Problem Set No. 4

Due: Wednesday, January 26, 2011

Objective: To use the First Law and the concepts of enthalpy and heat capacity to assess processes in open and closed systems.

Note: Numerical values for some problems have been changed from those in the book.

Problem 13 (thought problem)

For many gases at low densities and pressures (where ideal gas behavior is obtained), C_V is fit well by the following functional form:

$$C_V/R = A + BT + CT^2$$

where A, B, C are all constants, with appropriate temperature units so that the RHS of this equation is dimensionless.

a) How can a gas be both ideal and follow the equation above, at the same time?

b) Such a gas initially at T_1 expands slowly in an insulated piston to double its original volume; you would like to find the final temperature T_2. A friend suggests you may use the following equation that we derived in class:

$$\left(\frac{T_2}{T_1}\right) = \left(\frac{V_1}{V_2}\right)^{\frac{R}{C_V}} = \left(\frac{1}{2}\right)^{\frac{R}{C_V}}$$

where C_V is evaluated at T_1. What is wrong with your friend's statement? Find the correct equation that should be solved (implicitly) to find T_2.

Problem 14 (*Smith, van Ness, Abbott, 3.9, page 112)*

An ideal gas initially at 500 K and 12 bar undergoes a four-step mechanically reversible cycle in a closed system. In step 12, pressure decreases isothermally to 4 bar; in step 23, pressure decreases at constant volume to 3 bar; in step 34, volume decreases at constant pressure; and in step 41, the gas returns adiabatically to its initial state. Take $C_P = (7/2)R$ and $C_V = (5/2)R$.

(a) Sketch the cycle on a PV diagram.
(b) Determine T and P for states 1, 2, 3, and 4. Put your answer in the form of a table.
(c) Calculate $Q/n, W/n, \Delta U, \Delta H$ for each step of the cycle. Add these to your table.

Problem 15 (*Smith, van Ness, Abbott, 3.23, page 115)*

One mole of an ideal gas, initially at $40\ °\mathrm{C}$ and 1 bar, undergoes the following mechanically reversible changes. It is compressed isothermally to a point such that when it is heated at constant volume to $130\ °\mathrm{C}$ its final pressure is 12 bar. Calculate $Q, W, \Delta U$, and ΔH for the process. Take $C_P = (7/2)R$ and $C_V = (5/2)R$.

Problem 16 (*Smith, van Ness, Abbott, 3.17, page 114)*

A rigid, nonconducting tank with a volume of 4 m^3 is divided into two unequal parts by a thin membrane. One side of the membrane, representing 1/3 of the tank, contains argon gas at 6 bar and 80 °C, and the other side, representing 2/3 of the tank, is evacuated. The membrane ruptures and the gas fills the tank. What is the final temperature of the gas? How much work is done? Is the process reversible? Assume argon is an ideal gas and has $C_P = (5/2)R$ and $C_V = (3/2)R$.

Problem 17 (*Smith, van Ness, Abbott, 2.29, page 60)*

Steam flows at steady state through a converging, insulated nozzle, 25 cm long and with an inlet diameter of 6 cm. At the nozzle entrance (state 1), the temperature and pressure are 300 °C and 600 kPa, and the velocity is 25 m/s. At the nozzle exit (state 2), the steam temperature and pressure are 250 °C and 330 kPa. Property values are:

H_1 = 3,112.5 kJ kg^{-1} $\qquad$ V_1 = 388.61 cm^3 g^{-1}
H_2 = 2,945.7 kJ kg^{-1} $\qquad$ V_2 = 667.75 cm^3 g^{-1}

What is the velocity of the steam at the nozzle exit, and what is the exit diameter?

Problem 18 (*Smith, van Ness, Abbott, 2.42, page 62)*

Ethylene enters a turbine at 8 bar and 430 K, and exhausts at 1 atm and 315 K. For a mass flow rate of 6.0 kg/s, determine the cost C of the turbine, in the two cases below, if the cost is given by C/\$ = 15200 $(|\dot{W}|/\mathrm{kW})^{0.573}$.

a) Assume that ethylene behaves as an ideal gas with $C_P = 2.2$ kJ/ kg K.

b) Assume that the following data for ethylene are known: H_1 = 761.1 kJ/kg, H_2 = 536.9 kJ/kg.