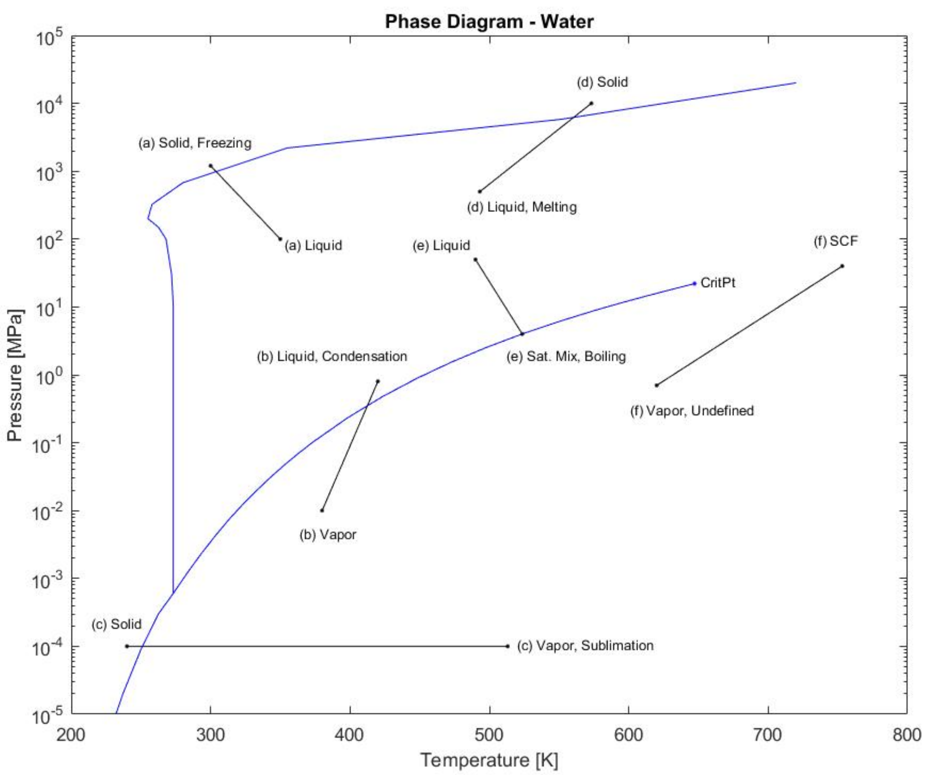
Homework #2

MEMS 0051 - Introduction to Thermodynamics

Assigned: May 14th, 2020
Due: May 21st, 2020

Problem #1

1. Given the MATLAB script "`Phase_diagram.m`", plot each of the following points and indicate, on the graph, if the substance is existing as a solid, liquid, vapor, or super-critical fluid. Additionally, for the process, plot the initial and final state, and indicate what type of process has occurred, i.e. sublimation, deposition, vaporization, condensation, melting or freezing. An example of how to plot a point, a line, and text is included within the MATLAB script.
   (a) 350 [K] and 100 [MPa] $\rightarrow$ 300 [K] and 1200 [MPa] liquid, solid, freezing
   (b) 380 [K] and 10 [kPa] $\rightarrow$ 420 [K] and 0.8 [MPa] vapor, liquid, condensation
   (c) 240 [K] and 100 [Pa] $\rightarrow$ 240 °C and 0.1 [kPa] solid, vapor, sublimation
   (d) 300 °C and 10 [GPa] $\rightarrow$ 220 °C and 0.5 [GPa] solid, liquid, melting
   (e) 490 [K] and 50 [MPa] $\rightarrow$ 523.55 [K] and 4 [MPa] liquid, saturated mixture, ready to boil/boiling
   (f) 480 °C and 40 [MPa] $\rightarrow$ 620 [K] and 700 [kPa] supercritical fluid, vapor, no identifiable process



2. Pasta often includes directions for different cooking times at different elevations above sea level. How is the cooking time at an elevation of 2 [km] different from that at sea level? Why is this?

