Herbal Oil Production

(1) $\log_{10} P^{sat}\{bar\} = A - \frac{B}{T\{K\} + C}$

Menthol Antoine Constants

$A = 5.38347$
$B = 2405.946$
$C = 111$

Temp Range: 329–485 K

Normal BP of menthol (M) = 63°C = 336.15K

A)

(0) Extractor Output, Super-heated: $T_0 = 110°C$, $P_0 =$, $\dot{n}_0 = \dot{n}_1$, $y_{0,H_2O} = 0.20$, $y_{0,M} = 1 - y_{0,H_2O}$ → Cooler →

(1) Feed: $T_1 = 95°C$, $P_1 = 1 atm$, $\dot{n}_1 =$, $y_{1,H_2O} = y_{0,H_2O}$, $y_{1,M} = y_{0,M}$ → Condenser ($P_{condenser} =$, $T_{condenser} =$)

(3) Vapor Product: $T_3 = T_2$, $P_3 = P_2$, $\dot{n}_3 =$, $y_{3,H_2O} =$, $y_{3,M} = 1 - y_{3,H_2O}$ → Rest of Production

(2) Condensate: $\dot{n}_2 = 100\ mol/hr$, $x_{2,H_2O} =$, $x_{2,M} = 1 - x_{2,H_2O}$, $T_2 = T_{condenser}$, $P_2 = P_{condenser}$

Givens & Want-to-Know

B) $P_{condenser} = 1\ atm$

D) Want to know: $\dot{n}_3$

Additional EQs

Antoine (1) $\log_{10} P^{sat}_{H_2O} = A - \frac{B}{T+C}$

(2) $\log_{10} P^{sat}_{m} = A - \frac{B}{T+C}$

Bubble Point (3) $P^{tot} = x_{2,H_2O} P^{sat}_{H_2O} + x_{2,m} P^{sat}_{m}$

Dew Point (4) $1 = \frac{y_{3,m} P^{tot}}{P^{sat}_{m}} + \frac{y_{3,H_2O} P^{tot}}{P^{sat}_{H_2O}}$

Raoult's (5) $y_{3,m} P = x_{2,m} P^{sat}_{m}$

B.4 T in °C, P^{sat} in mmHg

Antoine Constants for H_2O

0–60°C: $A = 8.10765$; $B = 1750.286$; $C = 235$

60–150°C: $A = 7.96681$; $B = 1668.210$; $C = 228$ ← Only Useful Here

B) $P_{condenser} = 1$ — Pseudo How to Solve

Plot should be x, y (mol fraction of menthol)

$T_{boil,H_2O}(1atm) = 100.3°C$ Wolfram

$T_{boil,m}(1atm) = 63°C$ Given (normal)

Evenly distribute Temp Values: $\frac{100.3 - 63}{33 - 3}$

$P^{sat}_m (bar) = 10^\wedge\left(A - \frac{B}{T_K + C}\right)$ D3

$P^{sat}_{H_2O}(mmHg) = 10^\wedge\left(A - \frac{B}{T_C + C}\right)$ F3

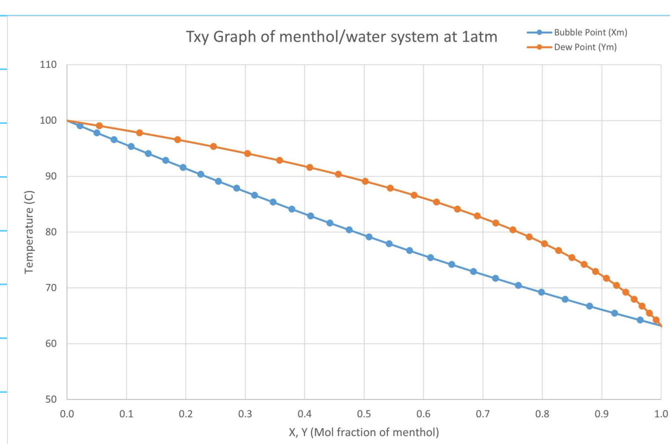
$1\ bar \times \frac{750.06156\ mmHg}{1\ bar}$ E3

Binary Bubble Pt.

$$P^{tot} = x_m P^{sat}_m + (1 - x_m) P^{sat}_{H_2O}$$
$$= x_m P^{sat}_m + P^{sat}_{H_2O} - x_m P^{sat}_{H_2O}$$
$$= x_m (P^{sat}_m - P^{sat}_{H_2O}) + P^{sat}_{H_2O}$$

