

CHAPTER 5

Energy balance

5.1. Introduction:

As with mass, energy can be considered to be separately conserved in all but nuclear process. The conservation of energy, however, differ from that of mass in that energy can be generated (or consumed) in a chemical process. The Total enthalpy of the outlet streams will not be equal that of the inlet streams if energy is generated or consumed in the processes; such as that due to heat of reaction.

In process design, energy balance is made to determine the energy requirements of the process: the heating, cooling and power required. Inplant operation, an energy balance on the plant operation will show the pattern of energy usage and suggest areas for conservation and savings.

5.2. Conservation of energy:

The general equation can be written for conservation of energy is:

$$\text{Energy out} = \text{Energy in} - \text{Generation} - \text{Consumption} - \text{Accumulation.}$$

This is a statement of the first law of thermodynamics.

Chemical reaction will evolve energy (exothermic) or consume energy (endothermic). For steady –state process the accumulation of both mass and energy will be zero.

5.3. Energy balance calculations:

-symbols used in this chapter:

C_{pi} = Heat capacity of component (i).

T = Temperature of stream in degree Kelvin.

M_{ij} = Mole flow of component (i) in stream (j).

H_j = Total enthalpy of stream (j).

H_{ij} = enthalpy of component (i) in stream (j).

-Heat capacity constants for ideal gases.

Table (5.1) Heat capacity constants for ideal gases.

component	A	B	C	D	E
methanol	3.93E-01	8.79E-01	1.92E+00	5.37E-01	896.7
isobutylene	6.13E-06	2.07E-05	1.55E-03	1.21E-05	6.76E+02
1-butenes	6.43E-06	2.06E-05	1.68E-03	1.33E-05	757.06
2-butenes	5.77E-06	2.12E-05	1.63E-03	1.29E-05	739.1
mtbe	9.78E-06	3.09E-05	1.64E-03	2.10E-05	731.191
H2O	3.34E-06	2.68E-06	2.61E-03	8.90E-07	100

- Heat capacity equation for ideal gases:

$$C_p^0 = C1 + C2 \left[\frac{C3/T}{\sinh(C3/T)} \right]^2 + C4 \left[\frac{C5/T}{\cosh(C5/T)} \right]^2$$

- Heat capacity constant for liquid:

Table(5.2) Heat capacity constants for liquid.

Component	A	B	C	D	E
methanol	106	-0.362	0.938E-3	0	0
isobutylene	179.34	-1.467	0.010323	-0.3E-4	3.40E-08
1-butenes	140.12	-0.55487	0.0026242	-3.00E-06	0
2-butenes	112.76	-0.1047	0.000521	0	0
mtbe	140.12	-0.0009	0.000563	0	0
H2O	276	2.09	0.00825	1.41E-05	9.37E-09

- Heat capacity equation for liquid:

$$C_p = A + BT + CT^2 + DT^3 + ET^4$$

5.3.1. Energy balance around summing point:

$$Q - W = \Delta H$$

W = 0, Q = 0(adiabatic mixing).

$$\Delta H = H_{\text{out}}$$

$$H_1 + H_{15} = H_3$$

$$H_2 + H_3 = H_4$$

$$H_1 = H_2 = 0; \text{ so:}$$

$$H_{15} = H_3 = H_4$$

$$H_{15} = H_{\text{MTBE15}} + H_{\text{M15}} + H_{\text{ISO15}} + H_{1\text{-BUT15}} + H_{2\text{-BUT15}} - H_{\text{W15}}$$

$$P_T = 4.95 \text{ bar.}$$

T= 314.3°K (bubble point), this temperature gives:

$$\sum Y_i = \sum P_i(T)X_i/P_T = 1$$

$$P_i = \text{EXP} (A+B/T+C \text{ Ln}T+ DT^E).$$

Where:

P_i : is vapor presser of component(i).

Table (5.3) summarizes the results:

Table (5.3) bubble point calculation of stream 15.

