CHEE 204: Assignment 10 - Distillation Column Optimization

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90/100

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Proposed Optimization Conditions

The reference temperature adopted in the program was 25°C in the liquid phase.

Acetone was chosen to be the purified component in the top stream because it may achieve the highest profit since its selling price is large than toluene and nearly twice that of benzene; furthermore, it is the most volatile component, and, thus, easier to target in the outlet vapour stream. Its vapor composition must exceed 0.99 to be considered pure enough to sell. ✓

We initially aimed to get the composition of acetone as close to 0.990 as possible, since the profit associated with an increase in composition between 0.990 and 1.00 is negligible while the cost becomes excessively large. So, by keeping Qr constant, we were able to determine the associated Qc value to achieve an almost 99% acetone purity. Doing this for several Qr points allowed us to develop a database of R ($= |\frac{Qc}{Qr}|$) values, providing a range of "optimal" R values that put us in the aforementioned composition range. Then, we could iterate over a range of Qr values, multiplying each by the R values to determine the associated Qc, to deduce the highest profit (or lowest cost) possible for that pair of heat duties. ✓

Through this iterative process, we determined that an optimal solution can be achieved when the input heating duties of the reboiler and condenser are Qr = 250 $\frac{kJ}{mol}$ and Qc = -232.6 $\frac{kJ}{mol}$, respectively.

The composition of the stream exiting the top of the column as vapor is:

$$y_{\text{Acetone}} = 0.990709 \approx 0.991$$

$$y_{\text{Benzene}} = 0.009290 \approx 0.001$$

$$y_{\text{Toluene}} = 0.000001 \approx 0.000$$

What was your intital guess? What happens at different R?

And the composition of the stream exiting the bottom of the column as liquid is:

$$x_{\text{Acetone}} = 0.027573 \approx 0.028$$

$$x_{\text{Benzene}} = 0.484053 \approx 0.484$$

$$x_{\text{Toluene}} = 0.488374 \approx 0.488$$

Once the ideal heat duties were specified, we iterated through each tray to determine which would yield the highest profit (Figure 1):

