Family Name	
Given Names	
Student Number	
Teaching Period	Semester 1, 2017

FINAL EXAMINATION

ENG341 – Separation Process Principles

DURATION

Reading Time:	**10** minutes
Writing Time:	**180** minutes

INSTRUCTIONS TO CANDIDATES

EXAM CONDITIONS

You may begin writing from the commencement of the examination session. The reading time indicated above is provided as a guide only.

This is a CLOSED BOOK examination

Any non-programmable calculator is permitted

No handwritten notes are permitted

No dictionaries are permitted

ADDITIONAL AUTHORISED MATERIALS	EXAMINATION MATERIALS TO BE SUPPLIED
No additional printed material is permitted	1 x 16 Page Book 1 x Scrap Paper

THIS EXAMINATION IS PRINTED

DOUBLE-SIDED.

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<u>Question 1</u> ***(32 marks)***

A distillation column with two feeds is separating ethanol (EtOH) and water (W) at a pressure of 1.0 atm. The column has a total condenser with saturated liquid reflux and a partial re-boiler. Feed 1 (F1) is a saturated liquid and contains 42 mol% EtOH. Feed 2 (F2) contains 18 mol% EtOH and enters the column as a two-phase mixture with 30% vapor. The flow rate of F2 is 100 kmol/h. The external reflux ratio R is 0.5, and the distillate (D) flow rate is 80 kmol/h. The molar fraction of EtOH in D is x_D = 0.66; and the molar fraction of EtOH in the bottom product, B, is x_B = 0.04. Constant molar overflow (CMO) assumption is valid, and equilibrium curve is given in Figure 1 below.

a) *Find the flow rates F1 and B.*
b) *Find the liquid and vapor flow rates, L' and V', in the middle section.*
c) *Determine and plot the operating lines.*
d) *Find both optimum feed locations and the total number of equilibrium stages.*