Component	A	B	C	D	E	P*	Xi	Yi
methanol	81.768	6876	-8.71	7.19E-06	2	495.2472	1	1.0002
isobutylene	9.52E	4876	- 12.6	1.78E-2	1	3.74E4	0	0
1-butenes	67.78	4429	-7.20	8.40E-06	2	3.80E4	0	0
2-butenes	77.551	4848	-8.78	1.17E-05	2	2.47E4	0	0
mtbe	55.875	5132	-4.96	1.91E-17	6	2.05E3	0	0
water	73.649	7258.2	-7.30	4.17E-06	2	58.3110	0	0
$\sum Y_i$							1	1.0002

$$H_{\text{MTBE15}} = M_{\text{MTBE15}} \int_{298}^{314.3} c_p dt$$

M_{MTBE15} from material balance caculation = 0.00Kmol/h.

$$H_{\text{MTBE15}} = 0.00\text{KJ/h}$$

also, from material balance caculation:

$M_{\text{ISO15}} = M_{1\text{-BUT15}} = M_{2\text{-BUT15}} = M_{\text{W15}} = 0.00\text{Kmol/h}$; so:

$$H_{\text{ISO15}} = H_{1\text{-BUT15}} = H_{2\text{-BUT15}} = H_{\text{W15}} = 0.00\text{KJ/h.}$$

$$H_{M15} = M_{M15} \int_{298}^{314.3} cp \, dt$$

M_{M15} from material balance calculation = 2053.16Kmol/h.

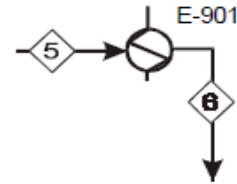
$$H_{M15} = 2053.16 * [106(314.3-298) - 0.362/2(314.3^2-298^2) + 0.938E-3/3(314.3^3-298^3)]$$

$$H_{M15} = 2781433.8KJ/h.$$

$H_4 = H_5$ (No change in enthalpy through the pump)

5.3.2. Energy balance around heat exchanger (E901):

$$Q - W = \Delta H$$



$$W=0$$

$$Q = \Delta H = H_6 - H_5$$

$$H_6 = H_{MTBE6} + H_{M6} + H_{ISO6} + H_{1-BUT6} + H_{2-BUT6} - H_{W6}$$

$V/F = 1$ (completely vapor), $T_6 = 358^\circ K$

$$H_{MTBE6} = M_{MTBE6} \left[\int_{298}^{358} cp \, dt + \lambda_{298} \right].$$

M_{MTBE6} from material balance calculation = 0.00Kmol/h.

$$H_{MTBE6} = 0.00KJ/h.$$

$$H_{M6} = M_{M6} \left[\int_{298}^{358} cp \, dt + \lambda_{298} \right].$$

M_{M6} from material balance calculation = 4176.10Kmol/h.

$$H_{M6} = 4176.1 * [106(358-298) - 0.362/2(358^2-298^2) + 0.938E-3/3(358^3-298^3) - 200.66]$$

$$H_{M6} = 21326949.95KJ/h.$$

$$H_{ISO6} = M_{iso6} \left[\int_{298}^{358} cp \, dt + \lambda_{298} \right].$$

M_{iso6} from material balance calculation = 2088.05Kmol/h.

$$H_{ISO6} = 2088.05 * [179.34 (358-298) - 1.467/2(358^2-298^2) + 0.010323/3(358^3-298^3) - 0.3E-4/4(358^4-298^4) + 3.40E-08/5(358^5-298^5) - 16.9059].$$

$$H_{ISO6} = 17992470.95KJ/h.$$

$$H_{1-but6} = M_{1-but6} \left[\int_{298}^{358} cp \, dt + \lambda_{298} \right].$$

M_{1-but6} from material balance calculation = 1817.511622Kmol/h.

$$H_{1-but6} = 1817.511622 * [140.12 (358-298) - 0.55487/2(358^2-298^2) + 0.26242E-2/3(358^3-298^3) - 3.00E-06/4(358^4-298^4) - 0.53974].$$

$$H_{1-but6} = 14664582.86 \text{KJ/h.}$$

$$H_{2-but6} = M_{2-but6} \left[\int_{298}^{358} c_p dt + \lambda_{298} \right].$$

M_{2-but6} from material balance calculation = 5172.917692 Kmol/h.

