Mech 414 Thermodynamics 2 **Quiz 1** **November 11, 2008** **90 Minutes**

Name ___________________________

Hello people. Please read the questions carefully. As you solve them, indicate clearly your system/CV boundaries and any assumptions you might make. When possible, please state in words what you are trying to solve/your approach so that we can follow your work and give you credit. This is especially important if you run out of time. Keep track of time; if you get stuck, move on. At the end of the quiz, return the question sheet with the solution booklet. This is a closed book, closed neighbor quiz. One A4 sheet of your own notes is allowed.

Some potentially useful equations

Incompressible substance with constant specific heats: $\Delta h = \Delta u + v\Delta P$; $\Delta u = c\Delta T$; $\Delta s = c \ln(T_2/T_1)$

Exergy balance for a closed system: $E_2 - E_1 = \int \left(1 - \frac{T_0}{T_b}\right) \delta Q - [W - P_0(V_2 - V_1)] - E_d$

SHORT ANSWER (PLEASE KEEP YOUR ANSWERS SHORT) (15 points; 10 minutes)

1. What guarantees a net power output from the ideal Rankine cycle? (5 points)
2. What guarantees a net power output from the ideal Otto cycle? (5 points)
3. Why does the use of regenerative feedwater heating (or simply "regeneration") improve the efficiency of the ideal Rankine cycle? (5 points)

Problem 1 (20 points; 15 minutes)

A steam turbine in a Rankine cycle has an isentropic efficiency of 80%. Steam enters the first stage of the turbine at 8 MPa and 500 deg C. 20% of the steam is extracted to an open feedwater heater operating at 1.4 MPa. The condenser pressure is 7.5 kPa. The turbine is adiabatic. What is the power output of the turbine per kg steam?

Problem 2 (30 points; 20 minutes)

A cup of tea of mass m is initially at a temperature T_1. We would like to use the hot tea as a source of heat to drive a Carnot engine that rejects heat to the environment at T_o.

a) Using an entropy balance, show that the heat rejected from the Carnot cycle to the environment is $Q_L = T_o(S_1 - S_o)$, where S_1 is the initial entropy of the tea, and S_o is the entropy of the tea when it finally reaches equilibrium with the surroundings. (15 points)
b) If the initial internal energy of the tea is U_1 and the final internal energy is U_o, how much work is produced by the heat engine, in terms of $m, U_o, U_1, S_1, S_o, T_o$? (10 points)
c) What is the relationship between the exergy of your tea at its initial state, and your answer obtained in part b)? (5 points)

Problem 3 (30 points; 20 minutes)

Instead of connecting it to a Carnot engine, you decide to *drink* (!) the tea of Problem 2. To remain at its equilibrium temperature (e.g. 37.5 deg C if you are human) your body rejects the thermal energy it receives from the tea to the surroundings. The heat rejection process from your body to the surroundings occurs at a temperature of T_b, which is higher than T_o. How much exergy will be destroyed as a result of you drinking the tea? Consider your skin temperature to be T_b, and limit your system of analysis to the tea and your body (i.e. do not include the exergy destroyed in the immediate surroundings as the heat travels from the surface of your skin through the surrounding air layer). Solve using the exergy balance equation in terms of m, T_o, T_1, and T_b. You will also need the specific heat of the tea, which is c. Neglect changes in potential energy.

Short answer

1. $W_{net} = W_t - W_p = \int_t v\,dP - \int_p v\,dP = \int (v_t - v_p)\,dP$ +1 +1

since $dP_t = dP_p$ +2

$\Rightarrow W_{net} = \int (v_t - v_p)\,dP > 0$

since v_t is for vapor phase $O[1000]$

+1 v_l is for liquid phase $O[1]$

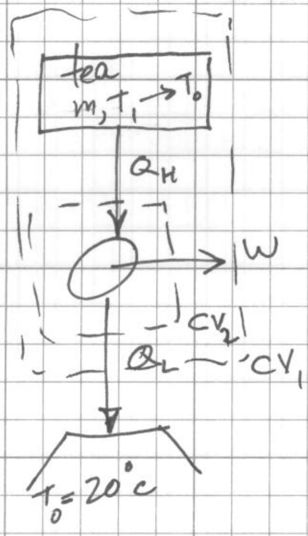
2. $W_{net} = -W_{comp} + W_{expn} = -\int_1^2 P\,dV + \int_3^4 P\,dV = \int \left(\bar{P}_{3\to4} - \bar{P}_{1\to2}\right) dV$ +1 +1

+2 since dV is same for expn & compression

+1 since the average pressure during expansion is greater than during compression, W_{net} is positive.