   The time required to fully cook pasta <u>increases</u> as height from sea level increases. This is because the boiling point of water is dependent upon pressure. As pressure decreases with increasing altitude, water boils at lower and lower temperatures, thus requiring longer cooking times.

3. Imagine you are on a space flight from Earth to the International Space Station. As your ship approaches the station, you suddenly feel discomfort and realize the saliva on your tongue has started bubbling. If the flight was comfortable just moments ago, what could be happening to cause this?

   Assuming the temperature inside the ship was comfortable, something has occurred to cause the pressure inside the vessel to be drastically reduced, enough to cause the water in your saliva to boil.

Problem #2

Given the following properties, determine the remaining properties (i.e. pressure, temperature, specific volume and quality, if applicable), for water. Indicate if the water is existing as a compressed/subcooled liquid, saturated liquid water, saturated vapor or superheated steam. Additionally, using the Matlab Script titled "`Pv_and_Tv_curves`.m", plot and label each item on both a $P-\nu$ and $T-\nu$ diagram. Note: interpolation may be required multiple times.

(a) $P = 500$ [kPa], $T = 130$ °C

Looking at Table B.1.1 on page 776 of the steam tables, water at 130 °C has a saturation pressure of 270.1 [kPa]. The given pressure is greater than the saturation pressure ($\mathrm{P} > \mathrm{P_{sat}}$), which indicates it is existing as a compressed/subcooled liquid. Alternatively, we could look at Table B.1.2 on page 780 and see for an entry of 500 [kPa] that the saturation temperature is 151.86 °C. The given temperature is less than the saturation temperature ($\mathrm{T} < \mathrm{T_{sat}}$), which indicates again it is existing as a compressed/subcooled liquid.

Using Table B.1.4 on page 790, the specific volume corresponds to 130 °C and 500 [kPa] and is found by interpolating between the 120 °C and 140 °C entries:

$$\frac{(130-120)\,[^\circ\mathrm{C}]}{(140-120)\,[^\circ\mathrm{C}]} = \frac{(\nu - 0.001060)\,[\mathrm{m^3/kg}]}{(0.001\,080 - 0.001\,060)\,[\mathrm{m^3/kg}]} \implies \nu = 0.001\,070\,[\mathrm{m^3/kg}]$$

Alternatively, we recognize that water is an incompressible substance and can use the saturate water temperature table (B.1.1) on page 776 and take the specific volume corresponding to the given temperature. We note the saturated liquid specific volume taken at 130 °C is the same as the specific volume taken from the compressed/subcooled liquid table.

(b) $P = 520$ [kPa], $\nu = 0.180\,46$ [m^3/kg]

Looking at Table B.1.2 on page 780, it is likely the fluid is existing as saturated water. We interpolate between 500 and 550 [kPa] to determine the saturation temperature:

$$\frac{(520-500)\,[\mathrm{kPa}]}{(550-500)\,[\mathrm{kPa}]} = \frac{(T - 151.86)\,[^\circ\mathrm{C}]}{(155.48 - 151.86)\,[^\circ\mathrm{C}]} \implies T = 153.31\,[^\circ\mathrm{C}]$$

We interpolate between 500 and 550 [kPa] to determine the saturated liquid specific volume:

$$\frac{(520-500)\,[\mathrm{kPa}]}{(550-500)\,[\mathrm{kPa}]} = \frac{(\nu_f - 0.001\,093)\,[\mathrm{m^3/kg}]}{(0.001\,097 - 0.001\,093)\,[\mathrm{m^3/kg}]} \implies \nu_f = 0.001\,095\,[\mathrm{m^3/kg}]$$

We interpolate between 500 and 550 [kPa] to determine the saturated vapor specific volume:

$$\frac{(520-500)\,[\mathrm{kPa}]}{(550-500)\,[\mathrm{kPa}]} = \frac{(\nu_f - 0.374\,89)\,[\mathrm{m^3/kg}]}{(0.342\,68 - 0.374\,89)\,[\mathrm{m^3/kg}]} \implies \nu_g = 0.362\,01\,[\mathrm{m^3/kg}]$$

