Mer231 - Thermodynamics
Exam 2
October 25, 2010

Part A  40 points

Closed Notes/Book

Name: SOLUTION
Problem 1 (40 points)

(a) Water is heated in a closed pan on top of a stove while being stirred by a paddle wheel. During the process, 20 kJ of heat is transferred from the stove to the water and 5 kJ of heat is lost from the pan to the surrounding air. The paddle wheel work amounts to 200 Nm. Determine the final energy of the system if its initial energy is 10 kJ.

\[ Q = \Delta E + W \] (COE)

\[ 20 - 5 = E_2 - E_1 - 0.2 \]

\[ E_2 - E_1 = 15.2 \text{ kJ} \]

\[ E_2 = 25.2 \text{ kJ} \]

(b) List and describe the mechanism for two of the three ways in which heat can be transferred.

1. Conduction - heat transfer in a solid material
2. Convection - heat transfer from a surface to/from a fluid
3. Radiation - heat transfer by electromagnetic waves

(c) A steady flow mixing chamber has two inlets and one outlet. At inlet 1 the mass flow rate is 1 kg/s, and at inlet 2 the mass flow rate is 3 kg/s. If the average velocity at the outlet is 2 m/s and the area of the outlet is 0.1 m², what is the specific volume of the outlet fluid?

\[ \dot{m}_3 = \dot{m}_1 + \dot{m}_2 \] (COM)

\[ \dot{m}_3 = 4 \text{ kg/s} \]

\[ \frac{\dot{m}}{A} = \gamma \]

\[ \gamma = 0.05 \text{ m}^3/\text{kg} \]

(d) If the change in energy of a closed system is known for a process between two end states, can you determine if the energy change was due to work, to heat transfer, or to some combination of work and heat transfer? Why or why not?

\[ \begin{align*}
\text{NO} \\
\Delta E = Q - W = \text{known.} \]
\end{align*} \]

\[ Q, W \] are path functions!

(e) An ideal gas in a piston/cylinder is heated with 2 kJ during an isothermal process. How much work is done? Explain your answer.

\[ Q = \Delta E + W \]

Since process is isothermal, ideal gas

\[ \Delta E = 0 \] (ignore KE, PE)

\[ W = Q = 2 \text{ kJ} \]
(f) In what forms can energy cross the boundaries of a closed system? In what forms can energy cross the boundaries of an open system?

Closed system: heat, work
Open system: heat, work, w/mass

(g) For the setup shown to the right, the gas pressure is initially 100 kPa and it takes 300 kPa of pressure to lift the piston off of the lower stops. The volume at the lower stops is 1 m³ and the final volume at the upper stops is 2 m³. The piston comes in contact with a linear spring when the volume reaches 1.5 m³ and it takes a gas pressure of 500 kPa to completely compress the spring. Heat is added to the system until the pressure reaches 700 kPa. Draw this process on a P-V diagram and label (P, V) of all points.

(h) Is it possible to compress an ideal gas isothermally in an adiabatic piston cylinder device? Explain.

\[ Q = \Delta E + W \]
\[ \Delta E = 0 \text{ (isothermal ideal gas)} \]
\[ Q = 0 \Rightarrow \text{adiabatic} \]

(i) A two-phase, saturated liquid-vapor mixture of H₂O, initially at P₁ and T₁, is stirred in a closed rigid, well-insulated tank until only saturated vapor remains at state 2. Sketch this process on a p-v diagram. Include the steam dome! Does the area under the process curve represent the work required to do the process? Why or why not?

The area does not represent work done to stir the mixture (it is shaft work).

(j) In the indicated regions of a phase diagram, the following properties completely fix the state of a substance.

a. P and T in a saturated mixture (liquid-vapor equilibrium regime)
b. x and T for a compressed liquid
c. T and h for a superheated vapor.
d. T and u for an ideal gas
e. T and v in any region.
Mer231 - Thermodynamics

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October 25, 2010

Part B 60 points

Open Book

Name: SOLUTION
Problem 2 (30 points). An adiabatic air compressor is to be powered by a direct-coupled adiabatic steam turbine that is also driving a generator. Steam enters the turbine at 8 MPa and 500 °C at a rate of 25 kg/s and exits at 10 kPa and a quality of 0.92. Air enters the compressor at 98 kPa and 300 K at a rate of 10 kg/s and exits at 1 MPa and 620 K. Note: You may assume that the air can be modeled as an ideal gas.

