SOLUTION

CHE 305 – Separation Processes
Spring 2010 – Homework #6

1. A mixture of ethanol and water is to be separated using distillation. You plan to use a simulator to help with the design; however, you need to get guess values first. Obtain an XY diagram using ChemCAD. The column operates at atmospheric pressure.

a. Determine the minimum number of stages to obtain $x_D = 0.86$ and $x_B = 0.0005$.

b. The fermentation broth has an overall composition of 12 mole% ethanol. The broth is preheated by direct injection of steam, resulting in a reduction of the overall composition (to 10 mole%) and 55% vaporization of the feed.

   i. Determine the slope of the q-line.

   ii. Draw your q-line on your XY phase diagram.

c. From part b, what is the minimum reflux ratio to get 86% purity of ethanol in the distillate?

2. Answer the following questions for a distillation column.

Given:

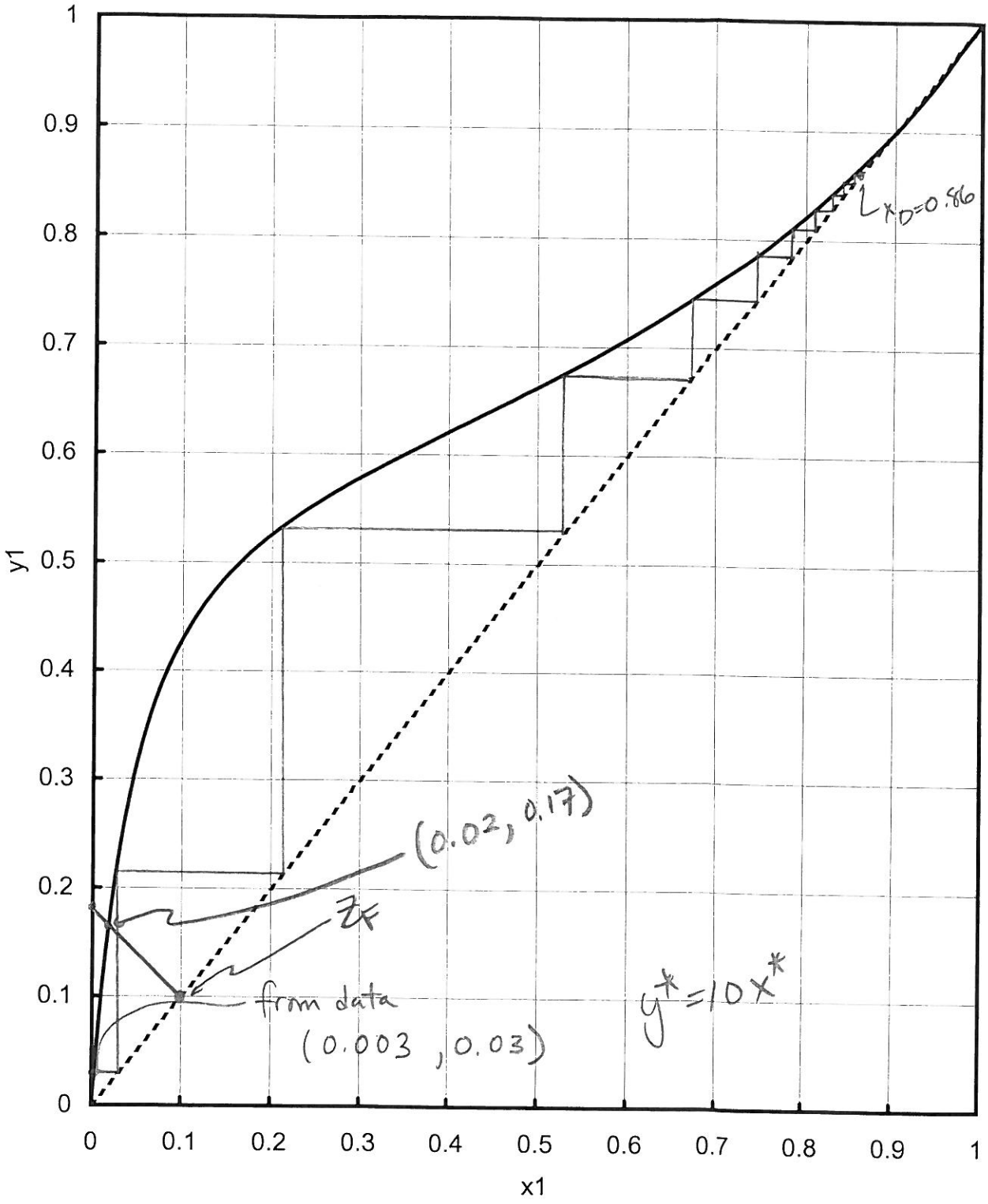
- Equilibrium Curve $$y_N^* = \frac{5x_N^*}{1+4x_N^*}$$
- Rectifier Operating Line $$y_{N+1} = \frac{7}{12}x_N + \frac{0.98}{2.4}$$
- Murphree Efficiency $$\eta_M = \frac{y_N - y_{N+1}}{y_N^* - y_{N+1}}$$