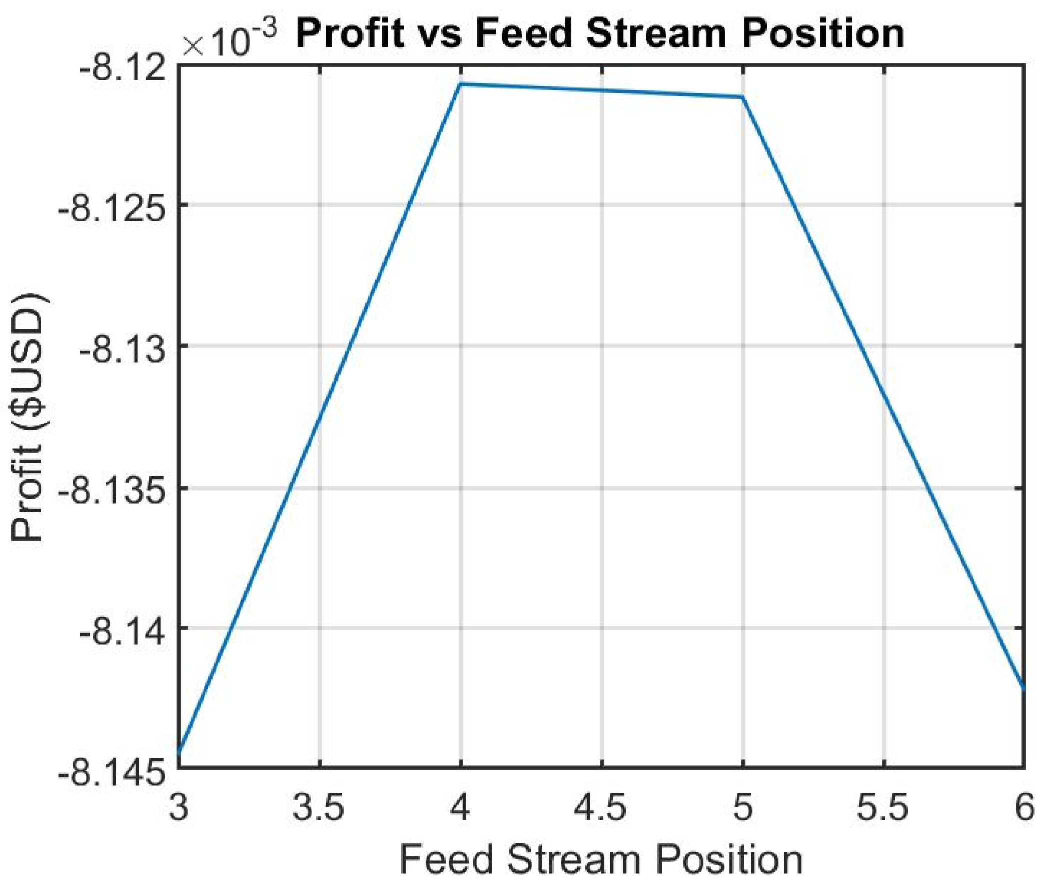

Figure 1: Profit and Varying Feed Trays

In Figure 1, the profit is maximized (or cost minimized) at -0.0081 USD when the feed is supplied at the 4^{th} tray in the distillation column.

In general, the given conditions of the problem make it impossible to incur a positive profit. Neglecting the costs associated with heating, we can determine the maximum profit by comparing the cost of the liquid feed to the revenue from the fully separated acetone stream (i.e. $\frac{1}{3}$ moles of acetone separated in top stream). Such calculations show that positive profit can never be achieved as feed costs outweigh the highest possible revenue; therefore, any additional heating costs will only further decrease the profit.

Alternative Scenarios

As it is not possible to incur a positive profit under the given operating conditions, further investigation was done to determine the break-even point. The two variables investigated include the market price of acetone and the cost of the liquid feed. As previously described, decreasing the cost of the heating duties would prove futile as the cost of the liquid feed always surpasses the revenue of the purified stream.

Firstly, by steadily increasing the market price for acetone, the break-even point can be determined (Figure 2).

