Mer232 – Thermodynamics II
Final Exam
June 10, 2008

Open Book & 3 “crib” sheets
2 hrs or so

Name: SOLUTIONS

Problem 1: ________ /25
Problem 2: ________ /25
Problem 3: ________ /25
Problem 4: ________ /25
Total: ________ /100

Class avg = 76

Have a Nice summer!

Spring 2008
Problem 1

A mixture of propane ($C_3H_8$) and 200% theoretical air enters a combustion chamber at 25 °C, 300 kPa, and the products of combustion exit the chamber at 1400 K and $P = 300$ kPa. You may assume that this is a steady state steady flow process, the reactants and product gases can be modeled as ideal gases and that complete combustion occurs.

(a) Write the combustion equation for this reaction.

\[ C_3H_8 + 10(0.2 + 3.76N_2) \rightarrow 3(0.2 + 4H_2O + SO_2 + 3.76N_2) \]

(4 points)

(b) Calculate the air fuel ratio on a mass basis and on a mole basis.

\[ AF_{\text{mass}} = \frac{m_{\text{air}}}{m_{\text{fuel}}} = \frac{10(4.76)(29)}{1(44.097)} = 31.3 \text{ kg air/kg fuel} \]

\[ AF_{\text{mole}} = \frac{N_{\text{air}}}{N_{\text{fuel}}} = \frac{10(4.76)}{1} = 47.6 \text{ mole air/mole fuel} \]

(4 points)
(c) How much heat is released, per kmol of fuel, during combustion?

\[ \Delta h_{1400-298} = 14400 - 298 \]

\[
\begin{align*}
\text{C}_3\text{H}_8 & \quad \bar{h}_f^0 & \quad -103,850 \\
\text{O}_2 & \quad - & \quad 45648 - 8682 = 36966 \text{ kJ/kmol} \\
\text{N}_2 & \quad - & \quad 43605 - 8669 = 34936 \text{ kJ/kmol} \\
\text{H}_2\text{O(g)} & \quad -241820 & \quad 65271 - 9364 = 55907 \text{ kJ/kmol} \\
\end{align*}
\]

\[ Q_{\text{cal}} = H_f - H_p \]

\[ Q = (\bar{h}_f^0)_{\text{C}_3\text{H}_8} - 3(\bar{h}_f^0 + \Delta h)_{\text{O}_2} - 4(\bar{h}_f^0 + \Delta h)_{\text{H}_2\text{O}} - 5(\bar{h}_f^0 + \Delta h)_{\text{O}_2} - 37.6(\bar{h}_f^0 + \Delta h)_{\text{N}_2} \]

\[ Q_{\text{cal}} = 204,1057 \text{ kJ/kmol propane} \]

(10 points)

(d) At what temperature will the water in the products start to condense?

Calculate partial pressure of H\(_2\)O:

\[ P_{\text{H}_2\text{O}} = \frac{N_{\text{H}_2\text{O}}}{N_{\text{total}}} \]

\[ P = \frac{4}{49.6} (300) = 24.2 \text{ kPa} \]

\[ T_{\text{Sat}}(24.2) \approx 640^\circ\text{C} \]

(4 points)

(e) Without doing any further calculations, how does your answer to parts (c) and (d) change if the products of combustion are at 700 K instead of 1400 K. Explain.

Part c: The same, \( H_p \) becomes more negative, therefore \( Q_{\text{cal}} \) increases

Part d: No change

(3 points)
Problem 2

Steam is supplied in a pipe at 3 MPa, 700 °C. A turbine with an isentropic efficiency of 67% is connected to the pipe by a valve and it exhausts at 300 kPa. The steam is throttled down to 1.8 MPa before entering the turbine. **NOTE:** You do not need to interpolate to get properties – just round to nearest value.

**State any assumptions used.**

(a) Calculate the actual turbine work (in kJ/kg).

\[ \Delta KE = \Delta PE = 0 \]

\[ T_0 = 298 \text{ K} \]

\[ S_{SS} = \frac{\text{kJ/kgK}}{\text{kJ/kgK}} \]

\[ P_2 = 1.8 \text{ MPa} \]

\[ T_2 \approx 690 \text{ °C} \]

\[ h_2 = h_1 = 3912 \text{ kJ/kg} \]

\[ s_2 \approx 8.0 \text{ kJ/kg K} \]

\[ P_3 = 300 \text{ kPa} \]

\[ T_3 = 400 \text{ °C} \]

\[ h_3 \approx 3275.5 \text{ kJ/kg} \]

\[ w_s = h_2 - h_3 = 3912 - 3275.5 = 636.5 \text{ kJ/kg} \]

\[ w_a = \eta w_s = \frac{\text{kJ/kg}}{\text{kJ/kg}} \]

(b) What is the change in exergy through the valve?

\[ \gamma_2 - \gamma_1 = h_2 + h_1 - t_0 (s_2 - s_1) \]

\[ \text{Assume } T_0 = 298 \text{ K} \]

\[ \gamma_2 - \gamma_1 = -298 (8 - 7.759) \]

\[ = -71.8 \text{ kJ/kg} \]

\[ (6 \text{ points}) \]

\[ (6 \text{ points}) \]
(c) How much exergy is destroyed in the turbine expansion process?

\[ X_{\text{dest}} = T_{\text{os gen}} = 70 \, m \, (s_3 - s_2) \]

\[ X_{\text{dest}} = \frac{298 \, (8.327 - 8)}{m} = 97.4 \, \text{kJ/kg} \]