a. The McCabe-Thiele analysis for a proposed distillation column resulted in an estimate of 8 theoretical stages. After pilot testing, it was determined that 14 trays were required, as well as a partial reboiler. Determine the overall efficiency of the column.

b. Experimental data for the top tray in the column showed a liquid phase mole fraction of 0.96. If the column was operating at 100% efficiency, what would you expect the distillate composition to be?

c. The actual distillate composition was found to be 0.98. What is the Murphree Efficiency of the column? (HINT: First determine the vapor composition leaving tray 2.)

XY Phase Diagram for Ethanol (1) and Water (2) at 1 bar



Hw #6 SOLUTION

① See attached XY phase diagram.

A) Manually step stages from $X_D = 0.86$ to $(0.003, 0.03)$

11 stages to that point.

Then, from equations:

EQ LINE: $y^* = 10x^*$ (see diagram)

OP LINE: $y = x$

STAGE	x	y
11	0.003	0.03
12	0.0003	0.003

$< 0.0005 \Rightarrow$ DONE

$\Rightarrow$ **12 stages** $\leftarrow$ MINIMUM # of STAGES

B) $z_F = 0.1$

$\psi = 0.55$

Slope q-line: $\frac{\psi - 1}{\psi} = \frac{0.55 - 1}{0.55} = \frac{-0.45}{0.55} = -0.818$

See attached diagram for q-line

c) from diagram, two points on ROP

$(0.86, 0.86), (0.02, 0.17)$

$$\text{Slope} = \frac{0.86 - 0.17}{0.86 - 0.02} = 0.821 = \frac{R}{R+1}$$

$$0.821R + 0.821 = R$$

$$0.821 = 0.179R$$

$$\Rightarrow \boxed{R = 4.59} \leftarrow R_{MIN}$$

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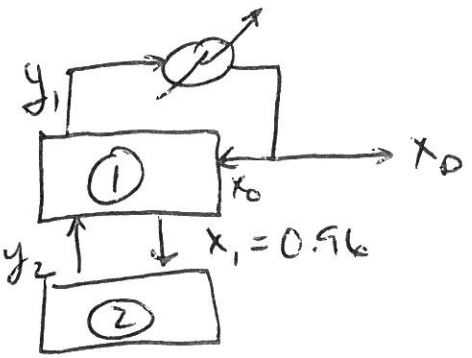
(2) a) McCabe-Thiele $\Rightarrow$ 8 theoretical stages

Pilot study $\Rightarrow$ 14 trays + Partial Reboiler = 15 stages

$$\eta_o = \frac{8}{15} = 0.533 \quad \text{or} \quad \boxed{53.3\%}$$

b)



y_1 is in EQ w/ x_1

$$\Rightarrow y_1 = \frac{5(0.96)}{1 + 4(0.96)}$$

$$\boxed{y_1 = 0.992}$$

c) $y_1^* = 0.992$

$x_1 = 0.96$ $\Rightarrow$ Need y_2

$y_1 = 0.98$ y_2 & x_1 on Operating Line

$$y_2 = \frac{7}{12}(0.96) + \frac{0.98}{2.4} \Rightarrow y_2 = 0.968$$

$$\eta_M = \frac{0.98 - 0.968}{0.992 - 0.968} = 0.5 \text{ or } \boxed{50\%}$$