LAMPIRAN A
PERHITUNGAN NERACA MASSA

Basis perhitungan = 1 jam operasi

Satuan berat = Kilogram (kg)

Bahan baku = - Benzen (C₆H₆); BM = 78,11 kg/kmol
- Propilen (C₃H₆); BM = 42,08 kg/kmol
- Propana (C₃H₈); BM = 44,09 kg/kmol

Produk akhir = Isopropilbenzen (C₉H₁₂); BM = 120,19 kg/kmol

Produk samping = Diisopropilbenzen (C₁₂H₁₈); BM = 162 kg/kmol

(Kemurnian Isopropilbenzen = 99,20%) (chemicals@merck.co.id, 2010)

Kapasitas produksi dalam satu jam operasi:

\[
\frac{2500 \text{ Ton}}{1 \text{ Tahun}} \times \frac{1 \text{ Tahun}}{330 \text{ hari}} \times \frac{1000 \text{ Kg}}{1 \text{ Ton}} \times \frac{1 \text{ Hari}}{24 \text{ jam}}
\]

= 315,6565 kg/jam

Jumlah hari operasi = 330 hari

Jumlah jam operasi = 24 jam

Perhitungan neraca massa dilakukan dengan alur mundur, dimana perhitungan dimulai dari alur produk sampai ke alur bahan baku. Adapun kemurnian Isopropilbenzen (IPB) adalah 99,20% dengan sisanya adalah Diisopropilbenzen (DIPB).
A.1 Akumulator (AC-102)

Fungsi : Untuk mengumpulkan destilat yang keluar dari Menara destilsi II (MD-102) yang telah dikondensasi di kondensor (E-108) dan membagi menjadi aliran produk dan aliran recycle.

![Diagram]

Komposisi Produk dari data spesifikasi produk Isopropilbenzena :
(chemicals(at)merck.co.id, 2010)

- Cumene : \(X^{27} = 0,992\)
- DIPB : \(X^{27} = 0,001\)
- Benzene : \(X^{27} = 0,007\)

\(F^{27} = 315,6565 \text{ kg/jam} \) (Data kapasitas produk)

Berdasarkan dari data-data pabrik yang sudah berdiri bahwa rasio reflux maksimal pada destilasi adalah 15% dari laju alir destilat (hasil destilasi). (setiawan,2002)

Jadi, \(F^{26} = 0,15 \times F^{27}\)

Maka \(F^{26} = 0,15 \times 315,6565 \text{ kg/jam} = 47,3485 \text{ kg/jam}\)

Neraca massa total = \(F^{25} = F^{26} + F^{27}\)

\(F^{26} = 47,3485 + 315,6565 = 363,0050\)

**Alur 27**

\(F^{27} = 315,6565 \text{ kg/jam}\)

IPB : \(F^{27}_{IPB} = 0,9920 \times 315,6565 = 313,1312 \text{ kg/jam}\)

DIPB : \(F^{27}_{DIPB} = 0,0010 \times 315,6565 = 0,3157 \text{ kg/jam}\)

Benzene : \(F^{27}_{Benzene} = 0,0070 \times 315,6565 = 2,2096 \text{ kg/jam}\)

**Alur 26**

\(F^{26} = 47,3485 \text{ kg/jam}\)

IPB : \(F^{26}_{IPB} = 0,9920 \times 47,3485 = 46,9696 \text{ kg/jam}\)
DIPB : $F_{DIPB}^{26} = 0.0010 \times 47,3485 = 0.0474 \text{ kg/jam}$

Benzene : $F_{Benzene}^{26} = 0.0070 \times 47,3485 = 0.3315 \text{ kg/jam}$

Alur 25

$F^{25} = 363,0050 \text{ kg/jam}$

IPB : $F_{IPB}^{25} = 0.9920 \times 363,0050 = 360,1008 \text{ kg/jam}$

DIPB : $F_{DIPB}^{25} = 0.0010 \times 363,0050 = 0.3631 \text{ kg/jam}$

Benzene : $F_{Benzene}^{25} = 0.0070 \times 363,0050 = 2.5411 \text{ kg/jam}$

Tabel LA.1 Neraca Massa Akumulator (AC-102)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kg/jam)</th>
<th>Keluar (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 25</td>
<td>Alur 26</td>
</tr>
<tr>
<td>Benzen</td>
<td>2.5411</td>
<td>0.3315</td>
</tr>
<tr>
<td>Propilen</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Propana</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Isopropilbenzen</td>
<td>360,1008</td>
<td>46,9696</td>
</tr>
<tr>
<td>Diiisopropilbenzen</td>
<td>0.3631</td>
<td>0.0474</td>
</tr>
<tr>
<td>Total</td>
<td>363,0050</td>
<td>47,3485</td>
</tr>
</tbody>
</table>

A.2 Menara Distilasi (MD-102)

Fungsi: Untuk memisahkan Isopropilbenzen dengan Diiisopropilbenzen.

Asumsi komposisi pada alur umpan berdasarkan pabrik yang sudah berdiri:
- \( X_{\text{IPB}} = 0,9100 \)
- \( X_{\text{DIPB}} = 0,0836 \)
- \( X_{\text{Benzene}} = 0,0064 \)

(Setiawan, 2002)

Pada destilasi diinginkan:
- \( X_D = 0,992 \)
- \( X_B = 0,008 \)

\[
X_F = X_{\text{IPB}} = 0,91
\]

\[
\frac{B}{F} = \frac{(X_D - X_F)}{(X_D - X_B)} = \frac{(0,992 - 0,91)}{(0,992 - 0,008)} = 0,0833
\]

\[
\frac{F^{22}}{F^{31}} = 0,0833
\]

\[
F^{31} = 0,0833F^{22}
\]

Neraca massa total

\[
F^{22} = F^{27} + F^{31}
\]

\[
F^{22} = F^{27} + 0,0833 F^{22}
\]

\[
0,9167F^{22} = F^{27}
\]

\[
F^{22} = \frac{F^{27}}{0,9167} = 344,34 \text{ kg/jam}
\]

\[
F^{31} = F^{22} - F^{27} = 344,34 - 315,6565 = 28,6835 \text{ kmol/jam}
\]

Alur 27

\[
F^{27} = 315,6565 \text{ kg/jam}
\]

IPB : \( F_{\text{IPB}}^{27} = 0,9920 \times 315,6565 = 313,1342 \text{ kg/jam} \)

DIPB : \( F_{\text{DIPB}}^{27} = 0,0010 \times 315,6565 = 0,3157 \text{ kg/jam} \)

Benzene : \( F_{\text{Benzene}}^{27} = 0,0070 \times 315,6565 = 2,2096 \text{ kg/jam} \)

Alur 22

\[
F^{22} = 344,34 \text{ kg/jam}
\]

IPB : \( F_{\text{IPB}}^{22} = 0,91 \times 344,34 = 313,3494 \text{ kg/jam} \)

DIPB : \( F_{\text{DIPB}}^{22} = 0,0836 \times 344,34 = 28,7810 \text{ kg/jam} \)

Benzene : \( F_{\text{Benzene}}^{22} = 0,0064 \times 344,34 = 2,2096 \text{ kg/jam} \)
Alur 31

\[ F_{31} = 28,6835 \text{ kg/jam} \]

IPB : \[ F_{IPB}^{31} = F_{IPB}^{22} - F_{IPB}^{27} = 0,2182 \text{ kg/jam} \]

DIPB : \[ F_{DIPB}^{31} = F_{DIPB}^{22} - F_{DIPB}^{27} = 28,4653 \text{ kg/jam} \]

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kg/jam)</th>
<th>Keluar (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 22</td>
<td>Alur 27</td>
</tr>
<tr>
<td>Benzen</td>
<td>2,2096</td>
<td>2,2096</td>
</tr>
<tr>
<td>Propilen</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Propana</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Isopropilbenzen</td>
<td>313,3494</td>
<td>313,1312</td>
</tr>
<tr>
<td>Diisopropilbenzen</td>
<td>28,7810</td>
<td>0,3157</td>
</tr>
<tr>
<td>Total</td>
<td>344,34</td>
<td>315,6565</td>
</tr>
</tbody>
</table>

A.3 Reboiler (E-110)

Fungsi : Untuk menaikkan temperatur campuran sampai ke titik didihnya sebelum dimasukkan ke kolom destilasi

Berdasarkan Geankoplis (2003), untuk kondisi umpan masuk dalam keadaan bubble point (cair jenuh) sehingga \( q = 1 \).

\[ V_d = V_b + (1-q) F \]  
\[ V_b = V_d \]
\[ = 363,0050 \text{ kg/jam} \]

\[ L_b = V_b + B \]
\[ = 363,0050 + 28,6835 \]
= 391,6885 kg/jam

Alur 31

\[ F^{31} = 28,6835 \text{ kg/jam} \]

\[ \text{IPB} : F_{IPB}^{31} = F_{IPB}^{22} - F_{IPB}^{27} = 0,2182 \text{ kg/jam} \]

\[ \text{DIPB} : F_{DIPB}^{31} = F_{DIPB}^{22} - F_{DIPB}^{27} = 28,4653 \text{ kg/jam} \]

Alur 30

\[ F^{30} = 363,0050 \text{ kg/jam} \]

\[ \text{IPB} : F_{IPB}^{30} = 0,008 \times 363,0050 = 2,9040 \text{ kg/jam} \]

\[ \text{DIPB} : F_{DIPB}^{30} = 0,992 \times 363,0050 = 360,1010 \text{ kg/jam} \]

Alur 29

\[ F^{29} = 391,6885 \text{ kg/jam} \]

\[ \text{IPB} : F_{IPB}^{29} = 0,008 \times 391,6885 = 3,1335 \text{ kg/jam} \]

\[ \text{DIPB} : F_{DIPB}^{29} = 0,992 \times 391,6885 = 388,5550 \text{ kg/jam} \]

Tabel LA.3 Neraca Massa Reboiler (E-110)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kg/jam)</th>
<th>Keluar (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 29</td>
<td>Alur 30</td>
</tr>
<tr>
<td>Benzen</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Propilen</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Propana</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Isopropilbenzen</td>
<td>3,1335</td>
<td>2,9040</td>
</tr>
<tr>
<td>Diisopropilbenzen</td>
<td>388,5550</td>
<td>360,1010</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>391,6885</td>
<td>363,0050</td>
</tr>
</tbody>
</table>

Universitas Sumatera Utara
A.4 Menara Distilasi (MD-101)

Fungsi: Untuk memisahkan Benzen dengan Campuran Isopropilbenzen dan Diisopropilbenze

Asumsi komposisi pada alur umpan berdasarkan pabrik yang sudah berdiri:
- \( X_{\text{IPB}} = 0,2336897 \)
- \( X_{\text{DIPB}} = 0,0163103 \)
- \( X_{\text{Benzene}} = 0.75 \)

(setiawan, 2002)

Komposisi Umpan Menara Distilasi (MD-102) sama dengan komposisi hasil bawah Menara Distilasi (MD-101), komposisi hasil bawah MD-101:
- \( X_D = 0,91 \)
- \( X_B = 0,09 \)
- \( X_F = X_{\text{BENZEN}} = 0,75 \)

\[
B = \frac{(X_D - X_F)}{(X_D - X_B)} = \frac{(0,91 - 0,75)}{(0,91 - 0,09)} = 0,1951
\]

(McCabe, 1997)

\[
\frac{F^{22}}{F^{15}} = 0,1951
\]

\[
F^{15} = \frac{F^{22}}{0,1951}
\]

\[
F^{15} = 1764,9411 \text{ kg/jam}
\]

Neraca massa total

\[
F^{23} = F^{15} - F^{22}
\]

\[
F^{23} = 1764,9411 - 344,34
\]

\[
F^{23} = 1420,6011 \text{ kg/jam}
\]
Alur 22

\[ F_{22} = 344,34 \text{ kg/jam} \]

\[
\begin{align*}
\text{IPB} : F_{IPB}^{22} &= 0,91 \times 344,34 = 313,3494 \text{ kg/jam} \\
\text{DIPB} : F_{DIPB}^{22} &= 0,0836 \times 344,34 = 28,7810 \text{ kg/jam} \\
\text{Benzene} : F_{Benzene}^{22} &= 0,0064 \times 344,34 = 2,2096 \text{ kg/jam}
\end{align*}
\]

Alur 15

\[ F_{15} = 1764,9411 \text{ kg/jam} \]

\[
\begin{align*}
\text{Benzene} : F_{Benzene}^{15} &= 0,75 \times 1764,9411 = 1323,7115 \text{ kg/jam} \\
\text{IPB} : F_{IPB}^{15} &= 0,2336897 \times 1764,9411 = 412,4486 \text{ kg/jam} \\
\text{DIPB} : F_{DIPB}^{15} &= 0,0163103 \times 1764,9411 = 28,7810 \text{ kg/jam}
\end{align*}
\]

Alur 23

\[ F_{23} = 1420,6011 \text{ kg/jam} \]

\[
\begin{align*}
\text{Benzene} : F_{Benzene}^{23} &= F_{15} - F_{22}^{22} = 1321,5091 \text{ kg/jam} \\
\text{IPB} : F_{IPB}^{23} &= F_{15}^{15} - F_{22}^{22} = 99,0992 \text{ kg/jam}
\end{align*}
\]

Tabel LA.4 Neraca Massa Menara Distilasi (MD-101)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kg/jam)</th>
<th>Keluar (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 15</td>
<td>Alur 22</td>
</tr>
<tr>
<td>Benzen</td>
<td>1323,7115</td>
<td>2,2096</td>
</tr>
<tr>
<td>Propilen</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Propana</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Isopropilbenzen</td>
<td>412,4486</td>
<td>313,3494</td>
</tr>
<tr>
<td>Diisopropilbenzen</td>
<td>28,7810</td>
<td>28,7810</td>
</tr>
<tr>
<td>Total</td>
<td>1764,9411</td>
<td>344,34</td>
</tr>
<tr>
<td></td>
<td>1764,9411</td>
<td>1764,9411</td>
</tr>
</tbody>
</table>
A.5 Akumulator (AC-101)

Fungsi: Untuk mengumpulkan destilat dengan komposisi sebagian besar Benzen yang keluar dari kondensor E-107 dan membagi aliran produk dan aliran recyle.

Komposisi Produk:
- Benzene: $X_{23} = 0,9302$
- IPB: $X_{23} = 0,0698$

$F_{23} = 1420,6011 \text{ kg/jam}$

Asumsi $F_{19} = 0,15 \times F_{23}$

Maka $F_{19} = 0,15 \times 1420,6011 \text{ kg/jam} = 213,0902 \text{ kg/jam}$

Neraca massa total

$F_{18} = F_{19} + F_{23}$

$F_{18} = 213,0902 + 1420,6011 = 1633,6913 \text{ kg/jam}$

Alur 23

$F_{23} = 1420,6011 \text{ kg/jam}$

Benzene:

$F_{Benzene}^{23} = F_{Benzene}^{15} - F_{Benzene}^{22} = 1321,5091 \text{ kg/jam}$

IPB:

$F_{IPB}^{23} = F_{IPB}^{15} - F_{IPB}^{22} = 99,0992 \text{ kg/jam}$

Alur 19

$F_{19} = 213,0902 \text{ kg/jam}$

Benzene:

$F_{Benzene}^{19} = 0,9302 \times 213,0902 = 198,2166 \text{ kg/jam}$

IPB:

$F_{IPB}^{19} = 0,0698 \times 213,0902 = 14,8736 \text{ kg/jam}$

Alur 18
\[ F^{18} = 1633.6913 \text{ kg/jam} \]

Benzen : \[ F^{18}_{IPB} = F^{19}_{Benzene} + F^{23}_{Benzene} = 1519.7185 \text{ kg/jam} \]

IPB : \[ F^{18}_{DIPB} = F^{19}_{IPB} + F^{23}_{IPB} = 113.9728 \text{ kg/jam} \]

**Tabel LA.5 Neraca Massa Akumulator (AC-101)**

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kg/jam)</th>
<th>Keluar (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 18</td>
<td>Alur 19</td>
</tr>
<tr>
<td>Benzen</td>
<td>1519.7185</td>
<td>198.2166</td>
</tr>
<tr>
<td>Propilen</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Propana</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Isopropilbenzen</td>
<td>113.9728</td>
<td>14.8736</td>
</tr>
<tr>
<td>Diisopropilbenzen</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1633.6913</strong></td>
<td><strong>213.0902</strong></td>
</tr>
</tbody>
</table>

**A.6 Reboiler (E-106)**

Fungsi : Untuk menaikkan temperatur campuran sampai ke titik didihnya sebelum dimasukkan ke kolom destilasi

\[
V_d = V_b + (1-q) F \quad \text{(Geankoplis, 2003)}
\]

\[
V_b = V_d = 1633.6913 \text{ kg/jam}
\]

\[
L_b = V_b + B = 1633.6913 + 344.34 = 1978.0313 \text{ kg/jam}
\]
Alur 22
F^{22} = 344,34 kg/jam
IPB : F^{IPB}_{IPB} = 0,91 \times 344,34 = 313,3494 kg/jam
DIPB : F^{DIPB}_{DIPB} = 0,0836 \times 344,34 = 28,7810 kg/jam
Benzene : F^{Benzene}_{Benzene} = 0,0064 \times 344,34 = 2,2096 kg/jam

Alur 21
F^{21} = Vb = 1633,6913 kg/jam
Benzene : F^{Benzene}_{Benzene} = 0,0064 \times 1633,6913 = 10,4557 kg/jam
IPB : F^{IPB}_{IPB} = 0,91 \times 1633,6913 = 1486,659 kg/jam
DIPB : F^{DIPB}_{DIPB} = 0,0836 \times 1633,6913 = 136,5766 kg/jam

Alur 20
F^{20} = Lb = 1978,0313 kg/jam
Benzene : F^{Benzene}_{Benzene} = F^{21}_{Benzene} + F^{22}_{Benzene} = 12,6595 kg/jam
IPB : F^{IPB}_{IPB} = F^{21}_{IPB} + F^{22}_{IPB} = 1800,0084 kg/jam
DIPB : F^{DIPB}_{DIPB} = F^{21}_{DIPB} + F^{22}_{DIPB} = 165,3534 kg/jam

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kg/jam)</th>
<th>Keluar (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 20</td>
<td>Alur 21</td>
</tr>
<tr>
<td>Benzen</td>
<td>12,6595</td>
<td>10,4557</td>
</tr>
<tr>
<td>Propilen</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Propana</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Isopropilbenzen</td>
<td>1800,0084</td>
<td>1486,659</td>
</tr>
<tr>
<td>Diisopropilbenzen</td>
<td>165,3534</td>
<td>136,5766</td>
</tr>
<tr>
<td>Total</td>
<td>1978,0313</td>
<td>1633,6913</td>
</tr>
</tbody>
</table>
A.7 Flash Drum (V-101)

Fungsi: Untuk memisahkan antara fase cair dan fase gas.

Pemisahan yang terjadi pada Flash Drum berdasarkan kemungkinan terpisah yang sangat besar antara fasa uap dan fasa gas, fasa gas yang lebih ringan massanya akan naik secara otomatis, sedangkan fasa cair yang mempunyai massa lebih berat akan turun secara gravitasi.

Asumsi komposisi pada alur produk reaktor menuju flash drum berdasarkan pabrik yang sudah berdiri sebelumnya:

\[
\begin{align*}
X_{\text{Propilen}} &= 0,0078 \\
X_{\text{Propena}} &= 0,0048 \\
X_{\text{Benzen}} &= 0,7406 \\
X_{\text{IPB}} &= 0,2307 \\
X_{\text{DIPB}} &= 0,0161
\end{align*}
\]

(Setiawan, 2002)

Dari komposisi umpan masuk ke Separator drum, didapat:

\[
\begin{align*}
X_{\text{Gas}} &= 0,0126 \\
X_{\text{Liquid}} &= 0,9874
\end{align*}
\]

Neraca massa total:

\[
\begin{align*}
F_{14} &= X_{\text{Liquid}} = 1764,9411 \text{ kg/jam} \\
F_{13} &= 1/ X_{\text{Liquid}} \times F_{15} = 1787,4631 \text{ kg/jam} \\
F_{16} &= F_{13} - F_{14} = 22,522 \text{ kg/jam}
\end{align*}
\]

Alur 14

\[
\begin{align*}
F_{14} &= 1764,9411 \text{ kg/jam} \\
F_{14}^{\text{Benzene}} &= 0,75 \times 1764,9411 = 1323,7115 \text{ kg/jam}
\end{align*}
\]
IPB  :  \( F_{IPB}^{14} = 0,2336897 \times 1764,9411 \) = 412,4486 kg/jam
DIPB  :  \( F_{DIPB}^{14} = 0,0163103 \times 1764,9411 \) = 28,7810 kg/jam

Alur 13
\( F^{13} \)
Benzen  :  \( F_{Benzen}^{13} = F_{Benzene}^{14} \) = 1323,7115 kg/jam
Popilen  :  \( F_{Propilen}^{13} = F^{13} \times 0,0078 \) = 13,9422 kg/jam
Propena  :  \( F_{Propena}^{13} = F^{13} \times 0,0048 \) = 8,5798 kg/jam
IPB  :  \( F_{IPB}^{13} = F_{IPB}^{14} \) = 412,4486 kg/jam
DIPB  :  \( F_{DIPB}^{13} = F_{DIPB}^{14} \) = 28,7810 kg/jam

Alur 16
\( F^{16} \)
Popilen  :  \( F_{Propilen}^{16} = F_{Propilen}^{13} \) = 13,9422 kg/jam
Propena  :  \( F_{Propena}^{16} = F_{Propena}^{13} \) = 8,5798 kg/jam

Tabel LA.7 Neraca Massa Flash Drum (V-101)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kg/jam)</th>
<th>Keluar (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 13</td>
<td>Alur 14</td>
</tr>
<tr>
<td>Benzen</td>
<td>1323,7115</td>
<td>1323,7115</td>
</tr>
<tr>
<td>Propilen</td>
<td>13,9422</td>
<td>-</td>
</tr>
<tr>
<td>Propana</td>
<td>8,5798</td>
<td>-</td>
</tr>
<tr>
<td>Isopropilbenzen</td>
<td>412,4486</td>
<td>412,4486</td>
</tr>
<tr>
<td>Diisopropilbenzen</td>
<td>28,7810</td>
<td>28,7810</td>
</tr>
<tr>
<td>Total</td>
<td>1787,4631</td>
<td>1764,9411</td>
</tr>
<tr>
<td></td>
<td>1787,4631</td>
<td>1787,4631</td>
</tr>
</tbody>
</table>
A.8 Reaktor (R-201)

Fungsi: Sebagai tempat berlangsungnya reaksi pembentukan Isoprophylbenzene (cumene).

Reaksi:

\[
\text{C}_3\text{H}_6(g) + \text{C}_6\text{H}_6(g) \rightarrow \text{C}_9\text{H}_{12}(g) \quad \ldots (1)
\]

\[
\text{C}_9\text{H}_{12}(g) + \text{C}_3\text{H}_6(g) \rightarrow \text{C}_{12}\text{H}_{18}(g) \quad \ldots (2)
\]

Reaksi terjadi secara eksotermal dan didapatkan konversi Propilen sebesar 89%

Alur 11

Total : \[ F_{11}^{11} = F_{13}^{13} = 1787,4631 \text{ kg/jam} \]

Benzen : \[ F_{11}^{11} \text{ Benzene} = 1323,7115 \text{ kg/jam} \]

\[ N_{11}^{11} \text{ Benzene} = \frac{F_{14}^{14} \text{ Benzene}}{78,11 \text{ kg/kmol}} = 16,9467 \text{ kmol/jam} \]

Propylen : \[ F_{11}^{11} \text{ Propilen} = 13,9422 \text{ kg/jam} \]

\[ N_{11}^{11} \text{ Propilen} = \frac{F_{16}^{16} \text{ Propilen}}{42,08 \text{ kg/kmol}} = 0,3313 \text{ kmol/jam} \]

Propana : \[ F_{11}^{11} \text{ Propana} = 8,5798 \text{ kg/jam} \]

\[ N_{11}^{11} \text{ Propana} = \frac{F_{16}^{16} \text{ Propana}}{44,09 \text{ kg/kmol}} = 0,1945 \text{ kmol/jam} \]

IPB : \[ F_{11}^{11} \text{ IPB} = 412,4486 \text{ kg/jam} \]

\[ N_{11}^{11} \text{ IPB} = \frac{F_{14}^{14} \text{ IPB}}{120,19 \text{ kg/kmol}} = 3,4316 \text{ kmol/jam} \]

DIPB : \[ F_{11}^{11} \text{ DIPB} = 28,7810 \text{ kg/jam} \]

\[ N_{11}^{11} \text{ DIPB} = \frac{F_{14}^{14} \text{ DIPB}}{162 \text{ kg/kmol}} = 0,1776 \text{ kmol/jam} \]

\[ N_{11}^{11} \text{ Total} = \sum N_{i}^{11} = 21,0817 \text{ kmol/jam} \]
\[ N^{\text{out}} = N^{\text{in}} + \sigma_s r_s \]  
(Reklaitis, 1983)

\[ \sigma_1 \text{ Propilen} = -1 \quad \sigma_2 \text{ IPB} = -1 \]
\[ \sigma_1 \text{ Benzen} = -1 \quad \sigma_2 \text{ Propilen} = -1 \]
\[ \sigma_1 \text{ IPB} = 1 \quad \sigma_2 \text{ DIPB} = 1 \]

\[ N^{\text{in}} = N^{\text{out}} - \sigma_s r_s \]

IPB  :  \[ N_{\text{IPB}}^{10} = 3,4316 - r_1 - r_2 \]  
....(1)

Propilene  :  \[ N_{\text{Propilene}}^{10} = 0,3313 + r_1 - r_2 \]  
....(2)

Benzene  :  \[ N_{\text{Benzene}}^{10} = 16,9466 - r_1 \]  
....(3)

Diisoprophiilbenzene  :  \[ N_{\text{DIPB}}^{10} = 0,1776 + r_2 \]  
....(4)

Pada alur masuk ke reaktor, umpan tidak mengandung DIPB, maka persamaan (4) menjadi:

\[ N_{\text{DIPB}}^{10} = 0,1776 + r_2 \]

\[ 0 = 0,1776 + r_2 \]

\[ r_2 = -0,1776 \]

Laju alir mol IPB pada alur masuk sama dengan alur recycle dari Menara Destilasi I (MD-101)

\[ F_{\text{IPB}}^{23} = 99,0992 \text{ kg/jam} \]

\[ N_{\text{IPB}}^{23} = F_{\text{IPB}}^{23} / 120,19 \text{ kg/kmol} = 0,8245 \text{ mol/jam} \]

Substitusi persamaan (1)

\[ N_{\text{IPB}}^{10} = 3,4316 - r_1 - r_2 \]

\[ 0,8245 \text{ mol/jam} = 3,4316 - r_1 - r_2 \]

\[ r_1 = 2,7847 \]

Alur 10

\[ F^{10} = F^{11} = 1787,4631 \text{ kg/jam} \]

Propana  :  \[ F_{\text{Propana}}^{10} = F_{\text{Propana}}^{11} = 8,5798 \text{ kg/jam} \]

\[ N_{\text{Propana}}^{10} = N_{\text{Propana}}^{11} = 0,1945 \text{ mol/jam} \]

IPB  :  \[ N_{\text{IPB}}^{10} = N_{\text{IPB}}^{23} = 0,8245 \text{ mol/jam} \]
Benzene : $N_{\text{benzene}}^{10} = 16,9467 - r_1 \rightarrow \text{Persamaan (3)}$

$= 16,9467 - 2,7847 = 19,7314 \text{ kmol/jam}$

$F_{\text{benzene}}^{10} = 19,7314 \frac{\text{kmol}}{\text{jam}} \times 78,11 \frac{\text{kg}}{\text{kmol}} = 1541,2196 \text{ kg/jam}$

Propylene : $N_{\text{propylene}}^{10} = 0,3313 + r_1 - r_2 \rightarrow \text{Persamaan (2)}$

$= 0,3313 + 2,7847 + 0,1776 = 3,2936 \text{ kmol/jam}$

$F_{\text{propylene}}^{10} = 3,2936 \frac{\text{kmol}}{\text{jam}} \times 42,08 \frac{\text{kg}}{\text{kmol}} = 138,5645 \text{ kg/jam}$

$N_{\text{Total}}^{10} = \sum N_x^{10} = 24,044 \text{ kmol/jam}$

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kg/jam)</th>
<th>Keluar (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 10</td>
<td>Alur 11</td>
</tr>
<tr>
<td>Benzen</td>
<td>1541,2196</td>
<td>1323,7115</td>
</tr>
<tr>
<td>Propylen</td>
<td>138,5645</td>
<td>13,9422</td>
</tr>
<tr>
<td>Propana</td>
<td>8,5798</td>
<td>8,5798</td>
</tr>
<tr>
<td>Isopropilbenzen</td>
<td>99,0992</td>
<td>412,4486</td>
</tr>
<tr>
<td>Diisopropilbenzen</td>
<td>-</td>
<td>28,7810</td>
</tr>
<tr>
<td>Total</td>
<td>1787,4631</td>
<td>1787,4631</td>
</tr>
</tbody>
</table>

A.9 Mixing Point II (M-102)

Fungsi : Untuk mencampur umpan benzene dan Propilen yang akan di reaksikan di Reaktor (R-10)
<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kg/jam)</th>
<th>Keluar (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzen</td>
<td>1541,2196</td>
<td></td>
</tr>
<tr>
<td>Propilen</td>
<td>-</td>
<td>138,5645</td>
</tr>
<tr>
<td>Propana</td>
<td>-</td>
<td>8,5798</td>
</tr>
<tr>
<td>Isopropilbenzen</td>
<td>-</td>
<td>99,0992</td>
</tr>
<tr>
<td>Diisopropilbenzen</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>1640,3188</td>
<td>147,1521</td>
</tr>
</tbody>
</table>

Tabel LA.9 Neraca Massa Mixing Point II (M-102)
A.10 Vaporizer (E-101)

Fungsi: untuk menaikkan temperatur hasil bottom yang berasal dari kolom destilasi serta mengubah fasanya menjadi gas.

Pada vaporizer terjadi perubahan fasa yaitu dari fasa cair ke fasa gas. Perubahan fasa terjadi dengan jalan memanaskan cairan sampai pada titik didihnya. Diasumsikan bahwa 80% cairan yang masuk ke dalam vaporizer berubah menjadi gas serta keluaran dari vaporizer pada alur 7 semuanya berwujud gas dan recycle cairan yang belum menguap masuk pada alur 7R.

**Alur 7**

\[ F^7 = 1640,3188 \text{ kg/jam} \]

IPB:
\[ F_{IPB} = 99,0992 \text{ kg/jam} \]

Benzen:
\[ F_{Benzen} = 1541,2196 \text{ kg/jam} \]

**Alur 6**

\[ F^9 = 1640,3188 \text{ kg/jam} \]

IPB:
\[ F_{IPB} = 99,0992 \text{ kg/jam} \]

Benzen:
\[ F_{Benzen} = 1541,2196 \text{ kg/jam} \]

**Alur 7R**

\[ F^{7R} = 0,2 \times F^6 = 328,0637 \text{ kg/jam} \]

IPB:
\[ F_{IPB}^{7R} = 0,2 \times F_{IPB}^6 = 19,8198 \text{ kg/jam} \]

Benzen:
\[ F_{Benzen}^{7R} = 0,2 \times F_{Benzen}^6 = 308,2439 \text{ kg/jam} \]
### Tabel LA.10 Neraca Massa Vaporizer (E-101)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Masuk (kg/jam)</th>
<th>Keluar (kg/jam)</th>
<th>Reflux (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 6</td>
<td>Alur 7</td>
<td>Alur 7R</td>
</tr>
<tr>
<td>Benzen</td>
<td>1541,2196</td>
<td>1541,2196</td>
<td>308,2439</td>
</tr>
<tr>
<td>Propilen</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Propana</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Isopropilbenzen</td>
<td>99,0992</td>
<td>99,0992</td>
<td>19,8198</td>
</tr>
<tr>
<td>Diisopropilbenzen</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>1640,3188</td>
<td>1640,3188</td>
<td>328,0637</td>
</tr>
</tbody>
</table>

### A.11 Mixing Point I (M-101)

Fungsi: Untuk mencampur umpan benzen recycle dengan benzen murni dari Tangki bahan baku.

Neraca massa total

\[ F^6 = F^9 = 1640,3188 \text{ kg/jam} \]

\[ F^5 = F^6 - F^{23} = 1640,3188 - 1420,6011 = 219,7177 \text{ kg/jam} \]

**Alur 6**

\[ F^9 = 1640,3188 \text{ kg/jam} \]

\[ IPB : F^6_{IPB} = F^9_{IPB} = 99,0992 \text{ kg/jam} \]

\[ Benzen : F^6_{Benzen} = F^9_{Benzen} = 1541,2196 \text{ kg/jam} \]

**Alur 23**

\[ F^{23} = 1420,6011 \text{ kg/jam} \]

\[ IPB : F^{23}_{IPB} = F^{15}_{IPB} - F^{22}_{IPB} = 99,0992 \text{ kg/jam} \]

\[ Benzen : F^{23}_{Benzen} = F^{15}_{Benzen} - F^{22}_{Benzen} = 1321,5019 \text{ kg/jam} \]
Alur 5

\[ F_5 = 219,7177 \text{ kg/jam} \]

Benzen :  
\[ F_{\text{Benzen}}^5 = F_{\text{Benzen}}^6 - F_{\text{Benzene}}^{23} = 219,7177 \text{ kg/jam} \]

Tabel LA.11 Neraca Massa Mixing Point I (M-101)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Keluar (kg/jam)</th>
<th>Masuk (kg/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alur 6</td>
<td>Alur 5</td>
</tr>
<tr>
<td>Benzen</td>
<td>1541,2196</td>
<td>219,7177</td>
</tr>
<tr>
<td>Propilen</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Propana</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Isopropilbenzen</td>
<td>99,0992</td>
<td>-</td>
</tr>
<tr>
<td>Diisopropilbenzen</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>1640,3188</td>
<td>219,7177</td>
</tr>
<tr>
<td></td>
<td>1640,3188</td>
<td>1640,3188</td>
</tr>
</tbody>
</table>
LAMPIRAN B
PERHITUNGAN NERACA ENERGI

Basis perhitungan : 1 jam operasi
Satuan operasi : kJ/jam
Temperatur basis : 25°C = 298,15 K

Tabel LB.1 Kapasitas panas cair $C_p = a + bT + cT^2 + dT^3$ [J/mol. K]

<table>
<thead>
<tr>
<th>Komponen</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₆H₆</td>
<td>-7,27329</td>
<td>7,70541E-01</td>
<td>-1,64818E-03</td>
<td>1,89794E-06</td>
</tr>
<tr>
<td>C₇H₈</td>
<td>12,28877</td>
<td>9,18751E-01</td>
<td>-4,34735E-03</td>
<td>7,94316E-06</td>
</tr>
<tr>
<td>C₈H₈</td>
<td>33,7507</td>
<td>7,46408E-01</td>
<td>-3,64966E-03</td>
<td>7,10670E-06</td>
</tr>
<tr>
<td>C₉H₁₂</td>
<td>-47,3271</td>
<td>1,40532</td>
<td>-2,43735E-03</td>
<td>2,10281E-06</td>
</tr>
<tr>
<td>C₁₀H₁₈</td>
<td>-21,466</td>
<td>1,28851</td>
<td>-2,22048E-03</td>
<td>1,91681E-06</td>
</tr>
</tbody>
</table>

(Sumber : Reklaitis, 1983)

Tabel LB.2 Panas Laten [J/mol]

<table>
<thead>
<tr>
<th>Komponen</th>
<th>BM</th>
<th>BP (K)</th>
<th>ΔHvl</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₆H₆</td>
<td>78</td>
<td>353,261</td>
<td>30763,4</td>
</tr>
<tr>
<td>C₇H₈</td>
<td>42</td>
<td>225,461</td>
<td>18372,6</td>
</tr>
<tr>
<td>C₈H₈</td>
<td>44</td>
<td>231,091</td>
<td>18773,1</td>
</tr>
<tr>
<td>C₉H₁₂</td>
<td>120</td>
<td>432,378</td>
<td>38241,8</td>
</tr>
<tr>
<td>C₁₀H₁₈</td>
<td>162</td>
<td>438,161</td>
<td>38867,2</td>
</tr>
</tbody>
</table>

(Sumber : Reklaitis, 1983)

Tabel LB.3 Kapasitas panas gas $C_p = a + bT + cT^2 + dT^3 + eT^4$ [J/mol. K]

<table>
<thead>
<tr>
<th>Komponen</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>D</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₆H₆</td>
<td>18,5868</td>
<td>-1,17439E-02</td>
<td>1,27514E-03</td>
<td>-2,07984E-06</td>
<td>1,05329E-09</td>
</tr>
<tr>
<td>C₇H₈</td>
<td>26,3657</td>
<td>7,12795E-02</td>
<td>3,38448E-04</td>
<td>-5,15275E-07</td>
<td>2,30475E-10</td>
</tr>
<tr>
<td>C₈H₈</td>
<td>42,2659</td>
<td>-0,131469</td>
<td>1,17000E-03</td>
<td>-1,69695E-06</td>
<td>8,1891E-10</td>
</tr>
<tr>
<td>C₉H₁₂</td>
<td>-46,1396</td>
<td>-0,829738</td>
<td>-6,20486E-04</td>
<td>2,39055E-07</td>
<td>-3,72820E-11</td>
</tr>
<tr>
<td>C₁₀H₁₈</td>
<td>-19,5616</td>
<td>0,724058</td>
<td>-4,70818E-04</td>
<td>1,464E-07</td>
<td>-1,61041E-11</td>
</tr>
</tbody>
</table>

(Sumber : Reklaitis, 1983)
Tabel LB.4 Panas reaksi pembentukan fasa gas [ J/mol ]

<table>
<thead>
<tr>
<th>Komponen</th>
<th>$\Delta H_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>C6H6</td>
<td>19,82</td>
</tr>
<tr>
<td>C3H6</td>
<td>4,88</td>
</tr>
<tr>
<td>C3H8</td>
<td>-24,82</td>
</tr>
<tr>
<td>C9H12</td>
<td>0,94</td>
</tr>
<tr>
<td>C12H18</td>
<td>-3,33</td>
</tr>
</tbody>
</table>

(Sumber : Reklaitis, 1983)

Tabel LB.5 Tekanan uap Antoine (kPa) $\ln P = A - \frac{B}{T+C}$

<table>
<thead>
<tr>
<th>Komponen</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>C6H6</td>
<td>14,1603</td>
<td>2948,78</td>
<td>-44,5633</td>
</tr>
<tr>
<td>C3H6</td>
<td>13,8782</td>
<td>1875,25</td>
<td>-22,9101</td>
</tr>
<tr>
<td>C3H8</td>
<td>13,7097</td>
<td>1872,82</td>
<td>-25,1011</td>
</tr>
<tr>
<td>C9H12</td>
<td>13,9908</td>
<td>3433,51</td>
<td>-66,0278</td>
</tr>
<tr>
<td>C12H18</td>
<td>14,2225</td>
<td>3633,94</td>
<td>-59,9427</td>
</tr>
</tbody>
</table>

(Sumber : Reklaitis, 1983)

Persamaan untuk menghitung kapasitas panas (Reklaitis, 1983) :

$$Cp = a + bT + cT^2 + dT^3$$ ..........................(1)

Jika $Cp$ adalah fungsi dari temperatur maka persamaan menjadi :

$$\int_{T_1}^{T_2} Cp dT = \int_{T_1}^{T_2} (a + bT + cT^2 + dT^3)dT$$ ..........................(2)

$$\int_{T_1}^{T_2} Cp dT = a(T_2 - T_1) + \frac{b}{2}(T_2^2 - T_1^2) + \frac{c}{3}(T_2^3 - T_1^3) + \frac{d}{4}(T_2^4 - T_1^4)$$ ..........................(3)

Untuk sistem yang melibatkan perubahan fasa persamaan yang digunakan adalah :

$$\int_{T_1}^{T_2} Cp dT = \int_{T_1}^{T_2} Cp_{in} dT + \int_{T_1}^{T_2} Cp_{out} dT$$ ..........................(4)

Perhitungan energi untuk sistem yang melibatkan reaksi :

$$\frac{dQ}{dt} = r\Delta H_r + N \int_{T_1}^{T_2} Cp dT_{out} - N \int_{T_1}^{T_2} Cp dT_{in}$$ ..........................(5)
B.1 Compresor (JC-101)
Fungsi : Menaikkan tekanan umpan propylene dan propane sebelum bercampur dengan umpan benzene yang akan diumpakan ke reaktor

\[ \Delta S = C_p \lg \frac{P_2}{P_1}, \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} + S_2 - S_1 \]  

(Smith, 2001)

Pada entropi tetap, \( S_2 = S_1 \)

Maka:

\[ 0 = C_p \frac{\lg \frac{P_2}{P_1}}{\ln \frac{T_2}{T_1}} - R \ln \frac{P_2}{P_1} + 0 \]

\[ R \ln \frac{P_2}{P_1} = C_p \frac{\lg \frac{P_2}{P_1}}{\ln \frac{T_2}{T_1}} \]

\[ \frac{C_p}{R_1} \ln \frac{T_2}{T_1} = \ln \frac{P_2}{P_1} \]

\[ \ln \frac{T_2}{T_1} = \frac{1}{C_p} \ln \frac{P_2}{P_1} \]

\[ \ln T_2 - \ln T_1 = \frac{1}{C_p} \ln \frac{P_2}{P_1} \]

\[ T_2 = \exp \left( \frac{\ln \frac{P_2}{P_1}}{C_p} \right) + \ln T_1 \]

\[ \ln \frac{P_2}{P_1} = 0,8754 \]

\[ \frac{C_p}{R_1} = 76,6801 \]

\[ \ln T_1 = 6,2897 \]

\[ \ln T_2 = 545,19 \text{ K} \]
Panas masuk pada suhu 539,01 K (265,86 °C)

Panas Masuk pada alur 3: \( Q_{in} = \sum N_i \left( \int_{298,15}^{539,01} C_{p(l)} \, dT + (\Delta H_{vl}) + \int_{298,15}^{539,01} C_{p(g)} \, dT \right) \)

Tabel LB.10 Panas Masuk Compresor (JC-102)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>( N ) (kmol)</th>
<th>( \Delta H_{vl} )</th>
<th>( \int_{298,15}^{539,01} C_{p(l)} , dT )</th>
<th>( \int_{298,15}^{539,01} C_{p(g)} , dT )</th>
<th>( Q_{in} ) (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>3.2928</td>
<td></td>
<td>20346,7861</td>
<td>66997,8972</td>
<td></td>
</tr>
<tr>
<td>Propana</td>
<td>0.1945</td>
<td></td>
<td>22271,7359</td>
<td>4331,8526</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>71329,7499</strong></td>
</tr>
</tbody>
</table>

Panas keluar pada suhu 545,19 K (272,04 °C)

Panas Masuk pada alur 4: \( Q_{out} = \sum N_i \left( \int_{298,15}^{545,19} C_{p(l)} \, dT + (\Delta H_{vl}) + \int_{298,15}^{545,19} C_{p(g)} \, dT \right) \)

Tabel LB.11 Panas Keluar Compresor pada (JC-102)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>( N ) (kmol)</th>
<th>( \Delta H_{vl} )</th>
<th>( \int_{298,15}^{548,82} C_{p(l)} , dT )</th>
<th>( \int_{298,15}^{545,19} C_{p(g)} , dT )</th>
<th>( Q_{out} ) (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>3.2928</td>
<td></td>
<td>20979,84232</td>
<td>69082,42478</td>
<td></td>
</tr>
<tr>
<td>Propana</td>
<td>0.1945</td>
<td></td>
<td>22984,80443</td>
<td>4470,54462</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>73552,9692</strong></td>
</tr>
</tbody>
</table>

\[
\frac{dQ}{dt} = Q_{out} - Q_{in} = [73552,9692 - 71329,7499] \text{ kJ/jam}
\]

\[= 2223,2193 \text{ kJ/jam}\]

**B.2 Heater (E-103)**

Fungsi: Menaikkan temperatur umpan Propylene dan propane sebelum masuk ke reaktor (R–101).

Superheated steam (360°C)

\[P = 1 \text{ atm}\]
Neraca energi:

\[
\frac{dQ}{dT} - \frac{dW}{dT} = \sum_{i} N_i H_i(T_i, P_i) - \sum_{j} N_j H_j(T_j, P_j)
\]

Karena sistem tidak melakukan kerja, maka \( \frac{dW}{dT} = 0 \)

Sehingga,

\[
\frac{dQ}{dT} = \sum_{i} N_i H_i(T_i, P_i) - \sum_{j} N_j H_j(T_j, P_j)
\]

**Panas masuk** \( T = 303,15 \) K (30 °C)

Panas masuk pada alur 2: \( Q_{\text{in}} = \sum_{i} \int_{298,15}^{308,26} N_i C_{p,i} dT \)

**Tabel LB.8 Panas masuk Heater (E-103)**

<table>
<thead>
<tr>
<th>Komponen</th>
<th>( N ) (kmol)</th>
<th>( \int_{298,15}^{303,15} C_{p,i} dT )</th>
<th>( Q_{\text{in}} ) (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>3,2928</td>
<td>331,3418</td>
<td>1091,0424</td>
</tr>
<tr>
<td>Propana</td>
<td>0,1945</td>
<td>345,3572</td>
<td>67,1720</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>1158,2143</strong></td>
</tr>
</tbody>
</table>

**Panas keluar pada suhu 539,01 K (265,86 °C)**

Panas keluar pada alur 3: \( Q_{\text{out}} = \sum_{i} \int_{298}^{539,01} N_i C_{p,i} dT \)
Tabel LB.9. Panas Keluar Heater (E-103)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kmol)</th>
<th>$\int_{298}^{539.01} Cp_T (g) dT$</th>
<th>Q out (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>3,2928</td>
<td>20346,7861</td>
<td>66997,8973</td>
</tr>
<tr>
<td>Propana</td>
<td>0.1945</td>
<td>26439,8457</td>
<td>5142,5500</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>72140,4473</td>
</tr>
</tbody>
</table>

Neraca Energi Total Sistem:

$$\frac{dQ}{dt} = Q_{out} - Q_{in}$$

$$= [72140,4473 - 1158,2143] \text{kJ/jam}$$

$$= 70982,2329 \text{kJ/jam}$$

Media pemanas yang dipakai *superheated steam* pada 360 °C, kemudian keluar pada suhu 150 °C (1atm).

$$\frac{dQ}{dt} = m \cdot Cp \cdot \Delta T$$

Steam yang diperlukan adalah:

$$q_{heater} = \frac{\Delta H (360^\circ C \text{Superheated Steam} - 150^\circ C \text{Kondensat})}{(3195,8761 \text{kJ/kg} - 2776,2993 \text{kJ/kg})} = \frac{70982,2329 \text{kJ/jam}}{419,5768 \text{kJ/kg}}$$

$$= 169,1757 \text{kg/jam}$$

B.3 Compresor (JC-102)

Fungsi: Menaikkan tekanan umpan Benzen dan IPB sebelum bercampur dengan umpan Propilen yang akan diumpakan ke reaktor
\[ \Delta S = C_{p}^{ig}, \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} + S_2 - S_1 \]  

(Smith, 2001)

Pada entropi tetap, \( S_2 = S_1 \)

Maka:

\[ 0 = C_{p}, \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} + 0 \]

\[ R \ln \frac{P_2}{P_1} = C_{p}, \ln \frac{T_2}{T_1} \]

\[ \frac{C_{p}^{ig}}{R_1} \ln \frac{T_2}{T_1} = \ln \frac{P_2}{P_1} \]

\[ \ln \frac{T_2}{T_1} = \frac{1}{C_{p}^{ig}} \ln \frac{P_2}{P_1} \]

\[ \ln T_2 - \ln T_1 = \frac{1}{C_{p}^{ig}} \ln \frac{P_2}{P_1} \]

\[ T_2 = \exp \left( \frac{\ln \frac{P_2}{P_1}}{C_{p}^{ig} \frac{R}{R}} \right) + \ln T_1 \]

\[ \ln \frac{P_2}{P_1} = 2,8904 \]

\[ \frac{C_{p}^{ig}}{R_1} = 170,0945 \]

\[ \ln T_1 = 6,2964 \]

\[ T_2 = 551,9224 \text{ K} \]

**Panas masuk pada suhu 542,62 K (269,47 °C)**

Panas Masuk pada alur 3: \( Q_{in} = \sum N \int_{298,15}^{542,62} C_{p}^{(l)}dT + (\Delta Hvl) + \int_{298,15}^{542,62} C_{p}^{(g)}dT \)

Tabel LB.10 Panas Masuk Compresor (JC-102)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kmol)</th>
<th>( \Delta Hvl )</th>
<th>( \int_{298,15}^{542,62} C_{p}^{(l)}dT )</th>
<th>( \int_{298,15}^{542,62} C_{p}^{(g)}dT )</th>
<th>( Q_{in} ) (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>benzene</td>
<td>19,7314</td>
<td>18773,1000</td>
<td>7409,7918</td>
<td>23466,8412</td>
<td>979658,7425</td>
</tr>
<tr>
<td>IPB</td>
<td>0,8245</td>
<td>66008,3707</td>
<td></td>
<td></td>
<td>54423,9017</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1034082,6442</strong></td>
</tr>
</tbody>
</table>
Panas keluar pada suhu 551,92 K (278,77 °C)

Panas Masuk pada alur 4: \( Q_{\text{out}} = \sum N_i \left( \int_{298,15}^{551,92} C_{p,i} \, dT + \int_{298,15}^{551,92} C_{p,(g)} \, dT \right) \)

Tabel LB.11 Panas Keluar Compresor pada (JC-102)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kmol)</th>
<th>( \Delta H_{\text{vl}} )</th>
<th>( \int_{298,15}^{551,92} C_{p,(i)} , dT )</th>
<th>( \int_{298,15}^{551,92} C_{p,(g)} , dT )</th>
<th>( Q_{\text{out}} ) (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>benzene</td>
<td>19,7314</td>
<td>18773,1000</td>
<td>7409,7918</td>
<td>24839,8628</td>
<td>1006750,3817</td>
</tr>
<tr>
<td>IPB</td>
<td>0,8245</td>
<td></td>
<td>69137,1244</td>
<td></td>
<td>57003,5591</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1063753,9408</strong></td>
</tr>
</tbody>
</table>

\[
\frac{dQ}{dt} = Q_{\text{Out}} - Q_{\text{In}} \\
= [1063753,9408 - 1034082,6442] \text{kJ/jam} \\
= 29671,2966 \text{kJ/jam}
\]

B.4 Vaporizer (E-101)

Fungsi: Menguapkan umpan benzene yang menganding IPB sebelum dimasukkan ke reactor.

Superheated steam 360 °C, 1 atm

Benzena (i) 
IPB (i)
T= 76,66 °C
P= 1 atm

Superheated steam 150 °C, 1 atm

Benzena (g) 
IPB (g)
T= 92,314 °C
P= 1 atm

Untuk menentukan suhu operasi Vaporizer, dilakukan dengan perhitungan bubble point hingga tercapai syarat \( \sum \frac{y_i}{K_i} = 1 \)

\( P = 1 \text{ atm} \)  \( K = \frac{P_i}{P} \)  \( \text{Trial} : T = 365,464 \text{ K} \) (92,314 °C)

Tabel LB.12 Data perhitungan suhu operasi Vaporizer (E-101)
<table>
<thead>
<tr>
<th>komponen</th>
<th>T</th>
<th>P uap</th>
<th>P uap (atm)</th>
<th>yi</th>
<th>K</th>
<th>yi/Ki</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>365,4640</td>
<td>144,2037</td>
<td>1,4233</td>
<td>0,9599</td>
<td>1,4233</td>
<td>0,6744</td>
</tr>
<tr>
<td>IPB</td>
<td>365,4640</td>
<td>12,4811</td>
<td>0,1232</td>
<td>0,0401</td>
<td>0,1232</td>
<td>0,3256</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0000</td>
</tr>
</tbody>
</table>

Suhu operasi untuk Vaporizer (E-101) adalah: 365,4640 K (92,314 °C).

**Panas masuk pada suhu 349,81 K (76,66 °C)**

Panas keluar pada alur 6: \( Q_{in} = \sum N_i \left( \int_{BP}^{298,15} \! C_{p(l)} \, dT + (\Delta Hvl) + \int_{BP}^{349,81} \! C_{p(g)} \, dT \right) \)

**Tabel LB.13 Panas masuk Vaporizer (E-101)**

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kg/jam)</th>
<th>( \Delta Hvl )</th>
<th>( \int_{BP}^{298,15} ! C_{p(l)} , dT )</th>
<th>( \int_{BP}^{349,81} ! C_{p(g)} , dT )</th>
<th>Q in (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzena</td>
<td>19,7314</td>
<td>6920,5902</td>
<td></td>
<td></td>
<td>136552,9331</td>
</tr>
<tr>
<td>IPB</td>
<td>0,8245</td>
<td>11549,8879</td>
<td></td>
<td></td>
<td>9522,8826</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>146075,8157</td>
</tr>
</tbody>
</table>

**Panas keluar pada suhu 365,464 K (92,314 °C)**

Panas keluar pada alur 7: \( Q_{out} = \sum N_i \left( \int_{BP}^{298,15} \! C_{p(l)} \, dT + (\Delta Hvl) + \int_{BP}^{365,464} \! C_{p(g)} \, dT \right) \)

**Tabel LB.14 Panas Keluar Vaporizer (E-101)**

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kg/jam)</th>
<th>( \Delta Hvl )</th>
<th>( \int_{BP}^{298,15} ! C_{p(l)} , dT )</th>
<th>( \int_{BP}^{365,464} ! C_{p(g)} , dT )</th>
<th>Q out (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzena</td>
<td>19,7314</td>
<td>18773,1</td>
<td>7409,7918</td>
<td>1222,3794</td>
<td>540744,3694</td>
</tr>
<tr>
<td>IPB</td>
<td>0,8245</td>
<td>15301,3224</td>
<td></td>
<td>12615,9403</td>
<td>12615,9403</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>553360,3097</td>
</tr>
</tbody>
</table>

**Neraca Energi Total Sistem :**

\[
\frac{dQ}{dt} = Q_{Out} - Q_{In}
\]

\[
= [553360,3097 - 146075,8157] \text{ kJ/jam}
\]

\[
= 407284,4940 \text{ kJ/jam}
\]
Media pemanas yang dipakai superheated steam pada 360 °C, kemudian keluar pada 150 °C (1 atm).

\[
\frac{dQ}{dt} = m \cdot C_p \cdot \Delta T
\]

Steam yang diperlukan adalah :

\[
q_{heater} = \frac{\Delta H(360^0 C_{Saturated \ Steam} - 150^0 C_{Kondensat})}{407284,4940 \text{kJ/jam}} = 407284,4940 \text{kJ/jam}
\]

\[
(3195,8761 \text{kJ/kg} - 2776,2993 \text{kJ/kg}) = 419,5768 \text{kJ/kg}
\]

\[
= 970,7029 \text{kg/jam}
\]

B.5 Heater (E-102)

Fungsi: Menaikkan temperature benzene dan IPB sebelum diumpankan ke reaktor

\[
\begin{align*}
\text{Superheated steam (360°C)} & \quad \text{P = 1 atm} \\
\text{Benzena (g)} & \quad T = 115,93 \text{°C} \\
\text{IPB (g)} & \quad P = 2 \text{ atm} \\
\text{Superheated steam (150°C)} & \quad \text{P = 1 atm}
\end{align*}
\]

Panas masuk pada suhu 365,464 K (92,314 °C)

Panas Masuk pada alur 7: \[
Q_{in} = \sum N \left( \int_{298,15}^{365,464} C_{p(I)} dT + \int_{298,15}^{365,464} C_{p(G)} dT \right)
\]

Tabel LB.15 Panas Masuk Heater (E-102)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kg/jam)</th>
<th>(\Delta H_{vl})</th>
<th>(\int C_{p(I)} dT)</th>
<th>(\int C_{p(G)} dT)</th>
<th>Q in (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzena</td>
<td>19,7314</td>
<td>18773,1</td>
<td>7409,7918</td>
<td>1222,3794</td>
<td>540744,3694</td>
</tr>
<tr>
<td>IPB</td>
<td>0,8245</td>
<td>15301,3224</td>
<td></td>
<td></td>
<td>12615,9403</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>553360,3097</td>
</tr>
</tbody>
</table>

Universitas Sumatera Utara
Panas keluar pada suhu 542,62 K (269,47 °C)

Panas Masuk pada alur 8: \[ Q_{out} = \sum N_i \left( \int_{BP}^{BP} \Delta T \left( \int_{BP}^{298,15 \Delta Hvl} \right) + \int_{BP}^{542,62 \Delta Hvl} \right) \]

Tabel LB.16 Panas Keluar Heater (E-102)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kg/jam)</th>
<th>( \Delta Hvl )</th>
<th>( \int_{BP}^{BP} \Delta T )</th>
<th>( \int_{BP}^{542,62} \Delta T )</th>
<th>Q out (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzena</td>
<td>19,7314</td>
<td>18773.1</td>
<td>7409,7918</td>
<td>23466,8412</td>
<td>979658,7425</td>
</tr>
<tr>
<td>IPB</td>
<td>0.8245</td>
<td>12363,6950</td>
<td></td>
<td></td>
<td>10193,8665</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>989852,6090</td>
</tr>
</tbody>
</table>

Neraca Energi Total Sistem:
\[
\frac{dQ}{dt} = Q_{Out} - Q_{In}
\]
\[
= [989852,6090 - 553360,3097] \text{kJ/jam}
\]
\[
= 436492,2993 \text{kJ/jam}
\]

Media pemanas yang dipakai superheated steam pada 300 °C, kemudian keluar pada 150 °C (1 atm).
\[
\frac{dQ}{dt} = m \cdot C_p \cdot \Delta T
\]

Steam yang diperlukan adalah:
\[
\Delta H \left( 360^\circ C \text{Superheated Steam} - 150^\circ C \text{Kondensat} \right)
\]
\[
\frac{436492,2993}{(3195,8761 - 2776,2993)} = 436492,2993 \text{kJ/jam}
\]
\[
= 1040,3154 \text{ kg/jam}
\]
B.6 Kompresor (JC-103)

Fungsi: Menaikkan tekanan Propilen dan propana sebelum dibakar di udara

\[ \Delta S = C_p^{ig} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} + S_2 - S_1 \]  

(Smith, 2001)

Pada entropi tetap, \( S_2 = S_1 \)

Maka:

\[ 0 = C_p^{ig} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} + 0 \]

\[ R \ln \frac{P_2}{P_1} = C_p^{ig} \ln \frac{T_2}{T_1} \]

\[ \frac{C_p^{ig}}{R} \ln \frac{T_2}{T_1} = \ln \frac{P_2}{P_1} \]

\[ \ln \frac{T_2}{T_1} = \frac{1}{C_p^{ig}} \ln \frac{P_2}{P_1} \]

\[ \ln T_2 - \ln T_1 = \frac{1}{C_p^{ig}} \ln \frac{P_2}{P_1} \]

\[ T_2 = \exp \left( \frac{\ln \frac{P_2}{P_1}}{C_p^{ig}} \right) + \ln T_1 \]

\[ \ln \frac{P_2}{P_1} = 0,4055 \]

\[ \ln T_1 = 5,8094 \]

\[ \frac{C_p^{ig}}{R} = 34,6506 \]

\[ T_2 = 337,33 \text{ K} \]
Panas masuk pada suhu 333,41 K (60,26 °C)

Panas Masuk pada alur 8: \( Q_{\text{in}} = \sum \Delta H_{\text{hv}} \left( \int_{298,15}^{333,41} \left[ \int_{(l)} C_p \, dT + \int_{(g)} C_p \, dT \right] \right) \)

Tabel LB.17 Panas Masuk Compresor (JC-103)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>( N ) (kg/jam)</th>
<th>( \Delta H_{\text{hv}} )</th>
<th>( \int_{298,15} \int_{(l)} C_p , dT )</th>
<th>( \int_{333,41} \int_{(g)} C_p , dT )</th>
<th>( Q_{\text{in}} ) (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>0,3313</td>
<td></td>
<td>2422,3162</td>
<td></td>
<td>802,5134</td>
</tr>
<tr>
<td>propane</td>
<td>0,1945</td>
<td></td>
<td>2543,7929</td>
<td></td>
<td>494,7677</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1297,2811</strong></td>
</tr>
</tbody>
</table>

Panas keluar pada suhu 337,33 K (64,18 °C)

Panas Masuk pada alur 9: \( Q_{\text{out}} = \sum \Delta H_{\text{hv}} \left( \int_{298,15}^{337,33} \left[ \int_{(l)} C_p \, dT + \int_{(g)} C_p \, dT \right] \right) \)

Tabel LB.18 Panas Keluar Compresor (JC-103)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>( N ) (kg/jam)</th>
<th>( \Delta H_{\text{hv}} )</th>
<th>( \int_{298,15} \int_{(l)} C_p , dT )</th>
<th>( \int_{337,33} \int_{(g)} C_p , dT )</th>
<th>( Q_{\text{out}} ) (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>0,3313</td>
<td></td>
<td>2704,1550</td>
<td></td>
<td>895,8866</td>
</tr>
<tr>
<td>propane</td>
<td>0,1945</td>
<td></td>
<td>2842,5181</td>
<td></td>
<td>552,8698</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1448,7563</strong></td>
</tr>
</tbody>
</table>

Neraca Energi Total Sistem:

\[
\frac{dQ}{dt} = Q_{\text{out}} - Q_{\text{in}}
\]

\[
= [1297,2811 - 1448,7563] \text{kJ/jam}
\]

\[
= 151,4752 \text{kJ/jam}
\]
B.7 Reaktor (R-101)

Fungsi : Tempat berlangsungnya reaksi pembentukan Isoprophylbenzene (cumene)

Panas masuk pada suhu 278,23 °C (551,38 K)

Panas masuk pada alur 10: 

\[ Q_{in} = \sum N \left( \int_{298,15}^{BP} \Delta H + \int_{BP}^{551,38} \Delta H \right) + \int_{BP}^{550,57} \Delta H \]

Tabel LB.19 Panaş masuk Reaktor (R-101)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kmol)</th>
<th>ΔHvl</th>
<th>( \int_{298,15}^{BP} \Delta H )</th>
<th>( \int_{BP}^{550,57} \Delta H )</th>
<th>Q in (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>3.2936</td>
<td></td>
<td>21617,3487</td>
<td>71198,8998</td>
<td></td>
</tr>
<tr>
<td>Propana</td>
<td>0.1945</td>
<td></td>
<td>23703,4680</td>
<td>4610,3245</td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>19,7314</td>
<td></td>
<td>30763,400 0</td>
<td>7411,3639 24758,6866</td>
<td>1241765,085</td>
</tr>
<tr>
<td>IPB</td>
<td>0.8245</td>
<td></td>
<td>38241,800 0</td>
<td>32627,557 6 28294,1258</td>
<td>81760,2921</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>1399334,601</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Panas keluar pada suhu 278,23 °C (551,38 K)
Panas keluar pada alur 11: \[ Q_{out} = \sum N_i \left( \int_{BP}^{NBP} \Delta H_{vl}(dT) + (\Delta H_{vl}) + \int_{BP}^{NBP} \Delta H_{BP}(dT) \right) \]

Tabel LB.20 Panas keluar Reaktor (R-101)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>( N ) (kmol)</th>
<th>( \Delta H_{vl} )</th>
<th>( \int_{BP}^{NBP} \Delta H_{BP}(dT) )</th>
<th>( \int_{BP}^{NBP} \Delta H_{BP}(dT) )</th>
<th>( Q_{out} ) (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>0.3313</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propana</td>
<td>0.1945</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>16.9467</td>
<td>30763,4000</td>
<td>7411,3639</td>
<td>24758,6866</td>
<td>1066514,3056</td>
</tr>
<tr>
<td>IPB</td>
<td>3.4316</td>
<td>38241,8000</td>
<td>32627,5576</td>
<td>28294,1258</td>
<td>340289,4097</td>
</tr>
<tr>
<td>DIPB</td>
<td>0.1776</td>
<td>38867,2000</td>
<td>34642,0773</td>
<td>27161,6631</td>
<td>17879,1590</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1436455,0265</strong></td>
</tr>
</tbody>
</table>

Reaksi:

\[ \text{C}_3\text{H}_6(\text{g}) + \text{C}_6\text{H}_6(\text{g}) \rightarrow \text{C}_9\text{H}_{12}(\text{g}) \] … (1)

\[ \text{C}_9\text{H}_{12}(\text{g}) + \text{C}_3\text{H}_6(\text{g}) \rightarrow \text{C}_{12}\text{H}_{18}(\text{g}) \] … (2)

Panas reaksi pada berbagai suhu dapat ditentukan dengan menggunakan persamaan berikut:

\[ \Delta H_{R,T} = \Delta H_{R,298} + \int_{298,15}^{T} \Delta C_P \cdot dT \]

\[ \Delta H_{R,298} = \left( \sum \Delta H_{f,298}^{\text{prod}} \right)_{\text{reak tan}} - \left( \sum \Delta H_{f,298}^{\text{reak tan}} \right) \]

\[ \int_{298,15}^{T} \Delta C_P \cdot dT = \int \left( C_P^{\text{IPB}} - C_P^{\text{propylene}} - C_P^{\text{Benzene}} \right) \cdot dT \]