$$H_{2-but6} = 5172.917692 * [112.76 (358-298) - 0.1047 / 2(358^2-298^2) + 0.521E-3 / 3(358^3-298^3) - 8.78031]$$

$$H_{2-but6} = 41739225.95 \text{KJ/h.}$$

$$H_6 = 21326949.95 + 17992470.95 + 14664582.86 + 41739225.95$$

$$H_6 = 95723229.71 \text{KJ/h.}$$

$$Q = m * \lambda_{\text{steam}}$$

$$Q = 114767838.5$$

$$m = 114767838.5 * 18 / 36098.259 = 57227.7 \text{Kg/h.}$$

5.3.3. Energy balance around reactor (R901):

The conversion in the reactor is 80% and the reactor is adiabatic. So we calculate the adiabatic temperature (T_7) from equation below.

$$\text{Conversion}(x) = \frac{\sum \theta_i \int_{358}^{T_7} c_{pi} dt}{-\Delta H_R}$$

Where:

θ_i = ratio of component(i) in the feed to reference component (isobutylene feed).

Table (5.4) ratio of component(i) in the feed to isobutylene feed.

Component	θ_i
methanol	2.00
isobutylene	1.00
1-butenes	0.87
2-butenes	2.48
mtbe	0.00
water	0.00

$-\Delta H_R$ = heat of reaction at the adiabatic temperature (T_7):

$$-\Delta H_R(T_7) = \Delta H^\circ_R + \int_{298}^{T_7} \Delta c_p dt$$

$$\Delta H^\circ_R = H_{MTB6} - H_M - H_{ISO}$$

$$\Delta H^\circ_R = -2.80E+04 \text{ KJ/Kmol.}$$

$$\int_{298}^{T_7} \Delta c_p dt = \int_{298}^{T_7} (c_{pMTB6} - c_{pM} - c_{pISO}) dt.$$

Solving for T_7 by tray and error, by using excel sheet:

$$T_7 = 403^\circ\text{K.}$$

$$H_7 = H_{MTBE7} + H_{M7} + H_{ISO7} + H_{1-BUT7} + H_{2-BUT7} - H_{W7}$$

$$H_{MTBE7} = M_{MTBE7} \left[\int_{298}^{403} c_p dt + \lambda_{298} \right].$$

M_{MTBE7} from material balance calculation = 1660Kmol/h.

$$H_{Mtbe7} = 1660 * [140.12 (403-298) - 0.9E-3/2(403^2-298^2) + 0.563E-3/3(403^3-298^3) - 283.4992].$$

$$H_{Mtbe7} = 16066714.2\text{KJ/h.}$$

$$H_{M7} = M_{M7} \left[\int_{298}^{403} c_p dt + \lambda_{298} \right].$$

M_{M7} from material balance calculation = 2516.10Kmol/h.

$$H_{M7} = 2516.1 * [106(304-298) - 0.362/2(403^2-298^2) + 0.938E-3/3(403^3-298^3) - 200.66].$$

$$H_{M7} = 11295476.78\text{KJ/h.}$$

$$H_{ISO7} = M_{iso7} \left[\int_{298}^{403} c_p dt + \lambda_{298} \right].$$

M_{iso7} from material balance calculation = 428.05Kmol/h.

$$H_{ISO6} = 428.05 * [179.34 (403-298) - 1.467/2(403^2-298^2) + 0.010323/3(403^3-298^3) - 0.3E-4/4(403^4-298^4) + 3.40E-08/5(403^5-298^5) - 16.9059].$$

$$H_{ISO6} = 3375687.845\text{KJ/h.}$$

$$H_{1-but7} = M_{1-but7} \left[\int_{298}^{403} c_p dt + \lambda_{298} \right].$$

M_{1-but7} from material balance calculation = 1817.511622Kmol/h.

$$H_{1-but7} = 1817.511622 * [140.12 (403-298) - 0.55487/2(403^2-298^2) + 0.26242E-2/3(403^3-298^3) - 3.00E-06/4(430^4-298^4) - 0.53974].$$

$$H_{1-but7} = 11737411.97\text{KJ/h.}$$

$$H_{2-but7} = M_{2-but7} \left[\int_{298}^{403} c_p dt + \lambda_{298} \right].$$



M_{2-but7} from material balance calculation = 5172.917692Kmol/h.

