamma} - 1 \right]$$ .... Geankoplis 3[rd].ed, p.139, eq(3.3-14)

di mana : R = 8314,3 j/kmol

γ = 1,4 (untuk udara, Geankoplis, 3[rd].ed, p.139)

T_1= 30 °C

M= 28,84 kg udara/mol

P_2= 2 atm

P_1= 1 atm

$$-Ws = \frac{1,4}{1,4 - 1} \times \frac{8314,3 \times 303}{28,84} \times \left[\left(\frac{2}{1} \right)^{(1,4-1)/1,4} - 1 \right]$$

= 66.959,5150 j/kg

$$\text{brake kw} = \frac{-Ws.m}{\eta.1000};$$

di mana : m = kapasitas = 4,8058 kg/s

η = 0,8

$$\text{brake kw} = \frac{66.959{,}5150 \times 4{,}8058}{0{,}8 \times 1000} = 40{,}2241 \text{ kw}$$

$$= 40{,}2241 \text{ kw} \times \frac{1 \text{ Hp}}{0{,}7457 \text{ kw}} = 53{,}9414 \text{ Hp}$$

bahan konstruksi = wrought iron

jumlah = 1 buah

Heat Exchanger (E-236)

Fungsi : Untuk memanaskan udara yang dipakai pada rotary dryer

Type : Shell and Tube Heat Exchanger

Kondis operasi : T steam masuk, T_1 = 120°C

t udara masuk, t_1 = 30°C

t udara keluar, t_2 = 100°C

1. Q = 7.474.393,8560 kkal/hari = 1.235.865,1619 Btu/jam

   Massa steam = 17.198,2230 kg/hari = 1.304,2251 lb/jam

   Massa udara = 415.217,5209 kg/hari = 38.141,1894 lb/jam

2. $\Delta T_{LMTD} = \dfrac{(120-30)-(120-100)}{\ln\dfrac{(120-30)}{(120-100)}} = 46{,}5402°C = 115{,}7723\ °F$

3. $Tc = \dfrac{T_2 + T_1}{2} = \dfrac{120+120}{2} = 120°C$

   $tc = \dfrac{t_2 + t_1}{2} = \dfrac{100+30}{2} = 65°C$

Trial Ud

Dari table 8 hal 840 kern, Ud overall berkisar antara 5-50 Btu/jam.ft^2.°F.

Dicoba trial Ud = 20 Btu/jam.ft^2.°F , maka :

$$A = \frac{Q}{Ud.\Delta T_{LMTD}} = \frac{1.235.865,1619}{20.115,7723} = 533,7483 ft^2$$

Asumsi dipakai pipa ¾ in OD, 16 BWG, panjang 16 ft

Dari Kern, p843 , table 10 diperoleh data :

a' = 0,302 in^2

a'' = 0,1963 ft^2/ft

$$\text{Jumlah tube} = \frac{A}{a''.L} = \frac{533,7483}{0,19633.16} = 169,9402$$

Standarisasi, Nt = 177 (Kern, p.842, table 9, ¾ in OD on 1 square pitch, 1 passes)

Bagian Shell

ID shell = 17 ¼ in

Bagian Tube

OD = ¾ in, 16 BWG

ID = 0,620 in = 0,0517 ft

L = 16 ft, pt = 1 in

Nt = 177

N = 2 passes

Evaluasi Perpindahan Panas (Rd)

Shell, udara	Tube, Steam
4. ID shell = 17 ¾ in ; B = 5 in Pt = 1 in C' = 1 – ¾ = 0,25 in $As = \frac{ID.C'.B}{144.Pt} = \frac{17,25.0,25.5}{144.1}$	4'. $at = \frac{Nt\tan dar.a't}{144.n}$ $= \frac{177x0,3020}{144x2} = 0,1856\ ft^2$

$= 0{,}1497\ ft^2$ 5. $Gs = \dfrac{M}{as} = \dfrac{38.141{,}1894}{0{,}1497}$ $= 254.716{,}8130$ lb/jam.ft^2 6. pada tc = 65°C (Geankoplis A.3-3) didapatkan : μ = 0,01948 x 2,42 = 0,0471 lb/jam.ft Cp = 0,24069 Btu/lbm.ft K = 0,01538 Btu/ft.F.jam Dari fig 28 didapat : De = 0,95 in = 0,0792 ft $Res = \dfrac{De.Gs}{\mu} = \dfrac{0{,}0792.254.716{,}8130}{0{,}041}$ $= 427.755{,}5498$ 7. jH = 420 8. $\left(\dfrac{Cp.\mu}{k}\right)^{1/3} = \left(\dfrac{0{,}24069.0{,}0471}{0{,}01548}\right)^{1/3}$ $= 0{,}9036$ 9. $ho = jH.\dfrac{k}{De}.\left(\dfrac{Cp.\mu}{k}\right)^{1/3}$ $= 420.\dfrac{0{,}01538}{0{,}079}.0{,}936$ $= 73{,}7279$ Btu/jam.ft^2.°F	5'. $Gt = \dfrac{m}{at} = \dfrac{1.304{,}2251}{0{,}1856}$ $= 7.026{,}9171$ lb/ft^2.jam 6'. ID = 0,620 in = 0,057 ft viskositas steam pada suhu 120°C = 0,333 lb/ft.jam (Geankoplis, A.2-12) $Ret = \dfrac{ID.Gt}{\mu} = \dfrac{0{,}057 \times 7.026{,}9171}{0{,}0333}$ $= 10.902{,}6242$ 7'. hio = 1500 Btu/jam.ft^2.°F

10. $Uc = \dfrac{hio.ho}{hio + ho} = \dfrac{1500x73{,}7279}{1500 + 73{,}7279} = 70{,}2738$ Btu/j.ft^2.°F

A terkoreksi = Nt.L.a" = 177×16×0,1963 ft^2/ft = 555,9216 ft^2

$$U_D \text{ terkoreksi} = \frac{Q}{Aterkoreksi.\Delta T_{LMTD}} = 19{,}2023 \text{ Btu/j.ft}^2.^\circ F$$

14. $$Rd = \frac{U_C - U_D}{U_C \cdot U_D} = \frac{70{,}2738 - 19{,}2023}{70{,}2738 \times 19{,}2023} = 0{,}00378$$

Presurre Drop

Shell,udara	Tube
1. Res = 427.755,5498 fs = 0,001 (Kern, p.839,fig 29) $N+1 = \frac{12.L}{B}$ (eq 7.43, Kern) $= \frac{12.16}{5} = 38{,}4$ 2. $\Delta Ps = \frac{f.Gs^2.Ds.(N+1)}{5{,}22.10^{10}.Des.\theta_s}$ = 0,7819 psi	1'. Ret = 5.541,3121 ft = 0,0003 2'. $\Delta Pt = \frac{f.Gt^2.Dt.L.n}{5{,}22.10^{10}.Dt.\theta_t}$ = 0,0467 3'. ΔPr diabaikan

1500	H outside	73,7279
U_C	70,2738	
U_D	19,2023	
R_D Calculated = 0,00378		
R_D Reguired = 0,003		
0,3734	Calculated ΔP	0,7819
10	Allowable ΔP	10

Spesifikasi :

Heat Exchanger (E-236)

Type : Shell and tube heat exchanger

Ukuran :

- Untuk tube : diameter luar = ¾ in, 16 BWG

  jumlah = 177 buah

  panjang = 16 ft

  passes = 2

  pengaturan = square pitch, Pt = 1 in

- Untuk shell : diameter = 17 ¼ in

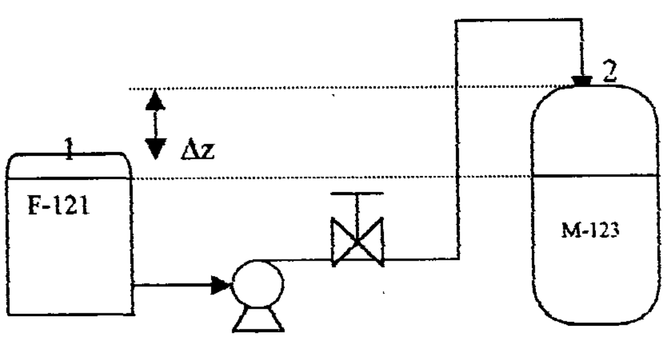
  passes = 1

Bahan : stainless steel

Jumlah : 1 unit

Spesifikasi perhitungan Pompa

Pompa (L-122)



Fungsi : Mengalirkan asam asetat glasial dari tangki penampung asam asetat glasial (F-121) menuju ke tangki pengencer asam asetat (M-123).

Asumsi : Setiap kali pembuatan larutan asam asetat 10% dipakai untuk 7 hari.

Waktu pembuatan larutan asam asetat = 10 menit

Kebutuhan asam asetat glasial untuk 7 hari = 2,9546 kg × 7 = 20,6820 kg

Asam asetat tersebut akan dialirkan dengan menggunakan pompa selama 10 menit.

$$\text{Massa asam asetat yang dialirkan} = \frac{20{,}6820\ \text{kg} \times 2{,}2046\ \text{lb/kg}}{10\ \text{mnt} \times 60\ \text{s/mnt}} = 0{,}076\ \text{lb/s}$$

ρ asam asetat 100% pada 30°C = 1,038 kg/lt = 64,8023 lb/ft^3 (Perry, 7th ed)

$$\text{Rate asam asetat} = \frac{m}{\rho} = \frac{0{,}076\ \text{lb/s}}{64{,}8023\ \text{lb/ft}^3} = 0{,}0012\ \text{ft}^3/\text{s} = 0{,}5264\ \text{gpm}$$

μ asam asetat 100% pada 30°C = 1,12 cp = 0,00075 lb/ft.s

Trial aliran turbulen:

$Di_{opt} = 3{,}9 .\ qf^{0,45} .\ \rho^{0,13}$ (Peters, Timmerhaus, 1991)

$Di_{opt} = 3{,}9 .\ (0{,}0012)^{0,45} .\ (64{,}8023)^{0,13} = 0{,}3219$ in

Dari Geankoplis hal 892, dipilih pipa berukuran ¼ in schedule 40:

OD = 0,540 in

ID = 0,364 in = 0,0303 ft

A = 0,00072 ft^2

$$\text{Kecepatan linear (v)} = \frac{qf}{A} = \frac{0{,}0012\ \text{ft}^3/\text{s}}{0{,}00072\ \text{ft}^2} = 1{,}6288\ \text{ft/s}$$

$$N_{Re} = \frac{\rho .\ ID .\ v}{\mu} = \frac{64{,}8023\ \text{lb/ft}^3 .0{,}0303\ \text{ft} .1{,}6288\ \text{ft/s}}{0{,}00075\ \text{lb/ft.s}} = 4253{,}9429\ \text{(aliran turbulen)}$$

Trial cocok.

Dengan menggunakan persamaan Bernoulli:

$$\frac{1}{2.\alpha.gc}(v_2^{\ 2} - v_1^{\ 2}) + \frac{g}{gc}(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + Ws = 0$$

Perhitungan $\sum F$:

- Loss karena sudden kontraksi, hc

$$F = hc = Kc.\frac{v^2}{2.\alpha.gc}$$

Kc = 0,55 ($A_2/A_1 \approx 0$), α = 1 (aliran turbulen)

$$F = hc = 0{,}55 \times \frac{(1{,}6288\ ft/s)^2}{2.\,1.\,32{,}174\ lbm.ft/lbf.s^2} = 0{,}0227\ ft.lbf/lbm$$

- Loss karena friksi pada pipa lurus, Ff

Digunakan pipa comersial steel, ε = 0,00015 ft

ε/D = 0,00015/0,0303 = 0,004975

Dari fig. 14-1 Peters and Timmerhaus 4th ed, diperoleh f = 0,011

Direncanakan : beda ketinggian (Δz) = 1,4 ft

Panjang pipa lurus (ΔL) = 10 ft

$$F = Ff = 4.\,f.\frac{\Delta L}{D}.\frac{v^2}{2.gc}$$

$$F = Ff = 4.\,0{,}011.\frac{10\ ft}{0{,}0303\ ft}.\frac{(1{,}6288\ ft/s)^2}{2.\,32{,}174\ lbm.ft/lbf.s^2} = 0{,}5980\ ft.lbf/lbm$$

- Loss karena friksi pada elbow dan valve, hf

Terdapat 3 buah elbow 90° dan 1 buah gate valve.

