MECH 310 Thermodynamics I — January 12, 2009
American University of Beirut, Fall 2008 — Handout # Quiz 2

Quiz 2

- This is a closed book 90 minutes exam. You allowed to bring one A4 hand written cheat sheet which will be collected at end of exam. It is recommended that you read the whole exam before you start solving.
- Write your name and section number on both the question and answer sheets.
- Clearly identify your control mass / control volume.

Problem 1[1] (20 points)
Based on the idea of Maxwell's deamon, Richard Feynman[2] proposed a perpetual motion machine. The PMM, depicted in Figure 1, consists of a ratchet (asymmetric gear) that rotates freely in one direction but is prevented from rotating in the opposite direction by a pawl. The ratchet is connected by a massless and frictionless rod to a paddle wheel that is immersed in a bath of molecules at temperature T_1. The molecules constitute a heat bath in that they undergo random (Brownian) motion with a mean kinetic energy that is determined by the temperature. Each time a molecule collides with a paddle, it imparts an impulse that exerts a torque on the ratchet (the mechanism is imagined to be small enough that this tiny force could move it). Because the pawl only allows motion in one direction, the net effect of many such random collisions should be for the ratchet to rotate continuously in that direction. The ratchet's motion then can be used to do work on other systems, for example lifting a weight against gravity. The energy necessary to do this work apparently would come from the heat bath, without any heat gradient.
(a) Does the machine violate the first law of thermodynamics? Explain.
(b) Does the machine violate the second law of thermodynamics? If yes, which form of the second law statement does Feynman's machine violate?
(c) Prove that Feynman's machine cannot work as proposed.

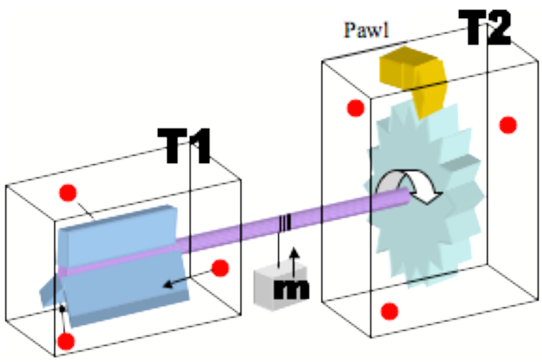

Figure 1: Schematic for problem 1.

[1] This problem is pretty much copied form wikipedia website with minor modifications.
[2] American Physicist and Nobel Prize winner.

Problem 2 (40 points)
Consider the power generation cycle operating between a high temperature reservoir (HTR) with $T_H = 310°C$ and a low temperature reservoir (LTR) at $T_L = 30°C$. The operation is steady with steam mass flow rate of 105 kg/s. The steam generator receives heat from the HTR and the condenser rejects heat to the LTR. Due to (viscous) friction, steam flow undergoes 12 kPa pressure drop across the condenser and 20 kPa pressure drop across the steam generator. The turbine loses 846 kW of heat to the surrounding due to imperfect insulation. The pump operation is reversible and adiabatic.
(a) Calculate the power generated by the turbine, the power consumed by the pump, the heat received from the HTR by the boiler and the heat rejected to the LTR by the condenser.
(b) Calculate the efficiency of the cycle? How does it compare with that of Carnot?
(c) Calculate the entropy generated in the turbine and pump. Assume that the turbine loses heat at its mean temperature.
(d) Explain how the cycle described in this problem differs from Carnot cycle.

