# LAMPIRAN A

## PERHITUNGAN NERACA MASSA

Hasil perhitungan neraca massa pada prarancangan pabrik biodiesel dari minyak jelantah adalah sebagai berikut :

Kapasitas produksi : 100.000 ton/thn atau 12626.263 kg/jam

Waktu bekerja / tahun : 330 hari

Satuan operasi : kg/jam

Komposisi Reaktan

1. Minyak Jelantah (WCO)
   a. Kandungan air : 0.15%
   b. Kotoran : 0.02%
   c. FFA : 2%
   d. Trigliserida : 100% - (0.15 + 0.02% + 2%) = 97.83%
   e.

**Tabel A.1. Komposisi minyak jelantah**

| Senyawa | Komposisi | BM (kg/kmol) |
|---|---|---|
| Trigliserida | 97,83% | 858 |
| FFA | 2% | 268,9520 |
| Air | 0,15% | 18 |
| Kotoran | 0,02% | 60,0900 |

**Tabel A.2 Komposisi FFA pada minyak kelapa sawit**

| Asam lemak | | Komposisi | Gugus |
|---|---|---|---|
| Palmitat | C16:0 | 44,00% | $CH_3(CH_2)_{14}COOH$ |
| Oleat | C18:1 | 39,50% | $CH_3(CH_2)_7CH=CH(CH_2)_7COOH$ |
| Linoleat | C18:2 | 10,00% | $CH_3(CH_2)_4CH=CHCH_2C=C(CH_2)_7COOH$ |
| Stearat | C18:0 | 4,50% | $CH_3(CH_2)_{16}COOH$ |
| Miristat | C14:0 | 1,30% | $CH_3(CH_2)_{12}COOH$ |
| Laurat | C12:0 | 0,50% | $CH_3(CH_2)_{10}COOH$ |

(Hambali, 2008)

2. Methanol : 98%, sisanya diasumsikan air.

3. Komposisi katalis, KOH : 100%

**Tabel A.3. Berat molekul komponen**

| No | Senyawa | Rumus Molekul | BM (kg/kmol) |
|---|---|---|---|
| 1. | Asam Palmitat | $C_{16}H_{32}O_2$ | 256 |
| 2. | Asam Oleat | $C_{18}H_{34}O_2$ | 282 |
| 3. | Asam Linolet | $C_{18}H_{32}O_2$ | 280 |
| 4. | Asam Strearat | $C_{18}H_{36}O_2$ | 284 |
| 5. | Asam Miristat | $C_{14}H_{28}O_2$ | 228 |
| 6. | Asam Laurat | $C_{12}H_{24}O_2$ | 200 |
| 7. | Asam Palmitoleat | $C_{16}H_{30}O_2$ | 254 |
| 8. | Tri Palmitat | $C_{51}H_{98}O_6$ | 806 |
| 9. | Tri Oleat | $C_{57}H_{104}O_6$ | 884 |
| 10. | Tri Linoleat | $C_{57}H_{98}O_6$ | 878 |
| 11. | Tri Stearat | $C_{57}H_{110}O_6$ | 890 |
| 12. | Tri Miristat | $C_{45}H_{86}O_6$ | 722 |
| 13. | Tri Laurat | $C_{39}H_{74}O_6$ | 638 |
| 14. | Tri Palmitoleat | $C_{51}H_{92}O_6$ | 800 |
| 15. | Metil Palmitat | $C_{17}H_{34}O_2$ | 270 |
| 16. | Metil Oleat | $C_{19}H_{36}O_2$ | 296 |
| 17. | Metil Linoleat | $C_{19}H_{34}O_2$ | 294 |
| 18. | Metil Strearat | $C_{19}H_{38}O_2$ | 298 |
| 19. | Metil Mirisstat | $C_{15}H_{30}O_2$ | 242 |
| 20. | Metil Laurat | $C_{13}H_{26}O_2$ | 214 |
| 21 | Metil Palmitoleat | $C_{17}H_{32}O_2$ | 268 |
| 22. | Metanol | $CH_4O$ | 32 |
| 23. | Asam Sulfat | $H_2SO_4$ | 98 |
| 24. | Natrium Hidroksida | NaOH | 40 |

| | | | |
|---|---|---|---|
| 25. | Natrium Sulfat | $Na_2SO_4$ | 142 |
| 26. | Air | $H_2O$ | 18 |
| 27. | Gliserol | $C_3H_8O_3$ | 92 |
| 28. | Kotoran (pasir halus) | | 60,09 |

BM FFA rata-rata = (44,00% × 256) + (39,50% × 282) + ( 10,00% × 280) + (4,50% × 284) + (1,30% × 228) + (0,50% × 200) + (0,20% × 254 )
= 268,9520 kg/kmol

BM trigliserida = (44,00% × 806) + (39,50% × 884) + ( 10,00% × 878) + (4,50% × 890) + (1,30% × 722) + (0,50% × 638) + (0,20% × 800)
= 845,846 kg/kmol

BM metil ester = (44,00% × 270) + (39,50% × 296) + ( 10,00% × 294) + (4,50% × 298) + (1,30% × 242) + (0,50% × 214) + (0,20% × 268)
= 283,282 kg/kmol

Basis : 14027,268 kg Trigliserida

TG = Trigliserida
ME = *Methyl Ester*
FFA = *Free Fatty Acid*

Diketahui BM KOH = 39 kg/mo; BM H2O = 18 kg/mol; BM CH3OH = 32 kg/mol

**1. Mixer**

Berfungsi untuk mencampurkan metanol dengan KOH. Rasio metanol dengan Trigliserida yang digunakan untuk transesterifikasi adalah 6 : 1. Jumlah KOH yang digunakan adalah 2,5% berat minyak jelantah.

