APPENDIX

APPENDIX A

PERHITUNGAN NERACA MASSA

Satuan : kg

Kapasitas produksi : 7.794.000 kg/tahun

1 tahun : 300 hari

1 hari : 25.980 kg

Basis : 1 hari

Proses : kontinyu

Untuk mendapatkan susu bubuk tinggi protein sebanyak 25.980 kg, diperlukan susu segar sebesar 671.406,6098 kg, dengan komposisi susu sebagai berikut:

Tabel A.1 Komposisi susu segar masuk [8]

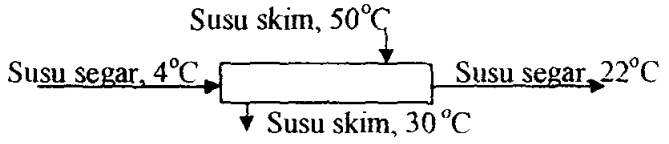
Komposisi	% berat
Lemak	3,90
Protein	3,40
Laktosa	4,80
Abu	0,72
Air	87,18
Total	**100,00**

Jumlah masing – masing komponen dalam susu :

- Lemak = 671.406,610 x 0,039 = 26.184,8578 kg
- Protein = 671.406,610 x 0,034 = 22.827,8247 kg
- Laktosa = 671.406,610 x 0,048 = 32.227,5173 kg
- Abu = 671.406,610 x 0,0072 = 4.834,1276 kg
- Air = 671.406,610 x 0,873 = 585.332,2824 kg +

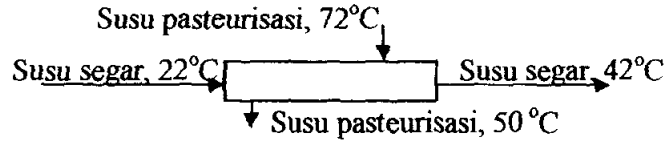
Massa susu segar keluar = 671.406,6098 kg

1. *Plate Heat Exchanger* 1 (E-110)



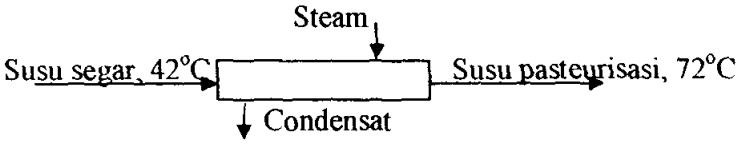
Masuk (kg)			Keluar (kg)		
Dari Tangki Penyimpanan			Ke *plate heat exchanger* 2 (E-120)		
Susu segar 4°C		**671.406,6098**	**Susu segar 22°C**		**671.406,6098**
- Lemak	26.184,8578		- Lemak	26.184,8578	
- Protein	22.827,8247		- Protein	22.827,8247	
- Laktosa	32.227,5173		- Laktosa	32.227,5173	
- Abu	4.834,1276		- Abu	4.834,1276	
- Air	585.332,2824		- Air	585.332,2824	
Dari *plate heat exchanger* 2 (E-120)			Ke tangki penampungan (F-150)		
Susu skim 50°C			**Susu skim 30°C**		
		671.406,6098			**671.406,6098**
- Lemak	523,6972		- Lemak	523,6972	
- Protein	22.827,8247		- Protein	22.827,8247	
- Laktosa	32.227,5173		- Laktosa	32.227,5173	
- Abu	4.834,1276		- Abu	4.834,1276	
- Air	585.332,2824		- Air	585.332,2824	
Total		**1.342.813,2196**	**Total**		**1.342.813,2196**

2. *Plate Heat Exchanger* 2 (E-120)



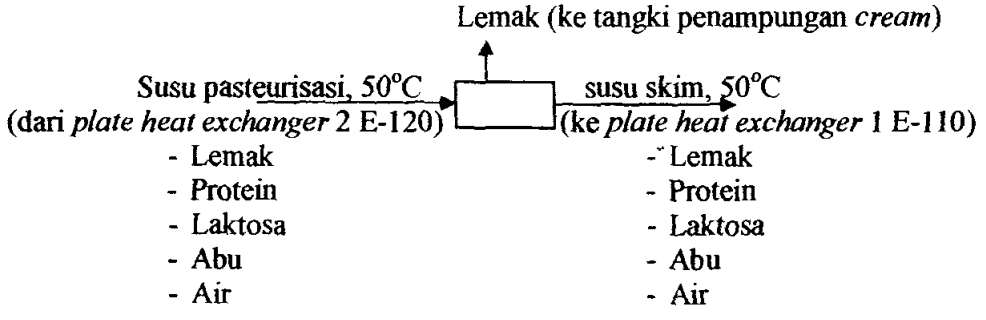
Masuk (kg)			Keluar (kg)		
Dari *plate heat exchanger* 1 (E-110)			Ke *plate heat exchanger* 3 (E-130)		
Susu segar 22°C		**671.406,6098**	**Susu segar 42°C**		**671.406,6098**
- Lemak	26.184,8578		- Lemak	26.184,8578	
- Protein	22.827,8247		- Protein	22.827,8247	
- Laktosa	32.227,5173		- Laktosa	32.227,5173	
- Abu	4.834,1276		- Abu	4.834,1276	
- Air	585.332,2824		- Air	585.332,2824	
Dari *plate heat exchanger* 3 (E-130)			Ke *Centrifugal Separator* (H-140)		
Susu pasteurisasi 72°C			**Susu pasteurisasi 50°C**		
		671.406,6098			**671.406,6098**
- Lemak	26.184,8578		- Lemak	26.184,8578	
- Protein	22.827,8247		- Protein	22.827,8247	
- Laktosa	32.227,5173		- Laktosa	32.227,5173	
- Abu	4.834,1276		- Abu	4.834,1276	
- Air	585.332,2824		- Air	585.332,2824	
Total		**1.342.813,2196**	**Total**		**1.342.813,2196**

3. *Plate Heat Exchanger* (E-130)



Masuk (kg)			Keluar (kg)		
Dari *plate heat exchanger* 2 (E-120)			Ke *plate heat exchanger* 2 (E-120)		
Susu segar 42°C			**Susu pasteurisasi 72°C**		
		671.406,6098			**671.406,6098**
- Lemak	26.184,8578		- Lemak	26.184,8578	
- Protein	22.827,8247		- Protein	22.827,8247	
- Laktosa	32.227,5173		- Laktosa	32.227,5173	
- Abu	4.834,1276		- Abu	4.834,1276	
- Air	585.332,2824		- Air	585.332,2824	
Total		**671.406,6098**	**Total**		**671.406,6098**

4. *Centrifugal Separator* (H-140)



Data :

1. Kandungan lemak pada susu skim keluar dari *centrifugal separator* adalah 0,08 % [8]

Sentrifugasi digunakan untuk memisahkan globula lemak susu (*cream*) sehingga didapatkan susu skim dengan kandungan lemak maksimal 0,1-0,2%[12]. C*entrifugal separator* memiliki efesiensi pemisahan yang baik pada suhu 50°C[12]. Lemak dapat dipisahkan dari susu dengan menggunakan gaya sentrifugal karena partikel lemak memiliki ukuran paling besar dibandingkan dengan komponen-komponen lain dalam susu.

Tabel. A.1 Ukuran partikel berbagai kompnen dalam susu [9]

Komponen	Ukuran
Lemak	± 5. 10^3 nm
Protein	10 nm s/d 100 nm
laktosa	1 nm
Abu	± 0,5 nm
Air	0,1 nm

Kandungan lemak keluar dari *centrifugal separator* adalah 0,08 % [8], massa lemak pada susu (X):

$$\frac{X}{671.406{,}6098-(26.184{,}8578-X)} = 0{,}08\%$$

$$X = 523{,}6972 \text{ kg}$$

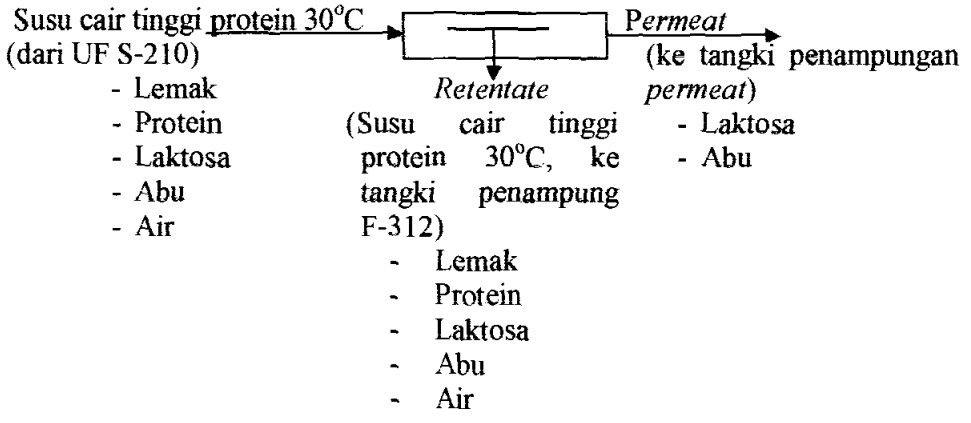
Masuk (kg)			Keluar (kg)		
Dari *plate heat exchanger* 2 (E-120)			Ke *plate heat exchanger* 1 (E-110)		
Susu pasteurisasi 50°C		**671.406,6098**	**Susu skim 50°C**		**645.745,4492**
- Lemak	26.184,8578		- Lemak	523,6972	
- Protein	22.827,8247		- Protein	22.827,8247	
- Laktosa	32.227,5173		Laktosa	32.227,5173	
- Abu	4.834,1276		- Abu	4.834,1276	
- Air	585.332,2824		- Air	585.332,2824	
			Ke tangki *cream*		
			Lemak		**25.661,1606**
Total		**671.406,6098**	**Total**		**671.406,6098**

5. Tangki Penampungan (F-150)

Susu skim 30°C → [ ] → susu skim 30°C

Masuk (kg)			Keluar (kg)		
Dari *plate heat exchanger* 1 (E-110)			Ke membran UF (S-210)		
Susu skim 30°C		**645.745,4492**	**Susu skim 30°C**		**645.745,4492**
- Lemak	523,6972		- Lemak	523,6972	
- Protein	22.827,8247		- Protein	22.827,8247	
- Laktosa	32.227,5173		- Laktosa	32.227,5173	
- Abu	4.834,1276		- Abu	4.834,1276	
- Air	585.332,2824		- Air	585.332,2824	
Total		**645.745,4492**	**Total**		**645.745,4492**

6. DF (S-220)



Data :

1. Dari massa susu skim yang masuk membran UF (S-210), didapatkan 16,7% massa susu cair tinggi protein [8].
2. Kandungan laktosa dan abu pada keluar membran DF (S-220) adalah 0,08% dan 1,67% [8].

Massa susu cair tinggi protein setelah keluar dari membran DF, didapatkan dari perhitungan:

$$\textit{Massa susu cair tinggi protein} = 0{,}167 * \textit{Massa susu skim}$$
$$= 0{,}167 * 645.745{,}4491$$
$$= 107.839{,}49 \, kg / hari$$

Asumsi yang digunakan:

1. Kandungan air susu masuk membran DF sama dengan kandungan air susu keluar dari membran DF.
2. Air diafiltrasi hanya digunakan untuk meloloskan laktosa dan abu yang tersisa setelah penyaringan UF [11].
3. Protein dan lemak tersaring sempurna sehingga pada *permeate* tidak ada kandungan keduanya, hal ini disebabkan karena ukuran molekul

protein dan lemak lebih besar dibandingkan dengan ukuran laktosa dan abu (protein dan lemak sebagai *trace elements*) [9].

massa laktosa abu dan air keluar dari membran DF adalah:

$$\begin{aligned}
Massa\,laktosa &= 0{,}08\% * Massa\,susu\,cair\,tinggi\,protein\,keluar\,membran\,DF \\
&= 0{,}08\% * 107.839{,}49 \\
&= 86{,}0994\,kg \\
Massa\,abu &= 1{,}67\% * Massa\,susu\,cair\,tinggi\,protein\,keluar\,membran\,DF \\
&= 1{,}67\% * 107.839{,}49 \\
&= 1.797{,}3248\,kg \\
Massa\,air &= Massa\,susu\,cair\,tinggi\,protein\,keluar\,membran\,DF - \\
&\quad (massa\,protein + masssa\,lemak + massa\,laktosa + massa\,abu) \\
&= 107.839{,}49 - (22.827{,}7247\,kg + 523{,}6972\,kg + 86{,}0994\,kg + 1.797{,}3248\,kg) \\
&= 82.389{,}2945
\end{aligned}$$

Massa laktosa dan abu yang harus dihilangkan sebagai permeat:

$$Massa\,laktosa = 4.264{,}1130\,{}^{kg}/_{hari} - 86{,}09940\,{}^{kg}/_{hari} = 4.178{,}0136\,{}^{kg}/_{hari}$$

$$Massa\,abu = 1.913{,}8103\,{}^{kg}/_{hari} - 1.797{,}3248\,{}^{kg}/_{hari} = 116{,}4855\,{}^{kg}/_{hari}$$

Massa laktosa dan abu yang tertahan di membran:

Asumsi: 1% dari massa laktosa dan abu yang harus dihilangkan

Massa laktosa tertahan = $4.178{,}0136\,{}^{kg}/_{hari}$ x 1% = $41{,}7801\,{}^{kg}/_{hari}$

Massa abu tertahan = $116{,}4855\,{}^{kg}/_{hari}$ x 1% = $1{,}1649\,{}^{kg}/_{hari}$

Massa laktosa ke tangki penampungan *permeat*

$$= 4.178{,}0136\,{}^{kg}/_{hari} - 41{,}7801\,{}^{kg}/_{hari} = 4.136{,}2335\,{}^{kg}/_{hari}$$

Massa abu ke tangki penampungan *permeat*

$$= 116{,}4855\,{}^{kg}/_{hari} - 1{,}1649\,{}^{kg}/_{hari} = 115{,}3206\,{}^{kg}/_{hari}$$

Masuk (kg)		Keluar (kg)	
Dari membran UF (S-210)		Ke tangki penampungan (F-312)	
Susu cair tinggi protein 30°C	**111.918,7406**	***(Retentate)* Susu cair tinggi protein 30°C**	**107.624,2415**
- Lemak	523,6972	- Lemak	523,6972
- Protein	22.827,8247	- Protein	22.827,8247
- Laktosa	4.264,1130	- Laktosa	86,0994
- Abu	1.913,8103	- Abu	1.797,3248
- Air	82.389,2954	- Air	82.389,2954
		Ke tangki penampungan *permeat*	
		Permeat	**4.251,5541**
		- Laktosa	4.136,2335
		- Abu	115,3206
		Tertahan di membran	
		Permeat	**42,9450**
		- Laktosa	41,7801
		- Abu	1,1649
Total	**111.918,7406**	**Total**	**111.918,7406**

7. UF (S-210)

Susu skim 30°C (dari tangki penampung F-150)
- Lemak
- Protein
- Laktosa
- Abu
- Air

Retentate (Susu cair tinggi protein 30°C) (ke tangki penampung F-312)
- Lemak
- Protein
- Laktosa
- Abu
- Air

Permeat (ke tangki penampungan *permeat*)
- Laktosa
- Abu

Data :

1. Kandungan laktosa dan abu pada keluar membran UF masing-masing 3,81% dan 1,71% [8].

Massa laktosa dan protein pada keluar membran UF adalah:

misal: massa laktosa adalah x dan massa abu adalah y, maka:

$$3{,}81\% = \frac{massa\,laktosa}{massa\,lemak + massa\,protein + massa\,laktosa + massa\,abu + massa\,air}$$

$$3{,}81\% = \frac{x}{523{,}6972 + 22.827{,}8247 + x + y + 82.389{,}2954}$$

$$x = (105.740{,}8173 + x + y) * 3{,}81\%$$

$$x = 4.028{,}7251 + 0{,}0381x + 0{,}0381y$$

$$0{,}9619x = 4.028{,}7251x + 0{,}0381y$$

$$x = 4.188{,}2993 + 0{,}039614y$$

$$1{,}71\% = \frac{massa\,abu}{massa\,lemak + massa\,protein + massa\,laktosa + massa\,abu + massa\,air}$$

$$1{,}71\% = \frac{y}{523{,}6972 + 22.827{,}8247 + x + y + 82.389{,}2954}$$

$$y = (105.740{,}8173 + x + y) * 1{,}71\%$$

$$y = 1.808{,}168 + 0{,}0171x + 0{,}0171y$$

$$0{,}9829y = 1.808{,}168 + 0{,}0171 * (4.188{,}2993 + 0{,}03961y)$$

$$0{,}9829y = 1.879{,}7879 + 6{,}77331 * 10^{-4}\, y$$

$$y = \frac{1.879{,}7879}{0{,}9822}$$

$$y = 1.913{,}81\,kg$$

$$x = 4.264{,}113\,kg$$

Jadi massa laktosa keluar dari membran UF sebesar 4.264,1130 kg, sedangkan massa abu keluar dari membran UF sebesar 1.913,8103 kg

Massa laktosa dan abu yang harus dihilangkan sebagai permeat:

$$Massa\,laktosa = 32.227{,}5173\,{}^{kg}/_{hari} - 4.264{,}1130\,{}^{kg}/_{hari} = 27.963{,}4043\,{}^{kg}/_{hari}$$

$$Massa\,abu = 4.834{,}1276\,{}^{kg}/_{hari} - 1.913{,}8103\,{}^{kg}/_{hari} = 2.920{,}3173\,{}^{kg}/_{hari}$$

Massa laktosa dan abu yang tertahan di membran:

Asumsi: 1% dari massa laktosa dan abu yang harus dihilangkan

Massa laktosa tertahan $= 27.963{,}4043\,{}^{kg}/_{hari}$ x 1% $= 279{,}634\,{}^{kg}/_{hari}$

Massa abu tertahan $= 2.920{,}3173\,{}^{kg}/_{hari}$ x 1% $= 29{,}2032\,{}^{kg}/_{hari}$

Massa laktosa ke tangki penampungan *permeat*

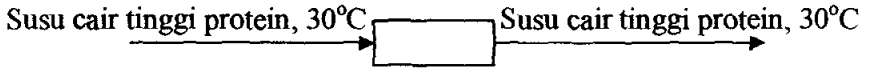
$$= 27.963{,}4043 \ {}^{kg}/_{hari} - 279{,}634 \ {}^{kg}/_{hari} = 27.683{,}7703 \ {}^{kg}/_{hari}$$

Massa abu ke tangki penampungan *permeat*

$$= 2.920{,}3173 \ {}^{kg}/_{hari} - 29{,}2032 \ {}^{kg}/_{hari} = 2.891{,}1141 \ {}^{kg}/_{hari}$$

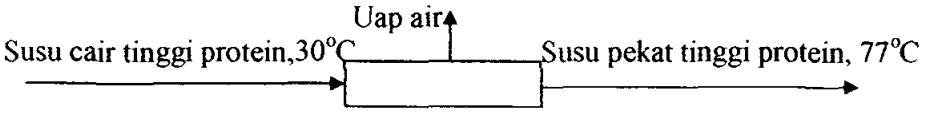
Masuk (kg)		Keluar (kg)	
Dari tangki penampungan (F-140)		Ke membran DF (S-220)	
Susu skim 30°C	**645.745,4492**	***(Retentate)* Susu cair tinggi protein 30°C**	**111.918,7406**
- Lemak	523,6972	- Lemak	523,6972
- Protein	22.827,8247	- Protein	22.827,8247
- Laktosa	32.227,5173	- Laktosa	4.264,1130
- Abu	4.834,1276	- Abu	1.913,8103
- Air	585.332,2824	- Air	82.389,2954
		Ke tangki penampungan *permeat*	
		Permeat	**533.517,8714**
		- Laktosa	27.683,7703
		- Abu	2.891,1141
		- Air	502.942,9870
		Tertahan di membran	
		Permeat	**308,8372**
		- Laktosa	279,6340
		- Abu	29,2032
Total	**645.745,4492**	**Total**	**645.745,4492**

8. Tangki Penampungan (F-312)



Masuk (kg)		Keluar (kg)	
Dari tangki penampungan (F-140)		Ke *Falling Film Evaporator* (V-310)	
Susu cair tinggi protein 30°C	**107.624,2415**	**Susu cair tinggi protein 30°C**	**107.624,2415**
- Lemak	523,6972	- Lemak	523,6972
- Protein	22.827,8247	- Protein	22.827,8247
- Laktosa	86,0994	- Laktosa	86,0994
- Abu	1.797,3248	- Abu	1.797,3248
- Air	82.389,2954	- Air	82.389,2954
Total	**107.624,2415**	**Total**	**107.624,2415**

9. *Falling Film Evaporator* (V-310)



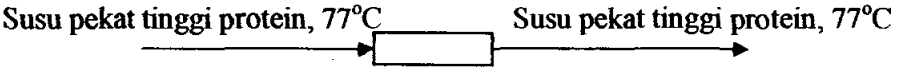
Data :

1. Kandungan air pada susu pekat tinggi protein adalah 55 % [12]

$$\textit{Massa air teruapkan} = 45\% * \textit{Massa air dalam susu cair tinggi protein}$$
$$= 0{,}45 * 82.389{,}2954$$
$$= 37.075{,}1829\, kg / hari$$
$$\textit{Massa air sisa dalam susu} = 55\% * \textit{Massa air dalam susu cair tinggi protein}$$
$$= 0{,}55 * 82.389{,}2954$$
$$= 45.314{,}1125\, kg / hari$$

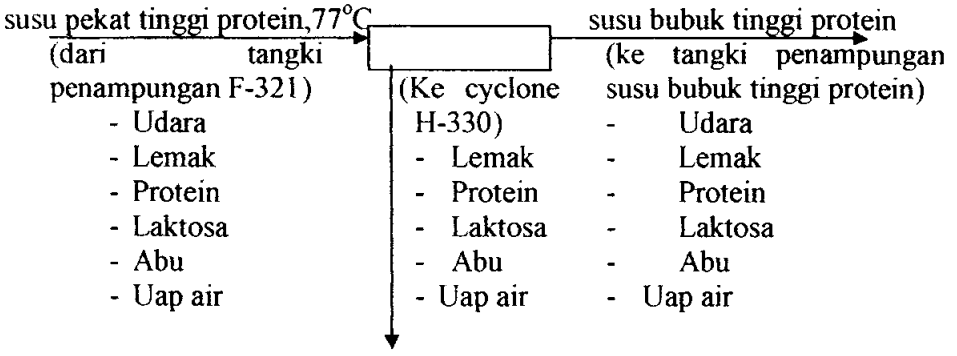
Masuk (kg)		Keluar (kg)	
Dari tangki penampungan (F-312)		Ke membran DF (S-220)	
Susu cair tinggi protein 30°C	**107.624,2415**	**Susu pekat tinggi protein 77°C**	**70.549,0586**
- Lemak	523,6972	- Lemak	523,6972
- Protein	22.827,8247	- Protein	22.827,8247
- Laktosa	86,0994	- Laktosa	86,0994
- Abu	1.797,3248	- Abu	1.797,3248
- Air	82.389,2954	- Air	45.314,1125
		Ke *condenser* (G-313)	
		Uap Air	**37.075,1829**
Total	**107.624,2415**	**Total**	**107.624,2415**

10. Tangki penampungan (F-321)



Masuk (kg)		Keluar (kg)	
Dari Evaporator (V-310)		Ke *spray dryer* (B-320)	
Susu pekat tinggi protein 77°C	**70.549,0586**	**Susu pekat tinggi protein 77°C**	**70.549,0586**
- Lemak	523,6972	- Lemak	523,6972
- Protein	22.827,8247	- Protein	22.827,8247
- Laktosa	86,0994	- Laktosa	86,0994
- Abu	1.797,3248	- Abu	1.797,3248
- Air	45.314,1125	- Air	45.314,1125
Total	**70.549,0586**	**Total**	**70.549,0586**

11. *Spray Dryer* (B-320)



Asumsi : Massa lemak, laktosa, protein , abu ke cyclone adalah 0,5 %

Massa lemak ke cyclone : 0,005 * 523,6972 kg = 2,6185 kg

Massa protein ke cyclone : 0,005 * 22.827,8247 kg = 114,1391 kg

Massa laktosa ke cyclone : 0,005 * 86,0994 kg = 0,4305 kg

Massa abu ke cyclone : 0,005 * 1.797,3248 kg = 8,9866 kg

Massa lemak ke tangki penampungan : Massa lemak awal – massa lemak ke cyclone

523,6972 kg – 2,6185 kg = 521,0787 kg

Dengan cara seperti diatas dapat ditentukan protein, laktosa dan abu ke tangki penampungan.

Kandungan air dalam susu bubuk tinggi protein adalah 3% [12]. Massa air yang keluar dari spray dryer ditentukan dengan menggunakan cara di bawah ini :

$$\%\,air \text{ tangki } penampungan = \frac{m.air}{m.protein + m.lemak + m.laktosa + m.abu + m.air}$$

$$= \frac{x}{25108{,}7715 + x} * 100\%$$

$$3\% = \frac{x}{25108{,}7715 + x} * 100\%$$

$$x = 741{,}4920\ kg$$

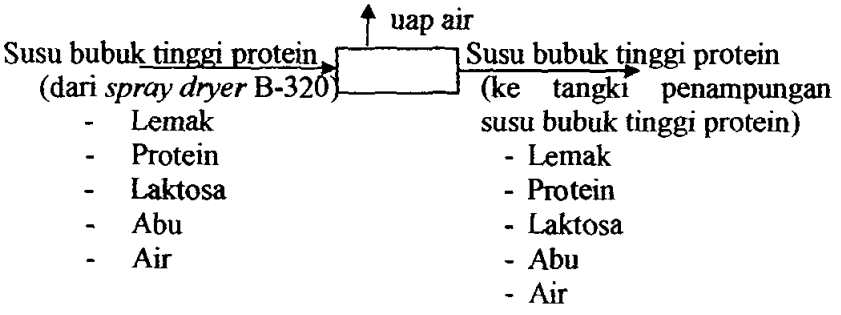
Jadi air yang keluar ke tangki penampungan 741,4920 kg

Massa air yang keluar ke cyclone = 45.314,1125 kg – 741,4920 kg

= 44.572,6204 kg

Masuk (kg)		Keluar (kg)	
Dari tangki penampungan (F-312)		Ke tangki penampungan susu bubuk tinggi protein	
Susu pekat tinggi protein 77°C		**Susu bubuk tinggi protein**	
	70.549,0586		**25.850,2634**
- Lemak	523,6972	- Lemak	521,0787
- Protein	22.827,8247	- Protein	22.713,6856
- Laktosa	86,0994	- Laktosa	85,6689
- Abu	1.797,3248	- Abu	1.788,3382
- Air	45.314,1125	- Air	741,4920
		Ke Cyclone (H-330)	
		Susu bubuk tinggi protein	
			126,1748
		- Lemak	2,6185
		- Protein	114,1391
		- Laktosa	0,4305
		- Abu	8,9866
		Uap air	**44.572,6204**
Total	**70.549,0586**	**Total**	**70.549,0586**

12. *Cyclone* (H-330)



Data :

1. Kandungan air pada susu adalah 3 %

Kandungan air dalam susu bubuk tinggi protein haruslah di bawah 3% karena dengan kandungan air di bawah 3% akan mencegah jamur untuk tumbuh.

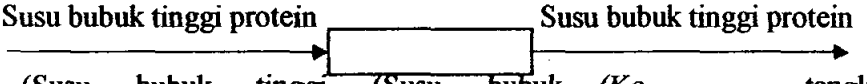
$$\%\,air \text{ tangki } penampungan = \frac{x}{44698{,}7952\text{kg} - (44572{,}6204 - x)} * 100\%$$

$$3\% = \frac{x}{126{,}1748 + x} * 100\%$$

$$x = 3{,}7307\ kg$$

Masuk (kg)			Keluar (kg)		
Dari *spray dryer* (B-320)			Ke tangki penampungan susu bubuk tinggi protein		
Susu bubuk tinggi protein		**126,1748**	**Susu bubuk tinggi protein**		**2129,9055**
- Lemak	2,6185		- Lemak	2,6185	
- Protein	114,1391		- Protein	114,1391	
- Laktosa	0,4305		- Laktosa	0,4305	
- Abu	8,9866		- Abu	8,9866	
Uap air		**44.572,6204**	- Air	3,7307	
			Ke *condenser* (E-331)		
			Uap Air		**44.568,8897**
Total		**44.698,7952**	**Total**		**44.698,7952**

13. Tangki Penampungan Susu Bubuk Tinggi Protein



(Susu bubuk tinggi protein Dari *Spray Dryer* B-320)
- Lemak
- Protein
- Laktosa
- Abu
- Air

(Susu bubuk tinggi protein dari *Cyclone* H-330)
- Lemak
- Protein
- Laktosa
- Abu
- Air

(Ke tangki penammpung susu bubuk tinggi protein)
- Lemak
- Protein
- Laktosa
- Abu
- Air

Masuk (kg)			Keluar (kg)		
Dari *spray dryer* (B-320)			Ke tangki penampungan susu bubuk tinggi protein		
Susu bubuk tinggi protein			**Susu bubuk tinggi protein**		
		25.850,2634			**25.980,1689**
- Lemak	521,0787		- Lemak	523.6972	
- Protein	22.713,6856		- Protein	22.827,8247	
- Laktosa	85,6689		- Laktosa	86,0994	
- Abu	1.788,3382		- Abu	1.797,3248	
- Air	741,4920		- Air	745,2228	
Dari Cyclone (H-330)					
Susu bubuk tinggi protein					
		2.129,9055			
- Lemak	2,6185				
- Protein	114,1391				
- Laktosa	0,4305				
- Abu	8,9866				
- Air	3,7307				
Total		**25.980,1689**	**Total**		**25.980,1689**

Catatan : 25.980,1689 kg/hari ~ 25.980 kg/hari, 0,1689 kg/hari tertinggal di tangki penampungan susu bubuk tinggi protein

APPENDIX B

PERHITUNGAN NERACA PANAS

Suhu referensi = 20 °C

Satuan energi = kilo Joule (kJ)

Satuan massa = kg

Tipe operasi = semikontinu

Basis waktu = 1 hari

Daftar harga Cp (kJ/kg^{0}K) padatan untuk tiap komponen :

- Protein $= \int Cp.dT = \int (2{,}0082 + 1{,}2089\times10^{-3}T - 1{,}3129\times10^{-6}T^2)$ [38]

- Lemak $= \int Cp.dT = \int (1{,}9842 + 1{,}4733\times10^{-3}T - 4{,}8008\times10^{-6}T^2)$ [38]

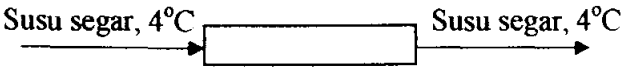
- Abu $= \int Cp.dT = \int (1{,}0926 + 1{,}8896\times10^{-3}T - 3{,}6817\times10^{-6}T^2)$ [38]

Cp air = 18,2964 + 47,212.10^{-2}.T – 133,88.10^{-5}.T^2 + 1314,2.10^{-9}.T^3 kJ/kmol.°K [39]

Cp laktosa = 0,287 kkal/kg.°K pada 20°C [23]

Cp uap air = 33,46 -0,6880. 10^{-2} T + 0,7604. 10^{-5} T^2– 3,593 $10^{-9}T^3$ J/mol °C [39]

- **Tangki penampung susu segar (F-100)**



MASUK

Q susu segar 4°C

- Air

$$\int_{293}^{277} Cp\,dT_{air} = \int_{293}^{277} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= [18{,}2964.(277-293)] + \left[\frac{47{,}212.10^{-2}}{2}(277^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(277^3 - 293^3)\right]$$
$$+ \left[\frac{1314{,}2.10^{-9}}{4}(277^4 - 293^4)\right]$$
$$= -1.192{,}3930 \text{ kJ/kmol} = -66{,}2441 \text{ kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{277} Cp\,dT_{air}$$
$$= 585.332{,}2824 \text{ kg.} - 66{,}2441 \text{ kJ/kg}$$
$$= -38.774.782{,}9395 \text{ kJ}$$

- Lemak

$$\int_{293}^{277} Cp\,dT_{lemak} = \int_{293}^{277} (1{,}9842. + 1{,}4733.10^{-3}T - 4{,}8008.10^{-6}T^2)\,dT$$

$$= \left[1{,}9842.(277-293) + \left[\frac{1{,}4733.10^{-3}}{2}.(277^2 - 293^2)\right] - \left[\frac{4{,}8008.10^{-6}}{3}.(277^3 - 293\right.\right.$$
$$= -32{,}2247 \text{ kJ/kg}$$

$$\Delta H_2 = m.\int_{293}^{277} Cp\,dT_{lemak}$$
$$= 26.184{,}8578 \text{kg} . - 32{,}2247 \text{ kJ/kg}$$
$$= -843.798{,}9154 \text{ kJ}$$

- Protein

$$\int_{293}^{277} Cp\,dT_{\text{protein}} = 2{,}0082.(277-293) + \frac{1{,}2089.10^{-3}}{2}.(277^2 - 293^2) - \frac{1{,}3129.10^{-6}}{3}.(277^3 - 293^3)$$
$$= -35{,}9371 \text{ kJ/kg}$$

$$\Delta H_3 = m.\int_{293}^{277} Cp\,dT_{\text{protein}}$$
$$= 22.827{,}8247 \text{ kg} .. - 35{,}9371 \text{ kJ/kg}$$
$$= -820.365{,}6152 \text{ kJ}$$

- Laktosa

$$\Delta H_4 = m.Cp_{\text{m laktosa}}.\Delta T$$
$$= 32.227.5173 \text{ kg}.0{,}287 \text{ kkal/kg}.^{o}\text{K}.\ (277 - 293)^{o}K$$
$$= -147.988{,}7593\, kkal = -619.184{,}9689 \text{ kJ}$$

- Abu

$$\int_{293}^{277} Cp\,dT_{\text{abu}} = 1{,}0926.(277-293) + \frac{1{,}8896.10^{-3}}{2}.(277^2 - 293^2) - \frac{3{,}6817.10^{-6}}{3}.(277^3 - 293^3)$$
$$= -21{,}3122 \text{ kJ/kg}$$

$$\Delta H_5 = m.\int_{293}^{277} Cp\,dT_{\text{abu}}$$
$$= 4.834.1276 \text{ kg} . - 21{,}3122 \text{ kJ/kg}$$
$$= 103.025{,}8070 \text{ kJ}$$

$$Q_{\text{masuk susu segar, } 4^{o}C} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$
$$= -41.161.158{,}2460 \text{ kJ}$$

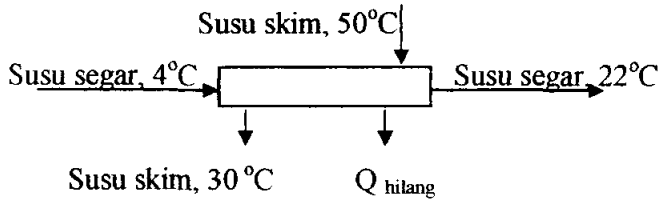
KELUAR

Q susu segar 4°C

$Q_{susu\ segar\ 4^oC\ keluar} = Q_{susu\ segar\ 4^oC\ masuk}$ = -41.161.158,2460 kJ

Masuk (kJ)			Keluar (kJ)		
Dari Truk Kontainer			Ke *plate heat exchanger* 1 (E-110)		
Susu segar 4°C		**-41.161.158,2460**	**Susu segar 22°C**		**-41.161.158,2460**
- Lemak	-843.798,9154		- Lemak	-843.798,9154	
- Protein	-820.365,6152		- Protein	-820.365,6152	
- Laktosa	-619.184,9689		- Laktosa	-619.184,9689	
- Abu	-103.025,8070		- Abu	-103.025,8070	
- Air	-38.774.782,9395		- Air	-38.774.782,9395	
Total		**-41.161.158,2460**	**Total**		**-41.161.158,2460**

- ***Plate Heat Exchanger* 1 (E-110)**



MASUK

1. **Q susu segar 4°C**

   Q masuk *plate heat exchanger* 1 (E-110) = Q susu segar 4°C keluar tangki penampung (F-100)

   = -41.161.158,2460 kJ

2. **Q susu skim 50°C**

- Air

$$= \int_{293}^{323} Cp\, dT_{air}$$

$$\int_{293}^{323} (18{,}2964 + 47.212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= [18,2964.(323-293)] + \left[\frac{47,212.10^{-2}}{2}(323-293^2)\right] - \left[\frac{133,88.10^{-5}}{3}.(323^3-293^3)\right] + \left[\frac{1314,2.10^{-9}}{4}(323^4-293^4)\right]$$

$$= 2.252,8363 \text{ kJ/kmol} = 125,1576 \text{ kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{323} Cp\, dT_{air}$$

$$= 585.332,2824 \text{ kg} . 125,1576 \text{ kJ/kg}$$

$$= 73.258.767,7139 \text{ kJ}$$

- Lemak

$$\int_{293}^{323} Cp\, dT_{lemak} = \int_{293}^{323} (1,9842. + 1,4733.10^{-3}T - 4,8008.10^{-6}T^2)\, dT$$

$$= \left[1,9842.(323-293) + \left[\frac{1,4733.10^{-3}}{2}.(323^2-293^2)\right] - \left[\frac{4,8008.10^{-6}}{3}.(323^3-293^3)\right]\right.$$

$$= 59,4658 \text{ kJ/kg}$$

$$\Delta H_2 = m.\int_{293}^{323} Cp\, dT_{lemak}$$

$$= 523,6972 \text{ kg}. 59,4658 \text{ kJ/kg}$$

$$= 31,142,0690 \text{ kJ/jam}$$

- Protein

$$\int_{293}^{323} Cp\, dT_{protein} = 2,0082(323-293) + \frac{1,2089.10^{-3}}{2}.(323^2-293^2) - \frac{1,3129.10^{-6}}{3}.(323^3-293^3)$$

$$= 67,6769 \text{ kJ/kg}$$

$$\Delta H_3 = m.\int_{293}^{323} Cp\, dT_{protein}$$

$$= 22.827,8247 \text{ kg}. 67,6769 \text{ kJ/kg}$$

$$= 1.544.915,8090 \text{ kJ}$$

- Laktosa

$$\Delta H_4 = m.Cp_{m\,laktosa}.\Delta T$$
$$= 1.342{,}8133 kg.0{,}287 kkal/kg.^{o}K.\ (323-293)^{o}K$$
$$= 277.478{,}9237\ kkal = 1.160.971{,}8166 kJ$$

- Abu

$$\int_{293}^{323} Cp\,dT_{abu} = 1{,}0926.(323-293) + \frac{1{,}8896.10^{-3}}{2}.(323^2 - 293^2)$$
$$- \frac{3{,}6817.10^{-6}}{3}.(323 - 293^3)$$
$$= 39{,}7518 kJ/kg$$

$$\Delta H_5 = m.\int_{293}^{323} Cp\,dT_{abu}$$
$$= 4.834{,}1276 kg\ .\ 39{,}7518 kJ/kg$$
$$= 192.165{,}2563 kJ$$

$$Q_{masuk\ susu\ skim\ 50^{o}C} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$
$$= 76.187.962{,}6649 kJ$$

KELUAR

1. Q susu segar T°C

- Air

$$\int_{293}^{T} Cp\,dT_{air} = \int_{293}^{T} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= [18{,}2964.(T-293)] + \left[\frac{47{,}212.10^{-2}}{2}(T^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(T^3 - 293^3)\right]$$
$$+ \left[\frac{1314{,}2.10^{-9}}{4}(T^4 - 293^4)\right]$$

$$\Delta H_1 = m. \int_{293}^{T} Cp\, dT_{air}$$

$$= 585.332,2824\ kg. \int_{293}^{298} Cp\, dT_{air}$$

- Lemak

$$\int_{293}^{T} Cp\, dT_{lemak} = \int_{293}^{T} (1,9842. + 1,4733.10^{-3} T - 4,8008.10^{-6} T^2)$$

$$= \left[1,9842.(T - 293) + \left[\frac{1,4733.10^{-3}}{2} .(T^2 - 293^2) \right] - \left[\frac{4,8008.10^{-6}}{3} .(T^3 - 293^3) \right] \right]$$

$$\Delta H_2 = m. \int_{293}^{T} Cp\, dT_{lemak}$$

$$= 26.184,8578 kg. \int_{293}^{T} Cp\, dT_{lemak}$$

- Protein

$$\int_{293}^{T} Cp\, dT_{protein} = 2,0082.(T - 293) + \frac{1,2089.10^{-3}}{2} .(T^2 - 293^2)$$

$$- \frac{1,3129.10^{-6}}{3} .(T^3 - 293^3)$$

$$\Delta H_3 = m. \int_{293}^{T} Cp\, dT_{protein}$$

$$= 22.827,8247 kg. \int_{293}^{T} Cp\, dT_{protein}$$

- Laktosa

$$\Delta H_4 = m. Cp_{m\,laktosa} . \Delta T$$

$$= 1.342,8133 kg. 0,287\ kkal/kg.^{o}K. (T - 293)^{o} K$$

- Abu

$$\int_{293}^{298} Cp\,dT_{abu} = 1{,}0926.(298-293) + \frac{1{,}8896.10^{-3}}{2}.(298^2 - 293^2)$$
$$- \frac{3{,}6817.10^{-6}}{3}.(298^3 - 293^3)$$
$$= 6{,}8503\ kJ/kg$$

$$\Delta H_5 = m.\int_{293}^{298} Cp\,dT_{abu}$$
$$= 4.834{,}1276\ kg\,.\,6{,}8503 kJ/kg$$
$$= 33.115{,}0687\ kJ$$

$Q_{\text{keluar susu segar } T^oC} = X\ kJ$

2. Q susu skim 30°C

- Air

$$= \int_{293}^{303} Cp\,dT_{air}$$

$$\int_{293}^{303} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= [18{,}2964.(303-293)] + \left[\frac{47{,}212.10^{-2}}{2}(303^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(303^3 - 293^3)\right]$$
$$+ \left[\frac{1314{,}2.10^{-9}}{4}(303^4 - 293^4)\right]$$
$$= 748{,}7445\ kJ/kmol = 41{,}5969\ kJ/kg$$

$$\Delta H_1 = m.\int_{293}^{303} Cp\,dT_{air}$$
$$= 585.332{,}2824\ kg\,.\,41{,}5969 kJ/kg$$
$$= 24.348.018{,}6695\ kJ$$

- Lemak

$$\int_{293}^{303} Cp\,dT_{\text{lemak}} = \int_{293}^{303} (1{,}9842. + 1{,}4733.10^{-3}T - 4{,}8008.10^{-6}T^2)\,dT$$

$$= \left[1{,}9842.(303-293) + \left[\frac{1{,}4733.10^{-3}}{2}.(303^2 - 293^2)\right] - \left[\frac{4{,}8008.10^{-6}}{3}.(303^3 - 293^3)\right]\right.$$

$$= 19{,}9687\ \text{kJ/kg}$$

$$\Delta H_2 = m.\int_{293}^{303} Cp\,dT_{\text{lemak}}$$

$$= 523{,}6972\text{kg}\,.\,19{,}9687\ \text{kJ/kg}$$

$$= 10.457{,}5679\ \text{kJ}$$

- Protein

$$\int_{293}^{303} Cp\,dT_{\text{protein}} = 2{,}0082.(303-293) + \frac{1{,}2089.10^{-3}}{2}.(303^2 - 293^2) - \frac{1{,}3129.10^{-6}}{3}.(303^3 - 293^3)$$

$$= 22{,}5185\ \text{kJ/kg}$$

$$\Delta H_3 = m.\int_{293}^{303} Cp\,dT_{\text{protein}}$$

$$= 22.827{,}8247\text{kg}.\ 22{,}5185\ \text{kJ/kg}$$

$$= 514.048{,}48250\ \text{kJ}$$

- Laktosa

$$\Delta H_4 = m.\,Cp_{m\,\text{laktosa}}.\,\Delta T$$

$$= 32.227.5173\text{kg}.\ 0{,}287\ \text{kkal/kg.}^{o}\text{K}.\ (303 - 293)^{o}K$$

$$= 92.492{,}9746 kkal = 386.990{,}6055\ \text{kJ}$$

- Abu

$$\int_{293}^{303} Cp\,dT_{\text{abu}} = 1{,}0926.(303-293) + \frac{1{,}8896.10^{-3}}{2}.(303^2 - 293^2) - \frac{3{,}6817.10^{-6}}{3}.(303^3 - 293^3)$$

$$= 13{,}2872\ \text{kJ/kg}$$

$$\Delta H_5 = m.\int_{293}^{303} Cp\,dT_{\text{abu}}$$

$$= 4.834{,}5173 kg\,.\,13{,}2872\ \text{kJ/kg}$$

$$= 64.232{,}0410\ \text{kJ}$$

$Q_{\text{keluar susu pasteurisasi hangat } 50^{o}C} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$

$= 25.323.747,3664 \text{ kJ}$

$Q_{\text{hilang}} = 5\ \% \text{ x } (Q_{\text{keluar susu skim } 50^{o}C})$

$= 0,05 \text{ x } (76.187.962,6649 \text{ kJ})$

$= 3.809.398,1332 \text{ kJ}$

$Q_{\text{masuk susu segar } 4^{o}C} + Q_{\text{masuk susu skim } 50^{o}C} = Q_{\text{keluar susu hangat } T^{o}C} + Q_{\text{keluar susu skim } 30^{o}C} + Q_{\text{hilang}}$

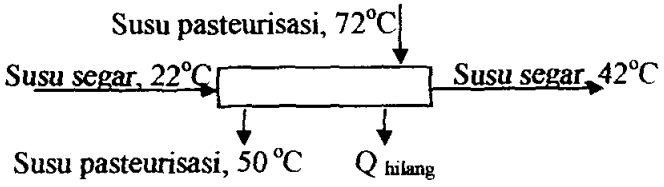
$- 41.161.158,2460 \text{ kJ} + 76.187.962,6649 \text{ kJ} = X + 25.323.747,3664 \text{ kJ} + 3.809.398,1332 \text{ kJ}$

$X = 5.893.658,9192 \text{ kJ}$

Dengan melakukan trial didapatkan $T = 22^{o}C$

Masuk (kJ)			Keluar (kJ)		
Dari Tangki Penyimpanan			Ke *plate heat exchanger* 2 (E-120)		
Susu segar 4°C		**-41.161.158,2460**	**Susu segar 22°C**		**5.893.658,9192**
- Lemak	-843.798,9154		- Lemak	119.733,3517	
- Protein	-820.365,6152		- Protein	117.312,3015	
- Laktosa	-619.184,9689		- Laktosa	88.381,0314	
- Abu	-103.025,8070		- Abu	14.682,0271	
- Air	-38.774.782,9395		- Air	5.553.550,2074	
Dari *plate heat exchanger* 2 (E-120)			Ke tangki penampungan (E-150)		
Susu skim 50°C		**76.187.962,6649**	**Susu sim 30°C**		**25.323.747,3664**
- Lemak	31.142,0690		- Lemak	10.457,5679	
- Protein	1.544.915,8090		- Protein	514.048,4825	
- Laktosa	1.160.971,8166		- Laktosa	386.990,6055	
- Abu	192.165,2563		- Abu	64.232,0410	
- Air	73.258.767,7139		- Air	24.348.018,6695	
			Q_{hilang}		**3.809.398,1333**
Total		**35.026.804,4189**	**Total**		**35.026.804,4189**

- ***Plate Heat Exchanger* (E-120)**



MASUK

1. Q susu segar 22°C

Q masuk *plate heat exchanger* (E-120) = Q susu segar 22°C keluar *plate heat exchanger* (E-110)

= 5.893.658,9192 kJ

2. Q susu pasteurisasi 72°C

- Air

$$\int_{293}^{345} Cp\,dT_{air} = \int_{293}^{345} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= \left[18{,}2964.(345-293)\right] + \left[\frac{47{,}212.10^{-2}}{2}(345-293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(345^3-293^3)\right] + \left[\frac{1314{,}2.10^{-9}}{4}(345^4-293^4)\right]$$

$$= 3.916{,}0170 \text{ kJ/kmol} = 217{,}5565 \text{ kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{345} Cp\,dT_{air}$$

$$= 585.332{,}2824 \text{ kg} . 217{,}5565 \text{kJ/kg}$$

$$= 127.342.843{,}9155 \text{kJ}$$

- Lemak

$$\int_{293}^{345} Cp\,dT_{lemak} = \int_{293}^{345} (1{,}9842. + 1{,}4733.10^{-3}T - 4{,}8008.10^{-6}T^2)dT$$

$$= \left[1{,}9842.(345-293) + \left[\frac{1{,}4733.10^{-3}}{2}.(345^2-293^2)\right] - \left[\frac{4{,}8008.10^{-6}}{3}.(345^3-293^3)\right]\right.$$

$$= 102{,}1575 \text{kJ/kg}$$

$$\Delta H_2 = m.\int_{293}^{345} Cp\,dT_{\text{lemak}}$$

$$= 26.184{,}2824\,kg.102{,}1575\,kJ/kg$$

$$= 31{,}142{,}0690\,kJ/jam$$

- Protein

$$\int_{293}^{345} Cp\,dT_{\text{protein}} = 2{,}0082.(345-293) + \frac{1{,}2089.10^{-3}}{2}.(345^2 - 293^2) - \frac{1{,}3129.10^{-6}}{3}.(345^3 - 293^3)$$

$$= 117{,}1575\,kJ/kg$$

$$\Delta H_3 = m.\int_{293}^{345} Cp\,dT_{\text{protein}}$$

$$= 22.827{,}8247\,kg.117{,}1575\,kJ/kg$$

$$= 2.682.656{,}2150\,kJ$$

- Laktosa

$$\Delta H_4 = m.Cp_{\text{m laktosa}}.\Delta T$$

$$= 32.227{,}5173\,kg.0{,}287\,kkal/kg.^{o}K.\ (345-293)^{o}K$$

$$= 480.963{,}4677\ kkal = 2.012.351{,}1489\,kJ$$

- Abu

$$\int_{293}^{345} Cp\,dT_{\text{abu}} = 1{,}0926.(345-293) + \frac{1{,}8896.10^{-3}}{2}.(345^2 - 293^2) - \frac{3{,}6817.10^{-6}}{3}.(345 - 293^3)$$

$$= 68{,}6348\,kJ/kg$$

$$\Delta H_5 = m.\int_{293}^{345} Cp\,dT_{\text{abu}}$$

$$= 4.834{,}1276\,kg\,.\,68{,}6348\,kJ/kg$$

$$= 331.789{,}2085\,kJ$$

$$Q_{\text{masuk susu pasteurisasi } 72^{\circ}C} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$

$$= 135.044.619{,}2840\ kJ$$

KELUAR

1. Q susu segar T°C

- Air

$$\int_{293}^{T} Cp\,dT_{air} = \int_{293}^{T} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= [18{,}2964.(T-293)] + \left[\frac{47{,}212.10^{-2}}{2}(T-293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(T^3-293^3)\right] + \left[\frac{1314{,}2.10^{-9}}{4}(T^4-293^4)\right]$$

$$\Delta H_1 = m.\int_{293}^{T} Cp\,dT_{air}$$

$$= 585.332{,}2824\ kg.\int_{293}^{298} Cp\,dT_{air}$$

- Lemak

$$\int_{293}^{T} Cp\,dT_{lemak} = \int_{293}^{T} (1{,}9842. + 1{,}4733.10^{-3}T - 4{,}8008.10^{-6}T^2)$$

$$= \left[1{,}9842.(T-293) + \left[\frac{1{,}4733.10^{-3}}{2}.(T^2-293^2)\right] - \left[\frac{4{,}8008.10^{-6}}{3}.(T^3-293^3)\right]\right]$$

$$\Delta H_2 = m.\int_{293}^{T} Cp\,dT_{lemak}$$

$$= 26.184{,}8578\,kg.\int_{293}^{T} Cp\,dT_{lemak}$$

- Protein

$$\int_{293}^{T} Cp\,dT_{protein} = 2{,}0082.(T-293) + \frac{1{,}2089.10^{-3}}{2}.(T^2-293^2) - \frac{1{,}3129.10^{-6}}{3}.(T^3-293^3)$$

$$\Delta H_3 = m.\int_{293}^{T} Cp\,dT_{protein}$$

$$= 22.827{,}8247\,kg.\int_{293}^{T} Cp\,dT_{protein}$$

- Laktosa

$$\Delta H_4 = m.Cp_{m\,laktosa}.\Delta T$$
$$= 1.342{,}8133\,kg.0{,}287\,kkal/kg.^{o}K.\,(T-293)^{o}K$$

- Abu

$$\int_{293}^{298} Cp\,dT_{abu} = 1{,}0926.(298-293) + \frac{1{,}8896.10^{-3}}{2}.(298^2-293^2) - \frac{3{,}6817.10^{-6}}{3}.(298^3-293^3)$$
$$= 6{,}8503\,kJ/kg$$

$$\Delta H_5 = m.\int_{293}^{298} Cp\,dT_{abu}$$
$$= 4.834{,}1276\,kg\,.\,6{,}8503 kJ/kg$$
$$= 33.115{,}0687\,kJ$$

$$Q_{\text{keluar susu segar } T^{o}C} = X\,kJ$$

2. Q susu pasteurisasi 50°C

- Air

$$\int_{293}^{323} Cp\,dT_{air} = \int_{293}^{323} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$
$$= [18{,}2964.(323-293)] + \left[\frac{47{,}212.10^{-2}}{2}(323-293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(323^3-293^3)\right] + \left[\frac{1314{,}2.10^{-9}}{4}(323^4-293^4)\right]$$
$$= 2.252{,}8363\ kJ/kmol = 125{,}1576\ kJ/kg$$

$$\Delta H_1 = m.\int_{293}^{323} Cp\,dT_{air}$$
$$= 585.332{,}2824\ kg\,.\,125{,}1576 kJ/kg$$
$$= 73.258.767{,}7139 kJ$$