Untuk reaksi 1:

\[ \Delta H_{R,298}^{\text{f}} = 1,87 - (4,88 + 19,82) \]

\[ = -22.83 \text{ kcal/mol} \]

\[ = -0,0955 \text{ kJ/kmol} \]
\[
\int_{298,15}^{550,57} \Delta C_p \cdot dT = \int_{298,15}^{550,57} \left( -91,092 - 0,7702T + (-2,2341 \cdot 10^{-3}T^2) + (2,8342 \cdot 10^{-6}T^3) + (-1,3210 \cdot 10^{-9}T^4) \right) \cdot dT \\
= 1,7301 \text{ kJ/kmol}
\]

\[
\Delta H_{R,549,73} = \Delta H_{R,298}^O + \int_{298,15}^{550,57} \Delta C_p \cdot dT \\
= -0,0955 + 1,7301 = 1,6345 \text{ kJ/mol}
\]

Untuk reaksi 2:

\[
\Delta H_{R,298}^O = -3,33 - 4,88 -1,87 \\
= -10,08 \text{ kcal/mol} \\
= -0,0421 \text{ kJ/kmol}
\]

\[
\int_{298,15}^{550,57} \Delta C_p \cdot dT = \int_{298,15}^{550,57} (0,2123 - (-0,17696T) + (-1,8878 \cdot 10^{-4}T^2) + 4,2262 \cdot 10^{-7}T^3 + (-2,0930 \cdot 10^{-10}T^4)) \cdot dT \\
= -20,9656 \text{ kJ/kmol}
\]

\[
\Delta H_{R,298,15} = \Delta H_{R,298}^O + \int_{298,15}^{549,73} \Delta C_p \cdot dT \\
= -0,0421 + (-20,9656) = -21,0078 \text{ kJ/mol}
\]

r_1 = 2,7847 kmol/jam

r_2 = -0,1776 kmol/jam

\[
\sum r \cdot \Delta H_R = r_1 \cdot \Delta H_{R1} + r_2 \cdot \Delta H_{R2} \\
= (2,7847 \times (1,6285)) + (-0,1776 \times (-20,9242)) \\
= 8,2827 \text{ kJ/jam}
\]

Q = \sum r \cdot \Delta H_R + Q_{out} - Q_{in}

= 8,2827 + (1436455,026– 1399334,602)

= 37128,7075 kJ/jam

Media pendingin yang digunakan adalah Dowtherm-A, dari data yang dikeluarkan

*Trademark of The Dow Chemical Company, 2001*

\[
\Delta H(30 \degree C) = 28,66 \text{ kJ/kg} \\
\Delta H(255 \degree C) = 458,2 \text{ kJ/kg} \\
\Delta H = 458,2 - 28,66 = 429,54 \text{ kJ/kg}
\]
Jumlah cairan pendingin yang diperlukan:

\[ m = \frac{Q}{\Delta H} \]

\[ m = \frac{37128,7075 \text{ kJ/jam}}{429,54 \text{ kJ/kg}} \]

\[ m = 86,4383 \text{ kg/jam} \]

**B.8 Expander (EV-101)**

Fungsi: Menurunkan tekanan hasil keluaran reactor sebelum didingunkan dan di kondensasi.

\[ \Delta S = C_{p,g} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} + S_2 - S_1 \]

(Smith, 2001)

Pada entropi tetap, \( S_2 = S_1 \)

Maka:

\[ 0 = C_{p,g} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} + 0 \]

\[ \ln \frac{T_2}{T_1} = \frac{1}{C_{p,g}} \ln \frac{P_2}{P_1} \]

\[ R \ln \frac{P_2}{P_1} = C_{p,g} \ln \frac{T_2}{T_1} \]

\[ \ln T_2 - \ln T_1 = \frac{1}{C_{p,g}} \ln \frac{P_2}{P_1} \]

\[ T_2 = \exp \left( \frac{\ln \frac{P_2}{P_1}}{C_{p,g}} \right) + \ln T_1 \]

\[ \ln \frac{P_1}{P_2} = -2,8904 \]

\[ \frac{C_{p,g}}{R_1} = 467,2952 \]

\[ \ln T_1 = 6,3124 \]

\[ T_2 = 547,98 \]
Panas masuk pada suhu 278,23 °C (551,38 K)

Panas Masuk pada alur 11: 

\[
Q_{in} = \sum N_i \left[ \int_{298,15}^{BP} \Delta H_{vl}(i) \, dT + \int_{298,15}^{551,38} \Delta H_{vl}(g) \, dT + \int_{298,15}^{BP} \int_{298,15}^{BP} \Delta H_{vl}(l) \, dT \right]
\]

Tabel LB.21 Panas Masuk *Expander* (EV-101)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kg/jam)</th>
<th>∆Hvl</th>
<th>BP [\text{kJ/Jam}]</th>
<th>551,38 [\text{kJ/Jam}]</th>
<th>Q in (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>0.3313</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propana</td>
<td>0.1945</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>16.9467</td>
<td>18773.1</td>
<td>7409,7918</td>
<td>24759,7677</td>
<td>863309,9680</td>
</tr>
<tr>
<td>IPB</td>
<td>3.4316</td>
<td>38241.6</td>
<td>30763,5738</td>
<td>29749,9796</td>
<td>338888,1845</td>
</tr>
<tr>
<td>DIPB</td>
<td>0.1776</td>
<td>38867.2</td>
<td>42892,9860</td>
<td>20650,7400</td>
<td>18188,1805</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1232158,4852</strong></td>
</tr>
</tbody>
</table>

Panas keluar pada suhu 274,83 °C (547,98 K)

Panas Masuk pada alur 12: 

\[
Q_{out} = \sum N_i \left[ \int_{298,15}^{BP} \Delta H_{vl}(i) \, dT + \int_{298,15}^{547,98} \Delta H_{vl}(g) \, dT + \int_{298,15}^{BP} \int_{298,15}^{BP} \Delta H_{vl}(l) \, dT \right]
\]

Tabel LB.22 Panas Keluar *Expander* pada (EV-101)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kg/jam)</th>
<th>∆Hvl</th>
<th>BP [\text{kJ/Jam}]</th>
<th>547,98 [\text{kJ/Jam}]</th>
<th>Q out (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>0.3313</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propana</td>
<td>0.1945</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>16.9467</td>
<td>18773.1</td>
<td>7409,7918</td>
<td>24256,0905</td>
<td>854774,3024</td>
</tr>
<tr>
<td>IPB</td>
<td>3.4316</td>
<td>38241.6</td>
<td>30763,5738</td>
<td>28870,1606</td>
<td>335868,9977</td>
</tr>
<tr>
<td>DIPB</td>
<td>0.1776</td>
<td>38867.2</td>
<td>42892,9860</td>
<td>19770,0556</td>
<td>18031,7709</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1220253,8997</strong></td>
</tr>
</tbody>
</table>

Neraca Energi Total Sistem:

\[
\frac{dQ}{dt} = Q_{Out} - Q_{In}
\]

\[
= [1220253,8997 - 1232158,4852] \text{kJ/jam}
\]

\[
= 11904,5855 \text{kJ/jam}
\]
B.9 Condencor Subcooler (E-104)

Fungsi : Menurunkan temperature keluaran reaktor dan mengkondensasikan benzene, IPB dan DIPB

Dowtherm A (30 °C)
P = 1 atm

Perhitungan suhu operasi kondensor :
Untuk menentukan suhu operasi (suhu keluaran) pada kondensor, dilakukan perhitungan dew point untuk komponen benzene, Propilen, Propana, IPB dan DIPB hingga syarat \( \sum xi.K = 1 \) terpenuhi,
P = 1 atm
K = Pi/P

Trial : T = 333,415 K (60,26 °C)

<table>
<thead>
<tr>
<th>Komp.</th>
<th>T</th>
<th>P uap</th>
<th>P uap (atm)</th>
<th>xi</th>
<th>K</th>
<th>xi.K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>333,415</td>
<td>52,0221</td>
<td>0,5134</td>
<td>0,8038</td>
<td>0,5134</td>
<td>0,4127</td>
</tr>
<tr>
<td>Propilen</td>
<td>333,415</td>
<td>2537,2670</td>
<td>25,0428</td>
<td>0,0157</td>
<td>25,0428</td>
<td>0,3935</td>
</tr>
<tr>
<td>Propana</td>
<td>333,415</td>
<td>2070,0050</td>
<td>20,4309</td>
<td>0,0092</td>
<td>20,4309</td>
<td>0,1884</td>
</tr>
<tr>
<td>IPB</td>
<td>333,415</td>
<td>3,1576</td>
<td>0,0311</td>
<td>0,1627</td>
<td>0,0311</td>
<td>0,0050</td>
</tr>
<tr>
<td>DIPB</td>
<td>333,415</td>
<td>2,5455</td>
<td>0,0251</td>
<td>0,0084</td>
<td>0,0251</td>
<td>0,0002</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1.00007</strong></td>
</tr>
</tbody>
</table>

Dari hasil perhitungan dew point didapat temperature 333,415 K adalah suhu dimana Benzene, IPB, dan DIPB seluruhnya mencair, sedangkan Propilen dan Propana masih dalam fase uap pada suhu tersebut, sehingga dapat dengan mudah dipisahkan pada flash drum (F-101).
Panas masuk pada suhu 547,98 K (274,83 °C)

Panas masuk pada alur 12: 

$$Q_{in} = \sum N_i \int_{298,15}^{BP} \left[ \int_{BP}^{547,98} C_{p(l)}dT + (\Delta Hvl) + \int_{BP}^{547,98} C_{p(g)}dT \right]$$

Tabel LB.24 Panas Masuk Condensor Subcooler (E-104)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>$N$ (kg/jam)</th>
<th>$\Delta Hvl$</th>
<th>$BP$ $\int_{298,15}^{BP} C_{p(l)}dT$</th>
<th>$BP$ $\int_{BP}^{547,98} C_{p(g)}dT$</th>
<th>$Q_{in}$ (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>0.3313</td>
<td></td>
<td>21266,2344</td>
<td>7045,5034</td>
<td></td>
</tr>
<tr>
<td>Propana</td>
<td>0,1945</td>
<td></td>
<td>23307,5850</td>
<td>4533,3253</td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>16,9467</td>
<td>18773,1</td>
<td>7409,7918</td>
<td>24256,0905</td>
<td>854774,3024</td>
</tr>
<tr>
<td>IPB</td>
<td>3,4316</td>
<td>38241,6</td>
<td>30763,5738</td>
<td>28870,1606</td>
<td>335868,9977</td>
</tr>
<tr>
<td>DIPB</td>
<td>0,1776</td>
<td>38867,2</td>
<td>42892,9860</td>
<td>19770,0556</td>
<td>18031,7709</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1220253,8997</td>
</tr>
</tbody>
</table>

Panas keluar pada suhu 60,26 °C (333,41 K)

Panas keluar pada alur 13: 

$$Q_{out} = \sum N_i \int_{298,15}^{BP} \left[ \int_{BP}^{333,41} C_{p(l)}dT + (\Delta Hvl) + \int_{BP}^{333,41} C_{p(g)}dT \right]$$

Tabel LB.25 Panas Keluar Condensor Subcooler (E-104)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>$N$ (kg/jam)</th>
<th>$\Delta Hvl$</th>
<th>$BP$ $\int_{298,15}^{BP} C_{p(l)}dT$</th>
<th>$BP$ $\int_{BP}^{333,41} C_{p(g)}dT$</th>
<th>$Q_{out}$ (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>0.3313</td>
<td></td>
<td>2422,3162</td>
<td>802,5134</td>
<td></td>
</tr>
<tr>
<td>Propana</td>
<td>0,1945</td>
<td></td>
<td>2543,7929</td>
<td>494,7677</td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>16.9467</td>
<td>7409,7918</td>
<td></td>
<td>125571,5194</td>
<td></td>
</tr>
<tr>
<td>IPB</td>
<td>3,4316</td>
<td>7743,1118</td>
<td></td>
<td>26571,2625</td>
<td></td>
</tr>
<tr>
<td>DIPB</td>
<td>0,1776</td>
<td>7910,5396</td>
<td></td>
<td>1404,9118</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>154844,9749</td>
</tr>
</tbody>
</table>

Neraca Energi Total Sistem:

$$\frac{dQ}{dt} = Q_{out} - Q_{in}$$

$$= [154844,9749 - 1220253,8997] \text{kJ/jam}$$

$$= 1065408,9248 \text{kJ/jam}$$
Air pendingin yang diperlukan adalah:

\[
m = \left( \frac{q}{\Delta H(240^\circ C - 30^\circ C)} \right)
\]

\[
= \frac{1065408,9248 \text{ kJ/jam}}{458,2 \text{ kj/kg} - 28,66 \text{ kj/kg}}
\]

\[
= \frac{1065408,9248 \text{ kJ/jam}}{429,54 \text{ kj/kg}}
\]

\[
= 2480,3485 \text{ kg/jam}
\]

**B.10 Heater (E-105)**

Fungsi: Menaikkan temperatur umpan destilasi hingga suhu umpan destilasi pada kondisi cair jenuh sebelum masuk ke Menara Destilasi (MD-101).

Neraca energi:

\[
\sum_{\text{out}} \Delta Q - \sum_{\text{in}} \Delta Q = \sum_{\text{out}} N_j H_j(T_j, P_j) - \sum_{\text{in}} N_j H_j(T_j, P_j)
\]

Karena sistem tidak melakukan kerja, maka \(\frac{dW}{dT} = 0\)

Sehingga, \(\frac{dQ}{dT} = \sum_{\text{out}} N_j H_j(T_j, P_j) - \sum_{\text{in}} N_j H_j(T_j, P_j)\)

Panas masuk \(T = 333,415 \text{ K (60,26}^\circ \text{C)}\)

Panas masuk pada alur 14: \(Q_m = \sum N_j \left( \int_{298,15}^{BP} \text{Cp}_{BP} \text{dT} + (\Delta Hv) + \int_{BP}^{333,415} \text{Cp}_{BP} \text{dT} \right)\)
Tabel LB.26 Panas masuk Heater (E-105)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kmol)</th>
<th>ΔHvl</th>
<th>$\int_{298.15}^{BP} Cp_{(l)}dT$</th>
<th>$\int_{BP}^{333.415} Cp_{(g)}dT$</th>
<th>Q in (kJ/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>16.9467</td>
<td>7409.7918</td>
<td> </td>
<td> </td>
<td>125571.5194</td>
</tr>
<tr>
<td>IPB</td>
<td>3.4316</td>
<td>7743.1118</td>
<td> </td>
<td> </td>
<td>26571.2625</td>
</tr>
<tr>
<td>DIPB</td>
<td>0.1776</td>
<td>7910.5396</td>
<td> </td>
<td> </td>
<td>1404.9118</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td> </td>
<td>153547.6938</td>
<td></td>
</tr>
</tbody>
</table>

Panas keluar pada suhu 386,73 K (113,58 °C)

Panas keluar pada alur 15: $Q_{out} = \sum N \left( \int_{298.15}^{BP} Cp_{(l)}dT + (\Delta Hvl) + \int_{BP}^{73.386} Cp_{(g)}dT \right)$

Tabel LB.27. Panas Keluar Heater (E-105)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kmol)</th>
<th>ΔHvl</th>
<th>$\int_{298.15}^{BP} Cp_{(l)}dT$</th>
<th>$\int_{BP}^{386.73} Cp_{(g)}dT$</th>
<th>Q out (kJ/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>17.6245</td>
<td>18773.1</td>
<td>7409.7918</td>
<td>3454.4605</td>
<td>502255.3187</td>
</tr>
<tr>
<td>IPB</td>
<td>3.5689</td>
<td>20581.9442</td>
<td> </td>
<td> </td>
<td>70628.9996</td>
</tr>
<tr>
<td>DIPB</td>
<td>0.1847</td>
<td>20922.0711</td>
<td> </td>
<td> </td>
<td>3715.7598</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>576600.0782</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Neraca Energi Total Sistem:

$$\frac{dQ}{dt} = Q_{Out} - Q_{In}$$

$$= [576600.0782 - 153547.6938] \text{kJ/jam}$$

$$= 423052.3843 \text{kJ/jam}$$

Media pemanas yang dipakai superheated steam pada 360 °C, kemudian keluar pada 150 °C (1 atm).

$$\frac{dQ}{dt} = m \cdot Cp \cdot \Delta T$$

Steam yang diperlukan adalah :

$$q_{heater} = \frac{\Delta H (360^0 C_{\text{Saturated Steam}} - 150^0 C_{\text{Kondenser}})}{\text{}}$$
$\frac{423052,3843 \text{ kJ/jam}}{423052,3843 \text{ kJ/jam}} = \frac{423052,3843 \text{ kJ/jam}}{419,5768 \text{ kJ/kg}}$

$= 1008,2834 \text{ kg/jam}$

**B.11 Menara destilasi 01 (MD-101)**

Fungsi : Untuk memisahkan Benzen dan Diisopropilbenzen sekaligus memekatkan Isopropilbenzen.

Menentukan suhu umpan masuk :

Umpan yang masuk ke kolom destilasi merupakan cairan jenuh, Untuk menentukan suhu umpan, maka dilakukan perhitungan bubble point dengan cara trial suhu umpan hingga syarat $\sum Y_i/K_i = 1$ terpenuhi,

P = 1 atm
K = $P_i/P$

Trial : $T = 386,73 \text{ K} \ (113,58 \ ^\circ\text{C})$

Tabel LB. 28 Penentuan Bubble poin umpan masuk Menara Destilasi (MD-101).

<table>
<thead>
<tr>
<th>Komp.</th>
<th>T</th>
<th>$P_{uap}$</th>
<th>$P_{uap}$ (atm)</th>
<th>$y_i$</th>
<th>K</th>
<th>$y_i/K$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>386.73</td>
<td>255.2738</td>
<td>2.5195</td>
<td>0.8244</td>
<td>2.5195</td>
<td>0.3272</td>
</tr>
<tr>
<td>IPB</td>
<td>386.73</td>
<td>26.6976</td>
<td>0.2635</td>
<td>0.1669</td>
<td>0.2635</td>
<td>0.6335</td>
</tr>
<tr>
<td>DIPB</td>
<td>386.73</td>
<td>22.2490</td>
<td>0.2195</td>
<td>0.0086</td>
<td>0.2195</td>
<td>0.0393</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.00008</td>
<td></td>
</tr>
</tbody>
</table>

Suhu pada umpan masuk destilasi adalah : $386,73 \text{ K} \ (113,58 \ ^\circ\text{C})$

**B.12 Condensor Subcooler (E-107)**

Fungsi : Mendinginkan dan mengkondensasi destilat untuk di umpankan kembali ke reaktor.

Air Pendingin (25 °C)

P = 1 atm

Benzena (g)  

T= 113,58 °C

P= 1 atm

Benzena (l)

IPB (g)

T= 81,87 °C

P= 1 atm

IPB (l)

Air pendingin bekas (70 °C)

P = 1 atm
Perhitungan suhu operasi kondensor:

Untuk menentukan suhu operasi (suhu keluaran) pada kondensor, dilakukan perhitungan *dew point* untuk komponen benzene dan IPB.

\[ \sum xi.K = 1 \text{ terpenuhi,} \]

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

\[ K = \frac{P_i}{P} \]

Trial : \( T = 355,02 \text{ K (81,87 °C)} \)

**Tabel LB 29. Penentuan suhu operasi Condensor Subcooler (E-107)**

<table>
<thead>
<tr>
<th>Komp.</th>
<th>T</th>
<th>P uap (atm)</th>
<th>xi</th>
<th>K</th>
<th>xi.K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>355.02</td>
<td>105.8581</td>
<td>0.9535</td>
<td>1.0448</td>
<td>0.9963</td>
</tr>
<tr>
<td>IPB</td>
<td>355.02</td>
<td>8.2468</td>
<td>0.0813</td>
<td>0.0813</td>
<td>0.0037</td>
</tr>
</tbody>
</table>

Total: 1.0000

Dari hasil perhitungan dew point untuk Benzene dan IPB didapat temperature 355,02 K adalah titik embun pertama sekali kedua komponen tersebut.

**Panas masuk pada suhu 386,73 K (113,58 °C)**

Panas masuk pada alur 17: \( Q_{out} = \sum N_i \left( \int_{BP}^{BP} \frac{dT}{CP_{(l)}} + (\Delta H_vl) + \int_{BP}^{BP} \frac{dT}{CP_{(g)}} \right) \)

**Tabel LB.30 Panas Masuk pada Condensor Subcooler (E-107)**

<table>
<thead>
<tr>
<th>Komponen</th>
<th>( N ) (kg/jam)</th>
<th>( \Delta H_vl )</th>
<th>( \int_{BP}^{BP} \frac{dT}{CP_{(l)}} )</th>
<th>( \int_{BP}^{BP} \frac{dT}{CP_{(g)}} )</th>
<th>( Q_{in} ) (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzen</td>
<td>19,451</td>
<td>18773.1</td>
<td>7409,7918</td>
<td>3454,4605</td>
<td>576627,2907</td>
</tr>
<tr>
<td>IPB</td>
<td>0.9482</td>
<td>20581,9442</td>
<td>20581,9442</td>
<td>19515,7995</td>
<td>19515,7995</td>
</tr>
</tbody>
</table>

Total: 596143,0901

**Panas keluar pada suhu 355,02 K (81,87 °C)**

Panas keluar pada alur 18: \( Q_{out} = \sum N_i \left( \int_{BP}^{BP} \frac{dT}{CP_{(l)}} + (\Delta H_vl) + \int_{BP}^{BP} \frac{dT}{CP_{(g)}} \right) \)
### Tabel LB.31 Panas Keluar Condensor Subcooler (E-107)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>(N) (kg/jam)</th>
<th>(\Delta H_{vl})</th>
<th>(\int_{298,15}^{BP} C_p(T),dT)</th>
<th>(\int_{BP}^{355.02} C_p(T),dT)</th>
<th>(Q_{out}) (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzen</td>
<td>19,451</td>
<td>7663,2452</td>
<td></td>
<td></td>
<td>149096,8645</td>
</tr>
<tr>
<td>IPB</td>
<td>0.9482</td>
<td>12785,0704</td>
<td></td>
<td></td>
<td>12122,8038</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>161219,6683</strong></td>
</tr>
</tbody>
</table>

#### Neraca Energi Total Sistem :

\[
\frac{dQ}{dt} = Q_{out} - Q_m
\]

\[
= [161219,6683 - 596143,0901] \text{kJ/jam}
\]

\[
= 434923,4218 \text{kJ/jam}
\]

**Air pendingin yang diperlukan adalah** :

\[
m = \left(\frac{q}{\Delta H(70^\circ C - 25^\circ C)}\right)
\]

\[
= \frac{434923,4218 \text{kJ/jam}}{(188,2144 \text{kJ/kg} - 0)}
\]

\[
= 2310,7869 \text{kg/jam}
\]

#### B.13 Reboiler (E-106)

**Fungsi** : Memanaskan kembali hasil bawah destilasi.
Perhitungan suhu operasi reboiler:
Untuk menentukan suhu operasi reboiler, dilakukan dengan perhitungan dew point hingga tercapai syarat \[ \sum \frac{Y_i}{K_i} = 1 \]

\[ P = 1 \text{ atm} \]
\[ K = \frac{P_i}{P} \]

Trial : \[ T = 432,43 \text{ K (159,28}^\circ\text{C)} \].

Tabel LB.32 Data perhitungan suhu operasi Reboiler (E-106)

<table>
<thead>
<tr>
<th>komponen</th>
<th>T</th>
<th>P uap</th>
<th>P uap (atm)</th>
<th>yi</th>
<th>K</th>
<th>yi/Ki</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>432.43</td>
<td>704.7599</td>
<td>6.9559</td>
<td>0.0100</td>
<td>6.9559</td>
<td>0.0014</td>
</tr>
<tr>
<td>IPB</td>
<td>432.43</td>
<td>101.5017</td>
<td>1.0018</td>
<td>0.9268</td>
<td>1.0018</td>
<td>0.9251</td>
</tr>
<tr>
<td>DipB</td>
<td>432.43</td>
<td>87.0759</td>
<td>0.8594</td>
<td>0.0631</td>
<td>0.8594</td>
<td>0.0736</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>1.0000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Maka suhu operasi reboiler adalah 432,43 K (159,28\(^{\circ}\)C).

**Panas masuk** \[ T = 386,73 \text{ K (113,58}^\circ\text{C)} \] dan tekanan 1 atm

Panas masuk pada alur 20: \[ Q_{in} = \sum N_i \left( \int_{298,15}^{BP} C_p(l) \,dT + \Delta Hvl + \int_{BP}^{386,73} C_p(g) \,dT \right) \]

Tabel LB.33 Panas masuk Reboiler (E-106)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kmol)</th>
<th>(\Delta Hvl)</th>
<th>(\int_{298,15}^{BP} C_p(l) ,dT)</th>
<th>(\int_{BP}^{386,73} C_p(g) ,dT)</th>
<th>(Q_{in}) (kJ/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0,162</td>
<td>18773,1</td>
<td>7409,7918</td>
<td>3454,4605</td>
<td>576627,2907</td>
</tr>
<tr>
<td>IPB</td>
<td>14,9763</td>
<td></td>
<td>20581,9442</td>
<td></td>
<td>19515,7995</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>596143,0901</td>
</tr>
</tbody>
</table>

Panas keluar \[ T = 432,43 \text{ K (159,28}^\circ\text{C)} \] dan tekanan 1 atm

Panas keluar pada alur 21: \[ Q_{out} = \sum N_i \left( \int_{298,15}^{BP} C_p(l) \,dT + \Delta Hvl + \int_{BP}^{432,4} C_p(g) \,dT \right) \]

Tabel LB.34 Panas keluar Reboiler (E-106)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kmol)</th>
<th>(\Delta Hvl)</th>
<th>(\int_{298,15}^{BP} C_p(l) ,dT)</th>
<th>(\int_{BP}^{432,4} C_p(g) ,dT)</th>
<th>(Q_{out}) (kJ/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Komponen</td>
<td>N (kmol)</td>
<td>ΔHvl</td>
<td>( \int_{BP} \left( C_p (l) \right) dT + \left( \int_{BP}^{432.4} \left( C_p (g) \right) dT \right)</td>
<td>Q out (kJ/jam)</td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>---------</td>
<td>------</td>
<td>-------------------------------------------------</td>
<td>----------------</td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
<td>0.0282</td>
<td>18773.1</td>
<td>7409.7918 + 8682.7003</td>
<td>983,2097</td>
<td></td>
</tr>
<tr>
<td>IPB</td>
<td>2.6071</td>
<td>38241.6</td>
<td>30763,5738 + 1468,3037</td>
<td>183731,4033</td>
<td></td>
</tr>
<tr>
<td>DIPB</td>
<td>0.1776</td>
<td>33057,5276</td>
<td>30763,5738 + 1468,3037</td>
<td>5871,0169</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>190585,6299</td>
<td></td>
</tr>
</tbody>
</table>

\[
Q = Q_{out} - Q_{in} = (190585,6299 + 904233,0504) - 334397,7795 = 760420,9008 \text{ kJ/jam}
\]

Steam yang diperlukan adalah:

\[
m = \frac{Q_{heater}}{\Delta H (360^oC \text{ Saturated Steam} - 150^oC \text{ Condensat})} = \frac{760420,9008 \text{ kJ/jam}}{(3195,8761 - 2777,2993)} = 1812,3518 \text{ kg/jam}
\]

Panas keluar \( T = 432,43 \text{ K (159,28 \text{oC})} \) dan tekanan 1 atm

Panas keluar pada alur 22: 

\[
Q_{out} = \sum N_i \left( \int_{BP}^{289.15} C_p (l) dT + \left( \int_{BP}^{432.4} C_p (g) dT \right) \right)
\]
B.14 Menara destilasi 02 (MD-102)

Fungsi: Untuk memekatkan Isopropilbenzen.

Menentukan suhu umpan masuk destilasi:
Umpan yang masuk ke kolom destilasi merupakan cairan jenuh. Untuk menentukan suhu umpan, maka dilakukan perhitungan bubble point dengan cara trial suhu umpan hingga syarat \[ \sum Y_i/K_i = 1 \] terpenuhi,

\[ P = 1 \text{ atm} \]
\[ K = P_i/P \]

Trial: \[ T = 432,43 \text{ K} \ (159,28 \, ^\circ \text{C}) \]

Tabel LB. 36 Penentuan Bubble poin umpan masuk Destilasi (MD-102)

<table>
<thead>
<tr>
<th>Komp.</th>
<th>T</th>
<th>( P_{\text{uap}} ) (atm)</th>
<th>yi</th>
<th>K</th>
<th>yi/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>432.43</td>
<td>704,7875</td>
<td>6,9562</td>
<td>0.0100</td>
<td>6,9562</td>
</tr>
<tr>
<td>IPB</td>
<td>432.43</td>
<td>101,5069</td>
<td>1,0018</td>
<td>0.9268</td>
<td>1,0018</td>
</tr>
<tr>
<td>DIPB</td>
<td>432.43</td>
<td>87,0805</td>
<td>0,8594</td>
<td>0.0631</td>
<td>0,8594</td>
</tr>
</tbody>
</table>

| Total | | | | | 1.0000 |

Suhu umpan masuk pada Menara Destilasi (MD-102) adalah: 432,43 K (159,28 \, ^\circ \text{C})

B.15 Condensor Subcooler (E-108)

Fungsi: Mendinginkan dan mengkondensasi destilat untuk di umpankan kembali ke reaktor.
**Perhitungan suhu operasi kondensor:**

Untuk menentukan suhu operasi (suhu keluaran) pada kondensor, dilakukan perhitungan *dew point* untuk komponen benzene dan IPB dan DIPB.

\[ \sum x_iK = 1 \text{ terpenuhi,} \]

P = 1 atm

K = \( \frac{P_i}{P} \)

Trial : \( T = 429,92 \) K (156,77 °C)

**Tabel LB.37 Penentuan suhu operasi Condensor Subcooler (E108)**

<table>
<thead>
<tr>
<th>Komp.</th>
<th>T</th>
<th>P uap (atm)</th>
<th>xi</th>
<th>K</th>
<th>xi.K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>429,92</td>
<td>670,7520</td>
<td>0,0107</td>
<td>6,6203</td>
<td>0,0710</td>
</tr>
<tr>
<td>IPB</td>
<td>429,92</td>
<td>95,1561</td>
<td>0,9391</td>
<td>0,9391</td>
<td>0,9284</td>
</tr>
<tr>
<td>DIPB</td>
<td>429,92</td>
<td>81,5060</td>
<td>0,8044</td>
<td>0,8044</td>
<td>0,0006</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>1.00001</td>
<td></td>
</tr>
</tbody>
</table>

Dari hasil perhitungan *dew point* untuk Benzene, IPB dan DIPB didapat temperature 429,92 K.

**Panas masuk pada suhu 432,43 K (159,28 °C)**

Panas masuk pada alur 24: 
\[ Q_{\text{in}} = \sum N_i \left( \int_{298,15}^{BP} C_{p(l)} \, dT + \int_{289,15}^{432,43} C_{p(g)} \, dT + \int_{BP}^{432,43} C_{p(g)} \, dT \right) \]

**Tabel LB.38 Panas Masuk pada Condensor Subcooler (E-108)**

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kg/jam)</th>
<th>( \Delta H_{vl} )</th>
<th>( \int_{298,15}^{BP} C_{p(l)} , dT )</th>
<th>( \int_{289,15}^{432,43} C_{p(g)} , dT )</th>
<th>( \int_{BP}^{432,43} C_{p(g)} , dT )</th>
<th>Q in (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0.0325</td>
<td>18773.1</td>
<td>7409,7918</td>
<td>8682,9415</td>
<td>1133,1396</td>
<td>211139,8250</td>
</tr>
<tr>
<td>IPB</td>
<td>2.996</td>
<td>38241.6</td>
<td>30763,5738</td>
<td>1468,7331</td>
<td></td>
<td>72,7278</td>
</tr>
<tr>
<td>DIPB</td>
<td>0.0022</td>
<td>33058,0787</td>
<td></td>
<td></td>
<td></td>
<td>211212,5528</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Panas keluar pada suhu 429,92 K (156,77 °C)
Panas keluar pada alur 25 : \( Q_{\text{out}} = \sum N \left( \int_{298.15}^{\text{BP}} \left(Cp_{(l)} \text{dT} + (\Delta H_{\text{vl}}) + \int_{\text{BP}}^{429.92} \left(Cp_{(g)} \text{dT} \right) \right) \right) \)

Tabel LB.39 Panas Keluar Condensor Subcooler (E-108)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>( N ) (kg/jam)</th>
<th>( \Delta H_{\text{vl}} )</th>
<th>( \int_{298.15}^{\text{BP}} \left(Cp_{(l)} \text{dT} \right) )</th>
<th>( \int_{\text{BP}}^{429.92} \left(Cp_{(g)} \text{dT} \right) )</th>
<th>( Q_{\text{out}} ) (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0.0325</td>
<td>18773.1</td>
<td>7409,7918</td>
<td>8381,1768</td>
<td>1123,,3322</td>
</tr>
<tr>
<td>IPB</td>
<td>2.996</td>
<td>31956,4539</td>
<td></td>
<td></td>
<td>95741,5358</td>
</tr>
<tr>
<td>DIPB</td>
<td>0.0022</td>
<td>32368,2288</td>
<td></td>
<td></td>
<td>71,2101</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>95812,7459</strong></td>
</tr>
</tbody>
</table>

**Neraca Energi Total Sistem :**

\[ \frac{dQ}{dt} = Q_{\text{out}} - Q_{\text{in}} \]

\[ = [95812,7459 - 211212,5528] \text{kJ/jam} \]

\[ = 115399,8068 \text{kJ/jam} \]

Air pendingin yang diperlukan adalah :

\[ m = \left( \frac{q}{\Delta H(70^\circ \text{C} - 25^\circ \text{C})} \right) \]

\[ = \frac{115399,8068 \text{kJ/jam}}{(188,2144 \text{kJ/kg} - 0)} \]

\[ = 613,1294 \text{kg/jam} \]

**B.16 Reboiler (E-110)**

Fungsi : Memanaskan kembali hasil bawah destilasi.
**Perhitungan suhu operasi reboiler:**

Untuk menentukan suhu operasi reboiler, dilakukan dengan perhitungan *dew point* hingga tercapai syarat \( \sum Y_i/K_i = 1 \)

\[ P = 1 \, \text{atm} \]
\[ K = P_i/P \]

**Trial:** \( T = 438.25 \, \text{K} \) (165,102 °C)

Tabel LB.38 Data perhitungan suhu operasi *reboiler*

Maka suhu operasi reboiler adalah 438,25 K (165,102 °C).

Tabel LB.40 Data perhitungan suhu operasi *Reboiler* (E110)

<table>
<thead>
<tr>
<th>Komp.</th>
<th>T</th>
<th>( P , \text{uap} ) (atm)</th>
<th>( P , \text{uap} ) (atm)</th>
<th>( Y_i )</th>
<th>K</th>
<th>( Y_i/K_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPB</td>
<td>438.25</td>
<td>117.5065</td>
<td>1.1597</td>
<td>0.0107</td>
<td>1.1597</td>
<td>0.0092468</td>
</tr>
<tr>
<td>DIPB</td>
<td>438.25</td>
<td>101.1659</td>
<td>0.9985</td>
<td>0.9892</td>
<td>0.9985</td>
<td>0.9907542</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1.0000009</strong></td>
</tr>
</tbody>
</table>

Panas masuk \( T = 432.43 \, \text{K} \) (159,28 °C) dan tekanan 1 atm

**Tabel LB.41 Panas masuk Reboiler (E-110)**

<table>
<thead>
<tr>
<th>Komponen</th>
<th>( N ) (kmol)</th>
<th>( \Delta Hvl )</th>
<th>( \int_{298,15}^{BP} C_P(\text{l}) , dT )</th>
<th>( \int_{298,15}^{BP} C_P(\text{g}) , dT )</th>
<th>( Q, \text{in} ) (kJ/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPB</td>
<td>0.026</td>
<td>38241.6</td>
<td>30763,5738</td>
<td>1468,7331</td>
<td>1832,3216</td>
</tr>
<tr>
<td>DIPB</td>
<td>2.3984</td>
<td>33058,0787</td>
<td></td>
<td></td>
<td>79286,4958</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>81118,8174</strong></td>
</tr>
</tbody>
</table>

Panas keluar \( T = 438.25 \, \text{K} \) (165,10 °C) dan tekanan 1 atm

**Tabel LB.42 Panas keluar Reboiler (E110)**

<table>
<thead>
<tr>
<th>Komponen</th>
<th>( N ) (kmol)</th>
<th>( \Delta Hvl )</th>
<th>( \int_{298,15}^{BP} C_P(\text{l}) , dT )</th>
<th>( \int_{298,15}^{BP} C_P(\text{g}) , dT )</th>
<th>( Q, \text{out} ) (kJ/jam)</th>
</tr>
</thead>
</table>

Universitas Sumatera Utara
Panas keluar $T = 438.25 \, K \, (165,10 \, ^\circ C)$ dan tekanan 1 atm

Panas keluar pada alur 31: $Q_{out} = \sum N_i \left( \int_{BP}^{BP} \frac{dT}{C_p(l)} + (\Delta H_{vl}) + \int_{BP}^{BP} \frac{438.25}{C_p(g)} \frac{dT}{BP} \right)$

<table>
<thead>
<tr>
<th>Komponen</th>
<th>$N$ (kmol)</th>
<th>$\Delta H_{vl}$</th>
<th>$\int_{BP}^{BP} \frac{C_p(l)}{298,15} \frac{dT}{BP}$</th>
<th>$\int_{BP}^{BP} \frac{C_p(g)}{BP} \frac{dT}{BP}$</th>
<th>$Q_{out}$ (kJ/jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPB</td>
<td>0.0018</td>
<td>38241.6</td>
<td>30763,5738</td>
<td>2723,7950</td>
<td>129,1121</td>
</tr>
<tr>
<td>DIPB</td>
<td>0.1757</td>
<td>34667,3820</td>
<td></td>
<td></td>
<td>6091,0590</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6220,1712</td>
</tr>
</tbody>
</table>

$Q = Q_{out} - Q_{in}$

$= (6220,1712 + 78787,3248) - 81118,8174$

$= 3888,6785 \, kJ/jam$

Steam yang diperlukan adalah:

$$m = \frac{m}{\Delta H (360^\circ C_{\text{Saturated Steam}} - 150^\circ C_{\text{Kondensat}})}$$

$$m = \frac{3888,6785 \, \text{kJ/jam}}{3195,8761 - 2776,2993} \approx \frac{3888,6785 \, \text{kJ/jam}}{419,5768 \, \text{kJ/kg}}$$

$m = 9,2680 \, \text{kg/jam}$
B.17 Cooler (E-109)

Fungsi : Menurunkan temperatur hasil keluaran atas destilasi MD-102

Air pendingin (25 °C)

P = 1 atm

Benzena (l)  
IPB (l)  
DIPB (l)

T= 156.77 °C

T= 30 °C

Benzena (l)  
IPB (l)  
DIPB (l)

Air pendingin bekas (70 °C)

P = 1 atm

Panas masuk pada suhu 429,92 K (156,77 °C)

\[ \text{Q in} = \sum N \left( \int_{BP}^{298.15} CP_{(l)} dT + (\Delta Hvl) + \int_{BP}^{429.92} CP_{(g)} dT \right) \]

Tabel LB.44 Panas Masuk Cooler (E-109)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kg/jam)</th>
<th>( \Delta Hvl )</th>
<th>( \int_{298.15}^{BP} CP_{(l)} dT )</th>
<th>( \int_{BP}^{429.92} CP_{(g)} dT )</th>
<th>Q in (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0.0282</td>
<td>18773.1</td>
<td>7409.7918</td>
<td>8381,1768</td>
<td>974,7067</td>
</tr>
<tr>
<td>IPB</td>
<td>2.6053</td>
<td>31956,4539</td>
<td>83256,1493</td>
<td>61,4996</td>
<td></td>
</tr>
<tr>
<td>DIPB</td>
<td>0.0019</td>
<td>32368,2288</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total 84292,3556</td>
</tr>
</tbody>
</table>

Panas keluar pada suhu 303,15 K (30 °C)

\[ \text{Q out} = \sum N \left( \int_{298.15}^{BP} CP_{(l)} dT + (\Delta Hvl) + \int_{BP}^{303.15} CP_{(g)} dT \right) \]
Tabel LB.45 Panas Keluar Cooler (E-109)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kg/jam)</th>
<th>∆Hvl</th>
<th>$\int C_p(i) , dT_{298,15}$</th>
<th>$\int C_p(p) , dT_{303,15}$</th>
<th>Q out (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0.0282</td>
<td>634.9425</td>
<td></td>
<td></td>
<td>17,9054</td>
</tr>
<tr>
<td>IPB</td>
<td>2.6053</td>
<td>1060.0692</td>
<td></td>
<td></td>
<td>2761.7984</td>
</tr>
<tr>
<td>DIPB</td>
<td>0.0019</td>
<td>1086.5219</td>
<td></td>
<td></td>
<td>2,0644</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>****</td>
<td>****</td>
<td>****</td>
<td>****</td>
<td><strong>2781.7682</strong></td>
</tr>
</tbody>
</table>

**Neraca Energi Total Sistem:**

$$\frac{dQ}{dt} = Q_{out} - Q_{in}$$

$$= [2781.7682 - 84292.3556] \text{ kJ/jam}$$

$$= 81510.5875 \text{ kJ/jam}$$

Air pendingin yang diperlukan adalah:

$$m = \left( \frac{q}{\Delta H(70^\circ C - 25^\circ C)} \right)$$

$$= \frac{81510.5875 \text{ kJ/jam}}{188.2144 \text{ kJ/kg}}$$

$$= 433.0730 \text{ kg/jam}$$

B.18 Cooler (E-111)

Fungsi : Menurunkan temperatur hasil keluaran bawah destilasi MD-102

Air pendingin (25 °C)

P = 1 atm

T = 165.10 °C

IPB (l) DIPB (l)

Air pendingin bekas (70 °C)

P = 1 atm

IPB (l) DIPB (l)
Panas masuk pada suhu 438,25 K (165,10 °C)

Panas masuk pada alur 31: \[ Q_{out} = \sum N \left( \int_{298,15}^{BP} \Delta H_{vl} \right) dT + \left( \int_{298,15}^{438,25} \Delta H_{vl} \right) dT \]

Tabel LB.46 Panas Masuk Cooler (E-111)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kg/jam)</th>
<th>( \Delta H_{vl} )</th>
<th>( \int_{298,15}^{BP} \Delta C_{p(l)} dT )</th>
<th>( \int_{298,15}^{438,25} \Delta C_{p(g)} dT )</th>
<th>Q in (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPB</td>
<td>0.0018</td>
<td>38241,6</td>
<td>30763,5738</td>
<td>2723,7950</td>
<td>129,1121</td>
</tr>
<tr>
<td>DIPB</td>
<td>0.1757</td>
<td>34667,3820</td>
<td></td>
<td></td>
<td>6091,0590</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>6220,1712</strong></td>
</tr>
</tbody>
</table>

Panas keluar pada suhu 303,15 K (30 °C)

Panas keluar pada alur 32: \[ Q_{out} = \sum N \left( \int_{298,15}^{BP} \Delta H_{vl} \right) dT + \left( \int_{298,15}^{303,15} \Delta H_{vl} \right) dT \]

Tabel LB.47 Panas Keluar Cooler (E-111)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>N (kg/jam)</th>
<th>( \Delta H_{vl} )</th>
<th>( \int_{298,15}^{BP} \Delta C_{p(l)} dT )</th>
<th>( \int_{298,15}^{303,15} \Delta C_{p(g)} dT )</th>
<th>Q out (kJ/Jam)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPB</td>
<td>0.0018</td>
<td>1060,0692</td>
<td></td>
<td></td>
<td>1,9081</td>
</tr>
<tr>
<td>DIPB</td>
<td>0.1757</td>
<td>1086,5219</td>
<td></td>
<td></td>
<td>190,9019</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>192,8100</strong></td>
</tr>
</tbody>
</table>

Neraca Energi Total Sistem:

\[ \frac{dQ}{dt} = Q_{out} - Q_{in} \]

\[ = [192,8100 - 6220,1712] \text{kJ/jam} \]

\[ = 6027,3611 \text{ kJ/jam} \]

Air pendingin yang diperlukan adalah:

\[ m = \left( \frac{q}{\Delta H (70°C - 25°C)} \right) \]

\[ = \frac{6027,3611 \text{kJ/jam}}{(188,2144 kJ / kg)} \]
= $\frac{6027,3611 \text{kJ/jam}}{188,2144 \text{kJ/kg}}$

= 32,0239 kg/jam
LC.1 Tangki Penyimpanan Propylene dan Propana (TT – 101)

Fungsi : Menyimpan gas propylene untuk kebutuhan 10 hari

Bahan konstruksi : \textit{Low alloy steel SA-353}

Bentuk : Silinder vertikal dengan alas dan tutup \textit{ellipsoidal}

Jenis sambungan : \textit{Single welded butt joints}

Jumlah : 1 unit

Kondisi operasi :

- Tekanan : 7.5 atm
- Temperatur : 30 °C = 303.15 K
- Laju alir massa : 147,1443 kg/jam

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Laju Alir kg/jam</th>
<th>Fraksi</th>
<th>Densitas Kg/m³</th>
<th>ρ Campuran</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>138,5645</td>
<td>0,9416</td>
<td>520</td>
<td>489,6794</td>
</tr>
<tr>
<td>Propana</td>
<td>8,5798</td>
<td>0,0584</td>
<td>585</td>
<td>34,1106</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>523,7900</td>
</tr>
</tbody>
</table>

(Sumber: Perry, 1999)

Kebutuhan perancangan = 10 hari

Faktor kelonggaran = 20%

Perhitungan:

a. Volume Tangki

\[
\text{Volume cairan, } V_1 = \frac{147,1443 \text{ kg/jam} \times 10 \text{ hari} \times 24 \text{ jam/hari}}{523,7900 \text{ kg/m}^3} = 67,4213 \text{ m}^3
\]

Direncanakan membuat 1 tangki dan faktor kelonggaran 20%, maka :

\[
\text{Volume 1 tangki, } V_1 = \frac{(0,2 \times 67,4213) + 67,4213 \text{ m}^3}{1} = 80,9056 \text{ m}^3
\]
b. Diameter dan Tinggi Shell

Direncanakan:

- Tinggi silinder (Hs) : Diameter (D) = 4 : 3
- Tinggi tutup (Hd) : 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 (Vh) :
  
  \[ V_h = \frac{2\pi}{3} R^2 H_d = \frac{\pi}{6} D^2 \left( \frac{1}{4} D \right) = \frac{\pi}{24} D^3 \]  
  
  (Brownell & Young, 1959)

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

  80,9056 m³ = 1,1775 D³

  D = 4,0958 m = 161,2518 inc

  Hs = \frac{4}{3} D = 5,4610 m

c. Diameter dan tinggi tutup

Diameter tutup = Diameter tangki = 4,0958 m

Tinggi tutup (Hd) = \frac{1}{4} D = 1,0239 m

Tinggi tangki = Hs + Hd = (5,4610 + 1,0239×2) m = 7,5089 m

d. Tebal shell tangki

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

- Allowable stress (S) = 22500 psia
- Joint efficiency (E) = 0,8
- Corrosion allowance (C) = 0,25 mm/tahun  
  
  (Peters dkk, 2004)
- Umur tangki (n) = 10 tahun

Volume cairan = 67,4213 m³

Tinggi cairan dalam tangki = \( \frac{67,4213 \text{ m}^3}{80,9056 \text{ m}^3} \times 5,4610 \text{ m} = 4,5508 \text{ m} \)

Tekanan Hidrostatik:
\[
P_{\text{Hidrostatik}} = \rho \times g \times h
\]
\[
= 523,7900 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 4,5508 \text{ m} = 0,2305 \text{ atm}
\]

Tekanan operasi (\( P_o \)) = 7,5 atm

\( P = 7,5 \text{ atm} + 0,2305 \text{ atm} = 7,7305 \text{ atm} \)

\( P_{\text{design}} = (1,2) \times (7,7305) = 9,2766 \text{ atm} = 136,3288 \text{ psi} \)

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

\[
t = \frac{PR}{SE - 0,6P} = \left( \frac{136,3288 (80,6259 \text{ in})}{22500 \text{ psia}(0,8) - 0,6(136,3288 \text{ psi})} \right)
\]
\[
= 0,6134 \text{ in}
\]

Faktor korosi = 0,0098 in/tahun

Maka tebal shell yang dibutuhkan dengan perkiraan umur alat adalah 10 tahun
\[
= 0,6134 + (10 \times 0,0098)
\]
\[
= 0,7116 \text{ in}
\]

Tebal shell standar yang digunakan = 1 in
(Brownell & Young, 1959)
e. Tebal tutup tangki
   Tutup atas tangki terbuat dari bahan yang sama dengan shell.
   Tebal tutup atas yang digunakan = 1 in
Untuk menjaga temperatur penyimpanan digunakan insulasi jenis fine powder (Walas dkk, 2005).

**LC.2 Heater (HE – 103)**

Fungsi : Menaikkan suhu umpan propilen sebelum dicampur dengan umpan benzen

Jenis : *Double Pipe Exchanger*

Dipakai : 20-ft hairpins of 2 x 1\(\frac{1}{4}\) in IPS pipe

- Fluida panas
  - Laju alir fluida panas = 169,1757 kg/jam = 372,9707 lbm/jam
  - Temperatur awal (T₁) = 360°C = 680 °F
  - Temperatur akhir (T₂) = 150 °C = 302 °F

- Fluida dingin
  - Laju alir fluida dingin = 147,1443 kg/jam = 324,3993 lbm/jam
  - Temperatur awal (t₁) = 30°C = 86 °F
  - Temperatur akhir (t₂) = 265,86 °C = 510,548 °F

\[
\text{Panas yang diserap (Q)} = 70982,2329 \text{ kJ/jam} = 67277,9112 \text{ Btu/jam}
\]

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

<table>
<thead>
<tr>
<th>Fluida Panas</th>
<th>Fluida Dingin</th>
<th>Selisih</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁ = 680 °F</td>
<td>Temperatur yang lebih tinggi</td>
<td>t₂ = 510,548 °F</td>
</tr>
<tr>
<td>T₂ = 302 °F</td>
<td>Temperatur yang lebih rendah</td>
<td>t₁ = 86 °F</td>
</tr>
<tr>
<td>T₁ – T₂ = 378 °F</td>
<td>Selisih</td>
<td>t₂ – t₁ = 424,548 °F</td>
</tr>
</tbody>
</table>
LMTD = \frac{\Delta t_2 - \Delta t_1}{\ln \left( \frac{\Delta t_2}{\Delta t_1} \right)} = \frac{46,548}{\ln \left( \frac{216}{169,452} \right)} = 191,7855 \, ^\circ F

R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{378}{424,548} = 0,8903

S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{424,548}{680 - 86} = 0,7147

Dari Gambar 19, Kern, 1965 diperoleh \( F_T = 0,81 \)
Maka \( \Delta t = F_T \times LMTD = 0,83 \times 191,7855 = 155,3462 \, ^\circ F \)

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

\[ T_c = \frac{T_1 + T_2}{2} = \frac{680 + 302}{2} = 491 \, ^\circ F \]

\[ t_c = \frac{t_1 + t_2}{2} = \frac{86 + 510,548}{2} = 298,274 \, ^\circ F \]

Dalam perancangan ini digunakan Double Pipe Exchanger dengan spesifikasi:
- Diameter luar \textit{inner pipe} (OD) = 1,66 in = 0,13833 ft
- Diameter dalam \textit{anulus} (ID2) = 2,067 in = 0,17225 ft
- Diameter dalam \textit{inner pipe} (ID1) = 1,38 in = 0,115 ft

Dari tabel 6.2 (Kern, 1965), pada jenis ini Flow Area pada \textit{inner pipe} lebih besar dari pada \textit{anulus}, maka laju alir yang paling besar mengalir di \textit{inner pipe}

\textbf{Fluida panas : steam, inner pipe}

(3) Flow area tube, \( a_t = 0,182 \, \text{in}^2 \)

\[ a_t = \pi \times D^2 / 4 \]  
(Pers. (6.3), Kern, 1965)

\[ a_t = 3,14 \times 0,115^2 / 4 = 0,01038 \, \text{ft}^2 \]

(4) Kecepatan massa:

\[ G_i = \frac{w}{a_i} \]  
(Pers. (7.2), Kern, 1965)
(5) Bilangan Reynold:

Pada $T_c = 491 \, ^\circ F$

$\mu = 0,0116 \, cP = 0,0281 \, \text{lbm/ft}^2\cdot\text{jam}$

ID = 1,38 in = 0,115 ft

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

$Re_t = \frac{0,115 \times 35926,0384}{0,0281} = 147174,9223$

(6) Taksir $jH$ dari Gambar 24 Kern (1965), diperoleh $jH = 320$ pada $Re_t = 147174,9223$

(7) Pada $T_c = 491 \, ^\circ F$

$c = 0,92 \, \text{Btu/lbm.}^{-\circ F}$  

$k = 0,0188 \, \text{Btu/jam lbm ft.}^{-\circ F}$

$$\left(\frac{c \mu}{k}\right)^\frac{1}{\gamma} = \left(\frac{0,92 \times 0,0281}{0,0188}\right)^\frac{1}{\gamma} = 1,29409$$

(8) $h_i = jH \times \frac{k}{ID} \times \left(\frac{c \mu}{k}\right)^\frac{1}{\gamma}$

$$h_i = 320 \times \frac{0,0188}{0,115} \times 1,29409 = 67,6979$$

$$h_{io} = \frac{h_i}{\phi_i} \times \frac{ID}{OD}$$

$$h_{io} = 67,6979 \times \frac{1,38}{1,66} = 56,2790$$

Fluida dingin: gas, anulus

(3') Flow area anulus

$$a_s = \pi \times \frac{ID^2 - OD^2}{4}$$

(Pers. (7.1), Kern, 1965)
\[ \alpha_s = 3,14 \times (0,17225^2 - 0,13833^2) / 4 = 0,00826 \text{ft}^2 \]

(4’’) Kecepatan massa

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

\[ G_s = \frac{147,1443}{0,00826} = 39230,0629 \text{lbm/jam.ft}^2 \]

(5’’) Bilangan Reynold

Pada \( t_c = 298,274 \degree F \)

\( \mu = 0,0183 \text{ cP} = 0,0442 \text{ lbm/ft}^2 \cdot \text{jam} \)

\[ D_e = \pi \times \frac{ID^2 - OD^2}{OD^2} = 0,0761 \]

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

\[ \text{Re}_s = \frac{0,0761 \times 39230,0629}{0,0442} = 67455,4459 \]

(6’’) Taksir \( J_H \) dari Gambar 24, Kern, diperoleh \( J_H = 185 \) pada \( \text{Re}_s = 67455,4459 \)

(7’’) Pada \( t_c = 298,274 \degree F \)

\( c = 0,191 \text{ Btu/lbm.} \degree F \)

\( k = 0,03 \text{ Btu/jam lbm ft.} \degree F \)

\[ \left( \frac{c \mu}{k} \right)^{1/3} = \left( \frac{0,191 \times 0,0442}{0,03} \right)^{1/3} = 0,6557 \]

(8’’) \( \dot{h}_u = J_H \times \frac{k}{D_e} \times \left( \frac{c \mu}{k} \right)^{1/3} \)

\[ \dot{h}_u = 185 \times \frac{0,03}{0,0761} \times 0,6557 = 47,7919 \]
(9’) Clean Overall Coefficient, \( U_C \)

\[
U_C = \frac{h_w \times h_a}{h_w + h_a} = \frac{56,2790 \times 47,7919}{56,2790 + 47,7919} = 25,8447 \text{ Btu/jam.ft}^2.\circ\text{F}
\]

(Pers. (6.38), Kern, 1965)

(10’) Rd teori = 0,002

\[
\frac{1}{U_d} = \left( \frac{1}{U_C} \right) + Rd
\]

\[
\frac{1}{U_d} = \left( \frac{1}{25,8447} \right) + 0,002
\]

\[
\frac{1}{U_d} = 0,04069
\]

\[
U_d = 24,5744 \text{ Btu/hr.ft}^2.\circ\text{F}
\]

(11) Faktor pengotor, \( R_d \)

\[
R_d = \frac{U_C - U_d}{U_C \times U_d} = \frac{25,8447 - 24,5744}{25,8447 \times 24,5744} = 0,002
\]

(Pers. (6.13), Kern, 1965)

\( R_d \) hitung \( \geq \) \( R_d \) ketentuan (0,002), maka spesifikasi dapat diterima.

(11) Required Surface, \( A \)

\[
A = \frac{Q}{U_d \times \text{LMTD}}
\]

\( A = 15,0608 \text{ ft}^2 \)

Required Length = \( \frac{A}{0,435} \) = 34,6226 lin ft

\[
\frac{34,6226}{40} = 0,8655 \text{ dibulatkan menjadi } 1
\]

Jadi jumlah hairpin = 1 \times 20 = 20 hairpin

**Pressure drop**

**Fluida dingin : gas, anulus**

(1) \( D_e = 0,0339 \)

Untuk \( \text{Re}_a = 47397,8686 \)

\( f = 0,0063 \text{ ft}^2/\text{in}^2 \)

\( s = 0,69 \)

(Gambar 26, Kern, 1965)
\[ \rho = 43,125 \]

\[ \Delta F_a = \frac{f \times G_a^2 \times L}{2 \times g \times \rho^2 \times D_e} \]  
(Pers. (7.53), Kern, 1965)

\[ \Delta F_a = 0,0892 \text{ ft} \]

\[ V = \frac{G_s}{3600 \times \rho} = 0,2526 \]

\[ F_1 = \frac{3 \times V^2}{2 \times g} = 0,00297 \text{ ft} \]

\[ \Delta P_a = \frac{(\Delta F_a + F_1) \times \rho}{144} = 0,0276 \text{ psi} \]

Yang diperbolehkan = 10 psi

**Fluida panas : steam, inner pipe**

(1') Untuk \( \text{Re}_p = 147174,9223 \)

\[ f = 0,0053 \text{ ft}^2/\text{in}^2 \]  
(Gambar 29, Kern, 1965)

\[ s = 1 \]

\[ \rho = 62,5 \]

(2') \[ \Delta F_p = \frac{f \times G_a^2 \times L}{2 \times g \times \rho^2 \times D} = 0,8714 \text{ ft} \]

(3') \[ \Delta P_p = \frac{(\Delta F_p \times \rho}{144} = 0,37825 \text{ psi} \]

Yang diperbolehkan = 10 psi

**I.C.3 Compresor (JC-101)**

Fungsi : Menaikkan sekaligus mengalirkan umpan propilen

Jenis : *Multistage reciprocating compressor*
Jumlah : 1 unit
Kondisi Operasi :
- Tekanan Masuk : 7,5 atm = 15870,927 lbf/ft²
- Tekanan Keluar : 18 atm = 38090,226 lbf/ft²

Tabel LC.2 Data pada alur 3

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Laju Alir kg/jam</th>
<th>Fraksi</th>
<th>Densitas Kg/m³</th>
<th>ρ Campuran</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>138,5645</td>
<td>0,941</td>
<td>520</td>
<td>489,6794</td>
</tr>
<tr>
<td>Propana</td>
<td>8,5798</td>
<td>0,059</td>
<td>585</td>
<td>34,1106</td>
</tr>
<tr>
<td>Total</td>
<td>523,39</td>
<td>1</td>
<td>32,35 (lbm/ft³)</td>
<td></td>
</tr>
</tbody>
</table>

\[ H_p = \frac{3,13 \times 10^5 \cdot \frac{1}{(1-\eta)}}{ (\frac{\eta}{\kappa})^{\frac{2}{(k-1)}}} \cdot P_1 \cdot Q_{fm} \left[ \left( \frac{\rho}{\rho_c} \right)^{\frac{k-1}{k}} - 1 \right] \]  

(Timmerhaus, 1991)
dimana:
\[ Q_{fm} = \frac{F}{\rho} = \frac{147,1443}{523,3909} = 0,2811 \text{ m}^3/\text{jam} = 0,1673 \text{ ft}^3/\text{menit} = 0,00278 \text{ ft}^3/\text{s} \]
\[ k = \text{rasio panas spesifik} = 1,4 \]
\[ \eta = \text{efisiensi kompresor} = 80 \% \]
\[ H_p = \frac{3,13 \times 10^5 \cdot \frac{1}{(1-0,8)}}{ (\frac{0,8}{1,4})^{\frac{2}{(1,4-1)}}} \cdot 15870,92 \cdot 0,1673 \left[ \left( \frac{38090,2}{15870,9} \right)^{\frac{1,4-1}{1,4}} - 1 \right] \]
\[ = 0,08 \text{ HP} \]
Jika efisiensi motor adalah 80 \%, maka :
\[ \text{Daya actual, } P = \frac{0,08}{0,80} = 0,1 \text{ HP} \]

Diameter pipa ekonomis (De) dihitung dengan persamaan :
\[ De = 3,9(Q)^{0,45} \left( \frac{\eta}{\rho} \right)^{0,13} \]  

(Timmerhaus, 1991)
\[ = 3,9 \left( 0,00278\text{ft}^3/\text{s} \right)^{0,45} \left( 32,3508 \text{ lbm/ft}^3 \right)^{0,13} \]
\[ = 0,43 \text{ in} \]

Dari Appendiks A.5 Geankoplis, 2003, dipilih pipa commercial steel :

Ukuran nominal : 0,5 in
Schedule number : 40
Diameter Dalam (ID) : 0,622 in = 15,80 mm
Diameter Luar (OD) : 0,840 in = 21,34 mm
Inside sectional area : 0,00211 ft²

LC.4 Tangki Penyimpanan Benzene (TT – 102)
Fungsi : Menyimpan benzene murni untuk kebutuhan 10 hari
Bahan konstruksi : Low alloy steel SA-285
Bentuk : Silinder vertikal dengan alas datar dan tutup ellipsoidal
Jenis sambungan : Single welded butt joints
Jumlah : 1 unit

Kondisi operasi :
Tekanan = 1 atm
Temperatur = 30 °C = 303,15 K
Laju Alir Massa = 219,7177 kg/jam
Kebutuhan perancangan = 10 hari
Faktor kelonggaran = 20%

Tabel LC.3 Data pada Alur 2

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Laju Alir</th>
<th>Fraksi</th>
<th>Densitas Kg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>219,7177</td>
<td>1</td>
<td>873,8</td>
</tr>
</tbody>
</table>

(Sumber: Perry, 1999)

Perhitungan:
a. Volume Tangki

Volume larutan, \( V_l = \frac{219,7177 \text{ kg/jam} \times 10 \text{ hari} \times 24 \text{ jam/hari}}{873,8 \text{ kg/m}^3} = 60,3481 \text{ m}^3 \)

Direncanakan membuat 1 tangki dan faktor kelonggaran 20%, maka :

Volume 1 tangki, \( V_1 = \frac{1,2 \times 60,3481 \text{ m}^3}{1} = 72,4178 \text{ m}^3 \)
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 & Young, 1959)

   - Volume tangki (V) :
   \[ V_t = V_s + V_h \]

   \[ \frac{3}{8} \pi D^3 = 72,4178 \text{ m}^3 = 1,1781 \text{ D}^3 \]

   \[ D = 3,9472 \text{ m} = 155,4033 \text{ in} \]

   \[ H_s = \frac{4}{3} D = 5,2630 \text{ m} \]

c. Diameter dan tinggi tutup

   Diameter tutup = Diameter tangki = 3,9472 m

   Tinggi tutup (H_d) = \frac{1}{4} D = 0,9868 m

   Tinggi tangki = H_s + H_d = (5,2630 + 0,9868) m = 6,2498 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) = 0,8
   - Corrosion allowance (C) = 0,25 mm/tahun (Peters dkk, 2004)
      = 0,0098 in/tahun
   - Umur tangki (n) = 10 tahun
Volume cairan = 60,3481 m³

Tinggi cairan dalam tangki = \( \frac{60,3481 \text{ m}^3}{72,4178 \text{ m}^3} \times 5,263 \text{ m} = 4,3858 \text{ m} \)

Tekanan Hidrostatik:

\[
P_{\text{hidrostatik}} = \rho \times g \times l
\]
\[
= 873,8 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 4,3858 \text{ m} = 0,37 \text{ atm}
\]

\[P_0 = 1 \text{ atm}\]

\[P = 1 \text{ atm} + 0,37 \text{ atm} = 1,37 \text{ atm}\]

\[P_{\text{design}} = 1,2 \times 1,37 = 1,64 \text{ atm} = 24,17 \text{ psi}\]

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

\[
t = \frac{24,17 \text{ psi} \times 77,701 \text{ in}}{13,750 \text{ psia} \times (0,8) - 0,6(24,17 \text{ psi})}
\]

\[= 0,1709 \text{ in}\]

Faktor korosi = 0,0098 in/tahun

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

\[= 0,1709 + (10 \times 0,0098) = 0,269 \text{ in}\]

Tebal shell standar yang digunakan = 0,5 in (Brownell & Young, 1959)

e. Tebal tutup tangki

Tutup atas tangki terbuat dari bahan yang sama dengan shell.

