Distillation of a binary mixture of methanol and water (McCabe-Thiele construction)

In industries, it is a common practice to introduce multiple feeds, at different locations, along a column. Similarly, a product stream of a desired composition may be withdrawn from an appropriate tray. For e.g., methanol of different purities (in a water-methanol mixture) may be required for different applications and in such cases, instead of building a separate column, a much easier solution would be to design a column in which a sidestream containing the required methanol purity is withdrawn at an appropriate location. In such cases, the first step towards designing a column involves a complete determination of the operating lines and the location of feed/product inlets and outlets.

Consider a stream of aqueous methanol having 45% (by mol) methanol which is fed into a distillation column. The feed rate is 500 kmol/hr and consists of 80% liquid and 20% vapour. It is required to separate this mixture such that the top product contains 97% methanol and no more than 2% methanol is present in the bottom product. A liquid side-stream containing 70% methanol also needs to be withdrawn at a rate of 50 kmol/hr. The reflux is returned to the top tray as a saturated liquid at a reflux ratio which is 2.5 times the minimum reflux ratio. Based on this information, we need to figure out the number of ideal trays required for the separation as well as the location of the feed tray and the tray from which the sidestream needs to be withdrawn.

(i) The methanol-water vapour-liquid equilibrium data is given below. Here x and y are in mole fractions. Use your favourite fitting function in MATLAB to fit the x - y data to the functional form:

$$y = \frac{ax}{1 + bx + cx^2}$$

Use this fitted curve for subsequent calculations. Show both the tabulated and the fitted curve in the same plot (Name this Figure 1).

(1 points)

x	0	0.02	0.04	0.06	0.08	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95	1.0
y	0	0.134	0.23	0.304	0.365	0.418	0.579	0.665	0.729	0.779	0.825	0.87	0.915	0.958	0.979	1

(ii) To solve this problem, we need to divide the column into three sections as shown below and determine the operating lines in each section:

Section I – Condenser, reflux drum and all stages prior to the sidestream removal stage

Section II – Sidestream stage and all stages prior to the feed stage

Section III – Feed stage and all stages below along with the reboiler

To determine the operating lines, the liquid and vapour flow rates in each section need to be calculated. The ratio of the liquid and vapour flow rates will be equal to the slope of the operating line in a particular section.

(iii) First, perform an overall material balance to obtain the values of D and W.

(5 points)

(iv) On a separate Figure 2, first plot the fitted equilibrium curve. Next, locate the points $D(x_D, x_D)$, $W(x_w, x_w)$, $S(x_s, x_s)$ and $F(z_{F,} z_{F,})$ on Figure 2. Determine the equation of the feed line from the supplied information. Plot this line in the same figure.

(7 points)

(v) Similarly, determine the equation of the side-stream line from the supplied information. Plot this line in the same figure.

(7 points)

(vi) Use the side-stream line to determine the pinch point of this system. From this calculate the minimum and actual reflux ratio.

(20 points)

(vii) Once you have the reflux ratio, calculate the actual liquid and vapour flow rates in Section I, and use them to obtain the operating line in this section. Plot this line in Figure 2.

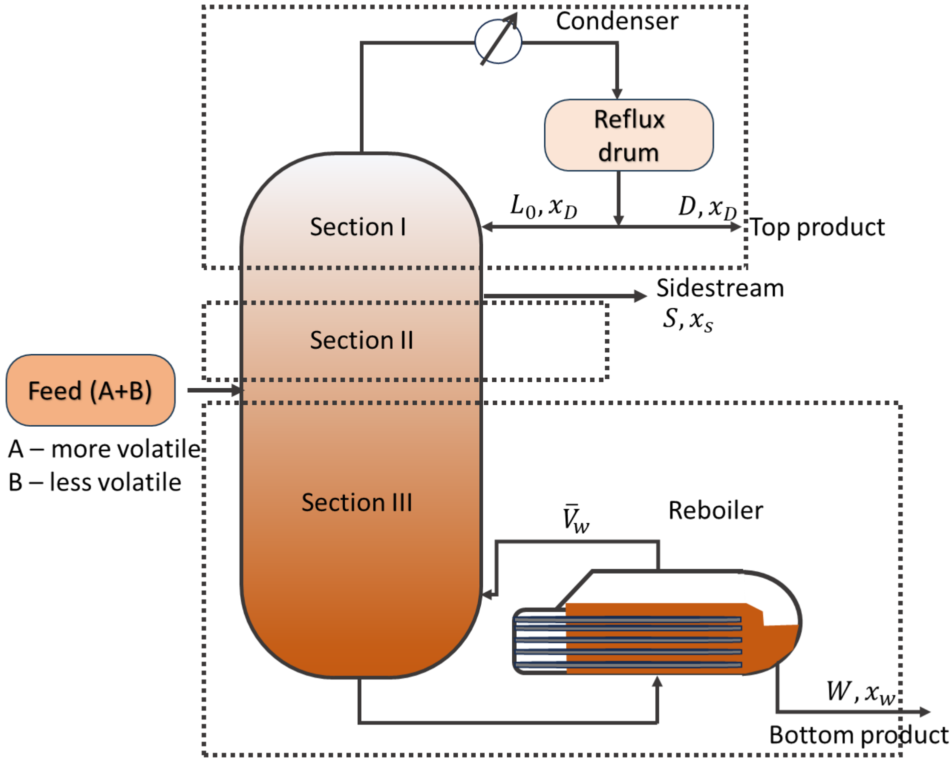
(15 points)

(viii) Do the same for Sections II and III.

(15 + 15 points)

(ix) Use MATLAB to perform the McCabe-Thiele construction to determine the number of ideal trays required for the given system. Show the construction in Figure 2 and locate the feed tray and the tray from which the sidestream needs to be withdrawn.

(15 points)


Condenser
Reflux drum
Section I
L_0, x_D
D, x_D
Top product
Sidestream
S, x_s
Section II
Feed (A+B)
A – more volatile
B – less volatile
Section III
$\bar{V}_w$
Reboiler
W, x_w
Bottom product