- Lemak

$$\int_{293}^{323} Cp\,dT_{\text{lemak}} = \int_{293}^{323} (1{,}9842. + 1{,}4733.10^{-3}T - 4{,}8008.10^{-6}T^2)\,dT$$

$$= \left[1{,}9842.(323-293) + \left[\frac{1{,}4733.10^{-3}}{2}.(323^2 - 293^2)\right]\right] - \left[\frac{4{,}8008.10^{-6}}{3}.(323^3 - 293^3)\right]$$

$$= 59{,}4658 \text{kJ/kg}$$

$$\Delta H_2 = m.\int_{293}^{323} Cp\,dT_{\text{lemak}}$$

$$= 26.184{,}8578 \text{kg}.\ 59{,}4658 \text{kJ/kg}$$

$$= 1.557.103{,}4494 \text{kJ/jam}$$

- Protein

$$\int_{293}^{323} Cp\,dT_{\text{protein}} = 2{,}0082(323-293) + \frac{1{,}2089.10^{-3}}{2}.(323^2 - 293^2)$$

$$- \frac{1{,}3129.10^{-6}}{3}.(323^3 - 293^3)$$

$$= 67{,}6769 \text{kJ/kg}$$

$$\Delta H_3 = m.\int_{293}^{323} Cp\,dT_{\text{protein}}$$

$$= 22.827{,}8247 \text{kg}.\ 67{,}6769 \text{kJ/kg}$$

$$= 1.544.915{,}8090 \text{kJ}$$

- Laktosa

$$\Delta H_4 = m.Cp_{\text{m laktosa}}.\Delta T$$

$$= 1.342{,}8133 \text{kg}.0{,}287 \text{ kkal/kg.}^{\circ}\text{K}.\ (323 - 293)^{\circ} K$$

$$= 277.478{,}9237\ kkal = 1.160.971{,}8166 \text{kJ}$$

- Abu

$$\int_{293}^{323} Cp\,dT_{\text{abu}} = 1{,}0926(323-293) + \frac{1{,}8896.10^{-3}}{2}.(323^2 - 293^2)$$

$$- \frac{3{,}6817.10^{-6}}{3}.(323 - 293^3)$$

$$= 39{,}7518 \text{kJ/kg}$$

$$\Delta H_5 = m.\int_{293}^{323} Cp\, dT_{abu}$$

$$= 4.834{,}1276\,kg \,.\, 39{,}7518\,kJ/kg$$

$$= 192.165{,}2563\,kJ$$

$Q_{masuk\ susu\ pasteurisasi\ 50^oC} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$

$= 77.713.924{,}0453$ kJ

$Q_{hilang} = 5\ \% \times (Q_{keluar\ susu\ pasteurisasi\ 72^oC})$

$= 0{,}05 \times (135.044.619{,}2840$ kJ)

$= 6.752.230{,}9642$ kJ

$Q_{masuk\ susu\ segar\ 22^oC} + Q_{masuk\ susu\ pasteurisasi\ 72^oC} = Q_{keluar\ susu\ segar\ T^oC} + Q_{keluar\ susu\ pasteurisasi\ 50^oC} + Q_{hilang}$

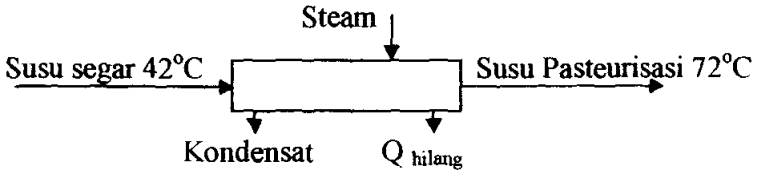
5.893.658,9192 kJ + 135.044.619,2840 kJ = X + 77.713.924,0453 kJ + 6.752.230,9642 kJ

X = 56.472.123,1937 kJ

Dengan melakukan trial didapatkan T = 43°C

Masuk (kJ)			Keluar (kJ)		
Dari *plate heat exchanger* 1 (E-110)			Ke *plate heat exchanger* 3 (E-130)		
Susu segar 22°C		**5.893.658,9192**	**Susu segar 42°C**		**56.472.123,1937**
- Lemak	119.733,3517		- Lemak	1.136.178,9815	
- Protein	117.312,3015		- Protein	1.122.992,3995	
- Laktosa	88.381,0314		- Laktosa	844.508,5844	
- Abu	14.682,0271		- Abu	139.954,3433	
- Air	5.553.550,2074		- Air	53.228.488,8851	
Dari *plate heat exchanger* 3 (E-130)			Ke *Centrifugal Separator* (H-140)		
Susu pasteurisasi 72°C		**135.044.619,2840**	**Susu pasteurisasi 50°C**		**77.713.924,0453**
- Lemak	2.674.978,7961		- Lemak	1.557.103,4494	
- Protein	2.682.656,2150		- Protein	1.544.915,8090	
- Laktosa	2.012.351,1489		- Laktosa	1.160.971,8166	
- Abu	331.789,2085		- Abu	192.165,2563	
- Air	127.342.843,9155		- Air	73.258.767,7139	
			Q_{hilang}		**6.752.230,9642**
Total		**140.938.278,2032**	**Total**		**140.938.278,2032**

- ***Plate Heat Exchanger* (E-130)**



MASUK

Q masuk *plate heat exchanger* (E-130) = Q susu segar 42°C keluar *plate heat exchanger* (E-120)

= 56.472.123,1937 kJ

KELUAR

- Air

$$\int_{293}^{345} Cp\,dT_{air} = \int_{293}^{345} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= \left[18{,}2964.(345-293)\right] + \left[\frac{47{,}212.10^{-2}}{2}(345-293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(345^3-293^3)\right]$$

$$+ \left[\frac{1314{,}2.10^{-9}}{4}(345^4-293^4)\right]$$

$$= 3.916{,}0170 \text{ kJ/kmol} = 217{,}5565 \text{ kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{345} Cp\,dT_{air}$$

$$= 585.332{,}2824 \text{ kg}.217{,}5565 \text{kJ/kg}$$

$$= 127.342.843{,}9155 \text{kJ}$$

- Lemak

$$\int_{293}^{345} Cp\,dT_{lemak} = \int_{293}^{345} (1{,}9842. + 1{,}4733.10^{-3}T - 4{,}8008.10^{-6}T^2)dT$$

$$= \left[1{,}9842.(345-293) + \left[\frac{1{,}4733.10^{-3}}{2}.(345^2-293^2)\right] - \left[\frac{4{,}8008.10^{-6}}{3}.(345^3-293^3)\right]\right.$$

$$= 102{,}1575 \text{kJ/kg}$$

$$\Delta H_2 = m.\int_{293}^{345} Cp\,dT_{\text{lemak}}$$
$$= 26.184{,}8578\,kg.102{,}1575\,kJ/kg$$
$$= 2.674.978{,}7961\,kJ/jam$$

- Protein

$$\int_{293}^{345} Cp\,dT_{\text{protein}} = 2{,}0082.(345-293)+\frac{1{,}2089.10^{-3}}{2}.(345^2-293^2)$$
$$-\frac{1{,}3129.10^{-6}}{3}.(345^3-293^3)$$
$$= 117{,}5169\,kJ/kg$$

$$\Delta H_3 = m.\int_{293}^{345} Cp\,dT_{\text{protein}}$$
$$= 22.827{,}8247\,kg.117{,}5169\,kJ/kg$$
$$= 2.682.656{,}2150\,kJ$$

- Laktosa

$$\Delta H_4 = m.Cp_{\text{laktosa}}.\Delta T$$
$$= 1.342{,}8133\,kg.0{,}287\,kkal/kg.^{o}K.\ (345-293)^{o}K$$
$$= 480.963{,}4677\ kkal = 2.012.351{,}1489\,kJ$$

- Abu

$$\int_{293}^{345} Cp\,dT_{\text{abu}} = 1{,}0926.(345-293)+\frac{1{,}8896.10^{-3}}{2}.(345^2-293^2)$$
$$-\frac{3{,}6817.10^{-6}}{3}.(345-293^3)$$
$$= 68{,}6348\,kJ/kg$$

$$\Delta H_5 = m.\int_{293}^{345} Cp\,dT_{\text{abu}}$$
$$= 4.834{,}1276\,kg\,.68{,}6348\,kJ/kg$$
$$= 331.789{,}2085\,kJ$$

$$Q_{\text{keluar}} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$
$$= 135.044.619{,}2840\ kJ$$

$Q_{masuk} + Q_{steam} = Q_{keluar} + Q_{hilang}$

$Q_{hilang} = 5\ \% Q_{steam}$

$56.472.123,1937\ kJ + Q_{steam} = 135.044.619,2840\ kJ + 0,05\ Q_{steam}$

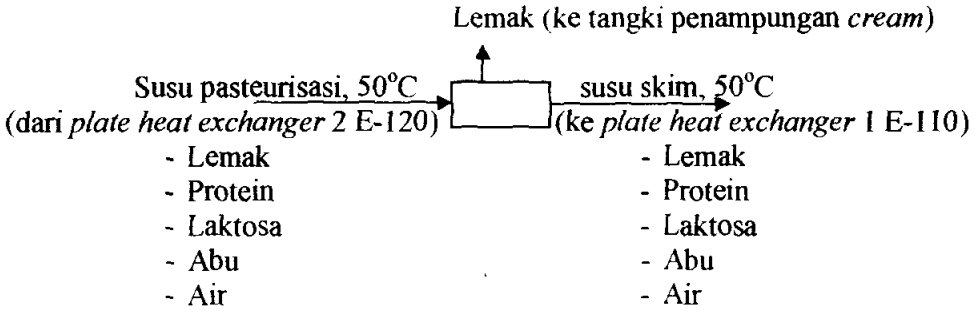
$Q_{steam} = 82.707.890,6213\ kJ$

$Q_{hilang} = 0,05\ .\ 82.707.890,6213\ kJ$

$= 4.135.394,5311\ kJ$

Masuk (kJ)		Keluar (kJ)	
Dari *Plate heat exchanger* 2 (F-120)		Ke *plate heat exchanger* 2 (F-120)	
Susu hangat 42°C	**56.472.123,1937**	**Susu pasteurisasi 72°C**	**135.044.619,2840**
- Lemak	1.136.178,9815	- Lemak	2.674.978,7961
- Protein	1.122.992,3995	- Protein	2.682.656,2150
- Laktosa	844.508,5844	- Laktosa	2.012.351,1489
- Abu	139.954,3433	- Abu	331.789,2085
- Air	53.228.488,8851	- Air	127.342.843,9155
Q_{steam}	**82.707.890,6213**	**Q_{hilang}**	**4.135.394,5311**
Total	**139.180.013,8150**	**Total**	**139.180.013,8150**

- ***Centrifugal Separator* (H-130)**



MASUK

Q masuk *centrifugal Separator* (H-140) = Q susu pasteurisasi 50°C keluar tangki penampung (E-120)

$= 77.713.924,0452\ kJ$

KELUAR

1. Menuju ke tangki penampungan (F-140)

- Air

$$= \int_{293}^{323} Cp\,dT_{air}$$

$$\int_{293}^{323} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= [18{,}2964.(323-293)] + \left[\frac{47{,}212.10^{-2}}{2}(323^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(323^3 - 293^3)\right.$$

$$+ \left[\frac{1314{,}2.10^{-9}}{4}(323^4 - 293^4)\right]$$

$$= 2.252{,}8363 \text{ kJ/kmol} = 125{,}1576 \text{ kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{323} Cp\,dT_{air}$$

$$= 585.332{,}2824 \text{ kg} . 125{,}1576 \text{ kJ/kg}$$

$$= 73.258.767{,}7139 \text{ kJ}$$

- Lemak

$$\int_{293}^{323} Cp\,dT_{lemak} = \int_{293}^{323} (1{,}9842. + 1{,}4733.10^{-3}T - 4{,}8008.10^{-6}T^2)\,dT$$

$$= \left[1{,}9842.(323-293) + \left[\frac{1{,}4733.10^{-3}}{2}.(323^2 - 293^2)\right] - \left[\frac{4{,}8008.10^{-6}}{3}.(323^3 - 29\right.\right.$$

$$= 59{,}4658 \text{ kJ/kg}$$

$$\Delta H_2 = m.\int_{293}^{323} Cp\,dT_{lemak}$$

$$= 523{,}69728 \text{ kg} . 59{,}4658 \text{ kJ/kg}$$

$$= 31.142{,}0690 \text{ kJ}$$

- Protein

$$\int_{293}^{323} Cp\,dT_{protein} = 2{,}0082.(323-293)+\frac{1{,}2089.10^{-3}}{2}.(323^2-293^2)-\frac{1{,}3129.10^{-6}}{3}.(323^3-293^3)$$

$$= 67{,}6769 \text{kJ/kg}$$

$$\Delta H_3 = m.\int_{293}^{277} Cp\,dT_{protein}$$

$$= 22.827{,}8247 \text{kg}.\ 67{,}6769 \text{kJ/kg}$$

$$= 1.544.915{,}8090 \text{kJ}$$

- Laktosa

$$\Delta H_4 = m.Cp_{m\,laktosa}.\Delta T$$

$$= 32.227.5173 \text{kg}.\ 0{,}287 \text{kkal/kg.}^{o}\text{K}.\ (323-293)^{o}K$$

$$= 277.478.9237 kkal = 1.160.971{,}8166 \text{kJ}$$

- Abu

$$\int_{293}^{323} Cp\,dT_{abu} = 1{,}0926.(323-293)+\frac{1{,}8896.10^{-3}}{2}.(323^2-293^2)-\frac{3{,}6817.10^{-6}}{3}.(323^3-293^3)$$

$$= 39{,}7518 \text{kJ/kg}$$

$$\Delta H_5 = m.\int_{293}^{323} Cp\,dT_{abu}$$

$$= 4.834{,}5173 kg\ .\ 39{,}7518 \text{kJ/kg}$$

$$= 192.165{,}2563 \text{kJ}$$

$$Q_{keluar} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$

$$= 76.187.962{,}6649 \text{kJ}$$

2. Menuju tangki lemak

$$\int_{293}^{323} Cp\,dT_{lemak} = \int_{293}^{323} (1{,}9842. + 1{,}4733.10^{-3}T - 4{,}8008.10^{-6}T^2)\,dT$$

$$= \left[1{,}9842.(323-293)+\left[\frac{1{,}4733.10^{-3}}{2}.(323^2-293^2)\right]-\left[\frac{4{,}8008.10^{-6}}{3}.(323^3-293^3)\right]\right.$$

$$= 59{,}4658 \text{kJ/kg}$$

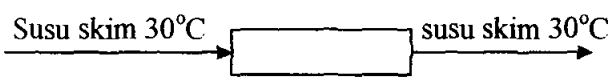
$$\Delta H = m.\int_{293}^{323} Cp\,dT_{\text{lemak}}$$

$$= 25.661{,}1606\,\text{kg} \,.\, 59{,}4658\,\text{kJ/kg}$$

$$= 1.525.961{,}3804\,\text{kJ}$$

Masuk (kJ)		Keluar (kJ)	
Dari *plate heat exchanger* 2 (E-120)		Ke *plate heat exchanger* 1 (E-110)	
Susu pasteurisasi 50°C	**77.713.924,0452**	**Susu skim 50°C**	**76.187.962,6648**
- Lemak	1.557.103,4494	- Lemak	31.142,0690
- Protein	1.544.915,8090	- Protein	1.544.915,8090
- Laktosa	1.160.971,8166	- Laktosa	1.160.971,8166
- Abu	192.165,2563	- Abu	192.165,2563
- Air	73.258.767,7139	- Air	73.258.767,7139
		Ke tangki *cream*	
		Lemak	**1.525.961,3804**
Total	**77.713.924,0452**	**Total**	**77.713.924,0452**

- **Tangki Penampung (F-150)**



MASUK

Q masuk Tangki Penampung (F-140) = Q susu skim hangat 50°C keluar *centrifugal Separator* (H-130) = 76.187.962,6648 kJ

KELUAR

- Air

$$\int_{293}^{303} Cp\,dT_{\text{air}} = \int_{293}^{303} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= [18{,}2964.(303-293)] + \left[\frac{47{,}212.10^{-2}}{2}(303^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(303^3 - 293^3)\right]$$
$$+ \left[\frac{1314{,}2.10^{-9}}{4}(303^4 - 293^4)\right]$$
$$= 748{,}7445 \text{ kJ/kmol} = 41{,}5969 \text{ kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{323} Cp\, dT_{air}$$
$$= 585.332{,}2824 \text{ kg} . 41{,}5969 \text{kJ/kg}$$
$$= 24.348.018{,}6695 \text{ kJ}$$

- Lemak

$$\int_{293}^{303} Cp\, dT_{lemak} = \int_{293}^{303} (1{,}9842. + 1{,}4733.10^{-3} T - 4{,}8008.10^{-6} T^2)\, dT$$
$$= \left[1{,}9842.(303-293) + \left[\frac{1{,}4733.10^{-3}}{2}.(303^2 - 293^2)\right] - \left[\frac{4{,}8008.10^{-6}}{3}.(303^3 - 293^3)\right]\right.$$
$$= 19{,}9687 \text{ kJ/kg}$$

$$\Delta H_2 = m.\int_{293}^{303} Cp\, dT_{lemak}$$
$$= 523{,}6972\, kg .\ 19{,}9687 \text{ kJ/kg}$$
$$= 10.457{,}5679 \text{ kJ}$$

- Protein

$$\int_{293}^{303} Cp\, dT_{protein} = 2{,}0082.(303-293) + \frac{1{,}2089.10^{-3}}{2}.(303^2 - 293^2) - \frac{1{,}3129.10^{-6}}{3}.(303^3 - 293^3)$$
$$= 22{,}5185 \text{kJ/kg}$$

$$\Delta H_3 = m.\int_{293}^{303} Cp\, dT_{protein}$$
$$= 22.827{,}8247 \text{kg}. 22{,}5185 \text{ kJ/kg}$$
$$= 514.048{,}4825 \text{ kJ}$$

- Laktosa

$$\Delta H_4 = m.Cp_{m\,laktosa}.\Delta T$$
$$= 32.227.5173 \text{ kg}.\ 0{,}287 \text{ kkal/kg.}^{o}\text{K}.\ (303 - 293)^{o}K$$
$$= 92.492{,}9746 kkal = 386.990{,}6055 \text{ kJ}$$

- Abu

$$\int_{293}^{303} Cp\,dT_{abu} = 1{,}0926.(303-293)+\frac{1{,}8896.10^{-3}}{2}.(303^2-293^2)-\frac{3{,}6817.10^{-6}}{3}.(303^3-293^3)$$

$$= 13{,}2872 \text{ kJ/kg}$$

$$\Delta H_5 = m.\int_{293}^{323} Cp\,dT_{abu}$$

$$= 4.834{,}5173 kg .13{,}2872 \text{kJ/kg}$$

$$= 64.232{,}0410 \text{kJ}$$

$Q_{keluar} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$

$= 25.323.747{,}3664$ kJ

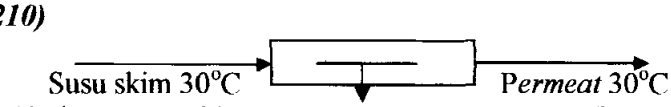
$Q_{susu\ skim\ hangat\ 50^oC\ masuk} = Q_{susu\ skim\ 30^oC\ keluar} + Q_{air\ pendingin}$

$76.187.962{,}6648$ kJ $= 25.323.747{,}3664$ kJ $+ Q_{air\ pendingin}$

$Q_{air\ pendingin} = 50.864.215{,}2984$ kJ

Masuk (kJ)		Keluar (kJ)	
Dari *plate heat exchanger* 1 (E-110)		Ke UF (S-210)	
Susu skim hangat 50°C	**76.187.962,6648**	**Susu skim hangat 30°C**	**25.323.747,3664**
- Lemak	31.142,0690	- Lemak	10.457,5679
- Protein	1.544.915,8090	- Protein	514.048,4825
- Laktosa	1.160.971,8166	- Laktosa	386.990,6055
- Abu	192.165,2563	- Abu	64.232,0410
- Air	73.258.767,7139	- Air	24.348.018,6695
		$Q_{air\ pendingin}$	**50.864.215,2984**
Total	**76.187.962,6648**	**Total**	**76.187.962,6648**

- ***UF (S-210)***



Susu skim 30°C (dari tangki penampung F-150)
- Lemak
- Protein
- Laktosa
- Abu
- Air

Retentate (Susu cair tinggi protein 30°C) (ke tangki penampung F-312)
- Lemak
- Protein
- Laktosa
- Abu
- Air

Permeat 30°C (ke tangki penampungan *permeat*)
- Laktosa
- Abu

MASUK

Q masuk UF (S-210) = Q susu skim 30°C keluar tangki penampung (H-140) = 25.323.747,3664 kJ

KELUAR

1. *Retentate* (susu cair tingi protein 30°C)

- Air

$$= \int_{293}^{303} Cp\, dT_{air}$$

$$\int_{293}^{303} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= [18{,}2964.(303-293)] + \left[\frac{47{,}212.10^{-2}}{2}(303^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(303^3 - 293^3)\right] + \left[\frac{1314{,}2.10^{-9}}{4}(303^4 - 293^4)\right]$$

$$= 748{,}7445 \text{ kJ/kmol} = 41{,}5969 \text{ kJ/kg}$$

$$\Delta H_1 = m. \int_{293}^{323} Cp\, dT_{air}$$

$$= 82.389{,}2954 \text{ kg} . 41{,}5969 \text{kJ/kg}$$

$$= 3.427.140{,}7252 \text{ kJ}$$

- Lemak

$$\Delta H_2 = m.\int_{293}^{303} Cp\,dT_{\text{lemak}}$$
$$= 523{,}6972\,kg\,.\ 19{,}9687\,\text{kJ/kg}$$
$$= 10.457{,}5679\,\text{kJ}$$

- Protein

$$\int_{293}^{303} Cp\,dT_{\text{protein}} = 2{,}0082.(303-293) + \frac{1{,}2089.10^{-3}}{2}.(303^2-293^2) - \frac{1{,}3129.10^{-6}}{3}.(303^3-293^3)$$
$$= 22{,}5185\,\text{kJ/kg}$$
$$\Delta H_3 = m.\int_{293}^{303} Cp\,dT_{\text{protein}}$$
$$= 22.827{,}8247\,\text{kg}.\ 22{,}5185\,\text{kJ/kg}$$
$$= 514.048{,}4825\,\text{kJ}$$

- Laktosa

$$\Delta H_4 = m.Cp_{m\,\text{laktosa}}.\Delta T$$
$$= 4.264{,}1130\,\text{kg}.\ 0{,}287\,\text{kkal/kg.}^{o}\text{K}.\ (303-293)^{o}K$$
$$= 12.238{,}0043\,kkal = 51.203{,}8100\,\text{kJ}$$

- Abu

$$\int_{293}^{303} Cp\,dT_{\text{abu}} = 1{,}0926.(303-293) + \frac{1{,}8896.10^{-3}}{2}.(303^2-293^2) - \frac{3{,}6817.10^{-6}}{3}.(303^3-293^3)$$
$$= 13{,}2872\,\text{kJ/kg}$$
$$\Delta H_5 = m.\int_{293}^{323} Cp\,dT_{\text{abu}}$$
$$= 1.913{,}8103\,kg\,.13{,}2872\,\text{kJ/kg}$$
$$= 25.429.1885\,\text{kJ}$$

$$Q_{\text{retentate}} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$
$$= 4.028.279{,}7742\,\text{kJ}$$

2. *Permeate*

- Air

$$= \int_{293}^{303} Cp\,dT_{air}$$

$$\int_{293}^{303} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= [18{,}2964.(303-293)] + \left[\frac{47{,}212.10^{-2}}{2}(303^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(303^3 - 293^3)\right]$$

$$+ \left[\frac{1314{,}2.10^{-9}}{4}(303^4 - 293^4)\right]$$

$$= 748{,}7445 \text{ kJ/kmol} = 41{,}5969 \text{ kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{323} Cp\,dT_{air}$$

$$= 502.942{,}9870\,kg\,.\,41{,}5969 kJ/kg$$

$$= 20.920.877{,}9442\,kJ$$

- Lemak

$$\Delta H_2 = m.\int_{293}^{303} Cp\,dT_{lemak}$$

$$= 0\,kg\,.\int_{293}^{303} Cp\,dT_{lemak}$$

$$= 0\,kJ$$

- Protein

$$\Delta H_3 = m.\int_{293}^{303} Cp\,dT_{protein}$$

$$= 0\,kg.\int_{293}^{303} Cp\,dT_{protein}$$

$$= 0\,kJ$$

- Laktosa

$$\Delta H_4 = m.Cp_{m\,laktosa}.\Delta T$$
$$= 27.683{,}7703\,kg.\ 0{,}287\,kkal/kg.^{o}K.\ (303-293)^{o}K$$
$$= 79.452{,}4207\,kkal = 332.428{,}9281\,kJ$$

- Abu

$$\int_{293}^{303} Cp\,dT_{abu} = 1{,}0926.(303-293) + \frac{1{,}8896.10^{-3}}{2}.(303^2-293^2) - \frac{3{,}6817.10^{-6}}{3}.(303^3-293^3)$$
$$= 13{,}2872\ kJ/kg$$
$$\Delta H_5 = m.\int_{293}^{323} Cp\,dT_{abu}$$
$$= 2.891{,}1141\,kg\,.13{,}2872\,kJ/kg$$
$$= 38.414{,}8236\,kJ$$

$$Q_{permeate} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$
$$= 21.291.721{,}6959\ kJ$$

3. *Permeat* yang tertahan di membran

- Air

$$\int_{293}^{303} Cp\,dT_{air} = \int_{293}^{303} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$
$$= [18{,}2964.(303-293)] + \left[\frac{47{,}212.10^{-2}}{2}(303^2-293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(303^3-293^3)\right]$$
$$+ \left[\frac{1314{,}2.10^{-9}}{4}(303^4-293^4)\right]$$
$$= 748{,}7445\ kJ/kmol = 41{,}5969\ kJ/kg$$

$$\Delta H_1 = m.\int_{293}^{323} Cp\,dT_{air}$$
$$= 0\,kg\,.41{,}5969\,kJ/kg$$
$$= 0\,kJ$$

- Lemak

$$\Delta H_2 = m.\int_{293}^{303} Cp\,dT_{\text{lemak}}$$
$$= 0\,kg.\int_{293}^{303} Cp\,dT_{\text{lemak}}$$
$$= 0\,kJ$$

- Protein

$$\Delta H_3 = m.\int_{293}^{303} Cp\,dT_{\text{protein}}$$
$$= 0\,kg.\int_{293}^{303} Cp\,dT_{\text{protein}}$$
$$= 0\,kJ$$

- Laktosa

$$\Delta H_4 = m.Cp_{\text{m laktosa}}.\Delta T$$
$$= 279{,}6340\,kg.\ 0{,}287\,kkal/kg.^{o}K.\ (303-293)^{o}K$$
$$= 802{,}5496\,kkal = 3.357,,8674\,kJ$$

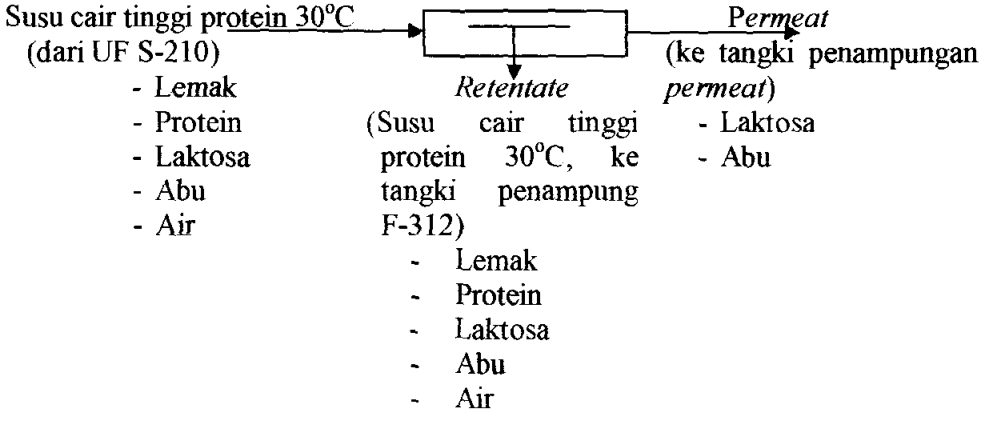
- Abu

$$\int_{293}^{303} Cp\,dT_{\text{abu}} = 1{,}0926(303-293) + \frac{1{,}8896.10^{-3}}{2}.(303^2-293^2) - \frac{3{,}6817.10^{-6}}{3}.(303^3-293^3)$$
$$= 13{,}2872\,kJ/kg$$
$$\Delta H_5 = m.\int_{293}^{323} Cp\,dT_{\text{abu}}$$
$$= 29{,}2032\,kg\,.13{,}2872\,kJ/kg$$
$$= 3.745{,}8963\,kJ$$

$$Q_{\text{tertahan}} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$
$$= 3.745{,}8963\ kJ$$

Masuk (kJ)			Keluar (kJ)		
Dari tangki penampung (F-150)			Ke membran DF (S-220)		
Susu skim 30°C		**25.323.747,3664**	***(Retentate)* Susu cair tinggi protein 30°C**		**4.028.279,7742**
- Lemak	10.457,5679		- Lemak	10.457,5679	
- Protein	514.048,4825		- Protein	514.048,4825	
- Laktosa	386.990,6055		- Laktosa	51.203,8100	
- Abu	64.232,0410		- Abu	25.429,1885	
- Air	24.348.018,6695		- Air	3.427.140,7252	
			Ke tangki *permeat*		
			Permeate, 30°C		**21.291.721,6959**
			- Lemak	0,0000	
			- Protein	0,0000	
			- Laktosa	332.428,9281	
			- Abu	38.414,8236	
			- Air	20.920.877,9442	
			Tertahan di membran		
			Permeate, 30°C		***3.745,8963***
			- Lemak	0,0000	
			- Protein	0,0000	
			- Laktosa	3.357,8674	
			- Abu	388,0289	
			- Air	0,0000	
Total		**25.323.747,3664**	**Total**		**25.323.747,3664**

- ***DF (S-220)***



MASUK

Q masuk DF (S-220) = Q susu tinggi protein (*retentate*) 30°C keluar UF (S-210

= 4.028.279,7742 kJ

KELUAR

1. Sebagai *Retentate* (susu cair tinggi protein 30°C)

- Air

$$= \int_{293}^{303} Cp\,dT_{air}$$

$$\int_{293}^{303} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= [18{,}2964.(303-293)] + \left[\frac{47{,}212.10^{-2}}{2}(303^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(303^3 - 293^3)\right] + \left[\frac{1314{,}2.10^{-9}}{4}(303^4 - 293^4)\right]$$

$$= 748{,}7445 \text{ kJ/kmol} = 41{,}5969 \text{ kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{323} Cp\,dT_{air}$$

$$= 82.389{,}2954 \text{ kg} . 41{,}5969 \text{kJ/kg}$$

$$= 3.427.140{,}7252 \text{ kJ}$$

- Lemak

$$\int_{293}^{303} Cp\,dT_{lemak} = \int_{293}^{303} (1{,}9842. + 1{,}4733.10^{-3}T - 4{,}8008.10^{-6}T^2)\,dT$$

$$= \left[1{,}9842.(303-293) + \left[\frac{1{,}4733.10^{-3}}{2}.(303^2 - 293^2)\right] - \left[\frac{4{,}8008.10^{-6}}{3}.(303^3 - 293^3)\right]\right.$$

$$= 19{,}9687 \text{ kJ/kg}$$

$$\Delta H_2 = m.\int_{293}^{303} Cp\,dT_{lemak}$$

$$= 523{,}6972 kg . 19{,}9687 \text{ kJ/kg}$$

$$= 10.457{,}5679 \text{ kJ}$$

- Protein

$$\int_{293}^{303} Cp\,dT_{protein} = 2{,}0082.(303-293)+\frac{1{,}2089.10^{-3}}{2}.(303^2-293^2)-\frac{1{,}3129.10^{-6}}{3}.(303^3-293^3)$$

$$= 22{,}5185 kJ/kg$$

$$\Delta H_3 = m.\int_{293}^{303} Cp\,dT_{protein}$$

$$= 22.827{,}8247 kg.\ 22{,}5185 kJ/kg$$

$$= 514.048{,}4825 kJ$$

- Laktosa

$$\Delta H_4 = m.Cp_{m\,laktosa}.\Delta T$$

$$= 86{,}0994 kg.\ 0{,}287 kkal/kg.^{o}K.\ (303-293)^{o}K$$

$$= 247{,}1053\ kkal = 1.033{,}8884 kJ$$

- Abu

$$\int_{293}^{303} Cp\,dT_{abu} = 1{,}0926.(303-293)+\frac{1{,}8896.10^{-3}}{2}.(303^2-293^2)-\frac{3{,}6817.10^{-6}}{3}.(303^3-293^3)$$

$$= 13{,}2872 kJ/kg$$

$$\Delta H_5 = m.\int_{293}^{323} Cp\,dT_{abu}$$

$$= 1.797{,}3248 kg.\ 13{,}2872 kJ/kg$$

$$= 23.881.4223 kJ$$

$$Q_{retentate} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$

$$= 3.976.562{,}0863 kJ$$

2. *Permeate*

- Air

$$\int_{293}^{303} Cp\,dT_{air}$$

$$\int_{293}^{303} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= [18{,}2964.(303-293)] + \left[\frac{47{,}212.10^{-2}}{2}(303^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(303^3 - 293^3)\right]$$
$$+ \left[\frac{1314{,}2.10^{-9}}{4}(303^4 - 293^4)\right]$$
$$= 748{,}7445 \text{ kJ/kmol} = 41{,}5969 \text{ kJ/kg}$$

$$\Delta H_1 = m. \int_{293}^{323} Cp\, dT_{air}$$
$$= 0 \text{ kg} . 41{,}5969 \text{ kJ/kg}$$
$$= 0 \text{ kJ}$$

- Lemak

$$\Delta H_2 = m. \int_{293}^{303} Cp\, dT_{lemak}$$
$$= 0 kg . . \int_{293}^{303} Cp\, dT_{lemak}$$
$$= 0 \text{ kJ}$$

- Protein

$$\Delta H_3 = m. \int_{293}^{303} Cp\, dT_{protein}$$
$$= 0 \text{ kg}. \int_{293}^{303} Cp\, dT_{protein}$$
$$= 0 \text{ kJ}$$

- Laktosa

$$\Delta H_4 = m. Cp_{m\,laktosa} . \Delta T$$
$$= 4.136{,}2335 \text{ kg}. \ 0{,}287 \text{ kkal/kg.}^{o}\text{K}. \ (303 - 293)^{o} K$$
$$= 11.870{,}9902 kkal = 49.668{,}2228 \text{kJ}$$

- Abu

$$\int_{293}^{303} Cp\,dT_{abu} = 1{,}0926.(303-293) + \frac{1{,}8896.10^{-3}}{2}.(303^2 - 293^2) - \frac{3{,}6817.10^{-6}}{3}.(303^3 - 293^3)$$

$$= 13{,}2872 \text{ kJ/kg}$$

$$\Delta H_5 = m.\int_{293}^{323} Cp\,dT_{abu}$$

$$= 115{,}3206 kg\,.13{,}2872 \text{kJ/kg}$$

$$= 1.532{,}2879 \text{ kJ}$$

$$Q_{permeate} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$

$$= 51.200{,}5108 \text{ kJ}$$

3. *Permeate*

- Air

$$\int_{293}^{303} Cp\,dT_{air}$$

$$\int_{293}^{303} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= \left[18{,}2964.(303-293)\right] + \left[\frac{47{,}212.10^{-2}}{2}.(303^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(303^3 - 293^3)\right]$$

$$+ \left[\frac{1314{,}2.10^{-9}}{4}(303^4 - 293^4)\right]$$

$$= 748{,}7445 \text{ kJ/kmol} = 41{,}5969 \text{ kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{323} Cp\,dT_{air}$$

$$= 0 \text{ kg}\,.41{,}5969 \text{kJ/kg}$$

$$= 0 \text{ kJ}$$

- Lemak

$$\Delta H_2 = m. \int_{293}^{303} Cp\, dT_{\text{lemak}}$$

$$= 0\,kg. \int_{293}^{303} Cp\, dT_{\text{lemak}}$$

$$= 0\,kJ$$

- Protein

$$\Delta H_3 = m. \int_{293}^{303} Cp\, dT_{\text{protein}}$$

$$= 0\,kg. \int_{293}^{303} Cp\, dT_{\text{protein}}$$

$$= 0\,kJ$$

- Laktosa

$$\Delta H_4 = m.Cp_{m\,\text{laktosa}}.\Delta T$$

$$= 41{,}7801\,kg.\ 0{,}287\,kkal/kg.^{o}K.\ (303-293)^{o}K$$

$$= 119{,}9089\,kkal = 501{,}6988\,kJ$$

- Abu

$$\int_{293}^{303} Cp\, dT_{\text{abu}} = 1{,}0926.(303-293) + \frac{1{,}8896.10^{-3}}{2}.(303^2-293^2) - \frac{3{,}6817.10^{-6}}{3}.(303^3-293^3)$$

$$= 13{,}2872\ kJ/kg$$

$$\Delta H_5 = m. \int_{293}^{323} Cp\, dT_{abu}$$

$$= 1{,}1649\,kg.13{,}2872\,kJ/kg$$

$$= 15{,}4783\ kJ$$

$$Q_{\text{tertahan}} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$

$$= 517{,}1770\ kJ$$

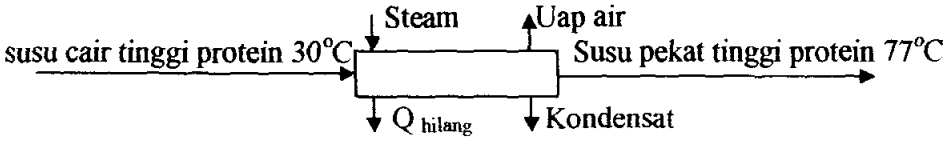
Masuk (kJ)		Keluar (kJ)	
Dari membran UF (S-210)		Ke tangki penampungan (F-312)	
Susu skim 30°C	**4.028.279,7742**	***(Retentate)* Susu cair tinggi protein 30°C**	**3.976.562,0863**
- Lemak	10.457,5679	- Lemak	10.457,5679
- Protein	514.048,4825	- Protein	514.048,4825
- Laktosa	51.203,8100	- Laktosa	10.457,5679
- Abu	25.429,1885	- Abu	23.881,4223
- Air	3.427.140,7252	- Air	3.427.140,7252
		Ke tangki *permeat*	
		Permeate	**51.200,5108**
		- Lemak	0,0000
		- Protein	0,0000
		- Laktosa	49,668,2228
		- Abu	1.532,2879
		- Air	0,0000
		Tertahan di membran	
		Permeate	**517,1771**
		- Lemak	0,0000
		- Protein	0,0000
		- Laktosa	501,6988
		- Abu	15,4783
		- Air	0,0000
Total	**4.028.279,7742**	**Total**	**4.028.279,7742**

- ***Tangki Penampung (F-312)***

Q susu cair tinggi protein 30°C masuk tangki penampung (F-312) = Q susu cair tinggi protein 30°C keluar tangki penampung (F-312) = Q susu cair tinggi protein (*retentate*) 30°C keluar membran DF (S-220) = 3.976.562,0863 kJ.

Masuk (kJ)		Keluar (kJ)	
Dari membran DF (S-220)		Ke falling film evaporator (V-310)	
Susu cair tinggi protein 30°C	**3.976.562,0863**	***(Retentate)* Susu cair tinggi protein 30°C**	**3.976.562,0863**
- Lemak	10.457,5679	- Lemak	10.457,5679
- Protein	514.048,4825	- Protein	514.048,4825
- Laktosa	50.169,9216	- Laktosa	50.169,9216
- Abu	23.881,4223	- Abu	23.881,4223
- Air	3.427.140,7252	- Air	3.427.140,7252
Total	**3.976.562,0863**	**Total**	**3.976.562,0863**

- ***Falling Film Evaporator (V-310)***



MASUK

Q masuk *falling film evaporator* (V-310) = Q susu tinggi protein (*retentate*) 30°C keluar tangki penampung (F-312)

= 3.976.562,0863 kJ

KELUAR

1. Sebagai susu pekat tinggi protein

- Air

$$\int_{293}^{350} Cp\,dT_{air} = \int_{293}^{350} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= \left[18{,}2964.(350-293)\right] + \left[\frac{47{,}212.10^{-2}}{2}(350^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(350^3 - 293^3)\right] + \left[\frac{1314{,}2.10^{-9}}{4}(350^4 - 293^4)\right]$$

$$= 4.295{,}2031 \text{ kJ/kmol} = 238{,}6224 \text{ kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{350} Cp\,dT_{air}$$

$$= 45.314{,}1125 \text{ kg} \,.\, 238{,}6224 \text{ kJ/kg}$$

$$= 10.812.961{,}9299 \text{ kJ}$$

$$\Delta H_1 = m.\int_{293}^{350} Cp\,dT_{air}$$
$$= 45.314{,}1125\,kg\,.\,238{,}6224\,kJ/kg$$
$$= 10.812.961{,}9299\,kJ$$

- Lemak

$$\int_{293}^{350} Cp\,dT_{lemak} = \int_{293}^{350} (1{,}9842. + 1{,}4733.10^{-3}T - 4{,}8008.10^{-6}T^2)\,dT$$
$$= \left[1{,}9842.(503-293) + \left[\frac{1{,}4733.10^{-3}}{2}.(350^2 - 293^2)\right] - \left[\frac{4{,}8008.10^{-6}}{3}.(350^3 - 293^3)\right]\right]$$
$$= 111{,}7396\,kJ/kg$$

$$\Delta H_2 = m.\int_{293}^{350} Cp\,dT_{lemak}$$
$$= 523{,}6972\,kg\,.\,111.7396\,kJ/kg$$
$$= 58.517{,}7341\,kJ$$

- Protein

$$\int_{293}^{350} Cp\,dT_{protein} = 2{,}0082.(350-293) + \frac{1{,}2089.10^{-3}}{2}.(350^2 - 293^2) - \frac{1{,}3129.10^{-6}}{3}.(350^3 - 293^3)$$
$$= 128{,}8657\,kJ/kg$$

$$\Delta H_3 = m.\int_{293}^{350} Cp\,dT_{protein}$$
$$= 22.827{,}8247\,kg.128{,}8657\,kJ/kg$$
$$= 2.941.723{,}3921\,kJ$$

- Laktosa

$$\Delta H_4 = m.Cp_{m\,laktosa}.\Delta T$$
$$= 86{,}0994\ kg.\ 0{,}287\ kkal/kg.^{o}K.\ (350 - 293)^{o}K$$
$$= 1.408{,}5000\,kkal = 5.893{,}1639\,kJ$$

- Abu

$$\int_{293}^{350} Cp\,dT_{abu} = 1{,}0926(350-293) + \frac{1{,}8896.10^{-3}}{2}.(350^2 - 293^2) - \frac{3{,}6817.10^{-6}}{3}.(350^3 - 293^3)$$
$$= 75{,}1580\,kJ/kg$$

$$\Delta H_5 = m.\int_{293}^{350} Cp\,dT_{abu}$$

$$= 1.797{,}3248 kg . 75{,}1580 kJ/kg$$

$$= 135.083{,}2763 kJ$$

$$Q_{keluar} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$

$$= 13.954.179{,}4964 \text{ kJ}$$

2. Sebagai uap air

$$cp\,uap\,air = \int_{293}^{350} Cp\,dT_{air}$$

$$= \int_{293}^{350} (34{,}46 + 0{,}6880^{-2} T + 0{,}7604.10^{-5} T^2 - 3{,}593.10^{-9}.T^3).dT$$

$$= [34{,}46.(77-20)] + \left[\frac{0{,}6880^{-2}}{2}(77^2 - 20^2)\right] + \left[\frac{0{,}7604.10^{-5}}{3}.(77^3 - 20^3)\right]$$

$$- \left[\frac{3{,}593.10^{-9}}{4}(77^4 - 20^4)\right]$$

$$= 1.946{,}3057 \text{ kJ/mol} = 108.1281 \text{ kJ/ kg}$$

$$\Delta H = m.\int_{293}^{323} Cp\,dT_{air}$$

$$= 37075{,}1829 kg . 108.1281 kJ/kg$$

$$= 4.008.868{,}8593 kJ$$

$$Q_{masuk} + Q_{steam} = Q_{susu\ pekat\ tinggi\ protein} + Q_{uap\ air} + Q_{hilang}$$

Asumsi : $Q_{hilang} = 5\ \% Q_{steam}$

$$3.976.562{,}0863 \text{ kJ} + Q_{steam} = 13.954.179{,}4964 \text{ kJ} + 4.008.868.8593 \text{ kJ} + 0{,}05$$

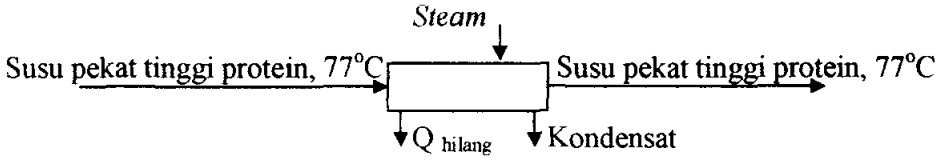
$$Q_{steam}$$

$$0.95\ Q_{steam} - 13.986.486{,}2694$$

$$Q_{steam} = 14.722.617{,}1256 \text{ kJ}$$

Masuk (kJ)		Keluar (kJ)	
Dari tangki penampung (F-312)		Ke tangki penampungan (F-321)	
Susu cair tinggi protein 30°C	**3.976.562,0863**	**Susu pekat tinggi protein 77°C**	**13.954.179,4964**
- Lemak	10.457,5679	- Lemak	58.517,7341
- Protein	514.048,4825	- Protein	2.941.723,3921
- Laktosa	50.169,9216	- Laktosa	5.893,1639
- Abu	23.881,4223	- Abu	135.083,2763
- Air	3.427.140,7252	- Air	10.812.961,9299
		Uap air	**4.008.868,8593**
Q steam	**14.722.617,1256**	**Q hilang**	**736.130,8563**
Total	**18.699.179,2120**	**Total**	**18.699.179,2120**

- ***Tangki Penampung (F-321)***



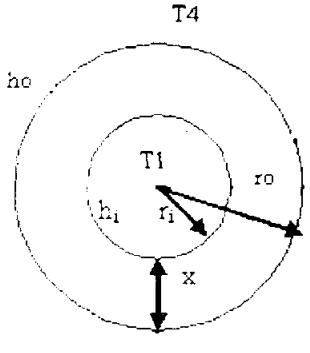
MASUK

Q Susu pekat tinggi protein 77°C masuk tangki penampung *(F-321)* = Q Susu pekat tinggi protein 77°C keluar tangki penampung *(F-321)* = Q susu pekat tinggi protein 77°C keluar *falling film evaporator* (V-310) = 13.954.179,4964 kJ

Menghitung Q_{hilang} dan Q_{steam}

Data : Temperatur susu masuk, T1 = 77°C = 350 K

Asumsi : Temperatur udara luar, T4 = 30°C = 303 K



ho = 2,8 – 23 W/m^2.K (tabel 4.1.2, Geankoplis)

Diambil ho = 13 W/m^2.K

hi = 280-17.000 W/m^2.K (tabel 4.1.2, Geankoplis)

Diambil hi = 8640 W/m^2.K

Dari Appendix C didapat :

- Bahan tangki Carbon-Steel
- Di = 5,724 ft = 1,7447 m
- Tebal shell, ts = 3/16 in =0,0047 m
- Tinggi larutan (H_L) = 5,5407 ft = 1,6888 m

k = 45 W/m.K (App. A.3-16, Geankoplis)

r_i = Di/2 = 0,8724 m

r_o = r_i + ts

= 0,8724 + 0,0047

= 0,8771 m

A_i = $2\pi r_i . H_L$

= 2. π. 0,8724 m . 1,6888 m

= 9,2571 m^2

Ao = $2\pi r_o . H_L$

= 2. π. 0,8771 m . 1,6888 m

= 9,3069 m^2

$$Q = \frac{T1 - T4}{\frac{1}{h_i A_i} + \frac{x}{k.A_{ALM}} + \frac{1}{h_o.A_o}}$$ (pers 4.3-15,Geankoplis)

$$A_{ALM} = \frac{Ao - Ai}{\ln(\frac{Ao}{Ai})}$$

$$= \frac{9{,}3069 - 9{,}2571}{\ln(\frac{9{,}3069}{9{,}2571})}$$

$$= 9{,}2820 \text{ m}^2$$

$$Q = \frac{350 - 303}{1/(8640.9{,}2571).+0{,}0047/(45.9{,}2820)+1/(13.9{,}3069)}$$

$$= 5.670{,}2189 \text{ J/s}$$

Untuk 1 hari proses

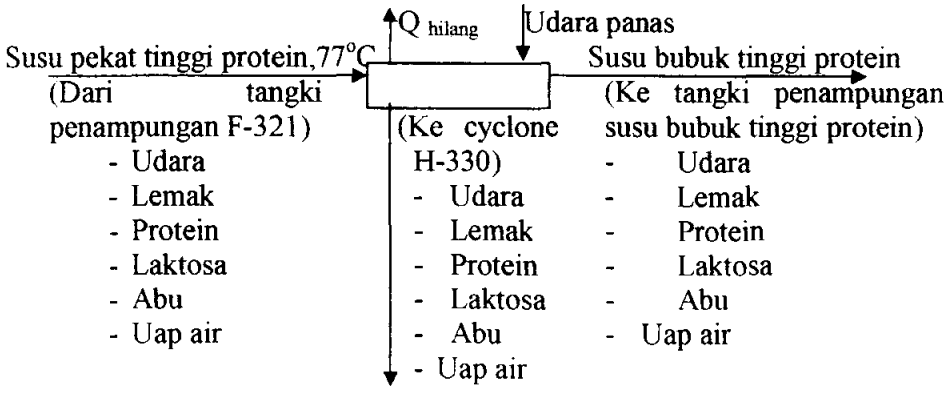
$$Q = 5.670{,}2189 J/s . \frac{3600\, s}{1\, jam} . \frac{24\, jam}{1\, hari} . \frac{1\, kJ}{1000\, J}$$

$$= 489.906{,}9107 \text{ kJ/hari}$$

$Q_{hilang} = Q_{steam} = Q = 489.906{,}9107$ kJ/hari

Masuk (kJ)		Keluar (kJ)	
Dari *falling film evaporator* (V-310)		Ke *spray dryer* (B-320)	
Susu cair tinggi protein 30°C	**13.954.179,4964**	**Susu pekat tinggi protein 77°C**	**13.954.179,4964**
- Lemak	58.517,7341	- Lemak	58.517,7341
- Protein	2.941.723,3921	- Protein	2.941.723,3921
- Laktosa	5.893,1639	- Laktosa	5.893,1639
- Abu	135.083,2763	- Abu	135.083,2763
- Air	10.812.961,9299	- Air	10.812.961,9299
Q_{steam}	**489.906,9107**	**Q_{hilang}**	**489.906,9107**
Total	**14.651.888,4712**	**Total**	**14.651.888,4712**

- ***Spray Dryer* (B-320)**



MASUK

Q masuk ke *spray dryer (B-320)* = Q susu tinggi protein keluar *falling film evaporator* (V-310) = 13.954.179,4964 kJ

KELUAR

1. Susu bubuk tinggi protein

- Air

$$= \int_{293}^{358} Cp\,dT_{air} \int_{293}^{358} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= \left[18{,}2964.(358-293)\right] + \left[\frac{47{,}212.10^{-2}}{2}(358^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(358^3 - 293^3)\right]$$

$$+ \left[\frac{1314{,}2.10^{-9}}{4}(358^4 - 293^4)\right]$$

$$= 4.902{,}8389 \text{ kJ/kmol} = 272{,}3799 \text{ kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{323} Cp\,dT_{air}$$

$$= 741{,}4920\,kg\,.\,272{,}3799 \text{ kJ/kg}$$

$$= 201.967{,}5586 \text{ kJ}$$

- Lemak

$$\int_{293}^{358} Cp\,dT_{lemak} = \int_{293}^{323} (1{,}9842. + 1{,}4733.10^{-3}T - 4{,}8008.10^{-6}T^2)\,dT$$

$$= \left[1{,}9842.(323-293) + \left[\frac{1{,}4733.10^{-3}}{2}.(323^2 - 293^2)\right] + \left[\frac{4{,}8008.10^{-6}}{3}.(323^3 - 293^3)\right]\right]$$

$$= 126.9725 \text{kJ/kg}$$

$$\Delta H_2 = m.\int_{293}^{323} Cp\,dT_{lemak}$$

$$= 521{,}0787\,kg\,.\,126.9725 \text{kJ/kg}$$

$$= 66.162{,}6557 \text{ kJ}$$

- Protein

$$\int_{293}^{358} Cp\,dT_{protein} = 2{,}0082.(358-293) + \frac{1{,}2089.10^{-3}}{2}.(358^2 - 293^2) - \frac{1{,}3129.10^{-6}}{3}.(358^3 - 293^3)$$

$$= 147{,}0386 \text{kJ/kg}$$

$$\Delta H_3 = m.\int_{293}^{350} Cp\,dT_{protein}$$

$$= 22.713{,}6856 \text{kg}.147.0386 \text{kJ/kg}$$

$$= 3.339.788{,}9886 \text{ kJ}$$

- Laktosa

$$\Delta H_4 = m.Cp_{m\,laktosa}.\Delta T$$

$$= 85{,}6689 \text{kg}.\ 0{,}287 \text{kkal/kg.}^{o}\text{K}.\ (358-293)^{o}K$$

$$= 1{,}598.1533 kkal = 6.686{,}6732 \text{kJ}$$

- Abu

$$\int_{293}^{358} Cp\,dT_{abu} = 1{,}0926.(358-293) + \frac{1{,}8896.10^{-3}}{2}.(358^2 - 293^2) - \frac{3{,}6817.10^{-6}}{3}.(358^3 - 293^3)$$

$$= 85{,}5589 \text{ kJ/kg}$$

$$\Delta H_5 = m.\int_{293}^{323} Cp\,dT_{abu}$$

$$= 1.788{,}3382 kg.85{,}5589 \text{kJ/kg}$$

$$= 153.008{,}3349 \text{kJ}$$

$$Q_{keluar} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4 + \Delta H_5$$

$$= 3.767.614{,}2110 \text{ kJ}$$

2. Bubuk protein ke cyclone

- Lemak

$$\int_{293}^{358} Cp\,dT_{lemak} = \int_{293}^{358} (1{,}9842. + 1{,}4733.10^{-3}T - 4{,}8008.10^{-6}T^2)$$

$$= \left[1{,}9842.(358-293) + \left[\frac{1{,}4733.10^{-3}}{2}.(358^2 - 293^2)\right] - \left[\frac{4{,}8008.10^{-6}}{3}.(358^3 - 293^3)\right]\right]$$

$$= 126.9725 \text{kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{358} Cp\,dT_{\text{lemak}}$$

$$= 2{,}6185\,kg\,.126.9725 \text{kJ/kg}$$

$$= 332{,}4757 \text{kJ}$$

- Protein

$$\int_{293}^{358} Cp\,dT_{\text{protein}} = 2{,}0082.(358-293) + \frac{1{,}2089.10^{-3}}{2}.(358^2 - 293^2) - \frac{1{,}3129.10^{-6}}{3}.(358^3 - 293^3)$$

$$= 147{,}0386 \text{ kJ/kg}$$

$$\Delta H_2 = m.\int_{293}^{358} Cp\,dT_{\text{protein}}$$

$$= 114{,}1391 \text{ kg}.147.0386 \text{ kJ/kg}$$

$$= 16.782{,}8592 \text{ kJ}$$

- Laktosa

$$\Delta H_3 = m.\,Cp_{\text{m laktosa}}.\Delta T$$

$$= 0.4305 \text{kg}.\ 0{,}287 \text{ kkal/kg.}^{o}\text{K}.\ (358 - 293)^{o}K$$

$$= 8{,}0309\,kkal = 33.6014 \text{ kJ}$$

- Abu

$$\int_{293}^{358} Cp\,dT_{\text{abu}} = 1{,}0926.(358-293) + \frac{1{,}8896.10^{-3}}{2}.(358^2 - 358^2) - \frac{3{,}6817.10^{-6}}{3}.(358^3 - 358^3)$$

$$= 85{,}5589 \text{ kJ/kg}$$

$$\Delta H_4 = m.\int_{293}^{323} Cp\,dT_{\text{abu}}$$

$$= 8{,}9866\ kg\,.85{,}5589 \text{ kJ/kg}$$

$$= 768.8861 \text{kJ}$$

$$Q_{\text{keluar}} = \Delta H_1 + \Delta H_2 + \Delta H_3 + \Delta H_4$$

$$= 17.917{,}8224 \text{ kJ}$$

$$Q_{\text{hilang}} = 10\ \%\ Q_{\text{udara panas}}$$ (Stanley M. Walas, 1988)