Tebal tutup atas yang digunakan = 0,5 in
LC.5 Pompa Benzena (P-01)

Fungsi : Memompa benzene dari tangki bahan baku (TT-102)
Jenis : Pompa sentrifugal
Jumlah : 1 unit

Kondisi operasi :
Tekanan = 1 atm
Temperatur = 30 °C
Laju alir massa (F) = 219,718 kg/jam = 0,1345 lbm/s

Tabel LC.4 Data pada alur 2

<table>
<thead>
<tr>
<th>Komponen</th>
<th>( \rho ) campuran</th>
<th>( \mu ) campuran</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>873,8 kg/m³ (54,5509 lbm/ft³)</td>
<td>0,57 cp 0,000383 lbm/ft.s</td>
</tr>
</tbody>
</table>

(Sumber: Geankoplis, 2003; Perry, 1999)

Laju alir volumetrik,
\[
m_v = \frac{219,718 \text{ kg/jam}}{873,8 \text{ kg/m}^3} = 0,2514 \text{ m}^3/\text{jam} = 0,000070 \text{ m}^3/\text{s} = 0,00246 \text{ ft}^3/\text{s}
\]

Desain pipa:
\[
D_{i_{opt}} = 0,363 (m_v)^{0,45} (\rho)^{0,13} \\
= 0,363 (0,000070 \text{ m}^3/\text{s})^{0,45} (873,8 \text{ kg/m}^3)^{0,13} \\
= 0,0118 \text{ m} = 0,4648 \text{ in}
\]

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 = 0,0158 m
Diameter Luar (OD) : 0,84 in = 0,07 ft
Inside sectional area : 0,00211 ft²
Kecepatan linier, \( v = \frac{Q}{A} = \frac{0.00246 \text{ ft}^3/\text{s}}{0.00211 \text{ ft}^2} = 1.1689 \text{ ft/s} = 0.3563 \text{ m/s} \)

Bilangan Reynolds:
\[
N_{Re} = \frac{\rho \times v \times D}{\mu}
\]
\[
= \frac{(54,5509 \text{ lbm/ft}^3)(1,1689 \text{ ft/s})(0.0518 \text{ ft})}{0.0003 \text{ lbm/ft.s}}
\]
\[
= 8629,643 \text{ (Turbulen)}
\]

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

Pada \( N_{Re} = 8629,643 \) dan \( \varepsilon/D = \frac{0.000046 \text{ m}}{0.0157 \text{ m}} = 0.0029 \)

Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga \( f = 0.0083 \)

**Friction loss:**

1. **Sharp edge entrance:**
\[
h_c = 0.55 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2g_c} = 0.55(1 - 0) \frac{1.1689^2}{2(32,174)} = 0.0116 \text{ ft.lbf/lbm}
\]

1. **Elbow 90°:**
\[
h_f = n.Kf. \frac{v^2}{2.g_c} = 1(0.75) \frac{1,1689^2}{2(32,174)} = 0,0159 \text{ ft.lbf/lbm}
\]

1. **Check valve:**
\[
h_f = n.Kf. \frac{v^2}{2.g_c} = 1(2) \frac{1,1689^2}{2(32,174)} = 0.0424 \text{ ft.lbf/lbm}
\]

Pipa lurus 70 ft:
\[
F_f = 4f \frac{\Delta L_g v^2}{D^2.g_c} = 4(0,0083) \frac{(70)(1,1689)^2}{0,0518(32,174)} = 0,9521 \text{ ft.lbf/lbm}
\]

1. **Sharp edge exit:**
\[
h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right) ^2 \frac{v^2}{2g_c} = 1 \left( 1 - 0 \right) ^2 \frac{1,1689^2}{2(32,174)} = 0,0212 \text{ ft.lbf/lbm}
\]

Total friction loss:
\[
\sum F = 1,0434 \text{ ft.lbf/lbm}
\]

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

\[ P_2 = 2 \text{ atm} \]

\[ \Delta P = 1 \text{ atm} = 2116,228 \text{ lbf/ft}^2 \]

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

\[
\text{maka: } 0 + \frac{32,174}{32,174}(20) + \frac{2116,228}{54,5509} + 1,0434 + W_s = 0
\]

\[ W_s = 59,837 \text{ ft.lbf/lbm} \]

Efisiensi pompa, \( \eta = 70 \% \)

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

\[ = \frac{59,837}{0,7} \]

\[ = 85,4815 \text{ ft.lbf/lbm}. \]

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

\[ = 0,1345 \text{ lbm/s} \times 85,4815 \text{ ft.lbf/lbm} \]

\[ = 11,5017 \text{ ft.lbf/lbm} \]

\[ = 0,0209 \text{ hp} \]

Maka dipilih pompa dengan daya motor 1/4 hp.

**LC.6 Vaporizer (E – 101)**

**Fungsi**: Menguapkan umpan benzen yang mengandung sedikit IPB

**Jenis**: 3 – 6 shell and tube exchanger

**Dipakai**: 1 in OD tube 12 BWG, panjang = 16 ft, 6 pass

- Fluida panas

  Laju alir fluida panas = 970,7029691 kg/jam = 2140,0449 lbm/jam

  Temperatur awal \( (T_1) \) = 360 °C = 680 °F

  Temperatur akhir \( (T_2) \) = 150 °C = 302 °F
- Fluida dingin

Laju alir fluida dingin = 1640,3188 kg/jam = 3616,3028 lbm/jam

Untuk mencegah fluida menguap semua, diasumsikan hanya 80% fluida yang menguap, sehingga:

Laju alir fluida dingin = 0,8 x 3616,3028 lbm/jam = 2893,0423 lbm/jam

Temperatur awal (t₁) = 76,66 °C = 169,9950 °F

Temperatur akhir (t₂) = 92,314 °C = 198,1652 °F

Panas yang diserap (Q) = 407284,494 kJ/jam = 386029,6988 Btu/jam

(1) Δt = LMTD = 270,189 °F

(2) Te = \frac{\Delta t_e}{\Delta t_w} = \frac{302 - 169,9950}{680 - 169,9950} = 0,2588

K_e = 0,37

F_e = 0,32

T_e = 302 + 0,32 (680-302) = 422,96 °F

Dalam perancangan ini digunakan vaporizer dengan spesifikasi:
- Diameter luar tube (OD) = 1 in
- Jenis tube = 12 BWG
- Pitch (P₁) = 1 1/4 in square pitch
- Panjang tube (L) = 16 ft

Fluida panas: steam, tube

(3) Flow area tube, \(a_t\) = 0,479 in²

\(a_t = \frac{N_t \times a_t}{144 \times n}\) (Tabel 10, Kern, 1965)

\(a_t = \frac{48 \times 0,479}{144 \times 3} = 0,053 \text{ ft}^2\) (Pers. (7.48), Kern, 1965)

(4) Kecepatan massa:

\(G_t = \frac{w}{a_t}\) (Pers. (7.2), Kern, 1965)
\[ G_i = \frac{2140.0449}{0.0532} = 40209.6120 \text{ lbm/jam.ft}^2 \]

(5) Bilangan Reynold:

Pada \( T_c = 491 \, ^\circ\text{F} \)

\[ \mu = 0.017 \, \text{cP} = 0.0414 \, \text{lbm/ft}^2\text{.jam} \]  

(Gambar 14, Kern, 1965)

Dari tabel 10, Kern, untuk 1 in OD, 12 BWG, diperoleh :

ID = 0,782 in = 0,0651 ft

\[ \text{Re}_c = \frac{\text{ID} \times G_i}{\mu} \]  

(Pers.(7.3), Kern, 1965)

\[ \text{Re}_c = \frac{0.0651 \times 40209.6120}{0.0411} = 63692.9116 \]

(6) Taksir \( J_H \) dari Gambar 24, Kern, diperoleh \( J_H = 300 \) pada \( \text{Re}_c = 63692.9116 \)

(7) Pada \( t_c = 184.08 \, ^\circ\text{F} \)

\[ c = 0,182 \, \text{Btu/lbm.}^\circ\text{F} \]

\[ k = 0,02 \, \text{Btu/jam lbm ft.}^\circ\text{F} \]

\[ \left( \frac{c \mu}{k} \right)^{\frac{1}{2}} = \left( \frac{0.182 \times 0.0411}{0.02} \right)^{\frac{1}{2}} = 0.7207 \]

(8) \[ \frac{h}{\phi_s} = J_H \times \frac{k}{D_s} \times \left( \frac{c \mu}{k} \right)^{\frac{1}{2}} \]

\[ \frac{h}{\phi_s} = 300 \times \frac{0.02}{0.0651} \times 0.7207 = 268.7505 \]

(9) \[ \frac{h}{\phi_s} = \frac{h}{\phi_s} \times \frac{\text{ID}}{\text{OD}} \]

\[ \frac{h}{\phi_s} = 268.7505 \times \frac{0.782}{1} = 210.1629 \]

Fluida dingin : bahan, shell

(9’) asumsi \( h_0 = 200 \)
\( t_w = t_c + \frac{h_0}{\frac{\phi_i h_0}{\phi_t} + \frac{h_0}{\phi_s}} (T_c - t_c) \)

\[
t_w = 169,9950 + \frac{210,1629}{210,1629 + 200} (422,96 - 169,9950) = 299,611
\]

\( \Delta t_w = 299,611 - 169,9950 = 129,616 \)

Dari gambar 15.11, kern nilai \( h_0 \) > 200, maka \( h_0 \) yang digunakan adalah 200.

(11) **Clean Overall Coefficient, \( U_C \)**

\[
U_C = \frac{h_{io} h_0}{h_{io} + h_0} = \frac{171,633 \times 200}{171,633 + 200} = 102,4777 \text{Btu/jam.ft}^2.\text{°F}
\]

(Pers. (6.38), Kern, 1965)

(14) **Desain Overall Coefficient**

\[
A = 48 \times 0,2618 \times 16 = 217,8176 \text{ft}^2
\]

\[
U_D = \frac{Q}{A \times \Delta t} = \frac{529039,1179}{217,8176 \times 215,848} = 7,5235
\]

(Pers. (6.13), Kern, 1965)

(15) Faktor pengotor, \( R_d \)

\[
R_d = \frac{U_C - U_D}{U_C \times U_D} = \frac{102,47 - 7,5235}{102,47 \times 7,5235} = 0,123
\]

(Pers. (6.13), Kern, 1965)

\( R_d \) hitung ≥ \( R_d \) ketentuan (0,003), maka spesifikasi pendingin dapat diterima.

**Pressure drop**

**Fluida panas : sisi tube**

(1) Untuk \( Re_i = 100318,46 \)

\[
f = 0,00016 \text{ft}^2/\text{in}^2
\]

\[
s = 1
\]

\[
\phi_t = 1
\]

(2) \( \Delta P_t = \frac{f \cdot G_t^2 \cdot L \cdot n}{5,22 \cdot 10^{10} \cdot \text{ID} \cdot s \cdot \phi_t} \)

(Pers. (7.53), Kern, 1965)
\[ \Delta P_t = \frac{(0,00016) \times (63331,482)^2 \times (16) \times (4)}{(5,22 \times 10^{10}) \times (0,0651) \times (1) \times (1)} = 0,00005 \text{ psi} \]

(3) \[ G_t = 63331,482, \quad \frac{V^2}{2g} = 0,001 \]

\[ \Delta P_v = \frac{4 \cdot n \cdot \nu^2}{s \cdot \frac{2}{g} \cdot l} = \frac{4 \cdot 6}{1} \times 0,001 = 0,026 \]

(4) \[ \Delta P = \Delta P_t + \Delta P_v = 0,00005 + 0,026 = 0,02605 \text{ psi} \]

**Fluida dingin : sisi shell**

(1') Untuk \( Re_s = 119093,8768 \)

\[ f = 0,0013 \text{ ft}^2/\text{in}^2 \quad \text{(Gambar 29, Kern, 1965)} \]

\[ \phi_s = 1,1568 \]

\[ s = 0,98 \]

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

\[ N + 1 = 12 \times \frac{16}{5} = 38,4 \quad \text{(Pers. (7.43), Kern, 1965)} \]

\[ D_s = 13,25 \text{ in} /12 = 1,1041 \text{ ft} \]

(3') \[ \Delta P_s = \frac{f \cdot G_s^2 \cdot D_s^3 \cdot (N+1)}{5,22 \times 10^{10} \cdot D_e^2 \cdot s \cdot \phi_s} \quad \text{(Pers. (7.44), Kern, 1965)} \]

\[ \Delta P_s = \frac{0,0013 \times (40873,0184)^2 \times (1,1041) \times (38,4)}{5,22 \times 10^{10} \times (0,0825) \times (0,98) \times (1,1568)} = 0,5653 \text{ psi} \]

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

**LC.7 Heater (E – 102)**

Fungsi : Meningkatkan temperature benzene dan IPB sebelum diumpankan ke reaktor (R-101)

Jenis : 3 – 6 shell and tube exchanger

Dipakai : 1 in OD tube 8 BWG, panjang = 16 ft, 6 pass

- Fluida panas
Laju alir fluida panas  =  1040,315497 kg/jam  =  2293,5151 lbm/jam  
Temperatur awal (T₁) =  360 °C  =  680 °F  
Temperatur akhir (T₂) =  150 °C  =  302 °F  

- Fluida dingin  
Laju alir fluida dingin =  1640,3188 kg/jam  = 3616,3028 lbm/jam  
Temperatur awal (t₁) =  92,314 °C  =  198,1652 °F  
Temperatur akhir (t₂) =  269,47 °C  =  517,0514 °F  

Panas yang diserap (Q) =  436492,2993  kJ/jam = 413713,2479Btu/jam  

(1) ∆t = beda suhu sebenarnya  

<table>
<thead>
<tr>
<th>Fluida Panas</th>
<th>Fluida Dingin</th>
<th>Selisih</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁ = 680 °F</td>
<td>t₂ = 517,051°F</td>
<td>∆t₁ = 162,948°F</td>
</tr>
<tr>
<td>T₂ = 302 °F</td>
<td>t₁ = 198,165°F</td>
<td>∆t₂ = 103,834°F</td>
</tr>
<tr>
<td>T₁ – T₂ = 378 °F</td>
<td>t₂ – t₁ = 318,88 °F</td>
<td>∆t₁ – ∆t₂ = -59,1138 °F</td>
</tr>
</tbody>
</table>

\[
LMTD = \frac{\Delta t_2 - \Delta t_1}{\ln \frac{\Delta t_2}{\Delta t_1}} = \frac{-59,1138}{\ln \frac{103,834}{162,954}} = 131,179 °F
\]

\[
R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{378}{318,8862} = 1,1853
\]

\[
S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{318,8862}{680 - 198,1652} = 0,6618
\]

Dari Gambar 20, Kern, 1965 diperoleh Fₚ = 0,86  
Maka ∆t = Fₚ × LMTD = 0,86× 131,179 = 112,814 °F
(2) $T_c$ dan $t_c$

$$T_c = \frac{T_1 + T_2}{2} = \frac{680 + 302}{2} = 491^\circ F$$

$$t_c = \frac{t_1 + t_2}{2} = \frac{92,314 + 269,473}{2} = 357,608^\circ F$$

Dalam perancangan ini digunakan *heat exchanger* dengan spesifikasi:

- Diameter luar *tube* (OD) = 1 in
- Jenis *tube* = 8 BWG
- Pitch (PT) = 1\(\frac{3}{4}\) 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 $U_D = 5-50$, dan faktor pengotor ($R_d$) = 0,003. Diambil $U_D = 18$ Btu/jam-ft\(^2\).\(^\circ\)F

Luas permukaan untuk perpindahan panas,

$$A = \frac{Q}{U_D \times \Delta t} = \frac{413713,2479 \text{ Btu/jam}}{18 \text{ Btu/jam} \cdot \text{ft}^2 \cdot \text{°F}} \times 112,814 \text{ °F} = 203,734 \text{ ft}^2$$

Luas permukaan luar ($a''$) = 0,2618 ft\(^2\)/ft

(Tabel 10, Kern)

Jumlah tube, $N_t = \frac{A}{L \times a''} = \frac{203,734 \text{ ft}^2}{16 \text{ ft} \times 0,2618 \text{ ft}^2/\text{ft}} = 48,6378$ buah

b. Dari Tabel 9, hal 842, Kern, 1965, nilai yang terdekat adalah 48 *tube* dengan ID *shell* 12 in.

c. Koreksi $U_D$

$$A = L \times N_t \times a''$$

$$= 16 \text{ ft} \times 48 \times 0,2618 \text{ ft}^2/\text{ft}$$

$$= 201,062 \text{ ft}^2$$

$$U_D = \frac{Q}{A \cdot \Delta t} = \frac{413713,2479 \text{ Btu/jam}}{201,062 \text{ ft}^2 \times 112,814 \text{ °F}} = 18,2392 \frac{\text{Btu}}{\text{jam} \cdot \text{ft}^2 \cdot \text{°F}}$$
Fluida panas : steam, tube

(3) Flow area tube, $a_t = 0.355 \text{ in}^2$ (Tabel 10, Kern, 1965)

$$a_t = \frac{N_t \times a'_t}{144 \times n}$$ (Pers. (7.48), Kern, 1965)

$$a_t = \frac{48 \times 0.355}{144 \times 6} = 0.01972 \text{ ft}^2$$

(4) Kecepatan massa:

$$G_t = \frac{w}{a_t}$$ (Pers. (7.2), Kern, 1965)

$$G_t = \frac{2293.5151}{0.01972} = 116290.9 \text{ lbm/jam.ft}^2$$

(5) Bilangan Reynold:

Pada $T_c = 491 \text{ °F}$

$$\mu = 0.0181 = 0.0438$$ (Gambar 14, Kern, 1965)

Dari tabel 10, Kern, untuk 1 in OD, 8 BWG, diperoleh : ID = 0.67 in = 0.0558 ft

$$Re_t = \frac{ID \times G_t}{\mu}$$ (Pers.(7.3), Kern, 1965)

$$Re_t = \frac{0.0558 \times 116290.9}{0.0438} = 148233.2$$

(10) Taksir $jH$ dari Gambar 24 Kern (1965), diperoleh $jH = 340$ pada $Re_t = 148233.2$

(11) Pada $T_c = 491 \text{ °F}$

$c = 0.19 \text{ Btu/lb.m.°F}$ (Gambar 2, Kern, 1965)

$k = 0.03 \text{ Btu/jam lbm ft.°F}$ (Tabel 5, Kern, 1965)

$$\left(\frac{c\mu}{k}\right)^{\frac{1}{3}} = \left(\frac{0.19 \times 0.0438}{0.03}\right)^{\frac{1}{3}} = 0.65219$$

(12) $$\frac{h_t}{\phi_t} = jH \times \frac{k}{ID} \times \left(\frac{c\mu}{k}\right)^{\frac{1}{3}}$$
\[
\frac{h}{\varphi_t} = 340 \times 0.03 \times 0.65219 = 119,147
\]
\[
\frac{h_w}{\varphi_t} = \frac{h}{\varphi_t} \cdot \frac{ID}{OD}
\]
\[
\frac{h_w}{\varphi_t} = 119,147 \times \frac{0.67}{1} = 79,828.3
\]

(10) Pada \( t_w = 412,0182 \) \(^{0}F\), maka \( \mu_w = 0,0173 \text{ lbm/ft}^2\text{.jam} \)
\[
\varphi_s = \left(\frac{\mu}{\mu_w}\right)^{0.14} = \left(\frac{0.0438}{0.0173}\right)^{0.14} = 1,1389 \quad \text{(Kern, 1965)}
\]
\[
h_s = \frac{h_w}{\varphi_s} = 79,828.3 \times 1,1389 = 90,9158 \text{ Btu/jam ft}^2\text{.F}
\]

**Fluida dingin : gass, shell**

(3') Flow area shell
\[
a_s = \frac{D_s \times C \times B}{144 \times P_t} \text{ ft}^2
\quad \text{(Pers. (7.1), Kern, 1965)}
\]

\( D_s \) = Diameter dalam shell = 13,25 in
\( B \) = Baffle spacing = 5 in
\( P_t \) = Tube pitch = 1,25 in
\( C' \) = Clearance = \( P_t - OD \)
\[
= 1,25 - 1 = 0.25 \text{ in}
\]
\[
a_s = \frac{13,25 \times 0.25 \times 5}{144 \times 1.25} = 0,092 \text{ ft}^2
\]

(4') Kecepatan massa
\[
G_s = \frac{w}{a_s}
\quad \text{(Pers. (7.2), Kern, 1965)}
\]
\[
G_s = \frac{3616,3028}{0.092} = 39301,7062 \text{ lbm/jam.ft}^2
\]
(5’) Bilangan Reynold

Pada $t_c = 357,608^\circ F$

$$\mu = 0,0117 = 0,0283$$

Dari Gambar 28, Kern, untuk 1 in dan 1/4 square pitch, diperoleh $D_e = 0,99$ in.

$$De = 0,99/12 = 0,0825 \text{ ft}$$

$$Re_s = \frac{D_e \times G_s}{\mu}$$ (Pers. (7.3), Kern, 1965)

$$Re_s = \frac{0,0825 \times 39301,7062}{0,0283} = 114515,461$$

(6’) Taksir $J_H$ dari Gambar 28, Kern, diperoleh $J_H = 198$ pada $Re_s = 114515$

(7’) Pada $t_c = 357,608^\circ F$

$$c = 0,59 \text{ Btu/lbm} \cdot ^\circ F$$

$$k = 0,0161 \text{ Btu/jam lbm ft.} ^\circ F$$

$$\left(\frac{c \cdot \mu}{k}\right)^{\frac{1}{2}} = \left(\frac{0,59 \times 0,0283}{0,0161}\right)^{\frac{1}{2}} = 1,01237$$

(8’) $h_w = J_H \times k \times \left(\frac{c \cdot \mu}{k}\right)^{\frac{1}{2}}$

$$h_w = 198 \times \frac{0,0161}{0,0825} \times 1,01237 = 39,1182$$

(9’) Temperatur dinding pipa

$$t_w = t_c + \frac{h_w}{\frac{k}{\phi_s} + \frac{h_0}{\phi_s}}(T_i - t_c)$$

$$t_w = 357,608 + \frac{39,1182}{45,2542 + 39,1182} (491 - 357,608)$$

$$t_w = 401,4771^\circ F$$

(10’) Pada $t_w = 401,4771754^\circ F$, maka $\mu_w = 0,01 \text{ lbm/ft}^2 \cdot \text{jam}$
\[ \varphi_s = \left( \frac{\mu}{\mu_w} \right)^{0.14} = \left( \frac{0.0283}{0.01} \right)^{0.14} = 1.1568 \]  
(Kern, 1965)

\[ h_o = \frac{h_{\varphi_s}}{\varphi_s} = 39.1182 \times 1.1568 = 45.2542 \text{Btu/jam ft}^2 \text{°F} \]

(11) \textit{Clean Overall Coefficient, } U_C

\[ U_C = \frac{h_{\varphi_s} \times h_o}{h_{\varphi_s} + h_o} = \frac{90.9158 \times 45.2542}{90.9158 + 45.2542} = 30.2146 \text{Btu/jam ft}^2 \text{°F} \]  
(Pers. (6.38), Kern, 1965)

(12) Faktor pengotor, \( R_d \)

\[ R_d = \frac{U_C - U_d}{U_C 	imes U_d} = \frac{30.2146 - 18.2391}{30.2146 \times 18.2391} = 0.0217 \]  
(Pers. (6.13), Kern, 1965)

\( R_d \text{ hitung} \geq R_d \text{ ketentuan} (0.003) \), maka spesifikasi pendingin dapat diterima.

\textit{Pressure drop}

\textbf{Fluida panas : sisi tube}

(1) Untuk \( \text{Re}_t = 178653 \)

\[ f = 0.0013 \text{ ft}^2/\text{in}^2 \]  
(Gambar 29, Kern, 1965)

\[ s = 0.98 \]  
(Gambar 6, Kern, 1965)

(2) \[ \Delta P_t = \frac{f \cdot G_t \cdot 2 \cdot L \cdot n}{5.22 \cdot 10^{10} \cdot ID \cdot s \cdot \varphi_t} \]  
(Pers. (7.53), Kern, 1965)

\[ \Delta P_t = \frac{(0.0012) \times (140156) \times (16) \times (6)}{(5.22 \cdot 10^{10}) \times (0.0558) \times (1) \times (1,1389)} = 0.68175 \text{ psi} \]

(3) Dari Gambar 27, Kern, 1965 diperoleh \[ \frac{V^2}{2g'} = 0.004 \]
\[ \Delta P_r = \frac{4n}{s} \cdot \frac{V^2}{2g'} \]
\[ = \frac{(4)(6)}{1} \cdot 0.04 \]
\[ = 0.096 \text{ psi} \]
\[ \Delta P_T = \Delta P_i + \Delta P_r \]
\[ = 0.6817 \text{ psi} + 0.096 \text{ psi} \]
\[ = 0.0174 \text{ psi} \]

\[ \Delta P_T \text{ yang diperbolehkan} = 2 \text{ psi} \]

**Fluida dingin : sisi shell**

(1') Untuk \( Re_s = 119093.8768 \)
\[ f = 0.0013 \text{ ft}^2/\text{in}^2 \]
\[ \phi_s = 1.1568 \]
\[ s = 0.98 \]

(2') \( N + 1 = 12 \times \frac{L}{B} \)
\[ N + 1 = 12 \times \frac{16}{5} = 38.4 \]
\( D_s = 13.25 \text{ in} / 12 = 1.1041 \text{ ft} \)

(3') \[ \Delta P_s = \frac{f \cdot G_s^2 \cdot D_s \cdot (N+1)}{5.22 \times 10^{10} \cdot D_e \cdot s \cdot \phi_s} \]
\[ \Delta P_s = \frac{0.0013 \times (40873.0184)^2 \times (1.1041) \times (38.4)}{5.22 \times 10^{10} \times (0.0825) \times (0.98) \times (1.1568)} = 0.5653 \text{ psi} \]

\( \Delta P_s \text{ yang diperbolehkan} = 10 \text{ psi} \)

**LC.8 Compresor (JC-102)**

Fungsi : Menaikkan tekanan umpan benzene sebelum bercampur dengan umpan propilen

Jenis : *Multistage reciprocating compressor*
Jumlah : 1 unit
Kondisi Operasi :
Tekanan Masuk : 1 atm  2116,12364 lbf/ft²
Tekanan Keluar : 18 atm = 38090,2 lbf/ft²

Tabel LC.5 Data pada alur 8

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Laju Alir (kg/jam)</th>
<th>Densitas (kg/m³)</th>
<th>Volume (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>1541,2196</td>
<td>4,367</td>
<td>352,924</td>
</tr>
<tr>
<td>IPB</td>
<td>99,0992</td>
<td>3,397</td>
<td>29,1726</td>
</tr>
<tr>
<td>Total</td>
<td>1640,3188</td>
<td>4,3083</td>
<td>382,097</td>
</tr>
</tbody>
</table>

Hp = \frac{3,13 \times 10^6 \cdot P_1 \cdot Q_{fm}}{(k-1)} \cdot \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1 \quad \text{(Timmerhaus, 1991)}

dimana:

- Q_{fm} = \frac{F}{\rho} = \frac{1640,3188}{4,308} = 382,1 \text{ m}^3/\text{jam} = 224,86 \text{ ft}^3/\text{menit}
- k = \text{rasio panas spesifik} = 1,4
- \eta = \text{efisiensi kompresor} = 80 \%

Hp = \frac{3,13 \times 10^6 \cdot 2116,12}{(1,4+1)} \cdot 224,86 \left(\frac{2116,12}{38090,2}\right)^{\frac{1,4-1}{1,4}} - 1

= 65,2884 HP

Jika efisiensi motor adalah 80 %, maka :

Daya actual, P = \frac{65,2884}{0,80} = 81,6106 HP

Diameter pipa ekonomis (De) dihitung dengan persamaan :

De = 3,9(Q)^{0,45} \cdot (\rho)^{0,13} \quad \text{(Timmerhaus, 1991)}

= 3,9 \left(3,77 \text{ ft}^3/\text{s}\right)^{0,45} \cdot (0,26 \text{ lbm/ft}^3)^{0,13}

= 5,97 \text{ in}

Dari Appendiks A.5 Geankoplis, 2003, dipilih pipa commercial steel :
Ukuran nominal : 6 in
Schedule number : 40
Diameter Dalam (ID) : 6,065 in = 0,50542 ft = 0,15405 m
Diameter Luar (OD) : 6,625 in = 0,55208 ft
Inside sectional area : 0,2006 ft²

L.C.9 Reaktor (R-101)
Fungsi : Tempat berlangsungnya reaksi pembentukan Isopropylbenzene
Jenis : Reaktor fixed bed multitubular
Bentuk : silinder vertikal dengan alas dan tutup ellipsoidal
Bahan konstruksi : carbon steel SA-285 grade A
Jumlah : 1 unit

Reaksi:
\[
\text{C}_3\text{H}_6(g) + \text{C}_6\text{H}_6(g) \rightarrow \text{C}_9\text{H}_{12}(g) \quad \ldots(1)
\]
(Propilen) (Benzen) (Cumen)

\[
\text{C}_9\text{H}_{12}(g) + \text{C}_3\text{H}_6(g) \rightarrow \text{C}_{12}\text{H}_{18}(g) \quad \ldots(2)
\]
(Cumen) (Propilen) (Diisopropilbenzene)

Temperatur masuk = 278,23 °C = 551,38 K
Temperatur keluar = 278,23 °C = 551,38 K
Tekanan operasi = 18 atm = 1823,85 kpa
Laju alir massa = 1787,4631 kg/jam
Laju alir molar = 24,044 kmol/jam

\[
\text{Waktu tinggal (}\tau\text{) reactor} = 0,0043 \text{ jam} = 15,48 \text{ detik} \quad \text{(Setiawan, 2002)}
\]

Perhitungan
Desain Tangki

\[
C_{ao} = \frac{n}{V} = \frac{P_i}{RT} = \frac{24,044kPa}{60,433m^3} = 0,39 \text{ kmol/m}^3
\]

a. Volume reaktor

\[
V = \tau \frac{F_{ao}}{C_{ao}} = \frac{0,0043 \text{ jam}^{-1} \cdot (24,044 \text{ kmol/jam})}{0,39 \text{ kmol/m}^3} = 0,2598 \text{ m}^3
\]
Setiap 1 m\(^3\) katalis dapat menghasilkan sekitar 7.452 kg cumene / jam (Setiawan, 2002).

Cumene yang dihasilkan dalam reaktor adalah 313,3494 kg/jam. Maka jumlah katalis yang dibutuhkan adalah:

\[
\frac{313,3494}{7,452} = 0,0420 \text{ m}\(^3\)
\]

Volume total reaktor = 0,2598 + 0,0420 = 0,3019 m\(^3\)

Faktor kelonggaran = 20%

Volume reaktor = 1,2 x 0,3019 = 0,3622 m\(^3\)

b. Jumlah tube

Direncanakan:

- Diameter tube = 0,0423 m = 4,23 cm = 1,6665 in
- Panjang tube = 7,2 m
- Pitch (P\(_T\)) = 0,0529 triangular pitch

Jumlah tube = \[
\frac{V_{\text{reaktor}}}{V_{\text{tube}}} = \frac{0,3622}{\pi \cdot \frac{0,04233 \cdot 7,2}{4}} = 35,774 \approx 36
\]

a. Tebal tube

Tekanan operasi = 18 atm = 264,528 psi
Faktor kelonggaran = 20 %
Maka, \(P_{\text{desain}} = (1,2) (264,528) = 317,4336 \text{ psi}\)

\(Joint \ efficiency = 0,8\) (Brownell & Young,1959)

\(Allowable \ stress = 11200 \text{ psi}\) (Brownell & Young,1959)

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

\[= \frac{(317,434\text{psi}) \left(\frac{1,666}{2}\text{ in}\right)}{(11200 \text{ psi})(0,8) - 0,6(317,434\text{psi})}\]

\[= 0,030 \text{ in} = 0,7661 \text{ mm}\]

Faktor korosi = 0,0098 in/tahun
Umur alat = 10 tahun

Maka tebal tube yang dibutuhkan = 0,030 in + (0,0098).10 in = 0,128 in

Tebal tube standar yang digunakan = 0,2 in (Brownell & Young,1959)

d. Diameter dan tinggi shell
PT = jarak antara 2 pusat pipa
PT = 1,25 OD = 0,053 m
C’ = Clearance = PT - OD
   = 0,1 m = 0,42 inch
CD = PT sin 60\(^\circ\)

\[
IDs = \left(\frac{4 \cdot 0,866 \cdot Nt \cdot P_T^2}{\pi}\right)^{0.5}
\]
\[
= \left(4 \cdot 0,866 \cdot 36 \cdot 0,0520^2\right)^{0.5}
\]
\[
= 0,33 m = 13,1280 \text{ in}
\]

Tinggi shell (H) = panjang tube = 7,2 m

e. Diameter dan tinggi tutup

Diameter tutup = diameter tangki = 0,33 m
Rasio axis = 2 : 1 (Brownell & Young,1959)
Tinggi tutup = \(\frac{1}{2} \left(\frac{0,33}{2}\right)\) = 0,08 m

f. Tebal shell dan tebal tutup

Tekanan operasi = 18 atm = 264,528 psi
Faktor kelonggaran = 20 %
Maka, P_{desain} = (1,2) (264,528) = 317,434 psi
Joint efficiency = 0,8 (Brownell & Young,1959)
Allowable stress = 11200 psia (Brownell & Young,1959)

\[
t = \frac{PR}{SE-0,6P}
\]
\[
= \left(\frac{317,434\text{psi}}{11200\text{ psi}}\right)\left(\frac{13,12}{2}\right)\text{in}
\]
\[
= \frac{0,2376 \text{ in}}{6,0350 \text{ mm}}
\]
Faktor korosi = 0,0098 in/tahun
Umur alat = 10 tahun
Maka tebal *shell* yang dibutuhkan = 0,2376 in + (0,0098).(10) in = 0,3356 in
Tebal *shell* standar yang digunakan = 0,4 in (Brownell & Young, 1959)

**LC.10 Ekspander (EV-101)**

**Fungsi**: Menurunkan tekanan produk keluaran reaktor (R-101)

**Jenis**: Centrifugal expander

**Jumlah**: 1 unit

**Data**: 
- \(m = 1787,4631 \text{ kg/jam} = 0,49651753 \text{ kg/detik}\)

\[
\text{Laju alir volumetrik } (m_v) = \frac{N \times 8,314 \text{ m}^3/\text{mol.K} \times 551,38 \text{ K}}{1823,85 \text{ kPa}}
\]

\[
= \frac{21,0817 \text{ kmol} \times 8,314 \text{ m}^3/\text{mol.K} \times 551,38 \text{ K}}{1823,85 \text{ kPa}}
\]

\[= 52,9883 \text{ m}^3/\text{jam}\]

\[
\rho_{\text{campuran}} = \frac{m}{m_v} = 33,7331 \text{ kg/m}^3
\]

**Tekanan masuk** (\(P_1\)) = 18 atm = 1823,850 kPa

**Tekanan keluar** (\(P_2\)) = 1 atm = 101,325 kPa

**Efisiensi ekspander** = 60% (Peters dkk, 2004)

**Daya yang dihasilkan** :

\[
P = \eta . m . \frac{(P_2 - P_1)}{\rho}
\]

**Dimana**: 
- \(P\) = daya (kW)
- \(m\) = laju alir massa (kg/detik)
- \(P_1\) = Tekanan masuk (kPa)
- \(P_2\) = Tekanan keluar (kPa)
- \(\eta\) = efisiensi
- \(\rho\) = densitas (kg/m\(^3\))

Maka :

\[
P = \eta . m . \frac{(P_2 - P_1)}{\rho}
\]

\[
= \frac{0,6 . (0,49 \text{kg} / \text{det})(101,325 \text{kPa} - 1823,85 \text{kPa})}{33,73 \text{kg} / \text{m}}
\]
Maka daya yang dihasilkan ekspander adalah: 20,6826 Hp

LC.11 Kondensor Sub Cooler (E – 104)

Fungsi: Mengembun sebagian produk keluaran reaktor

Jenis: Double Pipe Exchanger

Dipakai: 20-ft hairpins of 3 x 2 in IPS pipe

- Fluida panas
  - Laju alir fluida panas = 1787,46 kg/jam = 3940,70 lbm/jam
  - Temperatur awal (T<sub>1</sub>) = 274,83°C = 526,69 °F
  - Temperatur akhir (T<sub>2</sub>) = 60,26 °C = 140,47 °F

- Fluida dingin
  - Laju alir fluida dingin = 5660,61 kg/jam = 12479,58 lbm/jam
  - Temperatur awal (t<sub>1</sub>) = 25°C = 77 °F
  - Temperatur akhir (t<sub>2</sub>) = 70 °C = 158 °F

Panas yang diserap (Q) = 70982,232 kJ/jam = 67277,911 Btu/jam

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

<table>
<thead>
<tr>
<th>Fluida Panas</th>
<th>Fluida Dingin</th>
<th>Selisih</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt; = 526,6 °F</td>
<td>t&lt;sub&gt;2&lt;/sub&gt; = 158°F</td>
<td>( \Delta t_1 = 368,6 ) °F</td>
</tr>
<tr>
<td>T&lt;sub&gt;2&lt;/sub&gt; = 140,4°F</td>
<td>t&lt;sub&gt;1&lt;/sub&gt; = 77 °F</td>
<td>( \Delta t_2 = 63,4 ) °F</td>
</tr>
<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt; – T&lt;sub&gt;2&lt;/sub&gt; = 386,2 °F</td>
<td>t&lt;sub&gt;2&lt;/sub&gt; – t&lt;sub&gt;1&lt;/sub&gt; = 368,6 °F</td>
<td>( \Delta t_2 – \Delta t_1 = -305,2 ) °F</td>
</tr>
</tbody>
</table>

\[
\text{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\lnleft(\frac{\Delta t_2}{\Delta t_1}\right)} = \frac{-305,2}{\lnleft(\frac{63,4}{368,6}\right)} = 173,4 \text{ °F}
\]
\[ R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{386.2}{81} = 4.7681 \]

\[ S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{81}{526.6 - 77} = 0.18 \]

Dari Gambar 19, Kern, 1965 diperoleh \( F_T = 0.98 \)
Maka \( \Delta t = F_T \times \text{LMTD} = 0.98 \times 173.49 = 170.02 \, ^\circ\text{F} \)

\[ T_c = \frac{T_1 + T_2}{2} = \frac{526.6 + 140.4}{2} = 333.58 \, ^\circ\text{F} \]
\[ t_c = \frac{t_1 + t_2}{2} = \frac{77 + 158}{2} = 117.5 \, ^\circ\text{F} \]

Dalam perancangan ini digunakan **Double Pipe Exchanger** dengan spesifikasi:
- Diameter luar \( \text{inner pipe} \) (OD) = 2.6 in = 0.2166 ft
- Diameter dalam \( \text{anulus} \) (ID2) = 3.23 in = 0.2697 ft
- Diameter damal \( \text{inner pipe} \) (ID1) = 2.05 in = 0.1708 ft

Dari tabel 6.2 (Kern, 1965), pada jenis ini \( \text{Flow Area} \) pada \( \text{inner pipe} \) lebih besar dari pada \( \text{anulus} \), maka laju alir yang paling besar mengalir di \( \text{inner pipe} \)

**Fluida Dingin : Air Pendingin , \text{inner pipe}**

(3) Flow area tube, \( a_t = 0.022 \, \text{in}^2 \)
\[ a_t = \pi \times D^2 / 4 \] (Pers. (6.3), Kern, 1965)
\[ a_t = 3.14 \times 0.17^2 / 4 = 0.022 \, \text{ft}^2 \]

(4) Kecepatan massa:
\[ G_t = \frac{w}{a_t} \] (Pers. (7.2), Kern, 1965)
\[ G_t = \frac{5660.6127}{0.022} = 172011.99 \, \text{lbm/jam.ft}^2 \]

(5) Bilangan Reynold:
Pada $t_c = 117.5 \, ^\circ F$

$\mu = 0.61 \, \text{cP} = 1.47 \, \text{lbm/ft}^2 \cdot \text{jam}$  

$ID = 2.05 \, \text{in} = 0.17 \, \text{ft}$

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

$Re_t = \frac{0.17 \times 172011.99}{1.47} = 19906.0981$

(9) Taksir $jH$ dari Gambar 24 Kern (1965), diperoleh $jH = 3.5$ pada $Re_t = 98962.6721$

(10) Pada $t_c = 117.5 \, ^\circ F$

$c = 1.02 \, \text{Btu/lbm} \cdot ^\circ F$  

$k = 0.369 \, \text{Btu/jam lbm ft} \cdot ^\circ F$  

$(c \mu)^{1/2} = \left(1.02 \times 1.47\right)^{1/2} = 1.5979$

$(11) h_t = jH \times \frac{k}{ID} \times \left(\frac{c \mu}{k}\right)^{1/2}$

$h_t = 3.5 \times \frac{0.369}{0.1708} \times 1.5979 = 2.20$

$h_{io} = \frac{h_t \times ID}{\varphi_t \times OD}$

$h_{io} = 2.20 \times \frac{2.05}{2.6} = 1.734$

**Fluida Panas : Bahan, anulus**

(3') Flow area anulus

$a_s = \pi \times \frac{ID^2 - OD^2}{4}$  

$a_s = 3.14 \times (0.2697^2 - 0.2166^2) / 4 = 0.0202 \, \text{ft}^2$

(4') Kecepatan massa

$G_s = \frac{w}{a_s}$  

(Pers. (7.1), Kern, 1965)
\[ G_s = \frac{12479.58}{0.0202} = 615413.62 \text{ lb}_m/\text{jam}.\text{ft}^2 \]

(5') Bilangan Reynolds

Pada \( t_c = 298,27 \, ^\circ\text{F} \)

\[ \mu = 0.0183 \, \text{cP} = 0.0442 \, \text{lb}_m/\text{ft}^2 \cdot \text{jam} \]

\[ D_e = \pi \times \frac{ID_e^2 - OD_e^2}{OD_e^2} = 0.0761 \quad \text{(Pers. (6.3), Kern, 1965)} \]

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

\[ \text{Re}_e = \frac{0.0761 \times 39230.0629}{0.0442} = 67455.4459 \]

(6') Taksir \( J_H \) dari Gambar 24, Kern, diperoleh \( J_H = 185 \) pada \( \text{Re}_e = 67455.4459 \)

(7') Pada \( t_c = 298,274 \, ^\circ\text{F} \)

\[ c = 0.191 \, \text{Btu/lb}_m \cdot ^\circ\text{F} \]

\[ k = 0.03 \, \text{Btu/jam lbm ft.} ^\circ\text{F} \]

\[ \left( \frac{c \cdot \mu}{k} \right)^{1/3} = \left( \frac{0.191 \times 0.0442}{0.03} \right)^{1/3} = 0.6557 \]

(8') \( h_o = J_H \times \frac{k}{D_e} \times \left( \frac{c \cdot \mu}{k} \right)^{1/3} \)

\[ h_o = 185 \times \frac{0.03}{0.0761} \times 0.6557 = 47.7919 \]

(9') Clean Overall Coefficient, \( U_c \)

\[ U_c = \frac{h_\infty \times h_o}{h_\infty + h_o} = \frac{56,2790 \times 47,7919}{56,2790 + 47,7919} = 25,8447 \, \text{Btu/jam.ft}^2. ^\circ\text{F} \]

(Pers. (6.38), Kern, 1965)

(10') Rd teori = 0.002
\[ \frac{1}{U_d} = \left( \frac{1}{U_c} \right) + Rd \]
\[ \frac{1}{U_d} = \left( \frac{1}{25,8447} \right) + 0.002 \]
\[ \frac{1}{U_d} = 0.04069 \]
\[ U_d = 24,5744 \text{ Btu/hr.ft}^2.\text{°F} \]

(11) Faktor pengotor, \( R_d \)

\[ R_d = \frac{U_c - U_D}{U_c \times U_D} = \frac{25,8447 - 24,5744}{25,8447 \times 24,5744} = 0.002 \quad \text{(Pers. (6.13), Kern, 1965)} \]

\( R_d \text{ hitung} \geq R_d \text{ ketentuan (0,002), maka spesifikasi dapat diterima.} \)

(11) Required Surface, \( A \)

\[ A = \frac{Q}{U_d \times \text{LMTD}} \]
\[ A = 15,0608 \text{ ft}^2 \]

Required Length = \( A \times 0.435 \times \frac{34,6226}{40} = 0,8655 \) dibulatkan menjadi 1

Jadi jumlah hairpin = 1 x 20 = 20 hairpin

**Pressure drop**

**Fluida dingin : gas, anulus**

(2) \( D_e' = 0,0339 \)

Untuk \( Re_a' = 47397,8686 \)

\[ f = 0.0063 \text{ ft}^2/\text{in}^2 \]

\[ s = 0.69 \]

\[ \rho = 43,125 \]

(2) \[ \Delta F_a = \frac{f \times G_a^2 \times L}{2 \times g \times \rho^2 \times D_e'} \quad \text{(Pers. (7.53), Kern, 1965)} \]

\( \Delta F_a = 0.0892 \text{ ft} \)
(3) \[ V = \frac{G_s}{3600 \times \rho} = 0.2526 \]

\[ F_1 = \frac{V^2}{2 \times g} = 0.00297 \text{ ft} \]

\[ \Delta P = \frac{(\Delta F_a + F_1) \times \rho}{144} = 0.0276 \text{ psi} \]

Yang diperbolehkan = 10 psi

Fluida panas : steam, inner pipe

(1') Untuk Re_p = 147174,9223

\[ f = 0.0053 \text{ ft}^2/\text{in}^2 \]

\[ s = 1 \]

\[ \rho = 62.5 \]

(2') \[ \Delta F_p = \frac{f \times G_a^2 \times L}{2 \times g \times \rho^2 \times D} = 0.8714 \text{ ft} \]

(3') \[ \Delta P = \frac{\Delta F_a \times \rho}{144} = 0.37825 \text{ psi} \]

Yang diperbolehkan = 10 psi

LC.12 Flash Drum (F-101)

Fungsi : Memisahkan campuran fasa gas dengan fasa cair

Bahan konstruksi : Low alloy steel SA-353

Bentuk : Silinder vertikal dengan tutup ellipsoidal

Jenis sambungan : Double welded butt joints

Jumlah : 1 unit

Kondisi operasi :

Tekanan = 1 atm
Temperatur = 60,26 °C  
Laju alir gas (\(F_{gas}\)) = 22,522 kg/jam  
Laju alir cairan (\(F_{cairan}\)) = 1764,9411 kg/jam  
Laju alir gas (\(N_{gas}\)) = 0,5258 kmol/jam  
Laju alir cairan (\(N_{cairan}\)) = 20,5559 kmol/jam  
Kebutuhan perancangan = 1 jam  
Faktor kelongaran = 20 %

Tabel LC.6  Komposisi gas pada Flash drum (F-101)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>BM (g/mol)</th>
<th>(F) (kg)</th>
<th>(N) (kmol)</th>
<th>Fraksi mol (X)</th>
<th>BM x X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propilene</td>
<td>42,08</td>
<td>13,9422</td>
<td>0,3313</td>
<td>0,63</td>
<td>26,5140</td>
</tr>
<tr>
<td>Propana</td>
<td>44,09</td>
<td>8,5798</td>
<td>0,1945</td>
<td>0,37</td>
<td>16,3094</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>22,522</td>
<td>0,5258</td>
<td>1</td>
<td>42,8235</td>
</tr>
</tbody>
</table>

Tabel LC.7  Komposisi cairan pada flash drum (F-101)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>BM (g/mol)</th>
<th>(F) (kg)</th>
<th>(N) (kmol)</th>
<th>Fraksi mol (X)</th>
<th>BM x X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>78,11</td>
<td>1323,7115</td>
<td>16,9467</td>
<td>0,8244</td>
<td>64,3954</td>
</tr>
<tr>
<td>IPB</td>
<td>120,19</td>
<td>412,4486</td>
<td>3,4316</td>
<td>0,1669</td>
<td>20,0645</td>
</tr>
<tr>
<td>DIPB</td>
<td>162</td>
<td>28,7810</td>
<td>0,1776</td>
<td>0,0086</td>
<td>1,3996</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1787,4631</td>
<td>21,0817</td>
<td>1</td>
<td>85,85962867</td>
</tr>
</tbody>
</table>

\[
\rho_{gas} = \frac{P \times BM}{R \times T} = \frac{1 \text{ atm} \times 42,8235 \text{ g/mol}}{(82,057 \times 10^{-3} \text{ m}^3 \cdot \text{atm/mol.K})(333,41\text{K})}
\]

\[
= 1,4808 \text{ kg/m}^3 = 0,0925 \text{ lbm/ft}^3
\]

\[
\rho_{cairan} = \frac{P \times BM}{R \times T} = \frac{1 \text{ atm} \times 85,8596 \text{ g/mol}}{(82,057 \times 10^{-3} \text{ m}^3 \cdot \text{atm/mol.K})(333,41\text{K})}
\]

\[
= 1,8885 \text{ kg/m}^3 = 0,1178 \text{ lbm/ft}^3
\]

Volume gas, \(V_{gas}\) = \(\frac{F}{\rho_{gas}}\) = \(\frac{23,43 \text{ kg}}{1,4808 \text{ kg/m}^3}\) = 15,8225 m\(^3\)/jam = 0,1552 ft\(^3\)
Volume cairan, \( V_{\text{ciran}} = \frac{F}{\rho} = \frac{1835.5 \text{kg}}{1.8885 \text{kg/m}^3} = 971.9354 \text{ m}^3/\text{jam} = 9.5343 \text{ ft}^3 \)

Kecepatan linear yang diijinkan:
\[
u = 0.14 \sqrt{\frac{\rho_{\text{ciran}} - 1}{\rho_{\text{gas}}}}
\]
(Wallas, 2005)
\[
u = 0.14 \sqrt{\frac{0.1178 - 1}{0.0925}} = 0.0732 \text{ ft/detik}
\]

Diameter tangki:
\[
D = \sqrt{\frac{V}{\frac{\pi}{4}.u}}
\]
(Wallas, 2005)
\[
D = \sqrt{\frac{9.6895}{\frac{\pi}{4}.0.0732}} = 12.9855 \text{ ft} = 3.9569 \text{ m}
\]

Tinggi kolom uap minimum = 5.5 ft

Waktu tinggal (\( t \)) = 10 menit = 600 detik

Tinggi cairan, \( L_{\text{ciran}} = \frac{V_{\text{ciran}} \cdot t}{(\pi/4).D^2} = \frac{9.5343(600)}{(\pi/4).12.9855^2} = 43.2165 \text{ ft} = 23.894 \text{ m}
\]

Panjang kolom:
\[
L = L_{\text{ciran}} + L_{\text{uap}} = 43.2165 + 5.5 = 48.7165 \text{ ft}
\]
\[
\frac{L}{D} = 3.7516
\]

Karena \( 3 < L/D < 5 \) maka spesifikasi tangki vertikal dapat diterima.

Perhitungan tebal shell tangki:
\[
P_{\text{hidrostatik}} = \rho \times g \times 1 = 1.8885 \times 9.8 \times 23.894 = 0.442 \text{ kpa} = 0.0043 \text{ atm}
\]
\[
P_0 = 101.325 \text{ kpa} = 1 \text{ atm}
\]

Faktor kelonggaran = 20 %

Universitas Sumatera Utara
P_{desain} = (1,2) \times (0,0043 + 1) = 1,0043 \text{ atm} = 101,7606 \text{ kPa} = 14,756 \text{ psi}

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

- *Allowable stress* (S) = 155132,1 kPa = 22500 psi
- *Joint efficiency* = 0,8
- *Corrosion allowance* = 0,0098 in/tahun (Peters dkk, 2004)
- Umur tangki = 10 tahun

a. Tebal *shell* tangki:

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

\[
= \frac{(14,766 \text{ psi})(\frac{12,985}{2} \text{ in})}{(22500 \text{ psi})(0,8) - 0,6(14,766 \text{ psi})} + (10)(0,0098 \text{ in/thn}) = 0,103 \text{ in}
\]

Tebal *shell* tangki yang digunakan adalah 1/4 in.

b. Tutup tangki

- Diameter tutup = diameter tangki = 12,9855 ft = 3,9569 m
- Rasio axis = \( L_h : D = 1 : 4 \)
- \( L_h = 0,99 \text{ m} \)

\( L \) (panjang tangki) = \( L_s + 2L_h \)
\( L_s \) (panjang shell) = \( L - 2L_h = 23,894 - 2(0,99) = 21,914 \text{ m} \)

Tutup atas tangki terbuat dari bahan yang sama dengan shell sehingga tebal tutup 1/4 in.

**LC.13 Pompa Umpan Destilasi I (P-03)**

Fungsi : Mengalirkan hasil bawah flash drum untuk diumpankan ke menara destilasi (MD-101)

Jenis : Pompa sentrifugal

Jumlah : 1 unit

Kondisi operasi :

Tekanan = 1 atm
Temperatur = 60,26 °C
Laju alir massa (F) = 1764,9411 kg/jam = 1,0808 lbm/s

Tabel LC.8 Data pada alur 14

<table>
<thead>
<tr>
<th>Komponen</th>
<th>x</th>
<th>(\rho) x</th>
<th>(\mu) x</th>
<th>(\rho) campuran</th>
<th>(\mu) campuran</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0,75</td>
<td>873,8 kg/m³</td>
<td>0,31 cp</td>
<td>655,35 kg/m³</td>
<td>0,232 cp</td>
</tr>
<tr>
<td>IPB</td>
<td>0,23</td>
<td>862 kg/m³</td>
<td>0,4 cp</td>
<td>201,44 kg/m³</td>
<td>0,093 cp</td>
</tr>
<tr>
<td>DIPB</td>
<td>0,02</td>
<td>859 kg/m³</td>
<td>0,415 cp</td>
<td>14,007 kg/m³</td>
<td>0,0067 cp</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1</td>
<td></td>
<td></td>
<td><strong>870,8011 kg/m³</strong></td>
<td><strong>0,332 cp</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>54,3637 lbm/ft³</strong></td>
<td><strong>0,0002 lbm/ft.s</strong></td>
</tr>
</tbody>
</table>

(Sumber: Geankoplis, 2003; Perry, 1999)

Laju alir volumetrik,
\[m_v = \frac{1764,94 \text{ kg/jam}}{870,801 \text{ kg/m}^3} = 2,02 \text{ m}^3/\text{jam} = 0,00056 \text{ m}^3/\text{s} = 0,019 \text{ ft}^3/\text{s}\]

Desain pipa:
\[D_{i, opt} = 0,363 (m_v)^{0,45} (\rho)^{0,13}\]
\[= 0,363 (0,00058 \text{ m}^3/\text{s})^{0,45} (870,799 \text{ kg/m}^3)^{0,13}\]
\[= 0,0301 \text{ m} = 1,1884 \text{ in}\]

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

Ukuran nominal : 1,25 in

Schedule number : 40

Diameter Dalam (ID) : 1,38 in = 0,115 ft

Diameter Luar (OD) : 1,66 in = 0,1383 ft

Inside sectional area : 0,0104 ft²

Kecepatan linier, \[v = \frac{Q}{A} = \frac{0,0198 \text{ ft}^3/\text{s}}{0,0233 \text{ ft}^2} = 0,8532 \text{ ft/s} = 0,2600 \text{ m/s}\]

Bilangan Reynold:
\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]
\[ = \frac{(54,3637 \text{ lbm/ft}^3)(0,8532 \text{ ft/s})(0,1722 \text{ ft})}{0,0002 \text{ lbm/ft.s}} \]
\[ = 35735,42 \text{ (Turbulen)} \]

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

Pada \( N_{Re} = 35735,42 \) dan \( \varepsilon/D = \frac{0,000046 \text{ m}}{0,0525 \text{ m}} = 0,0008 \)

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

*Friction loss:*

1. *Sharp edge entrance:*
   \[ h_e = 0,55 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha} = 0,55(1-0) \frac{0,8532^2}{2(1)(32,174)} \]
   \[ = 0,0062 \text{ ft.lbf/lbm} \]

1. *elbow 90°:*
   \[ h_f = n.Kf. \frac{v^2}{2.g_c} = 1(0,75) \frac{0,8532^2}{2(32,174)} = 0,0084 \text{ ft.lbf/lbm} \]

1. *check valve:*
   \[ h_f = n.Kf. \frac{v^2}{2.g_c} = 1(2) \frac{0,8532^2}{2(32,174)} = 0,0226 \text{ ft.lbf/lbm} \]

Pipa lurus 100 ft:
\[ F_f = 4f \frac{\Delta L \cdot v^2}{D.2.g_c} = 4(0,006) \frac{(100)(0,8532)^2}{(0,1722)(2)(32,174)} \]
\[ = 1576 \text{ ft.lbf/lbm} \]

1. *Sharp edge exit:*
   \[ h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1(1-0) \frac{0,8532^2}{2(1)(32,174)} \]
   \[ = 0,0113 \text{ ft.lbf/lbm} \]

Total *friction loss:*
\[ \sum F = 0,2063 \text{ ft.lbf/lbm} \]

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: \( v_1 = v_2 \)

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

\( \Delta P = 0 \text{ atm} = 0 \text{ lb/ft}^2 \)
tinggi pemompaan $\Delta Z = 30 \text{ ft}$

maka : $0 + \frac{32,174}{32,174}(30) + \frac{5,8538}{54,3636} + W_s = 0$

$W_s = 30,2063 \text{ ft.lbf/lbm}$

Efisiensi pompa, $\eta = 70 \%$

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

$= \frac{30,2063}{0,7}$

$= 43,1518 \text{ ft.lbf/lbm}$.

Daya pompa: $P = m \times W_p$

$= 1,0808 \text{ lbm/s} \times 43,1518 \text{ ft.lbf/lbm}$

$= 46,6398 \text{ ft.lbf/lbm}$

$= 0,0848 \text{ hp}$

Maka dipilih pompa dengan daya motor 1/4 hp.

**LC.14 Heater (HE – 105)**

Fungsi : Menaikkan suhu umpan destilasi sampai suhu operasi destilasi

Jenis : $1–2$ shell and tube exchanger

Dipakai : 1,25 in OD tube 18 BWG, panjang = 16 ft, 2 pass

- Fluida panas
  Laju alir fluida panas = 1008,2834 kg/jam = 2222,8961 lbm/jam
  Temperatur awal ($T_1$) = 360$^\circ$C = 680$^\circ$F
  Temperatur akhir ($T_2$) = 150 $^\circ$C = 302 $^\circ$F

- Fluida dingin
  Laju alir fluida dingin = 1764,9411 kg/jam = 3891,0494 lbm/jam
  Temperatur awal ($t_1$) = 60,265$^\circ$C = 140,477$^\circ$F
  Temperatur akhir ($t_2$) = 113,58 $^\circ$C = 236,444 $^\circ$F
Panas yang diserap (Q) = 423052,3843 kJ/jam = 400974,7165 Btu/jam

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

<table>
<thead>
<tr>
<th>Fluida Panas</th>
<th>Fluida Dingin</th>
<th>Selisih</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_1 = 680 , ^\circ\text{F} )</td>
<td>Temperatur yang lebih tinggi</td>
<td>( t_2 = 113,58 , ^\circ\text{F} )</td>
</tr>
<tr>
<td>( T_2 = 302 , ^\circ\text{F} )</td>
<td>Temperatur yang lebih rendah</td>
<td>( t_1 = 60,265 , ^\circ\text{F} )</td>
</tr>
<tr>
<td>( T_1 - T_2 = 378 , ^\circ\text{F} )</td>
<td>Selisih</td>
<td>( t_2 - t_1 = 95,967 , ^\circ\text{F} )</td>
</tr>
</tbody>
</table>

\[
LMTD = \frac{\Delta t_2 - \Delta t_1}{\ln \left( \frac{\Delta t_2}{\Delta t_1} \right)} = \frac{406,242}{\ln \left( \frac{443,556}{37,314} \right)} = 164,108 \, ^\circ\text{F}
\]

\[
R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{468}{61,758} = 7,5779
\]

\[
S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{61,758}{680 - 174,686} = 0,1222
\]

Dari Gambar 19, Kern, 1965 diperoleh \( F_T = 0,9 \)

Maka \( \Delta t = F_T \times LMTD = 0,9 \times 168,108 = 147,697 \, ^\circ\text{F} \)

(6) \( T_c \) dan \( t_c \)

\[
T_c = \frac{T_1 + T_2}{2} = \frac{680 + 212}{2} = 446 \, ^\circ\text{F}
\]

\[
t_c = \frac{t_1 + t_2}{2} = \frac{174,686 + 236,444}{2} = 205,565 \, ^\circ\text{F}
\]

Dalam perancangan ini digunakan heat exchanger dengan spesifikasi:
- Diameter luar tube (OD) = 1,25 in
- Jenis tube = 18 BWG
- Pitch (P_T) = 1,5625 in square pitch
- Panjang tube (L) = 16 ft

a. Dari Tabel 8, hal. 840, Kern, 1965, exchanger untuk fluida panas light organics dan fluida dingin light organics, diperoleh U_D = 5 - 50, dan faktor pengotor (R_d) = 0,001.

Ditambah U_D = 15 Btu/jam-ft²°C

Luas permukaan untuk perpindahan panas,

\[ A = \frac{Q}{U_D \times \Delta t} = \frac{443182,1513 \text{ Btu/jam}}{15 \frac{\text{Btu}}{\text{jam} \cdot \text{ft}^2 \cdot ^\circ \text{F}}} = 200,041 \text{ ft}^2 \]

Luas permukaan luar (a") = 0,3271 ft²/ft  

(Tabel 10, Kern)

Jumlah tube, \( N_t = \frac{A}{L \times a'} = \frac{200,041 \text{ ft}^2}{16 \text{ ft} \times 0,3271 \text{ ft}^2/\text{ft}} = 38,2224 \) buah

b. Dari Tabel 9, hal. 842, Kern, 1965, nilai yang terdekat adalah 40 tube dengan ID shell 15,25 in.

c. Koreksi U_D

\[ A = L \times N_t \times a' \]
\[ = 16 \text{ ft} \times 40 \times 0,3271 \text{ ft}^2/\text{ft} \]
\[ = 209,344 \text{ ft}^2 \]

\[ U_D = \frac{Q}{A \times \Delta t} = \frac{443182,1513 \text{ Btu/jam}}{209,344 \text{ ft}^2 \times 147,697 ^\circ \text{F}} = 14,3334 \frac{\text{Btu}}{\text{jam} \cdot \text{ft}^2 \cdot ^\circ \text{F}} \]

Fluida panas : steam, tube

(3) Flow area tube,\( a_T' = 1,04 \text{ in}^2 \)  

(Tabel 10, Kern, 1965)

\[ a_T' = \frac{N_t \times a'}{144 \times n} \]

(Pers. (7.48), Kern, 1965)

\[ a_T' = \frac{40 \times 1,04}{144 \times 2} = 0,1444 \text{ ft}^2 \]
(4) Kecepatan masa:

\[ G_t = \frac{w}{a_t} \]  

\[ G_T = \frac{1983.0543}{0.1444} = 13728,8 \text{ lbm/jam.ft}^2 \]  

(Pers. (7.2), Kern, 1965)

(5) Bilangan Reynold:

Pada \( T_c = 446 \, ^\circ\text{F} \)

\( \mu = 0,0169 \, \text{cP} = 0,0409 \, \text{lbm/ft}^2\cdot\text{jam} \)  

(Gambar 14, Kern, 1965)

Dari tabel 10, Kern, untuk 1,25 in OD, 18 BWG, diperoleh:

\[ \text{ID} = 1,15 \text{ in} = 0,0958 \text{ ft} \]

\[ \text{Re}_t = \frac{\text{ID} \times G_t}{\mu} \]  

(Pers.(7.3), Kern, 1965)

\[ \text{Re}_r = \frac{0,0958 \times 13728,8}{0,0409} = 32169,8 \]

(9) Taksir \( j_H \) dari Gambar 24 Kern (1965), diperoleh \( j_H = 87 \) pada \( \text{Re}_T = 32169,8 \)

(10) Pada \( T_c = 446 \, ^\circ\text{F} \)

\( c = 0,82 \, \text{Btu/lbm.}^\circ\text{F} \)  

(Gambar 2, Kern, 1965)

\( k = 0,0217 \, \text{Btu/jam lbm ft.}^\circ\text{F} \)  

(Tabel 5, Kern, 1965)

\[ \left( \frac{c \cdot \mu}{k} \right)^{\frac{1}{2}} = \left( \frac{0,92 \times 0,0409}{0,0271} \right)^{\frac{1}{2}} = 1,1561 \]

(11) \[ \frac{h_i}{\varphi_t} = j_H \times \frac{k}{\text{ID}} \times \left( \frac{c \cdot \mu}{k} \right)^{\frac{1}{2}} \]

\[ \frac{h_i}{\varphi_t} = 87 \times \frac{0,0217}{0,0958} \times 1,1561 = 22,7762 \]

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

\[ \frac{h_{io}}{\varphi_t} = 22,7762 \times \frac{1,15}{1,25} = 20,9541 \]
(9) Pada \( t_w = 397,437 \, ^{\circ}\text{F} \), maka \( \mu_w = 0,018 \) lbm/ft\(^2\)-jam

\[
\varphi_s = \left( \frac{\mu}{\mu_w} \right)^{0.14} = \left( \frac{0,0409}{0,018} \right)^{0.14} = 1,1217
\]

(Kern, 1965)

\[
h_w = \frac{h_{io}}{\varphi_s} \times \varphi_s = 20,9541 \times 1,1217 = 23,5055\text{Btu/jam ft}^2 \, {^{{}^{\circ}\text{F}}}
\]

**Fluida dingin : liquid, shell**

(3') Flow area shell

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

(D_s = Diameter dalam shell = 15,25 in

B = Baffle spacing = 5 in

P_T = Tube pitch = 1,5625 in

C' = Clearance = P_T – OD

\[= 1,5625 – 1,25 = 0,3125 \, \text{in}\]

\[
a_s = \frac{15,25 \times 0,3125 \times 5}{144 \times 1,5625} = 0,1059 \, \text{ft}^2
\]

(4') Kecepatan massa

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

\[
G_s = \frac{4044,4013}{0,1059} = 38189,8 \, \text{lbm/jam ft}^2
\]

(5') Bilangan Reynold

Pada \( t_c = 205,565 \, ^{\circ}\text{F} \)

\( \mu = 0,2666 \) cP = 1,6451 lbm/ft\(^2\)-jam

Dari Gambar 28, Kern, untuk 1 1/4 in dan 1 9/16 in \textit{square pitch}, diperoleh \( D_e = 1,23 \) in.