(6 points)

(d) What is the second law efficiency of the turbine?

\[ \eta_{\text{II}} = \frac{W_{\text{u}}}{W_{\text{rev}}} \]

\[ W_{\text{rev}} = h_3 - h_2 = h_3 - h_2 - 70 \, (s_3 - s_2) \]

\[ = 34855 - 3912 - 298 \, (8.327 - 8) \]

\[ = 524 \, \text{kJ/kg} \]

\[ \eta_{\text{II}} = \frac{426.5}{524} = 81.4\% \]
Problem 3

You have just washed your hair and now blow dry it in a room at 23 °C, 1 atm and 80% relative humidity (state 1). The 500 W dryer heats the air to 45 °C (state 2), blows it through your hair where the air becomes saturated (state 3), and then flows on to hit a window where it cools to 15 °C (state 4).

State any assumptions used.

Air + water vapor can be modeled as ideal gases

\( P_{atm} = 101.3 \text{kPa} \)

(a) What is the specific humidity at state 1 and what are the specific and relative humidity at state 2? Identify both states on the attached psychrometric chart.

\[ w_1 = 0.0145 \quad \text{(from psychrometric chart)} \]

\[ w_2 = w_1 - 0.0145 \]

\[ \phi_2 = 24\% \]

\[ h_1 = 60 \text{ kJ/kg air} \]

\[ h_2 = 82 \text{ kJ/kg air} \]

(b) Using the information about states 1 and 2, determine the airflow rate.

\[ m_a h_1 + \phi = m_a h_2 \]

\[ m_a = \frac{\phi}{h_2 - h_1} = \frac{0.5 \text{ kW}}{82 - 60 \text{ kJ/kg air}} \]

\[ m_a = 0.022 \text{ kg/s} \]

(6 points)

(7 points)
(c) What is the specific humidity and temperature at state 3. Identify state 3 on the attached psychrometric chart. **Hint:** Treat process 2-3 as an adiabatic saturation process.

\[
\text{From chart: } w_3 = 0.022 \\
T_3 = 26^\circ C
\]

(6 points)

(d) Determine how much water condenses onto the window and identify state 4 on the attached chart.

\[
\text{From chart: } w_4 = 0.011 \\
T_4 = 15^\circ C
\]

\[
\dot{m}_{\text{cond}} = \dot{m}_a (w_3 - w_4) \\
= 0.022 (0.022 - 0.011)
\]

\[
\dot{m}_{\text{cond}} = 2.4 \times 10^{-4} \text{ kg/s}
\]

(6 points)
Problem 4

Air undergoes an Ericsson refrigeration cycle which is the reverse of the Ericsson power cycle (see Figure 9-26 on page 514 in your textbook for a description of the power cycle). At the beginning of the isothermal compression the pressure and temperature are 100 kPa and 310 K respectively. The pressure ratio during the isothermal compression is 3. During the isothermal expansion the temperature is 270 K.

**State any assumptions used.**  
Ideal gas

(a) Draw the cycle on a Ts and Pv diagram. Clearly indicate the direction of processes (ie show refrigeration not power generation).

\[
\begin{align*}
T_1 &= T_2 = 310 \text{ K} \\
T_3 &= T_4 = 270 \text{ K} \\
P_1 &= P_4 = 100 \text{ kPa} \\
P_2 &= P_3 = 300 \text{ kPa}
\end{align*}
\]

(b) Calculate the amount of heat transferred in the isothermal expansion and isothermal compression process.

**Isothermal Expansion Process: 3 \rightarrow 4**

\[
Q = T \Delta S
\]

For ideal gases: \[\Delta S = C_p \ln \frac{T_4}{T_3} - R \ln \frac{P_4}{P_3}\]

\[
S_4 - S_3 = -0.287 \text{ kJ/K} \frac{\text{k}}{1} = 0.315 \text{ kJ/K}
\]

\[Q_{3 \rightarrow 4} = 85.1 \text{ kJ/kg}\]

\[Q_{1 \rightarrow 2} = T \Delta S = 310 (-0.287 \ln \frac{1}{3})\]

\[Q_{1 \rightarrow 2} = 97.74 \text{ kJ/kg}\]
(c) Calculate the coefficient of performance and compare it to coefficient of performance for a Carnot refrigeration operating between the same two temperatures.

\[
\text{COP} = \frac{\text{Energy sought}}{\text{Energy cost}} = \frac{Q_H}{Q_H - Q_L} = \frac{85.1}{97.7 - 85.1} = 6.75
\]

\[
\text{Carnot: COP} = \frac{1}{T_H/T_L - 1} = 6.75
\]

(10pts)
**Bonus 1:** You hear an airplane traveling at an elevation of 500 m above the ground 1 second after it passes directly overhead. How fast is the airplane traveling?

\[ L = Vt = CT \]
\[ L = \sqrt{KRT} = 346 \text{ m/s} \]

\[ M = \frac{1}{\sin \alpha} = \frac{\sqrt{H^2 + L^2}}{H} \]

\[ M^2 = \frac{H^2 + C^2 M^2 t^2}{H^2} \]

\[ M = \frac{H}{\sqrt{H^2 - C^2 M^2 t^2}} = \frac{500}{\sqrt{500^2 - 346^2 (1)^2}^{1/2}} \]

**Bonus 2:** Explain the figure plotted below. What is plotted on the y-axis and what do the peaks correspond to?

\[ M = 1.38 \]
\[ V = 479 \text{ m/s} \]