Relative humidity rata-rata di Indonesia = 80 %

(http://www.atlapedia.com/online/countries/indones.htm)

$$H_R = 80 = 100\frac{Pa}{Pas} \quad \text{.....(1)}$$

T_o = 20°C dan P = 101,325 kPa, maka Pas = 2,346 kPa

(Geankoplis, 1993)

Substitusi Pas = 2,346 kPa ke persamaan (1), sehingga didapatkan:

$$Pa = \left(\frac{80}{100}\right).2{,}346\,kPa = 1{,}8768 \text{ kPa}$$

Mencari humidity udara masuk dryer (Geankoplis, 1993)

$$H_1 = \frac{18{,}02}{28{,}97}\left(\frac{Pa}{P - Pa}\right) = \frac{18{,}02}{28{,}97}\left(\frac{1{,}8768}{101{,}325 - 1{,}8768}\right)$$

= 0,0117 kg H_2O/kg udara kering

Suhu udara masuk dryer = 125°C

Entalpi udara masuk dryer

$Hg_1 = Cs.(T\text{-}To)+H_1.\lambda o$ .....(2)

Di mana $Cs = 1{,}005 + 1{,}88\ H_1$

λo pada To = 20°C = 2454,113 kJ/kg (Geankoplis, 1993)

Persamaan (2) menjadi $Hg_1 = (1{,}005+1{,}88.H_1).(T\text{-}To) + H_1.2454{,}113$

$= (1{,}005+1{,}88.0{,}0117).(125\text{-}20)+0{,}0117.2454{,}113$

= 136,5477 kJ/kg udara kering

Suhu udara keluar dryer = 85 °C

Entalpi udara keluar *spray dryer*

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

$= (1{,}005+1{,}88\ H_2).(85\text{-}30)+H_2.2454{,}113$

$= 55{,}275 + 2557{,}513.H_2$ kJ/kg udara kering

Neraca massa air

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

$G.0,0117 + 45.314,1125 = G.H_2 + 741,4920$

$$G=\frac{44572,6205}{(H_2-0,0117)}\ \text{kg/kg udara kering}.....(3)$$

Neraca panas total

Q udara masuk + Q susu masuk = Q udara keluar + Q cyclone + Q susu keluar + Q loss

$G.Hg_1 + 13.954.179,4964 = G.Hg_2 + 3.767.614,2110 + 17.917,8224 + 10\%.\ G.Hg_1$

$90\%.\ G.Hg_1 + 13.954.179,4964 = G\ (55,275 + 2557,513.H_2) + 3,785,532.0333$

$0,9\ .\ 136,5477\ G + 10.168.647,4630 = G\ (55,275 + 2557,513.H_2)$

$G\ (55,275 + 2557,513\ H_2 - 122,8929\ )$

$$G=\frac{10.168.647,4630}{(2557,513H_2-67,6179)}$$

Dari persamaan (3) dan (4)

$$\frac{44572,6205}{(H_2-0,0117)}=\frac{10.168.647,4630}{(2557,513H_2-67,6179)}$$

$H_2 = 0,0279$ kg H_2O/kg udara kering

$Hg_2 = 55,275 + 2557,513.\ 0,0279 = 126,6296$ kJ/kg udara kering

$$G=\frac{10.168.647,4630}{(2557,513.0,0279-67,6179)}=2.721.281,586\ \text{kg udara kering}$$

Q udara masuk = $G.Hg_1 = 2.721.281,586.\ 136,5477 = 371.584.741.6323$ kJ

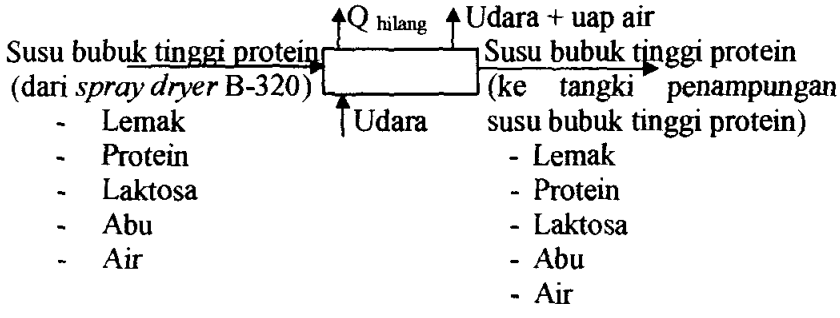
Q udara keluar = $G.Hg_2 = 2.721.281,586.\ 126,6296 = 344.594.798.7333$ kJ

Massa udara masuk = $(1+H_1).G = (1+0,0117).\ 2.721.281,586 = 2.753.120.581$ kg

Massa udara keluar = $(1+H_2).G = (1+0{,}0279).2.721.281{,}586 = 2.797.693{,}2011$ kg

Masuk (kJ)			Keluar (kJ)		
Dari tangki penampung (F-321)			Ke tangki penampung		
Susu pekat tinggi protein 30°C		**13.954.179,4964**	**Susu bubuk tinggi protein**		**3.767.614,2110**
- Lemak	58.517,7341		- Lemak	66.162,6557	
- Protein	2.941.723,3921		- Protein	3.339.788,9886	
- Laktosa	5.893,1639		- Laktosa	6.686,6732	
- Abu	135.083,2763		- Abu	153.008,3349	
- Air	10.812.961,9299		- Air	201.967,5586	
			Ke Cyclone		
			Susu bubuk tinggi protein		**17.917,8224**
			- Lemak	332,4757	
			- Protein	16.782,8592	
			- Laktosa	33,6014	
			- Abu	768,886	
$Q_{udara\ masuk}$		**371.584.741,6323**	**$Q_{udara\ keluar}$**		**344.594.798,7333**
			Q_{hilang}		**37.158.590,3619**
Total		**385.538.921,1287**	**Total**		**385.538.921,1287**

- ***Cyclone (H-330)***



MASUK

- $Q_{Udara\ masuk}$ dari udara keluar spray dryer (B-320)

  = 344.594.798.7333 kJ

- Q Susu Bubuk protein dari keluar spray dryer (B-320)

  = 17.917,8224 kJ

Total Q masuk = 344.612.716,5557 *kJ*

KELUAR

1. Ke tangki penampung susu bubuk tinggi protein

- Bubuk protein = 17.917,8224 kJ
- Air

$$\int_{293}^{358} Cp\,dT_{air} = \int_{293}^{358} (18{,}2964 + 47{,}212.10^{-2}T - 133{,}88.10^{-5}T^2 + 1314{,}2.10^{-9}.T^3).dT$$

$$= \left[18{,}2964.(358-293)\right] + \left[\frac{47{,}212.10^{-2}}{2}(358^2 - 293^2)\right] - \left[\frac{133{,}88.10^{-5}}{3}.(358^3 - 293^3)\right] + \left[\frac{1314{,}2.10^{-9}}{4}(358^4 - 293^4)\right]$$

$$= 4.902{,}8389 \text{ kJ/kmol} = 272{,}3799 \text{ kJ/kg}$$

$$\Delta H_1 = m.\int_{293}^{358} Cp\,dT_{air}$$

$$= 3{,}7307\,kg\,.\,272{,}3799 \text{kJ/kg}$$

$$= 1.016{,}1678 kJ$$

Q keluar ke tangki penampungan susu bubuk = 18.933,9902 kJ

Asumsi : Q_{hilang} = 5 % Q masuk

Neraca panas total

ΔH_{masuk} = Q keluar ke tangki penampungan susu bubuk + Q_{hilang} + $Q_{udara\ keluar}$

344.612.716,5557 kJ = 18.933,9902 kJ + 0,05.(344.612.716,5557 kJ) + $Q_{udara\ keluar}$

Q udara keluar = 327.363.146,7377 kJ

Masuk (kJ)			Keluar (kJ)		
Dari tangki penampung (F-321)			Ke tangki penampung		
Bubuk protein		**17.917,8224**	**Susu bubuk tinggi protein**		**18.933,9902**
- Lemak	332,4757		- Lemak	332,4757	
- Protein	16.782,8592		- Protein	16.782,8592	
- Laktosa	33,6014		- Laktosa	33,6014	
- Abu	768,886		- Abu	768,886	
			- Air	1016,1678	
			Ke kondenser		
$Q_{udara\ masuk}$		**344.594.798,7333**	**$Q_{udara\ keluar}$**		**327.363.146,7377**
			Q_{hilang}		**17.230.635,8278**
Total		**344.612.716,5557**	**Total**		**344.612.716,5557**

APPENDIX C

SPESIFIKASI PERALATAN

1. Tangki Penampungan Susu Segar (F-100)

Fungsi : Menampung susu segar sebelum diolah menjadi susu bubuk tinggi protein.

Tipe : Silinder tegak dengan tutup atas berbentuk plat datar dan tutup bawah berbentuk *dished head.*

Dasar pemilihan : Untuk menampung bahan yang berbentuk cair.

Kondisi operasi :

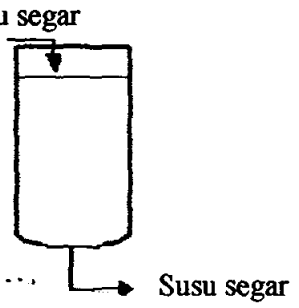
- T = 4°C
- Tekanan 1 atm
- Waktu tinggal 24 jam

Sistem operasi : *Batch*

Jumlah : 12 buah

Karena 1 hari proses adalah 24 jam dan tangki yang dimiliki sebanyak 12 buah, maka satu tangki digunakan untuk menampung susu segar selama 2 jam proses.

Gambar :



Perhitungan :

Rate larutan masuk : 671.406,6097 $^{kg}/_{hari}$ = 27.975,2754 $^{kg}/_{jam}$

ρ susu (4°C) : 1033,7- 0,2308T – 0,00246 T^2 [5]

: 1.032,7374 $^{kg}/_{m^3}$ = 64,4751 $^{lbm}/_{ft^3}$

Volume larutan total :

$$\frac{27.975,2754\,^{kg}/_{jam}}{1.032,7374\,^{kg}/_{m^3}}.2\ jam = 54,1769\ m^3 = 1.913,1524\ ft^3$$

Diambil : tinggi tangki (H_t) = 1,1 x Diameter tangki (D_t)

Volume shell = $(\pi/4).D_t^{\,2}.H_t = (\pi/4).D_t^2.1,5.D_t = (\pi/4).1,5.D_t^3$

Volume torispherical dished head (ft^3) = 0,000049 x D_t^3 (in)

[22, pers 5.11, hal 88]

Volume tangki penampung = volume shell + volume *dished head*

Diambil : volume tangki penampung = 1,3 . volume larutan total

Volume tangki = volume cylindrical shell + volume dished head

$$1,3 \times 1.913,1424\ ft^3 = (\pi/4) \times D_t^2 \times H_t + 0,000049 \times D_t^3 \times \left(\frac{1\ ft}{12\ in}\right)^3$$

$$2.487{,}0953\,ft^3 = (\pi/4)\times\left(\frac{H_t}{1{,}1}\right)^2 \times H_t + 4{,}9.10^{-5} \times \left(\frac{H_t}{1{,}1}\right)^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$2.487{,}0953\,ft^3 = 0{,}6491\,H_t^3$$

$$H_t = 15{,}6481\,ft$$

Digunakan 2 course 8 ft, sehingga $H_t \approx 16$ ft

Volume tangki = volume cylindrical shell + volume dished head

$$1{,}3\times 1.913{,}1424\,ft^3 = (\pi/4)\times D_t^2 \times H_t + 0{,}000049 \times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$2.487{,}0953\,ft^3 = (\pi/4)\times D_t^2 \times \left(\frac{1\,ft}{12\,in}\right)^2 \times 16\,ft + 0{,}000049 \times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$2.487{,}0953\,ft^3 = 0{,}0873\times D_t^2 + 2{,}8356\times 10^{-8} D_t^3$$

$$D_t = 168{,}7824\,in = 14{,}0651\,ft$$

Volume larutan dalam dish $= 0{,}000049 \,.\, D^3$

$= 0{,}000049 \,.\, (168{,}7824\text{ in})^3$

$= 235{,}6012\text{ ft}^3$

Volume larutan dalam shell = vol. lart. total – vol. lart. dalam dish

$= 2.487{,}0953\text{ ft}^3 - 235{,}6012\text{ ft}^3$

$= 2.251{,}4941\text{ ft}^3$

Tinggi lart. dalam shell (H_L) $= \dfrac{vol\,lart\,dlm\,shell}{\frac{\pi}{4} D_t^2}$

$$= \frac{2.251{,}4941\,ft^3}{\frac{\pi}{4}.(14{,}0651\,ft)^2}$$

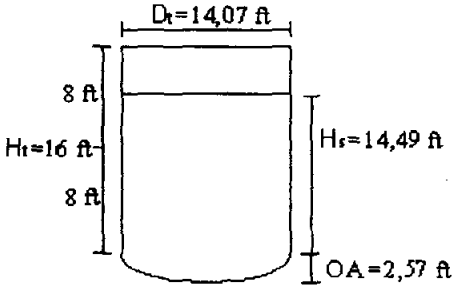
$= 14{,}49$ ft

P operasi = P hidrostatis $= \left(\dfrac{\rho \times H_L}{144}\right)$ psi

$$= \left(\frac{64{,}4751\, {}^{lbm}/_{ft^3} \times 14{,}4909\, ft}{144} \right)$$

= 6,4882 psi

P desain = 1,5 x P operasi = 1,5 x 6,4882 psi = 9,7323 psi



Tebal *Shell*

Menghitung tebal shell untuk course 1 (8 ft dari dasar):

$$t_s = \frac{P.D_t}{2.f.E} + c$$ [22, pers 3.16]

dimana :

P = P desain = 9,7323 psi

D_t = 168,7824 in

Konstruksi: Bahan konstruksi = *Stainless steel-316L*, dengan:

f = Strees maksimum yang diijinkan = 23.000 psi

Tipe sambungan = *Double-welded butt joint*, dengan

E = *Welded-joint efficiency* = 0,8 [22, Tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_s = \frac{(9{,}7323\, psi) \times (168{,}7824\, in)}{2 \times (23.000\, psi) \times (0{,}8)} + 0{,}125\, in$$

$= 0{,}1696 \text{ in} \approx \frac{3}{16} \text{ in}$

Menghitung tebal shell untuk course 2 (8 hingga 16 ft dari dasar):

$H_L = 14{,}4909 \text{ ft} - 8 \text{ ft} = 6{,}4909 \text{ ft}$

$$P_{hidrostatis} = \frac{H_L \text{ x } \rho \text{ susu}}{144}$$

$$= \frac{6{,}4909 ft \times 64{,}4751 {}^{lbm}/_{ft^3}}{144}$$

$= 2{,}9063 \text{ psi}$

$P_{design} = 1{,}5 \text{ x } P_{hidrostatis}$

$= 1{,}5 \text{ x } 2{,}9063 \text{ psi}$

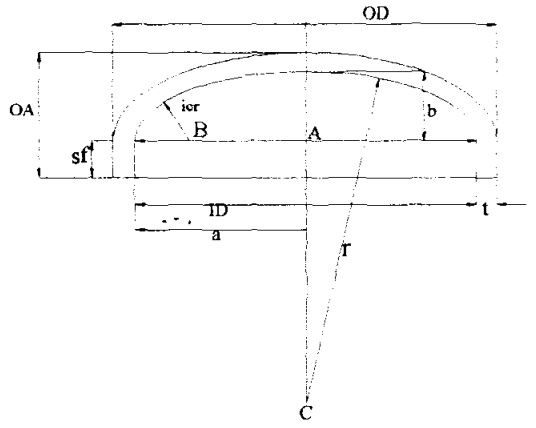
$= 4{,}3594 \text{ psi}$

$$\text{Tebal shell } (t_s) = \frac{P_{design} \times D_t}{2 \times f \times E} + c$$

$$= \frac{(4{,}3594\ psi) \times (168{,}7824\ in)}{2 \times (23.000\ psi) \times (0{,}8)} + 0{,}125\ in$$

$= 0{,}145 \text{ in.} \approx 3/16 \text{ in.}$

Tebal *dished head*



r (*crown radius / radius of dish*) = 168,7824 in

icr (*inside corner radius / knuckle radius*) = 6% x 168,7824 in = 10,1269 in

$$W = \frac{1}{4}\times\left[3+\sqrt{\frac{r}{icr}}\right] \qquad \text{[22, pers 7,76]}$$

$$= \frac{1}{4}\times\left[3+\sqrt{\frac{168,7824}{10,1269}}\right]$$

$$= 1,7706$$

$$a = \frac{D_t}{2} = \frac{168,7824\ in}{2} = 84,3912\ in$$

$$AB = \frac{D_t}{2} - icr = \frac{168,7824\ in}{2} - 10,1269 in = 74,2643\ in$$

BC = r – icr = (168,7824-10,1269) in = 158,5666 in

$$b = r - \sqrt{BC^2 - AB^2} = 168,7824 - \sqrt{158,5666^2 - 74,2643^2} = 28,5812\ in$$

$$t_d = \frac{P\times r\times W}{2\times f\times E - 0,2\times P} + c \qquad \text{[22, pers 7.77, p.138]}$$

dimana :

P = P desain = 9,7323 psi

Konstruksi : Bahan konstruksi = *Stainless steel-316 L*, dengan

f = stress maksimum yang diijinkan = 23.000 psi

Tipe sambungan = double-welded butt joint, dengan

E = welded-joint efficiency = 0,8 [22, tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_d = \frac{(9{,}7323\ psi)\times(168{,}7824\ in)\times 1{,}7706}{(2\times 23.000\ psi\times 0{,}8)-(0{,}2\times 9{,}7323)} + 0{,}125\ in$$

$$= 0{,}2040 \approx \tfrac{1}{4}\ \text{in}$$

Dipilih panjang straight-flange (sf) = 2 in [22, tabel 5.8, hal 93]

OA = t_d + b + sf

= ($\frac{1}{4}$ + 28,5812 + 2) in

= 30,8312 in = 2,5692 ft ≈ 2,57 ft

Tinggi tangki keseluruhan = tinggi shell + tinggi dish

= 16 ft + 2,57 ft

= 18,57 ft

Tebal plat datar (t_f) = 3/16 in.

Spesifikasi :

Tangki

Kapasitas : 1.913,1524 ft^3

Diameter : 14,0651 ft

Tinggi tutup bawah (dished head): 2 ft

Tinggi shell : 16 ft

Tinggi tangki total : 18,57 ft

Tebal *shell course* 1 : 0,1696 in $\approx \frac{3}{16}$ in

Tebal *shell course* 2 : 0,145 in $\approx \frac{3}{16}$ in

Tebal tutup bawah (*dished head*) : 0,2040 in $\approx \frac{1}{4}$ in

Bahan konstruksi : *Stainless steel-316 L*

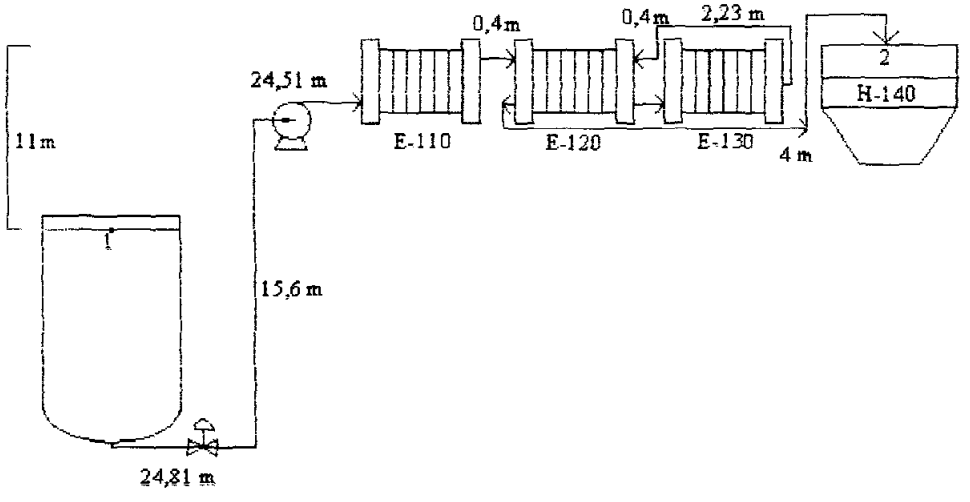
Jumlah tangki : 24 buah

2. Pompa (L-111)

Fungsi : Mengalirkan susu segar dari tangki penampungan untuk dipasteurisasi

Tipe : *Centrifugal pump*

Jumlah : 1 buah



Perhitungan :

$T = 4^oC$

Massa susu segar 4°C masuk = 27.975,2754 kg/jam = 7,771 kg/s

ρ susu (4°C) : $1033,7 - 0,2308T - 0,00246\ T^2$ [5]

: $1.032,7374\ {}^{kg}/_{m^3} = 64,4751\ {}^{lbm}/_{ft^3}$

Viskositas : 0,0009 kg/m.s = 0,0006 lb/ft.s

$$\text{Rate volumetrik} = \frac{27.975,2754\ {}^{kg}/_{jam}}{1.032,7374\ {}^{kg}/_{m^3}} = 27,0885\ {}^{m^3}/_{jam} = 0,2657\ {}^{ft^3}/_{s}$$

Optimum inside diameter (Di,opt) dengan asumsi aliran turbulen.

$Di,opt = 3,9\ q_f^{\ 0,45}\ \rho^{0,13}$ [28, pers 45, hal 381]

dimana : q_f = flow rate, ft^3/s

ρ = densitas fluida, lb/ft^3

$Di,opt = 3,9\ (0,2657)^{0,45}\ (64,4751)^{0,13} = 3,692$ inch ≈ 4,026 inch.

Digunakan pipa berukuran 4 inch, sch.40 [20, App.A-5]

ID = 4,026 inch = 0,3355 ft = 0,1023 m

A = 0,0884 ft^2

$$\text{Kecepatan linier (v)} = \frac{q_f}{A} = \frac{0,2657\ ft^3/s}{0,0884\ ft^2} = 3,0057\ ft/s = 0,9161\ m/s$$

$$N_{Re} = \frac{\rho \times v \times ID}{\mu}$$

$$= \frac{(64,4751\ {}^{lb}/_{ft^3})(3,0057\ {}^{ft}/_{s})(0,3355\ ft)}{0,0006\ {}^{lb}/_{ft.s}}$$

=108.362,4785 (turbulen) (asumsi benar)

Digunakan commercial steel : $\varepsilon = 4{,}6.10^{-5}$ m

$$\text{harga } \frac{\varepsilon}{ID} = \frac{4{,}6.10^{-5}}{0{,}1023} = 0{,}0004$$

$$f = 0{,}005 \qquad \text{[20, Fig.2.10-3]}$$

Panjang ekivalen :

- 13 buah standard elbow 90°; $K_f = 0{,}75$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 0{,}75 \times \frac{0{,}9161^2}{2} = 0{,}3147\, m^2/s^2$$

karena ada 13 buah maka = 0,3147 m^2/s^2 x 13 = 4,0911 m^2/s^2

- 6 buah standard tee; K_f = 1 [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 1 \times \frac{0{,}9161^2}{2} = 0{,}4196\, m^2/s^2$$

karena ada 6 buah maka = 0,4196 m^2/s^2 x 6 = 2,5176 m^2/s^2

- 3 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0{,}9161^2}{2} = 2{,}5177\, m^2/s^2$$

karena ada 3 buah maka = 2,5177 m^2/s^2 x 2 = 7,5531 m^2/s^2

- Friksi karena pipa lurus

panjang pipa lurus =

ΔL = 24,81m +15,6 + 0,4 m + 0,4 m + 24,51 m + 2,23 m + 4 m + 2 m

= 73,95 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}005 \times \frac{73{,}95}{0{,}1023} \times \frac{0{,}9161^2}{2} = 6{,}0666\, m^2/s^2$$

[20, pers.2.10-6]

- Friksi *sudden contraction* dari tangki ke pipa dan dari *plate heat exchanger* ke pipa

$$h_c = 0{,}55 \times \left(1 - \frac{A_2}{A_1}\right) \times \frac{v_2^{\,2}}{2\alpha} = 0{,}55 \times (1-0) \times \frac{0{,}9161^2}{2} = 0{,}2484 \, m^2/s^2$$

  - Karena luas area tangki (A_1) >>> dari pada luas area pipa (A_2), maka

$$\frac{A_2}{A_1} \approx 0$$

  - Karena ada 5 kali *sudden contraction* maka:

$$= 5 \text{ x } 0{,}2484 \ m^2/s^2 = 1{,}242 \ m^2/s^2$$

- Friksi *sudden enlargement* dari pipa ke *plate heat exchanger* dan dari pipa ke sentrifugal separator

$$h_{ex} = \left(1 - \frac{A_1}{A_2}\right)^2 \times \frac{v_2^{\,2}}{2\alpha} = (1-0)^2 \times \frac{0{,}9161^2}{2} = 0{,}4196 \, m^2/s^2$$

  - Karena luas area pipa (A_1) <<< dari pada luas area *plate heat exchanger* (A_2), maka $\frac{A_1}{A_2} \approx 0$

  - Karena ada 5 kali *sudden enlargement* maka:

$$= 5 \text{ x } 0{,}4196 \ m^2/s^2 = 2{,}0981 \ m^2/s^2$$

$$\Sigma F = 4{,}0911 + 2{,}5176 + 7{,}5531 + 6{,}0666 + 1{,}242 + 2{,}0981 = 23{,}5685 \, m^2/s^2$$

Persamaan Bernoulli :

$$-w_s = \Sigma F + \frac{v_2^{\,2} - v_1^{\,2}}{2\alpha} + (z_2 - z_1)\ g + \frac{\Delta P}{\rho} \qquad \text{[20, pers.2.7-28]}$$

dimana : $Z_2 - Z_1 = 7{,}9$ m

$P_1 = 101.325\ N/m^2$

$P_2 = 101.325\ N/m^2 - (\Delta P_{E-110} + \Delta P_{E-120\ susu\ segar} + \Delta P_{E-130} + \Delta P_{E-120\ susu\ pasteurisasi})$

$= 101.325\ N/m^2 - (0{,}734\ psia + 0{,}638\ psia + 0{,}2325\ psia + 0{,}622\ psia)$

$= 85.973{,}8169\ N/m^2$

$\Delta P = P_1 - P_2 = 101.325\ N/m^2 - 85.973{,}8169\ N/m^2 = 15.351{,}1831\ N/m^2$

$v_1 = 0$, $v_2 = 0{,}9161$ m/s

$$-w_s = 23{,}5685 + \frac{0{,}9161^2 - 0^2}{2} + 11 \times 9{,}8067 + \frac{15.351{,}1831}{1.032{,}7374}$$

$-w_s = 146{,}7264\ m^2/s^2 = 146{,}7264\ J/kg$

Efisiensi pompa (η) = 50% [28, fig 13-37, p.550]

$$W_p = -\frac{Ws}{\eta} = \frac{146{,}7264}{0{,}50} = 293{,}4575\ \frac{J}{kg}$$

Flow rate = 7,771 kg/s

$$\text{hp pompa} = 293{,}4575\ {}^{J}\!/_{kg} \times 7{,}771\ {}^{kg}\!/_{s} = 2{,}2804\ kW = 3{,}0581\ hp$$

Efisiensi motor = 83% [31, fig 14-38, p 521]

Sehingga dipakai pompa dengan motor = 3,0581/0,83 hp = 3,68 hp ≈ 4 hp

Spesifikasi alat :

Fungsi : Mengalirkan susu segar untuk diolah menjadi susu skim

Tipe : *Centrifugal pump*

Rate aliran pompa : 27,0885 m^3/jam

Ukuran pipa : 4 in sch 40

Power motor : 4 hp

Bahan konstruksi : *Stainless steel*

Jumlah : 1 buah

3. *Plate Heat Exchanger* (E-110)

Fungsi : Untuk memanaskan susu segar dari 4°C ke 22°C

Tipe : *Plate and frame*

Dasar pemilihan : Mudah dibersihkan, luas area perpindahan panas besar

Kondisi operasi :

Jenis fluida	**Panas : Susu skim 50°C**	**Dingin : Susu 4°C**
Flow rate, kg/hari	645.745,4492	671.406,6098
Suhu masuk, °C	50	4
Suhu keluar, °C	30	22
ρ, kg/m^3	1020.5320	1030.2840
k, W/m.K	0.5931	0,5572
μ, kg/m.s	0.0008	0,0009
Cp, J/kg.K	3931.4000	3886.0400
Rd	0,003	0,003

1. Direncanakan menggunakan bahan *stainless steel* dengan :

   Tebal bahan plat (δ) = 0,0005 m

   k = 8.000 W/m.K

   Jenis plate : HM

   HPCD = 0,26 [45]

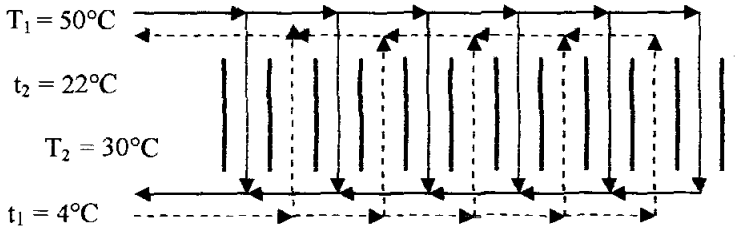
   VPCD = 1,04 [45]

Port nozzle (D) = 0,075 m

Compressed pitch = 0,0032 m/plate

Tipe : gasket

2. Gambar secara sket :



3. Neraca panas :

Q_H = 50.864.215,2985 kJ/hari

= 588.706,1956 W

Qc = 47.054.817,1652 kJ/hari

= 544.615,9394 W

4. Rd total = 0,003

Rd total = $1/U_D - 1/U_C$;

Trial U_C = 6550 W/m^2.°K (Dari Perry, 1997, untuk sistem perpindahan panas air-air, U_C = 5700 – 7400 W/m^2.°K)

$$U_D = \frac{1}{\text{Rd total} + \frac{1}{U_C}} = \frac{1}{0{,}003 + \frac{1}{6550}} = 317.1913 \text{ W/m}^2.^\circ\text{K}$$

$$\Delta T_{LTMD} = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln\left(\frac{T_1 - t_1}{T_2 - t_2}\right)}$$

$$= \frac{(323 - 298) - (303 - 277)}{\ln\left(\frac{323 - 298}{303 - 277}\right)}$$

$$= 26{,}9876\ K$$

5. $A = \frac{Q_h}{2.U_D.\Delta T_{LTMD}} = \frac{588.706{,}1956\ W}{2.318{,}9655 W/m^2.K.\ 26{,}9876 K} = 34{,}386\ m^2$

dipilih plat jenis HM dengan [45]:

projected area = $A_p = 0{,}27\ m^2$

developed area = $A_d = 0{,}35\ m^2$

$\varphi = A_d/A_p = 0{,}35/0{,}27 = 1{,}296.$

Jumlah plat untuk perpindahan panas, $n = A/A_d$

$= 34{,}386/0{,}35 = 98{,}246 \approx 99$

$U_D = \frac{588706{,}1956 W}{99.0{,}35.m.26{,}9876 K} = 311{,}6273\ W/m^2.^\circ K$ (U_D terkoreksi)

$n = n_{ch} + n_{cc} - 1$; dengan n_{ch} = jumlah channel untuk fluida panas

n_{cc} = jumlah channel untuk fluida dingin

$n + 1 = n_{ch} + n_{cc} = 99 + 1 = 100$ buah

$n_{ch} = n_{cc} = 50$

6. Spesifikasi dari plat :

$W = HPCD + D + 0{,}015 = 0{,}260 + 0{,}075 + 0{,}015 = 0{,}35$ m

$A_p = 0{,}27\ m^2 = L.W = 0{,}35.L \rightarrow L = 0{,}771$ m

Pitch plat (PT) = 0,0032 ; b = PT – δ = 0,0032 – 0,0005 = 0,0027 m

Luas penampang aliran fluida dalam channel

(Sc) = W.b

= 0,35. 0,0027

= 0,000945 m^2

$$De = \frac{2b}{\varphi} = \frac{2.0,0027}{1,296} = 0,0042 \text{ m}$$

Fluida panas (Susu skim 50°C)	Fluida dingin (susu segar 4°C)
$7.\ G_h = \frac{M}{n_{ch}.Sc}$ $= \frac{7,474\,kg/s}{50.0,000945} = 156.612 kg/m^2.s$ $Re = \frac{De.G_h}{\mu}$ $= \frac{0,0042m.156,612\,kg/m^2.s}{0,0008 kg/m.s} = 847,272$	$7'.\ G_C = \frac{m}{n_{CC}.Sc}$ $= \frac{7,771 \text{ kg/s}}{50.0,000945 m^2}$ $= 162,8353 kg/m^2.s$ $Re = \frac{De.G_C}{\mu}$ $= \frac{0,0042m.162,8353\,kg/m^2.s}{0,0009\,kg/m.s}$ $= 753,695$
$8.\ Pr = \frac{Cp.\mu}{k}$ $= \frac{3931,4 J/kg.K\ 0,0008 kg/m.s}{0,5931 \text{ W/m.K}}$ $= 5,104$	$8'.\ Pr = \frac{Cp.\mu}{k}$ $= \frac{3886,04 J/kg.K\ 0,0009 kg/m.s}{0,5572 \text{ W/m.K}}$ $= 6,277$
$9'.\ h_h = 0,37 \text{ x } N_{Re}^{0.67} \text{ x } N_{PR}^{0.33} . \frac{k}{De}$ $= 0,37.(847,272)^{0.67}.(5,104)^{0.33} . \frac{0,5931}{0,0042}$ $= 8260,8742\,W/m^2.{}^oK$	$9'.\ h_C = 0,37 \text{ x } N_{Re}^{0.67} \text{ x } N_{PR}^{0.33} . \frac{k}{De}$ $= 0,37.(753,695)^{0.67}.(6,277)^{0.33} . \frac{0,5572}{0,0042}$ $= 7682,4227\,W/m^2.{}^oK$

10. $U_C = \left(\frac{1}{h_h} + \frac{\delta}{k} + \frac{1}{h_C}\right)^{-1}$

$= \left(\frac{1}{8260,8742} + \frac{0,0005}{8000} + \frac{1}{7682,4227}\right)^{-1} = 3979,5874 \text{ W/m}^2.^\circ\text{K}$

11. Rd $= 1/U_D - 1/U_C = (1/311.6273) - (1/3979,5874) = 0.0030 = 0,003$

Fluida panas (susu panas 50°C)	Fluida dingin (susu segar 4°C)
1. Re = 847,272	1'. Re = 753,695
2. $f = \frac{2,5}{\text{Re}^{0,3}} = \frac{2,5}{847,272^{0.3}} = 0,3308$	2'. $f = \frac{2,5}{\text{Re}^{0,3}} = \frac{2,5}{753,695^{0.3}} = 0,3426$
3. $\Delta P_h = \frac{2.f.G^2.L}{\rho.De}$ $= \frac{2.0,3308.(156,612)^2.0,771}{1020,532.0,0042}$ $= 2944,3641 N/m^2 = 0,427$ psia	3'. $\Delta P_C = \frac{2.f.G^2.L}{\rho.De}$ $= \frac{2.0,3426.(162,8353)^2.0,771}{1030,284.0,0042}$ $= 3265,5622 N/m^2 = 0,474$ *psia*
4. $G' = \frac{M}{\frac{\pi}{4}.Dp^2} = \frac{7,4739 kg/s}{\frac{\pi}{4}.(0,075m)^2}$ $= 1692,6043 kg/m^2.s$	4'. $G' = \frac{M}{\frac{\pi}{4}.Dp^2} = \frac{7,771 kg/s}{\frac{\pi}{4}.(0,075m)^2}$ $= 1759,8663 kg/m^2.s$
5. $\text{Re} = \frac{D_p.G'}{\mu} = \frac{0,075.1692,6043}{0,0008}$ $= 164.864,0508$	5'. $\text{Re} = \frac{D_p.G'}{\mu} = \frac{0,075.1759,8663}{0,0009} = 146.655,5289$
6. $f = \frac{2,5}{\text{Re}^{0.33}} = \frac{2,5}{164.864,0508^{0.3}} = 0,0680$	6'. $f = \frac{2,5}{\text{Re}^{0,3}} = \frac{2,5}{146.655,5289^{0.3}} = 0,0705$
7. $\Delta P_p = \frac{2.f.G'^2.L}{\rho.D_p}$ $= \frac{2.0,0680.(1692,6043)^2.99.0,0032}{1020,532.0,075}$ $= 1613.7652 N/m^2 = 0,234$ *psia*	7'. $\Delta P_p = \frac{2.f.G'^2.L}{\rho.D_p}$ $= \frac{2.0,0705.(1759,8663)^2.99.0,0032}{1030,284.0,075}$ $= 1789.8095 \text{ N/m}^2 = 0,260$ psia
8. $\Delta P_T = \Delta P_h + \Delta P_p$ $= 0,427 + 0,234 = 0661$ psia	8'. $\Delta P_T = \Delta P_C + \Delta P_p$ $= 0,474 + 0,260 = 0,734$ psia

Ringkasan perhitungan

	Fluida panas (susu panas 50°)	Fluida dingin (susu segar 4°C)
h, $W/m^2.°K$	8260,8742	7682,4227
ΔP *calculated*, psia	0,661	0,734
U_C, $W/m^2.°K$	3979,5874	
U_D, $W/m^2.°K$	311,6273	
Rd *calculated*, $m^2.°K/W$	0,003	

Spesifikasi :

Tebal bahan plat, δ : 0,0005 m

HPCD : 0,26 m

VPCD : 1,04 m

Port nozzle, D : 0,075 m

Compressed pitch : 0,0032 m/plate.

projected area, A_p : 0,27 m^2

developed area, A_d : 0,35 m^2

Jumlah plat, n : 156

Bahan konstruksi : *Stainless steel* 316L

Tipe : gasket

Jenis plate : HM

4. *Plate Heat Exchanger* (E-120)

Fungsi : Untuk memanaskan susu segar 22°C menjadi 44°C

Tipe : *Plate and frame*

Dasar pemilihan : Mudah dibersihkan, luas area perpindahan panas besar

Kondisi operasi :

Jenis fluida	**Panas : Susu pasteurisasi 72°C**	**Dingin : Susu segar 22°C**
Flow rate, kg/hari	671.406,6097	671.406,6097
Suhu masuk, °C	72	22
Suhu keluar, °C	50	43
ρ, kg/m^3	1010.4680	1023.6010
k, W/m.K	0.6210	0.5831
μ, kg/m.s	0.0007	0.0008
Cp, J/kg.K	3966.6800	3918.8000
Rd	0,003	0,003

1. Direncanakan menggunakan bahan *stainless steel* dengan :

   k = 8.000 W/m.K

   Tebal bahan plat (δ) = 0,0005 m

   Jenis plate : HM

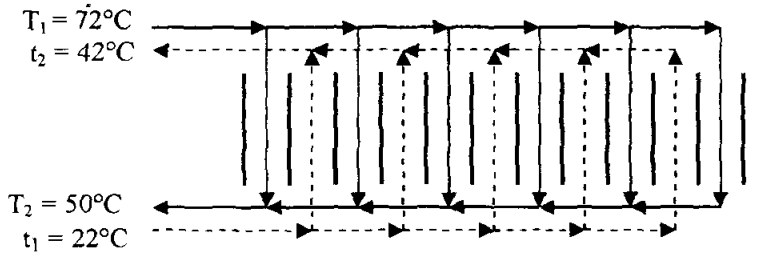
   HPCD = 0,26

   VPCD = 1,04

   Port nozzle (D) = 0,075 m

   Compressed pitch = 0,0032 m/plate

   Tipe : gasket



2. Neraca Panas

   Q_H = 57.330.695,2387 kJ/hari

= 708.523,0491 W

Qc = 50.578.464,2745 kJ/hari

= 630.372,2277 W

3. Rd total = 0,003

Rd total = $1/U_D - 1/U_C$

Trial U_C = 6550 W/m^2.°K (Dari Perry, 1997, untuk sistem perpindahan panas uap air-air, U_C = 5700 – 7400 W/m^2.°K)

$$U_D = \frac{1}{\text{Rd total} + \frac{1}{U_C}} = \frac{1}{0{,}003 + \frac{1}{6550}} = 317.191 \text{ W/m}^2.^\circ\text{K}$$

$$\Delta T_{LMTD} = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln\left(\frac{T_1 - t_1}{T_2 - t_2}\right)}$$

$$= \frac{(72 - 22) - (50 - 43)}{\ln\left(\frac{72 - 22}{50 - 43}\right)}$$

= 28,4971 K

4. $$A = \frac{Q_h}{2 \times U_D \times \Delta t_{LMTD}} = \frac{708.523{,}0491}{2 \times 317{,}191 W/m^2 K \times 28{,}4971 K} = 39{,}192 m^2$$

5. Dipilih plat jenis HM dengan [45]:

projected area = A_p = 0,27 m^2

developed area = A_d = 0,35 m^2

$\varphi = A_d / A_p$ = 0.35/0,27 = 1,296.

Jumlah plat untuk perpindahan panas, n = A/A_d

= 39.192/0,35 = 112.98 ≈ 113.0000

$$U_D = \frac{708.523{,}0491\ W}{113.0{,}35\,m^2.28{,}4971\,K} = 317{,}802\ \text{W/m}^2.^\circ\text{K}$$ (U_D terkoreksi)

$n = n_{ch} + n_{cc} - 1$; dengan

n_{ch} = jumlah channel untuk fluida panas

n_{cc} = jumlah channel untuk fluida dingin

$n + 1 = n_{ch} + n_{cc} = 113 + 1 = 57$ buah

6. Spesifikasi dari plat :

$W = HPCD + D + 0{,}015 = 0{,}260 + 0{,}075 + 0{,}015 = 0{,}35$ m

$A_p = 0{,}27\ m^2 = L.W = 0{,}35.L \rightarrow L = 0{,}771$ m

Pitch/plat (PT) = 0,0032 ; $b = PT - \delta = 0{,}0032 - 0{,}0005 = 0{,}0027$ m

Luas penampang aliran fluida dalam channel

(Sc) = W.b

$= 0{,}35.\ 0{,}0027$

$= 0{,}000945\ m^2$

$$De = \frac{2b}{\varphi} = \frac{2.0{,}0027}{1{,}296} = 0{,}0042\ \text{m}$$

Fluida panas (susu pasteurisasi 72°C)	Fluida dingin (susu segar 22°C)
7. $G_h = \frac{M}{n_{ch}.Sc}$ $= \frac{7,771 kg/s}{57.0,000945} = 144.266 kg/m^2.s$ $Re = \frac{De.G_h}{\mu}$ $= \frac{0,0042m.144,266 kg/m^2.s}{0.0007 kg/m.s} = 858.532$	7'. $G_C = \frac{m}{n_{CC}.Sc}$ $= \frac{7,771 \text{ kg/s}}{57.0,000945 m^2}$ $= 144,266 kg/m^2.s$ $Re = \frac{De.G_C}{\mu}$ $= \frac{0,0042m.144,266 kg/m^2.s}{0,0008 kg/m.s}$ $= 751.216$
8. $Pr = \frac{Cp.\mu}{k}$ $= \frac{3966.68 J/kg.K.0.0007 kg/m.s}{0.6210 W/m.K}$ $= 4.471$	8'. $Pr = \frac{Cp.\mu}{k}$ $= \frac{3918.8 J/kg.K\ 0,0008 kg/m.s}{0.5831 W/m.K}$ $= 5,3765$
9'. $h_C = 0,37 \times N_{Re}^{0,67} \times N_{PR}^{0,33} . \frac{k}{De}$ $= 0,37.(858,532)^{0,67}.(4,471)^{0,33} . \frac{0,6210}{0,0042}$ $= 8353,412 W/m^2.^oK$	9'. $h_C = 0,37 \times N_{Re}^{0,67} \times N_{PR}^{0,33} . \frac{k}{De}$ $= 0,37.(751,216)^{0,67}.(5,3765)^{0,33} . \frac{0,5831}{0,0042}$ $= 7622,2405 W/m^2.^oK$

10. $U_C = \left(\frac{1}{h_h} + \frac{\delta}{k} + \frac{1}{h_C} \right)^{-1}$

$= \left(\frac{1}{8353,412} + \frac{0,0005}{8000} + \frac{1}{7622,2405} \right)^{-1} = 3984.5545 W/m^2.^oK$

11. Rd $= 1/U_D - 1/U_C = (1/314.3238) - (1/3984.5545) = 0,0029 < 0,003$ (tidak memenuhi syarat perpindahan panas).

Kesimpulannya PHE harus dirancang ulang. Agar Rd lebih besar → U_D diperkecil → dengan memperkecil laju aliran tiap plate yaitu dengan cara menambah jumlah plat. Dicoba n = 117, sehingga proses perhitungan dimulai dari tahap 7.

Fluida panas (susu pasteurisasi 72°C)	Fluida dingin (susu segar 22°C)
7. $G_h = \frac{M}{n_{ch}.Sc}$ $= \frac{7,771 kg/s}{59.0,000945} = 139.376 kg/m^2.s$ $Re = \frac{De.G_h}{\mu}$ $= \frac{0,0042m.139,376 kg/m^2.s}{0,0007 kg/m.s} = 829.4295$	7'. $G_C = \frac{m}{n_{CC}.Sc}$ $= \frac{7,771 kg/s}{59.0,000945 m^2}$ $= 139.3760 kg/m^2.s$ $Re = \frac{De.G_C}{\mu}$ $= \frac{0,004167.105,427}{0,0007} = 627,592$
8. $Pr = \frac{Cp.\mu}{k}$ $= \frac{3966.68 J/kg.K.0.0007 kg/m.s}{0.6210 W/m.K}$ $= 4.471$	8'. $Pr = \frac{Cp.\mu}{k}$ $= \frac{3918.8 J/kg.K 0,0008 kg/m.s}{0.5831 W/m.K}$ $= 5,3765$
9'. $h_C = 0,37 \times N_{Re}^{0,67} \times N_{PR}^{0.33} . \frac{k}{De}$ $= 0,37.(829,4295)^{0,67}.(4,471)^{0.33} . \frac{0,6210}{0,0042}$ $= 8162.6127 W/m^2.^oK$	9'. $h_C = 0,37 \times N_{Re}^{0,67} \times N_{PR}^{0,33} . \frac{k}{De}$ $= 0,37.(7627,592)^{0,67}.(5,3765)^{0,33} . \frac{0,5831}{0,0042}$ $= 7448.1421 W/m^2.^oK$

10. $U_C = \left(\frac{1}{h_h} + \frac{\delta}{k} + \frac{1}{h_C} \right)^{-1}$

$= \left(\frac{1}{8162,6127} + \frac{0,0005}{8000} + \frac{1}{7448,1421} \right)^{-1} = 3893.5660 \ W/m^2.^\circ K$

11. $U_D = \frac{708.523,0491 \ W}{117.0,35 m^2.87,6471 K} = 303.578 \ W/m^2.^\circ K$ (U_D terkoreksi)

12. Rd $= 1/U_D - 1/U_C = (1/303.578) - (1/3893.5660) = 0.0030 > 0,003$

(memenuhi syarat perpindahan panas)

Fluida panas (susu pasteurisasi 72°C)	Fluida dingin (susu segar 22°C)
1. Re = 829.4295	1'. Re = 725.7508
2. $f = \frac{2,5}{Re^{0,3}} = \frac{2,5}{829.4295^{0,3}} = 0.3329$	2'. $f = \frac{2,5}{Re^{0,3}} = \frac{2,5}{725.7508^{0,3}} = 0.3465$
3. $\Delta P_h = \frac{2.f.G^2.L}{\rho.De}$ $= \frac{2.0,3329.(139,376)^2.0,771}{1010,468.0,0042}$ $= 2370.2597\ N/m^2 = 0,344$psia	3'. $\Delta P_C = \frac{2.f.G^2.L}{\rho.De}$ $= \frac{2.0,3465.(139,3760)^2.0,771}{1023,6010.0,0042}$ $= 2435.4846 N/m^2 = 0,353\ psia$
4. $G' = \frac{M}{\frac{\pi}{4}.D_p^2} = \frac{7,771 kg/s}{\frac{\pi}{4}.(0,075m)^2}$ $= 1759.8663 kg/m^2.s$	4'. $G' = \frac{M}{\frac{\pi}{4}.D_p^2} = \frac{7,771 kg/s}{\frac{\pi}{4}.(0,075m)^2} = 1759.8663$
5. $Re = \frac{D_p.G'}{\mu} = \frac{0,075.1759.8663 kg/m^2.s}{0.0007 kg/m.s}$ $= 188557.1085$	5'. $Re = \frac{D_p.G'}{\mu} = \frac{0,075.1759,8863}{0,0008}$ $= 164987.47$
6. $f = \frac{2,5}{Re^{0,33}} = \frac{2,5}{188557.1085^{0,3}} = 0.0654$	6'. $f = \frac{2,5}{Re^{0,3}} = \frac{2,5}{164987.4700^{0,3}} = 0.0680$
7. $\Delta P_p = \frac{2.f.G'^2.L}{\rho.D_p}$ $= \frac{2.0,0654.(1759,8663)^2.117.0,0032}{1010.4680.0,075}$ $= 1914.6116 N/m^2 = 0,278\ psia$	7'. $\Delta P_p = \frac{2.f.G'^2.L}{\rho.D_p}$ $= \frac{2.0,068.(1759,8663)^2.117.0,0032}{1023.6010.0,075}$ $= 1967.2979$ N/m^2 $= 0,285$psia
8. $\Delta P_T = \Delta P_h + \Delta P_p$ $= 0,344 + 0,278 = 0,622$ psia	8'. $\Delta P_T = \Delta P_C + \Delta P_p$ $= 0,353 + 0,285 = 0,638$ psia

Ringkasan perhitungan

	Fluida panas (susu pasteurisasi 72°C)	Fluida dingin (susu segar 22°C)
h, W/m^2.°K	8162.6127	7448.1421
ΔP *calculated*, psia	0,622	0,638
U_C, W/m^2.°K	3893.5660	
U_D, W/m^2.°K	303,578	
Rd *calculated*, m^2.°K/W	0,003	

Spesifikasi :

Tebal bahan plat, δ : 0,0005 m

HPCD : 0,26 m

VPCD : 1,04 m

Port nozzle, D : 0,075 m

Compressed pitch : 0,0032 m/plate.

projected area, A_p : 0,27 m^2

developed area, A_d : 0,35 m^2

Jumlah plat, n : 117

Bahan konstruksi : stainless steel

Tipe : gasket

Jenis plate : HM

4. ***Plate Heat Exchanger*** **(E-130)**

Fungsi : Untuk pasteurisasi susu segar dari suhu 44°C menjadi 72°C

Tipe : *Plate and frame*

Dasar pemilihan : Mudah dibersihkan, luas area perpindahan panas besar

Kondisi operasi :

Jenis fluida	**Panas : Steam**	**Dingin :Susu 42°C**
Flow rate, kg/hari	38040,7833	671.406,6097
Suhu masuk, °C	130	22
Suhu keluar, °C	130	43
ρ, kg/m^3	0,5524	1012,552
k, W/m.K	0,0279	0.6157
μ, kg/m.s	1,413.10^{-5}	0.0007
Cp, J/kg.K	1900,88	3959,96
Rd	0,003	0,003

1. Direncanakan menggunakan bahan *stainless steel* dengan :

   k = 8.000 W/m.K

   Tebal bahan plat (δ) = 0,0005 m

   Jenis plate : HM

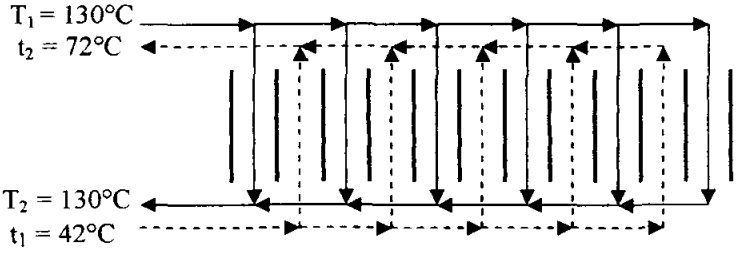
   HPCD = 0,26

   VPCD = 1,04

   Port nozzle (D) = 0,075 m

   Compressed pitch = 0,0032 m/plate

   Tipe : gasket



2. Neraca Panas

   Q_H = 82.707.890,62 kJ/hari

= 957267,2526 W

Qc = 78.572.496,09 kJ/hari

= 909403,8899 W

3. Rd total = 0,003

Rd total = $1/U_D - 1/U_C$

Trial U_C = 6550 W/m^2.°K (Dari Perry, 1997, untuk sistem perpindahan panas uap air-air, U_C = 5700 – 7400 W/m^2.°K)

$$U_D = \frac{1}{\text{Rd total} + \frac{1}{U_C}} = \frac{1}{0{,}003 + \frac{1}{6550}} = 317.191 \text{ W/m}^2.^\circ\text{K}$$

$$\Delta T_{LMTD} = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln\left(\frac{T_1 - t_1}{T_2 - t_2}\right)}$$

$$= \frac{(130-42)-(130-22)}{\ln\left(\frac{130-42}{130-22}\right)}$$

$$= 71{,}9608 \text{ K}$$

4. $$A = \frac{Q_h}{2.U_D.\Delta t_{LTMD}} = \frac{957267{,}2527}{2.317{,}191\ W/m^2.K.\ 71{,}9618\ \text{K}} = 20{,}969 \text{ m}^2$$

5. Dipilih plat jenis HM dengan [45]:

projected area = A_p = 0,27 m^2

developed area = A_d = 0,35 m^2

$\varphi = A_d/A_p = 0{,}35/0{,}27 = 1{,}296$.

