Problem Set No. 8

Due: Wednesday, March 2, 2011

Objective: To understand and perform calculations involving the entropy and the second law of thermodynamics for closed, open, and cyclical processes. To understand and perform calculations involving fundamental thermodynamic relations and potentials (U, H, A, G, and S).

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

Problem 39 (*thought problem)*

Draw a Venn diagram showing the relationship between the following closed processes: adiabatic, reversible, and isentropic. (You can check what a Venn diagram is at Wikipedia.)

Problem 40 (*Smith, van Ness, Abbot, 5.46, page 197)*

A Hilsch vortex tube operates with no moving mechanical parts, and splits a gas stream into two streams: one warmer and the other cooler than the entering stream. Air enters one such tube at $5\ bar$ and $20\ ^\circ C$. A fraction of it leaves in the warm stream at $1\ atm$ and $25\ ^\circ C$, and the remainder in the cool stream at 1 atm. The mass flowrate of warm air leaving is 6 times that of the cool air. Assume air to be an ideal gas with $C_P/R = 7/2$.

(a) What is the temperature of the exiting cool stream?

(b) Prove that this process is possible.

Problem 41 (*Smith, van Ness, Abbott, 5.39, page 19)*

A steady-flow adiabatic turbine (expander) accepts carbon dioxide at $550\ K$ and $4\ bar$ and discharges at $1.2\ bar$. Assume that CO_2 is well-described as an ideal gas with T-dependent C_P.

(a) What is the exit temperature of the turbine, in K, if it is maximally efficient (i.e., the rate of entropy generation is zero)?

(b) What is the work produced by the turbine (kJ per mol CO_2) if it is maximally efficient?

(c) Instead, it is found that the actual work produced by the turbine is only 70% of the result from part (b). In this case, what is the new exit temperature of the turbine stream, in K, and how much entropy is generated per mol CO_2?

Problem 42 (*Smith, van Ness, Abbott, 6.20, page 243)*

If careful enough, very pure liquid water can be supercooled (subcooled) at atmospheric pressure to temperatures well below 0 ℃. Assume 1 kg has been cooled as a liquid to -8 ℃. A small ice crystal (of negligible mass) is then added to "seed" the supercooled liquid such that a portion of it crystallizes irreversibly and the system then obtains solid-liquid equilibrium. Note that the latent heat of fusion of water at 0℃ is 333.4 J/g and the specific heat of supercooled liquid water is 4.226 J / g / ℃ (which you can assume to be constant).

(a) If the subsequent change occurs adiabatically at atmospheric pressure, what fraction of the system freezes and what is the final temperature? Hint: use the first law to find what the enthalpy change must be, and then find an equivalent reversible process from initial and final states that will enable you to compute it.

(b) What is ΔS_{world} for the process? Hint: again, use a reversible processes for computing ΔS_{world}.

Some dramatic video demonstrations of supercooled water freezing, as well as instructions for how you can do it yourself at home, can be found at:

http://www.youtube.com/results?search_type=&search_query=supercooled+water

Problem 43 (*Smith, van Ness, Abbott, 6.29, page 243)*

Throttling is a common process step whereby a gas passes through a well-insulated nozzle and its pressure drops substantially, often resulting in a temperature drop (see p. 264).

(a) Steam at $300\ psia$ and $500\ °\mathrm{F}$ is throttled to $20\ psia$. What is the temperature of the steam in its final state and what is the entropy change? Hint: you may want to consult the steam tables.

(b) What would be the final temperature and entropy change for an ideal gas?

Problem 44 (*Smith, van Ness, Abbott, 6.5, page 241)*

For a certain pure fluid, the Gibbs free energy can be written as the following functionality:

$$G(T,P) = \Gamma(T) + RT\ln P$$

where $\Gamma(T)$ is an arbitrary temperature-dependent function. Since G is given as a function of its *natural* variables, you can use it to determine all other thermodynamic properties. Determine for this fluid expressions for V, S, H, U, C_P, and C_V. You answers will contain the first and second temperature derivatives of $\Gamma(T)$, denoted as $\Gamma'(T)$ and $\Gamma''(T)$, respectively. What fluid is this?