Dari Geankoplis tabel 2.10-1, hal 93, didapat:

Kf = 3 × 0,75 + 0,17 = 2,42

$\alpha = 1$ (aliran turbulen)

$$F = hf = Kf.\frac{v^2}{2.\alpha.\,gc}$$

$$F = hf = 2{,}42 \times \frac{(1{,}6288\ ft/s)^2}{2.\,1.\,32{,}174\ lbm.ft/lbf.s^2} = 0{,}0998\ ft.lbf/lbm$$

$\Sigma F = 0{,}0227 + 0{,}5980 + 0{,}0998 = 0{,}7204$ ft.lbf/lbm

Pressure drop (ΔP) ≈ 0

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

$$-Ws = \left(\frac{(1{,}6288\ ft/s)^2}{2.\,1.\,32{,}174\ lbm.ft/lbf.s^2}\right) + \frac{32{,}174\ ft/s^2}{32{,}174\ lbm.ft/lbf.s^2}.1{,}4\ ft + 0 + 0{,}7204\ ft.lbf.lbm$$

$-Ws = 2{,}1617$ ft.lbf/lbm

Dari Peters and Timmerhaus 4th ed, fig 14-36: ηpompa = 15%

$$\text{Brake Hp} = \frac{-Ws.\,m}{\eta.\,550} = \frac{2{,}1617\ ft.lbf/lbm.\ 0{,}076\ lbm/s}{0{,}15.\,550} = 0{,}0020\ Hp$$

Dari Peters and Timmerhaus 4th ed, fig 14-38: ηmotor = 80%

$$\text{Power motor} = \frac{0{,}0020}{0{,}8} = 0{,}0025\ Hp \approx 0{,}25\ Hp$$

Spesifikasi pompa:

Tipe : Centifugal pump

Rate pompa : 0,5264 gpm

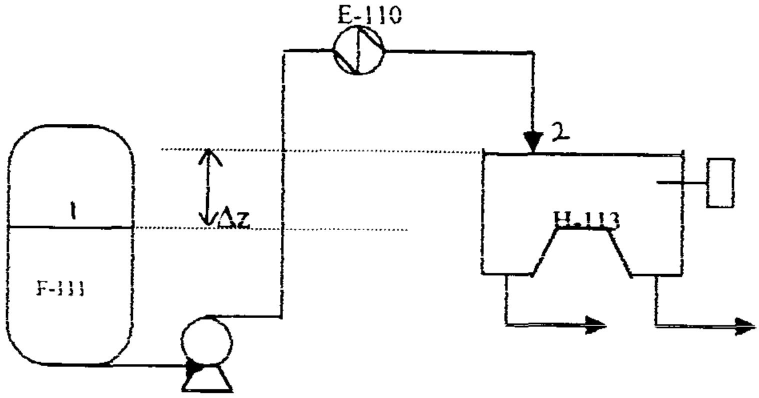
Pipa berukuran ¼ in schedule 40:

Power motor : 0,25 Hp

Bahan konstruksi : Stainless steel

Jumlah : 1 buah

Pompa (L-112)



Fungsi : Mengalirkan susu segar dari tangki penampung susu segar (F-111) menuju ke centrifuge (H-113).

Kebutuhan susu segar = 219059,8665 kg/hari

Massa susu segar yang dialirkan = $\dfrac{219059{,}8665\ \text{kg} \times 2{,}2046\ \text{lb/kg}}{24\ \text{jam} \times 3600\ \text{s/jam}} = 5{,}5896\ \text{lb/s}$

ρ susu = 1,0309 kg/lt = 64,3591 lb/ft^3 (Geankoplis, 1997)

Rate susu = $\dfrac{m}{\rho} = \dfrac{5{,}5896\ lb/s}{64{,}3591\ lb/ft^3} = 0{,}0869\ ft^3/s = 38{,}9827$ gpm

μ susu = 2,12 cp = 0,0014 lb/ft.s

Trial aliran turbulen:

$Di_{opt} = 3{,}9.\ qf^{0,45}.\ \rho^{0,13}$ (Peters, Timmerhaus, 1991)

$Di_{opt} = 3{,}9.\ (0{,}0869)^{0,45}.\ (64{,}3591)^{0,13} = 2{,}2317$ in

Dari Geankoplis hal 892, dipilih pipa berukuran 2½ in schedule 40:

OD = 2,875 in

ID = 2,469 in = 0,2058 ft

A $= 0{,}03322\ ft^2$

Kecepatan linear (v) $= \dfrac{qf}{A} = \dfrac{0{,}0869\ ft^3/s}{0{,}03322\ ft^2} = 2{,}6145\ ft/s$

$$N_{Re} = \frac{\rho .\ ID.\ v}{\mu} = \frac{64{,}3591\ lb/ft^3 .0{,}2058\ ft.2{,}6145\ ft/s}{0{,}0014\ lb/ft.s} = 24302{,}4266$$

(aliran turbulen) Trial cocok

Dengan menggunakan persamaan Bernoulli:

$$\frac{1}{2.\alpha.gc}(v_2^2 - v_1^2) + \frac{g}{gc}(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + Ws = 0$$

Perhitungan ΣF:

- Loss karena sudden kontraksi, hc

$$F = hc = Kc.\frac{v^2}{2.\alpha.gc}$$

Kc = 0,55 ($A_2/A_1 \approx 0$), α = 1 (aliran turbulen)

$$F = hc = 0{,}55 \times \frac{(2{,}6145\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2} = 0{,}0584\ ft.lbf/lbm$$

- Loss karena friksi pada pipa lurus, Ff

Digunakan pipa comersial steel, ε = 0,00015 ft

ε/D = 0,00015/0,2058 = 0,00073

Dari fig. 14-1 Peters and Timmerhaus 4th ed, diperoleh f = 0,0065

Direncanakan : beda ketinggian (Δz) = 10 ft

Panjang pipa lurus (ΔL) = 80 ft

$$F = Ff = 4.\,f.\frac{\Delta L}{D}.\frac{v^2}{2.gc}$$

$$F = Ff = 4.\,0{,}0065.\frac{80\ ft}{0{,}2058\ ft}.\frac{(2{,}6145\ ft/s)^2}{2.\,32{,}174\ lbm.ft/lbf.s^2} = 1{,}0739\ ft.lbf/lbm$$

- Loss karena friksi pada elbow dan valve, hf

Terdapat 4 buah elbow 90°

Dari Geankoplis tabel 2.10-1, hal 93, didapat:

$Kf = 4 \times 0{,}75 = 3$

$\alpha = 1$ (aliran turbulen)

$$F = hf = Kf.\frac{v^2}{2.\alpha.\,gc}$$

$$F = hf = 3 \times \frac{(2{,}6145\ ft/s)^2}{2.\,1.\,32{,}174\ lbm.ft/lbf.s^2} = 0{,}3187\ ft.lbf/lbm$$

$\Sigma F = 0{,}0584 + 1{,}0739 + 0{,}3187 = 1{,}4510$ ft.lbf/lbm

Pressure drop (ΔP) ≈ 0

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

$$-Ws = \left(\frac{(2{,}6145\ ft/s)^2}{2.\,1.\,32{,}174\ lbm.ft/lbf.s^2}\right) + \frac{32{,}174\ ft/s^2}{32{,}174\ lbm.ft/lbf.s^2}.10\ ft + 0 + 1{,}4510\ ft.lbf.lbm$$

$-Ws = 11{,}5572$ ft.lbf/lbm

Dari Peters and Timmerhaus 4th ed, fig 14-36: ηpompa = 28%

$$\text{Brake Hp} = \frac{-Ws.\,m}{\eta.\,550} = \frac{11{,}5572\ ft.lbf/lbm.\,5{,}5896\ lbm/s}{0{,}28.\,550} = 0{,}4195\ Hp$$

Dari Peters and Timmerhaus 4[th] ed, fig 14-38: ηmotor = 80%

$$\text{Power motor} = \frac{0{,}4195}{0{,}8} = 0{,}5244\ \text{Hp} \approx 1\ \text{Hp}$$

Spesifikasi pompa:

Tipe : Centifugal pump

Rate pompa : 38,9827 gpm

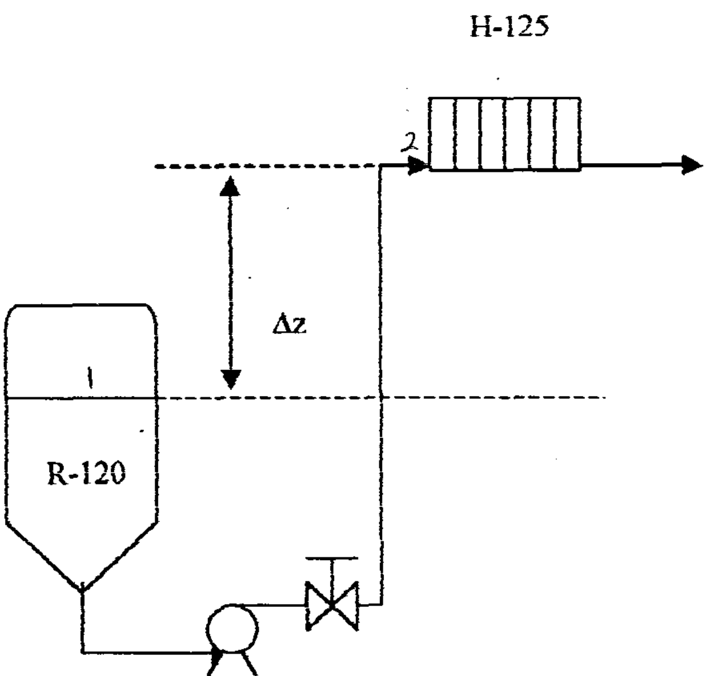
Pipa berukuran 2½ in schedule 40

Power motor : 1 Hp

Bahan konstruksi : Stainless steel

Jumlah : 1 buah

Pompa (L-124)



Fungsi : Mengalirkan susu segar dari reaktor (R-120) menuju ke tangki penampung (F-126).

Massa larutan whey yang dialirkan = 197735,4509 kg/hari

$$= \frac{197735{,}4509\ \text{kg} \times 2{,}2046\ \text{lb/kg}}{24\ \text{jam} \times 3600\ \text{s/jam}} = 5{,}0455\ \text{lb/s}$$

ρ larutan whey = 59,7701 lb/ft³

$$\text{Rate larutan whey} = \frac{m}{\rho} = \frac{5{,}0455\ \text{lb/s}}{59{,}7701\ \text{lb/ft}^3} = 0{,}0844\ \text{ft}^3\text{/s} = 37{,}8903\ \text{gpm}$$

μ larutan whey = 1,4 cp = 0,00094 lb/ft.s

Trial aliran turbulen:

$Di_{opt} = 3{,}9 .\ qf^{0{,}45} .\ \rho^{0{,}13}$ (Peters, Timmerhaus, 1991)

$Di_{opt} = 3{,}9 .\ (0{,}0844)^{0{,}45} .\ (59{,}7701)^{0{,}13} = 2{,}1822$ in

Dari Geankoplis hal 892, dipilih pipa berukuran 2½ in schedule 40:

OD = 2,875 in

ID = 2,469 in = 0,2058 ft

A = 0,03322 ft²

$$\text{Kecepatan linear (v)} = \frac{qf}{A} = \frac{0{,}0844\ \text{ft}^3\text{/s}}{0{,}03322\ \text{ft}^2} = 2{,}5411\ \text{ft/s}$$

$$N_{Re} = \frac{\rho .\ ID .\ v}{\mu} = \frac{59{,}7701\ \text{lb/ft}^3 .0{,}2058\ \text{ft}.2{,}5411\ \text{ft/s}}{0{,}00094\ \text{lb/ft.s}} = 33217{,}1903$$

(aliran turbulen) Trial cocok

Dengan menggunakan persamaan Bernoulli:

$$\frac{1}{2 .\ \alpha .\ gc}(v_2^{\ 2} - v_1^{\ 2}) + \frac{g}{gc}(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + Ws = 0$$

Perhitungan ΣF:

- Loss karena sudden kontraksi, hc

$$F = hc = Kc.\frac{v^2}{2 .\alpha .\ gc}$$

$Kc = 0{,}55$ ($A_2/A_1 \approx 0$), $\alpha = 1$ (aliran turbulen)

$$F = hc = 0{,}55 \times \frac{(2{,}5411 \text{ ft/s})^2}{2.\,1.\,32{,}174 \text{ lbm.ft/lbf.s}^2} = 0{,}0552 \text{ ft.lbf/lbm}$$

- Loss karena friksi pada pipa lurus, Ff

Digunakan pipa comersial steel, $\varepsilon = 0{,}00015$ ft

$\varepsilon/D = 0{,}00015/0{,}2058 = 0{,}00073$

Dari fig. 14-1 Peters and Timmerhaus 4th ed, diperoleh $f = 0{,}0062$

Direncanakan : beda ketinggian (Δz) = 6 ft

Panjang pipa lurus (ΔL) = 30 ft

$$F = Ff = 4.\,f.\frac{\Delta L}{D}.\frac{v^2}{2.gc}$$

$$F = Ff = 4.\,0{,}0062.\frac{30 \text{ ft}}{0{,}2058 \text{ ft}}.\frac{(2{,}5411 \text{ ft/s})^2}{2.\,32{,}174 \text{ lbm.ft/lbf.s}^2} = 0{,}3629 \text{ ft.lbf/lbm}$$

- Loss karena friksi pada elbow dan valve, hf

Terdapat 3 buah elbow 90° dan 1 buah gate valve

Dari Geankoplis tabel 2.10-1, hal 93, didapat:

$Kf = 3 \times 0{,}75 + 0{,}17 = 2{,}42$

$\alpha = 1$ (aliran turbulen)

$$F = hf = Kf.\frac{v^2}{2\alpha.\,gc}$$

$$F = hf = 2{,}42 \times \frac{(2{,}5411 \text{ ft/s})^2}{2.\,1.\,32{,}174 \text{ lbm.ft/lbf.s}^2} = 0{,}2428 \text{ ft.lbf/lbm}$$

- Loss karena sudden enlargemen, hex

$$F = hex = Kex.\frac{v^2}{2.\alpha.\ gc}$$

Kex = 1 ($A_1/A_2 \approx 0$), α = 1 (aliran turbulen)

$$F = hex = 1 \times \frac{(2{,}5411\ ft/s)^2}{2.\ 1.\ 32{,}174\ lbm.ft/lbf.s^2} = 0{,}1003\ ft.lbf/lbm$$

ΣF = 0,0552 + 0,3629 + 0,2428 + 0,1003 = 0,7612 ft.lbf/lbm

Pressure drop (ΔP) ≈ 0

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

$$-Ws = \left(\frac{(2{,}5411\ ft/s)^2}{2.\ 1.\ 32{,}174\ lbm.ft/lbf.s^2}\right) + \frac{32{,}174\ ft/s^2}{32{,}174\ lbm.ft/lbf.s^2}.6\ ft + 0 +$$
0,7612 ft.lbf.lbm

