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Determination of the Actual Reflux Ratio of a Binary distillation Column using Excel

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--ABSTRACT---
The importance of the equilibrium (x-y) curve in the determination of the minimum reflux ratio in the design of a binary distillation column was explained. This study shows the use of MS Excel drawing tools to construct the q-line for the determination of the minimum reflux ratio in the McCabe-Thiele diagram. The feed enters at its bubble point since the q-line is vertical. A careful study reveals that without the determination of the actual reflux ration, the flow rates of vapour ands liquid cannot be evaluated. The value of the minimum reflux ratio and the actual reflux ratio calculated was 0.979 and 1.958 respectively.

KEYWORDS;- *Equilibrium curve, minimum reflux ratio, actual efflux ratio, distillation, excel*

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I. INTRODUCTION

The Reflux ratio is the ratio between the boil up rate and the take-off rate or in other words, it is the ratio between the amount of reflux that goes back down the distillation column and the amount of reflux that is collected in the receiver (distillate). Distillation is one of the oldest unit operations and is the most widely used separation technique in process industry. Distillation is a separation process used to separate two or more components into an overhead distillate and bottoms where the bottoms product is liquid, and the distillate may be liquid or a vapor or both [11; 12; 13; 14]. Distillation is based on the fact that the vapor of a boiling mixture will be richer in the components that have lower boiling points.

There are many types of distillation columns, each one of them is designed to be used in specific kind of separation. Depending on how they are operated they can be classified to: Continuous or Batch distillation columns [2; 11]. Binary distillation is a special distillation process. It is a multistage process for separating a mixture of two components [5; 8; 9]. The separation process requires that (i) a second phase be formed so that both vapor and liquid phases can contact each other on each stage within a separation column, (ii) the components have different volatilities so that they will partition between the two phases to different extents, and (iii) the two phases can be separated by gravity or other mechanical means [16].

A binary distillation column showing the feed, reboiler, condenser, reflux, stripping section, rectifying section and trays is shown in Figure 1. Ideally, the more volatile component is separated as vapor and flows out from top. The less volatile component flows out at bottom as liquid. The product for a binary distillation process is a pure component, or technically a purer component. The component can be obtained by collecting the vapor flow or the liquid flow. There are two ways to do distillation calculations by McCabe Thiele method. One is graphical method and other way is by using any other commercial simulation software. The graphical method is by hand and is time consuming. The use of the commercial simulation software though is costly and requires license is the best especially when different mixtures are involved. In this paper, Ms –Excel is used to determine the actual reflux ratio of a binary distillation column.

The McCabe Thiele’s equations are given elsewhere [3; 11; 12; 13; 14; 19].

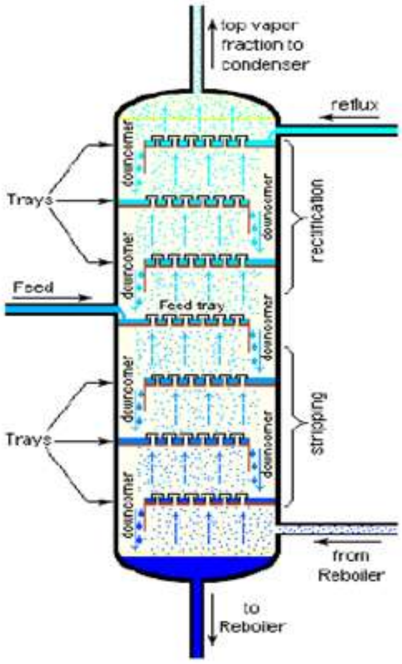


Figure 1. Binary distillation column showingwith feed, reboiler, condenser and trays.

II. METHODOLOGY

2.1 The Procedure

McCabe and Thiele method uses the equilibrium curve diagram to determine the number of theoretical stages (trays) required to achieve a desired degree of separation. It assumes constant molar overflow and this implies that: (i) molal heats of vaporization of the components are roughly the same; (ii) heat effects are negligible. The information required for the systematic calculation are the vapour liquid equilibrium (VLE) data, feed condition (temperature, composition), distillate and bottom compositions; and the reflux ratio, which is defined as the ratio of reflux liquid over the distillate product. Figure 1 is usually separated into the top section and bottom section of the binary distillation column. The detail procedures for the McCabe and Thiele Method are shown elsewhere [1; 3; 5; 7; 9; 16; 19].

