Homework #1

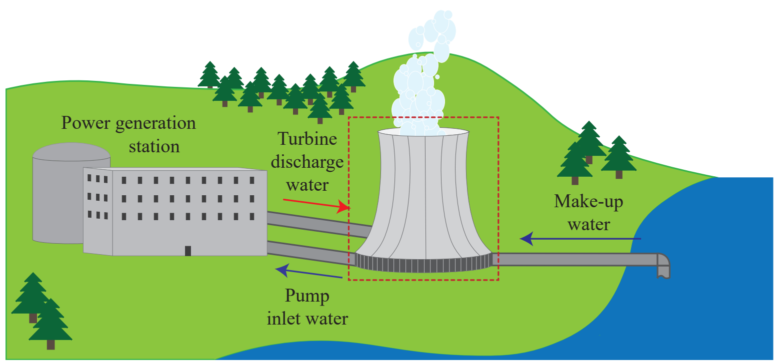
MEMS 0051 - Introduction to Thermodynamics

Assigned January 10th, 2020
Due: January 17th, 2020

Problem #1

Consider a power plant shown below. The red dashed line is the control surface (C.S.) around the cooling tower. Answer the following questions.

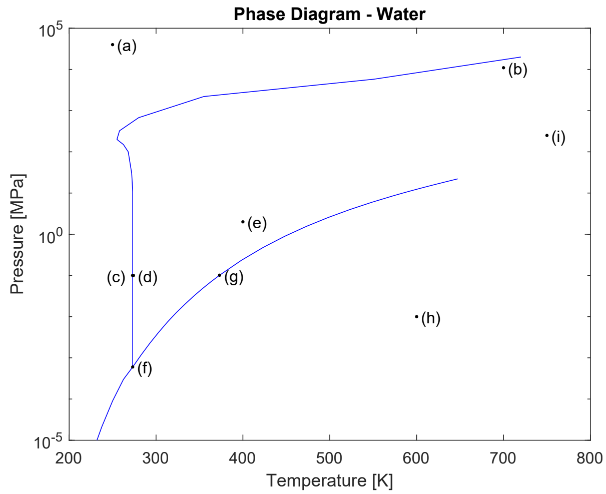
(a) Is the control volume (C.∀.) an open or closed system? open
(b) Is the C.∀. that of an isolated system? no, this is not an isolated system
(c) Is the C.S. stationary or moving? stationary



Problem #2

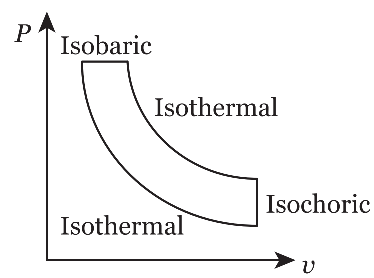
Given the Matlab script for the phase diagram of water, determine the phase(s) based upon the following properties. Plot the phase diagram and label each state (i.e. (a), (b), (c), etc.).

(a) 250 [K] and $4{\cdot}10^4$ [MPa] solid
(b) 700 [K] and $1.1{\cdot}10^4$ [kPa] liquid
(c) 273 [K] and 100 [kPa] solid
(d) 274 [K] and 100 [kPa] liquid
(e) 400 [K] and 2,000 [kPa] liquid
(f) 273.16 [K] and 600 [Pa] triple point
(g) 373.15 [K] and 101.325 [kPa] liquid and vapor
(h) 600 [K] and 10,000 [Pa] vapor
(i) 750 [K] and 250 [MPa] undefined



Problem #3

Given the $P-\nu$ diagram for the diesel cycle to the right, and based upon the processed learned in Lecture 1, identify and label the three processes that comprise this cycle.



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 a given property.

(a) Electrical conductivity Intensive
(b) Dynamic viscosity Intensive
(c) Thermal conductivity Intensive
(d) Modulus of elasticity Intensive
(e) Modulus of rigidity Intensive
(f) Dieletric strength Intensive
(g) Permeability Intensive
(h) Emissivity Intensive
(i) Boiling point Intensive
(j) Yield strength Intensive

Problem #5

1 [kg] of compressed water at 500 [kPa] and 20 °C has a specific volume of 0.001002 [m^3/kg], is contained in a piston-cylinder device. The water is then heated in a constant pressure process such that final volume is ten times that of the initial volume. Determine:

(a) the final specific volume;

State 1:	$\rightarrow P = c \rightarrow$	State 2:
ν_1=0.001002 [m^3/kg]		ν_2=10ν_1
m_1=1 [kg]		m_2=m_1=1 [kg]
P_1=500 [kPa]		P_2=P_1=500 [kPa]

Since the mass is constant, the final volume is ten times the initial volume, which implies the final specific volume is ten times the initial specific volume. Thus ν_2=0.01002 [m^3/kg].

(b) specify if this system is a open or closed, a control mass and/or isolated.
The system is a control mass. That is, it is closed, but not isolated because heat is crossing the control surface.