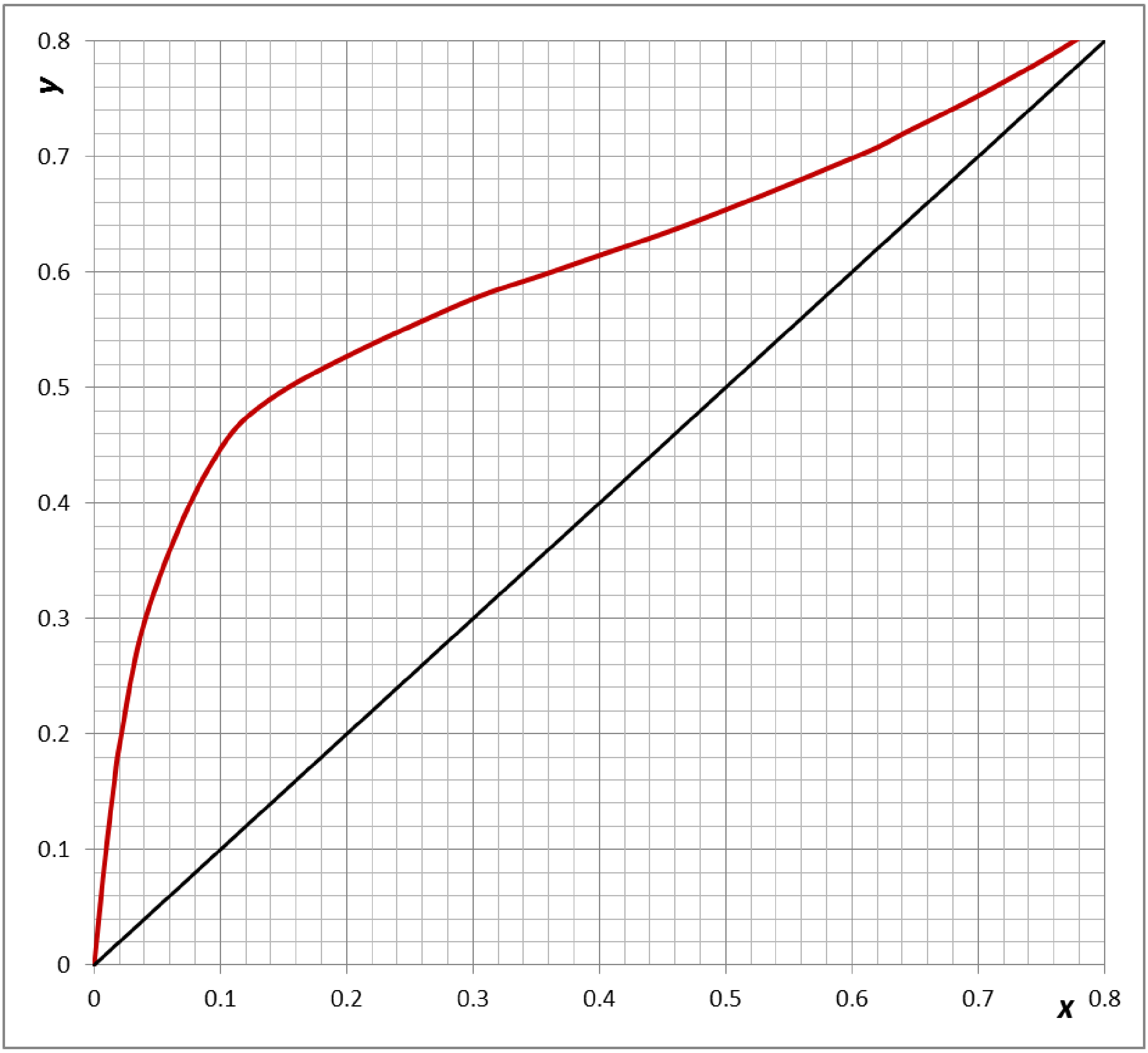


Figure 1. Equilibrium curve for Question 1

<u>Question 2</u> ***(33 marks)***

We wish to absorb ammonia from an air stream using water at 0°C and a total pressure of 1.30 atm. Equilibrium data are given in the Table 1 below. The entering water stream is pure water. The entering vapor is 17.2 wt % ammonia. We desire to recover 98% of the ammonia in the water outlet stream. The total gas flow rate is 1050 kg/h. We want to use a solvent rate (L) that is 1.5 times the minimum solvent rate (L_{min}). Assume that temperature is constant at 0°C, water is non-volatile, and air does not dissolve in water.

Find L_{min}, L, and the number of theoretical stages N.

Table 1. Equilibrium data for Question 2.

g NH_3/1g H_2O	***Partial pressure of NH3, mmHg***
0.05	11.2
0.075	17.7
0.100	25.1
0.15	42.7
0.20	64
0.25	89.5
0.30	119
0.40	190
0.50	275
0.60	380

<u>Note:</u> *You may use graph paper on page 7 to solve this question.*

Question 3 ***(35 marks)***

We are extracting acetic acid from water with isopropyl ether at 20°C and 1 atm pressure. Equilibrium data are given in the Table 2 below. The column has three equilibrium stages. The entering feed rate is 1000 kg/h. The feed is 40 wt % acetic acid and 60 wt % water. The exiting extract stream has a flow rate of 2500 kg/h with 20 wt % acetic acid. The entering extract stream is not 100% pure isopropyl ether, and does not contain water. Find:

a) The exit raffinate concentration.

b) The required entering extract stream concentration.