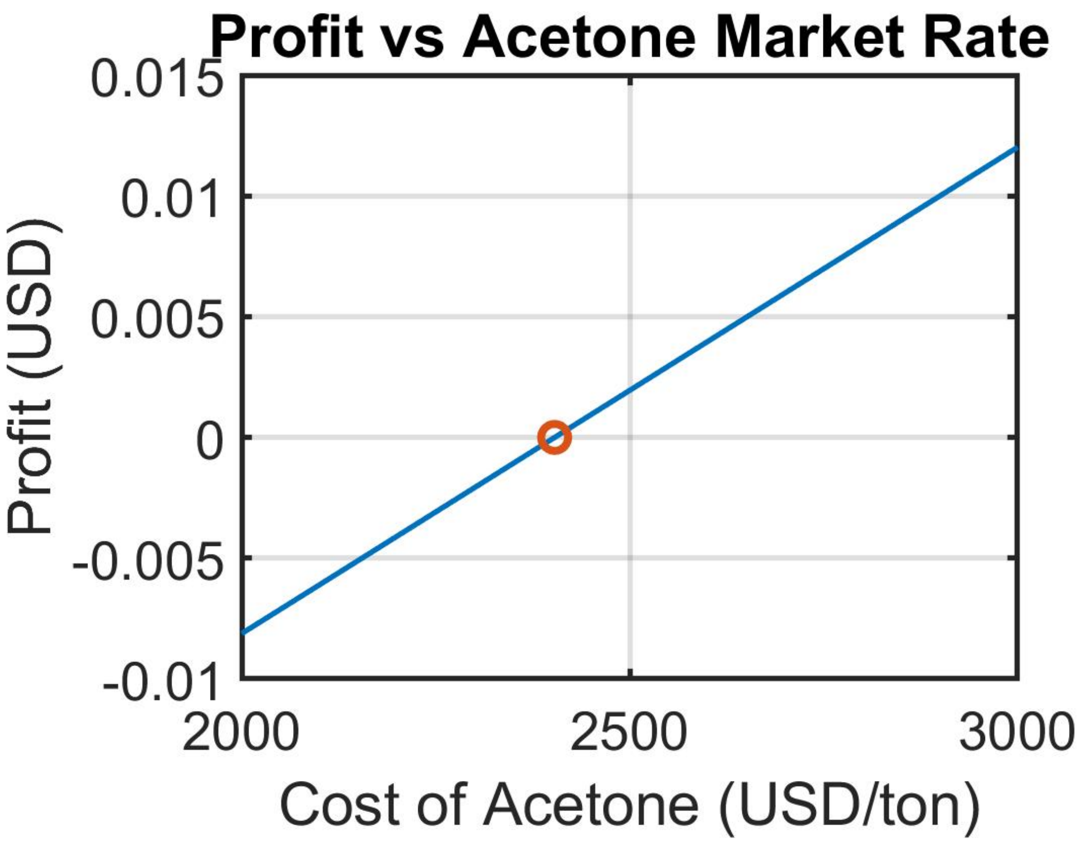

Figure 2: Profit and Varying Acetone Market Prices

From Figure 2, the break-even point occurs at a selling price of 2403.29 $\frac{USD}{ton}$, an increase of approximately 20%. For any price above this value, we realize profit.

Secondly, we can observe how profit changes as the cost of the liquid feed decreases

(Figure 3).

