Homework #2 Solutions

MEMS 0051 - Introduction to Thermodynamics

Assigned January 19th, 2018
Due January 26th, 2018

Problem #1

Consider a 2,000 [kg] car driving up a 10 [m] tall hill. The car is driving at a velocity of 10 [m/s] and has a total internal energy (U) of 600 [kJ] [1 kJ = 10^3 J]. Determine:

(a) Determine the kinetic energy (KE) of the car [kJ].

$$KE = \frac{mV^2}{2} = \frac{2,000\,[\text{kg}](10\,[\text{m/s}])^2}{2} = 100\,[\text{kJ}]$$

(b) Determine the potential energy (PE) of the car based on the hill height [kJ].

$$PE = mgh = (2,000\,[\text{kg}])(9.81\,[\text{m/s}^2])(10\,[\text{m}]) = 196\,[\text{kJ}]$$

(c) Determine the total energy (E) of the car [kJ].

$$E = U + KE + PE = 600 + 100 + 196 = 896\,[\text{kJ}]$$

(d) Determine the total specific energy (e) of the car [kJ/kg].

$$e = \frac{E}{m} = \frac{896\,[\text{kJ}]}{2,000\,[\text{kg}]} = 0.448\,[\text{kJ/kg}]$$

(e) Determine the specific internal energy (u) of the car [kJ/kg].

$$u = \frac{U}{m} = \frac{600\,[\text{kJ}]}{2,000\,[\text{kg}]} = 0.3\,[\text{kJ/kg}]$$

Problem #2

Answer the following questions based on the P-T diagram for CO2 given below. (Short answers are fine, no need to re-draw the diagram on your solution)

1. What phase is CO_2 in at the following temperature and pressure combinations?
   (a) 250 K, 10^4 [kPa] liquid
   (b) 170 K, 10^2 [kPa] solid
   (c) 270 K, 10^1 [kPa] vapor
   (d) 330 K, 10^2 [kPa] supercritical fluid
2. Consider a piece of dry ice that is dropped into a room at 20 °C and 1 atm (101.3 [kPa]). What phase change(s) will the dry ice undergo? sublimation (solid to gas)
3. Consider CO_2 gas enclosed in an isothermal chamber fixed at 250 K. More CO_2 is injected into the chamber, causing the internal pressure to rise from 100 [kPa] to 10^4 [kPa]. What phase change(s) will the CO_2 undergo? condensation (vapor to liquid)

Problem #3

Answer the following questions based on the T-v diagram for H_2O given below. (Short answers are fine, no need to re-draw the diagram on your solution)

1. What phase(s) of H_2O are present at the following conditions?
   (a) 200 °C, 2 [m^3/kg] vapor
   (b) 200 °C, 10^{-4} [m^3/kg] liquid
   (c) 0.1 [MPa], 0.1 [m^3/kg] liquid+vapor
   (d) 400 °C, 10^{-2} [m^3/kg] supercritical fluid
2. What phase change is occurring for a mass of H_2O going from B→C on the diagram? vaporization (liquid to gas)
3. Let's say that we know the temperature and pressure of a mass of H_2O are 1 [MPa] and 179.9 °C. Can we determine the specific volume of this sample? Why or why not? No, because those are the saturation temperature and pressure; a third property is needed to fix the state in the two-phase region.
4. Consider liquid water enclosed in a piston-cylinder. The water is heated, causing an isobaric expansion at 0.1 [MPa] until all of the water boils, making saturated vapor. What is the final specific volume of the sample? 2 [m^3/kg]

Problem #4

You will need the steam tables (Tables B.1.1-B.1.5) in order to complete these exercises.