The quality is found by:

$$x = \frac{\nu - \nu_f}{\nu_g - \nu_f} = \frac{(0.180\,46 - 0.001\,095)\,[\mathrm{m^3/kg}]}{(0.362\,01 - 0.001\,095)\,[\mathrm{m^3/kg}]} = 0.496\,7$$

(c) $P = 2{,}000$ [kPa], $x = 0.8$

Since quality is given, the fluid is existing as saturated water. Looking at Table B.1.2 on page 780, the saturation temperature is found to be 212.42 °C. The specific volume is determined from the definition of quality:

$$\nu = \nu_f + x\nu_{fg} = (0.001\,177\,[\mathrm{m^3/kg}]) + (0.8)(0.098\,45\,[\mathrm{m^3/kg}]) = 0.079\,94\,[\mathrm{m^3/kg}]$$

(d) $P = 950$ [kPa], $T = 320$ °C

Looking at Table B.1.2 on page 782, the given temperature is greater than the saturation temperature, thus the fluid exists as a superheated vapor, and the quality is undefined. Looking at Table B.1.3 on page 785, we see the specific volume exists between 300 and 350 °C. Constructing an intermediate temperature table for 950 [kPa], the specific volume at 800 [kPa] is:

$$\frac{(320-300)\,[^\circ\mathrm{C}]}{(350-300)\,[^\circ\mathrm{C}]} = \frac{(\nu_{800\,[\mathrm{kPa}]} - 0.324\,11)\,[\mathrm{m^3/kg}]}{(0.354\,39 - 0.324\,11)\,[\mathrm{m^3/kg}]} \implies \nu_{800\,[\mathrm{kPa}]} = 0.336\,22\,[\mathrm{m^3/kg}]$$

Constructing an intermediate temperature table for 320 °C, the specific volume at 1000 [kPa] is:

$$\frac{(320-300)\,[^\circ\mathrm{C}]}{(350-300)\,[^\circ\mathrm{C}]} = \frac{(\nu_{1,000\,[\mathrm{kPa}]} - 0.257\,94)\,[\mathrm{m^3/kg}]}{(0.282\,47 - 0.257\,94)\,[\mathrm{m^3/kg}]} \implies \nu_{1,000\,[\mathrm{kPa}]} = 0.267\,75\,[\mathrm{m^3/kg}]$$

Interpolating between 800 and 1000 [kPa] at 320 °C:

$$\frac{(\nu_{320\,^\circ\mathrm{C}} - 0.336\,22)\ [\mathrm{m^3/kg}]}{(0.267\,75 - 0.336\,22)\ [\mathrm{m^3/kg}]} = \frac{(950-800)\ [[\mathrm{kPa}]}{(1,000-800)\ [\mathrm{kPa}]} \implies \nu_{320\,^\circ\mathrm{C}} = 0.284\,87\ [\mathrm{m^3/kg}]$$

(e) $T = 325$ °C, $\nu = 0.001\ 528$ [m^3/kg]

Looking at Table B.1.1 on page 778, the given specific volume is equal to the saturated liquid specific volume. Thus, the fluid exists as a saturated liquid, with a quality of $x = 0$ and a saturation pressure of $\mathrm{P_{sat}} = 12{,}040$ [kPa].

(f) $T = 103$ °C, $x = 0.2$

Since quality is given, the fluid is existing as saturated water. Looking at Table B.1.1 on page 776, we interpolate between 105 and 100 °C to determine the saturation pressure:

$$\frac{(103-100)\,^\circ\mathrm{C}}{(105-100)\,^\circ\mathrm{C}} = \frac{(P - 101.3)\,[\mathrm{kPa}]}{(120.8 - 101.3)\,[\mathrm{kPa}]} \implies P = 113\,[\mathrm{kPa}]$$