$F_{TG}$ = 97,83% × Basis

= 97,83% × 14027,268 kg/jam

= 13722,876 kg/jam

$n_{TG}$ = $F_{TG}$ × $BM_{TG}$

= 13722,876 kg/jam × 858 kg/kmol

= 15,994 kmol/jam

**Arus 1**

| | | | |
|---|---|---|---|
| $F_1$ KOH | = | 2.5% x berat minyak | |
| | = | 2.5% x 13722.876 kg/jam | |
| | = | 343.072 | kg/jam |
| $n_1$ KOH | = | F KOH/BM KOH | |
| | = | 343.072 kg/jam) / (39 kg/kmol) | |
| | = | 8.797 | kmol/jam |

**Arus 2**

| | | | |
|---|---|---|---|
| $n_2$ Metanol | = | 3 x n TG | |
| | = | 47.982 | kmol/jam |
| $F_2$ Metanol | = | n2 MeOH x BM Metanol | |
| | = | 1535.427 | kg/jam |
| $F_2$ $H_2O$ | = | (2%/98%) x $F_2$ Metanol | |
| | = | 31.335 | kg/jam |
| $n_2$ $H_2O$ | = | F H2O/BM $H_2O$ | |
| | = | 1.741 | kmol/jam |

**Arus 3**

| | | | | |
|---|---|---|---|---|
| $n_3$ Metanol | = | $n_2$ Metanol = | 47.982 | kmol/jam |
| $F_3$ Metanol | = | $F_2$ Metanol = | 1535.427 | kg/jam |
| $n_3$ $H_2O$ | = | $n_2$ $H_2O$ | 1.741 | kmol/jam |
| $F_3$ $H_2O$ | = | $F_2$ $H_2O$ | 31.335 | kg/jam |
| $n_3$ KOH | = | $n_1$ KOH | 8.797 | kmol/jam |
| $F_3$ KOH | = | $F_1$ KOH | 343.072 | kg/jam |

**1. Neraca Massa di Mixer (M-01)**

| No. | Komponen | Masuk | | | | Keluar | |
|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3 | |
| | | Massa (kg/jam) | Mol (kmol/jam) | Massa (kg/jam) | Mol (kmol/jam) | Massa (kg/jam) | Mol (kmol/jam) |
| 1 | MeOH | 0.000 | 0.000 | 1535.427 | 47.982 | 1535.427 | 47.982 |
| 2 | H2O | 0.000 | 0.000 | 31.335 | 1.741 | 31.335 | 1.741 |
| 3 | KOH | 343.072 | 8.797 | 0.000 | 0.000 | 343.072 | 8.797 |
| **Total** | | **343.072** | **8.797** | **1566.762** | **49.723** | **1909.834** | **58.520** |
| | | **58.520** | | | | **58.520** | |

## 2. Reaktor

Berfungsi untuk mereaksikan Trigliserida dengan metanol dengan bantuan Kalium Hidroksida (KOH) sebagai katalis untuk menghasilakan *Methyl Ester* (biodiesel).

**Arus 4**

$F_4$ TG = 97.83% x Basis
= 97.83% x 14027.268 kg/jam
= 13722.876 kg/jam

$n_4$ TG = F4 TG/BM TG
= (13722.876 kg/jam) / (858 kg/kmol)
15.994 kmol/jam

$F_4$ FFA = 2% x Basis
= 2% x 14027.268 kg/jam
= 280.545 kg/jam

$n_4$ FFA = F4 FFA/BM FFA
= (280.545 kg/jam) / (268.952 kg/kmol)
= 1.043 kmol/jam

$F_4$ $H_2O$ = 0.15% x Basis
= 0.15% x 14027.268 kg/jam
= 21.041 kg/jam

$n_4$ $H_2O$ = F4 $H_2O$ /BM $H_2O$
= (21.041 kg/jam) / (18 kg/kmol)
= 1.169 kmol/jam

$F_4$ Kotoran = 0.02% x Basis
= 0.02% x 14027.268 kg/jam
= 2.805 kg/jam

$n_4$ Kotoran = F4 Kotoran/BM kotoran
= (2.805 kg/jam) / (60.09 kg/kmol)
= 0.047 kmol/jam

**Arus 4**

| No. | Komponen | Massa | Mol |
|---|---|---|---|
| | | kg/jam | kmol/jam |
| 1 | TG | 13722.876 | 15.994 |
| 2 | FFA | 280.545 | 1.043 |
| 3 | H2O | 21.041 | 1.169 |
| 4 | Kotoran | 2.805 | 0.047 |
| **Total** | | **14027.268** | **18.253** |

