Kapasitas Produksi = 58000 ton/tahun
1 Tahun Operasi = 330 hari
1 Tahun Produksi = 24 jam

Kapasitas Produksi dalam 1 jam operasi:

\[
\text{Kapasitas Produksi dalam 1 jam operasi} = \frac{58000 \text{ ton/tahun}}{330 \text{ hari}} \times \frac{1000 \text{ kg/ton}}{1 \text{ ton}} \times \frac{1 \text{ tahun}}{330 \text{ hari}} \times \frac{1 \text{ hari}}{24 \text{ jam}}
\]

= 7323,2323 kg/jam

Basis perhitungan : 1 jam operasi
Kemurnian produk : 30%

LA.1 Kolom Hidrolisa (KH-101)

Gliserol murni sebagai produk = 0,3 x 7323,2323
= 2196,9697 kg/jam

Kmol Gliserol = \( \frac{2196,9697 \text{ kg/jam}}{92,097 \text{ kg/kmol}} \)
= 23,8550 kmol/jam

CPO yang dibutuhkan untuk menghasilkan gliserol sebanyak 23,8550 kmol dengan konversi reaksi adalah

\[ \text{N}^{\text{in}} \times 0.99 = 23,8550 \text{ kmol} \]
\[ \text{N}^{\text{in}} = \frac{23,8550 \text{ kmol}}{0.99} \]
\[ = 24,0959 \text{ kmol} \]
Jumlah trigliserida masuk:

<table>
<thead>
<tr>
<th>Asam</th>
<th>Persentase</th>
<th>Jumlah</th>
<th>Kmolar/jam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linoleat</td>
<td>10,00%</td>
<td>879,411 x 24,0959 kmol/jam</td>
<td>2119,0200 kg/jam</td>
</tr>
<tr>
<td>Miristat</td>
<td>2,30%</td>
<td>723,183 x 24,0959 kmol/jam</td>
<td>400,7921 kg/jam</td>
</tr>
<tr>
<td>Palmitat</td>
<td>43,00%</td>
<td>807,345 x 24,0959 kmol/jam</td>
<td>8365,0929 kg/jam</td>
</tr>
<tr>
<td>Stearat</td>
<td>4,70%</td>
<td>891,507 x 24,0959 kmol/jam</td>
<td>1009,6382 kg/jam</td>
</tr>
<tr>
<td>Oleat</td>
<td>40,00%</td>
<td>885,459 x 24,0959 kmol/jam</td>
<td>8534,3726 kg/jam</td>
</tr>
<tr>
<td><strong>Total Trigliserida</strong></td>
<td></td>
<td></td>
<td><strong>20428,9158 kg/jam</strong></td>
</tr>
</tbody>
</table>

Jumlah Trigliserida masuk (F²) = 20428,9158 kg/jam

Kmol Trigliserida yang bereaksi (r) = (0,99) (24,0959 kmol/jam) -(-1) = 23,8550 kmol/jam

Kmol Trigliserida sisa (Nout) = N^in - r = 24,0959 kmol/jam - 23,8550 kmol/jam = 0,2410 kmol/jam

Jumlah Trigliserida yang tak terkonversi:

<table>
<thead>
<tr>
<th>Asam</th>
<th>Persentase</th>
<th>Jumlah</th>
<th>Kmolar/jam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linoleat</td>
<td>10,00%</td>
<td>879,411 x 0,2410 kmol/jam</td>
<td>21,1938 kg/jam</td>
</tr>
<tr>
<td>Miristat</td>
<td>2,30%</td>
<td>723,183 x 0,2410 kmol/jam</td>
<td>4,0086 kg/jam</td>
</tr>
<tr>
<td>Palmitat</td>
<td>43,00%</td>
<td>807,345 x 0,2410 kmol/jam</td>
<td>83,6652 kg/jam</td>
</tr>
<tr>
<td>Stearat</td>
<td>4,70%</td>
<td>891,507 x 0,2410 kmol/jam</td>
<td>10,0981 kg/jam</td>
</tr>
<tr>
<td>Oleat</td>
<td>40%</td>
<td>885,459 x 0,2410 kmol/jam</td>
<td>85,3582 kg/jam</td>
</tr>
<tr>
<td><strong>Total Trigliserida</strong></td>
<td></td>
<td></td>
<td><strong>204,3239 kg/jam</strong></td>
</tr>
</tbody>
</table>

Asam lemak terbentuk:

\[ N^{out} = N^{in} + 3r = 0 + 3 (23,8550) = 71,565 \text{ kmol} \]

Asam lemak yang terbentuk:

<table>
<thead>
<tr>
<th>Asam</th>
<th>Persentase</th>
<th>Jumlah</th>
<th>Kmolar/jam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linoleat</td>
<td>10,00%</td>
<td>280,454 x 71,565 kmol/jam</td>
<td>2007,0691 kg/jam</td>
</tr>
<tr>
<td>Miristat</td>
<td>2,30%</td>
<td>228,378 x 71,565 kmol/jam</td>
<td>375,9090 kg/jam</td>
</tr>
<tr>
<td>Palmitat</td>
<td>43,00%</td>
<td>256,432 x 71,565 kmol/jam</td>
<td>7891,1691 kg/jam</td>
</tr>
</tbody>
</table>

Universitas Sumatera Utara
As. Stearat $= 4.70\% \times 284.486 \times 71.565 \text{ kmol/jam} = 956.8843 \text{ kg/jam}$

As. Oleat $= 40\% \times 282.47 \times 71.565 \text{ kmol/jam} = 8085.9862 \text{ kg/jam}$

**Total Asam lemak** $= 19316.9347 \text{ kg/jam}$

Maka asam lemak yang terbentuk ($F_{\text{Asam lemak}}^6$) $= 19317.0177 \text{ kg/jam}$

Jumlah Air yang bereaksi untuk konversi 99\% terhadap trigliserida:

$= 3r \times \text{BM Air}$

$= 3 \times 23.8550 \text{ kmol/jam} \times 18.016 \text{ kmol/jam}$

$= 1289.3126 \text{ kg/jam}$

Jumlah air yang diumpankan ($F_{\text{Air}}^4$) $= 20428.9158 \text{ kg/jam} \times 70\%$

$= 14300.2410 \text{ kg/jam}$

Air dari steam ($F_{\text{Air}}^5$) $= 9564.7062 \text{ kg/jam}$

Total air masuk $= 14300.2410\text{kg/jam} + 9564.7062 \text{ kg/jam}$

$= 23864.9472 \text{ kg/jam}$

Total air keluar $= \text{Air Masuk} - \text{Air yang bereaksi}$

$= 23864.9472 \text{ kg/jam} - 1289.3125 \text{ kg/jam}$

$= 22575.6347 \text{ kg/jam}$

Pada alur 6 diasumsikan air 10\% terikut dan CPO terikut sebesar 20\%

$F_{\text{Air}}^6$ $= 10/100 \times 22575.6347 \text{ kg/jam}$

$= 2257.5635 \text{ kg/jam}$

$F_{\text{Air}}^7$ $= \text{total air keluar} - F_{\text{Air}}^6$

$= 22575.6347 \text{ kg/jam} - 2257.5635 \text{ kg/jam}$

$= 20318.0712 \text{ kg/jam}$

$F_{\text{CPO}}^6$ $= 20/100 \times 204.3239 \text{ kg/jam}$

$= 40.8648 \text{ kg/jam}$

$F_{\text{CPO}}^7$ $= 204.3239 \text{ kg/jam} - 40.8648 \text{ kg/jam}$

$= 163.4591 \text{ kg/jam}$

Universitas Sumatera Utara
Tabel LA.1 Hasil Perhitungan Neraca Massa Kolom Hidrolisa

<table>
<thead>
<tr>
<th>KOMPONEN</th>
<th>Massa Masuk (kg/jam)</th>
<th>Massa Keluar (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 2</td>
<td>Alur 4</td>
</tr>
<tr>
<td>CPO</td>
<td>20428,9158</td>
<td>-</td>
</tr>
<tr>
<td>Air</td>
<td>-</td>
<td>14300,2410</td>
</tr>
<tr>
<td>Steam</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Asam Lemak</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Gliserol</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td>20428,9158</td>
<td>14300,2410</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>44293,8630</strong></td>
<td><strong>44293,8630</strong></td>
</tr>
</tbody>
</table>

LA.2 *FLASH TANK ASAM LEMAK (FT-101)*

Persamaan neraca massa pada flash tank asam lemak

\[ F^6 = F^8 + F^{10} \]

\[ F^6 \text{ Asam Lemak} = F^{10} \text{ Asam Lemak} \]
\[ = 19316,9347 \text{ kg/jam} \]

\[ F^{10} \text{ Air} = F^6 \text{ Air} - F^8 \text{ Air} \]

Diasumsikan 80% air dari alur 6 terbuang pada alur 8

\[ F^8 \text{ Air} = 80/100 \times 2257,5635 \text{ kg/jam} \]
\[ = 1806,0508 \text{ kg/jam} \]

\[ F^{10} \text{ Air} = 2257,5635 \text{ kg/jam} - 1806,0508 \text{ kg/jam} \]
\[ = 451,5127 \text{ kg/jam} \]

\[ F^{10} \text{ CPO} = F^6 \text{ CPO} \]
\[ = 40,8648 \text{ kg/jam} \]
### Tabel LA.2 Neraca massa pada Flash Tank Asam Lemak

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (Kg/jam)</th>
<th>Keluar (Kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 6</td>
<td>Alur 8</td>
</tr>
<tr>
<td>Asam Lemak</td>
<td>19316,9347</td>
<td>-</td>
</tr>
<tr>
<td>CPO</td>
<td>40,8648</td>
<td>-</td>
</tr>
<tr>
<td>Air</td>
<td>2257,5635</td>
<td>1806,0058</td>
</tr>
<tr>
<td>Sub Total</td>
<td>21615,3630</td>
<td>1806,0058</td>
</tr>
<tr>
<td>Total</td>
<td>21615,3630</td>
<td>21615,3630</td>
</tr>
</tbody>
</table>

### LA.3 Flash Tank Gliserol (FT-102)

![Diagram of Flash Tank](image)

Neraca massa total:

\[
F^7 = F^9 + F^{11}
\]

\[
F^{11}\text{ Gliserol} = F^7_{\text{gliserol}}
= 2196,9697 \text{ kg/jam}
\]

\[
F^{11}\text{ CPO} = F^7\text{ CPO}
= 163,4591 \text{ kg/jam}
\]

\[
F^{11}_{\text{air}} = F^7_{\text{air}} - F^9_{\text{air}}
\]

Di asumsikan 20% air dari alur 7 terbuang pada alur 11

\[
F^9_{\text{air}} = \frac{20}{100} \times 20318,0712 \text{ kg/jam}
= 4063,6142 \text{ kg/jam}
\]

\[
F^{11}_{\text{air}} = F^7_{\text{air}} - F^9_{\text{air}}
= 20318,0712 \text{ kg/jam} - 4063,6142 \text{ kg/jam}
= 16254,4570 \text{ kg/jam}
\]
Tabel LA.3 Hasil Perhitungan Neraca Massa pada Flash Tank Gliserol

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (Kg/jam)</th>
<th>Keluar (Kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 7</td>
<td>Alur 9</td>
</tr>
<tr>
<td>Gliserol</td>
<td>2196,9697</td>
<td>-</td>
</tr>
<tr>
<td>CPO</td>
<td>163,4591</td>
<td>-</td>
</tr>
<tr>
<td>Air</td>
<td>20318,0712</td>
<td>4063,6142</td>
</tr>
<tr>
<td>Sub Total</td>
<td>22678,5</td>
<td>4063,6142</td>
</tr>
<tr>
<td>Total</td>
<td><strong>22678,5</strong></td>
<td><strong>22678,5</strong></td>
</tr>
</tbody>
</table>

LA.4 SKIMMER (SK-101)

![Diagram of Skimmer](image)

Persamaan neraca massa pada Skimmer

\[ F_{11}^{11} = F_{12}^{11} + F_{13}^{13} \]

\[ F_{13}^{13} \text{ Gliserol} = F_{11}^{11} \text{ Gliserol} \]
\[ = 2196,9697 \text{ kg/jam} \]

\[ F_{12}^{12} \text{ CPO} = F_{11}^{11} \text{ CPO} \]
\[ = 163,4591 \text{ kg/jam} \]

\[ F_{13}^{13} \text{ Air} = F_{11}^{11} \text{ Air} \]
\[ = 16254,4570 \text{ kg/jam} \]
Tabel LA.4 Neraca massa pada Skimmer

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (Kg/jam)</th>
<th>Keluar (Kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 11</td>
<td>Alur 12</td>
</tr>
<tr>
<td>Gliserol</td>
<td>2196,9697</td>
<td>-</td>
</tr>
<tr>
<td>CPO</td>
<td>163,4591</td>
<td>163,4591</td>
</tr>
<tr>
<td>Air</td>
<td>16254,4570</td>
<td>-</td>
</tr>
<tr>
<td>Sub Total</td>
<td>18614,8858</td>
<td>163,4591</td>
</tr>
<tr>
<td>Total</td>
<td>18614,8858</td>
<td></td>
</tr>
</tbody>
</table>

LA.5 EVAPORATOR I (EV-101)

Neraca massa total : \( F_{13} = F_{14} + F_{15} \)

Pada evaporator ini, kemurnian produk menjadi 25%, maka :

\[
\begin{align*}
F_{15} & = 100/25 \times 2196,9697 \text{ kg/jam} \\
& = 8787,8788 \text{ kg/jam} \\
F_{15} \text{ Air} & = 75/100 \times 8787,8788 \text{ kg/jam} \\
& = 6590,9091 \text{ kg/jam} \\
F_{15} \text{ Gliserol} & = 2196,9697 \text{ kg/jam} \\
F_{14} \text{ Air} & = F_{13} \text{ Air} - F_{15} \text{ Air} \\
& = 16254,4570 \text{ kg/jam} - 6590,9091 \text{ kg/jam} \\
& = 9663,5479 \text{ kg/jam}
\end{align*}
\]
Tabel LA.5 Hasil Perhitungan Neraca Massa Evaporator I

<table>
<thead>
<tr>
<th>KOMPONEN</th>
<th>Massa Masuk (kg/jam)</th>
<th>Massa Keluar (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 13</td>
<td>Alur 14</td>
</tr>
<tr>
<td>Gliserol</td>
<td>2196,9697</td>
<td>-</td>
</tr>
<tr>
<td>Air</td>
<td>16254,4570</td>
<td>9663,5479</td>
</tr>
<tr>
<td>Sub Total</td>
<td>18451,4267</td>
<td>9663,5479</td>
</tr>
<tr>
<td>Total</td>
<td>18451,4267</td>
<td></td>
</tr>
</tbody>
</table>

LA.6 EVAPORATOR II (EV-102)

Neraca massa total: \( F^{15} = F^{16} + F^{17} \)

Pada evaporator ini, kemurnian produk menjadi 30%, maka

Pada Evaporator kemurnian Gliserol + Air menjadi 30%, maka:

\[ F^{17} = \frac{100}{30} \times 2196,9697 \text{ kg/jam} \]
\[ = 7323,2323 \text{ kg/jam} \]

\[ F^{17} \text{ Air} = \frac{70}{100} \times 7323,2323 \text{ kg/jam} \]
\[ = 5126,2626 \text{ kg/jam} \]

\[ F^{17} \text{ Gliserol} = 2196,9697 \text{ kg/jam} \]

\[ F^{16} \text{ Air} = F^{15} \text{ Air} - F^{17} \text{ Air} \]
\[ = 6590,9091 \text{ kg/jam} - 5126,2626 \text{ kg/jam} \]
\[ = 1464,6465 \text{ kg/jam} \]
Tabel LA.6 Hasil Perhitungan Neraca Massa Evaporator II

<table>
<thead>
<tr>
<th>KOMPONEN</th>
<th>Massa Masuk (kg/jam)</th>
<th>Massa Keluar (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 15</td>
<td>Alur 16</td>
</tr>
<tr>
<td>Gliserol</td>
<td>2196,9697</td>
<td>-</td>
</tr>
<tr>
<td>Air</td>
<td>6590,9091</td>
<td>1464,6465</td>
</tr>
<tr>
<td>Sub Total</td>
<td>8787,8788</td>
<td>1464,6465</td>
</tr>
<tr>
<td>Total</td>
<td>8787,8788</td>
<td>8787,8788</td>
</tr>
</tbody>
</table>
LAMPIRAN B
NERACA PANAS

Basis perhitungan = 1 jam operasi
Suhu lingkungan = 25°C = 298 K

Steam yang digunakan
Suhu = 275°C = 548 K
Tekanan = 54 bar = 53,3 atm
Satuan perhitungan = kcal/jam

Data kapasitas panas (Cp) dalam kcal/kg°C
(Perry’s 1999)
- Cp CPO = 0,5254
- Cp air = 1
- Cp Gliserol = 0,542
- Cp Asam miristat = 0,492
- Cp Asam palmitat = 0,43
- Cp Asam stearat = 0,399
- Cp Asam oleat = 0,4955
- Cp Asam linoleat = 0,4836

Data panas pembentukan pada 25°C dalam kcal/kmol
(Perry’s 1999)
- ΔH_f 298 K Trigliserida = -379,038
- ΔH_f 298 K H2O = -68,32
- ΔH_f 298 K Gliserol = -139,80
- ΔH_f 298 K Asam miristat = -128,83
- ΔH_f 298 K Asam palmitat = -138,71
- ΔH_f 298 K Asam stearat = -148,59
- ΔH_f 298 K Asam oleat = -120,75
- ΔH_f 298 K Asam linoleat = -92,91
LB.1 *Heater Air* (HE-101)

**T in** = 30°C

**T out** = 80°C

Neraca Panas Total

\[
Q_1 + Q_{\text{steam}} = Q_2
\]

Panas masuk alur 1

\[
Q_1 = m \cdot c_p \cdot \Delta t = (14.300,2410 \text{ kg/jam}) (1 \text{ kkal/kg.}^0\text{C}) (30-25)^0\text{C} = 71501,205 \text{ kkal/jam}
\]

Panas keluar alur 2

\[
Q_2 = m \cdot c_p \cdot \Delta t = (14.300,2410 \text{ kg/jam}) (1 \text{ kkal/kg.}^0\text{C}) (80-30)^0\text{C} = 786513,255 \text{ kkal/jam}
\]

Panas steam

\[
Q_{\text{steam}} = Q_2 - Q_1 = (786513,255 - 71501,205) \text{ kkal/jam} = 715012,05 \text{ kkal/jam}
\]

Steam yang digunakan adalah superheated steam pada 1 atm 150°C, kemudian keluar sebagai kondensat pada 90°C (1 atm).

Dari Tabel *Steam* Smith, 2004 diperoleh:

\[
H (150^0\text{C}) = 663,084 \text{ kkal/kg}
\]

\[
H_v (100^0\text{C}) = 639,152 \text{ kkal/kg}
\]

\[
H_l (100^0\text{C}) = 100,1 \text{ kkal/kg}
\]
H (90\(^\circ\)C) = 90,02 kkal/kg

\[ q = [H(150\(^\circ\)C) - H_v(100\(^\circ\)C)] + [H_v(100\(^\circ\)C) - H_l(100\(^\circ\)C)] + [H_l(100\(^\circ\)C) - H(90\(^\circ\)C)] \]

\[ q = [663,084 - 639,152] + [639,152 - 100,1] + [100,1 - 90,02] \]

\[ q = 573,064 \text{ kkal/kg} \]

Massa steam, \( m_s = \frac{Q_{\text{steam}}}{q} \)

\[ = \frac{715012,05 \text{ kcal/jam}}{573,064 \text{ kkal/kg}} \]

\[ = 1247,7 \text{ kg/jam} \]

Tabel LB.1 Neraca Panas Pada \textit{Heater} Air

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kkal/jam)</th>
<th>Keluar (kkal/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 1</td>
<td>Alur 2</td>
</tr>
<tr>
<td>Air</td>
<td>71501,205</td>
<td>786513,255</td>
</tr>
<tr>
<td>Steam</td>
<td>715012,05</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>786513,255</td>
<td>786513,255</td>
</tr>
</tbody>
</table>

LB. 2 \textit{Heater} CPO (HE-102)

\[ Q^3 + Q_{\text{steam}} = Q^4 \]
Panas masuk alur 3

\[ Q^3_{\text{CPO}} = m \cdot c_p \cdot \Delta t \]
\[ = (20.428,9158 \text{ kg/jam}) (0,5254 \text{ kcal/kg.}^0\text{C}) (30-25)^0\text{C} \]
\[ = 53666,7618 \text{ kcal/jam} \]

Panas keluar alur 4

\[ Q^4_{\text{CPO}} = m \cdot c_p \cdot \Delta t \]
\[ = (20.428,9158 \text{ kg/jam}) (0,5254 \text{ kcal/kg.}^0\text{C}) (80-30)^0\text{C} \]
\[ = 590334,3977 \text{ kcal/jam} \]

Panas steam

\[ Q_{\text{steam}} = Q^4_{\text{CPO}} - Q^3_{\text{CPO}} \]
\[ = (590334,3977 - 53666,7618) \text{ kcal/jam} \]
\[ = 536667,6181 \text{ kcal/jam} \]

Steam yang digunakan adalah superheated steam pada 1 atm 150\(^0\)C, kemudian keluar sebagai kondensat pada 90\(^0\)C (1 atm).

Dari Tabel *Steam* Smith, 2004 diperoleh:

\[ H(150^0\text{C}) = 663,084 \text{ kcal/kg} \]
\[ H_v(100^0\text{C}) = 639,152 \text{ kcal/kg} \]
\[ H_l(100^0\text{C}) = 100,1 \text{ kcal/kg} \]
\[ H(90^0\text{C}) = 90,02 \text{ kcal/kg} \]

\[ q = [H(150^0\text{C}) - H_v(100^0\text{C})] + [H_v(100^0\text{C}) - H_l(100^0\text{C})] + [H_l(100^0\text{C}) - H(90^0\text{C})] \]
\[ q = [663,084 - 639,152] + [639,152 - 100,1] + [100,1 - 90,02] \]
\[ q = 573,064 \text{ kcal/kg} \]

Massa steam, \( m_s \)

\[ = \frac{Q_{\text{steam}}}{q} \]
\[ = \frac{643510,845 \text{ kcal/jam}}{573,064 \text{ kcal/kg}} \]
\[ = 935,7929 \text{ kg/jam} \]
**Tabel LB.2 Neraca Panas Pada *Heater CPO***

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kkal/jam)</th>
<th>Keluar (kkal/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alur 3</strong></td>
<td><strong>Alur 4</strong></td>
<td></td>
</tr>
<tr>
<td>CPO</td>
<td>53666,7618</td>
<td>590334,3977</td>
</tr>
<tr>
<td>Steam</td>
<td>536667,6181</td>
<td>590334,3977</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>590334,3977</strong></td>
<td><strong>590334,3977</strong></td>
</tr>
</tbody>
</table>

**LB.3 Kolom Hidrolisa (KH-101)**

Reaksi Hidrolisa

\[
\begin{align*}
CH_2 - O - C - R & \rightarrow CH_2 - OH \\
CH - O - C - R_{(1)} + 3H_2O_{(1)} & \rightarrow CH - OH_{(1)} + 3RCOOH_{(1)} \\
CH_2 - O - C - R & \rightarrow CH_2 - OH
\end{align*}
\]

Konversi 99%

T in = 80\(^0\)C

T out = 255 \(^0\)C

**Neraca Panas Total**

\[
Q^2 + Q^4 + Q_{steam} + \Delta H_R = Q^6 + Q^7
\]
**Panas masuk**

\[ Q_{in} = Q^2 + Q^4 \]

= (590334,3799 + 786513,255) kkal/jam

= 1376847,6349 kkal/jam

**Panas Reaksi**

\[ \Delta H_{R298K} = \Delta H_{R298K\,Produk} - \Delta H_{R298K\,Reaktan} \]

\[ \Delta H_{R298K\,Produk} = \Delta H_{R298K\,Gliserol} + \Delta H_{R298K\,Miristat} + \Delta H_{R298K\,Palmitat} + \Delta H_{R298K\,Stearat} + \Delta H_{R298K\,Oleat} + \Delta H_{R298K\,Linoleat} \]

\[ = [(-139,80 \times 23,8550)+(-128,83 \times 1,6460)+(-138,71 \times 30,7729)+( -148,59 \times 0,8957465)+(-120,75 \times 28,6260)+(-92,91 \times 7,1565)] \text{kkal/kmol} \]

\[ = [(-3334,9290)+(-212,0517)+(-4268,5099)+(-499,7900)+(-3456,5847)+(-664,9095)] \text{kkal/kmol} \]

\[ = -12436,7747 \text{kkal/kmol} \]

\[ \Delta H_{R298K\,Reaktan} = \Delta H_{R298K\,Trigliserida} + \Delta H_{R298K\,H_2O} \]

\[ = [(-379,038 \times 23,8550)+(-68,32 \times 794,4578333)] \text{kkal/kmol} \]

\[ = [(9041,95149)+(-54277,3592)] \text{kkal/kmol} \]

\[ = -63319,3107 \text{kkal/kmol} \]

\[ \Delta H_{R298K} = \Delta H_{R298K\,Produk} - \Delta H_{R298K\,Reaktan} \]

\[ = -12436,7747 + 63319,3107 \text{kkal/kmol} \]

\[ = 50882,5359 \text{kkal/kmol} \]

**Panas keluar**

**Panas asam lemak yang keluar**

| As. | Linoleat | = 2007,0662 x 0,4836 x (255-25) | = 223241,9593 kkal/jam |
| As. | Miristat | = 375,9058 x 0,492 x (255-25) | = 42537,5003 kkal/jam |
| As. | Palmitat | = 7891,1581 x 0,43 x (255-25) | = 780435,5361 kkal/jam |
| As. | Stearat | = 956,8830 x 0,399 x (255-25) | = 87813,1529 kkal/jam |
| As. | Oleat | = 8085,9749x 0,4955 x (255-25) | = 921518,1295 kkal/jam |

**Total Asam lemak**

= 2.055.546,2781 kkal/jam

**Q_6\ CPO**

= m.Cp.dT

= 40,8648 kg/jam x 0,5254 kkal/kg.\textsuperscript{0}C x (255-25)\textsuperscript{0}C

= 4938,1842 kkal/jam

*Universitas Sumatera Utara*
\[ Q^7 \text{ CPO} = m \cdot C_p \cdot dT \]
\[ = 163,4591 \text{ kg/jam} \times 0,5254 \text{ kcal/kg.}^0\text{C} \times (255-25) ^0\text{C} \]
\[ = 19752,7245 \text{ kcal/jam} \]

\[ Q^6 \text{ Air} = m \cdot C_p \cdot dT \]
\[ = 5204,3714 \text{ kg/jam} \times 1 \text{ kcal/kg.}^0\text{C} \times (255-25) ^0\text{C} \]
\[ = 1197005,422 \text{ kcal/jam} \]

\[ Q^7 \text{ Air} = m \cdot C_p \cdot dT \]
\[ = 7806,5571 \text{ kg/jam} \times 1 \text{ kcal/kg.}^0\text{C} \times (255-25) ^0\text{C} \]
\[ = 1795508,1330 \text{ kcal/jam} \]

\[ Q^7 \text{ Gliserol} = m \cdot C_p \cdot dT \]
\[ = 2196,9697 \text{ kg/jam} \times 0,542 \text{ kcal/kg.}^0\text{C} \times (255-25) ^0\text{C} \]
\[ = 273874,2428 \text{ kcal/jam} \]

**Total Panas Keluar**
\[ = Q \text{ Gliserol} + Q \text{ Asam Lemak} + Q \text{ air} + Q \text{ CPO} \]
\[ = (273874,2428 + 2055546,2781 + 2992513,555 + 24690,9087) \text{ kcal/jam} \]
\[ = 5346624,9846 \text{ kcal/jam} \]

**Panas steam yang dibutuhkan**
\[ Q_{\text{steam}} = Q_{\text{keluar}} - [\Delta H_R ^{298 \text{ K}} + Q_{\text{masuk}}] \]
\[ = [5346624,9846 - (50882,5359 + 1251679,668)] \text{ kcal/jam} \]
\[ = 4044062,7807 \text{ kcal/jam} \]

Dari Tabel *Steam* Smith, 2004 diperoleh:

\[ H (275^\circ\text{C}) = 672,83 \text{ kcal/kg} \]
\[ H (200^\circ\text{C}) = 263,877 \text{ kcal/kg} \]

\[ \Delta H = H (275^\circ\text{C}) - H (200^\circ\text{C}) \]
\[ = 408,9530 \text{ kcal/kg} \]

**Massa steam, ms**
\[ = \frac{Q_{\text{steam}}}{\Delta H} \]
\[ = \frac{4044062,7807 \text{ kcal/jam}}{408,9530 \text{ kcal/kg}} \]
\[ = 9888,8204 \text{ kg/jam} \]
### Tabel LB.3 Neraca Panas Pada Kolom Hidrolisa

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kkal/jam)</th>
<th>Keluar (kkal/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 2</td>
<td>Alur 4</td>
</tr>
<tr>
<td>CPO</td>
<td>590334,3799</td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>1197005,422</td>
<td></td>
</tr>
<tr>
<td>Asam lemak</td>
<td>205549,4578</td>
<td></td>
</tr>
<tr>
<td>Gliserol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panas Reaksi</td>
<td>58265,2469</td>
<td></td>
</tr>
<tr>
<td>Sub Total</td>
<td>648599,6268</td>
<td>786513,255</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5346628,1643</td>
<td>5346628,1643</td>
</tr>
</tbody>
</table>

### LB.4 Flash Tank Asam Lemak (FT-101)

Asam Lemak
CPO
Air
$T = 255^0\text{C}$
$P = 53,3 \text{ atm}$
$T_{\text{in}} = 255^0\text{C}$
$T_{\text{out}} = 110^0\text{C}$

Flash Tank
Asam Lemak

Uap Air
$T = 110^0\text{C}$
$P = 1 \text{ atm}$

### Neraca Panas Total

Panas masuk = panas keluar

\[
Q^6 = Q^8 + Q^{10}
\]

Panas masuk

\[
Q^6 = 3257493,0639 \text{ kkal/jam}
\]
Panas keluar
Panas asam lemak yang keluar

As. Linoleat = 2007,0691 x 0,4836 x (110-25) = 82502,5824 kkal/jam
As. Miristat = 375,9090 x 0,492 x (110-25) = 15720,5144 kkal/jam
As. Palmitat = 7891,1961 x 0,43 x (110-25) = 288422,2306 kkal/jam
As. Stearat = 956,8843 x 0,399 x (110-25) = 32452,7310 kkal/jam
As. Oleat = 8085,9862 x 0,4955 x (110-25) = 340561,5238 kkal/jam
Total Asam lemak = 759659,5822 kkal/jam

Q\textsuperscript{10}\text{CPO} = m.Cp.dT
= 40,8648 kg/jam x 0,5254 kkal/kg.\textsuperscript{0}C x (110-25)\textsuperscript{0}C
= 1824,9811 kkal/jam

Q\textsuperscript{10}\text{Air} = m.Cp.dT
= 451,5127 kg/jam x 1 kkal/kg.\textsuperscript{0}C x (110-25)\textsuperscript{0}C
= 38378,5795 kkal/jam

Q\textsuperscript{10}\text{Total} = Q\textsuperscript{10}\text{Asam Lemak} + Q\textsuperscript{10}\text{CPO} + Q\textsuperscript{10}\text{Air}
= (759659,5822+ 1824,9811+ 38378,5795) kkal/jam
= 799863,1428 kkal/jam

Q\textsuperscript{8}\text{Air} = m.Cp.dT
= 1806,0508 kg/jam x 1 kkal/kg.\textsuperscript{0}C x (110-25)\textsuperscript{0}C
= 153514,3180 kkal/jam

Total Panas Keluar = Q\textsuperscript{8} + Q\textsuperscript{10}
= 153514,3180 kkal/jam + 799863,1428 kkal/jam
= 953377,4608 kkal/jam

Panas yang hilang ke lingkungan
Q loss = Q masuk - Q keluar
= 3257493,0639 kkal/jam – 933377,4608 kkal/jam
= 2304115,6031 kkal/jam
Tabel LB.4 Neraca Panas *Flash Tank* Asam Lemak

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kkal/jam)</th>
<th>Keluar (kkal/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 6</td>
<td>Alur 8</td>
</tr>
<tr>
<td>CPO</td>
<td>4938,1842</td>
<td>1824,9811</td>
</tr>
<tr>
<td>Air</td>
<td>1197005,422</td>
<td>153514,3180</td>
</tr>
<tr>
<td>Asam lemak</td>
<td>2055549,4578</td>
<td>759659,5822</td>
</tr>
<tr>
<td>Sub Total</td>
<td>3257493,0639</td>
<td>153514,3180</td>
</tr>
<tr>
<td>Q</td>
<td>2304115,6031</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>3257493,0639</td>
<td>3257493,0639</td>
</tr>
</tbody>
</table>

**LB.5 Flash Tank Gliserol (FT-102)**

T in = 255\(^\circ\)C  
T out = 110\(^\circ\)C  

**Neraca Panas Total**

\[
Q^7 = Q^9 + Q^{11}
\]

**Panas masuk**

\[
Q^7 = 2089135,1004 \text{ kkal/jam}
\]

**Panas keluar**

\[
Q^{11} \text{ Gliserol} = m \cdot \text{Cp.dT} \\
= 2196,9697 \text{ kg/jam} \times 0,542 \text{ kkal/kg.}^{0}\text{C} \times (110-25)\text{C} \\
= 101214,3941 \text{ kkal/jam}
\]
\[ Q^{11} \text{CPO} = m \cdot \text{Cp} \cdot dT \]
\[ = 163,4591 \text{ kg/jam} \times 0.5254 \text{ kcal/kg.}^0 \text{C} \times (110-25)^0 \text{C} \]
\[ = 7299,9199 \text{ kcal/jam} \]

\[ Q^{11} \text{Air} = m \cdot \text{Cp} \cdot dT \]
\[ = 16254,4570 \text{ kg/jam} \times 1 \text{ kcal/kg.}^0 \text{C} \times (110-25)^0 \text{C} \]
\[ = 1381628,845 \text{ kcal/jam} \]

\[ Q^{11} \text{Total} = Q^{11} \text{ Gliserol} + Q^{11} \text{ CPO} + Q^{11} \text{ Air} \]
\[ = (101214,3941 + 7299,9199 + 1381628,845) \text{ kcal/jam} \]
\[ = 1490143,159 \text{ kcal/jam} \]

\[ Q^9 \text{Air} = m \cdot \text{Cp} \cdot dT \]
\[ = 4063,6142 \text{ kg/jam} \times 1 \text{ kcal/kg.}^0 \text{C} \times (110-25)^0 \text{C} \]
\[ = 345407,2070 \text{ kcal/jam} \]

Total Panas Keluar = \[ Q^9 + Q^{11} \]
\[ = 345407,2070 \text{ kcal/jam} + 1490143,159 \text{ kcal/jam} \]
\[ = 1835550,3660 \text{ kcal/jam} \]

Panas yang hilang ke lingkungan
\[ Q \text{ loss} = Q \text{ masuk} - Q \text{ keluar} \]
\[ = 2089135,1004 \text{ kcal/jam} - 1835550,3660 \text{ kcal/jam} \]
\[ = 253584,7343 \text{ kcal/jam} \]

Tabel LB.5 Neraca Panas *Flash Tank* Gliserol

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kkal/jam)</th>
<th>Keluar (kkal/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 7</td>
<td>Alur 9</td>
</tr>
<tr>
<td>CPO</td>
<td>19752,7246</td>
<td></td>
</tr>
<tr>
<td>Air</td>
<td>1795508,1330</td>
<td>345407,2070</td>
</tr>
<tr>
<td>Gliserol</td>
<td>273874,2428</td>
<td>101214,3941</td>
</tr>
<tr>
<td>Sub Total</td>
<td>2089135,1004</td>
<td>345407,2070</td>
</tr>
<tr>
<td>Q</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>2089135,1004</td>
<td>2089135,1004</td>
</tr>
</tbody>
</table>
L.B.6 Skimmer (SK-101)

<table>
<thead>
<tr>
<th>Entry</th>
<th>Exit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gliserol</td>
<td>Gliserol</td>
</tr>
<tr>
<td>CPO</td>
<td>CPO</td>
</tr>
<tr>
<td>Air</td>
<td>Air</td>
</tr>
</tbody>
</table>

\[ T_{in} = 110^0C \]
\[ T_{out} = 90^0C \]

Neraca Panas Total

Panas masuk = panas keluar
\[ Q^{11} = Q^{12} + Q^{13} \]

Panas masuk
\[ Q^{11} = 1490143,1590 \text{ kkal/jam} \]

Panas keluar
\[ Q^{13} \text{ Gliserol} = m.Cp.dT \]
\[ = 2196.9697 \text{ kg/jam x 0,542 kkal/kg} \cdot (90-25) \cdot (90-25) \text{ C} \]
\[ = 77399,2425 \text{ kkal/jam} \]
\[ Q^{13} \text{ Air} = m.Cp.dT \]
\[ = 16254,4570 \text{ kg/jam x 1 kkal/kg} \cdot (90-25) \cdot (90-25) \text{ C} \]
\[ = 1056539,7050 \text{ kkal/jam} \]
\[ Q^{13} \text{ Total} = Q^{13} \text{ Gliserol} + Q^{13} \text{ Air} \]
\[ = (77399,2425 + 1056539,7050) \text{ kkal/jam} \]
\[ = 1133938,9475 \text{ kkal/jam} \]
\[ Q^{12} \text{ CPO} = m.Cp.dT \]
\[ = 163,4591 \text{ kg/jam x 0,5254 kkal/kg} \cdot (90-25) \cdot (90-25) \text{ C} \]
\[ = 5582,2917 \text{ kkal/jam} \]

Total Panas Keluar = \[ Q^{12} + Q^{13} \]
\[ = 5582,2917 \text{ kkal/jam} + 1133938,9475 \text{ kkal/jam} \]
\[ = 1139521,2393 \text{ kkal/jam} \]
Panas yang hilang ke lingkungan

\[ Q_{\text{loss}} = Q_{\text{masuk}} - Q_{\text{keluar}} = 1490143,1590 \text{ kkal/jam} - 1139521,2393 \text{ kkal/jam} = 350621,9197 \text{ kkal/jam} \]

Tabel LB.6 Neraca Panas Pada Skimmer

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kkal/jam)</th>
<th>Keluar (kkal/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 11</td>
<td>Alur 12</td>
</tr>
<tr>
<td>CPO</td>
<td>7299,9199</td>
<td>5582,2917</td>
</tr>
<tr>
<td>Air</td>
<td>1381628,845</td>
<td>1056539,7050</td>
</tr>
<tr>
<td>Gliserol</td>
<td>101214,3941</td>
<td>77399,2425</td>
</tr>
<tr>
<td>Sub Total</td>
<td>1490143,1590</td>
<td>5582,2917</td>
</tr>
<tr>
<td>Q</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>1490143,1590</td>
<td>1490143,1590</td>
</tr>
</tbody>
</table>

LB.7 Evaporator I (EV-101)

\[
\begin{align*}
\text{Uap Air} & \quad T = 100^\circ \text{C} \\
\text{Steam} & \quad T = 150^\circ \text{C} \\
\text{Gliserol} & \quad T = 100^\circ \text{C} \quad P = 1 \text{ atm} \\
\text{Air} & \quad T = 90^\circ \text{C} \quad P = 1 \text{ atm} \\
\text{Kondensat} & \quad T = 110^\circ \text{C} \quad P = 1 \text{ atm}
\end{align*}
\]

\[ T_{\text{in}} = 90^\circ \text{C} \]
\[ T_{\text{out}} = 100^\circ \text{C} \]

Neraca Panas Total

\[ Q^{13} + Q_{\text{Steam}}^{14} = Q^{14} + Q^{15} \]
Panas masuk

\[ Q^{13} = 113398,9475 \text{ kkal/jam} \]

Panas keluar

\[ Q^{15} \text{ Gliserol} = m.C_p.dT \]
\[ = 2196,9697 \text{ kg/jam} \times 0,542 \text{ kkal/kg.}^0\text{C} \times (100-25)^0\text{C} \]
\[ = 89306,8183 \text{ kkal/jam} \]

\[ Q^{15} \text{ Air} = m.C_p.dT \]
\[ = 6590,9091 \text{ kg/jam} \times 1 \text{ kkal/kg.}^0\text{C} \times (100-25)^0\text{C} \]
\[ = 494318,1825 \text{ kkal/jam} \]

\[ Q^{15} \text{ Total} = Q^{15} \text{ Gliserol} + Q^{15} \text{ Air} \]
\[ = (89306,8183 + 494318,1825) \text{ kkal/jam} \]
\[ = 583625,0008 \text{ kkal/jam} \]

\[ Q^{14} \text{ Air} = m.C_p.dT \]
\[ = 9663,5479 \text{ kg/jam} \times 1 \text{ kkal/kg.}^0\text{C} \times (100-25)^0\text{C} \]
\[ = 724766,0925 \text{ kkal/jam} \]

Total Panas Keluar

\[ = Q^{14} + Q^{15} \]
\[ = 724766,0925 \text{ kkal/jam} + 583625,0008 \text{ kkal/jam} \]
\[ = 1308391,0933 \text{ kkal/jam} \]

\[ dQ (Q_{\text{steam}}) = Q_{\text{keluar}} - Q_{\text{masuk}} \]
\[ = 1308391,0933 \text{ kkal/jam} - 113398,9475 \text{ kkal/jam} \]
\[ = 1174452,1458 \text{ kkal/jam} \]

Steam yang digunakan adalah superheated steam pada 1 atm 150 \text{^0C}, kemudian keluar sebagai kondensat pada 90\text{^0C} (1 atm).

Dari Tabel Steam Smith, 2004 diperoleh:

\[ H (150^0\text{C}) = 663,084 \text{ kkal/kg} \]
\[ H_v (100^0\text{C}) = 639,152 \text{ kkal/kg} \]
\[ H_l (100^0\text{C}) = 100,1 \text{ kkal/kg} \]
\[ H (90^0\text{C}) = 90,02 \text{ kkal/kg} \]

\[ q = [H(150^0\text{C}) - H_v(100^0\text{C})] + [H_v(100^0\text{C}) - H_l(100^0\text{C})] + [H_l(100^0\text{C}) - H(90^0\text{C})] \]
\[ q = [663,084 - 639,152] + [639,152 - 100,1] + [100,1 - 90,02] \]
\[ q = 573,064 \text{ kkal/kg} \]
Massa steam, \( m_s = \frac{Q_{steam}}{q} \)

\[ = \frac{174452,1458 \text{ kcal/jam}}{573,064 \text{ kcal/kg}} \]

\[ = 304,42 \text{ kg/jam} \]

Tabel LB.7 Neraca Panas Evaporator I

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Alur 13 (kkal/jam)</th>
<th>Alur 14</th>
<th>Alur 15 (kkal/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gliserol</td>
<td>77399,2425</td>
<td>-</td>
<td>89306,8183</td>
</tr>
<tr>
<td>Air</td>
<td>1056539,7050</td>
<td>724766,0925</td>
<td>494318,1825</td>
</tr>
<tr>
<td>Steam</td>
<td>174452,1458</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sub total</td>
<td>1308391,0933</td>
<td>724766,0925</td>
<td>583625,0008</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1308391,0933</td>
<td>1308391,0933</td>
<td></td>
</tr>
</tbody>
</table>

LB.8 Evaporator II (EV-102)

\[ T_{in} = 100^{0}C \]

\[ T_{out} = 105^{0}C \]

\[ P = 1 \text{ atm} \]

Panas masuk = panas keluar

\[ Q^{15} + Q_{steam} = Q^{16} + Q^{17} \]
Panas masuk

\[ Q^{15} = 583625,0008 \text{ kkal/jam} \]

Panas keluar

\[ Q^{17} \text{ Gliserol} = m \cdot C_p \cdot dT \]
\[ = 2196,9697 \text{ kg/jam} \times 0,542 \text{ kkal/kg.}^{0}C \times (105-25)^{0}C \]
\[ = 95260,6062 \text{ kkal/jam} \]

\[ Q^{17} \text{ Air} = m \cdot C_p \cdot dT \]
\[ = 5126,2626 \text{ kg/jam} \times 1 \text{ kkal/kg.}^{0}C \times (105-25)^{0}C \]
\[ = 410101,0080 \text{ kkal/jam} \]

\[ Q^{17} \text{ Total} = Q^{17} \text{ Gliserol} + Q^{17} \text{ Air} \]
\[ = (95260,6062 + 410101,0080) \text{ kkal/jam} \]
\[ = 505361,6142 \text{ kkal/jam} \]

\[ Q^{16} \text{ Air} = m \cdot C_p \cdot dT \]
\[ = 1464,6465 \text{ kg/jam} \times 1 \text{ kkal/kg.}^{0}C \times (105-25)^{0}C \]
\[ = 117171,7200 \text{ kkal/jam} \]

Total Panas Keluar

\[ = Q^{16} + Q^{17} \]
\[ = 117171,7200 \text{ kkal/jam} + 505361,6142 \text{ kkal/jam} \]
\[ = 622533,3342 \text{ kkal/jam} \]

\[ dQ(Q_{\text{steam}}) = Q_{\text{keluar}} - Q_{\text{masuk}} \]
\[ = 622533,3342 \text{ kkal/jam} - 583625,0008 \text{ kkal/jam} \]
\[ = 38908,3334 \text{ kkal/jam} \]

Steam yang digunakan adalah superheated steam pada 1 atm 150 \(^{0}C\), kemudian keluar sebagai kondensat pada 90\(^{0}C\) (1 atm).