-Ws = 6,8616 ft.lbf/lbm

Dari Peters and Timmerhaus 4th ed, fig 14-36: ηpompa = 30%

$$\text{Brake Hp} = \frac{-Ws.\ m}{\eta.\ 550} = \frac{6{,}8616\ ft.lbf/lbm.\ 5{,}0455\ lbm/s}{0{,}3.\ 550} = 0{,}2098\ Hp$$

Dari Peters and Timmerhaus 4th ed, fig 14-38: ηmotor = 80%

$$\text{Power motor} = \frac{0{,}2098}{0{,}8} = 0{,}2623\ Hp \approx 0{,}5\ Hp$$

Spesifikasi pompa:

Tipe : Centifugal pump

Rate pompa : 37,8903 gpm

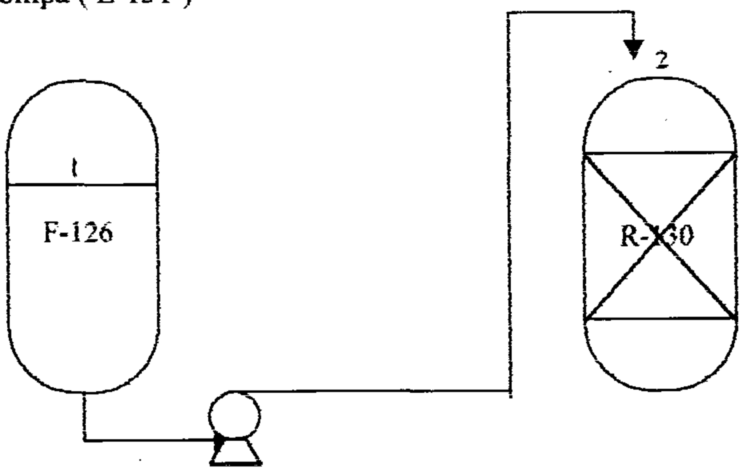
Pipa berukuran 2½ in schedule 40

Power motor : 0,5 Hp

Bahan konstruksi : Stainless steel

Jumlah : 1 buah

Pompa (L-131)



Fungsi : Mengalirkan larutan whey dari tangki penampung (F-126) menuju ke tangki demineralisasi (R-130).

Massa larutan whey yang dialirkan = 190741,8168 kg/hari

$$= \frac{190741{,}8168 \text{ kg} \times 2{,}2046 \text{ lb/kg}}{24 \text{ jam} \times 3600 \text{ s/jam}} = 4{,}8670 \text{ lb/s}$$

ρ larutan whey = 59,4917 lb/ft^3

$$\text{Rate larutan whey} = \frac{m}{\rho} = \frac{4{,}8670 \text{ lb/s}}{59{,}4917 \text{ lb/ft}^3} = 0{,}0818 \text{ ft}^3\text{/s} = 36{,}7212 \text{ gpm}$$

μ larutan whey = 0,6320 cp = 0,000425 lb/ft.s

Trial *aliran turbulen*:

$Di_{opt} = 3{,}9.\ qf^{0,45}.\ \rho^{0,13}$ (Peters, Timmerhaus, 1991)

$Di_{opt} = 3{,}9.\ (0{,}0818)^{0,45}.\ (59{,}4917)^{0,13} = 2{,}1503$ in

Dari Geankoplis hal 892, dipilih pipa berukuran 2½ in schedule 40:

OD = 2,875 in

ID = 2,469 in = 0,2058 ft

A $= 0{,}03322\ ft^2$

Kecepatan linear (v) = $\frac{qf}{A} = \frac{0{,}0818\ ft^3/s}{0{,}03322\ ft^2} = 2{,}4627\ ft/s$

$$N_{Re} = \frac{\rho.\ ID.\ v}{\mu} = \frac{59{,}4917\ lb/ft^3 . 0{,}2058\ ft . 2{,}4627\ ft/s}{0{,}000425\ lb/ft.s} = 70957{,}5933$$

(aliran turbulen) Trial cocok

Dengan menggunakan persamaan Bernoulli:

$$\frac{1}{2.\alpha.gc}(v_2{}^2 - v_1{}^2) + \frac{g}{gc}(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + Ws = 0$$

Perhitungan ΣF:

- Loss karena sudden kontraksi, hc

$$F = hc = Kc.\frac{v^2}{2.\alpha.\ gc}$$

Kc = 0,55 ($A_2/A_1 \approx 0$), α = 1 (aliran turbulen)

$$F = hc = 0{,}55 \times \frac{(2{,}4627\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2} = 0{,}0518\ ft.lbf/lbm$$

- Loss karena friksi pada pipa lurus, Ff

Digunakan pipa comersial steel, ε = 0,00015 ft

ε/D = 0,00015/0,2058 = 0,00073

Dari fig. 14-1 Peters and Timmerhaus 4th ed, diperoleh f = 0,0055

Direncanakan : beda ketinggian (Δz) = 4 ft

Panjang pipa lurus (ΔL) = 40 ft

$$F = Ff = 4.\ f.\frac{\Delta L}{D}.\frac{v^2}{2.gc}$$

$$F = Ff = 4.\ 0,0055.\frac{40\ ft}{0,2058\ ft}.\frac{(2,4627\ ft/s)^2}{2.\ 32,174\ lbm.ft/lbf.s^2} = 0,4031\ ft.lbf/lbm$$

- Loss karena friksi pada elbow dan valve, hf

Terdapat 4 buah elbow 90°

Dari Geankoplis tabel 2.10-1, hal 93, didapat:

$Kf = 4 \times 0,75 = 3$

$\alpha = 1$ (aliran turbulen)

$$F = hf = Kf.\frac{v^2}{2.\alpha.\ gc}$$

$$F = hf = 3 \times \frac{(2,4627\ ft/s)^2}{2.\ 1.\ 32,174\ lbm.ft/lbf.s^2} = 0,2827\ ft.lbf/lbm$$

$\Sigma F = 0,0518 + 0,4031 + 0,2827 = 0,7377$ ft.lbf/lbm

Pressure drop (ΔP) ≈ 0

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

$$-Ws = \left(\frac{(2,4627\ ft/s)^2}{2.\ 1.\ 32,174\ lbm.ft/lbf.s^2}\right) + \frac{32,174\ ft/s^2}{32,174\ lbm.ft/lbf.s^2}.4\ ft + 0 + 0,7377\ ft.lbf.lbm$$

$-Ws = 4,8319$ ft.lbf/lbm

Dari Peters and Timmerhaus 4th ed, fig 14-36: ηpompa = 30%

$$\text{Brake Hp} = \frac{-Ws.\ m}{\eta.\ 550} = \frac{4,8319\ ft.lbf/lbm.\ 4,8670\ lbm/s}{0,3.\ 550} = 0,1425\ Hp$$

Dari Peters and Timmerhaus 4th ed, fig 14-38: ηmotor = 80%

$$\text{Power motor} = \frac{0,1425}{0,8} = 0,1782\ Hp \approx 0,25\ Hp$$

Spesifikasi pompa:

Tipe : Centifugal pump

Rate pompa : 36,7212 gpm

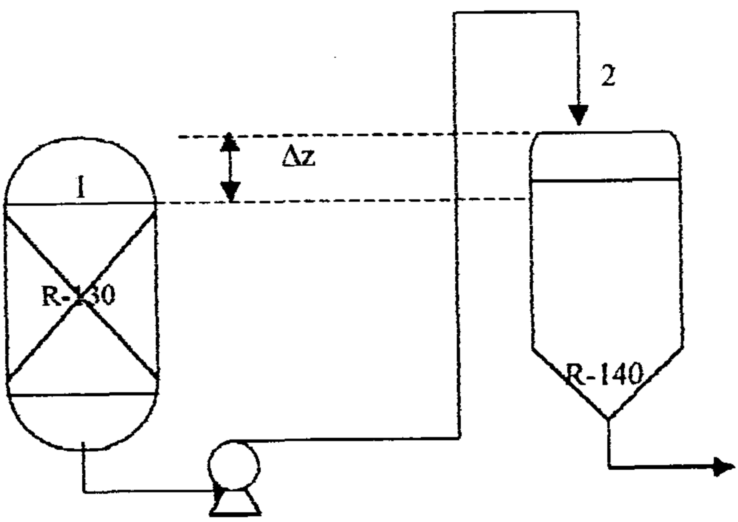
Pipa berukuran 2½ in schedule 40

Power motor : 0,25 Hp

Bahan konstruksi : Stainless steel

Jumlah : 1 buah

Pompa (L-141)



Fungsi : Mengalirkan larutan whey dari tangki demineralisasi (R-130) menuju ke tangki deproteinaiser (R-140).

Massa larutan whey yang dialirkan = 189326,5035 kg/hari

$$= \frac{189326{,}5035 \text{ kg} \times 2{,}2046 \text{ lb/kg}}{24 \text{ jam} \times 3600 \text{ s/jam}} = 4{,}8309 \text{ lb/s}$$

ρ larutan whey = 59,2298 lb/ft^3

$$\text{Rate larutan whey} = \frac{m}{\rho} = \frac{4{,}8309 \text{ lb/s}}{59{,}2298 \text{ lb/ft}^3} = 0{,}0816 \text{ ft}^3\text{/s} = 36{,}6099 \text{ gpm}$$

μ larutan whey = 0,6320 cp = 0,000425 lb/ft.s

Trial aliran turbulen:

$Di_{opt} = 3{,}9.\ qf^{0,45}.\ \rho^{0,13}$ (Peters, Timmerhaus, 1991)

$Di_{opt} = 3{,}9.\ (0{,}0816)^{0,45}.\ (59{,}2298)^{0,13} = 2{,}1462$ in

Dari Geankoplis hal 892, dipilih pipa berukuran 2½ in schedule 40:

OD = 2,875 in

ID = 2,469 in = 0,2058 ft

A = 0,03322 ft^2

$$\text{Kecepatan linear (v)} = \frac{qf}{A} = \frac{0{,}0816\ ft^3/s}{0{,}03322\ ft^2} = 2{,}4552\ ft/s$$

$$N_{Re} = \frac{\rho.\ ID.\ v}{\mu} = \frac{59{,}2298\ lb/ft^3 .0{,}2058\ ft.2{,}4551\ ft/s}{0{,}000425\ lb/ft.s} = 70431{,}0845$$

(aliran turbulen) Trial cocok

Dengan menggunakan persamaan Bernoulli:

$$\frac{1}{2.\alpha.gc}(v_2^2 - v_1^2) + \frac{g}{gc}(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + Ws = 0$$

Perhitungan ΣF:

- Loss karena sudden kontraksi, hc

$$F = hc = Kc.\frac{v^2}{2.\alpha.gc}$$

Kc = 0,55 ($A_2/A_1 \approx 0$), α = 1 (aliran turbulen)

$$F = hc = 0{,}55 \times \frac{(2{,}4552\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2} = 0{,}0515\ ft.lbf/lbm$$

- Loss karena friksi pada pipa lurus, Ff

Digunakan pipa comersial steel, ε = 0,00015 ft

ε/D = 0,00015/0,2058 = 0,00073

Dari fig. 14-1 Peters and Timmerhaus 4th ed, diperoleh f = 0,0055

Direncanakan : beda ketinggian (Δz) = 4 ft

Panjang pipa lurus (ΔL) = 40 ft

$$F = Ff = 4.\ f.\frac{\Delta L}{D}.\frac{v^2}{2.gc}$$

$$F = Ff = 4.\ 0{,}0055.\frac{40\ ft}{0{,}2058\ ft}.\frac{(2{,}4552\ ft/s)^2}{2.\ 32{,}174\ lbm.ft/lbf.s^2} = 0{,}4007\ ft.lbf/lbm$$

- Loss karena friksi pada elbow dan valve, hf

Terdapat 4 buah elbow 90°

Dari Geankoplis tabel 2.10-1, hal 93, didapat:

Kf = 4 × 0,75 = 3

α = 1 (aliran turbulen)

$$F = hf = Kf.\frac{v^2}{2\alpha.\ gc}$$

$$F = hf = 3\times\frac{(2{,}4552\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2} = 0{,}2810\ ft.lbf/lbm$$

ΣF = 0,0515 + 0,4007 + 0,2810 = 0,7332 ft.lbf/lbm

Pressure drop (ΔP) ≈ 0

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

$$-Ws = \left(\frac{(2{,}4552\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2}\right) + \frac{32{,}174\ ft/s^2}{32{,}174\ lbm.ft/lbf.s^2}.6\ ft + 0 +$$

0,7332 ft.lbf.lbm

-Ws = 4,8269 ft.lbf/lbm

Dari Peters and Timmerhaus 4th ed, fig 14-36: ηpompa = 30%

$$\text{Brake Hp} = \frac{-Ws.\,m}{\eta.\,550} = \frac{4{,}8269\ ft.lbf/lbm.\ 4{,}8309\ lbm/s}{0{,}3.\ 550} = 0{,}1413\ Hp$$

Dari Peters and Timmerhaus 4th ed, fig 14-38: ηmotor = 80%

$$\text{Power motor} = \frac{0{,}1413}{0{,}8} = 0{,}1767\ Hp \approx 0{,}25\ Hp$$

Spesifikasi pompa:

Tipe : Centifugal pump

Rate pompa : 36,6099 gpm

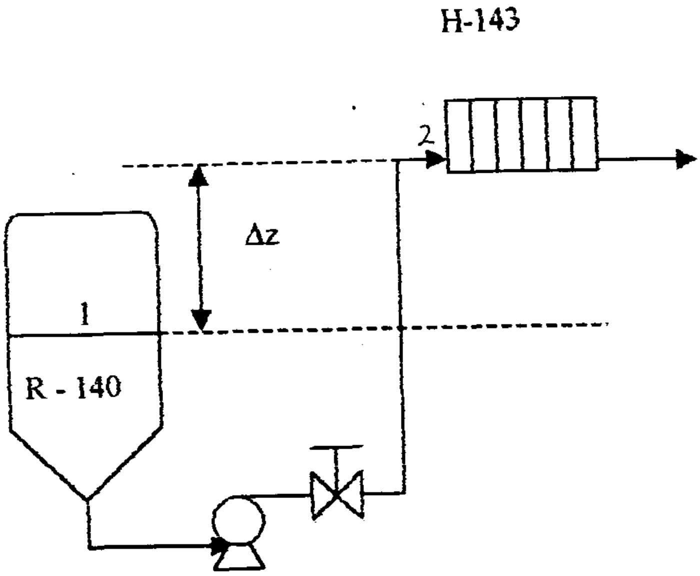
Pipa berukuran 2½ in schedule 40

Power motor : 0,25 Hp

Bahan konstruksi : Stainless steel

Jumlah : 1 buah

Pompa (L-142)



Fungsi : Mengalirkan larutan dari tangki deproteinaiser (R-140) menuju ke tangki penampung (F-144).

