Problem 1) (55 points)

A distillation column is used for the separation of propane and butane. The equilibrium data is given in the attached figure. A partial condenser and partial reboiler are employed in this system. The feed to this column consists of 225 kgmoles/hr of a 58% butane feed stream which is 48.3% saturated vapor. A saturated liquid sidestream containing 72% is removed from this system. While some of the liquid from the partial condenser is returned as reflux to the top of the column, some of this liquid is also removed from the system as a liquid distillate product at a composition of 0.9 (i.e. there are two distillate product streams, one liquid and one vapor stream). The reflux ratio for his system is defined as $L_R/D_{\text{total}}$ and is equal to 4.997. The flow rates of vapor distillate and the liquid distillate and the sidestream are set equal. 10.745% of the propane entering in the feed leaves in the bottoms product. Assuming constant molal overflow, construct a schematic of this column and determine the following:

1) All external flow rates and compositions
2) All internal flow rates
3) The equation for the top operating line and the intersection of this line with the x=y line (What is the significance of the composition of this intersection point).
4) On the accompanying figure construct all operating lines and Q lines.
5) The number of stages and optimum location of the feed and side stream (counting from the bottom up).
6) If the heat of vaporization at the condenser conditions is 4000 kJ/kg mole, what is the heat duty in the condenser for this system?

\[ L_R = 4.997 \]
\[ D_{\text{tot}} = S = D_V = D_L \]
\[ L = 410.335 \]
\[ V = 283.415 \]
\[ x_B = 0.08 \]
\[ x_D = 0.9 \]
\[ y_D = 0.96 \]
\[ y_D D_V + x_D D_L + x_S S + x_B B \]
\[ 0.10746 \times 0.42 \times 225 = \text{propane} = B x_B \]
\[ 225 = D_V + D_L + S \text{ (3 S) } + B \]
\[ 225 = 3S + B \]
\[ (0.42 \times 225) = y_D D_V + x_D D_L + x_S S + x_B B \]
\[ (0.42 \times 225) = 0.96 S + 0.95 S + 0.72 S + x_B B \]
\[ 94.5 = 2.58 S + x_B B \]
\[ \frac{z}{R+1} = 0.07 \]
\[ \frac{R}{R+1} = 0.833 \]
\[ y = 0.833x + 0.07 \]
\[ \therefore \text{plot} \quad y = x \]
\[ \therefore x = 0.833x \]

Slope of top op. line: \[ \frac{R}{R+1} = 0.833 \]

Since the vapor and liquid are both accounted for in \( R \), the point of intersection with \( x-y \) line can be taken as an average of \( x_0 \) and \( y_0 \). That avg value is \( x = 0.93 \)

op. line passes through \( x, y = (0.93, 0.93) \)

\[ y - 0.93 = 0.833(x - 0.93) \]
\[ y = 0.833x + 0.155 \]
\[ q = \frac{4F}{F} = 0.517 \]
\[ q = \frac{4F}{F} - 1 = -1.07 \]

Feed line \( y = -1.07x + 0.87 \)

\[ \frac{z}{V} \text{ for 2nd op. line: } \frac{294.01}{392.01} = 0.75 \]

Optimum fuel location = 3-6th stage
Optimum side-stage location = 6th stage

Flow rate of vapor condensed = \( 4L + D_L = 326.7 + 32.69 \)
\[ = 359.4 \text{ kmol/h} \]

Heat duty = \[ \frac{4000 \text{ kJ}}{1 \text{ kmol}} \times 259.4 \text{ kmol} \]
\[ = 1437600 \text{ kJ/h} \]
\[ = 399.33 \text{ kW} \]
Equilibrium Data for Propane-Butane at 101.43 kPa
Problem 2) (45 points)

A distillation column is used to process a feed stream containing 300 kg mol/hr of 24% ethanol with an enthalpy of 428 kJ/kg mole (the equilibrium diagram is given is the attached figure). A total condenser and partial reboiler are used in this system. The distillation tower has two exiting streams, a distillate product containing 80% ethanol and a bottoms product. The heat of vaporization at the feed composition is 7000 kJ/kg mole and the heat of a saturated vapor at the feed composition is 11,250 kJ/kg mole. The reflux ratio in the condenser is set at 2.8 times the minimum reflux. The boil up ratio of the reboiler is equal to 1.152. Construct a flow chart of this distillation column and determine the following assuming constant molal overflow.

1. The minimum and actual reflux ratios.
2. On the figure construct the operating lines and the q line for the actual reflux condition.
3. The composition of the bottoms product.
4. The number of stages and optimum location of the feed stream (counting from the bottom up).
5. The compositions of the passing streams between the second and third trays from the bottom (not counting the partial reboiler stage).
6. The number of stages and optimum location of the feed stream if a Murphree efficiency of 50% is employed (again, counting from the bottom up and assuming 100% efficiency for the partial reboiler).
Equilibrium Data for Ethanol-Water at 101.43 kPa

\[ q = \frac{H_V - H_f}{H_V - H_L} = \frac{11250 - 4178}{3100} = 1.5716. \]

\[ 0.72 - 0.2 = 1.268 \]
\[ 0.51 + 0.2 = 0.71 \]
\[ 0.68 - 0.3 = 1.368 \]
\[ 0.41 - 0.2 \]
\[ 0.42 - 0.7447 = -1.268x \]
\[ x = 0.1143 \]