$$H_{2-but7} = 5172.917692 * [112.76(403-298) - 0.1047 / 2(403^2-298^2) + 0.521E-3 / 3(403^3-298^3) - 8.78031]$$

$$H_{2-but7} = 34508550.26KJ/h.$$

$$H_7 = 1.4672E11KJ/h.$$

5.3.4. Energy balance around distillation column (T901):

$$Q_r - Q_c = H_9 + H_8 - H_7$$

$$H_9 = H_{MTBE9} + H_{M9} + H_{ISO9} + H_{1-BUT9} + H_{2-BUT9} - H_{W9}$$

$$P_T = 19 \text{ bar.}$$

$$T = 313.3^\circ K \text{ (bubble point).}$$

$$H_{MTBE9} = M_{MTBE9} \int_{298}^{313.3} c_p dt.$$

M_{MTBE9} from material balance calculation = 0.00Kmol/h.

$$H_{M9} = 0.00KJ/h.$$

$$H_{M9} = M_{M9} \int_{298}^{313.3} c_p dt.$$

M_{M9} from material balance calculation = 2428.73Kmol/h.

$$H_{M9} = 2428.73 * [106(313.3-298) - 0.362/2(313.3^2-298^2) + 0.938E-3/3(313.3^3-298^3)].$$

$$H_{M9} = 3084349.641KJ/h.$$

$$H_{ISO9} = M_{ISO9} \int_{298}^{313.3} c_p dt.$$

M_{ISO9} from material balance calculation = 428.05Kmol/h.

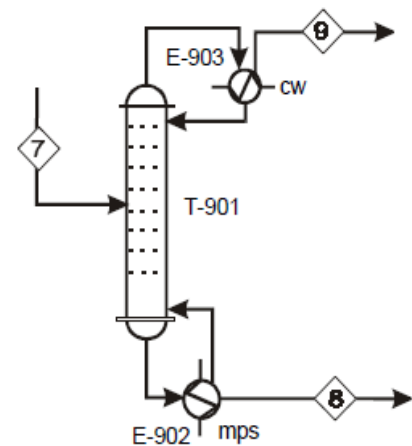
$$H_{ISO9} = 428.05 * [179.34 (313.3-298) - 1.467/2(313.3^2-298^2) + 0.010323/3(313.3^3-298^3) - 0.3E-4/4(313.3^4-298^4) + 3.40E-08/5(313.3^5-298^5)].$$

$$H_{ISO9} = 8.84E5KJ/h.$$

$$H_{1-but9} = M_{1-but9} \int_{298}^{313.3} c_p dt.$$

M_{1-but9} from material balance calculation = 1817.511622Kmol/h.

$$H_{1-but9} = 1817.511622 * [140.12 (313.3-298) - 0.55487/2(313.3^2-298^2) + 0.26242E-2/3(313.3^3-298^3) - 3.00E-06/4(313.3^4-298^4)].$$



$$H_{1-but9} = 3615478.074 \text{KJ/h.}$$

$$H_{2-but9} = M_{2-but9} \int_{298}^{313.3} cp \, dt.$$

$$M_{2-but9} \text{ from material balance caculation} = 5172.917692 \text{Kmol/h.}$$

$$H_{2-but9} = 5172.917692 * [112.76(313.3-298) - 0.1047 / 2(313.3^2 - 298^2) + 0.521E-3 / 3(313.3^3 - 298^3)].$$

$$H_{2-but9} = 10244724.91 \text{KJ/h.}$$

$$H_9 = 17829041.27 \text{KJ/h.}$$

- Condencer duty calculation:

$$\text{Vapor temp.} = 319.8^\circ\text{K (dew point).}$$

$$Q_c = (1 + R)(H_{V9} - H_9).$$

$$R = 1.8 \text{ (see ch.6).}$$

H_{V9} Can be calculated by using heat capacity constants for ideal gases, with the fallowing equation:

$$H_{iV9} = M_{i9} \left[\int_{298}^{319.8} cp \, dt + \lambda_{298} \right].$$

$$\rightarrow H_{V9} = 18886227.06 \text{KJ/h.}$$

$$\therefore Q_c = 2.8(18886227.06 - 17829041.27)$$

$$Q_c = 2960120.19 \text{KJ/h.}$$

-Amount of cooling water:

$$M = \frac{Q_c}{cp_{\text{water}} \Delta T} = \frac{2960120.19}{4.18(40-30)} = 70816.27 \text{Kg/h.}$$