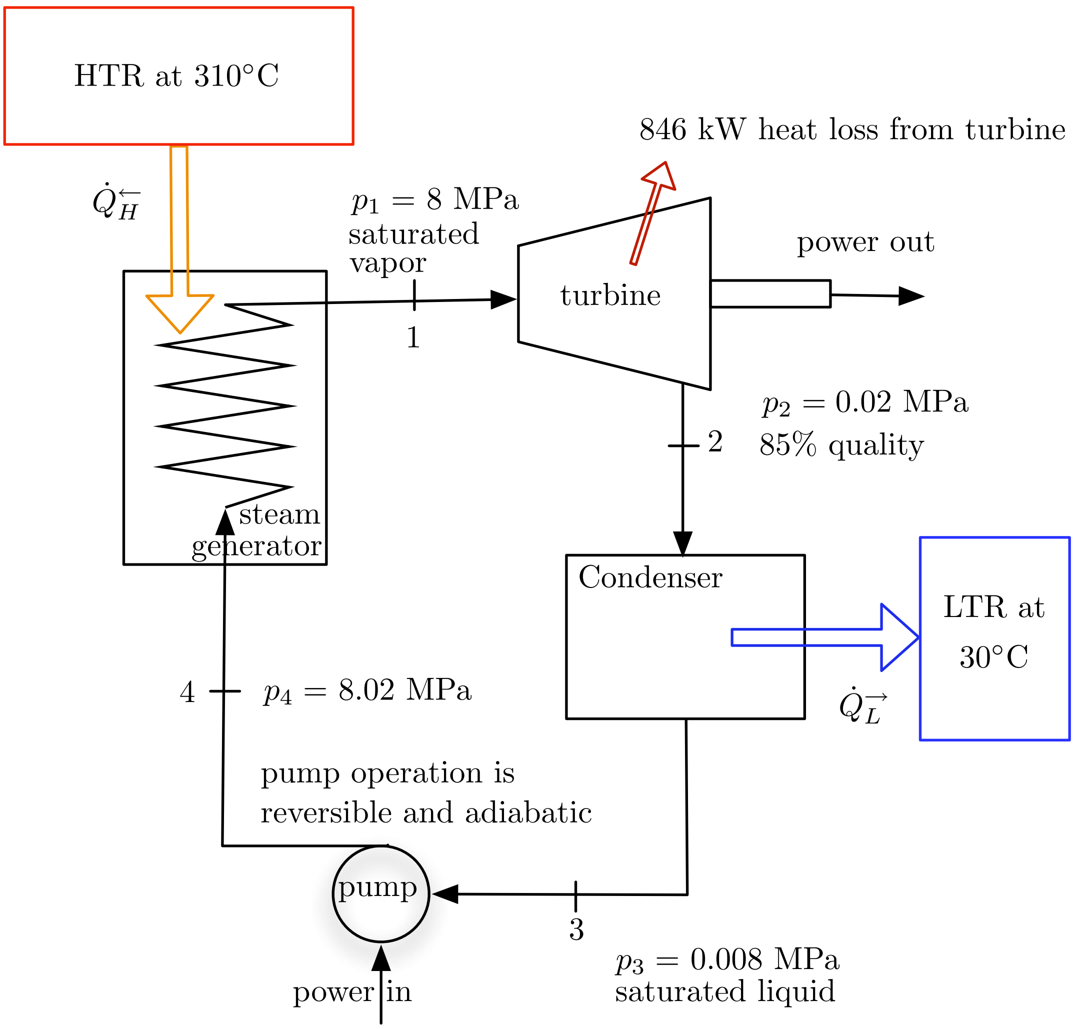

Figure 2: Schematic for problem 2.

Problem 2 Solution (30 points)
(a) We first identify the states:
<u>State 1</u>:
$h_1 = 2758.61$ kJ/kg.
$s_1 = 5.7448$ kJ/kg.K.

<u>State 2</u>:
$h_2 = 2255.315$ kJ/kg.
$s_2 = 6.8459$ kJ/kg.K.

<u>State 3</u>:
$h_3 =$173.852 kJ/kg.
$s_3 = 0.5925$ kJ/kg.K.

<u>State 4</u>:
$h_4 =$181.908 kJ/kg.
$s_4 = 0.5925$ kJ/kg.K.

First law for turbine, $\dot{W}_t^{\rightarrow} = \dot{m}(h_1 - h_2) - \dot{Q}_t^{\rightarrow} = 105(2758.61 - 2255.315) - 846 = 52000$ kW.

First law condenser, $\dot{Q}_L^{\rightarrow} = \dot{m}(h_2 - h_3) = 105(2255.315 - 173.852) = 2.18553615 \times 10^5$ kW.

First law pump, $\dot{W}_p^{\leftarrow} = \dot{m}(h_4 - h_3) = 105(181.908 - 173.852) = 846$ kW.

First law boiler, $\dot{Q}_H^{\leftarrow} = \dot{m}(h_1 - h_4) = 105(2758.61 - 181.908) = 2.70553 \times 10^5$ kW.

(b) Efficiency $\eta = \frac{\dot{W}_{net}^{\rightarrow}}{\dot{Q}_H^{\leftarrow}} = \frac{52000-846}{2.70553\times 10^5} = 0.189$

Carnot $\eta_{carnot} = 1 - \frac{T_L}{T_H} = 1 - \frac{273+30}{273+310} = 0.48$.