Jumlah plat untuk perpindahan panas, $n = A/A_d$

$=20{,}969/0{,}35 = 60{,}91 \approx 61$

$$U_D = \frac{957267{,}2527\ W}{2.61.0{,}35\,m^2.71{,}9618\,K} = 311{,}5369\ \text{W/m}^2.^\circ\text{K}$$ (U_D terkoreksi)

n = n_{ch} + n_{cc} – 1 ; dengan n_{ch} = jumlah channel untuk fluida panas

n_{cc} = jumlah channel untuk fluida dingin

n + 1 = n_{ch} + n_{cc} = 61 + 1 = 31 buah

6. Spesifikasi dari plat :

W = HPCD + D + 0,015 = 0,260 + 0,075 + 0,015 = 0,35 m

A_p = 0,27 m^2 = L.W = 0,35.L → L = 0,771 m

Pitch/plat (PT) = 0,0032 ; b = PT – δ = 0,0032 – 0,0005 = 0,0027 m

Luas penampang aliran fluida dalam channel

(Sc) = W.b

= 0,35. 0,0027

= 0,000945 m^2

$$De = \frac{2b}{\varphi} = \frac{2.0{,}0027}{1{,}296} = 0{,}0042 \text{ m}$$

Fluida panas (saturated steam)	Fluida dingin (susu segar 22°C)
7. $G_h = \frac{M}{n_{ch}.Sc}$ 0,4403 $= \frac{0,4403\,kg/s}{31.0,000945} = 15,0294\,kg/m^2.s$ $Re = \frac{De.G_h}{\mu}$ $= \frac{0,0042m.15,0294\,kg/m^2.s}{1,41.10^{-5}\,kg/m.s} = 4430,875$	7'. $G_C = \frac{m}{n_{CC}.Sc}$ $= \frac{7,771\text{ kg/s}}{31.0,000945\,m^2}$ $= 265,264\ kg/m^2.s$ $Re = \frac{De.G_C}{\mu}$ $= \frac{0,0042m.265,264\,kg/m^2.s}{0,0007\,kg/m.s}$ $= 1578,592$
8. $Pr = \frac{Cp.\mu}{k}$ $= \frac{1900,88\,J/kg.K.1,41.10^{-5}kg/m.s}{0.0279\text{ W/m.K}}$ $= 0,963$	8'. $Pr = \frac{Cp.\mu}{k}$ $= \frac{3959,96J/kg.K\,0,0007\,kg/m.s}{0.6157\text{ W/m.K}}$ $= 4,5021$
9'. $h_C = 0,37 \text{ x } N_{Re}^{0,67} \text{ x } N_{PR}^{0,33} . \frac{k}{De}$ $= 0,37.(4430,875)^{0,67}.(0,963)^{0,33}.\frac{0,0279}{0,0042}$ $= 678,918 W/m^2.^oK$	9'. $h_C = 0,37 \text{ x } N_{Re}^{0,67} \text{ x } N_{PR}^{0,33} . \frac{k}{De}$ $= 0,37.(1578,592)^{0,67}.(4,5021)^{0,33}.\frac{0,6157}{0,0042}$ $= 12483,911 W/m^2.^oK$

10. $$U_C = \left(\frac{1}{h_h} + \frac{\delta}{k} + \frac{1}{h_C}\right)^{-1}$$

$$= \left(\frac{1}{678,918} + \frac{0,0005}{8000} + \frac{1}{12483,911}\right)^{-1} = 461,261\text{ W/m}^2.^\circ\text{K}$$

11. Rd = $1/U_D - 1/U_C = (1/311,5369) - (1/461,261) = 0,0017 < 0,003$ (tidak memenuhi syarat perpindahan panas).

Kesimpulannya PHE harus dirancang ulang. Agar Rd lebih besar dan agar $\Delta P_{T\ stram} < 1$ psia→ U_D diperkecil → dengan memperkecil laju aliran tiap plate

yaitu dengan cara menambah jumlah plat. Dicoba n = 277, sehingga proses perhitungan dimulai dari tahap 7.

Fluida panas (saturated steam 130°C)	Fluida dingin (susu segar 22°C)
$7.\ G_h = \frac{M}{n_{ch}.Sc}$ $= \frac{0,4403 kg/s}{139.0,000945} = 3,4258 kg/m^2.s$ $Re = \frac{De.G_h}{\mu}$ $= \frac{0,0042m.3,4258 kg/m^2.s}{1,41.0^{-5}\ kg/m.s} = 1009,979$	$7'.\ G_C = \frac{m}{n_{CC}.Sc}$ $= \frac{7,771 kg/s}{139.0,000945 m^2}$ $= 60,4646 kg/m^2.s$ $Re = \frac{De.G_C}{\mu}$ $= \frac{0,004167.60,4646}{0,0007} = 359,826$
$8.\ Pr = \frac{Cp.\mu}{k}$ $= \frac{1900,88 J/kg.K.1,41.10^{-5} kg/m.s}{0.0279\ W/m.K}$ $= 0,963$	$8'.\ Pr = \frac{Cp.\mu}{k}$ $= \frac{3959,96 J/kg.K\ 0,0007 kg/m.s}{0.6157\ W/m.K}$ $= 4,5021$
$9'.\ h_C = 0,37\ x\ N_{Re}^{0,67}\ x\ N_{PR}^{0,33}.\frac{k}{De}$ $= 0,37.(1009,979)^{0,67}.(0,963)^{0,33}.\frac{0,0279}{0,0042}$ $= 252,0915 W/m^2.^oK$	$9'.\ h_C = 0,37\ x\ N_{Re}^{0,67}\ x\ N_{PR}^{0,33}.\frac{k}{De}$ $= 0,37.(359,826)^{0,67}.(4,5021)^{0,33}.\frac{0,6157}{0,0042}$ $= 4635,4503 W/m^2.^oK$

$$10.\ U_C = \left(\frac{1}{h_h} + \frac{\delta}{k} + \frac{1}{h_C}\right)^{-1}$$

$$= \left(\frac{1}{252,0915} + \frac{0,0005}{8000} + \frac{1}{4635,4503}\right)^{-1} = 239,0855\ W/m^2.^\circ K$$

$$11.\ U_D = \frac{708.523,0491\ W}{117.0,35 m^2.87,6471 K} = 70,125 W/m^2.^\circ K \quad (U_D \text{ terkoreksi})$$

12. Rd = $1/U_D - 1/U_C = (1/239,0855) - (1/70,125) = 0.0097 > 0,003$

(memenuhi syarat perpindahan panas)

Fluida panas (*saturated steam* 130°C)	Fluida dingin (susu segar 4°C)
1. Re = 1009,9789	1'. Re = 352,0600
2. $f = \frac{2,5}{Re^{0,3}} = \frac{2,5}{1009,9789^{0,3}} = 0.3138$	2'. $f = \frac{2,5}{Re^{0,3}} = \frac{2,5}{352,06^{0,3}} = 0,4305$
3. $\Delta P_h = \frac{2.f.G^2.L}{\rho.De}$ $= \frac{2.0,3138.(3,4258)^2.0,771}{0,5524.0,0042}$ $= 2469,2148 N/m^2 = 0,3451 psia$	3'. $\Delta P_C = \frac{2.f.G^2.L}{\rho.De}$ $= \frac{2.0,4305.(60,4646)^2.0,771}{1012,552.0,0042}$ $= 551,0924 N/m^2 = 0,0814 psia$
4. $G' = \frac{M}{\frac{\pi}{4}.Dp^2} = \frac{0,4403 kg/s}{\frac{\pi}{4}.(0,075m)^2}$ $= 99,7111 kg/m^2.s$	4'. $G' = \frac{M}{\frac{\pi}{4}.Dp^2} = \frac{7,771 kg/s}{\frac{\pi}{4}.(0,075m)^2} = 1759.8663$
5. $Re = \frac{D_p.G'}{\mu} = \frac{0,075.99,7711 kg/m^2.s}{1,41.10^{-5} kg/m.s}$ $= 529252,1444$	5'. $Re = \frac{D_p.G'}{\mu} = \frac{0,075.1759,8863}{0,0007}$ $= 188557,1085$
6. $f = \frac{2,5}{Re^{0,33}} = \frac{2,5}{529252,1444^{0,3}} = 0,0480$	6'. $f = \frac{2,5}{Re^{0,3}} = \frac{2,5}{188557,1085^{0,3}} = 0,0654$
7. $\Delta P_p = \frac{2.f.G'^2.L}{\rho.D_p}$ $= \frac{2.0,0480.(99,7711)^2.277.0,0032}{1,41.10^{-5}0.0,075}$ $= 4492,8627 N/m^2 = 0,6516 psia$	7'. $\Delta P_p = \frac{2.f.G'^2.L}{\rho.D_p}$ $= \frac{2.0,0654.(1759,8663)^2.277.0,0032}{1012,552.0,075}$ $= 1023,5737 N/m^2 = 0,1511 psia$
8. $\Delta P_T = \Delta P_h + \Delta P_p$ $= 0,3513 + 0,6515 = 0,9967$ psia	8'. $\Delta P_T = \Delta P_C + \Delta P_p$ $= 0,0814 + 0,1511 = 0,2325$ psia

Ringkasan perhitungan

	Fluida panas (saturated steam)	Fluida dingin (susu segar)
h, W/m^2.°K	252,0915	4635,4503
ΔP *calculated*, psia	0,9967	0,2325
U_C, W/m^2.°K	239,0855	
U_D, W/m^2.°K	70,125	
Rd *calculated*, m^2.°K/W	0,003	

Spesifikasi :

Tebal bahan plat, δ : 0,0005 m

HPCD : 0,26 m

VPCD : 1,04 m

Port nozzle, D : 0,075 m

Compressed pitch : 0,0032 m/plate.

projected area, A_p : 0,27 m^2

developed area, A_d : 0,35 m^2

Jumlah plat, n : 277

Bahan konstruksi : stainless steel

Tipe : gasket

Jenis plate : *HM*

5. ***Centrifugal Separator* (H-140)**

Fungsi : Memisahkan lemak susu dari susu

Tipe : Disk

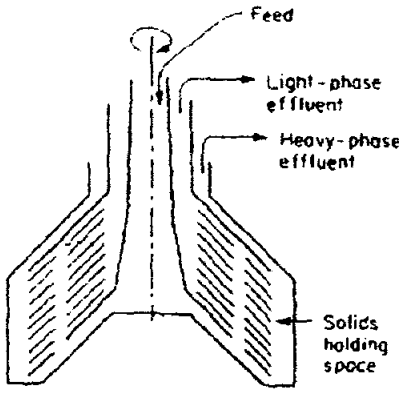
Dasar pemilihan : Dapat digunakan untuk memisahkan lemak susu dari cairan susu; sehingga didapatkan susu skim dan lemak susu.

Kondisi operasi : 50°C

Sistem operasi : Kontinyu

Jumlah : 1 buah

Gambar :



Perhitungan :

Rate susu masuk = 671.406,6098 kg/jhari

ρ susu 50°C = 1016,01 kg/m^3

Waktu operasi = 24 jam

Kapasitas $= \dfrac{671.406,6097\, kg/hari}{1016,01\, kg/m^3} = 660,8270\, m^3/hari$

$$= 660,8270 \frac{m^3}{hari} \cdot \frac{hari}{24\, jam} \cdot \frac{1\, jam}{60\, menit} \cdot \frac{264,17\, gallon}{1\, m^3}$$

= 121,23 gallon/menit

Dipilih centrifuge dengan spesifikasi sebagai berikut [23, tabel 18-12]:

Tipe	: Disk
Bowl diameter, in	: 24
Speed, rpm	: 4.000
Mak. Centrifugal x gravity	: 5.500
Kapasitas	: liquid 20-200 gpm
Power	: 5 Hp

6. Tangki Penampungan Lemak Akhir

Fungsi : Menampung lemak susu setelah dipisahkan dengan menggunakan *centrifugal separator*

Tipe : Silinder tegak dengan tutup atas berbentuk plat datar dan tutup bawah berbentuk *dished head.*

Dasar pemilihan : Untuk menampung bahan yang berbentuk cair.

Kondisi operasi :

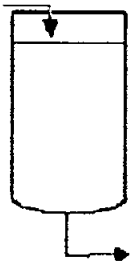
- T = 30°C
- Tekanan 1 atm
- Waktu tinggal 24 jam

Sistem operasi : *Batch*

Jumlah : 1 buah

Gambar :

Lemak susu (dari *centrifugal separator*)



Lemak susu (untuk dijual)

Perhitungan :

Rate larutan masuk : $25.661.1606\ ^{kg}/_{hari} = 1.069{,}215\ ^{kg}/_{jam}$

ρ susu (30°C) : $915\ ^{kg}/_{m^3} = 57{,}1246\ ^{lbm}/_{ft^3}$ [5]

waktu tinggal : 1 hari = 24 jam

volume larutan total : $\frac{25.661{,}1606\ kg/hari}{915\ kg/m^3}.1\,hari = 28{,}045\ m^3 = 990{,}3525\ ft^3$

Diambil : tinggi tangki (H_t) = 1,5 . Diameter tangki (D_t)

Volume shell = $(\pi/4).D_t^{\,2}.H_t = (\pi/4).D_t^2.1{,}5.D_t = (\pi/4).1{,}5.D_t^3$

Volume torispherical dished head (ft^3) = 0,000049 x D_t^3 (in)

[22, pers 5.11, hal 88]

Volume tangki penampung = volume shell + volume *dished head*

Diambil : volume tangki penampung = 1,3 . volume larutan total

Volume tangki = volume cylindrical shell + volume dished head

$$1{,}3\times 990{,}3525\,ft^3 = (\pi/4)\times D_t^2 \times H_t + 0{,}000049\times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$1.287{,}4583\,ft^3 = (\pi/4)\times\left(\frac{H_t}{1{,}5}\right)^2 \times H_t + 4{,}9.10^{-5}\times\left(\frac{H_t}{1{,}5}\right)^3 \times\left(\frac{1\,ft}{12\,in}\right)^3$$

$$1.287{,}4583\,ft^3 = 0{,}3491\,H_t^3$$

$$H_t = 15{,}45\,ft$$

Digunakan 2 course 8 ft, sehingga $H_t \approx 16$ ft

Volume tangki = volume cylindrical shell + volume dished head

$$1{,}3\times 990{,}3525\,ft^3 = (\pi/4)\times D_t^2 \times H_t + 0{,}000049\times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$1.287{,}4583\,ft^3 = (\pi/4)\times D_t^2 \times\left(\frac{1\,ft}{12\,in}\right)^2 \times 16\,ft + 0.000049\times D_t^3 \times\left(\frac{1\,ft}{12\,in}\right)^3$$

$$1.287{,}4583\,ft^3 = 0{,}0873\times D_t^2 + 2{,}8356\times 10^{-8} D_t^3$$

$$D_t = 121{,}437\ in = 10{,}1196\,ft$$

Volume larutan dalam dish = 0,000049 . D^3

$= 0{,}000049 \,.\, (121{,}437 \text{ in})^3$

$= 87{,}7504 \text{ ft}^3$

Volume larutan dalam shell = vol. lart. total – vol. lart. dalam dish

$= 990{,}3525 \text{ ft}^3 - 87{,}7504 \text{ ft}^3$

$= 902{,}6021 \text{ ft}^3$

Tinggi lart dalam shell (H_L) $= \dfrac{vol\ lart\ dlm\ shell}{\frac{\pi}{4}.D_t^2}$

$= \dfrac{902{,}6021 ft^3}{\frac{\pi}{4}.(10{,}1196 ft)^2}$

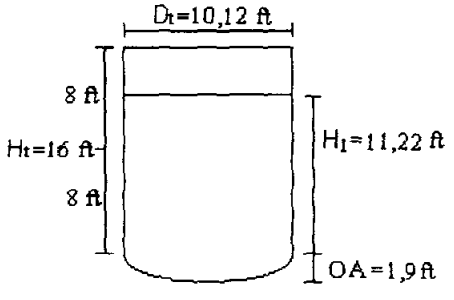
$= 11{,}22$ ft

P operasi = P hidrostatis $= \left(\dfrac{\rho \times H_L}{144}\right)$ psi

$= \left(\dfrac{57{,}1246 \, lbm/ft^3 \times 11{,}2222 ft}{144}\right)$

$= 4{,}4518$ psi

P desain = 1,5 x P operasi = 1,5 x 4,4518 psi = 6,6778 psi



Tebal *Shell*

Menghitung tebal shell untuk course 1 (8 ft dari dasar):

$$t_s = \frac{P.D_t}{2.f.E} + c$$ [22, pers 3.16]

dimana :

P = P desain = 6,6778 psi

D_t = 121,437 in

Konstruksi : Bahan konstruksi = *Stainless steel-316L*, dengan

f = Strees maksimum yang diijinkan = 23.000 psi

Tipe sambungan = *Double-welded butt joint*, dengan

E = *Welded-joint efficiency* = 0,8

[22, Tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_s = \frac{(6,6778\ psi)\times(121,437\ in)}{2\times(23.000\ psi)\times(0,8)} + 0,125\ in$$

= 0,1470 in ≈ $\frac{3}{16}$ in

Menghitung tebal shell untuk course 2 (8 hingga 16 ft dari dasar):

H_L = 11,2222 ft - 8 ft = 3,2222 ft

$$P_{hidrostatis} = \frac{H_L \times \rho\ lemak}{144}$$

$$= \frac{3,2222\ ft \times 57,1246\ lbm/ft^3}{144}$$

= 1,2782 psi

P_{design} = 1,5 x $P_{hidrostatis}$

= 1,5 x 1,2782 psi

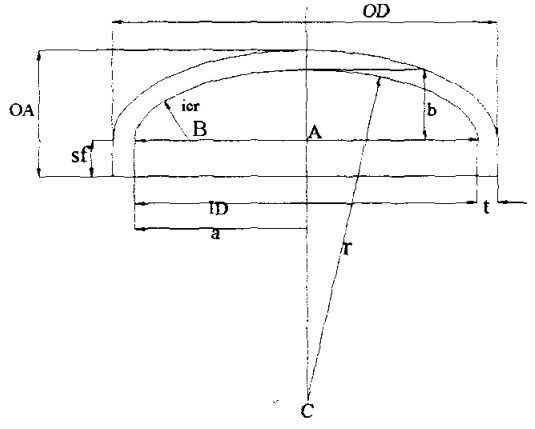
= 1,9174 psi

Tebal shell (t_s) $= \frac{P_{design} \times D_t}{2 \times f \times E} + c$

$= \frac{(1{,}9174\ psi) \times (121{,}437\ in)}{2 \times (23.000\ psi) \times (0{,}8)} + 0{,}125\ in$

= 0,1313 in. ≈ 3/16 in.

Tebal *dished head*



r (*crown radius / radius of dish*) = 121,437 in

icr (*inside corner radius / knuckle radius*) = 6% x 121,437 in = 7,2862 in

$W = \frac{1}{4} \times \left[3 + \sqrt{\frac{r}{icr}}\right]$ [22, pers 7,76]

$= \frac{1}{4} \times \left[3 + \sqrt{\frac{121{,}437}{7{,}2862}}\right]$

= 1,7706

$$a = \frac{D_t}{2} = \frac{121,437\ in}{2} = 60,7185\ in$$

$$AB = \frac{D_t}{2} - icr = \frac{121,437\ in}{2} - 7,2862 in = 53,4323\ in$$

BC = r – icr = (121,437-7,2862) in = 114,1508 in

$$b = r - \sqrt{BC^2 - AB^2} = 121,437 - \sqrt{114,1508^2 - 53,4323^2} = 20,5638\ in$$

$$t_d = \frac{P \times r \times W}{2 \times f \times E - 0,2 \times P} + c$$ [22, pers 7.77, hal138]

dimana :

P = P desain = 6,6778 psi

Konstruksi : Bahan konstruksi = *Stainless steel-316 L*, dengan

f = stress maksimum yang diijinkan = 23.000 psi

Tipe sambungan = double-welded butt joint, dengan

E = welded-joint efficiency = 0,8

[22, tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_d = \frac{(6,6778\ psi) \times (121,437\ in) \times 1,7706}{(2 \times 23.000\ psi \times 0,8) - (0,2 \times 6,6778)} + 0,125 in$$

$$= 0,164 \approx 3/16 \text{ in}$$

Dipilih panjang straight-flange (sf) = 2 in [22, tabel 5.8, p.93]

OA = t_d + b + sf

= ($3/16$ + 20,5638 + 2) in

= 22,7513 in = 1,8959 ft ≈ 1,9 ft

Tinggi tangki keseluruhan = tinggi shell + tinggi dish

= 16 ft + 2 ft

= 18 ft

Tebal plat datar (t_f) = 3/16 in.

Spesifikasi :

Tangki

Kapasitas : 990,3525 ft^3

Diameter : 10,1196 ft

Tinggi tutup bawah (dished head): 2 ft

Tinggi shell : 16 ft

Tinggi tangki total : 18 ft

Tebal *shell course* 1 : 0,1470 in $\approx \frac{3}{16}$ in

Tebal *shell course* 2 : 0,1313 in $\approx \frac{3}{16}$ in

Tebal tutup bawah (dished head) : 0,164 in $\approx \frac{3}{16}$ in

Bahan konstruksi : *Stainless steel-316 L*

Jumlah tangki : 1 buah

7. Tangki Penampungan (F-150)

Fungsi : Menjaga kontinuitas aliran susu skim dari *centrifugal separator* ke membran

Tipe : Silinder tegak dengan tutup atas berbentuk plat datar dan tutup bawah berbentuk *dished head.*

Dasar pemilihan : Untuk menampung bahan yang berbentuk cair.

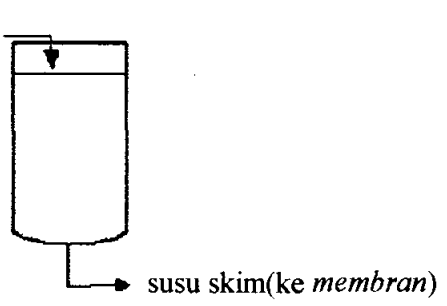
Kondisi operasi :

- T = 30°C
- Tekanan 1 atm
- Waktu tinggal 4 jam

Sistem operasi : *Batch*

Jumlah : 1 buah

Gambar :



Perhitungan :

Rate larutan masuk : $26.906,0604\ ^{kg}/_{jam}$

ρ susu (30°C) : $1033.7 - 0.2308T - 0.00246\ T^2$

$$1016,01\ ^{kg}/_{m^3} = 63,3886\ ^{lbm}/_{ft^3}$$

waktu tinggal : 4 jam

volume larutan total :

$$\frac{26.906,0604\ ^{kg}/_{jam}}{1061,01\ ^{kg}/_{m^3}} .4\ jam = 101,4366\ m^3 = 3700,7934\ ft^3$$

Diambil : tinggi tangki (H_t) = 1,5 . Diameter tangki (D_t)

Volume shell = $(\pi/4).D_t^2.H_t = (\pi/4).D_t^2.1{,}5.D_t = (\pi/4).1{,}5.D_t^3$

Volume torispherical dished head (ft^3) = 0,000049 x D_t^3 (in)

[22, pers 5.11, hal 88]

Volume tangki penampung = volume shell + volume *dished head*

Diambil : volume tangki penampung = 1,3 . volume larutan total

Volume tangki = volume cylindrical shell + volume dished head

$$1{,}3 \times 3700{,}7934\, ft^3 = (\pi/4) \times D_t^2 \times H_t + 0{,}000049 \times D_t^3 \times \left(\frac{1\, ft}{12\, in}\right)^3$$

$$4.811{,}0314\, ft^3 = (\pi/4) \times \left(\frac{H_t}{1{,}5}\right)^2 \times H_t + 4{,}9.10^{-5} \times \left(\frac{H_t}{1{,}5}\right)^3 \times \left(\frac{1\, ft}{12\, in}\right)^3$$

$$4.811{,}0314\, ft^3 = 0{,}3491 H_t^3$$

$$H_t = 23{,}9752\, ft$$

Digunakan 3 course 8 ft, sehingga $H_t \approx 24$ ft

Volume tangki = volume cylindrical shell + volume dished head

$$1{,}3 \times 3.700{,}7934\, ft^3 = (\pi/4) \times D_t^2 \times H_t + 0{,}000049 \times D_t^3 \times \left(\frac{1\, ft}{12\, in}\right)^3$$

$$4.811{,}0314\, ft^3 = (\pi/4) \times D_t^2 \times \left(\frac{1\, ft}{12\, in}\right)^2 \times 24\, ft + 0{,}000049 \times D_t^3 \times \left(\frac{1\, ft}{12\, in}\right)^3$$

$$4.811{,}0314\, ft^3 = 0{,}1309 \times D_t^2 + 2{,}8356 \times 10^{-8} D_t^3$$

$$D_t = 191{,}7081\, in = 15{,}9716\, ft$$

Volume larutan dalam dish = 0,000049 . D^3

= 0,000049 . (191,7081 in)^3

= 345,2371 ft^3

Volume larutan dalam shell = vol. lart. total – vol. lart. dalam dish

$= 3.700{,}7934\ ft^3 - 345{,}2371\ ft^3$

$= 3.355{,}5563\ ft^3$

Tinggi lart. dalam shell (H_L) $= \dfrac{vol.lart.dlm.shell}{\frac{\pi}{4}.D_t^2}$

$= \dfrac{3.355{,}5563 ft^3}{\frac{\pi}{4}.(15{,}9716 ft)^2}$

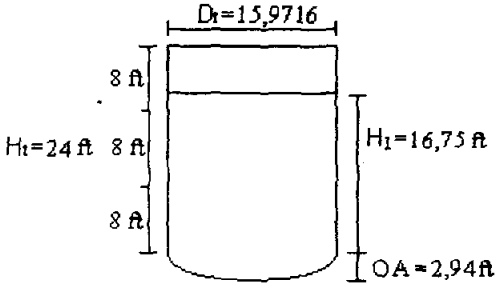
$= 16{,}75$ ft

P operasi = P hidrostatis $= \left(\dfrac{\rho \times H_L}{144}\right)$ psi

$= \left(\dfrac{63{,}3886\ ^{lbm}/_{ft^3} \times 16{,}7486 ft}{144}\right)$

$= 7{,}3727$ psi

P desain = 1,5 x P operasi = 1,5 x 7,3727 psi = 11,0591 psi



Tebal *Shell*

Menghitung tebal shell untuk course 1 (8 ft dari dasar):

$$t_s = \frac{P.D_t}{2.f.E} + c$$ [22, pers 3.16]

dimana :

P = P desain = 11,0591 psi

D_t = 191,7081 in

Konstruksi : Bahan konstruksi = *Stainless steel-316L*, dengan

F = strees maksimum yang diijinkan = 23.000 psi

Tipe sambungan = D*ouble-welded butt joint*, dengan

E = *Welded-joint efficiency* = 0,8

[22, Tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_s = \frac{(11{,}0591\,psi)\times(191{,}7081\,in)}{2\times(23.000\times 0{,}8)} + 0{,}125\,in$$

= 0,1826 in ≈ $3/16$ in

Menghitung tebal shell untuk course 2 (8 hingga 16 ft dari dasar):

H_L = 16,7486 ft - 8 ft = 8,7486 ft

$$P_{hidrostatis} = \frac{H_L \text{ x } \rho \text{ peppermint oil}}{144}$$

$$= \frac{8.7486\,ft \times 63{,}3886\,lbm/ft^3}{144}$$

= 3,8511 psi

P_{design} = 1,5 x $P_{hidrostatis}$

1,5 x 3,8511psi

= 5,7767 psi

$$\text{Tebal shell } (t_s) = \frac{P_{design} \times D_t}{2 \times f \times E} + c$$

$$= \frac{5,7767 \text{ psi} \times 191,7081 \text{ in.}}{2 \times 23.000 \text{ psi} \times 0,8} + 0,125 \text{ in.}$$

$$= 0,1551 \text{ in.} \approx 3/16 \text{ in.}$$

Menghitung tebal shell untuk course 3 (16 hingga 24 ft dari dasar):

$H_L = 16,7486 \text{ ft} - 16 \text{ ft} = 0,7486 \text{ ft}$

$$P_{hidrostatis} = \frac{H_L \times \rho \text{ peppermint oil}}{144}$$

$$= \frac{0,7486 \, ft \times 63,3886 \, lbm/ft^3}{144}$$

$$= 0,3295 \text{ psi}$$

$$P_{design} = 1,5 \times P_{hidrostatis}$$

$$= 1,5 \times 0,3295 \text{ psi}$$

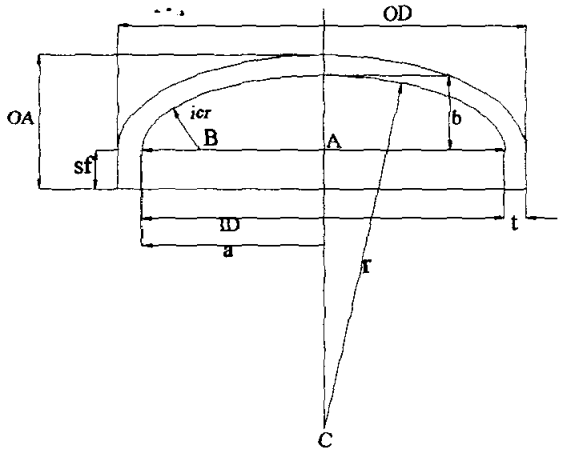
$$= 0,5 \text{ psi}$$

$$\text{Tebal shell } (t_s) = \frac{P_{design} \times D_t}{2 \times f \times E} + c$$

$$= \frac{0,5 \text{ psi} \times 191,7081 \text{ in.}}{2 \times 23.000 \text{ psi} \times 0,8} + 0,125 \text{ in.}$$

$$= 0,1276 \text{ in.} \approx 3/16 \text{ in.}$$

Tebal *dished head*



r (*crown radius / radius of dish*) = 191,7081 in

icr (*inside corner radius / knuckle radius*) = 6% x 191,7081 in = 11,5025 in

$$W = \frac{1}{4}\times\left[3+\sqrt{\frac{r}{icr}}\right] \qquad \text{[22, pers 7,76]}$$

$$= \frac{1}{4}\times\left[3+\sqrt{\frac{191,7081}{11,5025}}\right]$$

$$= 1,7706$$

$$a = \frac{D_t}{2} = \frac{191,7081\,in}{2} = 95,8541in$$

$$AB = \frac{D_t}{2} - icr = \frac{191,7081in}{2} - 11,5025in = 84,3516\,in$$

BC = r – icr = (191,7081-11,5025) in = 180,2056 in

$$b = r - \sqrt{BC^2 - AB^2} = 191,7081 - \sqrt{180,2056^2 - 84,3516^2} = 32,4634\,in$$

$$t_d = \frac{P \times r \times W}{2 \times f \times E - 0{,}2 \times P} + c$$ [22, pers 7.77, p.138)

dimana :

P = P desain = 11,0591 psi

Konstruksi : Bahan konstruksi = *Stainless steel-316 L*, dengan

f = stress maksimum yang diijinkan = 23.000 psi

Tipe sambungan = *Double-welded butt joint*, dengan

E = *Welded-joint efficiency* = 0,8

[22, tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_d = \frac{(11{,}0591\,psi) \times (191{,}7081\,in) \times 1{,}7706}{2 \times ((23.000\,psi) \times 0{,}8) - (0{,}2 \times 11{,}1874\,psi)} + 0{,}125\,in$$

$= 0{,}2270 \text{ in} \approx \frac{1}{4} \text{ in}$

Dipilih panjang straight-flange (sf) = 2,5 in [22, tabel 5.8, hal 93]

OA $= t_d + b + sf$

$= (\frac{5}{16} + 32{,}4634 + 2{,}5) \text{ in}$

$= 35{,}2759 \text{ in} = 2{,}9397 \text{ ft} \approx 2{,}94 \text{ ft}$

Tinggi tangki keseluruhan = tinggi shell + tinggi dish

= 24 ft + 2,94 ft

= 26,94 ft

Tebal plat datar (t_f) = 3/16 in.

Spesifikasi :

Tangki

Kapasitas : 3700,7934 ft^3

Diameter : 191,7081 in = 15,9716 ft

Tinggi tutup bawah (dished head): 2,94 ft

Tinggi shell : 24 ft

Tinggi tangki total : 26,94 ft

Tebal *shell course* 1 : 0,1826 in $\approx \frac{3}{16}$ in

Tebal *shell course* 2 : 0,1551 in $\approx \frac{3}{16}$ in

Tebal *shell course* 3 : 0,1276 in $\approx \frac{3}{16}$ in

Tebal tutup bawah (dished head) : 0,2270 in $\approx \frac{1}{4}$ in

Bahan konstruksi : *Stainless steel-316 L*

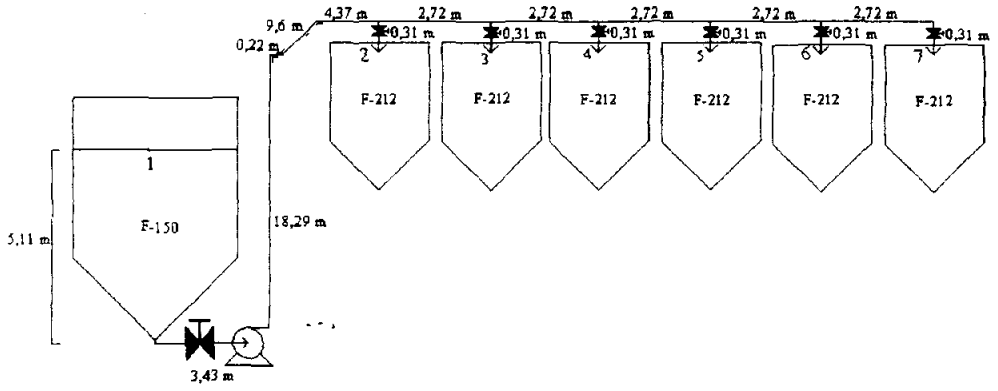
Jumlah tangki : 1 buah

8. Pompa (L-151)

Fungsi : Mengalirkan susu skim dari tangki penampungan (F-150) ke tangki *batch ultrafiltrasi.*

Tipe : *Centrifugal pump*

Jumlah pompa : 4 buah (dari tangki F-150 ada 4 buah pompa yang disusun secara paralel yang mengalirkan susu skim ke 6 tangki F-212)



Perhitungan :

T = 30°C

Massa susu yang harus dipindahkan :

$$\frac{645.745,4491 \text{ kg/hari}}{4 \text{ aliran} \times 7 \text{ batch}/\text{hari}} = 23.062,3375 kg$$

ρ susu : 1033,7- 0,2308T – 0,00246 T^2

: 1.024,56 kg/m^3 = 63,9645 lbm/ft^3

Viskositas : 0,0008 kg/m.s = 0,0005 lb/ft.s

Massa susu 23.062,3375 kg harus dipindahkan dalam waktu 5 menit, maka:

$$\text{Rate volumetrik} = \frac{23.062,3375 kg}{1.024,56 kg/m^3 \times 10 menit} = 2,251 m^3/menit = 1,3248 ft^3/s$$

Optimum inside diameter (Di,opt) dengan asumsi jenis aliran turbulen

$$Di,opt = 3,9\ q_f^{0,45}\ \rho^{0,13}$$ [28, pers 45, hal 381]

dimana : q_f = flow rate, ft^3/s

ρ = densitas fluida, lb/ft^3

Di,opt = 3,9 $(1,3248)^{0,45}$ $(63,9645)^{0,13}$ = 7,56 inch ≈ 7,981 inch.

Digunakan pipa berukuran 8 inch, sch.40 [20, App.A-5]

ID = 7,625 inch = 0,6354 ft = 0,1937 m

A = 0,3474 ft^2

Kecepatan linier (v_1) = $\frac{q_f}{A} = \frac{1{,}3248\ ft^3/s}{0{,}3474\ ft^2}$ = 3,8135 ft/s = 1,1624 m/s

$$N_{Re} = \frac{\rho \times v_1 \times ID}{\mu}$$

$$= \frac{(63{,}9645\ lb/ft^3)(3{,}8135\ ft/s)(0{,}6354\ ft)}{0{,}0005\ lb/ft.s}$$

=309.986,4221 (turbulen) (asumsi benar)

Digunakan commercial steel : $\varepsilon = 4{,}6.10^{-5}$ m

$$\text{harga } \frac{\varepsilon}{ID} = \frac{4{,}6.10^{-5}}{0{,}1937} = 0{,}0002$$

f = 0,0045 [20, Fig.2.10-3]

$m_1 = \frac{23.062{,}3375\ kg}{5\ menit}$ = 76,8745 kg/s

Untuk aliran setelah percabangan:

$m_2 = m_3 = m_4 = m_5 = m_6 = m_7 = m = \frac{76{,}8745 kg/s}{6} = 12{,}8124$ kg/s

$v_2 = v_3 = v_4 = v_5 = v_6 = v_7 = v =$

$$v = \frac{massa\ susu}{\rho \times A} = \frac{12{,}8124\ kg/s}{1024{,}56\ kg/m^3 \times 0{,}0323 m^2} = 0{,}3872\ m/s$$

$$N_{Re} = \frac{\rho \times v \times ID}{\mu}$$

$$= \frac{1024{,}56 kg/m^3 \times 0{,}3872 m/s \times 0{,}1937 m}{0{,}0008 kg/m.s}$$

$$= 96.053{,}3197 (turbulen)$$

$Z_2 = Z_3 = Z_4 = Z_5 = Z_6 = Z_7 = 12{,}8784$ m

$p_2 = p_3 = p_4 = p_5 = p_6 = p_7 = 1$ atm$= 101.325$ N/m^2

$\alpha = 1$ (aliran turbulen)

Panjang ekivalen :

- Menghitung $\sum F_1$ (dari tangki F-150 ke percabangan 1)

  - 4 buah standard elbow 90°; $K_f = 0{,}75$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 0{,}75 \times \frac{1{,}1624^2}{2} = 0{,}5067 \, m^2/s^2$$

  Karena ada 4 buah maka = 0,5067 m^2/s^2 x 4 = 2,0268 m^2/s^2

  - 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{1{,}1624^2}{2} = 4{,}0535 \, m^2/s^2$$

  - panjang pipa lurus = 3,43 m + 18,29 m + 0,22 m + 9,6 m + 4,37 m

  = 35,91 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}007 \times \frac{35{,}91}{0{,}115} \times \frac{1{,}1624^2}{2} = 5{,}9069 \, m^2/s^2$$

[20, pers.2.10-6]

  - Friksi *sudden contraction* dari tangki ke pipa

$$h_c = 0{,}55 \times \left(1 - \frac{A_2}{A_1}\right) \times \frac{v_2^2}{2\alpha} = 0{,}55 \times (1 - 0) \times \frac{1{,}1624^2}{2} = 0{,}3716 \, m^2/s^2$$

Karena luas area tangki (A_1) >>> dari pada luas area pipa (A_2), maka

$$\frac{A_2}{A_1} \approx 0$$

- Friksi *tee*

$$h_f = K_f \times \frac{v^2}{2} = 1 \times \frac{1,1624^2}{2} = 0,6756 \ {}^{m^2}/_{s^2}$$

$$\Sigma F_1 = 2,0268 + 4,0535 + 5,9069 + 0,3716 + 0,6756 = 13,0344 \ {}^{m^2}/_{s^2}$$

- Menghitung $\sum F_2$ (dari percabangan 1 tangki F-212)

- 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0,3872^2}{2} = 0,4498 \ {}^{m^2}/_{s^2}$$

- Panjang pipa lurus = 0,31 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0,007 \times \frac{0,31}{0,115} \times \frac{0,3872^2}{2} = 0,0057 \ {}^{m^2}/_{s^2}$$

[20, pers.2.10-6]

$$\Sigma F_2 = 0,4498 + 0,0057 = 0,4555 \ {}^{m^2}/_{s^2}$$

- Menghitung $\sum F_3$ (dari tangki percabangan 1 tangki F-212)

- 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0{,}3872^2}{2} = 0{,}4498 \; {}^{m^2}/_{s^2}$$

- Friksi *tee*

$$h_f = K_f \times \frac{v^2}{2} = 1 \times \frac{0{,}3872^2}{2} = 0{,}075 \; {}^{m^2}/_{s^2}$$

- Panjang pipa lurus = 2,72 m + 0,31 m = 3,03 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}007 \times \frac{3{,}03}{0{,}115} \times \frac{0{,}3872^2}{2} = 0{,}055 {}^{m^2}/_{s^2}$$

[20, pers.2.10-6]

- $\Sigma F_3 = 0{,}4498 + 0{,}075 + 0{,}055 = 0{,}5798 {}^{m^2}/_{s^2}$

- Menghitung $\sum F_4$ (dari tangki percabangan 2 tangki F-212)

- 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0{,}3872^2}{2} = 0{,}4498 \; {}^{m^2}/_{s^2}$$

- Friksi *tee*

$$h_f = K_f \times \frac{v^2}{2} = 1 \times \frac{0{,}3872^2}{2} = 0{,}075 \; {}^{m^2}/_{s^2}$$

- Panjang pipa lurus = 2,72 m + 0,31 m = 3,03 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}007 \times \frac{3{,}03}{0{,}115} \times \frac{0{,}3872^2}{2} = 0{,}055 \, m^2/s^2$$

[20, pers.2.10-6]

- $\Sigma F_4 = 0{,}4498 + 0{,}075 + 0{,}055 = 0{,}5798 \, m^2/s^2$

- Menghitung $\sum F_5$ (dari tangki percabangan 3 tangki F-212)

- 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0{,}3872^2}{2} = 0{,}4498 \, m^2/s^2$$

- Friksi *tee*

$$h_f = K_f \times \frac{v^2}{2} = 1 \times \frac{0{,}3872^2}{2} = 0{,}075 \, m^2/s^2$$

- Panjang pipa lurus = 2,72 m + 0,31 m = 3,03 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}007 \times \frac{3{,}03}{0{,}115} \times \frac{0{,}3872^2}{2} = 0{,}055 \, m^2/s^2$$

[20, pers.2.10-6]

$$\Sigma F_5 = 0{,}4498 + 0{,}075 + 0{,}055 = 0{,}5798 \, m^2/s^2$$

- Menghitung $\sum F_6$ (dari tangki percabangan 4 tangki F-212)

  - 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0{,}3872^2}{2} = 0{,}4498 \; m^2/s^2$$

  - Friksi *tee*

$$h_f = K_f \times \frac{v^2}{2} = 1 \times \frac{0{,}3872^2}{2} = 0{,}075 \; m^2/s^2$$

  - Panjang pipa lurus = 2,72 m + 0,31 m = 3,03 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}007 \times \frac{3{,}03}{0{,}115} \times \frac{0{,}3872^2}{2} = 0{,}055 \; m^2/s^2$$

[20, pers.2.10-6]

$$\Sigma F_6 = 0{,}4498 + 0{,}075 + 0{,}055 = 0{,}5798 \; m^2/s^2$$

- Menghitung $\sum F_7$ (dari tangki percabangan 5 tangki F-212)

  - 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0{,}3872^2}{2} = 0{,}4498 \; m^2/s^2$$

- 1 buah standard elbow 90°; $K_f = 0,75$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 0,75 \times \frac{0,3872^2}{2} = 0,056\, m^2/s^2$$

- Panjang pipa lurus = 2,72 m + 0,31 m = 3,03 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0,007 \times \frac{3,03}{0,115} \times \frac{0,3872^2}{2} = 0,055\, m^2/s^2$$

[20, pers.2.10-6]

$$\Sigma F_3 = 0,4498 + 0,0562 + 0,05 = 0,556\, m^2/s^2$$

Persamaan Bernoulli

$$\begin{aligned} m_1(-w_s) = {} & m_2 \times \left[\frac{p_2}{\rho} + \frac{v_2^2}{2\alpha} + g \times Z_2\right] + m_3 \times \left[\frac{p_3}{\rho} + \frac{v_3^2}{2\alpha} + g \times Z_3\right] \\ & + m_4 \times \left[\frac{p_4}{\rho} + \frac{v_4^2}{2\alpha} + g \times Z_4\right] + m_5 \times \left[\frac{p_5}{\rho} + \frac{v_5^2}{2\alpha} + g \times Z_5\right] \\ & + m_6 \times \left[\frac{p_6}{\rho} + \frac{v_6^2}{2\alpha} + g \times Z_6\right] + m_7 \times \left[\frac{p_7}{\rho} + \frac{v_7^2}{2\alpha} + g \times Z_7\right] \\ & - m_1 \times \left[\frac{p_1}{\rho} + \frac{v_1^2}{2\alpha} + g \times Z_1\right] + m_1 \times \Sigma F_1 + m_2 \times \Sigma F_2 \\ & + m_3 \times \Sigma F_3 + m_4 \times \Sigma F_4 + m_5 \times \Sigma F_5 + m_6 \times \Sigma F_6 + m_7 \times \Sigma F_7 \end{aligned}$$

$$\begin{aligned} m_1(-w_s) = {} & \left(6 \times m \times \left[\frac{p}{\rho} + \frac{v^2}{2} + g \times Z\right]\right) - m_1 \times \left[\frac{p_1}{\rho} + \frac{v_1^2}{2} + g \times Z\right] + (m_1 \times \Sigma F_1) \\ & + (m \times (\Sigma F_2 + \Sigma F_3 + \Sigma F_4 + \Sigma F_5 + \Sigma F_6 + \Sigma F_7)) \end{aligned}$$

$$76{,}8745(-w_s) = \left(6 \times 12{,}8124 \times \left[\frac{101.325}{1.024{,}56} + \frac{0{,}3872^2}{2} + 9{,}8067 \times 18{,}29\right]\right) -$$

$$\left(76{,}8745 \times \left[\frac{101.325}{1.024{,}56} + \frac{1{,}1624^2}{2} + 9{,}8067 \times 5{,}2369\right]\right) + (76{,}8745 \times 13{,}0344) +$$

$$(12{,}8124 \times (0{,}4555 + 0{,}5798 + 0{,}5798 + 0{,}5798 + 0{,}5798 + 0{,}556))$$

$$-w_s = \frac{17.317{,}1639 - 150{,}9284 + 1.002{,}0129 + 48{,}5039}{76{,}8745}$$

$$-w_s = 236{,}9674\, {}^{m^2}\!/_{s^2} = 236{,}9674\, {}^{J}\!/_{kg}$$

Efisiensi pompa (η) = 70 % [28, fig 13-37, p.550]

$$W_p = -\frac{Ws}{\eta} = \frac{236{,}9674}{0{,}7} = 338{,}5249 \frac{J}{kg}$$

$$\text{Flow rate} = \frac{23.062{,}3375\, kg}{10\, menit} = 2.306{,}2338\, {}^{kg}\!/_{menit} = 38{,}4372\, {}^{kg}\!/_{s}$$

$$\text{hp pompa} = 338{,}5249\, {}^{J}\!/_{kg} \times 38{,}4372\, {}^{\text{kg}}\!/_{\text{s}} = 13{,}317 \text{ kW} = 17{,}859 \text{ hp}$$

Efisiensi motor = 88% [28, fig 14-38, p 551]

Sehingga dipakai pompa dengan motor = 17,859 hp/0,88= 20,295 hp ≈ 21 hp

Spesifikasi alat :

Fungsi : Mengalirkan susu skim untuk diolah menjadi susu cair tinggi protein

Tipe : *Centrifugal pump*

Rate aliran pompa : 2,251 m^3/menit

Ukuran pipa : 8 in sch 40

Power motor : 21 hp

Bahan konstruksi : *Stainless steel* 316-L

Jumlah pompa : 4 buah

9. Tangki penampung untuk *batch* ultrafiltrasi (F-212)

Fungsi : Penampung susu skim untuk dilakukan proses pemisahan *ultrafiltrasi.*

Tipe : Silinder tegak dengan tutup atas berbentuk plat datar dan tutup bawah berbentuk *dished head.*

Dasar pemilihan : Untuk menampung bahan yang berbentuk cair.

Kondisi operasi :

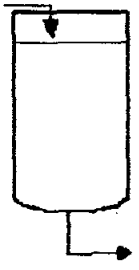
- T = 30°C
- Tekanan 1 atm
- Waktu tinggal 3 jam

Sistem operasi : *Batch*

Jumlah : 24 buah

Gambar :

Susu skim (dari tangki F-150)



susu tinggi protein

Perhitungan :

Massa susu masuk (perbatch):

$$= \frac{645.745,4491 \text{ kg/hari}}{24 \text{ tangki} \times 7\text{batch}} = 3.843,7229 \ kg$$

ρ susu (30°C) : $1033,7 - 0,2308T - 0,00246\ T^2$ [5]

$$= 1024,562 \ {}^{kg}/_{m^3} = 63,9645 \ {}^{lbm}/_{ft^3}$$

Volume larutan total : $\frac{3.843,7229 \text{ kg}}{1024,562 \ {}^{kg}/_{m^3}} = 3,7515 m^3 = 147,4857 ft^3$

Diambil : tinggi tangki (H_t) = Diameter tangki (D_t)

Volume shell = $(\pi/4).D_t^{\ 2}.H_t = (\pi/4).D_t^2.1,5.D_t = (\pi/4).1,5.D_t^3$

Volume torispherical dished head (ft^3) = 0,000049 x D_t^3 (in)

[22, pers 5.11, hal 88]

Volume tangki penampung = volume shell + volume *dished head*

Diambil : volume tangki penampung = 1,3 . volume larutan total

Volume tangki = volume cylindrical shell + volume dished head

$$1,3 \times 147,4857 ft^3 = (\pi/4) \times D_t^2 \times H_t + 0,000049 \times D_t^3 \times \left(\frac{1 ft}{12 in}\right)^3$$

$$191{,}7315\,ft^3 = (\pi/4)\times H_t^{\,2}\times H_t + 4{,}9.10^{-5}\times H_t^{\,3}\times\left(\frac{1\,ft}{12\,in}\right)^3$$

$$191{,}7315\,ft^3 = 0{,}7854\,H_t^3$$

$$H_t = 6{,}249\,ft$$

Digunakan 1 course 6 ft, sehingga $H_t \approx 6$ ft

Volume tangki = volume cylindrical shell + volume dished head

$$147{,}4857\,ft^3 = (\pi/4)\times D_t^2\times H_t + 0{,}000049\times D_t^3\times\left(\frac{1\,ft}{12\,in}\right)^3$$

$$147{,}4857\,ft^3 = (\pi/4)\times D_t^2\times\left(\frac{1\,ft}{12\,in}\right)^2\times 6\,ft + 0{,}000049\times D_t^3\times\left(\frac{1\,ft}{12\,in}\right)^3$$

$$147{,}4857\,ft^3 = 0{,}0327\times D_t^2 + 2{,}8356\times 10^{-8} D_t^3$$

$$D_t = 67{,}2575\,in = 5{,}6569\,ft$$

Volume larutan dalam dish $= 0{,}000049\ .\ D^3$

$= 0{,}000049\ .\ (67{,}2575\text{ in})^3$

$= 14{,}91\text{ ft}^3$

Volume larutan dalam shell = vol. lart. total – vol. lart. dalam dish

$= 115{,}9195\text{ ft}^3 - 14{,}91\text{ ft}^3$

$= 101{,}0095\text{ ft}^3$

Tinggi lart. dalam shell (H_L) $= \dfrac{vol.lart.dlm.shell}{\frac{\pi}{4}.D_t^2}$

$$= \frac{101{,}0095\,ft^3}{\frac{\pi}{4}.(5{,}6569\,ft)^2}$$

$= 4{,}0189$ ft

P operasi = P hidrostatis $= \left(\dfrac{\rho\times H_L}{144}\right)$ psi

$$= \left(\frac{63{,}9645\, lbm/ft^3 \times 4{,}0189\, ft}{144} \right)$$

= 1,7785 psi

P desain = 1,5 x P operasi = 1,5 x 1,7785 psi = 2,6667 psi

Tebal *Shell*

$$t_s = \frac{P.D_t}{2.f.E} + c$$ [22, pers 3.16]

dimana :

P = P desain = 2,6667 psi

D_t = 67,8833 in

Konstruksi : bahan konstruksi = *Stainless Steel-316L*, dengan

f = Strees maksimum yang diijinkan = 23.000 psi

Tipe sambungan = D*ouble-welded butt joint*, dengan

E = *Welded-joint efficiency* = 0,8

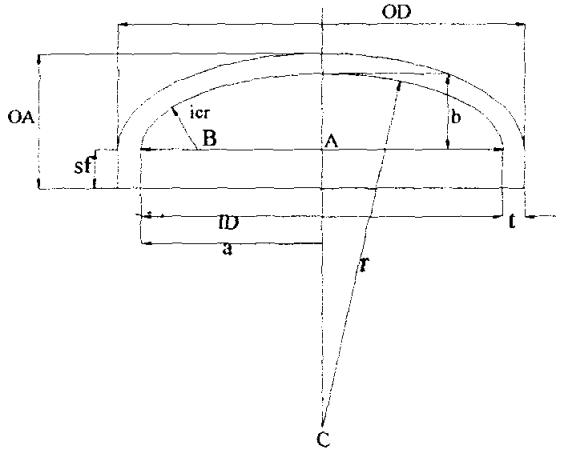
[22, Tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_s = \frac{(2{,}6667\, psi) \times (67{,}8833\, in)}{2 \times (23.000 \times 0{,}8)} + 0{,}125\, in$$

= 0,1299 in ≈ $3/16$ in

Tebal *dished head*



r (*crown radius / radius of dish*) = 67,8833 in

icr (*inside corner radius / knuckle radius*) = 6% x 67,8833 in = 4,073 in

$$W = \frac{1}{4}\times\left[3+\sqrt{\frac{r}{icr}}\right]$$ [22, pers 7,76]

$$= \frac{1}{4}\times\left[3+\sqrt{\frac{67,8833}{4,073}}\right]$$

$$= 1,7706$$

$$a = \frac{D_i}{2} = \frac{67,8833\ in}{2} = 33,9417\ in$$

$$AB = \frac{D_i}{2} - icr = \frac{67,8833\ in}{2} - 4,073 in = 29,8687\ in$$

BC = r - icr = (67,8833-4,073) in = 63,8103 in

$$b = r - \sqrt{BC^2 - AB^2} = 67,8833 - \sqrt{63,8103^2 - 29,8687^2} = 11,4952\ in$$

$$t_d = \frac{P\times r\times W}{2\cdot f\cdot E - 0,2\times P} + c$$ [22, pers 7.77, p.138]

dimana :

P = P desain = 2,6667 psi

Konstruksi : Bahan konstruksi = *Stainless Steal-316L*, dengan

f = Stress maksimum yang diijinkan = 23.000 psi

Tipe sambungan = *Double-welded butt joint*, dengan

E = *Welded-joint efficiency* = 0,8

[22, tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_d = \frac{(2{,}6667\,psi)\times(67{,}8833in)\times 1{,}7706}{2\times((23.000psi)\times 0{,}8)-(0{,}2\times 2{,}6667\,psi)} + 0{,}125in$$

$$= 0{,}1337 \text{ in} \approx \frac{3}{16} \text{ in}$$

Dipilih panjang *straight-flange* (sf) = 2 in [22, tabel 5.8, p.93]

OA = t_d + b + sf

$= (\frac{3}{16} + 11{,}4952 + 2)$ in

= 13,6827 in = 1,1419 ft

Tinggi tangki keseluruhan = tinggi *shell* + tinggi *dish*

= 6 ft + 1,1419 ft

= 7,1419 ft

Tebal plat datar (t_f) = 3/16 in.