Massa larutan yang dialirkan = 189326,5035 kg/hari

$$= \frac{189326{,}5035 \text{ kg} \times 2{,}2046 \text{ lb/kg}}{24 \text{ jam} \times 3600 \text{ s/jam}} = 4{,}8309 \text{ lb/s}$$

ρ larutan = 58,5336 lb/ft^3

$$\text{Rate larutan} = \frac{m}{\rho} = \frac{4{,}8309 \text{ lb/s}}{58{,}5336 \text{ lb/ft}^3} = 0{,}0825 \text{ ft}^3\text{/s} = 37{,}0453 \text{ gpm}$$

μ larutan = 0,5964 cp = 0,0004 lb/ft.s

Trial aliran turbulen:

$Di_{opt} = 3{,}9.\ qf^{0,45}.\ \rho^{0,13}$ (Peters, Timmerhaus, 1991)

$Di_{opt} = 3{,}9.\ (0{,}0825)^{0,45}.\ (58{,}5336)^{0,13} = 2{,}1543$ in

Dari Geankoplis hal 892, dipilih pipa berukuran 2½ in schedule 40:

OD = 2,875 in

ID = 2,469 in = 0,2058 ft

A = 0,03322 ft^2

$$\text{Kecepatan linear (v)} = \frac{qf}{A} = \frac{0{,}0825 \text{ ft}^3\text{/s}}{0{,}03322 \text{ ft}^2} = 2{,}4844 \text{ ft/s}$$

$$N_{Re} = \frac{\rho.\ ID.\ v}{\mu} = \frac{58{,}5336 \text{ lb/ft}^3 . 0{,}2058 \text{ ft} . 2{,}4844 \text{ ft/s}}{0{,}0004 \text{ lb/ft.s}} = 74628{,}4544$$

(aliran turbulen) Trial cocok

Dengan menggunakan persamaan Bernoulli:

$$\frac{1}{2.\alpha.gc}(v_2^2 - v_1^2) + \frac{g}{gc}(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + Ws = 0$$

Perhitungan ΣF:

- Loss karena sudden kontraksi, hc

$$F = hc = Kc.\frac{v^2}{2.\alpha.\,gc}$$

Kc = 0,55 ($A_2/A_1 \approx 0$), α = 1 (aliran turbulen)

$$F = hc = 0{,}55 \times \frac{(2{,}4844\ ft/s)^2}{2.\,1.\,32{,}174\ lbm.ft/lbf.s^2} = 0{,}0528\ ft.lbf/lbm$$

- Loss karena friksi pada pipa lurus, Ff

Digunakan pipa comersial steel, ε = 0,00015 ft

ε/D = 0,00015/0,2058 = 0,00073

Dari fig. 14-1 Peters and Timmerhaus 4[th] ed, diperoleh f = 0,0056

Direncanakan : beda ketinggian (Δz) = 6 ft

Panjang pipa lurus (ΔL) = 30 ft

$$F = Ff = 4.\,f.\frac{\Delta L}{D}.\frac{v^2}{2.gc}$$

$$F = Ff = 4.\,0{,}0056.\frac{30\ ft}{0{,}2058\ ft}.\frac{(2{,}4844\ ft/s)^2}{2.\,32{,}174\ lbm.ft/lbf.s^2} = 0{,}3133\ ft.lbf/lbm$$

- Loss karena friksi pada elbow dan valve, hf

Terdapat 3 buah elbow 90° dan 1 buah gate valve.

Dari Geankoplis tabel 2.10-1, hal 93, didapat:

Kf = 3 × 0,75 + 0,17 = 2,42

α = 1 (aliran turbulen)

$$F = hf = Kf.\frac{v^2}{2.\alpha.\,gc}$$

$$F = hf = 2{,}42 \times \frac{(2{,}4844\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2} = 0{,}2321\ ft.lbf/lbm$$

- Loss karena sudden enlargemen, hex

$$F = hex = Kex.\frac{v^2}{2.\alpha.gc}$$

Kex = 1 ($A_1/A_2 \approx 0$), α = 1 (aliran turbulen)

$$F = hex = 1 \times \frac{(2{,}4844\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2} = 0{,}0959\ ft.lbf/lbm$$

$\Sigma F = 0{,}0528 + 0{,}3133 + 0{,}2321 + 0{,}0959 = 0{,}6941$ ft.lbf/lbm

Pressure drop (ΔP) $\approx$ 0

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

$$-Ws = \left(\frac{(2{,}4844\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2}\right) + \frac{32{,}174\ ft/s^2}{32{,}174\ lbm.ft/lbf.s^2}.6\ ft + 0 +$$
0,6941 ft.lbf.lbm

-Ws = 6,7900 ft.lbf/lbm

Dari Peters and Timmerhaus 4th ed, fig 14-36: ηpompa = 32%

$$\text{Brake Hp} = \frac{-Ws.m}{\eta.550} = \frac{6{,}7900\ ft.lbf/lbm.\ 4{,}8309\ lbm/s}{0{,}32.\ 550} = 0{,}1864\ Hp$$

Dari Peters and Timmerhaus 4th ed, fig 14-38: ηmotor = 80%

$$\text{Power motor} = \frac{0{,}1864}{0{,}8} = 0{,}2330\ Hp \approx 0{,}25\ Hp$$

Spesifikasi pompa:

Tipe : Centifugal pump

Rate pompa : 37,0453 gpm

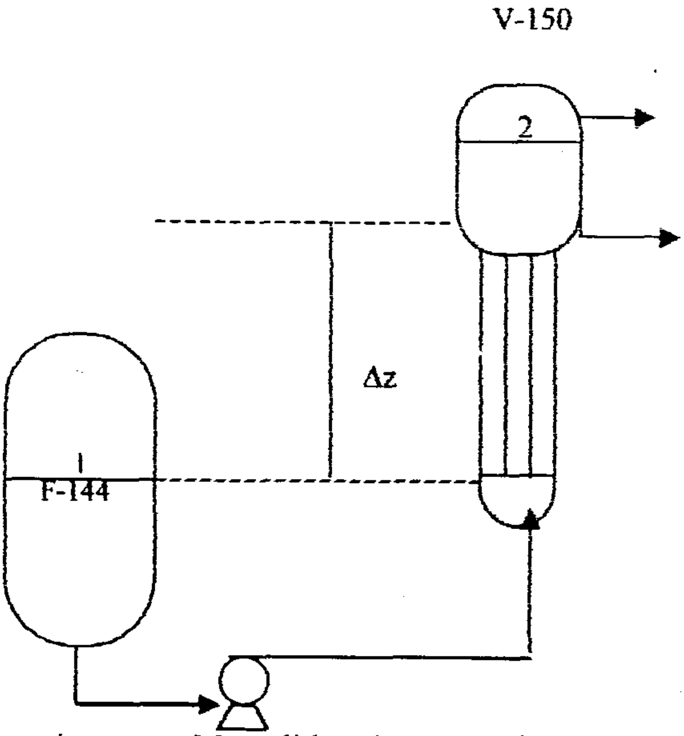
Pipa berukuran 2½ in schedule 40

Power motor : 0,25 Hp

Bahan konstruksi : Stainless steel

Jumlah : 1 buah

Pompa (L-151)



Fungsi : Mengalirkan larutan dari tangki penampung (F-144) menuju ke evaporator (V-150).

Massa larutan yang dialirkan = 187607,9187 kg/hari

$$= \frac{187607,9187 \text{ kg} \times 2,2046 \text{ lb/kg}}{24 \text{ jam} \times 3600 \text{ s/jam}} = 4,7870 \text{ lb/s}$$

ρ larutan = 58,5521 lb/ft^3

$$\text{Rate larutan} = \frac{m}{\rho} = \frac{4,7870 \text{ lb/s}}{58,5521 \text{ lb/ft}^3} = 0,0818 \text{ ft}^3\text{/s} = 36,6975 \text{ gpm}$$

μ larutan = 0,6013 cp = 0,0004 lb/ft.s

Trial aliran turbulen:

$Di_{opt} = 3{,}9.\ qf^{0,45}.\ \rho^{0,13}$ (Peters, Timmerhaus, 1991)

$Di_{opt} = 3{,}9.\ (0{,}0818)^{0,45}.\ (58{,}5521)^{0,13} = 2{,}1453$ in

Dari Geankoplis hal 892, dipilih pipa berukuran 2½ in schedule 40:

OD = 2,875 in

ID = 2,469 in = 0,2058 ft

A = 0,03322 ft^2

$$\text{Kecepatan linear (v)} = \frac{qf}{A} = \frac{0{,}0818\ ft^3/s}{0{,}03322\ ft^2} = 2{,}4578\ ft/s$$

$$N_{Re} = \frac{\rho.\ ID.\ v}{\mu} = \frac{58{,}5521\ lb/ft^3.0{,}2058\ ft.2{,}4578\ ft/s}{0{,}0004\ lb/ft.s} = 73253{,}8879$$

(aliran turbulen) Trial cocok

Dengan menggunakan persamaan Bernoulli:

$$\frac{1}{2.\alpha.gc}(v_2^2 - v_1^2) + \frac{g}{gc}(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + Ws = 0$$

Perhitungan $\sum F$:

- Loss karena sudden kontraksi, hc

$$F = hc = Kc.\frac{v^2}{2\alpha.gc}$$

Kc = 0,55 ($A_2/A_1 \approx 0$), $\alpha = 1$ (aliran turbulen)

$$F = hc = 0{,}55 \times \frac{(2{,}4578\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2} = 0{,}0516\ ft.lbf/lbm$$

- Loss karena friksi pada pipa lurus, Ff

Digunakan pipa comersial steel, $\varepsilon = 0{,}00015$ ft

$\varepsilon/D = 0{,}00015/0{,}2058 = 0{,}00073$

Dari fig. 14-1 Peters and Timmerhaus 4th ed, diperoleh f = 0,0055

Direncanakan : beda ketinggian (Δz) = 15 ft

Panjang pipa lurus (ΔL) = 50 ft

$$F = Ff = 4.\ f.\frac{\Delta L}{D}.\frac{v^2}{2.gc}$$

$$F = Ff = 4.\ 0{,}0055.\frac{50\ ft}{0{,}2058\ ft}.\frac{(2{,}4578\ ft/s)^2}{2.\ 32{,}174\ lbm.ft/lbf.s^2} = 0{,}5019\ ft.lbf/lbm$$

- Loss karena friksi pada elbow dan valve, hf

Terdapat 2 buah elbow 90°.

Dari Geankoplis tabel 2.10-1, hal 93, didapat:

Kf = 2 × 0,75 = 1,5

α = 1 (aliran turbulen)

$$F = hf = Kf.\frac{v^2}{2.\alpha.\ gc}$$

$$F = hf = 1{,}5 \times \frac{(2{,}4578\ ft/s)^2}{2.\ 1.\ 32{,}174\ lbm.ft/lbf.s^2} = 0{,}1408\ ft.lbf/lbm$$

- Loss karena sudden enlargemen, hex

$$F = hex = Kex.\frac{v^2}{2.\alpha.\ gc}$$

Kex = 1 ($A_1/A_2 \approx 0$), α = 1 (aliran turbulen)

$$F = hex = 1 \times \frac{(2{,}4578\ ft/s)^2}{2.\ 1.\ 32{,}174\ lbm.ft/lbf.s^2} = 0{,}0939\ ft.lbf/lbm$$

ΣF = 0,0516 + 0,5019 + 0,1408 + 0,0939 = 0,7882 ft.lbf/lbm

Pressure drop (ΔP) ≈ 0

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

$$-Ws = \left(\frac{(2{,}4578\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2}\right) + \frac{32{,}174\ ft/s^2}{32{,}174\ lbm.ft/lbf.s^2}.15\ ft + 0 + 0{,}7882\ ft.lbf.lbm$$

-Ws = 15,8821 ft.lbf/lbm

Dari Peters and Timmerhaus 4th ed, fig 14-36: ηpompa = 32%

$$\text{Brake Hp} = \frac{-Ws.m}{\eta.550} = \frac{15{,}8821\ ft.lbf/lbm.4{,}7870\ lbm/s}{0{,}32.550} = 0{,}4320\ Hp$$

Dari Peters and Timmerhaus 4th ed, fig 14-38: ηmotor = 80%

$$\text{Power motor} = \frac{0{,}4320}{0{,}8} = 0{,}5400\ Hp \approx 1\ Hp$$

Spesifikasi pompa:

Tipe : Centifugal pump

Rate pompa : 36,6975 gpm

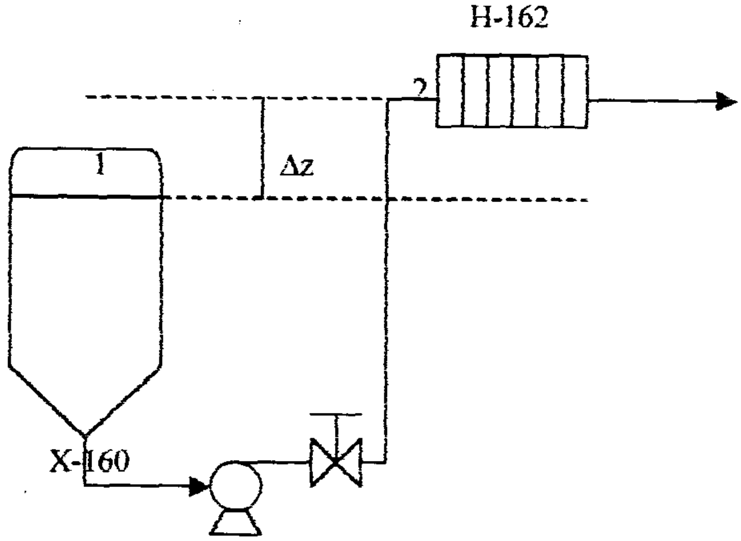
Pipa berukuran 2½ in schedule 40

Power motor : 1 Hp

Bahan konstruksi : Stainless steel

Jumlah : 1 buah

Pompa (L-161)



Fungsi : Mengalirkan slurry dari (X-160) menuju ke filter press (H-162).