2.2 Problem and specifications

Suppose, we are going to design a distillation column to separate benzene-toluene mixture with feed flow rate 3000Kmole/hr, the feed is saturated liquid, the feed has 60% mol fraction of benzene and the over head product has 0.95 mol fraction of benzene and the bottom product contain 0.05 mol fraction of benzene. The system operates in partial reboiler and total condenser modes. The distillation column also operates at atmospheric pressure (p= 1atm) and the operating reflux ratio is 2. The design specifications are shown in table 1. The variables in table 1 that are not found in the design problem can be obtained from literatures [3; 10; 11; 12; 13; 14; 19].

Table 1: Design specifications

Feed rate	3000 Kmole/hr
Feed composition	60% benzene, 40% toluene
Column operating pressure	Atmospheric (1atm)
Column reboiler	Partial
Column condenser	Total
Distillate composition, x_d	95% benzene
Bottom composition, x_b	95% toluene
Relative volatility of benzene to toluene	2.3
Reflux ratio	2
Molecular weight of benzene, MW_{lk}	78.114 kg/kmol
Molecular weight of toluene, MW_{Hk}	92.141 kg/kmol
Boiling point of benzene	80.1 ^{0}C
Boiling point of toluene	110.6 ^{0}C
Vapour density of benzene	2.77kg/m^3
Vapou density of toluene	876kg/m^3
Plate or tray spacing	0.5m

2.3 Assumptions

The McCabe-Thiele method of column design is used with the following assumptions inherent in the calculation:

- Constant vapor and liquid flow rates in any given section of the tower.
- The latent heat of evaporation is approximately constant with composition and also does not vary much as we proceed from tray to tray.
- The system is non-foaming and non corrosive, and thus we can use carbon steel rather than stainless steel as our material of construction.

2.4 Steps taken to determine the actual reflux ratio

Though our concern in this study is the determination of the actual reflux ratio of a binary distillation Column using Excel, the following steps should be followed in the binary distillation column design [8; 12; 14; 15]:

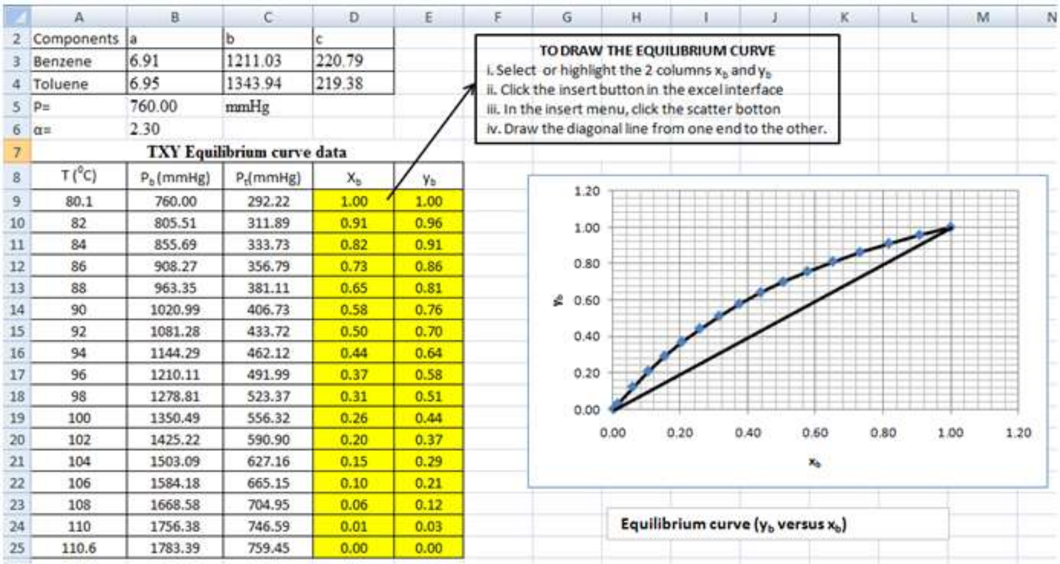
i. Determine the vapor-liquid equilibrium curve (x-y diagram) from Antoine data.
ii. Obtain the physical data of benzene and toluene required for the design.
iii. Calculate the flow rate of various stream through the column
iv. Calculate the minimum reflux ratio and the minimum number of trays required.
v. Using the physical data and flow rates calculate the reboiler and condenser duties.
vi. Calculate maximum and minimum liquid and vapor flow rates.
vii. To start the iteration, select reasonable plate spacing and using the trial plate spacing calculate the column diameter.
viii. Select a trial plate layout, select down-comer area, active, area and size, weir height and length.
ix. From this data check that the weeping rate is satisfactory.
x. Calculate the plate pressure drop.
xi. Check that the down-comer area backup is acceptable.
xii. If at any stage some of the values are too high or low select new trial values and repeat the iterations above.