**Umpan masuk reaktor (arus 3 dan 4)**

| No. | Komponen | Arus 3 | | Arus 4 | |
|---|---|---|---|---|---|
| | | Massa (kg/jam) | Mol (kmol/jam) | Massa (kg/jam) | Mol (kmol/jam) |
| 1 | MeOH | 1535.427 | 47.982 | 0 | 0 |
| 2 | H2O | 31.335 | 1.741 | 21.041 | 1.169 |
| 3 | KOH | 343.072 | 8.797 | 0 | 0 |
| 4 | TG | 0 | 0 | 13722.876 | 15.994 |
| 5 | FFA | 0 | 0 | 280.545 | 1.043 |
| 6 | H2O | 0 | 0 | 21.041 | 1.169 |
| 7 | Kotoran | 0 | 0 | 2.805 | 0.047 |
| **Total** | | **1909.834** | **58.520** | **14048.309** | **19.422** |

**Reaksi Transesterifikasi Reaktor-1**

Konversi (X) = 0.740
n4 TG = 15.994 kmol/jam
TG bereaksi = n4 TG x Konversi (X)
= 11.836 kmol/jam
Metanol bereaksi = (3/1) x n4 TG x Konversi (X)
= 35.507 kmol/jam

**Stoikiometi Reaksi pada reaktor R-01**

| | **Trigliserida** | **+** | **3 MeOH** | **⟶** | **3 ME** | **+** | **Gliserol** |
|---|---|---|---|---|---|---|---|
| Mula | 15,994 | | 47,982 | | 0,000 | | 0,000 |
| Reaksi | 11,836 | | 35,507 | | 35,507 | | 11,836 |
| Sisa | 4,158 | | 12,457 | | 35507 | | 11,836 |

| | | | |
|---|---|---|---|
| $n_5$ ME | = | (3/1) x $n_5$ TG x Konversi (X) | |
| | = | 35.507 | kmol/jam |
| $F_5$ ME | = | $n_5$ ME x BM ME | |
| | = | 35.507 kmol/jam x 282.952 kg/kmol | |
| | = | 10046.704 | kg/jam |
| | | | |
| $n_5$ GL | = | (1/1) x $n_4$ TG x Konversi (X) | |
| | = | (1/1) x 15.994 kmol/jam x 74% | |
| | = | 11.836 | kmol/jam |
| $F_5$ GL | = | $n_5$ GL x BM GL | |
| | = | 11.836 kmol/jam x 92.09 kg/kmol | |
| | = | 1089.939 | kg/jam |
| | | | |
| $n_5$ TG | = | $n_4$ TG - TG bereaksi | |
| | = | 15.994 kmol/jam - (74% x 15.994) | |
| | = | 4.158 | kmol/jam |
| $F_5$ TG | = | $n_5$ TG x BM TG | |
| | = | 4.158 kmol/jam x 858 kg/kmol | |
| | = | 3567.948 | kg/jam |
| | | | |
| $n_5$ MeOH | = | $n_3$ MeOH - n MeOH bereaksi | |
| | = | 47.982 kmol/jam - 35.507 kmol/jam | |
| | = | 12.475 | kmol/jam |
| $F_5$ MeOH | = | $n_5$ MeOH x BM MeOH | |
| | = | 12.475 kmol/jam x 32 MeOH | |
| | = | 399.211 | kg/jam |
| | | | |
| $n_5$ FFA | = | $n_4$ FFA = | 1.043 kmol/jam |
| $F_5$ FFA | = | $F_4$ FFA = | 280.545 kg/jam |
| | | | |
| $n_5$ H2O | = | $n_3$ $H_2O$ + $n_4$ $H_2O$ | |
| | = | 1.741 + 1.169 | kmol/jam |
| | = | 2.910 | kmol/jam |
| $F_5$ H2O | = | $n_5$ H2O x BM H2O | |
| | = | 2.910 kmol/jam x 18 kg/kmol | |
| | = | 52.376 | kg/jam |
| | | | |
| $n_5$ Kotoran | = | $n_4$ Kotoran | 0.047 kmol/jam |
| $F_5$ Kotoran | = | $F_4$ Kotoran | 2.805 kg/jam |
| | | | |
| $n_5$ KOH | = | $n_3$ KOH | 8.797 kmol/jam |
| $F_5$ KOH | = | $F_3$ KOH | 343.072 kg/jam |

**Arus 5 (Keluar reaktor-1)**

| No. | Komponen | Massa | Mol |
|---|---|---|---|
| | | kg/jam | kmol/jam |
| 1 | Metanol | 399.211 | 12.475 |
| 2 | $H_2O$ | 52.376 | 2.910 |
| 3 | KOH | 343.072 | 8.797 |
| 4 | TG | 3567.948 | 4.158 |
| 5 | FFA | 280.545 | 1.043 |
| 6 | Kotoran | 2.805 | 0.047 |
| 7 | ME | 10046.704 | 35.507 |
| 8 | GL | 1089.939 | 11.836 |
| **Total** | | **15782.600** | **76.772** |