Dari Tabel *Steam* Smith, 2004 diperoleh:

\[ H(150^{0}C) = 663,084 \text{ kkal/kg} \]
\[ H_v(100^{0}C) = 639,152 \text{ kkal/kg} \]
\[ H_l(100^{0}C) = 100,1 \text{ kkal/kg} \]
\[ H(90^{0}C) = 90,02 \text{ kkal/kg} \]

\[ q = [H(150^{0}C) - H_v(100^{0}C)] + [H_v(100^{0}C) - H_l(100^{0}C)] + [H_l(100^{0}C) - H(90^{0}C)] \]
\[ q = [663,084 - 639,152] + [639,152 - 100,1] + [100,1 - 90,02] \]
\[ q = 573,064 \text{ kkal/kg} \]
Massa steam, \( m_s = \frac{Q_{\text{steam}}}{q} \) = 38908,3334 kcal/jam / 573,064 kcal/kg = 67,8952 kg/jam

Tabel LB.8 Neraca Panas Evaporator II

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kkal/jam)</th>
<th>Keluar (kkal/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 15</td>
<td>Alur 16</td>
</tr>
<tr>
<td>Gliserol</td>
<td>89306,8183</td>
<td>95260,6062</td>
</tr>
<tr>
<td>Air</td>
<td>494318,1825</td>
<td>117171,7200</td>
</tr>
<tr>
<td>Steam</td>
<td>38908,3334</td>
<td></td>
</tr>
<tr>
<td>Sub total</td>
<td>622533,3342</td>
<td>117171,7200</td>
</tr>
<tr>
<td>TOTAL</td>
<td>622533,3342</td>
<td>622533,3342</td>
</tr>
</tbody>
</table>

LB.9 Coolers (HE-103)

Air
T = 120\(^0\)C
P = 1 atm

Air Pendingin
T = 30\(^0\)C
P = 1 atm

Air
T = 30\(^0\)C
P = 1 atm

Neraca Panas Total
\[ Q^{27} - Q^{26} = Q^{29} + Q^{28} \]
Panas masuk

\[ Q^{26} = 498921.5250 \text{ kkal/jam} \]

Panas keluar

\[ Q^{27} \text{ Air} = m \cdot C_p \cdot \Delta T \]

= 5869.665 kg/jam x 1 kkal/kg.\(0^0\text{C}\) x (30-25)\(0^0\text{C}\)

= 322831.5750 kkal/jam

\[ dQ = Q\text{masuk} - Q\text{keluar} \]

= 498921.5250 kkal/jam - 322831.5750 kkal/jam

= 176089.95 kkal/jam

Jadi panas yang diserap air pendingin = 176089.95 kkal/jam

masa air pendingin yang dibutuhkan

\[ \text{Massa air, } m_s = \frac{Q_{\text{steam}}}{C_{\text{pair}} \cdot \Delta t} \]

= \frac{176089.95 \text{ kkal/jam}}{1 \text{ kkal/kg.} \ 0^0\text{C} + 30^0\text{C}}

= 5869.665 kg/jam

Tabel LB.9 Neraca Panas **Cooler**

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kkal/jam)</th>
<th>Keluar (kkal/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 26</td>
<td>Alur 27</td>
</tr>
<tr>
<td>Air</td>
<td>498921.5250</td>
<td>322831.5750</td>
</tr>
<tr>
<td>Air pendingin</td>
<td></td>
<td>176089.95</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>498921.5250</strong></td>
<td><strong>498921.5250</strong></td>
</tr>
</tbody>
</table>
**LAMPIRAN C**

**PERHITUNGAN SPESIFIKASI PERALATAN**

**LC.1 Tangki Bahan Baku CPO (TK-101)**

**Fungsi** : Untuk penyimpanan bahan baku CPO selama 10 hari

**Jumlah** : 1 unit

**Bentuk** : Tangki berbentuk silinder vertical dengan alas datar dan tutup elipsoidal

**Bahan** : *Carbon Steel, SA-285 Gr.C* (Brownell, 1959)

**Kondisi operasi** : - Temperatur = 30°C
- Tekanan = 1 atm

**Perhitungan:**

*a. Volume Tangki*

Kebutuhan CPO/jam = 20428,9158 kg/jam

Kebutuhan 10 hari = 20428,9158 kg/jam x 24 jam/ hari x 10 hari = 4902939,792 Kg

Densitas CPO ($\rho$) = 895 kg/m$^3$ (Perry, 1999)

Volume CPO = $\frac{m}{\rho} = \frac{4902939,792}{895} = 5478,145 m^3$

Faktor kelonggaran (fk) = 20 % (Brownell & Young, 1959)

Volume tangki, $V_T = (1 + 0,2) \times 5478,145 m^3$

= 6573,774 m$^3$

*b. Diameter dan Tinggi Shell*

Direncanakan:

- Tinggi silinder ($H_s$) : Diameter (D) = 4 : 3
- Tinggi tutup ($H_d$) : Diameter (D) = 1 : 4
- Volume shell tangki (Vs):
  \[ V_S = \pi R^2 H_s = \frac{\pi}{4} D^2 \left( \frac{4}{3} D \right) \]
  \[ V_S = \frac{\pi}{3} D^3 \]

- Volume tutup tangki (V_e):
  \[ V_h = \frac{2\pi}{3} R^2 H_d = \frac{\pi}{6} D^2 \left( \frac{1}{4} D \right) = \frac{\pi}{24} D^3 \]

(Brownell & Young, 1959)

- Volume tangki (V):
  \[ V_t = V_s + V_h \]
  \[ = \frac{3}{8} \pi D^3 \]

  \[ 6573,774 \text{ m}^3 = 1,1775 D^3 \]
  \[ D^3 = 5582,8229 \text{ m}^3 \]
  \[ D = 17,7399 \text{ m} = 698,42 \text{ in} \]
  \[ H_s = \frac{4}{3} D = 23,6532 \text{ m} \]

c. Diameter dan tinggi tutup

  Diameter tutup = diameter tangki = 17,7399 m
  Tinggi tutup (H_d) = \( \frac{1}{4} D = 4,4349 \text{ m} \)
  Tinggi tangki = H_s + H_d = (23,6532 + 4,4349) m = 28,0881 m

d. Tebal shell tangki

  Direncanakan menggunakan bahan konstruksi Carbon Steel, SA-285 Gr.C
diperoleh data :
  - Allowable stress (S) = 13750 psia
  - Joint efficiency (E) = 0,85
  - Corrosion allowance (C) = 1,524 mm/tahun (Peters dkk, 2004)
    = 0,06 in/tahun
- Umur tangki \((n)\) = 10 tahun

Volume cairan = 6573,774 m\(^3\)

Tinggi cairan dalam tangki = \(\frac{5478,145 \text{ m}^3}{6573,774 \text{ m}^3} \times 23,6532 \text{ m} = 19,711 \text{ m}\)

Tekanan Hidrostatik:
\[ P_{\text{Hidrostatik}} = \rho \times g \times h \]
\[ = 895 \text{ kg/m}^3 \times 9.8 \text{ m/det}^2 \times 19.711 \text{ m} = 1.7062 \text{ atm} \]

Tekanan operasi \((P_o)\) = 1 atm

\[ P = P_o + P_{\text{Hidrostatik}} = 2.7062 \text{ atm} \]

\[ P_{\text{design}} = (1.2) \times (2.7062) = 3.2474 \text{ atm} = 47,7248 \text{ psi} \]

Tebal *shell* tangki:
\[ t = \frac{PR}{SE - 0.6P} \]  
(Walas dkk, 2005)

Dimana:
- \(P\) = tekanan desain (psig)
- \(R\) = jari-jari dalam tangki (in)
- \(S\) = *allowable stress* (psia)
- \(E\) = *joint efficiency*

\[ t = \frac{PR}{SE - 0.6P} = \left( \frac{47,7248 \times 698.42/2 \text{ in}}{13750 \text{ psia}(0.85) - 0.6(47,7248 \text{ psi})} \right) 
= 1.4294 \text{ in} \]

Faktor korosi = 0,06 in/tahun

Maka tebal *shell* yang dibutuhkan dengan perkiraan umur alat adalah 10 tahun

\[ = 1.4294 + (10 \times 0.06) \]
\[ = 2.0294 \text{ in} \]

Dipilih tangki dengan tebal 2,5 in
LC.2 Tangki Bahan Baku Air (TK-102)

Fungsi : Untuk penyimpanan bahan baku air selama 10 hari
Jumlah : 1 unit
Bentuk : Tangki berbentuk silinder vertikal dengan alas datar dan tutup elipsoidal
Bahan : *Carbon Steel*, SA-285 Gr. C

Kondisi operasi : 
- Temperatur = 300°C
- Tekanan = 1 atm

**Perhitungan:**

a. Volume Tangki

Kebutuhan air/jam = 14300,2410 kg/jam
Kebutuhan 10 hari = 14300,2410 kg/jam x 24 jam/hari x 10 hari = 3432057,84 Kg

Densitas Air (ρ) = 995,647 kg/m³

\[
\frac{m}{\rho} = \frac{3432057,84 \text{kg}}{995,647 \text{kg/m}^3} = 3447,0629 \text{ m}^3
\]

Faktor kelonggaran (fk) = 20 %

Volume tangki, \( V_T \) = (1 + 0,2) x 3447,0629 m³
= 4136,4755 m³

b. Diameter dan Tinggi Shell

Direncanakan:
- Tinggi silinder (\( H_s \)) : Diameter (D) = 4 : 3
- Tinggi tutup (\( H_d \)) : Diameter (D) = 1 : 4

- Volume shell tangki (Vs) :
\[ V_s = \pi R^2 H_s = \frac{\pi}{4} D^2 \left( \frac{4}{3} D \right) \]

\[ V_s = \frac{\pi}{3} D^3 \]

- Volume tutup tangki \((V_h)\):

\[ V_h = \frac{2\pi}{3} R^2 H_d = \frac{\pi}{6} D^2 \left( \frac{1}{4} D \right) = \frac{\pi}{24} D^3 \]

(Brownell & Young, 1959)

- Volume tangki \((V)\):

\[ V_t = V_s + V_h = \frac{3}{8} \pi D^3 \]

4136,4755 m³ = 1,1775 \(D^3\)

\[ D^3 = 3512,9303 \text{ m}^3 \]

\[ D = 15,2016 \text{ m} = 598,4877 \text{ in} \]

\[ H_s = \frac{4}{3} D = 20,2688 \text{ m} \quad \text{Tinggi tutup (dished)} \]

c. Diameter dan tinggi tutup

Diameter tutup = diameter tangki = 15,2016 m

Tinggi tutup \((H_d)\) = \(\frac{1}{4} D\) = 3,8004 m

Tinggi tangki = \(H_s + H_d = (20,2688 + 3,8004) \text{ m} = 24,0692 \text{ m} \)

d. Tebal shell tangki

Direncanakan menggunakan bahan konstruksi Carbon Steel SA –285 Grade C
diperoleh data:

- Allowable stress \((S)\) = 13750 psia
- Joint efficiency \((E)\) = 0,85
- Corrosion allowance \((C)\) = 1,524 mm/tahun (Peters dkk, 2004)

= 0,06 in/tahun

- Umur tangki \((n)\) = 10 tahun

Volume cairan = 3447,0629 m³
Tinggi cairan dalam tangki = $\frac{3447,0629 \text{ m}^3}{4136,4755 \text{ m}^3} \times 20,2688 \text{ m} = 16,8906 \text{ m}$

Tekanan Hidrostatik:

$$P_{\text{Hidrostatik}} = \rho \times g \times l$$

$$= 995,647 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 16,8906 \text{ m} = 1,6265 \text{ atm}$$

$$P_o = 1 \text{ atm}$$

$$P = 1 \text{ atm} + 1,6265 \text{ atm} = 2,6265 \text{ atm}$$

$$P_{\text{design}} = 1,2 \times 2,6265 = 3,1518 \text{ atm} = 46,319 \text{ psi}$$

Tebal shell tangki:

$$t = \frac{PR}{SE - 0,6P}$$

(Walas dkk, 2005)

Dimana :

- **P** = tekanan desain (psig)
- **R** = jari-jari dalam tangki (in)
- **S** = allowable stress (psia)
- **E** = joint efficiency

$$t = \frac{PR}{SE - 0,6P} = \left( \frac{(46,319 \text{ psi}) (598,4877/2 \text{ in})}{(13750 \text{ psia})(0,85) - 0,6(46,319 \text{ psi})} \right) = 1,1887 \text{ in}$$

Faktor korosi = 0,06 in/tahun

Maka tebal shell yang dibutuhkan dengan perkiraan umur alat adalah 10 tahun

$$= 1,1887 + (10 \times 0,06)$$

$$= 1,7887 \text{ in}$$

Tebal shell standar yang digunakan = 2 in (Brownell & Young, 1959)

**LC.3 Tangki Produk Asam Lemak (TK-103)**

- **Fungsi** : Untuk penyimpanan produk asam lemak selama 10 hari
- **Jumlah** : 1 unit
- **Bentuk** : Tangki berbentuk silinder vertikal dengan alas datar dan tutup elipsoidal
Bahan : Carbon Steel, SA-285 (Brownell, 1959)

Kondisi operasi : -Temperatur = 110°C
- Tekanan = 1 atm

**Perhitungan:**

a. Volume Tangki

Produk/jam = 19809,3122 kg/jam
Kebutuhan 10 hari = 19809,3122 kg/jam x 24 jam/ hari x 10 hari
= 4754234,928 Kg

Densitas Asam lemak ($\rho$) = 0,9751 x 881,5 kg/m$^3$ = 859,5895 kg/m$^3$ (Perry, 1999)
Densitas Air ($\rho$) = 0,0227 x 995,647 kg/m$^3$ = 22,6937 kg/m$^3$ (Perry, 1999)
Densitas CPO ($\rho$) = 0,002 x 895 kg/m$^3$ = 1,8463 kg/m$^3$ (Perry, 1999)
Densitas Campuran ($\rho$) = 884,1295 kg/m$^3$

Volume campuran
\[
\frac{m}{\rho} = \frac{4754234,928 \text{ kg}}{884,1295 \text{ kg/m}^3} = 5377,306 \text{ m}^3
\]

Faktor kelonggaran (fk) = 20 % (Brownell & Young, 1959)

Volume tangki, $V_T$ = (1 + 0,2) x 5377,306 m$^3$
= 6452,7666 m$^3$

b. Diameter dan Tinggi Shell

- Tinggi silinder ($H_s$) : Diameter (D) = 4 : 3
- Tinggi tutup ($H_d$) : Diameter (D) = 1 : 4

- Volume shell tangki ($V_s$) :

\[
V_s = \pi R^2H_s = \frac{\pi D^2}{4} \left(\frac{4}{3}D\right)
\]

\[
V_s = \frac{\pi D^3}{3}
\]

- Volume tutup tangki ($V_e$) :

\[
V_h = \frac{2\pi}{3} R^2H_d = \frac{\pi D^2}{6} \left(\frac{1}{4}D\right) = \frac{\pi D^3}{24}
\]

(Brownell & Young, 1959)
- Volume tangki (V):

\[ V_t = V_s + V_h = \frac{3}{8} \pi D^3 \]

\[ 6452,7666 \text{ m}^3 = 1,1775 D^3 \]

\[ D^3 = 5480,0565 \text{ m}^3 \]

\[ D = 17,6303 \text{ m} = 694,108 \text{ in} \]

\[ H_s = \frac{4}{3} D = 23,5071 \text{ m} \]

c. Diameter dan tinggi tutup

Diameter tutup = diameter tangki = 17,6303 m

Tinggi tutup (\(H_d\)) = \(\frac{1}{4} D = 4,4075 \text{ m}\)

Tinggi tangki = \(H_s + H_d = (23,5071 + 4,4075) \text{ m} = 27,9147 \text{ m}\)

d. Tebal shell tangki

Direncanakan menggunakan bahan konstruksi Carbon Steel SA –285 Grade C
diperoleh data:

- Allowable stress (S) = 13750 psia
- Joint efficiency (E) = 0,85
- Corrosion allowance (C) = 1,524 mm/tahun (Peters dkk, 2004)
  = 0,06 in/tahun
- Umur tangki (n) = 10 tahun

Volume cairan = 5377,3054 m³

Tinggi cairan dalam tangki = \(\frac{5377,3054 \text{ m}^3}{6452,7666 \text{ m}^3} \times 23,5071 \text{ m} = 19,5893 \text{ m}\)

Tekanan Hidrostatik:

\[ P_{\text{hidrostatik}} = \rho \times g \times l \]

\[ = 893,4473 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 19,5893 \text{ m} = 1,6751 \text{ atm} \]

\[ P_o = 1 \text{ atm} \]
\[ P = 16 \text{ atm} + 1,6751 \text{ atm} = 2,6751 \text{ atm} \]

\[ P_{\text{design}} = 1,2 \times 2,6751 = 3,2101 \text{ atm} = 47,1758 \text{ psi} \]

Tebal *shell* tangki:

\[ t = \frac{PR}{SE - 0,6P} \]

(Walas dkk, 2005)

Dimana:

- **P** = tekanan desain (psig)
- **R** = jari-jari dalam tangki (in)
- **S** = *allowable stress* (psia)
- **E** = *joint efficiency*

\[ t = \frac{PR}{SE - 0,6P} \]

\[ = \left( \frac{47,1758 \text{ psi}}{(15037 \text{ psia})(0,85) - 0,6(47,1758 \text{ psi})} \right) \]

\[ = 1,4042 \text{ in} \]

Faktor korosi \[ = 0,06 \text{ in/tahun} \]

Maka tebal *shell* yang dibutuhkan dengan perkiraan umur alat adalah 10 tahun

\[ = 1,4042 + (10 \times 0,06) \]

\[ = 2,0042 \text{ in} \]

Tebal *shell* standar yang digunakan \[ = 2,25 \text{ in} \]  
(Brownell & Young, 1959)

**LC.4 Tangki Produk Gliserol (TK-104)**

Fungsi : Untuk penyimpanan produk Gliserol selama 10 hari

Jumlah : 1 unit

Bentuk : Tangki berbentuk silinder vertical dengan alas datar dan tutup elipsoidal

Bahan : *Carbon Steel, SA-28 Gr. C*  
(Brownell, 1959)

Kondisi operasi : -Temperatur = 105\(^0\)C

-Tekanan \[ = 1 \text{ atm} \]

**Perhitungan:**

Universitas Sumatera Utara
a. Volume Tangki

Produk/jam = 7323,2323 kg/jam
Kebutuhan 10 hari = 7323,2323 kg/jam x 24 jam/ hari x 10 hari = 1735735,752 Kg

Densitas Gliserol (ρ) = 0,3 x 1253,63 kg/m³ = 376,089 kg/m³ (Perry, 1999)

Densitas Air (ρ) = 0,7 x 995,647 kg/m³ = 696,9528 kg/m³ (Perry, 1999)

Densitas Campuran (ρ) = 1073,0419 kg/m³

Volume campuran \[ \frac{m}{\rho} = \frac{1735735,752 \ kg}{1073,0419 \ \frac{kg}{m^3}} = 1637,9376 \ m^3 \]

Faktor kelonggaran (fk) = 20 % (Brownell & Young, 1959)

Volume tangki, \[ V_T = (1 + 0,2) \times 1637,9376 \ m^3 \]
\[ = 1965,5252 \ m^3 \]

b. Diameter dan Tinggi Shell

Direncanakan:
- Tinggi silinder (Hₚ) : Diameter (D) = 4 : 3
- Tinggi tutup (Hₜ) : Diameter (D) = 1 : 4

- Volume shell tangki (Vs):
\[ V_s = \pi R^2 H_s = \frac{\pi}{4} D^2 \left( \frac{4}{3} D \right) \]
\[ V_s = \frac{\pi}{3} D^3 \]

- Volume tutup tangki (Vₜ):
\[ V_h = \frac{2\pi}{3} R^2 H_d = \frac{\pi}{6} D^2 \left( \frac{1}{4} D \right) = \frac{\pi}{24} D^3 \]
\[ \text{(Brownell & Young, 1959)} \]

- Volume tangki (V):
\[ V_t = V_s + V_h \]
\[ = \frac{3}{8} \pi D^3 \]
\[ 1965,5252 \ m^3 = 1,1775D^3 \]
Dari gambar, kita dapat melihat bahwa:

\[ D^3 = 1669.2358 \, m^3 \]
\[ D = 11.8624 \, m = 467.0226 \, in \]
\[ H_s = \frac{4}{3}D = 15.8165 \, m \]

**c. Diameter dan tinggi tutup**

Diameter tutup = diameter tangki = 11.8624 m

Tinggi tutup \( (H_d) = \frac{1}{4}D = 2.9656 \, m \)

Tinggi tangki = \( H_s + H_d = (15.8165 + 2.9656) \, m = 18.7821 \, m \)

**d. Tebal shell tangki**

Direncanakan menggunakan bahan konstruksi *Carbon Steel*, SA-28 Gr. C diperoleh data:

- *Allowable stress (S)* = 13750 psi
- *Joint efficiency (E)* = 0.85
- *Corrosion allowance (C)* = 1.524 mm/tahun (Peters dkk, 2004)
  = 0.06 in/tahun
- Umur tangki \( (n) = 10 \) tahun

Volume cairan = 1637.9376 m³

Tinggi cairan dalam tangki = \( \frac{1637.9376 \, m^3}{1965.5252 \, m^3} \times 15.8165 \, m = 13.1804 \, m \)

Tekanan Hidrostatik:

\[ P_{Hidrostatik} = \rho \times g \times l \]
\[ = 1073.0419 \, kg/m^3 \times 9.8 \, m/det^2 \times 13.1804 \, m = 1.3679 \, atm \]

Tekanan operasi \( (P_o) = 1 \) atm

\[ P = 1 \, atm + 1.36795 \, atm = 2.3679 \, atm \]

\[ P_{design} = (1.2) \times (2.3679) = 2.8414 \, atm = 41.7582 \, psi \]

**Tebal shell tangki:**

\[ t = \frac{PR}{SE - 0.6P} \]

(Walas dkk, 2005)

Dimana:
\[ P = \text{tekanan desain (psig)} \]
\[ R = \text{jari-jari dalam tangki (in)} \]
\[ S = \text{allowable stress (psia)} \]
\[ E = \text{joint efficiency} \]

\[ t = \frac{PR}{SE - 0.6P} = \left( \frac{13750 \text{ psia})(0.85) - 0.6(41,758\text{ psi})}{(41,758^2) (467,0226/2 \text{ in})} \]

= 0,8361 in

Faktor korosi = 0,06 in/tahun

Maka tebal shell yang dibutuhkan dengan perkiraan umur alat adalah 10 tahun

= 0,8361 + (10 x 0,06)

= 1,4361 in

Tebal shell standar yang digunakan = 1½ in (Brownell & Young, 1959)

LC.5 Tangki Penampungan CPO (TK-105)

Fungsi : Untuk penyimpanan residu CPO selama 10 hari

Jumlah : 1 unit

Bentuk : Tangki berbentuk silinder vertical dengan alas datar dan tutup elipsoidal

Bahan : Carbon Steel, SA-285 (Brownell, 1959)

Kondisi operasi : -Temperatur = 90° C

- Tekanan = 1 atm

Perhitungan:

a. Volume Tangki

Produk/jam = 163,4591 kg/jam

Kebutuhan 10 hari = 163,4591 kg/jam x 24 jam/hari x 10 hari

= 39230,184 Kg

Densitas CPO (\( \rho \)) = 895 kg/m^3 (Perry, 1999)
Volume campuran
\[ \frac{m}{\rho} = \frac{39230,184 \, kg}{895 \, kg/m^3} = 43,8326 \, m^3 \]

Faktor kelonggaran (fk) = 20 % \((Brownell & Young, 1959)\)

Volume tangki, \(V_T\)
\[ = (1 + 0,2) \times 43,8326 \, m^3 \]
\[ = 52,5991 \, m^3 \]

b. Diameter dan Tinggi Shell

Direncanakan:
- Tinggi silinder (\(H_s\)) : Diameter (\(D\)) = 4 : 3
- Tinggi tutup (\(H_d\)) : Diameter (\(D\)) = 1 : 4

- Volume shell tangki (\(V_s\)) :
\[ V_s = \pi R^2 H_s = \frac{\pi}{4} D^2 \left(\frac{4}{3} D\right) \]
\[ V_s = \frac{\pi}{3} D^3 \]

- Volume tutup tangki (\(V_e\)) :
\[ V_h = \frac{2\pi}{3} R^2 H_d = \frac{\pi}{6} D^2 \left(\frac{1}{4} D\right) = \frac{\pi}{24} D^3 \]
\((Brownell & Young, 1959)\)

- Volume tangki (\(V\)) :
\[ V_t = V_s + V_h \]
\[ = \frac{3}{8} \pi D^3 \]
\[ 52,5991 \, m^3 = 1,1775 \, D^3 \]
\[ D^3 = 44,6701 \, m^3 \]
\[ D = 3,5481 \, m = 139,6919 \, in \]
\[ H_s = \frac{4}{3} D = 4,7309 \, m \]

c. Diameter dan tinggi tutup
Diameter tutup = diameter tangki = 3,548 m

Tinggi tutup (H_d) = \frac{1}{4} D = 0,887 m

Tinggi tangki = H_s + H_d = (4,730 + 0,887) m = 5,6179 m

d. Tebal shell tangki

Direncanakan menggunakan bahan konstruksi Low alloy steel SA-353 diperoleh data:

- Allowable stress (S) = 13750 psia
- Joint efficiency (E) = 0,85
- Corrosion allowance (C) = 1,524 mm/tahun (Peters dkk, 2004)
  = 0,06 in/tahun
- Umur tangki (n) = 10 tahun

Volume cairan = 43,8326 m^3

Tinggi cairan dalam tangki = \frac{43,8326 m^3}{52,5991 m^3} \times 4,7309 m = 3,9424 m

Tekanan Hidrostatik:

\[ P_{\text{Hidrostatik}} = \rho \times g \times l \]

\[ = 895 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 3,9424 \text{ m} = 0,3412 \text{ atm} \]

Tekanan operasi (P_o) = 1 atm

\[ P = 1 \text{ atm} + 0,3412 \text{ atm} = 1,3412 \text{ atm} \]

\[ P_{\text{design}} = (1,2) \times (1,3412) = 1,6095 \text{ atm} = 23,6533 \text{ psi} \]

Tebal shell tangki:

\[ t = \frac{P R}{S E - 0,6P} \]

(Walas dkk, 2005)

Dimana:

P = tekanan desain (psig)
R = jari-jari dalam tangki (in)
S = allowable stress (psia)
E = \textit{joint efficiency}

\[
t = \frac{PR}{SE - 0.6P}
\]

\[
= \frac{(23,6533 \times 139,6919/2 \text{ in})}{(13750 \text{ psia})(0.85) - 0.6(23,6533 \text{ psi})}
\]

\[
= 0.1415 \text{ in}
\]

Faktor korosi = 0,06 in/tahun

Maka tebal \textit{shell} yang dibutuhkan dengan perkiraan umur alat adalah 10 tahun

\[
= 0,1415 + (10 \times 0,06)
\]

\[
= 0,7415 \text{ in}
\]

Tebal \textit{shell} standar yang digunakan = 0,75 in \hfill (Brownell & Young, 1959)

\textbf{LC. 6 Pompa Tangki CPO (P-101)}

Fungsi : Untuk memompakan CPO ke Heater CPO

Jenis : Pompa sentrifugal

Bahan konstruksi : \textit{Commercial Steel} \hfill (Brownell, 1959)

Jumlah : 1 unit

Kondisi operasi :

Tekanan = 1 atm

Temperatur = 30 \degree C

Laju alir massa (F) = 20428,9158 kg/jam

Densitas CPO (\(\rho\)) = 859 kg/m\(^3\)

Laju alir volumetrik,

\[
m_v = \frac{20428,9158 \text{ kg/jam}}{895 \text{ kg/m}^3}
\]

\[
= 0,0063 \text{ m}^3/\text{s} = 0,2239 \text{ ft}^3/\text{s}
\]

Desain pipa:

\[
D_{i,\text{opt}} = 0.363 \left( m_v \right)^{0.45} \left( \rho \right)^{0.13} \hfill (Peters \ dkk, \ 2004)
\]

\[
= 0.363 \left( 0.0063 \text{ m}^3/\text{s} \right)^{0.45} \left( 895 \text{ kg/m}^3 \right)^{0.13}
\]
= 0,09 m = 3,5461 in

Dari Tabel A.5-1 Geankoplis (2003), dipilih pipa dengan spesifikasi:

- **Ukuran nominal**: 4 in
- **Schedule number**: 40
- **Diameter Dalam (ID)**: 4,026 in = 0,3355 ft
- **Diameter Luar (OD)**: 4,5 in = 0,375 ft
- **Inside sectional area**: 0,0884 ft²

Kecepatan linier, \( v = \frac{Q}{A} = \frac{0,2239}{0,0884} = 2,5328 \text{ ft/s} \)

Bilangan *Reynold*: \( N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{(55,8744 \text{ lbm/ft}^3)(2,35328\text{ft/s})(0,3355\text{ft})}{0,0134 \text{ lbm/ft.s}} = 3543,3013 \) (Turbulen)

Untuk pipa *Commercial Steel* diperoleh harga \( \varepsilon = 0,000046 \) (Geankoplis, 2003)

Pada \( N_{Re} = 3543,3013 \) dan \( \varepsilon/D = \frac{0,000046 \text{ m}}{0,1022 \text{ m}} = 0,00044 \)

Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga \( f = 0,0065 \)

**Friction loss:**

1. *Sharp edge entrance*: \( h_c = 0,55 \left( 1 - \frac{A_1}{A_2} \right) \frac{v^2}{2\alpha} = 0,55(1 - 0) \frac{2,5328^2}{2(1)(32,174)} \)

   = 0,0548 ft.lbf/lbm

2. *elbow 90°*: \( h_f = \text{n.Kf.} \frac{v^2}{2.g_c} = 2(0,75) \frac{2,5328^2}{2(32,174)} = 0,1495 \text{ ft.lbf/lbm} \)

1. *check valve*: \( h_f = \text{n.Kf.} \frac{v^2}{2.g_c} = 1(2) \frac{2,5328^2}{2(32,174)} = 0,1993 \text{ ft.lbf/lbm} \)

Pipa lurus 20 ft: \( F_f = 4f \frac{\Delta L \cdot v^2}{D.2.g_c} = 4(0,0065) \frac{(20)(2,5328)^2}{0,3355.2(32,174)} \)

   = 0,1545 ft.lbf/lbm

1. *Sharp edge exit*: \( h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2\alpha.g_c} = 1 \left( 1 - 0 \right)^2 \frac{2,5328^2}{2(1)(32,174)} \)
Total friction loss: \( \sum F = 0,6579 \text{ ft.lbf/lbm} \)

Dari persamaan Bernoulli:

\[
\frac{1}{2\alpha} \left( v_2^2 - v_1^2 \right) + g(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \quad \text{(Geankoplis, 2003)}
\]

dimana: \( v_1 = v_2 \)

\( P_2 = 1 \text{ atm} \)

\( \Delta P = 0 \text{ atm} \)

tinggi pemompaan \( \Delta Z = 20 \text{ ft} \)

maka:

\[
0 + \frac{32,174}{32,174} \left( 20 \right) + 0 + 0,6579 + W_s = 0
\]

\( W_s = -20,6579 \text{ ft.lbf/lbm} \)

Efisiensi pompa, \( \eta = 80 \% \)

\[
W_p = -\frac{W_s}{\eta} \quad \text{(Geankoplis, 2003)}
\]

\[
= -\frac{121,8974}{0,80}
\]

\( = 25,8224 \text{ ft.lbf/lbm} \).

Daya pompa: \( P = m \times W_p \)

\[
= \frac{12,5104}{(0,45359)(3600)(550\text{ ft.lbf/s.hp})} \times 25,8224 \text{ ft.lbf/lbm}
\]

\( = 0,5873 \text{ hp} \)

Maka dipilih pompa dengan daya motor 1 hp.

**LC. 7 Pompa Tangki Air (P-102)**

- **Fungsi**: Untuk memompakan Air ke Heater Air
- **Jenis**: Pompa sentrifugal
- **Bahan konstruksi**: *Commercial Steel* *(Brownell, 1959)*
- **Jumlah**: 1 unit
- **Kondisi operasi**: 
Tekanan        =  1 atm
Temperatur       =  30 °C
Laju alir massa (F) = 14300,2410 kg/jam

Laju alir volumetrik,
\[ m_v = \frac{14300,241\text{ kg/jam}}{995,647\text{ kg/m}^3} = 0,0039\text{ m}^3/\text{s} = 0,1408\text{ ft}^3/\text{s} \]

Desain pipa:
\[ \text{Di}_{opt} = 0,363 (m_v)^{0.45} (\rho)^{0.13} \]  
(Peters dkk, 2004)
\[ = 0,363 (0,0039\text{ m}^3/\text{s})^{0.45} (995,647\text{ kg/m}^3)^{0.13} \]
\[ = 0,0741\text{ m} = 2,919\text{ in} \]

Dari Tabel A.5-1 Geankoplis (2003), dipilih pipa dengan spesifikasi:

- Ukuran nominal : 3 in
- Schedule number : 40
- Diameter Dalam (ID) : 3,068 in = 0,2556 ft
- Diameter Luar (OD) : 3,5 in = 0,2916 ft
- Inside sectional area : 0,0513 ft²

Kecepatan linier, \( v = \frac{Q}{A} = \frac{0,1408\text{ ft}^3/\text{s}}{0,0513\text{ ft}^2} = 2,7463\text{ ft/s} \)

Bilangan Reynolds:
\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]
\[ = \frac{(62,1578\text{ lbm/ft}^3)(2,7463\text{ ft/s})(0,2556\text{ ft})}{0,000672\text{ lbm/ft.s}} \]
\[ = 64946,5418 \text{ (Turbulen)} \]

Untuk pipa Commercial Steel diperoleh harga \( \varepsilon = 0,000046 \)  
(Geankoplis, 2003)

Pada \( N_{Re} = 764946,5418 \) dan \( \varepsilon/D = \frac{0,000046\text{ m}}{0,0779\text{ m}} = 0,00059 \)

Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga \( f = 0,0055 \)

Friction loss:
1. **Sharp edge entrance**: $h_e = 0.55 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2\alpha} = 0.55(1 - 0) \frac{2,7463^2}{2(1)(32,174)}$
\[ = 0.0644 \text{ ft.lbf/lbm}\]

2. **elbow 90°**: $h_f = n.Kf. \frac{v^2}{2.g_c} = 2(0.75) \frac{2,7463^2}{2(32,174)} = 0.1758 \text{ ft.lbf/lbm}$

1. **check valve**: $h_f = n.Kf. \frac{v^2}{2.g_c} = 1(2) \frac{2,7463^2}{2(32,174)} = 0.2344 \text{ ft.lbf/lbm}$

Pipa lurus 20 ft: $F_f = 4f \frac{\Delta L.v^2}{D.2.g_c} = 4(0.0055) \frac{(20).2,7463^2}{(0.2556)(2)(32,174)}$
\[ = 0.2017 \text{ ft.lbf/lbm}\]

1. **Sharp edge exit**: $h_{ex} = n \left(1 - \frac{A_1}{A_2}\right)^2 \frac{v^2}{2\alpha.g_c} = 1 \left(1 - 0\right)^2 \frac{2,7463^2}{2(1)(32,174)}$
\[ = 0.1177 \text{ ft.lbf/lbm}\]

**Total friction loss**: $\sum F = 0.7936 \text{ ft.lbf/lbm}$

Dari persamaan Bernoulli:
\[ \frac{1}{2\alpha} (v_2^2 - v_1^2) + g(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \]  
(Geankoplis, 2003)

dimana: $v_1 = v_2$

$P_2 = 1 \text{ atm}$

$\Delta P = 0 \text{ atm}$

tinggi pemompaan $\Delta Z = 20 \text{ ft}$

maka: $0 + \frac{32,174}{32,174} (20) + 0 + 0.7936 + W_s = 0$

$W_s = -20,7936 \text{ ft.lbf/lbm}$

Efisiensi pompa, $\eta = 80 \%$

$W_p = \frac{-W_s}{\eta}$  
(Geankoplis, 2003)
\[ = \frac{-20,7936}{0.8} \]
\[ = 25,992 \text{ ft.lbf/lbm}.\]
Daya pompa: 
\[ P = m \times W_p \]
\[ = \frac{8,7573 \text{ lbm/s} \times 125,992 \text{ ft.lbf/lbm}}{(0,45359)(3600)(550\text{ ft.lbf/s.hp})} \]
\[ = 0,4138 \text{ hp} \]

Maka dipilih pompa dengan daya motor 1/2 hp.

**LC. 8 Pompa Heater CPO (P-103)**

- **Fungsi**: Untuk memompa CPO ke Kolom Hidrolisa
- **Jenis**: Pompa piston
- **Bahan konstruksi**: *Commercial Steel* (Brownell, 1959)
- **Jumlah**: 1 unit
- **Kondisi operasi**:
  - Tekanan: 1 atm
  - Temperatur: 80 °C
  - Laju alir massa (F): 20428,9158 kg/jam

Laju alir volumetrik,

\[ m_v = \frac{20428,9158 \text{ kg/jam}}{895 \text{ kg/m}^3} = 0,00634 \text{ m}^3/\text{s} = 0,2239 \text{ ft}^3/\text{s} \]

Desain pipa:

\[ D_{i,\text{opt}} = 0,363 (m_v)^{0.45}\rho^{0.13} \]  
(Peters dkk, 2004)

\[ = 0,363 (0,0063 \text{ m}^3/\text{s})^{0.45} (895 \text{ kg/m}^3)^{0.13} \]
\[ = 0,09007 \text{ m} = 3,5461 \text{ in} \]

Dari Tabel A.5-1 Geankoplis (2003), dipilih pipa dengan spesifikasi:

- **Ukuran nominal**: 4 in
- **Schedule number**: 40
- **Diameter Dalam (ID)**: 4,026 in = 0,3355 ft
- **Diameter Luar (OD)**: 4,5 in = 0,375 ft
- **Inside sectional area**: 0,0884 ft²
Kecepatan linier, \( v = \frac{Q}{A} = \frac{0.2239 \text{ ft}^3/\text{s}}{0.0884 \text{ ft}^2} = 2.5328 \text{ ft/s} \)

Bilangan *Reynold*:
\[
N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{(55.87449 \text{ lbm/ft}^3)(2.5328 \text{ ft/s})(0.3355 \text{ ft})}{0.0134 \text{ lbm/ft.s}} = 3543.3013 \text{ (Turbulen)}
\]

Untuk pipa *Commercial Steel* diperoleh harga \( \varepsilon = 0.000046 \) (Geankoplis, 2003)

Pada \( N_{Re} = 3543.3013 \) dan \( \varepsilon/D = \frac{0.000046}{0.1022 \text{ m}} = 0.00044 \)

Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga \( f = 0.0065 \)

*Friction loss*:

1. *Sharp edge entrance*: \( h_c = 0.55 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2\alpha} = 0.55(1-0) \frac{2.5328^2}{2(1)(32,174)} = 0.0548 \text{ ft.lbf/lbm} \)

2. *elbow 90°*: \( h_f = n.Kf. \frac{v^2}{2.g_c} = 2(0.75) \frac{2.5328^2}{2(32,174)} = 0.1495 \text{ ft.lbf/lbm} \)

1. *check valve*: \( h_f = n.Kf. \frac{v^2}{2.g_c} = 1(2) \frac{2.5328^2}{2(32,174)} = 0.1993 \text{ ft.lbf/lbm} \)

Pipa lurus 20 ft: \( F_t = 4f \frac{\Delta L. v^2}{D.2.g_c} = 4(0.0065) \frac{(20)(2.5328)^2}{(0.3355)(2)(32,174)} = 0.1545 \text{ ft.lbf/lbm} \)

1. *Sharp edge exit*: \( h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2.\alpha.g_c} = 1 \left( 1 - 0 \right)^2 \frac{2.5328^2}{2(1)(32,174)} = 0.0996 \text{ ft.lbf/lbm} \)

*Total friction loss*: \( \sum F = 0.6579 \text{ ft.lbf/lbm} \)

Dari persamaan Bernoulli:
\[
\frac{1}{2\alpha} \left( v_2^2 - v_1^2 \right) + g(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0
\]

(Geankoplis, 2003)
dimana: $v_1 = v_2$

$P_2 = 53,3 \text{ atm}$

$\Delta P = 52,3 \text{ atm} = 110678,7 \text{ lb/ft}^2$

tinggi pemompaan $\Delta Z = 20 \text{ ft}$

maka :

$$0 + \frac{32,174}{32,174} (20) + \frac{110678,7}{55,87449} + 0,6579 + W_s = 0$$

$W_s = -2001,5034 \text{ ft.lbf/lbm}$

Efisiensi pompa, $\eta= 80 \%$

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

$$= - \frac{2001,5034}{0,80}$$

$$= 250,8792 \text{ ft.lbf/lbm}.$$ 

Daya pompa: $P = m \times W_p$

$$= \frac{12,51044}{(0,45359)(3600)(550\text{ft.lbf/s.hp})} \text{ lbm/s} \times 2501,879284 \text{ ft.lbf/lbm}$$

$$= 56,9083 \text{ hp}$$

Maka dipilih pompa dengan daya motor 57 hp.

**LC. 9 Pompa Heater Air (P-104)**

Fungsi : Untuk memompaikan Air ke Kolom Hidrolisa

Jenis : Pompa piston

Bahan konstruksi : *Carbon Steel, SA-285* (Brownell, 1959)

Jumlah : 1 unit

Kondisi operasi :

Tekanan = 1 atm

Temperatur = 80 °C

Laju alir massa (F) = 14300,241 kg/jam

Laju alir volumetrik,
\[ m_v = \frac{14300,241 \text{ kg/jam}}{995,647 \text{ kg/m}^3} = 0,00399 \text{ m}^3/\text{s} = 0,14088 \text{ ft}^3/\text{s} \]

Desain pipa:

\[ D_{i,\text{opt}} = 0,363 \left( m_v \right)^{0.45} (\rho)^{0.13} \]  
\[ = 0,363 \left( 0,00399 \text{ m}^3/\text{s} \right)^{0.45} (995,647 \text{ kg/m}^3)^{0.13} \]  
\[ = 0,07414 \text{ m} \approx 2,919 \text{ in} \]

Dari Tabel A.5-1 Geankoplis (2003), dipilih pipa dengan spesifikasi:

- Ukuran nominal : 3 in
- Schedule number : 40
- Diameter Dalam (ID) : 3,068 in = 0,2556 ft
- Diameter Luar (OD) : 3,5 in = 0,2916 ft
- Inside sectional area : 0,0513 ft²

\[ \text{Kecepatan linier}, v = \frac{Q}{A} = \frac{0,14088 \text{ ft}^3/\text{s}}{0,0513 \text{ ft}^2} = 2,7463 \text{ ft/s} \]

Bilangan Reynolds:

\[ N_{\text{Re}} = \frac{\rho \times v \times D}{\mu} = \left( \frac{62,1578 \text{ lbm/ft}^3 \times (2,7463 \text{ ft/s}) \times (0,2556 \text{ ft})}{0,000672 \text{ lbm/ft.s}} \right) \]
\[ = 64946,542 \text{ (Turbulen)} \]

Untuk pipa *Commercial Steel* diperoleh harga \( \varepsilon = 0,000046 \)  

(Geankoplis, 2003)

Pada \( N_{\text{Re}} = 64946,542 \) dan \( \varepsilon/D = \frac{0,000046 \text{ m}}{0,077928 \text{ m}} = 0,00059 \)

Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga \( f = 0,0055 \)

Friction loss:

1. *Sharp edge entrance*: 
\[ h_c = 0,55 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha} = 0,55(1 - 0) \frac{2,7463^2}{2(1)(32,174)} \]
\[ = 0,0644 \text{ ft.lbf/lbm} \]
2 elbow 90°: \[ h_f = n \cdot \frac{v^2}{2 \cdot g_c} = 2(0,80) \frac{2,7463^2}{2(32,174)} = 0,17582 \text{ ft.lbf/lbm} \]

1 check valve: \[ h_f = n \cdot \frac{v^2}{2 \cdot g_c} = 1(2) \frac{2,7463^2}{2(32,174)} = 0,2344 \text{ ft.lbf/lbm} \]

Pipa lurus 20 ft: \[ F_f = 4f \frac{\Delta L \cdot v^2}{D \cdot 2 \cdot g_c} = 4(0,0055) \frac{(20)(2,7463)^2}{(0,2556)2(32,174)} = 0,2017 \text{ ft.lbf/lbm} \]

1 Sharp edge exit: \[ h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \cdot \alpha \cdot g_c} = 1 \left( 1 - 0 \right)^2 \frac{2,7463^2}{2(0)(32,174)} = 0,1172 \text{ ft.lbf/lbm} \]

Total friction loss: \[ \sum F = 0,7936 \text{ ft.lbf/lbm} \]

Dari persamaan Bernoulli:
\[
\frac{1}{2 \alpha} \left( v_2^2 - v_1^2 \right) + g(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0
\]
(Geankoplis, 2003)

dimana: \( v_1 = v_2 \)

\( P_2 = 53,3 \text{ atm} \)

\( \Delta P = 52,3 \text{ atm} = 110678,7 \text{ lb} \cdot \text{ft}^2 \)

tinggi pemompaan \( \Delta Z = 20 \text{ ft} \)

maka:
\[
0 + \frac{32,174}{32,174} \frac{(20)(110678,7)}{62,15784} + 0,7936 + W_s = 0
\]

\( W_s = -1801,4013 \text{ ft.lbf/lbm} \)

Efisiensi pompa, \( \eta = 80 \% \)
\[
W_p = -\frac{W_s}{\eta}
\]
(Geankoplis, 2003)
\[
= -\frac{-1801,4013}{0,80}
= 2251,7516 \text{ ft.lbf/lbm.}
\]

Daya pompa:
\[
P = m \times W_p
\]
Maka dipilih pompa dengan daya motor 36 hp.

**LC. 10 Pompa Flash Tank Asam Lemak (P-105)**

Fungsi : Untuk memompakan Asam Lemak ke Tangki Asam Lemak  
Jenis : Pompa sentrifugal  
Bahan konstruksi : *Commercial Steel*  
Jumlah : 1 unit  
- Laju alir massa (F) = 19809,3122 kg/jam  
Densitas Asam lemak (ρ) = 0,9751 x 881,5 kg/m³ = 859,5896 kg/m³ (Perry, 1999)  
Densitas Air (ρ) = 0,0227 x 995,647 kg/m³ = 22,6936 kg/m³ (Perry, 1999)  
Densitas CPO (ρ) = 0,002 x 859 kg/m³ = 1,8462 kg/m³ (Perry, 1999)  
Densitas Campuran (ρ) = 884,1295 kg/m³  
- Viskositas (µ) = 0,0034 lb/ft.s (Perry, 1999)  

Laju alir volume, \( m_v \) = \( \frac{19809,3122 \text{ kg/jam}}{884,1295 \text{ kg/m}^3} \)  
= 0,0062 m³/s = 0,2197 ft³/s  

Desain pipa:  
\[ D_{i, opt} = 0,363 \left( m_v \right)^{0.45} (\rho)^{0.13} \] (Peters dkk, 2004)  
= 0,363 (0,0062 m³/s)⁰⁴⁵ (884, kg/1295 m³)⁰¹³  
= 0,0891 m = 3,511 in  

Dari Tabel A.5-1 Geankoplis (2003), dipilih pipa dengan spesifikasi:  
Ukuran nominal : 4 in  
*Schedule number* : 40  
Diameter Dalam (ID) : 4,026 in = 0,3355 ft  
Diameter Luar (OD) : 4,5 in = 0,375 ft
Inside sectional area : 0,0884 ft²

Kecepatan linier, \( v = \frac{Q}{A} = \frac{0,2197 \text{ ft}^3/\text{s}}{0,0884 \text{ ft}^2} = 2,4862 \text{ ft/s} \)

Sehingga:

\[
N_{Re} = \frac{\rho v D}{\mu} = \frac{884,1295 \text{ lb} / \text{ ft}^3 \times 2,4862 \text{ ft} / \text{s} \times 0,3355 \text{ ft}}{0,0034 \text{ lb} / \text{ ft.s}}
\]

\[
= 13321,884 \text{ (Turbulen)}
\]

Untuk pipa commercial steel, harga \( \varepsilon = 0,000046 \) (Geankoplis, 1997)

Pada \( N_{Re} = 13321,88 \) dan \( \varepsilon/D = 0,00045 \)

Dari Gambar 2.10-3 Geankoplis (2003) diperole harga \( f = 0,07 \)

**Friction loss:**

1. *Sharp edge entrance:* \( h_c = 0,55 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2\alpha} = 0,55(1-0) \frac{2,4862^2}{2(1)(32,174)} \)

\[
= 0,0528 \text{ ft.lbf/lbm}
\]

2. *Elbow 90°:* \( h_f = n.Kf. \frac{v^2}{2.g_c} = 2(0,80) \frac{2,4862^2}{2(32,174)} = 0,144 \text{ ft.lbf/lbm} \)

1. *Check valve:* \( h_f = n.Kf. \frac{v^2}{2.g_c} = 1(2) \frac{2,4862^2}{2(32,174)} = 0,1921 \text{ ft.lbf/lbm} \)

Pipa lurus 20 ft: \( F_f = 4f \frac{\Delta L.v^2}{D.2.g_c} = 4(0,007) \frac{(20)(2,4862)^2}{(0,3355)(2)(32,174)} \)

\[
= 0,1603 \text{ ft.lbf/lbm}
\]

1. *Sharp edge exit:* \( h_{ex} = n \left(1 - \frac{A_1}{A_2}\right)^2 \frac{v^2}{2\alpha.g_c} = 1 (1-0)^2 \frac{2,4862^2}{2(1)(32,174)} \)

\[
= 0,096 \text{ ft.lbf/lbm}
\]

Total friction loss: \( \sum F = 0,6454 \text{ ft.lbf/lbm} \)

Dari persamaan Bernoulli:

\[
\frac{1}{2\alpha} \left( v_2^2 - v_1^2 \right) + g(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \quad (\text{Geankoplis, 2003})
\]
dimana: \( v_1 = v_2 \)

\[ P_1 = P_2 = 1 \text{ atm} \]

\( \Delta P = 0 \)

tinggi pemompaan \( \Delta Z = 20 \text{ ft} \)

maka :
\[ 0 + \frac{32.174}{32.174}(20) + 0 + 0.6454 + W_s = 0 \]

\[ W_s = -20.6454 \text{ ft.lbf/lbm} \]

Efisiensi pompa, \( \eta = 80 \% \)

\[ W_p = -\frac{W_s}{\eta} \]

\[ = -\frac{20.6454}{0.8} \]

\[ = 25.8067 \text{ ft.lbf/lbm.} \]

Daya pompa: \( P = m \times W_p \)

\[ \geq \frac{12.131}{(0.45359)(3600)(550 \text{ ft.lbf/s.hp})} \text{ lbm/s} \times 25.8067 \text{ ft.lbf/lbm} \]

\[ = 0.5692 \text{ hp} \]

Maka dipilih pompa dengan daya motor 1 hp.