2.5 Determination of the Actual reflux ratio of a binary distillation Column using Excel

A detail design calculations of the TXY data and drawing of the equilibrium curve (XY) diagram of a binary distillation column has been done and reported elsewhere [19]. In their study, they calculated the TXY data and plotted the equilibrium curve (X-Y) diagram using hand and excel. The TXY data is presented in table 2 and how the equilibrium curve (X-Y) diagram was plotted with MS Excel is shown in figure 2.

Table 2. TXY data for benzene and toluene [19]

Temp. (^{0}C)	P_b^0 (mmHg)	P_t^0 (mmHg)	x_b	y_b
80.1	760.0	292.2	1.00	1.00
82	805.5	311.9	0.91	0.96
84	855.7	333.7	0.82	0.91
86	908.3	356.8	0.73	0.86
88	963.3	381.1	0.65	0.81
90	1021.0	406.7	0.58	0.76
92	1081.3	433.7	0.50	0.70
94	1144.3	462.1	0.44	0.64
96	1210.1	492.0	0.37	0.58
98	1278.8	523.4	0.31	0.51
100	1350.5	556.3	0.26	0.44
102	1425.2	590.9	0.20	0.37
104	1503.1	627.2	0.15	0.29
106	1584.2	665.2	0.10	0.21
108	1668.6	704.9	0.06	0.12
110	1756.4	746.6	0.01	0.03
110.6255	1784.5	760	0.00	0.00



Components	a	b	c
Benzene	6.91	1211.03	220.79
Toluene	6.95	1343.94	219.38
P=	760.00	mmHg	
α=	2.30		

