10.213 Chemical Engineering Thermodynamics
Spring 2002

Problem Set G
Due Wednesday, April 3, 2002 in lecture

Announcement: Test 2 will be held on Friday April 5, 2002 at 10-11 am. The test will be open book/open notes.

Note: In reporting thermodynamic quantities obtained from graphs, charts, and/or tables on your problem sets and tests, please note the relevant conditions. As an example: a solution might note "steam at T_1 = 300 °C and P_1 = 100 kPa, H_1 = 3074.5 kJ/kg (steam table)." Incorrect values that cannot be tracked down will receive no partial credit.

Problem 23
Steam enters the turbine of a power plant operating on the Rankine cycle at 3,300 kPa and exhausts at 50 kPa. Determine the thermal efficiency of the cycle and the quality of the exhaust stream from the turbine for turbine-inlet stream temperatures of:

a) 475 °C if you last name begins with A-D
b) 500 °C if your last name begins with E-L
c) 525 °C if your last name begins with M-Z
d) For all: Suggest whether an increase in the turbine inlet stream temperature produces an increase or decrease in
   i) the thermal efficiency and
   ii) the quality of the exhaust stream exiting the turbine
e) For all: If the turbine had an efficiency of 0.80, determine its impact on the thermal efficiency of the process at your temperature and its effect on the sizing of equipment (the boiler, condenser, etc.).

Problem 24
A two-stage cascade refrigeration system (Figure 9.3 in SVN&A) employs either difluoromethane (R32) or ammonia as refrigerant in Cycle 1 and tetrafluoroethane as refrigerant in Cycle 2. Thermodynamic data for tetrafluoroethane are available in SVN&A on pages 314 & 762 and for difluoromethane and ammonia at http://webbook.nist.gov/chemistry/fluid/. Cycle 1 operates with an evaporation temperature of -55 °F and a condensation temperature of 0 °F. Cycle 2 operates with an evaporation temperature of -10 °F and a condensation temperature of 90 °F. Both cycles employ compressors with efficiencies of 75%.
Solve the parts below, using difluoromethane as the refrigerant in Cycle 1 if your last name begins with A-I and using ammonia as the refrigerant in Cycle 1 if your last name begins with J-Z

a) Determine the pressure limits for the two cycles.
b) Determine the coefficient of performance for each cycle.
c) For a cooling rate of 200 BTU/s at –55 °F, determine
   i) the flow rates of tetrafluoroethane and difluoromethane or ammonia (in lb/s)
   ii) the power requirements for operation of each of the compressors
   iii) the heat output from the condenser in Cycle 1 (in BTU/s)
d) Determine the overall coefficient of performance for the two-stage cascade refrigeration system.

Instructional information for problem 24:
Data for Cycle 1 are to be obtained through the website: http://webbook.nist.gov/chemistry/ and its link "Thermophysical Properties of Fluid Systems." You should use units of °F for Temperature, psia for pressure, and BTU/lbm for enthalpy. As a helpful hint, you might consider drawing (at least for your first attempt) the refrigeration cycle on log P-H axes and deciding what parameters you will then need to solve this problem. I suggest that you begin the problem by using the "Saturation properties -- temperature increments" condition, defining the temperature limits on the next page, and the "View Table" function on the final page. Note that you can change the columns in the table and express "Phase" (to confirm whether you really are looking at data for a liquid or vapor) and also select enthalpic and entropic data for the liquid and vapor phases independently (note "(l)" and "(v)" in the selection box).

Problem 25
Electrical power is to be produced from a steam turbine connected to a nuclear reactor. Steam is obtained from the reactor at 500 ºF and 600 psia and exits a turbine at 20 psia. The turbine operates adiabatically.

a) Compute the maximum work per pound of steam that can be obtained from the turbine.

A clever chemical engineer has suggested to replace the single turbine considered above by two adiabatic turbines. In this modified process, the steam exiting from the first turbine is returned to the reactor, where it is reheated at constant pressure to 500 ºF, and then fed to the second stage of the turbine.

b) Draw a process flow sheet for this suggested operation with labeled streams, where P*.is the pressure for the stream exiting the first turbine
c) Compute the maximum work obtained per pound of steam if the two turbine process is used and the exhaust pressure from the first turbine is $P^* = \frac{1}{2}(600 + 20) = 310$ psia.
d) Compute the maximum work obtained per pound of steam if the two turbine process is used and the exhaust pressure from the first turbine is $P^* = (600 * 20)^{\frac{1}{2}} = 35$ psia.
e) Compute the heat adsorbed per pound of steam in the reheating steps in parts c) and d).
f) Using a Mollier diagram (H vs S), draw in blue ink the path for the process in c) and compute the maximum work obtained for this process.
g) Using the same Mollier diagram, draw in red (or a non-black, non-blue) ink the path for the process in d) and compute the maximum work obtained for this process.

Note: for parts a), c), d), and e), use steam tables.

Additional Practice Problem (not to be handed in)

Practice Problem P11
A conventional vapor-compression refrigeration system operates on the cycle of Fig 9.1 in SVN&A. The refrigerant is tetrafluoroethane (pages 314 & 762). For the following set of operating conditions, determine the circulation rate of the refrigerant, the heat-transfer rate in the condenser, the power requirement, the coefficient of performance of the cycle, and the coefficient of performance of a Carnot refrigeration cycle operating between the same temperature levels: Evaporation t = 0 °F; Condensation t = 80 °F; η(compressor) = 0.76; refrigeration rate = 300 Btu/s.