We interpolate between 105 and 100 °C to determine the saturated liquid specific volume:

$$\frac{(103-100)\ ^\circ\mathrm{C}}{(105-100)\ ^\circ\mathrm{C}} = \frac{(\nu_f - 0.001\,044)\,[\mathrm{m^3/kg}]}{(0.001\,047 - 0.001\,044)\,[\mathrm{m^3/kg}]} \implies \nu_f = 0.001\,046\,[\mathrm{m^3/kg}]$$

We interpolate between 105 and 100 °C to determine the saturated vapor specific volume:

$$\frac{(103-100)\ ^\circ\mathrm{C}}{(105-100)\ ^\circ\mathrm{C}} = \frac{(\nu_g - 1.672\,90)\,[\mathrm{m^3/kg}]}{(1.419\,36 - 1.672\,90)\,[\mathrm{m^3/kg}]} \implies \nu_g = 1.520\,78\,[\mathrm{m^3/kg}]$$

The specific volume is determined from the definition of quality:

$$\nu = \nu_f + x\nu_{fg} = (0.001\,046\,[\mathrm{m^3/kg}]) + (0.2)(1.520\,78\,[\mathrm{m^3/kg}]) = 0.305\,20\,[\mathrm{m^3/kg}]$$

(g) $P = 215$ [kPa], $T = 121.5$ °C

Looking at Table B.1.2 on page 780, the phase of the water is initially unclear. We can determine this by interpolating between 200 and 225 [kPa] for the saturation temperature:

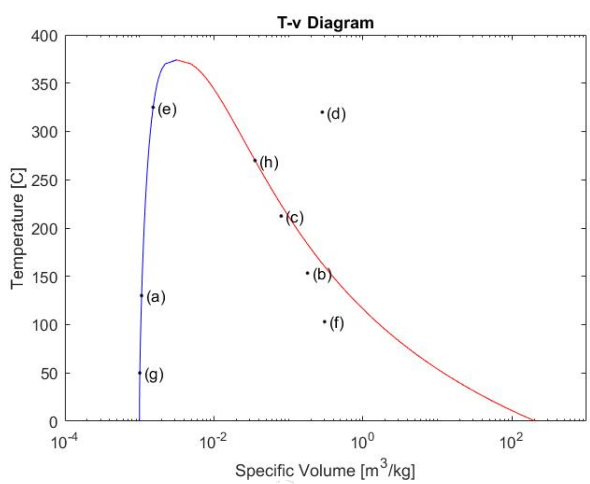
$$\frac{(215-200)\,[\text{kPa}]}{(225-200)\,[\text{kPa}]} = \frac{(T-120.23)\,^\circ\text{C}}{(124-120.23)\,^\circ\text{C}} \implies T = 122.49\,^\circ\text{C}$$

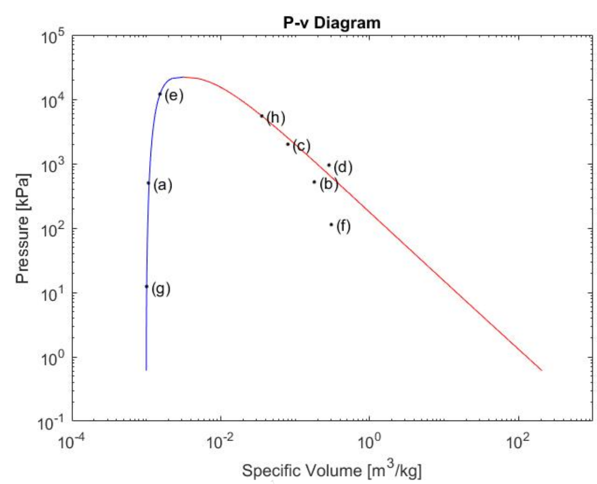
Since the given temperature is less than the saturation temperature for the given pressure, the fluid exists as a compressed/subcooled liquid, and thus the quality is undefined. Since the lowest pressure entry on Table B.1.4 on page 790 is 500 [kPa], we use Table B.1.1 on page 776 and interpolate between the 120 and 125 °C entries:

$$\frac{(121.5-120)\,^\circ\text{C}}{(125-120)\,^\circ\text{C}} = \frac{(\nu - 0.001\,060)\ [\text{m}^3/\text{kg}]}{(0.001\,065-0.001\,060)\ [\text{m}^3/\text{kg}]} \implies \nu = 0.001\,062\ [\text{m}^3/\text{kg}]$$