1. Determine the phase(s) for each of the following water states:
   (a) 70 °C, 50 [kPa] liquid
   (b) 100 °C, 0.1 [m^3/kg] liquid+vapor
   (c) 75 [kPa], 3.0 [m^3/kg] vapor
   (d) 10 [kPa], 50 °C vapor
   (e) 125 °C, 250 [kPa] liquid
2. Look up the requested properties for H2O at the following states:
   (a) Specific volume at 100 [kPa], 250 °C T T_{sat} for the given saturation pressure, meaning its a superheated vapor. Using Table B.1.3 on pg. 784, ν=2.40604 [m^3/kg]
   (b) Specific internal energy at 5,000 [kPa], 120 °C PP_{sat} for the given saturation temperature, meaning its a compressed liquid. Using Table B.1.4. on pg. 790, u=501.79 [kJ/kg], which is close to ν_f(120 °C)=503.48 [kJ/kg]
   (c) Specific volume for saturated liquid at 40 °C Using Table B.1.1 on pg. 776, ν_f=0.001008 [m^3/kg]
3. Use linear interpolation (show your work) to calculate the following properties for H_2O at the given states:
   (a) Specific internal energy at 10,000 [kPa], 75 °C Using Table B.1.4 on pg. 790:

$$\frac{75 - 60\,[^\circ\mathrm{C}]}{80 - 60\,[^\circ\mathrm{C}]} = \frac{u - 249.34\,[\mathrm{kJ/kg}]}{332.56 - 249.34\,[\mathrm{kJ/kg}]} \implies u = 311.755\,[\mathrm{kJ/kg}]$$

   (b) Specific volume of superheated steam existing at 250 °C and 1,700 [kPa] Using Table B.1.3 on pg. 786:

$$\frac{1,700 - 1,600\,[\mathrm{kPa}]}{1,800 - 1,600\,[\mathrm{kPa}]} = \frac{\nu - 0.14184\,[\mathrm{m}^3/\mathrm{kg}]}{0.12497 - 0.14184\,[\mathrm{m}^3/\mathrm{kg}]} \implies \nu = 0.133405\,[\mathrm{m}^3/\mathrm{kg}]$$

   (c) Specific volume of water existing at 375 °C and 5,500 [kPa] Using Table B.1.3 on pg. 788, we first interpolate to get ν(350 [°C]) at 5,500 [kPa]:

$$\frac{5,500 - 5,000\,[\mathrm{kPa}]}{6,000 - 5,000\,[\mathrm{kPa}]} = \frac{\nu - 0.05194\,[\mathrm{m}^3/\mathrm{kg}]}{0.04223 - 0.05194\,[\mathrm{m}^3/\mathrm{kg}]} \implies \nu = 0.047085\,[\mathrm{m}^3/\mathrm{kg}]$$

   Next we interpolate to get ν(400 [°C]) at 5,500 [kPa]:

$$\frac{5,500 - 5,000\,[\mathrm{kPa}]}{6,000 - 5,000\,[\mathrm{kPa}]} = \frac{\nu - 0.05781\,[\mathrm{m}^3/\mathrm{kg}]}{0.04739 - 0.05781\,[\mathrm{m}^3/\mathrm{kg}]} \implies \nu = 0.0526\,[\mathrm{m}^3/\mathrm{kg}]$$

Lastly, we interpolate between 350 [°C] and 400 [°C] at 5,500 [kPa]:

$$\frac{375 - 350\,[^\circ\mathrm{C}]}{400 - 350\,[^\circ\mathrm{C}]} = \frac{\nu - 0.047085\,[\mathrm{m}^3/\mathrm{kg}]}{0.0526 - 0.047085\,[\mathrm{m}^3/\mathrm{kg}]} \implies \nu = 0.0498425\,[\mathrm{m}^3/\mathrm{kg}]$$

This is seen graphically as:

5,000 [kPa]		5,500 [kPa]		6,000 [kPa]	
T [°C]	ν [m^3/kg]	T [°C]	ν [m^3/kg]	T [°C]	ν [m^3/kg]
350	0.05194	350	0.047085	350	0.04223
375		375	0.0498425	375	
400	0.05781	400	0.0526	400	0.04739