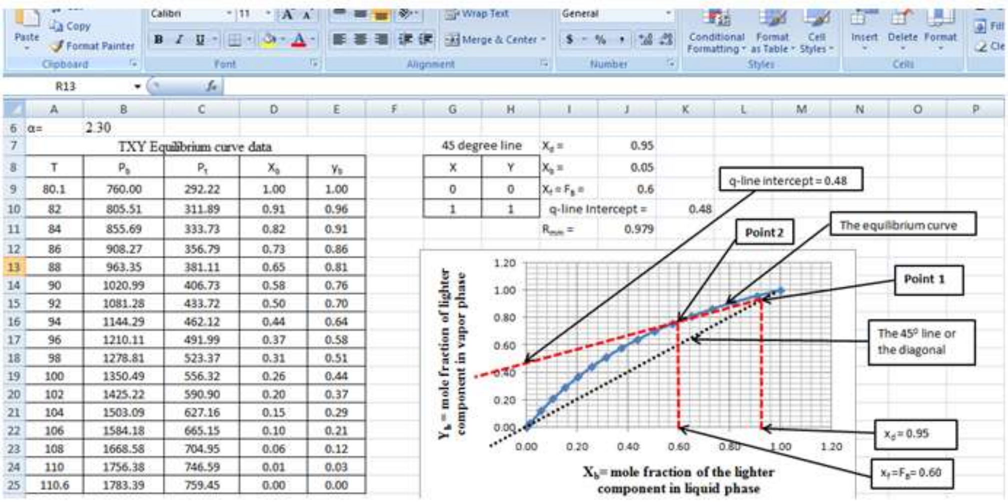
TXY Equilibrium curve data

T (°C)	P_b (mmHg)	P_t (mmHg)	X_b	Y_b
80.1	760.00	292.22	1.00	1.00
82	805.51	311.89	0.91	0.96
84	855.69	333.73	0.82	0.91
86	908.27	356.79	0.73	0.86
88	963.35	381.11	0.65	0.81
90	1020.99	406.73	0.58	0.76
92	1081.28	433.72	0.50	0.70
94	1144.29	462.12	0.44	0.64
96	1210.11	491.99	0.37	0.58
98	1278.81	523.37	0.31	0.51
100	1350.49	556.32	0.26	0.44
102	1425.22	590.90	0.20	0.37
104	1503.09	627.16	0.15	0.29
106	1584.18	665.15	0.10	0.21
108	1668.58	704.95	0.06	0.12
110	1756.38	746.59	0.01	0.03
110.6	1783.39	759.45	0.00	0.00

Figure 2. How to obtain the equilibrium curve with excel [19]

2.6 Determination of the Minimum reflux ratio(R_{mm}) of a binary distillation column:

To determine the minimum reflux ratio, Use the drawing tools of MS Excel to construct the q-line and identify its point of intersection with the equilibrium curve and then draw a line from product composition point on the 45˚diagonal line to this intersection point as shown in figure 3. The slope of the q-line is $R_{mm}/(1+R_{mm})$ and the intercept of the q- line on the y axis is $x_d/(1+R_{mm})$. Minimum reflux can be determined from either of these.



X	Y
0	0
1	1

T	P_b	P_t	X_b	Y_b
80.1	760.00	292.22	1.00	1.00
82	805.51	311.89	0.91	0.96
84	855.69	333.73	0.82	0.91
86	908.27	356.79	0.73	0.86
88	963.35	381.11	0.65	0.81
90	1020.99	406.73	0.58	0.76
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110	1756.38	746.59	0.01	0.03
110.6	1783.39	759.45	0.00	0.00

Figure3: Determination of the minimum reflux ratio using Excel

2.6.1 Explanation to figure 3

The q-line is drawn with excel drawing tools. Two points are very important to draw the q-line: **point 1** is the intersection of the diagonal line and X_d = 0.95 line and **point 2** is the intersection of the equilibrium (x-y) curve and the $X_f = F_B$ = 0.60 line as shown. The q-line is the straight line drawn from these two points to meet the y intercept at a particular point. In this graph the point is 0.48. This value is used to calculate the minimum reflux ratio.

This implies that $x_d/(1+R_{mm}) = 0.48$

$$\frac{0.95}{(1+R_{mm})} = 0.48$$

$$\frac{0.95}{(1+R_{mm})} = 0.48$$

$$R_{mm} = 0.979$$

Therefore the minimum reflux ratio is **0.979**

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2.7 Determination of the actual reflux ratio(R_{mm}) of a binary distillation column:

$R = (1.2 \ldots\ldots\ldots 2)R_{mm}$

$R = 2R_{min} = 2*0.979 =$ **1.958.**

So, the actual reflux ratio is 1.958

III. DISCUSSION AND CONCLUSION

This study shows the use of MS Excel drawing tools to construct the q-line for the determination of the minimum reflux ratio in the McCabe-Thiele diagram. The feed enters at its bubble point science the q-line is vertical. A careful study reveals that without the determination of the actual reflux ration, the flow rates of vapour ands liquid cannot be evaluated. The value of the minimum reflux ratio and the actual reflux ratio calculated was 0.979 and 1.958 respectively. Further work will be on the determination of the flow rates of vapour and liquid using MS Excel.

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