

Homework #1

MEMS 0051 - Introduction to Thermodynamics

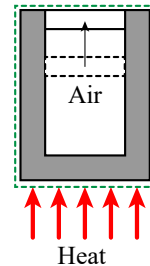
Assigned January 11th, 2019

Due: January 18th, 2019

Problem #1

Consider a piston cylinder shown to the right. The green dashed line is the control surface (C.S.) Answer the following questions.

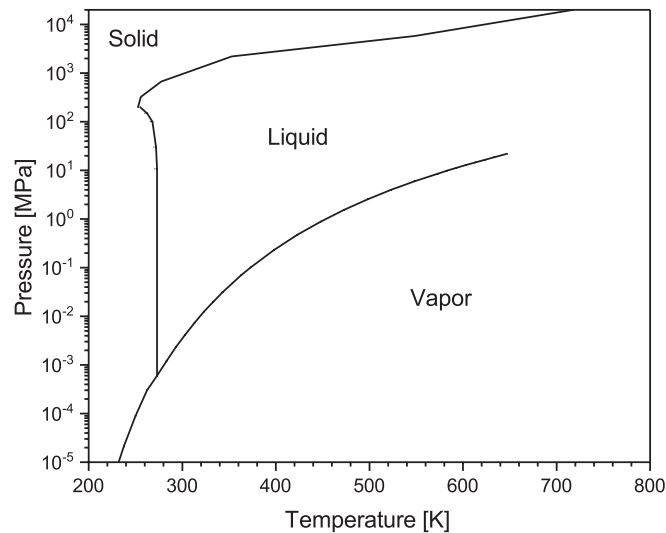
- (a) Is the control volume (C.V.) an open or closed system? **Closed System**
- (b) Is the C.V. that of an isolated system? **No**
- (c) Are the contents of the C.V. undergoing a process or cycle? **Process**



Problem #2

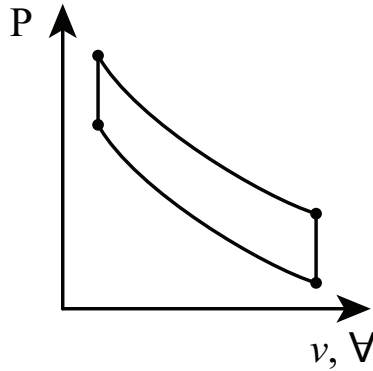
Given the phase diagram of water below, determine the phase based upon the following properties:

- (a) 200 [K] and 1 [MPa] **solid**
- (b) 220 [K] and 0.1 [kPa] **solid**
- (c) 400 [K] and 10,000 [MPa] **solid**
- (d) 326.85 [C] and 0.01 [MPa] **vapor**
- (e) 126.85 [C] and 0.1 [kPa] **vapor**
- (f) 400 [K] and 100 [MPa] **liquid**
- (g) 700 [K] and 100 [MPa] **undefined**



Problem #3

Given the $P - \nu$ diagram for the Otto cycle below, identify the two processes that comprise this cycle.



Solution:

The two processes that make up the Otto cycle are the isochoric process and isothermal process. The vertical lines are the isochoric processes where volume is constant, and the sloped curves are the isothermal processes where temperature is constant.

Problem #4

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 diffusivity **Intensive**
- (e) Total energy **Extensive**
- (f) Kinematic viscosity **Intensive**
- (g) Volume **Extensive**
- (h) Specific Heat Capacity **Intensive**
- (i) Magnetic permeability **Intensive**
- (j) Coefficient of thermal expansion **Intensive**

Problem #5

Water vapor at 350 [kPa], which has a specific volume of 0.52425 [m^3/kg], is contained in a piston-cylinder device. At this initial state, the piston is 0.2 [m] from the bottom of the cylinder. The water vapor is then cooled in a constant pressure process such that final volume occupies half the initial. Determine:

- (a) the final specific volume;
The final volume is one half of the initial volume. The specific volume is defined as the volume per unit mass:

$$\nu = \frac{V}{m}$$

Since this is a control mass, the mass at the initial and final state is the same. Recognizing that the final volume is half the initial volume, the specific volume at the final state is:

$$m = \frac{V_1}{\nu_1} = \frac{V_2}{\nu_2} \implies \nu_2 = \nu_1 \left(\frac{V_2}{V_1} \right) = \frac{\nu_1}{2} = \frac{0.52425 \text{ [m}^3/\text{kg}]}{2} = \boxed{0.262125 \text{ [m}^3/\text{kg]}}$$

(b) the final mass;

The final mass is the same as the initial mass:

$$m = \frac{V}{\nu} = \frac{\pi D^2 L}{4\nu} = \frac{\pi D^2 (0.2 \text{ [m]})}{4(0.52425 \text{ [m}^3/\text{kg]})}$$

(c) specify if this system is a open or closed, a control mass and/or isolated.

The system depicted is a control mass. It is not open because there is no mass crossing the control surface. It is not isolated because heat is removed (i.e. it is cooled).

Problem #6

There exists a container with a volume of 10 [m³]. This container is filled with 7 [m³] of coarse stone, which has a density of 1,575 [kg/m³], 1 [m³] of sand, which has a density of 1,482 [kg/m³], and the rest is filled with water, which has a density of 998 [kg/m³]. Determine:

- (a) the average specific volume;
- (b) the average density.

