MODULE 5: DISTILLATION

LECTURE NO. 7

Stepwise procedure to determine the number of theoretical trays:

Step 1: Draw the equilibrium curve and the enthalpy concentration diagram for the mixture to be separated

Step 2: Calculate the compositions of the feed, distillate and bottom products. Locate these compositions on the enthalpy-concentration diagram.

Step 3: Estimate the reflux rate for the separation and locate the rectifying section difference point as Δ_R as shown in Figure 5.23. Point y_1 is the intersection point of line joining point x_D and Δ_R and $H_{V\text{-}y}$ curve.

Step 4: Locate the stripping section difference point Δ_s. The point Δ_s is to be located at a point where the line from Δ_R through x_F intersects the x_B composition coordinate as shown in Figure 4.23.

Step 5: Step off the trays graphically for the rectifying section. Then the point of composition x_1 of liquid of top tray is to be determined from the equilibrium relation with y_1 of vapor which is leaving the tray and locate it to the $H_{L\text{-}x}$ curve. Then the composition y_2 is to be located at the point where the line of points Δ_R and x_1 intersects $H_{V\text{-}y}$ curve. This procedure is to be continued until the feed plate is reached.

Step 6: Similarly follow the same rule for stripping section. In the stripping section, the vapor composition y_B leaving the reboiler is to be estimated from the equilibrium relation. Then join the y_B and Δ_S to find the x_N. The vapor composition

y_N is to be determined by extending a tie line to saturated vapor curve $H_{V\text{-}y}$. The procedure is to be continued until the feed tray is attained.

Determination of the reflux rate:

The reflux rate can be calculated from the energy balance around the condenser as:

$$V_1 H_{V,1} == L_D H_D + D H_D + Q_C \qquad (5.51)$$

By substituting $V_1 = L_D + D$ into Equation (5.51) and rearranging, it can be written as:

$$\frac{L_D}{D} = \frac{(H_D + Q_C / D) - H_{V,1}}{H_{V,1} - H_D} = \frac{\overline{\Delta_R H_{V,1}}}{\overline{H_{V,1} H_D}} \qquad (5.52)$$

Where $\overline{\Delta_R H_{V,1}}$ and $\overline{H_{V,1} H_D}$ are the lengths of lines between points Δ_R and $H_{V,1}$ and $H_{V,1}$ and H_D. The internal reflux ratio between any two stages in rectifying section can be expressed as:

$$\frac{L_n}{V_{n+1}} = \frac{(H_D + Q_C / D) - H_{V,n+1}}{(H_D + Q_C / D) - H_{L,n}} = \frac{\overline{\Delta_R H_{V,n+1}}}{\overline{\Delta_R H_{L,n}}} \qquad (5.53)$$

