Homework 1 ANS

1. Please consider the questions below and give your own answers.

(1) What is a quasi-equilibrium process? What is its importance in engineering?

ANS: A process during which a system remains almost in equilibrium at all times is called a quasi-equilibrium process. Many engineering processes can be approximated as being quasi-equilibrium. The work output of a device is maximum and the work input to a device is minimum when quasi-equilibrium processes are used instead of nonquasi-equilibrium processes.

(2) Consider an alcohol and a mercury thermometer that read exactly 0 °C at the ice point and 100°C at the steam point. The distance between the two points is divided into 100 equal parts in both thermometers. Do you think these thermometers will give exactly the same reading at a temperature of, say, 30 °C? Explain.

ANS: Probably, but not necessarily. The operation of these two thermometers is based on the thermal expansion of a fluid. If the thermal expansion coefficients of both fluids vary linearly with temperature, then both fluids will expand at the same rate with temperature, and both thermometers will always give identical readings. Otherwise, the two readings may deviate.

(3) Consider two closed systems A and B. System A contains 300 kJ of thermal energy at 30 °C, whereas system B contains 200 kJ of thermal energy at 40 °C. Now the systems are brought into contact with each other. What is the direction of the heat transfer between them?

ANS: Heat transfer occurs from warmer to cooler objects. Therefore, heat will be transferred from system B to system A until both systems reach the same temperature.

(4) Someone claims that the absolute pressure in a liquid of constant density doubles when the depth is doubled. Do you agree? Explain.

ANS: No, the absolute pressure in a liquid of constant density does not double when the depth is doubled. It is the gage pressure that doubles when the depth is doubled.

(5) Consider an electric refrigerator located in a room. Determine the direction of the work and heat interactions (in or out) when the following are taken as the system:

(a) the contents of the refrigerator,

(b) all parts of the refrigerator including the contents,

(c) everything contained within the room during a winter day.

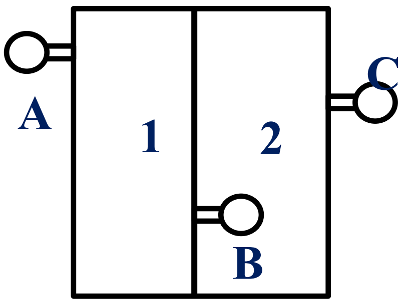
ANS:

(a) From the perspective of the contents, heat must be removed in order to reduce and maintain the content's temperature.

(b) Considering the system formed by the refrigerator box when the doors are closed, there are three interactions, electrical work and two heat transfers. There is a transfer of heat from the room air to the refrigerator through its walls. There is also a transfer of heat from the hot portions of the refrigerator (i.e., back of the compressor where condenser is placed) system to the room air. Finally, electrical work is being added to the refrigerator through the refrigeration system.

(c) Heat is transferred through the walls of the room from the warm room air to the cold winter air. Electrical work is being done on the room through the electrical wiring leading into the room.

2. A chamber is divided into two parts and equipped with three pressure monitors (as shown in the figure). If C is a positive pressure gauge with P_C = 40 kPa and B is a vacuum gauge with P_B = 60 kPa, please determine P_A.



ANS:

Because C is a vacuum gauge and B is a pressure gauge, therefore

$$P_2 = P_{atm} + P_c$$

$$P_1 = P_2 - P_B$$

Then, we have

$$P_1 = P_{atm} + P_c - P_B = P_{atm} - 20kPa < P_{atm}$$

So A is a vacuum gauge, thus

$$P_A = P_{atm} - P_1 = 20kPa$$

3. A 100-W fan is to circulate air through the ducts. The analysis of the flow shows that the fan needs to raise the pressure of air by 100 Pa to maintain flow. The fan is located in a horizontal duct whose diameter is 40 cm at both the inlet and the outlet. Determine the highest possible average flow velocity in the duct.

ANS:

For a control volume that encloses the fan unit, the energy balance can be written as

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{\text{in}} + \dot{m}(Pv)_1 = \dot{m}(Pv)_2 \;\rightarrow\; \dot{W}_{\text{in}} = \dot{m}(P_2 - P_1)v = \dot{V}\,\Delta P$$

since $\dot{m} = \dot{V}/v$ and the changes in kinetic and potential energies of gasoline are negligible, Solving for volume flow rate and substituting, the maximum flow rate and velocity are determined to be

$$\dot{V}_{\text{max}} = \frac{\dot{W}_{\text{in}}}{\Delta P} = \frac{100\,\text{J/s}}{100\,\text{Pa}}\left(\frac{1\,\text{Pa}\cdot\text{m}^3}{1\,\text{J}}\right) = 1.0\,\text{m}^3/\text{s}$$

$$V_{\text{max}} = \frac{\dot{V}_{\text{max}}}{\pi\,\cdot\,4} = \frac{1.0\,\text{m}^3/\text{s}}{\pi(0.40\,\text{m})^2/4} = 8.0\,\text{m/s}$$

4. Water is pumped from a lake to a storage tank 20 m above at a rate of 100 L/s while consuming 20 kW of electric power. Disregarding any frictional losses in the pipes and any changes in kinetic energy, determine (a) the overall efficiency of the pump-motor unit and (b) the pressure difference between the inlet and the exit of the pump.

