Homework #2

MEMS 0051 - Introduction to Thermodynamics

Assigned May 15$^{\text{th}}$, 2018
Due: May 21$^{\text{st}}$, 2018

Problem #1

Use the thermodynamic steam tables to determine the phase (compressed/subcooled liquid, saturated liquid, saturated water, saturated vapor, superheated vapor) of water at the following conditions. In addition to identifying the phase, create one T-ν and one P-ν diagram and plot each item with a dot, indicating it's phase as well. To create the T-ν and P-ν diagrams, plot temperature versus saturated liquid and vapor specific volume and pressure versus saturated liquid specific volume in Matlab. Ensure the x- and y-axis scales are appropriate (logarithmic and linear, respectively). Include axes labels, units and chart title.

(a) 100 °C, 101.3 [kPa]

Looking at Table B.1.1 on page 776 of the steam tables, water at 100 °C has a saturation pressure of 101.3 [kPa]. Therefore, it is existing as a saturated water. Without any other identifying property (i.e. quality), the specific volumes can range between that of the saturated liquid and saturated vapor specific volumes: $0.001044\,[\text{m}^3/\text{kg}] \leq \nu \leq 1.67290\,[\text{m}^3/\text{kg}]$.

(b) 180 °C, 2,000 [kPa]

Looking at Table B.1.1 on page 776 of the steam tables, water at 180 °C has a saturation pressure of 1,002.2 [kPa]. The given pressure is greater than the saturation pressure ($P > P_{\text{sat}}$), which indicates it is existing as a compressed/subcooled liquid. Alternatively, we could look at Table B.1.2 on page 782 and see for an entry of 2,000 [kPa] that the saturation temperature is 212.42 °C. The given temperature is less than the saturation temperature ($T < T_{\text{sat}}$), which indicates again it is existing as a compressed/subcooled liquid.

Using Table B.1.4 on page 790, the specific volume correspond to 180 °C and 2,000 [kPa] is found as 0.001127 [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 180 °C is the same as the specific volume taken from the compressed/subcooled liquid table.

(c) 160 °C, 400 [kPa]

Looking at Table B.1.1 on page 776 of the steam tables, water at 160 °C has a saturation pressure of 617.8 [kPa]. The given pressure is less than the saturation pressure ($P < P_{\text{sat}}$), which indicates it is existing as a superheated vapor. Alternatively, we could look at Table B.1.2 on page 780 and see for an entry of 400 [kPa] that the saturation temperature is 143.63 °C. The given temperature is greater than the saturation temperature ($T > T_{\text{sat}}$), which indicates again it is existing as a superheated vapor.

Using Table B.1.3 on page 784, the specific volume would exist between the temperature entries of 150 and 200 °C. Using interpolation, we can set up the following equation to determine the specific volume:

$$\frac{(160-150)\,[^\circ\text{C}]}{(200-150)\,[^\circ\text{C}]} = \frac{(\nu - 0.47084)\,[\text{m}^3/\text{kg}]}{(0.53422-0.47084)\,[\text{m}^3/\text{kg}]} \implies \nu = 0.483516\,[\text{m}^3/\text{kg}]$$

(d) 400 °C, 200 [kPa]

We immediately recognize 400 °C is greater than the critical temperature of water. This does not mean water is existing as a supercritical fluid, rather, it most likely will exist in the superheated vapor phase. Looking at Table B.1.2 on page 780, the given temperature is greater than the saturation temperature corresponding to 200 [kPa] which is 120.23 °C, i.e. $T > T_{\text{sat}}$, which indicates it is existing as a superheated vapor. Using Table B.1.3 on page 784, the specific volume is directly found as 1.54930 [m^3/kg].

(e) 133.5 °C, 300 [kPa]

The given temperature exists in between published temperature values in Table B.1.1 on page 776, so using Table B.1.2 on page 780, it is evident that the given temperature is less than the saturation temperature corresponding to 300 [kPa], i.e. $T < T_{\text{sat}}$. Thus, it is existing as a compressed/subcooled liquid. Consulting Table B.1.4 on page 790, there exists no 300 [kPa] pressure entry and the given temperature is between temperature entries. Using this table would require the use of interpolation three times. Thus, using Table B.1.1, the specific volume is taken as the saturated liquid specific volume evaluated at 133.5 °C, which is found via interpolation:

$$\frac{(133.5 - 130)\,[^\circ\mathrm{C}]}{(135 - 130)\,[^\circ\mathrm{C}]} = \frac{(\nu - 0.001070)\,[\mathrm{m}^3/\mathrm{kg}]}{(0.001075 - 0.001070)\,[\mathrm{m}^3/\mathrm{kg}]} \implies \nu = 0.001074\,[\mathrm{m}^3/\mathrm{kg}]$$

(f) 100 °C, 800 [kPa]

Looking at Table B.1.1 on page 776, the given pressure is greater than the saturation pressure of water at 100 °C, which indicates it is existing as a compressed/subcooled liquid. The specific volume is equal to the saturated liquid specific volume evaluated at 100 °C, which is taken as 0.001044 [m^3/kg] from Table B.1.1 on page 776, or can be determined via interpolation from Table B.1.4 on page 790 via the following equation:

$$\frac{(800 - 500)\,[\mathrm{kPa}]}{(2,000 - 500)\,[\mathrm{kPa}]} = \frac{(\nu - 0.001043)\,[\mathrm{m}^3/\mathrm{kg}]}{(0.001043 - 0.001043)\,[\mathrm{m}^3/\mathrm{kg}]} \implies \nu = 0.001043\,[\mathrm{m}^3/\mathrm{kg}]$$