$$H_8 = H_{MTBE8} + H_{M8} + H_{ISO8} + H_{1-BUT8} + H_{2-BUT8} - H_{W8}$$

$$H_{MTBE8} = M_{MTBE8} \int_{298}^{314.74} cp \, dt.$$

$$M_{MTBE8} \text{ from material balance caculation} = 1660 \text{Kmol/h.}$$

$$H_{Mtb8} = 1660 * [140.12 (314.74-298) - 0.9E-3 / 2(314.74^2 - 298^2) + 0.563E-3 / 3(314.74^3 - 298^3)].$$

$$H_{Mtb8} = 5356128.348 \text{KJ/h.}$$

$$H_{M8} = M_{M8} \int_{298}^{314.74} cp \, dt.$$

$$M_{M8} \text{ from material balance caculation} = 87.37 \text{Kmol/h.}$$

$$H_{M8} = 87.37 * [106(314.74-298) - 0.362 / 2(314.74^2 - 298^2) + 0.938E-3 / 3(314.74^3 - 298^3)].$$

$$H_{M8} = 121652.5772 \text{KJ/h.}$$

from material balance caculation:

$$M_{\text{ISO8}} = M_{1\text{-BUT8}} = M_{2\text{-BUT8}} = M_{\text{W8}} = 0.00\text{Kmol/h}; \text{ so:}$$

$$H_{\text{ISO8}} = H_{1\text{-BUT8}} = H_{2\text{-BUT8}} = H_{\text{W8}} = 0.00\text{KJ/h.}$$

$$\therefore H_8 = 5477780.925\text{KJ/h.}$$

- Reboiler duty calculation:

$$Q_r = Q_c + H_9 + H_8 - H_7$$

$$Q_r = 258116146.6\text{KJ/h.}$$

-Amount of stream needed:

$$M = \frac{Q_r}{\lambda_{\text{stream}}} = \frac{258116146.6}{36098.259} = \frac{7150.37\text{Kmol}}{\text{h}} = 128706.77\text{Kg/h.}$$

5.3.5. Energy balance around methanol absorber (T902):

This column run at 5bar and 363°K.

$$H_{10} = H_9$$

$$H_{11} = H_{11w}$$

$$H_{w11} = M_{w11} \int_{298}^{363} cp dt$$

M_{w11} from material balance caculation

$$= 12143.66\text{Kmol/h.}$$

$$H_{w11} =$$

$$12143.66 * [276 (363-298) - 2.09/2(363^2-298^2) + 0.00825/3(363^3-298^3) + 1.41\text{E-}05/4(363^4-298^4) + 9.37\text{E-}09/5(363^5-298^5)].$$

$$H_{w11} = 1972318662\text{KJ/h.}$$

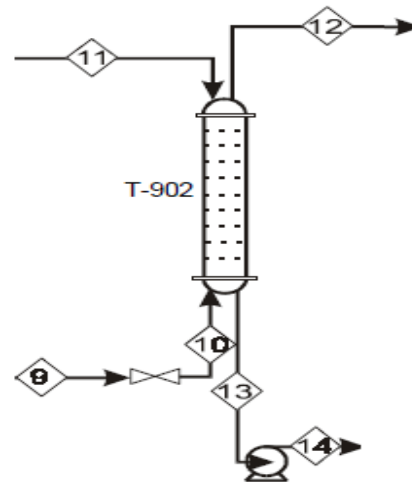
$$H_{12} = H_{\text{ISO12}} + H_{1\text{-BUT12}} + H_{2\text{-BUT12}} - H_{\text{W12}}$$

$$H_{\text{ISO12}} = M_{\text{iso12}} \int_{298}^{363} cp dt.$$

M_{iso12} from material balance caculation = 428.05Kmol/h.