\( D_e = 1,23/12 = 0,1025 \, \text{ft} \)

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

(Pers. (7.3), Kern, 1965)
\[ \text{Re}_s = \frac{0,1025 \times 38189,8}{0,6451} = 6067,3 \]

(6') Taksir \( J_H \) dari Gambar 28, Kern, diperoleh \( J_H = 46 \) pada \( \text{Re}_l = 6067,3 \)

(7') Pada \( T_c = 205,565 \, ^{0}\text{F} \)

\[ c = 1,4831 \text{ Btu/lbm} \, ^{0}\text{F} \]

\[ k = 0,081 \text{ Btu/jam lbm ft} \, ^{0}\text{F} \]

\[ \left( \frac{c \mu}{k} \right)^{\frac{1}{2}} = \left( \frac{1,4831 \times 0,6451}{0,081} \right)^{\frac{1}{2}} = 2,2774 \]

(8') \[ \frac{h_0}{\varphi_s} = J_H \times \frac{k}{D_c} \times \left( \frac{c \mu}{k} \right)^{\frac{1}{2}} \]

\[ h_0 = 46 \times \frac{0,081}{0,1025} \times 2,2774 = 82,789 \]

(9') Temperatur dinding pipa

\[ t_w = t_c + \frac{h_0}{\varphi_s} \times \frac{1}{\varphi_s} \left( T_c - t_c \right) \]

\[ t_w = 205,565 + \frac{82,789}{20,9541 + 82,789} \left( 446 - 205,565 \right) \]

\[ t_w = 397,437 \, ^{0}\text{F} \]

(10') Pada \( t_w = 397,437 \, ^{0}\text{F} \), maka \( \mu_w = 0,115 \text{ lbm/ft}^2 \cdot \text{jam} \)

\[ \varphi_s = \left( \frac{\mu}{\mu_w} \right)^{0,14} = \left( \frac{0,6451}{0,115} \right)^{0,14} = 1,273 \] (Kern, 1965)

\[ h_o = \frac{h_0}{\varphi_s} \times \varphi_s = 82,789 \times 1,273 = 115,397 \text{ Btu/jam ft}^2 \, ^{0}\text{F} \]
(11) *Clean Overall Coefficient, U_C*

\[ U_C = \frac{h_{in} \times h_{a}}{h_{in} + h_{a}} = \frac{23,5055 \times 105,397}{23,5055 + 105,397} = 19,2129 \text{ Btu/jam.ft}^2.\circ\text{F} \]

(Pers. (6.38), Kern, 1965)

(12) Faktor pengotor, \( R_d \)

\[ R_d = \frac{U_C - U_D}{U_C \times U_D} = \frac{19,2129 - 14,3334}{19,2129 \times 14,3334} = 0,017 \]

(Pers. (6.13), Kern, 1965)

\( R_d \) hitung \( \geq R_d \) ketentuan (0,001), maka spesifikasi pendingin dapat diterima.

**Pressure drop**

*Fluida panas : sisi tube*

(1) Untuk \( \text{Re}_{T} = 32169,8 \)

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

\( s = 1 \)

(2) \[ \Delta P_T = \frac{f \cdot G_T^2 \cdot L \cdot n}{5,22 \cdot 10^{10} \cdot \text{ID} \cdot s \cdot \phi_t} \]

\[ \Delta P_T = \frac{(0,0017) \times (13728,8)^2 \times (16) \times (2)}{(5,22 \cdot 10^{10}) \times (0,0958) \times (1) \times (1,1217)} = 0,00183 \text{ psi} \]

(3) Dari Gambar 27, Kern, 1965 diperoleh \[ \frac{V^2}{2g'} = 0,001 \]

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

\[ = \left(\frac{4n}{s}\right) \cdot 0,001 \]

\[ = 0,008 \text{ psi} \]

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

\[ = 0,00183 \text{psi} + 0,008 \text{psi} \]

\[ = 0,0098 \text{ psi} \]

\( \Delta P_T \) yang diperbolehkan = 10 psi
Fluida panas: sisi shell

(1') Untuk $Re_s = 6067,3$

$f = 0,0012 \text{ ft}^2/\text{in}^2$  

$\phi_s = 1,273$  

$s = 0,98$

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

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

(Pers. (7.43), Kern, 1965)

$D_s = 1,23/12 = 0,1025 \text{ ft}$

(3') $\Delta P_s = \frac{f . G}{s} \cdot D_s \cdot (N + 1) \cdot 5,22.10^{10} \cdot D_c \cdot s \cdot \phi_s$  

(Pers. (7.44), Kern, 1965)

$\Delta P_s = \frac{0,0012 \times (38189,8)^2 \times (0,1025) \times (38,4)}{5,22.10^{10} \times (0,1025) \times (0,98) \times (1,273)} = 0,00103 \text{ psi}$

$\Delta P_s$, yang diperbolehkan = 10 psi

LC.15 Menara Destilasi I (MD-101)

Fungsi: Menghilangkan benzene dari campuran IPB dan DIPB

Jenis: Sieve - tray

Bentuk: silinder vertikal dengan alas dan tutup ellipsoidal

Bahan konstruksi: Carbon steel SA - 285 grade A

Jumlah: 1 unit

Data: Dari perhitungan neraca massa dan neraca panas diperoleh:

$R_D = 0,15$  

$X_{HD} = 0,004$

$R_{DM} = R_D/1,2$

$= 0,125$  

$X_{HF} = 0,8244$

$X_{LF} = 0,0086$

$X_{LW} = 0,046$  

$D = 13,8647 \text{ kmol/jam}$

$X_{HW} = 0,7367$  

$W = 16,807 \text{ kmol/jam}$

$X_{LD} = 0,9267$
\[ \alpha_{LD} = \frac{K_{LK}}{K_{HK}} = \frac{0.9302}{0.0698} = 13.3266 \]

\[ \alpha_{LW} = \frac{K_{LK}}{K_{HK}} = \frac{0.9099}{0.0901} = 10.0987 \]

\[ \alpha_{L,av} = \sqrt{\alpha_{LD} \cdot \alpha_{LW}} = \sqrt{13.3266} \times (10.0987) = 11.6009 \]

(Geankoplis, 2003)

\[ N_m = \frac{\log[(X_{LD} / X_{HD})(X_{HW} / X_{LW})]}{\log(\alpha_{L,av})} \]

(Geankoplis, 2003)

\[ N_m = \frac{\log[(0.9267 / 0.004)(0.7367 / 0.0464)]}{\log(11.6009)} = 3.3496 \]

Dari Fig 11.7 – 3, Geankoplis, hal. 749, untuk \( \frac{R}{R+1} = 0.13 \) dan \( \frac{R_m}{R_m+1} = 0.11 \)

diperoleh \( \frac{N_m}{N} = 0.13 \); maka:

\[ N = \frac{N_m}{0.13} = \frac{3.3496}{0.13} = 25.7663 \]

Jumlah piring teoritis = 25.7663

Efisiensi piring = 85 \% (Geankoplis, 2003)

Maka jumlah piring yang sebenarnya = \( \frac{25.7663}{0.85} = 30.31 \) piring = 31 piring.

Jumlah piring total = 31 + 1 = 32 piring

Penentuan lokasi umpan masuk

\[ \log \frac{N}{N_s} = 0.206 \log \left[ \frac{16.807}{13.865} \cdot \frac{0.8244}{0.0086} \cdot \frac{0.046}{0.004} \right]^2 \] (Geankoplis, 2003)

\[ \frac{N}{N_s} = 7.3112 \]
\[ N_e = 7,3112 N_s \]
\[ N = N_e + N_s \]
\[ 32 = 7,3112 N_s + N_s \]
\[ N_s = 3,8502 \approx 4 \]
\[ N_e = 32 - 4 = 28 \]
Jadi, umpan masuk pada piring ke – 28 dari atas.

Design kolom direncanakan:

- Tray spacing \((t)\) = 0,6 m
- Hole diameter \((d_o)\) = 4,5 mm (Treybal, 1984)
- Space between hole center \((p')\) = 12 mm (Treybal, 1984)
- Weir height \((h_w)\) = 5 cm
- Pitch = triangular \(\frac{3}{4}\) in

Data:

Suhu dan tekanan pada destilasi MD-301 adalah 360,93K dan 1 atm.

Tabel LC.8 Komposisi Bahan pada Alur Vd Kolom Destilasi I MD-101

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Alur Vd (kmol/jam)</th>
<th>Fraksi mol</th>
<th>BM (g/mol)</th>
<th>Fraksi mol x BM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>19,4561</td>
<td>0.953</td>
<td>78.11</td>
<td>74,4801</td>
</tr>
<tr>
<td>IPB</td>
<td>0.9482</td>
<td>0.047</td>
<td>120.19</td>
<td>5,5853</td>
</tr>
<tr>
<td>Total</td>
<td>20,4043</td>
<td>1</td>
<td>80,0654</td>
<td></td>
</tr>
</tbody>
</table>

Laju alir massa gas \((G')\) = 20,4043 kmol/jam
\[ = \frac{20,4043}{3600} = 0,00566 \text{ kmol/detik} \]
\[ \rho_v = \frac{P (BM)_{av}}{RT} = \frac{(1\text{ atm})(80,0654 \text{ kg/kmol})}{(0,082 \text{ m}^3\text{ atm/kmol K})(386,73\text{K})} = 2,5247 \text{ kg/m}^3 \]

Laju alir volumetrik gas \((Q)\) = 0,00566 \(\times\) 22,4 \(\times\) \(\frac{386,73}{273,15}\) = 0,1797 m\(^3\)/s
Tabel LC.9 Komposisi Bahan pada Alur Lb Kolom Destilasi II MD-101

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Alur Lb (kg/jam)</th>
<th>Fraksi massa</th>
<th>$\rho$ (kg/m$^3$)</th>
<th>Fraksi massa x $\rho$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>12,6595</td>
<td>0.0064001</td>
<td>873.8</td>
<td>5.92364034</td>
</tr>
<tr>
<td>IPB</td>
<td>1800,0084</td>
<td>0.91</td>
<td>862</td>
<td>784.4199638</td>
</tr>
<tr>
<td>DIPB</td>
<td>165,3634</td>
<td>0.0836</td>
<td>859</td>
<td>71.81239276</td>
</tr>
<tr>
<td>Total</td>
<td>1978,0313</td>
<td>1</td>
<td>1</td>
<td>861.8247206</td>
</tr>
</tbody>
</table>

Laju alir massa cairan ($L'$) = 0,5494 kg/s

Laju alir volumetrik cairan ($q$) = \( \frac{0,5494}{861,8247} = 0,00063 \, m^3/s \)

Surface tension ($\sigma$) = 0,04 N/m (Lyman, 1982)

\[
\frac{A_o}{A_s} = 0,907 \left( \frac{d_o}{\rho'} \right)^2
\]

\[
\frac{A_o}{A_s} = 0,907 \left( \frac{0,0045}{0,0120} \right)^2 = 0,1275
\]

\[
q \left( \frac{\rho_L}{\rho_V} \right)^{1/2} = \frac{0,0007 \left( 861,8247 \right)^{1/2}}{0,1221 \left( 2,5715 \right)^{1/2}} = 0,09655
\]

\[
\alpha = 0,0744t + 0,01173 = 0,0744(0,6) + 0,01173 = 0,05637
\]

\[
\beta = 0,0304t + 0,05 = 0,0304(0,6) + 0,05 = 0,06824
\]

\[
C_F = \left[ a \log \frac{1}{(q/Q)(\rho_L/\rho_V)^{1/2}} + \beta \left( \frac{\sigma}{0,02} \right)^{0,2} \right] \left( 0,04 \right)_{0,02}^{0,2}
\]

\[
= 0,1550
\]
\[ V_F = C_F \left( \frac{\rho_L - \rho_V}{\rho_V} \right)^{0.5} \]

\[ = 0.1550 \left( \frac{861.8247 - 2.5715}{2.5715} \right)^{0.5} \]

\[ = 2.8599 \text{ m/s} \]

Asumsi 80% kecepatan flooding (Treybal, 1984)

\[ V = 0.8 \times 2.8599 = 2.2879 \text{ m/s} \]

\[ A_n = \frac{Q}{V} = \frac{0.1797}{2.2879} = 0.0785 \text{ m}^2 \]

Untuk \( W = 0.80T \) dari Tabel 6.1. Treybal, hal.162, diketahui bahwa luas downspout sebesar 14.145%.

\[ A_t = \frac{4.6562}{1 - 0.14145} = 5.4233 \text{ m}^2 \]

Column Diameter (T) \[ = \left\{ 4(5.4233)/\pi \right\}^{0.5} \]

\[ = 2.6284 \text{ m} \]

Weir length (W) \[ = 0.8(2.6284) \]

\[ = 2.1028 \text{ m} \]

Downspout area (A_d) \[ = 0.14145(0.7276) \]

\[ = 0.1029 \text{ m}^2 \]

Active area (A_a) \[ = A_t - 2A_d = 5.4233 - 2(0.00824) \]

\[ = 5.40684 \text{ m}^2 \]

Weir crest (h_1)

Misalkan \( h_1 = 0.007279 \text{ m} \)

\[ h_1/T = 0.007279/2.6284 = 0.00277 \]

\[
\frac{T}{W} = \frac{2.6284}{2.1028} = 1.25
\]

\[
\left( \frac{W_{eff}}{W} \right)^2 = \left( \frac{T}{W} \right)^2 - \left\{ \left[ \left( \frac{T}{W} \right)^2 - 1 \right]^{0.5} + 2\left( \frac{h_1}{T} \right) \left( \frac{T}{W} \right) \right\}^2
\]

\[
\left( \frac{W_{eff}}{W} \right)^2 = (1.25)^2 - \left\{ (1.25)^2 - 1 \right\}^{0.5} + 2(0.00277)(1.25)
\]

\[
\left( \frac{W_{eff}}{W} \right) = 1.238
\]
$h_1 = 0,666 \left( \frac{q}{W} \right)^{2/3} \left( \frac{W_{\text{eff}}}{W} \right)^{2/3}$

$h_1 = 0,666 \left( \frac{0,000663}{2,1028} \right)^{2/3} (1,238257)^{2/3}$

$h_1 = 0,0032277$

Perhitungan diulangi dengan memakai nilai $h_1 = 0,0032277$ m hingga nilai $h_1$ konstan pada nilai 0,0032277 m.

### Perhitungan Pressure Drop

**Dry pressure drop**

$A_0 = 0,1275 \times 5,4011 = 0,6886 \text{ m}^2$

$u_o = \frac{Q}{A_o} = 0,1797 \frac{0,6886}{0,6886} = 0,2610 \text{ m/s}$

$C_o = 1,346$ (Treybal, 1981)

$h_a = 51,0 \left( \frac{0,2610^2}{1,346^2} \right) \left( \frac{2,5247}{861,8247} \right)$

$hd = 0,0056 \text{ mm} = 0,00000562 \text{ m}$

### Hydraulic head

$V_a = \frac{Q}{A_a} = \frac{0,1797}{5,4011} = 0,332 \text{ m/s}$

$z = \frac{T + W}{2} = \frac{2,6284 + 2,1028}{2} = 2,3656$

$h_L = 0,0061 + 0,725 h_w - 0,238 h_w V_a \rho_v^{0.5} + 1,225 \left( \frac{q}{z} \right)$

$h_L = 0,0061 + 0,725 (0,05) - 0,238 (0,05)(0,0226)(2,247)^{0.5} + 1,225 \left( \frac{0,000663}{2,3656} \right)$

$h_L = 0,0420 \text{ m}$

**Residual pressure drop**
\[ h_R = \frac{6 \sigma g}{\rho_L d_o g} \]

\[ h_R = \frac{6 (0.04)(1)}{861.8247 (0.0045)(9.8)} = 0.0063 \text{ m} \]

**Total gas pressure drop**

\[ h_G = h_d + h_L + h_R \]

\[ h_G = 0.00000562 + 0.0420 + 0.0063 \]

\[ h_G = 0.048371 \text{ m} \]

**Pressure loss at liquid entrance**

\[ A_{da} = 0.025 \text{ W} = 0.025(2.1027) = 0.05257 \text{ m}^2 \]

\[ h_2 = \frac{3}{2g} \left( \frac{q}{A_{da}} \right)^2 \]

\[ h_2 = \frac{3}{2g} \left( \frac{0.0007}{0.05257} \right)^2 = 0.0000225 \text{ m} \]

**Backup in downspout**

\[ h_3 = h_G + h_2 \]

\[ h_3 = 0.04837 + 0.0000225 \]

\[ h_3 = 0.04839 \text{ m} \]

**Check on flooding**

\[ h_w + h_1 + h_3 = 0.05 + 0.00322 + 0.04839 \]

\[ h_w + h_1 + h_3 = 0.1016 \text{ m} \]

\[ t/2 = 0.6/2 = 0.3 \text{ m} \]

karena nilai \( h_w + h_1 + h_3 \) lebih kecil dari \( t/2 \), maka spesifikasi ini dapat diterima, artinya dengan rancangan plate seperti ini diharapkan tidak terjadi flooding.

Spesifikasi kolom destilasi

Tinggi kolom \( = 32 \times 0.6 \text{ m} = 19.2 \text{ m} \)

Tinggi tutup \( = \frac{1}{4}(2.6284) = 0.6571 \text{ m} \)

Tinggi total \( = 19.2 + 2(0.6571) = 20.51422 \text{ m} \)
Tekanan operasi = 1 atm = 101,325 kPa
Faktor kelonggaran = 5 %
P design = (1+0,05) x 101,325 kPa = 106,391 kPa = 15,430 psi

Joint efficiency (E) = 0,8 (Brownell & Young, 1959)
Allowable stress (S) = 11200 psi (Brownell & Young, 1959)
Faktor korosi = 0,0098 in/tahun
Umur = 10 tahun

Tebal shell tangki:
\[
t = \frac{PR}{SE - 0,6P} = \frac{(15,430)(103,482/2)}{(11200)(0,8) - 0,6(15,430)} = 3,5118 \text{ in}
\]
Maka tebal shell yang dibutuhkan = 3,5118 in + (0,0098)(10) in = 3,6098 in
Tebal shell standar yang digunakan = 3,75 in (Brownell & Young, 1959)
Tebal tutup tangki = tebal shell = 3,75 in

LC.16 Kondensor Sub Cooler (E – 107)
Fungsi : Mengkondensasikan uap dari kolom destilasi (MD–101).
Jenis : 1 – 2 shell and tube exchanger
Dipakai : 1 in OD tube 10 BWG, panjang = 16 ft, 2 pass

- Fluida panas
  Laju alir fluida panas = 1633,6913 kg/jam = 3601,6916 lbm/jam
  Diasumsi uap yang mengembun tertinggal 20%, maka
  Laju alir fluida panas = 3601,6916/0,8 = 4502,1145 lbm/jam
  Temperatur awal (T₁) = 113,58 °C = 236,444 °F
  Temperatur akhir (T₂) = 81,87 °C = 179,366 °F

- Fluida dingin
  Laju alir fluida dingin = 2786,1511 kg/jam = 6142,4438 lbm/jam
Temperatur awal \((t_1)\) = 25 °C = 77 °F  
Temperatur akhir \((t_2)\) = 70 °C = 158 °F  

Panas yang diserap \((Q)\) = 524393,77 kJ/jam = 497027,4361 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 = 236,44 , ^\circ F)</td>
<td>(t_2 = 158 , ^\circ F)</td>
<td>(\Delta t_1 = 78,44)</td>
</tr>
<tr>
<td>(T_2 = 166,78 , ^\circ F)</td>
<td>(t_1 = 77 , ^\circ F)</td>
<td>(\Delta t_2 = 89,78)</td>
</tr>
<tr>
<td>(T_1 - T_2 = 69,66 , ^\circ F)</td>
<td>(t_2 - t_1 = 81 , ^\circ F)</td>
<td>(\Delta t_2 - \Delta t_1 = 11,34 , ^\circ F)</td>
</tr>
</tbody>
</table>

\[LMTD = \frac{\Delta t_2 - \Delta t_1}{\ln \left( \frac{\Delta t_2}{\Delta t_1} \right)} = \frac{11,34}{\ln \left( \frac{89,78}{78,44} \right)} = 83,9864 \, ^\circ F\]

\[R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{69,66}{81} = 0,86\]

\[S = \frac{t_2 - t_1}{T_2 - T_1} = \frac{81}{236,44 - 77} = 0,508\]

Dari Gambar 18, Kern, 1965 diperoleh \(F_T = 0,86\)
Maka \(\Delta t = F_T \times LMTD = 0,95 \times 63,86 = 60,66 \, ^\circ F\)

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

\[T_c = \frac{T_1 + T_2}{2} = \frac{236,44 + 166,784}{2} = 201,614 \, ^\circ F\]

\[t_c = \frac{t_1 + t_2}{2} = \frac{77 + 158}{2} = 117,5 \, ^\circ F\]

Dalam perancangan ini digunakan kondensor dengan spesifikasi:
- Diameter luar tube (OD) = 1 in
- Jenis tube = 10 BWG
- Pitch (P₁) = 1 1/4 in square pitch
- Panjang tube (L) = 16 ft

a. Dari Tabel 8, hal. 840, Kern, 1965, cooler untuk fluida panas gas heavy organich dan fluida dingin air, diperoleh U₇ = 5-75, dan faktor pengotor (Rₐ) = 0,001.

Diamati U₇ = 30 Btu/jam-ft².°F

Luas permukaan untuk perpindahan panas,

\[ A = \frac{Q}{U₇ \times Δt} = \frac{497027,4361 \text{Btu/jam}}{30 \text{Btu/jam} \cdot \text{ft}² \cdot \text{°F} \times 72,2283 \text{°F}} = 229,3778 \text{ft}² \]

Luas permukaan luar (a") = 0,2618 ft²/ft (Tabel 10, Kern)

Jumlah tube, \( N₁ = \frac{A}{L \times a''} = \frac{229,3778 \text{ft}²}{16 \text{ft} \times 0,2618 \text{ft}²/\text{ft}} = 54,7597 \) buah

b. Dari Tabel 9, hal 842, Kern, 1965, nilai yang terdekat adalah 56 tube dengan ID shell 13,25 in.

c. Koreksi U₇

\[ A = L \times N₁ \times a'' = 16 \text{ft} \times 56 \times 0,2618 \text{ft}²/\text{ft} = 234,5728 \text{ft}² \]

\[ U₇ = \frac{Q}{A \cdot Δt} = \frac{497027,4361 \text{Btu/jam}}{234,5728 \text{ft}² \times 72,2283 \text{°F}} = 29,3356 \text{Btu/jam} \cdot \text{ft}² \cdot \text{°F} \]

Fluida panas: gas, tube

(3) Flow area tube, \( a'_{t} = 0,355 \text{ in}² \)

\[ a'_{t} = \frac{N₁ \times a'_{t}}{144 \times n} \] (Pers. (7.48), Kern, 1965)
(4) Kecepatan massa:

\[ G_i = \frac{w}{a_i} \]

\[ G_i = \frac{4682,0918}{0,069} = 67829,1 \text{ lbm/jam.ft}^2 \]

\[ V = \frac{G_i}{3600 \rho} \]

\[ V = \frac{67829,1}{3600 \times 62,5} = 0,3014 \text{ fps} \]

(5) Bilangan Reynold:

\[ \mu = 0,2583 \text{ cP} = 0,6250 \text{ lbm/ft}^2 \cdot \text{jam} \] (Gambar 14, Kern, 1965)

Dari tabel 10, Kern, untuk 1 in OD, 10 BWG, diperoleh:

\[ \text{ID} = 0,67 \text{ in} = 0,0558 \text{ ft} \]

\[ \text{Re}_v = \frac{\text{ID} \times G_i}{\mu} \] (Pers.(7.3), Kern, 1965)

\[ \text{Re}_v = \frac{0,0558 \times 67829,1}{0,6250} = 6058,57 \]

(6) \( h_i = 100 \) (Gambar 25, Kern, 1965)

(7) \( h_{io} = h_i \times \frac{\text{ID}}{\text{OD}} \)

\[ h_{io} = 100 \times \frac{0,67}{1} = 67 \] (Pers.(6.5), Kern, 1965)

Fluida dingin: water, shell

(3') Flow area shell

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

\[ D_s = \text{Diameter dalam shell} = 13,25 \text{ in} \]

\[ B = \text{Baffle spacing} = 5 \text{ in} \]
$P_T = \text{Tube pitch} = 1\frac{1}{4} \text{ in}$

$C' = \text{Clearance} = P_T - \text{OD}$

$= 1\frac{1}{4} - 1 = 0,25 \text{ in}$

$a_s = \frac{13,25 \times 0,25 \times 5}{144 \times 1,25} = 0,092 \text{ ft}^2$

(4’) Kecepatan massa

$$G_s = \frac{w}{g_s}$$

(Pers. (7.2), Kern, 1965)

$$G_s = \frac{6142,4438}{0,092} = 66755,62 \text{ lb}_m/\text{jam}.\text{ft}^2$$

(5’) Bilangan Reynold

Pada $t_c = 117,5^\circ \text{F}$

$\mu = 0,62 \text{ cP} = 1,5004 \text{ lb}_m/\text{ft}^2.\text{jam}$

Dari Gambar 28, Kern, untuk 1 in dan 1\(\frac{1}{4}\) square pitch, diperoleh $D_e = 0,99 \text{ in}$.

$De = 0,99/12 = 0,0825 \text{ ft}$

$$Re_s = \frac{D_e \times G_s}{\mu}$$

(Pers. (7.3), Kern, 1965)

$$Re_s = \frac{0,0825 \times 66755,62}{1,5004} = 3670,58$$

(6’) Asumsi $h = h_o = 200$

$t_w = t_o + \frac{h_o}{h_w + h_o} \times (T_v - t_s)$

$= 117,5 + \frac{200}{67 + 200} \times (201,614 - 117,5)$

$= 180,5067$

$t_r = (T_v + t_w)/2$

$= 149,0034$
(7) Dari fig 12 (Kern, 1965), untuk t = 166,1, diperoleh h = h_o = 229,7146 BTU/hr.ft².°F

(8) Clean Overall Coefficient, U_C

\[ U_C = \frac{h_o \times h_a}{h_o + h_a} = \frac{67 \times 229,7146}{67 + 229,7146} = 51,8709 \text{ Btu/jam.ft}^2.\text{°F} \]

(Pers. (6.38), Kern, 1965)

(9) Faktor pengotor, R_d

\[ R_d = \frac{U_C - U_D}{U_C \times U_D} = \frac{51,8709 - 29,3356}{51,8709 \times 29,3356} = 0,01 \]

(Pers. (6.13), Kern, 1965)

R_d hitung \geq R_d ketentuan (0.001), maka spesifikasi pendingin dapat diterima.

**Pressure drop**

**Fluida panas : sisi tube**

(1) Untuk Re_r = 6058,57

f = 0,0011 ft²/in² \hspace{1cm} \text{(Gambar 26, Kern, 1965)}

s = 98

\( \phi_r = 1 \)

(2) \[ \Delta P_r = \frac{f \cdot G_t^2 \cdot L \cdot n}{5,22 \times 10^{10} \cdot I_D \cdot s \cdot \phi_r} \]

\[ \Delta P_r = \frac{(0,00011) \times (67829,1)^2 \times (16) \times (2)}{(5,22 \times 10^{10}) \times (0,0558) \times (0,98) \times (1)} = 0,0056 \text{ psi} \]

(Pers. (7.53), Kern, 1965)

(3) Dari Gambar 27, Kern, 1965 diperoleh \( \frac{V^2}{2g} = 0,001 \)
\[ \Delta P_r = \frac{4n \cdot \frac{V^2}{s}}{2g'} \]
\[ = \frac{(4)(2)}{0.98} \cdot 0.001 \]
\[ = 0.00816 \text{ psi} \]

\[ \Delta P_T = \Delta P_t + \Delta P_r \]
\[ = 0.0056 \text{ psi} + 0.00816 \text{ psi} \]
\[ = 0.0138 \text{ psi} \]

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

**Fluida dingin : sisi shell**

(1') Untuk \( \text{Re}_s = 3670.58 \)
- \( f = 0.0027 \text{ ft}^2/\text{in}^2 \) (Gambar 29, Kern, 1965)
- \( \phi_s = 0.46 \)
- \( s = 1 \)

(2') \( N + 1 = 12 \times \frac{L}{B} \)
\[ N + 1 = 12 \times \frac{16}{5} = 38.4 \] (Pers. (7.43), Kern, 1965)
\[ D_s = 13.25/12 = 1.1041 \text{ ft} \]

(3') \[ \Delta P_s = \frac{f \cdot G^2 \cdot D_s \cdot (N+1)}{5.22 \times 10^{10} \cdot D_e \cdot s \cdot \phi_s} \]
\[ \Delta P_s = \frac{0.0027 \times (66755,62)^2 \times (1,1041) \times (38.4)}{5.22 \times 10^{10} \times (1,1041) \times (1) \times (0.46)} = 0.01 \text{ psi} \]

\( \Delta P_s \) yang diperbolehkan = 2 psi

**LC.17 Akumulator (AC-101)**

Fungsi : Mengumpulkan destilat yang keluar dari kondensor E-107.

Bahan konstruksi : *Carbon Steel* SA –285 Grade C

Bentuk : Silinder horizontal dengan tutup *ellipsoidal*

Jenis sambungan : *Single welded butt joints*
Jumlah : 1 unit
Kondisi operasi :
Tekanan = 101,325 kPa
Temperatur = 81,87 °C = 355,02 K
Kebutuhan perancangan = 1 jam
Faktor kelonggaran = 20%

Tabel LC.11 Data pada akumulator (AC-101)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>F (kg/jam)</th>
<th>Fraksi Berat</th>
<th>ρ (kg/m³)</th>
<th>ρ campuran (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>1519,7185</td>
<td>0,9303</td>
<td>873,8</td>
<td>812,8964</td>
</tr>
<tr>
<td>IPB</td>
<td>113,9728</td>
<td>0,0697</td>
<td>862</td>
<td>60,0814</td>
</tr>
<tr>
<td>Total</td>
<td>1633,6913</td>
<td>1</td>
<td>972,9778</td>
<td></td>
</tr>
</tbody>
</table>

Perhitungan:

a. Volume Tangki

Volume larutan, \( V_l = \frac{1633,69 kg/jam \times 1 \text{ jam}}{972,9778 kg/m^3} = 1,67 \text{ m}^3 \)

Volume tangki, \( V_t = (1,2) \times 1,67 \text{ m}^3 = 2,0148 \text{ m}^3 \)

Fraksi volum \( V_t/V_l = \frac{1,6790}{2,0148} = 0,8333 \)

Dari gambar 18.15 pada buku Walas dkk, *Chemical Process Equipment* diperoleh untuk fraksi volum 0,8333 maka H/D = 0,777

Asumsi L/D = 1,777

Digunakan dua buah tutup *ellipsoidal* maka volume tutup adalah:

\[ V_h = V_o (V/V_o) = 2 \left[ 0,1309D^3(2)(H/D)^2(1,5-H/D) \right] \]

(Walas dkk, 2005)

\[ = 2 \left[ 0,1309D^3(2)(0,777)^2(1,5-0,777) \right] \]

\[ = 0,2285D^3 \]

Kapasitas shell:

\[ \theta = 2 \arccos \left( 1-2H/D \right) = 2 \arccos \left( 1-2(0,777) \right) = 2 \arccos \left( 1-1,554 \right) \]

\[ = 4,3159 \text{ rad} \]
$$V_s = V_o (\frac{V}{V_o}) = \left( \frac{\pi}{4} \right) D^2 L \left( \frac{1}{2\pi} \right) (0 - \sin \theta)$$

(Walas dkk, 2005)

$$= \left( \frac{\pi}{4} \right) D^2 L \left( \frac{1}{2\pi} \right) (4,3159 - \sin 4,3159)$$

$$= 0,6548 D^2 L$$

Volume tangki $$= V_h + V_s = 0,2285D^3 + 0,6548 D^2 L$$

Dimana $$L/D = 1,777$$, maka volume tangki adalah:

$$V_t = 0,2285D^3 + 1,1636D^3 = 1,3921 D^3$$

$$2,0954 m^3 = 1,3921D^3$$

$$D = 3 \sqrt{\frac{2,0954}{1,3921}} = 1,1305 m = 44,5079 in.$$  

$$L = \frac{2,0954 - 0,2285(1,1305)^3}{0,6548(1,1305)^2} = 2,1093 m.$$  

Tinggi cairan $$= H/D = 0,777 (1,1305) = 0,8784 m.$$  

Perhitungan tinggi tutup:

$$H_4 = \frac{D}{4} = \frac{1,1305}{4} = 0,2826 m$$  

(Walas dkk, 2005)

Perhitungan tinggi shell:

$$H_s = L - 2H_4 = 2,1093 - 2(0,2826) = 1,5441 m.$$  

d. Tebal shell tangki

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

- Allowable stress ($S$) = 13750 psia
- Joint efficiency ($E$) = 0,8
- Corrosion allowance ($C$) = 0,25 mm/tahun  

(Peters dkk, 2004)

- Umur tangki ($n$) = 10 tahun

Tekanan Hidrostatik:

$$P_{hidrostatik} = \rho \times g \times l$$

$$= 972,9778 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 2,1093 \text{ m} = 0,1985 \text{ atm}$$

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

$$P = 1 \text{ atm} + 0,1985 \text{ atm} = 1,1985 \text{ atm}$$
\[ P_{design} = 1,2 \times 1,1985 = 1,4382 \text{ atm} = 21,1357 \text{ psi} \]

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

\[
t = \frac{PR}{SE - 0,6P} = \left( \frac{21,1357 \text{ psi}}{13750 \text{ psi}a} \right) \left( \frac{(44,5079/2 \text{ in})}{(0,8 - 0,6(21,1357 \text{ psi}))} \right)
\]

\[= 0,04 \text{ in} \]

Faktor korosi \[= 0,0098 \text{ in/tahun} \]

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

\[= 0,04 + (10 \times 0,0098)\]

\[= 0,138 \text{ in} \]

Tebal *shell* standar yang digunakan \[= \frac{1}{4} \text{ in} \] (Brownell & Young, 1959)

e. Tebal tutup tangki

Tutup atas tangki terbuat dari bahan yang sama dengan *shell*.

Tebal tutup atas yang digunakan \[= \frac{1}{4} \text{ in} \]

**LC.18 Pompa Recycle Benzena Dan IPB (P-102)**

Fungsi: Mengalirkan Benzene recycle dari menara destilasi I (MD-101) untuk diumpankan kembali ke reaktor (R-101)

Jenis: Pompa sentrifugal

Jumlah: 1 unit

Kondisi operasi:

Tekanan \[= 1 \text{ atm} \]
Temperatur = 74 °C
Laju alir massa (F) = 1420,6 kg/jam = 0,8699 lbm/s

Tabel LC.12 Data pada alur 2

<table>
<thead>
<tr>
<th>Komponen</th>
<th>x</th>
<th>ρ x</th>
<th>μ x</th>
<th>ρ campuran</th>
<th>μ campuran</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0,93</td>
<td>873,8 kg/m³</td>
<td>0,325 cp</td>
<td>821,822 kg/m³</td>
<td>0,302 cp</td>
</tr>
<tr>
<td>IPB</td>
<td>0,07</td>
<td>862 kg/m³</td>
<td>0,415 cp</td>
<td>60,154 kg/m³</td>
<td>0,029 cp</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>872,9765 kg/m³</td>
<td></td>
<td>54,4995 lbm/ft³</td>
<td>0,331 cp</td>
</tr>
</tbody>
</table>

(Sumber: Geankoplis, 2003; Perry, 1999)

Laju alir volumetrik,

\[ m_v = \frac{1420,6 \text{ kg/jam}}{872,977 \text{ kg/m}^3} = 1,6273 \text{ m}^3/\text{s} = 0,00045 \text{ m}^3/\text{s} = 0,0159 \text{ ft}^3/\text{s} \]

Desain pipa:

\[ D_{\text{opt}} = 0,363 (m_v)^{0,45} (\rho)^{0,13} \]

\[ = 0,363 (0,00045 \text{ m}^3/\text{s})^{0.45} (872,977 \text{ kg/m}^3)^{0.13} \]

\[ = 0,0275 \text{ m} = 1,0770 \text{ in} \]

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

Ukuran nominal : 0,75 in
Schedule number : 40
Diameter Dalam (ID) : 0,824 in = 0,0686 ft = 0,0209 m
Diameter Luar (OD) : 1,05 in = 0,0875 ft
Inside sectional area : 0,00371 ft²

Kecepatan linier, \( v = \frac{Q}{A} = \frac{0,0159 \text{ ft}^3/\text{s}}{0,00371 \text{ ft}^2} = 4,3026 \text{ ft/s} = 1,3114 \text{ m/s} \)

Bilangan *Reynold*:

\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]
Untuk pipa *Commercial Steel* diperoleh harga $\varepsilon = 0,000046$  

(Geankoplis, 2003)

Pada $N_{Re} = 72331$ dan $\varepsilon/D = \frac{0,000046 \text{ m}}{0,0209 \text{ m}} = 0,0021$

Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga $f = 0,0067$

*Friction loss*:

1. **Sharp edge entrance;** $h_e = 0,55 \left( \frac{A_1}{A_2} \right) \frac{v^2}{2\alpha} = 0,55\left(1-0\right) \frac{4,3026^2}{2(1)(32,174)}$

   $= 0,1582$ ft.lbf/lbm

2. **Elbow 90°;** $h_f = n.Kf.\frac{v^2}{2.g_c} = 2(0,75) \frac{4,3026^2}{2(32,174)} = 0,4315$ ft.lbf/lbm

1. **Check valve:**

   $h_f = n.Kf.\frac{v^2}{2.g_c} = 1(2) \frac{4,3026^2}{2(32,174)} = 0,5753$ ft.lbf/lbm

Pipa lurus 250 ft:

$F_f = 4f.\frac{\Delta L.v^2}{D.2.g_c} = 4(0,0067) \frac{(250)\left(4,3026\right)^2}{(0,0686)2(32,174)}$

$= 28,0710$ ft.lbf/lbm

1. **Sharp edge exit;**

   $h_{ex} = n\left(1-\frac{A_1}{A_2}\right)\frac{v^2}{2\alpha.g_c} = 1\left(1-0\right)\frac{4,3026^2}{2(1)(32,174)}$

   $= 0,2876$ ft.lbf/lbm

Total *friction loss*:

$\sum F = 29,5238$ 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: $v_1 = v_2$

$P_2 = 2$ atm

$\Delta P = 1$ atm $= 2116,228$ lbf/ft$^2$

tinggi pemompaan $\Delta Z = 20$ ft
maka : \[ 0 + \frac{32,174}{32,174}(20) + \frac{2116,228}{54,5509} + 29,5238 + W_s = 0 \]

\[ W_s = 88,3540 \text{ ft.lbf/lbm} \]

Efisiensi pompa, \( \eta = 70 \% \)

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

\[ = \frac{88,3540}{0,7} \]

\[ = 126,2201 \text{ ft.lbf/lbm.} \]

Daya pompa:

\[ P = m \times W_p \]

\[ = 0,8699 \text{ lbm/s} \times 129,2201 \text{ ft.lbf/lbm} \]

\[ = 109,8064 \text{ ft.lbf/lbm} \]

\[ = 0,1996 \text{ hp} \]

Maka dipilih pompa dengan daya motor 1/4 hp.

**LC.19 Reboiler (E – 106)**

Fungsi : Menguapkan cairan dari kolom destilasi I (MD–101).

Jenis : 1 – 2 shell and tube exchanger

Dipakai : 1 in OD tube 8 BWG, panjang = 16 ft, 2 pass

- Fluida panas

  Laju alir fluida panas = 1789,5296 kg/jam = 4880,31 lbm/jam

  Temperatur awal (T₁) = 360 °C = 680 °F

  Temperatur akhir (T₂) = 150 °C = 302 °F

- Fluida dingin

  Laju alir fluida dingin = 1978,0313 kg/jam = 4630,8353 lbm/jam

  Untuk mencegah fluida menguap semua, diasumsikan hanya 80% fluida yang menguap, sehingga :

  Laju alir fluida dingin = 0,8 x 4630,8353 = 3488,668 lbm/jam
Temperatur awal \( (t_1) \) = 113,58 °C = 236,444 °F 
Temperatur akhir \( (t_2) \) = 159,28 °C = 318,65 °F 

Panas yang diserap \( (Q) \) = 804089,45 kJ/jam = 762126,751 Btu/jam 

(1) Neraca panas

Temperatur umpan masuk adalah temperatur campuran umpan 4535,1529 lbm pada 236,444 °F dan umpan 1133,7882 lbm pada 318,65 °F. Sehingga temperatur umpan \( t = (0,8 \times 236,444) + (0,2 \times 318,65) = 252,885 \) °F

Preheating :

Entalpi cairan pada 252,885 °F = 131,95 Btu/lbm 
Entalpi cairan pada 318,65 °F = 140,24 Btu/lbm 
\( q_p = 5668,941 \times (140,24 - 131,95) = 46995,5218 \) Btu/jam

Penguapan isotermal :

Entalpi uap pada 318,65 °F = 202,1 Btu/lbm 
\( q_v = 4535,1529 \times (202,1 - 140,24) = 280544,5579 \) Btu/jam

\( \Delta t_p = \frac{(680 - 318,65) - (302 - 252,885)}{\ln \left( \frac{680 - 318,65}{302 - 252,885} \right)} = 156,4552 \) °F

\( \Delta t_v = 680 - 318,65 = 361,35 \) °F

\( \frac{q_p}{(\Delta t)_p} = \frac{46995,5218}{156,4552} = 300,3767 \)

\( \frac{q_v}{(\Delta t)_v} = \frac{280544,5579}{361,35} = 776,379 \)

\( \Delta t = \sum \frac{q_v}{(\Delta t)_v} = 707,799 \) °F

Dalam perancangan ini digunakan Reboiler dengan spesifikasi:

- Diameter luar tube (OD) = 1 in
- Jenis tube = 8 BWG
- Jumlah tube = 56
- Pitch ($P_t$) = 1,25 in *square pitch*
- Panjang *tube* ($L$) = 16 ft

**Fluida panas : steam, tube**

(3) Flow area tube, $a_t^i = 0,355 \text{ in}^2$ (Tabel 10, Kern, 1965)

$$a_t = \frac{N_t \times a_t^i}{144\times n}$$ (Pers. (7.48), Kern, 1965)

$$a_t = \frac{56 \times 0,355}{144 \times 2} = 0,069 \text{ ft}^2$$

(4) Kecepatan massa:

$$G_t = \frac{w}{a_t}$$ (Pers. (7.2), Kern, 1965)

$$G_t = \frac{4880,31}{0,08333} = 56311,27 \text{ lbm/jam.ft}^2$$

(5) Bilangan Reynold:

Pada $T_c = 491 \degree F$

$$\mu = 0,0182 \text{ cP} = 0,04404 \text{ lbm/ft}^2\cdot \text{jam}$$ (Gambar 14, Kern, 1965)

Dari tabel 10, Kern, untuk 1 in OD, 8 BWG, diperoleh :

ID = 0,67 in = 0,0558 ft

$$Re_t = \frac{ID \times G_t}{\mu}$$ (Pers. (7.3), Kern, 1965)

$$Re_t = \frac{0,0558 \times 3945,2585}{0,04404} = 72453,3$$

(6) $h_{io} = h_{io} = h_o \frac{ID}{OD}$

$$= h_o = 18,1798 \frac{0,67}{1} = 12,1805$$

**Fluida dingin : bahan, 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)
Ds = Diameter dalam shell = 13,75 in
B = Baffle spacing = 5 in
PT = Tube pitch = 1,25 in
C' = Clearance = PT – OD
    = 1,25 – 1 = 0,25 in
\[ a_s = \frac{13,25 \times 0,25 \times 5}{144 \times 1,25} = 0,0959 \text{ ft}^2 \]

(4') Kecepatan massa
\[ G_s = \frac{w}{a_s} \]  
(Pers. (7.2), Kern, 1965)
\[ G_s = \frac{5668,94}{0,0959} = 59369,3 \text{ lb}_m/\text{jam}.\text{ft}^2 \]

(5') Bilangan Reynold
Pada \( t_v = 252,885 \text{ °F} \)
\( \mu = 0,2277 \text{ cP} = 0,551 \text{ lb}_m/\text{ft}^2.\text{jam} \)
Dari Gambar 28, Kern, untuk 1 in dan 1,25 square pitch,
diperoleh \( D_s = 0,99 \text{ in} \).
\( D_e = 0,99/12 = 0,0825 \text{ ft} \)
\[ Re_s = \frac{D_s \times G_s}{\mu} \]  
(Pers. (7.3), Kern, 1965)
\[ Re_s = \frac{0,0825 \times 59369,3}{0,551} = 8888,68 \]

(6') Taksir \( J_H \) dari Gambar 28, Kern, diperoleh \( J_H = 15 \) pada \( Re_s = 8888,68 \)

(7') Pada \( t_c = 252,885 \text{ °F} \)
\( c = 0,5443 \text{ Btu/lb}_m.\text{°F} \)
\( k = 0,0567 \text{ Btu/jam lb}_m.\text{ft.°F} \)
\[ \left( \frac{c \mu}{k} \right)^{1/3} = \left( \frac{0,5643 \times 0,0549}{0,0567} \right)^{1/3} = 1,7634 \]
(8') \[
\frac{h_a}{\phi_a} = J_{hu} \times \frac{k}{D_e} \times \left( \frac{c \mu}{k} \right)^{\frac{1}{3}}
\]
\[
h_a = 15 \times 0.0567 \times 1.76346 = 18,1798
\]

**Clean overall coefficient untuk preheating** :
\[
U_p = \frac{h_{in} \times h_a}{h_{io} + h_o} = \frac{12,1805 \times 18,1798}{12,1805 + 18,1798} = 7,2938 \text{ Btu/jam.ft}^2 \cdot ^\circ F
\]

Permukaan bersih yang dibutuhkan untuk penguapan :
\[
A_p = \frac{q_p}{U_p(\Delta t)_p} = 44,1831 \text{ ft}^2
\]

**Penguapan** :
(9) Pada 318,65°F
\[
\mu = 0.0227 \text{ cP} = 0.0549 \text{ lbm/ft}^2 \cdot \text{jam}
\]
\[
Re_j = \frac{0.0825 \times 59369.3}{0.0549} = 89160.9
\]

(10) \( jH = 168 \)

(12) Pada 244,4°F, diperoleh :
\[
\left( \frac{c \mu}{k} \right)^{\frac{1}{3}} = 0.8146
\]
\[
(12) \frac{h_v}{\phi_v} = J_{hv} \times \frac{k}{D_e} \times \left( \frac{c \mu}{k} \right)^{\frac{1}{3}} = 96,2108
\]

**Clean overall coefficient untuk penguapan** :
\[
U_v = \frac{h_{in} \times h_a}{h_{io} + h_o} = \frac{12,1805 \times 96,2108}{12,1805 + 96,2108} = 10,8116 \text{ Btu/jam.ft}^2 \cdot ^\circ F
\]

Permukaan bersih yang dibutuhkan untuk penguapan :
\[
A_v = \frac{q_v}{U_v(\Delta t)_v} = 71,8092 \text{ ft}^2
\]
\[ Ac = A_p + A_v = 41,1831 + 71,8092 = 112,9923 \text{ ft}^2 \]

(13) **Clean Overall Coefficient, \( U_C \)**

\[ U_C = \frac{\sum UA}{Ac} = \frac{303,3767 + 776,3790}{112,9923} = 9,5294 \text{ Btu/jam. ft}^2.\circ F \]

(Pers. (6.38), Kern, 1965)

(13) **Design Overall Coefficient**

\[ A = N_i(L).(a^n) \]

\[ A = 56(16).(0.2618) = 234,573 \text{ ft}^2 \]

\[ \frac{Q}{A \times \Delta t} = \frac{762126,751}{234,573 \times 707,799} = 4,5903 \]

(Pers. (6.13), Kern, 1965)

Dari Table 8 Kern, 1965 Ud yang diizinkan = 5

(15) Faktor pengotor, \( R_d \)

\[ R_d = \frac{U_C - U_D}{U_C \times U_D} = \frac{9,5294 - 5}{9,5294 \times 5} = 0,095 \]

(Pers. (6.13), Kern, 1965)

\( R_d \) hitung \( \geq \) \( R_d \) ketentuan (0,003), maka spesifikasi pendingin dapat diterima.

**Pressure drop**

**Fluid panas : sisi tube**

(1) Untuk \( \text{Re}_t = 72453,3 \)

\[ f = 0,00015 \text{ ft}^2/\text{in}^2 \]

\[ s = 1 \]

\[ \phi_t = 1 \]

(2) \[ \Delta P_t = \left( \frac{1}{2} \right) \frac{f \cdot G_t \cdot L \cdot n}{5,22 \cdot 10^{10} \cdot ID \cdot s \cdot \phi_t} \]

(Pers. (7.53), Kern, 1965)

\[ \Delta P_t = \left( \frac{1}{2} \right) \frac{(0,00015) \times (57154,7)^2 \times (16) \times (2)}{(5,22 \cdot 10^{10}) \times (0,0558) \times (1) \times (1)} = 0,0027 \text{ psi} \]

**Fluid dingin : sisi shell**

(1') Untuk \( \text{Re}_s = 8888,68 \)

\[ f = 0,0022 \text{ ft}^2/\text{in}^2 \]

(Gambar 29, Kern, 1965)
\( \phi_s = 1 \)
\( s = 0.98 \)

(2') Panjang daerah preheating:

\[
L_p = \frac{L_A}{A_c}
\]

\[
= 16 \times \frac{(71,8092/112,9924)}{10,1684} = 10,1684 \text{ ft}
\]

(3') \( N + 1 = 12 \times \frac{L_p}{B} \)

\[
N + 1 = 12 \times \frac{10,1684}{5} = 24,4140 \quad \text{(Pers. (7.43), Kern, 1965)}
\]

\[
D_s = 13,73/12 = 1,1458 \text{ ft}
\]

(4') \( \Delta P_s = \left( \frac{1}{2} \right) f \frac{G_s^2}{\varphi_s} = \frac{D_s}{(N + 1)} \)

\[
\Delta P_s = \left( \frac{1}{2} \right) \frac{0,0022 \times (59369,3)^2 \times (1,1458) \times (24,4041)}{5,22 \times 10^{10} \times (0,0825) \times (0,98) \times (1)} = 0,0514 \text{ psi}
\]

Penguapan

(1') \( Re_x = 89160,9 \)
\( f = 0,0015 \)

(2') Panjang daerah penguapan:

\[
L_v = 16 - 10,1684 = 5,8316 \text{ ft}
\]

(3') Jumlah Crosses,

\[
N + 1 = 12 \times \frac{L_v}{B}
\]

\[
N + 1 = 12 \times \frac{5,8316}{5} = 13,9959 \quad \text{(Pers. (7.43), Kern, 1965)}
\]

\[
D_s = 13,25/12 = 1,1458 \text{ ft}
\]

(4') \( \Delta P_s = \left( \frac{1}{2} \right) f \frac{G_s^2}{\varphi_s} = \frac{D_s}{(N + 1)} \)

\[
\Delta P_s = \left( \frac{1}{2} \right) \frac{0,0022 \times (59369,3)^2 \times (1,1458) \times (24,4041)}{5,22 \times 10^{10} \times (0,0825) \times (0,98) \times (1)} = 0,0514 \text{ psi}
\]
\[
\Delta P_s = \frac{1}{2} \left( 0,0015 \times (59369,3)^2 \times (1,1458) \times (13,9959) \right) \times \left( 5,22 \times 10^{10} \times (0,0825) \times (0,98) \times (1) \right) = 0,0201 \text{ psi}
\]

\[
\Delta P_s = 0,0514 + 0,0201 = 0,0715
\]

**LC.20 Pompa Umpan Destilasi II (P-05)**

Fungsi : Mengalirkan hasil bawah menara destilasi I (MD-101) untuk diumpankan ke menara destilasi II (MD-102)

Jenis : Pompa sentrifugal

Jumlah : 1 unit

Kondisi operasi :

- Tekanan = 1 atm
- Temperatur = 159,25 °C
- Laju alir massa (F) = 344,34 kg/jam = 0,2108 lbm/s

Tabel LC.13 Data pada alur 20

<table>
<thead>
<tr>
<th>Komponen</th>
<th>x</th>
<th>ρ x</th>
<th>μ x</th>
<th>ρ campuran</th>
<th>μ campuran</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0,006</td>
<td>873,8 kg/m³</td>
<td>0,13 cp</td>
<td>5,6122 kg/m³</td>
<td>0,0008 cp</td>
</tr>
<tr>
<td>IPB</td>
<td>0,91</td>
<td>862 kg/m³</td>
<td>0,19 cp</td>
<td>784,4989 kg/m³</td>
<td>0,1729 cp</td>
</tr>
<tr>
<td>DIPB</td>
<td>0,083</td>
<td>859 kg/m³</td>
<td>0,21 cp</td>
<td>71,7232 kg/m³</td>
<td>0,0175 cp</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1</td>
<td><strong>861,825 kg/m³</strong></td>
<td><strong>0,1912 cp</strong></td>
<td><strong>53,8034 lbm/ft³</strong></td>
<td><strong>0,0001 lbm/ft.s</strong></td>
</tr>
</tbody>
</table>

(Sumber: Geankoplis, 2003; Perry, 1999)

Laju alir volumetrik,

\[
m_v = \frac{344,34 \text{ kg/jam}}{861,825 \text{ kg/m}^3} = 0,3995 \text{ m}^3/\text{s} = 0,00011 \text{ m}^3/\text{s} = 0,0039 \text{ ft}^3/\text{s}
\]

Desain pipa:

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

\[
= 0,363 \left( 0,00011 \text{m}^3/\text{s} ^{0,45} (861,825 \text{ kg/m}^3) ^{0,13} \right)
\]
\[= 0,0145 \text{ m} = 0,5715 \text{ in}\]

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

- **Ukuran nominal**: 0,75 in
- **Schedule number**: 40
- **Diameter Dalam (ID)**: 0,824 in = 0,0686 ft = 0,0209 m
- **Diameter Luar (OD)**: 1,05 in = 0,0875 ft
- **Inside sectional area**: 0,0031 ft²

Kecepatan linier, \(v = \frac{Q}{A} = \frac{0,0040 \text{ ft}^3/\text{s}}{0,0037 \text{ ft}^2} = 1,0986 \text{ ft/s} = 0,3348 \text{ m/s}\)

**Bilangan Reynolds (Re):**

\[N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{(53,8034 \text{ lbm/ft}^3)(1,0564 \text{ ft/s})(0,0686 \text{ ft})}{0,0001 \text{ lbm/ft.s}}\]

\[= 30363,43 \text{ (Turbulen)}\]

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

Pada \(N_{Re} = 30363,43\) dan \(\varepsilon/D = \frac{0,000046}{0,0209} = 0,0021\)

Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga \(f = 0,0075\)

**Friction loss:**

1. **Sharp edge entrance:** \(h_c = 0,55 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2\alpha} = 0,55(1 - 0) \frac{1,056^2}{2(1)(32,174)}\)
   \[= 0,0095 \text{ ft.lbf/lbm}\]

2. **elbow 90°:** \(h_f = n.Kf. \frac{v^2}{2g_c} = 3(0,75) \frac{1,056^2}{2(32,174)} = 0,039 \text{ ft.lbf/lbm}\)

3. **check valve:** \(h_f = n.Kf. \frac{v^2}{2g_c} = 1(2) \frac{1,056^2}{2(32,174)} = 0,0346 \text{ ft.lbf/lbm}\)

Pipa lurus 150 ft: \(F_f = 4f \frac{\Delta L \cdot v^2}{D.2g_c} = 4(0,0075) \frac{(150)(1,056)^2}{(0,0686)2(32,174)}\)
1. Sharp edge exit:

\[
\begin{align*}
1 \text{ Sharp edge exit:} & \quad h_{ex} = n \left(1 - \frac{A_1}{A_2}\right) \frac{v^2}{2 \alpha g_c} = 1 \left(1 - 0\right) \frac{1.056^2}{2 \left(174.32\right) - 0}\n= 0.0173 \text{ ft.lbf/lbm}
\end{align*}
\]

Total friction loss:

\[
\sum F = 1.2371 \text{ ft.lbf/lbm}
\]

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: \(v_1 = v_2\)

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

\(\Delta P = 0 \text{ atm} = 0 \text{ lb/ft}^2\)

tinggi pemompaan \(\Delta Z = 35 \text{ ft}\)

maka:

\[
0 + \left(\frac{32.174}{32.174}\right) + \frac{0}{53.8034} + 1.2371 + W_s = 0
\]

\[
W_s = 36.2371 \text{ ft.lbf/lbm}
\]

Efisiensi pompa, \(\eta = 70\%\)

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

(geankoplis, 2003)

\[
= \frac{36.2371}{0.7}
\]

\[
= 51.7673 \text{ ft.lbf/lbm}
\]

Daya pompa:

\[
P = \rho \times W_p
\]

\[
= 0.2108 \text{ lbm/s} \times 51.7673 \text{ ft.lbf/lbm}
\]

\[
= 10.9161 \text{ ft.lbf/lbm}
\]

\[
= 0.0198 \text{ hp}
\]

Maka dipilih pompa dengan daya motor 1/4 hp.
LC.21 Menara Destilasi II (MD-102)

Fungsi : Memekatkan produk utama IPB dari DIPB dan benzene
Jenis : Sieve – tray
Bentuk : silinder vertikal dengan alas dan tutup ellipsoidal
Bahan konstruksi : Carbon steel SA – 285 grade A
Jumlah : 1 unit

Data : Dari perhitungan neraca massa dan neraca panas diperoleh:

\[
\begin{align*}
R_D &= 0,15 \\
X_{HD} &= 0,0105 \\
R_{DM} &= R_D / 1,2 \\
X_{HF} &= 0,9617 \\
&= 0,125 \\
X_{LF} &= 0,0104 \\
X_{LW} &= 0,0106 \\
D &= 2,7381 \text{ kmol/jam} \\
X_{HW} &= 0,9894 \\
W &= 0,1844 \text{ kmol/jam} \\
X_{LD} &= 0,9886
\end{align*}
\]

\[
\begin{align*}
\alpha_{LD} &= \frac{K_{LK}}{K_{HK}} = \frac{0,9896}{0,03} = 32,9866 \\
\alpha_{LW} &= \frac{K_{LK}}{K_{HK}} = \frac{0,9907}{0,01} = 99,07 \\
\alpha_{L,av} &= \sqrt{\alpha_{LD} \cdot \alpha_{LW}} = \sqrt{(32,9866) \times (99,07)} = 57,1662
\end{align*}
\]

(Geankoplis,2003)

\[
N_m = \frac{\log[(X_{LD} / X_{HD})(X_{HF} / X_{LW})]}{\log(\alpha_{L,av})}
\]

(Geankoplis,2003)

\[
= \frac{\log[0,9886 / 0,0105)(0,9894 / 0,0106)]}{\log(57,1662)}
\]

\[
= 2,2445
\]

Dari Fig 11.7 – 3, Geankoplis, hal. 749, untuk \( \frac{R}{R + 1} = 0,13 \) dan \( \frac{R_m}{R_m + 1} = 0,11 \)

diperoleh \( \frac{N_m}{N} = 0,13 \); maka:
\[ N = \frac{N_m}{0,13} = \frac{2,2445}{0,13} = 17,2653 \]

Jumlah piring teoritis = 17,2653

Efisiensi piring = 85 % \hspace{1cm} \text{(Geankoplis, 2003)}

Maka jumlah piring yang sebenarnya = \[\frac{17,2653}{0,85} = 20,31 \text{ piring} \approx 21 \text{ piring} \]

Jumlah piring total = 21 + 1 = 22 piring

Penentuan lokasi umpan masuk

\[ \log \frac{N}{N_s} = 0,206 \log \left[ \frac{0,1844}{2,7381} \frac{0,9617}{0,0104} \left( \frac{0,0106}{0,0105} \right)^2 \right] \]

\[ \frac{N_e}{N_s} = 1,4632 \]

\[ N_e = 1,4632 N_s \]

\[ N = N_e + N_s \]

\[ 22 = 1,4632 N_s + N_s \]

\[ N_s = 8,9312 \approx 9 \]

\[ N_e = 22 - 9 = 13 \]

Jadi, umpan masuk pada piring ke – 13 dari atas.

Design kolom direncanakan:

- Tray spacing \( (t) \) = 0,6 m
- Hole diameter \( (d_o) \) = 4,5 mm \hspace{1cm} \text{(Treybal, 1984)}
- Space between hole center \( (p') \) = 12 mm \hspace{1cm} \text{(Treybal, 1984)}
- Weir height \( (h_w) \) = 5 cm
- Pitch = \text{triangular \( \frac{3}{4} \) in}

Data:

Suhu dan tekanan pada destilasi MD-301 adalah 360,93K dan 1 atm.
Tabel LC.14 Komposisi Bahan pada Alur Vd Kolom Destilasi II MD-102

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Alur Vd</th>
<th>Fraksi mol</th>
<th>BM</th>
<th>Fraksi mol x BM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(kmol/jam)</td>
<td>(g/mol)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benzen</td>
<td>0,0325</td>
<td>0,010724</td>
<td>78,11</td>
<td>0,8376</td>
</tr>
<tr>
<td>IPB</td>
<td>2,996</td>
<td>0,98855</td>
<td>120,19</td>
<td>118,8138</td>
</tr>
<tr>
<td>DIPB</td>
<td>0,0022</td>
<td>0,000726</td>
<td>162</td>
<td>0,117596</td>
</tr>
<tr>
<td>Total</td>
<td>3,0307</td>
<td>1</td>
<td></td>
<td>119,76910</td>
</tr>
</tbody>
</table>

Laju alir massa gas \( (G') = 3,0307 \text{ kmol/jam} \)

\[
\rho_v = \frac{P \times BM}{RT} = \frac{(1 \text{ atm})(119,7691 \text{ kg/kmol})}{(0,082 \text{ m}^3\text{atm/kmol K})(432,4\text{K})} = 3,3778 \text{ kg/m}^3
\]

Laju alir volumetrik gas \( (Q) = 0,00084 \times 22,4 \times \frac{432,4}{273,15} = 0,0298 \text{ m}^3/\text{s} \)

Tabel LC.15 Komposisi Bahan pada Alur Lb Kolom Destilasi II MD-102

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Alur Lb (kg/jam)</th>
<th>Fraksi massa</th>
<th>( \Box_L ) (kg/m³)</th>
<th>Fraksi massa x ( \Box_L )</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPB</td>
<td>3,1335</td>
<td>0.008</td>
<td>862</td>
<td>6.895000121</td>
</tr>
<tr>
<td>DIPB</td>
<td>388,555</td>
<td>0.992</td>
<td>859</td>
<td>852.1280995</td>
</tr>
<tr>
<td>Total</td>
<td>391,6885</td>
<td>1</td>
<td></td>
<td>859.0239997</td>
</tr>
</tbody>
</table>

Laju alir massa cairan \( (L') = 0,1088 \text{ kg/s} \)

Laju alir volumetrik cairan \( (q) = \frac{0,1088}{859,024} = 0,000126 \text{ m}^3/\text{s} \)

**Surface tension** \( (\sigma) = 0,04 \text{ N/m} \)

\[
\frac{A_s}{A_o} = 0,907 \left( \frac{d_o}{p'} \right)^2
\]

\[
\frac{A_s}{A_o} = 0,907 \left( \frac{0,0045}{0,0120} \right)^2 = 0,1275
\]
\[
\frac{q}{Q} \left( \frac{\rho_L}{\rho_V} \right)^{1/2} = \frac{0.00013 \left( \frac{859.02399}{3.3778} \right)^{1/2}}{0.0230} = 0.0676
\]

\[
\alpha = 0.0744t + 0.01173 = 0.0744(0.6) + 0.01173 = 0.05637
\]

\[
\beta = 0.0304t + 0.05 = 0.0304(0.6) + 0.05 = 0.06824
\]

\[
C_F = \left[ \alpha \log \left( \frac{1}{(q/Q)(\rho_L/\rho_V)^{1/2}} \right) + \beta \right]^{0.2} \frac{\sigma}{0.02}
\]

\[
= \left[ 0.05637 \log \left( \frac{1}{0.0676} \right) + 0.06824 \left( \frac{0.04}{0.02} \right) \right]^{0.2}
\]

\[
= 0.1541
\]

\[
V_F = C_F \left( \frac{\rho_L - \rho_V}{\rho_V} \right)^{0.5}
\]

\[
= 0.1541 \left( \frac{859.02399 - 3.3778}{3.3778} \right)^{0.5}
\]

\[
= 2.4530 \text{ m/s}
\]

Asumsi 80 % kecepatan flooding (Treybal, 1984)

\[ V = 0.8 \times 2.4530 = 1.9624 \text{ m/s} \]

\[ A_n = \frac{Q}{V} = \frac{0.0298}{1.9624} = 0.0152 \text{ m}^2 \]

Untuk W = 0,80T dari Tabel 6.1. Treybal, hal.162, diketahui bahwa luas downspout sebesar 14.145%.

\[ A_t = \frac{4.6562}{1 - 0.1415} = 5.4233 \text{ m}^2 \]

\[
\begin{align*}
\text{Column Diameter (T)} &= \left[ 4(5.4233)/\pi \right]^{0.5} = 2.6284 \text{ m} \\
\text{Weir length (W)} &= 0.8(2.6284) = 2.1028 \text{ m} \\
\text{Downspout area (A_d)} &= 0.14145(0.7276) = 0.1029 \text{ m}^2 \\
\text{Active area (A_a)} &= A_t - 2A_d = 5.4233 - 2(0.00824) = 5.40684 \text{ m}^2
\end{align*}
\]
Weir crest \( (h_1) \)

Misalkan \( h_1 = 0,007279 \) m

\[
\frac{h_1}{T} = \frac{0,007279}{2,6284} = 0,00277
\]

\[
\frac{T}{W} = \frac{2,6284}{2,1028} = 1,25
\]

\[
\left( \frac{W_{\text{eff}}}{W} \right)^2 = \left( \frac{T}{W} \right)^2 - \left[ \left( \frac{T}{W} \right)^2 - 1 \right]^{0.5} + 2 \left( \frac{h_1}{T} \right) \left( \frac{T}{W} \right)^2
\]

\[
\left( \frac{W_{\text{eff}}}{W} \right)^2 = (1,25)^2 - \left[ (1,25)^2 - 1 \right]^{0.5} + 2(0,00277)(1,25)^2
\]

\[
\left( \frac{W_{\text{eff}}}{W} \right)^2 = 1,238
\]

\[
h_1 = 0,666 \left( \frac{d}{W} \right)^{2/3} \left( \frac{W_{\text{eff}}}{W} \right)^{2/3}
\]

\[
h_1 = 0,666 \left( \frac{0,000126}{2,1028} \right)^{2/3} (1,238257)^{2/3}
\]

\[
h_1 = 0,00109
\]

Perhitungan diulangi dengan memakai nilai \( h_1 = 0,00109 \) m hingga nilai \( h_1 \) konstan pada nilai \( 0,00109 \) m.