(c) Since pump operation is reversible, then $(\dot{S}_{irr})_p = 0$.
Second law, turbine $0 = \dot{S}_Q^{\leftarrow} + \dot{m}(s_{in} - s_{out}) + \dot{S}_{irr}$, so that

$$\begin{aligned}(\dot{S}_{irr})_t &= \dot{S}_Q^{\rightarrow} + \dot{m}(s_{out} - s_{in}) = \frac{846}{0.5 \times (295.1 + 60.06) + 273} + 105 \times (6.8459 - 5.7448) \\ &= 117.49 \text{ kW/K}.\end{aligned}$$

Problem 3 (40 points)
Consider the system shown in Figure 3. Tank A has a volume of 100 L and contains initially saturated water vapor at 160°C. Initially, the valve is closed and Cylinder B is empty. When the valve is opened, water flows slowly into cylinder B. The piston mass, which is free to move, is 0.5 ton and cylinder B cross sectional area is 0.1 m^2. The process continues until thermodynamic equilibrium is reached. During the process, there is heat transfer with the surrounding such that the temperature of all the water remains at 160°C. The piston initial temperature is 30°C and its final temperature is 160°C. The piston material specific heat is 0.5 kJ/kg.K.
Find the heat transferred.

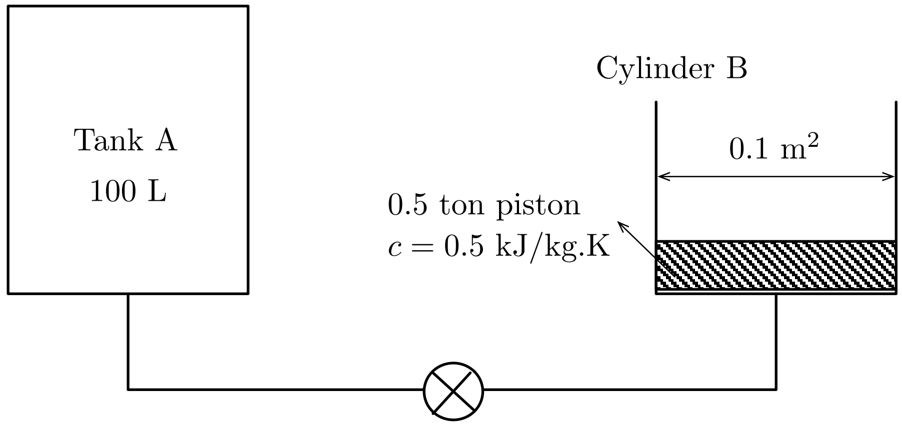

Figure 3: Schematic for problem 3.

Problem 3 Solution

State A1:
sat. vapor at 160°C.
p_{A1} = 6.178 bar
u_{A1}= 2568.4 kJ/kg
h_{A1} = 2758.1 kJ/kg
v_{A1} = 0.3071 m^3/kg
$m_{A1} = V_A/v_{A1}$ = 0.1/0.3071 = 0.3256 kg.

State A2:
p_{A2} = 150 kPa
T_{A2} = 160°C
superheated.
v_{A2} = 1.317 m^3/kg
u_{A2} = 2595.2 kJ/kg
h_{A2} = 2792.8 kJ/kg
$m_{A2} = V_A/v_{A2}$ = 0.1/1.317 = 0.07593 kg.

State B2:
p_{B2} = 150 kPa
T_{B2} = 160°C
superheated.
v_{B2} = 1.317 m^3/kg
u_{B2} = 2595.2 kJ/kg
h_{B2} = 2792.8 kJ/kg
$m_{B2} = m_{A1} - m_{A2}$ = 0.3256 - 0.07593 = 0.24967 kg.
$V_{B2} = m_{B2}v_{B2} = 0.24967 \times 1.317 = 0.3288$ m^3.

First law, unsteady, for the control volume consisting of A+B+piston:

$$
\begin{aligned}
& U_2 - U_1 = Q^{\leftarrow} + W^{\leftarrow} \\
\Rightarrow\quad & m_{A2}u_{A2} + m_{B2}u_{B2} - m_{A1}u_{A1} + m_p c_p (T_2 - T_1)_p + m_p g (z_2 - z_1)_p = Q^{\leftarrow} - p_B (V_2 - V_1)_B \\
\Rightarrow\quad & m_{A2}u_{A2} + m_{B2}u_{B2} - m_{A1}u_{A1} + m_p c_p (T_2 - T_1)_p + m_p g \frac{V_{2B}}{A} = Q^{\leftarrow} - p_B (V_2 - V_1)_B \\
\Rightarrow\quad & (0.3256)(2595.2) - (0.3256)(2568.4) + (500)(0.5)(160-30) + \frac{(500)(10)}{1000}\frac{0.3288}{0.1} = Q^{\leftarrow} - (150)(0.3288)
\end{aligned}
$$

Leading to $Q^{\leftarrow}$ =32574.48608 kJ.