ANS: (a) We take the free surface of the lake to be point 1 and the free surfaces of the storage tank to be point 2. We also take the lake surface as the reference level ($z_1 = 0$), and thus the potential energy at point 2 is $pe_2 = gz_2$. The flow energy at both points is zero since both 1 and 2 are open to the atmosphere ($P_1 = P_2 = P_{atm}$). Further, the kinetic energy at both points is zero since the water at both locations is essentially stationary. The mass flow rate of water and its potential energy at point 2 are

$$\dot{m} = \rho\dot{V} = \left(1000\text{kg}/\text{m}^3\right)\left(0.100\text{m}^3/\text{s}\right) = 100\text{kg}/\text{s}$$

$$pe_2 = gz_2 = \left(9.81\text{m}/\text{s}^2\right)(20\text{m})\left(\frac{1\text{kJ}/\text{kg}}{1000\text{m}^2/\text{s}^2}\right) = 0.1962\text{kJ}/\text{kg}$$

Then the rate of increase of the mechanical energy of water becomes

$$\Delta\dot{E}_{\text{mech,fluid}} = \dot{m}\left(e_{\text{mech,out}} - e_{\text{mech , in}}\right) = \dot{m}\left(pe_2 - 0\right) = \dot{m}pe_2 = (100\text{kg}/\text{s})(0.1962\text{kJ}/\text{kg}) = 19.6\text{kW}$$

The overall efficiency of the combined pump-motor unit is determined from its definition,

$$\eta_{\text{pump-motor}} = \frac{\Delta\dot{E}_{\text{mech, fluid}}}{\dot{W}_{\text{elect,in}}} = \frac{19.6\text{kW}}{20.0\text{kW}} = 0.98$$

(b) Now we consider the pump. The change in the mechanical energy of water as it flows through the pump consists of the change in the flow energy only since the elevation difference across the pump and the change in the kinetic energy are negligible. Also, this change must be equal to the useful mechanical energy supplied by the pump, which is 19.6 kW:

$$\Delta\dot{E}_{\text{mech,fluid}} = \dot{m}\left(e_{\text{mech,out}} - e_{\text{mech,in}}\right) = \dot{m}\frac{P_2 - P_1}{\rho} = \dot{V}\Delta P$$

Solving for ΔP and substituting,

$$\Delta P = \frac{\Delta\dot{E}_{\text{mech,fluid}}}{\dot{V}} = \frac{19.6\text{kJ / s}}{0.1\text{m}^3\text{ / s}}\left(\frac{1\text{kPa}\cdot\text{m}^3}{1\text{kJ}}\right) = 196\text{kPa}$$

Therefore, the pump must boost the pressure of water by 196 kPa in order to raise its elevation by 20 m.

5. Windmills slow the air and cause it to fill a larger channel as it passes through the blades. Consider a circular windmill with a 7-m-diameter rotor in a 8 m/s wind on a day when the atmospheric pressure is 100 kPa and the temperature is 20 °C. The wind speed behind the windmill is measured at 6.5 m/s. Determine the diameter of the wind channel downstream from the rotor and the power produced by this windmill, presuming that the air is incompressible.

ANS: The specific volume of the air is

$$v = \frac{RT}{P} = \frac{\left(0.287\text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K}\right)(293\text{K})}{100\text{kPa}} = 0.8409\text{m}^3/\text{kg}$$

The diameter of the wind channel downstream from the rotor is

$$A_1V_1 = A_2V_2 -> \left(\pi D_1^2/4\right)V_1 = \left(\pi D_2^2/4\right)V_2$$

$$-> D_2 = D_1\sqrt{\frac{V_1}{V_2}} = (7\text{m})\sqrt{\frac{8\text{m/s}}{6.5\text{m/s}}} = 7.77\text{m}$$

The mass flow rate through the wind mill is

$$m = \frac{A_1V_1}{v} = \frac{\pi(7\text{m})^2(8\text{m/s})}{4\left(0.8409\text{m}^3/\text{kg}\right)} = 366.1\text{kg/s}$$

The power produced is then

$$W = m\frac{V_1^2 - V_2^2}{2} = (366.1\text{kg/s})\frac{(8\text{m/s})^2 - (6.5\text{m/s})^2}{2}\left(\frac{1\text{kJ/kg}}{1000\text{m}^2/\text{s}^2}\right) = 3.98\text{kW}$$