(g) 100 [kPa], 1.500 [m^3/kg]

Looking at Table B.1.2 on page 780, the given specific volume is bounded between the saturated liquid and saturated vapor specific volume, i.e. $\nu_f(100\ [\mathrm{kPa}]) < \nu < \nu_g(100\ [\mathrm{kPa}])$, $0.001043\,[\mathrm{m}^3/\mathrm{kg}] < \nu < 1.69400\,[\mathrm{m}^3/\mathrm{kg}]$. Therefore, it is existing as a liquid, vapor mixture.

(h) 100 [kPa], 2.500 [m^3/kg]

Looking at Table B.1.2 on page 780, it is evident the specific volume is greater than the saturated vapor specific volume, i.e. $\nu > \nu_g(100\ [\mathrm{kPa}])$, 2.50 [m^3/kg]>1.694 [m^3/kg]. Thus, it exists as a superheated vapor.

(i) 500 [kPa], 0.001070 [m^3/kg]

Looking at Table B.1.2 on page 780, it is evident the specific volume is less than the saturated liquid specific volume, i.e. $\nu < \nu_f([500\ [\mathrm{kPa}])$, 0.001070 [m^3/kg]<0.001093 [m^3/kg]. Thus, it exists as a compressed/subcooled liquid.

(j) 50 °C, 5.0 [m^3/kg]

Looking at Table B.1.1 on page 776, the given specific volume is bounded between the saturated liquid and saturated vapor specific volume, i.e. $\nu_f(50\ ^\circ\mathrm{C}) < \nu < \nu_g(50\ ^\circ\mathrm{C})$, $0.001012\,[\mathrm{m}^3/\mathrm{kg}] < \nu < 12.0318\,[\mathrm{m}^3/\mathrm{kg}]$. Therefore, it is existing as a liquid, vapor mixture.

(k) 150 °C, 1.5 [m^3/kg]

Looking at Table B.1.1 on page 776, it is evident the specific volume is greater than the saturated vapor specific volume, i.e. $\nu > \nu_g(150\ ^\circ\text{C})$, 1.5 [$m^3$/kg]>0.39278 [$m^3$/kg]. Thus, it exists as a superheated vapor.

(l) 100 °C, 0.001043 [m^3/kg]

Looking at Table B.1.1 on page 776, it is evident the specific volume is less than the saturated liquid specific volume, i.e. $\nu < \nu_f(100\ ^\circ\text{C})$, 0.001043 [$m^3$/kg]<0.001044 [$m^3$/kg]. Thus, it exists as a compressed/subcooled liquid.

Problem #2

Determine the specific volume of the following states of water. Create one T-ν and one P-ν diagram and plot each item with a dot, indicating it's phase as well

(a) 320 °C, 200 [kPa]

Looking at Table B.1.1 on page 778, the saturation pressure corresponding to the given temperature is 11,274 [kPa], indicating it is existing as a superheated vapor. Alternatively, looking at Table B.1.2 on page 780, the saturation temperature corresponding to the given pressure is 120.23 °C which is less than the given temperature, further indicating it is a superheated vapor. Consulting the superheated steam table, Table B.1.3 on page 784, the specific volume can be determined by interpolating between 300 and 400 °C:

$$\frac{(320-300)\,[^\circ\text{C}]}{(400-300)\,[^\circ\text{C}]} = \frac{(\nu-1.31616)\,[\text{m}^3/\text{kg}]}{(1.54930-1.31616)\,[\text{m}^3/\text{kg}]} \implies \nu = 1.362728\,[\text{m}^3/\text{kg}]$$

(b) 105 °C, 2,000 [kPa]

Looking at Table B.1.1 on page 776, the given pressure is greater than the saturation pressure for the given temperature, indicating it is a compressed/subcooled liquid. Using the saturated liquid specific volume value for 105 °C, ν=0.001047 [m^3/kg].

Alternatively, you could interpolate between 100 and 120 °C on the compressed/subcooled liquid water table, Table B.1.4 on page 790, using the following:

$$\frac{(105-100)\,[^\circ\text{C}]}{(120-100)\,[^\circ\text{C}]} = \frac{(\nu-0.001043)\,[\text{m}^3/\text{kg}]}{(0.001059-0.001043)\,[\text{m}^3/\text{kg}]} \implies \nu = 0.001047\,[\text{m}^3/\text{kg}]$$

(c) 60 °C, 200 [kPa]

Looking at Table B.1.1 on page 776, the given pressure is greater than the saturation pressure for the given temperature, indicating it is a compressed/subcooled liquid. Using the saturated liquid specific volume value for the given temperature, ν=0.001017 [m^3/kg]. It is noted that the lowest entry for the compressed/subcooled liquid water table, Table B.1.4 on page 790, is 500 [kPa].

(d) Saturated liquid at 400 [kPa]

Using Table B.1.2 on page 780, ν=0.001084 [m^3/kg].

(e) Saturated vapor at 125 °C

Using Table B.1.1 on page 776, ν=0.77059 [m^3/kg].