(a) What is the rate of work delivered to the compressor?

(b) What is the net power delivered to the generator by the turbine?

(c) How would your answer to part (b) change if a throttling valve were placed at the inlet to the turbine?

(d) List any assumptions used to solve this problem.

(a) Apply COE to compressor:

\[ \dot{Q} + \dot{m}(h_1 + \frac{V_1^2}{2} + gZ_1) = \dot{W} + \dot{m}(h_2 + \frac{V_2^2}{2} + gZ_2) \]

Solve for \( \dot{W} = \dot{m}(h_1 - h_2) \)

Table A.7.1
\( h_1 = 300.476 \text{ kJ/kg} \)
\( h_2 = 628.38 \text{ kJ/kg} \)
\( \dot{W} = 10(300.476 - 628.38) = 3279 \text{ kW} \)

(b) Apply COE to steam turbine:

\[ \dot{Q} + \dot{m}(h_1 + \frac{V_1^2}{2} + gZ_1) = \dot{W} + \dot{m}(h_2 + \frac{V_2^2}{2} + gZ_2) \]

\( \dot{W} = \dot{m}(h_1 - h_2) \)

Table B.1.3
\( h_1 = 3398.27 \text{ kJ/kg} \)
Table B.1.2
\( h_f = 191.81 \text{ kJ/kg} \)
\( h_g = 2392.8 \)

\( \dot{W}_{t} = 25(3398.27 - 2393.2) \)
\( h_2 = 191.81 + .92(2392.8) = 2393.2 \)

\( \dot{W}_{\text{total}} = 251127 \text{ kJ} \)
\( \dot{W}_{\text{gen}} = \dot{W}_{\text{t}} + \dot{W}_{\text{gen}} \)

10

(c) With throttling valve

\( \Delta P \) cause \( \dot{Q} \) isenthalpic so \( h \) stays same

but \( \dot{m} \) will decrease, lowering \( \dot{W} \).
**Problem 3 (30 points)** An insulated, frictionless piston separates two masses of air (1 kg each) in a rigid tank. The initial pressure and temperature in each side are equal, as shown below. The tank is insulated except for the left end (Note: Tank B is insulated from Tank A). An amount of heat of 100 kJ is transferred through the left tank wall and the temperature inside Tank A becomes 400 K. Note: You may assume that the air can be modeled as an ideal gas.

(a) What is the initial volume of Tanks A and B? 15

(b) How much work is done on the air in Tank B? 10

(c) What is the final temperature and pressure of the air in Tank B? 10

(d) State any assumptions used in your solution to this problem 5

(a) USE I.G.L. \( PV = nRT \)
\[
V_A = V_B = \frac{mRT}{P} = \frac{(1 \text{ kg})(1.287 \text{ kJ/kgK})(300 \text{ K})}{200 \text{ kPa}} = 0.4365 \text{ m}^3
\]

**Total Volume** = 0.873 m^3

(b) Analyze CV around A:
\[
\dot{Q} = m(u_2 - u_1) + \frac{V_A^2}{2} + \frac{V_B^2}{2}
\]
\[
W = \dot{Q} + m(u_1 - u_2)
\]
\[
W_A = 100 + 1 \times (214.36 - 286.49) = 27.87 \text{ kJ}
\]

\[
W_B = -W_A = -27.87 \text{ kJ}
\]

(c) Analyze Tank B:
\[
0 = \dot{Q} + m(u_2 - u_1)
\]
\[
0 = -27.87 + (1)(u_2 - 214.36) \Rightarrow u_2 = 242.23 \text{ K}
\]

(d) \( P_A = P_B = \frac{m_A RT_A}{V_A} = \frac{m_B RT_B}{V_B} \)
\[
P_{B_2} = 246.4 \text{ kPa} = P_A
\]
\[
V_{B_2} = 0.394 \text{ m}^3
\]
\[
V_{A_2} = 0.466 \text{ m}^3
\]
**Bonus 1:** What was the score of the Union Men's Hockey Game on Saturday night (1/22) and who won?

**Bonus 2:** What is the name of my sailboat?