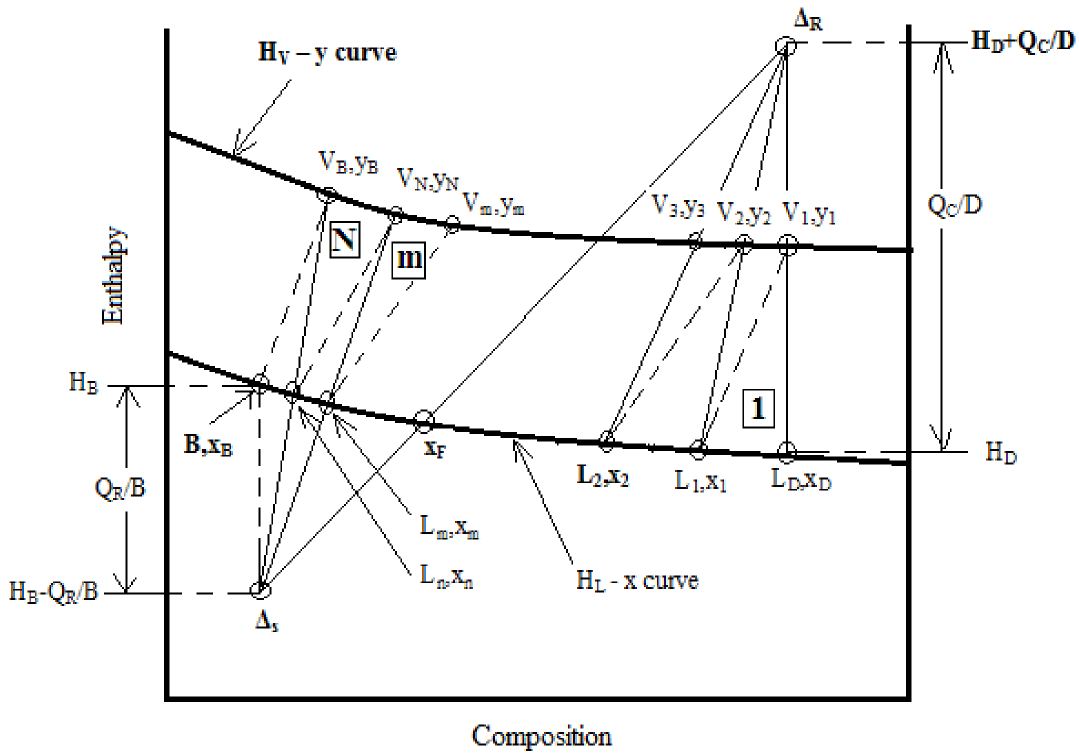

Figure 5.23: Representation of estimation of no of stages by Ponchon-Savarit Method

Whereas in the stripping section it can be expressed as:

$$\frac{L_{m-1}}{V_m} = \frac{H_{V,m} - (H_B - Q_R/B)}{H_{L,m-1} - (H_B - Q_R/B)} \tag{5.54}$$

The relationship between the distillate and bottom products in terms of compositions and enthalpies can be made from the material balance around the overall column which can be written as:

$$FH_F + Q_R = DH_D + BH_B + Q_C \tag{5.55}$$

Overall material balance F = D + B combining with Equation (5.55) yields

$$\frac{D}{B} = \frac{H_F - (H_B - Q_R/B)}{(H_D + Q_C/D) - H_F} = \frac{\overline{x_F \Delta_S}}{\overline{x_F \Delta_R}} \tag{5.56}$$

Minimum number of trays

In this method, if D approaches zero, the enthalpy coordinate (H_D +Q_C/D) of the difference point approaches infinity. Other way it can be said that Qc becomes large if L becomes very large with respect to D. Similarly enthalpy coordinate for stripping section becomes negative infinity as B approaches zero or liquid loading in the column becomes very large with respect to B. Then the difference points will locate at infinity. In such conditions, the trays required for the desired separation is referred as minimum number of trays. The thermal state of the feed has no effect on the minimum number of trays required for desired separation.

Minimum reflux

The minimum reflux for the process normally occurs at the feed tray. The minimum reflux rate for a specified separation can be obtained by extending the tie line through the feed composition to intersect a vertical line drawn through x_D. Extend the line to intersect the x_B composition line determines the boilup rate and the reboiler heat duty at minimum reflux.

Example problem 5.3:

A total of 100 gm-mol feed containing 40 mole percent n-hexane and 60 percent n-octane is fed per hour to be separated at one atm to give a distillate that contains 92 percent hexane and the bottoms 7 percent hexane. A total condenser is to be used and the reflux will be returned to the column as a saturated liquid at its bubble point. A reflux ratio of 1.5 is maintained. The feed is introduced into the column as a saturated liquid at its bubble point. Use the Ponchon-Savarit method and determine the following:

(i) Minimum number of theoretical stages

(ii) The minimum reflux ratio

(iii) The heat loads of the condenser and reboiler for the condition of minimum reflux.

(iv) The quantities of the diustillate and bottom streams using the actual reflux ratio.

(v) Actual number of theoretical stages

(vi) The heat load of the condenser for the actual reflux ratio

(vii) The internal reflux ratio between the first and second stages from the top of tower.

VLE Data, Mole Fraction Hexane, 1 atm

x	0	0.1	0.3	0.5	0.55	0.7	1
y	0	0.36	0.7	0.85	0.9	0.95	1

Enthalpy-Concentration Data

Mole fraction, Hexane		0	0.1	0.3	0.5	0.7	0.9	1
Enthalpy, Cal/gm-mol	Sat. Liquid	7000	6300	5000	4100	3400	3100	3000
	Sat. Vapor	15,700	15,400	14,700	13,900	12,900	11,600	10,000

Solution 5.3:

(i) The minimum number of stages can be obtained by drawing vertical operating lines that intersects as Δ_R tends to infinity. As shown in Figure E2, three stages required.