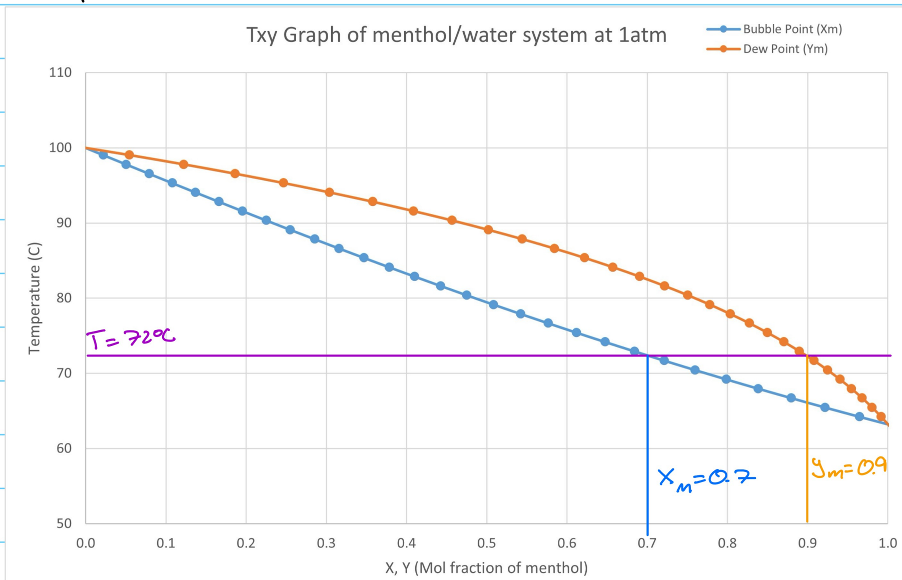
$$\Rightarrow x_m = \frac{P^{tot} - P^{sat}_{H_2O}}{P^{sat}_m - P^{sat}_{H_2O}} \quad G3$$

$$y_m = \frac{x_m P^{sat}_m}{P^{tot}} \quad H3$$



Herbal Oil Production (Continued)

C) Temperature = 72°C



At 72°C Outputs
Liquid: $x_{3,m} = 0.7$
$x_{3,H_2O} = 0.3$
Vapor: $y_{3,m} = 0.9$
$y_{3,H_2O} = 0.1$

D) Horizontal line under part D indicates that we should continue to use the same process conditions from B and C. I will assume $T_{condenser} = 72°C$ and $P_{condenser} = 1$ atm as the process conditions are only explicitly stated to change in part E.

DoF Condenser

2 Unknowns ($\dot{n}_1$, $\dot{n}_3$) All compositions can be read from Txy plot

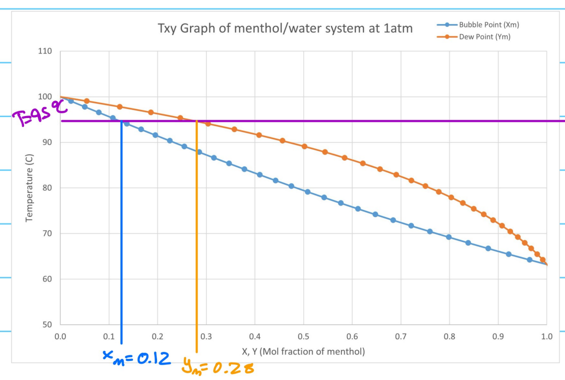
+0 Chemical Reactions

-2 Material Balances (H_2O & Menthol)

-0 Additional EQs

Soluble :)

Every stream is multiphase



Material Balances Condenser

From (c)

H_2O: $\dot{n}_1 y_{1,H_2O} + \dot{n}_1 x_{1,H_2O} = \dot{n}_2 x_{2,H_2O} + \dot{n}_3 y_{3,H_2O}$

M: $\dot{n}_1 y_{1,m} + \dot{n}_1 x_{1,m} = \dot{n}_2 x_{2,m} + \dot{n}_3 y_{3,m}$

Total: $\dot{n}_1 = \dot{n}_2 + \dot{n}_3$

From (c)		Inlet Conditions
$x_{3,m} = 0.7$	$y_{3,m} = 0.9$	$x_m = 0.12$
$x_{3,H_2O} = 0.3$	$y_{3,H_2O} = 0.1$	$y_m = 0.28$

How to Solve

(i) Use Txy diagram to get $x_{1,m}$, $y_{1,m}$ at 95°C and 1 atm (inlet conditions), and use PFD to get x_{1,H_2O} and y_{1,H_2O}

(ii) Substitute $\dot{n}_1 = \dot{n}_2 + \dot{n}_3$ into M balance to solve for $\dot{n}_3$

↳ Can do this bc 3 equations 2 unknowns.