Spesifikasi :

Tangki

Kapasitas : 115,9195 ft^3

Diameter : 5,6569 ft

Tinggi tutup bawah (dished head): 1,1419ft

Tinggi shell : 6 ft

Tinggi tangki total : 7,1419 ft

Tebal shell : 0,1299 in $\approx \frac{3}{16}$ in

Tebal tutup bawah (dished head) : 0,1337 in $\approx \frac{3}{16}$ in

Bahan konstruksi : *Stainless Steel-316L*

Jumlah tangki : 24 buah

10. Membran UF (S-210)

Fungsi : Memisahkan laktosa dan abu dari susu

Tipe : *Hollow fiber module*

Jenis membran : *polysulfone*

Dasar Pemilihan :

- *Hollow fiber module* memiliki luas area membran yang paling besar dan biaya investasi alat yang paling rendah
- *Polysulfone* memiliki range pH yang cocok digunakan untuk pemisahan laktosa dan abu dari susu

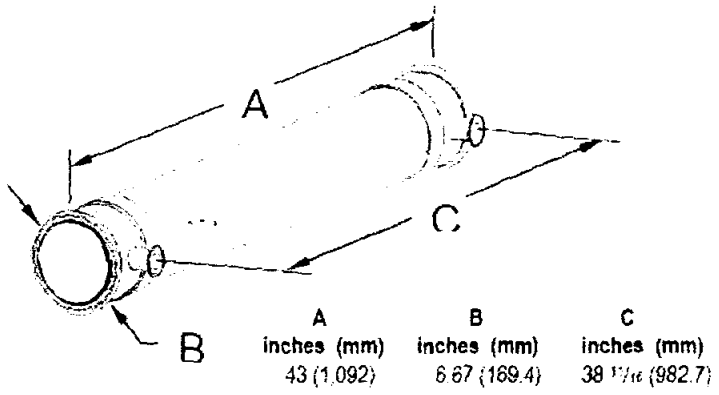
Kondisi operasi :

Laju alir total (kg/hari)	645.745,4491 kg/hari
Temperature (°C)	30

Sistem operasi : *Batch*

Jumlah : 24 *housing* @ 4 *cartridge*

Gambar cartridge [40]:



Penghitungan penentuan jumlah *module* yang digunakan

Data :

- Laju fluks rate awal [8] = 61,15 $^{liter}/_{m^2.h}$
- Laju fluks rate akhir [8] = 19,28 $^{liter}/_{m^2.h}$
- $V_{mula\text{-}mula\ tiap\ batch}$, 1 hari ada 7 *batch*

$$\frac{645.745,4492\,kg/hari}{1024,56\,kg/m^3}\frac{1\,hari}{7\,batch}=90,038\,m^3=90.038,02\,liter$$

- $V_{retentate\ tiap\ batch}$

$$\frac{111.918,7406\,kg/hari}{1024,56\,kg/m^3}\frac{1}{7\,bacth}=15,605\,m^3=15.605,13\,liter$$

- Laju fluks rata-rata,J_{avg} [14]

$$= fluks\ rate\ awal-(0,33\times(fluks\ rate\ awal-fluks\ rate\ akhir)$$

$$= 61,15\ ^{liter}/_{m^2.jam}-(0,33\times(61,15-19,28)\ ^{liter}/_{m^2.jam})$$

$$= 47,3329\ ^{liter}/_{m^2.jam}$$

- Waktu filtrasi : 3 jam (untuk tiap-tiap *housing*) [8]
- Luas permukaan total membran yang dibutuhkan [14]

$$A = \frac{V_{mula-mula} - V_{retentate}}{T \times J_{avg}}$$

$$A = \frac{90.038{,}02\,liter - 15.605{,}13\,liter}{3\,jam \times 47{,}3329\,liter/m^2.jam}$$

$$= 524{,}18\,m^2$$

Cartridge yang digunakan adalah tipe Romicon 6" memiliki luas permukaan 5,6 m^2 [8]

Jumlah *cartridge* yang digunakan adalah :

$$= \frac{524{,}18\,m^2}{5{,}6\,m^2} = 93{,}6 \approx 96 \text{ buah}$$

Tipe fiber yang digunakan adalah PM-30 [8], dengan spesifikasi :

ID = 1,1 mm

Tebal = 0,15 mm

OD = 1,4 mm

Panjang fiber = 1,09 m , jumlah fiber = 1000 buah

Perhitungan *housing*

Diameter cartdrige = 169,4 mm = 0,1694 m

Square area di sekitar *cartridge* = 0,1694m x 0,1694m = 0,0287 m^2

Luas area cartridge = π $(0{,}1694/2)^2$ = 0,0225 m^2

Hole ratio = 0,0225 m^2 / 0,0287 m^2

= 0,784

1 housing digunakan 4 buah *cartridge*

Housing area = 4 x 0,0225m^2 /(1-0,784)

= 0,417 m^2

Housing area = $\frac{\pi}{4}.ID^2$

0,417 m^2 = $\frac{\pi}{4}.ID^2$

ID = 0,729 m

Penghitungan tebal *Shell*

$$e = \frac{P_i.ID}{2f - P_i}$$

ΔP = 6 bar = 600.000 N/m^2

Pi = 1,1. 600.000 N/m^2

= 660.000

f = design stress = 1,75.10^8 N/m^2

$$e = \frac{660.000.0,729}{2.(1,75.10^8) - 660.000}$$
$$= 0,0013m = 1,377mm$$

Penghitungan tebal *head*

R_c, crown radius = ID = 0,729

R_c/R_k = 0,06

J = 0,8

$$Cs = \frac{3+\sqrt{Rc/Rk}}{4}$$

$$= \frac{3+\sqrt{0,06}}{4}$$

$$= 0,811$$

$$e = \frac{P_i . R_c . C_s}{2fJ + P_i(C_s - 0,2)}$$

$$= \frac{660.000.0,729.0,811}{2.1,75.10^8.0,8+660.000.(0,811-0,2)}$$

= 0,001392 m = 1,392 mm

Digunakan tebal yang sama untuk shell dan head, 1,392 mm

Corrosion allowance 2mm

Tebal total = tebal minimum yang dibutuhkan + *corrosion allowance*

= (1,392 + 2) = 3,392 mm

Tebal *head* yang terdekat adalah 3/16 in = 4,7625 mm

Penghitungan *Dead Weight*

a. Berat *column*

Volume silinder = 2. π. ri. L. t

= 2. 3,14. (0,729/2) m. 1,09 m. $4,7625.10^{-3}$ m

= $0,0119m^3$

Volume 2 head = 0,0809. (Do^3 - ID^3)

= 0,0809. (($0,729+2.4,7625.10^{-3}$)^3 – $0,729^3$)

= 0,00124 m^3

Volume total = 0,01314 m^3

Berat kolom = ρstainless steel . V total. g

= 7834 kg/m^3 . 0,01314m^3. 9,8 m/s^2

= 1008,800 N

b. Berat *Cartridge*

Volume tiap *cartridge* = $\frac{\pi . ID^2 . L}{4}$

= $\frac{\pi 0{,}729^2 . 1{,}09}{4}$

= 0,4547 m^3

Volume total *cartridge* = 4. 0,4547 = 1,8188 m^3

Berat *cartridge* = $\rho_{cartridge}$. V tiap cartridge. g

= 130 kg/m^3 . 1,8188 m^3. 9,8 m^2

= 2317,151 N

Total *dead weight* = 3325,951 N

Penghitungan Tekanan

a. *Internal Pressure*

$$\text{Longitudinal stress}, T_L = \frac{P_i ID}{4t}$$

$$= \frac{660.000\ N/m^2 . 0{,}729 m}{4.4{,}7625/1000\ m}$$

$$= 25{,}257\ \text{N/mm2}$$

$$\text{Circumferential stress}, T_H = \frac{P_i ID}{2t}$$

$$= \frac{660.000 N/m^2 . 0{,}729 m}{2.\ 3{,}7625/1000 m}$$

$$= 50{,}514\ \text{N/mm2}$$

b. Dead Weight Stress

$$Tw = \frac{W}{\pi.(ID+t)t}$$

$$= \frac{3325{,}951\ \text{N}}{3{,}14.(0{,}729 + 4{,}625.10^{-3}).4{,}625.10^{-3}}$$

$$= 0{,}343\ N/mm^2$$

Resultan longitudinal stress = 0,343 N/mm^2 + 25,257 N/mm^2

= 25,600 N/mm^2

c. Check Buckling

$\sigma_c = 2.10^4 . (t/Do)$

$= 2.10^4 . (4{,}7625.10^{-3} / (2.0{,}729 + 4{,}7625.10^{-3}))$

$= 65{,}117$

Resultan longitudinal stress < *critical buckling stress* (memenuhi)

Spesifikasi Module :

Jumlah module = 24 buah

Jenis module = *hollowfiber*

Jumlah cartridge/module = 4 buah

ID *chasing* = 0,729 m

Panjang *chasing* = 1,092 m

Tebal *chasing* = 4,7625 mm

Tipe fiber yang digunakan adalah PM-30, dengan spesifikasi :[8]

Jenis fiber = *polysulfone*

ID = 1,1 mm

Tebal = 0,15 mm

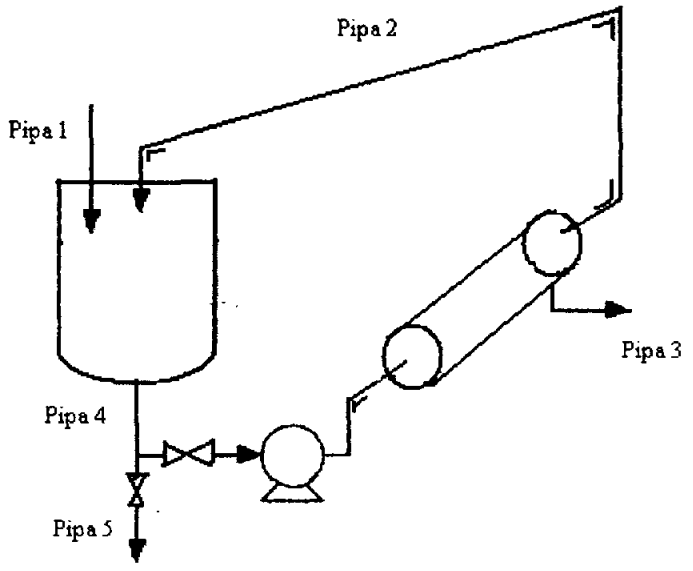
OD = 1,4 mm

Panjang fiber = 1,09 m , jumlah fiber = 1000 buah

Penghitungan Perpipaan

ρ = 1024,56 kg/m^3 [18]

μ = 0.0008 kg/m.s = 8 cp [18]



a. Pipa 2 = pipa 4

Laju susu masuk = 90038,02 *Liter / batch*

Laju pipa 2 = Volume mula-mula tiap batch/ 24 *housing*

= 90038,02 L/batch / 24 *housing*

= 3751,584 L /(batch. *housing*)

1 *batch* = 3jam

= 3751,584 L/ 3jam

= 1250,528 L/jam

qf = 0,000347 m^3/s = 0.0122 ft^3/s = 0,356 kg/s

Asumsi aliran turbulent dan Di > 1 in

Di_{opt} = 4,7 $qf^{0,49}$ $\mu^{0,14}$ [28, hal 381]

= 4,7 $0.0122^{0,49}$. $8^{0,14}$

= 0,7258 in

Dipakai diameter pipa 0,824 in, NPS=3/4 in, Sc 40. [20 App A.5-1]

Diameter pipa 0,824 in = 0,0209 m

Luas penampang pipa,A = $1/4\pi.D^2$

= ¼.3,14. $0,0209^2$

= 0,000343 m^2

Check asumsi aliran turbulent

$$N_{RE} = \frac{D.qf}{\mu.A}$$

$$= \frac{0,0209\,m.\ 0,356\,kg/s}{0,0008\,kg/m.s.0,000343\ m^2}$$

= 27.115,160

NRE> 2100, asumsi memenuhi

b. Pipa 3

Laju pipa 3 = 533.826,7086 kg/hari

1 hari = 7 *batch*

= 533.826,7086 kg/hari / 7 *batch*

= 76260,96 kg/*batch*

1 *batch* = 24 *housing*

$$= \frac{76260,96\,kg/batch}{24\,hou\sin g}$$

= 3177,539 kg/(batch. *housing*)

1 *batch* = 3 jam

$$= 3177,539\,kg/batch\,x\frac{1\,batch}{3\,jam}$$

= 1059,18 kg/jam

$$qf = \frac{1059{,}17\ kg/jam}{1024{,}56\ \frac{kg}{m^3}} \cdot \frac{1\ jam}{3600\ s}$$

$= 0{,}000287\ m^3/s = 0.0101\ ft^3/s = 0{,}294\ kg/s$

Trial aliran turbulent dan Di < 1 in

$Di_{opt} = 4{,}7\ qf^{0{,}49}\ \mu^{0{,}14}$ [28, hal 381]

$= 4{,}7\ 0.0101^{0{,}49}.\ 8^{0{,}14}$

$= 0{,}662$ in

Dipakai diameter pipa = 0,824 in, NPS = 3/4 in, Sc 40. [20 App A.5-1]

Diameter pipa 0,824 in = 0,0209 m

Luas penampang pipa,A $= 1/4\pi.D^2$

$= ¼.3{,}14.\ 0{,}0209^2$

$= 0{,}000343\ m^2$

Check asumsi aliran turbulent

$$N_{RE} = \frac{D.qf}{\mu.A}$$

$$= \frac{0{,}0209\ m.\ 0{,}294\ kg/s}{0{,}0008\ kg/m.s.0{,}000343 m^2}$$

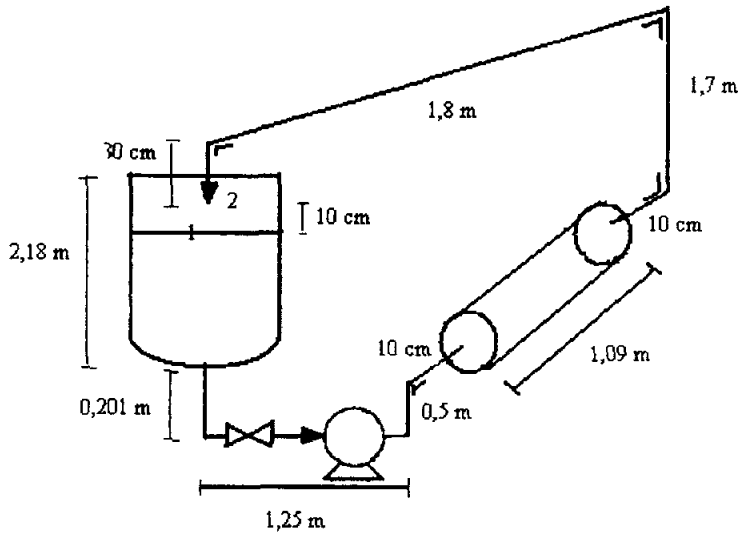
$= 22.392{,}857$

NRE> 2100, asumsi memenuhi

Spesifikasi Perpipaan

Pipa 2= pipa 3= pipa 4= pipa 5 ID=0.824 in, NPS=3/4 in, Sc 40

Penghitungan Pompa



Friksi pompa terdiri dari :

1. Sudden Contraction

$$h_c = 0{,}55.\frac{v^2}{2\alpha}$$

α untuk aliran turbulent = 1

Q,Debit = 0,000347 m^3/s

0,000347 m^3/s = 0,000343 m^2. v

v = 1,012 m/s

$$hc = 0{,}55.\frac{1{,}012^2}{2}$$

= 0,2816 m^2/s^2

2. Valve

Yang digunakan adalah globe valve, $K_f = 6$

$$h_c = 6.\frac{v^2}{2}$$

$$= 6.\frac{1{,}012^2}{2}$$

$$= 3{,}0724 \text{ m}^2/\text{s}^2$$

3. Elbow 90° sebanyak 6 buah

$$h_c = 6.K_f \frac{v^2}{2}$$

$K_f = 6$ [20 Tabel 2.10-1 hal 99]

$$= 6.0{,}75\frac{1{,}012^2}{2}$$

$$= 2{,}304 \text{ m}^2/\text{s}^2$$

4. Pipa 0,824 in (0,0209 m)

ΔL = 1,25 m + 0,5 m + 0,1 m + 0,1 m + 1,7 m + 1,8 m + 0,2 m + 0,3 m

= 5,95 m

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

$\varepsilon/D = 4{,}6.10^{-5}\text{m}/\ 0{,}0209\text{m}$

$= 0{,}022$

N_{RE} 27.115,160 dan ε/D 0,022 Fig 2.10-3 didapat f=0,016

$$F_f = 4.\ 0{,}016\ \frac{5{,}95}{0{,}0209}\frac{1{,}012^2}{2}$$

$= 9{,}332\ m^2/s^2$

5. Membran, dianggap pipa lurus dengan ID=0,729 m dan L=1,092 m

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

$\varepsilon/D = 4{,}6.10^{-5}\ m / 0{,}729\ m$

$= 0{,}0000631$

N_{RE} 27.115,160 dan ε/D 0,0000631 didapat f =0,006 [20 Fig 2.10-3]

$F_f = 4.\ 0{,}006\ \frac{1{,}092}{0{,}729}\frac{1{,}012^2}{2}$

$= 0{,}0184\ m^2/s^2$

Total friksi = $15{,}0084\ m^2/s^2$

Persamaan Bernoulli

$$\frac{1}{2\alpha}(v_2^{\ 2} - v_1^{\ 2}) + g(z_2 - z_1) + \frac{(p_2 - p_1)}{\rho} + \Sigma F + W_s = 0$$

$$\frac{1}{2}((1{,}012 m/s)^2 - 0) + 9{,}8 m/s^2 (0{,}1 m) + 0 + 15{,}0084 m^2/s^2 + W_s = 0$$

Ws = $-16{,}5004\ m^2/s^2$ = -16,5004 J/kg

Kapasitas 1250,528 L/jam = 5,51 gallon/menit

Didapat efisiensi pompa sebesar 30% [28, Fig 13-37 hal 550]

$W_s = -\eta W_p$

$-16{,}5004 = -0{,}3.\ W_p$

$W_p = 55{,}0013$ J/kg

Power pompa $= Wp.\ q_f.\ \rho_{susu}$

$= 55{,}0013$ J/kg . $0{,}000287\ m^3/s$. $1024{,}57\ kg/m^3$

= 0,01673 kW

= 0,022 Hp

Efesiensi motor = 80% [28, fig 14-38, p 521]

Sehingga dipakai pompa dengan motor = 0,022 Hp / 0,80 hp = 0,0275 hp ≈ 0,25 Hp

Spesifikasi Pompa

Tipe pompa : *Centrifugal pump*

Power pompa : 0,25 Hp

11. Tangki air diafiltrasi dan air pencucian

Fungsi : Menampung air diafiltrasi dan air pencucian sebelum digunakan

Tipe : Silinder tegak dengan tutup atas dan tutup bawah berbentuk plat datar.

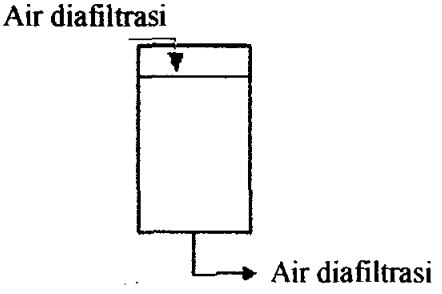
Dasar pemilihan : Untuk menampung bahan yang berbentuk cair.

Kondisi operasi :

- T = 30°C
- Tekanan 1 atm
- Waktu tinggal 24 jam
- Sistem operasi : *Batch*

Jumlah : 1 buah

Gambar :



Perhitungan :

Rate air diafiltrasi masuk : 490,8 $^{kg}/_{batch}$ = 163,6 $^{kg}/_{jam}$

ρ air (30°C) : 995,68 kg/m^3 = 62,1615 lb$_m$/ft^3 [20, app A-2]

Waktu tinggal : 1 hari = 7 batch

Volume air diafiltrasi : $\frac{490{,}8\,^{kg}/_{batch}}{995{,}68\,^{kg}/_{m^3}} . 7\,batch = 3{,}45\ m^3 = 121{,}85\ ft^3$

Volume air pencucian perhari:

- Untuk membran UF diperlukan air sebanyak 1 m^3/tangki, ada 24 tangki maka air yang dibutuhkan sebanyak 24 m^3.
- Untuk membran DF diperlukan air sebanyak 1 m^3/tangki, ada 3 tangki maka air yang dibutuhkan sebanyak 3 m^3.

Volume air total = 24 m^3 + 3 m^3 + 3,45 m^3

= 30,45 m^3 = 1.075,29 ft^3/hari

Diambil : Diameter tangki (D_t) = 1,5 x tinggi tangki (H_t)

Volume tangki penampung = volume cylindrical shell

Diambil : volume tangki penampung = 1,2 . volume larutan total

Volume tangki total= volume cylindrical shell

$$1{,}2 \times 1.075{,}29\,ft^3 = (\pi/4) \times D_t^2 \times H_t$$

$$1.290{,}35\,ft^3 = (\pi/4) \times (1{,}5 \times H_t)^2 \times H_t$$

$$1.290{,}35\,ft^3 = 1{,}7671 H_t^3$$

$$H_t = 9\,ft$$

Digunakan 1 course 8 ft, sehingga $H_t \approx 8$ ft

Volume tangki = volume cylindrical shell

$$1.290{,}35\,ft^3 = (\pi/4) \times D_t^2 \times H_t$$

$$1.290{,}35\,ft^3 = (\pi/4) \times D_t^2 \times \left(\frac{1\,ft}{12\,in}\right)^2 \times 8\,ft$$

$$1.920{,}35\,ft^3 = 0{,}0436 \times D_t^2$$

$$D_t = 209{,}79\,in = 17{,}48\,ft$$

Tinggi lart. dalam shell (H_L) $= \dfrac{vol\ lart\ dlm\ shell}{\frac{\pi}{4}.D_t^2}$

$$= \frac{1.075{,}29\,ft^3}{\frac{\pi}{4}.(17{,}48\,ft)^2}$$

$= 4{,}48$ ft

P operasi = P hidrostatis $= \left(\dfrac{\rho \times H_L}{144}\right)$ psi

$$= \left(\frac{62{,}1615\,lbm/ft^3 \times 4{,}48\,ft}{144}\right)$$

$= 1{,}9339$ psi

P desain = 1,5 x P operasi = 1,5 x 1,9339 psi = 2,9 psi

Tebal *Shell*

Menghitung tebal shell

$$t_s = \frac{P.D_t}{2.f.E} + c \qquad \text{[22, pers 3.16]}$$

dimana :

P = P desain = 2,9 psi

D_t = 209,79 in

Konstruksi : Bahan konstruksi = *Stainless steel-316L*, dengan

f = Strees maksimum yang diijinkan = 23.000 psi

Tipe sambungan = *Double-welded butt joint*, dengan

E = *Welded-joint efficiency* = 0,8

[22, Tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_s = \frac{(2{,}9\ psi)\times(209{,}79 in)}{2\times(23.000\ psi)\times(0{,}8)} + 0{,}125 in$$

$$= 0{,}1415 \text{ in} \approx \frac{3}{16} \text{ in}$$

Tebal plat datar (t_f) = 3/16 in.

Spesifikasi :

Tangki

Kapasitas : 1.075,2923 ft^3

Diameter : 17,4825 ft

Tinggi shell : 8 ft

Tebal *shell course* : 0,1415 in $\approx \frac{3}{16}$ in

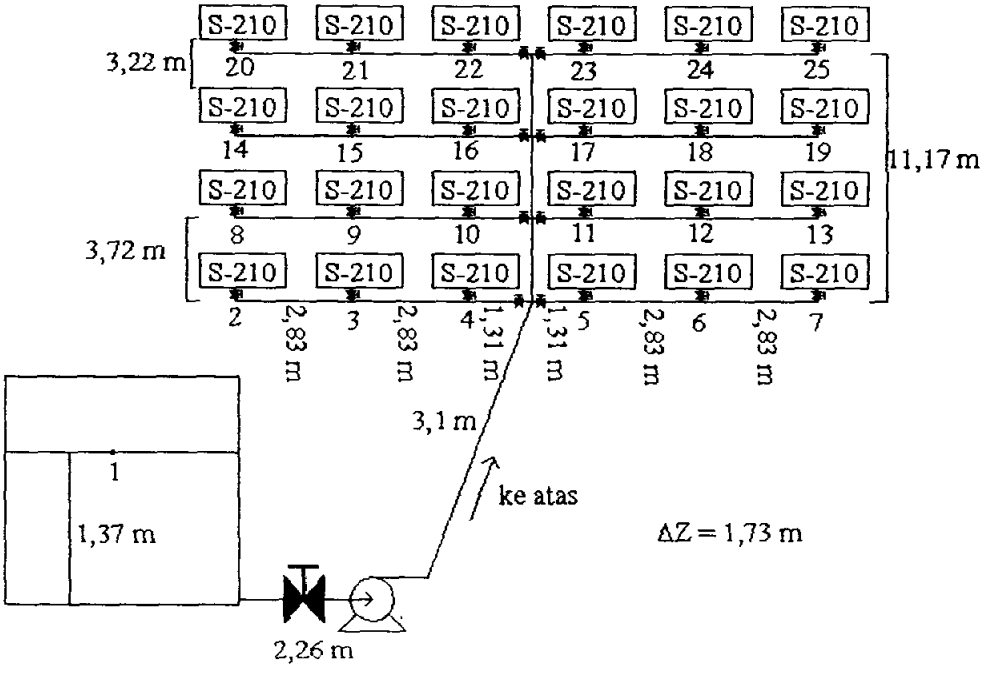
Bahan konstruksi : *Stainless steel-316 L*

Jumlah tangki : 1 buah

12. Pompa (L-213)

Fungsi : Mengalirkan air pencucian dari tangki air diafiltrasi ke membran *ultrafiltrasi* (S-210).

Tipe : *Centrifugal pump*



Perhitungan :

T = 30°C

Volume air yang harus dipindahkan : 24 m^3

ρ air $_{30°C}$ = 995,68 kg/m^3 = 62.1615 lb_m/ft^3 [20, App.A.2-3]

Viskositas : 0,0008 kg/m.s = 0.0005 lb/ft.s [20, App.A.2-4]

Volume air 24 m^3 harus dipindahkan dalam waktu 0,5 jam, maka:

$$\text{Rate volumetrik} = \frac{24\ m^3}{0{,}5\ jam} = 48\ {m^3}/{jam} = 0{,}47\ {ft^3}/{s}$$

Optimum inside diameter (Di,opt) dengan asumsi aliran turbulen:

$$Di,opt = 3{,}9\ q_f^{\,0,45}\ \rho^{0,13}$$ [28, pers 45, hal 381]

dimana : q_f = flow rate, ft^3/s

ρ = densitas fluida, lb/ft^3

$Di,opt = 3{,}9\ (0{,}47)^{0,45}\ (62{,}1615)^{0,13} = 4{,}7497$ inch $\approx 5{,}047$ inch.

Digunakan pipa berukuran 5 inch, sch.40 [20, App.A.5-1]

ID = 5,047 inch = 0,421 ft =0,128 m

A = 0,139 ft^2

$$\text{Kecepatan linier } (v_1) = \frac{q_f}{A} = \frac{0{,}47\ ft^3/s}{0{,}139\ ft^2} = 3{,}38\ ft/s = 1{,}03\ m/s$$

$$N_{Re} = \frac{\rho \times v_1 \times ID}{\mu}$$

$$= \frac{(62{,}1615\ {lb}/{ft^3})(3{,}38\ {ft}/{s})(0{,}421\ ft)}{0{,}0005\ {lb}/{ft.s}}$$

=176.909,1425 (turbulen, asumsi benar)

Digunakan commercial steel : $\varepsilon = 4{,}6.10^{-5}$ m

$$\text{harga } \frac{\varepsilon}{ID} = \frac{4{,}6.10^{-5}}{0{,}128} = 0{,}00036$$

f = 0,085 [20, Fig.2.10-3]

$$m_1 = \frac{24\ m^3 \times 995{,}68\ {kg}/{m^3}}{1800\ s} = 13{,}28\ kg/s$$

Untuk aliran setelah percabangan:

$m_2 = m_3 = m_4 = m_5 = m_6 = m_7 = m_8 = m_9 = m_{10} = m_{11} = m_{12} = m_{13} = m_{14} = m_{15} =$

$m_{16} = m_{17} = m_{18} = m_{19} = m_{20} = m_{21} = m_{22} = m_{23} = m_{24} = m_{25} = m =$

$$m = \frac{1 m^3 \times 995{,}68 \, kg/m^3}{1800 \, s} = 0{,}55 \text{ kg/s}$$

$v_2 = v_3 = v_4 = v_5 = v_6 = v_7 = v_8 = v_9 = v_{10} = v_{11} = v_{12} = v_{13} = v_{14} = v_{15} = v_{16} = v_{17} =$

$v_{18} = v_{19} = v_{20} = v_{21} = v_{22} = v_{23} = v_{24} = v_{25} = v$

$$\text{Rate volumetrik} = \frac{0{,}55 \, kg/s}{995{,}68 \, kg/m^3} = 0{,}006 \, m^3/s = 0{,}2 \, ft^3/s$$

Asumsi aliran turbulen:

Optimum inside diameter (Di,opt)

$$Di,opt = 3{,}9 \; q_f^{0{,}45} \; \rho^{0{,}13}$$ [28, pers 45, hal 381]

dimana : q_f = flow rate, ft^3/s

ρ = densitas fluida, lb/ft^3

$Di,opt = 3{,}9 \; (0{,}2)^{0{,}45} \; (62{,}1615)^{0{,}13} = 3{,}2336$ inch $\approx 3{,}548$ inch.

Digunakan pipa berukuran $3 \frac{1}{2}$ inch, sch.40 [20, App.A.5-1]

ID = 3,548 inch = 0,2957 ft =0,090 m

A = 0,0687 ft^2

$$N_{Re} = \frac{\rho \times v \times ID}{\mu}$$

$$= \frac{62{,}1615 \, lb_m / ft^3 \times 0{,}2 \, ft/s \times 0{,}115 \, ft}{0{,}0005 \, lb_m / ft.s}$$

$$= 2.859{,}429 \, (turbulen, asumsi \; benar)$$

Digunakan commercial steel : $\varepsilon = 4{,}6.10^{-5}$ m

$$\text{harga } \frac{\varepsilon}{ID} = \frac{4{,}6.10^{-5}}{0{,}09} = 0{,}0005$$

$$f = 0{,}013 \qquad \text{[20, Fig.2.10-3]}$$

$$v = \frac{massa\ air}{\rho \times A} = \frac{0{,}55\ kg/s}{995{,}68\ kg/m^3 \times 0{,}0064\ m^2} = 0{,}0863\ m/s = 0{,}28\ \text{ft/s}$$

$Z_2 = Z_3 = Z_4 = Z_5 = Z_6 = Z_7 = Z_8 = Z_9 = Z_{10} = Z_{11} = Z_{12} = Z_{13} = Z_{14} = Z_{15} = Z_{16} = Z_{17}$ $= Z_{18} = Z_{19} = Z_{20} = Z_{21} = Z_{22} = Z_{23} = Z_{24} = Z_{25} = Z = 3{,}1$ m

$P_2 = P_3 = P_4 = P_5 = P_6 = P_7 = P_8 = P_9 = P_{10} = P_{11} = P_{12} = P_{13} = P_{14} = P_{15} = P_{16} = P_{17} =$ $P_{18} = P_{19} = P_{20} = P_{21} = P_{22} = P_{23} = P_{24} = P_{25} = P = 1$ atm + 30 psia = 3,0408 atm = 308.109,06 N/m^2

Panjang ekivalen :

- Menghitung $\sum F_1$ (dari tangki F-150 ke percabangan 1, 2,3 dan 4)

- 2 buah standard elbow 90°; $K_f = 0{,}75$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 0{,}75 \times \frac{1{,}03^2}{2} = 0{,}3978\ m^2/s^2$$

karena ada 3 buah maka = 0,3978 m^2/s^2 x 2 = 0,7957 m^2/s^2

- 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{1{,}03^2}{2} = 3{,}1827\ m^2/s^2$$

- panjang pipa lurus = 2,26 m + 3,1 m + 3,72 m + 3,72 m + 3,72 m = 16,52 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}017 \times \frac{16{,}52}{0{,}09} \times \frac{1{,}03^2}{2} = 6{,}621\ m^2/s^2$$

[20, pers.2.10-6]

- Friksi *sudden contraction* dari tangki ke pipa

$$h_c = 0,55 \times \left(1 - \frac{A_2}{A_1}\right) \times \frac{v_2^2}{2\alpha} = 0,55 \times (1-0) \times \frac{1,03^2}{2} = 0,2917 \, m^2/s^2$$

Karena luas area tangki (A_1) >>> dari pada luas area pipa (A_2), maka $\frac{A_2}{A_1} \approx 0$

- Friksi *tee*

$$h_f = K_f \times \frac{v^2}{2} = 1 \times \frac{1,03^2}{2} = 0,5305 \, m^2/s^2$$

Karena ada 6 buah tee maka = $0,5305 \, m^2/s^2 \times 6 = 3,1827 \, m^2/s^2$

$$\Sigma F_1 = 0,7957 + 3,1827 + 6,621 + 0,2917 + 3,1827 = 14,0738 \, m^2/s^2$$

- Menghitung $\sum F_4$ dan $\sum F_5$ (dari percabangan 1 ke membran S-210)

- 2 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0,0863^2}{2} = 0,0223 \, m^2/s^2$$

Karena ada 2 valve maka = 2 x 0,0223 m^2/s^2 = 0,0446 m^2/s^2

- panjang pipa lurus = 1,32 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0,013 \times \frac{1,32}{0,115} \times \frac{0,0863^2}{2} = 0,002 \, m^2/s^2$$

[20, pers.2.10-6]

- 2 buah *tee*, $K_f = 1$

$$h_f = K_f \times \frac{v^2}{2} = 1 \times \frac{0,0863^2}{2} = 0,0037 \, m^2/s^2$$

Karena ada 2 valve maka = 2 x 0,0037 m^2/s^2 = 0,0074 m^2/s^2

$$\Sigma F_4 = \Sigma F_5 = 0{,}0223 + 0{,}002 + 0{,}0074 = 0{,}0317\ m^2/s^2$$

- Menghitung $\sum F_{10}$, $\sum F_{11}$ (dari percabangan 2 membran S-210), $\sum F_{16}$, $\sum F_{17}$ (dari percabangan 3 membran S-210), $\sum F_{22}$, $\sum F_{23}$ (dari percabangan 4 membran S-210).

$$\sum F_{10} = \sum F_{11} = \sum F_{16} = \sum F_{17} = \sum F_{22} = \sum F_{23} = \sum F_4 = 0{,}0317\ m^2/s^2$$

- Menghitung $\sum F_3$ (dari titik 4 ke membran S-210) dan $\sum F_6$ (dari titik 5 ke membran S-210)

- 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0{,}0863^2}{2} = 0{,}0223\ m^2/s^2$$

- panjang pipa lurus = 2,83 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}013 \times \frac{2{,}83}{0{,}115} \times \frac{0{,}0863^2}{2} = 0{,}0048\ m^2/s^2$$

(20, pers.2.10-6)

- 1 buah *tee*, $K_f = 1$

$$h_f = K_f \times \frac{v^2}{2} = 1 \times \frac{0{,}0863^2}{2} = 0{,}0037\ m^2/s^2$$

$$\Sigma F_3 = \Sigma F_6 = 0{,}0223 + 0{,}0048 + 0{,}0037 = 0{,}0308\ m^2/s^2$$

- Menghitung $\sum F_9$ (dari titik 10 ke membran S-210), $\sum F_{12}$ (dari titik 11 ke membran S-210), $\sum F_{15}$ (dari titik 16 ke membran S-210), $\sum F_{18}$ (dari titik 17 ke membran S-210), $\sum F_{21}$ (dari titik 22 ke membran S-210), $\sum F_{24}$ (dari titik 23 ke membran S-210),

$$\sum F_9 = \sum F_{12} = \sum F_{15} = \sum F_{18} = \sum F_{21} = \sum F_{24} = \sum F_3 = 0{,}0308\ m^2/s^2$$

- Menghitung $\sum F_2$ (dari titik 3 ke membran S-210) dan $\sum F_7$ (dari titik 6 ke membran S-210)

- 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0{,}0863^2}{2} = 0{,}0223 \, m^2/s^2$$

- panjang pipa lurus = 2,83 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}013 \times \frac{2{,}83}{0{,}115} \times \frac{0{,}0863^2}{2} = 0{,}0048 \, m^2/s^2$$

[20, pers.2.10-6]

- 1 buah standard elbow 90°, $K_f = 0{,}75$

$$h_f = K_f \times \frac{v^2}{2} = 0{,}75 \times \frac{0{,}0863^2}{2} = 0{,}0028 \, m^2/s^2$$

$$\Sigma F_2 = \Sigma F_7 = 0{,}0223 + 0{,}0048 + 0{,}0028 = 0{,}0299 \, m^2/s^2$$

- Menghitung $\sum F_8$ (dari titik 9 ke membran S-210), $\sum F_{14}$ (dari titik 13 ke membran S-210), $\sum F_{20}$ (dari titik 19 ke membran S-210), $\sum F_{13}$ (dari titik 12 ke membran S-210), $\sum F_{19}$ (dari titik 18 ke membran S-210), $\sum F_{25}$ (dari titik 24 ke membran S-210),

$$\sum F_8 = \sum F_{14} = \sum F_{20} = \sum F_{13} = \sum F_{19} = \sum F_{25} = \sum F_2 = 0{,}0299 \, m^2/s^2$$

Persamaan Bernoulli

$$m_1(-w_s) = m_2 \times \left[\frac{p_2}{\rho} + \frac{v_2^2}{2\alpha} + g \times Z_2\right] + m_3 \times \left[\frac{p_3}{\rho} + \frac{v_3^2}{2\alpha} + g \times Z_3\right] + m_4 \times \left[\frac{p_4}{\rho} + \frac{v_4^2}{2\alpha} + g \times Z_4\right]$$
$$+ \ldots\ldots + m_{25} \times \left[\frac{p_{25}}{\rho} + \frac{v_{25}^2}{2\alpha} + g \times Z_{25}\right] - m_1 \times \left[\frac{p_1}{\rho} + \frac{v_1^2}{2\alpha} + g \times Z_1\right]$$
$$+ m_1 \times \Sigma F_1 + m_2 \times \Sigma F_2 + m_3 \times \Sigma F_3 + m_4 \times \Sigma F_4 + \ldots\ldots + m_{25} \times \Sigma F_{25}$$

$$m_1(-w_s)=\left(24\times m\times\left[\frac{p}{\rho}+\frac{v^2}{2}+g\times Z\right]\right)-m_1\times\left[\frac{p_1}{\rho}+\frac{v_1^{\,2}}{2}+g\times Z_1\right]+(m_1\times\Sigma F_1)+(m\times(\Sigma F_2+\Sigma F_3+....+\Sigma F_2$$

$$13{,}28(-w_s)=\left(24\times 0{,}55\times\left[\frac{308.109{,}06}{1.024{,}56}+\frac{0{,}0863^2}{2}+9{,}8067\times 3{,}1\right]\right)-$$

$$\left(13{,}28\times\left[\frac{101.325}{1.024{,}56}+\frac{1{,}03^2}{2}+9{,}8067\times 1{,}37\right]\right)+(13{,}28\times 14{,}0738)+$$

$$(0{,}55\times((8\times 0{,}0317)+(8\times 0{,}0308)+(8\times 0{,}0299)))$$

$$-w_s=\frac{4.193{,}5425-1.545{,}6878+186{,}9+0{,}4066}{13{,}28}$$

$$-w_s=213{,}4911\,{}^{m^2}\!/_{s^2}=213{,}4911\,{}^{J}\!/_{kg}$$

Efisiensi pompa (η) = 30% [28, fig 13-37, p.550]

$$W_p=-\frac{Ws}{\eta}=\frac{213{,}4911}{0{,}3}=711{,}6369\,\frac{j}{kg}$$

Flow rate = $13{,}28\,{}^{kg}\!/_{s}$

hp pompa = $711{,}6369\,{}^{J}\!/_{kg}\times 13{,}28\,{}^{kg}\!/_{s}$ = 9,4505 kW = 12,67 hp

Efisiensi motor = 80% [28, fig 14-38, p 521]

Sehingga dipakai pompa dengan motor = 12,67 / 0,8 hp = 15,84 hp ≈ 16 hp

Spesifikasi alat :

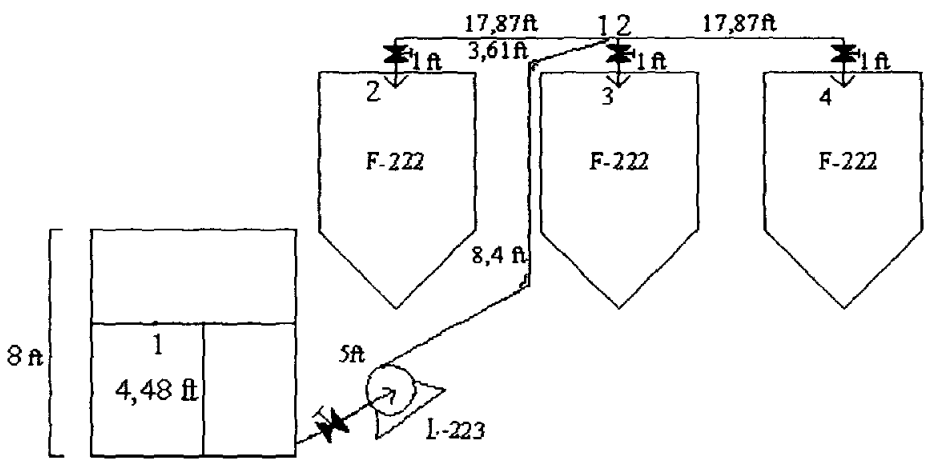
- Fungsi : Mengalirkan air pencucian
- Tipe : *Centrifugal pump*
- Rate aliran pompa : 48 m^3/jam
- Ukuran pipa : 5 in sch 40
- Power motor : 16 hp
- Bahan konstruksi : *Stainless steel*

- Jumlah : 1 buah

13. Pompa (L-223)

Fungsi : Mengalirkan air dari tangki air diafiltrasi ke tangki *batch* diafiltrasi (F-222).

Tipe : *Centrifugal pump*



Perhitungan :

T = 30°C

Massa air yang harus dipindahkan :490,8 kg

ρ air $_{30°C}$ = 995,68 kg/m^3 = 62,1615 lb$_m$/ft^3 [20, App.A.2-3]

Viskositas : 0,0008 kg/m.s = 0,0005 lb/ft.s [20, App.A.2-4]

Massa air 490,8 kg harus dipindahkan dalam waktu 2 jam, maka:

$$\text{Rate volumetrik} = \frac{490{,}8\,kg}{995{,}68\,\frac{kg}{m^3} \times 2\,jam} = 0{,}2465\,m^3/jam = 0{,}0024\,ft^3/s$$

Optimum inside diameter (Di,opt) dengan asumsi aliran laminer

$$Di,opt = 3{,}9\ q_f^{0{,}45}\ \rho^{0{,}13}$$ [28, pers 45, hal 381]

dimana : q_f = flow rate, ft^3/s

ρ = densitas fluida, lb/ft^3

Di,opt = 3,9 (0,0024) ^{0,45} (62,1615)^{0,13} = 0,4419 inch ≈ 0,493 inch.

Digunakan pipa berukuran $\frac{3}{8}$ inch, sch.40 [20, App.A.5-1]

ID = 0,493 inch = 0,0413 ft = 0,0126 m

A = 0,00133 ft^2

Kecepatan linier (v_1) = $\frac{q_f}{A} = \frac{0,0024\,ft^3/s}{0,00133 ft^2}$ = 1,8045 ft/s = 0,550 m/s

$$N_{Re} = \frac{\rho \times v_1 \times ID}{\mu}$$

$$= \frac{(62,1615\,lb/ft^3)(1,8045\,ft/s)(0,0413\,ft)}{0,0005\,lb/ft.s}$$

= 9.265,2773 (turbulen) (asumsi benar)

Digunakan commercial steel : $\varepsilon = 4,6.10^{-5}$ m

$$\text{harga } \frac{\varepsilon}{ID} = \frac{4,6.10^{-5}}{0,0126} = 0,0036$$

f = 0,085 [20, Fig.2.10-3]

$$m_1 = \frac{490,8\,kg}{2\,jam} = 0,0682 \text{ kg/s}$$

Untuk aliran setelah percabangan:

$$m_2 = m_3 = m_4 = m = \frac{0,0682\,kg/s}{3} = 0,0227 \text{ kg/s}$$

$$v_2 = v_3 = v_4 = v = \frac{massa\ air}{\rho \times A} = \frac{0{,}0227\ kg/s}{995{,}68\ kg/m^3 \times 0{,}0001 m^2} = 0{,}1845\ m/s = 0{,}6053\ \text{ft/s}$$

$$N_{Re} = \frac{\rho \times v \times ID}{\mu}$$

$$= \frac{62{,}1615 lb_m/ft^3 \times 0{,}6053\ ft/s \times 0{,}0413\ ft}{0{,}0005 lb_m/ft.s}$$

$$= 3.107{,}937\ (turbulen)$$

$Z_2 = Z_3 = Z_4 = 7{,}4$ ft = 2,26 m

$p_2 = p_3 = p_4 = 1$ atm= 101.325 N/m^2

$\alpha = 1$ (aliran turbulen)

Panjang ekivalen :

- Menghitung $\sum F_1$ (dari tangki F-150 ke percabangan 1)

- 2 buah standard elbow 90°; $K_f = 0{,}75$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 0{,}75 \times \frac{0{,}550^2}{2} = 0{,}1134\ m^2/s^2$$

karena ada 2 buah maka = 0,1134 m^2/s^2 x 2 = 0,2268 m^2/s^2

- 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0{,}550^2}{2} = 0{,}9075\ m^2/s^2$$

- panjang pipa lurus = 5 ft + 8,4 ft + 3,62 ft = 17,02 ft = 5,19 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}007 \times \frac{5{,}19}{0{,}115} \times \frac{0{,}550^2}{2} = 0{,}191\ m^2/s^2$$

[20, pers.2.10-6]

- Friksi *sudden contraction* dari tangki ke pipa

$$h_c = 0,55 \times \left(1 - \frac{A_2}{A_1}\right) \times \frac{v_2^{\,2}}{2\alpha} = 0,55 \times (1-0) \times \frac{0,550^2}{2} = 0,0832 \, {}^{m^2}\!/_{s^2}$$

Karena luas area tangki (A_1) >>> dari pada luas area pipa (A_2), maka $\frac{A_2}{A_1} \approx 0\,3$

- Friksi *tee*

$$h_f = K_f \times \frac{v^2}{2} = 1 \times \frac{0,55^2}{2} = 0,1513 \, {}^{m^2}\!/_{s^2}$$

$$\Sigma F_1 = 0,2268 + 0,9075 + 0,191 + 0,0832 + 0,1513 = 1,5598 \, {}^{m^2}\!/_{s^2}$$

- Menghitung $\sum F_2$ (dari percabangan 1 tangki F-222)

- 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0,1845^2}{2} = 0,1021 \, {}^{m^2}\!/_{s^2}$$

- panjang pipa lurus = 1 ft = 0,3048 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0,007 \times \frac{0,3048}{0,115} \times \frac{0,1845^2}{2} = 0,0013 \, {}^{m^2}\!/_{s^2}$$

[20, pers.2.10-6]

- Friksi *tee*

$$h_f = K_f \times \frac{v^2}{2} = 1 \times \frac{0{,}55^2}{2} = 0{,}1513 \; {}^{m^2}/_{s^2}$$

$$\Sigma F_2 = 0{,}1021 + 0{,}0013 + 0{,}1513 = 0{,}2547 {}^{m^2}/_{s^2}$$

- Menghitung $\sum F_3$ (dari tangki percabangan 1 tangki F-222)

- 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0{,}1845^2}{2} = 0{,}1021 \; {}^{m^2}/_{s^2}$$

- Friksi *elbow 90°*, $K_f = 0{,}75$

$$h_f = K_f \times \frac{v^2}{2} = 1 \times \frac{0{,}1845^2}{2} = 0{,}013 \; {}^{m^2}/_{s^2}$$

- panjang pipa lurus = 18,88 ft = 5,75 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}007 \times \frac{5{,}75}{0{,}115} \times \frac{0{,}1845^2}{2} = 0{,}0238 \; {}^{m^2}/_{s^2}$$

[20, pers.2.10-6]

$$\Sigma F_3 = 0{,}1021 + 0{,}013 + 0{,}0238 = 0{,}1389 {}^{m^2}/_{s^2}$$

- Menghitung $\sum F_4$ (dari tangki percabangan 2 tangki F-212)

- 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0{,}1845^2}{2} = 0{,}1021 \; {}^{m^2}\!/_{s^2}$$

- Friksi *elbow 90°*, $K_f = 0{,}75$

$$h_f = K_f \times \frac{v^2}{2} = 0{,}75 \times \frac{0{,}1845^2}{2} = 0{,}013 \; {}^{m^2}\!/_{s^2}$$

- panjang pipa lurus = 18,88 ft = 5,75 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}007 \times \frac{5{,}75}{0{,}115} \times \frac{0{,}1845^2}{2} = 0{,}0238 \; {}^{m^2}\!/_{s^2}$$

[20, pers.2.10-6]

$$\Sigma F_4 = 0{,}1021 + 0{,}013 + 0{,}0238 = 0{,}1389 \; {}^{m^2}\!/_{s^2}$$

PersamaanBernoulli:

$$\mathrm{m}_1(-w_s) = m_2 \times \left[\frac{p_2}{\rho} + \frac{v_2^{\,2}}{2\alpha} + g \times Z_2\right] + m_3 \times \left[\frac{p_3}{\rho} + \frac{v_3^{\,2}}{2\alpha} + g \times Z_3\right] + m_4 \times \left[\frac{p_4}{\rho} + \frac{v_4^{\,2}}{2\alpha} + g \times Z_4\right] -$$
$$m_1 \times \left[\frac{p_1}{\rho} + \frac{v_1^{\,2}}{2\alpha} + g \times Z_1\right] + m_1 \times \Sigma F_1 + m_2 \times \Sigma F_2 + m_3 \times \Sigma F_3 + m_4 \times \Sigma F_4$$

$$\mathrm{m}_1(-w_s) = \left(3 \times m \times \left[\frac{p}{\rho} + \frac{v^2}{2} + g \times Z\right]\right) - m_1 \times \left[\frac{p_1}{\rho} + \frac{v_1^{\,2}}{2\alpha} + g \times Z_1\right] + (m_1 \times \Sigma F_1) + (m \times (\Sigma F_2 + \Sigma F_3 + \Sigma F_4))$$

$$0{,}0682(-w_s) = \left(3 \times 0{,}0227 \times \left[\frac{101.325}{1.024{,}56} + \frac{0{,}1845^2}{2} + 9{,}8067 \times 2{,}26\right]\right) -$$
$$\left(0{,}0682 \times \left[\frac{101.325}{1.024{,}56} + \frac{0{,}55^2}{2} + 9{,}8067 \times 1{,}37\right]\right) + (0{,}0682 \times 1{,}5598)$$
$$+ (0{,}0227 \times (0{,}2547 + 0{,}1389 + 0{,}1389))$$
$$-w_s = \frac{10{,}4091 - 7{,}29 + 0{,}1064 + 0{,}012}{0{,}0682}$$
$$-w_s = 47{,}44 \; {}^{m^2}\!/_{s^2} = 47{,}44 \; {}^{J}\!/_{kg}$$

Efisiensi pompa (η) = 30% [28, fig 13-37, p.550]

$$W_p = -\frac{Ws}{\eta} = \frac{47,44}{0,3} = 158,14 \frac{j}{kg}$$

$$\text{Flow rate} = \frac{490,8\,kg}{2\,jam} = 245,4\,{}^{kg}/_{jam} = 0,0682\,{}^{kg}/_{s}$$

$$\text{hp pompa} = 158,14\,{}^{j}/_{kg} \times 0,0682\,{}^{kg}/_{s} = 10,78 \text{ W} = 0,0145 \text{ hp}$$

Efisiensi motor = 80% [28, fig 14-38, p 521]

Sehingga dipakai pompa dengan motor = 0,0145/0,8 hp = 0,018 hp ≈ 0,25 hp

Spesifikasi alat :

- Fungsi : Mengalirkan air untuk ditambahkan ke susu
- Tipe : *Centrifugal pump*
- Rate aliran pompa : 0,2465 m^3/jam
- Ukuran pipa : $^3/_8$ in sch 40
- Power motor : 0,25 hp
- Bahan konstruksi : *Stainless steel*

- Jumlah : 1 buah

14. Tangki penampung untuk *batch diafiltration* (F-222)

Fungsi : Sebagai penampung untuk *batch diafiltration*

Tipe : Silinder tegak dengan tutup atas berbentuk plat datar dan tutup bawah berbentuk *dished head.*

Dasar pemilihan : Untuk menampung bahan yang berbentuk cair.