Solution (a):

The total volume was given as 10 [m³]. Find the total mass of the system.

$$\begin{aligned} m_{total} &= (V_{stone}\rho_{stone} + V_{sand}\rho_{sand} + V_{water}\rho_{water}) \\ &= (7 \text{ [m}^3\text{]})(1,575 \text{ [kg/m}^3\text{]}) + (1 \text{ [m}^3\text{]})(1,482 \text{ [kg/m}^3\text{]}) + (2 \text{ [m}^3\text{]})(998 \text{ [kg/m}^3\text{]}) = 14,503 \text{ [kg]} \end{aligned}$$

The average specific volume will be the quotient of the total volume to the total mass.

$$\nu_{average} = \frac{V_{total}}{m_{total}} = \frac{10 \text{ [m}^3\text{]}}{14,503 \text{ [kg]}} = \boxed{0.0006895 \text{ [m}^3/\text{kg]}}$$

Solution (b):

The average density is simply the reciprocal of the average specific volume.

$$\rho_{average} = \frac{1}{\nu_{average}} = \frac{1}{6.895 \times 10^{-4} \text{ [m}^3/\text{kg]}} = \boxed{1450.3 \text{ [kg/m}^3\text{]}}$$

Problem #7

A pipe feeds water 20 [m] from the ground to a local reservoir. The water flows with a velocity of approximately 5 [m/s]. It also has a specific internal energy of 100 [kJ/kg]. What is the total specific energy of the system with respect to the ground?

Solution:

The total specific energy a controlled volume is defined as:

$$e = u + \frac{V^2}{2} + gz$$

Here, u is the specific internal energy, V is the velocity of the substance, g is the gravitational constant and z is the height with respect to some reference point. All components of energy have units of [kJ/kg]. Therefore, the total specific energy of the fluid at the specified height is:

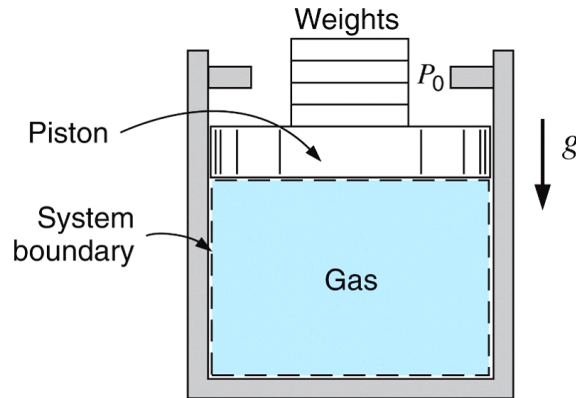
$$e = 100 \text{ [kJ/kg]} + \left(\frac{(5 \text{ [m/s]})^2}{2} + (9.81 \text{ [m/s}^2\text{)})(20 \text{ [m]}) \right) \left(\frac{1 \text{ [kJ/kg]}}{1,000 \text{ [m}^2\text{/s}^2\text{]}} \right)$$

$$e = 100.21 \text{ [kJ/kg]}$$

Problem #8

Consider the piston-cylinder assembly shown below. Assume that the fluid has been given sufficient time to expand, and that the piston has been stationary for awhile. Weights are then placed on the piston. Given that the total mass of the piston and the attached weights is 10 [kg] and the piston has a diameter of 5 [cm], answer the following:

- Determine the internal pressure of the fluid to reach static equilibrium;
- What happens if the diameter of the piston-cylinder assembly is halved?
- If air has a density 1.225 [kg/m³] and water has a density of 998 [kg/m³], which fluid will experience greater internal pressure if used in the piston-cylinder assembly?
- Can you assume quasi-static equilibrium throughout the fluid during compression? Explain.
- Did the fluid undergo a process or a cycle? Explain.
- Is the fluid an isolated system during this compression? Explain.



Solution (a):

The internal pressure is the ratio of the force acting normal to an area of interest.

$$P = \frac{F}{A}$$

The area on which the force acts normal to is the cross-sectional area of the piston. The force itself is the gravitational force of the weights

$$A_{piston} = \frac{(\pi)(0.05 \text{ [m]})^2}{4} = 0.002 \text{ [m}^2\text{]}$$

$$F = mg = (10 \text{ [kg]})(9.81 \text{ [m/s}^2\text{]}) = 98.1 \text{ [N]}$$

Therefore, the internal pressure of the fluid is:

$$P = \frac{98.1 \text{ [N]}}{0.002 \text{ [m}^2\text{]}} = 49.962 \text{ [kPa]}$$

Solution (b):

Decreasing the diameter by a factor of 2 reduces the cross-sectional area by a factor of 4. Since the weight does not change and since the internal pressure is inversely proportional to the cross-sectional area, it will increase by a factor of 4.

$$P = \frac{F}{(0.25)(A_{piston})} = \frac{98.1 \text{ [N]}}{(0.25)(0.002 \text{ [m}^2\text{]})} = \boxed{199.848 \text{ [kPa]}}$$

The area on which the force acts normal to is the cross-sectional area of the piston. The force itself is the gravitational force of the weights

$$A_{piston} = \frac{(\pi)(0.05 \text{ [m]})^2}{4} = 0.002 \text{ [m}^2\text{]}$$

$$F = mg = (10 \text{ [kg]})(9.81 \text{ [m/s}^2\text{]}) = 98.1 \text{ [N]}$$

Therefore, the internal pressure of the fluid is:

$$P = \frac{98.1 \text{ [N]}}{0.002 \text{ [m}^2\text{]}} = 199.848 \text{ [kPa]}$$

Solution (c):

Internal pressure on a fluid is not dependent on the fluid's density. It is merely the ratio of the force acting normal to an area of interest. Therefore, both fluids will experience the same internal pressure in the same setup.

Solution (d):

Quasi-static equilibrium can not be assumed throughout the compression process. This is because all the weights were placed on the piston at once.

Solution (e):

The fluid underwent a process. This is because there is no subsequent process to bring the piston back to its original state.

Solution (f):

The fluid is not isolated during the compression. This is because external work from the weights are compressing the fluid from outside the system's boundary.