**Neraca Massa di reaktor-1**

| No. | Komponen | Masuk | | | | Keluar | |
|---|---|---|---|---|---|---|---|
| | | Arus 3 | | Arus 4 | | Arus 5 | |
| | | Massa (kg/jam) | Mol (kmol/jam) | Massa (kg/jam) | Mol (kmol/jam) | Massa (kg/jam) | Mol (kmol/jam) |
| 1 | MeOH | 1535.427 | 47.982 | 0.000 | 0.000 | 399.211 | 12.475 |
| 2 | H2O | 31.335 | 1.741 | 21.041 | 1.169 | 52.376 | 2.910 |
| 3 | KOH | 343.072 | 8.797 | 0.000 | 0.000 | 343.072 | 8.797 |
| 4 | TG | 0.000 | 0.000 | 13722.876 | 15.994 | 3567.948 | 4.158 |
| 5 | FFA | 0.000 | 0.000 | 280.545 | 1.043 | 280.545 | 1.043 |
| 6 | Kotoran | 0.000 | 0.000 | 2.805 | 0.047 | 2.805 | 0.047 |
| 7 | ME | 0.000 | 0.000 | 0.000 | 0.000 | 10046.704 | 35.507 |
| 8 | GL | 0.000 | 0.000 | 0.000 | 0.000 | 1089.939 | 11.836 |
| **Total** | | **1909.834** | **58.520** | | **18.253** | **15782.600** | **76.772** |
| | | **76.772** | | | | **76.772** | |

**Reaksi Transesterifikasi reaktor-2**

Konversi (X) = 0.930

$n_4$ TG = 15.994 kmol/jam

TG bereaksi = n4 TG x Konversi (X)
= 14.874 kmol/jam

Metanol bereaksi = (3/1) x n4 TG x Konversi (X)
= 44.623 kmol/jam

**Stoikiometi Reaksi pada reaktor R-02**

| | **Trigliserida** | **+** | **3 MeOH** | ⟶ | **3 ME** | **+** | **Gliserol** |
|---|---|---|---|---|---|---|---|
| Mula | 15,994 | | 47,982 | | 0,000 | | 0,000 |
| Reaksi | 14,874 | | 44,623 | | 44,623 | | 44,623 |
| Sisa | 1,120 | | 3,359 | | 44,623 | | 44,623 |

| | | | |
|---|---|---|---|
| $n_6$ ME | = | (3/1) x n5 TG x Konversi (X) | |
| | = | 44.623 | kmol/jam |
| | | $n_6$ ME x BM | |
| $F_6$ ME | = | ME | |
| | = | 44.623 kmol/jam x 282.952 kg/kmol | |
| | = | 12626.263 | kg/jam |
| | | | |
| $n_6$ GL | = | (1/1) x $n_4$ TG x Konversi (X) | |
| | = | (1/1) x 15.994 kmol/jam x 93% | |
| | = | 14.874 | kmol/jam |
| $F_6$ GL | = | $n_6$ GL x BM GL | |
| | = | 14.874 kmol/jam x 92.09 kg/kmol | |
| | = | 1369.788 | kg/jam |
| $n_6$ TG | = | $n_4$ TG - TG bereaksi | |
| | = | 15.994 kmol/jam - (93% x 15.994) | |
| | = | 1.120 | kmol/jam |
| $F_6$ TG | = | $n_6$ TG x BM TG | |
| | = | 1.120 kmol/jam x 858 kg/kmol | |
| | = | 960.601 | kg/jam |
| $n_6$ Metanol | = | n Metanol mula - n Metanol bereaksi | |
| | = | 47.982 kmol/jam - 44.263 kmol/jam | |
| | = | 3.359 | kmol/jam |
| $F_6$ Metanol | = | $n_6$ MeOH x BM Metanol | |
| | = | 3.359 kmol/jam x 32 | |
| | = | 107.480 | kg/jam |
| | | | |
| $n_6$ FFA | = | $n_5$ FFA = | 1.043 kmol/jam |
| $F_6$ FFA | = | $F_5$ FFA = | 280.545 kg/jam |
| | | | |
| $n_6$ $H_2O$ | = | $n_5$ H2O | |
| | = | 2.910 | kmol/jam |
| $F_6$ $H_2O$ | = | $n_6$ H2O x BM $H_2O$ | |
| | = | 2.910 kmol/jam x 18 kg/kmol | |
| | = | 52.376 | kg/jam |
| | | | |
| $n_6$ Kotoran | = | $n_5$ Kotoran = | 0.047 kmol/jam |
| $F_6$ Kotoran | = | $F_5$ Kotoran = | 2.805 kg/jam |
| | | | |
| $n_6$ KOH | = | $n_5$ KOH = | 8.797 kmol/jam |
| $F_6$ KOH | = | $F_5$ KOH = | 343.072 kg/jam |

**Arus 6 (Keluar reaktor-2)**

| No. | Komponen | Massa | Mol |
|---|---|---|---|
| | | kg/jam | kmol/jam |
| 1 | MeOH | 107.480 | 3.359 |
| 2 | H2O | 52.376 | 2.910 |
| 3 | KOH | 343.072 | 8.797 |
| 4 | TG | 960.601 | 1.120 |
| 5 | FFA | 280.545 | 1.043 |
| 6 | Kotoran | 2.805 | 0.047 |
| 7 | ME | 12626.263 | 44.623 |
| 8 | GL | 1369.788 | 14.874 |
| **Total** | | **15742.931** | **76.772** |

