UNIVERSITY OF WATERLOO
DEPARTMENT OF ELECTRICAL ENGINEERING
ECE 309 Thermodynamics Electrical Engineering

Mid-Term Examination Spring 1996
M.M. Yovanovich June 22, 1996 9:00-11:00 A.M.

NOTE:

1. Open book examination. You are permitted to use your calculator, the text book and your lecture notes. One crib sheet (8.5 x 11) one side only.
2. Clear systematic solutions are required. Process diagrams and sketches of equipment showing locations referred to in your analysis are both essential. Marks will not be assigned for problems that require unreasonable (in the opinion of your professor) effort for the marker to decipher.
3. Very briefly state the assumptions that are made in each problem.
4. Ask for clarification if any problem statement is unclear.
5. The weight for each problem is indicated. You must answer all *three* problems.
6. Do not interpolate in the tables. Use the nearest points.

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1. (15) A fixed mass of an ideal gas undergoes three processes during a cycle. The first process from state 1 to state 2 is *isothermal* expansion; during the second process the volume is *constant* and the pressure is *increased* from P_2 to P_3, and the final process from state 3 to state 4 returns the system back to the initial state 1 is *constant pressure.*
   (a) Sketch and label the three processes on a P-V diagram.
   (b) Determine the net change in the internal energy during the cycle. Justify your answer.
   (c) Determine the net total work and total heat transfer for the cycle.
   (d) Develop the expression for $\frac{W_{14}}{P_1 V_1}$ in terms of the volume ratio $\frac{V_2}{V_1}$.

2. (25) A free piston-cylinder system contains 5 kilograms of saturated liquid (water) at 100 $^\circ C$ which undergoes an *isobaric/isothermal* process until all the liquid evaporates. The saturated vapor (steam) is next heated under constant pressure until its temperature is 350 $^\circ C$ (this is process 2-3). During the 3-4 process, the superheated steam is cooled under constant volume until all the steam is now saturated vapor at some new temperature and pressure. The final process (process 4-5) is *isobaric/isothermal* during which the steam is cooled until the specific volume of the liquid/vapor mixture is equal to the specific volume of the saturated vapor at state 2, i.e., $v_5 = v_2$.

   a) Sketch and label the four processes and the five end states on a T-v diagram.

   b) Determine from the attached tables of water/steam properties, the quality and the total enthalpy of the mixture at the end state.

3. (30) Two simple substances A and B occupy separate compartments of a cylindrical tank whose total volume is V. The initial total volumes of the two substances are V_{A1} and V_{A2} such that $V_{A1} = V/3$ and $V_{A2} = 2V/3$. The two compartments are separated by a frictionless movable piston as shown in the figure below. The entire tank is insulated from the its surroundings.

   Initially the substance A is saturated vapor at temperature T_{A1} and pressure P_{A1}, and substance B is a gas whose temperature is $T_{B1} < T_{A1}$ and pressure $P_{B1} = P_{A1} = P$.

   The final state of substance A, after it undergoes an *isobaric/isothermal* cooling process, is saturated liquid at temperature $T_{A2} = T_{A1}$ and $V_{A2} = V_{A1}/100$.

   The substance B undergoes a *polytropic* expansion process as it is heated; until it's in thermal equilibrium with substance A, i.e., $T_{B2} = T_{A2}$.

   Use the First Law of Thermodynamics to derive expressions for the total energy transfer by heat and work for each substance during the respective processes. Assume that the piston has negligible mass. The polytropic expansion process can be written as

$$PV^n = \text{constant}$$

   Can you demonstrate that the absolute values of the total heat and work for substance A and B are equal?

4. (30) Tank A as shown below has a volume of 0.4 m^3 and contains argon gas at 250 kPa, 30 $°C$. Cylinder B contains a frictionless piston of a mass such that a pressure of 150 kPa inside the cylinder is required to raise the piston. The valve connecting the two is now opened, allowing gas to flow into the cylinder. Eventually, the argon reaches a uniform state of 150 kPa, 40 $°C$ throughout. Calculate the work and heat transfer to the argon during this process (Treat argon as an ideal gas with $R = 0.20813$, $c_p = 0.5203$, and $c_v = 0.3122$. All in $kJ/kg \cdot K$).

Some Equations and Relationships

1. $E_1 + W_{1\to 2} + Q_{1\to 2} = E_2$
2. $e = u + \frac{1}{2}\bar{V}^2 + gz + \cdots$
3. $h \equiv u + Pv \qquad u = \frac{U}{M} \qquad v = \frac{V}{M}$
4. $v = (1-x)v_f + xv_g \qquad v_{fg} = v_g - v_f$
5. $\left(\frac{dE}{dt}\right)_{CV} = \dot{Q} + \dot{W} + \sum_{in}(e + Pv)\dot{M} - \sum_{out}(e + Pv)\dot{M}$
6. $\left(\frac{dM}{dt}\right)_{CV} = \sum_{in}\dot{M} - \sum_{out}\dot{M}$
7. $c_v \equiv \left(\frac{\partial u}{\partial T}\right)_V \qquad c_p \equiv \left(\frac{\partial h}{\partial T}\right)_P \qquad c_p = c_v + R$