Homework #1 Solutions

MEMS 0051 - Introduction to Thermodynamics

Assigned January 12^{th}, 2018
Due: January 19^{th}, 2018

Problem #1

Consider the refrigeration system shown below.

The red dashed line is the control surface (C.S.) Answer the following questions.

(a) This the control volume (C.∀.) an open or closed system? Closed
(b) Is the C.∀. an isolated system? No
(c) Are the contents of the C.∀. undergoing a process or cycle? Cycle

Problem #2

Now consider a C.S. around the condenser (the back of your refrigerator).

The red dashed line is the control surface (C.S.) Answer the following questions.

(a) Is this C.∀. a control mass? No
(b) Is the C.∀. an open or closed system? Open
(c) Are the contents of the C.∀. undergoing a process or cycle? Process

Problem #3

Given the following list of properties, determine if they are intensive or extensive (i.e. write "intensive" or "extensive" next the corresponding number on the homework submission sheet). You may have to research what a given property is.

(a) Temperature
Intensive
(b) Thermal conductivity
Intensive
(c) Density
Intensive
(d) Thermal diffsuvisity
Intensive
(e) Total energy
Extensive
(f) Electrical resistivity
Intensive
(g) Volume
Extensive
(h) Mass
Extensive
(i) Magnetic permeability
Intensive
(j) Coefficient of thermal expansion
Intensive

Problem #4

Consider a graduated cylinder that is filled with gasoline and water. The cross-sectional area of the cylinder is 3.5 [cm^2]. Since water is heavier than gasoline, it sits on the bottom and the volume is measured at 10 [mL]. The gasoline, sitting on top of the water, takes the height of the total fluid column to a measured volume of 25 [mL]. Determine the average specific volume of the combined fluid system. The density of water can be taken as 998 [kg/m^3] and that of gasoline as 719 [kg/m^3].

Solution:

$$\rho_f = \frac{m_{\mathrm{H_2O}} + m_{\mathrm{gasoline}}}{\forall_{\mathrm{H_2O}} + \forall_{\mathrm{gasoline}}}$$

The mass of water is:

$$m_{\mathrm{H_2O}} = 998\,[\mathrm{kg/m^3}] \cdot (1 \cdot 10^{-5})\,[\mathrm{m^3}] = 0.00998\,[\mathrm{kg}]$$

The volume of gasoline is the difference of the total volume of gasoline and water minus the volume of the water on the bottom:

$$\forall_{gasoline} = 25\,[\mathrm{mL}] - 10\,[\mathrm{mL}] = 15\,[\mathrm{mL}]$$

The mass of gasoline is:

$$m_{\mathrm{gasoline}} = 719\,[\mathrm{kg/m^3}] \cdot (1.5 \cdot 10^{-5})\,[\mathrm{m^3}] = 0.010785\,[\mathrm{kg}]$$

Therefore, the final density is:

$$\rho_f = \frac{0.020765\,[\mathrm{kg}]}{2.5 \cdot 10^{-5}\,[\mathrm{m^3}]} = 830.6\,[\mathrm{kg/m^3}]$$

Lastly, the specific volume is one over density:

$$\nu_f = 0.001204\,[\mathrm{m^3/kg}]$$

Problem #5

There exist many theories as to how persons are able to skate on ice. One theory is that friction generated between the skate and ice is sufficient to create a thin liquid layer between the skate and ice, allowing the skater to freely glide across the surface. Another theory is that tremendous pressure is generated underneath the skate, for the entire person's weight is concentrated on the blade of the skate, causing a change of phase from solid to liquid.

Assume the ice skate blade is approximately 1.0 to 1.5 [mm] thick and 5 [cm] long. Consider an average sized person weighs 62 [kg], and assume that only a small percentage of the blade is in contact with the ice (i.e. when you skate, the entirety of the blade is not in contact with the ice). Determine what percentage of a skate has to be in contact with the ice for the validity of the hypothesis that the presence of extreme pressure underneath the ice skate blade is a sufficient condition for a person to be able to skate on ice to be substantiated. Take the temperature of the ice as -10 °C, as shown by the thick, red vertical line on the phase diagram below.