**Neraca massa di Reaktor-2**

| No. | Komponen | Masuk | | Keluar | |
|---|---|---|---|---|---|
| | | Arus 5 | | Arus 6 | |
| | | Massa (kg/jam) | Mol (kmol/jam) | Massa (kg/jam) | Mol (kmol/jam) |
| 1 | MeOH | 399.211 | 12.475 | 107.480 | 3.359 |
| 2 | $H_2O$ | 52.376 | 2.910 | 52.376 | 2.910 |
| 3 | KOH | 343.072 | 8.797 | 343.072 | 8.797 |
| 4 | TG | 3567.948 | 4.158 | 960.601 | 1.120 |
| 5 | FFA | 280.545 | 1.043 | 280.545 | 1.043 |
| 6 | Kotoran | 2.805 | 0.047 | 2.805 | 0.047 |
| 7 | ME | 10046.704 | 35.507 | 12626.263 | 44.623 |
| 8 | GL | 1089.939 | 11.836 | 1369.788 | 14.874 |
| **Total** | | **15782.600** | **76.772** | **15742.931** | **76.772** |

**Reaksi di Netralizer**

**Arus 6 (masuk netralizer)**

| No. | Komponen | Massa | Mol |
|---|---|---|---|
| | | kg/jam | kmol/jam |
| 1 | MeOH | 107.480 | 3.359 |
| 2 | H2O | 52.376 | 2.910 |
| 3 | KOH | 343.072 | 8.797 |
| 4 | TG | 960.601 | 1.120 |
| 5 | FFA | 280.545 | 1.043 |
| 6 | Kotoran | 2.805 | 0.047 |
| 7 | ME | 12626.263 | 44.623 |
| 8 | GL | 1369.788 | 14.874 |
| **Total** | | **15742.931** | **76.772** |

Konversi (X) = 100%

$n_6$ KOH = 8.797 kmol/jam

Karena konversi reaksi 100%, maka reaktan akan habis bereaksi.

**Arus 7**

| No. | Komponen | Massa | Mol |
|---|---|---|---|
| | | kg/jam | kmol/jam |
| 1 | HCl | 316.682 | 8.797 |
| **Total** | | **316.682** | **8.797** |

| | **KOH** | + | **HCl** | ⟶ | **KCl** | + | **$H_2O$** |
|---|---|---|---|---|---|---|---|
| Mula | 8,797 | | 8,797 | | 0,000 | | 0,000 |
| Reaksi | 8,797 | | 8,797 | | 8,797 | | 8,797 |
| Sisa | 0,000 | | 0,000 | | 8,797 | | 8,797 |

$n_7$ HCl = $n_5$ KOH
= 8.797 kmol/jam

$F_7$ HCl = $n_7$ HCl x BM HCl
= 8.797 kmol/jam x 36
= 316.682 kg/jam

$n_7$ $H_2O$ = (1/1) x n7 HCl x konversi
= (1/1) x 8.797 kmol/jam x 100%
= 8.797 kmol/jam

$F_7$ $H_2O$ = $n_7$ $H_2O$ x BM $H_2O$
= 8.797 kmol/jam x 18 kg/mol
= 158.341 kg/jam

$n_8$ KCl = (1/1) x $n_7$ HCl x Konversi (X)
= (1/1) x 8.797 kmol/jam x 100%
= 8.797 kmol/jam
n8 KCl x

$F_8$ KCl = BM KCl
= 8.797 kmol/jam x 74 kg/kmol
= 650.957 kg/jam

$n_8$ $H_2O$ = $n_6$ $H_2O$ + n7 $H_2O$
= (2.910 + 8.797) kmol/jam
= 11.707 kmol/jam

$F_8$ $H_2O$ = $n_8$ $H_2O$ x $H_2O$ BM
= 11.707 kmol/jam x 18 kg/kmol
= 210.717 kg/jam

**Neraca massa di Netralizer**

| No. | Komponen | Masuk | | | | Keluar | |
|---|---|---|---|---|---|---|---|
| | | Arus 6 | | Arus 7 | | Arus 8 | |
| | | Massa (kg/jam) | Mol (kmol/jam) | Massa (kg/jam) | Mol (kmol/jam) | Massa (kg/jam) | Mol (kmol/jam) |
| 1 | Metanol | 107.480 | 3.359 | 0.000 | 0.000 | 107.480 | 3.359 |
| 2 | $H_2O$ | 52.376 | 2.910 | 158.341 | 8.797 | 210.717 | 11.707 |
| 3 | KOH | 343.072 | 8.797 | 0.000 | 0.000 | 343.072 | 8.797 |
| 4 | TG | 960.601 | 1.120 | 0.000 | 0.000 | 960.601 | 1.120 |
| 5 | FFA | 280.545 | 1.043 | 0.000 | 0.000 | 280.545 | 1.043 |
| 6 | Kotoran | 2.805 | 0.047 | 0.000 | 0.000 | 2.805 | 0.047 |
| 7 | ME | 12626.263 | 44.623 | 0.000 | 0.000 | 12626.263 | 44.623 |
| 8 | GL | 1369.788 | 14.874 | 0.000 | 0.000 | 1369.788 | 14.874 |
| 9 | HCl | 0.000 | 0.000 | 316.682 | 8.797 | 0.000 | 0.000 |
| 10 | KCl | 0.000 | 0.000 | 0.000 | 0.000 | 650.957 | 8.797 |
| **Total** | | **15742.931** | **76.772** | **475.023** | **17.593** | **16552.229** | **94.366** |
| | | **94.366** | | | | **94.366** | |