Massa slurry yang dialirkan = 15419,4023 kg/hari

$$= \frac{15419{,}4023 \text{ kg} \times 2{,}2046 \text{ lb/kg}}{24 \text{ jam} \times 3600 \text{ s/jam}} = 0{,}3934 \text{ lb/s}$$

ρ slurry = 77,7339 lb/ft^3

$$\text{Rate slurry} = \frac{m}{\rho} = \frac{0{,}3934 \text{ lb/s}}{77{,}7339 \text{ lb/ft}^3} = 0{,}0051 \text{ ft}^3\text{/s} = 2{,}2719 \text{ gpm}$$

μ slurry = 1,9346 cp = 0,0013 lb/ft.s

Trial aliran turbulen:

$Di_{opt} = 3{,}9.\ qf^{0,45}.\ \rho^{0,13}$ (Peters, Timmerhaus, 1991)

$Di_{opt} = 3{,}9.\ (0{,}0051)^{0,45}.\ (77{,}7339)^{0,13} = 0{,}6365$ in

Dari Geankoplis hal 892, dipilih pipa berukuran ¾ in schedule 40:

OD = 1,050 in

ID = 0,824 in = 0,0687 ft

A $= 0{,}00371\ ft^2$

$$\text{Kecepatan linear } (v) = \frac{qf}{A} = \frac{0{,}0051\ ft^3/s}{0{,}00371\ ft^2} = 1{,}3643\ ft/s$$

$$N_{Re} = \frac{\rho . ID . v}{\mu} = \frac{77{,}7339\ lb/ft^3 . 0{,}0687\ ft . 1{,}3643\ ft/s}{0{,}0013\ lb/ft.s} = 5601{,}6027$$

(aliran turbulen) Trial cocok

Dengan menggunakan persamaan Bernoulli:

$$\frac{1}{2.\alpha.gc}(v_2{}^2 - v_1{}^2) + \frac{g}{gc}(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + Ws = 0$$

Perhitungan ΣF:

- Loss karena sudden kontraksi, hc

$$F = hc = Kc.\frac{v^2}{2.\alpha.gc}$$

$Kc = 0{,}55$ ($A_2/A_1 \approx 0$), $\alpha = 1$ (aliran turbulen)

$$F = hc = 0{,}55 \times \frac{(1{,}3643\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2} = 0{,}0159\ ft.lbf/lbm$$

- Loss karena friksi pada pipa lurus, Ff

Digunakan pipa comersial steel, $\varepsilon = 0{,}00015$ ft

$\varepsilon/D = 0{,}00015/0{,}0687 = 0{,}0022$

Dari fig. 14-1 Peters and Timmerhaus 4th ed, diperoleh f = 0,01

Direncanakan : beda ketinggian (Δz) = 6 ft

Panjang pipa lurus (ΔL) = 30 ft

$$F = Ff = 4.f.\frac{\Delta L}{D}.\frac{v^2}{2.gc}$$

$$F = Ff = 4.\,0{,}01.\frac{30\ \text{ft}}{0{,}0687\ \text{ft}}.\frac{(1{,}3643\ \text{ft/s})^2}{2.\ 32{,}174\ \text{lbm.ft/lbf.s}^2} = 0{,}5055\ \text{ft.lbf/lbm}$$

- Loss karena friksi pada elbow dan valve, hf

Terdapat 3 buah elbow 90° dan 1 buah gate valve.

Dari Geankoplis tabel 2.10-1, hal 93, didapat:

$Kf = 3 \times 0{,}75 + 0{,}17 = 2{,}42$

$\alpha = 1$ (aliran turbulen)

$$F = hf = Kf.\frac{v^2}{2.\alpha.\ gc}$$

$$F = hf = 2{,}42 \times \frac{(1{,}3643\ \text{ft/s})^2}{2.\,1.\ 32{,}174\ \text{lbm.ft/lbf.s}^2} = 0{,}0700\ \text{ft.lbf/lbm}$$

- Loss karena sudden enlargemen, hex

$$F = hex = Kex.\frac{v^2}{2.\alpha.\ gc}$$

$Kex = 1$ ($A_1/A_2 \approx 0$), $\alpha = 1$ (aliran turbulen)

$$F = hex = 1 \times \frac{(1{,}3643\ \text{ft/s})^2}{2.\,1.\ 32{,}174\ \text{lbm.ft/lbf.s}^2} = 0{,}0289\ \text{ft.lbf/lbm}$$

$\Sigma F = 0{,}0159 + 0{,}5055 + 0{,}0700 + 0{,}0289 = 0{,}6203$ ft.lbf/lbm

Pressure drop (ΔP) ≈ 0

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

$$-Ws = \left(\frac{(1{,}3643\ \text{ft/s})^2}{2.\,1.\ 32{,}174\ \text{lbm.ft/lbf.s}^2}\right) + \frac{32{,}174\ \text{ft/s}^2}{32{,}174\ \text{lbm.ft/lbf.s}^2}.6\ \text{ft} + 0 + 0{,}6203\ \text{ft.lbf.lbm}$$

$-Ws = 6{,}6492$ ft.lbf/lbm

Dari Peters and Timmerhaus 4th ed, fig 14-36: ηpompa = 15%

$$\text{Brake Hp} = \frac{-Ws.m}{\eta.550} = \frac{6{,}6492\ \text{ft.lbf/lbm}.0{,}3934\ \text{lbm/s}}{0{,}15.550} = 0{,}0317\ \text{Hp}$$

Dari Peters and Timmerhaus 4th ed, fig 14-38: ηmotor = 80%

$$\text{Power motor} = \frac{0{,}0317}{0{,}8} = 0{,}0396\ \text{Hp} \approx 0{,}25\ \text{Hp}$$

Spesifikasi pompa:

Tipe : Centifugal pump

Rate pompa : 2,2719 gpm

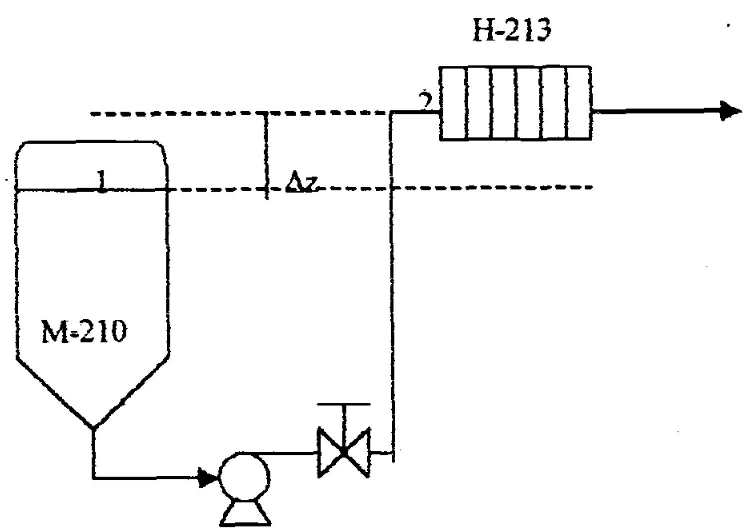
Pipa berukuran ¾ in schedule 40

Power motor : 0,25 Hp

Bahan konstruksi : Stainless steel

Jumlah : 1 buah

Pompa (L-212)



Fungsi : Mengalirkan slurry dari tangki pencuci (M-210) menuju ke filter press (H-213).

Massa slurry yang dialirkan = 27967,4958 kg/hari

$$= \frac{27967{,}4958\ \text{kg} \times 2{,}2046\ \text{lb/kg}}{24\ \text{jam} \times 3600\ \text{s/jam}} = 0{,}7136\ \text{lb/s}$$

ρ slurry = 60,6810 lb/ft^3

$$\text{Rate slurry} = \frac{m}{\rho} = \frac{0{,}7136\ \text{lb/s}}{60{,}6810\ \text{lb/ft}^3} = 0{,}0118\ \text{ft}^3/\text{s} = 5{,}2787\ \text{gpm}$$

μ slurry = 0,7441 cp = 0,0005 lb/ft.s

Trial aliran turbulen:

$Di_{opt} = 3{,}9.\ qf^{0,45}.\ \rho^{0,13}$ (Peters, Timmerhaus, 1991)

$Di_{opt} = 3{,}9.\ (0{,}0118)^{0,45}.\ (60{,}6810)^{0,13} = 0{,}9006$ in

Dari Geankoplis hal 892, dipilih pipa berukuran 1 in schedule 40:

OD = 1,315 in

ID = 1,049 in = 0,0874 ft

A = 0,0060 ft^2

$$\text{Kecepatan linear (v)} = \frac{qf}{A} = \frac{0{,}0118\ \text{ft}^3/\text{s}}{0{,}0060\ \text{ft}^2} = 1{,}9600\ \text{ft/s}$$

$$N_{Re} = \frac{\rho.\ ID.\ v}{\mu} = \frac{60{,}6810\ \text{lb/ft}^3 .0{,}0874\ \text{ft}.1{,}9600\ \text{ft/s}}{0{,}0005\ \text{lb/ft.s}} = 20794{,}2197$$

(aliran turbulen) Trial cocok

Dengan menggunakan persamaan Bernoulli:

$$\frac{1}{2.\ \alpha.\ gc}(v_2^2 - v_1^2) + \frac{g}{gc}(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + Ws = 0$$

Perhitungan ΣF:

- Loss karena sudden kontraksi, hc

$$F = hc = Kc.\frac{v^2}{2.\alpha.\ gc}$$

Kc = 0,55 ($A_2/A_1 \approx 0$), α = 1 (aliran turbulen)

$$F = hc = 0{,}55 \times \frac{(1{,}9600\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2} = 0{,}0328\ ft.lbf/lbm$$

- Loss karena friksi pada pipa lurus, Ff

Digunakan pipa comersial steel, ε = 0,00015 ft

ε/D = 0,00015/0,0874 = 0,0017

Dari fig. 14-1 Peters and Timmerhaus 4th ed, diperoleh f = 0,0072

Direncanakan : beda ketinggian (Δz) = 6 ft

Panjang pipa lurus (ΔL) = 30 ft

$$F = Ff = 4.\ f.\frac{\Delta L}{D}.\frac{v^2}{2.gc}$$

$$F = Ff = 4.\ 0{,}0072.\frac{30\ ft}{0{,}0874\ ft}.\frac{(1{,}9600\ ft/s)^2}{2.\ 32{,}174\ lbm.ft/lbf.s^2} = 0{,}5901\ ft.lbf/lbm$$

- Loss karena friksi pada elbow dan valve, hf

Terdapat 3 buah elbow 90° dan 1 buah gate valve.