(h) $T = 270$ °C, $\nu = 0.035\,64$ [m^3/kg]

Looking at Table B.1.1 on page 778, the given specific volume is equal to the saturated vapor specific volume, thus the fluid exists as a saturated vapor, with a quality of $x = 1$ and a saturation pressure of $\text{P}_{\text{sat}} = 5{,}498.7$ [kPa].





Problem #3

A piston-cylinder initially has a volume of 0.05 m^3 and contains saturated water at a temperature of 110 °C with a quality of 80%. It undergoes isochoric heating until the water reaches 150 °C. The piston-cylinder next experiences isobaric cooling until the water returns to 110 °C. Finally, an isothermal expansion process occurs until the water is once again a saturated mixture with a quality of 80%.

1. For each state, identify the phase(s) and determine the pressure, temperature, specific volume, and if applicable, quality.

There are three different states present in this problem. From the initial given information, we have:

State 1:	State 2:	State 3:
$\text{T}_1 = 110$°C	$\text{T}_2 = 150$°C	$\text{T}_3 = 110$°C
$\text{P}_1 = ?$	$\text{P}_2 = ?$	$\text{P}_3 = ?$
$\nu_1 = ?$	$\nu_2 = ?$	$\nu_3 = ?$
$\text{x}_1 = 0.8$	$\text{x}_2 = ?$	$\text{x}_3 = ?$
$\text{V}_1 = 0.05$ [m^3]		

Looking at Table B.1.1 on page 776, for $\text{T}_1 = \text{T}_{sat}$, we see the saturation pressure is $\text{P}_{sat} = 143.3$ [kPa]. Since we are given the quality at state 1, we know the water is a saturated mixture (composed of liquid and vapor), and the specific volume can be found using the definition of quality:

$$\nu_1 = \nu_f + x_1\nu_{fg} = (0.001\,052 + (0.8)(1.209\,09))\ [\text{m}^3/\text{kg}] = 0.968\,32\ [\text{m}^3/\text{kg}]$$

Now, we know the process between states 1 and 2 occurs at constant volume, meaning $\forall_2 = \forall_1$. Since this is a closed system, we can also say $\nu_2 = \nu_1$. Looking at Table B.1.1 on page 776, for $T_2 = T_{sat}$, the saturated vapor specific volume is $\nu_g = 0.392\,78$ [m^3/kg]. Since $\nu_2 > \nu_g$, the water is a superheated vapor. The quality, x_2, then is undefined, and the pressure is found by looking at Table B.1.3 on page 784 and interpolating between entries:

$$\frac{(0.968\,32 - 1.936\,36)\ [\mathrm{m}^3/\mathrm{kg}]}{(0.959\,64 - 1.936\,36)\ [\mathrm{m}^3/\mathrm{kg}]} = \frac{(P_2 - 100)\ [[\mathrm{kPa}]}{(200 - 100)\ [\mathrm{kPa}]} \implies P_2 = 199.11\ [\mathrm{kPa}]$$

Moving from states 2 to 3, we know the process occurs at a constant pressure, meaning that $P_3 = P_2$. Looking at Table B.1.2 on page 780, for $P_3 = P_{sat}$, we see $T_3 < T_{sat}$, which means the water is a compressed/subcooled liquid. Since we know the lowest pressure listed in Table B.1.4 is 500 [kPa], to find the specific volume, we look at Table B.1.1 on page 776:

$$\nu_3 = \nu_{f,110\ ^\circ\mathrm{C}} = 0.001\,052\ [\mathrm{m}^3/\mathrm{kg}]$$

Finally, moving from state 3 back to state 1, we know the process occurs at a constant temperature. As the piston-cylinder expands, the pressure will drop until it reaches the saturation pressure for T = 110 °C, which is $P_{sat} = 143.3$ [kPa]. Since the quality is the same as in state 1, the specific volume will also be the same, thus returning us to all the same properties found in state 1.