**L.C. 11 Pompa Flash Tank Gliserol (P-106)**

Fungsi : Untuk memompa Gliserol ke Skimmer

Jenis : Pompa sentrifugal

Bahan konstruksi : *commercial steel* (Brownell, 1959)

Jumlah : 1 unit

Laju alir massa (\( F \)) = 18614,8858 kg/jam

Densitas Gliserol (\( \rho \)) = 0,118 x 1253,63 kg/m\(^3\) = 147,9561 kg/m\(^3\) (Perry, 1999)

Densitas Air (\( \rho \)) = 0,8731 x 995,647 kg/m\(^3\) = 869,3956 kg/m\(^3\) (Perry, 1999)

Densitas CPO (\( \rho \)) = 0,0087 x 895 kg/m\(^3\) = 7,859 kg/m\(^3\) (Perry, 1999)
Densitas Campuran \((\rho)\) = 1025,2109 kg/m\(^3\)
- Viskositas \((\mu)\) = 0,0015 lb/ft.s \hspace{1cm} \text{(Perry, 1999)}

Laju alir volumetrik,
\[
m_v = \frac{18614,8858 \text{ kg/jam}}{1025,2109 \text{ kg/m}^3} = 0,005 \text{ m}^3/\text{s} = 0,1781 \text{ ft}^3/\text{s}
\]

Desain pipa:
\[
D_{i, opt} = 0,363 (m_v)^{0,45} (\rho)^{0,13} \hspace{1cm} \text{(Peters dkk, 2004)}
\]
\[
= 0,363 (0,005 \text{ m}^3/\text{s})^{0,45} (1025,2109 \text{ kg/m}^3)^{0,13}
\]
\[
= 0,0827 \text{ m} = 3,2562 \text{ in}
\]

Dari Tabel A.5-1 Geankoplis (2003), dipilih pipa dengan spesifikasi:
- Ukuran nominal : 3½ in
- Schedule number : 40
- Diameter Dalam (ID) : 3,548 in = 0,2956 ft
- Diameter Luar (OD) : 4 in = 0,3333 ft
- Inside sectional area : 0,0687 ft\(^2\)

Kecepatan linier, \(v = \frac{Q}{A} = \frac{0,1781 \text{ ft}^3/\text{s}}{0,0687 \text{ ft}^2} = 2,5925 \text{ ft/s}

Bilangan Reynold:
\[
N_{Re} = \frac{\rho \times v \times D}{\mu}
\]
\[
= \frac{(1025,2109 \times 2,5925) \text{ lbm/ft}^3 (2,866 \text{ ft/s})(0,2956 \text{ ft})}{(0,40095 \times 0,00067) \text{ lbm/ft.s}}
\]
\[
= 31961,1817 \text{ (Turbulen)}
\]

Untuk pipa \textit{Commercial Steel} diperoleh harga \(\varepsilon = 0,000046 \hspace{1cm} \text{(Geankoplis, 2003)}

Pada \(N_{Re} = 31961,1817 \text{ dan } \varepsilon/D = \frac{0,000046 \text{ m}}{0,09012 \text{ m}} = 0,00051

Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga f = 0,006

Friction loss:

1. Sharp edge entrance: 
\[ h_c = 0,55 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2\alpha} = 0,55(1-0) \frac{2,5925^2}{2(32,174)} = 0,0574 \text{ft.lbf/lbm} \]

1. Check valve: 
\[ h_f = n.Kf. \frac{v^2}{2.g_c} = 1(2) \frac{2,5925^2}{2(32,174)} = 0,2089 \text{ft.lbf/lbm} \]

1. Elbow 90°: 
\[ h_f = n.Kf. \frac{v^2}{2.g_c} = 1(0,75) \frac{2,5925^2}{2(32,174)} = 0,0783 \text{ft.lbf/lbm} \]

Pipa lurus 20 ft: 
\[ F_f = 4f \frac{\Delta L.v^2}{D.2.g_c} = 4(0,006) \frac{(20)2,5925^2}{(0,2956)2(32,174)} = 0,1695 \text{ft.lbf/lbm} \]

1. Sharp edge exit: 
\[ h_{ex} = n \left(1 - \frac{A_1}{A_2}\right) \frac{v^2}{2\alpha.g_c} = 1(1-0)^2 \frac{2,5925^2}{2(32,174)} = 0,1044 \text{ft.lbf/lbm} \]

Total friction loss: 
\[ \sum F = 0,6187 \text{ft.lbf/lbm} \]

Dari persamaan Bernoulli:
\[ \frac{1}{2\alpha}\left(v_2^2 - v_1^2\right) + g(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \]  
\[ \text{(Geankoplis, 2003)} \]

dimana: \( v_1 = v_2 \)
\( P_1 = P_2 = 1 \text{ atm} \)
\( \Delta P = 0 \)

tinggi pemompaan \( \Delta Z = 20 \text{ ft} \)

maka: 
\[ 0 + \frac{32,174}{32,174}(20)+0+0,6187 + W_s = 0 \]

\[ W_s = -20,6187 \text{ ft.lbf/lbm} \]

Efisiensi pompa, \( \eta = 80 \% \)
\[ W_p = \frac{W}{\eta} \]  
\[ \text{(Geankoplis, 2003)} \]
\[
\text{Daya pompa: } P = m \times Wp = \frac{11,3995 \text{ lbm/s} \times 25,7733 \text{ ft.lbf/lbm}}{(0,45359) (3600)(550\text{ft.lbf/s.hp})} = 0,5341 \text{ hp}
\]
Maka dipilih pompa dengan daya motor 1 hp.

**L.C. 12 Pompa Evaporator I (P-107)**

**Fungsi:** Untuk memompakan Gliserol ke Evaporator II

**Jenis:** Pompa sentrifugal

**Bahan konstruksi:** Commercial Steel \((Brownell, 1959)\)

**Jumlah:** 1 unit

**Laju alir massa \((F)\):** \(8787,8788 \text{ kg/jam}\)

**Densitas Gliserol \((\rho)\):** \(0,25 \times 1253,63 \text{ kg/m}^3 = 313,4075 \text{ kg/m}^3 \ (Perry, 1999)\)

**Densitas Air \((\rho)\):** \(0,75 \times 995,647 \text{ kg/m}^3 = 746,73525 \text{ kg/m}^3 \ (Perry, 1999)\)

**Densitas Campuran \((\rho)\):** \(1060,1427 \text{ kg/m}^3\)

**Viskositas \((\mu)\):** \(0,0104 \text{ lb/ft.s} \ (Perry, 1999)\)

Laju alir volumetrik,
\[
m_v = \frac{8787,8788 \text{ kg/jam}}{1060,1427 \text{ kg/m}^3} = 0,0023 \text{ m}^3/\text{s} = 0,0813 \text{ ft}^3/\text{s}
\]

**Desain pipa:**
\[
Di_{opt} = 0,363 (m_v)^{0.45}(\rho)^{0.13} \ (Peters dkk, 2004)
\]
\[
= 0,363 (0,0023 \text{ m}^3/\text{s})^{0.45} (1060,1427 \text{ kg/m}^3)^{0.13}
\]
\[
= 0,0583 \text{ m} = 2,298 \text{ in}
\]
Dari Tabel A.5-1 Geankoplis (2003), dipilih pipa dengan spesifikasi:

<table>
<thead>
<tr>
<th>Spesifikasi</th>
<th>Nilai</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ukuran nominal</td>
<td>2½ in</td>
</tr>
<tr>
<td>Schedule number</td>
<td>40</td>
</tr>
<tr>
<td>Diameter Dalam (ID)</td>
<td>2,469 in</td>
</tr>
<tr>
<td>Diameter Luar (OD)</td>
<td>2,875 in</td>
</tr>
<tr>
<td>Inside sectional area</td>
<td>0,03322 ft²</td>
</tr>
</tbody>
</table>

Kecepatan linier, \( v = \frac{Q}{A} = \frac{0,0813 \text{ ft}^3/\text{s}}{0,03322 \text{ ft}^2} = 2,4476 \text{ ft/s} \)

Bilangan Reynolds:

\[
N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{((790,28 \times 0,06243) \text{ lbm/ft}^3)(2,4476 \text{ ft/s})(0,2057 \text{ ft})}{(0,40095 \times 0,00067) \text{ lbm/ft.s}} = 3179,8474 \text{ (Turbulen)}
\]

Untuk pipa Commercial Steel diperoleh harga \( \varepsilon = 0,000046 \) (Geankoplis, 2003)

Pada \( N_{Re} = 3179,8474 \) dan \( \varepsilon/D = \frac{0,000046 \text{ m}}{0,06271 \text{ m}} = 0,000733 \)

Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga \( f = 0,012 \)

**Friction loss:**

1. **Sharp edge entrance:** \( h_c = 0,55 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2g_c} = 0,55(1 - 0) \frac{2,4476^2}{2(1)(32,174)} = 0,0512 \text{ ft.lbf/lbm} \)

2. **Check valve:** \( h_f = n.Kf. \frac{v^2}{2g_c} = 1(2) \frac{2,4476^2}{2(32,174)} = 0,1862 \text{ ft.lbf/lbm} \)

3. **Elbow 90°:** \( h_f = n.Kf. \frac{v^2}{2g_c} = 1(0,80) \frac{2,4476^2}{2(32,174)} = 0,2793 \text{ ft.lbf/lbm} \)

Pipa lurus 20 ft: \( F_f = 4f. \frac{D L v^2}{D.2.2.g_c} = 4(0,012) \frac{(20)(2,4476)^2}{(0,20575)(2)(32,174)} = 0,4344 \text{ ft.lbf/lbm} \)
1. **Sharp edge exit:**

\[
h_{ex} = n \left( \frac{1 - \frac{A_1}{A_2}}{2} \right)^2 \frac{v^2}{2 \alpha \gamma} = 1(0)2^2 \frac{2.4476^2}{2(1)32.174} = 0.0931 \text{ ft.lbf/lbm}
\]

**Total friction loss:**

\[
\sum F = 1.0442 \text{ ft.lbf/lbm}
\]

Dari persamaan Bernoulli:

\[
\frac{1}{2 \alpha} \left( v_2^2 - v_1^2 \right) + g(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \quad \text{(Geankoplis, 2003)}
\]

dimana: \( v_1 = v_2 \)

\( P_1 = P_2 = 1 \text{ atm} \)

\( \Delta P = 0 \)

tinggi pemompaan \( \Delta Z = 20 \text{ ft} \)

maka:

\[
0 + \frac{32.174}{32.174}(20) + 0 + 1.0442 + W_s = 0
\]

\( W_s = -21.0442 \text{ ft.lbf/lbm} \)

Efisiensi pompa, \( \eta = 80 \% \)

\[
W_p = -\frac{W_s}{\eta} \quad \text{(Geankoplis, 2003)}
\]

\[
= -\frac{21.0442}{0.8}
\]

\[
= 26.3053 \text{ ft.lbf/lbm}.
\]

Daya pompa: \( P = m \times W_p \)

\[
= \frac{5,3815}{(0.45359)(3600)(550 \text{ ft.lbf/s.hp})} \text{ lbm/s} \times 26.3053 \text{ ft.lbf/lbm}
\]

\[
= 0.2573 \text{ hp}
\]

Maka dipilih pompa dengan daya motor 1/2 hp.
LC. 13 Pompa Evaporator II (P-108)

Fungsi : Untuk memompakan Gliserol ke Cooler

Jenis : Pompa sentrifugal

Bahan konstruksi : Commercial Steel (Brownell, 1959)

Jumlah : 1 unit

Laju alir massa (F) = 7323,2323 kg/jam

Densitas Gliserol (\(\rho\)) = 0,3 x 1253,63 kg/m\(^3\) = 376,089 kg/m\(^3\) (Perry, 1999)

Densitas Air (\(\rho\)) = 0,7 x 995,647 kg/m\(^3\) = 696,9528 kg/m\(^3\) (Perry, 1999)

Densitas Campuran (\(\rho\)) = 1073,0419 kg/m\(^3\)

Viskositas (\(\mu\)) = 0,0029 lb/ft.s (Perry, 1999)

Laju alir volumetrik,

\[ m_v = \frac{7323,2323 \text{ kg/jam}}{1073,0419 \text{ kg/m}^3} = 0,0019 \text{ m}^3/\text{s} = 0,0669 \text{ ft}^3/\text{s} \]

Desain pipa:

\[ D_{i, opt} = 0,363 (m_v)^{0,45} (\rho)^{0,13} \] (Peters dkk, 2004)

\[ = 0,363 (0,0019 \text{ m}^3/\text{s})^{0,45} (1073,0419 \text{ kg/m}^3)^{0,13} \]

\[ = 0,0535 \text{ m} = 2,1088 \text{ in} \]

Dari Tabel A.5-1 Geankoplis (2003), dipilih pipa dengan spesifikasi:

Ukuran nominal : 2½ in

Schedule number : 40

Diameter Dalam (ID) : 2,469 in = 0,2057 ft

Diameter Luar (OD) : 2,875 in = 0,2395 ft

Inside sectional area : 0,03322 ft\(^2\)
Kecepatan linier, \( v = \frac{Q}{A} = \frac{0.06694 \text{ft}^3/\text{s}}{0.03322 \text{ft}^2} = 2.0152 \text{ ft/s} \)

Bilangan Reynolds:
\[
N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{(1073,041 \times 0,06243) \text{ lbm/ft}^3)(2,0152 \text{ ft/s})(0,2057\text{ft})}{(0,40095 \times 0,00067) \text{ lbm/ft.s}} = 9269,8305 \text{ (Turbulen)}
\]

Untuk pipa Commercial Steel diperoleh harga \( \varepsilon = 0,000046 \) \quad (Geankoplis, 2003)

Pada \( N_{Re} = 9269,83051 \) dan \( \varepsilon/D = \frac{0,000046 \text{ m}}{0,06271 \text{ m}} = 0,000733 \)

Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga \( f = 0,005 \)

Friction loss:

1. **Sharp edge entrance**: \( h_c = 0,55 \left( 1 - \frac{A_1}{A_2} \right) \frac{v^2}{2\alpha} = 0,55(1-0) \frac{2,0152^2}{2(1)(32,174)} = 0,0347 \text{ ft.lbf/lbm} \)

1. **Check valve**: \( h_f = n.Kf. \frac{v^2}{2.g_c} = 1(2) \frac{2,0152^2}{2(32,174)} = 0,1262 \text{ ft.lbf/lbm} \)

1. **Elbow 90°**: \( h_f = n.Kf. \frac{v^2}{2.g_c} = 1(0,8) \frac{2,0152^2}{2(32,174)} = 0,0473 \text{ ft.lbf/lbm} \)

Pipa lurus 20 ft: \( F_t = 4\frac{\Delta L.v^2}{D.2.g_c} = 4(0,0075) \frac{(20)(2,0152)^3}{(0,20575)(2)(32,174)} = 0,18404 \text{ ft.lbf/lbm} \)

1. **Sharp edge exit**: \( h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2\alpha.g_c} = 1(1-0)^2 \frac{2,0152^2}{2(1)(32,174)} = 0,0631 \text{ ft.lbf/lbm} \)

Total friction loss: \( \sum F = 0,4554 \text{ ft.lbf/lbm} \)

Dari persamaan Bernoulli:
\[ \frac{1}{2\alpha} \left( v_2^2 - v_1^2 \right) + g(z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \]  
(Geankoplis, 2003)

dimana: \( v_1 = v_2 \)
\( P_1 = P_2 = 1 \text{ atm} \)
\( \Delta P = 0 \)

tinggi pemompaan \( \Delta Z = 20 \text{ ft} \)

maka:
\[ 0 + \frac{32,174}{32,174} (20) + 0 + 0,4554 + W_s = 0 \]
\[ W_s = -20,4554 \text{ ft.lbf/lbm} \]

Efisiensi pompa, \( \eta = 80 \% \)
\[ W_p = \frac{- W_s}{\eta} \]  
(Geankoplis, 2003)
\[ = - \frac{20,4554}{0,8} \]
\[ = 25,5692 \text{ ft.lbf/lbm.} \]

Daya pompa: \( P = m \times W_p \)
\[ = \frac{4,48466}{(0,45359)(3600)(550 \text{ ft.lbf/s.hp})} \text{ lbm/s} \times 25,5692 \text{ ft.lbf/lbm} \]
\[ = 0,2084 \text{ hp} \]

Maka dipilih pompa dengan daya motor ¼ hp.

**LC.15 Heater CPO (HE – 101)**

Fungsi: Menaikkan temperature CPO sebelum diumpankan ke reaktor (R-101)

Jenis: 1 – 2 shell and tube exchanger

Dipakai: 3/4 in OD tube 18 BWG, panjang = 16 ft, 2pass

- Fluida panas
  - Laju alir fluida panas = 936,4897 kg/jam = 2064,6172 lbm/jam
  - Temperatur awal \( T_1 \) = 150 °C = 302 °F
Temperatur akhir ($T_2$) = 90 °C = 194 °F

- Fluida dingin
  Laju alir fluida dingin = 20428,9158 kg/jam = 45038,2852 lbm/jam
  Temperatur awal ($t_1$) = 30 °C = 86 °F
  Temperatur akhir ($t_2$) = 80 °C = 176 °F

Panas yang diserap ($Q$) = 2245417,314 kJ/jam = 2128236,6066 Btu/jam

(1) $\Delta t = \text{beda suhu sebenarnya}$

<table>
<thead>
<tr>
<th>Fluida Panas</th>
<th>Fluida Dingin</th>
<th>Selisih</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1 = 302$ °F</td>
<td>Temperatur yang lebih tinggi</td>
<td>$t_2 = 176$ °F</td>
</tr>
<tr>
<td>$T_2 = 194$ °F</td>
<td>Temperatur yang lebih rendah</td>
<td>$t_1 = 86$ °F</td>
</tr>
<tr>
<td>$T_1 - T_2 = 108$ °F</td>
<td>Selisih</td>
<td>$t_2 - t_1 = 90$ °F</td>
</tr>
</tbody>
</table>

$$LMTD = \frac{\Delta t_2 - \Delta t_1}{\ln\left(\frac{\Delta t_2}{\Delta t_1}\right)} = \frac{-18}{\ln\left(\frac{108}{126}\right)} = 116,7688 \degree F$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{108}{90} = 1,2$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{90}{302 - 126} = 0,4166$$

Dari Gambar 20, Kern, 1965 diperoleh $F_T = 0,875$
Maka $\Delta t = F_T \times LMTD = 0,875 \times 116,7688 = 102,1727 \degree F$
Dalam perancangan ini digunakan heat exchanger dengan spesifikasi:
- Diameter luar tube (OD) = 0,75 in
- Jenis tube = 18 BWG
- Pitch (PT) = 1 in square pitch
- Panjang tube (L) = 16 ft

a. Dari Tabel 8, hal. 840, Kern, 1965, heater untuk fluida panas steam dan fluida dingin gases, diperoleh $U_D = 6-60$, dan faktor pengotor $(R_d) = 0,003$. 
Dambil $U_D = 55 \text{ Btu/jam-}^{o}\text{F}$
Luas permukaan untuk perpindahan panas,
$$A = \frac{Q}{U_D \times \Delta t} = \frac{2128236,6066 \text{ Btu/jam}}{55 \frac{\text{Btu}}{\text{jam-}^{o}\text{F}}} \times 102,1727 \ ^{o}\text{F} = 378,7233 \ ft^2$$
Luas permukaan luar ($a''$) = 0,1963 $ft^2/ft$ (Tabel 10, Kern)

Jumlah tube, $N_t = \frac{A}{L \times a'} = \frac{378,7233 \ ft^2}{16ft \times 0,1963 \ ft^2/ft} = 120,5818$ buah

b. Dari Tabel 9, hal 842, Kern, 1965, nilai yang terdekat adalah 124 tube dengan ID shell 15,25 in.

c. Koreksi $U_D$
$$A = L \times N_t \times a' = 16ft \times 124 \times 0,1963 \ ft^2/ft = 389,4592 \ ft^2$$
$$U_D = \frac{Q}{A \times \Delta t} = \frac{2128236,6066 \text{ Btu/jam}}{389,4592 \ ft^2 \times 102,1727 \ ^{o}\text{F}} = 53,4838 \ \frac{\text{Btu}}{\text{jam-}^{o}\text{F}}$$

Fluida dingin : CPO, tube
(3) Flow area tube, \( a_t = 0.334 \text{ in}^2 \) 
\[
a_t = \frac{N_t \times a_t}{144 \times n}
\]
(Per. (7.48), Kern, 1965)
\[
a_t = \frac{124 \times 0.334}{144 \times 2} = 0.1438 \text{ ft}^2
\]

(4) Kecepatan massa:
\[
G_t = \frac{w}{a_t}
\]
(Pers. (7.2), Kern, 1965)
\[
G_t = \frac{45038,2852}{0.1438} = 313188,7712 \text{ lb/m}\text{jam}.\text{ft}^2
\]

(5) Bilangan Reynold:

Pada \( t_c = 131 \text{ ^\circ F} \)
\[
\mu = 19,9413 \text{ cP} = 48,2579 \text{ lb/m}\text{ft}^2\text{.jam}
\]
(Gambar 14, Kern, 1965)
Dari tabel 10, Kern, untuk 0.75 in OD, 18 BWG, diperoleh:
\[
\text{ID} = 0.625 \text{ in} = 0.0543 \text{ ft}
\]
\[
\text{Re}_T = \frac{\text{ID} \times G_t}{\mu}
\]
(Pers. (7.3), Kern, 1965)
\[
\text{Re}_T = \frac{0.0543 \times 313188,7712}{48,2579} = 352,6173
\]

(6) Taksir \( jH \) dari Gambar 24 Kern (1965), diperoleh \( jH = 20 \) pada \( \text{Re}_T 352,6173 \)

(7) Pada \( t_c = 131 \text{ ^\circ F} \)
\[
c = 0.9 \text{ Btu/lb}_m.\text{^\circ F}
\]
(Gambar 2, Kern, 1965)
\[
k = 0.4235 \text{ Btu/jam lb}_m \text{ ft.}^\circ \text{F}
\]
(Tabel 5, Kern, 1965)
\[
\left( \frac{c}{k} \right)^\frac{1}{3} = \left( \frac{0.9 \times 48,2579}{0.4235} \right)^\frac{1}{3} = 4,6807
\]

(8) \[
\frac{h_i}{\phi_t} = jH \times \frac{k}{\text{ID}} \times \left( \frac{c}{k} \right)^\frac{1}{3}
\]
\[
\frac{h_i}{\varphi_t} = 20 \times \frac{0.4235}{0.652} \times 4.6807 = 729.6865
\]

\[
\frac{h_{io}}{\varphi_t} = \frac{h_i}{\varphi_t} \times \frac{ID}{OD}
\]

\[
\frac{h_{io}}{\varphi_t} = 729.6865 \times \frac{0.652}{0.75} = 634.3408
\]

(9) Pada \( t_w = 139.3175 \, ^{0}\text{F} \), maka \( \mu_w = 11.436 \, \text{lb/ft}^2\cdot\text{jam} \)

\[
\varphi_s = \left( \frac{\mu}{\mu_w} \right)^{0.14} = \left( \frac{48.2579}{11.436} \right)^{0.14} = 1.2233 \quad \text{(Kern, 1965)}
\]

\[
h_s = \frac{h_{io}}{\varphi_s} = 634.3408 \times 1.2233 = 775.9952 \, \text{Btu/jam ft}^2 \, ^{0}\text{F}
\]

**Fluida panas : steam, shell**

(3’) Flow area shell

\[
a_s = \frac{D_s \times C \times B}{144 \times P_T} \, \text{ft}^2 \quad \text{(Pers. (7.1), Kern, 1965)}
\]

\( D_s = \text{Diameter dalam shell} = 15.25 \, \text{in} \)

\( B = \text{Baffle spacing} = 5 \, \text{in} \)

\( P_T = \text{Tube pitch} = 1 \, \text{in} \)

\( C' = \text{Clearance} = P_T - OD \\
= 1 - 0.75 = 0.25 \, \text{in} \)

\[
a_s = \frac{15.25 \times 0.25 \times 5}{144 \times 1} = 0.1323 \, \text{ft}^2
\]

(4’) Kecepatan massa

\[
G_s = \frac{w}{a_s} \quad \text{(Pers. (7.2), Kern, 1965)}
\]

\[
G_s = \frac{2064.6172}{0.1323} = 15596.3211 \, \text{lb}_m/\text{jam.} \text{ft}^2
\]

(5’) Bilangan Reynold

Pada \( T_c = 248 \, ^{0}\text{F} \)
μ = 0,19 = 0,4598

Dari Gambar 28, Kern, untuk \( \frac{3}{4} \) in dan 1 \textit{square pitch}, diperoleh \( D_e = 0,95 \) in.

De = 0,95/12 = 0,0791 ft

\[
Re_s = \frac{D_e \times G_s}{\mu} \quad \text{(Pers. (7.3), Kern, 1965)}
\]

\[
Re_s = \frac{0,0791 \times 15596,3211}{0,4598} = 2685,317
\]

(6') Taksir \( J_H \) dari Gambar 28, Kern, diperoleh \( J_H = 95 \) pada \( Re_s = 2685,317 \)

(7') Pada \( T_c = 248 \) °F

\[
c = 1 \text{ Btu/lb}_m \cdot ^\circ F
\]

\[
k = 0,012 \text{ Btu/jam lb}_m \text{ ft.} ^\circ F
\]

\[
\left( \frac{c \cdot \mu}{k} \right) = \left( \frac{1 \times 0,4598}{0,012} \right) = 3,3712
\]

(8') \[
\frac{h_u}{\varphi_s} = J_H \times \frac{k}{D_e} \times \left( \frac{c \cdot \mu}{k} \right) \]

\[
\frac{h_u}{\varphi_s} = 95 \times \frac{0,012}{0,0791} \times 3,3712 = 48,5465
\]

(9') Temperatur dinding pipa

\[
t_w = T_c + \frac{h_0}{\varphi_s} - \frac{h_0}{\varphi_s} \left( T_c - t_c \right)
\]

\[
t_w = 131 + \frac{48,5465}{634,3408 + 48,5465} (248 - 131)
\]

\[
t_w = 139,3175 \text{ °F}
\]

(10') Pada \( t_w = 139,3175 \text{ °F} \), maka \( \mu_w = 0,029 \text{ lb}/\text{ft}^2\cdot\text{jam} \)

\[
\varphi_s = \left( \frac{\mu}{\mu_w} \right)^{0,14} = \left( \frac{0,4598}{0,029} \right)^{0,14} = 1,4721 \quad \text{(Kern, 1965)}
\]
\[
h_o = \frac{h_w \times \varphi_s}{\varphi_s} = 48.5465 \times 1.4721 = 71.4658 \text{ Btu/jam ft}^2 \cdot \circ\text{F}
\]

(11) *Clean Overall Coefficient, U_C*

\[
U_C = \frac{h_w \times h_o}{h_w + h_o} = \frac{775.9952 \times 71.4658}{775.9952 + 71.4658} = 65.4391 \text{ Btu/jam ft}^2 \cdot \circ\text{F}
\]

(Pers. (6.38), Kern, 1965)

(12) Faktor pengotor, R_d

\[
R_d = \frac{U_C - U_D}{U_C \times U_D} = \frac{65.4391 - 53.4838}{65.4391 \times 53.4838} = 0.0034
\]

(Pers. (6.13), Kern, 1965)

R_d hitung ≥ R_d ketentuan (0.003), maka spesifikasi pendingin dapat diterima.

*Pressure drop*

**Fluida dingin: sisi tube**

(1) Untuk \( \text{Re}_t = 352.6173 \)

\[ f = 0.002 \text{ ft}^2/\text{in}^2 \]  
\[ s = 1.13 \]  

(Gambar 29, Kern, 1965)

\[ (2) \quad \Delta P_t = \frac{f \cdot G_t^2 \cdot L \cdot n}{5.22 \times 10^{10} \cdot \text{ID} \cdot s \cdot \varphi_t} \]  
\[ \Delta P_t = \frac{(0.003) \times (352.6173)^2 \times (16) \times (2)}{(5.22 \times 10^{10}) \times (0.0543) \times (1.13) \times (1.2233)} = 1.6861 \text{ psi} \]  

(Pers. (7.53), Kern, 1965)

\[ (3) \quad \text{Dari Gambar 27, Kern, 1965 diperoleh } \frac{V^2}{2g'} = 0.012 \]

\[ \Delta P_r = \frac{4n}{s} \cdot \frac{V^2}{2g'} \]
\[ = \frac{(4)(2)}{1.13} \cdot 0.012 \]
\[ = 0.084 \text{ psi} \]

\[ \Delta P_T = \Delta P_t + \Delta P_r \]
\[ = 1.6861 \text{ psi} + 0.084 \text{ psi} = 1.6861 \text{ psi} \]
\( \Delta P_T \) yang diperbolehkan = 10 psi

**Fluida panas : sisi shell**

(1') Untuk \( \text{Re}_s = 2685,3170 \)

\[
f = 0.025 \text{ ft}^2/\text{in}^2
\]

\( s = 1 \)

(2') \( N + 1 = 12 \times \frac{L}{B} \)

\[
N + 1 = 12 \times \frac{16}{5} = 38.4
\]

(Pers. (7.43), Kern, 1965)

\( D_s = 15.25 \text{ in} / 12 = 1.2708 \text{ ft} \)

(3') \[
\Delta P_s = \frac{f \cdot G_s^2 \cdot D_s \cdot (N + 1)}{5.22 \times 10^{10} \cdot D_e \cdot s \cdot \varphi_s}
\]

\[
\Delta P_s = \frac{0.0018 \times (15596.3211)^2 \times (1.1041) \times (38.4)}{5.22 \times 10^{10} \times (0.079) \times (1) \times (1.2708)} = 0.0030 \text{ psi}
\]

\( \Delta P_s \) yang diperbolehkan = 10 psi

**LC. 16 Heater Air (HE-102)**

Fungsi : Menaikkan temperature air sebelum diumpankan ke reaktor (KH-101)

Jenis : 2 – 4 shell and tube exchanger

Dipakai : 3/4 in OD tube 18 BWG, panjang = 16 ft, 4 pass

- Fluida panas

  Laju alir fluida panas = 1247,7023 kg/jam = 2750,7271 lb\text{m}/jam

  Temperatur awal \( (T_1) \) = 150 °C = 302 °F

  Temperatur akhir \( (T_2) \) = 90 °C = 194 °F

- Fluida dingin

  Laju alir fluida dingin = 14,300 kg/jam = 31526,7995 lb\text{m}/jam

  Temperatur awal \( (t_1) \) = 30 °C = 86 °F
Temperatur akhir \( t_2 \) = 80 °C = 176 °F

Panas yang diserap (Q) = 2991610,417 kJ/jam = 2835488,4245 Btu/jam

(1) \( \Delta t = \) beda suhu sebenarnya

<table>
<thead>
<tr>
<th>Fluida Panas</th>
<th>Fluida Dingin</th>
<th>Selisih</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_1 = 302 °F )</td>
<td>Temperatur yang lebih tinggi</td>
<td>( t_2 = 176 °F )</td>
</tr>
<tr>
<td>( T_2 = 194 °F )</td>
<td>Temperatur yang lebih rendah</td>
<td>( t_1 = 86 °F )</td>
</tr>
<tr>
<td>( T_1 - T_2 = 108 °F )</td>
<td>Selisih</td>
<td>( t_2 - t_1 = 90 °F )</td>
</tr>
</tbody>
</table>

\[
LMTD = \frac{\Delta t_2 - \Delta t_1}{\ln \left( \frac{\Delta t_2}{\Delta t_1} \right)} = \frac{-18}{\ln \left( \frac{108}{126} \right)} = 116,7688 °F
\]

\[
R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{108}{90} = 1,2
\]

\[
S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{90}{302 - 126} = 0,4166
\]

Dari Gambar 20, Kern, 1965 diperoleh \( F_T = 0,975 \)
Maka \( \Delta t = F_T \times LMTD = 0,975 \times 116,7688 = 113,849 °F \)

(2) \( T_c \) dan \( t_c \)

\[
T_c = \frac{T_1 + T_2}{2} = \frac{302 + 94}{2} = 248°F
\]

\[
t_c = \frac{t_1 + t_2}{2} = \frac{86 + 176}{2} = 131°F
\]

Dalam perancangan ini digunakan heat exchanger dengan spesifikasi:
- Diameter luar tube (OD) = 0,75 in
- Jenis tube = 18 BWG
- Pitch ($P_T$) = 1 in *square pitch*
- Panjang tube ($L$) = 16 ft
d. Dari Tabel 8, hal. 840, *Kern, 1965*, heater untuk fluida panas steam dan medium organics, diperoleh $U_D = 50-100$, dan faktor pengotor ($R_d$) = 0.003. 
Dimalbil $U_D = 99$ Btu/jam-ft$^2$-$^\circ$F

Luas permukaan untuk perpindahan panas,
$$A = \frac{Q}{U_D \times \Delta t} = \frac{2835488.4245 \text{ Btu/jam}}{99 \frac{\text{Btu}}{\text{jam} \cdot \text{ft}^2 \cdot ^\circ \text{F}}} \times 113.849 ^\circ \text{F} = 251.5712 \text{ ft}^2$$

Luas permukaan luar ($a''$) = 0.1963 ft$^2$/ft (Tabel 10, *Kern*)

Jumlah tube, $N_t = \frac{A}{L \times a''} = \frac{251.5712 \text{ ft}^2}{16 \text{ ft} \times 0.1963 \text{ ft}^2/\text{ft}} = 80.0978$ buah

f. Koreksi $U_D$
$$A = L \times N_t \times a''$$
$$= 16 \text{ ft} \times 82 \times 0.1963 \text{ ft}^2/\text{ft}$$
$$= 257.5456 \text{ ft}^2$$

$$U_D = \frac{Q}{A \cdot \Delta t} = \frac{2835488.4245 \text{ Btu/jam}}{257.5456 \text{ ft}^2 \times 113.849 ^\circ \text{F}} = 96.7034 \frac{\text{Btu}}{\text{jam} \cdot \text{ft}^2 \cdot ^\circ \text{F}}$$

**Fluida dingin : CPO, tube**

(3) Flow area tube, $a_i = 0.334 \text{ in}^2$ (Tabel 10, *Kern, 1965*)

$$a_i = \frac{N_t \times a'}{144 \times n}$$

(Pers. (7.48), *Kern, 1965*)

$$a_i = \frac{82 \times 0.334}{144 \times 4} = 0.0475 \text{ ft}^2$$

(4) Kecepatan massa:

$$G_i = \frac{w}{a_i}$$

(Pers. (7.2), *Kern, 1965*)

$$G_i = \frac{31526.7995}{0.0475} = 663043,5421 \text{ lb}_w/\text{jam} \cdot \text{ft}^2$$
(5) Bilangan Reynold:

Pada \( t_c = 131 \, ^\circ\text{F} \)

\[ \mu = 0,52 \, \text{cP} = 0,2584 \, \text{lb} / \text{ft}^2 \cdot \text{jam} \]  

(Gambar 14, Kern, 1965)

Dari tabel 10, Kern, untuk 0,75 in OD, 18 BWG, diperoleh:

ID = 0,625 in = 0,0543 ft

\[ \text{ID} \times \frac{G_i}{\mu} = \frac{0,0543 \times 663043,5421}{0,2584} = 28627,913 \]

(6) Taksir jH dari Gambar 24 Kern (1965), diperoleh jH = 100 pada \( \text{Re}_T \) 28627,913

(7) Pada \( t_c = 131 \, ^\circ\text{F} \)

\[ c = 1 \, \text{Btu/lb} \cdot ^\circ\text{F} \]  

(Gambar 2, Kern, 1965)

\[ k = 0,016 \, \text{Btu/jam} \cdot \text{lb} \cdot \text{ft} \cdot ^\circ\text{F} \]  

(Tabel 5, Kern, 1965)

\[ \left( \frac{c \cdot \mu}{k} \right)^{\frac{1}{3}} = \left( \frac{1 \times 0,2584}{0,016} \right)^{\frac{1}{3}} = 4,2844 \]

(8) \[ \frac{h_i}{\varphi_r} = jH \times \frac{k}{ID} \times \left( \frac{c \cdot \mu}{k} \right)^{\frac{1}{3}} \]

\[ \frac{h_i}{\varphi_r} = 100 \times \frac{0,016}{0,652} \times 4,2844 = 126,1691 \]

\[ \frac{h_{io}}{\varphi_r} = \frac{h_i}{\varphi_r} \times \frac{ID}{OD} \]

\[ \frac{h_{io}}{\varphi_r} = 126,1691 \times \frac{0,652}{0,75} = 109,6831 \]

(9) Pada \( t_w = 155,1702 \, ^\circ\text{F} \), maka \( \mu_w = 1,089 \, \text{lb} / \text{ft}^2 \cdot \text{jam} \)

\[ \varphi_r = \left( \frac{\mu}{\mu_w} \right)^{0,14} = \left( \frac{0,2584}{1,089} \right)^{0,14} = 1,0204 \]  

(Kern, 1965)
\[ h_o = \frac{h_{io}}{\varphi_o} \times \varphi_s = 109,6831 \times 1,0204 = 111,9258 \text{ Btu/jam ft}^2 \text{ °F} \]

**Fluida panas : steam, shell**

(3’) Flow area shell

\[ a_s = \frac{D_s \times C \times B}{144 \times P_T} \text{ ft}^2 \]

(Pers. (7.1), Kern, 1965)

D_s = Diameter dalam shell = 13,25 in
B = Baffle spacing = 5 in
P_T = Tube pitch = 1 in
C’ = Clearance = P_T - OD

\[ = 1 - 0,75 = 0,25 \text{ in} \]

\[ a_s = \frac{13,25 \times 0,25 \times 5}{144 \times 1} = 0,115 \text{ ft}^2 \]

(4’) Kecepatan massa

\[ G_s = \frac{w}{a_s} \]

(Pers. (7.2), Kern, 1965)

\[ G_s = \frac{2750,7271}{0,115} = 23915,7555 \text{ lbm/jam ft}^2 \]

(5’) Bilangan Reynold

Pada \( T_c = 248 \text{ °F} \)
\[ \mu = 0,015 = 0,0363 \]

Dari Gambar 28, Kern, untuk \( \frac{3}{4} \) in dan 1 square pitch, diperoleh \( D_e = 0,95 \) in.

\[ \text{De} = 0,95/12 = 0,0791 \text{ ft} \]

\[ \text{Re}_s = \frac{D_e \times G_s}{\mu} \]

(Pers. (7.3), Kern, 1965)

\[ \text{Re}_s = \frac{0,0791 \times 23915,7555}{0,0363} = 52157,869 \]

(6’) Taksir \( J_H \) dari Gambar 28, Kern, diperoleh \( J_H = 170 \) pada \( \text{Re}_s = 52157,869 \)

(7’) Pada \( T_c = 248 \text{ °F} \)
\[ c = 0.45 \text{ Btu/lb} \cdot ^\circ \text{F} \]
\[ k = 0.012 \text{ Btu/jam lb} \cdot \text{ft.} ^\circ \text{F} \]
\[
\left( \frac{c \cdot \mu}{k} \right)^{\frac{2}{3}} = \left( \frac{0.45 \times 0.0363}{0.012} \right)^{\frac{2}{3}} = 1.1082
\]

\[
(8') \quad \frac{h_0}{\varphi_s} = J_H \times k \times \frac{c \cdot \mu}{D_c} \left( \frac{c \cdot \mu}{k} \right)^{\frac{2}{3}}
\]
\[
\frac{h_0}{\varphi_s} = 170 \times \frac{0.012}{0.0791} \times 1.1082 = 28.5583
\]

(9') Temperatur dinding pipa
\[
t_w = t_c + \frac{h_0}{\varphi_s} \left( T_c - t_c \right) \left( \frac{h_0}{\varphi_s} \right) + \frac{h_0}{\varphi_s} T_c - t_c
\]
\[
t_w = 131 + \frac{28.5583}{109.6831 + 28.5583} (248 - 131)
\]
\[
t_w = 155.1702 \text{ } ^\circ \text{F}
\]

(10') Pada \( t_w = 155.1702 \text{ } ^\circ \text{F} \), maka \( \mu_w = 0.029 \text{ lb} / \text{ft}^2 \cdot \text{jam} \)
\[
\varphi_s = \left( \frac{\mu}{\mu_w} \right)^{0.14} = \left( \frac{0.0363}{0.029} \right)^{0.14} = 1.0317 \quad \text{(Kern, 1965)}
\]
\[
h_o = \frac{h_0}{\varphi_s} = 28.5583 \times 1.0317 = 29.4646 \text{ Btu/jam ft}^2 \cdot ^\circ \text{F}
\]

(11) \textit{Clean Overall Coefficient}, \( U_C \)
\[
U_C = \frac{h_m \times h_o}{h_m + h_o} = \frac{111.9258 \times 29.46468}{111.9258 + 29.4646} = 23.3244 \text{ Btu/jam ft}^2 \cdot ^\circ \text{F}
\quad \text{(Pers. (6.38), Kern, 1965)}
\]

(12) Faktor pengotor, \( R_d \)
\[ R_d = \frac{U_c - U_D}{U_c \times U_D} = \frac{96,7034 - 23,3244}{96,7034 \times 23,3244} = 0,032 \quad \text{(Pers. (6.13), Kern, 1965)} \]

\[ R_d \text{ hitung} \geq R_d \text{ ketentuan} \ (0,003) \text{, maka spesifikasi pendingin dapat diterima.} \]

**Pressure drop**

**Fluida dingin : sisi tube**

(1) Untuk \( Re_t = 28627,913 \)

\[ f = 0,00019 \text{ ft}^2/\text{in}^2 \]  

\[ s = 1 \]  

\[ \Delta P_t = \frac{f \cdot G_t^2 \cdot L \cdot n}{5,22 \cdot 10^{10} \cdot \text{ID} \cdot s \cdot \varphi_t} \]  

\[ \Delta P_t = \frac{(0,00019) \times (663043,5)^2 \times (16) \times (4)}{(5,22 \cdot 10^{10}) \times (0,0543) \times (1) \times (1,0204)} = 1,847 \text{ psi} \]

(2) Dari Gambar 27, Kern, 1965 diperoleh \( \frac{V^2}{2g'} = 0,045 \)

\[ \Delta P_r = \frac{4n \cdot V^2}{s \cdot 2g'} \]

\[ = \frac{(4)(4)}{1,13} \cdot 0,045 \]

\[ = 0,72 \text{ psi} \]

\[ \Delta P_T = \Delta P_t + \Delta P_r \]

\[ = 1,847 \text{ psi} + 0,72 \text{ psi} = = 2,56 \text{ psi} \]

\( \Delta P_T \) yang diperbolehkan = 10 psi

**Fluida panas : sisi shell**

(1') Untuk \( Re_s = 52157,869 \)

\[ f = 0,0017 \text{ ft}^2/\text{in}^2 \]  

\[ s = 0,9 \]  

(2') \( N + 1 = 12 \times \frac{L}{B} \)

\[ N + 1 = 12 \times \frac{16}{5} = 38,4 \]  

\[ \quad \text{(Pers. (7.43), Kern, 1965)} \]

Universitas Sumatera Utara
D_s = 13,25 in /12 = 1,1041 ft

\[ \Delta P_s = \frac{f \cdot G_s^2 \cdot D_s \cdot (N+1)}{5,22 \cdot 10^{10} \cdot D_e \cdot s \cdot \varphi_s} \] (Pers. (7.44), Kern, 1965)

\[ \Delta P_s = \frac{0,0017 \times (23915,7555)^2 \times (1,1041) \times (38,4)}{5,22 \times 10^{10} \times (0,079) \times (0,9) \times (1,0317)} = 0,0007 \text{ psi} \]

\[ \Delta P_s \text{ yang diperbolehkan} = 10 \text{ psi} \]

**LC.26 Cooler (HE – 103)**

**Fungsi** : Mendinginkan produk untuk sisimpan dalam tangki penyimpanan  
**Jenis** : *Duble-pipe counterflow exchanger*  
**Dipakai** :  
- 2,067 in ID = 0,1722 ft (*annulus*)  
- 1,65 in OD = 0,1375 ft (*annulus*)  
- 1,38 in ID = 0,115 ft (*inner-pipe*)

- Fluida panas  
  - Laju alir fluida panas = 5869,665 kg/jam = 12940,4639 lb_m/jam  
  - Temperatur awal (T_1) = 110 °C = 248 °F  
  - Temperatur akhir (T_2) = 80 °C = 176 °F

- Fluida dingin  
  - Laju alir fluida dingin = 5869,665 kg/jam = 12940,4639 lb_m/jam  
  - Temperatur awal (t_1) = 30°C = 86 °F  
  - Temperatur akhir (t_2) = 60 °C = 140 °F

Panas yang diserap (Q) = 736760,351 kJ/jam = 698311,3292 Btu/jam

(1) \( \Delta t \) = beda suhu sebenarnya

<table>
<thead>
<tr>
<th>Fluida Panas</th>
<th>Fluida Dingin</th>
<th>Selisih</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_1 = 248 \text{ °F} )</td>
<td>Temperatur yang lebih tinggi ( t_2 = 140 \text{ °F} )</td>
<td>( \Delta t_1 = 108 \text{ °F} )</td>
</tr>
<tr>
<td>( T_2 = 176 \text{ °F} )</td>
<td>Temperatur yang lebih rendah ( t_1 = 86 \text{ °F} )</td>
<td>( \Delta t_2 = 90 \text{ °F} )</td>
</tr>
</tbody>
</table>
\( T_1 - T_2 = 72 \, ^\circ F \)  
\( t_2 - t_1 = 54 \, ^\circ F \)  
\( \Delta t_2 - \Delta t_1 = -18 \, ^\circ F \)

\[ \text{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \left( \frac{\Delta t_2}{\Delta t_1} \right) / \ln \left( \frac{90}{108} \right) } = 98,7266 \, ^\circ F \]

\[ R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{72}{54} = 1,333 \]

\[ S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{54}{248 - 86} = 0,333 \]

Dari Gambar 19, Kern, 1965 diperoleh \( F_T = 0,95 \)
Maka \( \Delta t = F_T \times \text{LMTD} = 0,95 \times 98,7266 = 93,7903 \, ^\circ F \)

(2) \( T_c \) dan \( t_c \)
\[ T_c = \frac{T_1 + T_2}{2} = \frac{248 + 176}{2} = 212 \, ^\circ F \]
\[ t_c = \frac{t_1 + t_2}{2} = \frac{140 + 86}{2} = 113 \, ^\circ F \]

**Fluida panas : liquid, inner-pipe**

(3) Flow area tube, \( a_i \)
\[ \text{ID}_2 = 1,38 \text{ in}^2 \quad = 0,115 \text{ ft} \]  
(Tabel 11, Kern, 1965)
\[ a_i = \frac{\pi (\text{ID}_2^2)}{4} \]  
(Kern, 1965)
\[ a_i = 3,14 \left( \frac{0,115}{4} \right) = 0,0103 \text{ ft}^2 \]

(4) Kecepatan massa:
\[ G_i = \frac{w}{a_i} \]  
(Pers. (7.2), Kern, 1965)
\[ G_i = \frac{12940,4639}{0,0103} = 1246477,681 \text{ lb}_m/\text{jam} \cdot \text{ft}^2 \]
(5) Bilangan Reynold:

Pada $T_c = 212 \, ^\circ F$

$\mu = 0, 24 \, cP = 0,5808 \, lb_m/ft^2\cdot jam$  

(Gambar 14, Kern, 1965)

$Re_t = \frac{ID_2 \times G_t}{\mu}$  

(Pers.(7.3), Kern, 1965)

$Re_t = \frac{0,115^2 \times 1246477,681}{0,5808} = 246806,0147$

Taksir $jH$ dari Gambar 24 Kern (1965), diperoleh $jH = 320$ pada $Re_T = 246806$

(6) Pada $T_c = 212 \, ^\circ F$

$c = 1 \, Btu/lb_m, ^\circ F$  

(Gambar 2, Kern, 1965)

$k = 0,0183 \, Btu/jam lb_m ft. ^\circ F$  

(Tabel 5, Kern, 1965)

$\left(\frac{c \times \mu}{k}\right)^{\frac{1}{2}} = \left(\frac{1 \times 0,5808}{0,0183}\right)^{\frac{1}{2}} = 3,1661$

(7) $h_i = jH \times \frac{k}{ID_2} \times \left(\frac{c \times \mu}{k}\right)^{\frac{1}{2}} \left(\frac{\mu}{\mu_w}\right)$  

(Pers.(6.15a), Kern, 1965)

$h_i = 320 \times \frac{0,0183}{0,115} \times 3,1661.(l) = 161,223$

(8) Koreksi $h_i$ pada permukaan OD

$h_{so} = h_i \left(\frac{ID_2}{OD}\right)$

$h_{so} = 161,223 \times \frac{1,38}{1,65} = 134,841$

Fluida dingin : water, annulus

(3’) Flow area shell

$a_s = \pi \left(\frac{ID_1^2 - OD^2}{4}\right)$
\[ a_s = \frac{3.14(0.17225^2 - 0.1375)}{4} = 0.0084 \text{ ft}^2 \]  
(Kern, 1965)

(4') Kecepatan massa

\[ G_s = \frac{w}{a_s}, \quad (\text{Pers. (7.2), Kern, 1965}) \]

\[ G_s = \frac{12940.4639}{0.0084} = 1531489.64 \text{ lb}_m/\text{jam}.\text{ft}^2 \]

(5') Bilangan Reynold

Pada \( t_c = 113 \degree \text{F} \)

\[ \mu = 0.65 \text{ cP} = 1.573 \text{ lb}_m/\text{ft}^2 \cdot \text{jam} \]  
(Gambar 14, Kern, 1965)

\[ \text{De} = \frac{(ID^2 - OD)}{OD} \quad (\text{Pers. (6.3), Kern, 1965}) \]

\[ = \frac{(0.17225^2 - 0.1375^2)}{0.1375} = 0.0782 \text{ ft} \]

\[ \text{Re}_s = \frac{D_e \times G_s}{\mu} \quad (\text{Pers. (7.3), Kern, 1965}) \]

\[ \text{Re}_s = \frac{0.0782 \times 1531489.64}{1.573} = 76216.458 \]

(6') Taksir \( J_H \) dari Gambar 24, Kern, diperoleh \( J_H = 220 \) pada \( \text{Re}_s = 76216.458 \)

(7') Pada \( t_c = 113 \degree \text{F} \)

\[ c = 1 \text{Btu}/\text{lb}_m.\degree \text{F} \]  
(Gambar 2, Kern 1965)

\[ k = 0.0168 \text{ Btu/jam} \text{ lb}_m \text{ ft.}\degree \text{F} \]  
(Tabel 4, Kern 1965)

\[ \left( \frac{c\mu}{k} \right)^{\frac{1}{2}} = \left( \frac{1 \times 1.573}{0.0168} \right)^{\frac{1}{2}} = 4.5408 \]

\[ h_o = jH \frac{k}{D_e} \left( \frac{c\mu}{k} \right)^{\frac{1}{2}} \left( \frac{\mu}{\mu_w} \right)^{0.14} \quad (\text{Pers. 6.15b, Kern 1965}) \]

\[ h_o = 220 \frac{0.0168}{0.0728} 4.5408.(1) = 214.3918 \]

(8) \textit{Clean Overall Coefficient, U_C}
\[ U_c = \frac{h_w \times h_a}{h_w + h_a} = \frac{134,8414 \times 214,3918}{2134,8414 + 214,3918} = 82,7782 \text{ Btu/jam} \cdot \text{ft}^2 \cdot ^\circ \text{F} \]

(Pers. (6.7), Kern, 1965)

(9) \( \text{Rd (diperbolehkan)} = 0,003 \)

\[
\frac{1}{U_d} = \frac{1}{U_c} + Rd
\]

(Pers. (6.10), Kern, 1965)

\[
\frac{1}{U_d} = \frac{1}{82,7782} + 0,003 = 0,015
\]

\[ U_d = 1/0,015 = 66,3109 \text{ Btu/(jam)(ft}^2)(^\circ \text{F}) \]

(10)

\[
A = \frac{Q}{U_d(\Delta t)}
\]

\[ A = \frac{698311,329}{66,3109 \cdot (98,7266)} = 106,6668 \text{ ft}^2 \]

Pipa Standart = 0,435 ft²

Panjang pipa yang diperbolehkan

\[ 106,6668 \div 0,435 = 245,211 \text{lin ft} \]

\[ \text{Hairpins} = \frac{245,211}{40} = 6,1302 = 7 \text{ hairpins} \]

Dipilih panjang hairpins = 36 ft

Surface supplied = (36 ft x 7 hairpins) x 0.435 \( \text{ft}^2 \)

= 109,62 \( \text{ft}^2 \)

(11) Koreksi \( U_d = \frac{698311,329}{109,62 \cdot (98,7266)} = 64,5245 \text{ Btu/(jam)(ft}^2)(^\circ \text{F}) \)

Faktor pengotor, \( R_d \)

\[ R_d = \frac{U_c - U_D}{U_c \times U_D} = \frac{82,778 - 64,5245}{82,778 \times 64,5245} = 0,0034 \]

(Pers. (6.13), Kern, 1965)
R_d hitung ≥ R_d ketentuan (0,003), maka spesifikasi pendingin dapat diterima.