Dari Geankoplis tabel 2.10-1, hal 93, didapat:

Kf = 3 × 0,75 + 0,17 = 2,42

α = 1 (aliran turbulen)

$$F = hf = Kf.\frac{v^2}{2.\alpha.\ gc}$$

$$F = hf = 2{,}42 \times \frac{(1{,}9600\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2} = 0{,}1445\ ft.lbf/lbm$$

- Loss karena sudden enlargemen, hex

$$F = hex = Kex.\frac{v^2}{2.\alpha.\ gc}$$

Kex = 1 ($A_1/A_2 \approx 0$), α = 1 (aliran turbulen)

$$F = hex = 1 \times \frac{(1{,}9600\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2} = 0{,}0597\ ft.lbf/lbm$$

ΣF = 0,0328 + 0,5901 + 0,1445 + 0,0597 = 0,8271 ft.lbf/lbm

Pressure drop (ΔP) ≈ 0

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

$$-Ws = \left(\frac{(1{,}9600\ ft/s)^2}{2.1.32{,}174\ lbm.ft/lbf.s^2}\right) + \frac{32{,}174\ ft/s^2}{32{,}174\ lbm.ft/lbf.s^2}.6\ ft + 0 + 0{,}8271\ ft.lbf.lbm$$

-Ws = 6,8868 ft.lbf/lbm

Dari Peters and Timmerhaus 4th ed, fig 14-36: ηpompa = 15%

$$Brake\ Hp = \frac{-Ws.\ m}{\eta.\ 550} = \frac{6{,}8868\ ft.lbf/lbm.\ 0{,}7136\ lbm/s}{0{,}15.\ 550} = 0{,}0596\ Hp$$

Dari Peters and Timmerhaus 4th ed, fig 14-38: ηmotor = 80%

$$Power\ motor = \frac{0{,}0596}{0{,}8} = 0{,}0745\ Hp \approx 0{,}25\ Hp$$

Spesifikasi pompa:

Tipe : Centifugal pump

Rate pompa : 5,2787 gpm

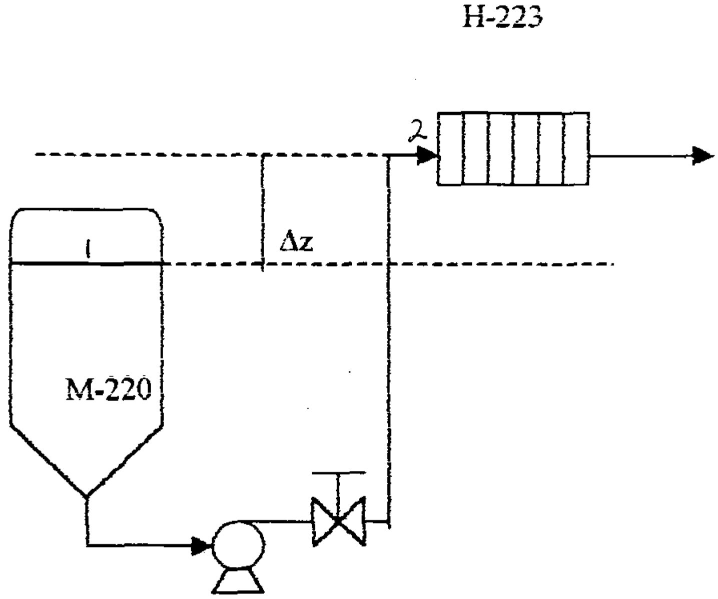
Pipa berukuran 1 in schedule 40

Power motor : 0,25 Hp

Bahan konstruksi : Stainless steel

Jumlah : 1 buah

Pompa (L-222)



Fungsi : Mengalirkan slurry dari tangki pencuci (M-220) menuju ke tangki penampung (F-224).

Massa slurry yang dialirkan = 27972,9368 kg/hari

$$= \frac{27972,9368 \text{ kg} \times 2,2046 \text{ lb/kg}}{24 \text{ jam} \times 3600 \text{ s/jam}} = 0,7138 \text{ lb/s}$$

ρ slurry = 60,6314 lb/ft^3

$$\text{Rate slurry} = \frac{m}{\rho} = \frac{0,7138 \text{ lb/s}}{60,6314 \text{ lb/ft}^3} = 0,0118 \text{ ft}^3/\text{s} = 5,2841 \text{ gpm}$$

μ slurry = 0,7441 cp = 0,0005 lb/ft.s

Trial aliran turbulen:

$Di_{opt} = 3,9.\ qf^{0,45}.\ \rho^{0,13}$ (Peters, Timmerhaus, 1991)

$Di_{opt} = 3,9.\ (0,0118)^{0,45}.\ (60,6314)^{0,13} = 0,9010$ in

Dari Geankoplis hal 892, dipilih pipa berukuran 1 in schedule 40:

OD = 1,315 in

ID = 1,049 in = 0,0874 ft

A = 0,0060 ft^2

$$\text{Kecepatan linear } (v) = \frac{qf}{A} = \frac{0{,}0118 \text{ ft}^3/\text{s}}{0{,}0060 \text{ ft}^2} = 1{,}9620 \text{ ft/s}$$

$$N_{Re} = \frac{\rho.\,ID.\,v}{\mu} = \frac{60{,}6314 \text{ lb/ft}^3 . 0{,}0874 \text{ ft}. 1{,}9620 \text{ ft/s}}{0{,}0005 \text{ lb/ft.s}} = 20798{,}2652$$

(aliran turbulen) Trial cocok

Dengan menggunakan persamaan Bernoulli:

$$\frac{1}{2.\alpha.gc}(v_2{}^2 - v_1{}^2) + \frac{g}{gc}(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + Ws = 0$$

Perhitungan ΣF:

- Loss karena sudden kontraksi, hc

$$F = hc = Kc.\frac{v^2}{2\alpha.\,gc}$$

Kc = 0,55 ($A_2/A_1 \approx 0$), α = 1 (aliran turbulen)

$$F = hc = 0{,}55 \times \frac{(1{,}9620 \text{ ft/s})^2}{2.1.32{,}174 \text{ lbm.ft/lbf.s}^2} = 0{,}0329 \text{ ft.lbf/lbm}$$

- Loss karena friksi pada pipa lurus, Ff

Digunakan pipa comersial steel, ε = 0,00015 ft

ε/D = 0,00015/0,0874 = 0,0017

Dari fig. 14-1 Peters and Timmerhaus 4^{th} ed, diperoleh f = 0,0072

Direncanakan : beda ketinggian (Δz) = 6 ft

Panjang pipa lurus (ΔL) = 30 ft

$$F = Ff = 4.\, f.\frac{\Delta L}{D}.\frac{v^2}{2.gc}$$

$$F = Ff = 4.\, 0{,}0072.\frac{30\ ft}{0{,}0874\ ft}.\frac{(1{,}9620\ ft/s)^2}{2.\,32{,}174\ lbm.ft/lbf.s^2} = 0{,}5913\ ft.lbf/lbm$$

- Loss karena friksi pada elbow dan valve, hf

Terdapat 3 buah elbow 90° dan 1 buah gate valve.

Dari Geankoplis tabel 2.10-1, hal 93, didapat:

$Kf = 3 \times 0{,}75 + 0{,}17 = 2{,}42$

$\alpha = 1$ (aliran turbulen)

$$F = hf = Kf.\frac{v^2}{2.\alpha.\, gc}$$

$$F = hf = 2{,}42 \times \frac{(1{,}9620\ ft/s)^2}{2.\,1.\,32{,}174\ lbm.ft/lbf.s^2} = 0{,}1448\ ft.lbf/lbm$$

- Loss karena sudden enlargemen, hex

$$F = hex = Kex.\frac{v^2}{2.\alpha.\, gc}$$

$Kex = 1$ ($A_1/A_2 \approx 0$), $\alpha = 1$ (aliran turbulen)

$$F = hex = 1 \times \frac{(1{,}9620\ ft/s)^2}{2.\,1.\,32{,}174\ lbm.ft/lbf.s^2} = 0{,}0598\ ft.lbf/lbm$$

$\Sigma F = 0{,}0329 + 0{,}5913 + 0{,}1448 + 0{,}0598 = 0{,}8288$ ft.lbf/lbm

Pressure drop (ΔP) ≈ 0

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

$$-Ws = \left(\frac{(1{,}9620\ ft/s)^2}{2.\,1.\,32{,}174\ lbm.ft/lbf.s^2}\right) + \frac{32{,}174\ ft/s^2}{32{,}174\ lbm.ft/lbf.s^2}.6\ ft + 0 + 0{,}8288\ ft.lbf.lbm$$

-Ws = 6,8886 ft.lbf/lbm

Dari Peters and Timmerhaus 4[th] ed, fig 14-36: ηpompa = 15%

$$\text{Brake Hp} = \frac{-Ws.\,m}{\eta.\,550} = \frac{6{,}8886\ ft.lbf/lbm.\ 0{,}7138\ lbm/s}{0{,}15.\ 550} = 0{,}0596\ Hp$$

Dari Peters and Timmerhaus 4[th] ed, fig 14-38: ηmotor = 80%

$$\text{Power motor} = \frac{0{,}0596}{0{,}8} = 0{,}0745\ Hp \approx 0{,}25\ Hp$$

Spesifikasi pompa:

Tipe : Centifugal pump

Rate pompa : 5,2841 gpm

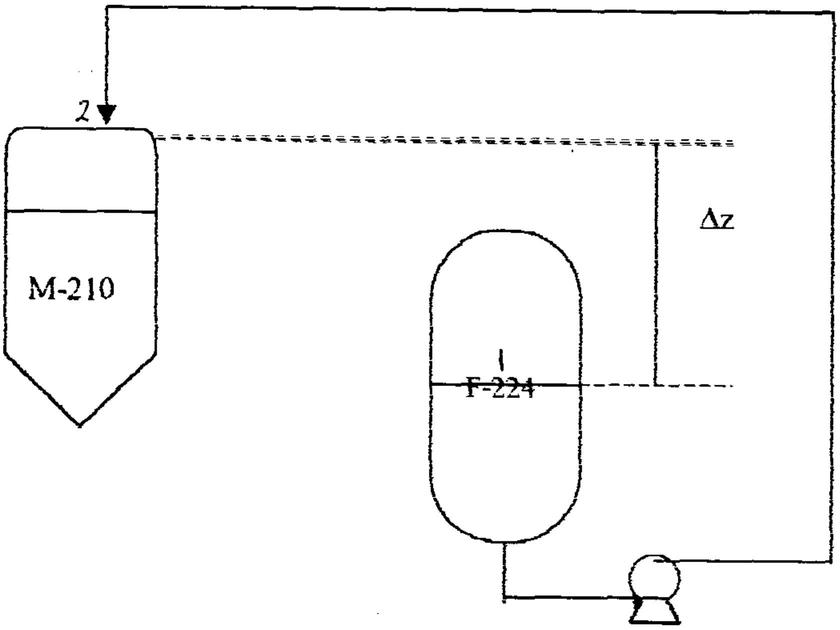
Pipa berukuran 1 in schedule 40

Power motor : 0,25 Hp

Bahan konstruksi : Stainless steel

Jumlah : 1 buah

Pompa (L-225)



Fungsi : Merecycle air pencuci dari tangki penampung (F-224) menuju ke tangki pencuci (M-210).

Massa air pencuci yang dialirkan = 20979,4533 kg/hari

$$= \frac{20979{,}4533\ kg \times 2{,}2046\ lb/kg}{24\ jam \times 3600\ s/jam} = 0{,}5353\ lb/s$$

ρ air pencuci ≈ ρ air = 62,43 lb/ft^3

Rate air pencuci = $\frac{m}{\rho} = \frac{0{,}5353\ lb/s}{62{,}43\ lb/ft^3}$ = 0,0086 ft^3/s = 3,8488 gpm

μ air pencuci = 0,7441 cp = 0,0005 lb/ft.s

Trial aliran turbulen:

$Di_{opt} = 3{,}9.\ qf^{0,45}.\ \rho^{0,13}$ (Peters, Timmerhaus, 1991)

$Di_{opt} = 3{,}9.\ (0{,}0086)^{0,45}.\ (62{,}43)^{0,13} = 0{,}7842$ in

Dari Geankoplis hal 892, dipilih pipa berukuran ¾ in schedule 40:

OD = 1,050 in

ID = 0,824 in = 0,0687 ft

A $= 0,00371\ ft^2$

Kecepatan linear (v) = $\dfrac{qf}{A} = \dfrac{0,0086\ ft^3/s}{0,00371\ ft^2} = 2,3112\ ft/s$

$$N_{Re} = \frac{\rho.\ ID.\ v}{\mu} = \frac{62,43\ lb/ft^3 . 0,0687\ ft . 2,3112\ ft/s}{0,0005\ lb/ft.s} = 19815,8305$$

(aliran turbulen) Trial cocok

Dengan menggunakan persamaan Bernoulli:

$$\frac{1}{2.\alpha.\ gc}(v_2{}^2 - v_1{}^2) + \frac{g}{gc}(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + Ws = 0$$

Perhitungan $\sum F$:

- Loss karena sudden kontraksi, hc

$$F = hc = Kc.\frac{v^2}{2.\alpha.\ gc}$$

Kc = 0,55 ($A_2/A_1 \approx 0$), $\alpha = 1$ (aliran turbulen)

$$F = hc = 0,55 \times \frac{(2,3112\ ft/s)^2}{2.\ 1.\ 32,174\ lbm.ft/lbf.s^2} = 0,0457\ ft.lbf/lbm$$

- Loss karena friksi pada pipa lurus, Ff

Digunakan pipa comersial steel, $\varepsilon = 0,00015$ ft

$\varepsilon/D = 0,00015/0,0687 = 0,0017$

Dari fig. 14-1 Peters and Timmerhaus 4th ed, diperoleh f = 0,0075

Direncanakan : beda ketinggian (Δz) = 10 ft

Panjang pipa lurus (ΔL) = 100 ft

$$F = Ff = 4.\ f.\frac{\Delta L}{D}.\frac{v^2}{2.gc}$$

$$F = Ff = 4.\ 0{,}0075.\frac{100\ \text{ft}}{0{,}0687\ \text{ft}}.\frac{(2{,}3112\ \text{ft/s})^2}{2.\ 32{,}174\ \text{lbm.ft/lbf.s}^2} = 3{,}6268\ \text{ft.lbf/lbm}$$

- Loss karena friksi pada elbow dan valve, hf

Terdapat 4 buah elbow 90°

Dari Geankoplis tabel 2.10-1, hal 93, didapat:

$Kf = 4 \times 0{,}75 = 3$

$\alpha = 1$ (aliran turbulen)

$$F = hf = Kf.\frac{v^2}{2\alpha.\ gc}$$

$$F = hf = 3 \times \frac{(2{,}3112\ \text{ft/s})^2}{2.\ 1.\ 32{,}174\ \text{lbm.ft/lbf.s}^2} = 0{,}2490\ \text{ft.lbf/lbm}$$

$\Sigma F = 0{,}0457 + 3{,}6268 + 0{,}2490 = 3{,}9215$ ft.lbf/lbm

Pressure drop (ΔP) ≈ 0

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

$$-Ws = \left(\frac{(2{,}3112\ \text{ft/s})^2}{2.\ 1.\ 32{,}174\ \text{lbm.ft/lbf.s}^2}\right) + \frac{32{,}174\ \text{ft/s}^2}{32{,}174\ \text{lbm.ft/lbf.s}^2}.10\ \text{ft} + 0 + 3{,}9215\ \text{ft.lbf.lbm}$$