(d) Specific volume of water at 75 °C and 500 [kPa] Using Table B.1.4 on pg. 790:

$$\frac{75 - 60\,[^\circ\mathrm{C}]}{80 - 60\,[^\circ\mathrm{C}]} = \frac{\nu - 0.001017\,[\mathrm{m}^3/\mathrm{kg}]}{0.001029 - 0.001017\,[\mathrm{m}^3/\mathrm{kg}]} \implies \nu = 0.001026\,[\mathrm{m}^3/\mathrm{kg}]$$

(e) Specific volume of water at 100 °C and 1,500 [kPa] Using Table B.1.4 on pg. 790:

$$\frac{1,500 - 500\,[\mathrm{kPa}]}{2,000 - 500\,[\mathrm{kPa}]} = \frac{\nu - 0.001043\,[\mathrm{m}^3/\mathrm{kg}]}{0.001043 - 0.001043\,[\mathrm{m}^3/\mathrm{kg}]} \implies \nu = 0.001043\,[\mathrm{m}^3/\mathrm{kg}]$$

(f) Specific volume of water at 22.5 °C and 17,500 [kPa] Using Table B.1.4 on pg. 791, we first interpolate to get ν(20 [°C]) at 17,500 [kPa]:

$$\frac{17,500 - 15,000\,[\mathrm{kPa}]}{20,000 - 15,000\,[\mathrm{kPa}]} = \frac{\nu - 0.000995\,[\mathrm{m}^3/\mathrm{kg}]}{0.000993 - 0.000995\,[\mathrm{m}^3/\mathrm{kg}]} \implies \nu = 0.000994\,[\mathrm{m}^3/\mathrm{kg}]$$

Next we interpolate to get ν(00 [°C]) at 17,500 [kPa]:

$$\frac{17,500 - 15,000\,[\mathrm{kPa}]}{20,000 - 15,000\,[\mathrm{kPa}]} = \frac{\nu - 0.001001\,[\mathrm{m}^3/\mathrm{kg}]}{0.000999 - 0.001001\,[\mathrm{m}^3/\mathrm{kg}]} \implies \nu = 0.001\,[\mathrm{m}^3/\mathrm{kg}]$$

Lastly, we interpolate between 20 [°C] and 40 [°C] at 17,500 [kPa]:

$$\frac{22.5 - 20\,[^\circ\mathrm{C}]}{40 - 20[^\circ\mathrm{C}]} = \frac{\nu - 0.000994\,[\mathrm{m}^3/\mathrm{kg}]}{0.001 - 0.000994\,[\mathrm{m}^3/\mathrm{kg}]} \implies \nu = 0.00099475\,[\mathrm{m}^3/\mathrm{kg}]$$

This is seen graphically as:

15,000 [kPa]		17,500 [kPa]		20,000 [kPa]	
T [°C]	ν [m^3/kg]	T [°C]	ν [m^3/kg]	T [°C]	ν [m^3/kg]
20	0.000995	20	0.000994	20	0.000993
22.5		22.5	0.00099475	22.5	
40	0.001001	40	0.001	40	0.000999

4. Your friend asks you for the specific volume (ν) of liquid water at room conditions (25 °C, 100 [kPa]), but you can't find that low of a pressure in the compressed liquid water table. Is it okay to use the saturated liquid value (ν_f) at 25 °C as an approximation? Why or why not? Yes, it is okay to use the saturated liquid value as an approximation because liquid water is incompressible, so specific volume doesn't vary much with pressure ($\nu \approx \nu_f$).
5. Now your (pesky) friend asks you for the specific volume (ν) of water vapor at 200 °C, 50 [kPa]. Is it okay to use the saturated vapor value (ν_g) at 200 °C as an approximation? Why or why not? No, it is not okay to use the saturated vapor volume as an approximation because water vapor is a compressible gas, so specific volume varies significantly with pressure. In this case, ν=4.35595 [m^3/kg], which is about 40x greater than the saturated value of ν_g=0.12736 [m^3/kg].