2. Do these processes represent a cycle? Why or why not?

   Yes, these processes do represent a cycle. The system, i.e. the water, goes through different changes of state and returns to its initial state.

3. Calculate the total mass, and if applicable, the mass of the liquid and vapor at each state within the vapor dome.

   Since this is a closed system, and because $\forall_2 = \forall_1$, we can find the total mass from the properties at state 2:

$$m = \frac{\forall_2}{\nu_2} = \frac{0.05\ [\mathrm{m}^3]}{0.968\,32\ [\mathrm{m}^3/\mathrm{kg}]} = 0.0516\ \ [\mathrm{kg}]$$

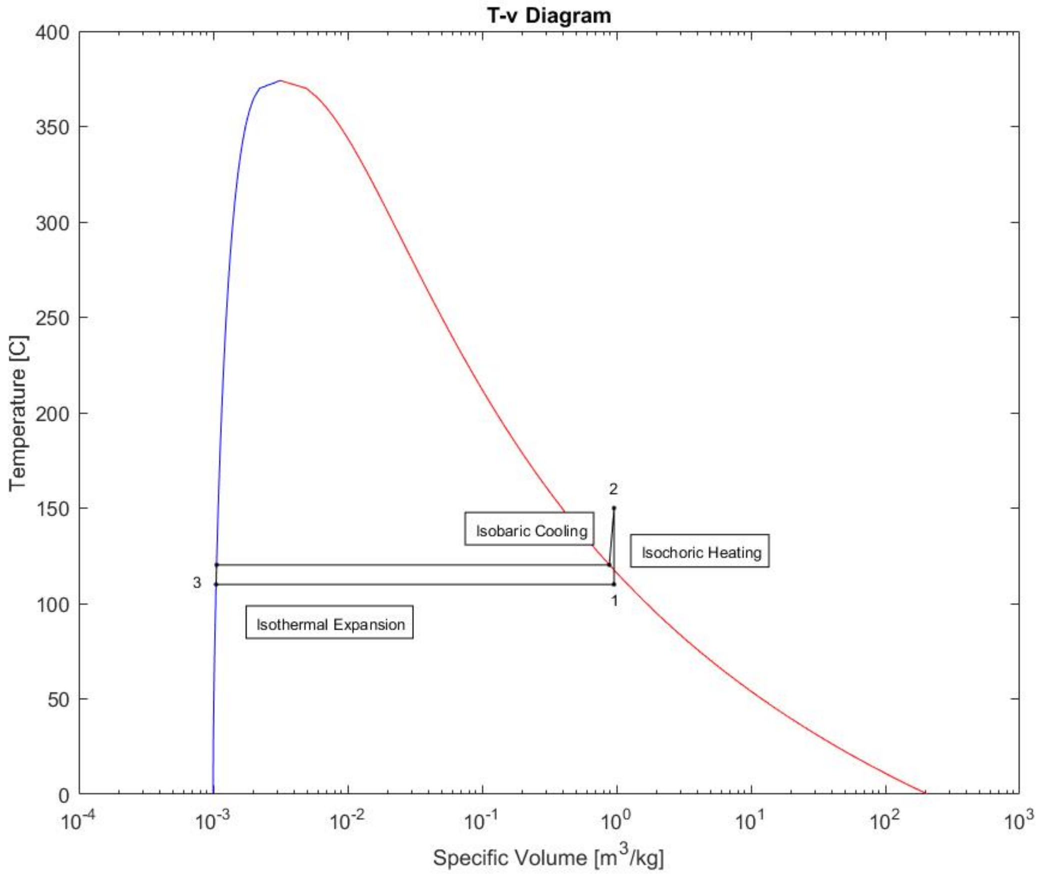
   Note that the mass at state 2 must be the same as at state 3. State 1 is the only state within the vapor dome. From the definition of quality, we can find the mass of the vapor:

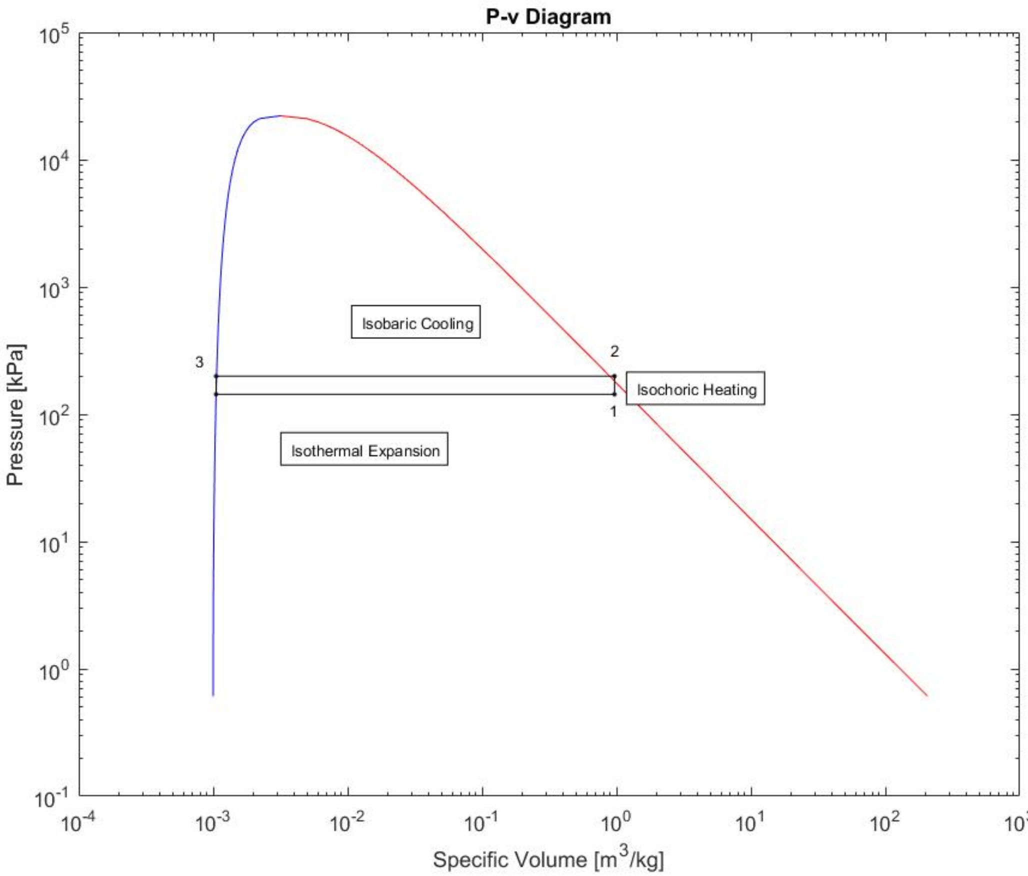
$$m_{vap} = m x_1 = (0.0516\,[\mathrm{kg}])(0.8) = 0.0413\ \ [\mathrm{kg}]$$

   Finally, the mass of the liquid phase must be the remaining mass:

$$m_{liq} = m - m_{vap} = (0.0516 - 0.0413)\,[\mathrm{kg}] = 0.0103\ \ [\mathrm{kg}]$$

4. Given the MATLAB script "`Pv_and_Tv_curves.m`", plot and label each of the states. For the process, plot lines between each state, and indicate what type of process has occurred, i.e. isobaric, isochoric or isothermal. An example of how to plot a point, a line, and text is included within the MATLAB script.





Problem #4

Create an interpolation script in MATLAB. The interpolation script should have six inputs and one output. You are to use the input command to request user data. User your script, which is to be submitted to (use MATLAB online grader utility), to interpolate the following data.

Problem #5

Create a program in MATLAB to calculate the quality of saturated water. The script should have three input: saturated liquid specific volume, saturated vapor specific volume, and specific volume.