

CHAPTER 4

Material balance

4.1 Introduction:

Are the basis of process design. The material balance taken over the complete process will determine the quantities of raw materials required and products produced. Balance over individual process units set the process stream flow and composition. A good understanding of material balance calculation is essential in process design.

Material balance are also usefull tools for the study of plant operation and trouble shooting. They can be used to check performance against design; to extend the often limited data available from plant instrumentation; to check instrument calibrations; and to locate sources of material loss.

The general conservation equation for any process system can be written as:

$$\text{Material out} = \text{material in} + \text{generation} - \text{consumption} - \text{accumulation}$$

-ASSUMPTIONS:

The material balance calculation will be based on the following assumption:

- The basis one hour.
- The plant works 330 day in a year and 24 hour per day.
- steady state operation.
- single pass conversion is 80%.

The material balance calculation will be based on flow sheet in figure (3.1).

-Symbols used in this chapter:

$F_i \equiv$ Total mole flow of stream i

$MTBE_i$, M_i , W_i , ISO_i , $BUTE_i \equiv$ Mole fraction of MTBE, Methanol, Water, isobutene and butene respectively.

4.2. Calculations:

Amount of stream 8 =1660Kmol/h.

Average molecular weight of stream 8:

$$= M_W (\text{MTBE}) \times m_{\text{mtbe}} + M_W(\text{Methanol}) \times m_{\text{meth}}$$

$$= 88.15 \times 0.95 + 32.04 \times 0.05 = 85.34 \text{ kg/kmole}$$

4.2.1. Over all material balance:

$$F_1 + F_2 + F_{11} = F_8 + F_{12} + F_{16}$$

Methanol balance:

$$F_1 * 1 + F_2 * 0 + F_{11} * 0 = F_8 * 0 + F_{12} * 0 + F_{16} * 0.03 + 1747.37 * 0.05 + 1660$$

$$F_1 - 0.03F_{16} = 1747.3685$$

Isobutylene balance:

$$F_1 * 0 + F_2 * \text{ISO}_2 + F_{11} * 0 = F_8 * 0 + F_{12} * \text{ISO}_{12} + F_{16} * 0 + 1660$$

$$0.23F_2 - \text{ISO}_{12}F_{12} = 1660$$

Water balance:

$$F_1 * 0 + F_2 * 0 + F_{11} * 1 = F_8 * 0 + F_{12} * 0 + F_{16} * 0.97$$

$$F_{11} - 0.97F_{16} = 0$$

Other butane balance:

$$F_1 * 0 + F_2 * 0.77 + F_{11} * 0 = F_8 * 0 + F_{12} * \text{BUTE}_{12} + F_{16} * 0$$

$$F_2 * 0.77 - \text{BUTE}_{12}F_{12} = 0$$

$$F_1 + F_{15} = F_3$$

Methanol balance:

$$F_1 * 1 + F_{15} * 1 = F_{3*1}$$

$$F_2 + F_3 = F_4$$

Methanol balance:

$$F_2 * 0 + F_3 * 1 = F_4 * M_4$$

Isobutene:

$$F_2 * 0.23 + F_3 * 0 = F_4 * \text{ISO}_4$$

Other butane:

$$F_2 * 0.77 + F_3 * 0 = F_4 * \text{BUTE}_4$$

$$F_4 = F_5 = F_6$$

4.2.2. Material balance around reactor(R-901):

$$F_6 - \text{Reacted} = F_7$$

Methanol balance:

From equation

Given MTBE generated=1660 then

$$m_{\text{meth}} F_6 - 1660 = M_7 F_7$$

Isobutene:

$$m_{\text{iso}} F_6 - 1660 = \text{ISO}_7 F_7$$

$$m_{\text{iso}} F_6 = \frac{1660}{0.795} = 2088.05$$

$$2088.05 - 1660 = \text{ISO}_7 F_7 = 428.05$$

Butane balance:

$$\text{BUTE}_6 F_6 = \text{BUTE}_7 F_7$$

MTBE balance:

$$0 * F_6 - 1660 = \text{MTBE}_7 F_7$$

$$\text{MTBE}_7 F_7 = 1660$$

Note:

$$\text{At stream } F_6 : \quad \frac{\text{Methanol}}{\text{ISO}} = 2$$

$$(2 * \text{ISO}) * F_6 = 4176.1$$

$$4176.1 - 1660 = M_7 F_7 = 2516.10$$

Given:

$$\text{At } F_2 : \quad \text{ISO}_2 = 32\% , \text{ BUTE}_2 = 77\%$$

$$\text{amount of ISO} = 2088.05$$

$$\text{amount of butenes} = \frac{2088.5}{0.23} * 0.77 = 6990.43$$

$$F_2 = 9078$$

$$F_7 = 1660 + 428.05 + 2516.10 + 6990.43 = 11594.53$$

From

$$F_6 - \text{Reacted} = F_7$$

$$F_6 - 1660 = F_7$$

$$F_6 = 11594.53 + 1660 = 13254.53$$



From equation:

$$F_4 = F_5 = F_6$$

$$F_4 = 13254.53$$

$$F_2 + F_3 = F_4$$

$$9078 + F_3 = 13254.53, F_3 = 4176.53$$

4.2.3. Material balance around distillation column (T-901):

$$F_7 = F_8 + F_9$$

$$11594.53 - 1747.37 = 9847.21 = F_9$$

Methanol balance:

$$M_7 F_7 = M_8 F_8 + M_9 F_9$$

$$2516.10 - 87.37 = 2428.73 = M_7 F_7 = M_7 F_9$$

Isobutene balance:

$$ISO_{iso} F_7 = ISO_{iso} F_8 + ISO_{iso} F_9$$

$$428.05 = 0 + ISO_9 F_9, \quad ISO_9 F_9 = 428.05$$

Other butane balance:

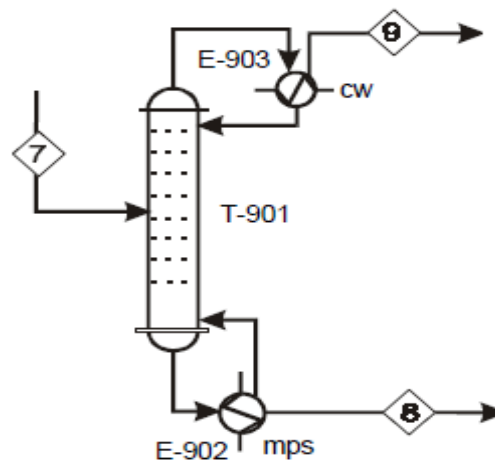
$$BUTE_7 F_7 = BUTE_8 F_8 + BUTE_9 F_9$$

$$6990.43 = 0 + BUTE_9 F_9$$

$$BUTE_9 F_9 = 6990.43$$

$$F_9 = F_{10}$$

$$F_{10} = 6990.43$$



4.2.4. Material balance around methanol absorber (T-902):

$$F_{10} + F_{11} = F_{12} + F_{13}$$

To calculate F_{12}

$$0.23 F_2 + ISO_{12} F_{12} = 1660$$

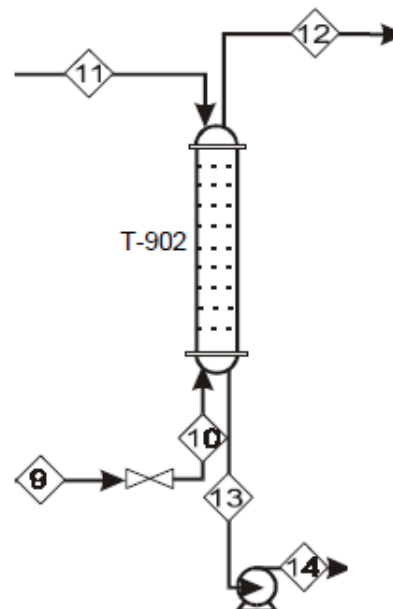
$$ISO_{12} F_{12} = 428.05$$

$$0.77 F_2 - BUTE_{12} F_{12} = 0$$

$$BUTE_{12} F_{12} = 6990.43$$

Given mixed butane only component in this stream

$$F_{12} = ISO_{12} F_{12} + BUTE_{12} F_{12} = 7418.48$$



$$F_{11} = 5 * 2428.732 = 12143.66$$

$$F_{12} = 7418.48$$

Methanol balance:

$$M_{10}F_{10} + M_{11}F_{11} = M_{12}F_{12} + M_{13}F_{13}$$

$$2428.73 + 0 * F_{11} = 0 * F_{12} + M_{13}F_{13}$$

$$M_{13}F_{13} = 2428.73$$

Isobutene balance:

$$ISO_{10}F_{10} + ISO_{11}F_{11} = ISO_{12}F_{12} + ISO_{13}F_{13}$$

$$428.05 + 0 * F_{11} = ISO_{12}F_{12} + 0 * F_{13}$$

$$ISO_{12}F_{12} = 3.51$$

Other butane balance:

$$BUTE_{10}F_{10} + BUTE_{11}F_{11} = BUTE_{12}F_{12} + BUTE_{13}F_{13}$$

$$6990.43 + 0 * F_{11} = BUTE_{12}F_{12} + 0 * F_{13}$$

$$BUTE_{12}F_{12} = 6990.43$$

Water balance:

$$W_{10}F_{10} + W_{11}F_{11} = W_{12}F_{12} + W_{13}F_{13}$$

$$0 * F_{10} + 1 * F_{11} = 0 * F_{12} + W_{12} * 14572.39$$

$$W_{13}F_{13} = 12143.66$$

$$F_{13} = F_{14}$$

4.2.5. Material balance around tower (T-903):

$$F_{14} = F_{15} + F_{16}$$

$$14572.39 = F_{15} + F_{16}$$

Methanol balance:

$$2428.73 = 1 * F_{15} + 0.03 * F_{16}$$

Water balance:

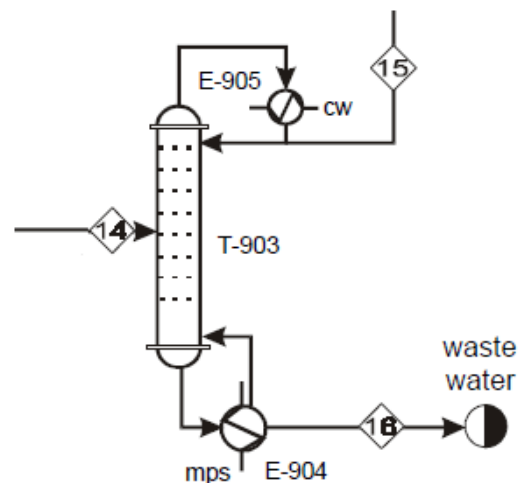
$$12143.66 = 0 * F_{15} + 0.97 * F_{16}$$

$$F_{16} = 12519.24$$

$$W_{16}F_{16} = 12143.66$$

$$0.03 * F_{16} = 0.03 * 12519.24 = 375.58$$

$$F_{15} = 2053.16$$



$$F_1 + F_{15} = F_3$$

$$F_1 = F_3 - F_{15} = 4176.10 - 2053.16 = 2122.95$$

$$F_1 = 2122.95$$

Table (4.1) summary of material balance calculation by using Excel sheet.

Component	1	2	3	4	5	6	7
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 of Table (4.1) summary of material balance calculation by using Excel sheet.

8	9	10	11	12	13	14	15	16
87.36842	2428.732	2428.732	0	0	2428.732	2428.732208	2053.155062	375.5771
0	428.0503	428.0503	0	428.0503	0	0	0	0
0	1817.512	1817.512	0	1817.512	0	0	0	0
0	5172.918	5172.918	0	5172.918	0	0	0	0
1660	0	0	0	0	0	0	0	0
0	0	0	12143.66	0	12143.66	12143.66104	0	12143.66
1747.368	9847.212	9847.212	12143.66	7418.48	14572.39	14572.39325	2053.155062	12519.24

