Quiz 2

- This is a closed book exam.
- You have 90 minutes.
- Write your name and section number on both the question and answer sheets.
- It is recommended that you read the whole exam before you start solving.

Problem 1 (40 points)
A rigid metal tank of volume V is connected to the atmosphere through a valve. Atmospheric pressure and temperature are p_0 and T_0 respectively. Initially the tank is evacuated and the valve is closed. The valve is then opened and air flows into the tank. During the first few seconds (from $t = 0$ to $t = t_1$), air flows rapidly into the tank at a decreasing mass flow rate until the pressure inside the tank increased, from zero to p_0. Following this fast process is another long process (from $t = t_1$ to $t = t_2$) during which air flows into the tank at a very small flow rate while the pressure in the tank remains p_0. The second process ends when the air flow goes to zero. Air is modeled as an ideal gas with specific heat ratio $\gamma = c_p/c_v$, with c_p and c_v are respectively the constant pressure and constant volume specific heats.
(a) Argue why the first process may be modeled as adiabatic.
(b) What is the temperature at time $t = t_1$? Express your answer in terms of given quantities.
(c) What the amount of heat transfer between the tank and the atmosphere? Express your answer in terms of given quantities.

Problem 2 (20 points)
A system undergoes a cyclic process while interacting exclusively with a thermal reservoir. Explain whether any of these effects violates the second law.
(a) No external effect except the rise of a weight.
(b) No external effect except the fall of a weight.

Problem 3(40 points)
In a chemical plant, ethyl alcohol vapor, is produced at the top of a rectification column at 1 atm and saturation temperature $T_{1\text{ atm}} = 60.7\ °\text{C}$ as shown in the Figure below. The vapor is condensed for further processing and shipment.Condensation is achieved by heat transfer to boiling water at a temperature close to the saturation temperature of ethyl alcohol $T_{1\text{ atm}}$. At this temperature, the pressure of boiling water is less than 1 atm and is achieved by a pumping device powered by high-pressure steam as shown in the figure. Under steady-state, bulk-flow conditions, and for the data listed in the figure, answer the rate following questions:
(a) If no temperature difference is necessary for the operation of the condenser, what are the temperature and pressure of the boiling water?
(b) What is the rate of heat transfer across the condenser surface?
(c) What is the liquid flow rate entering the water side of the condenser ?
(d) What is the smallest flow rate of 7-bar steam through the pumping device and what is the corresponding temperature of the discharge stream? Note that the discharge stream must not contain liquid water.

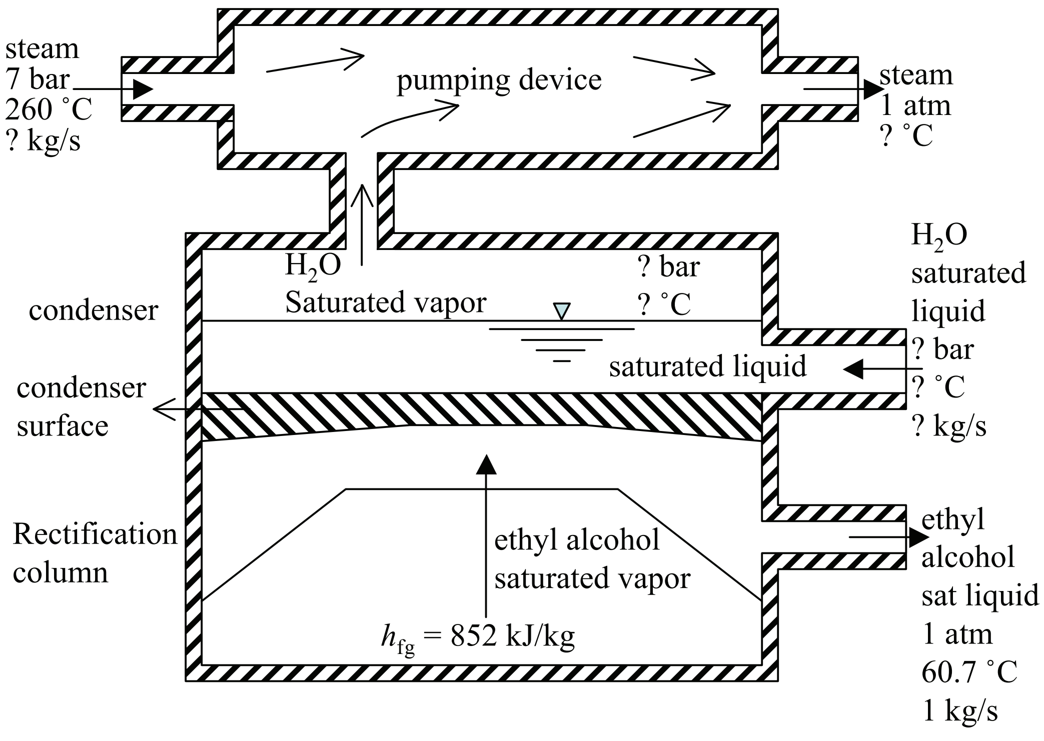

Figure 1: Schematic for problem 3.