Problem #6

There exists a container with a volume of 18.9 [L]. This container is filled with 68 [kg] of steel (ρ_S=7,750 [kg/m^3]) shot, with 5 [L] of sand, which has a density of 1,482 [kg/m^3], and the rest is filled with water, which has a density of 998 [kg/m^3]. Determine:

(a) the volume-weighted average specific volume;
The volume-weighted average specific volume is calculated as:

$$\nu = \frac{\forall_S + \forall_{sand} + \forall_{H_2O}}{m_S + m_{sand} + m_{H_2O}}$$

The mass of the steel is provided. The density of the steel is found as:

$$\forall_S = \frac{m_S}{\rho_S} = \frac{68\,[\text{kg}]}{7,750\,[\text{kg/m}^3]} = 0.0088\,[\text{m}^2] = 8.8\,[\text{L}]$$

The volume of sand is provided. The mass of sand is found as:

$$m_{sand} = \rho_{sand}\forall_{sand} = (1,482\,[\text{kg/m}^3])(0.005\,[\text{m}^3]) = 7.41\,[\text{kg}]$$

The volume of water is found via subtraction to be 5.1 [L]. The mass is found as:

$$m_{H_2O} = \rho_{H_2O}\forall_{H_2O} = (998\,[\text{kg/m}^3])(0.0051\,[\text{m}^3]) = 5.09\,[\text{kg}]$$

Therefore:

$$\nu = \frac{0.0189\,[\text{m}^3]}{80.5\,[\text{kg}]} = 2.3478 \cdot 10^{-4}\,[\text{m}^3/\text{kg}]$$

(b) the average density. The density is one per the specific volume:

$$\rho = \frac{1}{\nu} = \frac{1}{2.3478 \cdot 10^{-4}\,[\text{m}^3/\text{kg}]} = 4,259.3\,[\text{kg/m}^3]$$

Problem #7

Water flows through a pipe from a high-elevation reservoir to a low-elevation reservoir purely via gravity-driven flow. If the change of elevation between the high- and low-elevation reservoirs is 15 [m], the average velocity of the water is 3 [m/s], and the water is at standard-temperature standard-pressure (i.e. has a specific internal energy of 104.86 [kJ/kg]), what is the total specific energy of the system at the exit of the pipe with respect to the high-elevation reservoir?
Taking the high-elevation reservoir as the reference:

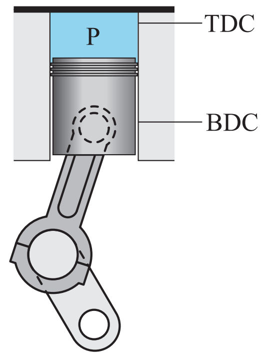
$$e = u + \frac{V^2}{2} + g\Delta z = (104.86\,[\text{kJ/kg}]) + \left(\frac{(3\,[\text{m/s}])^2}{2}\right)\left(\frac{1\,[\text{kJ/kg}]}{1,000\,[\text{m}^2/\text{s}^2]}\right) + (9.81\,[\text{m/s}^2])(-15\,[\text{m}])\left(\frac{1\,[\text{kJ/kg}]}{1,000\,[\text{m}^2/\text{s}^2]}\right)$$

$$e = 104.717\,[\text{kJ/kg}]$$

Problem #8

Consider the piston-cylinder assembly shown to the right (neglecting the heads, and intake and exhaust vales). Both intake and exhaust valves are closed. The piston starts at bottom dead center (BDC) and compresses to top dead center (TDC). The displacement of the piston is 0.5 [L], and the compression ratio is 10.5:1. The bore diameter is 83 [mm] and the stroke length is 92 [mm]. Assume that the fluid, which is air, has been given sufficient time to compress. If it takes 5.5 [kN] to compress the air, i.e. move the piston from BDC to TDC, answer the following:

(a) Determine the internal pressure of the fluid after compression, assuming the initial pressure was 101.352 [kPa];
(b) What happens if the diameter of the piston-cylinder assembly is halved?
(c) Can you assume quasi-static equilibrium throughout the fluid during compression? Explain.
(d) Did the fluid undergo a process or a cycle? Explain.
(e) Is the fluid an isolated system during this compression? Explain.



(a) The pressure is found by taking the force applied per the area of the piston, added to the atmospheric pressure:

$$P = \frac{F}{A} + P_{atm} = \frac{5.5\,[\text{kN}]}{\left(\pi\dfrac{(0.083\,[\text{m}])^2}{4}\right)} + 101.325\,[\text{kPa}] = 1,1178\,[\text{kPa}]$$

(b) If the diameter of the piston is halved:

$$P = \frac{F}{A} + P_{atm} = \frac{5.5\,[\text{kN}]}{\left(\pi\dfrac{(0.083\,[\text{m}])^2}{16}\right)} + 101.325\,[\text{kPa}] = 4,167.4\,[\text{kPa}]$$

(c) Yes, we assume the process is quasi-equilibrium because the fluid has been given sufficient time to compress.
(d) The fluid underwent a process.
(e) The fluid is not assumed isolated. Although there is no heat being transferred to or from the control volume, work is being supplied to the system..