**Pressure drop**

**Fluida panas : inner-pipe**

(1) Untuk \( \text{Re}_t = 246806,0147 \)

\[
f = 0,0035 + \frac{0,264}{\text{Re}} \]

\[
f = 0,0035 + \frac{0,264}{246806,0147} = 0,0049
\]

\[
s = 1, \ p = 1 (62,5)
\]

\[
s = 62,5
\]

\[
(\text{Tabel 6, Kern, 1965})
\]

\[
\Delta F_t = \frac{4f \cdot G^2 \cdot L}{2g \ \rho^2 \ D}
\]

\[
\Delta F_t = \frac{4(0,0049) \cdot 1246477,68)^2 \cdot 36}{2(4,18)(10^3)(62,5)^2(0,0049)} = 2,939
\]

(2) \( \Delta P_t = \left( \frac{2,939(62,5)}{144} \right) = 1,276 \text{ psi} \)

\( \Delta P_t \) yang diperbolehkan = 10 psi

**Fluida dingin : annulus**

(1') \( D_e = (\text{ID}_1 - \text{OD}) \)

\( D_e = (0,17225 - 0,1375) = 0,03475 \text{ ft} \)

\[
\text{Re}_e = \frac{D_e (G_e)}{\mu}
\]

\[
\text{Re}_e = \frac{0,03475(1531489,64)}{1,573} = 33832,972
\]
$f = 0.0035 + \frac{0.264}{\text{Re}_e} = 0.0068$  \hspace{1cm} (Pers. 3.47b, Kern 1965)

$s = 1, \quad p = 62.5 \times 1 = 62.5$  \hspace{1cm} (Tabel 6, Kern, 1965)

$\Delta F_s = \frac{4f \cdot G^2 \cdot L}{2g \cdot p^2 \cdot D_e}$

$\Delta F_s = \frac{4 \cdot (0.0068) \cdot 1531489.64^2 \cdot (36)}{2 \cdot (4.18) \cdot (10^8) \cdot (62.5^2) \cdot (0.03475)} = 20.255$

$V = \frac{G}{3600p}$

(3')

$V = \frac{1531489.64}{3600 \cdot (62.5)} = 6.806$

$F_i = 3 \cdot \frac{V^2}{2g^2}$

$F_i = 3 \cdot \frac{6.806^2}{2 \cdot (32,2)} = 2.158$

$\Delta p_s = \frac{(\Delta F + F_i \cdot s)}{144}$

$\Delta p_s = \frac{(20.255 + 2.158) \cdot (62.5)}{144} = 9.728 \text{ psi}$

$\Delta P_s$ yang diperbolehkan = 10 psi

**I.C. 18 Kolom Hidrolisa (KH-101)**

Fungsi : Tempat mereaksikan CPO dengan Air

Jenis : Silinder vertikal dengan alas *ellipsoidal* dan tutup datar

Bahan konstruksi : *Carbon Steel SA –285*  \hspace{1cm} (*Brownell, 1959*)

Jumlah : 1 unit

Kondisi operasi : -Temperatur = 255°C

- Tekanan = 53,3 atm

**Perhitungan:**

a. Volume

Waktu Tinggal = 2 jam  \hspace{1cm} (*Ecogreen*)
Laju alir air masuk  = 44293,8630 kg/jam  

Densitas Air (ρ)  = 0,3228 x 995,647 kg/m$^3$  

1999) 

= 321,4438 kg/m$^3$

Densitas CPO (ρ)  = 0,4612 x 895 kg/m$^3$  

1999) 

= 412,7858 kg/m$^3$

Densitas Steam (ρ)  = 0,2159 x 30,8642 kg/m$^3$  

1999) 

= 6,6647 kg/m$^3$

Densitas Campuran  = (321,4438  + 412,7858 + 6,6647) kg/m$^3$ 

= 740,8944 kg/m$^3$

Volume Total  = $\rho = \frac{44293,8630}{740,8944}$ m$^3$/jam 

= 59,7843 m$^3$/jam 

Volume Selama 2 jam  = 59,7843 m$^3$/jam x 2 jam 

= 119,5686 m$^3$

Faktor kelonggaran (fk)  = 20 %  

(Brownell & Young, 1959)

Volume tangki, V_T  = (1 + 0,2) x 119,5686 m$^3$ 

= 143,4823 m$^3$

b. Diameter dan Tinggi Shell 

Volume silinder tangki (Vs)  

$V_s = \frac{\pi x D_t^2 x H_s}{4}$  

(Brownell & Young, 1959)

Dimana :  

$V_s$  = Volume silinder (m$^3$)  

$D_t$  = Diameter tangki (m) 

$H_s$  = Tinggi tangki silinder (m) 

Direncanakan perbandingan tinggi tangki dengan diameter tangki
Hs : Dt = 3 : 2, Maka:

\[ V_s = \frac{1}{4} \pi D_t^2 H_s \]  
\[ (\text{Hs : Dt} = 3 : 2) \]

\[ V_s = \frac{3}{8} \pi D_t^3 = 1,1775 D_t^3 \]

Volume tutup tangki *ellipsoidal* (*Vh*)

\[ V_h = \frac{1}{24} \pi D_t^3 = 0,1308 D_t^3 \]  
\[ (Brownell \ & \ Young, 1959) \]

Volume tangki (*Vt*)

\[ V_t = V_s \]
\[ 143,4823 \ m^3 = 1,1775 \ D_t^3 \]
\[ D_t = 4,9576 \ m = 195,1841 \ \text{in} \]
\[ r = \frac{1}{2} \times D_t = \frac{1}{2} \times (4,9576) = 2,4788 \ m = 97,592 \ \text{in} \]

Tinggi silinder (*Hs*):

\[ H_s = \frac{3}{2} \times D_t = \frac{3}{2} \times 4,9576 \ m = 7,436 \ m = 292,7762 \ \text{in} \]

Tinggi cairan dalam tangki (*Hc*)

\[ \text{Volume tangki (Vt)} = 143,4823 \ m^3 \]
\[ \text{Volume cairan (Vc)} = 119,5686 \ m^3 \]
\[ \text{Tinggi silinder (Hs)} = 7,436 \ m \]

\[ \text{Tinggi cairan dalam tangki (Hc)} = \frac{\text{Volume cairan x tinggi silinder}}{\text{volume tan gki}} \]
\[ = \frac{119,5686 \times 7,436}{143,4823} = 6,19711 \ m = 243,9802 \ \text{in} \].

c. Diameter dan tinggi tutup

Diameter tutup = diameter tangki = 4,9576 m

\[ \text{Tinggi tutup (Hd)} = \frac{1}{4} D = 1,2394 \ m \]

Tinggi tangki

\[ = H_s + H_d = (7,436 + 1,2394) \ m = 8,6759 \ m \]
d. Tebal shell tangki

Direncanakan menggunakan bahan konstruksi Carbon Steel SA –285 Grade C
diperoleh data:

- Allowable stress (S) = 13750 psia

(Brownell, 1959)

- Joint efficiency (E) = 0,85
- Corrosion allowance (C) = 0,06 in/tahun

(Brownell, 1959)

- Umur tangki (n) = 10 tahun

Tekanan Hidrostatik:

 Tekanan Hidrostatik:

\[ P_{\text{Hidrostatik}} = \rho \times g \times l \]

\[ = 740,8944 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 6,1971 \text{ m} = 0,444 \text{ atm} \]

Tekanan operasi (\(P_o\)) = 53,3 atm + 0,444 atm

\[ = 53,744 \text{ atm} \]

\[ P_{\text{design}} = (1,2) \times (53,744) = 64,4928 \text{ atm} \]

Tebal shell tangki:

\[ t = \frac{PR}{SE - 0,6P} \]  

(Walas dkk, 2005)

Dimana:

P = tekanan desain (psig)
R = jari-jari dalam tangki (in)
S = allowable stress (psia)
E = joint efficiency

\[ t = \frac{PR}{SE - 0,6P} \]

\[ = \left( \frac{(947,781)(97,592/2 \text{ in})}{(13750 \text{ psia})(0,8) - 0,6(947,781 \text{ psi})} \right) \]

\[ = 4,4335 \text{ in} \]

Tebal shell standar yang digunakan = 5 in  

(Brownell & Young, 1959)
LC. 19 Flash Tank Asam Lemak (FT-101)

Fungsi: Mengurangi kadar air pada produk asam lemak yang keluar dari kolom hidrolisa

Jenis: silinder horizontal dengan alas dan tutup ellipsoidal

Bahan konstruksi: Carbon Steel SA –285 (Brownell, 1959)

Jumlah: 1 unit

Perhitungan:

a. Volume

Laju alir masuk = 21615,3630 kg/jam (Lampiran A)

Densitas Air ($\rho$) = 0,1044 x 995,647 kg/m$^3$ (Perry, 1999)

= 103,9879 kg/m$^3$

Densitas CPO ($\rho$) = 0,00189 x 847,7 kg/m$^3$ (Perry, 1999)

= 1,6920 kg/m$^3$

Densitas Asam Lemak ($\rho$) = 0,893 x 881,5 kg/m$^3$ (Perry, 1999)

= 787,7673 kg/m$^3$

Densitas Campuran = (103,9879 + 1,69204 + 787,7673) kg/m$^3$

= 893,4473 kg/m$^3$

a. Volume Tangki

Suhu masuk pada Flash Tank Fatty Acid = 255 $^0$C = 528,15 K

Volume cairan = \[ \sum \frac{F_{air}}{\rho_{air}} = \frac{21615,36307}{893,4473} = 24,19321 \ m^3 \]

dengan faktor kelonggaran 20%, maka :

Volume tangki, $V_1$ = (1 + 0,2) x 24,1932 m$^3$ = 29,0318 m$^3$

b. Diameter dan Tinggi Shell
➢ Tinggi silinder \( (H_s) \) : Diameter \( (D) \) = 4 : 3
➢ Tinggi tutup \( (H_d) \) : Diameter \( (D) \) = 1 : 4

- Volume shell tangki \( (V_s) \):
  \[
  V_s = \pi R^2 H_s = \frac{\pi}{4} D^2 \left( \frac{4}{3} D \right) \\
  V_s = \frac{\pi}{3} D^3
  \]

- Volume tutup tangki \( (V_h) \):
  \[
  V_h = \frac{2\pi}{3} R^2 H_d = \frac{\pi}{6} D^2 \left( \frac{1}{4} D \right) = \frac{\pi}{24} D^3 \\
  (Brownell, 1959)
  \]

- Volume tangki \( (V) \):
  \[
  V_t = V_s + V_h \\
  = \frac{3}{8} \pi D^3 \\
  29,0318 \ m^3 = 1,1775 \ D^3 \\
  D^3 = 24,6554 \ m^3 \\
  D = 2,9105 \ m \\
  D = 114,5873 \ in \\
  H_s = \frac{4}{3} D = 3,8806 \ m
  \]

c. Diameter dan tinggi tutup
Diameter tutup = diameter tangki = 2,9105 m
Tinggi tutup \( (H_d) \) = \( \frac{1}{4} D = 0,7276 \ m \\
Tinggi tangki = H_s + H_d = (3,88068 + 0,7276) m = 4,6083 m

d. Tebal shell tangki
Direncanakan tangki menggunakan bahan konstruksi Carbon Steel SA-285 Grade C, sehingga diperoleh data:
- Allowable stress \( (S) \) = 13.700 Psia = 94.458,1709 kPa
- Joint efficiency \( (E) \) = 0,85
- Corrosion allowance \( (C) \) = 0,125 in/tahun
- Umur tangki \( (n) \) = 10 tahun

(Wallace, 1990)
Volume cairan = 24,1932 m$^3$
Volume tangki = 29,0318 m$^3$
Tinggi shell = 3,880 m

Tinggi cairan dalam tangki ($l$) = \( \frac{24,1932 \text{ m}^3}{29,0318 \text{ m}^3} \times 3,880 \text{ m} = 3,2339 \text{ m} \)

P Hidrostatik = 893,4473 x 9.8 x 3,2339
= 0,2794 atm
P = 0,2794 atm + 0,66 atm = 0,9394
P desain = 1,2 x 0,9394 = 1,1273 atm = 114,2279 kPa

Tebal shell tangki:
\[
t = \frac{PD}{2SE - 1,2P} + nC
\]
\[
= \left( \frac{(114,2279 \text{ kPa})(114,58734 \text{ in})}{2(94.458,1709 \text{ kPa})(0,85) - 1,2(114,2279 \text{ kPa})} \right) + (10 x 0,125 \text{ in})
\]
\[= 1,8186 \text{ in}\]

Tebal shell standar yang digunakan = 2 in \((Brownell,1959)\)

e. Tebal tutup tangki

Tutup atas tangki terbuat dari bahan yang sama dengan shell.

Tebal tutup atas yang digunakan = 2 in

LC. 20 Flash Tank Gliserol (FT-102)

Fungsi : Mengurangi kadar air pada produk Gliserol yang keluar dari kolom hidrolisa

Jenis : silinder horizontal dengan alas dan tutup ellipsoidal

Bahan konstruksi : Carbon Steel SA –285 \((Brownell, 1959)\)

Jumlah : 1 unit

Perhitungan:
a. Volume

Laju alir masuk = 22678,5 kg/jam \((Lampiran A)\)

Densitas Air ($\rho$) = 0,8959 x 995,647 kg/m$^3$ \((Perry, 1999)\)

= 892,0178 kg/m$^3$
Densitas CPO (\(\rho\)) = 0.0072 \times 895 \text{ kg/m}^3 \quad \text{(Perry, 1999)}
= 6.4508 \text{ kg/m}^3

Densitas gliserol (\(\rho\)) = 0.0968 \times 1253.63 \text{ kg/m}^3 \quad \text{(Perry, 1999)}
= 121.4448 \text{ kg/m}^3

Densitas Campuran = (892.0178 + 6.4508 + 121.4448) \text{ kg/m}^3
= 1019.9135 \text{ kg/m}^3

b. Volume Tangki

Suhu masuk pada Flash Tank Gliserol = 255 \text{ ^\circ C} = 528.15 \text{ K}

Volume cairan = \sum \frac{F_{air}}{\rho_{cair}} = \frac{22678.5}{1019.9135} = 22.2357 \text{ m}^3

dengan faktor kelonggaran 20\%, maka :

Volume tangki, \(V_t\) = \(1 + 0.2\) \times 22.2357 \text{ m}^3 = 26.6828 \text{ m}^3

c. Diameter dan Tinggi Shell

- Tinggi silinder (\(H_s\)) : Diameter (\(D\)) = 4 : 3
- Tinggi tutup (\(H_d\)) : Diameter (\(D\)) = 1 : 4

- Volume shell tangki (\(V_s\)) :

\[
V_s = \pi R^2 H_s = \frac{\pi}{4} D^2 \left(\frac{4}{3} D\right)
\]

\[
V_s = \frac{\pi}{3} D^3
\]

- Volume tutup tangki (\(V_h\)) :

\[
V_h = \frac{2\pi}{3} R^2 H_d = \frac{\pi}{6} D^2 \left(\frac{1}{4} D\right) = \frac{\pi}{24} D^3
\]

\[
(Brownell, 1959)
\]

- Volume tangki (\(V\)) :

\[
V_t = V_s + V_h
\]

\[
= \frac{3}{8}\pi D^3
\]

\[
26.6828 \text{ m}^3 = 1.1775 \text{ } D^3
\]

\[
D^3 = 22.6605 \text{ m}^3
\]

\[
D = 2.8298 \text{ m}
\]

\[
D = 111.4095 \text{ in}
\]
\[ H_s = \frac{4}{3} D = 3.773 \text{ m} \]

d. Diameter dan tinggi tutup

Diameter tutup = diameter tangki = 2,8298 m

Tinggi tutup (H_d) = \( \frac{1}{4} D = 0.7074 \text{ m} \)

Tinggi tangki = H_s + H_d = (3.773 + 0.7074) m = 4.4803 m

e. Tebal shell tangki

Direncanakan tangki menggunakan bahan konstruksi Carbon Steel SA-285 Grade C, sehingga diperoleh data :

- Allowable stress (S) = 13.700 Psia = 94.458,1709 kPa
- Joint efficiency (E) = 0.85
- Corrosion allowance (C) = 0,125 in/tahun
- Umur tangki (n) = 10 tahun (Wallace, 1990)

Volume cairan = 22,2357 m³

Volume tangki = 26,6828 m³

Tinggi shell = 3,773 m

Tinggi cairan dalam tangki \( l = \frac{22,2357 \text{ m}^3}{26,6828 \text{ m}^3} \times 3,773 \text{ m} = 3,1442 \text{ m} \)

\( P \) Hidrostatik = 1019,9135 x 9.8 x 3,1442

= 0.3101 atm

\( P \) = 0,3101 atm + 0,66 atm = 0,9701

\( P \) desain = 1,2 x 0,9701 = 1,1641 atm = 117,9524 kPa

Tebal shell tangki:

\[
t = \frac{PD}{2SE - 1,2P} + nC
= \left( \frac{(117,9524 \text{ kPa}) (111,4095 \text{ in})}{2(94.458,1709 \text{ kPa})(0.85) - 1,2(117,9524 \text{ kPa})} \right) + (10 \times 0.125 \text{ in})
= 1.8235 \text{ in}
\]

Tebal shell standar yang digunakan = 2 in (Brownell, 1959)
f. Tebal tutup tangki
Tutup atas tangki terbuat dari bahan yang sama dengan shell,
Tebal tutup atas yang digunakan = 2 in

LC. 21 Tangki Evaporator I (EV-101)
Fungsi : untuk mengurangi kadar air (H2O)
Jumlah : 1 Buah
Spesifikasi :
1. Tipe : Silinder tegak dengan tutup dan alas berbentuk ellipsoidal.
2. Bahan Konstruksi : stainless steel 316
3. Volume :

Tabel LC-1. Komponen Bahan Yang Terdapat pada Evaporator I

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Laju Massa (kg/ jam)</th>
<th>% Berat</th>
<th>Densitas (kg/m³)</th>
<th>Viskositas cP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gliserol</td>
<td>2196,9697</td>
<td>0,8809</td>
<td>1253,63</td>
<td>14,60</td>
</tr>
<tr>
<td>Air</td>
<td>16254,4570</td>
<td>0,1190</td>
<td>995,647</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>18451,4267</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

ρcampuran = 1026,3644 kg/m³ = 64,0738 lb/m³

Penguapan dalam heat exchanger dilakukan selama 15 menit, maka:
t = 15 menit = 0,25 jam
Faktor keamanan, fk = 20% = 0,2

Volume bahan masuk,

\[
V_c = \frac{18451,4267 \times 0,25 \text{ jam}}{1026,3644 \text{ kg/m}^3} = 4,4943 \text{ m}^3
\]

Kapasitas volume tangki,

\[
V_t = V_c (1,2 + fk) = 4,4943 (1 + 0,2 ) = 5,3931 \text{ m}^3
\]

Diameter :
Evaporator didesain berbentuk silinder tegak dengan alas dan tutup berbentuk ellipsoidal. Direncanakan perbandingan antara tinggi heat exchanger dan tinggi *head* dengan diameter heat exchanger:

$$\frac{Hs}{D} = \frac{3}{2}, \quad \frac{Hh}{D} = \frac{1}{4}$$

Volume silinder,

$$V_s = 1,1775 \ D^3$$  
(Perhitungan sebelumnya)

Volume tutup tangki:

$$V_h = 0,1309 \ D^3$$  
(Perhitungan sebelumnya)

Volume tangki  

$$= V_s + 2 \times V_h$$

$$= 1,1775 \ D^3 + 2 \times 0,1309 \ D^3$$

$$= 1,4393 \ D^3$$

$$D^3 = 3,747 \ m^3$$

$$D = 1,5532 \ m = 61,1502 \ in$$

Tinggi:

Tinggi tangki:

$$H_s = \frac{3}{2} \times D = \frac{3}{2} \times 1,5532 = 2,3298 \ m$$

Tinggi alas dan tutup:

$$H_h = 2 \times (\frac{1}{4} \times D) = 2 \times (\frac{1}{4} \times 1,5532) = 0,7766 \ m$$

Tinggi total tangki

$$= H_s + H_h$$

$$= 2,3298 \ m + 0,7766 \ m = 3,1064 \ m$$

Tinggi cairan dalam tangki,

$$H_c = \frac{4xVc}{\pi D^2} = \frac{4x4,4943}{3,14x1,5532^2} = 2,3731 \ m = 93,4326 \ in$$

Tekanan hidrostatik:

$$P = \rho \ g \ h$$

$$= 1026,3644 \ kg/m^3 \times 9,8 \ m/s^2 \times 2,3731 \ m$$

$$= 23870,4639 \ N/m^2 = 3,4621 \ psi$$
Faktor kelonggaran = 20%

\[ P_{\text{operasi}} = Po + P_{\text{hidrostatik}} \]

Dimana, \( Po = 1 \text{ atm} = 14,696 \text{ psi} \)
\[ P_{\text{operasi}} = 14,696 \text{ psi} + 3,4621 \text{ psia} = 18,1581 \text{ psia} \]
\[ P_{\text{design}} = 1,2 \times P_{\text{operasi}} = 1,2 \times 18,1581 \text{ psia} = 21,7897 \text{ psia} \]

**Tebal Dinding:**

Bahan konstruksi tangki *stainless steel 316*

Maksimum *allowed stress*, \( f = 12.650 \text{ psi} \) (Brownell, 1959)

Effisiensi sambungan, \( E = 0,85 \) (Brownell, 1959)

Faktor korosi, \( C = 0,0125 \text{ in/tahun} \)

Umur alat, \( n = 10 \text{ tahun} \)

Tebal plat minimum :

\[
t = \frac{PxD}{12,650 \times 0,85 - 0,6 \times P} + (Cxn)
\]

\[
t = \frac{21,78971 \times 61,1502}{12,650 \times 0,85 - 0,6 \times 21,7897} + (0,0125 \times 10)
\]

\[ = 0,249 \text{ in} \]

(dipilih tebal dinding standar 0, 25 inch)

**Tube,**

Direncanakan pipa yang dipakai sebagai aliran *steam* adalah pipa dengan ukuran nominal 1¼ in *schedule 40* dengan ketentuan sebagai berikut (Kern, 1965):

- OD = 1,65 in = 0,1375 ft
- ID = 1,380 in = 0,115 ft
- Luas permukaan (A) = 0,435 ft²/ft

Luas permukaan perpindahan panas,

\[ A = \frac{dQ}{U \cdot x \Delta T} \]

Dimana:
dQ = panas yang yang dibawa oleh air pendingin, BTU/jam
 = 583625,0008 kkal/jam = 2315450,7225 BTU/jam

\[ \Delta T = \text{perbedaan temperatur fluida masuk dan keluar} \]

\[ = T_1 = 194^0 \text{F}, T_2 = 212^0 \text{F}, \Delta T = 18^0 \text{F} \]

\[ U_D = \text{koefisien perpindahan panas, BTU/jam.}^{0'} \text{F.}. \text{ft}^2 \]

Besar \( U_D \) berada antara 0 – 50 BTU/jam.\(^{0'}\text{F.}.\text{ft}^2 \) \( \text{(Perry, 1997)} \)

\( U_D \) yang diambil adalah 50 BTU/jam.\(^{0'}\text{F.}.\text{ft}^2 \)

Sehingga,

\[ A = \frac{2315450,7225}{50 \times 18} = 2572,723 \text{ ft}^2 \]

\[ L = \frac{A_{tot}}{A_{ft}} = \frac{2572,723}{0,435} = 5914,3058 \text{ ft} \]

Diasumsikan \( \frac{D_c}{D_t} = 0,7 \), maka

\[ D_c = 0,7 \times 3,4109 \text{ ft} = 2,3876 \text{ ft} \]

Panjang 1 lilitan \( = \pi \times D_c \)

\( = 3,14 \times 2,3876 \text{ ft} = 7,4971 \text{ ft} \)

Jumlah lilitan pipa \( = \frac{5914,3058}{7,4971} = 788,88 \) lilitan

Maka jumlah lilitan pipa yang dipakai adalah sebanyak 789 lilitan.

**LC. 22 Tangki Evaporator II (EV-102)**

Fungsi : untuk mengurangi kadar air (H\(_2\)O)

Jumlah : 1 Buah

Spesifikasi :

1. Tipe : Silinder tegak dengan tutup dan alas berbentuk ellipsoidal.

2. Bahan Konstruksi : stainless steel 316
3. Volume

Tabel LC-2. Komponen Bahan Yang Terdapat pada Evaporator II

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Laju Massa (kg/jam)</th>
<th>% Berat</th>
<th>Densitas (kg/m³)</th>
<th>Viskositas cP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gliserol</td>
<td>2196,9697</td>
<td>0,25</td>
<td>1253,63</td>
<td>14,60</td>
</tr>
<tr>
<td>air</td>
<td>6590,9091</td>
<td>0,75</td>
<td>995,647</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>8787,8788</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

ρ<sub>campuran</sub> = 1060,14275 kg/m³ = 66,1825 lb<sub>m</sub>/ft³

Penguapan dalam heat exchanger dilakukan selama 15 menit, maka:

- t = 15 menit = 0,25 jam
- Faktor keamanan, fk = 20% = 0,2

Volume bahan masuk, $V_c = \frac{8787,8788 \text{ kg}}{1060,14275 \text{ kg/m}^3} \times 0,25 \text{ jam} = 2,0723 \text{ m}^3$

Kapasitas volume tangki,

$V_t = V_c (1,2 + fk) = 2,0723 (1 + 0,2) = 2,4868 \text{ m}^3$

Diameter :

Evaporator didesain berbentuk silinder tegak dengan alas dan tutup berbentuk ellipsoidal. Direncanakan perbandingan antara tinggi heat exchanger dan tinggi head dengan diameter heat exchanger :

$$\frac{H_s}{D} = \frac{3}{2}, \quad \frac{H_h}{D} = \frac{1}{4}$$

Volume silinder,

$V_s = 1,1775 \text{ D}^3$  
(Perhitungan sebelumnya)

Volume tutup tangki :

$V_h = 0,1309 \text{ D}^3$  
(Perhitungan sebelumnya)

Volume tangki = $V_s + 2xV_h$

2,4868 m³ = 1,1775 D³ + 2x0,1309 D³
2,4868 m³ = 1,4393 D³
D³ = 1,7277 m³
D = 1,1999 m = 47,242 in

Tinggi:
Tinggi tangki,
\[ H_s \text{ } = \frac{3}{2} \times D = \frac{3}{2} \times 1,1999 = 1,7999 \text{ m} \]
Tinggi alas dan tutup,
\[ H_h = 2 \times \left( \frac{1}{4} x D \right) = 2 \times \left( \frac{1}{4} \times 1,1999 \right) = 0,5999 \text{ m} \]
Tinggi total tangki = Hs + Hh
\[ = 1,7999 \text{ m} + 0,5999 \text{ m} = 2,3999 \text{ m} \]

Tinggi cairan dalam tangki,
\[ H_c = \frac{4 \times V_c}{\pi D^2} = \frac{4 \times 2,0723}{3,14 \times 1,1999^2} = 1,8334 \text{ m} = 72,182 \text{ in} \]

Tekanan hidrostatik :
\[ P = \rho \ g \ h \]
\[ = 1060,14275 \text{ kg/m}^3 \times 9,8 \text{ m/s}^2 \times 72,182 \text{ m} \]
\[ = 19048,2051 \text{ N/m}^2 = 2,7627 \text{ psi} \]
Faktor kelonggaran = 20%

\[ P_{operasi} = P_0 + \ P_{hidrostatik} \]

Dimana, \[ Po = 1 \text{ atm} = 14,696 \text{ psi} \]
\[ P_{operasi} = 14,696 \text{ psi} + 2,7627 \text{ psi} = 17,4587 \text{ psi} \]
\[ P_{design} = 1,2 \times P_{operasi} = 1,2 \times 17,4587 \text{ psi} = 20,9504 \text{ psi} \]

Tebal Dinding:
Bahan konstruksi tangki \textit{stainless steel} 316

Maksimum \textit{allowed stress}, \[ f = 12.650 \text{ psi} \] (Brownell,1959)

Effisiensi sambungan, \[ E = 0,85 \] (Brownell,1959)

Faktor korosi, \[ C = 0,0125 \text{ in/tahun} \]

Umur alat, \[ n = 10 \text{ tahun} \]
Tebal plat minimum :

\[ t = \frac{PxD}{12.650 \times 0.85 - 0.6xP} + (Cxn) \]

\[ t = \frac{20.9504 \times 47.24204}{12.650 \times 0.85 - 0.6 \times 20.9504} + (0.0125 \times 10) \]

\[ = 0.21 \text{ in} \]

(dipilih tebal dinding standar 0, 25 inchi)

*Tube*,

Direncanakan pipa yang dipakai sebagai aliran *steam* adalah pipa dengan ukuran nominal 1¼ in *schedule* 40 dengan ketentuan sebagai berikut (Kern, 1965) :

- OD = 1,65 in = 0,1375 ft
- ID = 1,380 in = 0,115 ft
- Luas permukaan (A) = 0,435 ft²/ft

Luas permukaan perpindahan panas,

\[ A = \frac{dQ}{U_D \times \Delta T} \]

Dimana :

- \( dQ \) = panas yang dibawa oleh air pendingin, BTU/jam
  
  = 505361,6142 kkal/jam = 2004951,6609 BTU/jam

- \( \Delta T \) = perbedaan temperatur fluida masuk dan keluar
  
  = \( T_1 = 212 \, ^0\text{F}, T_2 = 221 \, ^0\text{F}, \Delta T = 9 \, ^0\text{F} \)

- \( U_D \) = koefisien perpindahan panas, BTU/jam.\( ^0\text{F}.\text{ft}^2 \)

  Besar \( U_D \) berada antara 0 – 50 BTU/jam.\( ^0\text{F}.\text{ft}^2 \) (Perry, 1997)

  \( U_D \) yang diambil adalah 50 BTU/jam.\( ^0\text{F}.\text{ft}^2 \)

Sehingga,

\[ A = \frac{2004951,6609}{50 \times 9} = 4455,4481 \text{ ft}^2 \]
L = \frac{Atot}{Aft} = \frac{4455.4481}{0.435} = 10242.4095 \text{ ft}

\text{Diasumsikan} \ \frac{Dc}{Dt} = 0.7, \ \text{maka}

Dc = 0.7 \times 3.4109 \text{ ft} = 2.3876 \text{ ft}

\text{Panjang 1 lilitan} = \pi \times Dc

= 3.14 \times 2.3876 \text{ ft} = 7.4971 \text{ ft}

Jumlah lilitan pipa = \frac{10242.4095}{7.4971} = 1366.2 \text{ lilitan}

Maka jumlah lilitan pipa yang dipakai adalah sebanyak 1366 lilitan.

**LC. 23 Skimmer (SK-101)**

Fungsi : Memisahkan gliserol yang bercampur didalam larutan CPO

Bentuk : Horizontal silinder

Bahan : *Carbon steel, SA-285, Gr. C*

Jumlah : 1 Unit

Kondisi operasi

Temperatur : \text{90}^\circ \text{C}

Tekanan : 1 atm = 14,696 psia

Laju alir massa (F) = 18614,8858 kg/jam = 26452,1565 lb\text{/jam}

**Tabel LC.3 Komposisi Umpan Masuk Skimmer**

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Lj Massa (kg/jam)</th>
<th>% Berat</th>
<th>$\rho$ (kg/m$^3$)</th>
<th>$\mu$ (cP)</th>
<th>Lj Massa Fasa atas (kg/jam)</th>
<th>Lj Massa Fasa bawah (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gliserol</td>
<td>2196,9697</td>
<td>0,118022</td>
<td>1253,63</td>
<td>21,2</td>
<td>-</td>
<td>2196,9697</td>
</tr>
<tr>
<td>CPO</td>
<td>163,4591</td>
<td>0,008781</td>
<td>895</td>
<td>19,94</td>
<td>163,4591</td>
<td>-</td>
</tr>
<tr>
<td>Air</td>
<td>16254,4570</td>
<td>0,873197</td>
<td>995,647</td>
<td>1</td>
<td>-</td>
<td>16254,4570</td>
</tr>
<tr>
<td>$\Sigma$</td>
<td>18614,8858</td>
<td>1,0000</td>
<td>-</td>
<td>-</td>
<td>163,4591</td>
<td>18451,4267</td>
</tr>
</tbody>
</table>
\[ \rho_{\text{camp}} = \sum (\% \text{ Berat} \times \rho_i) = 1025.2109 \text{ kg/m}^3 = 64.0016 \text{ lb}_n/\text{ft}^3 \]

**Lapisan Bawah (A)**

Terdiri dari Gliserol dan Air

Laju massa A = 18451,4267 kg/jam

Densitas lapisan bawah (*heavy*)

\[ \rho_{\text{campuran}} = 1026.3644 \text{ kg/m}^3 = 64.0736 \text{ lb}_n/\text{ft}^3 \]

**Lapisan Atas (B)**

Terdiri dari metil CPO

Laju massa B = 163,4591 kg/jam

Densitas lapisan atas (*light*):

\[ \rho_{\text{campuran}} = 895 \text{ kg/m}^3 = 55.8728 \text{ lb}_n/\text{ft}^3 \]

cara menghitung \( \mu_{\text{campuran}} \):

\[
\ln \mu_{\text{campuran}} = \sum (\% \text{ berat} \times \ln \mu) \\
\mu_{\text{campuran}} = e^{\ln \mu_{\text{campuran}}} \\
\mu_{\text{campuran}} = 3.5503 \text{ cP}
\]

Perhitungan waktu pemisahan:

\[ t = \frac{6.24 \mu}{\rho_A - \rho_B} \]

dimana:

\[ t \quad = \quad \text{waktu paruh (jam)} \]
\[ \rho_A, \rho_B \quad = \quad \text{densitas zat cair A dan B (lb}_n/\text{ft}^3) \]
\[ \mu \quad = \quad \text{viskositas fasa kontinu (cP)} \]

Maka:

\[ t = \frac{6.24 \times 3.5503}{(64.0736 - 55.8728)} = 2.7014 \text{ jam} \]

**Desain Tangki Skimmer**

a. Volume tangki
Volume larutan, \[ V_1 = \frac{18614,8858 \frac{kg}{jam} \times 2,7014 \text{ jam}}{1025,2109 \frac{kg}{m^3}} = 49,051 \text{ m}^3 \]

Skimmer 95% penuh, maka volume skimmer yang diperlukan:
\[ V_t = \frac{49,051}{0.95} = 51,6326 \text{ m}^3 \]

b. Diameter dan Tinggi shell

Volume silinder (\( V_s \))
\[ V_s = \frac{1}{4} \pi D^2 H_s \quad \text{dengan asumsi Hs : D = 3 : 2} \]
Maka \( V_s = \frac{3}{8} \pi D^3 = 1,1775 D^3 \)

Volume head skimmer (\( V_h \))
\[ V_h = \frac{\pi}{24} D^3 = 0,131 D^3 \quad \text{(Brownell & Young, 1959)} \]

Volume skimmer (\( V_t \))
\[ V_t = V_s + 2 V_h \]
\[ 77,9425 \text{ m} = 1,1775 D^3 + (2 \times 0,131 D^3) \]
\[ D = 3,345 \text{ m} = 131,6941 \text{ in} \]

Tinggi silinder (\( H_s \))
\[ H_s = \frac{3}{2} x D = \frac{3}{2} \times 3,345 \text{ m} = 5,0175 \text{ m} \]

Tinggi total dekanter (\( H_t \))
\[ H_t = H_s = 5,0175 \text{ m} \]

Tinggi cairan dalam silinder (\( H_{cs} \))
Dari Fig. 18.16, Walas, 1988, di dapat harga H/D = 0.8
\[ Maka: H_{cs} = 0,75 \times D = 0,75 \times 3,345 \text{ m} \]
\[ = 2,5087 \text{ m} = 98,7706 \text{ in} \]

Tinggi tutup
\[ = \frac{1}{4} \times D \]
\[ = 0,8362 \text{ m} \]
Volume cairan penuh (L)

asumsi, \( L : D = 5 : 1 \)

sehingga: \( L = \frac{5}{1} D = 5 \times 3,345 \text{ m} = 16,725 \text{ m} = 658,470.6 \text{ in} \)

Tekanan hidrostatik:

\[
P = \rho \ g \ h
\]

\[
= 1025,2109 \ \text{kg/m}^3 \times 9,8 \ \text{m/s}^2 \times 2,5087 \ \text{m}
\]

\[
= 25205,8644 \ \text{N/m}^2 = 3,6704 \ \text{psia}
\]

Faktor kelonggaran = 20%

\( P_{\text{operasi}} = P_0 + P_{\text{hidrostatik}} \)

Dimana, \( P_0 = 1 \ \text{atm} = 14,696 \ \text{psi} \)

\( P_{\text{operasi}} = 14,696 \ \text{psi} + 3,6704 \ \text{psia} = 18,3665 \ \text{psia} \)

\( P_{\text{design}} = 1,2 \times P_{\text{operasi}} = 1,2 \times 18,3138 \ \text{psia} = 22,0397 \ \text{psia} \)

Digunakan bahan konstruksi Carbon steel, SA-285, Gr C (Tabel 18.5, Walas,1988)

Tekanan izin, \( S = 13.750 \ \text{psi} \)

Ef. Sambungan, \( E_j = 0,85 \)

\[
C = 0,0003 \ \text{in/tahun} \quad \text{(Perry, 1999)}
\]

\[
n = 10 \ \text{tahun}
\]

Izin korosi, \( C_c = 0,0003 \ \text{in/tahun x 10 tahun} = 0,003 \ \text{in} \)

Tebal Cylindrical shell dekanter, (Tabel 18.4, Walas,1988)

\[
ts = \frac{PR}{SE - 0,6 P} + C_c
\]

\[
= \frac{22,0397 \times 65,84707}{13705 \times 0,85 - 0,6 \times 22,0397} + 0,003 \ \text{in} = 0,1243 \ \text{in}
\]

Maka dipilih tebal plat tangki = 1/4 in = 0,25 in

c. Perhitungan lubang keluaran zat cair

Tinggi zat cair, \( Z_T = 2,5087 \ \text{m} \)

Tinggi zat cair berat, \( Z_{AI} = \frac{18451,4267}{18614,8858} \times 2,5087 = 2,4867 \ \text{m} \)

Dari Warren L. McCabe, 1994, hlm. 34
\[ Z_{A1} = \frac{Z_{A2} - Z_T (\rho_B/\rho_A)}{1 - \rho_B/\rho_A} \]

\[ 2.4867 \text{ m} = \frac{Z_{A2} - 2.5087(55,8728/64,0736)}{1 - (55,8728/64,0736)} \]

\[ Z_{A2} = 2.5059 \text{ m} \]
LAMPIRAN D
PERHITUNGAN SPESIFIKASI PERALATAN UTILITAS

LD.1 Screening (SC)
Fungsi : Menyaring partikel-partikel padat yang besar (lebih besar dari 20 mm).
Jenis : Bar screen
Jumlah : 1 unit
Bahan konstruksi : Stainless steel

Kondisi operasi :
Temperatur = 30°C
Densitas air ($\rho$) = 995,68 kg/m$^3$ (Geankoplis, 2003)
Laju alir massa (F) = 12680,9685 kg/jam

Laju alir volumetrik (Q) = \(\frac{12680,9685 \text{ kg/jam}}{995,68 \text{ kg/m}^3 \times 3600 \text{ s/jam}} = 0,0035 \text{ m}^3/\text{s}\)

Dari Tabel 5.1 Physical Chemical Treatment of Water and Wastewater.
Ukuran bar :
lebar bar = 5 mm ; tebal bar = 20 mm ; bar clear spacing = 20 mm ; slope = 30°

Direncanakan ukuran screening:
Panjang screen = 1 m ; Lebar screen = 1 m

Gambar LD-1 Sketsa Sebagian Bar Screen (dilihat dari atas)
Misalkan, jumlah bar = x
Maka, \[20x + 20(x + 1) = 1000\]
\[40x = 980\]
\[x = 24.975 \approx 25\] buah

Luas bukaan \((A_2) = 20(25 + 1) (1000) = 519500\) mm\(^2\) = 0.5195 m\(^2\)

Untuk pemurnian air sungai menggunakan bar screen, diperkirakan \(C_d = 0.6\) dan 30 \% screen tersumbat.

\[Head\ loss\ (\Delta h) = \frac{Q^2}{2gC_d^2A_2^2} = \frac{(0.0035)^2}{2(9.8)(0.6)^2(0.5195)^2}\]
\[= 6.57 \times 10^{-6}\ m\ dari\ air = 0.00657\ mm\ dari\ air\]

**L.D.2 Bak Sedimentasi (V-01)**

Fungsi: untuk mengendapkan partikel-partikel padatan kecil yang tidak tersaring dan terikut dengan air.

Jumlah: 1

Jenis: beton kedap air

Data:

Kondisi penyimpanan: temperatur = 30 °C
teakanan = 1 atm

Laju massa air: \(F = 12680.9685\) kg/jam

Densitas air: \(\rho = 995.68\) kg/m\(^3\)

Debit air/laju alir volumetrik, \(Q = \frac{F}{\rho} = 12.7359\ m^3/jam = 7.4958\ ft^3/mnt\)

Desain Perancangan:

Bak dibuat dua persegi panjang untuk desain efektif (Kawamura, 1991).

Perhitungan ukuran tiap bak:

Kecepatan pengendapan 0.1 mm pasir adalah (Kawamura, 1991):

\[v_0 = 1.57478\ ft/min\ atau\ 8\ mm/s\]
Desain diperkirakan menggunakan spesifikasi:

Kedalaman bak 7 ft
Lebar bak 1 ft

Kecepatan aliran \( v = \frac{Q}{A_t} = \frac{7,4958 \text{ ft}^3/\text{min}}{7 \text{ ft} \times 1 \text{ ft}} = 1,07 \text{ ft/min} \)

Desain panjang ideal bak: \( L = K \left( \frac{h}{v_0} \right) v \) (Kawamura, 1991)

dengan: \( K = \) faktor keamanan = 1,5
\( h = \) kedalaman air efektif (10 – 16 ft); diambil 10 ft.