(ii) Using Equation (5.52), the minimum reflux is

$$\frac{L_D}{D} = \frac{(H_D + Q_C / D) - H_{V,1}}{H_{V,1} - H_D} = \frac{\overline{\Delta_R H_{V,1}}}{\overline{H_{V,1} H_D}} = \frac{19000 - 11500}{11500 - 3000} = 0.88$$

(iii) From the Figure E2, $H_B - Q_R / B$=-5000

Q_R / B = 5000+7000 = 12000

$H_D + Q_C / D$ = 19000

Q_C / D= 19000-11500 =7500

(iv) The distillate and bottom flowrates are obtained by solving the overall and component material balances simultaneously

100 = D + B

0.4 (1000 = 0.92 D + 0.04 B

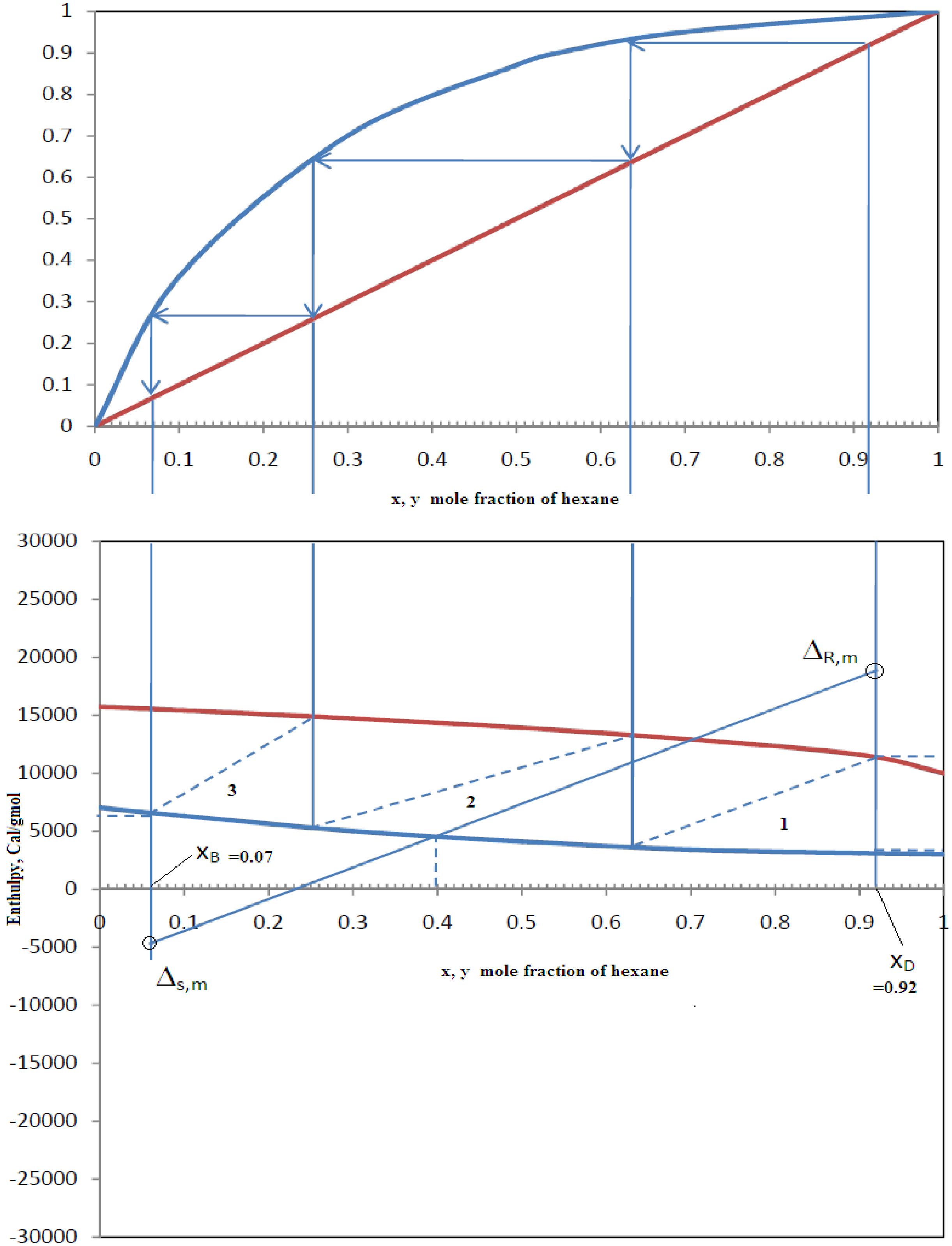

Figure E2: Minimum reflux and minimum stages for example problem 4.3

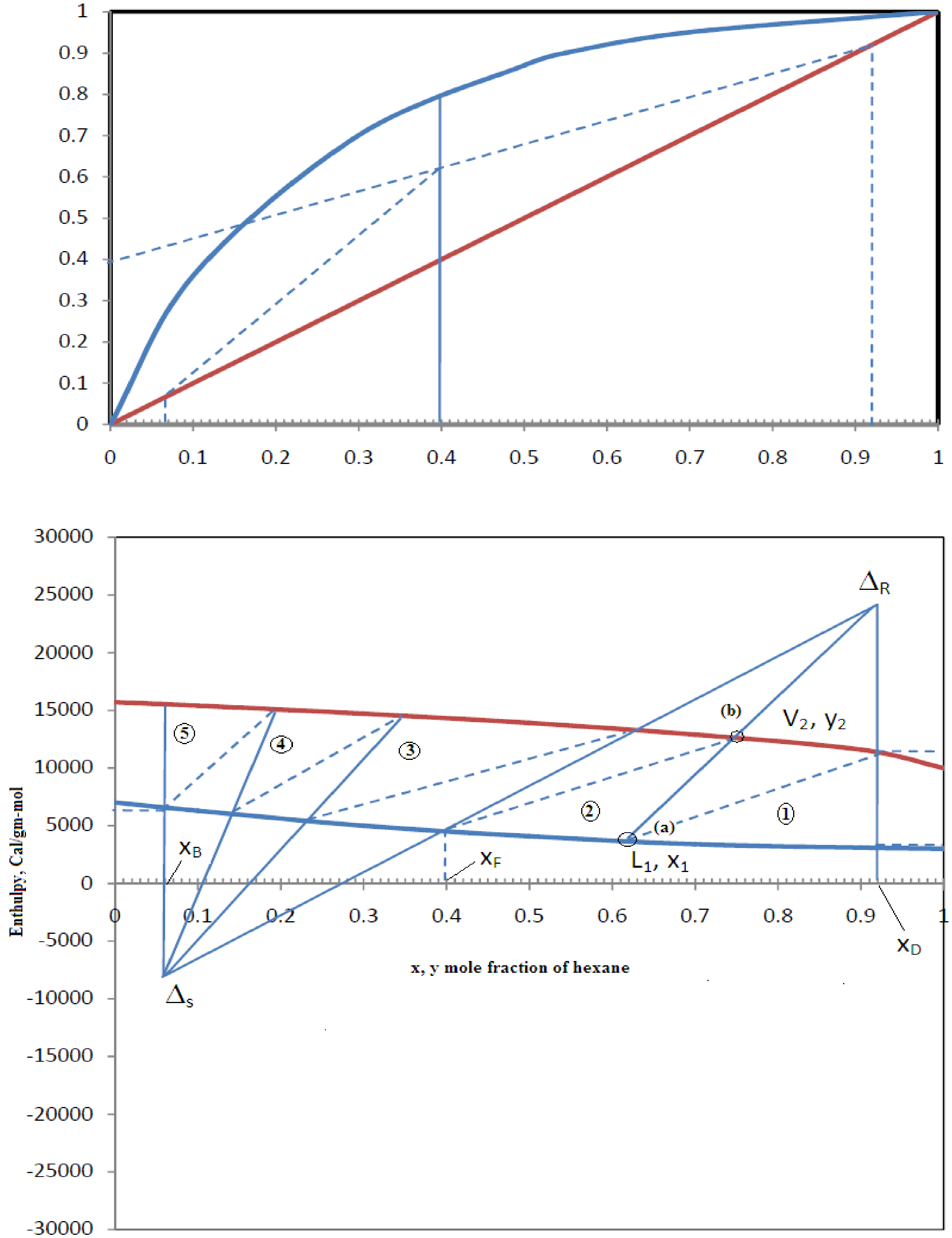

Figure E3: Actual stages for Example problem 4.3.

Thus D = 40.9 gmmol/h

B = 100 – 40.9 = 59.1 gmmol/h

(v) $\left(\frac{L_D}{D}\right)_{act} = 1.5\left(\frac{L_D}{D}\right)_{\min} = 1.5(0.88) = 1.32$

Using Equation (5.52) gives a new value for Δ_R :

$$1.32 = \frac{(H_D + Q_C / D) - 11500}{11500 - 3000}$$ Or, $H_D + Q_C / D = 22750$

A new Δ_R is located in Figure E3 and the actual number of theoretical stages is found as 5.

(vi) From the Figure E3

$H_D + Q_C / D = 22750$

So $Q_C / D = 22750 - 11500 = 11250$

(vii) Reading enthalpies for the points (a) and (b) and using Equation (5.53) gives

$$\frac{L_n}{V_{n+1}} = \frac{(H_D + Q_C / D) - H_{V,n+1}}{(H_D + Q_C / D) - H_{L,n}} = \frac{22750 - 12050}{22750 - 3750} = 0.563$$