Homework #1

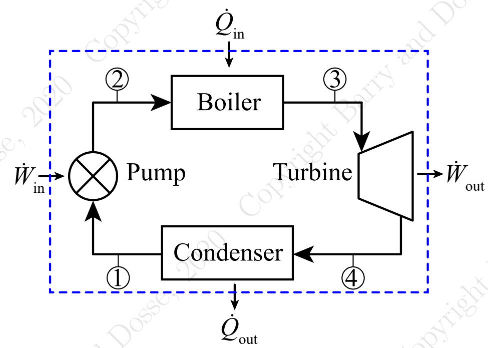
MEMS 0051 - Introduction to Thermodynamics

Assigned: May 7$^{\text{th}}$, 2020
Due: May 14$^{\text{th}}$, 2020

Problem #1

Consider the thermodynamic devices found in a power plant as shown below. The blue dashed line is the control surface (C.S.) Answer the following questions.

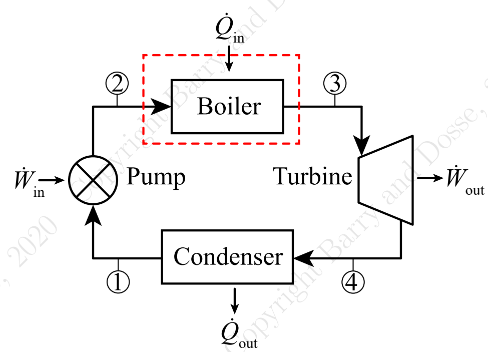
(a) Is the C.∀. a control mass? Yes
(b) Is the control volume (C.∀.) an open or closed system? Closed
(c) Are the contents of the C.∀. undergoing a process or cycle? Cycle



Problem #2

Consider the same power plant where the red dashed line is now the control surface (C.S.). Answer the following questions:

(a) Is the C.∀. a control mass? No
(b) Is the control volume (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 letter on the homework submission sheet). You may have to research what a given property is. You may have to research what a given property is.

(a) Pressure Intensive
(b) Specific volume Intensive
(c) Heat capacity Extensive
(d) Emissivity Intensive
(e) Seebeck coefficient Intensive
(f) Entropy Extensive
(g) Temperature Intensive
(h) Triple point Intensive
(i) Gibbs free energy Extensive
(j) Molar mass Intensive

Problem #4

Water is being pumped from ground level to the nozzle of a fire extinguishing system many stories high in a building. The water enters the pump at 2 [m/s] and at a height of 0 [m] and exits the nozzle at 20 [m/s] and at a height of 200 [m]. If the specific internal energy of the water is 83.91 [kJ/kg], determine the following:

(a) The specific energy of the water as it enters the pump;
The specific energy at the pump entrance is:

$$e_1 = u_1 + \frac{V_1^2}{2} + gz_1 = 83.91\ [\text{kJ/kg}] + \frac{(2\ [\text{m/s}])^2}{(1000\ [\text{J/kJ}])(2)} + \frac{(9.81\ [\text{m/s}^2])(0\ [\text{m}])}{1000\ [\text{J/kJ}]} = 83.912\ [\text{kJ/kg}]$$

(b) The specific energy of the water as it exits the nozzle;
The specific energy at the nozzle exit is:

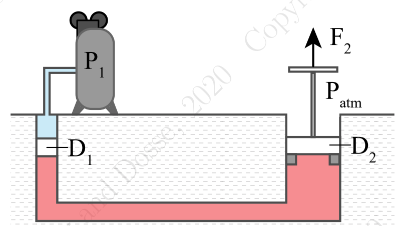
$$e_2 = u_2 + \frac{V_2^2}{2} + gz_2 = 83.91\ [\text{kJ/kg}] + \frac{(20\ [\text{m/s}])^2}{(1000\ [\text{J/kJ}])(2)} + \frac{(9.81\ [\text{m/s}^2])(200\ [\text{m}])}{1000\ [\text{J/kJ}]} = 86.072\ [\text{kJ/kg}]$$

(c) The change in the specific energy, i.e. the difference between the two specific energies;
Subtracting the specific energy at the nozzle exit from that at the pump entrance:

$$de = e_2 - e_1 = (86.072 - 83.912)\ [\text{kJ/kg}] = 2.16\ [\text{kJ/kg}]$$

Problem #5

Consider the hydraulic system to the right. A machine is able to apply force to piston #1. For piston-cylinder #1, the weight of the piston is initially supported by the hydraulic fluid, which exists between the two piston-cylinders as denoted by the red coloration. Piston #2 is initially resting on stops. Both pistons are made of steel with a density of 7,820 [kg/m^3]. Piston #1 has diameter 20 [cm] and thickness 5 [cm]. Piston #2 has diameter 40 [cm] and thickness 10 [cm]. Piston #2 is exposed to an atmospheric pressure of 100 [kPa]. Determine the following:



Note: image is not drawn to scale.