**Neraca Massa di Dekanter**

| No. | Komponen | Masuk | | Keluar | | | |
|---|---|---|---|---|---|---|---|
| | | Arus 8 | | Arus 9 (bawah) | | Arus 10 (atas) | |
| | | Massa (kg/jam) | Mol (kmol/jam) | Massa (kg/jam) | Mol (kmol/jam) | Massa (kg/jam) | Mol (kmol/jam) |
| 1 | MeOH | 107.480 | 3.359 | 0.000 | 0.000 | 107.480 | 3.359 |
| 2 | H2O | 210.717 | 11.707 | 0.000 | 0.000 | 210.717 | 11.707 |
| 3 | TG | 960.601 | 1.120 | 960.601 | 1.120 | 0.000 | 0.000 |
| 4 | FFA | 280.545 | 1.043 | 280.545 | 1.043 | 0.000 | 0.000 |
| 5 | Kotoran | 2.805 | 0.047 | 2.805 | 0.047 | 0.000 | 0.000 |
| 6 | ME | 12626.263 | 44.623 | 0.000 | 0.000 | 12626.263 | 44.623 |
| 7 | GL | 1369.788 | 14.874 | 1369.788 | 14.874 | 0.000 | 0.000 |
| 8 | KCl | 650.957 | 8.797 | 650.957 | 8.797 | 0.000 | 0.000 |
| **Total** | | **16209.157** | **85.569** | **3264.697** | **25.881** | **12944.460** | **59.689** |
| | | **85.569** | | **85.569** | | | |

**Neraca Massa di Evaporator**

| No. | Komponen | Masuk | | Keluar | | | |
|---|---|---|---|---|---|---|---|
| | | Arus 10 | | Arus 11 (bawah) | | Arus 12 (atas) | |
| | | Massa (kg/jam) | Mol (kmol/jam) | Massa (kg/jam) | Mol (kmol/jam) | Massa (kg/jam) | Mol (kmol/jam) |
| 1 | ME | 12626.263 | 44.623 | 12626.263 | 44.623 | 0.000 | 0.000 |
| 2 | Metanol | 107.480 | 3.359 | 0.000 | 0.000 | 107.480 | 3.359 |
| 3 | H2O | 210.717 | 11.707 | 0.000 | 0.000 | 210.717 | 11.707 |
| Total | | **12944.460** | **59.689** | **12626.263** | **44.623** | **318.197** | **15.065** |
| | | **59.689** | | **59.689** | | | |

**Neraca Massa Total**

| No. | Alat | Arus (kmol/jam) | |
|---|---|---|---|
| | | Masuk | Keluar |
| 1 | Mixer | 58.520 | 58.520 |
| 2 | Reaktor 1 | 76.772 | 76.772 |
| 3 | Reaktor 2 | 76.772 | 76.772 |
| 4 | Neutralizer | 94.366 | 94.366 |
| 5 | Decanter | 85.569 | 85.569 |
| 6 | Evaporator | 59.689 | 59.689 |
| **Total** | | **451.688** | **451.688** |

# LAMPIRAN B

## PERHITUNGAN REKATOR TRANSESTERIFIKASI

Fungsi : Mereaksikan trigliserida dengan metanol dengan katalis KOH

Bentuk : *silinder vertical* dengan alas dan tutup ellipsoidal

Jenis : *Continues Stirrer Tank Reactor* (CSTR)

Bahan konstruksi : *Carbon steel* SA-285 grade C

Jumlah : 1 unit

Temperatur : 70°C = 343,15 K

Tekanan : 1 atm = 14,696 psia

Waktu tinggal reaktor : 1 jam

| No. | Komp. | Massa (kg/jam) | Mol (Kmol) | Volume m3/jam | % Berat xi | Densitas kg/m3 | Viskositas Cp | xi,densitas kg/m3 | LN□ | Xi,Ln□i |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | TG | 7702,0858 | 8,9768 | 8,3537 | 0,3360 | 860,2021 | 6,6400 | 289,04758 | 1,8931 | 0,6361 |
| 2 | FFA | 553,3265 | 0,4821 | 0,6001 | 0,0241 | 61,7979 | 2,9400 | 1,4918172 | 1,0784 | 0,0260 |
| 3 | MeOH | 105,8316 | 3,3072 | 0,1338 | 0,0046 | 791,0000 | 0,7131 | 3,6521823 | -0,3381 | -0,0016 |
| 4 | H2O | 79,5727 | 4,4207 | 0,0796 | 0,0035 | 1000,0000 | 0,4670 | 3,4715572 | -0,7614 | -0,0026 |
| 5 | KOH | 506,7162 | 12,9927 | 0,2484 | 0,0221 | 2040,0000 | 0,0000 | 45,097806 | 0,0000 | 0,0000 |
| 6 | ME | 12625,0000 | 43,9390 | 15,7812 | 0,5508 | 855,3840 | 9,2550 | 471,14327 | 2,2252 | 1,2256 |
| 7 | GL | 1348,7816 | 14,6463 | 0,9147 | 0,0588 | 1201,9700 | 160,0000 | 70,728711 | 5,0752 | 0,2986 |
| Total | | 22921,3144 | 88,7649 | 26,1115 | 1,0000 | 6810,354 | 180,0151 | 884,63292 | 9,1723 | 2,1822 |