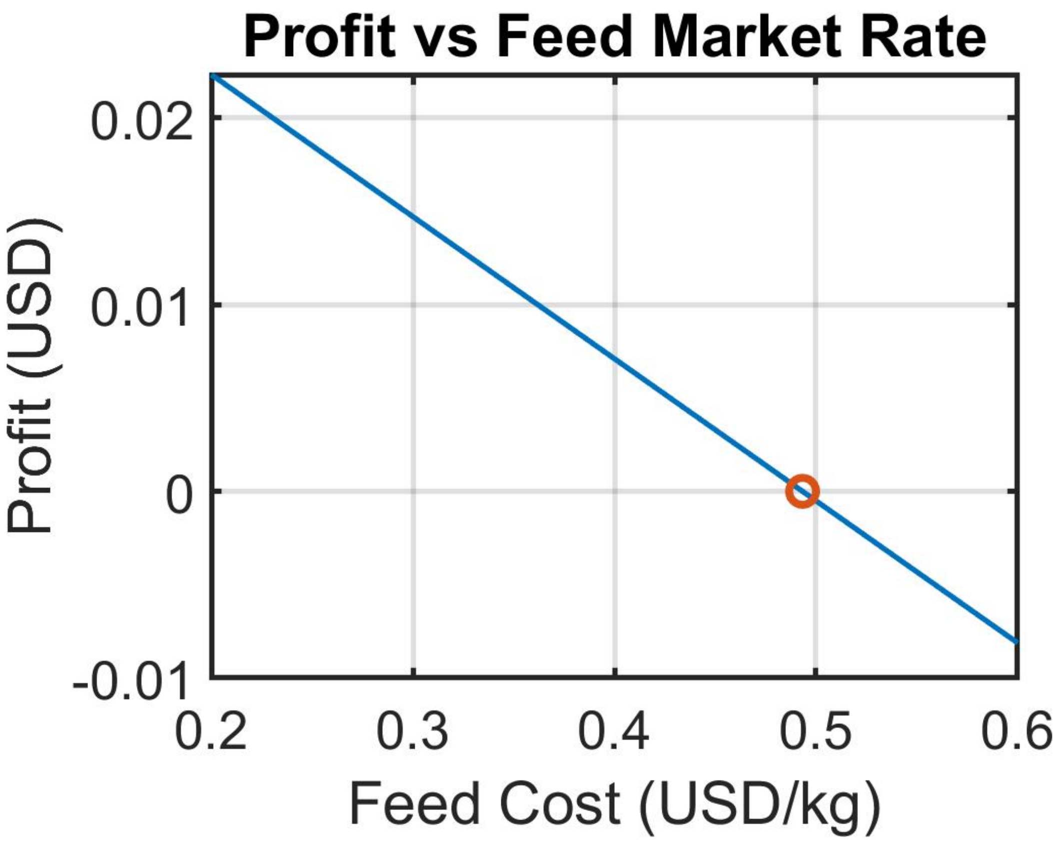

Figure 3: Profit and Varying Feed Costs

From Figure 3, the break-even point occurs when the selling price of the liquid feed is 0.49 $\frac{USD}{kg}$. Thus for any lower price, positive profit is achieved.

In short, the minimum price to sell pure acetone to realize profit would be 2403.29 $\frac{USD}{ton}$ at the proposed operating conditions. At the given market rates, a profit is unattainable; however, the best-case scenario we found was to minimize the losses to -0.0081 USD per mol of feed.

Operating Profiles

The following figures describe the operating conditions' molar flow rates, temperatures, and liquid/vapor compositions (Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9):