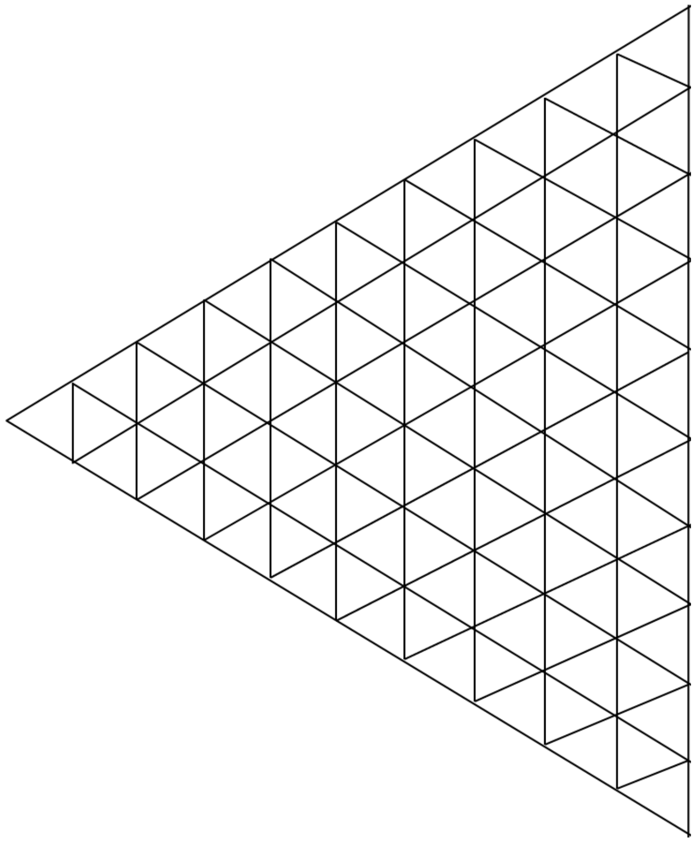
c) Flow rates of exiting raffinate and entering extract streams.

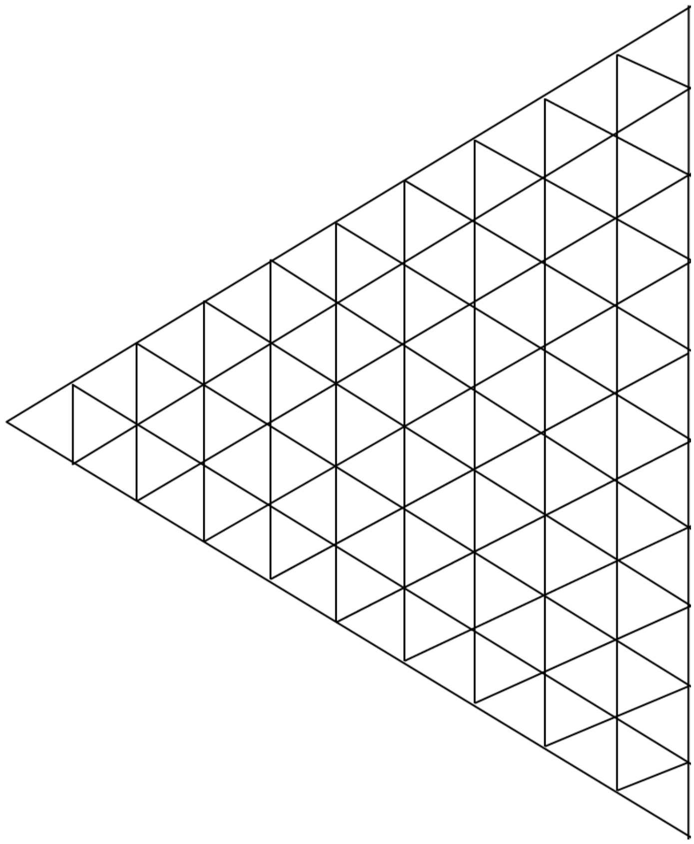
Table 2. Equilibrium data for Question 3.

(Points on the same row are in equilibrium!)

Water Layer, wt%			**Isopropyl Ether Layer, wt%**		
Acetic Acid	*Water*	*Isopropyl Ether*	*Acetic Acid*	*Water*	*Isopropyl Ether*
0.69	98.1	1.2	0.18	0.5	99.3
1.41	97.1	1.5	0.37	0.7	98.9
2.89	95.5	1.6	0.79	0.8	98.4
6.42	91.7	1.9	1.93	1.0	97.1
13.30	84.4	2.3	4.82	1.9	93.3
25.50	71.1	3.4	11.40	3.9	84.7
36.70	58.9	4.4	21.60	6.9	71.5
44.30	45.1	10.6	31.10	10.8	58.1
46.40	37.1	16.5	36.20	15.1	48.7