Densitas Campuran ($\rho$) = $\Sigma xi.\ \rho i$

= 884,6329 kg/$m^3$

Perhitungan :

**a. Volume larutan dan volume tangki**

Volume larutan, $V_1 = \tau \times Vo$

= 1 jam × 37,3334 $m^3$/jam

= 41,8694 $m^3$

Volume tangki, $V_t$ = ( 1+ 0,2) × 37,3334 $m^3$

= 44,8013 $m^3$

**b. Diameter dan tinggi tangki**

Asumsi H/D = 3/2

H = 1,5D (Ulrich, 1984 – hal 248)

$V_t = \frac{1}{4}\pi D^2 H$ (Brownell dan Young, 1959 – hal 41)

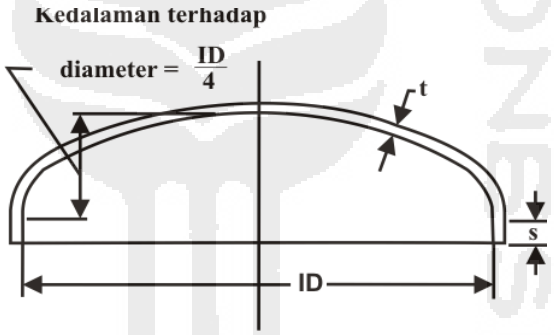
$V_t = \frac{1}{4}\pi D^2 \frac{3}{2} D$

$V_t = \frac{3}{8}\pi D^3$

$D = \left(\frac{V_t}{\frac{3}{8}\pi}\right)^{\frac{1}{3}}$

Volume tutup tangki (Ve)

Asumsi *Elipsoidal head*




$volume\ silinder = \frac{\mu}{4} D^2 H$

$44{,}8013 = \frac{3{,}14}{4} \times D^2 \times 1{,}5D$

$44{,}8013 = 4{,}71D^3$

$æ = 3{,}3633\ m$

Maka H = 1,5D

H = 1,5 × 3,3633 m

H = 5,04495 m

**c. Diameter dan tinggi tutup**

Diameter tutup = diameter tangki = 3,3633 m

Asumsi Hh : Di = 1 : 4

Tinggi tutup $= \frac{1}{4}(3{,}3633)$

$= 0{,}8408$ m

$= 32{,}1585$ in

Ve $= \frac{1}{24} \times \frac{22}{7} \times 3{,}3633^3$

$= 4{,}9800\ m^3$

Vs $= \frac{1}{4} \times \frac{22}{7} \times 3{,}3633^3$

$= 44{,}8013\ m^3$

Ve + Vs $= 4{,}5675\ m^3 + 41{,}1082\ m^3$

$= 45{,}6758\ m^3$

**d. Tebal *Shell* tangki**

tinggi larutan dalam tangki :

Volume larutan dibagian elisoidal bawah $= 4{,}5675\ m^3$

Volume larutan di bagian silinder $= V_l - V_l$ bagian ellipsoidal bawah

$= 41{,}8694\ m^3 - 4{,}5675\ m^3$

$= 37{,}3019\ m^3$

Tinggi larutan di bagian bawah silinder $= \frac{V_l \text{ silinder}}{Vs} \times H_s$

$= \frac{37{,}3019}{41{,}1082} \times 4{,}9009$

$= 4{,}4471$ m

Tinggi larutan dalam tangki $= 0{,}8168$ m + 4,4471 m

$= 5{,}2640$ m

$= 17{,}2702$ ft

Tekanan hidrostatik :

$P = \rho \frac{(H-1)}{144}$ (Brownell dan Young, 1959 – hal 46)

$$= 52{,}0153 \frac{(17{,}2702-1)}{144}$$

= 6,2342 psia

Faktor kelonggaran = 20%

Maka $P_{desain}$ = (1,2) ($P_{operasi}$)

= (1,2) (6,2342 psia + 14,696 psia)

= 25,1162 psia

Direncanakan bahan konstruksi *Carbon Steel* SA-285 *grade* C

*Allowable working stress* (f) : 13700 psia (Brownell dan Young, 1959 – hal 251)

*Joint efficiency* ( E) : 0,8 (Brownell dan Young, 1959 – hal 254)

$$t = \frac{P\, r_i}{f\, E - 0{,}6P}$$

$$= \frac{25{,}1162 \text{ psia} \times \frac{128{,}6341 \text{ in}}{2}}{13700 \text{ psia} \times 0{,}8 - 0{,}6 \times 25{,}1162 \text{ psia}}$$

=0,1389 in

Tebal *shell* standar yang digunakan = $\frac{3}{16}$ in (Brownell&Young, 1959 – hal 89)

**e. Tebal tutup tangki**

$$t = \frac{PD}{2\, f\, E - 0{,}2P}$$

$$= \frac{25{,}1162 \text{ psia} \times 128{,}6341 \text{ in}}{2 \times 13700 \text{ psia} \times 0{,}8 - 0{,}2 \times 25{,}1162 \text{ psia}}$$

= 0,1387 in

Tebal tutup tangki standar yang digunakan $= \frac{3}{16}\ in$ (Brownell&Young, 1959 – hal 89)