Maka: \( L = 1,5 \times (10/1,57) \times 1,07 \)
\[ = 10,23 \text{ ft} \]
Diambil panjang bak = 10 ft = 3,05 m

Uji desain:

Waktu retensi (t): \( t = \frac{V_a}{Q} = \frac{\text{panjang x lebar x tinggi}}{\text{laju alir volumetrik}} \)
\[ = \frac{10 \times 1 \times 7 \text{ ft}^3}{7,4958 \text{ ft}^3/\text{min}} = 9,3385 \text{ menit} \]


Surface loading: \( \frac{Q}{A} = \frac{\text{laju alir volumetrik}}{\text{luas permukaan masukan air}} \)
\[ = \frac{7,4958 \text{ ft}^3/\text{min} (7,481 \text{ gal/ft}^3)}{1 \text{ ft} \times 10 \text{ ft}} = 5,6076 \text{ gpm/ft}^2 \]

*Headloss* \((\Delta h)\); bak menggunakan gate valve, *full open* (16 in) :

\[
\Delta h = K \frac{v^2}{2 g}
\]

\[
= 0,12 \left[ \frac{1,07 \text{ ft/min.} \cdot \frac{1 \text{ min}}{60 \text{s}} \cdot \frac{1 \text{ m}}{3,2808 \text{ ft}}} {1 \text{ m/3,2808 ft}} \right]^2
\]

\[
= 2 (9,8 \text{ m/s}^2)
\]

\[
= 1,8117 \cdot 10^{-7} \text{ m dari air}
\]

**LD.3 Tangki Pelarutan Alum (V-02)**

- **Fungsi**: Membuat larutan alum \(\text{Al}_2(\text{SO}_4)_3\) 30%.
- **Bentuk**: Silinder vertikal dengan alas dan tutup datar
- **Bahan konstruksi**: *Carbon steel SA-283, Grade C*
- **Jenis sambungan**: *Single welded butt joints*
- **Jumlah**: 1 unit

**Kondisi operasi** :

- **Temperatur** = 30\(^\circ\)C
- **Tekanan** = 1 atm
- **\(\text{Al}_2(\text{SO}_4)_3\) yang digunakan** = 50 ppm
- **\(\text{Al}_2(\text{SO}_4)_3\) yang digunakan berupa larutan 30 % (%) berat**
- **Laju massa \(\text{Al}_2(\text{SO}_4)_3\) \((F)\)** = 0,634 kg/jam
- **Densitas \(\text{Al}_2(\text{SO}_4)_3\) 30 % \((\rho)\)** = 1363 kg/m\(^3\) = 85,090216 lb/ft\(^3\) (Perry dkk, 1999)
- **Viskositas \(\text{Al}_2(\text{SO}_4)_3\) 30 % \((\mu)\)** = 6,72 \(10^{-4}\) lbm/ft s = 1 cP (Kirk & Othmer, 1949)
- **Kebutuhan perancangan** = 30 hari

**Perhitungan ukuran tangki** :
1. Volume tangki

\[ V_{larutan} = \frac{0,634 \text{ kg/jam} \times 30 \text{ hari} \times 24 \text{ jam/hari}}{0,3 \times 1363 \text{ kg/m}^3} = 1,1164 \text{ m}^3 \]

Faktor kelonggaran : 20%

Volume tangki, \( V_t = 1,2 \times 1,1164 \text{ m}^3 = 1,3397 \text{ m}^3 \)

2. Diameter dan tinggi tangki

Direncanakan :

Tinggi tangki : diameter tangki \( H_s : D = 1 : 1 \)

Volume tangki (\( V_t \))

\[ V_t = \frac{1}{4} \pi D^2 H_s \]

\[ V_t = \frac{3}{8} \pi D^3 \]

\[ 1,3397 = \frac{3}{8} \pi D^3 \]

Maka, diameter tangki \( D = 1,195 \text{ m} = 47,0488 \text{ in} \)

tinggi tangki \( H_t = D = 1,195 \text{ m} = 47,0488 \text{ in} \)

3. Tebal shell tangki

Tinggi cairan dalam tangki, \( h = \frac{1,1164 \text{ m}^3}{1,3397 \text{ m}^3} \times 1,195 \text{ m} = 0,9958 \text{ m} \)

Tekanan hidrostatik :

\[ P = \rho \times g \times h = 1363 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 0,9958 \text{ m} = 13,302 \text{ kPa} \]

Tekanan operasi :

\[ P_{operasi} = 1 \text{ atm} = 101,325 \text{ kPa} \]

\[ P_{total} = 101,325 \text{ kPa} + 13,302 \text{ kPa} = 114,6272 \text{ kPa} \]

Faktor keamanan : 20%

\[ P_{design} = (1,2) (114,6272 \text{ kPa}) = 137,5527 \text{ kPa} \]

**Joint efficiency** : \( E \text{ = 0,8} \)  
(Brownell & Young, 1959)

**Allowable stress** : \( S \text{ = 12650 psia = 87218,71 kPa} \)  
(Brownell & Young, 1959)

Faktor korosi : \( C \text{ = 0,0089 in/tahun} \)  
(Peters dkk, 2004)

Umur alat : \( n = 10 \text{ tahun} \)

Tebal shell tangki :
t = \frac{PD}{2SE - 1.2P} + nC
= \frac{(137,5527 \text{ kPa})(1,195 \text{ m})(39.37 \text{ in}/\text{m})}{2(87218.71 \text{ kPa})(0.8) - 1.2(137,5527 \text{ kPa})} + 10(0.0098)
= 0.0464 \text{ in} + 0.098 \text{ in}
= 0.1444

Tebal shell standar yang digunakan = \frac{1}{4} \text{ in} \quad \text{(Brownell & Young, 1959)}

Perancangan Sistem Pengaduk

Jenis pengaduk : flat 6 blade turbin impeller

Jumlah baffle : 4 buah

Untuk turbin standar (Geankoplis, 2003), diperoleh :

Da/Dt = 1/3 ; Da = 1/3 \times 1,195 \text{ m} = 0,3983 \text{ m}
E/Da = 1 ; E = 0,3983 \text{ m}
L/Da = 1/4 ; L = 1/4 \times 0,3983 \text{ m} = 0,0995 \text{ m}
W/Da = 1/5 ; W = 1/5 \times 0,3983 \text{ m} = 0,0796 \text{ m}

J/Dt = 1/12 ; J = 1/12 \times 1,195 \text{ m} = 0,0995 \text{ m}

dimana : Dt = D = diameter tangki (m)
Da = Diameter impeller (m)
E = tinggi turbin dari dasar tangki (m)
L = panjang blade pada turbin (m)
W = lebar blade pada turbin (m)
J = lebar baffle (m)

Kecepatan pengadukan, N = 0.5 putaran/detik

Bilangan Reynold,

N_{Re} = \frac{\rho N (Da)^2}{\mu} = \frac{1363(0.5)0.3983^2}{10^{-3}} = 108040

N_{Re} > 10.000, maka perhitungan dengan daya pengaduk menggunakan rumus:

P = Np \frac{N^3}{D_a^5} \rho \quad \text{(Geankoplis, 2003)}

Np = 5 \quad \text{untuk} \quad N_{Re} = 108040 \quad \text{(Geankoplis, 2003)}

P = 5(0.5)^3(0.3983)^51363 = 8,544 \text{ watt} = 0,0114 \text{ hp}

Efisiensi motor = 80 \%

Daya motor = 0,0143 \text{ hp}

Digunakan daya motor standar 1/8 \text{ hp}
LD.4 Tangki Pelarutan Soda Abu (V-03)

Fungsi : Membuat larutan soda abu Na$_2$CO$_3$ 30%.
Bentuk : Silinder vertikal dengan alas dan tutup datar
Bahan konstruksi : Carbon steel SA-283, Grade C
Jenis sambungan : Single welded butt joints
Jumlah : 1 unit

Kondisi operasi :
Temperatur = 30°C
Tekanan = 1 atm
Na$_2$CO$_3$ yang digunakan = 27 ppm
Na$_2$CO$_3$ yang digunakan berupa larutan 30 % (% berat)
Laju massa Na$_2$CO$_3$ (F) = 0,3423 kg/jam
Densitas Na$_2$CO$_3$ 30 % ($\rho$) = 1327 kg/m$^3$ = 82,8428 lb/ft$^3$ (Perry dkk, 1999)
Viskositas Na$_2$CO$_3$ 30% ($\mu$) = 3,69 $10^{-4}$ lb ft/s = 0,549 cP (Kirk & Othmer, 1949)
Kebutuhan perancangan = 30 hari

Perhitungan ukuran tangki:
1. Volume tangki

$$ V_{larutan} = \frac{0,3423 \text{ kg/jam} \times 30 \text{ hari} \times 24 \text{ jam/hari}}{0,3 \times 1327 \text{ kg/m}^3} = 0,6192 \text{ m}^3 $$

Faktor kelonggaran : 20 %
Volume tangki, $V_t = 1,2 \times 0,6192 \text{ m}^3 = 0,743 \text{ m}^3$

2. Diameter dan tinggi tangki
Direncanakan :
Tinggi tangki : diameter tangki $H_s : D = 1 : 1$
Volume tangki ($V_t$)

$$ V_t = \frac{1}{4} \pi D^2 H_s $$

$$ V_t = \frac{3}{8} \pi D^3 $$

$$ 0,743 = \frac{3}{8} \pi D^3 $$
Maka, diameter tangki \( D = 0,9818 \text{ m} = 38,6564 \text{ in} \)

tinggi tangki \( H_t = D = 0,9818 \text{ m} = 38,6564 \text{ in} \)

3. Tebal \textit{shell} tangki

Tinggi cairan dalam tangki, \( h = \frac{0,6192 \text{ m}^3}{0,743 \text{ m}^3} \times 0,9818 \text{ m} = 0,8182 \text{ m} \)

Tekanan hidrostatik:
\[
P = \rho \times g \times h = 1327 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 0,8182 = 10,646 \text{ kPa}
\]

Tekanan operasi:
\[
P_{\text{operasi}} = 101,325 \text{ kPa}
\]
\[
P_{\text{total}} = 101,325 \text{ kPa} + 10,64 \text{ kPa} = 111,9657 \text{ kPa}
\]

Faktor keamanan : 20 %
\[
P_{\text{design}} = (1,2) (111,9657 \text{ kPa}) = 134,3589 \text{ kPa}
\]

\textit{Joint efficiency} : \( E = 0,8 \) (Brownell & Young, 1959)
\textit{Allowable stress} : \( S = 12650 \text{ psia} = 87218,71 \text{ kPa} \) (Brownell & Young, 1959)

Faktor korosi : \( C = 0,0098 \text{ in/tahun} \) (Peters dkk, 2004)

Umur alat : \( n = 10 \text{ tahun} \)

Tebal \textit{shell} tangki:
\[
t = \frac{PD}{2SE - 1,2P} + nC
\]
\[
= \left( \frac{134,3589 \text{ kPa}(0,9818 \text{ m})(39,37 \text{ in/1m})}{2(827218,71 \text{ kPa})(0,8) - 1,2(134,3589 \text{ kPa})} \right) + 10(0,0098) + 0,0372 + 0,098
\]
\[
= 0,1352
\]

Tebal \textit{shell} standar yang digunakan = \( \frac{1}{4} \text{ in} \) (Brownell & Young, 1959)

Perancangan Sistem Pengaduk

Jenis pengaduk : \textit{flat 6 blade turbin impeller}

Jumlah \textit{baffle} : 4 buah

Untuk turbin standar (Geankoplis, 2003), diperoleh:
\[
\frac{D_a}{D_t} = 1/3 \quad ; \quad D_a = 1/3 \times 0,9818 \text{ m} = 0,3272 \text{ m}
\]
\[
\frac{E}{D_a} = 1 \quad ; \quad E = 0,3272 \text{ m}
\]
\[
\frac{L}{D_a} = 1/4 \quad ; \quad L = 1/4 \times 0,3272 \text{ m} = 0,0818 \text{ m}
\]
\[
\begin{align*}
W/Da &= 1/5 \quad ; \quad W = 1/5 \times 0.3272 \text{ m} = 0.0654 \text{ m} \\
J/Dt &= 1/12 \quad ; \quad J = 1/12 \times 0.9818 \text{ m} = 0.0818 \text{ m}
\end{align*}
\]

dimana : Dt = D = diameter tangki (m) \\
Da = Diameter impeller (m) \\
E = tinggi turbin dari dasar tangki (m) \\
L = panjang blade pada turbin (m) \\
W = lebar blade pada turbin (m) \\
J = lebar baffle (m)

Kecepatan pengadukan, N = 1 putaran/detik

Bilangan Reynold, \( N_{Re} = \frac{\rho N (Da)^2}{\mu} = \frac{1327(1)(0.3272)^2}{0.00055} = 258629 \)

\( N_{Re} > 10.000 \), maka perhitungan dengan daya pengaduk menggunakan rumus:

\[
P = Np \cdot N^3 \cdot D_a^5 \cdot \rho
\]

\( Np = 5 \) untuk \( N_{Re} = 258629 \) \hspace{1cm} (Geankoplis, 2003)

\[
P = 5(1)^3(0.3272)^51327 = 24,918 \text{ watt} = 0.0334 \text{ hp}
\]

Efisiensi motor = 80 %

Daya motor = 0,0417 hp

Digunakan daya motor standar 1/8 hp

**L.D.5 Clarifier (V-04)**

Fungsi : Memisahkan endapan (flok-flok) yang terbentuk karena penambahan alum dan soda abu

Jenis : *External Solid Recirculation Clarifier*

Jumlah : 1 unit

Bahan konstruksi : *Carbon steel SA-283, Grade C*

**Data :**

- Laju massa air \( (F_1) \) = 12680,9685 kg/jam
- Laju massa \( Al_2(SO4)_3 \) \( (F_2) \) = 0,634 kg/jam
- Laju massa \( Na_2CO_3 \) \( (F_3) \) = 0,3423 kg/jam
- Laju massa total, m = 12681,9449 kg/jam
Densitas $\text{Al}_2(\text{SO}_4)_3 = 2710 \text{ kg/m}^3$ (Perry dkk, 1999)
Densitas $\text{Na}_2\text{CO}_3 = 2533 \text{ kg/m}^3$ (Perry dkk, 1999)
Densitas air = 995,68 kg/m$^3$ (Geankoplis, 2003)

Reaksi koagulasi:
$\text{Al}_2(\text{SO}_4)_3 + 3 \text{ Na}_2\text{CO}_3 + 3 \text{ H}_2\text{O} \rightarrow 2 \text{ Al(OH)}_3 + 3 \text{ Na}_2\text{SO}_4 + 3\text{CO}_2$

Diameter dan tinggi clarifier

Dari Metcalf & Eddy, 1984, untuk clarifier tipe upflow diperoleh:
Kedalaman air = 3-10 m
Settling time = 1-3 jam
Dipilih: kedalaman air (h) = 5 m, waktu pengendapan = 2 jam

Diameter dan Tinggi clarifier

Densitas larutan, $\rho = \frac{12681,9449}{12680,9685 + 0,634 + 0,3423 + \frac{2710}{2533}} = 995,7278 \text{ kg/m}^3$

Volume cairan, $V = \frac{12681,9449 \text{ kg/jam} \times 2 \text{ jam}}{995,7278 \text{ kg/m}^3} = 25,4727 \text{ m}^3$

Faktor kelonggaran = 20%

Volume clarifier = 1,2 x 25,4727 m$^3$ = 30,5672 m$^3$

a. Diameter dan tinggi clarifier

\[ \frac{H_s}{\frac{1}{2} D} \]

Volume silinder clarifier ($V_s$) = $V_s = \frac{\pi D^2 H_s}{4}$ (Brownell & Young, 1959)

Perbandingan tinggi silinder dengan diameter tangki ($H_s : D$) = 3:4

$V_s = \frac{\pi D^3}{3}$

Volume alas clarifier kerucut ($V_a$)
½ D

\[ H_c \]

Vs = \( \frac{\pi D^2 H_c}{12} \) .................................................. (Perry dkk, 1999)

Perbandingan tinggi kerucut dengan diameter kerucut \( (H_c : D) = 1:2 \)

\[ V_c = \frac{\pi D^3}{24} \] .................................................. (Perry dkk, 1999)

\[ \sim \] Volume clarifier \( (V) \)

\[ V = V_s + V_e = \frac{3\pi D^3}{8} \]

\[ 30,5672 \text{ m}^3 = 1,178097 D^3 \]

\[ D = 1,7315 \text{ m} ; \quad H_s = (4/3) \times D = 2,3087 \text{ m} \]

b. Diameter dan tinggi kerucut

Perbandingan tinggi kerucut dengan diameter clarifier \( (H_h : D) = 1:2 \)

Diameter tutup = diameter tangki = 1,7315 m

Tinggi tutup = \( \left( \frac{1,7315 \text{ m}}{2} \right) = 0,8657 \text{ m} \)

Tinggi total clarifier = 2,3087 m + 0,8657 m = 3,1744 m

c. Daya Pengaduk

Daya Clarifier

\[ P = 0,006 D^2 \] .................................................. (Ulrich, 1984)

Dimana:

\[ P = \text{daya yang dibutuhkan, kW} \]

Sehingga,

\[ P = 0,006 \times (5)^2 = 0,15 \text{ kW} = 0,201 \text{ hp} \]

Bila efisiensi motor = 60%, maka :

\[ P = \frac{0,201 \text{ hp}}{0,6} = 0,335 \text{ hp} \]

Maka dipilih motor dengan daya 1/2 hp.

**LD.6 Sand filter (V-05)**
Fungsi : Menyaring endapan (flok-flok) yang masih terikut dengan air yang keluar dari Clarifier (V-04)
Bentuk : Silinder vertikal dengan alas dan tutup datar
Bahan konstruksi : Carbon steel SA-283, Grade C
Jenis sambungan : Single welded butt joints
Jumlah : 1 unit

Kondisi operasi :
Temperatur  =  30°C
Laju massa air (F)    =  12680,9685 kg/jam
Densitas air ($\rho$)       =  995,68 kg/m$^3$  (Geankoplis, 2003)

Tangki Filtrasi dirancang untuk penampungan 1/4 jam operasi.

a. Dimensi Sand filter
Lapisan – lapisan media penyaring :
1. Pasir 10 in
2. Antarsit 20 in
3. Kerikil 16 in

Sehingga, total ketinggian media penyaring di dalam sand filter adalah 46 in (3,83ft).

Volume air yang harus tertampung  = $\frac{0,25 \text{ jam} \times 12680,9685 \text{ kg/jam}}{995,68 \text{ kg/m}^3}$
= 3,1839 m$^3$ = 112,4377 ft$^3$

Trial : Asumsi diameter = 5 ft
Rasio tinggi dan diameter (L/D) = 1,8
Ruang kosong antar media penyaring = 20%
Volume dished head di bagian atas diabaikan

Volume sand filter  = $\frac{\pi.D^2.L}{4}$
= $\frac{\pi.5^2.1.8.(5)}{4}$ = 176,625 ft$^3$

Volume media penyaring  = $\frac{\pi.D^2.L'}{4}$
Dimana L’ adalah tinggi media penyaring di dalam sand filter

Volume media penyaring = \( \frac{\pi \times 5^2 \times 3,83}{4} \) = 75,229 ft\(^3\)

Ruang kosong antar media penyaring = 0,2 \times (75,229) = 15,046 ft\(^3\)

Volume terpakai sand filter = (176,625 – (75,229 – 15,046)) = 116,4417 ft\(^3\)

Volume terpakai sand filter \( \approx \) Volume air yang harus tertampung

Spesifikasi dapat diterima

Direncanakan Volume bahan penyaring = \( \frac{1}{3} \) Volume tangki

Diameter (D) = 5 ft = 60 in = 1,524 m
Tinggi (H) = 9 ft = 102 in = 2,743 m

b. Tebal tangki

Tekanan hidrostatik :
\[ P = \rho \times g \times h = 995,68 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 2,743 \text{ m} = 26,767 \text{ kPa} \]

Tekanan operasi : \( P_{operasi} = 101,325 \text{ kPa} \)

\[ P_{total} = 101,325 \text{ kPa} + 26,767 \text{ kPa} = 128,0925 \text{ kPa} \]

Faktor keamanan : 20 \%

\[ P_{design} = (1,2) (128,0925 \text{ kPa}) = 134,497 \text{ kPa} \]

\[ Joint\ efficiency : E = 0,8 \]  \hspace{1cm} \text{ (Brownell & Young, 1959)}

\[ Allowable\ stress : S = 12650 \text{ psia} = 87218,71 \text{ kPa} \]  \hspace{1cm} \text{ (Brownell & Young, 1959)}

Faktor korosi : \( C = 0,0098 \text{ in/tahun} \)  \hspace{1cm} \text{ (Peters dkk, 2004)}

Umur alat : \( n = 10 \text{ tahun} \)

Tebal shell tangki :

\[ t = \frac{PD}{2SE - 1,2P} + nC \]

\[ = \frac{(134,497 \text{ kPa})(1,52 \text{ m})}{2(87218,71 \text{ kPa})(0,8) - 1,2(134,497 \text{ kPa})} + 10(0,0098 \text{ in}) \]

\[ = 0,0578 \times 39,37 + 0,098 = 0,156 \text{ in} \]

Tebal shell standar yang digunakan = 1/4 in  \hspace{1cm} \text{ (Brownell & Young, 1959)}

**LD.7 Bak Penampungan Air (V-06)**

Fungsi : Menampung air untuk didistribusikan

Jumlah : 1 unit
Bahan kontruksi : Beton kedap air

Kondisi operasi :

Temperatur = 30°C
Densitas air ($\rho$) = 995,68 kg/m$^3$ = 62,1939 lb/ft$^3$ (Geankoplis, 2003)
Laju alir massa (F) = 12680,9685 kg/jam

$$\text{Laju alir volumetrik (Q)} = \frac{12680,9685 \text{ kg/jam}}{995,68 \text{ kg/m}^3 \times 1 \text{ hari}/24 \text{ jam}} = 305,6637 \text{ m}^3/\text{hari}$$

Desain Perancangan :

Bak dibuat persegi panjang

Perhitungan ukuran bak :

Waktu tinggal air = 2 jam = 0,0833 hari (Perry dkk, 1999)
Volume air diolah = 305,6637 m$^3$/hari $\times$ 0,0833 hari = 25,4719 m$^3$
Bak terisi 90% maka volume bak = \( \frac{25,4719}{0,9} = 28,3021 \text{ m}^3 \)

Direncanakan ukuran bak sebagai berikut :

<table>
<thead>
<tr>
<th>Panjang bak (p)</th>
<th>Lebar bak (l)</th>
<th>Tinggi bak (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2 \times$ lebar</td>
<td>$2 \times$ lebar</td>
<td>lebar</td>
</tr>
<tr>
<td>$p = 2l$</td>
<td>$l = l$</td>
<td>$t = l$</td>
</tr>
</tbody>
</table>

Volume bak $V = p \times l \times t$

$28,3021 \text{ m}^3 = 2l \times l \times l$

$l = 2,4187 \text{ m}$

Jadi, panjang bak (p) = 4,8375 m
lebar bak (l) = 2,4187 m
tinggi bak (t) = 2,4187 m
luas bak (A) = 11,701 m$^2$

LD.8 Tangki Pelarutan Asam Sulfat (V-07)

Fungsi : Membuat larutan asam sulfat H$_2$SO$_4$ 5%.
Bentuk : Silinder vertikal dengan alas dan tutup datar
Bahan konstruksi : *Low-alloy steel* SA-353
Jenis sambungan : *Single welded butt joints*
Jumlah : 1 unit

Kondisi operasi :
Temperatur = 30°C
Tekanan = 1 atm

H₂SO₄ yang digunakan berupa larutan 5 % (% berat)
Laju massa H₂SO₄ (F) = 0,0137 kg/jam
Densitas H₂SO₄ 5 % (ρ) = 1028,86 kg/m³ = 66,2801 lbm/ft³ (Perry dkk, 1999)
Viskositas H₂SO₄ 5 % (μ) = 3,5 cP (Kirk & Othmer, 1949)
Kebutuhan perancangan = 30 hari

Perhitungan ukuran tangki :
1. Volume tangki

\[ V_{\text{larutan}} = \frac{0,0137 \text{ kg/jam} \times 30 \text{ hari} \times 24 \text{ jam/hari}}{0,05 \times 1028,86 \text{ kg/m}^3} = 0,1928 \text{ m}^3 \]

Faktor kelonggaran : 20 %
Volume tangki, \( V_t = 1,2 \times 0,1928 \text{ m}^3 = 0,2313 \text{ m}^3 \)

2. Diameter dan tinggi tangki

Direncanakan :
Tinggi tangki : diameter tangki \( H_s : D = 1 : 1 \)

Volume tangki (\( V_t \))

\[ V_t = \frac{1}{4} \pi D^2 H_s \]
\[ V_t = \frac{1}{4} \pi D^3 \]
\[ 0,2313 = \frac{1}{4} \pi D^3 \]

Maka, diameter tangki \( D = 0,6654 \text{ m} \)

tinggi tangki \( H_t = H_s = \left( \frac{H_s}{D} \right) \times D = 0,6654 \text{ m} \)
3. Tebal *shell* tangki

Tinggi cairan dalam tangki, \( h = \frac{0,1928 m^3}{0,2313 m^3} \times 0,6654 m = 0,5545 m \)

Tekanan hidrostatik :

\[ P = \rho \times g \times h = 1028,86 kg/m^3 \times 9,8 \text{ m/det}^2 \times 0,5545 = 5,5916 \text{ kPa} \]

Tekanan operasi :

\[ P_{\text{operasi}} = 1 \text{ atm} = 101,325 \text{ kPa} \]

\[ P_{\text{total}} = 101,325 \text{ kPa} + 5,5916 \text{ kPa} = 106,9166 \text{ kPa} \]

Faktor keamanan : 20 %

\[ P_{\text{design}} = (1,2) (106,9166 \text{ kPa}) = 112,2624 \text{ kPa} \]

*Joint efficiency* : \( E = 0,8 \) (Brownell & Young, 1959)

*Allowable stress* : \( S = 12650 \text{ psia} = 87218.71 \text{ kPa} \) (Brownell & Young, 1959)

Faktor korosi : \( C = 0,0098 \text{ in/tahun} \) (Peters dkk, 2004)

Umur alat : \( n = 10 \) tahun

Tebal *shell* tangki :

\[ t = \frac{PD}{2SE-1,2P} + nC \]

\[ = \frac{(112,2624 \text{ kPa})(0,6654)}{2(87218,71 \text{ kPa})(0,8)-1,2(112,2624 \text{ kPa})} + 10(0,0098 \text{ in}) \]

\[ = 0,021 + 0,098 \text{ in} \]

\[ = 0,119 \text{ in} \]

Tebal *shell* standar yang digunakan = 1/8 in (Brownell & Young, 1959)

**Perancangan Sistem Pengaduk**

Jenis pengaduk : *flat 6 blade turbin impeller*

Jumlah *baffle* : 4 buah

Untuk turbin standar (Geankoplis, 2003), diperoleh :

\[ Da/Dt = 1/3 \]

\[ Da = 1/3 \times 0,6654 = 0,2218 \text{ m} \]

\[ E/ Da = 1 \]

\[ E = 0,2218 \text{ m} \]

\[ L/ Da = 1/4 \]

\[ L = 1/4 \times 0,2218 = 0,0554 \text{ m} \]

\[ W/ Da = 1/5 \]

\[ W = 1/5 \times 0,2218 = 0,0443 \text{ m} \]

\[ J/ Da = 1/12 \]

\[ J = 1/12 \times 0,6654 = 0,0554 \text{ m} \]

dimana : \( Dt = D = \text{diameter tangki (m)} \)
Da = Diameter *impeller* (m)

E = tinggi turbin dari dasar tangki (m)

L = panjang *blade* pada turbin (m)

W = lebar *blade* pada turbin (m)

J = lebar *baffle* (m)

Kecepatan pengadukan, N = 1 putaran/detik

Bilangan Reynold,

\[
N_{Re} = \frac{\rho N (Da)^2}{\mu} = \frac{1028.86(1)(0.2218)^2}{0.01787} = 2833
\]

\(N_{Re} < 10.000\), maka perhitungan dengan daya pengaduk menggunakan rumus:

\[
P = Np N^\frac{1}{3} D_a^5 \rho
\]

\(Np = 5\) untuk \(N_{Re} = 2833\)  

\(P = 5(1)^\frac{1}{3}(0.2218)^5 1028.86 = 2.7632\) watt = 0,003 hp

Efisiensi motor = 80 %

Daya motor = 0,004 hp

Digunakan daya motor standar 1/8 hp

**L.D.9 Cation Exchanger (V-08)**

Fungsi: Mengikat logam-logam alkali dan mengurangi kesadahan air

Bentuk: Silinder vertikal dengan alas dan tutup elipsoidal

Bahan konstruksi: *Carbon steel SA-283, Grade C*

Jenis sambungan: *Single welded butt joints*

Jumlah: 1 unit

Kondisi operasi:

Temperatur = 30°C

Laju massa air (F) = 2738,4971 kg/jam

Densitas air (\(\rho\)) = 995,68 kg/m³  

Kebutuhan perancangan = 1 jam
**Ukuran Cation Exchanger**


- Diameter penukar kation = 2 ft = 0,6096 m
- Luas penampang penukar kation = 3,14 ft²

Faktor keamanan : 20 %

Tinggi resin = 2,5 ft = 0,76201 m
Tinggi silinder = 1,2 × 2,5 ft = 3 ft = 0,91441 m

Diameter tutup = diameter tangki = 0,6096 m = 2 ft = 24 in

Direncanakan rasio Tinggi tutup : Diameter tangki = 1 : 4

Tinggi tutup = ¼ × 0,6096 m = 0,152 m
Tinggi *cation exchanger* = 0,91441 + 2 (0,152) = 1,2192 m

Tebal dinding tangki:

Tekanan hidrostatik:

\[ P = \rho \times g \times h = 995,68 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 0,76201 = 7,4354 \text{ kPa} \]

Tekanan operasi:

\[ P_{\text{operasi}} = 1 \text{ atm} = 101,325 \text{ kPa} \]
\[ P_{\text{total}} = 101,325 \text{ kPa} + 7,4354 \text{ kPa} = 108,766 \text{ kPa} \]

Faktor keamanan : 20 %

\[ P_{\text{design}} = (1,2) (108,766 \text{ kPa}) = 114,2047 \text{ kPa} \]

*Joint efficiency* : \( E = 0,8 \) \hspace{1cm} (Brownell & Young, 1959)

*Allowable stress* : \( S = 12650 \text{ psia} = 87218,71 \text{ kPa} \) \hspace{1cm} (Brownell & Young, 1959)

Faktor korosi : \( C = 0,0098 \text{ in/tahun} \) \hspace{1cm} (Peters dkk, 2004)

Umur alat : \( n = 10 \) tahun

Tebal *shell* tangki:

\[ t = \frac{PD}{2SE - 1,2P} + nC \]
\[ = \frac{(114,2047 \text{ kPa})(0,6096)}{2(87218,71 \text{ kPa})(0,8) - 1,2(114,2047 \text{ kPa})} + 10 (0,0098 \text{ in}) \]
\[ = 0,000499 \times 39,37 \text{ in} + 0,098 \text{ in} \]
\[ = 0,1177 \text{ in} \]

Tebal *shell* standar yang digunakan = \( \frac{1}{8} \) in \hspace{1cm} (Brownell & Young, 1959)
**LD.10 Tangki Pelarutan NaOH (V-09)**

**Fungsi** : Membuat larutan natrium hidroksida (NaOH).

**Bentuk** : Silinder vertikal dengan alas dan tutup datar

**Bahan konstruksi** : *Carbon steel SA-283, Grade C*

**Jenis sambungan** : *Single welded butt joints*

**Jumlah** : 1 unit

**Kondisi operasi** :
- Temperatur  = 30°C
- Tekanan  = 1 atm

NaOH yang digunakan berupa larutan 4 % (% berat)

- Laju massa NaOH (F)  = 0,10083 kg/jam
- Densitas NaOH 4 % (ρ)  = 1518 kg/m³ = 94,7662 lbm/ft³ (Perry dkk, 1999)
- Viskositas NaOH 4 % (μ)  = 0,00043 lbm/ft s = 0,64 cP (Kirk & Othmer, 1949)

**Kebutuhan perancangan**  = 30 hari

**Perhitungan ukuran tangki** :

1. **Volume tangki**

   \[ V_{\text{larutan}} = \frac{0,10083 \text{ kg/jam} \times 30 \text{ hari} \times 24 \text{ jam/hari}}{0,04 \times 1518 \text{ kg/m}^3} = 1,1956 \text{ m}^3 \]

   Faktor kelonggaran : 20 %

   Volume tangki, \( V_t = 1,2 \times 1,1956 \text{ m}^3 = 1,4347 \text{ m}^3 \)

2. **Diameter dan tinggi tangki**

   Direncanakan : Tinggi tangki : diameter tangki  \( H_s : D = 1 : 1 \)

   Volume tangki (\( V_t \))

   \[ V_t = \frac{1}{4} \pi D^2 H_s \]

   \[ V_t = \frac{1}{4} \pi D^3 \]

   \[ 1,4347 = \frac{1}{4} \pi D^3 \]

   Maka, diameter tangki  \( D = 1,2226 \text{ m} \)

   tinggi tangki  \( H_t = H_s = \left( \frac{H_s}{D} \right) \times D = 1,2226 \text{ m} \)
3. Tebal *shell* tangki

Tinggi cairan dalam tangki, \( h = \frac{1,1956 \, m^3}{1,4347 \, m^3} \times 1,2226 \, m = 1,0188 \, m \)

Tekanan hidrostatik :

\[ P = \rho \times g \times h = 1518 \, kg/m^3 \times 9,8 \, m/det^2 \times 1,0188 = 15,1571 \, kPa \]

Tekanan operasi :

\[ P_{\text{operasi}} = 1 \, atm = 101,325 \, kPa \]

\[ P_{\text{total}} = 101,325 \, kPa + 15,1571 \, kPa = 116,8422 \, kPa \]

Faktor keamanan : 20 

\[ P_{\text{design}} = (1,2) (116,8422 \, kPa) = 122,3036 \, kPa \]

*Joint efficiency :* \( E = 0,8 \) (Brownell & Young, 1959)

*Allowable stress :* \( S = 12650 \, psia = 87218,71 \, kPa \) (Brownell & Young, 1959)

Faktor korosi : \( C = 0,0098 \, \text{in/tahun} \) (Peters dkk, 2004)

Umur alat : \( n = 10 \, \text{tahun} \)

Tebal tangki :

\[ t = \frac{PD}{2SE - 1,2P} + n \, C \]

\[ = \frac{(122,3036 \, kPa) (1,2226)}{2(87218,71 \, kPa)(0,8) - 1,2(122,3036 \, kPa)} + 10 (0,0098 \, \text{in}) \]

\[ = 0,0107 \times 39,37 \, \text{in} + 0,098 \, \text{in} \]

\[ = 0,14 \, \text{in} \]

Tebal standar yang digunakan = \( \frac{1}{4} \) \, \text{in} \) (Brownell & Young, 1959)

Perancangan Sistem Pengaduk

Jenis pengaduk : *flat 6 blade turbin impeller*

Jumlah *baffle* : 4 buah

Untuk turbin standar (Geankoplis, 2003), diperoleh :

\[ Da/Dt = 1/3 \quad ; \quad Da = 1/3 \times 1,2226 = 0,4075 \, m \]

\[ E/Da = 1 \quad ; \quad E = 0,4075 \, m \]

\[ L/Da = 1/4 \quad ; \quad L = 1/4 \times 0,4075 = 0,1018 \, m \]
W/Da = 1/5 ; W = 1/5 × 0.4075 = 0.0815 m
J/Dt = 1/12 ; J = 1/12 × 1.2226 = 0.1018 m
dimana : Dt = D = diameter tangki (m)
Da = Diameter impeller (m)
E = tinggi turbin dari dasar tangki (m)
L = panjang blade pada turbin (m)
W = lebar blade pada turbin (m)
J = lebar baffle (m)

Kecepatan pengadukan, N = 1 putaran/detik
Bilangan Reynold,
\[ N_{Re} = \frac{\rho N (Da)^2}{\mu} = \frac{1518(1)(0,4075)^2}{0,00064} = 393483 \]
\[ N_{Re} > 10.000, \text{ maka perhitungan dengan daya pengaduk menggunakan rumus:} \]
\[ P = Np N^{-1} D_a^{-5} \rho \]
Np = 5 untuk \( N_{Re} = 393483 \) (Geankoplis, 2003)
\[ P = 5(1)^3(0,4075)^5 1518 = 85,3384 \text{ watt} = 0,1144 \text{ hp} \]
Efisiensi motor = 80 %
Daya motor = 0,143 hp
Digunakan daya motor standar \( \frac{1}{4} \) hp

**LD.11 Anion Exchanger (V-10)**

Fungsi : Mengikat anion yang terdapat di dalam air
Bentuk : Silinder vertikal dengan alas dan tutup elipsoidal
Bahan konstruksi : *Carbon steel SA-283, Grade C*
Jenis sambungan : *Single welded butt joints*
Jumlah : 1 unit

Kondisi operasi :
Temperatur = 30°C
Laju massa air (F) = 2738,497 kg/jam
Densitas air (\( \rho \)) = 995,68 kg/m³ (Geankoplis, 2003)
Kebutuhan perancangan = 1 jam

Ukuran Anion Exchanger
- Diameter penukar kation = 2 ft = 0,6096 m
- Luas penampang penukar kation = 3,14 ft²

Faktor keamanan : 20 %
  - Tinggi resin = 2,5 ft = 0,76201 m
  - Tinggi silinder = 1,2 × 2,5 ft = 3 ft = 0,91441 m

Diameter tutup = diameter tangki = 0,6096 m = 2 ft
Direncanakan rasio Tinggi tutup : Diameter tangki = 1 : 4
  - Tinggi tutup = ¼ × 0,6096 m = 0,152 m
  - Tinggi *anion exchanger* = 0,91441 + 2 (0,152) = 1,219 m

Tebal dinding tangki

Tekanan hidrostatis :
\[ P = \rho \times g \times h = 996,24 \text{ kg/m}^3 \times 9,8 \text{ m/det} \times 0,76201 = 7,4354 \text{ kPa} \]

Tekanan operasi :
\[ P_{\text{operasi}} = 1 \text{ atm} = 101,325 \text{ kPa} \]
\[ P_{\text{total}} = 101,325 \text{ kPa} + 7,4354 \text{ kPa} = 108,76461 \text{ kPa} \]

Faktor keamanan : 20 %
\[ P_{\text{design}} = (1,2) (108,76461 \text{ kPa}) = 114,2047 \text{ kPa} \]

*Joint efficiency* : \( E = 0,8 \) (Brownell & Young, 1959)

*Allowable stress* : \( S = 12650 \text{ psia} = 87218,71 \text{ kPa} \) (Brownell & Young, 1959)

Faktor korosi : \( C = 0,0098 \text{ in/tahun} \) (Peters dkk, 2004)

Umur alat : \( n = 10 \) tahun

Tebal *shell* tangki :
\[
t = \frac{PD}{2SE - 1,2P} + nC = \frac{(114,2047 \text{ kPa})(0,6096)}{2(87218,71 \text{ kPa})(0,8) - 1,2(114,2047 \text{ kPa})} + 10 (0,0098 \text{ in})
\]
\[= 0,000499 x 39,37 \text{ in} + 0,098 \text{ in} = 0,1177 \text{ in} \]
Tebal *shell* standar yang digunakan = 1/8 in (Brownell & Young, 1959)

**LD.12 Deaerator (V-11)**

Fungsi : Menghilangkan gas-gas yang terlarut di dalam air  
Bentuk : Silinder horizontal dengan tutup elipsoidal  
Bahan konstruksi : *Carbon steel SA-283, Grade C*  
Jenis sambungan : *Single welded butt joints*  
Jumlah : 1 unit

**Kondisi operasi:**

Temperatur = 90°C  
Laju massa air (F) = 2738,497 kg/jam  
Densitas air (\(\rho\)) = 995,68 kg/m\(^3\) (Geankoplis, 2003)

Kebutuhan perancangan = 24 jam

**Perhitungan ukuran tangki:**

1. Volume tangki  
   \[ V_{air} = \frac{2738,497 \text{ kg/jam} \times 24 \text{ jam}}{995,68 \text{ kg/m}^3} = 68,0837 \text{ m}^3 \]  
   Faktor kelonggaran : 20 %  
   Volume tangki, \(V_t\) = 1,2 \(\times\) 68,0837 m\(^3\) = 81,7 m\(^3\)

2. Diameter dan tinggi tangki  
   Direncanakan :  
   Tinggi *shell* tangki : diameter tangki ; \(H_s : D = 3 : 2\)  
   Tinggi tutup tangki : diameter tangki ; \(H_h : D = 1 : 4\)  
   Volume *shell* tangki (\(V_s\))  
   \[ V_s = \frac{1}{4} \pi D^2 H_s = \frac{3}{8} \pi D^3 \]  
   Volume tutup tangki (\(V_h\)) elipsoidal  
   \[ V_h = \frac{\pi}{24} D^3 \] (Brownell & Young, 1959)
Volume tangki (V)

\[ V = V_s + 2 V_h \]

\[ 81,7 = \frac{11}{24} \pi D^3 \]

Maka, diameter tangki \( D = 3,8433 \text{ m} \)

tinggi shell tangki \( H_s = \left( \frac{H_s}{D} \right) \times D = 5,7649 \text{ m} \)

tinggi tutup tangki \( H_h = \left( \frac{H_h}{D} \right) \times D = 0,9608 \text{ m} \)

tinggi tangki \( H_t = H_s + 2 H_h = 7,6866 \text{ m} \)

3. Tebal shell tangki

Tinggi cairan dalam tangki, \( h = 3,6817 \text{ m} \times 5,7649 \text{ m} = 4,8041 \text{ m} \)

Tekanan hidrostatik :

\[ P = \rho \times g \times h = 996,24 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 4,8041 = 45,4486 \text{ kPa} \]

Tekanan operasi :

\[ P_{operasi} = 101,325 \text{ kPa} \]

\[ P_{total} = 101,325 \text{ kPa} + 45,4486 \text{ kPa} = 146,7736 \text{ kPa} \]

Faktor keamanan : 20 %

\[ P_{design} = (1,2) (146,7736 \text{ kPa}) = 154,1123 \text{ kPa} \]

*Joint efficiency* : \( E = 0,8 \) \hspace{1cm} (Brownell & Young, 1959)

*Allowable stress* : \( S = 12650 \text{ psia} = 87218,71 \text{ kPa} \) \hspace{1cm} (Brownell & Young, 1959)

Faktor korosi : \( C = 0,0098 \text{ in/tahun} \) \hspace{1cm} (Peters dkk, 2004)

Umur alat : \( n = 10 \text{ tahun} \)

Tebal *shell* tangki :
\[ t = \frac{PD}{2SE - 1,2P} + nC \]
\[ = \frac{(154,1123 \text{kPa})(3,8433)}{2(87218,71 \text{kPa})(0,8) - 1,2(154,1123 \text{kPa})} + 10(0,0098 \text{ in}) \]
\[ = 0,000425 \times 39,37 \text{ in} + 0,098 \text{ in} \]
\[ = 0,1147 \text{ in} \]

Tebal shell standar yang digunakan = 1/8 in  

(Brownell & Young, 1959)

**LD.13 Ketel Uap I (V-12)**

Fungsi : Menyediakan uap untuk keperluan proses

Jenis : Ketel pipa api

Bahan konstruksi : Carbon steel

Jumlah : 1 unit

Data :

\( H = \) jumlah panas yang diperlukan untuk menaikkan temperatur 30\(^\circ\)C menjadi 80\(^\circ\)C

\[ = 2776,2 - 376,92 = 2399,28 \text{ kJ/kg} = 5289,501 \text{ btu/lb} \]

Total kebutuhan uap (\( W \)) = 2214,8383 kg/jam = 4882,8768 lbm/jam

**Daya Ketel Uap**

\[ W = \frac{34,5 \times P \times 970,3}{H} \]

dimana:  
\( P = \) daya ketel uap (hp)  
\( W = \) kebutuhan uap (lbm/jam)  
\( H = \) kalor steam (Btu/lbm)

\[ P = \frac{5289,501 \times 4882,8768}{34,5 \times 970,3} = 771,5522 \text{ hp} \]

**Jumlah Tube**

Luas permukaan perpindahan panas, \( A = P \times 10 \text{ ft}^2/\text{hp} \)

\[ = 771,5522 \text{ hp} \times 10 \text{ ft}^2/\text{hp} \]
\[ = 7715,522 \text{ ft}^2 \]

Direncanakan menggunakan *tube* dengan spesifikasi:

- Panjang *tube*, \( L = 30 \text{ ft} \)
- Diameter *tube*, 4 in
- Luas permukaan pipa, \( a' = 1,178 \text{ ft}^2/\text{ft} \) (Kern, 1965)

Jumlah \textit{tube}

\[
N_t = \frac{A}{L \times a'} = \frac{7715.522}{30 \times 1.178} = 218,3226 = 218 \text{ buah}
\]

**LD.14 Ketel Uap II (V-13)**

Fungsi : Menyediakan uap untuk keperluan proses  
Jenis : Ketel pipa api  
Bahan konstruksi : \textit{Carbon steel}  
Jumlah : 1 unit

**Data :**

H = jumlah panas yang diperlukan untuk menaikkan temperatur 80\(^\circ\)C menjadi 255\(^\circ\)C  
\[
= 2817 – 898,182 = 1918,818 \text{ kJ/kg} = 4230,265 \text{ btu/lb}
\]

Total kebutuhan uap (W) = 11477,6474 kg/jam = 25303,851 lbm/jam

**Daya Ketel Uap**

\[
W = \frac{34,5 \times P \times 970,3}{H}
\]

dimana:  
P = daya ketel uap (hp)  
W = kebutuhan uap (lb\(_m\)/jam)  
H = kalor \textit{steam} (Btu/lb\(_m\))

\[
P = \frac{4230,265 \times 25303,851}{34,5 \times 970,3} = 3197,6359 \text{ hp}
\]

**Jumlah Tube**

Luas permukaan perpindahan panas, \( A = P \times 10 \text{ ft}^2/\text{hp} \)

\[
= 3197,6359 \text{ hp} \times 10 \text{ ft}^2/\text{hp}
\]

\[
= 31976,359 \text{ ft}^2
\]

Direncanakan menggunakan \textit{tube} dengan spesifikasi:  
- Panjang \textit{tube}, \( L = 30 \text{ ft} \)  
- Diameter \textit{tube}, 4 in  
- Luas permukaan pipa, \( a' = 1,178 \text{ ft}^2/\text{ft} \) (Kern, 1965)
Jumlah *tube*

\[ N_j = \frac{A}{L \times a} = \frac{31976,359}{30 \times 1,178} = 904,82 \approx 905 \text{ buah} \]

**L.D.15 Water Cooling Tower (V-14)**

**Fungsi**: menampung air untuk didistribusikan sebagai air domestik dan air umpan ketel

**Jumlah**: 1 buah

**Spesifikasi**:

1. **Tipe**: silinder tegak dengan tutup segmen bola
2. **Bahan Konstruksi**: *fiber glass*

Laju alir massa = 5869,665 kg/jam = 12928,7775 lb/jam

Direncanakan kebutuhan perancangan selama 3 jam.

Banyak air yang ditampung,

\[ = \frac{5869,665 \text{ kg/jam} \times 3 \text{ jam}}{995,9 \text{ kg/m}^3} = 17,681 \text{ m}^3 \]

Faktor keamanan 10%

Maka volume menara,

\[ = 1,1 \times 17,681 \text{ m}^3 = 19,449 \text{ m}^3 \]

Didesain 4 tangki menara air dengan volume 4,862 m³

Diambil tinggi tangki, \( H = \frac{3}{2} \times D \)

Volume \( = \frac{1}{4} \pi \times D^2 \times H = 1,1775 \times D^3 \)

4,862 \( = 1,1775 \times D^3 \)

\[ D = \sqrt[3]{\frac{14,1355}{1,1775}} = 1,604 \text{ m} = 5,263 \text{ ft} \]
H = \frac{3}{2} \times 1,604\text{ m} = 2,406\text{ m} = 7,893\text{ ft}

**L.D.16 Tangki Pelarutan Kaporit (V-15)**

- **Fungsi**: Membuat larutan kaporit Ca(ClO)\(_2\)
- **Bentuk**: Silinder vertikal dengan alas dan tutup datar
- **Bahan konstruksi**: Carbon steel SA-283, Grade C
- **Jenis sambungan**: Single welded butt joints
- **Jumlah**: 1 unit

**Kondisi operasi** :
- **Temperatur** = 30\(^\circ\)C
- **Tekanan** = 1 atm
- **Ca(ClO)\(_2\)** yang digunakan = 2 ppm
- **Laju massa Ca(ClO)\(_2\)** (F) = 0,0033 kg/jam
- **Densitas Ca(ClO)\(_2\)** 70 % (\(\rho\)) = 1272 kg/m\(^3\) = 79,4088 lb/ft\(^3\) (Perry dkk, 1999)
- **Viskositas Ca(ClO)\(_2\)** 70 % (\(\mu\)) = 0,00067 lbm/ft s = 1 cP (Kirk & Othmer, 1949)
- **Kebutuhan perancangan** = 90 hari

**Perhitungan ukuran tangki** :

1. Volume tangki

\[
V_{\text{larutan}} = \frac{0,0033 \text{ kg/jam} \times 90 \text{ hari} \times 24 \text{ jam/hari}}{1272 \text{ kg/m}^3} = 0,00627 \text{ m}^3
\]

Faktor kelonggaran : 20 %
Volume tangki, \(V_t = 1,2 \times 0,00627 \text{ m}^3 = 0,00752 \text{ m}^3\)

2. Diameter dan tinggi tangki

Direncanakan :

Tinggi tangki : diameter tangki \(H_s : D = 1 : 1\)

Volume tangki \((V_t)\)

\[
V_t = \frac{1}{4} \pi D^2 H_s
\]

\[
V_t = \frac{1}{4} \pi D^3
\]
0,00752 = \frac{1}{4} \pi D^3

Maka, diameter tangki \quad D = 0,2123 \, m

tinggi tangki \quad H_t = H_s = \left( \frac{H_s}{D} \right) \times D = 0,2123 \, m

3. Tebal shell tangki

Tinggi cairan dalam tangki, \quad h = \frac{0,00627 \, m^3}{0,00752 \, m^3} \times 0,212 \, m = 0,1769 \, m

Tekanan hidrostatik :

P = \rho \times g \times h = 1272 \, kg/m^3 \times 9,8 \, m/det^2 \times 0,1769 = 2,206 \, kPa

Tekanan operasi :

P_{operasi} = 1 \, atm = 101,325 \, kPa

P_{total} = 101,325 \, kPa + 2,206 \, kPa = 103,531 \, kPa

Faktor keamanan : 20 \%

P_{design} = (1,2) (103,531 \, kPa) = 108,708 \, kPa

*Joint efficiency* : \quad E = 0,8 \quad \text{(Brownell & Young, 1959)}

*Allowable stress* : \quad S = 12650 \, psia = 87218,71 \, kPa \quad \text{(Brownell & Young, 1959)}

Faktor korosi : \quad C = 0,0098 \, in/tahun \quad \text{(Peters dkk, 2004)}

Umur alat : \quad n = 10 \, tahun

Tebal tangki :

\quad t = \frac{PD}{2SE - 1,2P} + n \, C

\quad = \frac{(108,708 \, kPa)(0,185 \, m)}{2(87218,71 \, kPa)(0,8) - 1,2(108,708 \, kPa)} + 10 (0,0098 \, in)

\quad = 0,00017 \times 39,37 \, in + 0,098 \, in

\quad = 0,1045 \, in

Tebal standar yang digunakan = 1/8 \, in \quad \text{(Brownell & Young, 1959)}

**Perancangan Sistem Pengaduk**
Jenis pengaduk : flat 6 blade turbin impeller
Jumlah baffle : 4 buah

Untuk turbin standar (Geankoplis, 2003), diperoleh :

Da/Dt = 1/3 ; Da = 1/3 × 0,212 m = 0,0708 m
E/Da = 1 ; E = 0,0708 m
L/Da = 1/4 ; L = 1/4 × 0,0708 m = 0,0177 m
W/Da = 1/5 ; W = 1/5 × 0,0708 m = 0,0142 m
J/Dt = 1/12 ; J = 1/12 × 0,212 m = 0,0177 m

dimana : Dt = D = diameter tangki (m)
Da = Diameter impeller (m)
E = tinggi turbin dari dasar tangki (m)
L = panjang blade pada turbin (m)
W = lebar blade pada turbin (m)
J = lebar baffle (m)

Kecepatan pengadukan, N = 2,5 putaran/detik

Bilangan Reynold,

\[ N_{Re} = \frac{\rho N (Da)^2}{\mu} = \frac{1272(2,5)(0,0708)^2}{10^{-3}} = 15287,75 \]

\( N_{Re} > 10.000 \), maka perhitungan dengan daya pengaduk menggunakan rumus:

\[ P = N_p N^3 D_a^5 \rho \]

\( N_p = 5 \) untuk \( N_{Re} = 15287,75 \)

\[ P = 5(2,5)^3(0,0708)^5 1272 = 0,0889 \text{ watt} = 2,37.10^{-4} \text{ hp} \]

Efisiensi motor = 80 %

Daya motor = 2,96.10^{-4} \text{ hp}

Digunakan daya motor standar 1/8 hp

**LD.17 Tangki Utilitas (V-16)**

Fungsi : Menampung air untuk didistribusikan untuk kebutuhan domestik

Bentuk : Silinder vertikal dengan alas dan tutup datar

Bahan konstruksi : *Carbon steel SA-283, Grade C*

Jenis sambungan : *Single welded butt joints*
Jumlah : 1 unit

Kondisi operasi :

Temperatur   =  30°C
Laju massa air (F)    =  1162,7 kg/jam
Densitas air (ρ)       =  995,68 kg/m³  

Kebutuhan perancangan =  24 jam

Perhitungan ukuran tangki :

1. Volume tangki

\[ V_{\text{air}} = \frac{1162,7 \text{ kg/jam} \times 24 \text{ jam}}{995,68 \text{ kg/m}^3} = 28,03 \text{ m}^3 \]

Faktor kelonggaran : 20 %
Volume tangki, \( V_t = 1,2 \times 28,03 \text{ m}^3 = 33,63 \text{ m}^3 \)

2. Diameter dan tinggi tangki

Direncanakan : Tinggi tangki : diameter tangki \( H_s : D = 3 : 2 \)
Volume tangki (\( V_i \))

\[ V_i = \frac{3}{8} \pi D^3 \]
\[ \frac{28,03}{\pi} = \frac{3}{8} \pi D^3 \]

Maka, diameter tangki \( D = 4,4 \text{ m} \)

tinggi tangki \( H_i = H_s = \left( \frac{H_s}{D} \right) \times D = 6,6 \text{ m} \)

3. Tebal \textit{shell} tangki

Tinggi cairan dalam tangki, \( h = \frac{28,03 \text{ m}^3}{33,63 \text{ m}^3} \times 6,6 \text{ m} = 5,5 \text{ m} \)

Tekanan hidrostatik :

\[ P = \rho \times g \times h = 996,24 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 5,5 = 53,772 \text{ kPa} \]

Tekanan operasi :
P_{operasi} = 1 \text{ atm} = 101,325 \text{ kPa}

P_{total} = 101,325 \text{ kPa} + 53,772 \text{ kPa} = 155,097 \text{ kPa}

Faktor keamanan : 20 \%

P_{design} = (1,2) (155,097 \text{ kPa}) = 186,117 \text{ kPa}

Joint efficiency : E = 0,8 \quad \text{(Brownell & Young, 1959)}

Allowable stress : S = 12650 \text{ psia} = 87218,71 \text{ kPa} \quad \text{(Brownell & Young, 1959)}

Faktor korosi : C = 0,0098 \text{ in/tahun} \quad \text{(Peters dkk, 2004)}

Umur alat : n = 10 \text{ tahun}

Tebal shell tangki:

\[ t = \frac{PD}{2SE - 1,2P} + n \times C \]

\[ = \frac{(186,117 \text{ kPa})(3,862)}{2(87218,71 \text{ kPa})(0,8) - 1,2(186,117 \text{ kPa})} + 10 (0,0098 \text{ in}) \]

\[ = 0,00589 \times 39,37 \text{ in} + 0,098 \text{ in} \]

\[ = 0,33 \text{ in} \]

Tebal shell standar yang digunakan = 1/2 in \quad \text{(Brownell & Young, 1959)}

**LD.18 Tangki Bahan Bakar (V-17)**

Fungsi : Tempat penyimpanan bahan bakar.

