

ChE 201 – Spring 2003 – Exam #1
Pink Sheets Only – No Notes, No Textbook - Put all work and solutions in the blue book
For C_p use only the A and B terms from Table B.2

Problem 1

Propane is dehydrogenated over a metallic catalyst at 100 °C and 2 atm, producing propylene and hydrogen. In this highly efficient reactor, complete conversion is achieved. The reactor consists of a column with inner diameter 20 cm and height 2 m, packed with catalyst pellets. The column is steam-jacketed to maintain the reaction temperature.

The propylene/hydrogen mixture passes through a heat exchanger, where it is cooled to 30 °C. The propylene/hydrogen mixture is then fed to a membrane permeation separator. (The mixture must be cooled before the separator to prevent damage to the membrane.) The membrane in the membrane permeation separator is a hollow tube with pores small enough to allow H_2 to pass through the walls of the tube. The propylene/hydrogen mixture flows inside the membrane. Air flows in the annular region between the membrane and the outer metal wall of the separator. Hydrogen diffuses from the propylene/hydrogen mixture, through the membrane, and into the air. All inlet and exit streams for the membrane permeation separator are at 30 °C and 2 atm. When the propylene/hydrogen mixture leaves the membrane permeation separator, it is 95 mol % propylene. The membrane permeation separator is 2 m tall. The air is fed to the top, and the propylene/hydrogen mixture is fed to the bottom. The inner diameter of the membrane is 5 cm. The inner diameter of the outer metal wall is 10 cm.

When the air/hydrogen mixture leaves the membrane permeation separator, it passes through a valve and is burned at 1 atm in a boiler to produce steam. The air flow to the membrane permeation separator is set so that the air/hydrogen mixture fed to the boiler contains 80 % excess air. Combustion in the boiler is complete, and combustion products leave the boiler at 700 °C. The combustion products are used to preheat the water fed to the boiler. The boiler produces steam at 60 bar absolute and 400 °C. This steam is fed to a turbine located one floor (7 m) below the boiler. Steam exits the turbine at 20 bar and 250 °C. A pump located next to the turbine raises the pressure of the steam back to 60 bar without changing the temperature significantly, and then sends it to the preheater. The preheater is on the same floor as the boiler. Leaving the preheater and entering the boiler, the steam/water is 3 % vapor and 97 % liquid.

- a. (15 pts) Sketch the entire process as described.
- b. (20 pts) Choose the best utility stream for the propylene/hydrogen heat exchanger from the following 3 choices, and calculate the amount of utility H_2O needed per 100 moles propane fed to the process:
 1. Water entering at 15 °C and leaving at 20 °C
 2. Water entering as a saturated liquid at 2 bar and leaving as a saturated vapor at 2 bar.
 3. Water entering as a saturated vapor at 2 bar and leaving as a saturated liquid at 2 bar.
- c. (15 pts) For every kg of steam produced by the boiler, how much work is done by the turbine?

- d. (20 pts) For every kg of steam produced by the boiler, how much heat is transferred to the water in the boiler?
- e. (10 pts) Explain (1 – 2 sentences) why you cannot use the Mechanical Energy Balance to calculate the amount of work that must be done by the pump per kg of steam produced by the boiler.

Problem 2

(20 pts) (Adapted from Felder & Rousseau, 3rd edition, p. 417.) Molten sodium chloride is to be used as a constant-temperature bath for a high-temperature chemical reactor. Solid NaCl (200 kg) at 25 °C is charged into an insulated vessel, and a 3000 kW electric heater is turned on, changing the salt to a liquid at its normal melting point. Assume that C_p for solid NaCl is constant at 0.055 kJ/mol °C, and that the difference in density between liquid and solid NaCl is negligible. Other physical properties for NaCl may be found in Table B.1. How long will it take to melt all of the salt?