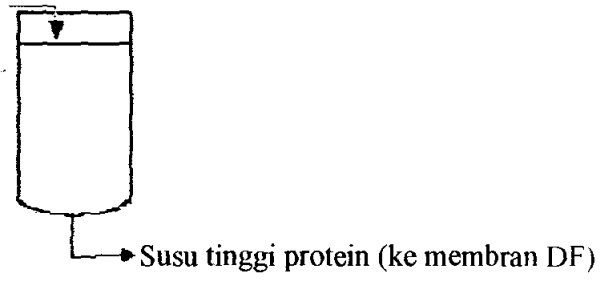
Kondisi operasi :

- T = 30°C
- Tekanan 1 atm
- Waktu tinggal 3 jam

Sistem operasi : *batch*

Jumlah : 3 buah

Gambar :



Perhitungan :

Massa susu + air *diafiltrasi* masuk (untuk 3 tangki) =16.095,929*liter*

$$\text{Untuk 1 tangki} = \frac{16.095{,}929\,liter}{3} = 5.365{,}3097\,liter$$

ρ susu : $1033,7 - 0,2308T - 0,00246\,T^2$

$$= 1024,562\ {}^{kg}/_{m^3} = 63,9645\ {}^{lbm}/_{ft^3}$$

volume larutan total : $= 189,4731\ ft^3\ /\ batch = 5,3655\ m^3$/batch

Diambil : tinggi tangki (H_t) = 1 x Diameter tangki (D_t)

Volume shell = $(\pi/4) D_t^{\,2} . H_t = (\pi/4) D_t^2 . 1,5 . D_t = (\pi/4)\, 1,5 . D_t^3$

Volume torispherical dished head (ft^3) = 0,000049 x D_t^3 (in)

[22, pers 5.11, hal 88]

Volume tangki penampung = volume shell + volume *dished head*

Diambil : volume tangki penampung = 1,3 . volume larutan total

Volume tangki = volume cylindrical shell + volume dished head

$$1,3 \times 189,4731\ ft^3 = (\pi/4) \times D_t^2 \times H_t + 0,000049 \times D_t^3 \times \left(\frac{1\ ft}{12\ in}\right)^3$$

$$246,315\ ft^3 = (\pi/4) \times H_t^{\,2} \times H_t + 4,9.10^{-5} \times H_t^{\,3} \times \left(\frac{1\ ft}{12\ in}\right)^3$$

$$246,315\ ft^3 = 0,7854\, H_t^3$$

$$H_t = 6,7941\ ft$$

Digunakan 1 course 6 ft, sehingga $H_t \approx 6$ ft

Volume tangki = volume cylindrical shell + volume dished head

$$246,315\ ft^3 = (\pi/4) \times D_t^2 \times H_t + 0,000049 \times D_t^3 \times \left(\frac{1\ ft}{12\ in}\right)^3$$

$$246,315\ ft^3 = (\pi/4) \times D_t^2 \times \left(\frac{1\ ft}{12\ in}\right)^2 \times 6\ ft + 0,000049 \times D_t^3 \times \left(\frac{1\ ft}{12\ in}\right)^3$$

$$264,315\ ft^3 = 0,0327 \times D_t^2 + 2,8356 \times 10^{-8} D_t^3$$

$$D_t = 86,7872\ in = 7,2322\ ft$$

Volume larutan dalam dish $= 0{,}000049 \cdot D^3$

$= 0{,}000049 \cdot (86{,}7872 \text{ in})^3$

$= 32{,}0305 \text{ ft}^3$

Volume larutan dalam shell = vol. lart. total – vol. lart. dalam dish

$= 189{,}4731 \text{ ft}^3 - 32{,}0305 \text{ ft}^3$

$= 157{,}4426 \text{ ft}^3$

Tinggi lart. dalam shell (H_L) $= \dfrac{vol.lart.dlm.shell}{\frac{\pi}{4}.D_t^2}$

$= \dfrac{157{,}4426 ft^3}{\frac{\pi}{4}.(7{,}2322 ft)^2}$

$= 3{,}8329 \text{ ft}$

P operasi = P hidrostatis $= \left(\dfrac{\rho \times H_L}{144}\right)$ psi

$= \left(\dfrac{63{,}9645 lbm/ft^3 \times 3{,}8329 ft}{144}\right)$

$= 1{,}7024 \text{ psi}$

P desain = 1,5 x P operasi = 1,5 x 1,7024 psi = 2,5536 psi

Tebal *Shell*

$$t_s = \frac{P.D_t}{2.f.E} + c \qquad \text{[22. pers 3.16]}$$

dimana :

P = P desain = 2,5536 psi

D_t = 86,7872 in

Konstruksi : Bahan konstruksi = *Stainless Steel-316L*, dengan

f = Strees maksimum yang diijinkan = 23.000 psi

Tipe sambungan = *Double-welded butt joint*, dengan

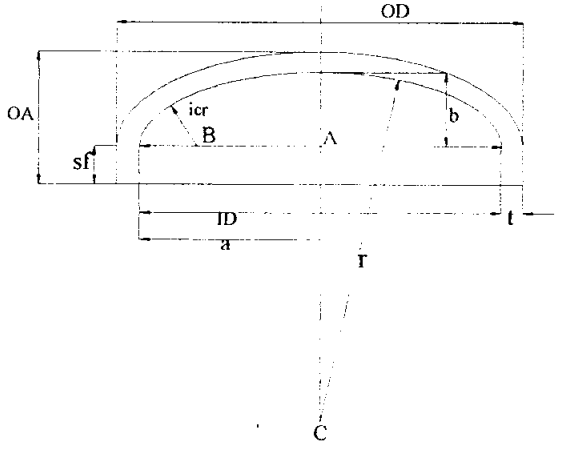
E = *welded-joint efficiency* = 0,8 [22, Tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_s = \frac{(2{,}5536\,psi)\times(86{,}7872\ in)}{2\times(23.000\times 0{,}8)} + 0{,}125\,in$$

$$= 0{,}1310 \text{ in} \approx \frac{3}{16} \text{ in}$$

Tebal *dished head*



r (*crown radius / radius of dish*) = 86,7872 in

icr (*inside corner radius / knuckle radius*) = 6% x 86,7872 in = 5,2072in

$$W = \frac{1}{4}\times\left[3+\sqrt{\frac{r}{icr}}\right] \qquad \text{[22, pers 7,76]}$$

$$= \frac{1}{4}\times\left[3+\sqrt{\frac{86{,}7872}{5{,}2072}}\right]$$

= 1,7706

a $= \frac{D_t}{2} = \frac{86{,}7872\ in}{2} = 43{,}3936\ in$

AB $= \frac{D_t}{2} - icr = \frac{86{,}7872\ in}{2} - 5{,}2072 in = 38{,}1864\ in$

BC = r – icr = (86,7872-5,2072) in = 81,58 in

b $= r - \sqrt{BC^2 - AB^2} = 86{,}7872 - \sqrt{81{,}58^2 - 38{,}1864^2} = 14{,}6963\ in$

$t_d = \frac{P \times r \times W}{2 \times f \times E - 0{,}2 \times P} + c$ [22, pers 7.77, p.138]

dimana :

P = P desain = 2,5536 psi

Konstruksi : Bahan konstruksi = *Stainless Steel-316L*, dengan

F = Stress maksimum yang diijinkan = 23.000 psi

Tipe sambungan = *Double-welded butt joint*, dengan

E = *Welded-joint efficiency* = 0,8 [22, tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$t_d = \frac{(2{,}5536\ psi) \times (86{,}7872 in) \times 1{,}7706}{2 \times ((23.000 psi) \times 0{,}8) - (0{,}2 \times 2{,}5536 psi)} + 0{,}125 in$

= 0,1357 in $\approx \frac{3}{16}$ in

Dipilih panjang straight-flange (sf) = 2 in [22, tabel 5.8, p.93]

OA = t_d + b + sf

= ($\frac{3}{16}$ + 14,6963 + 2) in

= 16,8838 in = 1,407 ft

Tinggi tangki keseluruhan = tinggi shell + tinggi dish

= 6 ft + 1,407 ft

= 7,407 ft

Tebal plat datar (t_f) = 3/16 in.

Spesifikasi :

Tangki

Kapasitas : 189,4731 ft^3

Diameter : 7,2322 ft

Tinggi tutup bawah (dished head): 1,407 ft

Tinggi shell : 6 ft

Tinggi tangki total : 7,407 ft

Tebal shell : 0,1310 in $\approx \frac{3}{16}$ in

Tebal tutup bawah (dished head) : 0,1357 in $\approx \frac{3}{16}$ in

Bahan konstruksi : *Stainless Steel-316L*

Jumlah tangki : 3 buah

15. Membran DF (S-220)

Fungsi : Memisahkan laktosa dan abu dari susu dengan penambahan air

Tipe : *Hollow fiber module*

Jenis membrane : *Polysulfone*

Dasar Pemilihan:

- *Hollow fiber module* memiliki luas area membran yang paling besar dan biaya investasi alat yang paling rendah
- *Polysulfone* memiliki range pH yang cocok digunakan untuk pemisahan laktosa dan abu dari susu

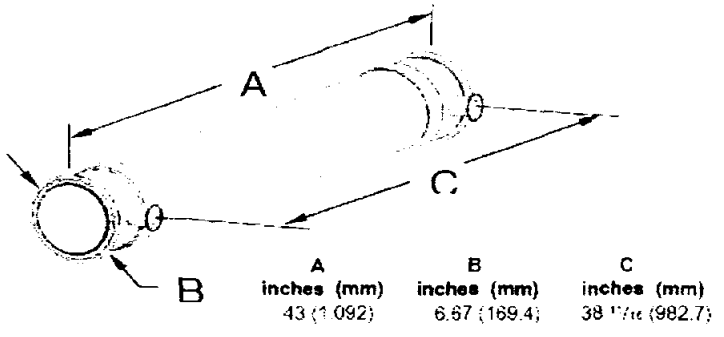
Kondisi operasi :

Laju alir total (kg/hari)	111.918,7406 kg/hari
Temperature (°C)	30

Sistem operasi : *Batch*

Jumlah : 1 housing @ 1 *cartridge*

Gambar [40] :



Penghitungan penentuan jumlah *module* yang digunakan

Data :

- Laju fluks rate awal [8] = 26,47 $Liter/m^2.h$
- Laju fluks rate akhir [8] = 19,28 $Liter/m^2.h$
- $V_{mula\text{-}mula\ tiap\ batch}$: 1 hari ada 7 *batch*

$$\frac{111.918,7406\,kg/hari}{1024,56\,kg/m^3}\frac{1\,hari}{7\,batch}=15,6051\,m^3=15.605,13\,liter$$

- V air yang ditambahkan = 80% x V permeate tiap batch [14]
- V permeate tiap batch = 4.294,4991 kg/hari / 7 batch

  = 613,499 kg/batch
- V air yang ditambahkan = 80 % 613,499 kg/batch

  = 490,799 kg/batch

  = 490,799 liter/batch
- Vmula-mula tiap batch = 15.605,13 liter + 490,799 liter

  = 16.095,929 liter
- $V_{retentate\ tiap\ batch}$

$$\frac{107.624,2415\ kg/hari}{1024,56\,kg/m^3}\frac{1}{7\,bacth}=15,006\,m^3=15.006,34\,liter$$

- Laju fluks rata-rata,J_{avg} [14]

$$fluks\ rate\ awal-(0,33\times(fluks\ rate\ awal-fluks\ rate\ akhir)$$

$$=26,47\ {}^{Liter}/_{m^2.jam}-(0,33\times(26,47-19,28)^{Liter}/_{m^2\ jam}$$

$$=24,097\ {}^{Liter}/_{m^2.h}$$

- Waktu filtrasi : 3 jam (tiap-tiap *housing*) [8]
- Luas permukaan total membran yang dibutuhkan [14]

$$A=\frac{V_{mula-mula}-V_{retentate}}{T\times J_{avg}}$$

$$A=\frac{16.095,929liter-15006,34liter}{3\,jam\times 24,097\,{}^{liter}/_{m^2.jam}}$$

$$=15,072\,m^2$$

Cartridge yang digunakan adalah tipe Romicon 6" memiliki luas permukaan 5,6 m^2 [8]

Jumlah *cartridge* yang digunakan adalah :

$$= \frac{15{,}072\, m^2}{5{,}6\, m^2} = 2{,}69 \approx 3 \text{ buah}$$

Tipe fiber yang digunakan adalah PM-30 [8], dengan spesifikasi :

ID = 1,1 mm

Tebal = 0,15 mm

OD = 1,4 mm

Panjang fiber = 1,09 m , jumlah fiber = 1000 buah

Perhitungan *housing*

Diameter cartdrige = 169,4 mm = 0,1694 m

Square area di sekitar *cartridge* = 0,1694m x 0,1694m = 0,0287 m^2

Luas area cartridge = π $(0{,}1694/2)^2$ = 0,0225 m^2

Hole ratio = 0,0225 m^2 / 0,0287 m^2

= 0;784

1 *housing* digunakan 1 buah *cartridge*

Housing area =1 x 0,0225m^2 /(1-0,784)

= 0,1042 m^2

Housing area = $\frac{\pi}{4} . ID^2$

$0{,}1042\ m^2 = \frac{\pi}{4}.ID^2$

$ID = 0{,}364\ m$

Penghitungan tebal *Shell*

$$e = \frac{P_i.D_i}{2f - P_i}$$

$\Delta P = 6\ bar = 600.000\ N/m^2$

$Pi = 1{,}1.\ 600.000\ N/m^2$

$= 660.000$

f = design stress $= 1{,}75.10^8\ N/m^2$

$$e = \frac{660.000.0{,}364}{2.(1{,}75.10^8) - 660.000}$$
$$= 0{,}000688m = 069mm$$

Penghitungan tebal *head*

R_c, crown radius = ID = 0,1327 m

$R_c/R_k = 0{,}06$

J = 0,8

$$Cs = \frac{3 + \sqrt{Rc / Rk}}{4}$$

$$= \frac{3 + \sqrt{0{,}06}}{4}$$

$= 0{,}811$

$$e = \frac{P_i . R_c . C_s}{2fJ + P_i(C_s - 0{,}2)}$$

$$= \frac{660.000.0{,}364\,0{,}811}{2.1{,}75.10^8.0{,}8 + 660.000.(0{,}811 - 0{,}2)}$$

= 0,000694 m = 0,69 mm

Digunakan tebal yang sama untuk shell dan head, 0,69 mm

Corrosion allowance 2mm

Tebal total = tebal minimum yang dibutuhkan + *corrosion allowance*

= (0,69 + 2) = 2,69 mm

Tebal *head* dan shell yang terdekat adalah 1/8 in = 3,175 mm

Penghitungan *Dead Weight*

a. Berat *column*

Volume silinder = 2. π. ri. L. t

= 2. 3,14. (0,364/2) m. 1,09 m. 3,175.10^{-3} m

= 0,00396m^3

Volume 2 head = 0,0809. (Do^3 - Di^3)

= 0,0809. (((0,364+2.3,175.10^{-3})^3 – 0,364^3)

= 0,00021 m^3

Volume total = 0,00417 m^3

Berat kolom = ρstainless steel . V total. g

= 7834 kg/m^3 . 0,00417 m^3. 9,8 m/s^2

= 320,144 N

c. Berat *Cartridge*

Volume *cartridge* $= \frac{\pi . Di^2 . L}{4}$

$= \frac{\pi . 0{,}364^2 . 1{,}09}{4}$

$= 0{,}113\ m^3$

Berat *cartridge* $= \rho_{cartridge} . V\ cartridge . g$

$= 130\ kg/m^3 . 0{,}113 m^3 . 9{,}8\ m^2$

$= 144{,}434\ N$

Total *dead weight* $= 464{,}578\ N$

Penghitungan Tekanan

a. *Internal Pressure*

$$Longitudinal\ stress, T_L = \frac{P_i . D_i}{4t}$$

$$= \frac{660.000\ N/m^2 . 0{,}364 m}{4 . 3{,}175/1000\ m}$$

$= 18{,}917\ N/mm^2$

$$Circumferential\ stress, T_H = \frac{P_i . D_i}{2t}$$

$$= \frac{660.000\ N/m^2 . 0{,}364 m}{2 . 3{,}175/1000\ m}$$

$= 37{,}833 N/mm^2$

b. Dead Weight Stress

$$Tw = \frac{W}{\pi.(Di+t)t}$$

$$= \frac{464{,}578}{3{,}14.(0{,}364 + 3{,}175.10^{-3}).3{,}175.10^{-3}}$$

$$= 0{,}127\ N/mm^2$$

Resultan longitudinal stress = 0,127N/mm^2 + 37,833 N/mm^2

= 37,9600 N/mm^2

c. Check Buckling

σ_c = 2.10^4. (t/Do)

= 2.10^4. ($3{,}175.10^{-3}$/ ($2.3{,}175.10^{-3}$+0,364))

= 171,459 N/mm^2

Resultan longitudinal stress < *critical buckling stress* (memenuhi)

Spesifikasi Module :

Jumlah module = 3 buah

Jenis module = *hollowfiber*

Jumlah cartridge/module = 1 buah

ID *chasing* = 0,364 m

Panjang *chasing* = 1,092 m

Tebal *chasing* = 3,175 mm

Tipe fiber yang digunakan adalah PM-30, dengan spesifikasi :

Jenis fiber = *polysulfone*

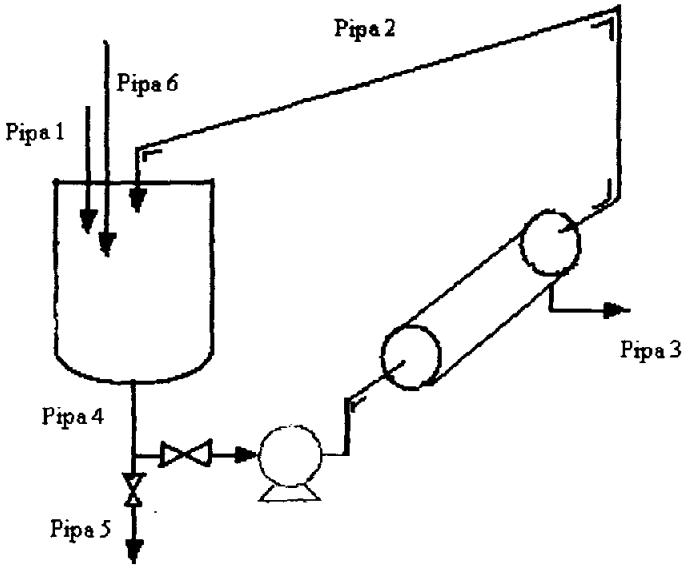
ID = 1,1 mm

Tebal = 0,15 mm

OD = 1,4 mm

Panjang fiber = 1,09 m , jumlah fiber = 1000 buah

Penghitungan Perpipaan



$\rho = 1024{,}56\ kg/m^3$

$\mu = 0.0008\ kg/m.s = 8\ cp$

a. Pipa 2 = pipa 4

Laju pipa = 16.095,929 liter/batch

$$= \frac{16.095{,}929\ liter/batch}{3\ hou\ \sin g}$$

1 batch = 3 housing

= 5365,310 liter/(batch.housing)

1 batch = 3 jam proses

$$Laju\ susu = \frac{5365{,}310\ liter/batch}{3\ jam}$$

$$= 1788{,}437\ liter/jam$$

qf = 0,000497 m^3/s = 0.0175 ft^3/s = 0,5092 kg/s

Trial aliran turbulent dan Di > 1 in

Di_{opt} = 3,9 $qf^{0,45}$ $\mu^{0,13}$ [28, hal 381]

= 3,9 $0.0175^{0,45}$. $8^{0,13}$

= 0,828 in

Dipakai diameter pipa =1,049 in, NPS =1 in, Sc 40. [20 App A.5-1]

Diameter pipa 1,049 in = 0,0266 m

Luas penampang pipa,A = $1/4\pi.D^2$

= ¼.3,14. $0{,}0351^2$

= 0,000554m^2

Check asumsi aliran turbulent

$$N_{RE} = \frac{D.qf}{\mu.A}$$

$$= \frac{0{,}0266\,m.\ 0{,}5092\ kg/s}{0{,}0008\,kg/m.s.0{,}000554\,m^2}$$

= 30561,191

NRE> 2100, asumsi memenuhi

b. Pipa 3 untuk pengeluaran permeat

Laju masuk pipa = 4.294,499 kg/hari

= 4294,499 kg/hari / 1024,56 kg/m^3

= 4,192 m^3/hari = 4192 liter/hari

= 4.192 liter/hari / 7batch

= 598,857 liter/batch

1 batch = 3 housing

Laju masuk pipa = 598,857 liter/batch / 3 housing

= 199,619 liter/(batch.housing)

1 batch = 3 jam proses

$$Laju\ susu = \frac{199{,}619\ liter/batch}{3\ jam}$$

$$= 66{,}540\ liter/jam$$

qf = 0,0000185m^3/s = 0,000653 ft^3/s = 0,0190 kg/s

Trial aliran turbulent dan D <1 in

$Di_{opt} = 4{,}7\ qf^{0,49}\ \mu^{0,14}$ [28, hal 381]

$= 4{,}7.\ 0{,}000653^{0,49}.\ 8^{0,14}$

= 0,173 in

Dipakai diameter pipa = 0,269 in, NPS = 0,125 in, Sc 40

[20 App A.5-1]

Diameter pipa 0,269 in = 0,00683 m

Luas penampang pipa,A = $1/4\pi.D^2$

= ¼.3,14. $(0{,}00683m)^2$

= 0.0000366 m^2

Check asumsi aliran turbulent

$$N_{RE} = \frac{D.qf}{\mu.A}$$

$$= \frac{0{,}00683m.\ 0{,}0190kg/s}{0{,}0008\ kg/m.s.0{,}0000366\ m^2}$$

= 4432,036

NRE> 2100, asumsi memenuhi

c. Pipa 6, untuk air diafiltrasi

Laju air masuk pipa = 490,799 liter/batch

1 batch = 3 housing

Laju air masuk pipa = 490,799 liter/batch / 3 housing

= 163,6000 liter/(batch.housing)

Air masuk pipa selama 2 jam

$$Laju\ air = \frac{163{,}600\ liter/batch}{2\ jam}$$

$$= 81{,}800\ liter/jam$$

qf = 0,0000227 m^3/s = 0,000802 ft^3/s = 0,0233kg/s

Trial aliran turbulent dan D <1 in

Di_{opt} = 4,7 $qf^{0,49}$ $\mu^{0,14}$ [28, hal 381]

= 4,7. $0{,}000802^{0,49}$. $8^{0,14}$

= 0,191 in

Dipakai diameter pipa = 0,269 in, NPS = 0,125 in, Sc 40

[20 App A.5-1]

Diameter pipa 0,269 in = 0,00683 m

Luas penampang pipa,A = $1/4\pi.D^2$

= ¼.3,14. $(0{,}00683m)^2$

= 0,0000366 m^2

Check asumsi aliran turbulent

$$N_{RE} = \frac{D.qf}{\mu.A}$$

$$= \frac{0{,}00683\,m.\ 0{,}0233\,kg/s}{0{,}0008\,kg/m.s.0{,}0000366\,m^2}$$

= 54350,75

NRE> 2100, asumsi memenuhi

Spesifikasi Pipa:

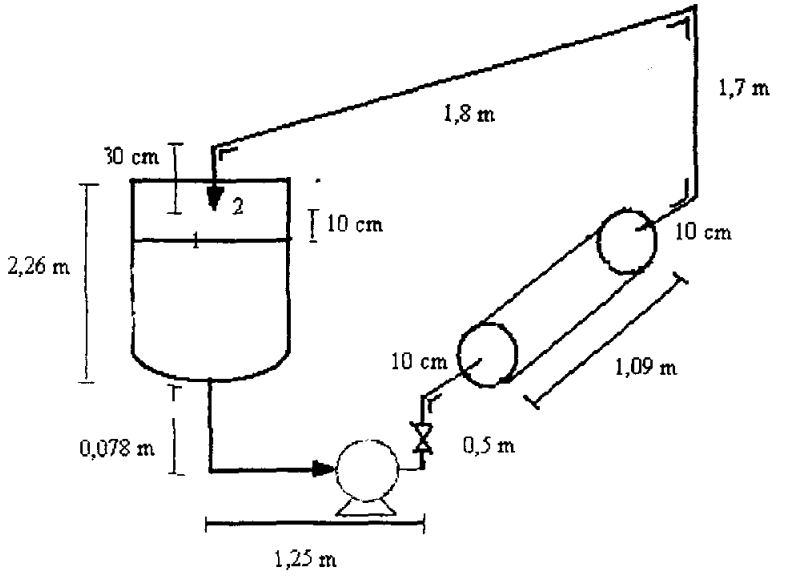
Pipa 2 untuk sirkulasi *retentate* ID = 1,049 in, NPS = 1 in, Sc 40

Pipa 4 untuk pemompaan *retentate* ID = 1,049 in, NPS = 1 in, Sc 40

Pipa 3 untuk pengeluaran *permeate* ID = 0,269 in, NPS = 0,125 in, Sc 40

Pipa 6 untuk air diafiltrasi 0,269 in, NPS = 0,125 in, Sc 40

Penghitungan Pompa



Friksi pompa terdiri dari :

1. Sudden Contraction

$h_c = 0{,}55.\frac{v^2}{2\alpha}$

α untuk aliran turbulent = 1

Q,Debit = 0,000497 m^3/s

0,000497 m^3/s = 0,000554m^2. v

v = 0,897 m/s

$hc = 0{,}55.\frac{0{,}897^2}{2}$

= 0,221 m^2/s^2

2. Valve

Yang digunakan adalah globe valve, $K_f = 6$

$h_c = 6.\frac{v^2}{2}$

$= 6.\frac{0{,}897^2}{2}$

= 2,414 m^2/s^2

3. Elbow 90° sebanyak 6 buah

$h_c = 6.K_f.\frac{v^2}{2}$

K_f = 0,75 [20 Tabel 2.10-1 hal 99]

$= 6.0{,}75\frac{0{,}897^2}{2}$

= 1,810 m^2/s^2

4. Pipa 1,049 in (0,0266m)

ΔL = 0,078 m + 1,25 m + 0,5 m + 0,1 m + 0,1 m + 1,7 m + 1,8 m + 0,3 m

= 5,828 m

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

ε/D = $4,6.10^{-5}$m/ 0,0266m

= 0,00173

N_{RE} =30561,191 dan ε/D =0,00173 Fig 2.10-3 didapat f =0,008

$F_f = 4.\ 0,008\ \frac{5,828}{0,0266}\frac{0,897^2}{2}$

= 2,821 m^2/s^2

5. Membran, dianggap pipa lurus dengan ID=0,364 m dan L=1,092 m

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

ε/D = $4,6.10^{-5}$ m/ 0,364 m

= 0,000126

N_{RE} =30561,191 dan ε/D =0,000126 Fig 2.10-3 f =0,013 [20 Fig 2.10-3]

$F_f = 4.\ 0,013\ \frac{1,092}{0,364}\frac{0,897^2}{2}$

= 0,063m^2/s^2

Total friksi = 7,318 m^2/s^2

Persamaan Bernoulli

$$\frac{1}{2\alpha}(v_2^{\ 2} - v_1^{\ 2}) + g(z_2 - z_1) + \frac{(p_2 - p_1)}{\rho} + \Sigma F + W_s = 0$$

$$\frac{1}{2}((0{,}897\,m/s)^2 - 0) + 9{,}8\,m/s^2(0{,}1\,m) + 0 + 7{,}318\,m^2/s^2 + W_s = 0$$

Ws = -8,700 m^2/s^2 = -8,700 J/kg

Kapasitas 1788,437 *liter / jam* = 7,87 gallon/menit

Didapat efisiensi pompa sebesar 30% [28, Fig 13-37 hal 550]

$W_s = -\eta W_p$

$-8{,}700 = -0{,}3 . W_p$

$W_p = 29{,}000$ J/kg

Power pompa = $Wp . q_f . \rho_{susu}$

= 29,000 J/kg . 0,000497 m^3/s . 1024,56 kg/m^3

= 0,014767kW

= 0,0198 hp

Spesifikasi Pompa :

Tipe pompa : *Centrifugal pump*

Power : 0,0198 hp

16. Tangki Penampungan Permeat

Fungsi : Menampung permeat yang telah dipisahkan dari susu dengan menggunakan membran

Tipe : Silinder tegak dengan tutup atas berbentuk plat datar dan tutup bawah berbentuk *dished head.*

Dasar pemilihan : Untuk menampung bahan yang berbentuk cair.

Kondisi operasi :

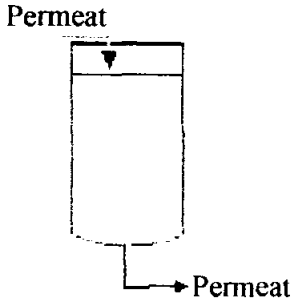
- T = 30°C
- Tekanan 1 atm
- Waktu tinggal 24 jam (kapasitas 2 jam dari kapasitas perhari)

Sistem operasi : *Batch*

Jumlah : 12 buah

Karena 1 hari proses adalah 24 jam dan tangki yang dimiliki sebanyak 12 buah, maka satu tangki digunakan untuk menampung permeat yang dihasilkan selama 2 jam proses.

Gambar :



Perhitungan :

Rate larutan masuk : 538.121,2076 $^{kg}/_{hari}$ =22.421,717 $^{kg}/_{jam}$

ρ permeat : 1.024,56 $^{kg}/_{m^3}$ = 63,9645 $^{lbm}/_{ft^3}$

Waktu tinggal : 1 hari = 24 jam

Kapasitas tangki :

Volume larutan total : $\frac{22.421,717\ ^{kg}/_{jam}}{1.024,56\ ^{kg}/_{m^3}} \cdot 2\ jam = 43,7685\ m^3 = 1.545,5970\ ft^3$

Diambil : tinggi tangki (H_t) = 1,1 x Diameter tangki (D_t)

Volume shell = $(\pi/4).D_t^{\,2}.H_t = (\pi/4).D_t^2.1{,}5.D_t = (\pi/4).1{,}5.D_t^3$

Volume torispherical dished head (ft^3) = 0,000049 x D_t^3 (in)

[22, pers 5.11, hal 88]

Volume tangki penampung = volume shell + volume *dished head*

Diambil : volume tangki penampung = 1,3 . volume larutan total

Volume tangki = volume cylindrical shell + volume dished head

$$1{,}3 \times 1.545{,}597\,ft^3 = (\pi/4) \times D_t^2 \times H_t + 0{,}000049 \times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$2.009{,}2762\,ft^3 = (\pi/4) \times \left(\frac{H_t}{1{,}1}\right)^2 \times H_t + 4{,}9.10^{-5} \times \left(\frac{H_t}{1{,}1}\right)^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$2.009{,}2762\,ft^3 = 0{,}6491 H_t^3$$

$$H_t = 14{,}5731\,ft$$

Digunakan 2 course 8 ft, sehingga $H_t \approx 16$ ft

Volume tangki = volume cylindrical shell + volume dished head

$$2.009{,}2762\,ft^3 = (\pi/4) \times D_t^2 \times H_t + 0{,}000049 \times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$2.009{,}2762\,ft^3 = (\pi/4) \times D_t^2 \times \left(\frac{1\,ft}{12\,in}\right)^2 \times 16\,ft + 0{,}000049 \times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$2.009{,}2762\,ft^3 = 0{,}0873 \times D_t^2 + 2{,}8356 \times 10^{-8} D_t^3$$

$$D_t = 151{,}7057\,in = 12{,}642\,ft$$

Volume larutan dalam dish = 0,000049 . D^3

= 0,000049 . (151,7057 in)^3

= 171,081 ft^3

Volume larutan dalam shell = vol. lart. total – vol. lart. dalam dish

= 1.545,597 ft^3 – 171,081 ft^3

$$=1.374{,}516\ ft^3$$

Tinggi lart. dalam shell (H_L) $= \dfrac{vol\ lart\ dlm\ shell}{\frac{\pi}{4}.D_t^2}$

$$= \frac{1.374{,}516\,ft^3}{\frac{\pi}{4}.(12{,}642\,ft)^2}$$

$$= 10{,}9504\ ft$$

P operasi = P hidrostatis $= \left(\dfrac{\rho \times H_L}{144}\right)$ psi

$$= \left(\frac{63{,}9645\ lbm/ft^3 \times 10{,}6504\ ft}{144}\right)$$

$$= 4{,}8641\ psi$$

P desain = 1,5 x P operasi = 1,5 x 4,8641 psi = 7,2962 psi

Tebal *Shell*

Menghitung tebal shell untuk course 1 (8 ft dari dasar):

$$t_s = \frac{P.ID}{2.f.E} + c$$

[22, pers 3.16]

dimana :

P = P desain = 7,2962 psi

ID = 151,7057 in

Konstruksi : Bahan konstruksi = *Stainless steel-316L*, dengan

f = strees maksimum yang diijinkan = 23.000 psi

Tipe sambungan = *double-welded butt joint*, dengan

E = *welded-joint efficiency* = 0,8 [22, Tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_s = \frac{(7{,}2962\,psi)\times(151{,}7057\,in)}{2\times(23.000\,psi)\times(0{,}8)} + 0{,}125\,in$$

$$= 0{,}1551 \text{ in} \approx \frac{3}{16} \text{ in}$$

Menghitung tebal shell untuk course 2 (8 hingga 16 ft dari dasar):

H_L = 10,9504 ft - 8 ft = 2,9504 ft

$$P_{hidrostatis} = \frac{H_L \text{ x } \rho_{permeat}}{144}$$

$$= \frac{2{,}9504\,ft\times 63{,}9645\,{}^{lbm}/_{ft^3}}{144}$$

= 1,3106 psi

P_{design} = 1,5 x $P_{hidrostatis}$

= 1,5 x 1,3106 psi

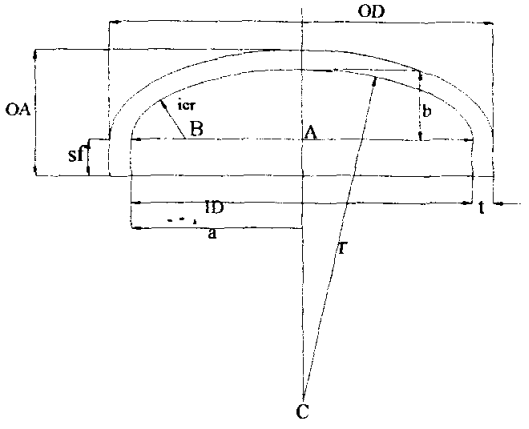
= 1,9658 psi

$$\text{Tebal shell } (t_s) = \frac{P_{design}\times ID}{2\times f\times E} + c$$

$$= \frac{(1{,}9658\,psi)\times(151{,}7057\,in)}{2\times(23.000\,psi)\times(0{,}8)} + 0{,}125\,in$$

= 0,1331 in. ≈ 3/16 in.

Tebal *dished head*



r (*crown radius / radius of dish*) = 151,7057 in

icr (*inside corner radius / knuckle radius*) = 6% x 151,7057 in = 9,1023 in

$$W = \frac{1}{4}\times\left[3+\sqrt{\frac{r}{icr}}\right] \qquad \text{[22, pers 7,76]}$$

$$= \frac{1}{4}\times\left[3+\sqrt{\frac{151,7057}{9,1023}}\right]$$

$$= 1,7706$$

$$a = \frac{ID}{2} = \frac{151,7057\ in}{2} = 75,8529\ in$$

$$AB = \frac{ID}{2} - icr = \frac{151,7057\ in}{2} - 9,1023in = 66,7506\ in$$

$$BC = r - icr = (151,7057\text{-}9,1023)\ in = 142,6034\ in$$

$$b = r - \sqrt{BC^2 - AB^2} = 151,7057 - \sqrt{142,6034^2 - 66,7506^2} = 25,6895\ in$$

$$t_d = \frac{P\times r\times W}{2\times f\times E - 0,2\times P} + c \qquad \text{[22, pers 7.77, p.138]}$$

dimana :

P = P desain = 7,2962 psi

Konstruksi : Bahan konstruksi = *Stainless steel-316 L*, dengan

f = stress maksimum yang diijinkan = 23.000 psi

Tipe sambungan = double-welded butt joint, dengan

E = welded-joint efficiency = 0,8 [22, tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_d = \frac{(7{,}2962\ psi)\times(151{,}7057\ in)\times 1{,}7706}{(2\times 23.000\ psi\times 0{,}8)-(0{,}2\times 7{,}2962)} + 0{,}125\ in$$

$$= 0{,}1783 \approx \frac{3}{16}\ \text{in}$$

Dipilih panjang straight-flange (sf) = 2 in [22, tabel 5.8, p.93]

OA = t_d + b + sf

= ($\frac{3}{16}$ + 25,6895 + 2) in

= 27,877 in = 2,32 ft

Tinggi tangki keseluruhan = tinggi shell + tinggi dish

= 16 ft + 2,32 ft

= 18,32 ft

Tebal plat datar (t_f) = 3/16 in.

Spesifikasi :

Tangki

Kapasitas : 1.545,5970 ft^3

Diameter : 12,642 ft

Tinggi tutup bawah (dished head): 2,32 ft

Tinggi shell : 16 ft

Tinggi tangki total : 18,32 ft

Tebal *shell course* 1 : 0,1551 in $\approx \frac{3}{16}$ in

Tebal *shell course* 2 : 0,1331 in $\approx \frac{3}{16}$ in

Tebal tutup bawah (dished head) : 0,1783 in $\approx \frac{3}{16}$ in

Bahan konstruksi : *Stainless steel-316 L*

Jumlah tangki : 12 buah

17. Tangki penampung susu cair tinggi protein setelah ultrafiltrasi (F-312)

Fungsi : Sebagai penampung susu cair tinggi protein ultrafiltrasi

Tipe : Silinder tegak dengan tutup atas berbentuk plat datar dan tutup bawah berbentuk *dished head.*

Dasar pemilihan : Untuk menampung bahan yang berbentuk cair.

Kondisi operasi :

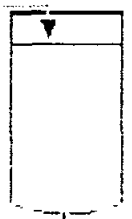
- T = 30°C
- Tekanan 1 atm
- Waktu tinggal 1 jam

Sistem operasi : *Batch*

Jumlah : 1 buah

Gambar :

Susu cair tinggi protein (dari membran)



Susu cair tinggi protein (ke evaporator)

Perhitungan :

Rate larutan masuk : 4.484,3434 $^{kg}/_{jam}$

ρ susu : $1033.7 - 0.2308T - 0.00246\ T^2$

$1024{,}56\ ^{kg}/_{m^3} = 64{,}1245\ ^{lbm}/_{ft^3}$

waktu tinggal : 3 jam

volume larutan total :

$$\frac{4.484{,}3434\ ^{kg}/_{jam}}{1024{,}56\ ^{kg}/_{m^3}}.3\ jam = 13{,}2411\ m^3 = 467{,}583\ ft^3$$

Diambil : tinggi tangki (H_t) = 1,5 . Diameter tangki (D_t)

Volume shell = $(\pi/4).D_t^{\,2}.H_t = (\pi/4).D_t^2.1{,}5.D_t = (\pi/4).1{,}5.D_t^3$

Volume torispherical dished head (ft^3) = 0,000049 x D_t^3 (in)

[22, pers 5.11, hal 88]

Volume tangki penampung = volume shell + volume *dished head*

Diambil : volume tangki penampung = 1,3 . volume larutan total

Volume tangki = volume cylindrical shell + volume dished head

$$1{,}3 \times 467{,}583\,ft^3 = (\pi/4) \times D_t^2 \times H_t + 0{,}000049 \times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$607{,}8579\,ft^3 = (\pi/4) \times \left(\frac{H_t}{1{,}5}\right)^2 \times H_t + 4{,}9.10^{-5} \times \left(\frac{H_t}{1{,}5}\right)^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$607{,}8579\,ft^3 = 0{,}3491\,H_t^3$$

$$H_t = 12{,}0305\,ft$$

Digunakan 1 course 8 ft dan 1 course 6 ft, sehingga $H_t \approx 14$ ft

Volume tangki = volume cylindrical shell + volume dished head

$$607{,}8579\,ft^3 = (\pi/4) \times D_t^2 \times H_t + 0{,}000049 \times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$607{,}8579\,ft^3 = (\pi/4) \times D_t^2 \times \left(\frac{1\,ft}{12\,in}\right)^2 \times 14\,ft + 0{,}000049 \times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$607{,}8579\,ft^3 = 0{,}0764 \times D_t^2 + 2{,}8356 \times 10^{-8} D_t^3$$

$$D_t = 89{,}1964\,in = 7{,}433\,ft$$

Volume larutan dalam dish $= 0{,}000049 \,.\, D^3$

$= 0{,}000049 \,.\, (89{,}1964 \text{ in})^3$

$= 34{,}7727 \text{ ft}^3$

Volume larutan dalam shell = vol. lart. total – vol. lart. dalam dish

$= 467{,}583 \text{ ft}^3 - 34{,}7727 \text{ ft}^3$

$= 432{,}8103 \text{ ft}^3$

Tinggi lart. dalam shell (H_L) $= \dfrac{vol.lart.dlm.shell}{\frac{\pi}{4} . D_t^2}$

$$= \frac{432{,}8103\,ft^3}{\frac{\pi}{4} . (7{,}433\,ft)^2}$$

H_L = 9,9742 ft

P operasi = P hidrostatis $= \left(\frac{\rho \times H_L}{144}\right)$ psi

$$= \left(\frac{64{,}1245\,lbm/ft^3 \times 9{,}9742\,ft}{144}\right)$$

= 4,4416 psi

P desain = 1,5 x P operasi = 1,5 x 4,4416psi = 6,6624 psi

Tebal *Shell*

Menghitung tebal shell untuk course 1 (0 ft dari dasar):

Menghitung tebal shell:

$$t_s = \frac{P.D_t}{2.f.E} + c \qquad \text{(22, pers 3.16)}$$

dimana :

P = P desain = 6,6624 psi

D_t = 89,1964 in

Konstruksi : bahan konstruksi = *Stainless steel-316 L*, dengan

f = strees maksimum yang diijinkan = 23.000 psi

tipe sambungan = *double-welded butt joint*, dengan

E = *welded-joint efficiency* = 0,8 [22, Tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_s = \frac{(6.6624\,psi) \times 89{,}1964}{2 \times 23.000 \times 0{,}8} + 0{,}125in$$

$= 0{,}1411 \text{ in} \approx {}^{3}/_{16} \text{ in}$

Menghitung tebal shell untuk course 2 (8 hingga 14 ft dari dasar):

H_L = 9,9742 ft - 6 ft = 3,9742 ft

$$P_{hidrostatis} = \frac{H_L \text{ x } \rho \text{ susu}}{144}$$

$$= \frac{3{,}9742\ ft \times 64{,}1245\ {}^{lbm}/_{ft^3}}{144}$$

= 1,7697 psi

P_{design} = 1,5 x $P_{hidrostatis}$

= 1,5 x 1,7697 psi

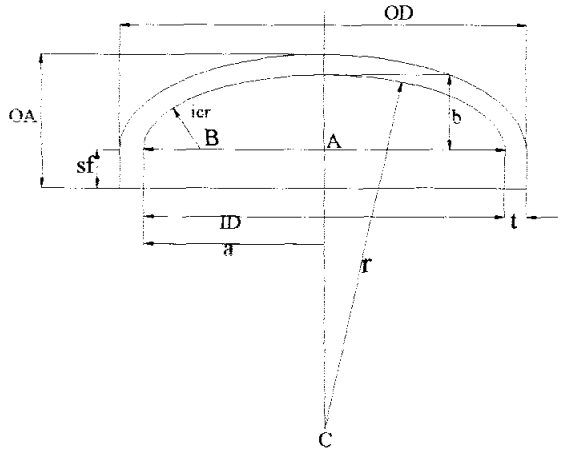
= 2,6546 psi

$$\text{Tebal shell } (t_s) = \frac{P_{design} \times D_t}{2 \times f \times E} + c$$

$$= \frac{(2{,}6546\ psi) \times (89{,}1964\ in)}{2 \times (23.000\ psi) \times (0{,}8)} + 0{,}125\ in$$

= 0,1314 in. ≈ 3/16 in.

Tebal *dished head*



r (*crown radius / radius of dish*) = 89,1964 in

icr (*inside corner radius / knuckle radius*) = 6% x 89,1964 in = 5,3518 in

$$W = \frac{1}{4} \times \left[3 + \sqrt{\frac{r}{icr}} \right]$$ [22, pers 7,76]

$$= \frac{1}{4} \times \left[3 + \sqrt{\frac{89,1964}{5,3518}} \right]$$

$$= 1,7706$$

$$a = \frac{D_t}{2} = \frac{89,1964\ in}{2} = 44,5982\ in$$

$$AB = \frac{D_t}{2} - icr = \frac{89,1964\ in}{2} - 5,3518 in = 39,2464\ in$$

BC = r – icr = (89,1964-5,3518) in = 83,8446 in

$$b = r - \sqrt{BC^2 - AB^2} = 89,1964 - \sqrt{83,8446^2 - 39,2464^2} = 15,1043 in$$

$$t_d = \frac{P \times r \times W}{2 \times f \times E - 0,2 \times P} + c$$ [22, pers 7.77, hal.138]

dimana :

P = P desain = 6,6624 psi

Konstruksi : bahan konstruksi = *Stainless steel-316 L*, dengan

f = stress maksimum yang diijinkan = 23.000 psi

tipe sambungan = double-welded butt joint, dengan

E = welded-joint efficiency = 0,8

(22, tabel 13.2)

c = *Corrosion allowance* = 0,125 in

$$t_d = \frac{(6{,}6624\,psi)\times(89{,}1964\,in)\times 1{,}7706}{2\times((23.000\,psi)\times 0{,}8)-(0{,}2\times 6{,}6624\,psi)} + 0{,}125\,in$$

$= 0,1536 \text{ in} \approx 3/16 \text{ in}$

Dipilih panjang straight-flange (sf) = 2 in (22, tabel 5.8, p.93)

OA $= t_d + b + sf$

$= (3/16 + 15{,}1043 + 2) \text{ in}$

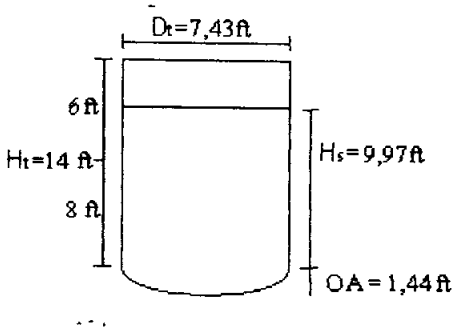
$= 17{,}29183 \text{ in} = 1{,}441 \text{ ft}$

Tinggi tangki keseluruhan = tinggi shell + tinggi dish

= 14 ft + 1,441 ft

= 15,441 ft

Tebal plat datar (t_f) = 3/16 in.



Spesifikasi :

Tangki

Kapasitas : 467,583 ft^3

Diameter : 7,433 ft

Tinggi tutup bawah (dished head): 1,441 ft

Tinggi shell : 14 ft

Tinggi tangki total : 15,441 ft

Tebal shell untuk course 1 : 0,1411 in $\approx \frac{3}{16}$ in

Tebal shell untuk course 2 : 0,1314 in $\approx \frac{3}{16}$ in

Tebal tutup bawah (dished head) : 0,1536 in $\approx \frac{3}{16}$ in

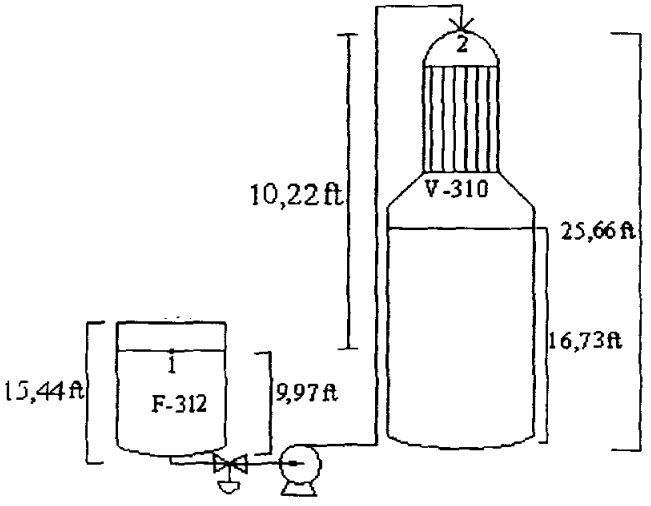
Bahan konstruksi : *Stainless steel-316 L*

Jumlah tangki : 1 buah

18. Pompa L-311

Fungsi : Mengalirkan susu tinggi protein dari tangki F-312 ke evaporator (V-310)

Tipe : *Centrifugal pump*



Perhitungan :

T = 30°C

Massa susu masuk = 4.484,3434 kg/jam = 1,2457 kg/s

ρ susu : $1033,7 - 0,2308T - 0,00246\ T^2$

: $1.024,562\ {}^{kg}/_{m^3} = 63,9647\ {}^{lbm}/_{ft^3}$

Viskositas : 0,0008 kg/m.s = 0,0005 lb/ft.s

$$\text{Rate volumetrik} = \frac{4.484,3434\ {}^{kg}/_{jam}}{1.024,562\ {}^{kg}/_{m^3}} = 0,4727\ {}^{m^3}/_{jam} = 0,0046\ {}^{ft^3}/_{s}$$

Optimum inside diameter (Di,opt) dengan asumsi tipe aliran turbulen.

$Di,opt = 3,9\ q_f^{\ 0,45}\ \rho^{0,13}$ [28, pers 45, hal 381]

dimana : q_f = flow rate, ft^3/s

ρ = densitas fluida, lb/ft^3

$Di,opt = 3,9\ (0,0046)^{0,45}\ (63,9647)^{0,13} = 0,5944$ inch $\approx 0,622$ inch.

Digunakan pipa berukuran $\frac{1}{2}$ inch, sch.40 [20, App.A-5]

ID = 0,622 inch = 0,5283 ft = 0,0158m

A = 0,00211 ft^2

Kecepatan linier (v) = $\frac{q_f}{A} = \frac{0{,}0046\ ft^3/s}{0{,}00211\ ft^2}$ = 2,1905 ft/s = 0,6677 m/s

$$N_{Re} = \frac{\rho \times v \times ID}{\mu}$$

$$= \frac{(63{,}9647\ lb/ft^3)(2{,}1905\ ft/s)(0{,}5283\ ft)}{0{,}0005\ lb/ft.s}$$

=148.045,166 (turbulen) (asumsi benar)

Digunakan commercial steel : $\varepsilon = 4{,}6.10^{-5}$ m

$$\text{harga } \frac{\varepsilon}{ID} = \frac{4{,}6.10^{-5}}{0{,}0158} = 0{,}0029$$

f = 0,007 [20, Fig.2.10-3]

Panjang ekivalen :

- 4 buah standard elbow 90°; K_f = 0,75 [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 0{,}75 \times \frac{2{,}1905^2}{2} = 1{,}7994\ m^2/s^2$$

karena ada 4 buah maka =1,7994 m^2/s^2 x 4 = 7,1976 m^2/s^2

- 1 buah globe valve; wide open K_f = 6 [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{2{,}1905^2}{2} = 14{,}3949\ m^2/s^2$$

- panjang pipa lurus = 35,333 ft

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}007 \times \frac{35{,}333}{0{,}115} \times \frac{2{,}1905^2}{2} = 20{,}6377 \, {}^{m^2}/_{s^2}$$

[20, pers.2.10-6]

- Friksi *sudden contraction* dari tangki *F-312* ke pipa

$$h_c = 0{,}55 \times \left(1 - \frac{A_2}{A_1}\right) \times \frac{v_2^2}{2\alpha} = 0{,}55 \times (1-0) \times \frac{2{,}1905^2}{2} = 1{,}3195 \, {}^{m^2}/_{s^2}$$

Karena luas area tangki (A_1) >>> dari pada luas area pipa (A_2), maka $\frac{A_2}{A_1} \approx 0$

$$\Sigma F = 7{,}1976 + 14{,}3949 + 20{,}6377 + 1{,}3195 + 2{,}3991 = 43{,}5497 \, {}^{m^2}/_{s^2}$$

Persamaan Bernoulli :

$$-w_s = \Sigma F + \frac{v_2^2 - v_1^2}{2\alpha} + (z_2 - z_1)\, g + \frac{\Delta P}{\rho} \qquad \text{(20, pers.2.7-28)}$$

dimana : $Z_2 - Z_1 = 10{,}2159$ ft $= 3{,}1138$ m

$P_1 = 101.325$ N/m^2

$P_2 = 0{,}4$ bar $= 40.000$ N/m^2

$\Delta P = P_2 - P_1 = 40.000$ N/m^2 $- 101.325$ N/m^2 $= -61.325$ N/m^2

$v_1 = 0$, $v_2 = 0, 6677$ m/s

$$-w_s = 43{,}5497 + \frac{0{,}6677^2 - 0^2}{2} + 3{,}1138 \text{ x } 9{,}8067 + \frac{-61.325}{1.024{,}562}$$

$-w_s = 16{,}853\ m^2/s^2$

$Ws = -16{,}853\ m^2/s^2 = -16{,}853\ J/kg$

Efisiensi pompa (η) = 30% [28, fig 13-37, p.550]

$$W_p = -\frac{Ws}{\eta} = \frac{16{,}853}{0{,}30} = 56{,}1767\frac{j}{kg}$$

Flow rate = 1,2457 kg/s

$$\text{hp pompa} = 56{,}1767\ {}^{j}/_{kg} \times 1{,}2457\ {}^{kg}/_{s} = 69{,}9793\ W = 0{,}0938\ hp$$

Efisiensi motor = 80% [28, fig 14-38, p 521]

Sehingga dipakai pompa dengan motor = 0,0938 / 0,80 hp = 0,1173 hp ≈ 0,25 hp

Spesifikasi :

- Fungsi : mengalirkan susu pekat tinggi protein untuk ditampung
- Tipe : *centrifugal pump*
- Rate aliran pompa : 0,4727 m^3/jam
- Ukuran pipa : $\frac{1}{2}$ in sch 40
- Power motor : 0,25 hp
- Bahan konstruksi : *stainless steel*
- Jumlah : 1 buah

19. Evaporator (V-310)

Fungsi : Untuk memekatkan susu cair tinggi protein

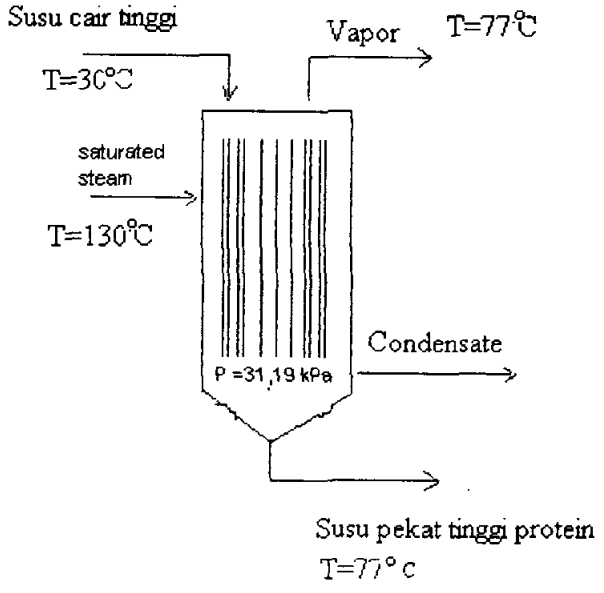
Tipe : *Falling Film Evaporator*

Dasar pemilihan : Digunakan untuk bahan yang tidak dapat tahan terhadap panas

Kondisi operasi :

Jenis fluida	**Panas : Steam 130°C**	**Dingin :Susu cair Tinggi protein 30°C**
Flow rate, kg/hari	6771,54	107624,2415
Suhu masuk, °C	130	303
Suhu keluar, °C	130	350

Gambar :



Penghitungan :

Desain evaporator dibagi menjadi 2 bagian, yaitu bagian penguapan dan bagian pemisahan liquida-uap yang berupa drum separator.