$-Ws = 14{,}0045$ ft.lbf/lbm

Dari Peters and Timmerhaus 4th ed, fig 14-36: ηpompa = 15%

$$\text{Brake Hp} = \frac{-Ws.\ m}{\eta.\ 550} = \frac{14{,}0045\ \text{ft.lbf/lbm.}\ 0{,}5353\ \text{lbm/s}}{0{,}15.\ 550} = 0{,}0909\ \text{Hp}$$

Dari Peters and Timmerhaus 4th ed, fig 14-38: ηmotor = 80%

Power motor = $\frac{0,0909}{0,8}$ = 0,1136 Hp ≈ 0,25 Hp

Spesifikasi pompa:

Tipe : Centifugal pump

Rate pompa : 3,8488 gpm

Pipa berukuran ¾ in schedule 40

Power motor : 0,25 Hp

Bahan konstruksi : Stainless steel

Jumlah : 1 buah

LAMPIRAN D
PERHITUNGAN ANALISA EKONOMI

LAMPIRAN D
PERHITUNGAN ANALISA EKONOMI

Harga alat akan berubah setiap saat tergantung pada kondisi ekonomi dan politik, untuk itu dibutuhkan suatu metode yang dapat dipakai untuk mengkonversi harga alat pada beberapa tahun yang lalu agar dapat diperoleh harga alat yang ekivalen untuk waktu sekarang,

Ekivalensi itu dapat dihitung dengan menggunakan persamaan :

$$\text{Harga alat saat ini} = \frac{\text{Indeks harga saat ini}}{\text{Indeks harga tahun X}} \times \text{Harga alat tahun X}$$

Harga alat pada tahun X yang digunakan dalam pra rencana ini didasarkan pada harga alat yang terdapat pada pustaka:

- Garret, D,E,,1989, " Chemichal Engineering Economics", Van Nostrand Reinhold, New York,

Dalam perhitungan ini digunakan indeks harga sebagai berikut:

- Chemical engineering plant cost index

  Tahun X (awal 1987) = 320 (Garret, p. 255)

  Data-data cost index tahun 1998 – 2002 adalah sebagai berikut:

Tahun	CE Cost Index
1998	389.5
1999	390.6
2000	394.1
2001	394.3
2002	395.6

(*Chemical Engineering, Januari 2002*)

Dari data-data diatas dengan cara ekstrapolasi diperoleh cost index untuk tahun 2006 = 402,34

A. Perhitungan Harga Peralatan

Contoh perhitungan :

Nama alat : Tangki penampung susu segar (F-111)

Fungsi : Untuk meyimpan susu selama 1 hari

Tipe : Silinder tegak dengan tutup atas dan bawah berbentuk dished head dilengkapi dengan pengaduk dan jaket pendingin

Jumlah : 3 buah

Untuk tangki berpengaduk dan berjaket dengan bahan mild steel:

Harga tahun 1987 : \$ 46000 (Garret, hal 258)

Faktor material untuk bahan stainless steel : 1,7

Harga alat saat ini : $\frac{402,34}{320} \times \$\ 46000 \times 1,7 = \$\ 98.321,8375$

Dengan cara yang sama didapatkan harga alat yang lain seperti pada tabel D.1.

Tabel D.1. Harga Peralatan Proses

Nama alat	Kode	Jumlah	Harga th 2003	Harga total (Rp.)
Tangki penampung susu	F-111	3	US\$ 98.321,8375	2.507.206.856,25
Pompa	L-112	1	Rp.2.000.000,0000	2.000.000,00
Tangki penyimpan asam asetat	F-121	1	US\$ 1.719,1589	14.612.851,06
Pompa	L-122	1	Rp. 750.000,0000	750.000,00
Tangki pengencer asam asetat	M-123	1	US\$ 1.876,5419	15.950.606,15
Heat exchanger	E-110	1	US\$ 20.981,6079	178.343.667,24
Centrifuge	H-113	1	US\$ 113.158,1250	961.844.062,50
Reaktor	R-120	1	US\$ 34.198,9000	290.690.650,00
Pompa	L-124	1	Rp.1.000.000,0000	1.000.000,00
Filter Press	H-125	2	US\$ 3.897,6688	66.260.368,75
Tangki Penampung	F-126	1	US\$ 8.801,1875	74.810.093,75
Pompa	L-131	1	Rp. 750.000,0000	750.000,00
Tangki demineralisasi	R-130	1	US\$ 251,4625	2.137.431,25
Pompa	L-141	1	Rp. 750.000,0000	750.000,00
Tangki deproteinaiser	R-140	1	US\$ 34.198,9000	290.690.650,00
Pompa	L-142	1	Rp. 750.000,0000	750.000,00
Filter Press	H-143	2	US\$ 3.897,6688	66.260.368,75
Tangki penampung	F-144	1	US\$ 8.801,1875	74.810.093,75
Pompa	L-151	1	Rp.2.000.000,0000	2.000.000,00
Evaporator	V-150	1	US\$ 251.462,5000	2.137.431.250,00
Kristaliser	X-160	1	US\$ 97.720,6309	830.625.362,48
Pompa	L-161	1	Rp. 750.000,0000	750.000,00
Filter Press	H-162	2	US\$ 3.897,6688	66.260.368,75
Screw conveyor	J-171	1	US\$ 3.269,0125	27.786.606,25
Rotary dryer	B-170	1	US\$ 23.637,4750	200.918.537,50
Blower	G-172	1	US\$ 67.894,8750	577.106.437,50
Cyclone	H-173	1	US\$ 4.526,3250	38.473.762,50
Screw conveyor	J-181	1	US\$ 3.269,0125	27.786.606,25
Ball mill	C-180	1	US\$ 32.690,1250	277.866.062,50
Screw conveyor	J-182	1	US\$ 3.269,0125	27.786.606,25
Screen	H-183	1	US\$ 23.888,9375	203.055.968,75

Bin laktosa	F-184	1	US$ 4.526,3250	38.473.762,50
Screw conveyor	J-211	1	US$ 3.269,0125	27.786.606,25
Tangki pencuci	M-210	1	US$ 15.087,7500	128.245.875,00
Pompa	L-212	1	Rp. 750.000,0000	750.000,00
Filter Press	H-213	2	US$ 3.897,6688	66.260.368,75
Screw conveyor	J-221	1	US$ 3.269,0125	27.786.606,25
Tangki pencuci	M-220	1	US$ 15.087,7500	128.245.875,00
Pompa	L-222	1	Rp. 750.000,0000	750.000,00
Filter Press	H-223	2	US$ 3.897,6688	66.260.368,75
Tangki Penampung	F-224	1	US$ 3.143,2813	26.717.890,63
Pompa	L-225	1	Rp. 750.000,0000	750.000,00
Screw conveyor	J-231	1	US$ 3.269,0125	27.786.606,25
Rotary dryer	B-230	1	US$ 23.637,4750	200.918.537,50
Blower	G-232	1	US$ 52.807,1250	448.860.562,50
Cyclone	H-233	1	US$ 3.646,2063	30.992.753,13
Screw conveyor	J-241	1	US$ 3.269,0125	27.786.606,25
Ball mill	C-240	1	US$ 20.745,6563	176.338.078,13
Screw conveyor	J-242	1	US$ 3.269,0125	27.786.606,25
Screen	H-243	1	US$ 23.888,9375	203.055.968,75
Bin casein	F-244	1	US$ 3.897,6688	33.130.184,38
Filter udara	H-234	1	US$ 1.000,0000	8.500.000,00
Blower	G-235	1	US$ 100.585,0000	854.972.500,00
Heat exchanger	E-236	1	US$ 17.602,3750	149.620.187,50
Total				11.669.241.211,93

Tabel D.2. Harga Peralatan Utilitas

Nama alat	Kode	Jumlah	Harga th 2003	Harga total (Rp.)
Boiler		1	US$ 28.918,1875	245.804.593,75
Tangki demineralisasi	F-247	1	US$ 5.532,1750	47.023.487,50
Tangki penampung air demineralisasi	F-248	1	US$ 2.011,7000	17.099.450,00
Tangki penampung umpan boiler	F-251	1	US$ 4.652,0563	39.542.478,13
Cooling tower	P-263	1	US$ 6.389,3438	54.309.422,40
Tangki refrigerant	F-265	3	US$ 66.637,5625	1.699.257.843,75
Generator		1	US$ 60.351,0000	512.983.500,00
Tangki penyimpan bahan bakar	F-264	1	US$ 30.175,5000	256.491.750,00
Pompa	L-246	1	Rp. 750.000,0000	750.000,00
Pompa	L-249	1	Rp. 750.000,0000	750.000,00
Pompa	L-252	1	Rp. 750.000,0000	750.000,00
Pompa	L-254	1	Rp. 750.000,0000	750.000,00
Pompa	L-255	1	Rp. 750.000,0000	750.000,00
Pompa	L-257	1	Rp. 750.000,0000	750.000,00
Pompa	L-258	1	Rp. 750.000,0000	750.000,00
Pompa	L-262	1	Rp.1.000.000,0000	1.000.000,00
Total				2.878.762.525,52

Tabel D.3. Bak Utilitas

Nama alat	Kode	Jumlah	Luas,m2
Bak penampung air	F-245	1	3.5
Bak penampung air sanitasi	F-256	1	1.5
Bak penampung air pendingin	F-261	1	6.25
Total			11.25

Harga bak = Rp.275.000,- /m^2

Total harga bak utilitas = 11,25 m^2 × (Rp.275.000,- /m^2)

= Rp.3.093.750,-

Krus dolar: 1 dolar = Rp. 8500,-

Total harga peralatan = Rp.11.669.241.211,93 + Rp.2.878.762.525,52 + Rp.3.093.750,-

= Rp.16.335.967.028,75

B. Perhitungan Harga Tanah dan Bangunan

Luas tanah = 9.500 m^2

Luas pabrik dan gudang = 4.000 m^2

Luas bangunan kantor = 300 m^2

Luas bangunan lain-lain = 5.200 m^2

Harga tanah = Rp. 200.000,- /m^2

Harga bangunan pabrik dan gudang = Rp. 1.000.000,-/m^2

Harga bangunan kantor = Rp. 1.250.000,-/m^2

Harga bangunan lain-lain = Rp. 750.000,-/m^2

Jadi :

Harga tanah = 9.000 m^2 × Rp.200.000,-/m^2 = Rp.1.900.000.000,-

Harga bangunan pabrik dan gudang = 4.000 m^2 x Rp. 1.000.000,-/m^2

= Rp.4.000.000.000,-/m^2

Harga bangunan kantor = 300 m^2 × Rp. 1.250.000,-/m^2

= Rp.375.000.000,-

Harga bangunan lain-lain = 5.200 m^2 × Rp. 750.000,-/m^2

= Rp.3.900.000.000,-

Total harga tanah dan bangunan = Rp.1.900.000.000,- + Rp.4.000.000.000,- +
Rp.375.000.000,- + Rp.3.900.000.000,-
= Rp.10.175.000.000,-

C. Perhitungan Harga Bahan Baku dan Harga Jual Produk

➢ Harga Bahan Baku

1. Susu segar

   Harga : Rp.1450,-/liter

   Kebutuhan : 212.500 liter/hari = 70.125.000 liter/tahun

   Total : Rp. 101.681.250.000,- / tahun

2. Asam asetat glasial

   Harga : Rp. 99.000,-/liter

   Kebutuhan : 2,9546 kg/hari / 1,0380 kg/liter = 2,8464 liter/hari
   = 939,3164 liter/tahun

   Total : Rp. 92.992.325,34/tahun

Total harga bahan baku per tahun:

= Rp. 101.681.250.000,- + Rp. 92.992.325,34

= Rp. 101.774.242.325,34

➢ Harga Jual Produk

1. Casein

   Harga : Rp. 620.000,- /kg

   Produksi : 1850136,0037 kg/tahun

   Total : Rp.1.147.084.322.290,92

2. Laktosa

   Harga : Rp. 245.000,-/kg

   Produksi : 3169664,9132 kg/tahun

   Total : Rp.776.567.903.743,66

Total harga jual produk per tahun:

= Rp.1.147.084.322.290,92 + Rp.776.567.903.743,66

= Rp.1.923.652.226.034,58

D. Perhitungan Gaji Karyawan

Perincian gaji karyawan tiap bulan dapat dilihat pada tabel D.4 berikut ini.