Bentuk : Silinder vertikal dengan alas dan tutup datar

Bahan konstruksi : *Carbon steel SA-283, Grade C*

Jenis sambungan : *Single welded butt joints*

Jumlah : 1 unit

Kondisi operasi :

Temperatur = 30\°C

Laju volum solar (Q) = 936,268 ltr/jam

Densitas solar (\(\rho\)) = 0,89 kg/liter

Kebutuhan perancangan = 10 hari
Perhitungan ukuran tangki:

1. Volume tangki

\[ V_{solar} = 936,268 \text{ ltr/jam} \times 24 \text{ jam/hari} \times 10 \text{ hari} \times 10^{-3} \text{ m}^3/\text{ltr} = 224,7044 \text{ m}^3 \]

Faktor kelonggaran : 20 %

Volume tangki, \( V_t = 1,2 \times 224,7044 \text{ m}^3 = 269,6452 \text{ m}^3 \)

2. Diameter dan tinggi tangki

Direncanakan : Tinggi tangki : diameter tangki \( H_s : D = 2 : 1 \)

Volume tangki (\( V_t \))

\[ V_t = \frac{1}{4} \pi D^2 H_s \]

\[ V_t = \frac{1}{8} \pi D^3 \]

\[ 269,6452 = \frac{1}{8} \pi D^3 \]

Maka, diameter tangki \( D = 7,0033 \text{ m} \)

tinggi tangki \( H_t = H_s = \left( \frac{H_s}{D} \right) \times D = 14,0067 \text{ m} \)

3. Tebal shell tangki

Tinggi cairan dalam tangki, \( h = \frac{224,7044 \text{ m}^3}{269,6452 \text{ m}^3} \times 14,0067 \text{ m} = 11,6723 \text{ m} \)

Tekanan hidrostatik :

\[ P = \rho \times g \times h = 890 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 11,6723 = 101,8058 \text{ kPa} \]

Tekanan operasi :

\[ P_{operasi} = 1 \text{ atm} = 101,325 \text{ kPa} \]

\[ P_{total} = 101,325 \text{ kPa} + 101,8058 \text{ kPa} = 203,1308 \text{ kPa} \]

Faktor keamanan : 20 %

\[ P_{design} = (1,2) \times (203,1308 \text{ kPa}) = 243,7569 \text{ kPa} \]

*Joint efficiency : \( E = 0,8 \) \quad \text{(Brownell & Young, 1959)}

*Allowable stress : \( S = 12650 \text{ psia} = 87218,71 \text{ kPa} \) \quad \text{(Brownell & Young, 1959)}

Faktor korosi : \( C = 0,0098 \text{ in/tahun} \) \quad \text{(Peters dkk, 2004)}

Umur alat : \( n = 10 \text{ tahun} \)
Tebal shell tangki :
\[
t = \frac{PD}{2SE - 1.2P} + n C = \frac{(243,759 \text{ kPa}) (7.0033)}{2(87218.71 \text{ kPa}) (0.8) - 1.2(243,759 \text{ kPa})} + 10 (0.0098 \text{ in})
\]
\[
= 0.0122 \times 39.37 \text{ in} + 0.098 \text{ in}
\]
\[
= 0.5806 \text{ in}
\]
Tebal shell standar yang digunakan = 3/4 in  
(Brownell & Young, 1959)

**L.D.19 Kompresor (JC-01)**

**Fungsi** : menaikkan tekanan steam dari ketel uap II (V-15) sebelum dialirkan ke proses

**Jenis** : Reciprocating compressor

**Jumlah** : 1 unit dengan 1 stages

**Data** :

Laju alir massa \((m)\) = 11477,65 kg/jam

Laju alir volumetrik \((m_v)\) = \[
\frac{N \times 83.14 \text{ dm}^3 \text{ bar/kmol.K} \times 548.15 \text{ K}}{101325 \text{ bar}}
\]
\[
= \frac{141 \text{ kmol} \times 83.14 \text{ dm}^3 \text{ bar/kmol.K} \times 548.15 \text{ K}}{101325 \text{ bar}}
\]
\[
= 28679.61 \text{ m}^3/\text{jam} = 7.96 \text{ m}^3/\text{detik}
\]

\[
\rho \ \text{campuran} = \frac{m}{m_v} = 0.4 \text{ kg/m}^3
\]

**Diameter pipa ekonomis (De) dihitung dengan persamaan** :

\[
De = 0.363 \ (m_v)^{0.45} \ (\rho)^{0.13}\]  
(Timmerhaus, 2004)
\[
= 0.363 \ (17.96)^{0.45} \ (0.4)^{0.13}
\]
\[
= 0.437 \text{ m} = 17.21 \text{ in}
\]

Dipilih material pipa commercial steel 18 inci Sch 20 :

- Diameter dalam (ID) = 17.25 in = 1,938 ft
- Diameter luar (OD) = 18 in = 1,435 ft
- Luas penampang (A) = 234 in\(^2\) = 19,5 ft\(^2\)
Daya kompresor:

\[ P = 2.78 \times 10^{-4} m_v \times p_1 \times \ln \left( \frac{p_2}{p_1} \right) \]

(Timmerhaus, 2004)

dimana : 

- \( P \) = daya (kW)
- \( m_v \) = laju alir (m\(^3\)/jam)
- \( p_1 \) = tekanan masuk = 101,325 kPa
- \( p_2 \) = tekanan keluar = 5400 kPa

\[ P = 2.78 \times 10^{-4} (28679,607) \times 101,325 \times \ln \left( \frac{5400}{101,325} \right) \]

= 710,343 kW

Jika efisiensi motor adalah 75%, maka :

\[ P = \frac{710,343}{0,75} = 947,125 \text{ kW} = 1270,115 \text{ hp} \]

Maka dipilih kompresor dengan daya 1270 hp

**L.D.19 Pompa Screening (P-01)**

Fungsi : Memompa air dari sungai ke bak sedimentasi (V-01)

Jenis : *Centrifugal pump*

Jumlah : 1 unit

Bahan konstruksi : *Commercial steel*

Kondisi operasi :

Temperatur = 30°C

Densitas air (\( \rho \)) = 995,68 kg/m\(^3\) = 62,1599 lb\(_m\)/ft\(^3\)  

(Geankoplis, 2003)

Viskositas air (\( \mu \)) = 0,836 cP = 0,000562 lb\(_m\)/ft s  

(Geankoplis, 2003)

Laju alir massa (\( F \)) = 12680,9685 kg/jam

Laju alir volumetrik (\( Q \)) = \[ \frac{12680,9685 \text{ kg/jam}}{995,68 \text{ kg/m}^3 \times 3600 \text{ s/jam}} \] = 0,00353 m\(^3\)/s = 0,1249 ft\(^3\)/s

Desain pompa:
untuk aliran turbulen $N_{Re} > 2100$

$$D_{opt} = 0,363 \frac{Q^{0.45} \rho^{0.13}}{\mu}$$ (Peters dkk, 2004)

$$= 0,363 \left(0,00353 \text{ m}^3/\text{s}\right)^{0.45} \left(995,68 \text{ kg/m}^3\right)^{0.13}$$

$$= 0,0702 \text{ m} = 2,7653 \text{ in}$$

Dari Tabel A.5-1 Geankoplis, 2003, dipilih pipa dengan spesifikasi:

- **Ukuran nominal**: 3 in
- **Schedule number**: 80
- **Diameter Dalam (ID)**: 2,9 in = 0,24167 ft
- **Diameter Luar (OD)**: 3,5 in = 0,29167 ft
- **Luas penampang dalam (A)**: 0,0513 ft$^2$

Kecepatan linier, $v = \frac{Q}{A} = 2,4352 \text{ ft/s}$

Bilangan Reynolds:

$$N_{Re} = \frac{\rho \times v \times D}{\mu}$$ (Peters dkk, 2004)

$$= \frac{(62,1599 \text{ lbm/ft}^3)(2,4311 \text{ ft/s})(0,24167 \text{ ft})}{0,000562 \text{ lbm/ft s}}$$

$$= 65121 \text{ (aliran turbulen)}$$

Untuk pipa Commercial Steel diperoleh harga $\varepsilon = 0,000046$ ; $\varepsilon/D = 0,00062$, pada $N_{Re} = 65121$ diperoleh harga faktor fanning $f = 0,006$ (Geankoplis, 2003).

**Friction loss**:

1. **sharp edge entrance**

$$h_c = 0,55 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 \alpha g_c} = 0,55 (1 - 0) \frac{2,4352^2}{2(1)(32,174)}$$

$$= 0,046 \text{ ft lbf/lbm}$$

1. **elbow 90°**

$$h_f = nKf \frac{v^2}{2 g_c} = 1(0,75) \frac{2,4532^2}{2(1)(32,174)} = 0,069 \text{ ft lbf/lbm}$$

1. **gate valve**

$$h_f = nKf \frac{v^2}{2 g_c} = 1(2) \frac{2,4532^2}{2(1)(32,174)} = 0,1843 \text{ ft lbf/lbm}$$
Pipa lurus 70 ft

\[ F_t = 4f \frac{\Delta L \nu^2}{D g_c} = 4(0.006) \frac{(70)(2.4532)^2}{(0.24167)(2)(32.174)} \]

\[ = 0.6407 \text{ ft lbf/lbm} \]

1 sharp edge exit

\[ h_{ex} = n \left(1 - \frac{A_1}{A_2}\right)^2 \frac{\nu^2}{2 \alpha g_c} = 1 \left(1 - 0\right) \frac{2.4532^2}{2(1)(32.174)} \]

\[ = 0.0921 \text{ ft lbf/lbm} \]

Total friction loss

\[ \sum F = 1,0324 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:

\[ \frac{1}{2 g_c} \left(v_2^2 - v_1^2\right) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \]

(Geankoplis, 2003)

dimana : \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 50 \) ft

\[ 0 + \frac{32.174}{32.174}(50) + 0 + 1.0324 + W_s = 0 \]

\[ -W_s = 51.0324 \text{ ft lbf/lbm} \]

Efisiensi pompa, \( \eta = 80 \% \)

\[ W_p = -W_s / \eta = 63.7905 \text{ ft lbf/lbm} \]

Daya pompa:

\[ P = \frac{W_p Q \rho}{550} = \frac{(63.7905)(0.0035)(62.1599)}{550} = 0.9 \text{ hp} \]

Digunakan daya motor standar 1 hp

**LD.20 Pompa Bak Sedimentasi (P-02)**

Fungsi : Memompa air dari Bak Sedimentasi (V-01) ke Clarifier (V-04)

Jenis : Centrifugal pump

Jumlah : 1 unit

Bahan konstruksi : Commercial steel

Kondisi operasi :
Temperatur = 30°C

Densitas air ($\rho$) = 995,68 kg/m$^3$ = 62,1599 lbm/ft$^3$ (Geankoplis, 2003)

Viskositas air ($\mu$) = 0,836 cP = 0,000562 lbm/ft s (Geankoplis, 2003)

Laju alir massa (F) = 12680,9685 kg/jam

Laju alir volumetrik (Q) = $\frac{12680,9685 \text{ kg/jam}}{995,68 \text{ kg/m}^3 \times 3600 \text{ s/jam}} = 0,0035 \text{ m}^3/\text{s} = 0,1249 \text{ ft}^3/\text{s}$

Desain pompa:

untuk aliran turbulen $N_{Re}$ > 2100

$D_{i, opt} = 0,363 \ Q^{0,45} \ \rho^{0,13}$ (Peters dkk, 2004)

$= 0,363 \ (0,0035 \text{ m}^3/\text{s})^{0,45} \ (995,68 \text{ kg/m}^3)^{0,13}$

$= 0,0702 \text{ m} = 2,7653 \text{ in}$

Dari Tabel A.5-1 Geankoplis,2003, dipilih pipa dengan spesifikasi:

- Ukuran nominal: 3 in
- Schedule number: 80
- Diameter Dalam (ID): 2,9 in = 0,24167 ft
- Diameter Luar (OD): 3,5 in = 0,29167 ft
- Luas penampang dalam (A): 0,0513 ft$^2$
- Kecepatan linier, $v = \frac{Q}{A} = 2,4352 \text{ ft/s}$

Bilangan Reynold:

$N_{Re} = \frac{\rho \times v \times D}{\mu}$ (Peters dkk, 2004)

$= \frac{(62,1599 \text{ lbm/ft}^3) (22,4352 \text{ ft/s}) (0,24167 \text{ ft})}{0,000562 \text{ lbm/ft s}}$

$= 65121$ (aliran turbulen)

Untuk pipa Commercial Steel diperoleh harga $\varepsilon = 0,000046$; $\varepsilon/D = 0,00062$, pada $N_{Re} = 67412,3$ diperoleh harga faktor fanning $f = 0,006$ (Geankoplis, 2003).
1 sharp edge entrance

\[ h_c = 0.55 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0.55 (1 - 0) \frac{2.4352^2}{2(1)(32,174)} \]

= 0,046 ft lbf/lbm

2 elbow 90°

\[ h_f = n \cdot Kf \cdot \frac{v^2}{2 g_c} = 2(0.75) \frac{2.4352^2}{2(1)(32,174)} = 0,1382 ft lbf/lbm \]

1 gate valve

\[ h_f = n \cdot Kf \cdot \frac{v^2}{2 g_c} = 1(2) \frac{2.4352^2}{2(1)(32,174)} = 0,1843 ft lbf/lbm \]

Pipa lurus 30 ft

\[ F_t = 4f \frac{\Delta L \cdot v^2}{D \cdot 2 \cdot g_c} = 4(0,006) \frac{(30)(2,4352)^2}{(0,24167)(2)(32,174)} \]

= 0,2745 ft lbf/lbm

1 sharp edge exit

\[ h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right) \frac{v^2}{2 \alpha g_c} = 1 (1 - 0) \frac{2.4352^2}{2(1)(32,174)} \]

= 0,0921 ft lbf/lbm

Total friction loss

\[ \Sigma F = 0,7354 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:

\[ \frac{1}{2} \frac{v_2^2 - v_1^2}{g_c} + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \Sigma F + W_s = 0 \]  

(Geankoplis, 2003)

dimana : \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 50 \text{ ft} \)

\[ 0 + \frac{32,174}{32,174} (50) + 0 + 0,7354 + W_s = 0 \]

\[-W_s = 50,7354 \text{ ft lbf/lbm} \]

Efisiensi pompa, \( \eta = 80 \% \)

\[ W_p = -W_s / \eta = 63,4192 \text{ ft lbf/lbm} \]

Daya pompa:

\[ P = \frac{W_p \cdot Q \cdot \rho}{550} = \frac{(63,4192)(0,1249)(62,1599)}{550} = 0,89 \text{ hp} \]

Digunakan daya motor standar 1 hp

**LD.21 Pompa Alum (P-03)***
Fungsi : Memompa larutan alum dari Tangki Pelarutan Alum (V-02) ke Clarifier (V-04)

Jenis : Centrifugal pump

Jumlah : 1 unit

Bahan konstruksi : Commercial steel

Kondisi operasi :
Temperatur = 30\(^\circ\)C

Densitas alum (\(\rho\)) = 1363 kg/m\(^3\) = 85,0915 lbm/ft\(^3\) (Perry dkk, 1999)

Viskositas alum (\(\mu\)) = 6,72 \(10^{-4}\) lbm/ft s = 1 cP (Kirk & Othmer, 1949)

Laju alir massa (F) = 0,634 kg/jam

Debit air/laju alir volumetrik, \(Q = \frac{F}{\rho} = 1,29.10^{-7}\) m\(^3\)/s = 4,56.10\(^{-6}\) ft\(^3\)/s

Desain pompa :
untuk aliran viscous \(N_{Re} < 2100\)

\[D_{i,opt} = 3 Q^{0.36} \mu^{0.18}\] (Peters dkk, 2004)

\[= 3 (4,56.10^{-6} \text{ ft}^3/\text{s})^{0.36} (0,000672 \text{ lbm/ft.s})^{0.18}\]

\[= 0,009625 \text{ ft} = 0,1154 \text{ in}\]

Dari Tabel A.5-1 Geankoplis, 2003, dipilih pipa dengan spesifikasi :

Ukuran nominal : 1/8 in

Schedule number : 40

Diameter Dalam (ID) : 0,269 in = 0,022417 ft

Diameter Luar (OD) : 0,405 in = 0,033750 ft

Luas penampang dalam (A) : 0,0004 ft\(^2\)

Kecepatan linier, \(v = \frac{Q}{A} = \frac{4,56.10^{-6} \text{ ft}^3/\text{s}}{0,0004 \text{ ft}^2} = 0,0114 \text{ ft/s}\)

Bilangan Reynolds :
\[N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{(85,0915 \text{ lbm/ft}^3)(0,0114 \text{ ft/s})(0,022417 \text{ ft})}{0,000672 \text{ lbm/ft s}}\]

\[= 32,3824 \text{ (aliran laminar)}\]
Untuk pipa *Commercial Steel* pada \( N_{Re} = 32,3824 \) diperoleh harga faktor *fanning* \( f = 0,4773 \) (Geankoplis, 2003).

*Friction loss*:

1. **sharp edge entrance**
   \[ h_c = 0,55 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0,55 (1 - 0) \frac{0,0114^2}{2(1)(32,174)} \]
   \[ = 1,01.10^{-6} \text{ ft lbf/lbm} \]

2. **elbow 90°**
   \[ h_f = n.Kf. \frac{v^2}{2 g_c} = 1(0,75) \frac{0,0114^2}{2(1)(32,174)} = 1,52.10^{-6} \text{ ft lbf/lbm} \]

3. **check valve**
   \[ h_f = n Kf \frac{v^2}{2 g_c} = 1(2) \frac{0,0114^2}{2(1)(32,174)} = 4,04.10^{-6} \text{ ft lbf/lbm} \]

Pipa lurus 30 ft \( F_l = 4f \frac{\Delta L v^2}{D 2 g_c} = 4(0,54) \frac{(30)(0,0114)^2}{(0,022417)(2)(32,174)} \]
\[ = 0,00534 \text{ ft lbf/lbm} \]

1. **sharp edge exit**
   \[ h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left( 1 - 0 \right) \frac{0,0114^2}{2(1)(32,174)} \]
   \[ = 2,02.10^{-6} \text{ ft lbf/lbm} \]

Total *friction loss* \( \sum F = 0,00535 \text{ ft lbf/lbm} \)

Dari persamaan Bernoulli:

\[
\frac{1}{2 g_c} (v_2^2 - v_1^2) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \quad \text{(Geankoplis, 2003)}
\]

dimana : \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 50 \text{ ft} \)

\[ 0 + \frac{32,174}{32,174} (50) + 0 + 0,00535 + W_s = 0 \]

\[ W_s = 50,00535 \text{ ft lbf/lbm} \]

Efisiensi pompa, \( \eta = 80 \% \)

\[ W_p = -W_s / \eta = 62,5067 \text{ ft lbf/lbm} \]

Daya pompa : \[ P = \frac{W_p \cdot Q \cdot \rho}{550} = \frac{(62,5067)(4,56.10^{-6})(85,09154)}{550} = 4.41^{-5} \text{ hp} \]
Digunakan daya motor standar 1/8 hp

**LD.22 Pompa Soda Abu (P-04)**

Fungsi : Memompa larutan soda abu dari Tangki Pelarutan Soda Abu (V-02) ke Clarifier (V-04)

Jenis : *Centrifugal pump*

Jumlah : 1 unit

Bahan konstruksi : *Commercial steel*

**Kondisi operasi :**

Temperatur = 30°C

Densitas soda abu ($\rho$) = 1327 kg/m$^3$ = 82,8423 lb$_m$/ft$^3$ (Perry dkk, 1999)

Viskositas soda abu ($\mu$) = 0,549 cP = 3,69 $10^{-4}$ lb$_m$/ft s (Kirk & Othmer, 1949)

Laju alir massa (F) = 0,3423 kg/jam

Debit air/laju alir volumetrik, $Q = \frac{F}{\rho} = \frac{0,3423 \text{ kg / jam}}{1327 \text{ kg/m}^3 \times 3600 \text{ s / jam}}$

$= 7,17.10^{-8} \text{ m}^3/\text{s} = 2,53.10^{-6} \text{ ft}^3/\text{s}$

**Desain pompa :**

untuk aliran viscous $N_{Re} < 2100$

$D_{i, opt} = 3 Q^{0.36} \mu^{0.18}$ (Peters dkk, 2004)

$= 3 (2,53.10^{-6} \text{ ft}^3/\text{s})^{0.36} (0,000369 \text{ lbm/ft.s})^{0.18}$

$= 0,00698 \text{ ft} = 0,08385 \text{ in}$

Dari Tabel A.5-1 Geankoplis,2003, dipilih pipa dengan spesifikasi :

Ukuran nominal : $\frac{1}{8}$ in

*Schedule number* : 40

Diameter Dalam (ID) : 0,269 in = 0,022417 ft

Diameter Luar (OD) : 0,405 in = 0,0338 ft

Inside sectional area $A$ : 0,0004 ft$^2$

Kecepatan linier, $v = \frac{Q}{A} = \frac{2,53.10^{-6} \text{ ft}^3/\text{s}}{0,0004 \text{ ft}^2} = 0,006327 \text{ ft/s}$

Bilangan Reynold :
Untuk pipa Commercial Steel pada \( N_{Re} = 31,8515 \) diperoleh harga faktor fanning \( f = 0,4853 \) (Geankoplis, 2003).

\[
N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{(82,8423 \text{ lbm/ft}^3)(0,006327 \text{ ft/s})(0,022417 \text{ ft})}{0,000369 \text{ lbm/ft s}} = 31,8515 \text{ (aliran laminar)}
\]

**Friction loss :**

1. **sharp edge entrance**

\[
h_c = 0,5 \left(1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0,5 (1 - 0) \frac{0,006327^2}{2(1)(32,174)}
\]

\[
h_c = 3,11 \times 10^{-7} \text{ ft lbf/lbm}
\]

1. **elbow 90°**

\[
h_f = n.K_f \frac{v^2}{2 g_c} = 1(0,75) \frac{0,006327^2}{2(32,174)} = 4,67 \times 10^{-7} \text{ ft lbf/lbm}
\]

1. **check valve**

\[
h_f = n.K_f \frac{v^2}{2 g_c} = 1(2) \frac{0,006327^2}{2(32,174)} = 1,24 \times 10^{-6} \text{ ft lbf/lbm}
\]

Pipa lurus 30 ft \( F_f = 4f \frac{\Delta L v^2}{D 2 g_c} = 4(0,5493) \frac{(30)(0,006327)^2}{(0,022417)(32,174)} \)

\[
F_f = 0,001673 \text{ ft lbf/lbm}
\]

1. **sharp edge exit**

\[
h_{ex} = n \left(1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left(1 - 0 \right) \frac{0,006327^2}{2(1)(32,174)}
\]

\[
h_{ex} = 6,22 \times 10^{-7} \text{ ft lbf/lbm}
\]

**Total friction loss**

\[
\sum F = 0,001676 \text{ ft lbf/lbm}
\]

Dari persamaan Bernoulli :

\[
\frac{1}{2 g_c} \left(v_2^2 - v_1^2\right) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \tag{Geankoplis, 2003}
\]

dimana : \( v_1 = v_2 ; \Delta v^2 = 0 ; P_1 = P_2 ; \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 50 \text{ ft} \)
0 + \frac{32,174}{32,174} (50) + 0 + 0,001676 + W_s = 0

-W_s = 50,0016 ft lbf/lbm

Efisiensi pompa, \( \eta = 80\% \)

\[ W_p = \frac{-W_s}{ \eta} = 62,502 \text{ ft lbf/lbm} \]

Daya pompa:

\[ P = \frac{W_p \rho Q}{550} = \frac{(62,502)(2,53.10^{-6})(82,84408)}{550} = 2,38.10^{-5} \text{ hp} \]

Digunakan daya motor standar 1/8 hp

**LD.23 Pompa Sand filter (P-05)**

Fungsi: Memompa air dari sand filter (V-05) ke Bak Penampung Air (V-06)

Jenis: Centrifugal pump

Jumlah: 1 unit

Bahan konstruksi: Commercial steel

Kondisi operasi:

Temperatur = 30\(^\circ\)C

Densitas air \( (\rho) \) = 995,68 kg/m\(^3\) = 62,1599 lbm/ft\(^3\) \hspace{1cm} \text{(Geankoplis, 2003)}

Viskositas air \( (\mu) \) = 0,836 cP = 0,000562 lbm/ft s \hspace{1cm} \text{(Geankoplis, 2003)}

Laju alir massa \( (F) \) = 12680,9685 kg/jam

\[ \text{Laju alir volumetrik (Q)} = \frac{12680,9685 \text{ kg/jam}}{995,68 \text{ kg/m}^3 \times 3600 \text{ s/jam}} = 0,00353 \text{ m}^3/s = 0,1249 \text{ ft}^3/s \]

Desain pompa:

untuk aliran turbulen \( N_{Re} > 2100 \)

\[ Di_{opt} = 0,363 Q^{0,45} \rho^{0,13} \hspace{1cm} \text{(Peters dkk, 2004)} \]

\[ = 0,363 \times (0,00353 \text{ m}^3/s)^{0,45} \times (995,68 \text{ kg/m}^3)^{0,13} \]

\[ = 0,07024 \text{ m} = 2,7653 \text{ in} \]

Dari Tabel A.5-1 Geankoplis, 2003, dipilih pipa dengan spesifikasi:

Ukuran nominal : 3 in
Schedule number : 80
Diameter Dalam (ID) : 2,9 in = 0,24167 ft
Diameter Luar (OD) : 3,5 in = 0,29167 ft
Luas penampang dalam (A) : 0,0513 ft²
Kecepatan linier, \( v = \frac{Q}{A} = 2,4352 \) ft/s

Bilangan Reynolds:
\[
N_{Re} = \frac{\rho \times v \times D}{\mu}
\]
(Peters dkk, 2004)
\[
= \frac{(62,1599 \text{ lbm/ft}²)(2,4352 \text{ ft/s})(0,24167 \text{ ft})}{0,000562 \text{ lbm/ft s}}
\]
\[
= 65121 \text{ (aliran turbulen)}
\]
Untuk pipa Commercial Steel diperoleh harga \( \varepsilon = 0,000046 \); \( \varepsilon/D = 0,00062 \), pada \( N_{Re} = 65121 \) diperoleh harga faktor fanning \( f = 0,006 \) (Geankoplis, 2003).

Friction loss:
1 sharp edge entrance
\[
h_c = 0,55 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0,55 (1 - 0) \frac{2,4352^2}{2(1)(32,174)}
\]
\[
= 0,046 \text{ ft lbf/lbm}
\]
3 elbow 90°
\[
h_f = n \cdot K_f \cdot \frac{v^2}{2 g_c} = 3(0,75) \frac{2,4352^2}{2(1)(32,174)} = 0,2073 \text{ ft lbf/lbm}
\]
1 gate valve
\[
h_f = n \cdot K_f \cdot \frac{v^2}{2 g_c} = 1(2) \frac{2,4352^2}{2(1)(32,174)} = 0,1843 \text{ ft lbf/lbm}
\]
Pipa lurus 80 ft
\[
F_f = 4f \frac{\Delta L v^2}{D 2 g_c} = 4(0,006) \frac{(80)(2,4352)^2}{(0,24167)(2)(32,174)}
\]
\[
= 0,7322 \text{ ft lbf/lbm}
\]
1 sharp edge exit
\[
h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right) \frac{v^2}{2 \alpha g_c} = 1 (1 - 0) \frac{2,4352^2}{2(1)(32,174)}
\]
\[
= 0,0921 \text{ ft lbf/lbm}
\]
Total friction loss
\[
\sum F = 1,2621 \text{ ft lbf/lbm}
\]
Dari persamaan Bernoulli:

\[
\frac{1}{2} \frac{v_2^2 - v_1^2}{g_c} + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0
\]

(Geankoplis, 2003)

dimana : \(v_1 = v_2\) ; \(\Delta v^2 = 0\) ; \(P_1 = P_2\) ; \(\Delta P = 0\)

tinggi pemompaan \(\Delta z = 60\) ft

\[
0 + \frac{32,174}{32,174} (60) + 0 + 1,2621 + W_s = 0
\]

\(-W_s = 61,2621\) ft lbf/lbm

Efisiensi pompa, \(\eta = 80\%\)

\(W_p = -W_s / \eta = 76,5777\) ft lbf/lbm

Daya pompa : \(P = \frac{W_p Q \rho}{550} = \frac{(76,5777)(0,1249)(62,1599)}{550} = 1,081\) hp

Digunakan daya motor standar 1 1/4 hp

**LD.24 Pompa Bak Penampungan Air (P-06)**

**Fungsi** : Memompa air dari bak penampungan air ke *cation exchanger* V-08, *water cooling tower* V-14, dan tangki utilitas V-16.

**Jenis** : *Centrifugal pump*

**Jumlah** : 1 unit

**Bahan konstruksi** : *Commercial steel*

**Kondisi operasi** :

**Temperatur** = 30°C

**Densitas air** \((\rho)\) = 995,68 kg/m³ = 62,1599 lb_{in}/ft³ (Geankoplis, 2003)

**Viskositas air** \((\mu)\) = 0,836 cP = 0,000562 lb_{in}/ft s (Geankoplis, 2003)

**Laju alir massa** \((F)\) = 12680,9685 kg/jam

**Laju alir volumetrik** \((Q)\) = \(\frac{12680,9685 \text{ kg/jam}}{995,68 \text{ kg/m}^3 \times 3600 \text{ s/jam}} = 0,00353 \text{ m}^3/\text{s} = 0,1249 \text{ ft}^3/\text{s}\)

**Desain pompa** :

untuk aliran turbulen \(N_{Re} > 2100\)
\[ Di_{\text{opt}} = 0.363 Q^{0.45} \rho^{0.13} \]  
\[ = 0.363 (0,00353 \text{ m}^3/\text{s})^{0.45} (995.68 \text{ kg/m}^3)^{0.13} \]
\[ = 0.07024 \text{ m} = 2,7653 \text{ in} \]

Dari Tabel A.5-1 Geankoplis, 2003, dipilih pipa dengan spesifikasi:

Ukuran nominal : 3 in 
Schedule number : 80 
Diameter Dalam (ID) : 2,9 in = 0,24167 ft 
Diameter Luar (OD) : 3,5 in = 0,29167 ft 
Luas penampang dalam (A) : 0,0513 ft\(^2\)
Kecepatan linier, \(v = \frac{Q}{A} = 2,4352 \text{ ft/s} \)

Bilangan Reynolds:
\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]  
\[ = \frac{(62,1599 \text{ lbm/ft}^3)(2,4352 \text{ ft/s})(0,24167 \text{ ft})}{0,000562 \text{ lbm/ft s}} \]
\[ = 65121 \text{ (aliran turbulen)} \]

Untuk pipa Commercial Steel diperoleh harga \( \varepsilon = 0,000046 ; \varepsilon/D = 0,00062 \), pada \( N_{Re} = 65121 \) diperoleh harga faktor fanning \( f = 0,006 \) (Geankoplis, 2003).

Friction loss:
\[ 1 \text{ sharp edge entrance } h_c = 0,55 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 \alpha g_c} = 0,55 (1 - 0) \frac{2,4352^2}{2(1)(32,174)} \]
\[ = 0,046 \text{ ft lbf/lbm} \]
\[ 4 \text{ elbow } 90^\circ h_f = n.Kf. \frac{v^2}{2 g_c} = 4(0,75) \frac{2,4352^2}{2(1)(32,174)} = 0,2764 \text{ ft lbf/lbm} \]
\[ 1 \text{ gate valve } h_f = n Kf. \frac{v^2}{2 g_c} = 1(2) \frac{2,4352^2}{2(1)(32,174)} = 0,1843 \text{ ft lbf/lbm} \]

Pipa lurus 120 ft \( F_f = 4f \frac{AL v^2}{D 2 g_c} = 4(0,006) \frac{(120)(2,4352)^2}{(0,24167)(2)(32,174)} \)
Dari persamaan Bernoulli:

\[
\frac{1}{2} g_c \left( v_2^2 - v_1^2 \right) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0
\]

(Geankoplis, 2003)

dimana : \( v_1 = v_2 ; \Delta v^2 = 0 ; P_1 = P_2 ; \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 60 \) ft

\[
0 + \frac{32,174}{32,174} (60) + 0 + 1,1674 + W_s = 0
\]

\[-W_s = 61,6974 \text{ ft lb/lbm} \]

Efisiensi pompa, \( \eta = 80 \% \)

\[
W_p = -W_s / \eta = 77,1218 \text{ ft lb/lbm}
\]

Daya pompa : \( P = \frac{W_p Q \rho}{550} = \frac{(77,1218)(0,1249)(62,1599)}{550} = 1,08 \text{ hp} \)

Digunakan daya motor standar 1 1/4 hp

**LD.25 Pompa Asam Sulfat (P-07)**

Fungsi : Memompa larutan asam sulfat dari Tangki Pelarutan Asam Sulfat (V-07) ke Cation Exchanger (V-08)

Jenis : Centrifugal pump

Jumlah : 1 unit

Bahan konstruksi : Commercial steel

Kondisi operasi :

Temperatur = 30\(^\circ\)C

Densitas asam sulfat (\( \rho \)) = 1061,7 kg/m\(^3\) = 66,2815 lbm/ft\(^3\) \( \) (Perry dkk, 1999)
Viskositas asam sulfat \( (\mu) = 17,86 \text{ cP} = 0,012001 \text{lbm/ft s} \) (Kirk & Othmer, 1949)

Laju alir massa \((F) = 0,0137 \text{ kg/jam}\)

Debit air/laju alir volumetrik, \( Q = \frac{F}{\rho} = \frac{0,0137 \text{ kg / jam}}{1061,7 \text{ kg/m}^3 \times 3600 \text{ s / jam}} \)

\[ = 3,6 \times 10^{-9} \text{ m}^3/\text{s} = 1,27 \times 10^{-7} \text{ ft}^3/\text{s} \]

**Desain pompa**:

untuk aliran **viscous** \( N_{Re} < 2100 \)

\[ \text{Di}_{opt} = 3 Q^{0.36} \mu^{0.18} \]

\( \text{(Peters dkk, 2004)} \)

\[ = 3 (1,27 \times 10^{-7} \text{ ft}^3/\text{s})^{0.36} (0,012001 \text{lbm/ft.s})^{0.18} \]

\[ = 0,004457 \text{ ft} = 0,05349 \text{ in} \]

Dari Tabel A.5-1 Geankoplis,2003, dipilih pipa dengan spesifikasi :

**Ukuran nominal** : 1/8 in

**Schedule number** : 40

**Diameter Dalam (ID)** : 0,269 in = 0,02242 ft

**Diameter Luar (OD)** : 0,405 in = 0,03375 ft

**Inside sectional area A** : 0,0004 \( \text{ft}^2 \)

Kecepatan linier, \( v = \frac{Q}{A} = \frac{1,27 \times 10^{-7} \text{ ft}^3/\text{s}}{0,0004 \text{ ft}^2} = 0,000318 \text{ ft/s} \)

**Bilangan Reynolds** :

\[ N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{(66,2815 \text{ lbm/ft}^3)(0,000318 \text{ ft/s})(0,02242 \text{ ft})}{0,012001 \text{ lbm/ft s}} \]

\[ = 0,03939 \text{ (aliran laminar)} \]

Untuk pipa **Commercial Steel** pada \( N_{Re} = 0,03939 \) diperoleh harga faktor **fanning** \( f = 406,1738 \) (Geankoplis, 2003).

**Friction loss** :

1 **sharp edge entrance** \( h_c = 0,5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0,5 (1 - 0) \frac{0,000318^2}{2(1)(32,174)} \)

\[ = 8,87 \times 10^{-10} \text{ ft lbf/lbm} \]

1 **elbow 90°** \( h_f = n.K f \frac{v^2}{2 g_c} = 1(0,75) \frac{0,000318^2}{2(32,174)} = 1,18 \times 10^{-9} \text{ ft lbf/lbm} \)
1 check valve

\[ h_f = nK_f \frac{v^2}{2g_c} = 1(2) \frac{0,000318^2}{2(32,174)} = 3,15 \times 10^{-9} \text{ ft lbf/lbm} \]

Pipa lurus 30 ft

\[ F_t = 4f \frac{\Delta L v^2}{D^2 g_c} = 4(59,08) \frac{(30)(0,000318)^2}{(0,03033)(2)(32,174)} \]

\[ = 0,00342 \text{ ft lbf/lbm} \]

1 sharp edge exit

\[ h_{ex} = n \left[ 1 - \frac{A_1}{A_2} \right] \frac{v^2}{2g_c} = 1 \left( 1 - 0 \right) \frac{0,000318^2}{2(1)(32,174)} \]

\[ = 1,57 \times 10^{-9} \text{ ft lbf/lbm} \]

Total friction loss \[ \Sigma F = 0,00342 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:

\[ \frac{1}{2g_c} \left( v_2^2 - v_1^2 \right) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \Sigma F + W_s = 0 \]

(Geankoplis, 2003)

dimana \[ v_1 = v_2 ; \Delta v^2 = 0 ; P_1 = P_2 ; \Delta P = 0 \]

tinggi pemompaan \[ \Delta z = 50 \text{ ft} \]

\[ 0 + \frac{32,174}{32,174} (50) + 0 + 0,00342 + W_s = 0 \]

\[ -W_s = 50,00342 \text{ ft lbf/lbm} \]

Efisiensi pompa, \[ \eta = 80 \% \]

\[ W_p = -W_s / \eta = 62,5042 \text{ ft lbf/lbm} \]

Daya pompa:

\[ P = \frac{W_p Q \rho}{550} = \frac{(62,5042)(1,27.10^{-7})(66,2815)}{550} = 5,96.10^{-7} \text{ hp} \]

Digunakan daya motor standar 1/8 hp

**LD.26 Pompa NaOH (P-08)**

Fungsi : Memompa larutan NaOH dari Tangki Pelarutan NaOH (V-09) ke *Anion Exchanger* (V-10)

Jenis : *Centrifugal pump*

Jumlah : 1 unit

Bahan konstruksi : Commercial steel

Kondisi operasi :
Temperatur  = 30°C
Densitas NaOH (\(\rho\))  = 1518 kg/m\(^3\) = 94,76813 lbm/ft\(^3\)  (Perry dkk, 1999)
Viskositas NaOH (\(\mu\))  = 0,00043 lbm/ft s = 0,64 cP  (Kirk & Othmer, 1949)
Laju alir massa (F)  = 0,10083 kg/jam
Debit air/laju alir volumetrik, Q = \(\frac{F}{\rho}\) = \(\frac{0,10083 \text{ kg/jam}}{1518 \text{ kg/m}^3 \times 3600 \text{ s/jam}}\)
   = 1,85.10\(^{-8}\) m\(^3\)/s = 6,52.10\(^{-7}\) ft\(^3\)/s

Desain pompa :
untuk aliran viscous \(N_{Re} < 2100\)
\[D_{i, opt} = 3 Q^{0.36} \mu^{0.18}\]
   = 3 \((6,52.10^{-7} \text{ ft}^3/\text{s})^{0.36} (0,00043 \text{ lbm/ft.s})^{0.18}\)
   = 0,004407 ft = 0,052889 in

Dari Tabel A.5-1 Geankoplis,2003, dipilih pipa dengan spesifikasi :

Ukuran nominal : \(\frac{1}{8}\) in

Schedule number : 40

Diameter Dalam (ID)  : 0,269 in = 0,022417 ft = 0,0068 m
Diameter Luar (OD)  : 0,405 in = 0,0338 ft

Inside sectional area A : 0,0004 ft\(^2\)

Kecepatan linier, \(v = \frac{Q}{A}\) = \(\frac{6,52.10^{-7} \text{ ft}^3/\text{s}}{0,0004 \text{ ft}^2}\) = 0,00162 ft/s

Bilangan Reynold :
\[N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{(94,76813 \text{ lbm/ft}^3) (0,00162 \text{ ft/s}) (0,022417 \text{ ft})}{0,00043 \text{ lbm/ft s}}\]
   = 8,0463 (aliran laminar)

Untuk pipa Commercial Steel pada \(N_{Re} = 8,0463\) diperoleh harga faktor fanning f = 1,9884 (Geankoplis, 2003).

Friction loss :
1 sharp edge entrance \(h_c = 0,5 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 \alpha g_c} = 0,5 (1 - 0) \frac{0,00162^2}{2(1)(32,174)}\)
\[ h_f = n \cdot K_f \cdot \frac{v^2}{2 \cdot g_c} \]

1 elbow 90°

\[ h_f = 1(0.75) \cdot \frac{0.00162^2}{2(32,174)} = 3.09 \times 10^{-8} \text{ ft lbf/lbm} \]

1 check valve

\[ h_f = 1(2) \cdot \frac{0.00162^2}{2(32,174)} = 8.25 \times 10^{-8} \text{ ft lbf/lbm} \]

Pipa lurus 30 ft

\[ F_f = 4 \cdot f \cdot \frac{\Delta L \cdot v^2}{D \cdot 2 \cdot g_c} = 4(0.581) \cdot \frac{(30)(0.00162)^2}{(0.022417)2(32,174)} \]

\[ = 0.000439 \text{ ft lbf/lbm} \]

1 sharp edge exit

\[ h_{ex} = n \left(1 - \frac{A_1}{A_2}\right) \cdot \frac{v^2}{2 \cdot \alpha \cdot g_c} = 1 \cdot (1 - 0) \cdot \frac{0.00162^2}{2(1)(32,174)} \]

\[ = 4.12 \times 10^{-8} \text{ ft lbf/lbm} \]

Total friction loss

\[ \sum F = 0.000439 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:

\[ \frac{1}{2 \cdot g_c} \left( v_2^2 - v_1^2 \right) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \]  \hspace{1cm} (Geankoplis, 2003)

dimana: \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 50 \text{ ft} \)

\[ 0 + \frac{32,174}{32,174}(50) + 0 + 0.000439 + W_s = 0 \]

\[ -W_s = 50,00044 \text{ ft lbf/lbm} \]

Efisiensi pompa, \( \eta = 80\% \)

\[ W_p = -W_s / \eta = 62,5005 \text{ ft lbf/lbm} \]

Daya pompa:

\[ P = \frac{W_p \cdot Q \cdot \rho}{550} = \frac{(62,5005)(6.52 \times 10^{-7})(94.76813)}{550} = 7.02 \times 10^{-6} \text{ hp} \]

Digunakan daya motor standar 1/8 hp

**LD.27 Pompa Cation Exchanger (P-9)**
Fungsi : Memompa air dari *Cation Exchanger* (V-09) ke *Anion Exchanger* (V-10)

Jenis : *Centrifugal pump*

Jumlah : 1 unit

Bahan konstruksi : *Commercial steel*

Kondisi operasi :

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nilai</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperatur</td>
<td>30°C</td>
</tr>
<tr>
<td>Densitas air ($\rho$)</td>
<td>995,68 kg/m$^3$ = 62,1599 lb$_m$/ft$^3$ (Geankoplis, 2003)</td>
</tr>
<tr>
<td>Viskositas air ($\mu$)</td>
<td>0,836 cP = 0,000562 lb$_m$/ft s (Geankoplis, 2003)</td>
</tr>
<tr>
<td>Laju alir massa ($F$)</td>
<td>2738,4971 kg/jam</td>
</tr>
<tr>
<td>Laju alir volumetrik ($Q$)</td>
<td>$\frac{2738,4971 \text{ kg/jam}}{995,68 \text{ kg/m}^3 \times 3600 \text{ s/jam}} = 0,000764 \text{ m}^3/\text{s} = 0,027 \text{ ft}^3/\text{s}$</td>
</tr>
</tbody>
</table>

Desain pompa :

untuk aliran turbulen $N_{Re} > 2100$

$$D_{i,\text{opt}} = 0,363 \frac{Q^{0,45} \rho^{0,13}}{(995,68 \text{ kg/m}^3)^{0,13}}$$

Peters dkk, 2004

$$D_{i,\text{opt}} = 0,363 \frac{(0,000764 \text{ m}^3/\text{s})^{0,45} (995,68 \text{ kg/m}^3)^{0,13}}{0,0352 \text{ m} = 1,3874 \text{ in}}$$

Dari Tabel A.5-1 Geankoplis,2003, dipilih pipa dengan spesifikasi :

Ukuran nominal : 1,5 in

*Schedule number* : 80

Diameter Dalam (ID) : 1,5 in = 0,125 ft

Diameter Luar (OD) : 1,9 in = 0,1583 ft

Luas penampang dalam (A) : 0,012 ft$^2$

Kecepatan linier, $v = \frac{Q}{A} = 2,2482 \text{ ft/s}$

Bilangan *Reynold* :

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

Peters dkk, 2004
Untuk pipa *Commercial Steel* diperoleh harga $\varepsilon = 0,000046$ ; $\varepsilon/D = 0,001207$, pada $N_{Re} = 31096,4465$ diperoleh harga faktor *fanning* $f = 0,007$ (Geankoplis, 2003).

*Friction loss*:

1 *sharp edge entrance*  
$$h_c = 0.5 \left(1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0.5 (1 - 0) \frac{2,2482^2}{2(1)(32,174)}$$
$$= 0,0392 \text{ ft lbf/lbm}$$

2 *elbow 90°*  
$$h_f = n.K_f \frac{v^2}{2 g_c} = 2(0,75) \frac{2,2482^2}{2(1)(32,174)} = 0,1178 \text{ ft lbf/lbm}$$

1 *gate valve*  
$$h_f = n K_f \frac{v^2}{2 g_c} = 1(2) \frac{2,2482^2}{2(1)(32,174)} = 0,1571 \text{ ft lbf/lbm}$$

Pipa lurus 30 ft  
$$F_f = 4f \frac{\Delta L \ v^2}{D \ 2 \ g_c} = 4(0,007) \frac{(30)(2,2482)^2}{(0,172252)(32,174)}$$
$$= 0,5278 \text{ ft lbf/lbm}$$

1 *sharp edge exit*  
$$h_{ex} = n \left(1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 \ (1 - 0) \frac{2,2482^2}{2(1)(32,174)}$$
$$= 0,0785 \text{ ft lbf/lbm}$$

Total *friction loss*  
$$\sum F = 0,9206 \text{ ft lbf/lbm}$$

Dari persamaan Bernoulli:

$$\frac{1}{2 \ g_c} \left(v_2^2 - v_1^2\right) + \frac{g_z}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0$$  
(Geankoplis, 2003)

dimana : $v_1 = v_2$ ; $\Delta v^2 = 0$ ; $P_1 = P_2$ ; $\Delta P = 0$

tinggi pemompaan $\Delta z = 50 \text{ ft}$

$$0 + \frac{32,174}{32,174} (50) + 0 + 0,9206 + W_s = 0$$

$$-W_s = 50,9206 \text{ ft lbf/lbm}$$
Efisiensi pompa, $\eta = 80\%$

\[ W_p = -W_s / \eta = 63,6508 \text{ ft lbf/lbm} \]

Daya pompa :
\[ P = \frac{W_p \rho Q \rho}{550} = \frac{(63,5137)(0,028)(62,1599)}{550} = 0,19 \text{ hp} \]

Digunakan daya motor standar 1/4 hp

**LD.28 Pompa Anion Exchanger (P-10)**

Fungsi : Memompa air dari *Anion Exchanger (V-10)* ke *Deaerator (V-11)*

Jenis : *Centrifugal pump*

Jumlah : 1 unit

Bahan konstruksi : *Commercial steel*

Kondisi operasi :

Temperatur = 30°C

Densitas air ($\rho$) = 995,68 kg/m$^3$ = 62,1599 lb$_{in}$/ft$^3$ (Geankoplis, 2003)

Viskositas air ($\mu$) = 0,836 cP = 0,000562 lb$_{in}$/ft s (Geankoplis, 2003)

Laju alir massa (F) = 2738,4971 kg/jam

\[
\text{Laju alir volumetrik (Q)} = \frac{2738,4971 \text{ kg/jam}}{995,68 \text{ kg/m}^3 \times 3600 \text{ s/jam}} = 0,000764 \text{ m}^3/\text{s} = 0,027 \text{ ft}^3/\text{s}
\]

Desain pompa:

untuk aliran turulen $N_{Re} > 2100$

\[
\text{Di}_{opt} = 0,363 Q^{0,45} \rho^{0,13} \quad \text{(Peters dkk, 2004)}
\]

\[
= 0,363 (0,000764 \text{ m}^3/\text{s})^{0,45} (995,68 \text{ kg/m}^3)^{0,13}
\]

\[
= 0,0352 \text{ m} = 1,3874 \text{ in}
\]

Dari Tabel A.5-1 Geankoplis,2003, dipilih pipa dengan spesifikasi :

Ukuran nominal : 1,5 in

*Schedule number* : 80

Diameter Dalam (ID) : 1,5 in = 0,125 ft
Diameter Luar (OD) : 1,9 in = 0,1583 ft
Luas penampang dalam (A) : 0,012 ft²
Kecepatan linier, v = \( \frac{Q}{A} \) = 2,2482 ft/s

Bilangan *Reynold*:
\[
N_{Re} = \frac{\rho \times v \times D}{\mu}
\]
\[
= \frac{(62,1599 \text{ lbm/ft}^3)(2,2482 \text{ ft/s})(0,125 \text{ ft})}{0,000562 \text{ lbm/ft s}}
\]
\[
= 31096,4465 (aliran turbulen)
\]

Untuk pipa *Commercial Steel* diperoleh harga \( \varepsilon = 0,000046 \); \( \varepsilon/D = 0,001207 \), pada
\( N_{Re} = 31096,4465 \) diperoleh harga faktor *fanning* \( f = 0,007 \) (Geankoplis, 2003).