Menghitung bagian penguapan

Bagian Shell	Bagian Tube
ID = 23,25 in (41, Tabel 9)	Jumlah dan panjang 70 buah, 8'0''
B = 15 in	OD,BWG,pitch $1^1/_2$ in, 16, $1^7/_8$ in square pitch
Passes = 1	Passes = 2

(1) Neraca Panas

Qsteam =14.722.617,1256 kJ/hari = 581.428,9047 Btu/jam

Qsusu cair tinggi protein = 3.976.562,0863 kJ/hari = 235.564,9256 Btu/jam

(2) T susu cair tinggi protein masuk,t_1 = 30°C = 85,73°F

T susu cair tinggi protein keluar,t_2 = 77°C = 170,33°F

T steam,T_1 = T steam keluar,T_2 = 130°C = 265,73°F

(2) Fluida panas Fluida dingin Beda

265,7300	Higher Temp (°F)	170,3300	95,4000
265,7300	Lower Temp(°F)	85,7300	180,0000
0,0000	Differences	84,6000	84,6000
(T_1-T_2)			(t_2-t_1)

LMTD = 133,2539 °F [41 pers. 5.14]
R = 0/84,6 = 0
S = 84,6/(265,73 – 85,73) = 0,47
FT = 1 [41, Fig 18]
Δt = FT x LMTD = 133,2539 °F

(3) Tc = (265,73 + 265,73)/2 = 265,73°F

tc = (170,33 +85,73)/2 = 128,03°F

Fluida panas, bagian shell, steam	Fluida dingin, bagian tube, susu cair tinggi protein
(4') Luas aliran, as = ID x C'B/144 PT [41, Pers. 7.1] = 23,25 x0,25x 15/144x1 = 0,6055 ft^2	(4) a't =1,47 in^2 [41, tabel10] at = (Nt × a't)/(144n) = (70. 1,47/144.2) = 0,7146 ft^2
(5') laju alir massa, Gs = W/as (41, pers. 7.2) = 622,0321/0,6055 = 1027,3563 lb/jam ft^2	(5) Gt = W/at = 20752,6598 lb/h ft^2
(6') De = 4 x luas aliran/ frictional wetted perimeter (41,pers. 6.4) =4 x0,6055 / (70x3,14x 1,5/12) =0,0881 ft	(6) D = 1,37 in = 0,1142 ft (41, tabel 10) μ = 1,7150 lb/ft h R_{et} = D Gt/ μ = 1381,5298
μ =0,0342 lb/ft jam (20, A.2-12) R_{es} = De x Gs / μ = 0,0881x 1027,3563/ 0,0342 = 2650,0775	
(7') jH =45 (41, Fig. 28)	
(8') Pada Tc = 265,73°F Cp = 0,4540 Btu/lb°F k = 0,0161 Btu/jam.ft°F (cp μ/k)$^{1/3}$ =(0,4540 x0,0342/0,0161)$^{1/3}$ = 0,9881	
(9') ho/Φs=jH. k/De x (cp μ /k)$^{1/3}$ ho/Φs = 45.0,0161/ 0,0881 . 0,9881 = 8,1148	(9) Kondensasi steam hio = 1500 Btu/jamft^2°F
(11') Pada tw= 264,99°F μ = 0,0313 lb/ft jam (μ/ μw)^{0,14} = (0,0342/0,0313)^{0,14} Φs = 1,0122	(10) tw = tc+hio/(hio+ho) (Tc-tc) (41 pers. 5.31a) = 264,99°F
(12') Koefisien koreksi = ho/Φs x Φs (41,pers.6.36) ho = 6,7624 x 1,0122 = 8,2142Btu/jam ft^2 °F	

(13') Uc = hio.ho/(hio+ho)

= 1500x 8,2142 / (1500 +8,2142)

= 8,1695 Btu/h ft² °F

(14') a'' = 0,1963 (41, Tabel 10)

A = Nt × L × a''

= 70 x 16 ft x 0,1963

= 219,8560 ft²

UD = Q/(A.Δt)

= 8,0407 Btu/h ft² °F

(15') Dirt factor, Rd :

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

$$= \frac{8,1695 - 8,0407}{8,1695.8,0407} = 0,0029 \text{ jam ft}^2 \text{ °F/Btu}$$

Kesimpulan

8,2142	h outside	1500,0000
UC	8,1695	
UD	8,0407	
Rd calculated		0,0029
Rd required		0,0030

Pressure Drop

(1) Spesifik volume stem V = 73,52 ft^3/lb $s = \frac{1/73,52}{62,5} = 0,0002$ R_{es} = 2650,0775, f =0,0028 (41, Fig.29) N+1 = 12L/B (41, pers 7.48) N+1 = 12.8/15 = 6,4000 = 7 Ds = 23,25/12 = 1,9375 ft ΔPs = f Gs^2 Ds (N+1)/(5.22 × 10^{10} De s Φs) (41, pers.7.44) = 0,03954	s =1 R_{et} = 1381,5298 f = 0,00047 ft^2/in^2 (41,Fig.26) ΔPt = f Gt^2 L n/(5.22 × 10^{10} D s Φt) (41, pers. 7.45) = 0,00054 psi $V^2/2g'$ =0,0070 psi (41, Fig 27) ΔPr = 4n/s $V^2/2g'$ = 0,0280 psi ΔPT = ΔPt+ΔPr = 0,00054 psi + 0,0280 psi = 0,0285 psi

Menghitung bagian pemisahan liquid-uap (drum separator)

L = 107.624,2415 kg/hari = 14.829,5048 lb/jam = 0,5693 lb/s

V = 37.075,1829 kg/hari = 3405,7173 lb/jam = 0,946 lb/s

P = 0,4 Bar = 40,53 kPa

Spesifik volume uap = 3,769 m^3/kg [20, A.2-9]

ρ_{uap} = 0,265 kg/m^3 = 0,015 lb/ft^3

$\rho_{susu\ pekat\ tinggi\ protein}$ = 1001,66 kg/m^3 = 56,73 lb/ft^3

$$\frac{w_L}{w_V}\sqrt{\frac{\rho_V}{\rho L}} = \frac{107.624,2415}{37.075,1829}\sqrt{\frac{0,015}{56,73}} = 0,0472$$

k_v = 0,35 [42 ,tabel 4-10]

$$V_{max} = kv\sqrt{\frac{\rho_L - \rho_V}{\rho_V}} = 0,35\sqrt{\frac{56,73 - 0,015}{0,015}} = 21,52 \text{ ft/s}$$

[42, pers 4-9]

$V_{design} = 0,75 \; . \; V_{max}$

$= 0,75 \; . \; 21,52$ ft/s $= 16,14$ ft/s

$$qv = \frac{w_V}{\rho_V} = \frac{0,946 \; lb/s}{0,015 lb/ft^3} = 63,067 ft^3/s$$

$$A = \frac{qv}{V_{design}} = \frac{63,067 ft^3/s}{16,14 ft/s} = 3,907 ft^2$$

$A = \pi/4x \; D^2$

$$D = \sqrt{\frac{4 \times 3,907}{3,14}} = 2,231 \text{ ft} = 0,6800 \text{ m}$$

Rate liquida = 14.829,5048 lb/jam

Waktu tinggal = 15 menit = 0,25 jam

Volume liquid $= \frac{rate liquid}{\rho} x waktu = \frac{14829,5048 lb/jam}{56,73 \text{ lb/ft}^3} x 0,25 jam =$

65,351 ft

Volume liquid $= \pi/4 . D^2 . H_L$

$65,351 \text{ ft}^3 = \pi/4 \; .(2,231 \text{ ft})^2 \; . H_L$

$H_L = 16,726 \text{ ft} = 5,1 \text{ m}$

tinggi ruang uap = 10 in [42,tabel 4-11]

$H_V = 10 \text{ in} = 0,28 \text{ m}$

Tinggi drum separator = 5,1 m + 0,28 m = 5,38 m

Tinggi total evaporator = tinggi bagian penguapan + tinggi drum separator

$$= \frac{8}{3,2808} m + 5,38 m$$
$$= 7,82 m$$

Spesifikasi :

Panjang tube	: 8 ft
Jumlah tube	: 70 buah
D_o tube	: 1 ½ in
D_i tube	: 1,37 in
ΔP_{tube}	: 0,0285 psi
ΔP_{shell}	: 0,0394 psi
Tinggi drum separator	: 5,38 m
Tinggi total evaporator	: 7,82 m
Jumlah evaporator	: 1 buah (*single effect evaporator*)

20. *Barometric Condensor* (G –313)

Fungsi : Mengkondensasikan uap dari evaporator

Tipe : counter flow Barometric Condensor

Dasar pemilihan : konstruksi lebih murah dan luas permukaan kontak lebih besar

Perhitungan :

Rate uap pada 170,6 °F (v) = 37.075,1829 kg/hari = 3.405,7173 lb/jam

λ uap pada 170,6 °F (λ) = 1134,548 – 138,571 = 995,9768 btu/lbm

[20, App. A.2-9]

Kebutuhan air pendingin

$$W\,(gpm) = \frac{Q}{500(Ts - tw - ta)}$$ [41. pers 14.4, hal.396]

Dimana :

Ts = suhu uap jenuh = 170,6°F

tw = suhu air pendingin = 30°C = 86°F

ta = derajat pendekatan terhadap Ts

untuk counter flow barometric condensor, ta = 5 °F [41, hal.397]

Q = v.λ = 3.405,7173 x 995,9768 = 3.392.015,369 btu/jam

$$W = \frac{3.392.015,369\ btu/jam}{500(170,6-86-5)^{\circ}F} = 85,2265 \text{ gpm}$$

Panjang tailing pipa

Persamaan bernoulli = $P_2 + \rho.g.h = P_1$

$P_2 = P_{uap}$ = 0,4 bar = 40.000 Pa

P_1 = 101,325 kpa = 101.325 Pa

ρ air = 995,68 kg/m^3

g = 9,80665 m/s^2

$$h = \frac{P_1 - P_2}{\rho.g} = \frac{101.325 - 40.000}{995,68.9,80665} = 6,28 \text{ m}$$

Spesifikasi

Tipe = counter flow barometic condensor

Rate uap = 37.075,1829 kg/hari = 3.405,7173 lb/jam

Kebutuhan air pendingin = 85,2265 gpm

Panjang tailing pipa = 6,2805 m

Bahan = *Stainless steel* 316L

Jumlah = 1 buah

21. Bak *Barometric Condenser* (F-315)

Fungsi : untuk menampung kondensasi uap air *barometric condenser* (G-313)

Bentuk : bak berbentuk kubus

Penghitungan :

Uap air yang menuju ke *barometric condenser* sebesar 37.075,1829 kg/hari.

Bak *barometric* dirancang untuk kapasitas 1 hari. Banyak air ang ditampung dalam 6 jam sebesar 9268,8 liter = 9,268 m^3.

Dengan asumsi Volume air = 80% volume bak

Volume bak = 100/80. 9,268 m^3

Volume bak = 11,585 m^3

Bentuk bak kubus jadi ukuran panjang,lebar dan tingginya adalah 2,26 m x 2,26 m x 2,26 m

22. *Vacuum Pump* (G-314)

Fungsi : Untuk memvakumkan evaporator (V-310)

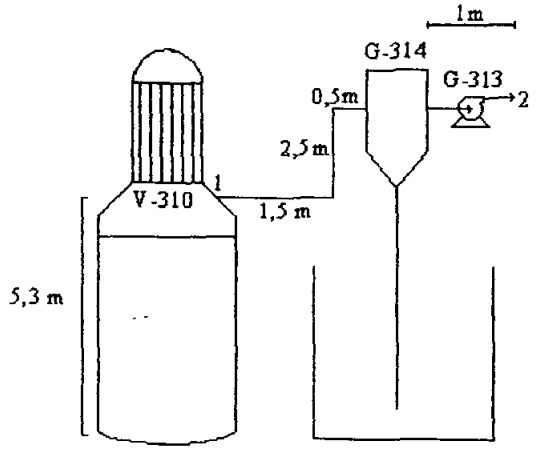
Type : *rotary vane pump*

Dasar Pemilihan : cocok untuk tekanan vakum yang rendah

Bahan konstruksi : *stainless steel* SA-240 Grade S tipe 304

Kondisi Operasi : Tekanan operasi = 0,4 bar

Gambar :



Laju uap air = 37.075,1829 kg/hari

= 0,0148 kmol/s (BM_{udara}=28,97kg/kmol)

Dimana :

γ udara = 1,4 (untuk gas diatomic)

Ep = 70 % [43, hal 195]

K = (γ -1) / (γ.Ep)

K = 1,4 – 1 / 1,4 . 0,7 = 0,408

N = 1/(1-K) [43, hal 195]

N = 1 / 1-0,408 = 1,689

Perhitungan power

$$H = \frac{ZRT}{(N-1)/N}\left[\left(\frac{P_2}{P_1}\right)^{(N-1)/N} - 1\right] \quad \text{[43, hal 195]}$$

Z = 1

$$H = \frac{1.\ 8{,}314\ .\ (273+77)}{(1{,}689-1)/1{,}689}\left[\left(\frac{1\,atm}{0{,}394\,atm}\right)^{(1{,}689-1)/1{,}689} - 1\right]$$

= 3297,09 J/kmol = 3,297 kJ/kmol

Power = H . M / Ep = 3,297 kJ/kmol . 0,0148 kmol/s / 0,7 = 0,0697 kW

Power = 0,0697 kW / 0,7457 = 0,093 Hp ≈ 0,25 Hp

Spesifikasi :

Fungsi : untuk memvakumkan evaporator (V-310)

Type : *rotary vane pump*

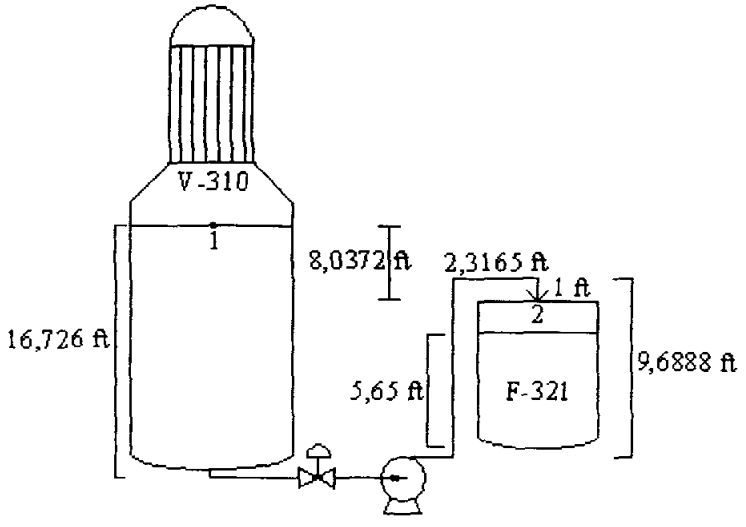
Power : 0,25 Hp

23. Pompa (L-316)

Fungsi : Mengalirkan susu tinggi protein pekat ke tangki penampungan F-321

Tipe : *centrifugal pump*

Gambar :



Perhitungan

T = 77°C

Massa susu masuk = 2.939,5441 kg/jam = 0,8165 kg/s

ρ susu =1033,7- 0,2308T – 0,00246 T^2

$$=1.001{,}3431\ {}^{kg}/_{m^3} = 62{,}5151\ {}^{lbm}/_{ft^3}$$

Viskositas : 0,001 kg/m.s = 0,0006 lb/ft.s

$$\text{Rate volumetrik} = \frac{2.939{,}5441\ {}^{kg}/_{jam}}{1.032{,}7374\ {}^{kg}/_{m^3}} = 2{,}8464\ {}^{m^3}/_{jam} = 0{,}0279\ {}^{ft^3}/_{s}$$

Optimum inside diameter (Di,opt)

$$Di,opt = 3{,}9\ q_f^{\,0,45}\ \rho^{0,13}$$ [28, pers 45, hal 381]

dimana : q_f = flow rate, ft^3/s

ρ = densitas fluida, lb/ft^3

$Di,opt = 3{,}9\ (0{,}0279)^{0,45}\ (62{,}5151)^{0,13} = 1{,}3337$ inch ≈ 1,380 inch.

Digunakan pipa berukuran $1\ {}^{1}/_{4}$ inch, sch.40 [20, App.A-5]

ID = 1,380 inch = 0,115 ft = 0,0351 m

A = 0,0104 ft^2

$$\text{Kecepatan linier (v)} = \frac{q_f}{A} = \frac{0{,}0279\ ft^3/s}{0{,}0104\ ft^2} = 2{,}6827\ ft/s = 0{,}8177\ m/s$$

$$N_{Re} = \frac{\rho \times v \times ID}{\mu}$$

$$= \frac{(62{,}5151\ {}^{lb}/_{ft^3})(2{,}6827\ {}^{ft}/_{s})(0{,}115\ ft)}{0{,}001\ {}^{lb}/_{ft.s}}$$

=19.286,5648 (turbulen)

Digunakan commercial steel : $\varepsilon = 4{,}6.10^{-5}$ m

$$\text{harga } \frac{\varepsilon}{ID} = \frac{4{,}6.10^{-5}}{0{,}115} = 0{,}0004$$

$$f = 0{,}007 \qquad \text{[20, Fig.2.10-3]}$$

Panjang ekivalen :

- 4 buah standard elbow 90°; $K_f = 0{,}75$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 0{,}75 \times \frac{0{,}8177^2}{2} = 0{,}2507 \, m^2/s^2$$

karena ada 4 buah maka =0,2507 m^2/s^2 x 4 = 1,0029 m^2/s^2

- 1 buah globe valve; wide open $K_f = 6$ [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0{,}8177^2}{2} = 2{,}0059 \, m^2/s^2$$

- panjang pipa lurus = 17,8781 ft = 5,4493 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0{,}007 \times \frac{5{,}4493}{0{,}115} \times \frac{0{,}8177^2}{2} = 0{,}4436 \, m^2/s^2$$

[20, pers.2.10-6]

- Friksi *sudden contraction* dari *evaporator* ke pipa

$$h_c = 0{,}55 \times \left(1 - \frac{A_2}{A_1}\right) \times \frac{v_2^2}{2\alpha} = 0{,}55 \times (1-0) \times \frac{0{,}8177^2}{2} = 0{,}1839 \, m^2/s^2$$

Karena luas area tangki (A_1) >>> dari pada luas area pipa (A_2). maka $\frac{A_2}{A_1} \approx 0$

- Friksi *sudden enlargement* dari pipa ke tangki F-321

$$h_{ex} = \left(1 - \frac{A_1}{A_2}\right)^2 \times \frac{v_2^2}{2\alpha} = (1-0)^2 \times \frac{0{,}8177^2}{2} = 0{,}3343\ {}^{m^2}/_{s^2}$$

Karena luas area pipa (A_1) <<< dari pada luas area *plate heat exchanger* (A_2),

maka $\frac{A_1}{A_2} \approx 0$.

$$\Sigma F = 0{,}2507 + 2{,}0059 + 0{,}4436 + 0{,}1839 + 0{,}3343 = 3{,}2814\ {}^{m^2}/_{s^2}$$

Persamaan Bernoulli :

$$-w_s = \Sigma F + \frac{v_2^2 - v_1^2}{2\alpha} + (z_2 - z_1)\ g + \frac{\Delta P}{\rho} \qquad (20, \text{pers.2.7-28})$$

dimana : $Z_2 - Z_1 = 8{,}0372$ ft $= 2{,}4498$ m

$P_1 = 0{,}4$ bar $= 40.000$ N/m^2

$P_2 = 101.325$ N/m^2

$\Delta P = P_2 - P_1 = -101.325$ N/m^2 $- 40.000$ N/m^2 $= 61.325$ N/m^2

$v_1 = 0$, $v_2 = 0{,}8177$ m/s

$$-w_s = 3{,}2184 + \frac{0{,}8177^2 - 0^2}{2} + 2{,}4498 \times 9{,}8067 + \frac{61.325}{1.001{,}3431}$$

$$-w_s = 88{,}8199 \text{ m}^2/\text{s}^2 = -139{,}2287 \text{ J/kg}$$

Efisiensi pompa (η) = 30% [28, fig 13-37, hal.550]

$$W_p = -\frac{Ws}{\eta} = \frac{88{,}8199}{0{,}30} = 296{,}0663\ \frac{j}{kg}$$

Flow rate = 0,8165 kg/s

$$\text{hp pompa} = 296{,}0663\ {}^{j}/_{kg} \times 0{,}8165\ {}^{kg}/_{s} = 241{,}738 \text{ W} = 0{,}3234 \text{ hp}$$

Efisiensi motor = 80% [28, fig 14-38, p 521]

Sehingga dipakai pompa dengan motor = 0,3234 / 0,80 hp = 0,4042 hp

Spesifikasi alat :

- Fungsi : mengalirkan susu pekat tinggi protein untuk ditampung
- Tipe : *centrifugal pump*
- Rate aliran pompa : 2,8464 m^3/jam
- Ukuran pipa : $1\frac{1}{4}$ in sch 40
- Power motor : 0,5 hp
- Bahan konstruksi : *stainless stell* 316L
- Jumlah : 1 buah

24. Tangki penampung susu pekat tinggi protein setelah Evaporator (F-321)

Fungsi : Sebagai penampung susu cair tinggi protein setelah evaporator

Tipe : Silinder tegak dengan tutup atas berbentuk plat datar dan tutup bawah berbentuk *dished head* dan dilengkapi dengan jaket pemanas.

Dasar pemilihan : untuk menampung bahan yang berbentuk cair.

Kondisi operasi :

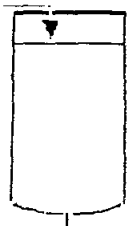
- T = 77°C
- Tekanan 1 atm
- Waktu tinggal 1 jam

Sistem operasi : continyu

Jumlah : 1 buah

Gambar :

Susu pekat tinggi protein (dari evaporator)



Susu pekat tinggi protein

(ke spray dyrer)

Perhitungan :

Rate larutan masuk : 2.939,5441 $^{kg}/_{jam}$

ρ susu : 1033.7- 0.2308T - 0.00246 T^2

1001,34 $^{kg}/_{m^3}$ = 62,4736 $^{lbm}/_{ft^3}$

waktu tinggal : 1 jam

volume larutan total :

$$\frac{2.939,5441\,^{kg}/_{jam}}{1001,34\,^{kg}/_{m^3}}.1\,jam = 2,9356\ m^3 = 103,6652\,ft^3$$

Diambil : tinggi tangki (H_t) = 1,5 . Diameter tangki (D_t)

Volume shell = $(\pi/4).D_t^2.H_t = (\pi/4).D_t^2.1,5.D_t = (\pi/4).1,5.D_t^3$

Volume torispherical dished head (ft^3) = 0,000049 x D_t^3 (in)

[22, pers 5.11, hal 88]

Volume tangki penampung = volume shell + volume *dished head*

Diambil : volume tangki penampung = 1,3 . volume larutan total

Volume tangki = volume cylindrical shell + volume dished head

$$1{,}3\times 103{,}6652 ft^3 = (\pi/4)\times D_t^2 \times H_t + 0{,}000049\times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$134{,}7648 ft^3 = (\pi/4)\times \left(\frac{H_t}{1{,}5}\right)^2 \times H_t + 4{,}9.10^{-5} \times \left(\frac{H_t}{1{,}5}\right)^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$134{,}7648\, ft^3 = 0{,}3491 H_t^3$$

$$H_t = 7{,}2813\, ft$$

Digunakan 1 course 8 ft, sehingga $H_t \approx 8$ ft

Volume tangki = volume cylindrical shell + volume dished head

$$1{,}3\times 103{,}6652 ft^3 = (\pi/4)\times D_t^2 \times H_t + 0{,}000049\times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$134{,}7648 ft^3 = (\pi/4)\times D_t^2 \times \left(\frac{1\,ft}{12\,in}\right)^2 \times 8\,ft + 0{,}000049\times D_t^3 \times \left(\frac{1\,ft}{12\,in}\right)^3$$

$$134{,}7648 ft^3 = 0{,}0436\times D_t^2 + 2{,}8356\times 10^{-8} D_t^3$$

$$D_t = 55{,}5953\, in = 4{,}6329 ft$$

Volume larutan dalam dish $= 0{,}000049 \,.\, D^3$

$= 0{,}000049 \,.\, (55{,}5953 \text{ in})^3$

$= 8{,}42 \text{ ft}^3$

Volume larutan dalam shell = vol. lart. total – vol. lart. dalam dish

$= 103{,}6652 \text{ ft}^3 - 8{,}42 \text{ ft}^3$

$= 95{,}2452 \text{ ft}^3$

Tinggi lart. dalam shell (H_L) $= \dfrac{vol.lart.dlm.shell}{\frac{\pi}{4}.D_t^2}$

$$= \frac{95{,}2452 ft^3}{\frac{\pi}{4}.(4{,}6329 ft)^2}$$

$= 5{,}65$ ft

P operasi = P hidrostatis $= \left(\frac{\rho \times H_L}{144}\right)$ psi

$$= \left(\frac{62{,}4736 \, lbm/ft^3 \times 5{,}65 \, ft}{144}\right)$$

$= 2{,}4512$ psi

P desain = 1,5 x P operasi = 1,5 x 2,4512 psi = 3,6768 psi

Tebal *Shell*

Menghitung tebal shell:

$t_s = \frac{P.ID}{2.f.E} + c$ [22, pers 3.16]

dimana :

P = P desain = 3,6768 psi

ID = 55,5953 in

Konstruksi : bahan konstruksi = *Stainless steel-316 L*, dengan

f = strees maksimum yang diijinkan = 23.000 psi

tipe sambungan = *double-welded butt joint*, dengan

E = *welded-joint efficiency* = 0,8

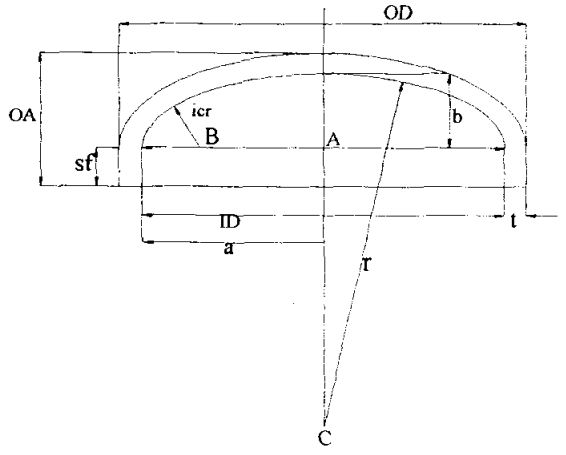
[22, Tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$$t_s = \frac{(3{,}6768\,psi)\times(55{,}5953\,in)}{2\times(23.000\times 0{,}8)} + 0{,}125\,in$$

$$= 0{,}1306 \text{ in} \approx \frac{3}{16} \text{ in}$$

Tebal *dished head*



r (*crown radius / radius of dish*) = 55,5953 in

icr (*inside corner radius / knuckle radius*) = 6% x 55,5953 in = 3,3357 in

$$W = \frac{1}{4}\times\left[3+\sqrt{\frac{r}{icr}}\right] \qquad \text{(22, pers 7,76)}$$

$$= \frac{1}{4}\times\left[3+\sqrt{\frac{55{,}5953}{3{,}3357}}\right]$$

$$= 1{,}7706$$

$$a = \frac{ID}{2} = \frac{55{,}5953\,in}{2} = 27{,}7977\,in$$

$$AB = \frac{ID}{2} - icr = \frac{68{,}6885\,in}{2} - 3{,}3357\,in = 24{,}462\,in$$

BC = r – icr = (55,5953-3,3357) in = 52,2596 in

$b = r - \sqrt{BC^2 - AB^2} = 52{,}2596 - \sqrt{52{,}2596^2 - 24{,}462^2} = 6{,}0787\ in$

$t_d = \frac{P \times r \times W}{2 \times f \times E - 0{,}2 \times P} + c$ (22, pers 7.77, p.138)

dimana :

P = P desain = 3,6768 psi

Konstruksi : bahan konstruksi = *Stainless steel-316 L*, dengan

f = stress maksimum yang diijinkan = 23.000 psi

tipe sambungan = double-welded butt joint, dengan

E = welded-joint efficiency = 0,8

[22, tabel 13.2]

c = *Corrosion allowance* = 0,125 in

$t_d = \frac{(3{,}6768\ psi) \times (52{,}2596\ in) \times 1{,}7706}{2 \times ((23.000\ psi) \times 0{,}8) - (0{,}2 \times 3{,}6768\ psi)} + 0{,}125\ in$

= 0, 1342 in $\approx \frac{3}{16}$ in

Dipilih panjang straight-flange (sf) = 2 in

[22, tabel 5.8, hal.93]

OA = t_d + b + sf

= ($\frac{3}{16}$ + 6,0787 + 2) in

= 8,2662 in = 0,6888 ft

Tinggi tangki keseluruhan = tinggi shell + tinggi dish

= 8 ft + 0,6888 ft

= 8,6888 ft

Tebal plat datar (t_f) = 3/16 in.

Spesifikasi :

Tangki

Kapasitas : 103,6652 ft^3

Diameter : 4,6329 ft

Tinggi tutup bawah (dished head) : 0,6888 ft

Tinggi shell : 8 ft

Tinggi tangki total : 8,6888 ft

Tebal shell : 0,1306 in $\approx \frac{3}{16}$ in

Tebal tutup bawah (dished head) : 0,1342 in $\approx \frac{3}{16}$ in

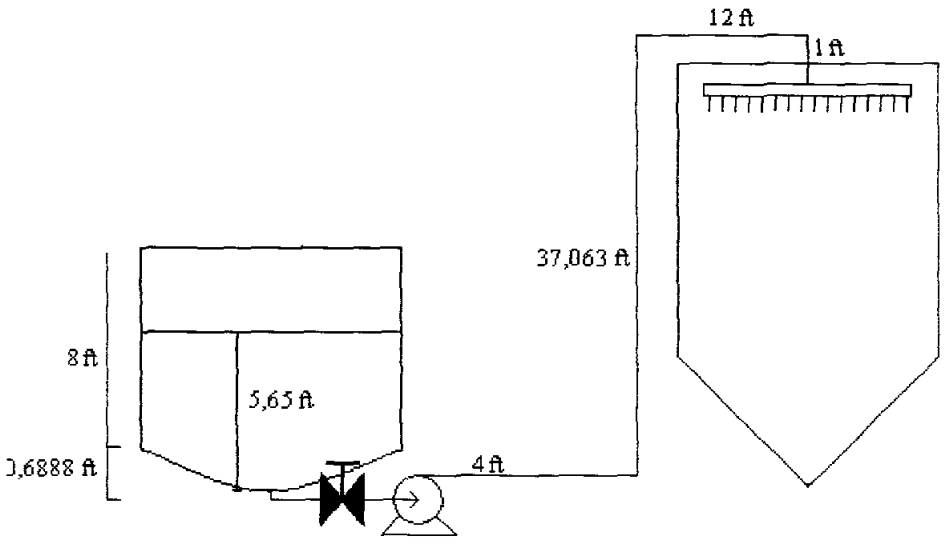
Bahan konstruksi : *Stainless steel-316 L*

Jumlah tangki : 1 buah

25. Pompa (L-322)

Fungsi : Memompa pekat tinggi protein menuju ke *spray dryer*

Tipe : Centrifugal pump



Density : 1033.7- 0.2308T - 0.00246 T^2

$= 1001{,}34\ {}^{kg}/_{m^3} = 62{,}4736\ {}^{lbm}/_{ft^3}$

Kapasitas : 2.939,5441 ${}^{kg}/_{jam}$ = 6.480,6193 lb/jam

Viskositas : 0,001 kg/m.s = 0,0006 lb/ft.s

$$\text{Rate volumetrik} = \frac{2.939{,}5441\ {}^{kg}/_{jam}}{1.001{,}34\ {}^{kg}/_{m^3}} = 2{,}9356\ {}^{m^3}/_{jam} = 0{,}0288\ {}^{ft^3}/_{s}$$

Optimum inside diameter (Di,opt)

$Di,opt = 3{,}9\ q_f^{\,0,45}\ \rho^{0,13}$ [28, pers 45, hal 381]

dimana : q_f = flow rate, ft^3/s

ρ = densitas fluida, lb/ft^3

$Di,opt = 3{,}9\ (0{,}0288)^{0,45}\ (62{,}4736)^{0,13} = 1{,}3528$ inch $\approx 1{,}380$ inch.

Digunakan pipa berukuran $1\ {}^{1}/_{4}$ inch, sch.40 [20, App.A-5]

ID = 1,380 inch = 0,3355 ft = 0,0351 m

A = 0,0104 ft^2

Kecepatan linier (v) = $\frac{q_f}{A} = \frac{0,0288 ft^3/s}{0,0104 ft^2}$ = 2,7692 ft/s = 0,8441 m/s

$$N_{Re} = \frac{\rho \times v \times ID}{\mu} \quad \ldots$$

$$= \frac{(62,4736 lb/ft^3)(2,7692 ft/s)(0,3355 ft)}{0,0006 lb/ft.s}$$

= 100.230,2074 (turbulen)

Digunakan commercial steel : $\varepsilon = 4,6.10^{-5}$ m

$$\text{harga } \frac{\varepsilon}{ID} = \frac{4,6.10^{-5}}{0,0351} = 0,0013$$

f = 0,005 [20, Fig.2.10-3]

Panjang ekivalen :

- 4 buah standard elbow 90°; K_f = 0,75 [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 0,75 \times \frac{0,8441^2}{2} = 0,2672 m^2/s^2$$

karena ada 4 buah maka =0,2672 m^2/s^2 x 4 = 1,0688 m^2/s^2

- 1 buah globe valve; K_f = 6 [20, tabel 2.10-1]

$$h_f = K_f \times \frac{v^2}{2} = 6 \times \frac{0,8441^2}{2} = 2,1375 m^2/s^2$$

- panjang pipa lurus = 54,063 ft = 16,4786 m

$$F_f = 4 \times f \times \frac{\Delta L}{ID} \times \frac{v^2}{2} = 4 \times 0,005 \times \frac{16,4786}{0,0351} \times \frac{0,8441^2}{2} = 3,345 m^2/s^2$$

[20, pers.2.10-6]

- Friksi dari tangki ke pipa

$$h_c = 0,55 \times \left(1 - \frac{A_2}{A_1}\right) \times \frac{v_2^2}{2\alpha} = 0,55 \times (1-0) \times \frac{0,8441^2}{2} = 0,1959 \, m^2/s^2$$

Karena luas area tangki (A_1) >>> dari pada luas area pipa (A_2), maka $\frac{A_2}{A_1} \approx 0$

$$\Sigma F = 1,0688 + 2,1375 + 3,345 + 0,1959 = 6,7472 \, m^2/s^2$$

Persamaan Bernoulli :

$$-w_s = \Sigma F + \frac{v_2^2 - v_1^2}{2\alpha} + (z_2 - z_1)\ g + \frac{\Delta P}{\rho}$$ [20, pers.2.7-28]

dimana : P_{tangki} = 1 atm = 101.325 N/m^2

$P_{atomizer}$ = 300 psia =2.068.428 N/m^2 [44]

ΔZ = 30,413 ft = 9,27 m

α = 1 (turbulen)

Menghitung power pompa

$$-W_s = 6,7472 + \frac{0,8441^2 - 0^2}{2} + 9,27 \text{ x } 9,8067 + \frac{2.068,428 - 101,325}{1001,34}$$

- $W_s = 2.062{,}8386 \frac{m^2}{s^2} = 2.062{,}8386 \frac{J}{kg}$

Efisiensi pompa (η) = 30% [28, fig 13-37, hal.550]

$$W_p = -\frac{Ws}{\eta} = \frac{2.062{,}8386}{0{,}30} = 6.876{,}1286 \frac{J}{kg}$$

Flow rate = 0,8165 kg/s

hp pompa $= 6.876{,}1286 \, {}^{J}/_{kg} \times 0{,}8165 \, {}^{kg}/_{s} = 5{,}6144$ kW = 7,529 hp

Efisiensi motor = 86% [31, fig 14-38, p 521]

Sehingga dipakai pompa dengan motor = 7,529 / 0,86 hp = 8,7546 hp ≈ 9 hp

Spesifikasi alat :

- Fungsi : Mengalirkan susu pekat tinggi protein untuk ditampung
- Tipe : *Centrifugal pump*
- Rate aliran pompa : 2,9356 m^3/jam
- Ukuran pipa : $1 \, {}^{1}/_{4}$ in sch 40
- Power motor : 9 hp
- Bahan konstruksi : *stainless stell*
- Jumlah : 1 buah

26. Blower (G-323)

Fungsi : mengalirkan udara panas

Type : centrifugal

Kapasitas : 114713,358 kg/jam = 1,103 kmol/s (BMudara=28,9 kg/kgmol)

Jumlah : 1 buah

Bahan konstruksi : carbon steel

Laju volumetrik : 1,103 . 22,4 . (30+273)/273 = 27,504 m^3/s

Efisiensi : 70 %

Perhitungan :

$K = \gamma\text{-}1 / \gamma.Ep$ [45, hal.3-6]

$N = 1 / 1\text{-}K$ [45, hal.3-7]

Dimana : γ udara = 1,4 (untuk gas diatomic)

$K = 1,4 - 1 / 1,4 . 0,7 = 0,408$

$N = 1 / 1\text{-}0,408 = 1,689$

Perhitungan power

$$H = \frac{ZRT}{(N-1)/N}\left[\left(\frac{P_2}{P_1}\right)^{(N-1)/N} - 1\right]$$

$Z = 1$

$$H = \frac{1.8,314.(273+30)}{(1,689-1)/1,689}\left[\left(\frac{29,4\ psia}{14,7\ psia}\right)^{(1,689-1)/1,689} - 1\right]$$

= 2018,014 J/kmol = 2,018 kJ/kmol

Power = w . M / Ep = 2,018 kJ/kmol . 1,103 kmol/s / 0,7 = 3,179 kW

Power = 3,179 kW / 0,7457 = 4,264 Hp ≈ 4,5 Hp

Spesifikasi :

Fungsi : mengalirkan udara panas

Type : centrifugal

Kapasitas : 114713,358 kg/jam = 1,103 kmol/s (BMudara=28,9 kg/kgmol)

Bahan konstruksi : carbon steel

Jumlah : 1 buah

Power : 4,5 Hp

27. *Spray dryer* (B-320)

Fungsi : Untuk mengeringkan susu pekat tinggi protein menjadi susu bubuk tinggi protein

Tipe : Bejana silinder dengan bagian bawah berbentuk konis dan tutup atas berbentuk *dished head*

Kapasitas : 70.549,0586 kg/hari

Kondisi operasi :

- Tekanan operasi = 1atm
- Temperatur bahan masuk = 77°C
- Temperatur udara panas masuk = 125°C

Laju pengeringan 44.572,6204 kg air/hari

Berdasarkan laju pengeringan dan suhu udara masuk dipilih :

Volume *chamber* = 8000 ft^3 [46 Fig. 20-72]

Diameter = 24,3 ft = 7,406 m [46 Fig. 20-72]

Lubang pengeluaran = 5 in = 0,4167 ft [47, hal 85]

Tinggi *shell*, Hs = 0,4 x D = 9,72 ft = 2,963 m [46 Fig. 20-72]

Volume silinder = $\pi/4$ x D^2 x Hs = $\pi/4$ x $(24,3\ ft)^2$ x (9,72 ft) = 4505,557 ft^3

Volume konis = volume *chamber* – volume silinder

= 8000 ft^3 – 4505,557 ft^3

= 3494,443 ft^3

M = 12 in = 1 ft (Hesse, hal 85)

Volume konis = 1/3 x $\pi/4$ x hc x (D^2+DM+M^2)

$3494,443 = 1/3 \times \pi/4 \times hc \times (24,3^2 + 24,3 \times 1 + 1^2)$

hc = 21,69 ft = 6,61 m

Untuk shell, tutup bagian atas, dan bawah dipilih bahan konstruksi *stainless steel-316 L* :

- f_{all} = allowable stress = 23.000 lb/in^2
- E = efisiensi sambungan = 0,8 (double welded butt joint, 22, p.245, tabel 13.2)
- ID = diameter shell = 7,406 m = 291,574 in
- P = 14,7 psia
- c = *Corrosion allowance* = 0,125 in

Tebal *shell*

$$ts = \frac{P \times r_i}{f_{all} \times E - 0,6 \times P} \quad (22, p.254, eq\ 13.1)$$

$$ts = \frac{14,7 \times 145,787}{23.000 \times 0,8 - 0,6 \times 14,7} = 0,1165\ in \approx \frac{3}{16}\ in$$

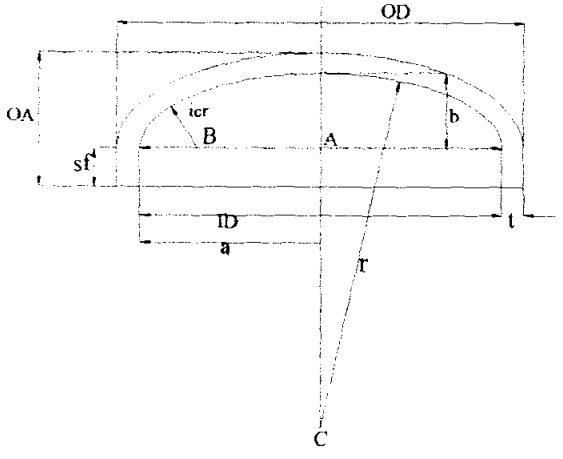
Tebal konis

Untuk ½ sudut puncak (α) tidak lebih besar dari 30° digunakan persamaan 6.154, p.118, 22.

$$t_c = \frac{P \times ID}{2 \times \cos\alpha \times (f_{all} \times E - 0{,}6 \times P)} + c$$

$$t_c = \frac{14{,}7 \times 291{,}574}{2 \times \cos 30 \times (23.000 \times 0{,}8 - 0{,}6 \times 14{,}7)} + 0{,}125 = 0{,}2326 \text{ in} \approx \frac{1}{4} \text{ in}$$

Tebal *Dished Head*



r (*crown radius / radius of dish*) = 291,574 in

icr (*inside corner radius / knuckle radius*) = 6% x 291,574 in = 17,494 in

$$W = \frac{1}{4} \times \left[3 + \sqrt{\frac{r}{icr}}\right] \qquad \text{[22, pers 7.76]}$$

$$= \frac{1}{4} \times \left[3 + \sqrt{\frac{291.574}{17.494}}\right]$$

$$= 1.7706$$

$$a = \frac{ID}{2} = \frac{291.574\ in}{2} = 145.787\ in$$

$$AB = \frac{ID}{2} - icr = \frac{291{,}574\ in}{2} - 17{,}494\ in = 128{,}293\ in$$

BC = r – icr = (291,574-17,494) in = 274,08 in

$$b = r - \sqrt{BC^2 - AB^2} = 291{,}574 - \sqrt{274{,}08^2 - 128{,}293^2} = 49{,}374\ in$$

$$t_d = \frac{P \times r \times W}{2 \times f \times E - 0{,}2 \times P} + c \qquad \text{(22, pers 7.77, p.138)}$$

$$t_d = \frac{(14{,}7\ psi) \times (291{,}574\ in) \times 1{,}7706}{2 \times ((23.000\ psi) \times 0{,}8) - (0{,}2 \times 14{,}7\ psi)} + 0{,}125\ in$$

= 0,3312 in ≈ $\frac{3}{8}$ in

Dipilih panjang straight-flange (sf) = 6 in [22, tabel 5.8, hal.93]

OA = t_d + b + sf

= ($\frac{1}{2}$ + 49,374 + 6) in

= 55,874 in = 4,656 ft ≈ 4,7 ft

Tinggi total = Hs + hc + OA= 2,963 m + 6,61 m + 1,419 m= 10,992 m = 36,063 ft

Spesifikasi :

Kapasitas	: 70.549,0586 kg/hari
Diameter	: 24,3 ft
Tinggi sprat dryer total	: 36,063 ft
Tebal shell	: 0,1165 in ≈ $\frac{3}{16}$ in

Tebal tutup bawah (konis) : 0,2326 in $\approx \frac{1}{4}$ in

Tebal tutup atas (dished head) : 0,3312 in $\approx \frac{3}{8}$ in

Bahan konstruksi : *Stainless steel-316 L*

Jumlah spray dryer : 1 buah

28. Atomizer

Jenis : *Centrifugal dish*

Menentukan putaran centrifugal dish :

$$\frac{Dvs}{r} = 0{,}4\left[\frac{\Gamma}{\rho_L \times N \times r^2}\right]^{0,6}\left[\frac{\mu}{\Gamma}\right]^{0,2}\left[\frac{\alpha \times \rho_L \times Lw}{\Gamma^2}\right]^{0,1} \quad (23, \text{pers.}12\text{-}65)$$

Dvs = diameter semprotan rata-rata $=6.10^{-5}$ m = $1{,}968.10^{-4}$ ft

Di = diameter dish = 0,25 m = 0,82 ft

r = jari-jari dish = 0,41 ft

Γ = kecepatan massa semprotan dari wetted dish peripheral, lb/min.ft

ρ_L = densitas slurry = 1001,34 kg/m^3 [18]

N = putaran dish, rpm

μ = viskositas liquid = 0,0005 lb/ft.s [18]

α = liquid retention,lb/min^2

Lw = wetted dish peripheral = π.di = 2,5761 ft

Massa feed masuk = 70.549,0586 kg/hari = 2939,544 kg/jam

$$\Gamma = \frac{\text{massa feed masuk}}{Lw} = \frac{2939{,}544\,kg/jam \times 2{,}2046\,\text{lb/kg}}{2{,}5761\,\text{ft} \times 60\,\text{menit/jam}} = 41{,}93\ \text{lb/min.ft}$$

$\alpha^{(1/4)} = R \times \rho_L$ [23, pers.12-66]

R = komponen paarachor = 271,7

ρ_L = densitas slurry, mol/cm^3

α = *liquid retention*, dyne

$BM_{campuran} = 0,55 \times 18,01 + 0,45 \times 368,39 = 72,41$ kg/kmol

$$\rho_L = \frac{784,0756 kg/m^3}{72,41 kg/kmol \times 1000} = 1,00134 \text{ mol/cm}^3$$

$\alpha^{(1/4)} = R \times \rho_L = 271,7 \times 1,00134 = 3,013$

$\alpha = 82,4491 \text{ lb/min}^2$

$$\frac{1,968.10^{-4}}{0,41} = 0,4\left[\frac{41,93}{1,00134 \times N \times 0,41^2}\right]^{0,6}\left[\frac{0,0005}{41,93}\right]^{0,2}\left[\frac{82,4491 \times 1,00134 \times 2,5761}{41,93^2}\right]^{0,1}$$

$N = 7727,7735 \text{ rpm} \approx 7728 \text{ rpm}$

Menghitung power yang dibutuhkan :

$P = 1,04.10^{-8} \times (r \times N)^2 \times W$

Dimana,

P = netto horse power

r = jari – jari dish

N = putaran dish = 7728 rpm

W = kecepatan feed = 154,2344 lb/min

$P = 1,04.10^{-8} \times (0,41 \times 7728)^2 \times 154,2344$

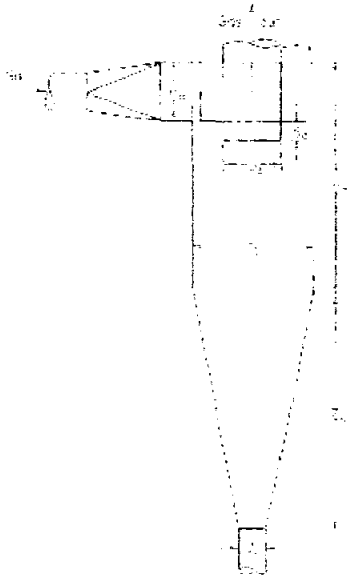
$P = 16,10 \text{ hp} \approx 17 \text{ hp}$

29. *Cyclone* (H-330)

Fungsi : Untuk memisahkan bubuk susu tinggi protein dari aliran udara

Kapasitas : 126,1748 kg padatan/hari

Gambar :



Perhitungan :

Mencari Diameter *cyclone* (Dc)

$$Dp = \left(\frac{9\,\mu D_c}{4\,\pi N_t V(\rho - \rho_g)} \right)^{0,5}$$ [44 pers 18.15 hal 618]

$D_{partikel}$ untuk susu bubuk tinggi protein adalah 60µm = 6.10^{-5} m = 0,0001968 ft [44, hal 604]

V= kecepatan masuk cyclone, 120 ft/s [44, hal 617]

$$Nt, number\ of\ turns\ gas = \left(0,1079 - 0,00077V + 1,924(10^{-6}V^{2})\right)^{-1}$$
$$= 5,185$$

$\mu = \mu_{udara} = 0,0209$ cp = $1,4.10^{-5}$ lbm/ft.s

$\rho = \rho_{partikel\ susu} = 75\ lb/ft^3$ [48]

$\rho_g = \rho_{udara} = 0{,}0632\ lb/ft^3$ [20, App.3-3 hal 971]

$$Dp = \left(\frac{9\,\mu D_c}{4\,\pi N_t V(\rho - \rho_g)} \right)^{0,5}$$

$$0{,}0001968 = \left(\frac{91{,}4.10^{-5}\, D_c}{4\,\pi 5{,}185.120(75 - 0{,}0632)} \right)^{0,5}$$

$$D_c = 5ft = 1{,}524\ m$$

5 ft = Bc x 4

BC = 1,25 ft

Hc = 2 x Bc

H_C = 2,5 ft

$$De = \frac{Dc}{2} = \frac{5}{2} = 2{,}5\ ft$$

Lc = 2 . Dc = 2 x 5 ft = 10 ft

$$Sc = \frac{Dc}{8} = \frac{5\,ft}{8} = 0{,}625\ ft$$

Zc = 2 . Dc = 2 x 5 ft = 10 ft

$$Jc = \frac{Dc}{4} = \frac{5\,ft}{4} = 1{,}25\ ft$$

Dimana :

Dc : Diameter cyclone, ft

De : Diameter lubang pengeluaran gas, ft

Hc : Diameter lubang masuk, ft

Lc : Tinggi cyclone bagian silinder, ft

Zc : Tinggi cyclone bagian kerucut, ft

Jc : Diameter lubang pengeluaran partikel, ft

Spesifikasi :

Tipe : Effluent Dust cyclone

Kapasitas : 126,1748 kg padatan/hari

Ukuran Bc : 1,25 ft

Dc : 5 ft

De : 2,5 ft

Hc : 2,5 ft

Lc : 10 ft

Sc : 0,625 ft

Zc : 10 ft

Jc : 1,25 ft

30. *Barometric condensor* (G –331)

Fungsi : Mengkondensasikan uap dari evaporator

Tipe : counter flow Barometric Condensor

Dasar pemilihan : konstruksi lebih murah dan luas permukaan kontak lebih besar

Perhitungan :

Rate uap pada 185 °F (v) = 44.568,8897 kg/hari = 4.094,0873 lb/jam

λ uap pada 185 °F (λ) = 1140,15 – 153,01 = 987,14 btu/lbm [20, App. A.2-9]

kebutuhan air pendingin

$$W\ (gpm) = \frac{Q}{500(Ts - tw - ta)}$$ [41, pers 14.4, hal.396]

Dimana :

Ts = suhu uap jenuh = 185°F

tw = suhu air pendingin = 30°C = 86°F

ta = derajat pendekatan terhadap Ts

untuk counter flow barometric condensor, ta = 5 °F [41, hal.397]

Q = v.λ = 4.094,0873 x 987,14 = 4.041.437,337 btu/jam

$$W = \frac{4.041.437,337\ btu/jam}{500(185 - 86 - 5)^{\circ}F} = 85,988\ gpm$$

Panjang tailing pipa

Persamaan bernoulli = $P_2 + \rho.g.h = P_1$

$P_2 = P_{uap}$ = 101,325 kpa = 101.325 Pa

P_1 = 101,325 kpa = 101.325 Pa

ρ air = 995,68 kg/m^3

g = 9,80665 m/s^2

$$h = \frac{P_1 - P_2}{\rho.g} = \frac{101.325 - 101.325}{995,68.9,80665} = 0\ m$$

Spesifikasi

Tipe	= counter flow barometic condensor
Rate uap	= 44.568,8897 kg/hari = 4.094,0873 lb/jam
Kebutuhan air pendingin	= 85,988 gpm
Panjang tailing pipa	= 0 m

Bahan = Stainless steel

Jumlah : 1 buah

31. Bak *Barometric Condenser* (F-332)

Fungsi : Untuk menampung kondensasi uap air *barometric condenser* (G-331)

Bentuk : Bak berbentuk kubus

Penghitungan :

Uap air yang menuju ke *barometric condenser* sebesar 44.572,6204 kg/hari.

Bak *barometric* dirancang untuk kapasitas hari. Banyak air ang ditampung dalam 6 jam sebesar 11143,155 liter = 11,143 m^3.

Dengan asumsi Volume air = 80% volume bak

Volume bak = 100/80. 11,143 m^3

Volume bak = 13,93 m^3

Bentuk bak kubus jadi ukuran panjang,lebar dan tingginya adalah 2,40 m x 2,40 m x 2,40 m

32. Silo susu bubuk tinggi protein (F-340)

Fungsi : Menyimpan susu bubuk tinggi protein.