$$H_{\text{ISO12}} = 428.05 * [179.34 (363-298) - 1.467/2(363^2-298^2) + 0.010323/3(363^3-298^3) - 0.3\text{E-}4/4(363^4-298^4) + 3.40\text{E-}08/5(363^5-298^5)].$$

$$H_{\text{ISO12}} = 4038036.682\text{KJ/h.}$$



$$H_{1-but12} = M_{1-but12} \int_{298}^{363} cp \, dt.$$

$$M_{1-but12} \text{ from material balance caculation} = 1817.511622 \text{Kmol/h.}$$

$$H_{1-but12} = 1817.511622 * [140.12 (363-298) - 0.55487/2(363^2-298^2) + 0.26242E-2/3(363^3-298^3) - 3.00E-06/4(363^4-298^4)].$$

$$H_{1-but12} = 15943036.3 \text{KJ/h.}$$

$$H_{2-but12} = M_{2-but12} \int_{298}^{363} cp \, dt.$$

$$M_{2-but12} \text{ from material balance caculation} = 5172.917692 \text{Kmol/h.}$$

$$H_{2-but12} = 5172.917692 * [112.76(363-298) - 0.1047 /2(363^2-298^2) + 0.521E-3 /363^3-298^3)].$$

$$H_{2-but12} = 45476091.78 \text{KJ/h.}$$

$$H_{12} = 4038036.682 + 159$$

$$43036.3 + 45476091.78$$

$$H_{12} = 65457164.76 \text{KJ/h.}$$

$$H_{13} = H_{M13} + H_{w13}$$

$$H_{M13} = M_{M13} \int_{298}^{363} cp \, dt.$$

$$M_{M13} \text{ from material balance caculation} = 2428.73 \text{Kmol/h.}$$

$$H_{M13} = 2428.73 * [106(363-298) - 0.362/2(363^2-298^2) + 0.938E-3/3(363^3-298^3)].$$

$$H_{M13} = 14073458.46 \text{KJ/h.}$$

$$H_{w13} = M_{w13} \int_{298}^{363} cp \, dt$$

$$M_{w13} \text{ from material balance caculation} = 12143.66 \text{Kmol/h.}$$

$$H_{w13} = 12143.66 * [276 (363-298) - 2.09/2(363^2-298^2) + 0.00825/3(363^3-298^3) + 1.41E-05/4(363^4-298^4) + 9.37E-09/5(363^5-298^5)].$$

$$H_{w13} = 1972318662 \text{KJ/h.}$$

$$H_{13} = 14073458.46 + 1972318662$$

$$H_{13} = 1972318662 \text{KJ/h.}$$

5.3.6. Energy balance around distillation column (T903):

$$Q_r - Q_c = H_{15} + H_{16} - H_{14}$$

$$H_{14} = H_{13} = 1972318662 \text{KJ/h (o change in enthalpy through the pump).}$$

$$H_{15} = 2781433.8 \text{ KJ/h.}$$

- Condenser duty calculation:

Vapor temp. = 322.1°K(dew point).

$$Q_c = (1 + R)(H_{V15} - H_{15}).$$

$$R = 3.84.$$

H_{V15} Can be calculated by using heat capacity constants for ideal gases, with the following equation:

$$H_{iV15} = M_{i15} \left[\int_{298}^{322.1} c_p dt + \lambda_{298} \right].$$

$$\rightarrow H_{V15} = 3744574.894 \text{ KJ/h.}$$

$$\therefore Q_c = 4.84(3744574.894 - 2781433.8)$$

$$Q_c = 4661602.895 \text{ KJ/h.}$$

-Amount of cooling water:

$$M = \frac{Q_c}{c_{p\text{water}} \Delta T} = \frac{4661602.895}{4.18(40-30)} = 111521.6 \text{ Kg/h.}$$

$$H_{16} = H_{\text{MTBE}16} + H_{\text{M}16} + H_{\text{ISO}16} + H_{1\text{-BUT}16} + H_{2\text{-BUT}16} - H_{\text{W}16}$$

from material balance calculation:

$$M_{\text{mtbe}16} = M_{\text{ISO}16} = M_{1\text{-BUT}16} = M_{2\text{-BUT}16} = 0.00 \text{ Kmole/h; so:}$$

$$H_{\text{mtbe}16} = H_{\text{ISO}16} = H_{1\text{-BUT}16} = H_{2\text{-BUT}16} = 0.00 \text{ KJ/h.}$$

$$H_{16} = H_{\text{W}16} + H_{\text{M}16}$$

$$H_{\text{M}16} = M_{\text{M}16} \int_{298}^{430.2} c_p dt.$$

$$M_{\text{M}16} \text{ from material balance calculation} = 375.58 \text{ Kmole/h.}$$

$$H_{\text{M}16} = 375.58 * [106(430.2-298) - 0.362/2(430.2^2-298^2) + 0.938E-3/3(430.2^3-298^3)].$$