**Perhitungan Pressure Drop**

**Dry pressure drop**

\[
A_0 = 0,1275 \times 5,4190 = 0,69092 \text{ m}^2
\]

\[
u_0 = \frac{Q}{A_0} = \frac{0,02985}{0,69092} = 0,0432 \text{ m/s}
\]

\[
C_o = 1,346
\]

(Treybal, 1981)

\[
h_d = 51,0 \left( \frac{0,0432^2}{1,346^2} \right) \left( \frac{3,3778}{859,02399} \right)
\]

\[
h_d = 0,00020 \text{ mm} = 0,0000021 \text{ m}
\]
Hydraulic head

\[ V_a = \frac{Q}{A_s} = \frac{0.0298}{5.4193} = 0.0055 \text{ m/s} \]

\[ z = \frac{T + W}{2} = \frac{2.6284 + 2.1028}{2} = 2.3655 \]

\[ h_L = 0.0061 + 0.725 h_w - 0.238 h_w V_a \rho_s^{0.5} + 1.225 \left( \frac{q}{z} \right) \]

\[ h_L = 0.0061 + 0.725 (0.05) - 0.238 (0.05)(0.0055)(3.377)^{0.5} + 1.225 \left( \frac{0.000126}{2.3655} \right) \]

\[ h_L = 0.04229 \text{ m} \]

Residual pressure drop

\[ h_R = \frac{6 \sigma g_c}{\rho_v d_v g} \]

\[ h_R = \frac{6 (0.04) (1)}{859,02399 (0.0045)(9.8)} = 0.0063 \text{ m} \]

Total gas pressure drop

\[ h_G = h_d + h_L + h_R \]

\[ h_G = 0.00000017 + 0.0423 + 0.0063 \]

\[ h_G = 0.04864 \text{ m} \]

Pressure loss at liquid entrance

\[ A_{da} = 0.025 \text{ W} = 0.025(2,1027) = 0.05257 \text{ m}^2 \]

\[ h_2 = \frac{3}{2g} \left( \frac{q}{A_{da}} \right)^2 \]

\[ h_2 = \frac{3}{2g} \left( \frac{0.00013}{0.05257} \right)^2 = 0.000001 \text{ m} \]

Backup in downspout

\[ h_3 = h_G + h_2 \]
\[ h_3 = 0,04864 + 0,000001 \]
\[ h_3 = 0,04864 \text{ m} \]

*Check on flooding*

\[ h_w + h_1 + h_3 = 0,05 + 0,00133 + 0,04864 \]

\[ h_w + h_1 + h_3 = 0,0998 \text{ m} \]

\[ t/2 = 0,6/2 = 0,3 \text{ m} \]

Karena nilai \( h_w + h_1 + h_3 \) lebih kecil dari \( t/2 \), maka spesifikasi ini dapat diterima, artinya dengan rancangan *plate* seperti ini diharapkan tidak terjadi *flooding*.

**Spesifikasi kolom destilasi**

- Tinggi kolom = 22 x 0,6 m = 13,2 m
- Tinggi tutup = \( \frac{1}{4} (2,6284) = 0,6571 \text{ m} \)
- Tinggi total = 13,2 + 2(0,6571) = 14,5142 m
- Tekanan operasi = 1 atm = 101,325 kPa
- Faktor kelonggaran = 5 %
- \( P_{design} = (1+0,05) \times 101,325 \text{ kPa} = 106,392 \text{ kPa} = 15,431 \text{ psi} \)

*Joint efficiency* (E) = 0,8  
*Allowable stress* (S) = 11200 psi  
Faktor korosi = 0,0098 in/tahun  
Umur = 10 tahun

**Tebal shell tangki:**

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

\[ t = \frac{(15,431)(103,482/2)}{(11200)(0,8) - 0,6(15,431)} \]

\[ = 3,5118 \text{ in} \]

Maka tebal shell yang dibutuhkan = 3,5118 in + (0,0098)(10) in = 3,6098 in
Tebal shell standar yang digunakan = 3,75 in (Brownell & Young, 1959)
Tebal tutup tangki = tebal shell = 3,75 in

**L.C.22 Kondensor Sub Cooler (E – 108)**

Fungsi : Mengkondensasikan uap dari kolom destilasi (MD–102).

Jenis : 1 – 2 shell and tube exchanger

Dipakai : 0,75 in OD tube 10 BWG, panjang = 16 ft, 2 pass

- **Fluida panas**
  - Laju alir fluida panas = 363,0050 kg/jam = 800,2932 lbm/jam
  - Diasumsi uap yang mengembun tertinggal 20%, maka
  - Laju alir fluida panas = 0,8 x 800,2932 = 640,2364 lbm/jam
  - Temperatur awal (T₁) = 159,288 °C = 318,7184 °F
  - Temperatur akhir (T₂) = 156,779 °C = 314,2022 °F

- **Fluida dingin**
  - Laju alir fluida dingin = 681,3386 kg/jam = 1502,1023 lbm/jam
  - Temperatur awal (t₁) = 25 °C = 77 °F
  - Temperatur akhir (t₂) = 70 °C = 158 °F

Panas yang diserap (Q) = 128237,752 kJ/jam = 121545,4588 Btu/jam

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

<table>
<thead>
<tr>
<th>Fluida Panas</th>
<th>Fluida Dingin</th>
<th>Selisih</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁ = 318,65 °F</td>
<td>t₂ = 158 °F</td>
<td>( \Delta t₁ = 160,65 ) °F</td>
</tr>
<tr>
<td>T₂ = 302,126 °F</td>
<td>t₁ = 77 °F</td>
<td>( \Delta t₂ = 225,126 ) °F</td>
</tr>
<tr>
<td>T₁ – T₂ = 16,52 °F</td>
<td>t₂ – t₁ = 81 °F</td>
<td>( \Delta t₂ – \Delta t₁ = 64,476 ) °F</td>
</tr>
</tbody>
</table>
\[
\text{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \left( \frac{\Delta t_2}{\Delta t_1} \right)} = \frac{64,476}{\ln \left( \frac{225,126}{160,65} \right)} = 191,0784 \degree F
\]

\[
R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{16,524}{81} = 0,204
\]

\[
S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{81}{318,65 - 77} = 0,3351
\]

Dari Gambar 18, Kern, 1965 diperoleh \( F_T = 0,99 \)

Maka \( \Delta t = F_T \times \text{LMTD} = 0,99 \times 191,0784 = 189,1674 \degree F \)

(3) \( T_c \) dan \( t_c \)

\[
T_c = \frac{T_1 + T_2}{2} = \frac{318,65 + 302,126}{2} = 310,388 \degree F
\]

\[
t_c = \frac{t_1 + t_2}{2} = \frac{77 + 158}{2} = 117,5 \degree F
\]

Dalam perancangan ini digunakan kondensor 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, cooler untuk fluida panas gas heavy organic dan fluida dingin air, diperoleh \( U_D = 5-75 \), dan faktor pengotor (\( R_d \)) = 0,001.

Diambil \( U_D = 8 \text{ Btu/jam} \cdot \text{ft}^2 \cdot \degree F \)

Luas permukaan untuk perpindahan panas,

\[
A = \frac{Q}{U_D \times \Delta t} = \frac{121545,4588 \text{ Btu/jam}}{8 \frac{\text{Btu}}{\text{jam} \cdot \text{ft}^2 \cdot \degree F} \times 189,1676 \degree F} = 80,3159 \text{ ft}^2
\]

Luas permukaan luar (\( a'' \)) = 0,1963 ft\(^2\)/ft

(Tabel 10, Kern)
Jumlah tube, \( N_t = \frac{A}{L \times a} = \frac{80,3159 \text{ ft}^2}{16 \text{ ft} \times 0.1963 \text{ ft}^2/\text{ft}} = 25,5718 \text{ buah} \)

e. Dari Tabel 9, hal 842, *Kern*, 1965, nilai yang terdekat adalah 26 tube dengan ID shell 8 in.

f. Koreksi \( U_D \)

\[
A = L \times N_t \times a' = 16 \text{ ft} \times 26 \times 0.1963 \text{ ft}^2/\text{ft} = 81,6608 \text{ ft}^2
\]

\[
U_D = \frac{Q}{A \times \Delta t} = \frac{121545,4588 \text{ Btu/jam}}{81,66086 \text{ ft}^2 \times 189,1676 \degree F} = 7,8682 \frac{\text{Btu}}{\text{jam} \cdot \text{ft}^2 \cdot \degree F}
\]

**Fluida panas : gas, heavy organich, tube**

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

\[
a_i = \frac{N_t \times a_i'}{144 \times n}
\]

\[
a_i = \frac{26 \times 0.334}{144 \times 2} = 0.0301 \text{ ft}^2
\]

(4) Kecepatan massa:

\[
G_t = \frac{w}{a_i}
\]

\[
G_t = \frac{1040,3117}{0.0301} = 34501,4 \text{ lbm/jam. ft}^2
\]

\[
V = \frac{G_t}{3600 \rho}
\]

\[
V = \frac{34501,4}{3600 \times 19,95} = 0.4803 \text{ fps}
\]

(5) Bilangan Reynold:

Pada \( T_c = 310,388 \degree F \)

\[
\mu = 0.1995 \text{ cP} = 0.4828 \frac{\text{lbm}}{\text{ft}^2 \cdot \text{jam}}
\]

(Diari 14, Kern, 1965)

Dari tabel 10, Kern, untuk 1 in OD, 18 BWG, diperoleh :

ID = 0,652 in = 0,0543 ft
\[ \text{Re}_t = \frac{\text{ID} \times \text{G}_t}{\mu} \]  
\[ \text{Re}_s = \frac{0,0543 \times 34501,4}{0,4828} = 3882,79 \]

(7) \( hi = 10 \)  

(7) \( h_{io} = h_i \times \frac{\text{ID}}{\text{OD}} \)

\[ h_{io} = 10 \times \frac{0,652}{0,75} = 8,6933 \]

Fluida dingin : water, shell

(3’) Flow area shell

\[ a_s = \frac{D_s \times C' \times B}{144 \times P_T} \text{ ft}^2 \]  
\( D_s \) = Diameter dalam shell = 8 in
\( B \) = Baffle spacing = 5 in
\( P_T \) = Tube pitch = 1 in
\( C' \) = Clearance = \( P_T \) – OD

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

\[ a_s = \frac{8 \times 0,25 \times 5}{144 \times 1} = 0,0694 \text{ ft}^2 \]

(4’) Kecepatan massa

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

\[ G_s = \frac{1502,1023}{0,0694} = 21630,27 \text{ lb}_m/\text{jam.ft}^2 \]

(5’) Bilangan Reynold

Pada \( t_c = 117,5 \text{ °F} \)
\( \mu = 0,62 \text{ cP} = 1,5004 \text{ lb}_m/\text{ft}^2 \cdot \text{jam} \)

Dari Gambar 28, Kern, untuk 1 in dan 1\( ^{1/4} \) square pitch, diperoleh \( D_e = 0,95 \text{ in} \).
De = 0,95/12 = 0,0791 ft

\[ Re_s = \frac{D_e \times G_s}{\mu} \]

\[ Re_s = \frac{0,0791 \times 21630,27}{1,5004} = 1141,293 \]

(6') Asumsi \( h = h_o = 200 \)

\[ t_w = t_a + \frac{h_o}{h_o + h_a} \times (T_v - t_a) \]

\[ = 117,5 + \frac{200}{8,6933 + 200} \times (310,388 - 117,5) \]

\[ = 303,3531 \]

\[ t_f = (T_v + t_w)/2 \]

\[ = 209,9265 \]

(7') Dari fig 12 (Kern, 1965), untuk \( t = 166,1 \), diperoleh \( h = h_o = 193,5321 \) BTU/hr.ft².°F

(8) **Clean Overall Coefficient**, \( U_C \)

\[ U_C = \frac{h_o \times h_a}{h_o + h_a} = \frac{8,6933 \times 193,5231}{8,6933 + 193,5231} = 8,3196 \text{Btu/jam.ft}^2.\text{°F} \]

(Pers. 6.48, Kern, 1965)

(9) Faktor pengotor, \( R_d \)

\[ R_d = \frac{U_C - U_D}{U_C \times U_D} = \frac{8,3196 - 7,8682}{8,3196 \times 7,8682} = 0,0068 \]

(Pers. 6.13, Kern, 1965)

\( R_d \) hitung \( \geq \) \( R_d \) ketentuan (0,001), maka spesifikasi pendingin dapat diterima.

**Pressure drop**

**Fluida panas : sisi tube**

(1) Untuk \( Re_T = 3882,79 \)

\[ f = 0,0023 \text{ ft}^2/\text{in}^2 \]

\[ s = 0,98 \]

(Gambar 26, Kern, 1965)
\[ \Delta P_t = \frac{\mu \cdot \gamma_T^2 \cdot L \cdot n}{5.22 \cdot 10^{10} \cdot D \cdot s \cdot \varphi_T} \]  

(Pers. (7.53), Kern, 1965)

\[ \Delta P_t = \frac{0.0023 \times (34501.4)^2 \times (16) \times (2)}{(5.22 \cdot 10^{10}) \times (0.0543) \times (0.98) \times (1)} = 0.0315 \text{ psi} \]

(3) Dari Gambar 27, Kern, 1965 diperoleh \( \frac{V^2}{2g'} = 0.001 \)

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

\[ = \frac{(4)(2) \cdot 0.001}{1} = 0.00816 \text{ psi} \]

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

\[ = 0.0315 \text{ psi} + 0.00816 \text{ psi} \]

\[ = 0.04 \text{ psi} \]

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

**Fluida dingin : sisi shell**

(1') Untuk \( Re_s = 1141.293 \)

\[ f = 0.0032 \text{ ft}^2/\text{in}^2 \]

(Pers. (7.43), Kern, 1965)

\[ \phi_s = 1 \]

\[ s = 1 \]

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

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

(Pers. (7.43), Kern, 1965)

\[ D_s = 8/12 = 0.6666 \text{ ft} \]

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

(Pers. (7.44), Kern, 1965)
ΔP_s = \frac{0.0032 \times (21630.27)^2 \times (0.0791) \times (38.4)}{5.22 \times 10^{10} \times (0.0791) \times (1) \times (0.46)} = 0.0012 \text{ psi}

ΔP_s yang diperbolehkan = 2 psi

LC.23 Akumulator (AC-102)

Fungsi : Mengumpulkan destilat yang keluar dari kondensor E-108.

Bahan konstruksi : Carbon Steel SA –285 Grade C

Bentuk : Silinder horizontal dengan tutup ellipsoidal

Jenis sambungan : Single welded butt joints

Jumlah : 1 unit

Kondisi operasi :

Tekanan = 101,325 kPa

Temperatur = 150,07 °C = 473,22 K

Kebutuhan perancangan = 1 jam

Faktor kelonggaran = 20%

Tabel LC.16 Data pada akumulator (AC-102)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>F (kg/jam)</th>
<th>Fraksi Berat</th>
<th>( \rho ) (kg/m³)</th>
<th>( \rho ) campuran (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>2,5411</td>
<td>0,0069</td>
<td>873,8</td>
<td>6,0292</td>
</tr>
<tr>
<td>IPB</td>
<td>360,1008</td>
<td>0,9920</td>
<td>862</td>
<td>855,1040</td>
</tr>
<tr>
<td>DIPB</td>
<td>0,3631</td>
<td>0,0011</td>
<td>859</td>
<td>0,9449</td>
</tr>
<tr>
<td>Total</td>
<td>363,0050</td>
<td>1</td>
<td>862,0781</td>
<td></td>
</tr>
</tbody>
</table>

Perhitungan:

a. Volume Tangki

Volume larutan, \( V_l \) = \frac{363,0050 \text{ kg/jam} \times 1 \text{ jam}}{862,0781 \text{ kg/m}^3} = 0,4210 \text{ m}^3

Volume tangki, \( V_t \) = (1,2) \times 0,4210 \text{ m}^3 = 0,5052 \text{ m}^3

Fraksi volum \( = \frac{V_l}{V_t} = \frac{0,4210}{0,5052} = 0,8333 \)
Dari gambar 18.15 pada buku Walas dkk, *Chemical Process Equipment* diperoleh untuk fraksi volum 0,8333 maka H/D = 0,777

Asumsi L/D = 1,777

Digunakan dua buah tutup ellipsoidal maka volume tutup adalah:

\[
V_h = V_o (V/V_o) = 2 \left[ 0.1309 D^3 (2)(H/D)^2 (1.5-H/D) \right]
\]

\[
= 2 \left[ 0.1309 D^3 (2)(0.777)^2 (1.5-0.777) \right]
\]

\[
= 0.2285 D^3
\]

Kapasitas shell:

\[
\theta = 2 \arccos \left( \frac{1}{2} \right) = 2 \arccos \left( \frac{1}{2}(0.777) = 2 \arccos \left( \frac{1}{2} \right) \right)
\]

\[
= 4.3159 \text{ rad}
\]

\[
V_s = V_o (V/V_o) = \left( \frac{D}{2} \right)^2 L \left( \frac{1}{2\pi} \right) \left( \theta - \sin \theta \right)
\]

\[
= \left( \frac{D}{2} \right)^2 L \left( \frac{1}{2\pi} \right) (4.3159 - \sin 4.3159)
\]

\[
= 0.6548 D^2 L
\]

Volume tangki = \(V_h + V_s = 0.2285 D^3 + 0.6548 D^2 L\)

Dimana L/D = 1,777, maka volume tangki adalah:

\(V_t = 0.2285 D^3 + 1.1636 D^3 = 1.3921 D^3\)

\(0.5255 \text{ m}^3 = 1.3921 D^3\)

\(D = \sqrt[3]{\frac{0.5255}{1.3921}} = 0.7466 \text{ m} = 29.3937 \text{ in.}\)

\(L = \frac{0.5255 - 0.2285(0.7466)}{0.6548(0.7466)^2} = 1.1793 \text{ m.}\)

Tinggi cairan = H/D = 0,777 (0,7466) = 0,5801 m.

Perhitungan tinggi tutup:

\(H_d = \frac{D}{4} = \frac{0.7466}{4} = 0.1867 \text{ m}\)

(Walas dkk, 2005)

Perhitungan tinggi shell:

\(H_s = L - 2H_d = 1.1793 - 2(0.1867) = 0.806 \text{ m.}\)

d. Tebal shell tangki
Direncanakan menggunakan bahan konstruksi Carbon Steel SA –285 Grade C
diperoleh data :
- Allowable stress (S) = 13750 psia
- Joint efficiency (E) = 0,8
- Corrosion allowance (C) = 0,25 mm/tahun  
  = 0,0098/tahun  
(Peters dkk, 2004)
- Umur tangki (n) = 10 tahun

Tekanan Hidrostatik:
\[ P_{\text{hidrostatik}} = \rho \times g \times l \]
\[ = 862,0781 \text{ kg/m}^3 \times 9,81 \text{ m/det}^2 \times 1,1793 \text{ m} = 0,0983 \text{ atm} \]
\[ P_0 = 1 \text{ atm} \]
\[ P = 1 \text{ atm} + 0,0983 \text{ atm} = 1,0983 \text{ atm} \]
\[ P_{\text{design}} = 1,2 \times 1,0983 = 1,4382 \text{ atm} = 19,369 \text{ psi} \]

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

\[ t = \frac{PR}{SE - 0,6P} = \left( \frac{19,369 \text{ psi} \times 29,39372 \text{ in}}{13750 \text{ psia}} \times 0,8 - 0,6(19,369 \text{ psi}) \right) \]
\[ = 0,026 \text{ in} \]

Faktor korosi = 0,0098 in/tahun

Maka tebal shell yang dibutuhkan dengan perkiraan umur alat adalah 10 tahun
\[ = 0,026 + (10 \times 0,0098) \]
\[ = 0,124 \text{ in} \]

Tebal shell standar yang digunakan = ¼ in  
(Brownell & Young, 1959)
e. Tebal tutup tangki

Tutup atas tangki terbuat dari bahan yang sama dengan shell.
Tebal tutup atas yang digunakan = ¼ in

**LC.24 Pompa Refluks Kondensor (P-06)**

Fungsi : Mengalirkan kondensat hasil atas menara destilasi II (MD-102) untuk diumpikan kembali ke menara destilasi II

Jenis : Pompa sentrifugal

Jumlah : 1 unit

Kondisi operasi :

<table>
<thead>
<tr>
<th>Tekanan</th>
<th>1 atm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperatur</td>
<td>156,779 °C</td>
</tr>
<tr>
<td>Laju alir massa (F)</td>
<td>363,005 kg/jam = 0,2223 lbm/s</td>
</tr>
</tbody>
</table>

Tabel LC.17 Data pada keluaran accumulator (AC-102)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>x</th>
<th>ρ x</th>
<th>μ x</th>
<th>ρ campuran</th>
<th>μ campuran</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0,007</td>
<td>873,8 kg/m³</td>
<td>0,15 cp</td>
<td>6,0182 kg/m³</td>
<td>0,0010 cp</td>
</tr>
<tr>
<td>IPB</td>
<td>0,992</td>
<td>862 kg/m³</td>
<td>0,202 cp</td>
<td>855,1497 kg/m³</td>
<td>0,2004 cp</td>
</tr>
<tr>
<td>DIPB</td>
<td>0,001</td>
<td>859 kg/m³</td>
<td>0,205 cp</td>
<td>0,9112 kg/m³</td>
<td>0,0002 cp</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1</td>
<td><strong>862,0781 kg/m³</strong></td>
<td><strong>0,2016 cp</strong></td>
<td><strong>53,8192 lbm/ft³</strong></td>
<td><strong>0,0001 lbm/ft.s</strong></td>
</tr>
</tbody>
</table>

(Sumber: Geankoplis, 2003; Perry, 1999)

Laju alir volumetrik,

\[
m_v = \frac{363,005 \text{ kg/jam}}{862,0781 \text{ kg/m}^3} \\
= 0,4210 \text{ m}^3/\text{jam} = 0,00011 \text{ m}^3/s = 0,0041 \text{ ft}^3/s
\]

Desain pipa:

\[
D_{i, opt} = 0,363 \left( m_v \right)^{0,45} \left( \rho \right)^{0,13} \\
= 0,363 \left( 0,00011 \text{m}^3/s \right)^{0,45} \left( 862,078 \text{ kg/m}^3 \right)^{0,13} \\
= 0,01486 \text{ m} = 0,5852 \text{ in}
\]

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

Ukuran nominal : 0,375 in
Schedule number : 40
Diameter Dalam (ID) : 0,493 in = 0,0411 ft = 0,0125 m
Diameter Luar (OD) : 0,675 in = 0,0562 ft
Inside sectional area : 0,00113 ft²
Kecepatan linier, \( v = \frac{Q}{A} = \frac{0,0041\text{ ft}^3/\text{s}}{0,00113\text{ ft}^2} = 3,6553\text{ ft/s} = 1,1141\text{ m/s} \)

Bilangan Reynolds:
\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]
\[ = \frac{(53,8191\text{ lbm/ft}^3)(3,6553\text{ ft/s})(0,0410\text{ ft})}{0,0001\text{ lbm/ft.s}} \]
\[ = 59648,74 \text{ (Turbulen)} \]

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

Pada \( N_{Re} = 59648,74 \) dan \( \varepsilon/D = \frac{0,000046 m}{0,0125 m} = 0,0036 \)

Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga \( f = 0,0062 \)

Friction loss:
1. Sharp edge entrance: \( h_e = 0,55 \left( 1 - \frac{A_e}{A_i} \right) \frac{v^2}{2a} = 0,55(1-0) \frac{(3,6553)^2}{2(1)(32,174)} \]
\[ = 0,1142\text{ ft.lbf/lbm} \]

4 elbow 90°: \( h_f = n.Kf. \frac{v^2}{2.g_c} = 4(0,75) \frac{3,6553^2}{2(32,174)} = 0,6229\text{ ft.lbf/lbm} \)

1 check valve: \( h_f = n.Kf. \frac{v^2}{2.g_c} = 1(2) \frac{3,6553^2}{2(32,174)} = 0,4152\text{ ft.lbf/lbm} \)

Pipa lurus 100 ft: \( F_f = 4f \frac{\Delta L. v^2}{D.2.g_c} = 4(0,0062) \frac{(100)(3,6553)^2}{(0,0410)(2)(32,174)} \]
\[ = 12,5342\text{ ft.lbf/lbm} \]
1. **Sharp edge exit**: 
\[
h_{ex} = n \left(1 - \frac{A_1}{A_2}\right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left(1 - 0\right)^2 \frac{3.6553^2}{2(1)(32.174)}
\]
\[= 0.2076 \text{ ft.lbf/lbm}
\]

**Total friction loss**: 
\[
\sum F = 13,8942 \text{ ft.lbf/lbm}
\]

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: \(v_1 = v_2\)

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

\(\Delta P = 0 \text{ atm} = 0 \text{ lbf/ft}^2\)

tinggi pemompaan \(\Delta Z = 15 \text{ ft}\)

maka:
\[
0 + \frac{32,174}{32,174}(15) + \frac{0}{53,8192} + 13,8942 + W_s = 0
\]

\(W_s = 28,8942 \text{ ft.lbf/lbm}\)

Efisiensi pompa, \(\eta = 70\%\)

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

\[= \frac{28,8942}{0.7}
\]

\[= 41,2775 \text{ ft.lbf/lbm.}
\]

Daya pompa: 
\[
P = m \times W_p
\]

\[= 0,2223 \text{ lbm/s} \times 41,2775 \text{ ft.lbf/lbm}
\]

\[= 9,1760 \text{ ft.lbf/lbm}
\]

\[= 0,0166 \text{ hp}
\]

Maka dipilih pompa dengan daya motor 1/4 hp.
LC.25  Cooler I (E – 109)

Fungsi : Mendinginkan produk IPB untuk disimpan dalam tangki produk (TT-103)

Jenis : Double-pipe exchanger

- Fluida panas
  Laju alir fluida panas = 315,6565 kg/jam = 695,9071 lbm/jam
  Temperatur awal (T₁) = 156,779 °C = 314,2022 °F
  Temperatur akhir (T₂) = 30 °C = 86 °F

- Fluida dingin
  Laju alir fluida dingin = 433,0730 kg/jam = 954,7676 lbm/jam
  Temperatur awal (t₁) = 25°C = 77 °F
  Temperatur akhir (t₂) = 70 °C = 158 °F

Panas yang diserap (Q) = 81510,5874 kJ/jam = 77256,8266 Btu/jam

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

<table>
<thead>
<tr>
<th>Fluida Panas</th>
<th>Temperatur yang lebih tinggi</th>
<th>Fluida Dingin</th>
<th>Selisih</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁ = 314,2022 °F</td>
<td>t₂ = 70 °F</td>
<td>( \Delta t_1 = 156,202 ) °F</td>
<td></td>
</tr>
<tr>
<td>T₂ = 86 °F</td>
<td>t₁ = 25 °F</td>
<td>( \Delta t_2 = 9 ) °F</td>
<td></td>
</tr>
<tr>
<td>T₁ – T₂ = 228,202 °F</td>
<td>t₂ – t₁ = 81 °F</td>
<td>( \Delta t_2 – \Delta t_1 = -147,2022 ) °F</td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln\left(\frac{\Delta t_2}{\Delta t_1}\right) + \ln\left(\frac{9}{156,202}\right)} = 51,5788 \degree F
\]

\[
R = \frac{T₁ - T₂}{\frac{t₂ - t₁}{81}} = 2,8173
\]
\[ S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{81}{314,2022 - 77} = 0,3414 \]

Dari Gambar 19, Kern, 1965 diperoleh \( F_T = 0,81 \)

Maka \( \Delta t = F_T \times \text{LMTD} = 0,81 \times 51,5788 = 41,7788 \, ^\circ\text{F} \)

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

\[ T_c = \frac{T_1 + T_2}{2} = \frac{314,2022 + 81}{2} = 200,1011 \, ^\circ\text{F} \]
\[ t_c = \frac{t_1 + t_2}{2} = \frac{77 + 158}{2} = 117,5 \, ^\circ\text{F} \]

Dalam perancangan ini digunakan Double Pipe Exchanger dengan spesifikasi:
- Diameter luar inner pipe (OD) = 1,66 in = 0,13833 ft
- Diameter dalam anulus (ID\(_2\)) = 2,067 in = 0,17225 ft
- Diameter dalam inner pipe (ID\(_1\)) = 1,38 in = 0,115 ft

Dari tabel 6.2 (Kern, 1965), pada jenis ini Flow Area pada inner pipe lebih besar dari pada anulus, maka laju alir yang paling besar mengalir di inner pipe

**Fluida Dingin : Air Pendingin , inner pipe**

(3) Flow area tube, \( a_t = 0,0103 \, \text{in}^2 \)

\[ a_t = \pi \times D^2 / 4 \quad \text{(Pers. (6.3), Kern, 1965)} \]
\[ a_t = 3,14 \times 0,115^2 / 4 = 0,0103 \, \text{ft}^2 \]

(4) Kecepatan massa:

\[ G_t = \frac{w}{a_t} \quad \text{(Pers. (7.2), Kern, 1965)} \]
\[ G_t = \frac{433,0730}{0,01038} = 91967,0647 \, \text{lbm/jam.ft}^2 \]

(5) Bilangan Reynold:

Pada \( t_c = 117,5 \, ^\circ\text{F} \)

\[ \mu = 0,61 \, \text{cP} = 1,4762 \, \text{lbm/ft}^2 \cdot \text{jam} \quad \text{(Gambar 14, Kern, 1965)} \]

ID = 1,38 in = 0,115 ft
\[
Re_t = \frac{ID \times G_i}{\mu} \\
Re_t = \frac{0,115 \times 91967,064}{1,4762} = 11231,9088
\]

(12) Taksir \( jH \) dari Gambar 24 Kern (1965), diperoleh \( jH = 50 \) pada \( Re_t = 11231,9088 \)

(13) Pada \( T_c = 491 \, ^{\circ}F \)
\[
c = 0,92 \text{ Btu/lbm.}^{\circ}F \\
k = 0,0188 \text{ Btu/jam lbm ft.}^{\circ}F
\]
\[
\left(\frac{c \times \mu}{k}\right)^{1/3} = \left(\frac{0,92 \times 0,0281}{0,0188}\right)^{1/3} = 1,598
\]

\[
h_i = jH \times \frac{k}{ID} \times \left(\frac{c \times \mu}{k}\right)^{1/3}
\]
\[
h_i = 320 \times \frac{0,0188}{0,115} \times 1,29409 = 54,2268
\]
\[
h_{lo} = \frac{h_i}{\varphi} \times \frac{ID}{OD}
\]
\[
h_{lo} = 67,6979 \times \frac{1,38}{1,66} = 45,0801
\]

**Fluida Panas : Liquid, anulus**

(3') Flow area anulus
\[
a_s = \pi \times \frac{ID^2 - OD^2}{4} \\
a_s = 3,14 \times (0,17225^2 - 0,13833^2) / 4 = 0,00826 \text{ ft}^2
\]

(4') Kecepatan massa
\[
G_s = \frac{w}{a_s} \\
G_s = \frac{315,6565}{0,00826} = 84157,0103 \text{lbm/jam ft}^2
\]

(5') Bilangan Reynold

Pada \( T_c = 200,10 \, ^{\circ}F \)
\[ \mu = 0.3891 \text{ cP} = 0.9416 \text{ lbm/ft}^2 \cdot \text{jam} \]

\[ D_e = \pi \times \frac{ID_e^2 - OD_e^2}{OD_e^2} = 0.0761 \]  
(Pers. (6.3), Kern, 1965)

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

\[ \text{Re}_e = \frac{0.0761 \times 84157,0103}{0.94} = 4341,1977 \]

(6') Taksir \( J_H \) dari Gambar 24, Kern, diperoleh \( J_H = 12 \) pada \( \text{Re}_e = 4341,1977 \)

(7') Pada \( T_c = 200,10 \text{°F} \)

\[ c = 0.509 \text{ Btu/lbm.\text{°F}} \]

\[ k = 0.078 \text{ Btu/jam lbm ft.\text{°F}} \]

\[ \left( \frac{c \cdot \mu}{k} \right)^{\frac{1}{3}} = \left( \frac{0.509 \times 0.941}{0.078} \right)^{\frac{1}{3}} = 1.83 \]

(8') \[ h_o = J_H \times \frac{k}{D_e} \times \left( \frac{c \cdot \mu}{k} \right)^{\frac{1}{3}} \]

\[ h_o = 12 \times \frac{0.078}{0.0761} \times 1.83 = 106,3045 \]

(9') Clean Overall Coefficient, \( U_c \)

\[ U_c = \frac{h_o \times h_o}{h_o + h_o} = \frac{45,0801 \times 106,30}{45,0801 + 106,30} = 31,655 \text{ Btu/jam ft}^2 \cdot \text{°F} \]  
(Pers. (6.38), Kern, 1965)

(10') Rd teori = 0,002

\[ \frac{1}{U_d} = \left( \frac{1}{U_c} \right) + Rd \]

\[ \frac{1}{U_d} = \left( \frac{1}{31,655} \right) + 0,002 \]

\[ U_d = 29,77 \text{ Btu/hr ft}^2 \cdot \text{°F} \]
(11) Faktor pengotor, \( R_d \)

\[
R_d = \frac{U_c - U_D}{U_c \times U_D} = \frac{31,655 - 29,77}{31,655 \times 29,77} = 0,002 \quad \text{(Pers. (6.13), Kern, 1965)}
\]

\( R_d \) hitung \( \geq R_d \) ketentuan (0,002), maka spesifikasi dapat diterima.

(11) Required Surface, \( A \)

\[
A = \frac{Q}{U_d \times LMTD}
\]

\( A = 53,08 \text{ ft}^2 \)

Required Length = \( \frac{A}{0,435} = 122,02 \text{ lin ft} \)

\[
\frac{122,02}{40} = 3,05 \text{ dibulatkan menjadi 3}
\]

Jadi jumlah hairpin = \( 3 \times 20 = 60 \) hairpin

**Pressure drop**

**Fluida Panas : liquid, anulus**

(3) \( D_e' = 0,0339 \)

Untuk \( Re_e' = 3031,2856 \)

\( f = 0,0126 \text{ ft}^2/\text{in}^2 \)

\( s = 0,69 \)

\( \rho = 43,125 \quad \text{(Gambar 26, Kern, 1965)} \)

(2) \( \Delta F_a = \frac{f \times G_a}{2 \times g \times \rho^2 \times D_e'} \)

\( \Delta F_a = 8126 \text{ ft} \)

(3) \( V = \frac{G}{3600 \times \rho} = 0,5420 \)

\( F_1 = \frac{\nu^2}{2 \times g} = 0,0136 \text{ ft} \)

\( \Delta P_a = \frac{(\Delta F_a + F_1) \times \rho}{144} = 0,02474 \text{ psi} \)

Yang diperbolehkan = 10 psi
Fluida Dingin : Air Pendingin, *inner pipe*

(1') Untuk \( Re_p = 11231,9088 \)

\[
f = 0,0088 \text{ ft}^2/\text{in}^2
\]

\[
s = 1
\]

\[
\rho = 62,5
\]

(2') \[
\Delta F_p = \frac{f \times G_a}{2 \times g \times \rho^2 \times D} = 9,46 \text{ ft}
\]

(3') \[
\Delta P_p = \frac{\Delta F_p \times \rho}{144} = 4,1069 \text{ psi}
\]

Yang diperbolehkan = 10 psi

**LC.26 Pompa Produk IPB (P-07)**

Fungsi : Mengalirkan produk ke tangki penyimpanan (TT-103)

Jenis : Pompa sentrifugal

Jumlah : 1 unit

Kondisi operasi :

| Tekanan | 1 atm |
| Temperatur | 30 °C |

Laju alir massa (F) = 315,6565 kg/jam = 0,1933 lbm/s

Tabel LC.18 Data pada keluaran cooler (HE-109)

<table>
<thead>
<tr>
<th>Komponen</th>
<th>x</th>
<th>( \rho \times x )</th>
<th>( \mu \times x )</th>
<th>( \rho \times \text{campuran} )</th>
<th>( \mu \times \text{campuran} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0,007</td>
<td>873,8 kg/m³</td>
<td>0,51 cp</td>
<td>6,1216 kg/m³</td>
<td>0,0036 cp</td>
</tr>
<tr>
<td>IPB</td>
<td>0,992</td>
<td>862 kg/m³</td>
<td>0,66 cp</td>
<td>855,1733 kg/m³</td>
<td>0,6547 cp</td>
</tr>
<tr>
<td>DIPB</td>
<td>0,001</td>
<td>859 kg/m³</td>
<td>0,667cp</td>
<td>0,7849 kg/m³</td>
<td>0,0006 cp</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>862,0799 kg/m³</td>
<td>0,6589 cp</td>
<td>53,8193 lbm/ft³</td>
<td>0,0001 lbm/ft.s</td>
</tr>
</tbody>
</table>

(Sumber: Geankoplis, 2003; Perry, 1999)
Laju alir volumetrik,

\[ m_v = \frac{315,6565 \text{ kg/jam}}{862,0799 \text{ kg/m}^3} \]

\[ = 0,3661 \text{ m}^3/\text{s} = 0,0001 \text{ m}^3/\text{s} = 0,0035 \text{ ft}^3/\text{s} \]

Desain pipa:

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

\[ = 0,363 (0,0001 \text{ m}^3/\text{s})^{0.45} (862,0799 \text{ kg/m}^3)^{0.13} \]

\[ = 0,0139 \text{ m} = 0,5495 \text{ in} \]

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

Ukuran nominal : 0,375 in

Schedule number : 40

Diameter Dalam (ID) : 0,493 in = 0,0411 ft = 0,0125 m

Diameter Luar (OD) : 0,675 in = 0,0562 ft

Inside sectional area : 0,00113 ft^2

Kecepatan linier, \( v = \frac{Q}{A} = \frac{0,0035 \text{ ft}^3/\text{s}}{0,00113 \text{ ft}^2} = 3,1785 \text{ ft/s} = 0,9688 \text{ m/s} \)

Bilangan Reynold:

\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]

\[ = \frac{(53,8193 \text{ lbm/ft}^3)(3,1785 \text{ ft/s})(0,0411 \text{ ft})}{0,0004 \text{ bm/ft.s}} \]

\[ = 15871,606 \text{ (Turbulen)} \]

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

Pada \( N_{Re} = 15871,606 \) dan \( \varepsilon/D = \frac{0,000046 \text{ m}}{0,0125 \text{ m}} = 0,0036 \)

Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga \( f = 0,0075 \)

*Friction loss:*

1. *Sharp edge entrance:* \( h_c = 0,55 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2\alpha} = 0,55 \left( 1 - \frac{3,1785}{2} \right) \frac{3,1785^2}{2(1)(32,174)} \)
1 elbow 90\(^\circ\):

\[
h_f = nK_f \frac{v^2}{2g_e} = 1(0,75) \frac{3,1785^2}{2(32,174)} = 0,1177 \text{ ft.lbf/lbm}
\]

1 check valve:

\[
h_f = nK_f \frac{v^2}{2g_e} = 1(2) \frac{3,1785^2}{2(32,174)} = 0,3140 \text{ ft.lbf/lbm}
\]

Pipa lurus 100 ft:

\[
F_f = 4f \frac{\Delta Lv^2}{D.2g_e} = 4(0,0075) \frac{(100)(3,1785)^2}{(0,0411)(2)(32,174)}
\]

\[
= 11,464 \text{ ft.lbf/lbm}
\]

1 Sharp edge exit:

\[
h_{ex} = n \left(1 - \frac{A_1}{A_2}\right)^\frac{v^2}{2xg_e} = 1 \left(1 - \frac{1}{2}\right)^\frac{3,1785^2}{2(1)(32,174)} = 0,1570 \text{ ft.lbf/lbm}
\]

Total friction loss:

\[
\sum F_f = 12,1400 \text{ ft.lbf/lbm}
\]

Dari persamaan Bernoulli:

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

(dimana: \(v_1 = v_2\))

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

\(\Delta P = 0 \text{ atm} = 0 \text{ lb/ft}^2\)

tinggi pemompaan \(\Delta Z = 10 \text{ ft}\)

maka:

\[
0 + \frac{32,174}{32,174}(10) + \frac{0}{53,8193} + 12,1400 + W_s = 0
\]

\[
W_s = 22,1400 \text{ ft.lbf/lbm}
\]

Efisiensi pompa, \(\eta = 70\%\)

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

\[
= \frac{22,1400}{0,7} = 31,6286 \text{ ft.lbf/lbm.}
\]
Daya pompa: \[ P = m \times W_p \]
\[ = 0,2010 \text{ lbm/s} \times 31,6286 \text{ ft.lbf/lbm} \]
\[ = 6,1139 \text{ ft.lbf/lbm} \]
\[ = 0,011 \text{ hp} \]
Maka dipilih pompa dengan daya motor 1/4 hp.

**LC.27 Tangki Penyimpanan IPB (TT – 103)**

- **Fungsi**: Menyimpan produk IPB untuk keperluan 10 hari
- **Bahan konstruksi**: *Carbon Steel SA –285 Grade C*
- **Bentuk**: Silinder vertikal dengan alas datar dan tutup *ellipsoidal*
- **Jenis sambungan**: *Single welded butt joints*
- **Jumlah**: 1 unit

**Kondisi operasi**:
- **Tekanan**: = 1 atm
- **Temperatur**: = 30 °C = 303,15 K
- **Laju Alir Massa**: = 315,6565 kg/jam
- **Kebutuhan perancangan**: = 10 hari
- **Faktor kelonggaran**: = 20 %

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Laju Alir kg/jam</th>
<th>Fraksi</th>
<th>Densitas Kg/m³</th>
<th>( \rho ) Campuran (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>2,2069</td>
<td>0,007</td>
<td>873,8</td>
<td>6,116</td>
</tr>
<tr>
<td>IPB</td>
<td>313,1312</td>
<td>0,992</td>
<td>862</td>
<td>855,104</td>
</tr>
<tr>
<td>DIPB</td>
<td>0,3157</td>
<td>0,001</td>
<td>859</td>
<td>0,859</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>315,6565</strong></td>
<td><strong>1</strong></td>
<td><strong>862,079</strong></td>
<td></td>
</tr>
</tbody>
</table>

(Sumber: Perry, 1999)
Perhitungan:

a. Volume Tangki

Volume larutan, \( V_l = \frac{315,6565 \text{ kg/jam} \times 10 \text{ hari} \times 24 \text{ jam/hari}}{862,079 \text{ kg/m}^3} = 87,8776 \text{ m}^3 \)

Direncanakan membuat 4 tangki dan faktor kelonggaran 20%, maka:

Volume 1 tangki, \( V_l = \frac{1,2 \times 87,8776 \text{ m}^3}{1} = 105,4532 \text{ m}^3 \)

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 & Young, 1959)

- Volume tangki (\( V_t \)) :

\[
V_t = V_s + V_h
\]

\[
105,4532 \text{ m}^3 = \frac{3}{8} \pi D^3
\]

\[
D = 4,4740 \text{ m} = 176,1428 \text{ in}
\]

\[
H_s = \frac{4}{3} D = 5,9653 \text{ m}
\]

c. Diameter dan tinggi tutup

Diameter tutup = Diameter tangki = 4,4740 m

Tinggi tutup (\( H_d \)) = \( \frac{1}{4} D = 1,1185 \text{ m} \)

Tinggi tangki = \( H_s + H_d = (5,9653 + 1,1185) \text{ m} = 7,0838 \text{ m} \)
d. Tebal *shell* tangki

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

- *Allowable stress* (*S*) = 13750 psia
- *Joint efficiency* (*E*) = 0,8
- *Corrosion allowance* (*C*) = 0,25 mm/tahun = 0,0098 in/tahun (Peters dkk, 2004)
- Umur tangki (*n*) = 10 tahun

Volume cairan = 87,8776 m$^3$

Tinggi cairan dalam tangki = \( \frac{87,8776 \text{ m}^3}{105,4532 \text{ m}^2} \times 5,9653 \text{ m} = 4,9711 \text{ m} \)

Tekanan Hidrostatik:

\[
P_{\text{hidrostatik}} = \rho \times g \times h
\]
\[
= 862,079 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 4,9711 \text{ m} = 0,41 \text{ atm}
\]

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

\[P = 1 \text{ atm} + 0,41 \text{ atm} = 1,41 \text{ atm}\]

\[P_{\text{design}} = 1,2 \times 1,41 = 1,69 \text{ atm} = 24,94 \text{ psi}\]

Tebal *shell* tangki:

\[t = \frac{P R}{SE - 0,6P}\]  
(Walas dkk, 2005)

Dimana:

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

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

\[= \frac{(24,94 \text{ psi})(88,0714 \text{ in})}{(13750 \text{ psia})(0,8) - 0,6(24,94 \text{ psi})}\]

= 0,1999 in
Faktor korosi = 0,0098 in/tahun
Maka tebal shell yang dibutuhkan dengan perkiraan umur alat adalah 10 tahun
= 0,1999 + (10 x 0,0098)
= 0,2982 in
Tebal shell standar yang digunakan = 0,3 in (Brownell & Young,1959)

e. Tebal tutup tangki
Tutup atas tangki terbuat dari bahan yang sama dengan shell.
Tebal tutup atas yang digunakan = 0,2982 in

LC.28 Reboiler (E – 110)
Fungsi : Menguapkan cairan dari kolom destilasi II (MD–102).
Jenis : 2 – 4 shell and tube exchanger
Dipakai : 1 in OD tube 10 BWG, panjang = 16 ft, 4 pass

- Fluida panas
Laju alir fluida panas = 9,268 kg/jam = 20,4325 lbm/jam
Temperatur awal (T₁) = 360 °C = 680 °F
Temperatur akhir (T₂) = 150 °C = 302 °F

- Fluida dingin
Laju alir fluida dingin = 391,6885 kg/jam = 863,5298 lbm/jam
Untuk mencegah fluida menguap semua, diasumsikan hanya 80% fluida yang menguap, sehingga :
Laju alir fluida dingin = 0,8*863,5298 = 690,8239 lbm/jam
Temperatur awal (t₁) = 159,28 °C = 318,71 °F
Temperatur akhir (t₂) = 165,102 °C = 329,183 °F

Panas yang diserap (Q) = 3888,6785 kJ/jam = 8573,1134 Btu/jam

(3) Neraca panas
Entalpi cairan pada 318,71 °F = 142,88 Btu/lbm
Entalpi cairan pada 329,183 °F = 158,40 Btu/lbm

\[ q_p = 1122,4344 \times (158,4 - 142,88) = 17420,1812 \text{ Btu/jam} \]

Penguapan isotermal:

Entalpi uap pada 329,162 °F = 218,85 Btu/lbm

\[ q_v = 897,9475 \times (218,85 - 158,4) = 54280,9255 \text{ Btu/jam} \]

\[ (\Delta t)_p = \ln \left( \frac{680 - 329,162}{338 - 320,752} \right) = 110,7298 \text{ °F} \]

\[ (\Delta t)_v = 680 - 329,162 = 350,838 \text{ °F} \]

\[ \frac{q_p}{(\Delta t)_p} = \frac{17420,1812}{110,7298} = 157,3214 \]

\[ \frac{q_v}{(\Delta t)_v} = \frac{54280,9255}{350,838} = 154,7179 \]

\[ \Delta t = \frac{Q}{\sum \frac{q_v}{(\Delta t)_v}} = 12,3998 \text{ °F} \]

Dalam perancangan ini digunakan Reboiler dengan spesifikasi:

- Diameter luar tube (OD) = 0,75 in
- Jenis tube = 8 BWG
- Jumlah tube = 26
- Pitch (P_t) = 1 in square pitch
- Panjang tube (L) = 16 ft

**Fluida panas : steam, tube**

(3) Flow area tube, \( a'_t = 0,182 \text{ in}^2 \) (Tabel 10, Kern, 1965)

\[ a_t = \frac{N_t \times a'_t}{144 \times n} \quad \text{(Pers. (7.48), Kern, 1965)} \]

\[ a_t = \frac{26 \times 0,182}{144 \times 2} = 0,0164 \text{ ft}^2 \]

(4) Kecepatan massa:

\[ G_i = \frac{w}{a_i} \quad \text{(Pers. (7.2), Kern, 1965)} \]
\[ G_r = \frac{22,0785}{0,0164} = 1343,7481 \text{ lb}_{m}/\text{jam} \cdot \text{ft}^2 \]

(5) Bilangan Reynold:

Pada \( T_c = 509 \, ^\circ\text{F} \)

\[ \mu = 0,0183 \text{ cP} = 0,0443 \text{ lb}_{m}/\text{ft}^2 \cdot \text{jam} \]

(Gambar 14, Kern, 1965)

Dari tabel 10, Kern, untuk 1 in OD, 8 BWG, diperoleh:

ID = 0,482 in = 0,0401 ft

\[ \text{Re}_r = \frac{ID \times G_r}{\mu} \]

(Pers. (7.3), Kern, 1965)

\[ \text{Re}_r = \frac{0,0401 \times 1343,7481}{0,0443} = 1218,7572 \]

(7) \( h_{io} = h_{io} = h_0 \frac{\text{ID}}{\text{OD}} \)

\[ h_{io} = 37,2481 \times \frac{0,482}{1} = 23,9381 \]

**Fluida dingin : bahan, shell**

(3') Flow area shell

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

(Ds = Diameter dalam shell = 8 in

B = Baffle spacing = 5 in

P_T = Tube pitch = 1 in

C' = Clearance = P_T − OD

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

\[ a_s = \frac{8 \times 0,25 \times 5}{144 \times 1} = 0,0694 \text{ ft}^2 \]

(4') Kecepatan massa

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

(Pers. (7.2), Kern, 1965)
\[ G_s = \frac{1122,4344}{0,0959} = 16163,1 \text{lbm/jam.ft}^2 \]

(5') Bilangan Reynold

Pada \( t_v = 320,752 \, ^\circ\text{F} \)
\[ \mu = 0,228 \, \text{cP} = 0,5517 \, \text{lbm/ft}^2\cdot\text{jam} \]

Dari Gambar 28, Kern, untuk 0,75 in dan 1 square pitch, diperoleh \( D_e = 0,95 \, \text{in} \).

\( D_e = 0,95/12 = 0,0791 \, \text{ft} \)

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

\[ \text{Re}_s = \frac{0,0791 \times 16163,1}{0,5517} = 2319,08 \]

(6') Taksir \( J_H \) dari Gambar 28, Kern, diperoleh \( J_H = 25 \) pada \( \text{Re}_s = 2319,08 \)

(7') Pada \( t_c = 320,752 \, ^\circ\text{F} \)
\[ c = 0,59 \, \text{Btu/lbm.}^\circ\text{F} \]
\[ k = 0,071 \, \text{Btu/jam lbm.} \, \text{ft.}^\circ\text{F} \]

\[ \left( \frac{c \mu}{k} \right)^{\frac{1}{2}} = \left( \frac{0,59 \times 0,0517}{0,05517} \right)^{\frac{1}{2}} = 1,6613 \]

(8') \[ \frac{h_o}{\varphi_s} = J_H \times \frac{k}{D_e} \times \left( \frac{c \mu}{k} \right)^{\frac{1}{2}} \]

\[ \frac{h_o}{\varphi_s} = 25 \times \frac{0,05517}{0,0791} \times 1,6613 = 37,2481 \]

\[ \frac{h_o}{\varphi_s} = 23,9381 \times 37,2481 = 14,5727 \, \text{Btu/jam.ft}^2 \, ^\circ\text{F} \]

Permukaan bersih yang dibutuhkan untuk penguapan :

\[ U_p = \frac{h_o \times h_o}{h_o + h_o} = \frac{23,9381 \times 37,2481}{23,9381 + 37,2481} = 14,5727 \, \text{Btu/jam.ft}^2 \, ^\circ\text{F} \]
\[ A_p = \frac{q_p}{U_p(\Delta t)_p} = 10,7956 \text{ ft}^2 \]

Penguapan:

(9) Pada 329,162 °F

\[
\mu = 0,023 \text{ cP} = 0,0556 \text{ lbm/ft}^2\cdot\text{jam} \]

\[ \text{Re}_s = \frac{0,0791 \times 16163,1}{0,0556} = 22989,1 \]

(10) \( jH = 90 \)

(11) Pada 329,162 °F, diperoleh:

\[ \left( \frac{c \cdot \mu}{k} \right)^{\frac{1}{3}} = 0,7741 \]

\[ \frac{h_a}{\phi_v} = \frac{J_H}{k} \times \frac{k}{D_s} \times \left( \frac{c \cdot \mu}{k} \right)^{\frac{1}{3}} = 63,3607 \]

*Clean overall coefficient* untuk penguapan:

\[ U_v = \frac{h_a \times h_o}{h_a + h_o} = \frac{23,9381 \times 63,3607}{23,9381 + 63,3607} = 17,374 \text{ Btu/jam. ft}^2. \circ F \]

Permukaan bersih yang dibutuhkan untuk penguapan:

\[ A_v = \frac{q_v}{U_v(\Delta t)_v} = 8,9051 \text{ ft}^2 \]

\[ Ac = A_p + A_v = 10,7956 + 8,9051 = 19,7007 \text{ ft}^2 \]

(13) *Clean Overall Coefficient, U_C*

\[ U_C = \frac{\sum U_A}{Ac} = \frac{157,3214 + 154,7179}{19,7007} = 15,839 \text{ Btu/jam. ft}^2. \circ F \]

(Pers. (6.38), Kern, 1965)
(14) *Desain Overall Coefficient*

\[ A = N_t(L).(a^a) \]

\[ A = 26(16).(0.1963) = 81,6608 \text{ft}^2 \]

\[ U_D = \frac{\frac{Q}{A \times \Delta t}}{81,6608 \times 12,3998} = 3,8211 \quad (\text{Pers. (6.13), Kern, 1965}) \]

Dari Table 8 Kern, 1965 Ud yang diizinkan = 5

(15) Faktor pengotor, \( R_d \)

\[ R_d = \frac{U_c - U_b}{U_c \times U_b} = \frac{15,839 - 5}{15,389 \times 5} = 0,13 \quad (\text{Pers. (6.13), Kern, 1965}) \]

\( R_d \) hitung \( \geq \) \( R_d \) ketentuan (0,003) , maka spesifikasi pendingin dapat diterima.

**Pressure drop**

*Fluida panas : sisi tube*

(1) Untuk \( \text{Re}_t = 1218,7572 \)

\[ f = 0,00015 \text{ ft}^2/\text{in}^2 \quad (\text{Gambar 26, Kern, 1965}) \]

\[ s = 1 \]

\[ \phi_t = 1 \]

\[ \Delta P_t = \left( \frac{1}{2} \right) \frac{f \cdot G \cdot 2 \cdot L \cdot n}{5,22 \times 10^{10} \cdot \text{ID} \cdot s \cdot \phi_t} \quad (\text{Pers. (7.53), Kern, 1965}) \]

\[ \Delta P_t = \left( \frac{1}{2} \right) \left( \frac{(0,0004) \times (1343,7481)^2 \times (16) \times (2)}{(5,22 \times 10^{10}) \times (0,0401) \times (1) \times (1)} \right) = 0,00001 \text{ psi} \]

*Fluida dingin : sisi shell*

(1') Untuk \( \text{Re}_s = 2319,08 \)

\[ f = 0,0028 \text{ ft}^2/\text{in}^2 \quad (\text{Gambar 29, Kern, 1965}) \]

\[ \phi_s = 1 \]

\[ s = 0,98 \]

(2') Panjang daerah preheating :

\[ L_p = L \cdot A_t/A_c \]
\[ (3') \quad N + 1 = 12 \times \frac{L_p}{B} \]

\[ N + 1 = 12 \times \frac{7,23234}{5} = 17,3575 \quad \text{(Pers. (7.43), Kern, 1965)} \]

\[ D_s = 8/12 = 0,666 \text{ ft} \]

\[ (4') \quad \Delta P_s = \left( \frac{1}{2} \right) \frac{f \cdot G_s^2 \cdot D_s \cdot (N + 1)}{5,22 \cdot 10^{10} \cdot D_e \cdot s \cdot \varphi_s} \quad \text{(Pers. (7.44), Kern, 1965)} \]

\[ \Delta P_s = \left( \frac{1}{2} \right) \frac{0,0028 \times (1663,1)^2 \times (0,6667) \times (17,3575)}{5,22 \times 10^{10} \times (0,0791) \times (0,98) \times (1)} = 0,0021 \text{ psi} \]

Penguapan

\[ (1') \quad R_e = 22989,1 \]

\[ f = 0,0018 \]

\[ (2') \quad \text{Panjang daerah penguapan:} \]

\[ L_v = 16 - 7,2323 = 8,7677 \text{ ft} \]

\[ (3') \quad \text{Jumlah Crosses,} \]

\[ N + 1 = 12 \times \frac{L_v}{B} \]

\[ N + 1 = 12 \times \frac{8,7677}{5} = 21,0425 \quad \text{(Pers. (7.43), Kern, 1965)} \]

\[ (4') \quad \Delta P_s = \left( \frac{1}{2} \right) \frac{f \cdot G_s^2 \cdot D_s \cdot (N + 1)}{5,22 \cdot 10^{10} \cdot D_e \cdot s \cdot \varphi_s} \quad \text{(Pers. (7.44), Kern, 1965)} \]

\[ \Delta P_s = \left( \frac{1}{2} \right) \frac{0,0018 \times (16163,1)^2 \times (0,6666) \times (21,0425)}{5,22 \times 10^{10} \times (0,0791) \times (0,98) \times (1)} = 0,0016 \text{ psi} \]

\[ \Delta P_s = 0,0021 + 0,0016 = 0,0037 \]
LC.29 Cooler (HE – 111)

Fungsi : Mendinginkan produk IPB untuk disimpan dalam tangki produk (TT-103)

Jenis : Duble-pipe counterflow exchanger

Dipakai : 1,38 in ID = 0,115 ft (annulus)
1,05 in OD = 0,0875 ft (inner-pipe)
0,824 in ID = 0,0687 ft (inner-pipe)

- Fluida panas
  Laju alir fluida panas = 28,6835 kg/jam = 63,2366 lbm/jam
  Temperatur awal (T1) = 165,102 °C = 329,183 °F
  Temperatur akhir (T2) = 30 °C = 86 °F

- Fluida dingin
  Laju alir fluida dingin = 32,0239 kg/jam = 1003,7452 lbm/jam
  Temperatur awal (t1) = 25 °C = 77 °F
  Temperatur akhir (t2) = 70 °C = 158 °F

  Panas yang diserap (Q) = 6027,3611 kJ/jam = 81219,9485 Btu/jam

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

<table>
<thead>
<tr>
<th>Fluida Panas</th>
<th>Fluida Dingin</th>
<th>Selisih</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_1 = 329,162 , ^\circ\text{F} )</td>
<td>Temperatur yang lebih tinggi</td>
<td>( t_2 = 158 , ^\circ\text{F} )</td>
</tr>
<tr>
<td>( T_2 = 86 , ^\circ\text{F} )</td>
<td>Temperatur yang lebih rendah</td>
<td>( t_1 = 77 , ^\circ\text{F} )</td>
</tr>
<tr>
<td>( T_1 - T_2 = 243,162^\circ \text{F} )</td>
<td>Selisih</td>
<td>( t_2 - t_1 = 81^\circ \text{F} )</td>
</tr>
</tbody>
</table>

\[
\text{LMTD} = \frac{\Delta t_2 - \Delta t_1}{\ln \left( \frac{\Delta t_2}{\Delta t_1} \right)} = \frac{-162,162}{\ln \left( \frac{9}{171,162} \right)} = 55,0562 \, ^\circ\text{F}
\]
\[ R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{243,162}{81} = 3,002 \]
\[ S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{81}{329,162 - 77} = 0,3212 \]

Dari Gambar 20, Kern, 1965 diperoleh \( F_T = 0,88 \)
Maka \( \Delta t = F_T \times \text{LMTD} = 0,88 \times 55,0652 = 48,4495 \degree F \)

(4) \( T_c \) dan \( t_c \)
\[ T_c = \frac{T_1 + T_2}{2} = \frac{329,162 + 86}{2} = 207,581 \degree F \]
\[ t_c = \frac{t_1 + t_2}{2} = \frac{77 + 158}{2} = 117,5 \degree F \]

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

(3) Flow area tube, \( a_t \)
\[ \text{ID}_2 = 0,824 \text{ in}^2 = 0,0686 \text{ ft} \]
\[ a_t = \frac{\pi (\text{ID}_2^2)}{4} \]
\[ \text{ID}_2 = 0,824 \text{ in}^2 = 0,0686 \text{ ft} \]
\[ a_t = \frac{\pi (0,0686^2)}{4} = 0,0037 \text{ ft}^2 \]

(4) Kecepatan massa:
\[ G_t = \frac{w}{a_t} \]
\[ G_t = \frac{62,6981}{0,0037} = 17749,7 \text{ lbm/jam} \cdot \text{ft}^2 \]

(5) Bilangan Reynold:
Pada \( T_c = 207,581 \degree F \)
\[ \mu = 0,3925 \text{ cP} = 0,9498 \text{ lbm/ft}^2 \cdot \text{jam} \]

Gambar 14, Kern, 1965
Taksir jH dari Gambar 24 Kern (1965), diperoleh jH = 2,2 pada ReT = 1283,16

(15) Pada Tc = 207,581 °F

c = 0,520 Btu/lbm.°F

k = 0,07 Btu/jam lbm ft.°F

\[
\left( \frac{c \cdot \mu}{k} \right)^{\frac{1}{3}} = \left( \frac{0,520 \times 0,9498}{0,07} \right)^{\frac{1}{3}} = 1,9180
\]

\[
h_i = jH \times \frac{k}{ID_2} \times \left( \frac{c \cdot \mu}{k} \right)^{\frac{1}{3}} \left( \frac{\mu}{\mu_w} \right)
\]

\[
h_i = 2,2 \times \frac{0,07}{0,0686} \times 1,9180 \times (1) = 22,6325
\]

(17) Koreksi hi pada permukaan OD

\[
h_{io} = h_i \left( \frac{ID_2}{OD} \right)
\]

\[
h_{io} \varphi_i = 22,6325 \times \frac{0,824}{1,05} = 17,7611
\]

Fluida dingin : water, annulus

(3’) Flow area shell

\[
a_s = \pi \left( \frac{ID_2^2 - OD^2}{4} \right)
\]

\[
a_s = 3,14 \left( \frac{0,115^2 - 0,0875^2}{4} \right) = 0,0043 \text{ ft}^2
\]
(4’') Kecepatan massa
\[ G_s = \frac{w}{a_s} \]  
(Pers. (7.2), Kern, 1965)
\[ G_s = \frac{1003,7452}{0,0043} = 229612,8 \text{lbm/jam.ft}^2 \]

(5’') Bilangan Reynold
Pada tc = 117,5 °F
\[ \mu = 0,61 \text{ cP} = 1,4762 \text{ lbm/ft}^2 \cdot \text{jam} \]  
(Gambar 14, Kern, 1965)
\[ \text{De} = \frac{(ID^2 - OD)}{OD} \]  
(Pers. (6.3), Kern, 1965)
\[ = \frac{(0,115^2 - 0,0875^2)}{0,0875} = 0,0636 \text{ ft} \]
\[ \text{Re}_c = \frac{D_c \times G_s}{\mu} \]  
(Pers. (7.3), Kern, 1965)
\[ \text{Re}_s = \frac{0,0636 \times 229612,8}{1,4762} = 9899,211 \]

(6’’) Taksir JH dari Gambar 24, Kern, diperoleh JH = 37 pada Re = 9899,211

(7’’) Pada tc = 117,5 °F
\[ c = 1,02 \text{ Btu/lbm.°F} \]  
(Gambar 2, Kern 1965)
\[ k = 0,3683 \text{ Btu/jam lbm. ft.°F} \]  
(Tabel 4, Kern 1965)
\[ \left( \frac{c \mu}{k} \right)^{1/3} = \left( \frac{1,02 \times 1,4762}{0,3683} \right)^{1/3} = 1,599 \]
\[ h_o = \frac{fH}{D_c} \left( \frac{c \mu}{k} \right)^{1/3} \left( \frac{\mu}{\mu_w} \right)^{0,14} \]  
(Pers. 6.15b, Kern 1965)
\[ h_o = 37 \frac{0,3683}{0,0636} \times 1,599 (1) = 342,3747 \]

(8) Clean Overall Coefficient, \( U_C \)
\[ U_C = \frac{h_{io} \times h_o}{h_{io} + h_o} = \frac{17,7611 \times 324,3747}{17,7611 + 324,3747} = 16,8816 \text{Btu/jam.ft}^2 \cdot \text{°F} \]
(9) Rd (diperbolehkan) = 0,003
\[
\frac{1}{U_d} = \frac{1}{U_c} + Rd
\]
\[
\frac{1}{U_d} = \frac{1}{16,8816} + 0,003 = 0,0622
\]
\[U_d = \frac{1}{0,0622} = 16,071 \text{ Btu/(jam)(ft}^2)(^\circ\text{F})
\]

(10)
\[
A = \frac{Q}{U_d(\Delta t)}
\]
\[
A = \frac{81219,9485}{16,0717.(55,0562)} = 91,7933
\]

Pipa Standart = 0,275 ft\(^2\) (Tabel 11, Kern, 1965)

Panjang pipa yang diperbolehkan
\[
\frac{91,7933}{0,275} = 333,7938 \text{ lin ft}
\]

Hairpins = \[ \frac{333,7938}{40} = 8,3448 \text{ = 9 hairpins} \]

Jumlah hairpins = 9 \times 20 = 180 hairpins

(11) Koreksi Ud = \[ \frac{81219,9485}{99.(55,0562)} = 14,9011 \text{ Btu/(jam)(ft}^2)(^\circ\text{F})
\]

Faktor pengotor, Rd
\[
R_d = \frac{U_c - U_D}{U_c \times U_D} = \frac{16,8851 - 14,9011}{16,8851 \times 14,9011} = 0,0078
\]

R\(_d\) hitung \(\geq\) R\(_d\) ketentuan (0,003), maka spesifikasi pendingin dapat diterima.
**Pressure drop**

**Fluida panas : sisi inner-pipe**

(1) Untuk $Re = 1283,16$

\[
f = 0,0035 + \frac{0,264}{Re} \quad \text{Pers. 3.47b, Kern 1965}
\]

\[
f = 0,0035 + \frac{0,264}{1283,16} = 0,0166
\]

\[
s = 0,88, p = 0,88 (62,5)
\]

\[s = 55 \]  

\[
\Delta F_i = \frac{4f \cdot G^2 \cdot L}{2g \cdot p^2 \cdot D}
\]

\[
\Delta F_i = \frac{4(0,0166) \cdot (17749,7)^2 \cdot 25}{2(4,18)(10^6) \cdot 55^2 (0,0686)} = 0,4808
\]

(2) \[
\Delta P_i = \left( \frac{0,4808 \cdot 55}{144} \right) = 0,1836 \text{ psi}
\]

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

**Fluida panas : annulus**

(1') $De = (ID_1 - OD)$  

\[De = (0,115 - 0,0875) = 0,0275 \text{ ft} \]

\[Re_e = \frac{De \cdot G_e}{\mu} \]

\[Re_e = \frac{0,0275 \cdot (229612,8)}{1,4762} = 4277,437 \]

\[
f = 0,0035 + \frac{0,264}{Re_e} = 0,0113 \quad \text{Pers. 3.47b, Kern 1965}
\]

\[s = 1, p = 62,5 \times 1 = 62,6 \]

\[s = 62,5 \times 1 = 62,6 \]

(Tabel 6, Kern, 1965)
\[(2') \quad \Delta F_s = \frac{4f. G^2_s \cdot L}{2g. p^2 D_e}\]

\[
\Delta F_s = \frac{4 \cdot (0,0113) \cdot 229612,8^2 \cdot (40)}{2(4,18) \cdot (10^8) \cdot (62,5^2) \cdot (0,0275)} = 1,0689 \text{ ft}
\]

\[V = \frac{G}{3600p}\]

\[
V = \frac{229612,8}{3600 \cdot (62,5)} = 1,0205
\]

\[F_1 = 3 \cdot \frac{V^2}{2g^2}\]

\[
F_1 = \frac{1,0205^2}{2 \cdot (32,2)} = 0,0485
\]

\[
\Delta p_s = \frac{\Delta F + F_1}{144} = \frac{(1,0689 + 0,0485) \cdot (62,5)}{144} = 0,485 \text{ psi}
\]

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

**LC.30 Pompa Produk Samping DIPB (P-08)**

Fungsi : Mengalirkan produk DIPB ke tangki penyimpanan (TT-104)

Jenis : Pompa sentrifugal

Jumlah : 1 unit

Kondisi operasi : 

Tekanan = 1 atm

Temperatur = 30 °C

Laju alir massa (F) = 28,6835 kg/jam = 0,0175 lbm/s

Tabel LC.20 Data pada alur 32

<table>
<thead>
<tr>
<th>Komponen</th>
<th>x</th>
<th>ρ x</th>
<th>μ x</th>
<th>ρ campuran</th>
<th>μ campuran</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPB</td>
<td>0,007</td>
<td>862 kg/m³</td>
<td>0,66 cp</td>
<td>5,785 kg/m³</td>
<td>0,0044 cp</td>
</tr>
<tr>
<td>DIPB</td>
<td>0,993</td>
<td>859 kg/m³</td>
<td>0,667 cp</td>
<td>853,234 kg/m³</td>
<td>0,6625 cp</td>
</tr>
</tbody>
</table>
Laju alir volumetrik,

\[
m_v = \frac{28,6835 \text{ kg/jam}}{859,020 \text{ kg/m}^3} = 0,0333 \text{ m}^3/\text{jam} = 0,00001 \text{ m}^3/\text{s} = 0,0003 \text{ ft}^3/\text{s}
\]

Desain pipa:

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

\[
= 0,363 (0,00001 \text{ m}^3/\text{s})^{0.45} (859,020 \text{ kg/m}^3)^{0.13}
\]

\[
= 0,0047 \text{ m} = 0,1869 \text{ in}
\]

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

- Ukuran nominal : 0,125 in
- Schedule number : 40
- Diameter Dalam (ID) : 0,269 in = 0,0224 ft = 0,0068 m
- Diameter Luar (OD) : 0,405 in = 0,0337 ft
- Inside sectional area : 0,0004 ft²

Kecepatan linier, \( v = \frac{Q}{A} = \frac{0,0003 \text{ ft}^3/\text{s}}{0,0004 \text{ ft}^2} = 0,8188 \text{ ft/s} = 0,2495 \text{ m/s} \)

Bilangan \textit{Reynold}:

\[
N_{\text{Re}} = \frac{\rho \times v \times D}{\mu}
\]

\[
= \frac{(53,6282 \text{ lbm/ft}^3)(0,8188 \text{ ft/s})(0,02241 \text{ ft})}{0,0004 \text{ lbm/ft.s}} = 2196,4838 \quad \text{(Turbulen)}
\]

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

Pada \( N_{\text{Re}} = 2196,4838 \) dan \( \varepsilon/D = \frac{0,000046 \text{ m}}{0,0063 \text{ m}} = 0,0067 \)
Dari Gambar 2.10-3 Geankoplis (2003) diperoleh harga \( f = 0,015 \)

*Friction loss:*

1. **Sharp edge entrance:**
   
   \[
   h_c = 0,55 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2\alpha} = 0,55(1-0) \frac{0,8188^2}{2(0,0075)(32,174)} = 0,0057 \text{ ft.lbf/lbm}
   \]

2. **elbow 90°:**
   
   \[
   h_f = n.Kf. \frac{v^2}{2.g_c} = 1(0,75) \frac{0,8188^2}{2(32,174)} = 0,0078 \text{ ft.lbf/lbm}
   \]

3. **check valve:**
   
   \[
   h_f = n.Kf. \frac{v^2}{2.g_c} = 1(2) \frac{0,8188^2}{2(32,174)} = 0,208 \text{ ft.lbf/lbm}
   \]

Pipa lurus 100 ft:

\[
F_f = 4f \frac{\Delta L.v^2}{D.2.g_c} = 4(0,0075) \frac{(100)(0,8188^2)}{(0,0224)(2)(32,174)} = 2,7890 \text{ ft.lbf/lbm}
\]

1. **Sharp edge exit:**
   
   \[
   h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right) \frac{v^2}{2.\alpha.g_c} = 1 (1-0) \frac{0,8188^2}{2(0,0075)(32,174)} = 0,0104 \text{ ft.lbf/lbm}
   \]

**Total friction loss:**

\[
\sum F = 2,8338 \text{ ft.lbf/lbm}
\]

Dari persamaan Bernoulli:

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

dimana: \( v_1 = v_2 \)

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

\( \Delta P = 0 \text{ atm} = 0 \text{ lb/ft}^2 \)

tinggi pemompaan \( \Delta Z = 40 \text{ ft} \)

maka:

\[
0 + \frac{32,174}{32,174} + 0 + \frac{0}{53,6282} + 2,8338 + W_s = 0
\]

\[
W_s = 42,8338 \text{ ft.lbf/lbm}
\]

Efisiensi pompa, \( \eta = 70\% \)

\[
W_p = \frac{W_s}{\eta} \tag{Geankoplis, 2003}
\]
\[
\frac{42,8338}{0,7} = 61,1911 \text{ ft.lbf/lbm.}
\]

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

\[
= 0,01756 \text{ lbm/s} \times 61,1911 \text{ ft.lbf/lbm}
= 1,0748 \text{ ft.lbf/lbm}
= 0,0019 \text{ hp}
\]

Maka dipilih pompa dengan daya motor 1/4 hp.