Note: *You may use the triangle diagrams, provided on pages 8 and 9, to solve this question.*





Resources

Distillation

$$F = B + D$$

$$Q_C = \left(1 + \frac{L_0}{D}\right) D(h_D - H_1) = \left(1 + \frac{L_0}{D}\right)\left(\frac{z - x_B}{x_D - x_B}\right) F(h_D - H_1)$$

$$Fz = Bx_B + Dx_D$$

$$Q_R = \left(\frac{z - x_B}{x_D - x_B}\right) Fh_D + \left(\frac{x_D - z}{x_D - x_B}\right) Fh_B - Fh_F + \left(1 + \frac{L_0}{D}\right)\left(\frac{z - x_B}{x_D - x_B}\right) F(H_1 - h_D)$$

$$D = \left(\frac{z - x_B}{x_D - x_B}\right) F$$

$$y_{n+1} = \frac{L_n}{V_{n+1}} x_n + \frac{Dx_D}{V_{n+1}} \qquad y = \frac{L}{V} x + \frac{Dx_D}{V} \qquad q = 1 - f$$

$$B = F - D = \left(\frac{x_D - z}{x_D - x_B}\right) F$$

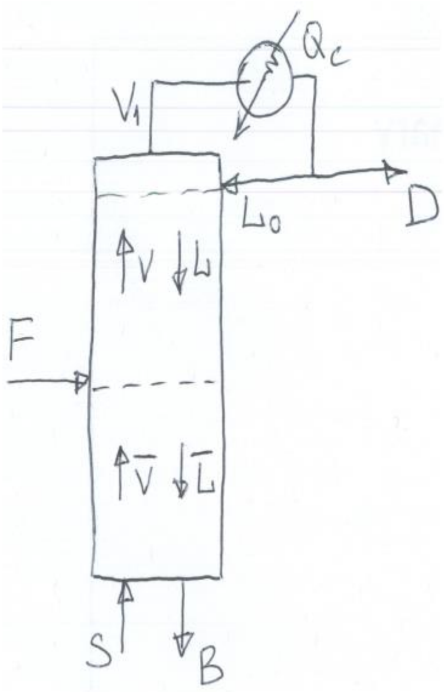
$$D = V_{n+1} - L_n \qquad D = V - L \qquad q \equiv \frac{\bar{L} - L}{F} \sim \frac{H - h_F}{H - h}$$

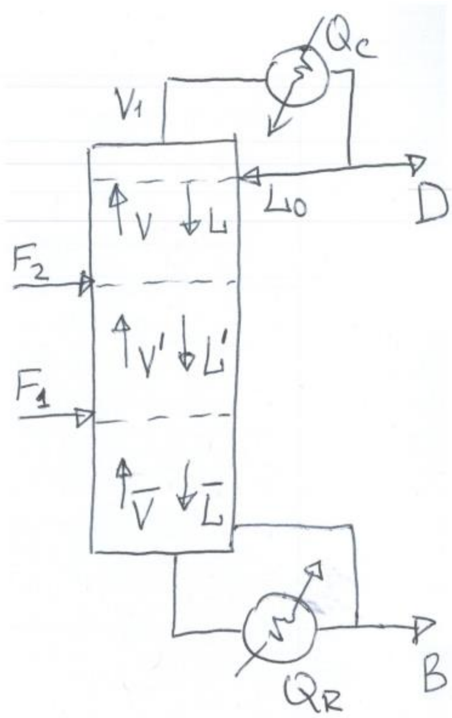
$$Fh_F + Q_C + Q_R = Dh_D + Bh_B$$

$$y_{m+1} = \frac{L_m}{V_{m+1}} x_m - \frac{Bx_B}{V_{m+1}} \qquad y = \frac{\bar{L}}{\bar{V}} x - \frac{Bx_B}{\bar{V}} \qquad q = 1 + \frac{c_{pL}(T_b - T_F)}{\Delta H^{vap}}$$