**Perancangan Sistem Pengaduk**

Jenis Pengaduk : Turbin *impeller* daun enam

Viskositas larutan pada T = 70°C

| Komponen | Laju alir massa (kg/jam) | Viskositas | % berat |
|---|---|---|---|
| Trigliserida | 24295,3242 | $2,25\times10^{-2}$ | 0,6964 |
| FFA | 32,1411 | $2,25\times10^{-2}$ | 0,0009 |
| Metil Ester | 758,0428 | $2,72\times10^{-3}$ | 0,0217 |
| Air | 227,4340 | $4,8\times10^{-4}$ | 0,0079 |
| Kotoran | 5,0181 | 4,17 | 0,0001 |
| Metanol | 9191,3938 | $3,5\times10^{-4}$ | 0,2634 |
| Asam Sulfat | 112,9081 | $8\times10^{-3}$ | 0,0032 |
| NaOH | 213,6465 | $1,6\times10^{-2}$ | 0,0061 |
| **Total** | **34885,9089** | | **1** |

**Viskositas campuran (μ campuran)**

ln μ campuran = $0,6964 \ln (2,25\times10^{-2}) + 0,0009 \ln (2,25\times10^{-2}) + 0,0217 \ln (2,72\times10^{-3}) + 0,0079 \ln (4,8\times10^{-4}) + 0,0001 \ln (4,17) + 0,2634 \ln (3,5\times10^{-4}) + 0,0032 \ln (8\times10^{-3}) + 0,0061 \ln (1,6\times10^{-2})$

μ campuran = 0,0069 kg/m.s

**Menghitung kecepatan agitator**

Tipe : Turbin dengan enam pisau datar dengan empat *baffels* (brownell)

W/Di = 0,17

Dt/Di = 3

Zt/Di = 2,7

Zi/Di = 0,75

Dt = 3,2673 m

= 10,7194 ft

Di = $\frac{3,2673}{3}$

= 1,0891 m

= 3,5731 ft

Zi = h = 5,2640 m

= 17,2701 ft

W = 1,0891 m × 0,17

= 0,1851 m

= 0,6074 ft

Zi = 1,0891 m × 0,75

= 0,8168 m

= 2,6798 ft

$$WELH = Zi \times \frac{\rho \text{ larutan}}{\rho \text{ air}}$$

$$= 5{,}2640 \times \frac{833{,}2058}{995}$$

= 4,4080 m

= 14,4619 ft

$$\frac{WELH}{2 \times Di} = \left(\frac{\pi Di \times N}{600}\right)$$

$$N^2 = \frac{WELH}{2Di} \times \left(\frac{600}{\pi Di}\right)$$

$$N = \sqrt{\frac{WELH}{2Di}} \times \left(\frac{600}{\pi Di}\right)$$

$$N = \sqrt{\frac{14{,}4619 \text{ ft}}{2 \times 3{,}5731 \text{ ft}}} \times \left(\frac{600}{\frac{22}{7} \times 3{,}5731 \text{ ft}}\right)$$

N = 76,0063 rpm

= 1,2667 rps

$$N_{Re} = \frac{\rho \times N \times (Da)^2}{\mu}$$

$$= \frac{833{,}2058 \frac{kg}{m^3} \times 1{,}2667 \text{ rps} \times (1{,}0891)^2}{0{,}0069 \text{ kg/ms}}$$

= 180988,25

Np = 5 (Brown, 1959 – hal 507)

$P = Np \times N^3 \times D_a^5 \times \rho$ (Geankoplis, 2003 – hal 159)

$P = 5 \times 1{,}2667^3 \times 1{,}0891 \times 833{,}2058$

= 180988,25 J/s

= 9,6767 hp

Maka dipilih daya motor dengan tenaga 3 hp

**Desain Jaket reaktor**

Jumlah steam = 13534,2774 kg/jam

ρ (140 °C) = 926,1831 kg/$m^3$

Vp $= \frac{13534{,}2774 \text{ kg/jam}}{926{,}1831 \text{ kg/m}^3}$

= 14,6129 $m^3$/jam

$V = \left(\frac{1}{4}\pi Dj^2.Zj + \frac{1}{24}\pi Dj^3\right) - \left(\frac{1}{4}\pi.OD^2.Zj + \frac{1}{24}\pi DO^3\right)$

= 14,6129

Dj = 3,7746 m = 148,6061 in

De = 1,0637 m

re = 0,5319 m

Zj = 6,5329 m = 17,2704 ft

$P_j = \rho \frac{(H-1)}{144}$ (Brownell dan Young, 1959 – hal 46)

$= 57{,}8197 \frac{(15{,}6169-1)}{144}$

= 6,5329 psia

P desain = 14,6960 psia + 6,5329 psia

= 21,2289 psia

Direncanakan bahan konstruksi *stainlees steel* SA-340

*Allowable working stress* (S) : 18700 psia (Brownell dan Young, 1959 – hal 251)

*Joint efficiency* ( E) : 0,8 (Brownell dan Young, 1959 – hal 254)

$t = \frac{P\, r_i}{f\, E - 0{,}6P}$

$= \frac{21{,}2289 \text{psia} \times \frac{148{,}6061 \text{ in}}{2}}{18700 \text{ psia} \times 0{,}8 - 0{,}6 \times 21{,}2289 \text{ psia}}$

t = 0,1055 in

Dipilih tebal jaket 3/16 in