**LC.31 Tangki Penyimpanan DIPB (TT – 104)**

Fungsi: Menyimpan produk samping DIPB untuk keperluan 10 hari

Bahan konstruksi: *Carbon Steel SA –285 Grade C*

Bentuk: Silinder vertikal dengan alas datar dan tutup *ellipsoidal*

Jenis sambungan: *Single welded butt joints*

Jumlah: 1 unit

Kondisi operasi:

- Tekanan: 1 atm
- Temperatur: 30 °C = 303,15 K
- Laju Alir Massa: 28,6835 kg/jam
- Kebutuhan perancangan: 10 hari
- Faktor kelonggaran: 20 %

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Laju Alir km/jam</th>
<th>Fraksi</th>
<th>Densitas Kg/m³</th>
<th>( \rho ) Campuran (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPB</td>
<td>0,2182</td>
<td>0,0076</td>
<td>862</td>
<td>6,5573</td>
</tr>
<tr>
<td>DIPB</td>
<td>28,4653</td>
<td>0,9923</td>
<td>859</td>
<td>852,4654</td>
</tr>
<tr>
<td>Total</td>
<td>28,6835</td>
<td>1</td>
<td>859,0228</td>
<td></td>
</tr>
</tbody>
</table>

(Sumber: Perry, 1999)
Perhitungan:

a. Volume Tangki

Volume larutan, \( V_l = \frac{28,6835 \text{ kg/jam} \times 10 \text{ hari} \times 24 \text{ jam/hari}}{859,0228 \text{ kg/m}^3} = 8,0138 \text{ m}^3 \)

Direncanakan membuat 1 tangki dan faktor kelonggaran 20%, maka :

Volume 1 tangki, \( V_l = 1,2 \times 8,0138 \text{ m}^3 / 1 = 9,6166 \text{ m}^3 \)

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

- Volume tangki (\( V_t \)) :
  \[ V_t = V_s + V_e \]
  \[ = \frac{3}{8} \pi D^3 \]
  \[ 9,6166 \text{ m}^3 = 1,1781 \text{ D}^3 \]
  \[ D = 2,0138 \text{ m} = 79,28 \text{ in} \]
  \[ H_s = \frac{4}{3} D = 2,6850 \text{ m} \]

c. Diameter dan tinggi tutup

Diameter tutup = Diameter tangki = 2,0138 m

Tinggi tutup (\( H_d \)) = \( \frac{1}{4} D = 0,5034 \text{ m} \)

Tinggi tangki = \( H_s + H_d = (2,6850 + 0,5043) \text{ m} = 3,1885 \text{ m} \)
d. Tebal *shell* tangki

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

- *Allowable stress* (*S*) = 13750 psia
- *Joint efficiency* (*E*) = 0,8
- *Corrosion allowance* (*C*) = 0,25 mm/tahun (Peters dkk, 2004) = 0,0098 in/tahun
- Umur tangki (*n*) = 10 tahun

Volume cairan = 8,0138 m³

Tinggi cairan dalam tangki = \( \frac{8,0138 \text{ m}^3}{9,6166 \text{ m}^3} \times 2,6850 \text{ m} = 2,2375 \text{ m} \)

Tekanan Hidrostatik:

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

\[ = 859,0201 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 2,2375 \text{ m} = 0,18 \text{ atm} \]

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

\[ P = 1 \text{ atm} + 0,18 \text{ atm} = 1,18 \text{ atm} \]

\[ P_{\text{design}} = 1,2 \times 1,18 = 1,42 \text{ atm} = 20,91 \text{ psi} \]

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*

\[ t = \frac{PR}{SE - 0,6P} = \left( \frac{20,91 \text{ psi}}{13750 \text{ psia}} \right) \left( \frac{39,64 \text{ in}}{0,8} \right) - 0,6(20,91 \text{ psi}) \]

\[ = 0,0754 \text{ in} \]
Faktor korosi = 0,0098 in/tahun

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

= 0,0754 + (10 x 0,0098)

= 0,1737 in

Tebal shell standar yang digunakan = 0,2 in (Brownell & Young, 1959)

e. Tebal tutup tangki

Tutup atas tangki terbuat dari bahan yang sama dengan shell.

Tebal tutup atas yang digunakan = 0,2 in.

**LC.32 Compresor (JC-103)**

Fungsi : Menaikkan sekaligus mengalirkan umpan propilen

Jenis : *Multistage reciprocating compressor*

Jumlah : 1 unit

Kondisi Operasi :

- Tekanan Masuk: 1 atm = 2116,1236 lbf/ft²
- Tekanan Keluar: 1,5 atm = 3174,1855 lbf/ft²

<table>
<thead>
<tr>
<th>Komponen</th>
<th>Laju Alir kg/jam</th>
<th>Fraksi</th>
<th>Densitas Kg/m³</th>
<th>ρ Campuran</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propylene</td>
<td>13,9422</td>
<td>0,61904804</td>
<td>1,748</td>
<td>1,0820</td>
</tr>
<tr>
<td>Propana</td>
<td>8,5798</td>
<td>0,38095196</td>
<td>1,882</td>
<td>0,7169</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>1.797 (Kg/m³)</td>
<td>0,111 (lbm/ft³)</td>
</tr>
</tbody>
</table>

\[
Hp = \frac{1,13 \times 10^5 F}{k \cdot \rho} \cdot \frac{Qfm}{P_1} \cdot \left( \frac{P_2}{P_1} \right)^{\frac{k-1}{k}} \cdot \left( \frac{\rho}{\rho_1} \right) \cdot \left( \frac{\rho}{\rho_2} \right)^{\frac{k-1}{k}} (Timmerhaus, 1991)
\]

dimana:

\[
Qfm = \text{laju alir} = \frac{F}{\rho} = \frac{22,522}{1,797} = \frac{12,5349}{1,797} \text{m}^3/\text{jam} = \frac{7,4612}{1,797} \text{ft}^3/\text{menit} = 0,1243 \text{ ft}^3/\text{s}
\]

\[
\eta = \text{efisiensi kompresor} = 80 \%
\]

k = rasio panas spesifik = 1,4
\[
\text{Hp} = \frac{3.03 \times 10^5 \times 1.4}{(1.4-1)} \times 2116,1236 \times 7.4612 \left[ \left( \frac{3174,1855}{2116,1236} \right)^{(1.4-1)/1.4} - 1 \right]
\]

\[
= 0,2056 \text{ HP}
\]

Jika efisiensi motor adalah 80 %, maka :

Daya actual, \( P = \frac{0.08}{0.80} = 0.2570 \text{HP} \)

Diameter pipa ekonomis (De) dihitung dengan persamaan :

\[
\text{De} = 3.9 (Q)^{0.45} (\rho)^{0.13} \quad \text{(Timmerhaus, 1991)}
\]

\[
= 3,9 \times (0,1243 \text{ft}^3/\text{s})^{0.45} (0,111 \text{ lbm/ft}^3)^{0.13}
\]

\[
= 1,14 \text{ in}
\]

Dari Appendiks A.5 Geankoplis, 2003, dipilih pipa commercial steel :

Ukuran nominal : 1,5 in

\text{Schedule number} : 40

Diameter Dalam (ID) : 1,61 in \quad = 40,89 \text{mm}

Diameter Luar (OD) : 1,9 in \quad = 48,26 \text{mm}

\text{Inside sectional area} : 0,0141 \text{ ft}^2
LAMPIRAN D
PERHITUNGAN SPESIFIKASI ALAT UTILITAS

L.D.1  

**Screening (SC)**

Fungsi : Menyaring partikel-partikel padat yang besar
Jenis : *Bar screen*
Jumlah : 1
Bahan konstruksi : *Stainless steel*

Kondisi operasi :
Temperatur = 30 °C
Densitas air (\(\rho\)) = 995,467 kg/m³ (Perry, 1997)

Laju alir massa (F) = 2268,91222 kg/jam

\[
Laju alir volume (Q) = \frac{2268,91222 \text{ kg/jam} \times 1 \text{ jam/3600 s}}{995,467 \text{ kg/m}^3} = 0,00063 \text{ m}^3/\text{s}
\]

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

Misalkan, jumlah bar = \(x\)
Maka, \(20x + 20(x + 1) = 1000\)
\[40x = 980\]
\[x = 24,975 \approx 25 \text{ buah}\]

Luas bukaan (\(A_2\)) = \(20(25 + 1)(1000) = 519500 \text{ mm}^2 = 0,5195 \text{ m}^2\)

Untuk pemurnian air sungai menggunakan *bar screen*, diperkirakan \(C_d = 0,6\) dan 30% *screen* tersumbat.
Head loss (Δh) = \( \frac{Q^2}{2gC_dA_y^2} = \frac{(0,0007)^2}{2(9,8)(0,6)^2(0,5195)^2} \)

= 0,0000002 m dari air  
= 0,0002105 mm dari air

**L.D.2 Bak Sedimentasi (BS)**

Fungsi : Untuk mengendapkan lumpur yang terikat dengan air.
Jumlah : 1
Jenis : beton kedap air
Kondisi operasi :

Temperatur = 30 °C  
Tekanan = 1 atm  
Densitas air (\( \rho \)) = 995,467 kg/m³ (Perry, 1997)
Laju alir massa (\( F \)) = 2268,91222 kg/jam

Laju air volumetrik, \( Q = \frac{F}{\rho} = \frac{2268,91222 \text{ kg/jam}}{995,467 \text{ kg/m}^3} = 2,79 \text{ m}^3/\text{jam} \)

= 0,0006 m³/s

Desain Perancangan :


Perhitungan ukuran tiap bak :

Kecepatan pengendapan 0,1 mm pasir adalah (Kawamura, 1991) :
\( v_0 = 1,57 \text{ ft/min atau 8 mm/s} \)

Desain diperkirakan menggunakan spesifikasi :

Kedalaman tangki 5 ft  
Lebar tangki 1 ft

Kecepatan aliran \( v = \frac{Q}{A_i} = \frac{1,3414 \text{ ft}^3/\text{min}}{5 \text{ ft} x 1 \text{ ft}} = 0,2682 \text{ ft/min} \)

Desain panjang ideal bak :  
\[ L = K \left( \frac{h}{v_0} \right) v \]  
(Kawamura, 1991)
dengan: \( K = \) faktor keamanan = 20%
\( h = \) kedalaman air efektif (10 – 16 ft); diambil 10 ft.

Maka: \( L = 1,2 \times (10/1,57) \times 0,2682 = 2,0506 \text{ ft} \)
Diambil panjang bak = 3,25 ft = 0,9906 m

Uji desain:
Waktu retensi (t): \( t = \frac{V_a}{Q} \)
\[ = \frac{\text{panjang x lebar x tinggi}}{\text{laju alir volumetrik}} \]
\[ = \frac{(3,25 \times 1 \times 5) \text{ ft}^3}{1,3414 \text{ ft}^3 / \text{min}} = 12,11 \text{ menit} \]

Surface loading: \( \frac{Q}{A} = \frac{\text{laju alir volumetrik}}{\text{luas permukaan masukan air}} \)
\[ = \frac{1,3414 \text{ ft}^3/\text{min (7,481 gal/ft}^3)}{1 \text{ ft x 3,25 ft}} \]
\[ = 3,0878 \text{ gpm/ft}^2 \]

Headloss (\( \Delta h \)): bak menggunakan gate valve, full open (16 in):
Kelonggaran (K) = 12%
\[ \Delta h = K \frac{v^2}{2g} \]
\[ \Delta h = 0,12 \frac{(0,3272 \text{ ft/min})/(3,0878)/(60s))^2}{2(9,8m/s^2)} = \]
\[ = 0,0000001 \text{ m} = 0,00001 \text{ mm dari air} \]
LD.3 Tangki Pelarutan Alum \([\text{Al}_2(\text{SO}_4)_3]\) (TP-01)

**Fungsi** : Membuat larutan alum \([\text{Al}_2(\text{SO}_4)_3]\)

**Bentuk** : Silinder tegak dengan alas dan tutup datar

**Bahan konstruksi** : Carbon Steel SA–283 grade C

**Jumlah** : 1

**Kondisi operasi**:
- **Temperatur** = 30 °C
- **Tekanan** = 1 atm
- **Al_2(SO_4)_3** yang digunakan = 50 ppm
- **Al_2(SO_4)_3** yang digunakan berupa larutan 30% (% berat)
- **Laju massa** \([\text{Al}_2(\text{SO}_4)_3]\) = 0,1134 kg/jam
- **Densitas** \([\text{Al}_2(\text{SO}_4)_3]\) 30% = 1363 kg/m\(^3\) = 85,0889 lbm/ft\(^3\) (Perry, 1999)
- **Kebutuhan perancangan** = 1 hari
- **Faktor keamanan** = 20%

**Perhitungan**:

**Ukuran Tangki**

**Volume larutan**, \(V_t = \frac{0,1134 \text{ kg/jam} \times 24 \text{ jam/hari} \times 30 \text{ hari}}{0,3 \times 1134 \text{ kg/m}^3}\)

\[= 0,1997 \text{ m}^3\]

**Volume tangki**, \(V_t = 1,2 \times 0,1997 \text{ m}^3 = 0,2397 \text{ m}^3\)

**Direncanakan perbandingan diameter dengan tinggi silinder tangki**, \(D : H = 1 : 1\)

\[= \left(\frac{V_t}{3,14}\right)^{1/3}\]

Maka: \(D = H\)

\[= \left(\frac{0,2397 \text{ m}^3}{3,14}\right)^{1/3}\]

\[= 0,6733 \text{ m} = 26,5117 \text{ in}\]

**Tinggi cairan dalam tangki** = \(\frac{\text{volumecairan} \times \text{tinggi silinder}}{\text{volumesilinder}}\)

\[= \frac{(0,1997)(0,6733)}{(0,2397)} = 0,5995 \text{ m}\]
Tebal Dinding Tangki

Tekanan hidrostatik, \( P_{\text{hid}} = \rho \times g \times l \)
\[ = 1363 \text{ kg/m}^3 \times 9.8 \text{ m/det}^2 \times 0.5995 \text{ m} \]
\[ = 8008.73 \text{ Pa} = 8.00873 \text{ kPa} \]

\( P_{\text{operasi}} = 1 \text{ atm} = 101,325 \text{ kPa} \)
\( P_{\text{total}} = 8,00873 \text{ kPa} + 101,325 \text{ kPa} \)
\[ = 109,3373 \text{ kPa} \]

Faktor kelonggaran = 20 %

Maka, \( P_{\text{design}} = 1.2 \times (109,3373 \text{ kPa}) \)
\[ = 131,2004 \text{ kPa} \]

\( \text{Joint efficiency} = 0.8 \) (Brownell, 1959)

\( \text{Allowable stress} = 12650 \text{ psia} = 87218.7 \text{ kPa} \) (Brownell, 1959)

Faktor korosi = 0,0098 in/thn

Direncanakan umur alat 10 tahun

Tebal shell tangki:
\[ t = \frac{PD}{2SE - 1.2P} \]
\[ t_{10\text{tahun}} = \frac{(131,2004 \text{ kPa})(0,7194/2)}{2(87218.7 \text{ kPa})(0,8) - 1.2(131,2004 \text{ kPa})} + 10\text{thn}(0,0098\text{in}) \]
\[ = 0,1246\text{in} \]

Tebal perancangan = ¼ in

Daya Pengaduk

Jenis pengaduk : flat 6 blade turbin impeller

Jumlah baffle : 4 buah

Untuk turbin standar (McCabe, 1999), diperoleh:

\( \frac{D_{a}}{D_{t}} = \frac{1}{3} \)
\( \frac{D_{a}}{E} = 1 \)
\( \frac{L}{D_{a}} = \frac{1}{4} \)
\( \frac{W}{D_{a}} = \frac{1}{5} \)
\( \frac{J}{D_{t}} = \frac{1}{12} \)

\( D_{a} = 1/3 \times 0.7194 \text{ m} = 0.2398 \text{ m} \)
\( E = 0.2398 \text{ m} \)
\( L = 1/4 \times 0.2398 \text{ m} = 0.0599 \text{ m} \)
\( W = 1/5 \times 0.2398 \text{ m} = 0.0479 \text{ m} \)
\( J = 1/12 \times 0.7194 \text{ m} = 0.0599 \text{ m} \)
dengan:
- $D_t =$ diameter tangki
- $D_a =$ diameter impeller
- $E =$ tinggi turbin dari dasar tangki
- $L =$ panjang blade pada turbin
- $W =$ lebar blade pada turbin
- $J =$ lebar baffle

Kecepatan pengadukan, $N = 1$ putaran/det

Viskositas $\text{Al}_2(\text{SO}_4)_3$, 30% = $6,72 \times 10^{-4}$ lbm/ft-detik (Othmer, 1967)

Bilangan Reynold,

$$N_{Re} = \frac{\rho N (D_a)^2}{\mu}$$

(Geankoplis, 1997)

$$N_{Re} = \frac{(1363)(1)(0,2398)^2}{6,72 \times 10^{-4}} = 78323,9173$$

$N_{Re} > 10.000$, maka perhitungan dengan daya pengaduk menggunakan rumus:

$$P = Np \rho N^3 D_a^5$$

(Geankoplis, 2003)

$Np = 5$ untuk $N_{Re} = 91564,33$

$P = 5(1)^3(0,2398)^5 1363 \approx 0,00541$ kW = 0,00725 hp

Efisiensi motor = 70%
Daya motor = 0,0103 hp
Digunakan daya motor standar $\frac{1}{4}$ hp

**L.D.4 Tangki Pelarutan Soda Abu [Na$_2$CO$_3$] (TP-02)**

**Fungsi** : Membuat larutan soda abu (Na$_2$CO$_3$)
**Bentuk** : Silinder tegak dengan alas dan tutup datar
**Bahan konstruksi** : Carbon Steel SA–283 grade C
**Jumlah** : 1

**Kondisi operasi** :
**Temperatur** = 30 °C
Tekanan = 1 atm
Na₂CO₃ yang digunakan = 27 ppm
Na₂CO₃ yang digunakan berupa larutan 30 % (% berat)
Laju massa Na₂CO₃ = 0,0747 kg/jam
Densitas Na₂CO₃ 30 % = 1327 kg/m³ = 82,845 lbm/ft³ (Perry, 1999)
Kebutuhan perancangan = 30 hari
Faktor keamanan = 20 %

Perhitungan Ukuran Tangki

Volume larutan, \( V_l = \frac{0,0747 \text{ kg/jam} \times 24 \text{ jam/hari} \times 30 \text{ hari}}{0,3 \times 1327 \text{ kg/m}^3} = 0,1351 \text{ m}^3 \)

Volume tangki, \( V_t = 1,2 \times 0,1351 \text{ m}^3 = 0,1621 \text{ m}^3 \)

Diameter dan tinggi tangki

Direncanakan :

Tinggi tangki : diameter tangki \( H_s : D = 1 : 1 \)

Volume tangki (\( V_t \))

\[ V_t = \frac{1}{4} \pi D^2 H_s \]

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

\[ 0,1621 \text{ m}^3 = \frac{3}{8} \pi D^3 \]

Maka, diameter tangki \( D = 0,5911 \text{ m} = 23,73 \text{ in} \)

tinggi tangki \( H_s = D = 0,5911 \text{ m} = 23,73 \text{ in} \)

Tebal shell tangki

Tinggi cairan dalam tangki, \( h = \frac{0,1351 \text{ m}^3}{0,1621 \text{ m}^3} \times 0,5911 \text{ m} = 0,4926 \text{ m} \)

Tekanan hidrostatik :

\[ P = \rho \times g \times h = 1327 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 0,4926 = 6,4063 \text{ kPa} \]

Tekanan operasi :

\[ P_{operasi} = 101,325 \text{ kPa} \]
\[ P_{\text{total}} = 101,325 \text{ kPa} + 6,4063 \text{ kPa} = 107,731 \text{ kPa} \]

Faktor keamanan : 20 

\[ P_{\text{design}} = (1,2) (107,731 \text{ kPa}) = 129,278 \text{ kPa} \]

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 : \( n = 10 \text{ tahun} \)

Tebal shell tangki :

\[ t = \frac{PD}{2SE - 1,2P} + nC \]

\[ t_{\text{total}} = \frac{(129,278 \text{ kPa})(0,5911/2) + 10(0,0098)}{2(87218,71)(0,8) - 1,2(129,278)} = 0,1159 \text{ in} \]

Tebal shell 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 :

\[ \frac{Da}{Dt} = \frac{1}{3} ; Da = \frac{1}{3} \times 0,5911 \text{ m} = 0,19705 \text{ m} \]
\[ \frac{E}{Da} = 1 ; E = 19705 \text{ m} \]
\[ \frac{L}{Da} = \frac{1}{4} ; L = \frac{1}{4} \times 0,19705 \text{ m} = 0492 \text{ m} \]
\[ \frac{W}{Da} = \frac{1}{5} ; W = \frac{1}{5} \times 0,19705 \text{ m} = 0,0394 \text{ m} \]
\[ \frac{J}{Dj} = 1/12 ; J = 1/12 \times 0,5911 \text{ m} = 0,492 \text{ m} \]

dimana :

\[ \text{Dt} = D = \text{diameter tangki (m)} \]
\[ \text{Da} = \text{Diameter impeller (m)} \]
\[ E = \text{tinggi turbin dari dasar tangki (m)} \]
\[ L = \text{panjang blade pada turbin (m)} \]
\[ W = \text{lebar blade pada turbin (m)} \]
\[ J = \text{lebar baffle (m)} \]
Kecepatan pengadukan, \( N = 1 \) putaran/detik

Bilangan Reynold, \( N_{Re} = \frac{\rho N (Da)^2}{\mu} = \frac{1327(1)(0,19705)^2}{0,00055} = 62895,8 \)

\( N_{Re} > 10.000 \), maka perhitungan dengan daya pengaduk menggunakan rumus:

\[ P = Np N^3 D_a^5 \rho \]

\( Np = 5 \) untuk \( N_{Re} = 73504,3 \)  

\[ P = 5(l)^3(0,19705)^5 \times 1327 = 0,0019 \text{ kW} = 0,0 \text{ hp} \]

Efisiensi motor = 70 %

Daya motor = 0,003 hp

Digunakan daya motor standar 1/4 hp

**LD.5 Tangki Pelarutan Asam Sulfat (H\(_2\)SO\(_4\)) (TP-03)**

**Fungsi**  : Membuat larutan asam sulfat

**Bentuk**  : Silinder tegak dengan alas dan tutup datar

**Bahan konstruksi**  : Low Alloy Steel SA–203 grade A

**Kondisi operasi** :

Temperatur = 30 °C

Tekanan = 1 atm

H\(_2\)SO\(_4\) yang digunakan mempunyai konsentrasi 5 % (% berat)

**Laju massa H\(_2\)SO\(_4\)**  = 0,1474 kg/jam

**Densitas H\(_2\)SO\(_4\)**  = 1061,7 kg/m\(^3\)  

(Perry, 1999)

**Kebutuhan perancangan**  = 30 hari

**Faktor keamanan**  = 20 %

**Perhitungan** :

Volume larutan, \( V_l = \frac{0,1474 \text{ kg/jam} \times 30 \text{ hari} \times 24 \text{ jam}}{0,05 \times 1061,7 \text{ kg/m}^3} = 2,0004 \text{ m}^3 \)

Volume tangki, \( V_t = 1,2 \times 2,0004 \text{ m}^3 = 2,4005 \text{ m}^3 \)

Direncanakan perbandingan diameter dengan tinggi silinder tangki, \( D : H = 1 : 1 \)
Volume tangki \( (V_t) \)
\[
V_t = \frac{1}{4} \pi D^2 H_s
\]
\[
V_t = \frac{1}{4} \pi D^3
\]
\[
2,4005 = \frac{1}{4} \pi D^3
\]
Maka, diameter tangki \( D = 1,4514 \) m = 57,14 in
tinggi tangki \( H_t = H_s = \frac{H_s}{D} \times D = 57,14 \) in

3. Tebal shell tangki

Tinggi cairan dalam tangki, \( h = \frac{2,0004 m^3}{2,4005 m^3} \times 1,2095 \) m

Tekanan hidrostatik :
\[
P = \rho \times g \times h = 1061,7 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 1,2095 = 12,5851 \text{ kPa}
\]

Tekanan operasi :
\[
P_{operasi} = 1 \text{ atm} = 101,325 \text{ kPa}
\]
\[
P_{total} = 101,325 \text{ kPa} + 12,5851 \text{ kPa} = 113,9101 \text{ kPa}
\]

Faktor keamanan : 20 %
\[
P_{design} = (1,2) (113,9101 \text{ kPa}) = 136,6921 \text{ kPa}
\]

\textit{Joint efficiency} : \( E = 0,8 \) \hspace{1cm} \text{(Brownell & Young, 1959)}

\textit{Allowable stress} : \( S = 12650 \text{ psia} = 87218.71 \text{ kPa} \) \hspace{1cm} \text{(Brownell & Young, 1959)}

Faktor korosi : \( C = 0,0098 \) in/tahun \hspace{1cm} \text{(Peters dkk, 2004)}

Umur alat : \( n = 10 \) tahun

Tebal shell tangki :
\[
t = \frac{PD}{2SE - 1,2P} + n C
\]
\[
t_{10\text{tahun}} = \frac{136,6921kPa(1,4514/2m)}{2(87218,17)(0,8) - 1,2(136,6921)} + 10(0,0098)
\]
\[
= 0,1540 \text{ in}
\]

Tebal shell standar yang digunakan = \( \frac{1}{4} \) in \hspace{1cm} \text{(Brownell & Young, 1959)}
Perancangan Sistem Pengaduk

Jenis pengaduk : *flat 6 blade turbin impeller*

Jumlah *baffle* : 4 buah

Untuk turbin standar (Geankoplis, 2003), diperoleh :

\[
\begin{align*}
\frac{Da}{Dt} &= \frac{1}{3} ; \quad Da = \frac{1}{3} \times 1,4514 = 0,4838 \text{ m} \\
\frac{E}{Da} &= 1 ; \quad E = 0,4838 \text{ m} \\
\frac{L}{Da} &= \frac{1}{4} ; \quad L = \frac{1}{4} \times 0,4838 = 0,1209 \text{ m} \\
\frac{W}{Da} &= \frac{1}{5} ; \quad W = \frac{1}{5} \times 0,4838 = 0,0967 \text{ m} \\
\frac{J}{Dt} &= \frac{1}{12} ; \quad J = \frac{1}{12} \times 1,4541 = 0,1209 \text{ m}
\end{align*}
\]

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, \(N_{Re}\),

\[
N_{Re} = \frac{\rho \cdot N \cdot (Da)^2}{\mu} = \frac{1061,7(1)(0,4541)^2}{0,01778 \text{ kg/m.s}} = 13904,816
\]

\(N_{Re} < 10.000\), maka perhitungan dengan daya pengaduk menggunakan rumus:

\[
P = Np \cdot N^3 \cdot Da^5 \cdot \rho
\]

\(Np = 5\) untuk \(N_{Re} = 12637,986\) \((\text{Geankoplis, 2003})\)

\[
P = 5(1)^3(0,4541)^51061,7 = 0,1407 \text{ kW} = 0,1887 \text{ hp}
\]

Efisiensi motor = 70 %

Daya motor = 0,2696 hp

Digunakan daya motor standar \(\frac{1}{4}\) hp

LD.6 Tangki Pelarutan NaOH (TP-04)

Fungsi : Tempat membuat larutan NaOH

Bentuk : Silinder tegak dengan alas dan tutup datar
Bahan konstruksi : *Carbon Steel SA-283 grade C*

Jumlah : 1 unit

Kondisi operasi :

Temperatur = 30 °C

Tekanan = 1 atm

Laju alir massa NaOH = 0,6090 kg/jam

Waktu regenerasi = 24 jam

NaOH yang dipakai berupa larutan 4% (% berat)

Densitas larutan NaOH 4% = 1518 kg/m³ = 94,7689 lbm/ft³ (Perry, 1999)

Kebutuhan perancangan = 30 hari

Faktor keamanan = 20%

Perhitungan :

Volume larutan, \( V_1 \) = \( \frac{(0,6090 \text{ kg/jam})(30 \text{ hari})(24 \text{ jam/hari})}{(0,04)(1518 \text{ kg/m}^3)} \) = 7,2223 m³

Volume tangki = 1,2 x 7,223 m³ = 8,6668 m³

Volume silinder tangki (Vs) = \( \frac{\pi D^2 H_s}{4} \) (Brownell, 1959)

Direncanakan : Tinggi tangki : diameter tangki \( H_s : D = 1 : 1 \)

Volume tangki (Vt)

\[ V_t = \frac{1}{4} \pi D^2 H_s \]

\( 8,6668 = \frac{1}{4} \pi D^3 \)

Maka, diameter tangki \( D = 2,2267 \) m

tinggi tangki \( H_t = H_s = \left( \frac{H_s}{D} \right) \times D = 2,2267 \) m

Tebal *shell* tangki

Tinggi cairan dalam tangki, \( h = \frac{7,2223 \text{ m}^3}{8,6668 \text{ m}^3} \times 2,2267 \text{ m} = 1,8555 \) m

Tekanan hidrostatik :

\[ P = \rho \times g \times h = 1518 \text{ kg/m}^3 \times 9,8 \text{ m/} \text{det}^2 \times 1,8555 = 27,6044 \text{ kPa} \]
Tekanan operasi:
\[ P_{\text{operasi}} = 1 \text{ atm} = 101,325 \text{ kPa} \]
\[ P_{\text{total}} = 101,325 \text{ kPa} + 27,6044 \text{ kPa} = 128,9294 \text{ kPa} \]

Faktor keamanan: 20 %
\[ P_{\text{design}} = (1,2) \times 128,9294 \text{ kPa} = 154,7153 \text{ kPa} \]

*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: \( n = 10 \text{ tahun} \)

Tebal tangki:
\[ t = \frac{PD}{2SE - 1,2P} + nC \]
\[ t_{\text{max}} = \frac{(154,7153 \text{ kPa})(2,22/2m)}{2(87218,71 \text{ kPa})(0,8) - 1,2(154,7153 \text{ kPa})} + 10 (0,0098 \text{ in}) \]
\[ = 0,1953 \text{ in} \]

Tebal shell standart yang dipilih = \( 1/4 \) in (Brownell & Young, 1959)

**Perancangan Sistem Pengaduk**

Jenis pengaduk: *flat 6 blade turbin impeller*

Jumlah baffle: 4 buah

Untuk turbin standar (Geankoplis, 2003), diperoleh:
\[ \frac{D_a}{D_t} = \frac{1}{3} ; \quad \frac{D_a}{D_t} = \frac{1}{3} \times 2,2267 = 0,7422 \text{ m} \]
\[ \frac{E}{D_a} = 1 ; \quad \frac{E}{D_a} = 0,7422 \text{ m} \]
\[ \frac{L}{D_a} = \frac{1}{4} ; \quad \frac{L}{D_a} = \frac{1}{4} \times 0,7422 = 0,1855 \text{ m} \]
\[ \frac{W}{D_a} = \frac{1}{5} ; \quad \frac{W}{D_a} = \frac{1}{5} \times 0,7422 = 0,1484 \text{ m} \]
\[ \frac{J}{D_t} = \frac{1}{12} ; \quad \frac{J}{D_t} = \frac{1}{12} \times 2,2267 = 0,1855 \text{ m} \]

dimana: \( D_t = D = \text{diameter tangki (m)} \)
\( D_a = \text{Diameter impeller (m)} \)
\( E = \text{tinggi turbin dari dasar tangki (m)} \)
\( L = \text{panjang blade pada turbin (m)} \)
\( W = \text{lebar blade pada turbin (m)} \)
\( J = \text{lebar baffle (m)} \)
Kecepatan pengadukan, \( N = 0,5 \) putaran/detik

Bilangan Reynold,

\[
N_{Re} = \frac{\rho N (Da)^2}{\mu} = 1518(0,5)(0,7422)^2 \times 0,00064 \text{ kg/m.s} = 652558,8
\]

\( N_{Re} > 10.000 \), maka perhitungan dengan daya pengaduk menggunakan rumus:

\[
P = Np N^3 D_a^5 \rho \]

\( Np = 5 \) untuk \( N_{Re} = 593276,87 \)

\( P = 5(0,5)^3(0,7422)^3 1518 = 0,2137 \text{ kW} = 0,2866 \text{ hp} \)

Efisiensi motor = 70 %

Daya motor = 0,4094 hp

Digunakan daya motor standar \( \frac{1}{2} \) hp

**LD.7 Tangki Pelarutan Kaporit [Ca(ClO)\textsubscript{2}] (TP-05)**

Fungsi : Membuat larutan kaporit [Ca(ClO)\textsubscript{2}]

Bentuk : Silinder tegak dengan alas dan tutup datar

Bahan konstruksi : *Carbon Steel SA–283 grade C*

Kondisi operasi:

Temperatur = 30 °C

Tekanan = 1 atm

Ca(ClO)\textsubscript{2} yang digunakan = 2 ppm

Ca(ClO)\textsubscript{2} yang digunakan berupa larutan 70 % (% berat)

Laju massa Ca(ClO)\textsubscript{2} = 0,0024 kg/jam

Densitas Ca(ClO)\textsubscript{2} 70 % = 1272 kg/m\textsuperscript{3} = 79,4088 lbm/ft\textsuperscript{3} (Perry, 1997)

Kebutuhan perancangan = 360 hari

Faktor keamanan = 20 %

Perhitungan :

Volume larutan,

\[
V_l = \frac{0,0024 \text{ kg/jam} \times 24 \text{ jam/hari} \times 360 \text{ hari}}{0,7 \times 1272 \text{ kg/m}^3} = 0,0233 \text{ m}^3
\]

Volume tangki,

\[
V_t = 1,2 \times 0,0233 \text{ m}^3 = 0,028 \text{ m}^3
\]
Direncanakan: Tinggi tangki : diameter tangki  \( H_s : D = 1 : 1 \)

**Volume tangki (\( V_t \))**

\[
V_t = \frac{1}{4} \pi D^2 H_s
\]

\[
V_t = \frac{1}{4} \pi D^3
\]

\[
0,028 \, \text{m}^3 = \frac{1}{4} \pi D^3
\]

Maka, diameter tangki

\[
D = \frac{0,028}{\pi} = 0,3326 \, \text{m}
\]

tinggi tangki

\[
H_t = H_s = \frac{H_s}{D} \times D = 0,3326 \, \text{m}
\]

**Tebal shell tangki**

Tinggi cairan dalam tangki, \( h = \frac{0,0240 \, m^3}{0,0288 \, m^3} \times 0,3326 \, m = 0,2771 \, m \)

Tekanan hidrostatik:

\[
P = \rho \times g \times h = 1272 \, \text{kg/m}^3 \times 9,8 \, \text{m/det}^2 \times 0,2771 = 3,4551 \, \text{kPa}
\]

Tekanan operasi:

\[
P_{\text{operasi}} = 1 \, \text{atm} = 101,325 \, \text{kPa}
\]

\[
P_{\text{total}} = 101,325 \, \text{kPa} + 3,4551 \, \text{kPa} = 104,7801 \, \text{kPa}
\]

Faktor keamanan : 20 %

\[
P_{\text{design}} = (1,2) \times 104,7801 \, \text{kPa} = 125,7362 \, \text{kPa}
\]

*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 tangki:

\[
t = \frac{PD}{2SE - 1,2P} + nC
\]

\[
t_{\text{10 tahun}} = \frac{(125,7362 \, \text{kPa})(0,3326/2 \, \text{m})}{2(87218,71 \, \text{kPa})(0,8) - 1,2(125,7362 \, \text{kPa})} + 10(0,0098 \, \text{in})
\]

\[
= 0,1098 \, \text{in}
\]

Tebal shell standar yang digunakan = \( \frac{1}{4} \) in \hspace{1cm} (Brownell & Young, 1959)
Perancangan Sistem Pengaduk

Jenis pengaduk : *flat 6 blade turbin impeller*

Jumlah *baffle* : 4 buah

Untuk turbin standar (Geankoplis, 2003), diperoleh :

\[
\begin{align*}
\frac{D_a}{D_t} &= \frac{1}{3} ; D_a = \frac{1}{3} \times 0,3326 = 0,1108 \text{ m} \\
\frac{E}{D_a} &= 1 ; E = 0,1108 \text{ m} \\
\frac{L}{D_a} &= \frac{1}{4} ; L = \frac{1}{4} \times 0,1108 = 0,0277 \text{ m} \\
\frac{W}{D_a} &= \frac{1}{5} ; W = \frac{1}{5} \times 0,1108 = 0,0221 \text{ m} \\
\frac{J}{D_t} &= \frac{1}{12} ; J = \frac{1}{12} \times 0,3326 = 0,0277 \text{ m}
\end{align*}
\]

dimana : 

- $D_t = D =$ diameter tangki (m)
- $D_a =$ 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, $N = 3$ putaran/detik

Bilangan Reynold,

\[
N_{Re} = \frac{\rho N (D_a)^2}{\mu} = \frac{1272(3)(0,1108)^2}{0,0014 \text{ kg/m.s}} = 44989,2487
\]

$N_{Re} > 10,000$, maka perhitungan dengan daya pengaduk menggunakan rumus :

\[
P = Np N^3 D_a^5 \rho
\]

$Np = 5$ untuk $N_{Re} = 44008,15$ (Geankoplis, 2003)

\[
P = 5(3)^5(0,1108)^5 1272 = 0,0028 \text{ kW} = 0,0038 \text{ hp}
\]

Efisiensi motor = 70 %

Daya motor = 0,0055 hp

Digunakan daya motor standar $\frac{1}{4}$ hp
**L.D.8 Clarifier (CL)**

Fungsi: Memisahkan endapan (flok-flok) yang terbentuk karena penambahan alum dan soda abu

Tipe: *External Solid Recirculation Clarifier*

Bentuk: *Circular desain*

Jumlah: 1 unit

Bahan konstruksi: *Carbon steel SA-283, Grade C*

Data:

- Laju massa air (*F₁*) = 2767,3999 kg/jam
- Laju massa Al₂(SO₄)₃ (*F₂*) = 0,1383 kg/jam
- Laju massa Na₂CO₃ (*F₃*) = 0,0747 kg/jam
- Laju massa total, *m* = 2767,6130 kg/jam

Densitas Al₂(SO₄)₃ = 2710 kg/m³ (Perry, 1999)

Densitas Na₂CO₃ = 2533 kg/m³ (Perry, 1999)

Densitas air = 995,467 kg/m³ (Perry, 1999)

Reaksi koagulasi:

\[
\text{Al}_2(\text{SO}_4)_3 + 3 \text{Na}_2\text{CO}_3 + 3 \text{H}_2\text{O} \rightarrow 2 \text{Al(OH)}_3 + 3 \text{Na}_2\text{SO}_4 + 3\text{CO}_2
\]

Perhitungan:

Dari Metcalf & Eddy, 1984, diperoleh:

Untuk *clarifier tipe upflow* (radial):

Kedalaman air = 3-5 m

*Settling time* = 1-3 jam

Dipilih: kedalaman air (H) = 5 m, waktu pengendapan = 2 jam

Diameter dan Tinggi *clarifier*

Densitas larutan,

\[
\rho = \frac{(2767,6130)}{995,467} + \frac{0,1383}{2710} + \frac{0,0747}{2533}
\]

ρ = 995,5148 kg/m³
Volume cairan, \( V = \frac{2767,6130 \text{ kg/jam} \times 2 \text{ jam}}{995,5148} = 5,5601 \text{ m}^3 \)

Faktor kelonggaran = 20%  
Volume clarifier = 1,2 x 5,5601 m³ = 6,6721 m³

\[ V = \frac{1}{4} \pi D^2 H \]
\[ D = \left( \frac{4V}{\pi H} \right)^{1/2} = \left( \frac{4 \times 6,6721}{3,14 \times 5} \right)^{1/2} = 1,1934 \text{ m} = 46,9867 \text{ in} \]

Tinggi clarifier (l) = 1,5 D = 1,7901 m

Tebal Dinding Tangki

Tekanan hidrostatik, \( P_{hid} = \rho g l \)  
\[ = 995,5148 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 1,7901 \text{ m} = 17,4652 \text{ kPa} \]

Tekanan oprasi, \( P_o = 1 \text{ atm} = 101,325 \text{ kPa} \)

\[ P_{operasi} = 17,4652 + 101,325 = 118,7902 \text{ kPa} \]

Faktor kelonggaran = 5%  
Maka, \( P_{design} = (1,05) (118,7902 \text{ kPa}) = 124,7297 \text{ kPa} \)

Joint efficiency = 0,8  (Brownell, 1959)

Allowable stress = 12650 psia = 87218,7 kPa  (Brownell, 1959)

Faktor korosi = 0,0089 in/thn

Umur alat diperkirakan 10 tahun.

Tebal shell tangki:

\[ t = \frac{PD}{2SE - 1,2P} \]
\[ t_{10 \text{ tahun}} = \frac{(124,7297 \text{ kPa})(1,1934/2\text{m})}{2(87218,7\text{ kPa})(0,8) - 1,2(124,7297 \text{ kPa})} + 10(0,0098) = 0,140 \text{ in} \]

Tebal shell standart yang dipilih = \( \frac{1}{4} \) in

Daya Clarifier

\[ P = 0,006 D^2 \]  (Ulrich, 1984)
dimana: \( P = \text{daya yang dibutuhkan, kW} \)

Sehingga,

\[
P = 0,006 \times (1,1934)^2 = 0,0085 \text{ kW} = 0,0085 \times (1/0,7457) = 0,0114 \text{ Hp}
\]

Effisiensi motor = 70 %

\[
P = 0,0163
\]

Maka daya motor yang dipilih 1/4 Hp

**L.D.9 Sand Filter (SF)**

Fungsi: Menyaring partikel – partikel yang masih terbawa dalam air yang keluar dari *clarifier*

Bentuk: Silinder tegak dengan alas dan tutup ellipsoidal

Bahan konstruksi: *Carbon steel SA-283 grade C*

Jumlah: 1

Kondisi operasi:

- Temperatur = 30 °C
- Tekanan = 1 atm
- Laju massa air = 3499,6392 kg/jam
- Densitas air = 995,467 kg/m³ (Geankoplis, 1997)

Tangki filter dirancang untuk penampungan \( 1/4 \) jam operasi.

Direncanakan volume bahan penyaring =1/3 volume tangki

**Ukuran Tangki Filter**

Volume air, \( V_a = \frac{3499,6392 \text{ kg/jam} \times 0,25 \text{ jam}}{995,467 \text{ kg/m}^3} = 0,8788 \text{ m}^3 \)

Volume tangki total = \( 4/3 \times 0,8788 \text{ m}^3 = 1,1718 \text{ m}^3 \)

Faktor keamanan 20 %, volume tangki = 1,20 x 1,1718 = 1,4062 m³

Volume silinder tangki (\( V_s \)) = \( \frac{\pi D^2 H_s}{4} \)

Direncanakan perbandingan tinggi tangki dengan diameter tangki \( D : H = 3 : 4 \)

\[
D = \frac{3V_s}{\pi (H/3)^2}
\]
\[ H = \frac{D(4)}{3} = 1,4712 \, m \]

Diameter tutup = diameter tangki = 1,1034 m

Tinggi tutup = \( \frac{1}{4} \) tinggi tangki = \( \frac{1,4712}{4} \) = 0,2758 m

Tinggi total = 2,0229 m

Tinggi penyaring \( h_f \) = \( \frac{1}{4} \) x 1,4712 m = 0,3678 m

Tinggi air (l) = \( \frac{V_{aw}(H)}{V_{t}} \)
\[ \frac{0,8788(1,4712)}{1,4062} = 0,9195 \, m \]

Tekanan hidrostatis, \( P_{hid} \) = \( \rho \times g \times l \)
\[ = 995,467 \, \text{kg/m}^3 \times 9,8 \, \text{m/det}^2 \times 0,9195 \, m \]
\[ = 8970,5905 \, \text{Pa} = 8,9706 \, \text{kPa} \]

Tekanan pada penyaring, \( P_f \) = \( h_f \times g \times \rho \)
\[ = 0,3678 \, m \times 9,8 \, \text{m/det}^2 \times 2200 \, \text{kg/m}^3 \]
\[ = 7930,0666 \, \text{Pa} = 7,93 \, \text{kPa} \]

Tekanan operasi, \( P_o \) = 1 atm = 101,325 kPa

Maka, \( P_{design} \) = (1,05)(8,9706 kPa + 7,93 kPa + 101,325 kPa)
\[ = 124,1369 \]

\textbf{Joint efficiency} = 0,8 \quad \text{(Brownell,1959)}

\textbf{Allowable stress} = 12650 \, \text{psia} = 87218,7 \, \text{kPa} \quad \text{(Brownell,1959)}

Faktor korosi = 0,0098 \, \text{in/thn}

Direncanakan umur tangki 10 thn.

Tebal shell tangki:
Tebal shell standart yang dipilih = ¼ in.

**LD.10 Penukar Kation/Cation Exchanger (CE)**

Fungsi : Mengurangi kesadahan air  
Bentuk : Silinder tegak dengan alas dan tutup ellipsoidal  
Bahan konstruksi : Carbon steel SA-283 grade C  
Kondisi operasi :  
- Temperatur = 30 °C  
- Tekanan = 1 atm  

Data :  
- Laju massa air = 1102,2214 kg/jam  
- Densitas air = 995,467 kg/m³ = 62,1985 lbm/ft³ (Perry, 1997)  
- Densitas resin = 0,7929 kg/ m³  
- Kebutuhan perancangan = 1 jam  
- Faktor keamanan = 20 %

**Ukuran Cation Exchanger**

Dari Tabel 12.4, *The Nalco Water Handbook*, diperoleh:  
- Diameter penukar kation = 2 ft = 0,609 m  
- Luas penampang penukar kation = 3,14 ft²  
Tinggi resin dalam *cation exchanger* = 2,5 ft = 0,7620 m  

Tinggi silinder = 1,2 x 0,762 m  
= 0,9144 m  

Diameter tutup = diameter tangki = 0,609 m  
Rasio axis = 2 : 1
Tinggi tutup = \( \frac{1}{2} (0,609) = 1 \text{ ft} = 0,3048 \text{ m} \)

(Brownell, 1959)

Sehingga, tinggi cation exchanger = 0,9144 m + 2(0,3048 m) = 1,5240 m

**Tebal Dinding Tangki**

Tekanan hidrostatik, \( P_{\text{hid}} \) = \( \rho \times g \times l \)
= 995,467 kg/m\(^3\) \times 9,8 m/det\(^2\) \times 0,762 m
= 7433,8397 Pa = 7,4338 kPa

Tekanan operasi, \( P_o \) = 1 atm = 101,325 kPa

Tekanan Resin, \( P_{\text{resin}} \) = \( \rho \times g \times l \)
= 0,7929 kg/m\(^3\) \times 9,8 m/det\(^2\) \times 0,762 m
= 5,9211 Pa = 0,0059 kPa

Faktor kelonggaran = 5%

Maka, \( P_{\text{design}} \) = (1,05) (7,4338 kPa + 101,325 kPa + 0,0059 kPa)
= 114,2029

*Joint efficiency* = 0,8

*Allowable stress* = 12650 psia = 87218,71 kPa

Faktor korosi = 0,0098 in/thn

Direncanakan umur alat 10 tahun

Tebal shell tangki:

\[
t = \frac{P_{D}}{2SE - 1,2P}
\]

\[
t_{\text{10tahun}} = \frac{(17,695 \text{ psia})(0,609/2 \text{ m})}{2(12650\text{psia})(0,8) - 1,2(17,695 \text{ psia})} + 10\text{thn}(0,0098\text{in/thn})
\]

= 0,117in

Tebal shell standart yang dipilih = ¼ in.
LD.11 Tangki Penukar Anion (anion exchanger) (AE)

Fungsi : Mengikat anion yang terdapat dalam air umpan ketel
Bentuk : Silinder tegak dengan tutup atas dan bawah elipsoidal
Bahan konstruksi : Carbon Steel SA-283 grade C
Jumlah : 1

Kondisi operasi :
Temperatur = 30 °C
Tekanan = 1 atm
Laju massa air = 1102,2214 kg/jam
Densitas air = 995,467 kg/m³ (Geankoplis, 1997)
Densitas resin = 0,7929 kg/m³
Kebutuhan perancangan = 1 jam
Faktor keamanan = 20 %

Ukuran Anion Exchanger

Dari Tabel 12.3, The Nalco Water Handbook, diperoleh:
- Diameter penukar anion = 2 ft = 0,6096 m = 24 in
- Luas penampang penukar anion = 3,14 ft² = 0,247 m

Tinggi resin dalam anion exchanger = 2,5 ft = 0,762 m

Tinggi silinder = 1,2 × 0,762 m
= 0,9144 m

Diameter tutup = diameter tangki = 0,6096 m = 24 in
Rasio axis = 2 : 1

Tinggi tutup = \( \frac{1}{2} \times 0,6096 \text{ m} = 0,3048 \text{ m} \) (Brownell, 1959)

Sehingga, tinggi anion exchanger = 0,9144 + 2(0,3048) = 1,5240 m

Tebal Dinding Tangki

Tekanan hidrostatik, \( P_{hid} = \rho \times g \times l \)
= 996,467 kg/m³ × 9,8 m/det² × 0,762 m
= 7433,8396 Pa = 7,4338 kPa

Tekanan operaso, \( P_o \) = 1 atm = 101,325 kPa
\[ P_{\text{resin}} = \rho \times g \times l \]
\[ = 0.7929 \text{ kg/m}^3 \times 9.8 \text{ m/det}^2 \times 0.7620 \text{ m} \]
\[ = 0.0059 \text{ kPa} \]

Faktor kelonggaran = 5%

Maka, \( P_{\text{design}} = (1.05) (7.4338 \text{ kPa} + 101.325 \text{ kPa} + 0.0059 \text{ kPa}) \]
\[ = 114.2029 \]

Joint efficiency = 0.8 \hspace{1cm} (Brownell, 1959)

Allowable stress = 12650 \text{ psia} = 87218.71 \text{ kPa} \hspace{1cm} (Brownell, 1959)

Faktor korosi = 0.0098 \text{ in/thn}

Direncanakan umur alat 10 tahun

Tebal shell tangki:
\[ t = \frac{PD}{2SE - 1.2P} \]
\[ t_{10\text{tahun}} = \frac{(17,695 \text{ psia})(0.609/2 \text{ m})}{2(12650\text{psia})(0.8) - 1.2(17,695 \text{ psia})} + 10\text{thn}(0.0098\text{in/thn}) \]
\[ = 0.1176\text{in} \]

Tebal shel standart yang dipilih = \( \frac{1}{4} \) in.

LD.12 Refrigerator I (RF-101)

Fungsi : Mendingin air pendingin hingga 25 °C

Jenis : Refrigerator

Bahan konstruksi : Carbon Steel SA–53 Grade B

Jumlah : 1 buah

Kondisi operasi :

Suhu air masuk menara (T_{L2}) = 66.7626 °C = 152.1726 °F

Suhu air keluar menara (T_{L1}) = 25 °C = 79 °F

Suhu udara (T_{G1}) = 30 °C = 77°F

Densitas air (25 °C) = 997,045 kg/m³ \hspace{1cm} (Perry, 1999)

Laju massa air pendingin (m) = 9,049,626 kg/jam
\[ = 19,950,8056 \text{ lb/jam} \]
H₂ tetrafluoroethane, T = 152,172 °F = 172,3 btu/lbm

H₁ tetrafluoroethane, T = 59 °F = 37,978 btu/lbm

\[ m = \frac{Q_c}{H_2 - H_4} = \frac{Q_c}{(172,3 - 37,978) \text{ btu/lbm}} \]

\[ Q_c = 2679832,1134 \text{ btu/jam} \]

\[ = 744,3978 \text{ btu/s} \]

**LD.13 Refrigerator II (RF-102)**

**Fungsi** : Mendingin Dowterm A hingga 30 °C

**Jenis** : Refrigerator

**Bahan konstruksi** : Carbon Steel SA–53 Grade B

**Jumlah** : 1 buah

**Kondisi operasi** :

- Suhu Dowterm A masuk menara (T₁₂) = 305 °C = 581 °F
- Suhu Dowterm A keluar menara (T₃₁) = 30 °C = 86 °F
- Suhu udara (T₃₁) = 30 °C = 77°F
- Densitas Dowterm A (25 °C) = 1056 kg/m³ (Anonim, 2010)
- Laju massa Dowterm A (m) = 86,4383 kg/jam

\[ = 190,5618 \text{ lb/jam} \]

H₂ tetrafluoroethane, T = 581 °F = 845.5 btu/lbm

H₁ tetrafluoroethane, T = 86 °F = 42,3 btu/lbm

\[ m = \frac{Q_c}{H_2 - H_4} = \frac{Q_c}{(845,5 - 42,3) \text{ btu/lbm}} \]

\[ Q_c = 153059,2997 \text{ btu/jam} \]

\[ = 42,5165 \text{ btu/s} \]

**LD.14 Tangki Utilitas-01 (TU-01)**

**Fungsi** : Menampung air untuk didistribusikan ke proses selanjutnya untuk menjadi steam, air pendingin dan air domestik.

**Bentuk** : Silinder tegak dengan alas dan tutup datar

**Bahan konstruks** : Carbon steel SA-283 grade C
Kondisi penyimpanan: Temperatur 25°C dan tekanan 1 atm
Jumlah: 1 unit

Kondisi operasi:
Temperatur = 30 °C
Laju massa air = 2767,3999 kg/jam
Densitas air = 995,467 kg/m³ = 62,1586 lbm/ft³ (Geankoplis, 1997)
Kebutuhan perancangan = 3 jam

Perhitungan:
Volume air, \( V_a \) = \( \frac{2767,3999 \text{ kg/jam} \times 3 \text{ jam}}{995,467 \text{ kg/m}^3} \) = 8,3400 m³

Faktor keamanan = 20%
Volume tangki, \( V_t \) = 1,2×8,3400 m³ = 10,0080 m³
Direncanakan perbandingan diameter dengan tinggi silinder, \( D : H = 2 : 3 \)

\[
\begin{align*}
V &= \frac{1}{4} \pi D^2 H \\
8,3400 m³ &= \frac{1}{4} \pi D^2 \left( \frac{3}{2} D \right) \\
10,0080 m³ &= \frac{3}{8} \pi D^3
\end{align*}
\]

\( D = 2,9433 m = 115,8781 \text{ in} \)
\( H = 4,4149 m \)

Tinggi cairan dalam tangki = \( \frac{\text{volume cairan} \times \text{tinggi silinder}}{\text{volumesilinder}} \)
= \( \frac{(8,3400)(4,4149)}{10,0080} \) = 3,6791 m

Tebal Dinding Tangki
Tekanan hidrostatik, \( P_{hid} \) = \( \rho \times g \times l \)
= 995,467 kg/m³ × 9,8 m/det² × 3,6791 m
= 35892,1043 Pa = 35,8921 kPa
Tekanan operasi, $P_o = 1$ atm $= 101,325$ kPa

Faktor kelonggaran $= 20\%$

Maka, $P_{design} = (1,2) (35,8921$ kPa $+ 101,325$ kPa) $= 164,6605$ kPa

$Joint eficiency = 0,8$ (Brownell, 1959)

$Allowable stress = 12650$ psia $= 87218,7$ kPa (Brownell, 1959)

Faktor korosi $= 0,0098$ in/thn.

Umur tangki dirancang untuk 10 tahun.

Tebal shell tangki:

$t = \frac{PD}{2SE - 1,2P}$(164,6605kPa)(2,9433/2m) $+ 100n(0,098in)$

$t_{10\text{thun}} = \frac{2(87218,7$ kPa$(0,8) - 1,2(164,6605$ kPa))}{(164,6605$kPa)(2,9433/2m)}$ $0,2349in$

Tebal shell standart yang dipilih $\frac{1}{4}$ in.

LD.15 Tangki Utilitas - 02 (TU-02)

Fungsi : Menampung air untuk kebutuhan domestik.

Bentuk : Silinder tegak dengan alas dan tutup datar.