*Friction loss*:

1. *sharp edge entrance* \( h_c = 0,5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0,5 (1 - 0) \frac{2,2482^2}{2(1)(32,174)} \)
\[
= 0,0392 \text{ ft lbf/lbm}
\]
2. *elbow 90°* \( h_f = n \cdot K_f \frac{v^2}{2 g_c} = 2(0,75) \frac{2,2482^2}{2(1)(32,174)} = 0,1178 \text{ ft lbf/lbm} \)
3. *gate valve* \( h_f = n \cdot K_f \frac{v^2}{2 g_c} = 1(2) \frac{2,2482^2}{2(1)(32,174)} = 0,1571 \text{ ft lbf/lbm} \)

Pipa lurus 30 ft \( F_f = 4f \frac{\Delta L}{D} \frac{v^2}{2 g_c} = 4(0,007) \frac{(30)(2,2482)^3}{(0,17225)2(32,174)} \)
\[
= 0,3393 \text{ ft lbf/lbm}
\]
4. *sharp edge exit* \( h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 (1 - 0) \frac{2,2482^2}{2(1)(32,174)} \)
\[
= 0,0785 \text{ ft lbf/lbm}
\]

Total *friction loss* \( \sum F = 0,7321 \text{ ft lbf/lbm} \)

Dari persamaan Bernoulli:
\[
\frac{1}{2} g_c \left( v_2^2 - v_1^2 \right) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \tag{Geankoplis, 2003}
\]
dimana : \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 50 \text{ ft} \)

\[
0 + \frac{32,174}{32,174} (50) + 0 + 0,7321 + W_s = 0
\]

\[-W_s = 50,73211 \text{ ft lbf/lbm} \]

Efisiensi pompa, \( \eta = 80 \% \)

\[
W_p = -W_s / \eta = 63,4151 \text{ ft lbf/lbm}
\]

Daya pompa : \( P = \frac{W_p Q \rho}{550} = \frac{(63,4151)(0,027)(62,1599)}{550} = 0,1933 \text{ hp} \)

Digunakan daya motor standar 1/4 hp

**LD.29 Pompa Kaporit (P-11)**

Fungsi : Memompa larutan kaporit dari Tangki Pelarutan Kaporit (V-15) ke Tangki Utilitas (V-16)

Jenis : *Centrifugal pump*

Jumlah : 1 unit

Bahan konstruksi : *Commercial steel*

Kondisi operasi :

Temperatur = 30\(^{\circ}\)C

Densitas kaporit (\( \rho \)) = 1272 kg/m\(^3\) = 79,41405 lbm/ft\(^3\)  (Perry dkk, 1999)

Viskositas kaporit (\( \mu \)) = 0,000672 lbm/ft s = 1 cP  (Kirk & Othmer, 1949)

Laju alir massa (\( F \)) = 0,0033 kg/jam

Debit air/laju alir volumetrik, \( Q = \frac{F}{\rho} = \frac{0,0033 \text{ kg / jam}}{1272 \text{ kg/m}^3 \times 3600 \text{ s / jam}} \)

\[= 7,25 \times 10^{-10} \text{ m}^3 / \text{s} = 2,56 \times 10^{-6} \text{ ft}^3 / \text{s} \]

Desain pompa :
untuk aliran viscous \( N_{Re} < 2100 \)

\[
\text{Di}_{\text{opt}} = 3 Q^{0.36} \mu^{0.18} \quad \text{(Peters dkk, 2004)}
\]
\[
= 3 \left(2,56 \cdot 10^{-8} \text{ ft}^3/\text{s}\right)^{0.36} \left(0,000672 \text{ lbm/ft.s}\right)^{0.18}
\]
\[
= 0,00149 \text{ ft} = 0,01788 \text{ in}
\]

Dari Tabel A.5-1 Geankoplis, 2003, dipilih pipa dengan spesifikasi:

- **Ukuran nominal**: \(\frac{1}{8} \text{ in}\)
- **Schedule number**: 40
- **Diameter Dalam (ID)**: 0,269 in = 0,0224 ft = 0,0068 m
- **Diameter Luar (OD)**: 0,405 in = 0,0338 ft
- **Inside sectional area** \( A \): 0,0004 ft\(^2\)

Kecepatan linier, \( v = \frac{Q}{A} \) = \(\frac{2,6 \cdot 10^{-8} \text{ ft}^3/\text{s}}{0,0004 \text{ ft}^2} = 6,4 \cdot 10^{-5} \text{ ft/s}\)

**Bilangan Reynold**:

\[
N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{(79,41045 \text{ lbm/ft}^3)(6,4 \cdot 10^{-5} \text{ ft/s})(0,0224 \text{ ft})}{0,000672 \text{ lbm/ft s}}
\]
\[
= 0,1696 \text{ (aliran laminar)}
\]

Untuk pipa *Commercial Steel* pada \( N_{Re} = 0,1696 \) diperoleh harga faktor *fanning* \( f = 94,304 \) (Geankoplis, 2003).

**Friction loss**:

1. **sharp edge entrance** \( h_c = 0,5 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 g_c} = 0,5 \left(1 - 0\right) \frac{6,4 \cdot 10^{-5}}{2(1)(32,174)}\)

\[
= 3,2 \cdot 10^{-11} \text{ ft lbf/lbm}
\]

1. **elbow 90°** \( h_f = n.Kf \frac{v^2}{2 g_c} = 1(0,75) \frac{(6,4 \cdot 10^{-5})^2}{2(32,174)} = 4,8 \cdot 10^{-11} \text{ ft lbf/lbm}\)

1. **check valve** \( h_f = n \frac{Kf}{2 g_c} = 1(2) \frac{(6,4 \cdot 10^{-5})^2}{2(32,174)} = 1,3 \cdot 10^{-10} \text{ ft lbf/lbm}\)

Pipa lurus 70 ft

\[
F_f = 4f \frac{\Delta L}{D} \frac{v^2}{2 g_c} = 4(94,304) \frac{(70)(6,4 \cdot 10^{-5})^2}{(0,022417)(2)(32,174)}
\]
\[
= 7,5 \cdot 10^{-5} \text{ ft lbf/lbm}
\]
1 sharp edge exit \[ h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 (1 - 0) \frac{6.4 \times 10^{-5}^2}{2(1)(32,174)} \]
\[ = 6.4 \times 10^{-11} \text{ ft lbf/lbm} \]
Total friction loss \[ \sum F = 7.5 \times 10^{-5} \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli :
\[ \frac{1}{2} \frac{g_c}{g_c} \left( v_2^2 - v_1^2 \right) + \frac{g_c}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \]
(Geankoplis, 2003)
dimana : \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)
tinggi pemompaan \( \Delta z = 50 \text{ ft} \)
\[ 0 + \frac{32,174}{32,174} (50) + 0 + 7.5 \times 10^{-5} + W_s = 0 \]
\[-W_s = 50,000075 \text{ ft lbf/lbm} \]
Efisiensi pompa, \( \eta = 80 \% \)
\[ W_p = -W_s / \eta = 62,5001 \text{ ft lbf/lbm} \]
Daya pompa :
\[ P = \frac{W_p Q \rho}{550} = \frac{(62,5001)(2.6 \times 10^{-8})(79,41045)}{550} = 2.3 \times 10^{-7} \text{ hp} \]

Digunakan daya motor standar 1/8 hp

**LD.30 Pompa Utilitas (P-12)**

Fungsi : Memompa air dari Tangki Utilitas (V-16) ke kebutuhan domestik

Jenis : *Centrifugal pump*

Jumlah : 1 unit

Bahan konstruksi : *Commercial steel*

Kondisi operasi :

Temperatur = 30\(^\circ\)C

Densitas air (\( \rho \)) = 995,68 kg/m\(^3\) = 62,1599 lb\(_m\)/ft\(^3\) (Geankoplis, 2003)

Viskositas air (\( \mu \)) = 0,836 cP = 0,000562 lb\(_m\)/ft s (Geankoplis, 2003)

Laju alir massa (F) = 1162,7 kg/jam
Laju alir volumetrik (Q) = \frac{1162,7 \text{ kg/jam}}{995,68 \text{ kg/m}^3 \times 3600 \text{ s/jam}} = 0,00032 \text{ m}^3/\text{s} \\
= 0,01145 \text{ ft}^3/\text{s}

Desain pompa:

untuk aliran turbulen \( N_{Re} > 2100 \)

\[
D_{i,\text{opt}} = 0,363 \ Q^0,45 \ \rho^{0,13} \\
= 0,363 \ (0,00032 \text{ m}^3/\text{s})^{0,45} \ (995,68 \text{ kg/m}^3)^{0,13} \\
= 0,02397 \text{ m} = 0,943 \text{ in}
\]

Dari Tabel A.5-1 Geankoplis, 2003, dipilih pipa dengan spesifikasi:

Ukuran nominal : 1 in

\text{Schedule number} : 80

Diameter Dalam (ID) : 0,957 in = 0,0797 ft

Diameter Luar (OD) : 1,315 in = 0,10958 ft

Luas penampang dalam (A) : 0,006 ft\(^2\)

Kecepatan linier, \( v = \frac{Q}{A} = 1,909 \text{ ft/s} \)

Bilangan \textit{Reynold}:

\[
N_{Re} = \frac{\rho \times v \times D}{\mu} \\
= \frac{(62,1599 \text{ lbm/ft}^3)(1,909 \text{ ft/s})(0,0797 \text{ ft})}{0,000562 \text{ lbm/ft s}} \\
= 16846,9 \text{ (aliran turbulen)}
\]

Untuk pipa \textit{Commercial Steel} diperoleh harga \( \varepsilon = 0,000046 ; \varepsilon/D = 0,00189 \), pada \( N_{Re} = 16846,9 \) diperoleh harga faktor \textit{fanning} \( f = 0,005 \) (Geankoplis, 2003).

\textit{Friction loss}:

\[
1 \textit{ sharp edge entrance} \ h_c = 0,5 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 \alpha g_c} = 0,5 \left(1 - 0\right) \frac{1,909^2}{2(1)(32,174)} \\
= 0,02832 \text{ ft lbf/lbm}
\]
2 elbow 90°
\[ h_f = n.K_f \cdot \frac{v^2}{2g_c} = 2(0,75) \cdot \frac{1,909^2}{2(1)(32,174)} = 0,08496 \text{ ft lbf/lbm} \]

1 gate valve
\[ h_f = n K_f \cdot \frac{v^2}{2g_c} = 1(2) \cdot \frac{1,909^2}{2(1)(32,174)} = 0,11328 \text{ ft lbf/lbm} \]

Pipa lurus 30 ft
\[ F_f = 4f \cdot \frac{\Delta L}{D} \cdot \frac{v^2}{2g_c} = 4(0,005) \cdot \frac{(30)(1,909)^2}{(0,17225)(2)(32,174)} = 0,42615 \text{ ft lbf/lbm} \]

1 sharp edge exit
\[ h_{ex} = n \left(1 - \frac{A_1}{A_2}\right)^2 \cdot \frac{v^2}{2g_c} = 1 \cdot (1 - 0) \cdot \frac{1,909^2}{2(1)(32,174)} = 0,05664 \text{ ft lbf/lbm} \]

Total friction loss \[ \sum F = 0,70936 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:
\[ \frac{1}{2g_c} \left( v_2^2 - v_1^2 \right) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \]

dimana : \( v_1 = v_2 ; \Delta v^2 = 0 ; P_1 = P_2 ; \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 50 \text{ ft} \)

\[ 0 + \frac{32,174}{32,174}(50) + 0 + 0,70936 + W_f = 0 \]

\[ -W_s = 50,70936 \text{ ft lbf/lbm} \]

Efisiensi pompa, \( \eta = 80\% \)
\[ W_p = -W_s / \eta = 63,3867 \text{ ft lbf/lbm} \]

Daya pompa :
\[ P = \frac{W_p \cdot Q \cdot \rho}{550} = \frac{(63,3867)(0,01145)(62,1599)}{550} = 0,082 \text{ hp} \]

Digunakan daya motor standar 1/8 hp

**L.D.31 Pompa Water Cooling Tower (P-13)**

Fungsi : Memompa air pendingin dari Water Cooling Tower (V-14) untuk keperluan air pendingin proses

Jenis : *Centrifugal pump*
Jumlah : 1 unit
Bahan konstruksi : *Commercial steel*

Kondisi operasi :
Temperatur = 30°C
Densitas air ($\rho$) = 995,68 kg/m$^3$ = 62,1599 lbm/ft$^3$ (Geankoplis, 2003)
Viskositas air ($\mu$) = 0,836 cP = 0,000562 lbm/ft s (Geankoplis, 2003)
Laju alir massa (F) = 5869,665 kg/jam
Laju alir volumetrik (Q) = \( \frac{5869,665 \text{ kg/jam}}{995,68 \text{ kg/m}^3 \times 3600 \text{ s/jam}} \) = 0,001638 m$^3$/s = 0,0578 ft$^3$/s

Desain pompa :
untuk aliran turbulen $N_{Re} > 2100$
$$D_{opt} = 0,363 \, Q^{0,45} \, \rho^{0,13}$$ (Peters dkk, 2004)
$$= 0,363 \, (0,001638 \, m^3/s)^{0,45} \, (995,68 \, kg/m^3)^{0,13}$$
$$= 0,0496 \, m = 1,955 \, in$$

Dari Tabel A.5-1 Geankoplis,2003, dipilih pipa dengan spesifikasi :
Ukuran nominal : 2 in
Schedule number : 80
Diameter Dalam (ID) : 1,939 in = 0,1616 ft
Diameter Luar (OD) : 2,375 in = 0,1979 ft
Luas penampang dalam (A) : 0,02 ft$^2$
Kecepatan linier, $v = \frac{Q}{A} = 2,8913 \, ft/s$

Bilangan *Reynold* :
$$N_{Re} = \frac{\rho \times v \times D}{\mu}$$ (Peters dkk, 2004)
$$= \frac{(62,1599 \, lbm/ft^3)(2,8913 \, ft/s)(0,1616 \, ft)}{0,000562 \, lbm/ft \, s}$$
$$= 51695,1246 \, (aliran \, turbulen)$$
Untuk pipa Commercial Steel diperoleh harga \( \varepsilon = 0,000046 \); \( \varepsilon/D = 0,000934 \), pada \( \text{N}_{\text{Re}} = 51695,1246 \) diperoleh harga faktor fanning \( f = 0,0045 \) (Geankoplis, 2003).

Friction loss:

1. sharp edge entrance
\[ h_c = 0,5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0,5 (1 - 0) \frac{2,8913^2}{2(0)(32,174)} \]
\[ = 0,0649 \text{ ft lbf/lbm} \]

2. elbow 90°
\[ h_f = n.Kf. \frac{v^2}{2 g_c} = 2(0,75) \frac{2,8913^2}{2(0)(32,174)} = 0,1948 \text{ ft lbf/lbm} \]

1. gate valve
\[ h_f = n Kf \frac{v^2}{2 g_c} = 1(2) \frac{2,8913^2}{2(0)(32,174)} = 0,2598 \text{ ft lbf/lbm} \]

Pipa lurus 30 ft
\[ F_f = 4f \frac{\Delta L v^2}{D 2 g_c} = 4(0,0045) \frac{(30)(2,8913)^2}{(0,17225)(2)(32,174)} \]
\[ = 0,4341 \text{ ft lbf/lbm} \]

1. sharp edge exit
\[ h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right) \frac{v^2}{2 \alpha g_c} = 1 (1 - 0) \frac{2,8913^2}{2(0)(32,174)} \]
\[ = 0,1299 \text{ ft lbf/lbm} \]

Total friction loss
\[ \sum F = 1,0837 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:
\[ \frac{1}{2 g_c} \left( v_2^2 - v_1^2 \right) + \frac{g}{g_c} \left( z_2 - z_1 \right) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \]
(Geankoplis, 2003)

dimana : \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 50 \) ft
\[ 0 + \frac{32,174}{32,174} (50) + 0 + 1,0837 + W_s = 0 \]
\[ -W_s = 51,0837 \text{ ft lbf/lbm} \]

Efisiensi pompa, \( \eta = 80 \% \)
\[ W_p = -W_s / \eta = 63,8546 \text{ ft lbf/lbm} \]

Daya pompa:
\[ P = \frac{W_p Q \rho}{550} = \frac{(63,8546)(0,0578)(62,1599)}{550} = 0,4173 \text{ hp} \]
Digunakan daya motor standar 1/2 hp

**LD.32 Pompa Deaerator (P-14)**

Fungsi : Memompa air dari Deaerator (V-11) ke Ketel Uap I (V-12) dan Ketel Uap II (V-13)

Jenis : *Centrifugal pump*

Jumlah : 1 unit

Bahan konstruksi : *Commercial steel*

**Kondisi operasi :**

Temperatur = 30°C

Densitas air ($\rho$) = 995,68 kg/m$^3$ = 62,1599 lb/ft$^3$ (Geankoplis, 2003)

Viskositas air ($\mu$) = 0,836 cP = 0,000562 lb/ft ft s (Geankoplis, 2003)

Laju alir massa ($F$) = 2738,4971 kg/jam

Laju alir volumetrik ($Q$) = \[Q = \frac{2738.4971 \text{ kg/jam}}{995.68 \text{ kg/m}^3 \times 3600 \text{ s/jam}} = 0.000764 \text{ m}^3/\text{s} = 0.027 \text{ ft}^3/\text{s} \]

Desain pompa :

untuk aliran turbulen $N_R > 2100$

\[D_{i, opt} = 0.363 \left[Q^{0.45} \rho^{0.13}\right] = 0.363 \left[0.000764 \text{ m}^3/\text{s}^{0.45} (995.68 \text{ kg/m}^3)^{0.13}\right] = 0.0352 \text{ m} = 1.3874 \text{ in} \]

Dari Tabel A.5-1 Geankoplis, 2003, dipilih pipa dengan spesifikasi :

Ukuran nominal : 1,5 in

Schedule number : 80

Diameter Dalam (ID) : 1,5 in = 0,125 ft

Diameter Luar (OD) : 1,9 in = 0,1583 ft

Luas penampang dalam (A) : 0,012 ft$^2$

Kecepatan linier, $v = \frac{Q}{A} = 2.2023 \text{ ft/s}$
Bilangan Reynolds:

\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]

\[ = \frac{(62,1599 \text{ lbm/ft}^3)(2,2023 \text{ ft/s})(0,125 \text{ ft})}{0,000562 \text{ lbm/ft s}} \]

\[ = 30461,8252 \text{ (aliran turbulen)} \]

Untuk pipa *Commercial Steel* diperoleh harga \( \varepsilon = 0,000046 \); \( \varepsilon/D = 0,001207 \), pada \( N_{Re} = 30461,8252 \) diperoleh harga faktor fanning \( f = 0,0055 \) (Geankoplis, 2003).

Friction loss:

1. *sharp edge entrance*
   \[ h_c = 0,5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 g_c} = 0,5 (1 - 0) \frac{2,2023^2}{2(1)(32,174)} \]
   \[ = 0,0376 \text{ ft lbf/lbm} \]

2. *elbow 90°*
   \[ h_f = n Kf \frac{v^2}{2 g_c} = 2(0,75) \frac{2,2023^2}{2(1)(32,174)} = 0,113 \text{ ft lbf/lbm} \]

1. *gate valve*
   \[ h_f = n Kf \frac{v^2}{2 g_c} = 1(2) \frac{2,3662^2}{2(1)(32,174)} = 0,1507 \text{ ft lbf/lbm} \]

Pipa lurus 30 ft
   \[ F_f = 4f \frac{\Delta L}{D} \frac{v^2}{2 g_c} = 4(0,0055) \frac{(30)(2,2023)^2}{(0,17225)(2)(32,174)} \]
   \[ = 0,398 \text{ ft lbf/lbm} \]

1. *sharp edge exit*
   \[ h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right) \frac{v^2}{2 g_c} = 1 (1 - 0) \frac{2,2023^2}{2(1)(32,174)} \]
   \[ = 0,0753 \text{ ft lbf/lbm} \]

Total friction loss \( \sum F = 0,7748 \text{ ft lbf/lbm} \)

Dari persamaan Bernoulli:

\[ \frac{1}{2 g_c} \left( v_2^2 - v_1^2 \right) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \]

(Geankoplis, 2003)

dimana : \( v_1 = v_2 ; \Delta v^2 = 0 ; P_1 = P_2 ; \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 50 \text{ ft} \)
\[ 0 + \frac{32,174}{32,174} (50) + 0 + 0,7748 + W_s = 0 \]

\[-W_s = 50,7748 \text{ ft lbf/lbm} \]

Efisiensi pompa, \( \eta \) = 80 \%

\[ W_p = -W_s / \eta = 63,4686 \text{ ft lbf/lbm} \]

Daya pompa :
\[ P = \frac{W_p Q \rho}{550} = \frac{(63,4686)(0,0269)(62,1599)}{550} = 0,1935 \text{ hp} \]

Digunakan daya motor standar 1/4 hp

**LD.33 Pompa Tangki Bahan Bakar 1 (P-15)**

Fungsi: Memompa bahan bakar solar dari TB-01 ke Generator

Jenis: Pompa **sentrifugal**

Bahan konstruksi: *Commercial Steel*

Jumlah: 1 unit

Kondisi operasi:
Temperatur = 30\(^\circ\)C

Densitas solar (\( \rho \)) = 890,0712 \( \text{kg/m}^3 \) = 55,56679 \( \text{lbm/ft}^3 \)  (Perry dkk, 1999)

Viskositas solar (\( \mu \)) = 0,000562 \( \text{lbm/ft s} \) = 0,836 cP  (Kirk & Othmer, 1949)

Laju alir massa (\( F \)) = 136,5637 \( \text{kg/jam} \)

Debit air/laju alir volumetrik, \( Q = \frac{F}{\rho} = \frac{136,5637 \text{ kg/jam}}{890,0712 \text{ kg/m}^3 \times 3600 \text{ s/jam}} \]
\[ = 4,26.10^{-5} \text{ m}^3/\text{s} = 0,001505 \text{ ft}^3/\text{s} \]

**Desain pompa:**

untuk aliran *viscous* \( N_{Re} > 2100 \)

\[ D_{opt} = 3 Q^{0.36} \mu^{0.18} \]  (Peters dkk, 2004)
\[ = 3 (0,001505)0,36 (0,000562)0,18 \]
\[ = 0,009477 \text{ ft} = 0,3731 \text{ in} \]

Dari Tabel A.5-1 Geankoplis,2003, dipilih pipa dengan spesifikasi:
Ukuran nominal : 1/4 in  
*Schedule number* : 40  
Diameter Dalam (ID) : 0,364 in = 0,0303 ft  
Diameter Luar (OD) : 0,54 in  
Inside sectional area A : 0,00072 ft$^2$  

Kecepatan linier, $v = \frac{Q}{A} = \frac{0,000464}{0,00072} = 0,6449$ ft/s  

**Bilangan Reynold** :  
$$N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{(55,56679 \ \text{lbm/ft}^3)(0,6449 \ \text{ft/s})(0,0303 \ \text{ft})}{0,000739 \ \text{lbm/ft s}}$$  
$$= 4766,574$$ (aliran laminar)  

Untuk pipa *Commercial Steel* pada $N_{Re} = 4766,574$ diperoleh harga faktor *fanning* $f = 0,03357$  

**Friction loss** :  

1. *sharp edge entrance*  
   $$h_c = 0,5\left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 \alpha g_c} = 0,5 (1 - 0) \frac{2,0903^2}{2(32,174)}$$  
   $$= 0,0339 \ \text{ft lbf/lbm}$$  

2. *elbow 90°*  
   $$h_f = n \cdot Kf \cdot \frac{v^2}{2 \ g_c} = 2(0,75) \frac{2,0903^2}{2(32,174)} = 0,1018 \ \text{ft lbf/lbm}$$  

1. *check valve*  
   $$h_f = n \cdot Kf \cdot \frac{v^2}{2 \ g_c} = 1(2) \frac{2,0903^2}{2(32,174)} = 0,1358 \ \text{ft lbf/lbm}$$  

Pipa lurus 30 ft  
$$F_f = 4f \frac{\Delta L \ v^2}{D \ 2 \ g_c} = 4(0,03375) \frac{(30)(2,0903^2)}{(0,0303)(2)(32,174)}$$  
$$= 0,9017 \ \text{ft lbf/lbm}$$  

1. *sharp edge exit*  
   $$h_{ex} = n \left(1 - \frac{A_1}{A_2}\right) \frac{v^2}{2 \alpha g_c} = 1 (1 - 0) \frac{2,0903^2}{2(1)(32,174)}$$  
   $$= 0,0679 \ \text{ft lbf/lbm}$$  

Total *friction loss*  
$$\sum F = 1,2412 \ \text{ft lbf/lbm}$$

Dari persamaan Bernoulli :
\[
\frac{1}{2} g_c \left( v_2^2 - v_1^2 \right) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0
\]  
(Geankoplis, 2003)

dimana: \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 50 \) ft

\[
0 + \frac{32,174}{32,174} (50) + 0 + 1,2412 + W_s = 0
\]

\[-W_s = 51,2412 \text{ ft lbf/lbm}\]

Efisiensi pompa, \( \eta = 80 \% \)

\[
W_p = -W_s / \eta = 64,0515 \text{ ft lbf/lbm}
\]

Daya pompa: 
\[
P = \frac{W_p Q \rho}{550} = \frac{64,0515(0,08363)(55,56679)}{550} = 0,00974 \text{ hp}
\]

Digunakan daya motor standar 1/8 hp

**L.D.34 Pompa Tangki Bahan Bakar 2 (P-16)**

Fungsi: Memompa bahan bakar solar dari TB-01 ke ketel uap KU-01

Jenis: Pompa *sentrifugal*

Bahan konstruksi: *Commercial Steel*

Jumlah: 1 unit

Kondisi operasi:

Temperatur = 30°C

Densitas solar \( \rho \) = 890,0712 kg/m\(^3\) = 55,56679 lb\(_m\)/ft\(^3\)  
(Perry dkk, 1999)

Viskositas solar \( \mu \) = 0,000562 lb\(_m\)/ft s = 0,836 cP  
(Kirk & Othmer, 1949)

Laju alir massa \( F \) = 696.7149 kg/jam

Debit air/laju alir volumetrik, \( Q = \frac{F}{\rho} = \frac{696,7149 \text{ kg/jam}}{890,0712 \text{ kg/m}^3 \times 3600 \text{ s/jam}} 
= 0,000217 \text{ m}^3/\text{s} = 0,0076 \text{ ft}^3/\text{s} \)

Desain pompa:

untuk aliran turbulen \( N_{Re} > 2100 \)

\[
D_{opt} = 0,363 Q^{0,45} \rho^{0,13}
\]  
(Peters dkk, 2004)

\[
= 0,363 (0,000217 \text{ m}^3/\text{s})^{0,45} (890 \text{ kg/m}^3)^{0,13}
\]
Dari Tabel A.5-1 Geankoplis, 2003, dipilih pipa dengan spesifikasi:

- **Ukuran nominal**: 1 in
- **Schedule number**: 80
- **Diameter Dalam (ID)**: 0,957 in = 0,0797 ft
- **Diameter Luar (OD)**: 1,315 in
- **Luas penampang dalam (A)**: 0,006 ft

Kecepatan linier, \( v = \frac{Q}{A} = 1,2798 \text{ ft/s} \)

**Bilangan Reynolds**: \( N_{Re} = \frac{\rho \times v \times D}{\mu} \) (Peters dkk, 2004)

\[
N_{Re} = \frac{(55,56679 \text{ lbm/ft}^3)(1,2798 \text{ ft/s})(0,0797 \text{ ft})}{0,000562 \text{ lbm/ft s}} = 10094,952 \text{ (aliran turbulen)}
\]

Untuk pipa *Commercial Steel* diperoleh harga \( \varepsilon = 0,000046 \); \( \varepsilon/D = 0,001892 \), pada \( N_{Re} = 10094,952 \) diperoleh harga faktor *fanning* \( f = 0,0084 \) (Geankoplis, 2003).

**Friction loss**:

- **1 sharp edge entrance**
  \[
h_c = 0,5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 g_c} = 0,5 \left( 1 - 0 \right) \frac{1,2798^2}{2(1)(32,174)} = 0,0127 \text{ ft lbf/lbm}
\]

- **2 elbow 90°**
  \[
h_f = n K_f \frac{v^2}{2 g_c} = 2(0,75) \frac{1,2798^2}{2(1)(32,174)} = 0,0381 \text{ ft lbf/lbm}
\]

- **1 gate valve**
  \[
h_f = n K_f \frac{v^2}{2 g_c} = 1(2) \frac{1,2798^2}{2(1)(32,174)} = 0,0509 \text{ ft lbf/lbm}
\]

- **Pipa lurus 30 ft**
  \[
  F_f = 4f \frac{\Delta L}{D^2} \frac{v^2}{2 g_c} = 4(0,084) \frac{(30)(1,2798)^2}{(0,0874^2)(2)(32,174)} = 0,3217 \text{ ft lbf/lbm}
\]
1 sharp edge exit

\[ h_{ex} = n \left(1 - \frac{A_1}{A_2}\right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left(1 - \frac{1}{2(1)(32.174)}\right) \]

\[ = 0.0254 \text{ ft lbf/lbm} \]

Total friction loss \[ \sum F = 0.449 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:

\[ \frac{1}{2} g_c \left(v_2^2 - v_1^2\right) + \frac{g_c}{\rho_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \]

(Geankoplis, 2003)

dimana \[ v_1 = v_2 ; \Delta v^2 = 0 ; P_1 = P_2 ; \Delta P = 0 \]

tinggi pemompaan \[ \Delta z = 50 \text{ ft} \]

\[ 0 + \frac{32.174}{32.174} (50) + 0 + 0.449 + W_s = 0 \]

\[ -W_s = 50.449 \text{ ft lbf/lbm} \]

Efisiensi pompa, \[ \eta = 80 \% \]

\[ W_p = -W_s / \eta = 63.126 \text{ ft lbf/lbm} \]

Daya pompa:

\[ P = \frac{W_p \rho Q \rho}{550} = \frac{(63.126)(0.00811)(55.5623)}{550} = 0.0489 \text{ hp} \]

Digunakan daya motor standar 1/8 hp

LD.35 Pompa Bak Penampung (PL-01)

Fungsi : Memompa limbah dari bak penampung ke tangki aerasi

Jenis : Pompa sentrifugal

Bahan konstruksi : Commercial Steel

Jumlah : 1 unit

Kondisi operasi :

Temperatur = 30°C

Densitas (\( \rho \)) = 1000.63 kg/m\(^3\) = 62.4689 lbm/ft\(^3\) (Perry dkk, 1999)

Viskositas (\( \mu \)) = 0.000527 lbm/ft s = 0.784 cP (Kirk & Othmer, 1949)

Laju alir volumetrik (\( Q \)) = 7.19.10\(^{-5}\) m\(^3\)/s = 0.002538 ft\(^3\)/s
Desain pompa:

untuk aliran turulen $N_{Re} > 2100$

$D_i_{opt} = 0.363 \frac{Q^{0.45} \rho^{0.13}}{\mu} \quad \text{(Peters dkk, 2004)}$

$= 0.363 \left(0.002538 \ m^3/s\right)^{0.45} \left(1000,63 \ kg/m^3\right)^{0.13}$

$= 0.01217 \ m = 0.4792 \ in$

Dari Tabel A.5-1 Geankoplis, 2003, dipilih pipa dengan spesifikasi:

Ukuran nominal : 0,5 in

Schedule number : 40

Diameter Dalam (ID) : 0,622 in = 0,0518 ft

Diameter Luar (OD) : 0,84 in

Luas penampang dalam (A) : 0,00211 ft$^2$

Kecepatan linier, $v = \frac{Q}{A} = 1,2026 \ ft/s$

Bilangan Reynolds:

$N_{Re} = \frac{\rho \times v \times D}{\mu} \quad \text{(Peters dkk, 2004)}$

$= \frac{(62,469 \ lbm/ft^3)(1,2026 \ ft/s)(0,0518 \ ft)}{0,000527 \ lbm/ft \ s}$

$= 7391,9 \ (aliran \ turulen)$

Untuk pipa Commercial Steel diperoleh harga $e = 0,000046$; $e/D = 0,002912$, pada

$N_{Re} = 7391,9$ diperoleh harga faktor fanning $f = 0,009$ (Geankoplis, 2003).

Friction loss:

1 *sharp edge entrance* $h_c = 0.5 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 \alpha g_c}$

$= 0.5(1 - 0) \frac{1,2026^2}{2(1)(32,174)}$

$= 0,0112 \ ft \ lbf/lbm$

2 *elbow 90°* $h_f = n.Kf. \frac{v^2}{2 g_c}$

$= 2(0.75) \frac{1,2026^2}{2(1)(32,174)}$

$= 0,0337 \ ft \ lbf/lbm$

1 *gate valve* $h_f = n.Kf. \frac{v^2}{2 g_c}$

$= 1(2) \frac{1,2026^2}{2(1)(32,174)}$

$= 0,0449 \ ft \ lbf/lbm$
Pipa lurus 30 ft  

\[ F_t = 4f \frac{\Delta L v^2}{D^2 g_c} = 4(0,009) \frac{(30)(1,2026)^2}{(0,115)2(32,174)} \]

\[ = 0,4683 \text{ ft lbf/lbm} \]

1 sharp edge exit  

\[ h_{ex} = n\left(1 - \frac{A_1}{A_2}\right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left(1 - 0\right) \frac{1,2026^2}{2(1)(32,174)} \]

\[ = 0,0224 \text{ ft lbf/lbm} \]

Total friction loss  

\[ \sum F = 0,5807 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:

\[ \frac{1}{2 g_c} \left(v_2^2 - v_1^2\right) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \quad \text{(Geankoplis, 2003)} \]

dimana : \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 50 \text{ ft} \)

\[ 0 + \frac{32,174}{32,174} (50) + 0 + 0,5807 + W_s = 0 \]

\[ -W_s = 50,5807 \text{ ft lbf/lbm} \]

Efisiensi pompa, \( \eta = 80 \% \)

\[ W_p = -W_s / \eta = 63,2259 \text{ ft lbf/lbm} \]

Daya pompa :  

\[ P = \frac{W_p Q \rho}{550} = \frac{(63,2259)(0,002538)(62,469)}{550} = 0,01822 \text{ hp} \]

Digunakan daya motor standar 1/8 \( \text{ hp} \)

**LD.36 Pompa Tangki Aerasi (PL-02)**

Fungsi : Memompa limbah dari tangki aerasi ke tangki sedimentasi

Jenis : Pompa *sentrifugal*

Bahan konstruksi : *Commercial Steel*

Jumlah : 1 unit

Kondisi operasi :

Temperatur  = 30\(^\circ\)C

Densitas (\( \rho \))  = 1000,63 kg/m\(^3\) = 62,4689 lbm/ft\(^3\)  \( \text{(Perry dkk, 1999)} \)
Viskositas (μ) = 0,000527 lbm/ft s = 0,784 cP (Kirk & Othmer, 1949)
Laju alir volumetrik (Q) = 0,000217 m³/s = 0,00768 ft³/s

Desain pompa:
untuk aliran turulen \(N_{Re} > 2100\)
\[
D_{i,\text{opt}} = 0,363 Q^{0,45} \rho^{0,13}\]  
\[
= 0,363 (0,000217 \text{ m}^3/\text{s})^{0,45} (1000,63 \text{ kg/m}^3)^{0,13}\]  
\[
= 0,02 \text{ m} = 0,7887 \text{ in}\]

Dari Tabel A.5-1 Geankoplis,2003, dipilih pipa dengan spesifikasi:
Ukuran nominal : 1 in
Schedule number : 40
Diameter Dalam (ID) : 1,049 in = 0,0874 ft
Diameter Luar (OD) : 1,315 in
Luas penampang dalam (A) : 0,00371 ft²
Kecepatan linier, \(v = \frac{Q}{A} = 1,28 \text{ ft/s}\)

Bilangan Reynolds:
\[
N_{Re} = \frac{\rho \times v \times D}{\mu}\]  
\[
= \frac{(62,469 \text{ lbm/ft}^3)(1,28 \text{ ft/s})(0,06867 \text{ ft})}{0,000527 \text{ lbm/ft s}}\]  
\[
= 13268,33 \text{ (aliran turulen)}\]

Untuk pipa Commercial Steel diperoleh harga \(\varepsilon = 0,000046 \); \(\varepsilon/D = 0,00172\), pada \(N_{Re} = 13268,33\) diperoleh harga faktor fanning \(f = 0,008\) (Geankoplis, 2003).

Friction loss:
1 sharp edge entrance \(h_c = 0,5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0,5(1 - 0) \frac{1,28^2}{2(1)(32,174)}\]  
\[
= 0,0127 \text{ ft lbf/lbm}\]

2 elbow 90° \(h_f = n.Kf. \frac{v^2}{2 g_c} = 2(0,75) \frac{1,28^2}{2(1)(32,174)} = 0,0381 \text{ ft lbf/lbm}\)
Dari persamaan Bernoulli:

\[
\frac{1}{2} g c \left(v_2^2 - v_1^2\right) + \frac{g}{\rho} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \tag{Geankoplis, 2003}
\]

dimana : \(v_1 = v_2\); \(\Delta v^2 = 0\); \(P_1 = P_2\); \(\Delta P = 0\)

tinggi pemompaan \(\Delta z = 50\) ft

\[
0 + \frac{32,174}{32,174} (50) + 0 + 0,4069 + W_s = 0
\]

\[-W_s = 50,4069\text{ ft lbf/lbm}\]

Efisiensi pompa, \(\eta = 80\%\)

\[
W_p = -W_s / \eta = 50,4069\text{ ft lbf/lbm}
\]

Daya pompa :

\[
P = \frac{W_p Q \rho}{550} = \frac{(50,4069)(0,00768)(62,469)}{550} = 0,0549\text{ hp}
\]

Digunakan daya motor standar \(1/8\) hp

**LD.37 Pompa Tangki Sedimentasi (PL-03)**

**Fungsi** : Memompa air resirkulasi dari tangki sedimentasi ke tangki aerasi

**Jenis** : Pompa *sentrifugal*

**Bahan konstruksi** : Commercial Steel

**Jumlah** : 1 unit
Kondisi operasi:
Temperatur \(= 30^\circ\text{C}\)
Densitas air \((\rho)\) \(= 1000,63 \text{ kg/m}^3\) = 62,4689 lbm/ft\(^3\) (Perry dkk, 1999)
Viskositas air \((\mu)\) \(= 0,000527 \text{ lbm/ft s} = 0,784 \text{ cP}\) (Kirk & Othmer, 1949)
Laju alir volumetrik \(= 0,000146 \text{ m}^3/\text{s} = 0,00514 \text{ ft}^3/\text{s}\)
Desain pompa:
untuk aliran turbulen \(N_{\text{Re}} > 2100\)
\[D_{i,\text{opt}} = 0,363 \times Q^{0,45} \rho^{0,13}\]
\[= 0,363 (0,000146 \text{ m}^3/\text{s})^{0,45} (100,63 \text{ kg/m}^3)^{0,13}\]
\[= 0,0167 \text{ m} = 0,6585 \text{ in}\]

Dari Tabel A.5-1 Geankoplis,2003, dipilih pipa dengan spesifikasi:

Ukuran nominal : 3/4 in
Schedule number : 40
Diameter Dalam (ID) : 0,824 in = 0,06867ft
Diameter Luar (OD) : 1,05 in
Luas penampang dalam (A) : 0,00371 \text{ ft}^2
Kecepatan linier, \(v = \frac{Q}{A} = 1,386 \text{ ft/s}\)

Bilangan Reynolds:
\[N_{\text{Re}} = \frac{\rho \times v \times D}{\mu}\]
\[= \frac{(62,469 \text{ lbm/ft}^3)(1,386 \text{ ft/s})(0,06867 \text{ ft})}{0,000527 \text{ lbm/ft s}}\]
\[= 11286,33\] (aliran turbulen)

Untuk pipa Commercial Steel diperoleh harga \(\varepsilon = 0,000046\) ; \(\varepsilon/D = 0,0022\), pada \(N_{\text{Re}} = 11286,33\) diperoleh harga faktor fanning \(f = 0,0085\) (Geankoplis, 2003).

Friction loss:
1 sharp edge entrance \(h_c = 0,5 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 \alpha g_c} = 0,5 (1 - 0) \frac{1,386^2}{2(1)(32,174)}\]
\[= 0,0143 \text{ ft lbf/lbm}\]
- 2 elbow 90°  
  \[ h_f = n.K_f \frac{v^2}{2g_c} = 2(0,75) \frac{1,386^2}{2(1)(32,174)} = 0,044 \text{ ft lbf/lbm} \]

- 1 gate valve  
  \[ h_f = n.K_f \frac{v^2}{2g_c} = 1(2) \frac{1,386^2}{2(1)(32,174)} = 0,059 \text{ ft lbf/lbm} \]

- Pipa lurus 30 ft  
  \[ F_f = 4f \frac{\Delta L}{D} \frac{v^2}{2g_c} = 4(0,0085) \frac{(30)(1,386)^2}{(0,172)2(32,174)} \]
  \[ = 0,4435 \text{ ft lbf/lbm} \]

- 1 sharp edge exit  
  \[ h_{ex} = n\left(1-\frac{A_1}{A_2}\right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left(1-0\right) \frac{1,386^2}{2(1)(32,174)} \]
  \[ = 0,029 \text{ ft lbf/lbm} \]

Total friction loss  
\[ \sum F = 0,5928 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:
\[ \frac{1}{2g_c} \left(v_2^2 - v_1^2\right) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2}{\rho} - P_1 + \sum F + W_s = 0 \]  
(Geankoplis, 2003)

dimana : \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 50 \text{ ft} \)

\[ 0 + \frac{32,174}{32,174} (50) + 0 + 0,5928 + W_s = 0 \]

\[ -W_s = 50,5928 \text{ ft lbf/lbm} \]

Efisiensi pompa, \( \eta = 80 \% \)

\[ W_p = -W_s / \eta = 63,241 \text{ ft lbf/lbm} \]

Daya pompa :  
\[ P = \frac{W_p \rho Q \rho}{550} = \frac{(63,241)(0,00514)(62,469)}{550} = 0,036 \text{ hp} \]

Digunakan daya motor standar 1/8 hp
LAMPIRAN E

PERHITUNGAN ASPEK EKONOMI

Dalam pra rancangan pabrik gliserol digunakan asumsi sebagai berikut:

Pabrik beroperasi selama 330 hari dalam setahun.

Kapasitas maksimum adalah 58.000 ton/tahun.

Perhitungan didasarkan pada harga peralatan tiba di pabrik atau purchased-equipment delivered (Peters dkk, 2004).


LE.1 Modal Investasi Tetap (Fixed Capital Investment)

LE.1.1 Modal Investasi Tetap Langsung (MITL)

LE.1.1.1 Biaya Tanah Lokasi Pabrik

Menurut keterangan masyarakat setempat, biaya tanah pada lokasi pabrik berkisar Rp 500.000/m².

Luas tanah seluruhnya = 9500 m²

Harga tanah seluruhnya = 9500 m² x Rp 500.000/m² = Rp 4.750.000.000,-

Biaya perataan tanah diperkirakan 5% dari harga tanah seluruhnya (Peters dkk, 2004).

Biaya perataan tanah = 0,05 x Rp 4.750.000.000,- = Rp 237.500.000,-

Total biaya tanah (A) = Rp 4.750.000.000,00 + Rp 237.500.000,00 = Rp 4.987.500.000,00

LE.1.1.2 Harga Bangunan

Tabel LE.1 Perincian Harga Bangunan dan Sarana Lainnya

<table>
<thead>
<tr>
<th>No.</th>
<th>Nama Bangunan</th>
<th>Luas (m²)</th>
<th>Harga (Rp/m²)</th>
<th>Jumlah (Rp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pos Keamanan</td>
<td>20</td>
<td>1.000.000</td>
<td>20.000.000</td>
</tr>
<tr>
<td>2</td>
<td>Parkir</td>
<td>300</td>
<td>800.000</td>
<td>240.000.000</td>
</tr>
<tr>
<td>3</td>
<td>Taman</td>
<td>300</td>
<td>800.000</td>
<td>240.000.000</td>
</tr>
<tr>
<td>4</td>
<td>Areal Bahan Baku</td>
<td>500</td>
<td>800.000</td>
<td>416.000.000</td>
</tr>
<tr>
<td>5</td>
<td>Ruang Kontrol</td>
<td>50</td>
<td>3.000.000</td>
<td>150.000.000</td>
</tr>
</tbody>
</table>
Harga bangunan saja = Rp 10.344.000.000,-
Harga sarana = Rp 900.000.000,-
Total biaya bangunan dan sarana (B) = Rp 11.244.000.000,-

**LE.1.1.3 Perincian Harga Peralatan**

Harga peralatan dapat ditentukan dengan menggunakan persamaan berikut:

\[ C_x = C_y \left( \frac{X_2}{X_1} \right)^m \left( \frac{I_x}{I_y} \right) \]

(Peters dkk, 2004)

dimana:  
\( C_x \) = harga alat pada tahun yang diinginkan  
\( C_y \) = harga alat pada tahun dan kapasitas yang tersedia  
\( X_1 \) = kapasitas alat yang tersedia  
\( X_2 \) = kapasitas alat yang diinginkan  
\( I_x \) = indeks harga pada tahun yang diinginkan  
\( I_y \) = indeks harga pada tahun yang tersedia
m = faktor eksponensial untuk kapasitas (tergantung jenis alat)

Untuk menentukan indeks harga pada tahun 2011 digunakan metode regresi koefisien korelasi:

\[
r = \frac{n \cdot \Sigma X_i \cdot Y_i - \Sigma X_i \cdot \Sigma Y_i}{\sqrt{[n \cdot \Sigma X_i^2 - (\Sigma X_i)^2] \cdot [n \cdot \Sigma Y_i^2 - (\Sigma Y_i)^2]}}
\]

(Montgomery, 1992)

Tabel LE.2 Harga Indeks Marshall dan Swift

<table>
<thead>
<tr>
<th>No.</th>
<th>Tahun (Xi)</th>
<th>Indeks (Yi)</th>
<th>Xi.Yi</th>
<th>Xi²</th>
<th>Yi²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1989</td>
<td>895</td>
<td>1780155</td>
<td>3956121</td>
<td>801025</td>
</tr>
<tr>
<td>2</td>
<td>1990</td>
<td>915</td>
<td>1820850</td>
<td>3960100</td>
<td>837225</td>
</tr>
<tr>
<td>3</td>
<td>1991</td>
<td>931</td>
<td>1853621</td>
<td>3964081</td>
<td>866761</td>
</tr>
<tr>
<td>4</td>
<td>1992</td>
<td>943</td>
<td>1878456</td>
<td>3968016</td>
<td>889249</td>
</tr>
<tr>
<td>5</td>
<td>1993</td>
<td>967</td>
<td>1927231</td>
<td>3972049</td>
<td>935089</td>
</tr>
<tr>
<td>6</td>
<td>1994</td>
<td>993</td>
<td>1980042</td>
<td>3976036</td>
<td>986049</td>
</tr>
<tr>
<td>7</td>
<td>1995</td>
<td>1028</td>
<td>2050860</td>
<td>3980025</td>
<td>1056784</td>
</tr>
<tr>
<td>8</td>
<td>1996</td>
<td>1039</td>
<td>2073844</td>
<td>3984016</td>
<td>1079521</td>
</tr>
<tr>
<td>9</td>
<td>1997</td>
<td>1057</td>
<td>2110829</td>
<td>3988009</td>
<td>1117249</td>
</tr>
<tr>
<td>10</td>
<td>1998</td>
<td>1062</td>
<td>2121876</td>
<td>3992004</td>
<td>1127844</td>
</tr>
<tr>
<td>11</td>
<td>1999</td>
<td>1068</td>
<td>2134932</td>
<td>3996001</td>
<td>1140624</td>
</tr>
<tr>
<td>12</td>
<td>2000</td>
<td>1089</td>
<td>2178000</td>
<td>4000000</td>
<td>1185921</td>
</tr>
<tr>
<td>13</td>
<td>2001</td>
<td>1094</td>
<td>2189094</td>
<td>4004001</td>
<td>1196836</td>
</tr>
<tr>
<td>14</td>
<td>2002</td>
<td>1103</td>
<td>2208206</td>
<td>4008004</td>
<td>1216609</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>27937</strong></td>
<td><strong>14184</strong></td>
<td><strong>28307996</strong></td>
<td><strong>55748511</strong></td>
<td><strong>14436786</strong></td>
</tr>
</tbody>
</table>

Sumber: Tabel 6-2. Peters dkk, 2004

Data: 

\[ n = 14 \quad \Sigma Xi = 27937 \quad \Sigma Yi = 14184 \]
\[ \Sigma XiYi = 28307996 \quad \Sigma Xi^2 = 55748511 \quad \Sigma Yi^2 = 14436786 \]

Dengan memasukkan harga-harga pada Tabel LE-2. maka diperoleh harga koefisien korelasi:

\[
r = \frac{(14) \cdot (28307996) - (27937)(14184)}{\sqrt{[(14) \cdot (55748511) - (27937)^2] \cdot [(14)(14436786) - (14184)^2]^{1/2}}} \approx 0.98 \approx 1
\]
Harga koefisien yang mendekati +1 menyatakan bahwa terdapat hubungan linier antar variabel X dan Y. sehingga persamaan regresi yang mendekati adalah persamaan regresi linier.