Problem 1 Solution
(b) Applying the first law of thermodynamics between $t = 0$ and $t = t_1$ and neglecting kinetic energy and potential energy changes, and noting that air flow into the tank is characterized by $h_0 = c_p T_0$, and that there is work (other than bulk) interactions. It is further assumed that the first process is adiabatic since it occurs very quickly (there is no time for heat transfer to take place), then

$$m_1 u_1 - m_0 u_0 = m_{\text{in}} h_{\text{in}}$$

where conservation of mass yields $m_{\text{in}} = m_1 - m_0 = m_1$ since $m_0 = 0$ (the tank is initially evacuated). Noting that $u_1 = c_v T_1$ and $h_{\text{in}} = c_p T_0$, then $T_1 = \gamma T_0$, with $\gamma = c_p/c_v$.

(c) Applying the first law of thermodynamics between $t = t_1$ to t_2,

$$\begin{aligned} & m_2 u_2 - m_1 u_1 = m_{\text{in}} h_{\text{in}} + Q^{\leftarrow}_{1-2} \\ \Rightarrow \quad & c_v \left(m_2 T_2 - m_1 T_1 \right) = (m_2 - m_1) c_p T_0 + Q^{\leftarrow}_{1-2} \end{aligned}$$

where $m_2 = p_2 V_2/(RT_2) = p_0 V/(RT_0)$ and $m_1 = p_1 V_1/(RT_1) = p_0 V/(\gamma R T_0)$. The heat transfer is then

$$\frac{c_v V}{R}(p_2 - p_1) = \frac{p_0 V}{RT_0}\left(1 - \frac{1}{\gamma}\right) c_p T_0 + Q^{\leftarrow}_{1-2}$$

Noting that $p_1 = p_2 = p_0$, then

$$Q^{\rightarrow}_{1-2} = \frac{p_0 V}{RT_0}\left(1 - \frac{1}{\gamma}\right) c_p T_0 = p_0 V$$

Problem 2 solution
(a) This violates the Kelvin Planck statement of the second law of thermodynamics.
(b) This does not violate the second law of thermodynamics because the device is receiving work (mgh) and transfers an equal amount of heat to the reservoir.
(c) This violates the Kelvin Planck statement of the second law of thermodynamics because increasing the voltage across the capacitor is equivalent to producing work (equal to $\frac{1}{2}CV^2$) while interacting with a single reservoir.
(d) This does not violate the second law of thermodynamics because the device is receiving work (equal to $\frac{1}{2}CV^2$) and transfers an equal amount of heat to the reservoir.

Problem 3 solution
(a) The temperature of the boiling water is 60.7 °C. The pressure is the saturated pressure of water at 60.7 °C, which is 19.940 kPa.
(b) The rate of heat transfer is obtained by applying 1st law for a control volume for the liquid section of the ethyl alcohol, so that $\dot{Q}^{\rightarrow} = \dot{m}_{\text{ethyl}}(h_{\text{in}} - h_{\text{out}}) = 852$ kJ.
(c) Applying the first law to the liquid water section, we get $\dot{m}_{\text{liq water}}(h_{\text{out}} - h_{\text{in}}) = \dot{Q}^{\leftarrow} =$ 852 kJ. Noting that liquid water entering is in the saturated state at 60.7 °Cand exiting as saturated vapor at the same temperature, we get $h_{\text{in}} = h_{fg}(60.7) = 2357.5$ kJ/kg leading to $\dot{m}_{\text{l water,in}} = 0.361$ kg/s.
(d) First law for the pumping section,

$$\dot{m}_{\text{sat vap in}} h_{\text{sat vap in}} + \dot{m}_{\text{steam in}} h_{\text{steam in}} = \left(\dot{m}_{\text{sat vap in}} + \dot{m}_{\text{steam in}}\right) h_{\text{steam out}}$$

where $\dot{m}_{\text{sat vap in}} = 0.361$ kg/s, $h_{\text{sat vap in}} = h_g(60.7) = 2609.6$ kJ/kg, $h_{\text{steam in}} = h(260°\text{C}, 7\text{ bar}) =$ 2975 kJ/kg. Then, we must have

$$942 + \dot{m}_{\text{steam in}}2975 = (0.361 + \dot{m}_{\text{steam in}})\, h_{\text{steam out}}(1\text{ atm}, T_{out})$$

Assuming that the discharge stream is saturated vapor at 1 atm, then $h_{\text{steam out}} = 2675.6$ kJ/kg and correspondingly $\dot{m}_{\text{steam in}} = 0.08$ kg/s.