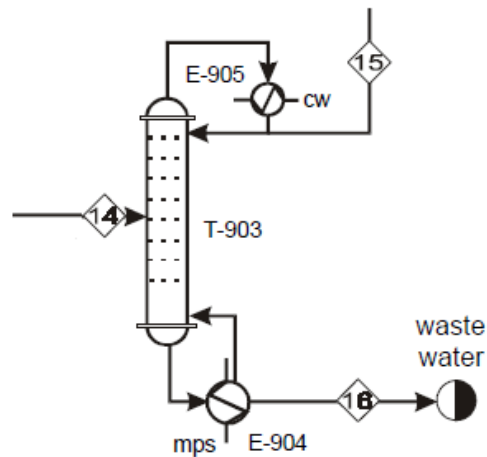
$$H_{\text{M}16} = 16824464.12 \text{ KJ/h.}$$

$$H_{\text{W}16} = M_{\text{W}16} \int_{298}^{430.2} c_p dt$$

$$M_{\text{W}16} \text{ from material balance calculation} = 12143.66 \text{ Kmole/h.}$$

$$H_{\text{W}16} = 12143.66 * [276(430.2-298) - 2.09/2(430.2^2-298^2) + 0.00825/3(430.2^3-298^3) + 1.41E-05/4(430.2^4-298^4) + 9.37E-09/5(430.2^5-298^5)].$$

$$H_{\text{W}16} = 5849089008 \text{ KJ/h.}$$



$$H_{16} = 16824464.12 + 5849089008$$

$$H_{16} = 5865913472 \text{KJ/h.}$$

- Reboiler duty calculation:

$$Q_r - Q_c = H_{15} + H_{16} - H_{14}$$

$$Q_r = 48907569980 \text{KJ/h.}$$

-Amount of stream needed:

$$M = \frac{Q_r}{\lambda_{\text{stream}}} = \frac{48907569980}{36098.259} = \frac{1354845.6 \text{Kmol}}{\text{h}} = 24387222.1 \text{Kg/h.}$$

Table (5.5) summary of agent amount.

Equipment	E901	E902	E903	E904	E905
Agent	mps	mps	cw	mps	cw
Temp.in (°C)	254	254	30	254	30
Temp.out(°C)	254	254	40	254	40
Flow(Kg/h)	57227.7	128706.77	70816.27	24387222.1	111521.6

Table (5.6) summary of energy balance calculation made by using Excel sheet

Component	1	2	3	4	5	6	7
P (bar)	4.9512	4.9512	4.9	4.9	20	20	20
T (K)	298	298	297.2406	298.0001	298.0001414	358.0001414	403
methanol	2122.945567	0	4176.101	4176.101	4176.100629	4176.100629	2516.100629
isobutylene	0	2088.050314	0	2088.05	2088.050314	2088.050314	428.0503145
1-butenes	0	1817.511622	0	1817.512	1817.511622	1817.511622	1817.511622
2-butenes	0	5172.917692	0	5172.918	5172.917692	5172.917692	5172.917692
mtbe	0	0	0	0	0	0	1660
water	0	0	0	0	0	0	0
Total	2122.945567	9078.479628	4176.101	13254.58	13254.58026	13254.58026	11594.58026

Continue Table (5.6) summary of energy balance calculation made by using Excel sheet

8	9	10	11	12	13	14	15	16
19.25	19	10	5	5	5	5.89132	4.9512	5.687
314.743 8	313.3	310.2	363	363	363	405.32	314.3	430.2
87.3684 2	2428.73 2	2428.73 2	0	0	2428.73 2	2428.73220 8	2053.15506 2	375.577 1
0	428.050 3	428.050 3	0	428.050 3	0	0	0	0
0	1817.51 2	1817.51 2	0	1817.51 2	0	0	0	0
0	5172.91 8	5172.91 8	0	5172.91 8	0	0	0	0
1660	0	0	0	0	0	0	0	0
0	0	0	12143.6 6	0	12143.6 6	12143.6610 4	0	12143.6 6
1747.36 8	9847.21 2	9847.21 2	12143.6 6	7418.48	14572.3 9	14572.3932 5	2053.15506 2	12519.2 4