Persamaan umum regresi linier: $Y = a + b \cdot X$

dengan: $Y$ = indeks harga pada tahun yang dicari (2010)
$X$ = variabel tahun ke $n - 1$
$a, b$ = tetapan persamaan regresi

Tetapan regresi ditentukan oleh: (Montgomery, 1992)
\[
b = \frac{(n \cdot \Sigma X_i Y_i) - (\Sigma X_i \cdot \Sigma Y_i)}{(n \cdot \Sigma X_i^2) - (\Sigma X_i)^2}
\]
\[
a = \frac{\Sigma Y_i \cdot \Sigma X_i^2 - \Sigma X_i \cdot \Sigma X_i Y_i}{n \cdot \Sigma X_i^2 - (\Sigma X_i)^2}
\]

Maka:
\[
b = \frac{(14)(28307996) - (27937)(14184)}{(14)(55748511) - (27937)^2} = \frac{53536}{3185} = 16,8089
\]
\[
a = \frac{(14184)(55748511) - (27937)(28307996)}{(14)(55748511) - (27937)^2} = \frac{-103604228}{3185} = -32528,8
\]

Sehingga persamaan regresi liniernya adalah:
\[
Y = a + b \cdot X
\]
\[
Y = 16,8089X - 32528,8
\]

Dengan demikian, harga indeks pada tahun 2011 adalah:
\[
Y = 16,809(2011) = 32528,8
\]
\[
Y = 1274,099
\]

Contoh perhitungan harga peralatan:

1. Tangki Penyimpanan CPO (TP-101)

Kapasitas tangki. \( X_2 = 6573,774 \text{ m}^3 \). Dari Gambar LE.1, diperoleh harga kapasitas tangki \( (X_1) 1 \text{ m}^3 \) pada tahun 2002 adalah \( (C_y) \) US$ 6700. Dari tabel 6-4, Peters dkk, 2004, faktor eksponen untuk tangki adalah \( (m) 0,49 \). Indeks harga pada tahun 2002 \( (I_y) 1103 \).

\[
C_x = C_y \times \left( \frac{X_2}{X_1} \right)^m \times \frac{I_x}{I_y}
\]

\[
C_x = \text{US$ 6700} \times \left( \frac{6573,774}{1} \right)^{0.49} \times \frac{1274,099}{1103}
\]

\[
C_x = \text{US$ 574.687} \times \left( \text{Rp8.565,-} \right) / \text{(US$ 1)}
\]

\[
C_x = \text{Rp 4.922.197.884,229,-/unit}
\]

Dengan cara yang sama diperoleh perkiraan harga alat lainnya yang dapat dilihat pada Tabel LE.3 untuk perkiraan peralatan proses dan Tabel LE.4 untuk perkiraan peralatan utilitas. Sedangkan untuk pompa non-impor, harga diambil dari PT Duta sarana tanggal 2 Agustus 2011.
Untuk harga alat impor sampai di lokasi pabrik ditambahkan biaya sebagai berikut:

- Biaya transportasi = 5 %
- Biaya asuransi = 1 %
- Bea masuk = 15 % (Rusjdi, 2004)
- PPn = 10 % (Rusjdi, 2004)
- PPh = 10 % (Rusjdi, 2004)
- Biaya gudang di pelabuhan = 0,5 %
- Biaya administrasi pelabuhan = 0,5 %
- Transportasi lokal = 0,5 %
- Biaya tak terduga = 0,5 %

Total = 43 %

Untuk harga alat non impor sampai di lokasi pabrik ditambahkan biaya sebagai berikut:

- PPn = 10 % (Rusjdi, 2004)
- PPh = 10 % (Rusjdi, 2004)
- Transportasi lokal = 0,5 %
- Biaya tak terduga = 0,5 %

Total = 21 %

<table>
<thead>
<tr>
<th>No.</th>
<th>Kode Alat</th>
<th>Unit</th>
<th>Ket*</th>
<th>Harga/Unit</th>
<th>Harga Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TK-101</td>
<td>1</td>
<td>I</td>
<td>Rp 4,922,197.884</td>
<td>Rp 4,922,197.884</td>
</tr>
<tr>
<td>2</td>
<td>TK-102</td>
<td>1</td>
<td>I</td>
<td>Rp 3,922,642.741</td>
<td>Rp 3,922,642.741</td>
</tr>
<tr>
<td>3</td>
<td>TK-301</td>
<td>1</td>
<td>I</td>
<td>Rp 4,877,590.669</td>
<td>Rp 4,877,590.669</td>
</tr>
<tr>
<td>4</td>
<td>TK-302</td>
<td>1</td>
<td>I</td>
<td>Rp 462,071.525</td>
<td>Rp 462,071.525</td>
</tr>
<tr>
<td>5</td>
<td>TK-303</td>
<td>1</td>
<td>I</td>
<td>Rp 2,724,170.931</td>
<td>Rp 2,724,170.931</td>
</tr>
<tr>
<td>6</td>
<td>FT-201</td>
<td>1</td>
<td>I</td>
<td>Rp 500,362.238</td>
<td>Rp 500,362.238</td>
</tr>
<tr>
<td>7</td>
<td>FT-202</td>
<td>1</td>
<td>I</td>
<td>Rp 480,097.750</td>
<td>Rp 480,097.750</td>
</tr>
<tr>
<td>8</td>
<td>SK-201</td>
<td>1</td>
<td>I</td>
<td>Rp 663,451.289</td>
<td>Rp 663,451.289</td>
</tr>
<tr>
<td>9</td>
<td>CH-201</td>
<td>1</td>
<td>I</td>
<td>Rp 1,596,474.898</td>
<td>Rp 1,596,474.898</td>
</tr>
<tr>
<td>10</td>
<td>E-301</td>
<td>1</td>
<td>I</td>
<td>Rp 96,578.169</td>
<td>Rp 96,578.169</td>
</tr>
<tr>
<td>11</td>
<td>E-302</td>
<td>1</td>
<td>I</td>
<td>Rp 59,763.558</td>
<td>Rp 59,763.558</td>
</tr>
<tr>
<td>12</td>
<td>HE-101</td>
<td>1</td>
<td>I</td>
<td>Rp 71,789.829</td>
<td>Rp 71,789.829</td>
</tr>
<tr>
<td>No.</td>
<td>Kode Alat</td>
<td>Unit</td>
<td>Ket*</td>
<td>Harga/Unit</td>
<td>Harga Total</td>
</tr>
<tr>
<td>-----</td>
<td>-----------</td>
<td>------</td>
<td>------</td>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td>1</td>
<td>SC</td>
<td>1 I</td>
<td>I</td>
<td>Rp 56.823.899</td>
<td>Rp 56.823.899</td>
</tr>
<tr>
<td>2</td>
<td>V-02</td>
<td>1 I</td>
<td>I</td>
<td>Rp 80.020.904</td>
<td>Rp 80.020.904</td>
</tr>
<tr>
<td>3</td>
<td>V-03</td>
<td>1 I</td>
<td>I</td>
<td>Rp 59.945.180</td>
<td>Rp 59.945.180</td>
</tr>
<tr>
<td>4</td>
<td>V-04</td>
<td>1 I</td>
<td>I</td>
<td>Rp 370.463.158</td>
<td>Rp 370.463.158</td>
</tr>
<tr>
<td>5</td>
<td>V-05</td>
<td>1 I</td>
<td>I</td>
<td>Rp 147.197.775</td>
<td>Rp 147.197.775</td>
</tr>
<tr>
<td>6</td>
<td>V-07</td>
<td>1 I</td>
<td>I</td>
<td>Rp 56.369.174</td>
<td>Rp 56.369.174</td>
</tr>
<tr>
<td>7</td>
<td>V-08</td>
<td>1 I</td>
<td>I</td>
<td>Rp 135.224.672</td>
<td>Rp 135.224.672</td>
</tr>
<tr>
<td>8</td>
<td>V-09</td>
<td>1 I</td>
<td>I</td>
<td>Rp 82.752.799</td>
<td>Rp 82.752.799</td>
</tr>
<tr>
<td>9</td>
<td>V-10</td>
<td>1 I</td>
<td>I</td>
<td>Rp 135.224.672</td>
<td>Rp 135.224.672</td>
</tr>
<tr>
<td>10</td>
<td>V-11</td>
<td>1 I</td>
<td>I</td>
<td>Rp 830.739.943</td>
<td>Rp 830.739.943</td>
</tr>
<tr>
<td>11</td>
<td>V-12</td>
<td>1 I</td>
<td>I</td>
<td>Rp 213.233.127</td>
<td>Rp 213.233.127</td>
</tr>
<tr>
<td>12</td>
<td>V-13</td>
<td>1 I</td>
<td>I</td>
<td>Rp 304.493.557</td>
<td>Rp 304.493.557</td>
</tr>
<tr>
<td>13</td>
<td>V-14</td>
<td>1 I</td>
<td>I</td>
<td>Rp 76.644.436</td>
<td>Rp 76.644.436</td>
</tr>
<tr>
<td>15</td>
<td>V-16</td>
<td>1 I</td>
<td>I</td>
<td>Rp 371.129.945</td>
<td>Rp 371.129.945</td>
</tr>
<tr>
<td>16</td>
<td>V-17</td>
<td>1 I</td>
<td>I</td>
<td>Rp 971.898.031</td>
<td>Rp 971.898.031</td>
</tr>
<tr>
<td>17</td>
<td>JC-01</td>
<td>1 I</td>
<td>I</td>
<td>Rp 5.729.557.139</td>
<td>Rp 5.729.557.139</td>
</tr>
</tbody>
</table>

Sub Total Impor Rp 9.628.032.585

<table>
<thead>
<tr>
<th>No.</th>
<th>Kode Alat</th>
<th>Unit</th>
<th>Ket*</th>
<th>Harga/Unit</th>
<th>Harga Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>V-01</td>
<td>1 NI</td>
<td>I</td>
<td>Rp 8.000.000</td>
<td>Rp 8.000.000</td>
</tr>
<tr>
<td>18</td>
<td>V-06</td>
<td>1 NI</td>
<td>I</td>
<td>Rp 6.000.000</td>
<td>Rp 6.000.000</td>
</tr>
<tr>
<td>19</td>
<td>P-01</td>
<td>1 NI</td>
<td>I</td>
<td>Rp 10.000.000</td>
<td>Rp 10.000.000</td>
</tr>
<tr>
<td>20</td>
<td>P-02</td>
<td>1 NI</td>
<td>I</td>
<td>Rp 10.000.000</td>
<td>Rp 10.000.000</td>
</tr>
</tbody>
</table>

Sub Total non-Impor Rp 80.000.000

Harga Total Rp 20.557.643.744

*)Keterangan: I: untuk peralatan impor. NI: untuk peralatan non impor.

Tabel LE.4 Estimasi Harga Peralatan Utilitas dan Pengolahan Limbah
| 21  | P-03  | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 22  | P-04  | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 23  | P-05  | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 24  | P-06  | 1    | NI  | Rp    | 20.000.000 | Rp    | 20.000.000 |
| 25  | P-07  | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 26  | P-08  | 2    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 27  | P-09  | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 28  | P-10  | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 29  | P-11  | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 30  | P-12  | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 31  | P-13  | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 32  | P-14  | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 33  | P-15  | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 34  | P-16  | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 35  | BP    | 1    | NI  | Rp    | 10.000.000 | Rp    | 10.000.000 |
| 36  | BS    | 1    | NI  | Rp    | 7.000.000   | Rp    | 7.000.000  |
| 37  | BN    | 1    | NI  | Rp    | 7.000.000   | Rp    | 7.000.000  |
| 38  | TA    | 1    | NI  | Rp    | 25.000.000  | Rp    | 25.000.000 |
| 39  | Activated Sludge | 1 | NI | Rp | 13.000.000 | Rp | 13.000.000 |
| 40  | TS    | 1    | NI  | Rp    | 82.577.970  | Rp    | 82.577.970 |
| 41  | Generator | 2 | NI  | Rp    | 400.000.000 | Rp    | 800.000.000 |

<table>
<thead>
<tr>
<th>Sub Total non-impor</th>
<th>Rp</th>
<th>1.128.577.970</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harga Total</td>
<td>Rp</td>
<td>5.027.053.417</td>
</tr>
</tbody>
</table>

*) Keterangan: I: untuk peralatan impor. NI: untuk peralatan non impor.

Total harga peralatan tiba di lokasi pabrik (*purchased-equipment delivered*) adalah:

\[
= 1.43 \times (Rp\ 20.477.643.744,- + \ Rp\ 9.628.032.585,-) + \\
1.21 \times (Rp\ 80.000.000,- + \ Rp\ 1.128.577.970,-) \\
\]

\[
= Rp\ 44.513.496.495,-
\]

Biaya pemasangan diperkirakan 30% dari total harga peralatan (Peters dkk, 2004).

Biaya pemasangan = 0,30 \times \ Rp\ 44.513.496.495,- \\

\[
= Rp\ 13.354.048.948,-
\]
LE.1.1.4 Instrumentasi dan Alat Kontrol
Diperkirakan biaya instrumentasi dan alat kontrol 26% dari total harga peralatan. (Peters dkk, 2004).

Biaya instrumentasi dan alat kontrol (D) = 0,26 × Rp 44.513.496.495,-
= Rp 11.573.509.089,-

LE.1.1.5 Biaya Perpipaan
Diperkirakan biaya perpipaan 60% dari total harga peralatan (Peters dkk, 2004).

Biaya perpipaan (E) = 0,6 × Rp 44.513.496.495,-
= Rp 26.708.097.897,-

LE.1.1.6 Biaya Instalasi Listrik
Diperkirakan biaya instalasi listrik 15% dari total harga peralatan (Peters dkk, 2004).

Biaya instalasi listrik (F) = 0,15 × Rp 44.513.496.495,-
= Rp 6.677.024.474,-

LE.1.1.7 Biaya Insulasi
Diperkirakan biaya insulasi 9% dari total harga peralatan (Peters dkk, 2004).

Biaya insulasi (G) = 0,09 × Rp 44.513.496.495,-
= Rp 4.006.214.685,-

LE.1.1.8 Biaya Inventaris Kantor
Diperkirakan biaya inventaris kantor 5% dari total harga peralatan dan pemasangan (Peters dkk, 2004).

Biaya inventaris kantor (H) = 0,05 × Rp 44.513.496.495,-
= Rp 2.225.674.825,-
LE.1.1.9 Biaya Perlengkapan Kebakaran dan Keamanan

Diperkirakan biaya perlengkapan kebakaran dan keamanan 2% dari total harga peralatan dan pemasangan (Peters dkk, 2004).

\[
\text{Biaya perlengkapan kebakaran dan keamanan (I) } = 0.02 \times \text{Rp 57.867.545.443,-} \\
= \text{Rp 1.157.350.909,-}
\]

LE.1.1.10 Sarana Transportasi

Tabel LE.5 Biaya Sarana Transportasi

<table>
<thead>
<tr>
<th>No.</th>
<th>Jenis Kendaraan</th>
<th>Unit</th>
<th>Tipe</th>
<th>Harga/ Unit (Rp)</th>
<th>Harga Total (Rp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Komisaris</td>
<td>1</td>
<td>Toyota Camry</td>
<td>Rp462.450.000</td>
<td>Rp462.450.000</td>
</tr>
<tr>
<td>2</td>
<td>Direktur</td>
<td>1</td>
<td>Fortuner</td>
<td>Rp429.600.000</td>
<td>Rp429.600.000</td>
</tr>
<tr>
<td>3</td>
<td>Manajer</td>
<td>4</td>
<td>Kijang Innova</td>
<td>Rp249.850.000</td>
<td>Rp999.400.000</td>
</tr>
<tr>
<td>4</td>
<td>Bus Karyawan</td>
<td>3</td>
<td>Bus</td>
<td>Rp280.200.000</td>
<td>Rp840.600.000</td>
</tr>
<tr>
<td>5</td>
<td>Truk</td>
<td>3</td>
<td>Truk</td>
<td>Rp242.350.000</td>
<td>Rp727.050.000</td>
</tr>
<tr>
<td>6</td>
<td>Mobil Pemasaran</td>
<td>3</td>
<td>Inova Diesel</td>
<td>Rp230.800.000</td>
<td>Rp692.400.000</td>
</tr>
<tr>
<td>7</td>
<td>Mobil Pemadam Kebakaran</td>
<td>2</td>
<td>Truk Tangki</td>
<td>Rp440.200.000</td>
<td>Rp880.400.000</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>Rp5.031.900.000</strong></td>
</tr>
</tbody>
</table>

(Sumber: www.hargatoyota.com, 13 Agustus 2011)

Total MITL = A + B + C + D + E + F + G + H + I + J
= Rp 131.478.817.321,-

LE.1.2 Modal Investasi Tetap Tak Langsung (MITTL)

LE.1.2.1 Pra Investasi

Diperkirakan 7% dari total harga peralatan (Peters dkk, 2004).

Pra Investasi (A) = 0,07 × Rp 44.513.496.495,- = Rp 3.115.944.755,-

LE.1.2.2 Biaya Engineering dan Supervisi

Diperkirakan 32% dari total harga peralatan (Peters dkk, 2004).

Biaya Engineering dan Supervisi (B) = 0,32 × Rp 44.513.496.495,-
= Rp 14.244.318.878,-
LE.1.2.3 Biaya Legalitas
Diperkirakan 4% dari total harga peralatan (Peters dkk, 2004).
Biaya Legalitas (C) = 0.04 × Rp 44.513.496.495,- = Rp 1.780.539.860,-

LE.1.2.4 Biaya Kontraktor
Diperkirakan 19% dari total harga peralatan (Peters dkk, 2004).
Biaya Kontraktor (D) = 0.19 × Rp 44.513.496.495,- = Rp 8.457.564.334,-

LE.1.2.5 Biaya Tak Terduga
Diperkirakan 10% dari total harga peralatan (Peters dkk, 2004).
Biaya Tak Terduga (E) = 0.1 × Rp 44.513.496,- = Rp 4.451.349.649,-

Total MITTL = A + B + C + D + E = Rp 32.049.717.476,-
Total MIT = MITL + MITTL
= Rp 131.478.817.321,- + Rp 32.049.717.476,-
= Rp 163.528.534.797,-

LE.2 Modal Kerja
Modal kerja dihitung untuk pengoperasian pabrik selama 3 bulan (90 hari).

LE.2.1 Persediaan Bahan Baku

LE.2.1.1 Bahan Baku Proses
1. *Crude Palm Oil* (CPO)
Kebutuhan = 20428,9158 kg/jam
Harga = Rp 7.223,-/kg (Blogger-KTI, 13 Agustus 2011)
Harga total = 90 hari × 24 jam/hari × 20428,9158 kg/jam × Rp 7.223
= Rp 319.172.959.660,-

LE.2.1.2 Persediaan Bahan Baku Utilitas
1. Alum. Al$_2$(SO$_4$)$_3$
Kebutuhan = 0,634 kg/jam
Harga = Rp 2.500 ,-/kg (PT. Bratachem, 2011)
Harga total = 90 hari × 24 jam/hari × 0,634 kg/jam × Rp 2.500,- /kg
= Rp 3.423.600,-
2. Soda abu. Na$_2$CO$_3$
   Kebutuhan = 3,4173 kg/jam
   Harga = Rp 3500,-/kg (PT. Bratachem, 2011)
   Harga total = 90 hari × 24 jam/hari × 3,4173 kg/jam × Rp 3500,-/kg
   = Rp 25.835.438,-

3. Kaporit
   Kebutuhan = 0.0033 kg/jam
   Harga = Rp 11.000,-/kg (PT. Bratachem, 2011)
   Harga total = 90 hari × 24 jam/hari × 0,0033 kg/jam × Rp 11.000,-/kg
   = Rp 78.408,-

4. H$_2$SO$_4$
   Kebutuhan = 0,0137 kg/jam
   Harga = Rp 35.000,-/kg (PT. Bratachem, 2011)
   Harga total = 90 hari × 24 jam × 0,0137 kg × Rp 35.000,-/kg
   = Rp 1.035.720,-

5. NaOH
   Kebutuhan = 0,100830 kg/jam
   Harga = Rp 5250,-/kg (PT. Bratachem, 2011)
   Harga total = 90 hari × 24 jam × 0,100830 kg × Rp 5250,-/kg
   = Rp 1.143.412,-

6. Solar
   Kebutuhan = 830,164 liter/jam
   Harga solar untuk industri = Rp. 10.644,-/liter (PT. Pertamina, 2011)
   Harga total = 90 hari × 24 jam/hari × 830,164 ltr/jam × Rp.10.644,-/liter
   = Rp 19.086.340.628,-

Total biaya persediaan bahan baku proses dan utilitas selama 3 bulan (90 hari) adalah Rp 338.290.816.866,-
LE.2.2 Kas

LE.2.2.1 Gaji Pegawai

Tabel LE.6 Perincian Gaji Pegawai

<table>
<thead>
<tr>
<th>Jabatan</th>
<th>Jumlah</th>
<th>Gaji/bulan (Rp)</th>
<th>Jumlah gaji/bulan (Rp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dewan Komisaris</td>
<td>1</td>
<td>20.000.000</td>
<td>20.000.000</td>
</tr>
<tr>
<td>Direktur</td>
<td>1</td>
<td>15.000.000</td>
<td>15.000.000</td>
</tr>
<tr>
<td>Staf Ahli</td>
<td>1</td>
<td>8.000.000</td>
<td>8.000.000</td>
</tr>
<tr>
<td>Sekretaris</td>
<td>1</td>
<td>3.000.000</td>
<td>3.000.000</td>
</tr>
<tr>
<td>Manajer Produksi</td>
<td>1</td>
<td>10.000.000</td>
<td>10.000.000</td>
</tr>
<tr>
<td>Manajer Teknik</td>
<td>1</td>
<td>10.000.000</td>
<td>10.000.000</td>
</tr>
<tr>
<td>Manajer Umum dan Keuangan</td>
<td>1</td>
<td>10.000.000</td>
<td>10.000.000</td>
</tr>
<tr>
<td>Manajer Pembelian dan Pemasaran</td>
<td>1</td>
<td>10.000.000</td>
<td>10.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Proses</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Laboratorium R&amp;D</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Utilitas</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Mesin</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Listrik</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Instrumentasi</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Pemeliharaan Pabrik</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Keuangan</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Administrasi</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Personalia</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Humas</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Keamanan</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Kepala Seksi Pembelian dan Pemasaran</td>
<td>1</td>
<td>5.000.000</td>
<td>5.000.000</td>
</tr>
<tr>
<td>Karyawan Produksi</td>
<td>60</td>
<td>2.000.000</td>
<td>120.000.000</td>
</tr>
<tr>
<td>Karyawan Teknik</td>
<td>16</td>
<td>2.000.000</td>
<td>32.000.000</td>
</tr>
<tr>
<td>Karyawan Umum dan Keuangan</td>
<td>12</td>
<td>2.000.000</td>
<td>24.000.000</td>
</tr>
<tr>
<td>Karyawan Pembelian dan</td>
<td>6</td>
<td>2.000.000</td>
<td>12.000.000</td>
</tr>
<tr>
<td>Pemasaran</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Dokter</td>
<td>2</td>
<td>4.000.000</td>
<td>8.000.000</td>
</tr>
<tr>
<td>Perawat</td>
<td>5</td>
<td>1.500.000</td>
<td>7.500.000</td>
</tr>
<tr>
<td>Petugas Keamanan</td>
<td>8</td>
<td>1.300.000</td>
<td>10.400.000</td>
</tr>
<tr>
<td>Petugas Kebersihan</td>
<td>10</td>
<td>1.100.000</td>
<td>11.000.000</td>
</tr>
<tr>
<td>Supir</td>
<td>5</td>
<td>1.500.000</td>
<td>7.500.000</td>
</tr>
<tr>
<td><strong>Jumlah</strong></td>
<td>145</td>
<td></td>
<td><strong>383.400.000</strong></td>
</tr>
</tbody>
</table>

Total gaji pegawai selama 1 bulan = Rp 383.400.000,-
Total gaji pegawai selama 3 bulan = Rp 1.150.200.000,-

**LE.2.2.2 Biaya Administrasi Umum**
Diperkirakan 20% dari gaji pegawai (Peters dkk, 2004)

\[
= 0.2 \times \text{Rp 1.150.200.000,-} \\
= \text{Rp 230.040.000,-}
\]

**LE.2.2.3 Biaya Pemasaran**
Diperkirakan 20% dari gaji pegawai (Peters dkk, 2004)

\[
= 0.2 \times \text{Rp 1.150.200.000,-} \\
= \text{Rp 230.040.000,-}
\]

**LE.2.2.4 Pajak Bumi dan Bangunan**
Menurut UU Perditjen Pajak PER-32/PJ/2008
- Nilai jual objek pajak (NJOP) yang tidak kena pajak untuk wilayah Belawan sebesar Rp 12.000.000,-
- Nilai jual objek pajak untuk tanah sebesar Rp 500.000,- per m²

**Wajib Pajak Pabrik Pembuatan Vinil Asetat**

<table>
<thead>
<tr>
<th>Nilai Perolehan Objek Pajak</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Tanah</td>
<td>Rp 4.750.000.000,-</td>
</tr>
<tr>
<td>- Bangunan</td>
<td>Rp 10.344.000.000,-</td>
</tr>
<tr>
<td><strong>Total NJOP</strong></td>
<td>Rp 15.094.000.000,-</td>
</tr>
<tr>
<td>Nilai Perolehan Objek Pajak Tidak Kena Pajak</td>
<td>(Rp. 12.000.000,-) +</td>
</tr>
<tr>
<td>Nilai Perolehan Objek Pajak Kena Pajak</td>
<td>Rp 15.082.000.000,-</td>
</tr>
</tbody>
</table>
Pajak yang Terutang (5% × NPOPKP) = Rp. 754.100.000,-

Tabel LE.7 Perincian Biaya Kas

<table>
<thead>
<tr>
<th>No.</th>
<th>Jenis Biaya</th>
<th>Jumlah</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gaji Pegawai</td>
<td>Rp 1.150.200.000</td>
</tr>
<tr>
<td>2</td>
<td>Administrasi Umum</td>
<td>Rp 230.040.000</td>
</tr>
<tr>
<td>3</td>
<td>Pemasaran</td>
<td>Rp 230.040.000</td>
</tr>
<tr>
<td>4</td>
<td>Pajak Bumi dan Bangunan</td>
<td>Rp 754.100.000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>Rp 2.364.380.000</strong></td>
</tr>
</tbody>
</table>

**LE.2.3 Biaya Start-Up**

Diperkirakan 8% dari Modal Investasi Tetap (Peters dkk, 2004)

\[ = 0.08 \times \text{Rp 163.528.534.797,-} \]

\[ = \text{Rp 13.082.282.784,-} \]

**LE.2.4 Piutang Dagang**

\[ PD = \frac{IP}{12} \times HPT \]

dimana:  
PD = piutang dagang  
IP = jangka waktu kredit yang diberikan (3 bulan)  
HPT = hasil penjualan tahunan

Penjualan:

1. Harga jual Gliserol = Rp 15.000,-/kg (BPS Indonesia, 2011)
   Produksi Gliserol = 7323,2323 kg/jam  
   Hasil penjualan gliserol tahunan yaitu:
   \[ = 7323,2323 \text{ kg/jam} \times 24 \text{ jam/hari} \times 330 \text{ hari/tahun} \times \text{Rp 15.000,-/kg} \]
   \[ = \text{Rp 869.999.997.240,-} \]

2. Harga jual asam lemak = Rp 12.000,-/kg
   Produksi asam lemak = 19809,3122 kg/jam  
   Hasil penjualan asam lemak tahunan yaitu:
   \[ = 19809,3122 \text{ kg/jam} \times 24 \text{ jam/hari} \times 330 \text{ hari/tahun} \times \text{Rp 12.000,-/kg} \]
   \[ = \text{Rp 941.338.515.744,-} \]
Hasil penjualan total tahunan = Rp 1.811.338.512.984,-

Piutang Dagang = \( \frac{3}{12} \times \text{Rp 1.811.338.512.984,-} \)

= Rp 452.834.628.246,-

Perincian modal kerja dapat dilihat pada tabel di bawah ini.

<table>
<thead>
<tr>
<th>No.</th>
<th>Jenis Biaya</th>
<th>Jumlah</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bahan Baku Proses dan Utilitas</td>
<td>Rp 338.290.816.866</td>
</tr>
<tr>
<td>2</td>
<td>Kas</td>
<td>Rp 2.364.380.000</td>
</tr>
<tr>
<td>3</td>
<td>Start Up</td>
<td>Rp 13.082.282.784</td>
</tr>
<tr>
<td>4</td>
<td>Piutang Dagang</td>
<td>Rp 452.834.628.246</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>Rp 806.572.107.896</strong></td>
</tr>
</tbody>
</table>

Total Modal Investasi = Modal Investasi Tetap + Modal Kerja

= Rp 163.528.534.797,- + Rp 806.572.107.896,-

= Rp 970.100.642.693,-

Modal ini berasal dari:

- Modal sendiri = 60% dari total modal investasi
  = 0,6 \times \text{Rp 970.100.642.693,-}
  = Rp 582.060.385.616,-

- Pinjaman dari Bank = 40% dari total modal investasi
  = 0,4 \times \text{Rp 970.100.642.693,-}
  = Rp 388.040.257.077,-

### LE.3 Biaya Produksi Total

#### LE.3.1 Biaya Tetap (Fixed Cost = FC)

#### LE.3.1.1 Gaji Tetap Karyawan

Gaji tetap karyawan terdiri dari gaji tetap tiap bulan ditambah 2 bulan gaji yang diberikan sebagai tunjangan. Sehingga:
Gaji total = \((12 + 2) \times Rp\ 383.400.000,- = Rp 5.367.600.000,-\)

**LE.3.1.2 Bunga Pinjaman Bank**
Bunga pinjaman bank adalah 14% dari total pinjaman (Bank Mandiri, 2010).
\[= 0.14 \times Rp\ 388.040.257.077,-\]
\[= Rp\ 54.325.635.991,-\]

**LE.3.1.3 Depresiasi dan Amortisasi**

**Tabel LE.9 Aturan depresiasi sesuai UU Republik Indonesia No. 17 Tahun 2000**

<table>
<thead>
<tr>
<th>Kelompok Harta Berwujud</th>
<th>Masa (tahun)</th>
<th>Tarif (%)</th>
<th>Beberapa Jenis Harta</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Bukan Bangunan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Kelompok 1</td>
<td>4</td>
<td>25</td>
<td>Mesin kantor. perlengkapan. alat perangkat/ <em>tools</em> industri.</td>
</tr>
<tr>
<td>2. Kelompok 2</td>
<td>8</td>
<td>12.5</td>
<td>Mobil. truk kerja</td>
</tr>
<tr>
<td>3. Kelompok 3</td>
<td>16</td>
<td>6.25</td>
<td>Mesin industri kimia. mesin industri mesin</td>
</tr>
<tr>
<td>II. Bangunan Permanen</td>
<td>20</td>
<td>5</td>
<td>Bangunan sarana dan penunjang</td>
</tr>
</tbody>
</table>

Sumber: Waluyo, 2000 dan Rusdji, 2004

Depresiasi dihitung dengan metode garis lurus dengan harga akhir nol.

\[D = \frac{P - L}{n}\]
dimana: $D = \text{depresiasi per tahun}$  
$P = \text{harga awal peralatan}$  
$L = \text{harga akhir peralatan}$  
$n = \text{umur peralatan (tahun)}$

Tabel LE.10 Perhitungan Biaya Depresiasi sesuai UU RI No. 17 Tahun 2000

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Biaya (Rp)</th>
<th>Umur (tahun)</th>
<th>Depresiasi (Rp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangunan</td>
<td>10.344.000.000</td>
<td>20</td>
<td>517.200.000</td>
</tr>
<tr>
<td>Peralatan proses dan utilitas</td>
<td>57.867.545.443</td>
<td>16</td>
<td>3.616.721.590</td>
</tr>
<tr>
<td>Instrumentasi dan pengendalian proses</td>
<td>11.573.509.089</td>
<td>4</td>
<td>2.893.377.272</td>
</tr>
<tr>
<td>Perpipaan</td>
<td>26.708.097.897</td>
<td>4</td>
<td>6.677.024.474</td>
</tr>
<tr>
<td>Instalasi listrik</td>
<td>6.677.024.474</td>
<td>4</td>
<td>1.669.256.119</td>
</tr>
<tr>
<td>Insulasi</td>
<td>4.006.214.685</td>
<td>4</td>
<td>1.001.553.671</td>
</tr>
<tr>
<td>Inventaris kantor</td>
<td>2.225.674.825</td>
<td>4</td>
<td>556.418.706</td>
</tr>
<tr>
<td>Perlengkapan keamanan dan kebakaran</td>
<td>1.157.350.909</td>
<td>4</td>
<td>289.337.727</td>
</tr>
<tr>
<td>Sarana transportasi</td>
<td>5.031.900.000</td>
<td>8</td>
<td>628.987.500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>17.849.877.060</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Semua modal investasi tetap langsung (MITL) kecuali tanah mengalami penyusutan yang disebut depresiasi. sedangkan modal investasi tetap tidak langsung (MITTL) juga mengalami penyusutan yang disebut amortisasi.


Untuk masa 4 tahun, maka biaya amortisasi adalah 25% dari MITTL sehingga:

$\text{Biaya amortisasi} = 0.25 \times \text{Rp} 32.049.717.476,-$
Total Biaya Depresiasi dan Amortisasi
= Rp 17.849.877.060,- + Rp 8.012.429.369,-
= Rp 25.862.306.429,-

LE.3.1.4 Biaya Tetap Perawatan

Biaya tetap perawatan terbagi menjadi:

1. Perawatan mesin dan alat-alat proses
   Perawatan mesin dan peralatan dalam industri proses berkisar 2 sampai 20%.
   diambil 8% dari harga peralatan terpasang di pabrik (Peters dkk, 2004).
   Biaya perawatan mesin = 0,08 \times Rp 57.867.545.443,-
   = Rp 4.629.403.635,-

2. Perawatan bangunan
   Diperkirakan 8 % dari harga bangunan (Peters dkk, 2004).
   = 0,08 \times Rp 10.344.000.000,-
   = Rp 827.520.000,-

3. Perawatan kendaraan
   Diperkirakan 8% dari harga kendaraan (Peters dkk, 2004).
   = 0,08 \times Rp 5.031.900.000
   = Rp 402.552.000,-

4. Perawatan instrumentasi dan alat kontrol
   Diperkirakan 8% dari harga instrumentasi dan alat kontrol (Peters dkk, 2004).
   = 0,08 \times Rp 11.573.509.089,-
   = Rp 925.880.727,-

5. Perawatan perpipaan
   Diperkirakan 8 % dari harga perpipaan (Peters dkk, 2004).
   = 0,08 \times Rp 26.708.097.897,-
6. Perawatan instalasi listrik
   Diperkirakan 8% dari harga instalasi listrik (Peters dkk, 2004).
   
   \[= 0.08 \times \text{Rp 6.677.024.474,-} = \text{Rp 534.161.958,-}\]

7. Perawatan insulasi
   Diperkirakan 8% dari harga insulasi (Peters dkk, 2004).
   
   \[= 0.08 \times \text{Rp 4.006.14.685,-} = \text{Rp 320.497.175,-}\]

8. Perawatan inventaris kantor
   Diperkirakan 8% dari harga inventaris kantor (Peters dkk, 2004).
   
   \[= 0.08 \times \text{Rp 2.225.674.825,-} = \text{Rp 178.053.986,-}\]

9. Perawatan perlengkapan kebakaran
   Diperkirakan 8% dari harga perlengkapan kebakaran (Peters dkk, 2004).
   
   \[= 0.08 \times \text{Rp 1.157.350.909,-} = \text{Rp 92.588.073,-}\]

   Total Biaya Perawatan = \text{Rp 9.219.785.386,-}

**LE.3.1.5 Biaya Tambahan Industri (Plant Overhead Cost)**

Biaya tambahan industri ini diperkirakan 10% dari modal investasi tetap. (Peters dkk, 2004)

\[\text{Plant Overhead Cost} = 0.1 \times \text{Rp 163.528.534.797,-} = \text{Rp 16.352.853.480,-}\]

**LE.3.1.6 Biaya Administrasi Umum**

Biaya administrasi umum selama 3 bulan adalah \text{Rp 230.040.000,-}

\[\text{Biaya administrasi umum selama 1 tahun} = 4 \times \text{Rp 230.040.000,-} = \text{Rp 920.160.000,-}\]
LE.3.1.7 Biaya Pemasaran dan Distribusi
Biaya pemasaran selama 3 bulan adalah Rp 230.040.000,-
Biaya pemasaran selama 1 tahun = 4 \times Rp 230.040.000,- = Rp 920.160.000,-
Biaya distribusi diperkirakan 50% dari biaya pemasaran. sehingga:
Biaya distribusi = 0.5 \times Rp 920.160.000,- = Rp 460.080.000,-
Biaya pemasaran dan distribusi = Rp 1.380.240.000,-

LE.3.1.8 Biaya Laboratorium, Penelitian dan Pengembangan
Diperkirakan 5% dari biaya tambahan industri (Peters dkk, 2004).
= 0,05 \times Rp 16.352.853.480,-
= Rp 817.642.674,-

LE.3.1.9 Hak Paten dan Royalti
Diperkirakan 1% dari modal investasi tetap (Peters dkk, 2004).
= 0,01 \times Rp 163.528.534.797,-
= Rp 1.635.285.348,-

LE.3.1.10 Biaya Asuransi
= 0,0031 \times Rp 131.478.817.321,-
= Rp 407.584.334,-
2. Biaya asuransi karyawan
Premi asuransi = Rp 300.000/tenaga kerja (PT Prudential Life Assurance, 2010).
Maka biaya asuransi karyawan = 145 orang \times Rp. 300.000,-/orang
= Rp 43.500.000,-
Total biaya asuransi = Rp 451.084.334,-

LE.3.1.11 Pajak Bumi dan Bangunan
Pajak Bumi dan Bangunan adalah Rp 754.100.000,-
Total Biaya Tetap $(Fixed\ Cost)$ = Rp 117.086.693.640,-

**LE.3.2 Biaya Variabel**

**LE.3.2.1 Biaya Variabel Bahan Baku Proses dan Utilitas per tahun**
Biaya persediaan bahan baku proses dan utilitas selama 90 hari adalah Rp 338.290.816.866,-
Total biaya persediaan bahan baku proses dan utilitas selama 1 tahun adalah:

\[
= Rp 338.290.816.866,- \times \frac{330}{90} = Rp 1.240.399.661.843,-
\]

**LE.3.2.2 Biaya Variabel Tambahan**
Biaya variabel tambahan terbagi menjadi:

1. **Biaya Perawatan dan Penanganan Lingkungan**
   Diperkirakan 5% dari biaya variabel bahan baku
   \[
   = 0,05 \times Rp\ 1.240.399.661.843,-
   \]
   \[
   = Rp\ 62.019.983.092,-
   \]

2. **Biaya Variabel Pemasaran dan Distribusi**
   Diperkirakan 1% dari biaya variabel bahan baku
   \[
   = 0,01 \times Rp\ 1.240.399.661.843,-
   \]
   \[
   = Rp\ 12.403.996.618,-
   \]

Total biaya variabel tambahan = Rp 74.423.979.711,-

**LE.3.3.3 Biaya Variabel Lainnya**
Diperkirakan 5% dari biaya variabel tambahan

\[
= 0,05 \times Rp\ 74.423.979.711,-
\]

\[
= Rp\ 3.721.198.986,-
\]

Total Biaya Variabel = Rp 1.318.544.840.539,-
Total Biaya Produksi = Biaya Tetap + Biaya Variabel
= Rp 117.086.693.640,- + Rp 1.318.544.840.539,-
= Rp 1.435.631.534.180,-

**LE.4 Perkiraan Laba/Rugi Perusahaan**

**LE.4.1 Laba Sebelum Pajak (Bruto)**
Laba atas penjualan = Total penjualan – Total biaya produksi
= Rp 375.706.978.804,-
Bonus perusahaan untuk karyawan 0,5% dari keuntungan perusahaan
= 0,005 × Rp 375.706.978.804,-
= Rp 1.878.534.894,-
Pengurangan bonus atas penghasilan bruto sesuai dengan UU RI No. 17/00 Pasal 6 ayat 1 sehingga:
Laba sebelum pajak (bruto) = Rp 373.828.443.910,-

**LE.4.2 Pajak Penghasilan**

- Penghasilan sampai dengan Rp 50.000.000,- dikenakan pajak sebesar 10 %.
- Penghasilan Rp 50.000.000,- sampai dengan Rp 100.000.000,- dikenakan pajak sebesar 15 %.
- Penghasilan di atas Rp 100.000.000,- dikenakan pajak sebesar 30 %.

Maka pajak penghasilan yang harus dibayar adalah:
- 30 % × (Rp 373.828.443.910,-) = Rp 112.148.533.173,-

**LE.4.3 Laba setelah pajak**
Laba setelah pajak = laba sebelum pajak – PPh
= Rp 373.828.443.910,- – Rp 112.148.533.173,-
= Rp 261.679.910.737,-

**LE.5 Analisa Aspek Ekonomi**
LE.5.1 Profit Margin (PM)

\[
PM = \frac{\text{Laba sebelum pajak}}{\text{Total penjualan}} \times 100 \%
\]

\[
PM = \frac{\text{Rp373.828.443.910,-}}{\text{Rp1.811.338.512.984,-}} \times 100\% 
\]

PM = 20,64 %

LE.5.2 Break Even Point (BEP)

\[
BEP = \frac{\text{Biaya Tetap}}{\text{Total Penjualan – Biaya Variabel}} \times 100 \%
\]

\[
BEP = \frac{\text{Rp117.086.693.640,-}}{\text{Rp1.811.338.512.984,-} - \text{Rp1.318.544.840.539,-}} \times 100 \% 
\]

BEP = 23,76 %

Kapasitas produksi pada titik BEP = 23,76 % \times 58.000 \text{ ton/tahun} 
= 13780 \text{ ton/tahun}

Nilai penjualan pada titik BEP = 23,76 % \times \text{Rp 1.811.338.512.984,-} 
= \text{Rp 430.370.050.201,-}

LE.5.3 Return on Investment (ROI)

\[
ROI = \frac{\text{Laba setelah pajak}}{\text{Total Modal Investasi}} \times 100 \%
\]

\[
ROI = \frac{\text{Rp 261.679.910.737,-}}{\text{Rp 970.100.642.693,-}} \times 100 \% 
\]

ROI = 26,97 %

LE.5.4 Pay Out Time (POT)

\[
POT = \frac{1}{0,2697} \times 1 \text{ tahun}
\]

POT = 3,7 tahun

LE.5.5 Return on Network (RON)

\[
RON = \frac{\text{Laba setelah pajak}}{\text{Modal sendiri}} \times 100 \%
\]


\[
RON = \frac{Rp\ 261.679.910.737,-}{Rp\ 582.060.385.616,-} \times 100\% \\
RON = 44,96\% 
\]

**LE.5.6 Internal Rate of Return (IRR)**

Untuk menentukan nilai IRR harus digambarkan jumlah pendapatan dan pengeluaran dari tahun ke tahun yang disebut “Cash Flow”. Untuk memperoleh cash flow diambil ketentuan sebagai berikut:
- Laba kotor diasumsikan mengalami kenaikan 10% tiap tahun.
- Masa pembangunan disebut tahun ke nol.
- Jangka waktu cash flow dipilih 10 tahun.
- Perhitungan dilakukan dengan menggunakan nilai pada tahun ke – 10.
- Cash flow adalah laba sesudah pajak ditambah penyusutan.

Dari Tabel LE.12. diperoleh nilai IRR = 35,43 %
### Tabel LE.11 Data Perhitungan BEP

<table>
<thead>
<tr>
<th>Kapasitas (%)</th>
<th>Biaya Tetap (Rp)</th>
<th>Biaya Variabel (Rp)</th>
<th>Total Biaya Produksi (Rp)</th>
<th>Total Penjualan (Rp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>117.086.693.640</td>
<td>0</td>
<td>117.086.693.640</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>117.086.693.640</td>
<td>131.854.484.054</td>
<td>248.941.177.694</td>
<td>181.133.851.298</td>
</tr>
<tr>
<td>20</td>
<td>117.086.693.640</td>
<td>263.708.968.108</td>
<td>380.795.661.748</td>
<td>362.267.702.597</td>
</tr>
<tr>
<td>30</td>
<td>117.086.693.640</td>
<td>395.563.452.162</td>
<td>512.650.145.802</td>
<td>543.401.553.895</td>
</tr>
<tr>
<td>40</td>
<td>117.086.693.640</td>
<td>527.417.936.216</td>
<td>644.504.629.856</td>
<td>724.535.405.194</td>
</tr>
<tr>
<td>50</td>
<td>117.086.693.640</td>
<td>659.272.420.270</td>
<td>776.359.113.910</td>
<td>905.669.256.492</td>
</tr>
<tr>
<td>60</td>
<td>117.086.693.640</td>
<td>791.126.904.324</td>
<td>908.213.597.964</td>
<td>1.086.803.107.790</td>
</tr>
<tr>
<td>70</td>
<td>117.086.693.640</td>
<td>922.981.388.378</td>
<td>1.040.068.082.018</td>
<td>1.267.936.959.089</td>
</tr>
<tr>
<td>80</td>
<td>117.086.693.640</td>
<td>1.054.835.872.431</td>
<td>1.171.922.566.072</td>
<td>1.449.070.810.387</td>
</tr>
<tr>
<td>90</td>
<td>117.086.693.640</td>
<td>1.186.690.356.485</td>
<td>1.303.777.050.126</td>
<td>1.630.204.661.686</td>
</tr>
<tr>
<td>100</td>
<td>117.086.693.640</td>
<td>1.318.544.840.539</td>
<td>1.435.631.534.180</td>
<td>1.811.338.512.984</td>
</tr>
</tbody>
</table>
Gambar LE.4 Grafik BEP

Biaya (Rp Miliar)

Kapasitas Produksi (%)

Biaya Tetap

Biaya Variabel

Biaya Produksi

Total Penjualan

BEP = 23,76%

Universitas Sumatera Utara
Tabel LE.12  Data Perhitungan IRR

<table>
<thead>
<tr>
<th>Tahun</th>
<th>Laba Sebelum Pajak (Rp)</th>
<th>Pajak (Rp)</th>
<th>Laba Setelah Pajak (Rp)</th>
<th>Deprisiasi (Rp)</th>
<th>Net cash flow (Rp)</th>
<th>P/F 35%</th>
<th>PV (Rp)</th>
<th>P/F 36%</th>
<th>PV (Rp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>970.100.642.693</td>
<td>-</td>
<td>970.100.642.693</td>
<td>-</td>
<td>970.100.642.693</td>
</tr>
<tr>
<td>1</td>
<td>373.828.443.910</td>
<td>112.148.533.173</td>
<td>261.679.910.737</td>
<td>25.862.306.429</td>
<td>287.542.217.166</td>
<td>0.7407</td>
<td>212.994.234.938</td>
<td>0.7353</td>
<td>211.428.100.857</td>
</tr>
<tr>
<td>2</td>
<td>411.211.288.301</td>
<td>123.363.386.490</td>
<td>287.847.901.811</td>
<td>25.862.306.429</td>
<td>313.710.208.239</td>
<td>0.5487</td>
<td>172.131.801.503</td>
<td>0.5407</td>
<td>169.609.757.915</td>
</tr>
<tr>
<td>3</td>
<td>452.332.417.131</td>
<td>135.699.725.139</td>
<td>316.632.691.992</td>
<td>25.862.306.429</td>
<td>342.494.998.421</td>
<td>0.4064</td>
<td>139.204.388.933</td>
<td>0.3975</td>
<td>136.156.227.110</td>
</tr>
<tr>
<td>4</td>
<td>497.565.658.844</td>
<td>149.269.697.653</td>
<td>348.295.961.191</td>
<td>25.862.306.429</td>
<td>374.158.267.620</td>
<td>0.3011</td>
<td>112.647.166.514</td>
<td>0.2923</td>
<td>109.370.377.876</td>
</tr>
<tr>
<td>5</td>
<td>547.322.224.729</td>
<td>164.196.667.419</td>
<td>383.125.557.310</td>
<td>25.862.306.429</td>
<td>408.987.863.739</td>
<td>0.2230</td>
<td>91.209.815.770</td>
<td>0.2149</td>
<td>87.905.465.718</td>
</tr>
<tr>
<td>6</td>
<td>602.054.447.202</td>
<td>180.616.334.161</td>
<td>421.438.113.041</td>
<td>25.862.306.429</td>
<td>447.300.419.470</td>
<td>0.1652</td>
<td>73.891.876.292</td>
<td>0.1580</td>
<td>70.691.281.589</td>
</tr>
<tr>
<td>7</td>
<td>662.259.891.922</td>
<td>198.677.967.577</td>
<td>463.581.924.345</td>
<td>25.862.306.429</td>
<td>489.444.230.774</td>
<td>0.1224</td>
<td>59.891.726.716</td>
<td>0.1162</td>
<td>56.876.236.986</td>
</tr>
<tr>
<td>8</td>
<td>728.485.881.114</td>
<td>218.545.764.334</td>
<td>509.940.116.780</td>
<td>25.862.306.429</td>
<td>535.802.423.209</td>
<td>0.0906</td>
<td>48.566.244.894</td>
<td>0.0854</td>
<td>45.781.857.204</td>
</tr>
<tr>
<td>9</td>
<td>801.334.469.226</td>
<td>240.400.340.768</td>
<td>560.934.128.458</td>
<td>25.862.306.429</td>
<td>586.796.434.887</td>
<td>0.0671</td>
<td>39.398.850.418</td>
<td>0.0628</td>
<td>36.866.956.904</td>
</tr>
<tr>
<td>10</td>
<td>881.467.916.148</td>
<td>264.440.374.844</td>
<td>617.027.541.304</td>
<td>25.862.306.429</td>
<td>642.889.847.732</td>
<td>0.0497</td>
<td>31.974.140.769</td>
<td>0.0462</td>
<td>29.699.386.891</td>
</tr>
</tbody>
</table>

\[
\text{IRR} = 35 + \frac{26.048.417.957}{26.048.417.957 - (-605.301.472)} \times (36 - 35) = 35,43 \%
\]