$\boxed{\text{Done, we have } \dot{n}_3\text{, production rate of vapor phase}}$

Herbal Oil Production (Continued)

E. Buyer requests $y_{3,H_2O} \leq 0.05$. $P_{condenser} = 1$ atm still; find $T_{condenser}$ for $y_{3,H_2O} = 0.05$ ← maximum allowable temp

Dew Point EQ: $1 = \frac{P y_{3,m}}{P_m^{sat}} + \frac{P y_{3,H_2O}}{P_{H_2O}^{sat}}$

T in K, P in bar → P_m^{sat}; $P_{H_2O}^{sat}$ ← T in C, P in mmHg

Pseudo "How to Solve"

(1) Find $y_{3,m}$ using PFD: $y_{3m} = 1 - y_{3,H_2O} = 1 - 0.05 = 0.95$

(2) Convert $P_{condenser}$ to bar and mmHg for dimensional homogeneity

$1 \text{ atm} \times \frac{1.013 \text{ bar}}{1 \text{ atm}}$ and $1 \text{ atm} \times \frac{760 \text{ mmHg}}{1 \text{ atm}}$ Conversions done in excel

(3) Substitute Antoine's Equation into Dew Point Equation

$$1 = \frac{y_{3,m} P}{10^{\wedge}\left(A - \frac{B}{T+C}\right)} + \frac{y_{3,H_2O} P}{10^{\wedge}\left(A - \frac{B}{T+C}\right)}$$

Final Answer is in °C, so guesses will be performed in °C

↳ P_m^{sat} is in terms of K, so shift left 273.15K

$$\Rightarrow \boxed{1 = \underbrace{\frac{y_{3,m} P^{\leftarrow bar}}{10^{\wedge}\left(A - \frac{B}{(T+273.15)+C}\right)}}_{P^*1} + \underbrace{\frac{y_{3,H_2O} P^{\leftarrow mmHg}}{10^{\wedge}\left(A - \frac{B}{T+C}\right)}}_{P^*2}}$$

P*1 ← in excel → P*2

(4) Guess a temperature of 80°C = T_{guess}

(5) Calculate Cells for P*1 and P*2 with T_{guess}

(6) Use Goal seek to find when T_{guess} in ☒ yields a value of 1

LHS Dew Point = 0.999937 when $T_{guess} = 66.36675$

$$\boxed{\text{Maximum allowed temperature: } 68.37°C}$$

Reflection Question

F) **Reflection**: Discuss the pros and cons of using Solver in excel vs. an already generated Txy diagram.

Solver is an extremely powerful tool that allows for determining accurate solutions via guessing. This is particularly useful for solving for Temperature from the Dew Point or Bubble Point equations. These questions can be hard or impossible to solve as they involve the unknown being in a fractional exponent. Excels ability to do this is great for these applications, but when I played around with it, it looks like Excel will give up after too many failed attempts. This seems like a small issue as you need to have a general idea of the range your goal is in, or else excel may just fail. This might be difficult in real world applications where behavior is more unpredictable. Also it is a little hard to set up sometimes as you need to keep track of the different references in complex equations and make sure all of your units are homogenous. That being said, it is great for more predictable systems like ones where a Txy plot is already generated and you know a standard operating range. Also the immense speed of the checks is great from a time saving point of view, and the UI is simple. For Txy plots, they can be very useful for quickly reading compositions based off provided temperature, or the other way around. This makes them very useful for the system they were designed for, but as soon as the operating pressure changes, the Txy plot doesn't work anymore. Despite the readability and ease of understanding, the Txy plot is much weaker than the Solver function in Excel which can react to changes in input data easily as you just have to rerun the command. You need to remake a full plot if you change the input parameters of a Txy plot, which can definitely be a downside. Overall, Txy and Solver plots in Excel aren't necessarily better than each other, and can be used well given that you understand the software and your situation lends itself to the strength of either method.