(a) The initial pressure of the system;
The initial pressure in the hydraulic fluid is equal to the atmospheric pressure plus the pressure due to supporting the mass of piston #1. The mass of piston #1 then is:

$$m_1 = \rho \forall_1 = (7,820\ [\text{kg/m}^2])\pi(0.1\ [\text{m}])^2(0.05\ [\text{m}]) = 12.284\ [\text{kg}]$$

The pressure from the piston is:

$$P_1 = \frac{F_1}{A_1} = \frac{mg}{A_1} = \frac{(12.284\ [\text{kg}])(9.81\ [\text{m/s}^2])}{0.0314\ [\text{m}^2]} = 3.838\ [\text{kPa}]$$

The initial pressure then is:

$$P_{\text{initial}} = P + P_{\text{atm}} = 3.838\ [\text{kPa}] + 100\ [\text{kPa}] = 103.836\ [\text{kPa}]$$

(b) The pressure required to lift piston #2 off the stops;
The pressure can be found in a similar fashion to piston #1. The mass of piston #2 is:

$$m_2 = \rho \forall_2 = (7,820\ [\text{kg/m}^2])\pi(0.2\ [\text{m}])^2(0.1\ [\text{m}]) = 98.297\ [\text{kg}]$$

The pressure required to lift piston #2 off the stops is:

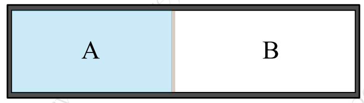
$$P_{\text{lift}} = P_2 + P_{\text{atm}} = \frac{F_2}{A_2} + P_{\text{atm}} = \frac{(98.297\ [\text{kg}])(9.81\ [\text{m/s}^2])}{0.12566\ [\text{m}^2]} + 100\ [\text{kPa}] = 107.674\ [\text{kPa}]$$

(c) The force the machine must apply to generate this pressure;
The force can be calculated as:

$$F_{\text{lift}} = P_{\text{lift}} A_1 = (107.674\ [\text{kPa}])(0.0314\ [\text{m}^2]) = 3.381\ [\text{kN}]$$

Problem #6

Two gases are held within a rigid container separated by a membrane, as shown to the right. Section A contains oxygen, O_2, and has a specific volume of 0.4 [m^3/kg]. Section B contains hydrogen, H_2, and occupies a volume of 1 [m^3]. In addition, the mass of each gas is the same. Now, the membrane ruptures and the two gases mix until they reach a uniform state. The total volume of the container is 1.5 [m^3]. Determine the following:



Note: image is not drawn to scale.

(a) The density of the hydrogen before membrane rupture;
The mass of O_2 must first be determined. Since we know the total volume and volume of section B, the volume of section A can be found by:

$$\forall_A = \forall_{\text{total}} - \forall_B = (1.5 - 0.5)\ [\text{m}^3] = 0.5\ [\text{m}^3]$$

The mass of the oxygen is:

$$m_A = \frac{\forall_A}{\nu_A} = \frac{0.5\ [\text{m}^3]}{0.4\ [\text{m}^3/\text{kg}]} = 1.25\ [\text{kg}]$$

Since the masses are equal, the mass of H_2 is also 1.25 [kg]. The density of the hydrogen then is:

$$\rho_B = \frac{m_B}{\forall_B} = \frac{1.25\ [\text{kg}]}{1\ [\text{m}^3]} = 1.25\ [\text{kg/m}^3]$$

(b) The final specific volume of the mixture;
The final specific volume can be found by:

$$\nu_{\text{final}} = \frac{\forall_{\text{total}}}{m_{\text{total}}} = \frac{\forall_{\text{total}}}{m_A + m_B} = \frac{1.5\ [\text{m}^3]}{(1.25 + 1.25)\ [\text{kg}]} = 0.6\ [\text{m}^3/\text{kg}]$$