Bahan konstruks : Carbon steel SA-283 grade C

Kondisi penyimpanan : Temperatur 25$^\circ$C dan tekanan 1 atm

Jumlah : 1 unit

Kondisi operasi :

Temperatur $= 30^\circ$C

Laju massa air $= 868,2457$ kg/jam

Densitas air $= 995,68$ kg/m$^3$ $= 62,1586$ lbm/ft$^3$ (Geankoplis, 1997)

Kebutuhan perancangan $= 3$ jam

Perhitungan :
Volume air, \( V_a = \frac{868,2457 \text{ kg/jam} \times 3 \text{ jam}}{995,467 \text{ kg/m}^3} = 2,6165 \text{ m}^3 \)

Faktor keamanan = 20 %

Volume tangki, \( V_t = 1,2 \times 2,6165 \text{ m}^3 = 3,1399 \text{ m}^3 \)

Direncanakan perbandingan diameter dengan tinggi silinder, \( D : H = 2 : 3 \)

\[
V = \frac{1}{4} \pi D^2 H
\]

\[
3,1399 \text{ m}^3 = \frac{1}{4} \pi D^2 \left( \frac{3}{2} D \right)
\]

\[
3,1399 \text{ m}^3 = \frac{3}{8} \pi D^3
\]

\[
D = 1,9999 \text{ m} = 78,7395 \text{ in}
\]

\[
H = 2,9999 \text{ m}
\]

Tinggi cairan dalam tangki = \( \frac{\text{volume cairan} \times \text{tinggi silinder}}{\text{volumesilinder}} \)

= \( \frac{2,6165 \text{ m}^3 \times 2,9999 \text{ m}}{3,1399} \) = 2,4999 m

Tebal Dinding Tangki

Tekanan hidrostatik, \( P_{\text{hid}} \) = \( \rho x g x l \)

= \( 995,467 \text{ kg/m}^3 \times 9,8 \text{ m/det}^2 \times 2,4999 \text{ m} \)

= 24388,72 Pa = 24,3887 kPa

Tekanan operasi, \( P_o \) = 1 atm = 101,325 kPa

Faktor kelonggaran = 20 %

Maka, \( P_{\text{design}} = (1,2) (24,3887 \text{ kPa} + 101,325 \text{ kPa}) \)

= 150,8564 kPa

Joint efficiency = 0,8 (Brownell,1959)

Allowable stress = 12650 psia = 87218,7 kPa (Brownell,1959)

Faktor korosi = 0,0098 in/thn

Umur tangki dirancang untuk 10 tahun.

Tebal shell tangki:
\[ t = \frac{PD}{2SE - 1.2P} \]
\[ t_{10 \text{ tahun}} = \frac{(150,8564 \text{kPa})(78,73/2 \text{ in})}{2(87218,7 \text{kPa})(0,8) - 1,2(150,8564 \text{kPa})} + 10\times(0,098 \text{in}) \]
\[ = 0,1406 \text{in} \]

Tebal shell standart yang dipilih ¼ in.

**L.D.16 Dearator (DE)**

Fungsi : Menghilangkan gas-gas yang terlarut dalam air umpan ketel
Bentuk  : Silinder horizontal dengan tutup atas dan bawah elipsoidal
Bahan konstruksi : Carbon steel SA-283 Grade C
Jumlah   : 1
Kondisi operasi : Temperatur = 90 °C
Tekanan   = 1 atm
Kebutuhan Perancangan = 3 jam
Laju alir massa air = 1102,2214 kg/jam
Densitas air (\(\rho\)) = 965,321 kg/m³ (Perry, 1999)
Faktor keamanan = 20%

**Perhitungan:**

Volume air, \(V_a = \frac{1102,2214 \text{ kg/jam} \times 24 \text{ jam}}{965,321 \text{ kg/m}^3} = 3,4254 \text{ m}^3\)

Volume tangki, \(V_t = 1,2 \times 3,4254 \text{ m}^3 = 4,1105 \text{ m}^3\)

Direncanakan perbandingan diameter dengan tinggi tangki, \(D : H = 2 : 3\)

\[ V = \frac{1}{4} \pi D^2 H \]
\[ 4,1105 \text{ m}^3 = \frac{1}{4} \pi D^3 \left(\frac{3}{2} \frac{D}{2}\right) \]
\[ 4,1105 \text{ m}^3 = \frac{3}{8} \pi D^3 \]

Maka: \(D = 1,4188 \text{ m} = 55,8592 \text{ in}\)
\(H = 2,1282 \text{ m} = 83,7888 \text{ in}\)
Tinggi cairan dalam tangki = \( \frac{3.4254}{4.1105} \times 2.1282 = 1.7735 \) m

Diameter tutup = diameter tangki = 55.8592 in

Direncanakan perbandingan diameter dengan tinggi tutup, D : H = 4 : 1

Tinggi tutup = \( \frac{1}{4} \times 55.8592 = 13.9648 \) in  

(Brownell, 1959)

Tebal tangki

Tekanan hidrostatik, \( P_{hid} = \rho \times g \times l \)

= \( 965.321 \text{ kg/m}^3 \times 9.8 \text{ m/det}^2 \times 2.1282 \text{ m} \)

= 16777.8903 Pa = 16.7778 kPa

\( P_{operasi} = 1 \text{ atm} = 101.325 \text{ kPa} \)

Faktor kelonggaran = 5 %

Maka, \( P_{design} = (1.05) (16.7778 \text{ kPa} + 101.325 \text{ kPa}) \)

= 124.0080 kPa

Joint efficiency = 0.8  

Allowable stress = 12650 psia = 87218.7 kPa  

(Brownell, 1959)

Faktor korosi = 0.0098 in/thn

Umur alat dirancang untuk 10 tahun

Tebal shell tangki:

\[
t = \frac{P_D}{2SE - 1.2P}
\]

\[
t_{10\text{tahun}} = \frac{(124,0080 \text{ kPa})(55.8592/2 \text{ in})}{2(87218.7 \text{kPa})(0.8) - 1.2(124,0080\text{kPa})} + 10\text{thn}(0.0098\text{in})
\]

= 0.1228 in

Dipilih tebal shell standart yang dipilih \( \frac{1}{4} \) in.
LD.17 Ketel Uap (KU)

Fungsi: Menyediakan uap untuk keperluan proses
Jenis: Ketel pipa api
Bahan konstruksi: Carbon steel
Jumlah: 1 unit

Data:

\[ H = \text{jumlah panas yang diperlukan untuk menaikkan temperatur } 111,7224 \degree C \text{ menjadi } 360 \degree C \]
\[ = 3195,83 - 2693,2 = 502,63 \text{ kJ/kg} = 1108,1081 \text{ btu/lb} \]

Total kebutuhan uap (W) = 6034,4666 kg/jam = 13303,7058 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)

\[ P = \frac{1108,1081 \times 13303,7058}{34,5 \times 970,3} = 440,3821 \text{ hp} \]

Jumlah Tube

Luas permukaan perpindahan panas, \( A = P \times 10 \text{ ft}^2/\text{hp} \)
\[ = 440,3821 \text{ hp} \times 10 \text{ ft}^2/\text{hp} \]
\[ = 4403,8201 \text{ ft}^2 \]

Direncanakan menggunakan tube dengan spesifikasi:
- Panjang tube, \( L = 30 \text{ ft} \)
- Diameter tube, 4 in = 0,3333 ft
- Luas permukaan pipa, \( a' = 1,178 \text{ ft}^2 \) (Kern, 1965)

Jumlah tube

\[ N_t = \frac{A}{L \times a} = \frac{4403,8201}{30 \times 1,178} = 124,6129 \approx 125 \text{ buah} \]
**LD.18  Tangki Bahan Bakar (TB)**

Fungsi : Menyimpan bahan bakar solar
Bentuk : Silinder tegak dengan alas dan tutup datar
Bahan konstruksi : *Carbon Steel* SA–283 grade C
Jumlah : 1 unit

Kondisi operasi :
Temperatur : 30 °C
Tekanan : 1 atm

Laju volume solar = 93,6387 L/jam = 0,0936 m³/jam
Densitas solar = 0,89 kg/L = 890 kg/m³
(Perry, 1997)

Kebutuhan perancangan = 7 hari

Perhitungan :

a. Volume Tangki

Volume solar (Va) = 0,0936 m³/jam x 7 hari x 24 jam/hari
= 15,7313 m³

Direncanakan membuat 1 tangki dan faktor kelonggaran 20%, maka :
Volume 1 tangki, V_l = 1,2 x 15,7313 m³ = 18,8775 m³

b. Diameter dan Tinggi Shell

Direncanakan : Tinggi tangki : diameter tangki H_s : D = 2 : 1

Volume tangki (V_t)

\[ V_t = \frac{1}{4} \pi D^2 H_s \]
\[ V_t = \frac{1}{8} \pi D^3 \]

18,8775 m³ = \(\frac{1}{8} \pi D^3\)

Maka, diameter tangki

\[ D = \frac{2,8864}{m} \]

tinggi tangki

\[ H_t = H_s = \left(\frac{2}{1}\right) \times D = 5,7728 \ m \]

3. Tebal *shell* tangki
Tinggi cairan dalam tangki, \( h = \frac{15,7313 \ m^3}{18,8775 \ m^3} \times 5,7728 \ m = 4,8106 \ m \)

Tekanan hidrostatik:
\[
P_{\text{hidrolisik}} = \rho \times g \times h
\]
\[
= 890 \ \text{kg/m}^3 \times 9,8 \ \text{m/det}^2 \times 4,8106
\]
\[
= 41958,857 \ \text{Pa} = 41,9589 \ \text{kPa}
\]

Tekanan operasi:
\[
P_{\text{operasi}} = 1 \ \text{atm} = 101,325 \ \text{kPa}
\]

Faktor keamanan : 20 %
\[
P_{\text{design}} = (1,2) (41,9589 \ \text{kPa} + 101,325 \ \text{kPa})
\]
\[
= 171,9406 \ \text{kPa}
\]

Joint efficiency : \( E = 0,8 \) \hspace{1cm} \text{(Brownell & Young, 1959)}

Allowable stress : \( S = 12650 \ \text{psia} = 87218,7 \ \text{kPa} \) \hspace{1cm} \text{(Brownell & Young, 1959)}

Faktor korosi : \( C = 0,0098 \ \text{in/tahun} \) \hspace{1cm} \text{(Peters dkk, 2004)}

Umur alat : \( n = 20 \ \text{tahun} \)

Tebal shell tangki:
\[
t = \frac{PD}{2SE - 1,2P} + nC
\]
\[
= \frac{(171,9406 \ \text{kPa})(113,638/2in)}{2(87218,71 \ \text{kPa})(0,8) - 1,2(171,9406\text{kPa})} + 20\text{thn} (0,0098 \ \text{in})
\]
\[
= 0,26 \text{in}
\]

Tebal shell standar yang digunakan = \( \frac{1}{4} \) in \hspace{1cm} \text{(Brownell & Young, 1959)}

**LD.19 Pompa Screening (PU-01)**

Fungsi : Memompa air dari sungai ke bak sedimentasi

Jenis : Pompa sentrifugal

Bahan konstruksi : Commercial Steel

Jumlah : 1 unit

Kondisi operasi : \( P = 1 \ \text{atm} \)
Temperatur = 30 °C

Laju alir massa (F) = 2767,3999 kg/jam = 1,6947 lbm/s

Densitas (ρ) = 995,467 kg/m³ = 62,1466 lbm/ft³

Viskositas (μ) = 0,85 cP = 0,00057 lbm/ft.s

Laju alir volumetrik, \( Q = \frac{F}{\rho} = \frac{2767,3999 \text{ kg/kJ}}{995,467 \text{ kg/m}^3} = 2,7800 \text{ m}^3/\text{jam} \)

\[= \frac{0,00077 \text{ m}^3/\text{det}}{0,0272 \text{ ft}^3/\text{s}} \]

Desain pompa:

untuk aliran turbulen \( N_{Re} > 2100 \)

\[ D_{opt} = 0,363 Q^{0,45} \rho^{0,13} \]

\[ = 0,363 (0,00077 \text{ m}^3/\text{s})^{0,45} (995,467 \text{ kg/m}^3)^{0,13} \]

\[ = 0,0354 \text{ m} = 1,3941 \text{ in} \]

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

- Ukuran nominal: 2 in
- Schedule number: 40
- Diameter Dalam (ID): 2,067 in = 0,1722 ft
- Diameter Luar (OD): 2,373 in
- Luas penampang dalam (A): 0,0233 ft²
- Kecepatan linier, \( v = \frac{Q}{A} = 1,48 \text{ ft/s} \)

Bilangan Reynolds:

\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]

\[ = \frac{(62,1466 \text{ lbm/ft}^3)(1,48 \text{ ft/s})(0,1722 \text{ ft})}{0,00057 \text{ lbm/ft.s}} \]

\[ = 27738,5425 \text{ (aliran turbulen)} \]

Untuk pipa Commercial Steel diperoleh harga \( \epsilon = 0,000046 \); \( \epsilon/D = 0,00087 \), pada \( N_{Re} = 27738,5425 \) diperoleh harga faktor fanning \( f = 0,0088 \) (Geankoplis, 2003).

Friction loss:
1 sharp edge entrance \( h_c = 0.5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0.5 (1 - 0) \frac{1,48^2}{2(1)(32,174)} \)
\[= 0.017 \text{ ft lbf/lbm} \]

1 elbow 90° \( h_f = n K_f \frac{v^2}{2 g_c} = 1(0,75) \frac{1,48^2}{2(1)(32,174)} = 0,0255 \text{ ft lbf/lbm} \)

1 gate valve \( h_f = n K_f \frac{v^2}{2 g_c} = 1(2) \frac{1,48^2}{2(1)(32,174)} = 0,068 \text{ ft lbf/lbm} \)

Pipa lurus 100 ft \( F_f = 4f \frac{\Delta L v^2}{D 2 g_c} = 4(0,0088) \left( \frac{100}{(0,1722)(2)(32,174)} \right) \)
\[= 0,6956 \text{ ft lbf/lbm} \]

1 sharp edge exit \( h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right) \frac{v^2}{2 \alpha g_c} = 1 (1 - 0) \frac{1,48^2}{2(1)(32,174)} \)
\[= 0,034 \text{ ft lbf/lbm} \]

Total friction loss \( \sum F = 0,8403 \text{ ft lbf/lbm} \)

Dari persamaan Bernoulli:
\[
\frac{1}{2 g_c} (v_2^2 - v_1^2) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_z = 0
\]
(Geankoplis, 2003)
dimana : \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 30 \text{ ft} \)
\[
0 + \frac{32,174}{32,174} (30) + 0 + 0,8403 + W_z = 0
\]
\(W_z = 30,8403 \text{ ft.lbf/lbm} \)

Efisiensi pompa, \( \eta = 70 \% \)
\( W_p = -Ws / \eta = 44,0576 \text{ ft lbf/lbm} \)

Daya pompa : \( P = \frac{W_p Q}{550} = \frac{(2,1431 \text{lbf/s})(44,0576 \text{ft.lbf/lbm})}{550} = 0,1343 \text{ hp} \)

Digunakan daya motor standar ¼ hp
LD.20 Pompa Sedimentasi (PU-02)

Fungsi : Memompa air dari bak sedimentasi menuju clarifier

Jenis : Pompa sentrifugal

Bahan konstruksi : Commercial Steel

Jumlah : 1 unit

Kondisi operasi : 
- \( P = 1 \) atm
- Temperatur = 30 °C

Laju alir massa (\( F \)) = 2767,3999 kg/jam = 1,6947 lbm/s

Densitas (\( \rho \)) = 995,467 kg/m³ = 62,1466 lbm/ft³

Viskositas (\( \mu \)) = 0,85 cP = 0,00057 lbm/ft.s

Laju alir volumetrik, 
\[
Q = \frac{F}{\rho} = \frac{2767,3999 \text{ kg/jam}}{995,467 \text{ kg/m}^3} = 2,7800 \text{ m}^3/\text{jam}
\]

\[
= 0,00077 \text{ m}^3/\text{det} = 0,0272 \text{ ft}^3/s
\]

Desain pompa :

untuk aliran turbulen \( N_{Re} > 2100 \)

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

\[
= 0,363 (0,00098 \text{ m}^3/\text{s})^{0,45} (995,467 \text{ kg/m}^3)^{0,13}
\]

\[
= 0,0393 \text{ m} = 1,5494 \text{ in}
\]

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

Ukuran nominal : 2 in

Schedule number : 40

Diameter Dalam (ID) : 2,067 in = 0,1722 ft

Diameter Luar (OD) : 2,373 in

Luas penampang dalam (A) : 0,0233 ft²

Kecepatan linier, \( v = \frac{Q}{A} = 1,48 \text{ ft/s} \)

Bilangan Reynolds :

\[
N_{Re} = \frac{\rho \times v \times D}{\mu} \quad \text{(Peters dkk, 2004)}
\]

\[
= \frac{(62,1466 \text{ lbm/ft}^3)(1,48 \text{ ft/s})(0,1722 \text{ ft})}{0,00057 \text{ lbm/ft s}} = 27738,5425 \text{ (aliran turbulen)}
\]
Untuk pipa *Commercial Steel* diperoleh harga \( \varepsilon = 0,000046 \); \( \varepsilon/D = 0,00087 \), pada \( N_{Re} = 27738,5425 \) diperoleh harga faktor fanning \( f = 0,0088 \) (Geankoplis, 2003).

**Friction loss:**

1. *sharp edge entrance*

\[
\begin{align*}
\centering
\text{hc} &= 0,5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0,5 \left( 1 - 0 \right) \frac{1,48^2}{2(1)(32,174)} \\
&= 0,017 \text{ ft lbf/lbm}
\end{align*}
\]

2. *elbow 90°*

\[
\begin{align*}
\text{hf} &= n.Kf. \frac{v^2}{2 g_c} = 2(0,75) \frac{1,48^2}{2(1)(32,174)} = 0,0255 \text{ ft lbf/lbm}
\end{align*}
\]

3. *gate valve*

\[
\begin{align*}
\text{hr} &= n.Kf. \frac{v^2}{2 g_c} = 1(2) \frac{1,48^2}{2(1)(32,174)} = 0,068 \text{ ft lbf/lbm}
\end{align*}
\]

Pipa lurus 30 ft

\[
\begin{align*}
\text{Ff} &= 4f \frac{\Delta L}{D} \frac{v^2}{2 g_c} = 4(0,0088) \frac{(30)(1,48^2)}{(0,1722)2(32,174)} \\
&= 0,2087 \text{ ft lbf/lbm}
\end{align*}
\]

1. *sharp edge exit*

\[
\begin{align*}
\text{h}_{\text{ex}} &= n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left( 1 - 0 \right) \frac{1,48^2}{2(1)(32,174)} \\
&= 0,034 \text{ ft lbf/lbm}
\end{align*}
\]

**Total friction loss**

\[
\sum F = 0,3789 \text{ ft lbf/lbm}
\]

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 \( \Delta z = 40 \text{ ft} \)

\[
0 + \frac{32,174}{32,174} (40) + 0 + 0,3789 + W_s = 0
\]

\( W_s = 40,3789 \text{ ft.lbf/lbm} \)

Efisiensi pompa, \( \eta = 70 \% \)

\[
W_p = -W_s / \eta = 57,6841 \text{ ft lbf/lbm}
\]
**LD.21 Pompa Alum (PU-03)**

**Fungsi** : Memompa alum dari tangki pelarutan alum ke klarifier

**Jenis** : Pompa *sentrifugal*

**Bahan konstruksi** : *Commercial Steel*

**Jumlah** : 1 unit

**Kondisi Operasi** : 1 atm

**Laju alir massa** \( F \) = 0,1383 kg/jam = 0,00011 lbm/s

**Densitas** \( \rho \) = 1363 kg/m³ = 85,0915 lbm/ft³

**Viskositas** \( \mu \) = 1 cP = 0,00067 lbm/ft.s

**Laju alir volumetrik** , \( Q = \frac{F}{\rho} = \frac{0,1749 kg/jam}{1363 kg/m³} = 0,000102 m³/jam \)

= 0,28 \( (10^{-7}) \) m³/det = 0,10 \( (10^{-5}) \) ft³/s

**Desain pompa** :

untuk aliran turbulen \( N_{Re} < 2100 \)

\[ D_{opt} = 3 Q^{0.36} \mu^{0.18} \]

\[ = 3 ((0,10 (10^{-5}) ft³/s)^{0.36} (0,00067 lbm/ft.s)^{0.18} \]

\[ = 0,005 ft = 0,0667 in \]

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

**Ukuran nominal** : 0,215 in

**Schedule number** : 80

**Diameter Dalam (ID)** : 0,215 in = 0,0179 ft

**Diameter Luar (OD)** : 0,405 in

**Luas penampang dalam (A)** : 0,00025 ft²

\[ Kecepatan linier, \ v = \frac{Q}{A} = 0,005 \text{ ft/s} \]

Bilangan *Reynold* :
\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]  
\[ = \frac{(85,0915 \text{ lbm/ft}^2)0,005 \text{ ft/s})(0,0179 \text{ ft})}{0,00067 \text{ lbm/ft s}} \]
\[ = 11,423 \text{ (aliran laminar/viscous)} \]

Untuk pipa *Commercial Steel* diperoleh harga \( f = 1,12 \)  

*Friction loss*:

1. **sharp edge entrance**
   \[ h_c = 0,5 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 g_c} = 0,5(1 - 0) \frac{0,005^2}{2(1)(32,174)} \]
   \[ = 0,0000002 \text{ ft lbf/lbm} \]

2. **elbow 90°**
   \[ h_f = n K_f \frac{v^2}{2 g_c} = 1(0,75) \frac{0,005^2}{2(1)(32,174)} \]
   \[ = 0,0000003 \text{ ft lbf/lbm} \]

3. **gate valve**
   \[ h_f = n K_f \frac{v^2}{2 g_c} = 1(2) \frac{0,005^2}{2(1)(32,174)} \]
   \[ = 0,0000008 \text{ ft lbf/lbm} \]

Pipa lurus 30 ft
\[ F_f = 4f \frac{\Delta L v^2}{D 2 g_c} = 4(1,12) \frac{(30)(0,005)^2}{(0,0179)(2)(32,174)} \]
\[ = 0,0023 \text{ ft lbf/lbm} \]

1. **sharp edge exit**
   \[ h_{ex} = n \left(1 - \frac{A_1}{A_2}\right) \frac{v^2}{2 g_c} = 1 \frac{0,005^2}{2(1)(32,174)} \]
   \[ = 0,00000039 \text{ ft lbf/lbm} \]

Total friction loss
\[ \sum F = 0,0024 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:
\[ \frac{1}{2 g_c} (v_2^2 - v_1^2) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \]  
\[ \text{dimana: } v_1 = v_2 ; \Delta v^2 = 0 ; P_1 = P_2 ; \Delta P = 0 \]

tinggi pemompaan \( \Delta z = 50 \text{ ft} \)
\[ 0 + \frac{32,174}{32,174} (50) + 0 + 0,0024 + W_s = 0 \]
\[ W_s = 50,0024 \text{ ft.lbf/lbm} \]  

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Efisiensi pompa, \( \eta = 70 \% \)

\[
W_p = -\frac{W_s}{\eta} = 71,4319 \text{ ft lbf/lbm}
\]

Daya pompa:
\[
P = \frac{W_p Q}{550} = \frac{(0,00011 \text{ lmb/s})(71,4319 \text{ ft lbf/lbm})}{550} = 0,000011 \text{ hp}
\]

Digunakan daya motor standar ¼ hp

**LD.22 Pompa Soda Abu (PU-04)**

Fungsi : Memompa soda abu dari tangki pelarutan soda abu ke klarifier

Jenis : Pompa sentrifugal

Bahan konstruksi : *Commercial Steel*

Jumlah : 1 unit

Kondisi Operasi : 1 atm

Laju alir massa (\( F \)) = 0,0747 kg/jam = 0,46 (10^{-3}) lbm/s

Densitas (\( \rho \)) = 1327 kg/m³ = 82,844 lbm/ft³

Viskositas (\( \mu \)) = 0,549 cP = 0,00037 lbm/ft.s

Laju alir volumetrik, \( \frac{Q}{\rho} = \frac{0,0747 \text{ kg/jam}}{1327 \text{ kg/m}^3} = 0,000056 \text{ m}^3/\text{jam} \)

= 0,156 (10^{-7}) m³/det = 0,55 (10^{-6}) ft³/s

Desain pompa:

untuk aliran turbulen \( N_{Re} < 2100 \)

\[
D_{i,\text{opt}} = 3 Q^{0,36} \mu^{0,18} \quad (Peters dkk, 2004)
\]

\[
= 3 ((0,55 (10^{-6}) \text{ ft}^3/\text{s})^{0,36} (0,00037 \text{ lbm/ft.s})^{0,18} = 0,0040 \text{ ft} = 0,0484 \text{ in}
\]

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

**Ukuran nominal** : 0,215 in

**Schedule number** : 80

**Diameter Dalam (ID)** : 0,269 in = 0,0179 ft

**Diameter Luar (OD)** : 0,405 in

**Luas penampang dalam (A)** : 0,00025 ft²
Kecepatan linier, \( v = \frac{Q}{A} = 0,0028 \text{ ft/s} \)

Bilangan *Reynold* :

\[
N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{(82.844 \text{ lbm/ft}^3)0,0028 \text{ ft/s})(0,0179 \text{ ft})}{0,00036 \text{ lbm/ft s}} = 11,2303 \text{ (aliran laminar/viscous)}
\]

Untuk pipa *Commercial Steel* diperoleh harga \( f = 1,14 \) \( \text{ (Geankoplis, 2003)} \)

*Friction loss :*

1. *sharp edge entrance* \( h_c = 0,5 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 \alpha g_c} = 0,5(1 - 0)\frac{0,0028}{2(1)(32,174)} = 0,0000001 \text{ ft lbf/lbm} \)

1. *elbow 90°* \( h_f = n.K_f \frac{v^2}{2 g_c} = 1(0,75)\frac{0,0028}{2(1)(32,174)} = 0,0000001 \text{ ft lbf/lbm} \)

1. *gate valve* \( h_f = n.K_f \frac{v^2}{2 g_c} = 1(2)\frac{0,0028}{2(1)(32,174)} = 0,0000002 \text{ ft lbf/lbm} \)

Pipa lurus 30 ft \( F_f = 4f \frac{\Delta L}{D \frac{v^2}{2 g_c}} = 4(1,14)\frac{(30)(0,0028)^2}{(0,0179)2(32,174)} = 0,00074 \text{ ft lbf/lbm} \)

1. *sharp edge exit* \( h_ex = n \left(1 - \frac{A_1}{A_2}\right)^2 \frac{v^2}{2 \alpha g_c} = 1(1 - 0)\frac{0,0028}{2(1)(32,174)} = 0,0000001 \text{ ft lbf/lbm} \)

Total *friction loss* \( \sum F = 0,00074 \text{ ft lbf/lbm} \)

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 \( \Delta z = 50 \text{ ft} \)
\[
0 + \frac{32,174}{32,174} (50) + 0 + 0,00074 + W_s = 0
\]

\( W_s = 50,00074 \text{ ft.lbf/lbm} \)

Efisiensi pompa, \( \eta = 70 \% \)

\( W_p = -W_s / \eta = 62,501 \text{ ft.lb/lb} \)

Daya pompa : 
\[
P = \frac{W_p Q}{550} = \frac{(0,000058 \text{ lbm/s})(62,501 \text{ ft.lbf/lb})}{550} = 0,52(10^5) \text{ hp}
\]

Digunakan daya motor standar \( \frac{1}{4} \text{ hp} \)

**LD.23 Pompa Umpam Filtrasi (PU-05)**

Fungsi : Memompa air dari klarifier ke tangki filtrasi

Jenis : Pompa sentrifugal

Bahan konstruksi : Commercial Steel

Jumlah : 1 unit

Kondisi operasi : 
- \( P = 1 \text{ atm} \)
- Temperatur = 30 \( ^\circ \text{C} \)

Laju alir massa (\( F \)) = 2767,3999 kg/jam = 1,6947 lbm/s

Densitas (\( \rho \)) = 995,467 kg/m\(^3\) = 62,1466 lbm/ft\(^3\)

Viskositas (\( \mu \)) = 0,85 cP = 0,00057 lbm/ft.s

Laju alir volumetrik, 
\[
Q = \frac{F}{\rho} = \frac{2767,3999 \text{ kg/kJ}}{995,467 \text{ kg/m}^3} = 2,7800 \text{ m}^3/\text{jam}
\]
\[
= 0,00077 \text{ m}^3/\text{det} = 0,0272 \text{ ft}^3/\text{s}
\]

Desain pompa :

untuk aliran turbulen \( N_R > 2100 \)

\[
D_{\text{opt}} = 0,363 Q^{0,45} \rho^{0,13}
\]
\[
= 0,363 (0,00077 \text{ m}^3/\text{s})^{0,45} (995,467 \text{ kg/m}^3)^{0,13}
\]
\[
= 0,0354 \text{ m} = 1,394 \text{ in}
\]

Dari Tabel A.5-1 Geankoplis,2003, dipilih pipa dengan spesifikasi :
Ukuran nominal : 2 in
Schedule number : 40
Diameter Dalam (ID) : 2,067 in = 0,1722 ft
Diameter Luar (OD) : 2,373 in
Luas penampang dalam (A) : 0,0233 ft²

Kecepatan linier, \( v = \frac{Q}{A} \) = 1,48 ft/s

Bilangan Reynolds:
\[
N_{Re} = \frac{\rho \times v \times D}{\mu}
\]
\[
= \left( \frac{62,1466 \text{ lbm/ft}^3)(1,48 \text{ ft/s}) (0,1722 \text{ ft})}{0,00057 \text{ lbm/ft s}} \right)
\]
\[= 27738,5425 \text{ (aliran turbulen)}
\]

Untuk pipa Commercial Steel diperoleh harga \( \varepsilon = 0,000046 ; \varepsilon/D = 0,00087, \) pada
\[
N_{Re} = 27738,5425 \text{ diperoleh harga faktor fanning } f = 0,0088 \text{ (Geankoplis, 2003).}
\]

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 \left( 1 - 0 \right) \frac{1,48^2}{2(1)(32,174)} \]
\[= 0,017 \text{ ft lbf/lbm}
\]
2 elbow 90° \( h_f = n.Kf \frac{v^2}{2 g_c} = 2(0,75) \frac{1,48^2}{2(1)(32,174)} = 0,051 \text{ ft lbf/lbm}
\]
1 gate valve \( h_f = n.Kf \frac{v^2}{2 g_c} = 1(2) \frac{1,48^2}{2(1)(32,174)} = 0,068 \text{ ft lbf/lbm}
\]
Pipa lurus 40 ft \( F_f = 4f \frac{\Delta L v^2}{D 2 g_c} = 4(0,0088) \frac{(40)(1,48)^2}{(0,1722)(2)(32,174)} \]
\[= 0,2782 \text{ ft lbf/lbm}
\]
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{1,48^2}{2(1)(32,174)} \]
\[= 0,034 \text{ ft lbf/lbm}
\]
Total friction loss \[ \sum F = 0,4485 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:

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

(Geankoplis, 2003)

dimana : \( v_1 = v_2 ; \Delta v^2 = 0 ; P_1 = P_2 ; \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 30 \text{ ft} \)

\[
0 + \frac{32,174}{32,174} (30) + 0 + 0,4485 + W_s = 0
\]

\( W_s = 30,4484 \text{ ft lbf/lbm} \)

Efisiensi pompa, \( \eta = 70 \% \)

\[ W_p = - \frac{W_s}{\eta} = 43,4978 \text{ ft lbf/lbm} \]

Daya pompa :

\[ P = \frac{W_p \cdot Q}{550} = \frac{(2,1431 \text{ lbm/s})(43,4978 \text{ ft lbf/lbm})}{550} = 0,1332 \text{ hp} \]

Digunakan daya motor standar ¼ hp

**L.D.24 Pompa I Utility (PU-06)**

Fungsi : Memompa air dari tangki filtrasi ke tangki utilitas TU-01

Jenis : Pompa sentrifugal

Bahan konstruksi : Commercial Steel

Jumlah : 1 unit

Kondisi operasi : \( P = 1 \text{ atm} \)

Temperatur : 30 °C

Laju alir massa (\( F \)) = 2767,3999 kg/jam = 1,6947 lbm/s

Densitas (\( \rho \)) = 995,467 kg/m³ = 62,1466 lbm/ft³

Viskositas (\( \mu \)) = 0,85 cP = 0,00057 lbm/ft.s

Laju alir volumetrik,

\[ Q = \frac{F}{\rho} = \frac{2767,3999 \text{ kg/kJ}}{995,467 \text{ kg/m}^3} = 2,7800 \text{ m}^3/\text{jam} \]

\[ = 0,00077 \text{ m}^3/\text{det} = 0,0272 \text{ ft}^3/\text{s} \]

Desain pompa :

untuk aliran turbulen \( N_{Re} > 2100 \)
\[
\text{Di}_{\text{opt}} = 0.363 \, Q^{0.45} \rho^{0.13} \quad \text{(Peters dkk, 2004)}
\]

\[
= 0.363 \left(0.00077 \, m^3/s\right)^{0.45} \left(995.467 \, kg/m^3\right)^{0.13}
\]

\[
= 0.0354 \, m = 1.394 \, \text{in}
\]

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

- **Ukuran nominal**: 2 in
- **Schedule number**: 40
- **Diameter Dalam (ID)**: 2.067 in = 0.1722 ft
- **Diameter Luar (OD)**: 2.373 in
- **Luas penampang dalam (A)**: 0.0233 ft²

Kecepatan linier, \( v = \frac{Q}{A} = 1.48 \, \text{ft/s} \)

**Bilangan Reynolds**:

\[
N_{Re} = \frac{\rho \times v \times D}{\mu} \quad \text{(Peters dkk, 2004)}
\]

\[
= \frac{(62.1466 \, lbm/ft^3)(1.48 \, ft/s)(0.1722 \, ft)}{0.00057 \, lbm/ft \cdot s}
\]

\[
= 27738.5425 \, \text{(aliran turbulen)}
\]

Untuk pipa Commercial Steel diperoleh harga \( \varepsilon = 0.000046 \); \( \varepsilon/D = 0.00087 \), pada \( N_{Re} = 27738.5425 \) diperoleh harga faktor fanning \( f = 0.0088 \) (Geankoplis, 2003).

**Friction loss**:

1. **sharp edge entrance**
   \[
h_c = 0.5 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 \alpha g_c} = 0.5 \left(1 - 0\right) \frac{1.48^2}{2(1)(32.174)}
   \]
   \[
   = 0.017 \, \text{ft lbf/lbm}
   \]

2. **elbow 90°**
   \[
h_f = n \cdot K_f \frac{v^2}{2 g_c} = 2(0.75) \frac{1.48^2}{2(1)(32.174)} = 0.051 \, \text{ft lbf/lbm}
   \]

3. **gate valve**
   \[
h_f = n \cdot K_f \frac{v^2}{2 g_c} = 1(2) \frac{1.48^2}{2(1)(32.174)} = 0.068 \, \text{ft lbf/lbm}
   \]

**Pipa lurus 50 ft**

\[
F_f = 4f \frac{\Delta L \cdot v^2}{D \cdot 2 \cdot g_c} = 4(0.0088) \frac{(50)(1.48)^2}{(0.1722)(2)(32.174)}
\]
1 sharp edge exit  
\[ h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left( 1 - 0 \right) \frac{1,482}{2(1)(32,174)} \]
\[ = 0,034 \text{ ft lbf/lbm} \]

Total friction loss  
\[ \sum F = 0,518 \text{ ft lbf/lbm} \]

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  \( \Delta z = 40 \text{ ft} \)
\[ 0 + \frac{32,174}{32,174} (40) + 0 + 0,518 + W_s = 0 \]

\[ W_s = 40,518 \text{ ft.lbf/lbm} \]

Efisiensi pompa,  \( \eta = 70 \% \)
\[ W_p = \frac{-W_s}{\eta} = 57,8829 \text{ ft lbf/lbm} \]

Daya pompa:  
\[ P = \frac{W_p Q}{550} = \frac{(2,143 lbf/s)(57,8829 ft.lbf/lbm)}{550} = 0,1775 \text{ hp} \]

Digunakan daya motor standar ¼ hp

LD.25 Pompa Kation Exchanger (PU-07)

Fungsi : Memompa air dari tangki utilitas TU-01 ke tangki kation
Jenis : Pompa *sentrifugal*
Bahan konstruksi : *Commercial Steel*
Jumlah : 1 unit
Kondisi operasi :  
\[ P = 1 \text{ atm} \]
\[ \text{Temperatur} = 30 ^\circ C \]

Laju alir massa (F)  \[ = 1102,2214 \text{ kg/jam} = 0,6749 \text{ lbm/s} \]
Densitas (\( \rho \))  \[ = 995,467 \text{ kg/m}^3 = 62,1466 \text{ lbm/ft}^3 \]
Viskositas (\( \mu \))  \[ = 0,85 \text{ cP} = 0,00057 \text{ lbm/ft.s} \]
Laju alir volumetrik, \( Q = \frac{F}{\rho} = \frac{1102.2214 \text{ kg/kJ}}{995.467 \text{ kg/m}^3} = 1.1072 \text{ m}^3/\text{jam} \)

\[ = 0.00031 \text{ m}^3/\text{det} = 0.0108 \text{ ft}^3/\text{s} \]

**Desain pompa**:

untuk aliran turulen \( N_{Re} > 2100 \)

\[ D_{i_{opt}} = 0.363 Q^{0.45} \rho^{0.13} \] (Peters dkk, 2004)

\[ = 0.363 (0.00031 \text{ m}^3/\text{s})^{0.45} (995.467 \text{ kg/m}^3)^{0.13} \]

\[ = 0.0234 \text{ m} = 0.9212 \text{ in} \]

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

- Ukuran nominal: 1.25 in
- Schedule number: 80
- Diameter Dalam (ID): 1.278 in = 0.1065 ft
- Diameter Luar (OD): 1.66 in
- Luas penampang dalam (A): 0.00891 ft²

Kecepatan linier, \( v = \frac{Q}{A} = 1.82 \text{ ft/s} \)

**Bilangan Reynolds**:

\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \] (Peters dkk, 2004)

\[ = \frac{(62.1466 \text{ lbm/ft}^3)(1.82 \text{ ft/s})(0.1065 \text{ ft})}{0.00057 \text{ lbm/ft s}} \]

\[ = 21090,9631 \text{ (aliran turulen)} \]

Untuk pipa *Commercial Steel* diperoleh harga \( \varepsilon = 0.000046 \); \( \varepsilon/D = 0.0014 \), pada \( N_{Re} = 21090,9631 \) diperoleh harga faktor *fanning* \( f = 0.0071 \) (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{1.82^2}{2(1)(32,174)} \]

\[ = 0.0257 \text{ ft lbf/lbm} \]

4 elbow 90° \( h_f = n.K_f \frac{v^2}{2g_c} = 4(0.75) \frac{1.82^2}{2(1)(32,174)} = 0.051 \text{ ft lbf/lbm} \)
1 gate valve

\[ h_f = n K_f \frac{v^2}{2 g_c} = 1(2) \frac{1.82^2}{2(32,174)} = 0.1544 \text{ ft lbf/lbm} \]

Pipa lurus 40 ft

\[ F_f = 4f \frac{\Delta L v^2}{D 2 g_c} = 4(0,0071) \frac{(40)(1.82)^2}{(0,1065)2(32,174)} = 0.5491 \text{ ft lbf/lbm} \]

1 sharp edge exit

\[ h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left( 1 - 0 \right) \frac{1.82^2}{2(32,174)} \]

\[ = 0.0515 \text{ ft lbf/lbm} \]

Total friction loss

\[ \sum F = 0.8838 \text{ ft lbf/lbm} \]

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 \( \Delta z = 30 \text{ ft} \)

\[ 0 + \frac{32,174}{32,174} (30) + 0 + 0.8838 + W_s = 0 \]

\[ W_s = 30,8838 \text{ ft lbf/lbm} \]

Efisiensi pompa, \( \eta = 70\% \)

\[ W_p = -W_s / \eta = 44,1197 \text{ ft lbf/lbm} \]

Daya pompa : \( P = \frac{W_p Q}{550} = \frac{(1.0078 \text{ lbm/s})(44,1197 \text{ ft lbf/lbm})}{550} = 0.0532 \text{ hp} \)

Digunakan daya motor standar \( \frac{1}{4} \text{ hp} \)

**LD.26 Pompa Refrigerator (PU-08)**

Fungsi : Memompa air dari tangki utilitas TU-01 ke Refrigerator

Jenis : Pompa sentrifugal

Bahan konstruksi : Commercial Steel

Jumlah : 1 unit

Kondisi operasi : \( P = 1 \text{ atm} \)
Temperature = 30 °C

Laju alir massa (F) = 769,9326 kg/jam = 0,4880 lbm/s

Densitas (ρ) = 995,467 kg/m³ = 62,1466 lbm/ft³

Viskositas (μ) = 0,85 cP = 0,00057 lbm/ft.s

Laju alir volumetrik, 
\[ Q = \frac{F}{\rho} = \frac{769,9326 \text{ kg/kJ}}{995,467 \text{ kg/m}^3} = 0,8005 \text{ m}^3/\text{jam} \]
\[ = 0,00022 \text{ m}^3/\text{det} = 0,0078 \text{ ft}^3/\text{s} \]

Desain pompa:
untuk aliran turulen \( N_{Re} > 2100 \)

\[ D_{opt} = 0,363 Q^{0,45} \rho^{0,13} \]
\[ = 0,363 (0,00022 \text{ m}^3/\text{s})^{0,45} (995,467 \text{ kg/m}^3)^{0,13} \]
\[ = 0,0202 \text{ m} = 0,7961 \text{ in} \]

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

Ukuran nominal : 1 in

Schedule number : 80

Diameter Dalam (ID) : 0,952 in = 0,0797 ft

Diameter Luar (OD) : 1,315 in

Luas penampang dalam (A) : 0,00499 ft²

Kecepatan linier, \( v = \frac{Q}{A} = 1,9913 \text{ ft/s} \)

Bilangan Reynolds :

\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]
\[ = \frac{(62,1466 \text{ lbm/ft}^3)(1,9913 \text{ ft/s})(0,0797 \text{ ft})}{0,00057 \text{ lbm/ft.s}} \]
\[ = 17278,9954 \text{ (aliran turulen)} \]

Untuk pipa Commercial Steel diperoleh harga \( \varepsilon = 0,000046 ; \varepsilon/D = 0,0018 \), pada \( N_{Re} = 17278,9954 \) diperoleh harga faktor fanning \( f = 0,0075 \) (Geankoplis, 2003).
Friction loss:

1 sharp edge entrance
\[ h_c = 0.5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0.5 (1 - 0) \frac{1.9913^2}{2(1)(32,174)} \]
\[ = 0.0308 \text{ ft lbf/lbm} \]

4 elbow 90°
\[ h_f = n K_f \frac{v^2}{2 g_c} = 4(0.75) \frac{1.9913^2}{2(1)(32,174)} = 0.1848 \text{ ft lbf/lbm} \]

1 gate valve
\[ h_f = n K_f \frac{v^2}{2 g_c} = 1(2) \frac{1.9913^2}{2(1)(32,174)} = 0.1544 \text{ ft lbf/lbm} \]

Pipa lurus 80 ft
\[ F_f = 4f \frac{\Delta L}{2 D g_c} = 4(0.0075) \frac{(80)(1.9913)^2}{(0.0797)(2)(32,174)} \]
\[ = 1.8545 \text{ ft lbf/lbm} \]

1 sharp edge exit
\[ h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right) \frac{v^2}{2 \alpha g_c} = 1 (1 - 0) \frac{1.9913^2}{2(1)(32,174)} \]
\[ = 0.0616 \text{ ft lbf/lbm} \]

Total friction loss
\[ \sum F = 2,255 \text{ ft lbf/lbm} \]

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

(Geankoplis, 2003)

dimana: \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 40 \text{ ft} \)

\[ 0 + \frac{32,174}{32,174} (40) + 0 + 2,255 + W_s = 0 \]

\( W_s = 42,255 \text{ ft.lbf/lbm} \)

Efisiensi pompa, \( \eta = 70 \% \)

\[ W_p = -W_s / \eta = 60,3643 \text{ ft lbf/lbm} \]

Daya pompa:
\[ P = \frac{W_p Q}{550} = \frac{(0.6175 \text{ lbf/s})(60,3643 \text{ ft.lbf/lbm})}{550} = 0.0524 \text{ hp} \]

Digunakan daya motor standar \( \frac{1}{4} \) hp
**LD.27 Pompa I Domestik (PU-09)**

*Fungsi*: Memompa air dari tangki utilitas TU-01 ke tangki utilitas TU-02 untuk kebutuhan domestik

*Jenis*: Pompa sentrifugal

*Bahan konstruksi*: Commercial Steel

*Jumlah*: 1 unit

*Kondisi operasi*: $P = 1$ atm

*Temperatur*: $30^\circ C$

*Laju alir massa*: $F = 868,2457$ kg/jam $= 0,5317$ lbm/s

*Densitas* ($\rho$): $995,467$ kg/m$^3$ $= 62,1466$ lbm/ft$^3$

*Viskositas* ($\mu$): $0,85$ cP $= 0,00057$ lbm/ft.s

*Laju alir volumetrik*: $Q = \frac{868,2457 \text{ kg/klj}}{995,467 \text{ kg/m}^3} = 0,8721$ m$^3$/jam

$= 0,00024$ m$^3$/det $= 0,0085$ ft$^3$/s

**Desain pompa**:

untuk aliran turbulen $N_{Re} > 2100$

$D_i^{opt} = 0,363 Q^{0,45} \rho^{0,13}$

$= 0,363 (0,00024 \text{ m}^3/\text{s})^{0,45} (995,467 \text{ kg/m}^3)^{0,13}$

$= 0,0210$ m $= 0,8274$ in

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

*Ukuran nominal*: 1 in

*Schedule number*: 80

*Diameter Dalam (ID)*: 0,952 in $= 0,0797$ ft

*Diameter Luar (OD)*: 1,315 in

*Luas penampang dalam (A)*: 0,00499 ft$^2$

*Kecepatan linier, $v = \frac{Q}{A} = 1,6696$ ft/s

**Bilangan Reynolds**: $N_{Re} = \frac{\rho \times v \times D}{\mu}$ (Peters dkk, 2004)
Untuk pipa *Commercial Steel* diperoleh harga $\varepsilon = 0,000046$ ; $\varepsilon/D = 0,0018$, pada $N_{Re} = 14487,39$ diperoleh harga faktor *fanning* $f = 0,008$ (Geankoplis, 2003).

*Friction loss*:

1. *sharp edge entrance*  
   
   $h_c = 0.5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0.5 (1 - 0) \frac{1,6696^2}{2(1)(32,174)}$
   
   $= 0,0216$ ft lbf/lbm

2. *elbow 90°*  
   
   $h_f = n K_f \frac{v^2}{2 g_c} = 2(0,75) \frac{1,6696^2}{2(1)(32,174)} = 0,065$ ft lbf/lbm

1. *gate valve*  
   
   $h_f = n K_f \frac{v^2}{2 g_c} = 1(2) \frac{1,6696^2}{2(1)(32,174)} = 0,0866$ ft lbf/lbm

Pipa lurus 30 ft  

$F_f = 4f \frac{\Delta L}{D} \frac{v^2}{2 g_c} = 3(0,008) \frac{(30)(1,6696)^2}{(0,0797)(2)(32,174)}$

$= 0,5214$ ft lbf/lbm

1. *sharp edge exit*  
   
   $h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left( 1 - 0 \right) \frac{1,6696^2}{2(1)(32,174)}$

$= 0,0433$ ft lbf/lbm

Total *friction loss*  

$\sum F = 0,7381$ ft lbf/lbm

Dari persamaan Bernoulli:

$$\frac{1}{2 g_e} \left( v_2^2 - v_1^2 \right) + \frac{g}{g_e} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0$$  

(Geankoplis, 2003)

dimana : $v_1 = v_2$ ; $\Delta v^2 = 0$ ; $P_1 = P_2$ ; $\Delta P = 0$

tinggi pemompaan $\Delta z = 50$ ft

$0 + \frac{32,174}{32,174}(00) + 0 + 0,7381 + W_s = 0$

$W_s = 50,7381$ ft lbf/lbm

Efisiensi pompa, $\eta = 70\%$
\[ W_p = \frac{W_s}{\eta} = 72,483 \text{ ft lbf/lbm} \]

Daya pompa: \[ P = \frac{W_p \cdot Q}{550} = \frac{(0,5177 \text{bm/s})(72,483\text{ ft lbf/lbm})}{550} = 0,0701 \text{ hp} \]

Digunakan daya motor standar \( \frac{1}{4} \text{ hp} \)

**LD.28 Pompa H\textsubscript{2}SO\textsubscript{4} (PU-10)**

Fungsi: Memompa H\textsubscript{2}SO\textsubscript{4} dari tangki H\textsubscript{2}SO\textsubscript{4} ke tangki kation

Jenis: Pompa sentrifugal

Bahan konstruksi: Commercial Steel

Jumlah: 1 unit

Kondisi Operasi: 1 atm

Laju alir massa (\( F \)) = 0,1474 kg/jam = 0,90 (10\(^{-4} \)) lbm/s

Densitas (\( \rho \)) = 1061,7 kg/m\(^3\) = 66,2815 lbm/ft\(^3\)

Viskositas (\( \mu \)) = 17,86 cP = 0,012 lbm/ft.s

Laju alir volumetrik, \( Q = \frac{F}{\rho} = \frac{0,1474 \text{ kg/kJ}}{1061,7 \text{ kg/m}^3} = 0,00013 \text{ m}^3/\text{jam} \)

= 0,39 (10\(^{-7} \)) \text{ m}^3/\text{det} = 0,13 (10^{-5}) \text{ ft}^3/s

Desain pompa:

untuk aliran turbulen \( N_{Re} < 2100 \)

\( D_{opt} = 3 \cdot Q^{0.36} \cdot \mu^{0.18} \) (Peters dkk, 2004)

= 3 \cdot (0,13 (10^{-5}) \text{ ft}^3/s)^{0.36} \cdot (0,012 \text{ lbm/ft.s})^{0.18}

= 0,0104 \text{ ft} = 0,125 \text{ in}

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

Ukuran nominal: 0,125 in

Schedule number: 80

Diameter Dalam (ID): 0,215 in = 0,01791 ft

Diameter Luar (OD): 0,405 in

Luas penampang dalam (A): 0,00025 ft\(^2\)

Kecepatan linier, \( v = \frac{Q}{A} = 0,0047 \text{ ft/s} \)
Bilangan Reynolds:

\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]

\[ = \frac{(66,2815 \text{ lbm/ft}^3) 0,0047 \text{ ft/s})(0,0179 \text{ ft})}{0,012 \text{ lbm/ft s}} \]

\[ = 0,467 \text{ (aliran laminar/viscous)} \]

Untuk pipa *Commercial Steel* diperoleh harga \( f = 34,22 \)  (Geankoplis, 2003)

**Friction loss**:

1. *sharp edge entrance*  
   \[ h_e = 0,5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0,5(1-0) \frac{0,0047^2}{2(1)(32,174)} \]
   \[ = 0,00000017 \text{ ft lbf/lbm} \]

2. *elbow 90°*  
   \[ h_f = n Kf \frac{v^2}{2 g_c} = 2(34,22) \frac{0,0047^2}{2(1)(32,174)} = 0,52(10^{-6}) \text{ ft lbf/lbm} \]

1. *gate valve*  
   \[ h_f = n Kf \frac{v^2}{2 g_c} = 1(2) \frac{0,0047^2}{2(1)(32,174)} = 0,00000069 \text{ ft lbf/lbm} \]

Pipa lurus 30 ft  
\[ F_f = 4f \frac{\Delta L \nu^2}{D 2 g_c} = 4(1,14) \frac{(30)(0,0047)^2}{(0,0179)2(32,174)} \]
\[ = 0,0795 \text{ ft lbf/lbm} \]

1. *sharp edge exit*  
   \[ h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left( 1 - 0 \right) \frac{0,0047^2}{2(1)(32,174)} \]
   \[ = 0,00000035 \text{ ft lbf/lbm} \]

Total friction loss  
\[ \sum F = 0,07952 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:

\[ \frac{1}{2 g_c} \left( v_2^2 - v_1^2 \right) + \frac{\Delta P}{\rho} + \frac{g_c (z_2 - z_1)}{\rho} + \sum F + W_s = 0 \]  (Geankoplis, 2003)

dimana: \( v_1 = v_2 \); \( \Delta \nu^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 30 \text{ ft} \)

\[ 0 + \frac{32,174}{32,174} (30) + 0 + 0,07952 + W_s = 0 \]
W_s = 30,0795 \text{ ft.lbf/lbm}

Efisiensi pompa, \(\eta = 70\%\)

\[ W_p = -\frac{W_s}{\eta} = 42,9707 \text{ ft lbf/lbm} \]

Daya pompa:
\[ P = \frac{W_p Q}{550} = \frac{(0,000078 \text{ lbm/s})(42,9707\text{ ft.lbf/lbm})}{550} = 0,71(10^{-5}) \text{ hp} \]

Digunakan daya motor standar \(\frac{1}{4}\) hp

**LD.29 Pompa Anion Exchanger (PU-11)**

Fungsi : Memompa air dari tangki kation ke tangki anion

Jenis : Pompa centrífugal

Bahan konstruksi : Commercial Steel

Jumlah : 1 unit

Kondisi operasi : P = 1 atm

Temperatur = 30 °C

Laju alir massa (\(F\)) = 1645,7636 kg/jam = 1,0078 lbm/s

Densitas (\(\rho\)) = 995,467 kg/m³ = 62,1466 lbm/ft³

Viskositas (\(\mu\)) = 0,85 cP = 0,00057 lbm/ft.s

Laju alir massa (\(F\)) = 1102,2214 kg/jam = 0,6749 lbm/s

Densitas (\(\rho\)) = 995,467 kg/m³ = 62,1466 lbm/ft³

Viskositas (\(\mu\)) = 0,85 cP = 0,00057 lbm/ft.s

Laju alir volumetrik, \(Q = \frac{F}{\rho} = \frac{1102,2214 \text{ kg/kJ}}{995,467 \text{ kg/m}^3} = 1,1072 \text{ m}^3/\text{jam} = 0,00031 \text{ m}^3/\text{det} = 0,0108 \text{ ft}^3/\text{s}\)

Desain pompa:

untuk aliran turbulen \(N_{Re} > 2100\)

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

\[ = 0,363 (0,00031 \text{ m}^3/\text{s})^{0.45} (995,467 \text{ kg/m}^3)^{0.13} \]

\[ = 0,0234 \text{ m} = 0,9212 \text{ in} \]

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

Ukuran nominal : 1,25 in
Schedule number : 80
Diameter Dalam (ID) : 1,278 in = 0,1065 ft
Diameter Luar (OD) : 1,66 in
Luas penampang dalam (A) : 0,00891 ft²

Kecepatan linier, \( v = \frac{Q}{A} = 1,82 \text{ ft/s} \)

Bilangan Reynold :
\[
N_{Re} = \frac{\rho \times v \times D}{\mu} = (62,1466 \text{ lbm/ft}^3)(1,82 \text{ ft/s})(0,1065 \text{ ft})
\]
\[
= 21090,9631 \text{ (aliran turbulen)}
\]

Untuk pipa \textit{Commercial Steel} diperoleh harga \( \varepsilon = 0,000046 \); \( \varepsilon/D = 0,0014 \), pada
\( N_{Re} = 21090,9631 \) diperoleh harga faktor \textit{fanning} \( f = 0,0071 \) (Geankoplis, 2003).

Friction loss :

1. \textit{sharp edge entrance} \( h_c = 0,5 \left(1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0,5(1-0) \frac{1,82^2}{2(1)(32,174)} = 0,0257 \text{ ft lbf/lbm} \)

4. \textit{elbow 90°} \( h_f = n \cdot K_f \cdot \frac{v^2}{2 g_c} = 4(0,75) \frac{1,82^2}{2(1)(32,174)} = 0,1591 \text{ ft lbf/lbm} \)

1. \textit{gate valve} \( h_f = n \cdot K_f \cdot \frac{v^2}{2 g_c} = 1(2) \frac{1,82^2}{2(1)(32,174)} = 0,1029 \text{ ft lbf/lbm} \)

Pipa lurus 40 ft \( F_f = 4f \frac{\Delta L \cdot v^2}{D^2 g_c} = 4(0,0071) \frac{(40)(1,82)^2}{(0,1065)^2(32,174)} = 0,5414 \text{ ft lbf/lbm} \)

1. \textit{sharp edge exit} \( h_{ex} = n \left(1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 (1-0) \frac{1,82^2}{2(1)(32,174)} = 0,0515 \text{ ft lbf/lbm} \)

Total friction loss \( \sum F = 0,8837 \text{ ft lbf/lbm} \)
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 \( \Delta z = 30 \text{ ft} \)

\[
0 + \frac{32,174}{32,174}(30) + 0 + 0,8837 + W_s = 0
\]

\( W_s = 30,8838 \text{ ft.lbf/lbm} \)

Efisiensi pompa, \( \eta = 70 \% \)

\[ W_p = \frac{-W_s}{\eta} = 44,1197 \text{ ft lbf/lbm} \]

Daya pompa:

\[ P = \frac{W_p \cdot Q}{550} = \frac{(1,0078\text{lbm/s})(44,1197\text{ft.lbf/lbm})}{550} = 0,0532 \text{ hp} \]

Digunakan daya motor standar \( \frac{1}{4} \text{ hp} \)

**LD.30 Pompa NaOH (PU-12)**

- **Fungsi**: Memompa NaOH dari tangki NaOH ke tangki anion
- **Jenis**: Pompa centrifugal
- **Bahan konstruksi**: Commercial Steel
- **Jumlah**: 1 unit
- **Kondisi Operasi**: 1 atm
- **Laju alir massa** (\( F \)) = 0,609 kg/jam = 0,00037 lbm/s
- **Densitas** (\( \rho \)) = 1518 kg/m\(^3\) = 94,7681 lbm/ft\(^3\)
- **Viskositas** (\( \mu \)) = 0,64 cP = 0,00043 lbm/ft.s

Laju alir volumetrik,

\[
Q = \frac{F}{\rho} = \frac{0,609 \text{ kg/kJ}}{1518 \text{ kg/m}^3} = 0,00040 \text{ m}^3/\text{jam} = 1,11 \left(10^{-7} \right) \text{ m}^3/\text{det} = 0,39 \left(10^{-5} \right) \text{ ft}^3/\text{s}
\]

Desain pompa:

untuk aliran turbulen \( N_{Re} < 2100 \)

\[
D_{opt} = 3Q^{0,36} \mu^{0,18}
\]

(Peters dkk, 2004)

\[
= 3 ((0,39 \left(10^{-5} \right) \text{ ft}^3/\text{s})^{0,36} (0,00043 \text{ lbm/ft.s})^{0,18}
= 0,0084 \text{ ft} = 0,1010 \text{ in}
\]
Dari Tabel A.5-1 Geankoplis, 2003, dipilih pipa dengan spesifikasi:

**Ukuran nominal**: 0,125 in

**Schedule number**: 80

**Diameter Dalam (ID)**: 0,215 in = 0,01791 ft

**Diameter Luar (OD)**: 0,405 in

**Luas penampang dalam (A)**: 0,00025 ft²

Kecepatan linier, \( v = \frac{Q}{A} = 0,0136 \text{ ft/s} \)

**Bilangan Reynold**:

\[
N_{Re} = \frac{\rho \times v \times D}{\mu} \]

\[
= 96,7681 \text{ lbm/ft}^2 \times 0,0136 \text{ ft/s} \times 0,01791 \text{ ft} = 0,00043 \text{ lbm/ft s}
\]

\( = 53,88033 \text{ (aliran laminar/viscous)} \)

Untuk pipa *Commercial Steel* diperoleh harga \( f = 0,297 \) (Geankoplis, 2003)

**Friction loss**:

1. **sharp edge entrance**
   \[
h_{e1} = 0,5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \sigma \alpha g_c} = 0,5 \frac{0,0136^2}{2 (1)(32,174)} = 0,0000014 \text{ ft lbf/lbm}
   \]

2. **elbow 90°**
   \[
h_{r2} = n \cdot K_f \frac{v^2}{2 \sigma g_c} = 2 (34,22) \frac{0,0136^2}{2 (1)(32,174)} = 0,0000043 \text{ ft lbf/lbm}
   \]

1. **gate valve**
   \[
h_{r1} = n \cdot K_f \frac{v^2}{2 \sigma g_c} = 1 \left( 2 \right) \frac{0,0136^2}{2 (1)(32,174)} = 0,0000058 \text{ ft lbf/lbm}
   \]

Pipa lurus 30 ft

\[
F_f = 4 \frac{f \Delta L}{\frac{D}{2 \sigma g_c}} = 4 \left( 0,297 \right) \frac{30 \times 0,0136^2}{(0,0179) \times 2 (32,174)} = 0,0057 \text{ ft lbf/lbm}
\]

1. **sharp edge exit**
   \[
h_{e2} = n \left( 1 - \frac{A_1}{A_2} \right) \frac{v^2}{2 \sigma \alpha g_c} = 1 \left( 1 - 0 \right) \frac{0,0136^2}{2 (1)(32,174)} = 0,0000029 \text{ ft lbf/lbm}
   \]
Total friction loss \[ \sum F = 0,0057 \text{ ft lbf/lbm} \]

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

dimana : \( v_1 = v_2 ; \Delta v^2 = 0 ; P_1 = P_2 ; \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 30 \text{ ft} \)
\[
\frac{0 + 32,174}{32,174} (30) + 0 + 0,0057 + W_s = 0
\]

\( W_s = 30,0057 \text{ ft.lbf/lbm} \)

Efisiensi pompa, \( \eta = 70 \% \)

\( W_p = -\frac{W_s}{\eta} = 42,8653 \text{ ft lbf/lbm} \)

Daya pompa : 
\[
P = \frac{W_p \cdot Q}{550} = \frac{(0,00032 \text{ lbm/s})(42,8653 \text{ ft lbf/lbm})}{550} = 0,000029 \text{ hp}
\]

Digunakan daya motor standar \( \frac{1}{4} \text{ hp} \)

**LD.31 Pompa Kaporit (PU-13)**

Fungsi : Memompa kaporit dari tangki kaporit ke TU-02

Jenis : Pompa sentrifugal

Bahan konstruksi : Commercial Steel

Jumlah : 1 unit

Kondisi Operasi : 1 atm

Laju alir massa (\( F \)) = 0,0024 kg/jam = 0,0000015 lbm/s

Densitas (\( \rho \)) = 1272 kg/m\(^3\) = 79,4104 lbm/ft\(^3\)

Viskositas (\( \mu \)) = 1 cP = 0,00067 lbm/ft.s

Laju alir volumetrik, \( Q = \frac{F}{\rho} = \frac{0,0024 \text{ kg/kJ}}{1272 \text{ kg/m}^3} = 0,20 \times 10^{-5} \text{ m}^3/jam \)

\( = 0,54 \times 10^{-7} \text{ m}^3/det = 0,19 \times 10^{-7} \text{ ft}^3/s \)

Desain pompa :
untuk aliran turbulen $N_{Re} < 2100$

\[ Di_{opt} = 3 Q^{0.36} \mu^{0.18} \]  
(Peters dkk, 2004)

\[ = 3 ((0.19 \times 10^{-7}) \text{ ft}^3/\text{s})^{0.36} (0.00067 \text{ lbm/ft.s})^{0.18} \]

\[ = 0.0013 \text{ ft} = 0.0159 \text{ in} \]

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

- Ukuran nominal : 0.125 in
- Schedule number : 80
- Diameter Dalam (ID) : 0.215 in = 0.01791 ft
- Diameter Luar (OD) : 0.405 in
- Luas penampang dalam ($A$) : 0.00025 ft$^2$
- Kecepatan linier, $v = \frac{Q}{A} = 0.000074 \text{ ft/s}$

**Bilangan Reynold**:

\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]  
(Peters dkk, 2004)

\[ = \frac{(79.4104 \text{ lbm/ft}^3)0.000074 \text{ ft/s}(0.0179 \text{ ft})}{0.00067 \text{ lbm/ft s}} \]

\[ = 0.1567 \text{ (aliran laminar/viscous)} \]

Untuk pipa *Commercial Steel* diperoleh harga $f = 102,074$  
(Geankoplis, 2003)

**Friction loss**:

1. sharp edge entrance $h_c = 0.5 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 \alpha g_c} = 0.5 (1 - 0) \frac{0.000074^2}{2(1)(32,174)}$

\[ = 0.43 \times 10^{-10} \text{ ft lbf/lbm} \]

2. elbow 90° $h_f = n.Kf. \frac{v^2}{2 g_c} = 2(34,22) \frac{0.000074^2}{2(1)(32,174)} = 0.13 (10^{-9}) \text{ ft lbf/lbm}$

1. gate valve $h_f = n Kf. \frac{v^2}{2 g_c} = 1(2) \frac{0.000074^2}{2(1)(32,174)} = 0.17 (10^{-9}) \text{ ft lbf/lbm}$

Pipa lurus 30 ft $F_f = 4f \frac{\Delta L \cdot v^2}{D \cdot 2 g_c} = 4(102,074) \frac{(30)(0.000074)^2}{(0.0179)(2)(32,174)}$
1 sharp edge exit

\[
h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left( 1 - 0 \right) \frac{0,000074^2}{2(1)(32,174)}
\]

\[
= 0,85 \times 10^{-10} \text{ ft lbf/lbm}
\]

Total friction loss

\[
\sum F = 0,0000582 \text{ ft lbf/lbm}
\]

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 \( \Delta z = 30 \text{ ft} \)

\[
0 + \frac{32,174}{32,174} (30) + 0 + 0,0000582 + W_s = 0
\]

\[W_s = 30,0000582 \text{ ft.lbf/lbm}\]

Efisiensi pompa, \( \eta = 70 \% \)

\[W_p = \frac{-W_s}{\eta} = 42,8572 \text{ ft lbf/lbm}\]

Daya pompa:

\[
P = \frac{W_p Q}{550} = \frac{0,15 (10^{-5}) \text{ lbm/s}}{(42,8572 \text{ ft.lbf/lbm})} = 0,118(10^{-6}) \text{ hp}
\]

Digunakan daya motor standar \( \frac{1}{4} \) hp

L.D.32 Pompa II Domestik (PU-14)

Fungsi: Memompa air dari tangki utilitas TU-01 ke distribusi domestik

Jenis: Pompa sentrifugal

Bahan konstruksi: Commercial Steel

Jumlah: 1 unit

Kondisi operasi: \( P = 1 \text{ atm} \)

Temperatur: \( 30^\circ\text{C} \)

Laju alir massa (F): 868,2457 kg/jam \( = 0,5317 \text{ lbm/s} \)

Densitas (\( \rho \)): 995,467 kg/m\(^3\) \( = 62,1466 \text{ lbm/ft}^3 \)

Viskositas (\( \mu \)): 0,85 cP \( = 0,00057 \text{ lbm/ft.s} \)
Laju alir volumetrik,

\[ Q = \frac{F}{\rho} = \frac{868,245 \text{ kg/kJ}}{995,467 \text{ kg/m}^3} = 0,8721 \text{ m}^3/\text{jam} \]

\[ = 0,00024 \text{ m}^3/\text{det} = 0,0085 \text{ ft}^3/\text{s} \]

**Desain pompa**:

untuk aliran turbulen \( N_{Re} > 2100 \)

\[ D_{i,\text{opt}} = 0,363 Q^{0,45} \rho^{0,13} \]

\( = 0,363 (0,00024 \text{ m}^3/\text{s})^{0,45} (995,467 \text{ kg/m}^3)^{0,13} \]

\[ = 0,0210 \text{ m} = 0,8274 \text{ in} \]

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

- **Ukuran nominal**: 1 in
- **Schedule number**: 80
- **Diameter Dalam (ID)**: 0,952 in = 0,0797 ft
- **Diameter Luar (OD)**: 1,315 in
- **Luas penampang dalam (A)**: 0,00499 ft²

Kecepatan linier,

\[ v = \frac{Q}{A} = 1,6696 \text{ ft/s} \]

**Bilangan Reynolds**:

\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]

\( = \frac{(62,1466 \text{ lbm/ft}^3)(1,6696 \text{ ft/s})(0,0797 \text{ ft})}{0,00057 \text{ lbm/ft s}} \]

\[ = 14487,39 \text{ (aliran turbulen)} \]

Untuk pipa *Commercial Steel* diperoleh harga \( \varepsilon = 0,000046 \); \( \varepsilon/D = 0,0018 \), pada \( N_{Re} = 14487,39 \) diperoleh harga faktor *fanning* \( f = 0,008 \) (Geankoplis, 2003).