$$B = L_m - V_{m+1} \qquad B = \bar{L} - \bar{V}$$

$$q = -\frac{c_{pV}(T_F - T_d)}{\Delta H^{vap}}$$





Absorption / Stripping

$$y_{n+1} = \left(\frac{L}{V}\right)x_n + y_1 - \left(\frac{L}{V}\right)x_0$$

$$y_n = \left(\frac{L}{V}\right)x_{n+1} + y_0 - \left(\frac{L}{V}\right)x_1$$

$$N = \frac{y_{n+1} - y_1}{y_1 - \frac{L}{V}x_0}$$

$$\frac{y_{N+1} - y_1^*}{y_1 - y_1^*} = \frac{1 - \left(\frac{L}{mV}\right)^{N+1}}{1 - \frac{L}{mV}}$$

$$N = \frac{ln\left[\left(1 - \frac{mV}{L}\right)\frac{y_{N+1} - y_1^*}{y_1 - y_1^*} + \frac{mV}{L}\right]}{ln\left(\frac{L}{mV}\right)}$$

$$\frac{y_{N+1} - y_1}{y_{N+1} - y_1^*} = \frac{\frac{L}{mV} - \left(\frac{L}{mV}\right)^{N+1}}{1 - \left(\frac{L}{mV}\right)^{N+1}}$$

$$N = \frac{ln\left[\frac{y_{N+1} - y_{N+1}^*}{y_1 - y_1^*}\right]}{ln\left(\frac{L}{mV}\right)}$$

$$y_{N+1}^* = mx_N$$

$$\frac{y_{N+1} - y_{N+1}^*}{y_1 - y_1^*} = \left(\frac{L}{mV}\right)^N$$

$$N = \frac{ln\left[\frac{y_{N+1} - y_{N+1}^*}{y_1 - y_1^*}\right]}{ln\left[\frac{y_{N+1} - y_1}{y_{N+1}^* - y_1^*}\right]}$$

$$y_1^* = mx_0$$

$$\frac{x_N - x_N^*}{x_0 - x_N^*} = \frac{1 - \frac{L}{mV}}{1 - \left(\frac{L}{mV}\right)^{N+1}}$$

$$N = \frac{ln\left[\left(1 - \frac{L}{mV}\right)\frac{x_0 - x_N^*}{x_N - x_N^*} + \frac{L}{mV}\right]}{ln\left(\frac{mV}{L}\right)}$$

$$\frac{x_N - x_N^*}{x_0 - x_0^*} = \left(\frac{L}{mV}\right)^N$$

$$N = \frac{ln\left[\frac{x_N - x_N^*}{x_0 - x_0^*}\right]}{ln\left(\frac{L}{mV}\right)} \qquad N = \frac{ln\left[\frac{x_N - x_N^*}{x_0 - x_0^*}\right]}{ln\left[\frac{x_0^* - x_N^*}{x_0 - x_N}\right]}$$

$$x_N^* = \frac{y_{N+1}}{m} \qquad x_0^* = \frac{y_1}{m}$$

$$K_n = \frac{y_n}{x_n} = \frac{Y_n/(1 + Y_n)}{X_n/(1 + X_n)}$$

$$Y_{n+1} = \left(\frac{L'}{V'}\right)X_n + Y_1 - \left(\frac{L'}{V'}\right)X_0$$

$$Y_n = \left(\frac{L'}{V'}\right)X_{n+1} + Y_0 - \left(\frac{L'}{V'}\right)X_1$$

Liquid - Liquid Extraction

$$F - E_1 = \cdots = R_{n-1} - E_n = \cdots = R_N - S = P$$

$$(x_i)_{n-1}R_{n-1} + (y_i)_{n+1}E_{n+1} = (x_i)_n R_n + (y_i)_n E_n$$

$$E_1/M = \overline{MR}_N/\overline{E_1R_N}$$

$$R_N/M = \overline{ME_1}/\overline{E_1R_N}$$

$$\frac{\overline{E_1P}}{\overline{FP}} = \frac{E_1 + P}{E_1} = \frac{F}{E_1}$$