Tipe : Silinder tegak dengan tutup atas berbentuk plat datar dan tutup bawah berbentuk *konis*

Dasar pemilihan : Beroperasi pada suhu ruang dan tekanan atmosfer

Kondisi operasi :

- T = 30°C

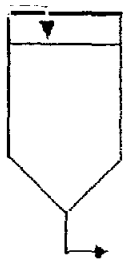
- Tekanan 1 atm
- Waktu tinggal 1 hari

Sistem operasi : *Batch*

Jumlah : 1 buah

Gambar :

Susu bubuk tinggi protein



Susu bubuk tinggi protein

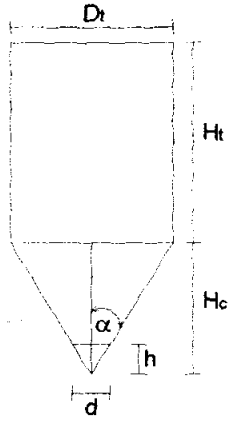
Perhitungan :

Rate susu bubuk masuk : $25.980,1689\ {}^{kg}/_{hari} = 1.082,5070\ {}^{kg}/_{jam}$

ρ susu bubuk tinggi protein = $996,445\ {}^{kg}/_{m^3} = 62,2093\ {}^{lbm}/_{ft^3}$

waktu tinggal : 1 hari = 24 jam

volume total: $\dfrac{25.980,1689\ {}^{kg}/_{jam}}{996,445\ {}^{kg}/_{m^3}} = 26,0729\ m^3 = 920,7108\ ft^3$



Diambil : tinggi tangki (H_t) = 1,5 x Diameter tangki (D_t)

$\alpha = 30°$

Diameter nozzle (d) = 10 in

Menhitung dimensi *cylindrical shell*

Volume tangki (V_t) = 1,2 x $V_{\text{susu bubuk}}$

= 1,2 x 920,7108

= 1.104,8530 ft^3

Vt = volume cylindrical shell + volume konis

$$V_t = \pi \times R_t^2 \times H_t + \left(\frac{1}{3} \times \pi \times R_t^2 \times H_c - \frac{1}{3} \times \pi \times r^2 \times h \right)$$

$$1.104{,}8530\, ft^3 = \pi \times R_t^2 \times 3R_t + \left(\frac{1}{3} \times \pi \times R_t^2 \times \frac{R_t}{\tan 30} - \frac{1}{3} \times \pi \times 0{,}4167^2 \times \frac{0{,}4167}{\tan 30} \right)$$

R_t = 4,6162 ft

H_t = 3 x R_t = 13.8487 ft

Digunakan 2 course 8 ft, sehingga $H_t \approx 16$ ft

Volume tangki = volume cylindrical shell + volume konis

$$V_t = \pi \times R_t^2 \times H_t + \left(\frac{1}{3} \times \pi \times R_t^2 \times H_c - \frac{1}{3} \times \pi \times r^2 \times h \right)$$

$$1.104{,}8530\ ft^3 = \pi \times R_t^{\,2} \times 16\ ft + \left(\frac{1}{3} \times \pi \times R_t^{\,2} \times \frac{R_t}{\tan 30} - \frac{1}{3} \times \pi \times 0{,}4167^2 \times \frac{0{,}4167}{\tan 30} \right)$$

$R_t = 4{,}3594$ ft

$$\text{Volume konis} = \frac{1}{3} \times \pi \times R_t^{\,2} \times \frac{R_t^{\,2}}{\tan 30} - \frac{1}{3} \times \pi \times r^2 \times \frac{r}{\tan 30}$$

$$= 150{,}0639\ ft^3$$

Menghitung tebal shell untuk course 1 (8 ft dari dasar):

Volume susu bubuk dalam shell = 0,25 x π x D_t^2 x tinggi bahan (H_s)

$$V_{\text{susu bubuk}} - V \text{ konis} = 0{,}25 \times \pi \times D_t^2 \times H_s$$

$$920{,}7108 - 150{,}0639 = 0{,}25 \times \pi \times 8{,}718^2 \times H_s$$

$$H_s = 12{,}9142 \text{ ft}$$

$$P_{\text{vertikal}} = \frac{Rt \times \rho}{2 \times \mu' \times K'} (1 - e^{-2\mu' K' Hs/Rt}) \qquad \text{[49, hal.762]}$$

dimana Rt : jari-jari dalam tangki, ft

μ' : koefisien friksi

K' : perbandingan *normal pressure* terhadap *applied pressure*

$$P_{\text{vertikal}} = \frac{Rt \times \rho}{2 \times \mu' \times K'} (1 - e^{-2\mu' K' Hs/Rt}) \qquad \text{[49, hal.762]}$$

$$= \frac{4{,}3594 \times 62{,}2093}{2 \times 0{,}45 \times 0{,}5} (1 - e^{-2 \times 0{,}45 \times 0{,}5 \times 12{,}9142/4{,}3594})$$

$= 443{,}7574$ lb/ft^2 $= 3{,}0816$ psi

$P_{\text{lateral}} = K' \times P_{\text{vertikal}}$ [49,hal.763]

$= 0{,}5 \times 3{,}0816$ psi

$= 1{,}5408$ psi

$P_{\text{design}} = 1{,}2 \times P_{\text{lateral}}$

= 1,2 x 1,5408 psi

= 1,8490 psi

Digunakan double welded butt joint, sehingga E = 0,8 [22, hal. 254]

Allowable working stress (f) untuk stainless steel 316-L 23.000 psi

D_t = 104,6272 in.

Corrosion allowance (c) = 0,125 in.

$$\text{Tebal shell } (t_s) = \frac{P_{design}\, D_t}{2\, f\, E} + c \qquad \text{[22, hal. 45]}$$

$$= \frac{1{,}8490 \text{ psi} \times 104{,}6272 \text{ in..}}{2 \times 23.000 \text{ psi} \times 0{,}8} + 0{,}125 \text{ in.}$$

= 0,1303 in. ≈ 3/16 in.

Menghitung tebal shell untuk course 2 (8 hingga 16 ft dari konis):

H_s = 12,9142 ft - 8 ft = 4,9142 ft

$$P_{vertikal} = \frac{Rt \times \rho}{2 \times \mu' \times K'} \left(1 - e^{-2\mu' K' Hs\, Rt}\right) \qquad \text{[49, hal.762]}$$

$$= \frac{4{,}3594 \times 62{,}2093}{2 \times 0{,}45 \times 0{,}5} \left(1 - e^{-2 \times 0{,}45 \times 0{,}5 \times 12{,}9142/4{,}3594}\right)$$

= 239,7752 lb/ft^2 = 1,6651 psi

$$P_{lateral} = K' \times P'_{vertikal} \qquad \text{[49., hal.763]}$$

= 0,5 x 1,6651 psi

= 0,8325 psi

$P_{design} = 1{,}2 \times P_{lateral}$

= 1,2 x 0,8325psi

= 0,9990 psi

$$t_s = \frac{P_{design}\ D_t}{2\,f\,E} + c \qquad \text{[22, hal. 45]}$$

$$= \frac{0{,}999\ \text{psi} \times 104{,}6272\ \text{in.}}{2 \times 23.000\ \text{psi} \times 0{,}8} + 0{,}125\ \text{in.}$$

$$= 0{,}1278\ \text{in.} \approx 3/16\ \text{in.}$$

Menghitung tebal konis:

$$H = (Hc\text{-}h) + H_s$$

$$= (4{,}3594/\tan 30 - 0{,}4167/\tan 30) + 12{,}9142\ \text{ft}$$

$$= 19{,}7427\ \text{ft}$$

$$P_{vertikal} = \frac{Rt \times \rho}{2 \times \mu' \times K'}\left(1 - e^{-2\mu' K' Hs/Rt}\right) \qquad \text{[49, hal.762]}$$

$$= \frac{4{,}359 \times 62{,}2093}{2 \times 0{,}45 \times 0{,}5}\left(1 - e^{-2 \times 0{,}45 \times 0{,}5 \times 19{,}7427/4{,}3594}\right)$$

$$= 524{,}1338\ \text{lb/ft}^2 = 3{,}6397\ \text{psi}$$

$$P_{lateral} = K' \times P_{vertikal} \qquad \text{[49, hal.763]}$$

$$= 0{,}5 \times 3{,}6397\ \text{psi}$$

$$= 1{,}8199\ \text{psi}$$

$$P_{design} = 1{,}2\,(P_{lateral} + P_{vertikal})$$

$$= 1{,}2 \times (1{,}8199 + 3{,}6397)\ \text{psi}$$

$$= 6{,}5515\ \text{psi}$$

$$\text{Tebal konis } (t_c) = \frac{P_{design} \times D_t}{2 \times \cos\alpha\,(f\,E - 0{,}6\,P_{design})} + c \qquad \text{[22, hal. 118]}$$

$$= \frac{6{,}5515\ \text{psi} \times 104.6272\ \text{in.}}{2 \times \cos 30 \times (23.000 \times 0{,}8 - 0{,}6 \times 6{,}5515\ \text{psi})} + 0{,}125\ \text{in.}$$

$$= 0{,}1465\ \text{in.} \approx 3/16\ \text{in.}$$

Tebal plat datar (t_f) = 3/16 in.

Spesifikasi Alat:

- Tinggi shell : 16 ft
- Diameter shell : 8,7188 ft
- Tebal *shell course* 1 (hingga 8 ft dari konis) : 3/16 in.
- Tebal *shell course* 2 (8 hingga 16 ft dari dasar) : 3/16 in.
- Tebal *shell course* 3 (12 hingga 18 ft dari dasar) : 3/16 in.
- Tebal konis : 3/16 in.
- Tebal plat datar : 3/16 in.

33. *Pneumatic Conveyor* (J-341)

Fungsi : Mengalirkan susu bubuk tinggi protein ke silo susu bubuk tinggi protein

Type : *Pressure pneumatic conveyor*

Kapasitas : 25.980,1689 kg/hari

Jumlah : 1 buah

Perhitungan :

Laju alir udara = 3300 ft/menit (44, Tabel 5.1, hal 72)

Laju alir udara, m'a $= \frac{3300\,ft/menit}{60\,menit/jam} \cdot \frac{3,14}{4} \cdot (0,075\,lb/ft^3) \cdot D^2$

$= 3.2381\ D^2$

Laju alir padatan, m's = 25.980,1689 kg/hari = 1.051 ton/jam

= 0.5841 lb/s

Densitas udara = 0,075 lb/ft^3 . (29,4 psia/14,7 psia)

= 0.15 lb/ft^3

Densitas campuran,ρ_m $= \dfrac{(m's + m'a)}{m's/\rho s + m'a/\rho a}$

$$= \frac{(3{,}2381\,D^2 + 0{,}5841)}{0{,}5841/56{,}634 + 3{,}2381D^2/0{,}15}$$

Kecepatan udara masuk, u = $3300/60.\left(\dfrac{14{,}7}{29{,}4}\right)$

= 27,5 lb/s

Le elbow = 1,6. 3,14/2.(12D)

= 30,2 D

Menghitung Friksi

- *Power untuk kompresi dari 14,7 atm dan suhu 85°C = 185°F menjadi 29,4 atm*

  k=(cp/cv)=1,4

  k/(k-1) = 3,5 [44 hal. 77]

  wc = 186,55. T.$((P_2/P_1)^{0,2857}$-1).m'a [44 pers.5.15 hal. 75]

  = 186,55.185.$((29{,}4/14{,}7)^{0,2857}$-1) 3.2381 D^2

- *Friksi udara*

  Panjang pipa lurus =70 ft

  Jumlah elbow = 5 buah

  nc, jumlah silo = 3 buah

$$w1 = u^2/2g.[1 + 2n_c + (0{,}015D).(L + \Sigma Le)] \quad \text{(44 pers 5.16 hal 75)}$$

$$= 27{,}5^2/(2.32{,}2).[1 + 2.1 + (0{,}015.D).(70 + 5.30{,}2D)]$$

- *Friksi padatan*

Ws = w2+w3+w4+w5 (44 pers 5.18-5.21 hal 75-76)

$$= (u^2/2g + \Delta Z + L \mp n.0{,}0488u^2)m's$$

$$= (27{,}5^2/2.32{,}2 + 60 + 70 + 5.0{,}0488.27{,}5^2)0{,}5841$$

= 159.738 ft.lbf/s

Wf = ws + w1

$$= 159.738 + 27{,}5^2/(2.32{,}2).[1 + 2.1 + (0{,}015.D).(70 + 5.30{,}2D)]$$

$$\Delta P = \frac{wf}{144(m'a + m's)}.\rho_m$$

$$= \frac{wf}{144(3{,}2381D^2 + 0{,}5841)}.\rho_m$$

[44 pers 5.24 hal 76]

$$P = \frac{wc + wf}{2750} \text{ Hp/tph}$$

[44 pers 5.23 hal 76]

$$\text{Saturation} = \frac{3300\,ft/menit.(3{,}14/4).D^2}{1051\,kg/jam.2\,lb/kg.\frac{jam}{60\,menit}}$$

[44 pers 5.25 hal 76]

Dari 44, tabel 5.1 hal 72,untuk panjang pipa lurus 100 ft didapat saturation = 0,9 dan hp/T = 1,5

Dengan menggunakan trial didapatkan Diameter pipa = 1,610 in, NPS=1,5 in

Saturation = 0,6 (cuft/menit udara)/(lb/menit padatan susu)

Power = 1,32 Hp/(ton susu bubuk/jam)

= 1,32 Hp/ (1,051 ton/jam)

= 1,25 Hp

Spesifikasi :

Fungsi : mengalirkan susu bubuk tinggi protein ke silo susu bubuk tinggi protein

Type : pressure pneumatic conveyor

Kapasitas : 25.980,1689 kg/hari

Jumlah : 1 buah

Power : 1,25 Hp

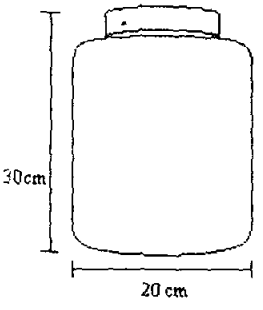
34. Gudang penyimpanan susu bubuk tinggi protein

Fungsi : Untuk menyimpan susu bubuk tinggi protein selama 5 hari sebelum dipasarkan

- **Perhitungan dimensi penyimpanan perhari**

Ukuran kaleng : Tinggi : 30 cm

Diameter : 20 cm

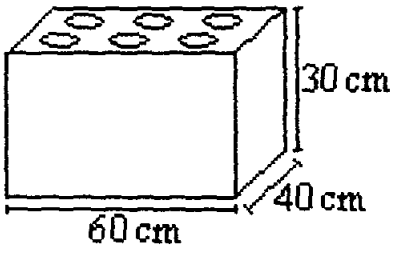


Dalam satu dos terdapat 6 kaleng plastik, maka dimensi dos:

Panjang = 60 cm

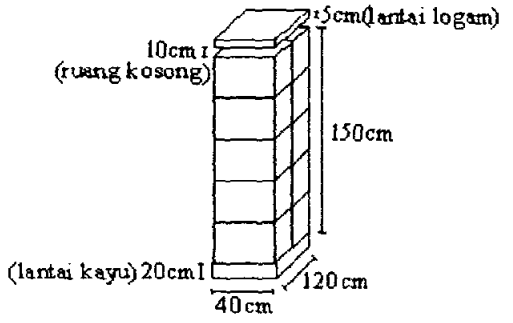
Lebar = 40 cm

Tinggi = 30 cm



Dos akan disusun sebanyak 5 tumpuk, sehingga tinggi tumpukan = 150 cm. Setiap 5 tumpukan dos akan ada ruang kosong = 10 cm, lantai kayu = 20 cm, lantai logam = 5 cm, maka tinggi total tumpukan = 150 cm + 35 cm = 185 cm.

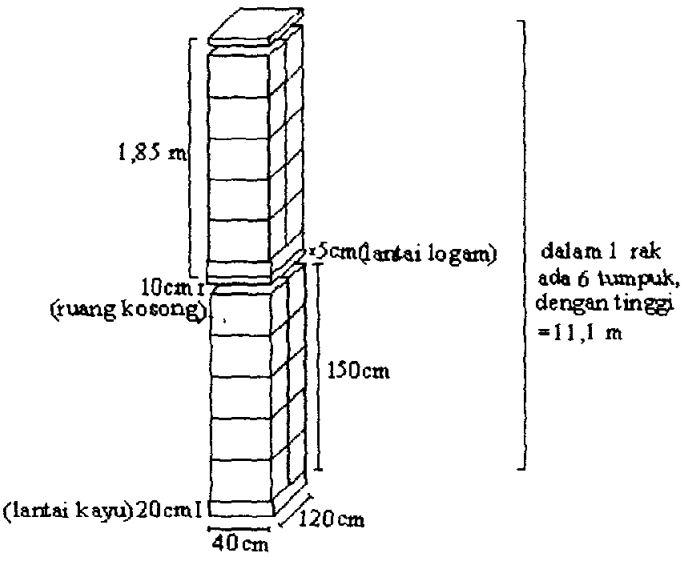
Gambar:



Dalam satu baris ada 4 tumpukan dos dengan spasi tiap 2 tumpukan dos selebar 10 cm, maka lebar 1 baris adalah:

$$\begin{aligned} lebar &= (lebar\,dos \times 4) + lebar\,spasi \\ &= (60\,cm \times 4) + 10\,cm \\ &= 250\,cm = 2{,}5\,m \end{aligned}$$

Dalam 1 rak, akan ada 6 tumpuk (@ 5 dos), maka tinggi total tumpukan besar = 6 x 185 cm = 1.110 cm = 11,1 m ≈ 12 m



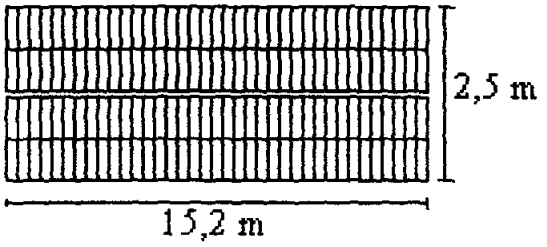
Jumlah dos dalam satu tumpukan besar per baris =

$$6 \times 5 \times 4 = 120^{dos}/_{tumpukan\ besar.baris} = 720^{kaleng}/_{tumpukan\ besar.baris}$$

Dalam 1 hari memproduksi 25.980 kaleng ≈ 26.000 kaleng, maka

dibutuhkan jumlah tumpukan besar sebanyak = $\frac{26.000}{720} = 36{,}1 \approx 37$ baris

Asumsi : Ada spasi 1 cm dalam setiap penataan tumpukan, maka panjang rak penyimpanan untuk 1 hari adalah: 37 x 41 cm = 15,17 m ≈ 15,2 m



Dimensi rak:

- Panjang = 15,2 m
- Lebar = 2,5 m

- Kapasitas dos = $37\,baris \times 720\,{}^{dos}/_{baris} = 26.640\,dos$

- **Perhitungan dimensi gudang**

  Karena sebelum di pasarkan, susu disimpan dahulu selama 5 hari, maka ada 6 rak. Setiap rak di beri spasi 2 m untuk *forklift* menata tumpukan di rak, 2,5 meter untuk memindahkan dos dari rak menuju ke truk. Dimensi gedung adalah sebagai berikut:

  - Panjang = 31,5 m
  - Lebar = 20 m

APPENDIX D

PERHITUNGAN ANALISA EKONOMI

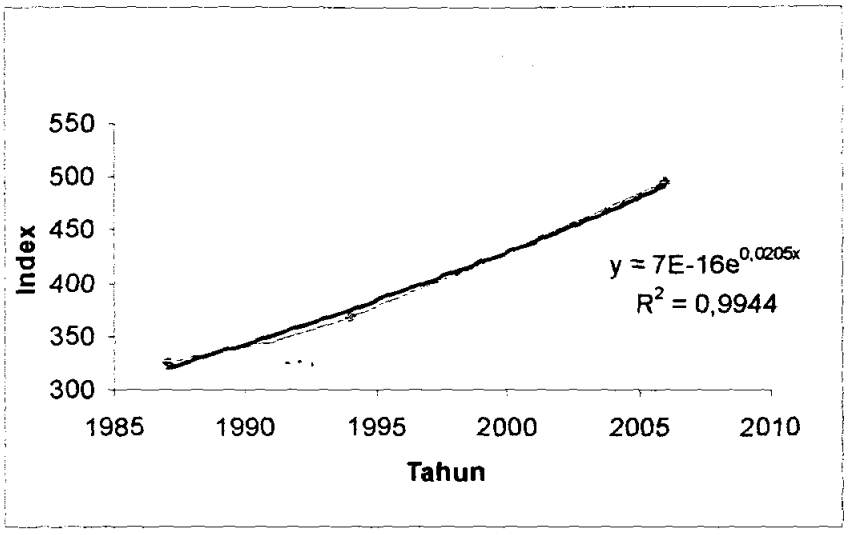
D.1 Perhitungan Harga Peralatan

Metode Perkiraan Harga

Dari tahun ke tahun harga peralatan selalu mengalami kenaikan seiring dengan perubahan kondisi ekonomi. Untuk memperkirakan harga peralatan tahun tertentu diperlukan suatu indeks yang dapat mengkonversikan harga peralatan tahun sebelumnya menjadi harga peralatan tahun tersebut. Metode yang digunakan untuk menentukan harga peralatan adalah metode *Cost Index* yang dihitung dengan persamaan :

$$\text{Harga alat tahun yang diinginkan} = \frac{\text{Cost index tahun diinginkan}}{\text{Cost index tahun A}} \text{Harga alat tahun A}$$

Pada perencanaan pabrik susu bubuk tinggi protein, harga peralatan yang digunakan didasarkan pada harga alat yang terdapat pada pustaka Peters & Timmerhauss, Ulrich, Garett dan harga peralatan dari internet. *Cost index* yang digunakan adalah dari Chemical Engineering Plant Cost Index. Diperkirakan pabrik didirikan tahun 2009, sehingga dengan linierisasi data-data tahun sebelumnya didapatkan :



Gambar D.1 Grafik hubungan *cost index* vs tahun

Tabel D.1. Daftar Index hasil regresi linear

Tahun Index	Index
1,987.00	320
1,990.00	364
2,003.00	476
2,007.00	517
2,009.00	538

Contoh perhitungan :

Nama alat : *Plate Heat Exchanger (E-110)*

Harga Tahun 1987 : $ 18.513

1 US$ = Rp. 9300,00

Harga Tahun 2007 = $\frac{538}{320} \times \$18.513 \times Rp..9300$ = Rp. 289.807.020

Dengan cara yang sama, harga peralatan disajikan pada Tabel D.2 untuk alat-alat proses dan Tabel D.3 untuk alat - alat utilitas.

Tabel D.2 Harga Alat Proses

Jenis alat	Jumlah	Harga ($)	Harga (Rp)	Index	Harga index (Rp)
Heat Exchanger (E-110)	1	18.513	172.170.900	1987	289.807.020
Heat Exchanger (E-120)	1	23.562	219.126.600	1987	368.845.298
Heat Exchanger (E-130)	1	13.464	125.215.200	1987	210.768.742
Tangki penampung susu segar	12	33.000	3.682.800.000	1990	5.436.705.835
Tangki penampung lemak	1	26.000	241.800.000	1990	356.955.434
Tangki F-150	1	52.000	483.600.000	1990	713.910.867
Tangki F-212	1	9.000	83.700.000	1990	123.561.496
Tangki air diafiltrasi	1	2.500	23.250.000	1990	34.322.638
Tangki F-222	1	10.500	97.650.000	1990	144.155.079
Tangki penampung permeat	12	35.000	3.906.000.000	1990	5.766.203.158
Tangki F-312	1	11.000	102.300.000	1990	151.019.607
Tangki F-321	1	8.000	74.400.000	1990	109.832.441
Pompa sentrifugal (L-111)	1	917	8.528.100	2007	8.885.019
Pompa sentrifugal (L-151)	4	736	27.379.200	2007	28.525.077
Pompa sentrifugal (L-211)	24	449	100.216.800	2007	104.411.084
Pompa sentrifugal (L-213)	1	2.758	25.649.400	2007	26.722.881
Pompa sentrifugal (L-221)	24	449	100.216.800	2007	104.411.084
Pompa sentrifugal (L-223)	1	449	4.175.700	2007	4.350.462
Pompa sentrifugal (L-311)	1	449	4.175.700	2007	4.350.462
Pompa sentrifugal (L-316)	1	546	5.077.800	2007	5.290.317
Pompa sentrifugal (L-322)	1	546	5.077.800	2007	5.290.317
Blower (G-323)	1	65.000	604.500.000	1990	892.388.584
Vaccum pump (G-314)	1	64.680	601.524.000	1987	1.012.516.505
Pneumatic conveyor (J-341)	1	120.507	1.120.715.100	1987	1.886.445.988
Centrifugal separator	1	100.000	930.000.000	1990	1.372.905.514
Membran S-210	524,18	1.000	4.874.874.000	2003	5.512.919.061
Membran S-220	15,07	1.000	140.169.600	2003	158.515.617
Falling Film Evaporator	1	43.100	400.830.000	2003	453.292.402
Spray dryer	1	885.600	8.236.080.000	1990	12.158.451.231
Cyclone	1	43.500	404.550.000	1987	680.959.616
Barometer kondenser (G-313)	1	2.476	23.026.800	1987	38.759.908
Barometer kondenser (G-331)	1	2.476	23.026.800	1987	38.759.908
Packaging Line	1	678.000	6.305.400.000	2007	6.569.294.266

Tabel D.3. Harga Alat Utilitas

Jenis alat	Jumlah	Harga ($)	Harga (Rp)	Index	Harga index (Rp)
Pompa sentrifugal (L-411)	1	485	4.510.500	2007	4.699.274
Pompa sentrifugal (L-421)	1	485	4.510.500	2007	4.699.274
Pompa sentrifugal (L-451)	1	485	4.510.500	2007	4.699.274
Pompa sentrifugal (L-461)	1	485	4.510.500	2007	4.699.274
Pompa sentrifugal (L-452)	1	485	4.510.500	2007	4.699.274
Refrigerator	1	70.080	651.744.000	1987	1.097.049.423
Burner udara panas	1	21.500	199.950.000	2007	208.318.329
Boiler	1	46.512	432.561.600	1987	728.110.199

Total harga alat proses dan alat utilitas adalah Rp. **46.830.507.239**

D.2 Perhitungan Harga Bahan Baku

Contoh perhitungan :

Susu cair didapatkan dari daerah-daerah di Australia dengan harga = Rp 6.000/ Liter. Susu segar yang dibutuhkan dalam 1 hari sebesar 671406,6098 kg/hari. Dengan densitas susu sebesar 1032,74 kg/m^3, maka susu segar yang dibutuhkan selama 1 tahun sebesar :

$$Harga\ susu\ segar/hari = \frac{671.406{,}6098 kg/hari \times \frac{1000 L}{1 m^3} \times \frac{Rp.6000{,}00}{Liter}}{1032{,}74 kg/m^3}$$

$$= \text{Rp. } 4.028.439.659$$

Harga susu segar/ tahun = Rp. 4.028.439.659,00/hari x 300 hari/tahun

= **1.208.531.897.640**

D.3 Perhitungan Harga Utilitas

Perhitungan harga utilitas terdiri dari biaya media filter (*sand filter, carbon filter* dan zeolit), NaCl untuk regenerasi, harga bahan bakar dan harga listrik.

Perhitungan tarif dasar listrik tiap bulan dihitung untuk keperluan industri dengan batas daya 200 kW berdasarkan PP no.76 tahun 2003 adalah sebagai berikut :

1. Biaya beban = Rp 29.500/ kW x 176,77 kW = Rp 5.214.678,00
2. Biaya Pemakaian

   Biaya pemakaian listrik untuk Waktu Beban Puncak (17.00-22.00) adalah Rp. 439,00 /kWh dan Luar Waktu Beban Pucak (22-17.00) adalah 1,4 x harga WBP sebebesar Rp.614,60/kWh untuk pemakaian listrik lebih dari 350 jam perbulan.

Tabel D.4 Biaya listrik dari lampu

	Waktu Hidup/hari	kW	Jumlah	kW total	WBP	LWBP	kWh (WBP)	kWh (LWBP)	Harga WBP (Rp)	Harga LWBP (Rp)
Pos keamanan kanan	12	0,04	2	0,08	6	6	0,48	0,48	295,01	210,72
Pos keamanan kiri	12	0,02	2	0,04	6	6	0,24	0,24	147,50	105,36
Pos keamanan tengah	12	0,02	2	0,04	6	6	0,24	0,24	147,50	105,36
Parkir sepeda motor	12	0,25	3	0,75	6	6	4,5	4,5	2.765,70	1.975,50
Parkir mobil pribadi	12	0,25	4	1	6	6	6	6	3.687,60	2.634,00
Parkir truk	12	0,25	17	4,25	6	6	25,5	25,5	15.672,30	11.194,50
Kantor lantai 1	12	0,04	42	1,68	6	6	0	20,16	-	8.850,24
Ruang penyimpanan susu segar	10	0,04	11	0,44	5	5	2,2	2,2	1.352,12	965,80
Kantor manager lantai 2	12	0,04	10	0,4	0	12	0	4,8	-	2.107,20
Ruang QC dan RnD	24	0,04	14	0,56	6	18	3,36	10,08	2.065,06	4.425,12
Ruang rapat	5	0,04	18	0,72	0	5	0	3,6	-	1.580,40
Area kosong lantai 2	24	0,04	7	0,28	6	18	1,68	5,04	1.032,53	2.212,56
Area proses lantai 2	24	0,04	53	2,12	6	18	12,72	38,16	7.817,71	16.752,24
Control room	24	0,04	5	0,2	6	18	1,2	3,6	737,52	1.580,40
Area proses lantai 3A	24	0,04	37	1,48	6	18	8,88	26,64	5.457,65	11.694,96
Area proses lantai 3B	12	0,04	37	1,48	6	6	8,88	8,88	5.457,65	3.898,32
Packaging Line	24	0,04	43	1,72	6	18	10,32	30,96	6.342,67	13.591,44
Gudang penyimpanan kaleng, dos & alumunium foil	24	0,04	8	0,32	6	18	1,92	5,76	1.180,03	2.528,64
Area kosong lantai 3	24	0,04	21	0,84	6	18	5,04	15,12	3.097,58	6.637,68

Area spraydryer, evaporator (untuk 3 lantai)	24	0,04	35	1,4	6	18	8,4	25,2	5.162,64	11.062,80
Gudang storage susu bubuk	24	0,04	17	0,68	6	18	4,08	12,24	2.507,57	5.373,36
Utilitas	12	0,25	4	1	6	6	6	6	3.687,60	2.634,00
Taman	12	0,04	3	0,12	6	6	0,72	0,72	442,51	316,08
Nama Perusahaan	12	0,02	4	0,08	6	6	0,48	0,48	295,01	210,72
Kantin	12	0,04	5	0,2	6	6	1,2	1,2	737,52	526,80
Mushola	12	0,04	3	0,12	6	6	0,72	0,72	442,51	316,08
Poliklinik	24	0,04	2	0,08	6	18	0,48	1,44	295,01	632,16
Koperasi	12	0,04	2	0,08	6	6	0,48	0,48	295,01	210,72
Bengkel	24	0,04	5	0,2	6	18	1,2	3,6	737,52	1.580,40
Check lock	12	0,04	2	0,08	6	6	0,48	0,48	295,01	210,72
Jalan	12	0,25	29	7,25	6	6	43,5	43,5	26.735,10	19.096,50
WC pos satpam kiri	24	0,02	1	0,02	6	18	0,12	0,36	73,75	158,04
WC pos satpam kiri	24	0,02	1	0,02	6	18	0,12	0,36	73,75	158,04
WC lantai 1	24	0,02	1	0,02	6	18	0,12	0,36	73,75	158,04
WC lantai 2	24	0,02	1	0,02	6	18	0,12	0,36	73,75	158,04
WC lantai 3	24	0,02	1	0,02	6	18	0,12	0,36	73,75	158,04
Tangga utama (untuk 3 buah)	12	0,04	3	0,12	6	6	0,72	0,72	442,51	316,08
Loading susu segar, lemak dan permeat	12	0,25	1	0,25	6	6	1,5	1,5	921,90	658,50
Ruang generator	12	0,04	1	0,04	6	6	0,24	0,24	147,50	105,36
Pengolahan limbah	12	0,25	2	0,5	6	6	3	3	1.843,80	1.317,00
Komputer (proses)	24	0,25	15	3,75	6	18	22,5	67,5	13.828,50	29.632,50
Komputer (office)	8	0,25	10	2,5	0	8	0	20	-	8.780,00
AC office	8	0,746	10	7,46	0	8	0	59,66	-	26.188,98

AC proses	24	0.746	4	2.9828	6	18	17.8968	53.6904	10.999.37	23.570.09
Kantin	24	0.746	2	1.4914	6	18	8.9484	26.8452	5.499.69	11.785.04
ruang rapat	2	0.746	4	2.9828	0	2	0	5.9656	-	2.618.90

Tabel D.5 Biaya listrik dari alat

Nama Alat	Waktu Hidup/hari	kW	Jumlah	kW total	WBP	LWBP	kWh (WBP)	kWh (LWBP)	Harga WBP (Rp)	Harga LWBP (Rp)
Pompa sentrifugal (L-111)	24	4,47	1	4,47	6	18	26,85	80,53	16.499,06	5.355,13
Pompa sentrifugal (L-151)	24	16,41	4	65,62	6	18	393,73	1.181,18	241.986,21	18.541,88
Pompa sentrifugal (L-211)	24	0,19	24	4,47	6	18	26,85	80,54	16.499,06	35.355,13
Pompa sentrifugal (L-221)	24	0,19	24	4,47	6	18	26,85	80,54	16.499,06	35.355,13
Pompa sentrifugal (L-213)	24	16	1	11,93	6	18	71,59	214,76	43.997,49	94.280,34
Pompa sentrifugal (L-223)	24	0,19	1	0,19	6	18	1,11	3,36	687,46	1.473,13
Pompa sentrifugal (L-311)	24	0,19	1	0,19	6	18	1,11	3,34	687,46	1.473,13
Pompa sentrifugal (L-316)	24	0,56	1	0,56	6	18	3,35	10,07	2.062,38	4.419,39
Pompa sentrifugal (L-322)	24	7,46	1	7,46	6	18	44,74	134,23	27.498,43	58.925,21
Blower (G-323)	24	3,36	1	3,36	6	18	20,13	60,40	12374,29	26.516,35
Atomizer	24	12,68	1	12,68	6	18	76,06	228,18	46.747,34	100.172,86
Vaccum pump (G-314)	24	0,19	1	0,19	6	18	1,11	3,36	687,46	1.473,13
Pneumatic Conveyor (J-341)	24	0,93	1	0,93	6	18	5,59	16,78	3.437,30	7.365,65
Centrifugal Separator	24	3,73	1	3,73	6	18	22,37	67,11	13.749,22	29.462,61

Tabel D.6 Biaya listrik dari Utilitas

Nama Alat	Waktu hidup	kW	Jumlah	kW total	WBP	LWBP	kWh (WBP)	kWh (LWBP)	Harga WBP (Rp)	Harga LWBP (Rp)
Pompa sentrifugal (L-411)	24	0,19	1	0,19	6	18	1,12	3,36	687,46	1.473,13
Pompa sentrifugal (L-421)	24	0,19	1	0,19	6	18	1,12	3,36	687,46	1.473,13
Pompa sentrifugal (L-451)	24	0,19	1	0,19	6	18	1,12	3,36	687,46	1.473,13
Pompa sentrifugal (L-461)	24	0,19	1	0,19	6	18	1,12	3,36	687,46	1.473,13
Pompa sentrifugal (L-452)	24	0,19	1	0,19	6	18	1,12	3,36	687,46	1.473,13
Refrigerator	24	3,73	1	3,73	6	18	22,37	67,11	13.749,22	29.462,61

Total biaya pemakaian/hari = biaya pemakaian WBP+ biaya LWBP

= Rp 593.540 + Rp. 1.227.981

= Rp. 1.821.521

Total biaya/tahun = biaya beban x 12 bulan + biaya pemakaian x 300 hari

= Rp. 5.214.678 x 12 bulan + Rp. 1.821.521 x 300 hari

= **Rp. 718.323.589**

Sehingga, biaya utilitas adalah sebagai berikut :

Tabel D.7 Biaya utilitas

Biaya	Rp/kg atau Rp/L	kebutuhan	harga/thn (Rp)
Media Filter	-	-	1.200.000,00
NaCl	500,00	39,31 kg/tahun	19.656,00
MFO	5.668,00	3.028,67 kg/hari	5.919.49.114,00
IDO	7.537,00	29,76 kg/bulan	2.774.859,00
Listrik			718.323.589
		Total	**6.641.809.218**

F.4 Perhitungan Harga Bahan Kemas

Produk susu bubuk tinggi protein dibungkus dengan *aluminium foil*. Setiap 500 gram susu bubuk tinggi protein dibungkus dengan sebuah aluminium foil, sehingga dalam setiap kaleng plastik terdapat 2 buah *aluminium foil*. Setelah itu, *aluminium foil* dikemas dalam kaleng plastik dan diberi sendok plastik. 1 kardus pengemas terdiri dari dari 6 buah kaleng plastik. Harga-harga bahan pengemas adalah sebagai berikut :

Tabel D.8 Harga bahan kemas

Bahan	Jumlah (buah)	Harga (Rp)	Harga/hari	Harga/thn (Rp)
Aluminium foil (2 buah)	52.500	500	26.250.000	7.794.000.000
Kaleng plastik + printing	26.500	2.000	53.000.000	15.588.000.000
Sendok plastik	26.500	150	3.975.000	1.169.100.000
Kardus	5.000	300	1.500.000	389.700.000
			Jumlah	**25.417.500.000**

D.5 Perhitungan Total Penjualan

Penjualan dibagi menjadi 2 produk, yaitu susu bubuk tinggi protein sebagai produk utama dan lemak + *permeate* sebagai produk samping. Harga jual susu bubuk tinggi protein per kg ditetapkan Rp.215.000,00. Harga lemak/kg ditetapkan Rp.5000 dan harga permeate/kg ditetapkan Rp.276,00 (Bab VI). Lemak yang dihasilkan sebesar 25.661,1606 kg/hari, dimana lemak yang terjual sebesar 25.600 kg/hari, sisanya hilang pada saat penyimpanan. *Permeate* yang dihasilkan sebesar 541.220,4255 kg/hari, dimana diasumsikan *permeate* yang dapat terjual sebesar 541.200kg/hari, sisanya hilang pada saat penyimpanan.

Tabel D.9 Tabel harga produk

Produk	Jumlah (kg/hari)	Harga/kg	Pendptn/ hari (Rp)	Pendptn/ tahun(Rp)
Susu bubuk tinggi protein	25.980	215.000	5.845.500.000	1.675.710.000.000
Lemak	25.600	5000	128.000.000	38.400.000
Permeate	541.200	276	149.371.200	44.811.360.000
			Total	**1.758.921.360.000**

F.6 Perhitungan Gaji Karyawan

Jumlah karyawan di pabrik Keju Kedelai ini adalah 109 orang, yang terdiri dari :

1. Karyawan non shift

Karyawan yang bekerja non shift adalah karyawan di bidang keuangan, HRD, pemasaran, bagian limbah, pegawai R&D, dan petugas kebersihan, dengan jam kerja Senin-Jumat pukul 08.00-16.00, dan Sabtu pukul 08.00-13.00.

2. Karyawan shift

Karyawan yang bekerja shift terdiri dari pegawai kesehatan, pegawai bagian bengkel, bagian *Quality Control*, bagian produksi, bagian utilitas, satpam, pegawai

gudang bahan baku, dan pegawai gudang bahan jadi. Jam kerja karyawan shift adalah dari hari Senin – Minggu dengan jadwal :

Shift 1: pukul 06.00-14.00

Shift 2: pukul 14.00-22.00

Shift 3: pukul 22.00-06.00

A,B,C,D merupakan nama regu

Pergantian shift dilakukan setiap dua hari sekali seperti terlihat dalam Tabel D.10, dimana jika pada hari tidak tertera nama regu, maka regu tersebut libur.

Tabel D.10 Shift pergantian kerja

Shift	Hari								
	Senin	Selasa	Rabu	Kamis	Jumat	Sabtu	Minggu	Senin	Selasa
1	A	A	D	D	C	C	B	B	A
2	B	B	A	A	D	D	C	C	B
3	C	C	B	B	A	A	D	D	C

Gaji dari masing-masing pegawai ditabelkan pada Tabel D.11

Tabel D.11 Gaji Karyawan

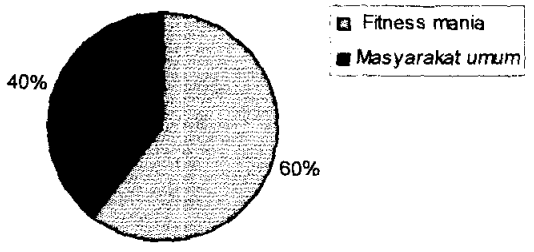
Jabatan	Jumlah pekerja	Jumlah grup	Total	Gaji	Gaji Total/bulan	Gaji Total/tahun (13 bulan)
Direktur	1	1	1	30.000.000,00	30.000.000,00	390.000.000,00
Manajer Umum	1	1	1	15.000.000,00	15.000.000,00	195.000.000,00
Manajer QC	1	1	1	7.500.000,00	7.500.000,00	97.500.000,00
Manajer RnD	1	1	1	7.500.000,00	7.500.000,00	97.500.000,00
Manajer proses	1	1	1	7.500.000,00	7.500.000,00	97.500.000,00
Manajer Utilitas&Limbah	1	1	1	7.500.000,00	7.500.000,00	97.500.000,00
karyawan RnD	3	1	3	1.800.000,00	5.400.000,00	70.200.000,00
Karyawan limbah	2	1	2	1.800.000,00	3.600.000,00	46.800.000,00
Manajer Keuangan	1	1	1	7.500.000,00	7.500.000,00	97.500.000,00
Pegawai keuangan	3	1	3	1.800.000,00	5.400.000,00	70.200.000,00
Akuntan	1	1	1	3.500.000,00	3.500.000,00	45.500.000,00
Kepala bengkel	1	1	1	3.500.000,00	3.500.000,00	45.500.000,00
Pegawai bengkel	5	1	5	1.800.000,00	9.000.000,00	117.000.000,00
Manajer HRD	1	1	1	7.500.000,00	7.500.000,00	97.500.000,00
Pegawai HRD	4	1	4	1.800.000,00	7.200.000,00	93.600.000,00
Manajer pemasaran	1	1	1	7.500.000,00	7.500.000,00	97.500.000,00
Pegawai pemasaran	3	1	3	1.800.000,00	5.400.000,00	70.200.000,00
Kepala gudang produk	1	1	1	3.500.000,00	3.500.000,00	45.500.000,00
Petugas kebersihan	10	1	10	800.000,00	8.000.000,00	104.000.000,00
Supervisor QC	1	4	4	3.500.000,00	14.000.000,00	182.000.000,00
Karyawan QC	3	4	12	1.800.000,00	21.600.000,00	280.800.000,00
Supervisor Utilitas	1	4	4	3.500.000,00	14.000.000,00,00	182.000.000,00
karyawan Utilitas	3	4	12	1.800.000,00	21.600.000,00	280.800.000,00
Supervisor Proses	1	4	4	3.500.000,00	14.000.000,00	182.000.000,00
Karyawan proses	12	4	48	1.800.000,00	86.400.000,00	1.123.200.000,00
Karyawan Packaging	16	4	64	1.800.000,00	115.200.000,00	1.497.600.000,00

Kepala keamanan	1	4	4	1.800.000,00	7.200.000,00	93.600.000,00
Anggota keamanan	8	4	32	1.000.000,00	32.000.000,00	416.000.000,00
Petugas polikliknik	1	4	4	1.800.000,00	7.200.000,00	93.600.000,00
Petugas kantin	3	4	12	800.000,00	9.600.000,00	124.800.000,00
Sopir Perusahaan	2	4	8	1.500.000,00	12.000.000,00	156.000.000,00
Pegawai bengkel	5	4	20	1.800.000,00	36.000.000,00	468.000.000,00
Pegawai gudang produk	3	4	12	1.200.000,00	14.400.000,00	187.200.000,00
Pegawai gudang kaleng	2	4	8	1.200.000,00	9.600.000,00	124.800.000,00
				Jumlah	**566.800.000,00**	**7.082.400.000,00**

APPENDIX E

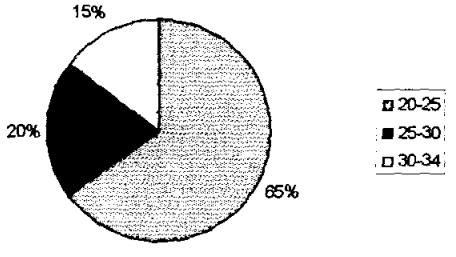
HASIL POLLING

Polling dilakukan kepada 100 responden laki-laki yang berada di lingkungan fitness yaitu Celebrity *Fitness Galaxy Mall* dan *Atlas Sport Club* dan lingkungan kampus Widya Mandala *Jl.* Kalijudan, yang mewakili masyarakat umum dengan usia responden 20-34 tahun. Gambar E.1. menunjukkan persentase keberadaan responden.



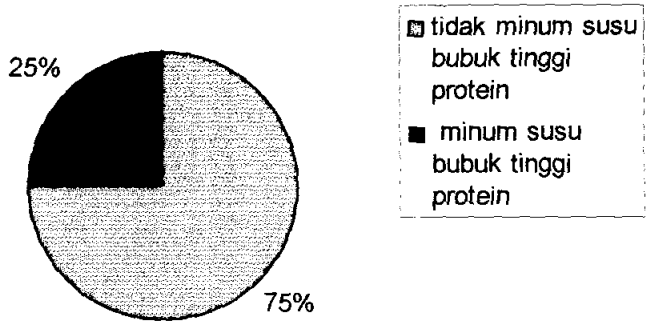
Gambar E.1. Persentase Keberadaan Responden

Gambar E.2 menunjukkan persentase usia responden. Responden terbesar pada kelompok usia 20-25 tahun



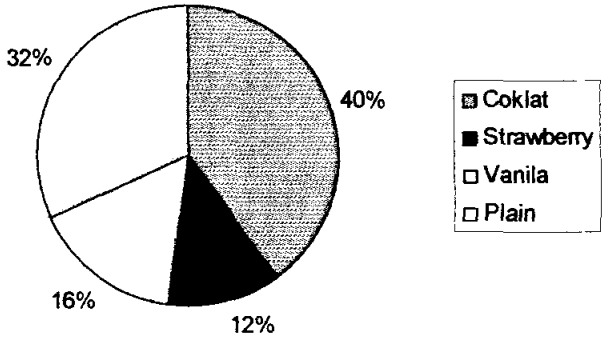
Gambar E.2. Persentase Usia Responden

Dari hasil polling terlihat bahwa orang yang minum susu bubuk tinggi protein sebesar 25% dan sisanya tidak minum susu bubuk tinggi protein. Menurut salah satu responden, alasan tidak meminum susu bubuk tinggi protein karena telah menggunakan suplemen nutrisi yang lain.

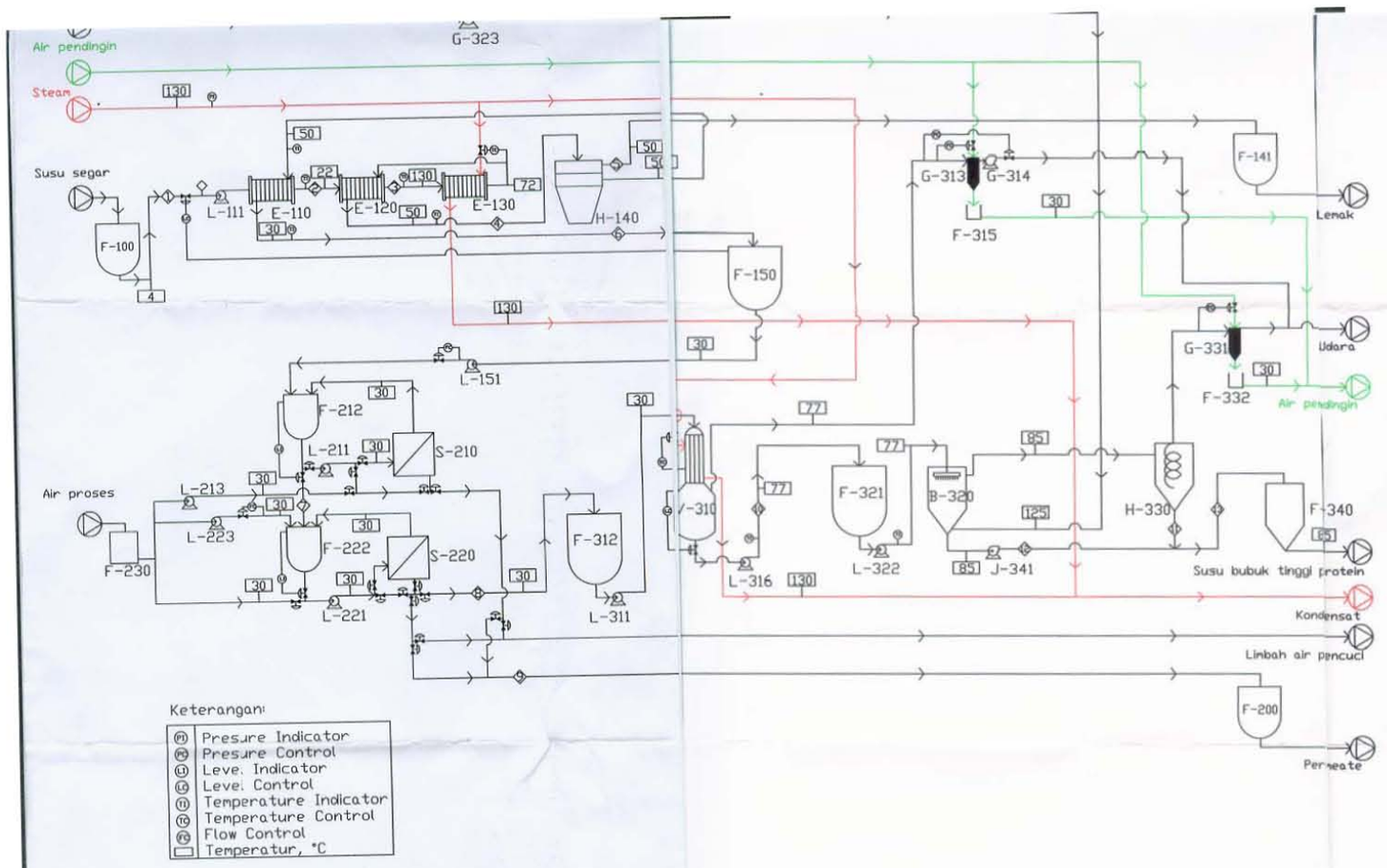


Gambar E.3. Persentase Responden Minum Susu Bubuk Tinggi Protein dan Tidak Minum Susu Bubuk Tinggi Protein

Dari antara responden yang minum susu bubuk protein, sebesar 40 % menyenangi rasa coklat, 32% menyenangi rasa plain, 16% menyenangi rasa vanilla dan sisanya menyenagi rasa strawberry. Menurut salah satu responden, rasa plain disenangi karena tidak ada tambahan perasa yang dapat meningkatkan kandungan lemak *preserving.*



Gambar E.4. Persentase Responden Minum Berbagai Rasa Susu Bubuk Tinggi Protein



Keterangan:

PI	Presure Indicator
PC	Presure Control
LI	Level Indicator
LC	Level Control
TI	Temperature Indicator
TC	Temperature Control
FC	Flow Control
	Temperatur, °C

E-110	Plate Heat Exchanger 1
L-111	Pompa Sentrifugal
E-120	Plate Heat Exchanger 2
E-130	Plate Heat Exchanger 3
H-140	Sentrifugal Separator
F-141	Tangki Penampung Lemak Susu
F-150	Tangki Penampung Susu Skim
L-151	Pompa Sentrifugal
F-200	Tangki Penampung Permeat
S-210	Ultrafiltrasi
L-211	Pompa Sentrifugal
F-212	Tangki Batch Ultrafiltrasi
L-213	Pompa Sentrifugal
S-220	Diafiltrasi
L-221	Pompa Sentrifugal
F-222	Tangki Batch Diafiltrasi
L-223	Pompa Sentrifugal
F-230	Tangki Penampung Air Pencuci Membran dan Diafiltrasi
V-310	Falling Film Evaporator
L-311	Pompa Sentrifugal
F-312	Tangki Penampung Susu Cair Tinggi Protein
G-313	Barometrik Kondenser
G-314	Pompa Vaccum
F-315	Tangki Penampung Kondensat
L-316	Pompa Sentrifugal
B-320	Spray Dryer
F-321	Tangki Penampung Susu Pekat Tinggi Protein
L-322	Pompa Sentrifugal
G-323	Blower
H-330	Cyclone
G-331	Barometrik Kondenser
F-332	Tangki Penampung Kondensat
F-340	Silo Susu Bubuk Tinggi Protein
J-341	Pneumatic Conveyor

Digambar oleh :
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FLOWSHEET PRARENCANA PABRIK
SUSU BUBUK TINGGI PROTEIN

JURUSAN TEKNIK KIMIA
FAKULTAS TEKNIK
UNIVERSITAS KATOLIK WIDYA MANDALA

No aliran / Komponen	1 Massa (kg)	2 Massa (kg)	3 Massa (kg)	4 Massa (kg)	5 Massa (kg)	6 Massa (kg)	7 Massa (kg)	8 Massa (kg)	9 Massa (kg)	10 Massa (kg)	11 Massa (kg)	12 Massa (kg)	13 Massa (kg)
Air	585.332,2824	585.332,2824	585.332,2824	585.332,2824	---	585.332,2824	82.389,2954	82.389,2954	502.942,9870	45.314,1125	3,7307	741,4920	745,2228
Lemak	26.184,8578	26.184,8578	26.184,8578	26.184,8578	25.661,1606	523,6972	523,6972	523,6972	---	523,6972	2.6185	521,0787	523,6972
Protein	22.827,8247	22.827,8247	22.827,8247	22.827,8247	---	22.827,8247	22.827,8247	22.827,8247	---	22.827,8247	114,1391	22.713,6856	22.827,8247
Laktosa	32.227,5173	32.227,5173	32.227,5173	32.227,5173	---	32.227,5173	4.264,1130	86,0994	31.820,0038	86,0994	0,4305	1.788,3382	86,0994
Abu	4.834,1276	4.834,1276	4.834,1276	4.834,1276	---	4.834,1276	1.913,8103	1.797,3248	3.006,4347	1.797,3248	8.9866	741,4920	1.797,3248