3. It increases the average temperature at which heat is added externally, by relying on internal bleed steam to pre-heat the water coming to the boiler/steam generator

Problem 2



a) 2nd law entropy balance on CV_1 +5

$$\Delta S_{CV_1} = -\frac{Q_L}{T_0} + \cancel{\sigma} = \cancel{\Delta S_{HE}}^{\text{cycle}} + \Delta S_{tea} = m(s_0 - s_1) \quad +5$$

$$\Rightarrow Q_L = m(s_1 - s_0) \quad +5$$

b) 1st law on CV_2

$$Q_H - Q_L = W \quad \text{since } \Delta U = 0 \text{ for cyclic H.E.} \quad +5$$

1st law on tea alone

$$\Delta U = Q - \cancel{W} = -Q_H$$

$$\Rightarrow m(u_1 - u_0) = Q_H \quad +5$$

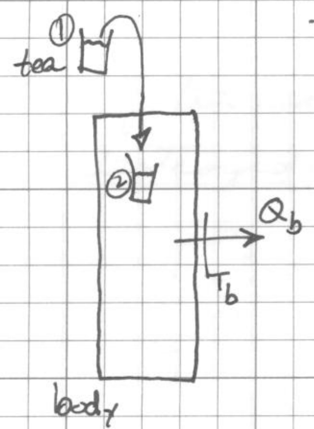
$$\Rightarrow W = m\left[(u_1 - u_0) - T_0(s_1 - s_0)\right]$$

or $\dfrac{W}{m} = (u_1 - u_0) - T_0(s_1 - s_0)$

c) The above equation for $\frac{W}{m}$ is the definition of exergy +5
for the tea. The exergy of a mass is the max work that can be
obtained from it as it comes to equil. w/its environment. In

this case, the max work is obtained via a totally reversible heat engine.

PROBLEM 3



system: tea + body

$$\Delta E_x = \Delta E_{x_{tea}} + \Delta E_{x_{body}} = \left(1 - \frac{T_0}{T_b}\right)Q_b \,*\, \cancel{(W - p_0\Delta V)}$$

$* - E_{xd}$

$$\Delta E_{x_{tea}} = (U_2 - U_1) - T_0(S_2 - S_1)$$
$$= m\left[C(T_b - T_1) - T_0 C \ln\frac{T_b}{T_1}\right]$$

$$\Delta E_{x_{body}} = U_2 - U_1 - T_0(S_2 - S_1)$$
$$= m_b\left[C_b\cancel{(T_b - T_b)} - T_0 C \ln \cancel{\frac{T_b}{T_b}}\right] = 0$$

note: we treated the body & tea as two discrete masses that retain their identity $\Rightarrow m_t = \text{const}$

$m_b = \text{const}$

$$\Rightarrow E_{xd} = \overset{\text{heat leaving system}}{-}\left(1 - \frac{T_0}{T_b}\right)Q_b - m\left[C(T_b - T_1) - T_0 C \ln\frac{T_b}{T_1}\right] \quad (I)$$

need Q_b where Q_b is the heat that needs to leave the body to maintain the temperature

1st law on body:

$$\Delta U_b = Q_{tea} - Q_b \Rightarrow Q_{tea} = Q_b$$

1st law on tea:

$$\Delta U = Q - \cancel{W} = \overset{\text{heat leaving the tea}}{-}Q_{tea}$$

$$\Rightarrow Q_{tea} = m(u_1 - u_2) = mC(T_1 - T_b) \quad (II)$$

combining I & II we get

$$E_{xd} = -\left(1 - \frac{T_0}{T_b}\right)mC(T_1 - T_b) - mC(T_b - T_1) + mCT_0 \ln\frac{T_b}{T_1}$$

$$= \cancel{mC(T_b - T_1)} + \frac{T_0}{T_b}mC(T_1 - T_b) - \cancel{mC(T_b - T_1)} + mCT_0 \ln\frac{T_b}{T_1}$$

$\cancel{\frac{T_0}{T_b}}$

$$E_{xd} = mC T_0 \left[\frac{T_1}{T_b} + \ln \frac{T_b}{T_1} - 1 \right]$$

note: if tea were at 37.5°C initially, no exergy would be destroyed.

$$\left[\frac{T_b}{T_b} + \ln \frac{T_b}{T_b} - 1 \right] = 0$$

Thermo II Quiz 1 correction sheet. Fall 2008-9

Problem 3

Correct application of exergy balance with a well defined CV	10 points
Change in exergy of the human body is zero	5 points
Change in exergy of the tea Ub-U1-To(Sb-S1)	3 points
Use of first law to find Qb = Qtea = (Ub-U1)	9 points
Delta S, U relations for an incompressible substance	3 points