

MODULE 5: DISTILLATION

LECTURE NO. 2

5.2. Distillation columns and their process calculations

There are many types of distillation columns each of which is designed to perform specific types of separations. One way of classifying distillation column type is to look at how they are operated. Based on operation, they are of two types: batch or differential and continuous columns.

5.2.1. Batch or differential distillation columns and their process calculation

In batch operation, the feed is introduced batch-wise to the column. That is, the column is charged with a 'batch' and then the distillation process is carried out. When the desired task is achieved, a next batch of feed is introduced. Consider a binary mixture of components A (more volatile) and B (less volatile). The system consists of a batch of liquid (fixed quantity) inside a kettle (or still) fitted with heating element and a condenser to condense the vapor produced as shown in Figure 5.7. The condensed vapor is known as the distillate. The distillate is collected in a condensate receiver. The liquid remaining in the still is known as the residual. The process is unsteady state. The concentration changes can be analyzed using the phase diagram, and detailed mathematical calculations carried out using the Rayleigh Equation. Readers are suggested to follow chapter 9 (Page 369) of text book “Mass-transfer operations” by R. E Treybal, third edition. As the process is unsteady state, the derivation is based on a differential approach to changes in concentration with time. Let L_1 = initial moles of liquid

originally in still, L_2 = final moles of liquid remained in still, x_1 = initial liquid composition in still (mole fraction of A), x_2 = final liquid composition in still (mole fraction A). At any time t , the amount of liquid in the still is L , with mole fraction of A in the liquid being x . After a small differential time ($t + dt$), a small amount of vapor dL is produced, and the composition of A in the vapor is y (mole fraction). The vapor is assumed to be in equilibrium with the residue liquid. The amount of liquid in the still is thus reduced from L to $(L - dL)$, while the liquid composition changed from x to $(x - dx)$. Then the material balance on A can be written as:

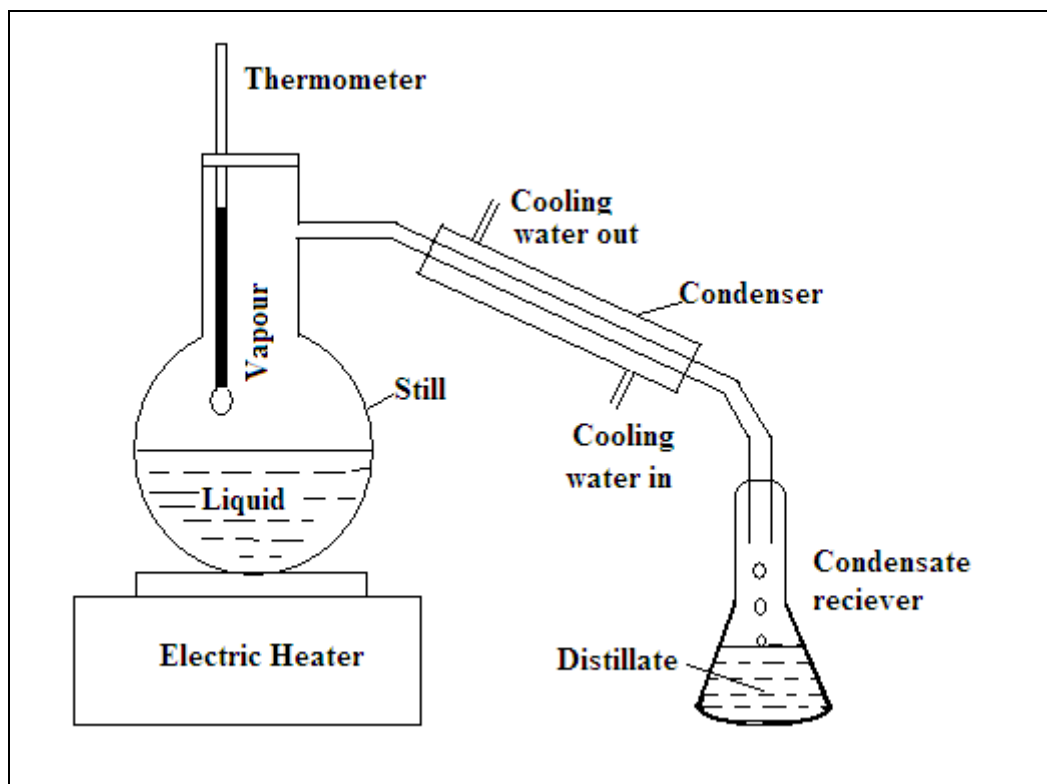


Figure 5.7: Simple batch or differential distillation process

Initial amount in still = Amount left in still + Amount vaporized

$$xL = (x - dx)(L - dL) + ydL \quad (5.6)$$

or

$$xL = xL - xdL - Ldx + dx dL + ydL \quad (5.7)$$

Neglecting the term $(dx)(dL)$, the Equation (5.7) may be written as:

$$Ldx = ydL - xdL \quad (5.8)$$

Re-arranging and Integrating from L_1 to L_2 , and from x_1 to x_2 , one can obtain the following Equation which is called Rayleigh Equation:

$$\ln\left(\frac{L_1}{L_2}\right) = \int_{x_2}^{x_1} \frac{1}{(y-x)} dx \quad (5.9)$$

The integration of Equation (5.9) can be obtained graphically from the equilibrium curve, by plotting $1/(y-x)$ versus x .

Example problem 5.1

A mixture of 40 mole % isopropanol in water is to be batch-distilled at 1 atm until 70 mole % of the charge has been vaporized. Calculate the composition of the liquid residue remaining in the still pot, and the average composition of the collected distillate. VLE data for this system, in mole fraction of isopropanol, at 1 atm are (Seader and Henley, 1998):

Temp.(K)	366	357	355.1	354.3	353.6	353.2	353.3	354.5
y	0.220	0.462	0.524	0.569	0.593	0.682	0.742	0.916
x	0.012	0.084	0.198	0.350	0.453	0.679	0.769	0.944

Solution 5.1:

Calculate $1/(y-x)$

As per Rayleigh Equation

$$\ln\left(\frac{L_1}{L_2}\right) = \int_{x_2}^{x_1} \frac{1}{(y-x)} dx$$

$$x_1 = 0.4$$

$$\text{Feed } L_1 = 100$$

$$\text{Distillate (D)} = 70$$

$$\text{Liquid residue as } L_2 = L_1 - D = 30$$

$$\text{Find } x_2 \text{ by equating } \ln\left(\frac{L_1}{L_2}\right) = \int_{x_2}^{x_1} \frac{1}{(y-x)} dx$$

$$\text{The value of } x_2 = 0.067$$

$$y_D = \frac{L_1 x_1 - L_2 x_2}{D} = 0.543$$