**Friction loss**:

\( 1 \text{ sharp edge entrance} \)

\[ h_c = 0,5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0,5 (1 - 0) \frac{1,6696^2}{2(1)(32,174)} \]

\[ = 0,0216 \text{ ft lbf/lbm} \]

\( 6 \text{ elbow } 90^\circ \)

\[ h_f = n.Kf \frac{v^2}{2 g_c} = 6(0,75) \frac{1,6696^2}{2(1)(32,174)} = 0,1949 \text{ ft lbf/lbm} \]
6 gate valve

\[ h_f = n K_f \frac{v^2}{2 g_c} = 6(2) \frac{1,6696^2}{2(1)(32,174)} = 0,5198 \text{ ft lbf/lbm} \]

Pipa lurus 303 ft

\[ F_f = 4f \frac{\Delta L v^2}{D 2 g_c} = 3(0,008) \frac{(300)(1,6696)^2}{(0,0797)2(32,174)} = 5,2147 \text{ ft lbf/lbm} \]

1 sharp edge exit

\[ h_{ex} = n \left(1 - \frac{A_1}{A_2}\right)^2 \frac{v^2}{2 \alpha g_c} = 1 \left(1 - 0\right) \frac{1,6696^2}{2(1)(32,174)} = 0,0433 \text{ ft lbf/lbm} \]

Total friction loss

\[ \sum F = 5,9945 \text{ ft lbf/lbm} \]

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 \( \Delta z = 50 \text{ ft} \)

\[ 0 + \frac{32,174}{32,174} (00) + 0 + 5,9945 + W_s = 0 \]

\( W_s = 55,9944 \text{ ft.lbf/lbm} \)

Efisiensi pompa, \( \eta = 70 \% \)

\[ W_p = -W_s / \eta = 79,9921 \text{ ft lbf/lbm} \]

Daya pompa:

\[ P = \frac{W_p Q}{550} = \frac{(0,5177 \text{bm/s})(79,9921 \text{ ft.lbf/lbm})}{550} = 0,0777 \text{ hp} \]

Digunakan daya motor standar ¼ hp

**L.D.33 Pompa Umpan Dearator (PU-15)**

Fungsi: Memompa air dari tangki anion ke deaerator

Jenis: Pompa *sentrifugal*

Bahan konstruksi: *Commercial Steel*

Jumlah: 1 unit

Kondisi operasi: \( P = 1 \text{ atm} \)
Temperatur = 30 °C

Laju alir massa (F) = 1102,2214 kg/jam = 0,6749 lbm/s
Densitas (ρ) = 995,467 kg/m³ = 62,1466 lbm/ft³
Viskositas (μ) = 0,85 cP = 0,00057 lbm/ft.s

Laju alir volumetrik, $Q = \frac{F}{\rho} = \frac{1102,2214 \text{ kg/kJ}}{995,467 \text{ kg/m}^3} = 1,1072 \text{ m}^3/\text{jam}$

= 0,00031 m³/det = 0,0108 ft³/s

Desain pompa:

untuk aliran turbulen $N_{Re} > 2100$

$D_{opt} = 0,363 Q^{0,45} \rho^{0,13}$ (Peters dkk, 2004)

= 0,363 (0,00031 m³/s)^{0,45} (995,467 kg/m³)^{0,13}

= 0,0234 m = 0,9212 in

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

Ukuran nominal : 1,25 in
Schedule number : 80
Diameter Dalam (ID) : 1,278 in = 0,1065 ft
Diameter Luar (OD) : 1,66 in
Luas penampang dalam (A) : 0,00891 ft²

Kecepatan linier, $v = \frac{Q}{A} = 1,82$ ft/s

Bilangan Reynolds:

$N_{Re} = \frac{\rho \times v \times D}{\mu}$ (Peters dkk, 2004)

= $\frac{(62,1466 \text{ lbm/ft}^3)(1,82 \text{ ft/s})(0,1065 \text{ ft})}{0,00057 \text{ lbm/ft s}}$

= 21090,9631 (aliran turbulen)

Untuk pipa Commercial Steel diperoleh harga $\varepsilon = 0,000046$ ; $\varepsilon/D = 0,0014$, pada $N_{Re} = 21090,9631$ diperoleh harga faktor fanning $f = 0,0071$ (Geankoplis, 2003).

Friction loss:
1 sharp edge entrance

\[ h_c = 0.5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0.5 (1 - 0) \frac{1.82}{21(32,174)} \]

\[ = 0.0257 \text{ ft lbf/lbm} \]

2 elbow 90°

\[ h_f = nKf \frac{v^2}{2 g_c} = 2(0.75) \frac{1.82}{21(32,174)} = 0.0794 \text{ ft lbf/lbm} \]

1 gate valve

\[ h_f = nKf \frac{v^2}{2 g_c} = 1(2) \frac{1.82}{21(32,174)} = 0.1144 \text{ ft lbf/lbm} \]

Pipa lurus 30 ft

\[ F_f = 4f \frac{\Delta L v^2}{D 2 g_c} = 4(0.0071) \frac{(30)(1.82)^2}{(0.1065)2(32,174)} \]

\[ = 0.4814 \text{ ft lbf/lbm} \]

1 sharp edge exit

\[ h_{exit} = n \left( 1 - \frac{A_1}{A_2} \right) \frac{v^2}{2 \alpha g_c} = 1(1 - 0) \frac{1.82}{21(32,174)} \]

\[ = 0.0515 \text{ ft lbf/lbm} \]

Total friction loss

\[ \sum F = 0.6692 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:

\[ \frac{1}{2 g_c} (v_2^2 - v_1^2) + \frac{g}{g_c} (z_2 - z_1) + \frac{P_2 - P_1}{\rho} + \sum F + W_s = 0 \]

(Geankoplis, 2003)

dimana: \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 30 \text{ ft} \)

\[ 0 + \frac{32,174}{32,174} (30) + 0 + 0.6692 + W_s = 0 \]

\[ W_s = 30.6692 \text{ ft lbf/lbm} \]

Efisien pompa, \( \eta = 70 \% \)

\[ W_p = -W_s / \eta = 43.8132 \text{ ft lbf/lbm} \]

Daya pompa:

\[ P = \frac{W_p Q}{550} = \frac{(1.0078 \text{ lbf/s})(43.8132 \text{ ft lbf/lbm})}{550} = 0.0531 \text{ hp} \]

Digunakan daya motor standar \( \frac{1}{4} \) hp
LD.34 Pompa Cooler (PU-16)

Fungsi: Memompa air dari Refrigerator menuju ke alat proses.

Jenis: Pompa sentrifugal

Bahan konstruksi: Commercial Steel

Jumlah: 1 unit

Kondisi operasi:

Tekanan = 1 atm
Temperatur = 25 °C

Laju alir massa (F) = 9049,6260 kg/jam = 5,5418 lbm/s
Densitas (ρ) = 997,045 kg/m³ = 62,2451 lbm/ft³
Viskositas (µ) = 0,95 cP = 0,00064 lbm/ft.s

Laju alir volumetrik, FQ = 9049,6260 kg/kJ 997,045 kg/m³ = 9,0764 m³/jam
= 0,00252 m³/det = 0,0890 ft³/s

Desain pompa:

untuk aliran turbulen N_Re > 2100

Di_opt = 0,363 Q_0,45 ρ_0,13 (Peters dkk, 2004)

= 0,363 (0,00252 m³/s)_0,45 (997,045 kg/m³)_0,13
= 0,0603 m = 2,374 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 = 0,2416 ft
Diameter Luar (OD) : 3,5 in
Luas penampang dalam (A) : 0,04587 ft²

Kecepatan linier, v = Q/A = 2,456 ft/s

Bilangan Reynold:

N_Re = ρ x v x D
(µ) (Peters dkk, 2004)
Untuk pipa Commercial Steel diperoleh harga $\varepsilon = 0,000046$ ; $\varepsilon/D = 0,00062$, pada $N_{Re} = 57873,6244$ diperoleh harga faktor fanning $f = 0,0058$ (Geankoplis, 2003).

Friction loss:

1. sharp edge entrance $h_c = 0,5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_c} = 0,5 (1 - 0) \frac{2,456^2}{2(1)(32,174)}$
   $= 0,0468 \text{ ft lbf/lbm}$

7. elbow 90° $h_f = n.Kf. \frac{v^2}{2 g_c} = 7(0,75) \frac{2,456^2}{2(1)(32,174)} = 0,4921 \text{ ft lbf/lbm}$

6. gate valve $h_f = n Kf \frac{v^2}{2 g_c} = 6(2) \frac{2,456^2}{2(1)(32,174)} = 1,1249 \text{ ft lbf/lbm}$

Pipa lurus 350 ft $F_f = 4f \frac{\Delta L \cdot v^2}{D^2 g_c} = 4(0,0058) \frac{(350)(2,456)^2}{(0,2416)(32,174)}$
   $= 3,1497 \text{ ft lbf/lbm}$

1. sharp edge exit $h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right) \frac{v^2}{2 \alpha g_c} = 1 (1 - 0) \frac{2,456}{2(1)(32,174)}$
   $= 0,0937 \text{ ft lbf/lbm}$

Total friction loss \( \sum F = 4,9073 \text{ ft lbf/lbm} \)

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 $\Delta z = 90$ ft

$0 + \frac{32,174}{32,174} \times 90 + 0 + 4,9073 + W_s = 0$

$W_s = 94,9073 \text{ ft.lbf/lbm}$

Efisiensi pompa, $\eta = 70\%$
\[ W_p = \frac{-W_s}{\eta} = 135,5819 \text{ ft lbf/lbm} \]

Daya pompa:
\[ P = \frac{W_p Q}{550} = \frac{(7,0124 \text{ lbm/s})(135,5819 \text{ ft.lbf/lbm})}{550} = 1,3396 \text{ hp} \]

Digunakan daya motor standar 2 hp

**L.D.35 Pompa Umpan Ketel Uap (PU-17)**

Fungsi: Memompa air dari deaerator ke ketel uap

Jenis: Pompa *sentrifugal*

Bahan konstruksi: *Commercial Steel*

Jumlah: 1 unit

Kondisi operasi:
\[ P = 1 \text{ atm} \]
\[ \text{Temperatur} = 90^\circ \text{C} \]

Laju alir massa (F):
\[ 1,102,2214 \text{ kg/jam} = 0,6749 \text{ lbm/s} \]

Densitas (ρ):
\[ 965,321 \text{ kg/m}^3 = 60,2646 \text{ lbm/ft}^3 \]

Viskositas (μ):
\[ 0,3 \text{ cP} = 0,0002 \text{ lbm/ft.s} \]

Laju alir volumetrik,
\[ Q = \frac{F}{\rho} = \frac{1,102,2214 \text{ kg/kJ}}{965,321 \text{ kg/m}^3} = 1,1418 \text{ m}^3/\text{jam} \]
\[ = 0,00031 \text{ m}^3/\text{det} = 0,0112 \text{ ft}^3/\text{s} \]

**Desain pompa:**

untuk aliran turbulen \(N_{Re} > 2100\)

\[ D_{opt} = 0,363 Q^{0,45} \rho^{0,13} \]
\[ = 0,363 (0,00031 \text{ m}^3/\text{s})^{0,45} (965,3221 \text{ kg/m}^3)^{0,13} \]
\[ = 0,0236 \text{ m} = 0,9303 \text{ in} \]

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

Ukuran nominal: 1,25 in

*Schedule number*: 80

Diameter Dalam (ID): 1,278 in = 0,1065 ft

Diameter Luar (OD): 1,66 in

Luas penampang dalam (A): 0,00891 ft²

Kecepatan linier,
\[ v = \frac{Q}{A} = 1,877 \text{ ft/s} \]
Bilangan Reynolds:
\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]
\[ = \frac{(60,2646 \text{ lbm/ft}^3)(1,877 \text{ ft/s})(0,1065 \text{ ft})}{0,0002 \text{ lbm/ft s}} \]
\[ = 59757,7288 \text{ (aliran turbulen)} \]

Untuk pipa Commercial Steel diperoleh harga \( \varepsilon = 0,000046 \); \( \varepsilon/D = 0,0014 \), pada \( N_{Re} = 59757,7288 \) diperoleh harga faktor fanning \( f = 0,006 \) (Geankoplis, 2003)

Friction loss:

1. sharp edge entrance \( h_e = 0,5 \left( 1 - \frac{A_2}{A_1} \right) \left( \frac{v^2}{2 \alpha g_c} \right) = 0,5(1-0) \frac{1,877^2}{2(1)(32,174)} \]
\[ = 0,0273 \text{ ft lbf/lbm} \]

2. elbow 90° \( h_f = nKf \left( \frac{v^2}{2 g_c} \right) = 2(0,75) \frac{1,877^2}{2(1)(32,174)} = 0,0821 \text{ ft lbf/lbm} \]

1. gate valve \( h_f = nKf \left( \frac{v^2}{2 g_c} \right) = 1(2) \frac{1,877^2}{2(1)(32,174)} = 0,1095 \text{ ft lbf/lbm} \]

Pipa lurus 50 ft \( F_f = 4f \frac{\Delta L}{D} \frac{v^2}{2 g_c} = 4(0,006) \frac{(50)(1,877^2)}{(0,1065)2(32,174)} \]
\[ = 0,6168 \text{ ft lbf/lbm} \]

1. sharp edge exit \( h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right) \left( \frac{v^2}{2 \alpha g_c} \right) = 1(1-0) \frac{1,877^2}{2(1)(32,174)} \]
\[ = 0,0547 \text{ ft lbf/lbm} \]

Total friction loss \( \sum F = 0,8906 \text{ ft lbf/lbm} \)

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 \( \Delta z = 50 \text{ ft} \)
\[ 0 + \frac{32,174}{32,174} (50) + 0 + 0,8906 + W_s = 0 \]
Ws = 50,890 ft.lbf/lbm
Efisiensi pompa, $\eta = 70\%$

$$W_p = -\frac{W_s}{\eta} = 72,7009 \text{ ft lbf/lbm}$$

Daya pompa :
$$P = \frac{W_p \times Q}{550} = \frac{1,0078 \text{ lbm/s} \times 72,7009 \text{ ft.lbf/lbm}}{550} = 0,0883 \text{ hp}$$

Digunakan daya motor standar $\frac{1}{4}$ hp

**LD.36 Pompa Bahan Bakar Ketel Uap (PU-18)**

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 : $P = 1 \text{ atm}$
Temperatur = 30 $^\circ\text{C}$

Laju alir massa ($F$) = 66,2149 kg/jam = 0,0405 lbm/s
Densitas ($\rho$) = 890,0712 kg/m$^3$ = 55,5668 lbm/ft$^3$
Viskositas ($\mu$) = 1 cP = 0,00067 lbm/ft.s

Laju alir volumetrik, $Q = \frac{F}{\rho} = \frac{66,2149 \text{ kg/kJ}}{890,0712 \text{ kg/m}^3} = 0,0743 \text{ m}^3$/jam

$$= 0,000021 \text{ m}^3/\text{det} = 0,00072 \text{ ft}^3/\text{s}$$

Desain pompa :
untuk aliran turbulen $N_{Re} > 2100$

$$D_{i,\text{opt}} = 0,363 \times Q^{0,45} \times \rho^{0,13} \quad \text{(Peters dkk, 2004)}$$

$$= 0,363 \times (0,000021 \text{ m}^3/\text{s})^{0,45} \times (890,0712 \text{ kg/m}^3)^{0,13}$$

$$= 0,0068 \text{ m} = 0,2693 \text{ in}$$

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

Ukuran nominal : 0,375 in
*Schedule number* : 80
Diameter Dalam (ID) : 0,423 in = 0,0352 ft
Diameter Luar (OD) : 0,675 in
Luas penampang dalam (A) : 0,00098 ft$^2$

Kecepatan linier, $v = \frac{Q}{A} = 1,0389$ ft/s

Bilangan Reynold :

\[ N_{Re} = \frac{\rho \times v \times D}{\mu} \]

\[ = \frac{(55,5668 \text{ lbm/ft}^3) (1,0389 \text{ ft/s}) (0,0352 \text{ ft})}{0,00067 \text{ lbm/ft s}} \]

\[ = 3028,3775 \text{ (aliran turbulen)} \]

Untuk pipa Commercial Steel diperoleh harga $\varepsilon = 0,00046$ ; $\varepsilon/D = 0,0042$, pada $N_{Re} = 3028,3775$ diperoleh harga faktor fanning $f = 0,007$ (Geankoplis, 2003).

Friction loss :

1. sharp edge entrance

\[ h_c = 0,5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2g_c} = 0,5 \left( 1 - 0 \right) \frac{1,0389^2}{2(1)(32,174)} \]

\[ = 0,0084 \text{ ft lbf/lbm} \]

1. elbow 90°

\[ h_f = n.K_f \frac{v^2}{2g_c} = 1(0,75) \frac{1,0389^2}{2(1)(32,174)} = 0,0251 \text{ ft lbf/lbm} \]

1. gate valve

\[ h_f = n.K_f \frac{v^2}{2g_c} = 1(2) \frac{1,0389^2}{2(1)(32,174)} = 0,0335 \text{ ft lbf/lbm} \]

Pipa lurus 50 ft

\[ F_f = 4f \frac{\Delta L}{D} \frac{v^2}{2g_c} = 4(0,007) \frac{(50)(1,389)^2}{(0,0352)2(32,174)} \]

\[ = 0,6662 \text{ ft lbf/lbm} \]

1. sharp edge exit

\[ h_{ex} = n \left( 1 - \frac{A_2}{A_1} \right)^2 \frac{v^2}{2g_c} = 1 \left( 1 - 0 \right) \frac{1,0389^2}{2(1)(32,174)} \]

\[ = 0,0167 \text{ ft lbf/lbm} \]

Total friction loss

\[ \sum F = 0,75 \text{ ft lbf/lbm} \]

Dari persamaan Bernoulli:

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

inggi pemompaan \( \Delta z = 40 \) ft

\[
0 + \frac{32.174}{32.174} \times (40) + 0 + 0.75 + W_s = 0
\]

\( W_s = 40.75 \) ft.lbf/lbm

Efisiensi pompa, \( \eta = 70 \% \)

\[
W_p = \frac{-W_s}{\eta} = 58.2144 \text{ ft lbf/lbm}
\]

Daya pompa : \( P = \frac{W_p Q}{550} = \frac{(0.0565\text{lbm/s})(58.2144\text{ft.lbf/lbm})}{550} = 0.0043 \) hp

Digunakan daya motor standar \( \frac{1}{4} \) hp

**LD.37 Pompa Bahan Bakar Generator (PU-19)**

**Fungsi** : Memompa bahan bakar solar dari TB-01 Generator

**Jenis** : Pompa sentrifugal

**Bahan konstruksi** : Commercial Steel

**Jumlah** : 1 unit

**Kondisi operasi** :
- \( P = 1 \) atm
- Temperatur = 30 °C

**Laju alir massa (F)** = 27,4243 kg/jam = 0,0168 lbm/s

**Densitas** (\( \rho \)) = 890,0712 kg/m³ = 55,5668 lbm/ft³

**Viskositas** (\( \mu \)) = 1 cP = 0,00067 lbm/ft.s

**Laju alir volumetrik**, \( Q = \frac{F}{\rho} = \frac{27,4243 \text{kg/kJ}}{890,0712 \text{kg/m}^3} = 0,0308 \) m³/jam

\( = 0,0000086 \text{ m}^3/\text{det} = 0,0003 \text{ ft}^3/\text{s} \)

**Desain pompa** :

\( D_{opt} = 0,363 Q^{0.45} \rho^{0.13} \)  

(Peters dkk, 2004)

\( = 0,363 (0,0000086 \text{ m}^3/\text{s})^{0.45} (890,0712 \text{ kg/m}^3)^{0.13} \)

\( = 0,0046 \text{ m} = 0,1811 \text{ in} \)
Dari Tabel A.5-1 Geankoplis, 2003, dipilih pipa dengan spesifikasi:

- **Ukuran nominal**: 0.25 in
- **Schedule number**: 80
- **Diameter Dalam (ID)**: 0.302 in = 0.0251 ft
- **Diameter Luar (OD)**: 0.54 in
- **Luas penampang dalam (A)**: 0.0005 ft²

**Kecepatan linier**, \( v = \frac{Q}{A} \) = 0.6045 ft/s

**Bilangan Reynolds**: 
\[
N_{Re} = \frac{\rho \times v \times D}{\mu} = \frac{(55.5668 \text{ lbm/ft}^3)(0.6045 \text{ ft/s})(0.0251\text{ ft})}{0.00067 \text{ lbm/ft s}} = 1257.9611 \text{ (aliran turbulen)}
\]

Untuk pipa *Commercial Steel* dengan \( N_{Re} = 1257.9611 \) diperoleh harga \( f = 0.013 \) (Geankoplis, 2003)

**Friction loss**:

1. **sharp edge entrance**  \( h_c = 0.5 \left( 1 - \frac{A_2}{A_1} \right) \frac{v^2}{2 \alpha g_e} = 0.5 (1 - 0) \frac{0.6045^2}{2(1)(32.174)} \)
   
   = 0.0028 ft lbf/lbm

2. **elbow 90°**  \( h_f = nKf\frac{v^2}{2g_e} = 2(0.75)\frac{0.6045^2}{2(1)(32.174)} = 0.0085 \text{ ft lbf/lbm} \)

3. **gate valve**  \( h_f = nKf\frac{v^2}{2g_e} = 1(2)\frac{0.6045^2}{2(1)(32.174)} = 0.0113 \text{ ft lbf/lbm} \)

Pipa lurus 70 ft  \( F_f = 4f\frac{\Delta L v^2}{D \times 2g_e} = 4(0.013)\frac{(70)(0.6045)^2}{(0.0251)(2)(32.174)} \)

   = 0.8035 ft lbf/lbm

1. **sharp edge exit**  \( h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_e} = 1 (1 - 0) \frac{0.6045^2}{2(1)(32.174)} \)
Dari persamaan Bernoulli:

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

(Geankoplis, 2003)

dimana : \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

tinggi pemompaan \( \Delta z = 40 \text{ ft} \)

\[
0 + \frac{32,174}{32,174}(40) + 0 + 0,8319 + W_s = 0
\]

\( W_s = 40,8319 \text{ ft.lbf/lbm} \)

Efisiensi pompa, \( \eta = 70 \% \)

\( W_p = -W_s / \eta = 58,3313 \text{ ft lbf/lbm} \)

Daya pompa : \( P = \frac{W_p Q}{550} = \frac{(0,0167 \text{ lbm/s})(58,3313 \text{ ft.lbf/lbm})}{550} = 0,0017 \text{ hp} \)

Digunakan daya motor standar \( \frac{1}{4} \text{ hp} \)

**LD.38 Pompa Dowterm A (PU-20)**

Fungsi : Memompa pendingin (Dowterm A) ke proses (Reaktor)

Jenis : Pompa centrifugal

Bahan konstruksi : Commercial Steel

Jumlah : 1 unit

Kondisi operasi : P = 1 atm

Temperatur = 30 °C

Laju alir massa (F) = 2566,7869 kg/jam = 1,5718 lbm/s

Densitas (\( \rho \)) = 1056 kg/m\(^3\) = 65,9257 lbm/ft\(^3\) (Anonim, 2010)

Viskositas (\( \mu \)) = 2,45 cP = 0,00165 lbm/ft.s (Anonim, 2010)

Laju alir volumetrik, \( Q = \frac{F}{\rho} = \frac{2566,7869 \text{ kg/kJ}}{1056 \text{ kg/m}^3} = 2,4306 \text{ m}^3/\text{jam} \)

\[ = 0,00068 \text{ m}^3/\text{det} = 0,0238 \text{ ft}^3/\text{s} \]
untuk aliran turbulen $N_{Re} > 2100$

$$D_{i, opt} = 0.363 \, Q^{0.45} \, \rho^{0.13}$$

(Peters dkk, 2004)

$$= 0.363 \, (0.00068 \text{ m}^3/\text{s})^{0.45} \, (1056 \text{ kg/m}^3)^{0.13}$$

$$= 0.0335 \text{ m} = 1.3224 \text{ in}$$

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

- **Ukuran nominal**: 1.5 in
- **Schedule number**: 80
- **Diameter Dalam (ID)**: 1.442 in = 0.1201 ft
- **Diameter Luar (OD)**: 1.75 in
- **Luas penampang dalam (A)**: 0.0113 ft$^2$

Kecepatan linier, $v = \frac{Q}{A} = 2,1034 \text{ ft/s}$

Bilangan *Reynold*:

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

(Peters dkk, 2004)

$$= \frac{(65,9257 \text{ lbm/ft}^3)(2,1034 \text{ ft/s})(0.1201 \text{ ft})}{0.00165 \text{ lbm/ft s}}$$

$$= 10121,5269 \text{ (aliran turbulen)}$$

Untuk pipa *Commercial Steel* diperoleh harga $\varepsilon = 0.000046$; $\varepsilon/D = 0.0024$, pada

$N_{Re} = 4518,5938$ diperoleh harga faktor *fanning* $f = 0.01$ (Geankoplis, 2003).

Friction loss:

1. **sharp edge entrance**

$$h_c = 0.5 \left(1 - \frac{A_2}{A_1}\right) \frac{v^2}{2 \alpha g_c} = 0.5(1-0) \frac{1,8249^2}{2(1)(32,174)}$$

$$= 0.0258 \text{ ft lbf/lbm}$$

2. **elbow 90°**

$$h_r = n \cdot Kf \frac{v^2}{2 g_c} = 2(0.75) \frac{1,8249^2}{2(1)(32,174)} = 0.0776 \text{ ft lbf/lbm}$$

1. **gate valve**

$$h_f = n \cdot Kf \frac{v^2}{2 g_c} = 1(2) \frac{1,8249^2}{2(1)(32,174)} = 0.1035 \text{ ft lbf/lbm}$$
Pipa lurus 40 ft

\[ F_t = 4f \frac{\Delta L v^2}{D \Delta g_c} = 4(0,01) \left( \frac{(40)(1,8249)^2}{(0,0618)2(32,174)} \right) = 1,3392 \text{ft lbf/lbm} \]

1 sharp edge exit

\[ h_{ex} = n \left( 1 - \frac{A_1}{A_2} \right)^2 \frac{v^2}{2 \alpha g_c} = 1 (1 - 0) \frac{1,8249^2}{2(1)(32,174)} = 0,0517 \text{ft lbf/lbm} \]

Total friction loss

\[ \sum F = 1,5979 \text{ft lbf/lbm} \]

Dari persamaan Bernoulli:

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

dimana : \( v_1 = v_2 \); \( \Delta v^2 = 0 \); \( P_1 = P_2 \); \( \Delta P = 0 \)

inggi pemompaan \( \Delta z = 40 \text{ ft} \)

\[ 0 + \frac{32,174}{32,174} (40) + 0 + 1,5979 + W_s = 0 \]

\( W_s = 41,5979 \text{ ft.lbf/lbm} \)

Efisiensi pompa, \( \eta = 70 \% \)

\[ W_p = -W_s / \eta = 59,4256 \text{ ft lbf/lbm} \]

Daya pompa:

\[ P = \frac{W_p Q}{550} = \frac{(0,3609 \text{ lbm/s})(59,4256 \text{ ft.lbf/lbm})}{550} = 0,0055 \text{ hp} \]

Digunakan daya motor standar ¼ hp
Dalam pra rancangan pabrik Isopropylbenzene, digunakan asumsi sebagai berikut:
Pabrik beroperasi selama 330 hari dalam setahun.
Kapasitas maksimum adalah 2.500 ton/tahun.
Perhitungan didasarkan pada harga peralatan tiba di pabrik atau purchased-equipment delivered (Peters dkk, 2004).
Harga alat disesuaikan dengan basis 1 Juli 2011. dimana nilai tukar dollar terhadap rupiah adalah US$ 1 = Rp 8.595,- (Bank Mandiri, 1 Juli 2011).

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 300.000/m².
Luas tanah seluruhnya = 13.430 m²
Harga tanah seluruhnya = 13.430 m² × Rp 300.000/m² = Rp 4.029.000.000,-
Biaya perataan tanah diperkirakan 5% dari harga tanah seluruhnya (Peters dkk, 2004).
Biaya perataan tanah = 0.05 × Rp 4.029.000.000,- = Rp 201.450.000,-
Total biaya tanah (A) = Rp 4.029.000.000,- + Rp 201.450.000 = Rp 4.230.450.000,-

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>30</td>
<td>Rp 300.000</td>
<td>Rp 9.000.000</td>
</tr>
<tr>
<td>2</td>
<td>Parkir (*)</td>
<td>200</td>
<td>Rp 300.000</td>
<td>Rp 60.000.000</td>
</tr>
<tr>
<td>3</td>
<td>Taman (*)</td>
<td>200</td>
<td>Rp 300.000</td>
<td>Rp 60.000.000</td>
</tr>
<tr>
<td>No.</td>
<td>Area/Unit</td>
<td>Total</td>
<td>Cost (Rp)</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>--------------------------</td>
<td>---------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Areal Bahan Baku</td>
<td>100</td>
<td>300.000</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Ruang Kontrol</td>
<td>100</td>
<td>1.000.000</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Areal Proses</td>
<td>2500</td>
<td>2.000.000</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Areal Produk</td>
<td>200</td>
<td>300.000</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Perkantoran dan Perpustakaan</td>
<td>150</td>
<td>1.500.000</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Laboratorium</td>
<td>100</td>
<td>2.000.000</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Poliklinik</td>
<td>50</td>
<td>700.000</td>
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<td>Kantin</td>
<td>80</td>
<td>350.000</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Ruang Ibadah</td>
<td>80</td>
<td>500.000</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Gudang Peralatan</td>
<td>100</td>
<td>600.000</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Unit Pemadam Kebakaran</td>
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<td>500.000</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Unit Pengolahan Air</td>
<td>500</td>
<td>1.000.000</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Pembangkit Listrik</td>
<td>200</td>
<td>1.000.000</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Pengolahan Limbah Domestik</td>
<td>100</td>
<td>750.000</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Pembangkit Uap</td>
<td>150</td>
<td>1.000.000</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Area Perluasan (*)</td>
<td>2500</td>
<td>500.000</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Perumahan Karyawan</td>
<td>4000</td>
<td>1.200.000</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Sarana Olahraga (*)</td>
<td>500</td>
<td>500.000</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Jalan (*)</td>
<td>900</td>
<td>300.000</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Bengkel</td>
<td>90</td>
<td>600.000</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Jarak Antar Bangunan</td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>13.430</strong></td>
<td><strong>13.506.000.000</strong></td>
<td></td>
</tr>
</tbody>
</table>

Harga bangunan saja = Rp 11.616.000.000,-

Harga sarana (*) = Rp 1.890.000.000,-

Total biaya bangunan dan sarana (B) = Rp 13.506.000.000,-
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:

\[ r = \frac{[n \cdot \sum X_i \cdot Y_i - \sum X_i \cdot \sum Y_i]}{\sqrt{[n \cdot \sum X_i^2 - (\sum X_i)^2] \cdot [n \cdot \sum Y_i^2 - (\sum Y_i)^2]}} \] (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>3968064</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></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>-----</td>
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<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>14</td>
<td>2002</td>
<td>1103</td>
<td>2208206</td>
<td>4008004</td>
<td>1216609</td>
</tr>
<tr>
<td>Total</td>
<td>27937</td>
<td>14184</td>
<td>28307996</td>
<td>55748511</td>
<td>14436786</td>
</tr>
</tbody>
</table>

Sumber: Tabel 6-2. Peters dkk, 2004

Data:  
\[ n = 14 \] \[ \sum X_i = 27937 \] \[ \sum Y_i = 14184 \] \[ \sum X_iY_i = 28307996 \] \[ \sum X_i^2 = 55748511 \] \[ \sum Y_i^2 = 14436786 \]

Dengan memasukkan harga-harga pada Tabel LE-2. maka diperoleh harga koefisien korelasi:

\[
\begin{align*}
r & = \frac{(14) \cdot (28307996) - (27937)(14184)}{\sqrt{[(14)(55748511) - (27937)^2] \cdot [(14)(14436786) - (14184)^2]}} \\
& \approx 0.98 \approx 1
\end{align*}
\]

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 (2011)  
\[ X \] = variabel tahun ke \( n - 1 \)  
\[ a, b \] = tetapan persamaan regresi

Tetapan regresi ditentukan oleh: (Montgomery, 1992)

\[
\begin{align*}
b & = \frac{(n \cdot \Sigma X_iY_i) - (\Sigma X_i \cdot \Sigma Y_i)}{n \cdot \Sigma X_i^2 - (\Sigma X_i)^2} \\
a & = \frac{\Sigma Y_i \cdot \Sigma X_i^2 - \Sigma X_i \cdot \Sigma X_iY_i}{n \cdot \Sigma X_i^2 - (\Sigma X_i)^2}
\end{align*}
\]

Maka:

\[
\begin{align*}
b & = \frac{(14)(28307996) - (27937)(14184)}{3185} = 16,8089 \\
a & = \frac{(14184)(55748511) - (27937)(28307996)}{3185} = -32528,8
\end{align*}
\]
Sehingga persamaan regresi liniernya adalah:

\[ Y = a + b \cdot X \]
\[ Y = 16,8089X - 32528,8 \]

Dengan demikian, harga indeks pada tahun 2011 adalah:

\[ Y = 16,809(2011) - 32528,8 \]
\[ Y = 1274,099 \]

Perhitungan harga peralatan menggunakan adalah harga faktor eksponsial \((m)\) \textit{Marshall & Swift}. Harga faktor eksponen ini beracuan pada Tabel 6-4. Peters., 2004. Untuk alat yang tidak tersedia, faktor eksponensialnya dianggap 0.6 (Peters dkk, 2004).

Contoh perhitungan harga peralatan:

1. **Tangki Penyimpanan Propilena (TT-101)**

   Kapasitas tangki. \( X_2 = 80,9056 \text{ m}^3 \). Dari Gambar LE.1. diperoleh untuk 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 \((I_y)\) 1122,818.

Gambar LE.1   Harga Peralatan untuk Tangki Penyimpanan \((\text{Storage})\) dan Tangki Pelarutan (Peters dkk, 2004)
Indeks harga tahun 2011 ($I_x$) adalah 1274,099. Maka estimasi harga tangki untuk ($X_2$) 80,9056 m$^3$ adalah:

$$C_x = \text{US$} 6700 \times \frac{80,9056^{10.49}}{1274,099}$$

$$C_x = \text{US$} 65,445 \times (\text{Rp} 8,595,\ldots)/\text{US$} 1$$

$$C_x = \text{Rp} 562,501,961,599,\ldots/\text{unit}$$

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.

Untuk harga alat impor sampai di lokasi pabrik ditambahkan biaya sebagai berikut:

- Biaya transportasi  = 5 %
- Biaya asuransi  = 1 %  
- Bea masuk  = 15 % (Rusjdi, 2004)
- PPh  = 10 % (Rusjdi, 2004)
- Bea 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:

- PPh  = 10 % (Rusjdi, 2004)
- Transportasi lokal  = 0,5 %
- Biaya tak terduga  = 0,5 %

Total  = 21 %
### Tabel LE.3  Estimasi Harga Peralatan Proses

<table>
<thead>
<tr>
<th>No.</th>
<th>Kode Alat</th>
<th>(Unit)</th>
<th>Ket *)</th>
<th>Harga/Unit (Rp)</th>
<th>Harga Total (Rp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tangki Propilen (TT-101)</td>
<td>1</td>
<td>I</td>
<td>562.501.962</td>
<td>562.501.962</td>
</tr>
<tr>
<td>2</td>
<td>Tangki Benzen (TT-102)</td>
<td>1</td>
<td>I</td>
<td>532.768.799</td>
<td>532.768.799</td>
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<tr>
<td>3</td>
<td>Tangki IPB (TT-103)</td>
<td>1</td>
<td>I</td>
<td>640.492.166</td>
<td>640.492.166</td>
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<tr>
<td>4</td>
<td>Tangki DIPB (TT-104)</td>
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<td>I</td>
<td>198.104.462</td>
<td>198.104.462</td>
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<tr>
<td>5</td>
<td>Kompresor (JC-101)</td>
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<td>I</td>
<td>5.599.302</td>
<td>5.599.302</td>
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<td>6</td>
<td>Kompresor (JC-102)</td>
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<td>810.967.688</td>
<td>810.967.688</td>
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<tr>
<td>7</td>
<td>Kompresor (JC-103)</td>
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<td>76.928.241</td>
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<tr>
<td>8</td>
<td>Reaktor (R-101)</td>
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<td>228.161.350</td>
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<td>9</td>
<td>Flash Drum (F-101)</td>
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<td>10</td>
<td>Menara Destilasi (MD-101)</td>
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<td>11</td>
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<td>181.528.237</td>
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<td>12</td>
<td>Akumulator (AC-101)</td>
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<td>133.454.922</td>
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<td>Akumulator (AC-102)</td>
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<td>14</td>
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<td>I</td>
<td>53.732.453</td>
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<tr>
<td>15</td>
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<td>16</td>
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<td>17</td>
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<td>I</td>
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<td>80.947.811</td>
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<td>18</td>
<td>Heater (E-105)</td>
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<td>54.852.264</td>
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<td>19</td>
<td>Reboiler (E-106)</td>
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<td>53.372.106</td>
<td>53.372.106</td>
</tr>
<tr>
<td>20</td>
<td>Condensor (E-107)</td>
<td>1</td>
<td>I</td>
<td>53.374.102</td>
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**Sub Total Impor**  
4.187.507.410

<table>
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<th>No.</th>
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<th>Ket *)</th>
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Tabel LE.4 Estimasi Harga Peralatan Utilitas

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<th>No.</th>
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*Keterangan : I: untuk peralatan impor. NI: untuk peralatan non impor.

Sub Total non-impor 32.000.000

Harga Total 4.219.507.410
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</tbody>
</table>

Total harga peralatan tiba di lokasi pabrik (*purchased-equipment delivered*) adalah:

\[
= 1,43 \times (\text{Rp} \ 4.187.507.410 + \text{Rp} \ 4.019.025.260) + \\
1,21 \times (\text{Rp} \ 32.000.000 + \text{Rp} \ 938.000.000) \\
= \text{Rp} \ 12.909.041.718,-
\]

Biaya pemasangan diperkirakan 30% dari total harga peralatan (Peters dkk, 2004).

\[
\text{Biaya pemasangan} = 0,30 \times 12.909.041.718,- \\
= \text{Rp} \ 3.872.712.515,-
\]

Harga peralatan + biaya pemasangan (A):

\[
= \text{Rp} \ 12.909.041.718,- + \text{Rp} \ 3.872.712.515,- \\
= \text{Rp} \ 16.781.754.233,-
\]

**LE.1.1.4 Instrumentasi dan Alat Kontrol**

Diperkirakan biaya instrumentasi dan alat kontrol 26% dari total harga peralatan. (Peters dkk, 2004).

\[
\text{Biaya instrumentasi dan alat kontrol} (B) = 0,26 \times 16.781.754.233,- \\
= \text{Rp} \ 4.363.256.101,-
\]

**LE.1.1.5 Biaya Perpipaan**

Diperkirakan biaya perpipaan 60% dari total harga peralatan (Peters dkk, 2004).

\[
\text{Biaya perpipaan} (C) = 0,6 \times 16.781.754.233,- \\
= \text{Rp} \ 10.069.052.540,-
\]

**LE.1.1.6 Biaya Instalasi Listrik**

Diperkirakan biaya instalasi listrik 15% dari total harga peralatan (Peters dkk, 2004).

\[
\text{Biaya instalasi listrik} (D) = 0,15 \times 16.781.754.233,- \\
= \text{Rp} \ 2.517.263.135,-
\]
LE.1.1.7 Biaya Insulasi
Diperkirakan biaya insulasi 9% dari total harga peralatan (Peters dkk, 2004).

Biaya insulasi (E) = 0,09 \times Rp \ 16.781.754.233,-
= Rp \ 1.510.357.881,-

LE.1.1.8 Biaya Inventaris Kantor
Diperkirakan biaya inventaris kantor 5% dari total harga peralatan (Peters dkk, 2004).

Biaya inventaris kantor (F) = 0,05 \times Rp \ 16.781.754.233,-
= Rp \ 839.087.712,-

LE.1.1.9 Biaya Perlengkapan Kebakaran dan Keamanan
Diperkirakan biaya perlengkapan kebakaran dan keamanan 2% dari total harga peralatan (Peters dkk, 2004).

Biaya perlengkapan kebakaran dan keamanan (G) = 0,02 \times Rp \ 16.781.754.233,-
= Rp \ 335.635.085,-

LE.1.1.10 Sarana Transportasi
Biaya kebutuhan kelengkapan kendaraan dan transportasi perusahaan (H)

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</table>

Total | Rp 5.492.000.000

(Sumber: anonim, 2011)
Total MITL  =  \( A + B + C + D + E + F + G + H \)  
  =  Rp59.644.856.686,-

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 \times Rp 16.781.754.233,-  
  =  Rp1.174.722.796,-

LE.1.2.2 Biaya Engineering dan Supervisi  
Diperkirakan 32% dari total harga peralatan (Peters dkk, 2004).  
Biaya Engineering dan Supervisi (B) = 0,32 \times Rp 16.781.754.233,-  
  =  Rp 5.370.161.355,-

LE.1.2.3 Biaya Legalitas  
Diperkirakan 4% dari total harga peralatan (Peters dkk, 2004).  
Biaya Legalitas (C) = 0,04 \times Rp 16.781.754.233,-  
  =  Rp 671.270.169,-

LE.1.2.4 Biaya Kontraktor  
Diperkirakan 19% dari total harga peralatan (Peters dkk, 2004).  
Biaya Kontraktor (D) = 0,19 \times Rp 16.781.754.233,-  
  =  Rp 3.188.533.304,-

LE.1.2.5 Biaya Tak Terduga  
Diperkirakan 37% dari total harga peralatan (Peters dkk, 2004).  
Biaya Tak Terduga (E) = 0,37 \times Rp 16.781.754.233,-  
  =  Rp 6.209.249.066,-

Total MITTL  =  A + B + C + D + E  =  Rp 16.613.936.691,-

Total MIT  =  MITL + MITTL  
  =  Rp 59.644.856.686,- + Rp 16.613.936.691,-  
  =  Rp 76.258.793.377,-
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. Propylene
   Kebutuhan = 147,1443 kg/jam
   Harga = US$ 1,3/kg
   = Rp 11.174,-/kg (Bataviace.co.id)
   Harga total = 90 hari × 24 jam/hari × 147,1443 kg/jam × Rp 11,174
   = Rp 3.551.292,366,-

2. Benzene
   Kebutuhan = 219,7177 kg/jam
   Harga = Rp.25.000,-/kg
   Harga total = 90 hari × 24 jam/hari × 219,7177 kg × Rp 25.000,-
   = Rp 11.864.755,800,-

3. Katalis asam phospat kiselguhr
   Kebutuhan = 0,042 m³
   = 0,042 m³ x 3363,66 kg/m
   = 141,2737 kg
   Masa regenerasi = 10 tahun
   Harga = US$ 4/kg = Rp 34.380/kg
   Harga total = Rp 34.380 x 141,2737 kg
   = Rp 121.425 (Untuk 3 bulan)

LE.2.1.2 Persediaan Bahan Baku Utilitas

1. Alum. Al₂(SO₄)₃
   Kebutuhan = 0,1134 kg/jam
   Harga = Rp 2.500,-/kg (PT. Bratachem, 2011)
   Harga total = 90 hari × 24 jam/hari × 0, 1134 kg/jam × Rp 2.500,-/kg
   = Rp 612.606,-

2. Soda abu. Na₂CO₃
   Kebutuhan = 0,0612 kg/jam

Universitas Sumatera Utara
Harga = Rp 3500,-/kg (PT. Bratachem, 2011)
Harga total = 90 hari \times 24 \text{ jam/hari} \times 0.0612 \text{ kg/jam} \times \text{Rp 3500,-/kg} 
= Rp 463.130,-

3. Kaporit
Kebutuhan = 0.0024 \text{ kg/jam}
Harga = Rp 11.000,-/kg (PT. Bratachem, 2011)
Harga total = 90 hari \times 24 \text{ jam/hari} \times 0.0024 \text{ kg/jam} \times \text{Rp 11.000,-/kg} 
= Rp 58.941,-

4. H₂SO₄
Kebutuhan = 0.1087 \text{ kg/jam}
Harga = Rp 35000,-/kg (PT. Bratachem, 2011)
Harga total = 90 hari \times 24 \text{ jam} \times 0.1087 \text{ kg} \times \text{Rp 35000,-/kg} 
= Rp 8.223.529,-

5. NaOH
Kebutuhan = 0.4492 \text{ kg/jam}
Harga = Rp 5250,-/kg (PT. Bratachem, 2010)
Harga total = 90 hari \times 24 \text{ jam} \times 0.4492 \text{ kg} \times \text{Rp 5250,-/kg} 
= Rp 5.094.069,-

6. Solar
Kebutuhan = 93.63 \text{ liter/jam}
Harga solar untuk industri
= Rp. 9.959,-/liter (Agen & transporter BBM industry PERTAMINA, 2011)
Harga total = 90 hari \times 24 \text{ jam} \times 93.63 \text{ ltr/jam} \times \text{Rp 9.959,-/liter} 
= 2.014.304.240,-

7. Dowtherm-A
Kebutuhan = 2566,7868 \text{ kg/jam}
Mas Regenerasi = 10 tahun
Harga total = SG$ 471/-/kg (www.sigmaaldrich.com, 28 Agustus 2011)
= 2566,7868 \text{ kg} \times \text{SG$ 471 \times 8595 \times 2 (Kurs SG$ terhadap rupiah 1 juli 2011, Bank Mandiri)} 
= Rp 16.770.646.177,-
Total biaya persediaan bahan baku proses dan utilitas selama 3 bulan (90 hari) adalah Rp34.215.572.284,-

LE.2.2 Kas

LE.2.2.1 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>Komisaris</td>
<td>1</td>
<td>30.000.000</td>
<td>30.000.000</td>
</tr>
<tr>
<td>Direktur</td>
<td>1</td>
<td>25.000.000</td>
<td>25.000.000</td>
</tr>
<tr>
<td>Sekretaris</td>
<td>1</td>
<td>3.000.000</td>
<td>3.000.000</td>
</tr>
<tr>
<td>Manager</td>
<td>2</td>
<td>15.000.000</td>
<td>30.000.000</td>
</tr>
<tr>
<td>Kepala Bagian</td>
<td>7</td>
<td>8.000.000</td>
<td>56.000.000</td>
</tr>
<tr>
<td>Kepala Seksi</td>
<td>19</td>
<td>5.000.000</td>
<td>95.000.000</td>
</tr>
<tr>
<td>Karyawan</td>
<td>81</td>
<td>3.000.000</td>
<td>243.000.000</td>
</tr>
<tr>
<td>Dokter</td>
<td>1</td>
<td>8.000.000</td>
<td>8.000.000</td>
</tr>
<tr>
<td>Perawat</td>
<td>2</td>
<td>1.750.000</td>
<td>3.500.000</td>
</tr>
<tr>
<td>Petugas Keamanan</td>
<td>12</td>
<td>3.000.000</td>
<td>36.000.000</td>
</tr>
<tr>
<td>Petugas Kebersihan</td>
<td>5</td>
<td>1.300.000</td>
<td>6.500.000</td>
</tr>
<tr>
<td>Supir</td>
<td>10</td>
<td>1.500.000</td>
<td>15.000.000</td>
</tr>
<tr>
<td></td>
<td>142</td>
<td></td>
<td>551.000.000</td>
</tr>
</tbody>
</table>

Total gaji pegawai selama 1 bulan = Rp 551.000.000,-
Total gaji pegawai selama 3 bulan = Rp 1.653.000.000,-

LE.2.2.2 Biaya Administrasi Umum

Diperkirakan 20% dari gaji pegawai (Peters dkk, 2004)

\[ 0.2 \times \text{Rp 1.653.000.000} = \text{Rp 330.600.000} \]
LE.2.2.3 Biaya Pemasaran
Diperkirakan 20% dari gaji pegawai (Peters dkk, 2004)

\[ = 0.2 \times Rp \ 1.653.000.000,- \]
\[ = Rp \ 330.600.000,- \]

LE.2.2.4 Pajak Bumi dan Bangunan
Menurut Peraturan Menteri Keuangan No: 67/PMK.03/2011
Nilai jual objek pajak (NJOP) yang tidak kena pajak untuk wilayah Medan sebesar Rp 24.000.000,- (Harian Medan Bisnis, 4 Juli 2011)

**Wajib Pajak Pabrik Pembuatan Isopropylbenzene**

Nilai Perolehan Objek Pajak
- Tanah \( \text{Rp} \ 4.029.000.000,- \)
- Bangunan \( \text{Rp} \ 13.506.000.000,- \)

Total NJOP \( \text{Rp} \ 17.553.000.000,- \)

Nilai Perolehan Objek Pajak (Tidak Kena Pajak) \( \text{Rp} \ 24.000.000,- \)

Nilai Perolehan Objek Pajak (Kena Pajak) \( \text{Rp} \ 17.511.000.000,- \)

Pajak yang Terutang \( (5\% \times \text{NPOPKP}) \) \( \text{Rp} \ 875.550.000,- \)

**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 1.653.000.000</td>
</tr>
<tr>
<td>2</td>
<td>Administrasi Umum</td>
<td>Rp 330.600.000</td>
</tr>
<tr>
<td>3</td>
<td>Pemasaran</td>
<td>Rp 330.600.000</td>
</tr>
<tr>
<td>4</td>
<td>Pajak Bumi dan Bangunan</td>
<td>Rp 875.550.000</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>Rp 3.189.750.000</strong></td>
</tr>
</tbody>
</table>

LE.2.3 Biaya Start-Up
Diperkirakan 8 % dari Modal Investasi Tetap (Peters dkk, 2004)

\[ = 0.08 \times \text{Rp} \ 76.258.793.377,- \]
\[ = \text{Rp} \ 6.100.703.470,- \]
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 *Isopropylbenzene* (IPB/Cumene)
   = Rp 110000,-/kg (Perbandingan harga PT.Merck Tbk, Indonesia, 2011)
   Produksi *Isopropylbenzene* = 2500 ton/tahun = 2.500.000 kg/tahun
   Hasil penjualan *Isopropylbenzene* tahunan yaitu:
   = 2.500.000 kg/tahun × Rp 110000,-/kg
   = Rp275.000.000.000,-

2. Harga jual *Diisopropilbenzene* = Rp 10.000,-/kg (PT.Merck Tbk, 2011)
   Produksi *Diisopropilbenzene* = 28,6835 kg/jam
   Hasil penjualan *Diisopropilbenzene* tahunan yaitu:
   = 28,6835 kg/jam × 24 jam/hari × 330 hari/tahun × Rp 10.000,-/kg
   = Rp 2.271.733.200,-

Hasil penjualan total tahunan = Rp 277.271.676.000,-

Piutang Dagang = \[ \frac{3}{12} \times \text{Rp} \ 277.271.676.000,- \]
 = Rp 69.317.919.000,-

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 34.215.572.284</td>
</tr>
<tr>
<td>2</td>
<td>Kas</td>
<td>Rp 3.189.750.000</td>
</tr>
<tr>
<td>3</td>
<td>Start Up</td>
<td>Rp 6.100.703.470</td>
</tr>
<tr>
<td>No</td>
<td>Piutang Dagang</td>
<td>Nilai</td>
</tr>
<tr>
<td>----</td>
<td>----------------</td>
<td>------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rp 69.317.919.000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>Rp 112.823.944.754</td>
</tr>
</tbody>
</table>

Total Modal Investasi = Modal Investasi Tetap + Modal Kerja
= Rp 76.258.793.377,- + Rp 112.823.944.754,-
= Rp 189.082.738.131,-

Modal ini berasal dari:
- Modal sendiri = 60% dari total modal investasi
  = 0.6 × Rp 189.082.738.131,-
  = Rp 113.449.642.878,-
- Pinjaman dari Bank = 40% dari total modal investasi
  = 0.4 × Rp 189.082.738.131,-
  = Rp 75.633.095.252,-

**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) × Rp 551.000.000,- = Rp7.714.000.000,-

**LE.3.1.2 Bunga Pinjaman Bank**
Bunga pinjaman bank adalah 14% dari total pinjaman (Bank Mandiri, 2010).

= 0.14 × Rp 75.633.095.252,-
= Rp 10.588.633.335,-

**LE.3.1.3 Depresiasi dan Amortisasi**
Pengeluaran untuk memperoleh harta berwujud yang mempunyai masa manfaat lebih dari 1 (satu) tahun harus dibebankan sebagai biaya untuk mendapatkan, menagih, dan memelihara penghasilan melalui penyusutan (Rusdji.
Pada perancangan pabrik ini, dipakai metode garis lurus atau *straight line method*. Dasar penyusutan menggunakan masa manfaat dan tarif penyusutan sesuai dengan Undang-undang Republik Indonesia No.17 Tahun 2000 Pasal 11 ayat 6 dapat dilihat pada tabel di bawah ini.

### 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>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</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>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:
- \(D\) = depresiasi per tahun
- \(P\) = harga awal peralatan
- \(L\) = harga akhir peralatan
- \(n\) = 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>11.625.000.000</td>
<td>20</td>
<td>580.800.000</td>
</tr>
<tr>
<td>Peralatan proses dan utilitas</td>
<td>16.781.754.233</td>
<td>16</td>
<td>1.048.859.640</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:

\[
\text{Biaya amortisasi} = 0.25 \times \text{Rp 16.613.936.691,}-
\]
\[
= \text{Rp 4.153.484.173,-}
\]

Total Biaya Depresiasi dan Amortisasi

\[
= \text{Rp 7.224.822.753,-} + \text{Rp 4.153.484.173,-}
\]
\[
= \text{Rp 11.378.306.925,-}
\]
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 × Rp 16.781.754.233,-
   = Rp 1.342.540.339,-

2. Perawatan bangunan
   Diperkirakan 8% dari harga bangunan (Peters dkk, 2004).
   = 0.08 × Rp 11.616.000.000,-
   = Rp 929.280.000,-

3. Perawatan kendaraan
   Diperkirakan 8% dari harga kendaraan (Peters dkk, 2004).
   = 0.08 × Rp 5.492.000.000,-
   = Rp 439.360.000,-

4. Perawatan instrumentasi dan alat kontrol
   Diperkirakan 8% dari harga instrumentasi dan alat kontrol (Peters dkk, 2004).
   = 0.08 × Rp 4.363.256.101,-
   = Rp 349.060.488,-

5. Perawatan perpipaan
   Diperkirakan 8% dari harga perpipaan (Peters dkk, 2004).
   = 0.08 × Rp 10.069.052.540,-
   = Rp 805.524.203,-

6. Perawatan instalasi listrik
   Diperkirakan 8% dari harga instalasi listrik (Peters dkk, 2004).
   = 0.08 × Rp 2.517.263.135,-
   = Rp 201.381.051,-

7. Perawatan insulasi
   Diperkirakan 8% dari harga insulasi (Peters dkk, 2004).
   = 0.08 × Rp 1.510.357.881,-
   = Rp 120.828.630,-
8. Perawatan inventaris kantor

Diperkirakan 8% dari harga inventaris kantor (Peters dkk, 2004).

\[ 0.08 \times \text{Rp 839.087.712,-} = \text{Rp 67.127.017,-} \]

9. Perawatan perlengkapan kebakaran

Diperkirakan 8% dari harga perlengkapan kebakaran (Peters dkk, 2004).

\[ 0.08 \times \text{Rp335.635.085,-} = \text{Rp 26.850.807,-} \]

Total Biaya Perawatan = Rp 4.281.952.535,-

LE.3.1.5 Biaya Tambah Industri (Plant Overhead Cost)

Biaya tambah industri ini diperkirakan 10% dari modal investasi tetap. (Peters dkk, 2004)

\[ \text{Plant Overhead Cost} = 0.1 \times \text{Rp 76.258.793.377,-} = \text{Rp 7.625.879.338,-} \]

LE.3.1.6 Biaya Administrasi Umum

Biaya administrasi umum selama 3 bulan adalah Rp 330.600.000,-

\[ 4 \times \text{Rp 330.600.000,-} = \text{Rp 1.322.400.000,-} \]

LE.3.1.7 Biaya Pemasaran dan Distribusi

Biaya pemasaran selama 3 bulan adalah Rp 330.600.000,-

\[ 4 \times \text{Rp 330.600.000,-} = \text{Rp 1.322.400.000,-} \]

Biaya distribusi diperkirakan 50% dari biaya pemasaran. sehingga :

\[ 0.5 \times \text{Rp 330.600.000,-} = \text{Rp 165.300.000,-} \]

Biaya pemasaran dan distribusi = Rp 495.900.000,-
LE.3.1.8 Biaya Laboratorium. Penelitian dan Pengembangan  
Diperkirakan 5% dari biaya tambahan industri (Peters dkk, 2004).  
\[= 0.05 \times \text{Rp 7.625.879.338,-} \]  
\[= \text{Rp 381.293.967,-}\]  

LE.3.1.9 Hak Paten dan Royalti  
Diperkirakan 1% dari modal investasi tetap (Peters dkk, 2004).  
\[= 0.01 \times \text{Rp 76.258.793.377,-} \]  
\[= \text{Rp 762.587.934,-}\]  

LE.3.1.10 Biaya Asuransi  
1. Biaya asuransi pabrik adalah 3.1 permil dari modal investasi tetap langsung  
   (Asosiasi Asuransi Jiwa Indonesia-AAJI, 2010).  
   \[= 0.0031 \times \text{Rp 59.644.856.686,-} \]  
   \[= \text{Rp 184.899.056,-}\]  
2. Biaya asuransi karyawan  
   Premi asuransi = Rp 300.000/tenaga kerja (PT Prudential Life Assurance, 2010).  
   Maka biaya asuransi karyawan = 142 orang \times \text{Rp. 300.000,-}/orang  
   \[= \text{Rp 42.600.000,-}\]  
   Total biaya asuransi = \text{Rp 227.499.056,-}\]  

LE.3.1.11 Pajak Bumi dan Bangunan  
Pajak Bumi dan Bangunan adalah Rp875.550.000,-  
Total Biaya Tetap (Fixed Cost) = \text{Rp 45.654.003.090,-}
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 34.215.572.284,-
Total biaya persediaan bahan baku proses dan utilitas selama 1 tahun adalah:
\[
= \text{Rp 34.215.572.284,-} \times \frac{330}{90} = \text{Rp 125.457.098.375,-}
\]

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
   \[
   = 0.05 \times \text{Rp 125.457.098.375,-} = \text{Rp 6.272.854.919,-}
   \]

2. Biaya Variabel Pemasaran dan Distribusi
   Diperkirakan 1% dari biaya variabel bahan baku
   \[
   = 0.01 \times \text{Rp 125.457.098.375,-} = \text{Rp 1.254.570.984,-}
   \]
Total biaya variabel tambahan = Rp 7.527.425.903,-

LE.3.3.3 Biaya Variabel Lainnya
Diperkirakan 5% dari biaya variabel tambahan
\[
= 0.05 \times \text{Rp 7.527.425.903,-} = \text{Rp 376.371.295,-}
\]
Total Biaya Variabel = Rp 133.360.895.573,-
Total Biaya Produksi = Biaya Tetap + Biaya Variabel
\[
= \text{Rp 45.654.003.090,-} + \text{Rp 133.360.895.573,-} = \text{Rp 179.014.898.663,-}
\]
LE.4 Perkiraan Laba/Rugi Perusahaan

LE.4.1 Laba Sebelum Pajak (Bruto)
Laba atas penjualan = Total penjualan – Total biaya produksi
= Rp 277.271.676.000,- – Rp179.014.898.663,-
= Rp 98.256.777.337,-
Bonus perusahaan untuk karyawan 0.5% dari keuntungan perusahaan
= 0.005 × Rp 98.256.777.337,-
= Rp 491.283.887,-
Pengurangan bonus atas penghasilan bruto sesuai dengan UU RI No. 17/00 Pasal 6 ayat 1 sehingga:
Laba sebelum pajak (bruto) = Rp 97.765.493.451,-

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:
10% x Rp 50.000.000,- = Rp 5.000.000,-
15% x Rp (100.000.000 – 50.000.000) = Rp 7.500.000,-
30% x Rp (97.615.493.451 – 100.000.000) = Rp 29.299.648.035,-
Total Pajak Penghasilan = Rp29.312.148.035,-

LE.4.3 Laba setelah pajak
Laba setelah pajak = laba sebelum pajak – PPh
= Rp 68.460.845.415,-
LE.5 Analisa Aspek Ekonomi

LE.5.1 Profit Margin (PM)

\[
PM = \frac{\text{Laba sebelum pajak}}{\text{Total penjualan}} \times 100\%
\]

\[
PM = \frac{\text{Rp} \, 97.765.493.451,-}{\text{Rp} \, 277.271.676.000,-} \times 100\%
\]

\[
PM = 35,26\% 
\]

LE.5.2 Break Even Point (BEP)

\[
\text{BEP} = \frac{\text{Biaya Tetap}}{\text{Total Penjualan} - \text{Biaya Variabel}} \times 100\%
\]

\[
\text{BEP} = \frac{\text{Rp} \, 45.654.003.090,-}{\text{Rp} \, 277.271.676.000,- - \text{Rp} \, 133.360.895.573,-} \times 100\%
\]

\[
\text{BEP} = 31,72\%
\]

Kapasitas produksi pada titik BEP \( = 31,72\% \times 2500 \text{ ton/tahun} \)
\( = 739,1 \text{ ton/tahun} \)

Nilai penjualan pada titik BEP \( = 31,72\% \times \text{Rp} \, 277.271.676.000,- \)
\( = \text{Rp} \, 87.961.179.247,- \)

LE.5.3 Return on Investment (ROI)

\[
\text{ROI} = \frac{\text{Laba setelah pajak}}{\text{Total Modal Investasi}} \times 100\%
\]

\[
\text{ROI} = \frac{\text{Rp} \, 68.460.845.415,-}{\text{Rp} \, 189.082.738.131,-} \times 100\%
\]

\[
\text{ROI} = 36,21\%
\]

LE.5.4 Pay Out Time (POT)

\[
\text{POT} = \frac{1}{0,3621} \times 1 \text{ tahun}
\]

\[
\text{POT} = 2,76 \text{ tahun}
\]
LE.5.5 *Return on Network* (RON)

\[
\text{RON} = \frac{\text{Laba setelah pajak}}{\text{Modal sendiri}} \times 100 
\]

\[
\text{RON} = \frac{\text{Rp 68.460.845.415,-}}{\text{Rp 113.449.642.878,-}} \times 100 
\]

\[
\text{RON} = 60,34 \%
\]

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 = 60,44%
### 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>45.654.003.090</td>
<td>0</td>
<td>45.654.003.090</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>45.654.003.090</td>
<td>13.336.089.557</td>
<td>58.990.092.647</td>
<td>27.727.167.600</td>
</tr>
<tr>
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BEP = 31,72%
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<th>Laba Setelah Pajak (Rp)</th>
<th>Depresiasi (Rp)</th>
<th>Net cash flow (Rp)</th>
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$$\text{IRR} = 60 + \frac{1.535.210.163}{1.535.210.163 - (-1.885.906.496)} \times (61 - 60) = 60,44\%$$

Universitas Sumatera Utara