Tabel D.4. Gaji Karyawan

No	Jabatan	Jumlah	Gaji/bulan (Rp)	Total (Rp)
1	Direktur Utama	1	12000000	12000000
2	Direktur Teknik & Produksi	1	8000000	8000000
3	Direktur Administrasi & Keuangan	1	8000000	8000000
4	Sekretaris	3	1000000	3000000
5	Kabag Produksi	1	2500000	2500000
6	Kabag Teknik	1	2500000	2500000
7	Kabag Keuangan	1	2500000	2500000
8	Kabag Pemasaran	1	2500000	2500000
9	Kabag Personalia & Umum	1	2500000	2500000
10	Kasie Proses	1	1500000	1500000
11	Kasie Penelitian & Pengembangan	1	1500000	1500000
12	Kasie Utilitas	1	1500000	1500000
13	Kasie Pemeliharaan & Perbaikan	1	1500000	1500000
14	Kasie Laboratorium & QC	1	1500000	1500000
15	Kasie Promosi & Penjualan	1	1500000	1500000
16	Kasie Keuangan	1	1500000	1500000
17	Kasie Pembelian	1	1500000	1500000
18	Kasie Gudang	1	1500000	1500000
19	Kasie Personalia	1	1500000	1500000
20	Kasie Keamanan	1	1500000	1500000
21	Seksi Proses	40	800000	32000000
22	Seksi Penelitian & Pengembangan	2	1000000	2000000
23	Seksi Utilitas	8	1000000	8000000
24	Seksi Pemeliharaan & Perbaikan	5	1000000	5000000
25	Seksi Laboratorium & QC	4	1000000	4000000
26	Seksi Promosi & Penjualan	4	1000000	4000000
27	Seksi Keuangan	2	1000000	2000000
28	Seksi Pembelian	2	1000000	2000000
29	Seksi Gudang	2	1000000	2000000
30	Seksi Personalia	5	800000	4000000
31	Seksi Keamanan	8	800000	6400000
32	Sopir & Pesuruh	6	750000	4500000
TOTAL		110		135900000

Biaya listrik total per tahun = biaya beban + biaya pemakaian listrik

= Rp. 420.000.000,- + Rp.3.144.465.020,17

= Rp. 3.564.465.020,17

3. Kebutuhan bahan bakar

Kebutuhan bahan bakar per tahun = 6.358.169,5844 kg

= 7.217.100,4937 liter

Harga bahan bakar per liter = Rp.1650,-

Biaya bahan bakar per tahun = 7.217.100,4937 liter × Rp.1440,-/liter

= Rp.11.908.215.814,61

4. Refrigerant (etilen glikol)

Asumsi: Refrigerant diganti setahun sekali

Kebutuhan etilen glikol per tahun = 21.047.715,7021 liter

Harga Etilen glikol = Rp.71.000,-/liter

Biaya refrigerant per tahun = 21.047.715,7021 liter × Rp.71.000,-/liter

= Rp.1.494.387.814.851,99

5. Kebutuhan NaCl untuk regenerasi resin

Mineral yang dihilangkan pada proses demineralisasi larutan whey = 1415,3134 kg/hari

Asumsi kandungan mineral dalam air = 750 mg/galon

Air yang diolah dalam demineralisasi air di utilitas = 62,2174 m^3/hari

Mineral yang dihilangkan pada proses demineralisasi air = 12,3270 kg/hari

Total mineral yang dihilangkan = 1415,3134 + 12,3270 = 1427,6404 kg/hari

Kebutuhan NaCl untuk regenerasi = 0,45 lb/kg mineral yang dihilangkan

(Powell, 1954, tabel 5.)

= 0,45 lb/kg × 1427,6404 kg/hari

= 642,4382 lb/hari = 291,4035 kg/hari

Harga NaCl = Rp.100.400,-/kg

Biaya untuk NaCl per tahun = 291,4035 kg/hari × Rp.100.400,-/kg × 330 hari/tahun

= Rp.9.654.781.727,49

Total biaya utilitas per tahun = Rp. 1.519.555.099.833,50

F. Pembagian Shift Karyawan

Untuk karyawan bagian proses, utilitas, dan keamanan dilakukan sistem 3 shift per hari yang terdiri atas 4 regu secara bergantian.

Shift pergantian kerja dilakukan dengan cara seperti pada tabel D.5.

Tabel D.5. Shift Pergantian Kerja

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: P = pagi, S = siang, M = malam, L = libur

Waktu pergantian shift untuk karyawan bagian proses, utilitas dan bagian keamanan berbeda. Untuk karyawan proses dan utilitas, pergantian karyawan yang ditetapkan adalah:

Shift 1 : 07.00 – 15.00

Shift 2 : 15.00 – 23.00

Shift 3 : 23.00 – 07.00

Sedangkan untuk karyawan bagian keamanan, pergantian yang ditetapkan adalah:

Shift 1 : 06.00 – 14.00

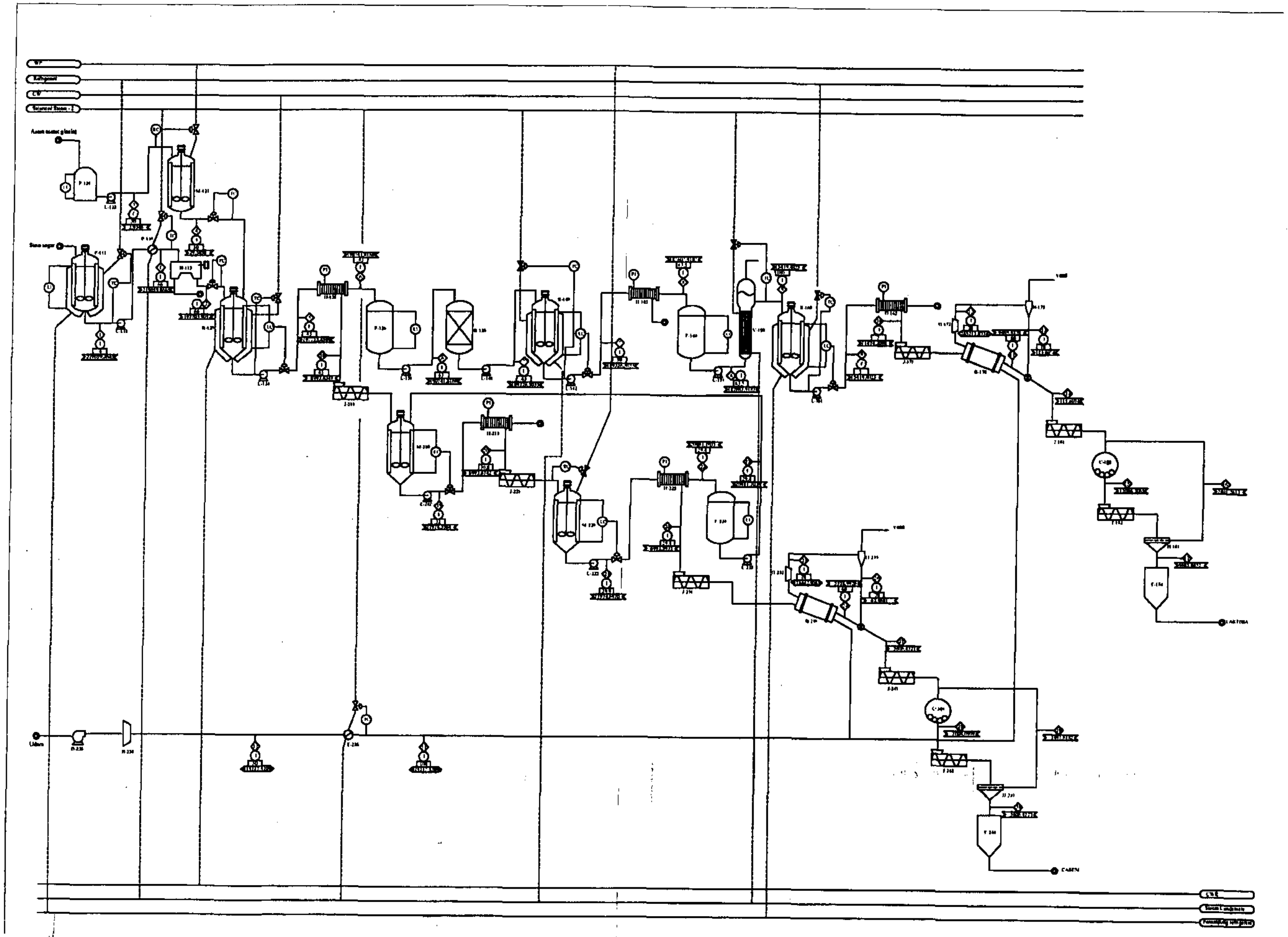
Shift 2 : 14.00 – 22.00

Shift 3 : 22.00 – 06.00

Untuk karyawan non-shift memiliki jam kerja:

Senin – Jumat : 08.00 – 16.00

Sabtu : 08.00 – 12.00



54	F-244	Bin Casein
53	H-243	Screen
52	J-242	Screw conveyor
51	C-240	Ball mill
50	J-241	Screw conveyor
49	E-236	Shell and Tube Heat Exchanger
48	G-235	Blower
47	H-234	Filter udara
46	H-233	Cyclone
45	G-232	Blower
44	B-230	Rotary dryer
43	J-231	Screw conveyor
42	L-225	Pompa
41	F-224	Tangki penampung
40	H-223	Filter Press
39	L-222	Pompa
38	M-220	Tangki pencuci 2
37	J-221	Screw conveyor
36	H-213	Filter Press
35	L-212	Pompa
34	M-210	Tangki pencuci 1
33	J-211	Screw conveyor
32	F-184	Bin Laktosa
31	H-183	Screen
30	J-182	Screw conveyor
29	C-180	Ball mill
28	J-181	Screw conveyor
27	H-173	Cyclone
26	G-172	Blower
25	B-170	Rotary dryer
24	J-171	Screw conveyor
23	H-162	Filter Press
22	L-161	Pompa
21	X-160	Kristaliser
20	V-150	Evaporator
19	L-151	Pompa
18	F-144	Tangki penampung
17	H-143	Filter Press
16	L-142	Pompa
15	R-140	Tangki deproteinasier
14	L-141	Pompa
13	R-130	Tangki demineralisasi
12	L-131	Pompa
11	F-126	Tangki penampung
10	H-125	Filter Press
9	L-124	Pompa
8	M-123	Tangki pengencer asam asetat
7	L-122	Pompa
6	F-121	Tangki penyimpan asam asetat
5	R-120	Reaktor
4	H-113	Centrifuge
3	E-110	Shell and Tube Heat Exchanger
2	L-112	Pompa
1	F-111	Tangki penyimpan susu segar
No.	Kode	Nama Peralatan

Nama Mahasiswa :
1. Liana Kentjono / 5203000014
2. Ivy Yuanita / 5203000054

Disetujui oleh: Tanda Tangan

Wenny Irawati, ST. MT.

FLOWSHEET
PABRIK CASEIN DAN LAKTOSA
JURUSAN TEKNIK KIMIA
FAKULTAS TEKNIK
UNIVERSITAS KATOLIK WIDYA MANDALA SURABAYA
2005

Keterangan	
	Nomor Neraca Bahan
	Suhu, °C
	Tekanan (atm)
	Aliran Gas (kg/hari)
	Aliran Fluida dan padatan (kg/hari)
FC	Flow Control
TC	Temperature Control
LC	Level Control
LI	Level Indicator
PI	Pressure Indicator
RC	Ratio Control

Komponen	1	2	3	4	5	6	7	8	9	10	11
Air	190801.1437	179188.7150		26.5912	179215.3062	177910.6637	177910.6637	177585.3072	5396.7908	1984.7720	142.3416
Ca^{2+} caseinate	5958.4284	5593.7900									
Casein					5594.9394						
Protein whey	1489.6071	1398.9475			1398.9475	1388.7635	1388.7635	13.8622	13.8622	5.0981	5.0216
Lemak	8543.3348	1.7087			1.7087	1.7087	1.7087	1.7087	1.7087	0.6284	0.6190
Laktosa	10733.9335	10080.6510			10080.6510	10007.2664	10007.2664	9988.9655	9988.9655	9477.1627	9335.0032
Mineral	1533.4191	1440.0930			1440.0930	1429.6095	14.2961	14.2700	14.2700	5.2480	5.1693
Asam asetat			2.9546	2.9546	0.2686	0.2686	0.2686	0.2686	0.2686		
Kalsium asetat					3.5365	3.5365	3.5365	3.5365	3.5365	1.3006	1.2811
O_2											
N_2											
Total	219059.8665	197705.9052	2.9546	29.5458	197735.4509	190741.8168	189326.5035	187607.9187	15419.4023	11474.2098	9489.4378

Komponen	12	13	14	15	16	17	18	19	20	21
Air	6611.6285	1.7341	144.0757	180.0946	36.0189	144.0757	1304.6426	22285.5449	1392.8565	22373.8793
Ca^{2+} caseinate										
Casein							5594.9394	5594.9394	5594.9394	5594.9394
Protein whey	0.0765	0.0612	5.0828	6.3535	1.2707	5.0828	*10.1840*	*10.1840*	*0.6365*	*0.6365*
Lemak	0.0094	0.0075	0.6265	0.7831	0.1566	0.6265		0.0000		
Laktosa	142.1574	113.7260	9448.7312	11810.9140	2362.1828	9448.7312	73.3846	73.3846	4.5866	4.5866
Mineral	0.0787	0.0630	5.2323	6.5404	1.3081	5.2323	10.4835	10.4835	0.6552	0.6552
Asam asetat								0.0000		
Kalsium asetat	0.0195	0.0156	1.2967	1.6209	0.3242	1.2967		0.0000		
O_2	50076.5805									
N_2	188383.3268									
Total	245213.8774	115.6074	9605.0452	12006.3065	2401.2613	9605.0452	6993.6341	27974.5364	6993.6742	27974.6970

Komponen	22	23	24	25	26	27	28	29	30	31
Air	20975.5118	1398.3675	27.6950	4742.8844	0.3374	28.0324	35.0405	7.0081	28.0324	8141.5200
Ca^{2+} caseinate										
Casein				83.9241	67.1391	5578.1546	6972.6932	1394.5386	5578.1546	
Protein whey	*0.6365*	*5594.9394*	*5511.0153*							
Lemak										
Laktosa	4.2999			0.0043	0.0034	0.2858	0.3573	0.0715	0.2858	
Mineral	0.6552	0.2867	0.2824							
Asam asetat										
Kalsium asetat										
O_2				35409.3797						85485.9602
N_2				133206.7139						321590.0407
Total	20981.1035	6993.5935	5538.9926	173442.9063	67.4801	5606.4727	7008.0909	1401.6182	5606.4727	415217.5209