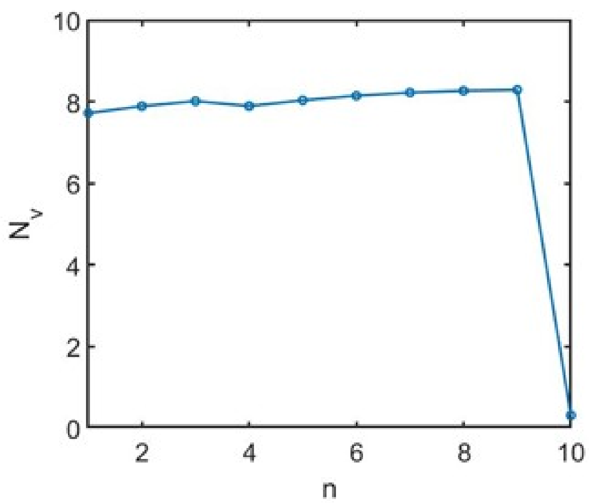

Figure 4: Moles of Vapour per Stage

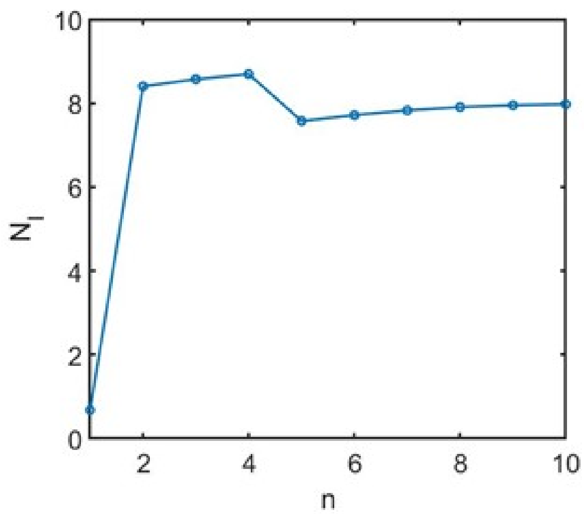

Figure 5: Moles of Liquid per Stage

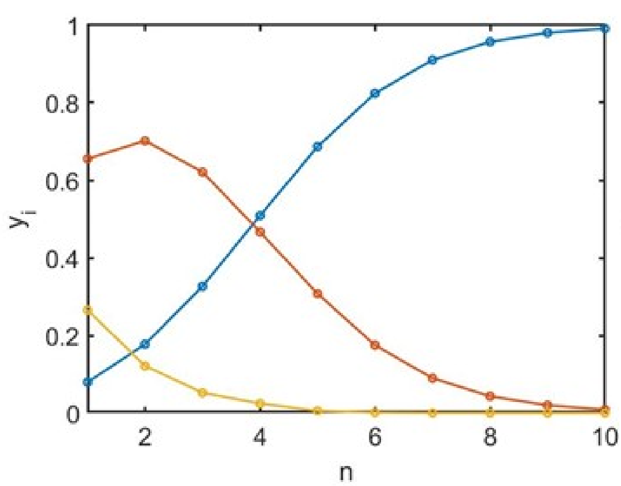

Figure 6: Vapour Composition per Stage

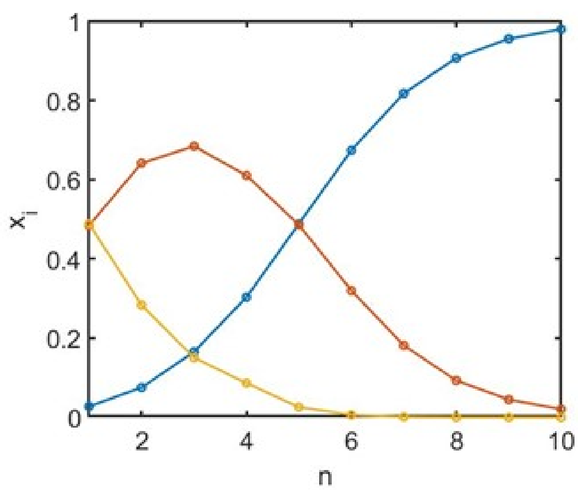

Figure 7: Liquid Composition per Stage

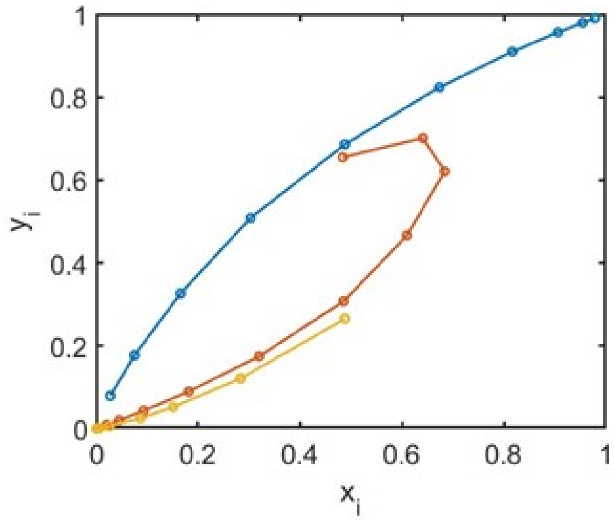

Figure 8: Vapour/Liquid Composition per Stage

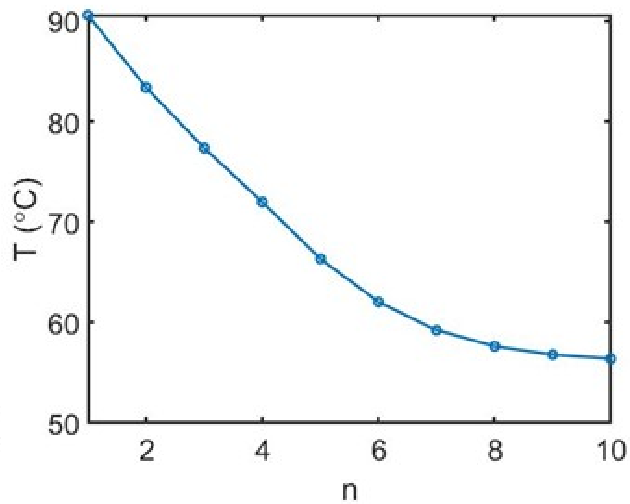

Figure 9: Temperature per stage