Solution:
At a temperature of -10 °C, the pressure at which there is a phase change from solid to liquid that will allow a person to skate is 100 [MPa], taken from the phase diagram. The area of the skate that is required to distribute 608.22 [N] (62 [kg]·9.81 [m/s^2]) of force to generate a pressure of 100 [MPa] is:

$$A = \frac{F}{P} = \frac{62\,[\mathrm{kg}] \cdot 9.81\,[\mathrm{m/s^2}]}{100 \cdot 10^6\,[\mathrm{N/m^2}]} = 6.0822 \cdot 10^{-6}\,[\mathrm{m^2}]$$

Now dividing this by the area of the skate:

$$\frac{A}{A_{\mathrm{skate}}} \cdot 100 = \frac{6.0822 \cdot 10^{-6}\,[\mathrm{m^2}]}{0.001 \rightarrow 0.0015\,[\mathrm{m}] \cdot 0.05\,[\mathrm{m}]} \cdot 100 = 8.11 - 12.12\%$$

Problem #6

Consider the piston-cylinder assembly shown below. Assume that the gas has been given sufficient time to expand, and that the piston has been stationary for awhile. You can also assume that the cylinder walls are conductive (e.g. heat transfer is possible through the walls). The system boundary (control surface) surrounds all to gas inside the cylinder, as shown by the dashed lines in the picture. Answer the following questions about this system along with brief explanations (a few words) for each answer.

(a) Is the selected control volume a closed system? Explain.
Yes, gas is confined by the piston/mass can't escape across the control surface .

(b) Assume that we know one property about the gas: temperature. Do we know the state of the gas? Explain.
No, we need to know two properties about the gas to determine the state.

(c) Is the gas in thermodynamic equilibrium? Explain.
Yes, the gas is in both thermal equilibrium and mechanical equilibrium because we're told that the piston has been "stationary for awhile".

Now assume that heavy weights are added to the piston, causing it to lower quickly to a new height, compressing the gas.

(a) Can you assume quasi-static equilibrium throughout the gas during compression? Explain.
No because we're told that the piston lowered quickly, and quasi-static equilibrium can only be assumed for very slow processes that give the gas enough time to re-equilibrate at each step in the process.

(b) Did the gas undergo a process or a cycle? Explain.
A process because the gas went from one state to a different (compressed) state and didn't return to its original state.

(c) Is the gas an isolated system during this compression? Explain.
No, the gas is not an isolated system because there is work transfer at the piston boundary and heat transfer at all control surface boundaries.

(d) Is this compression isochoric? Explain.
No, this is not an isochoric process because the gas volume changes during compression.

Now assume that the gas reaches an internal pressure of 1.5 bar after the compression is done. The pressure outside the piston-cylinder is 1 bar. We also know that the piston diameter is 20 cm.

(a) How much force does the gas push upward on the piston (in Newtons)?
The force the gas exerts on the piston is the pressure of gas times the area of the piston (this force is upward):

$$F_{gas} = P_{\text{gas}} \cdot A_{\text{piston}} = (1.5 \cdot 10^5\,[\text{N/m}^2])\left(\frac{\pi(0.2[\text{m}]^2)}{4}\right) = 4,712\,[\text{N}]$$

(b) How much force does the atmosphere push downward on the piston (in Newtons)?
The force atmosphere exerts on the piston is the pressure of the atmosphere times the area of the piston (this force is downward):

$$F_{gas} = P_{\text{atm}} \cdot A_{\text{piston}} = (1 \cdot 10^5\,[\text{N/m}^2])\left(\frac{\pi(0.2[\text{m}]^2)}{4}\right) = 3,142\,[\text{N}]$$

(c) How much does the piston weigh (in Netwons)? Applying a force balance, where the weight acts downward, we have:

$$F_{\text{weight}} = F_{\text{gas}} - F_{\text{atm}} = 1,570\,[\text{N}]$$