

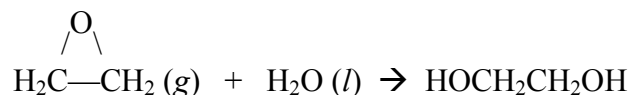
10.213 Chemical Engineering Thermodynamics
Spring 2002

Test 1
March 8, 2002
Open Book/Open Notes
55 Minutes

Instructions: Place your solution to each problem in a different blue book. Budget your time effectively, attempt all problems, and avoid getting stuck on any one problem.
Note any assumptions Good luck!

Problem 1 (50 points; 25 points for each part)

Ethylene glycol [HOCH₂CH₂OH], also known as 1,2-ethanediol, is prepared by the hydrolysis of ethylene oxide [cyclic-CH₂CH₂O] in the reaction shown below:



Consider a single-pass process where ethylene oxide is combined with water to generate ethylene glycol. In the process, the molar water to ethylene ratio entering the reactor is 5 and the reaction proceeds with 90% conversion of the entering ethylene oxide. The reactants (gaseous ethylene oxide and liquid water) enter the reactor at 80 °C. The products from the reactor are separated by distillation in a second processing unit yielding a top stream that is water-rich (and also contains some ethylene oxide but no ethylene glycol) and a bottom stream (the product) that is ethylene glycol-rich. An analysis of the bottom stream shows that it has an ethylene glycol to water molar ratio of 10 and contains no ethylene oxide.

For convenience, use the labels E for ethylene oxide, W for water, and G for ethylene glycol as your subscripts on flows. It is recommended that you draw a process flow sheet for each part of the problem and include appropriate labeling of streams before trying to solve the problem. Note: solving part b) does not require solving part a) and the flow sheets for the two parts are different.

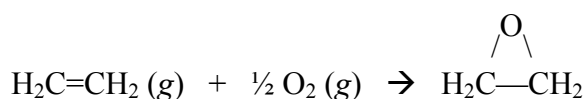
- a) If the reactants are stored at 25 °C and must be heated to 80 °C before entering the reactor, determine
 - i) the amount of heat that must be provided to the process per mole of ethylene oxide in the feed stream and
 - ii) the amount of heat that must be provided to the process *per mole of ethylene glycol produced in the final product stream*.
- b) The generation of ethylene glycol by the process examined in a) generates an environmentally unfriendly aqueous waste stream that contains ethylene oxide, a carcinogen. To remedy this situation, a modified process has been developed where the water-rich stream containing ethylene oxide that exits the separation unit is instead recycled back to mix with the

input streams to the reactor. As in a), the molar ratio of water to ethylene oxide that enters the reactor is 5, the reaction proceeds with 90% conversion of the entering ethylene oxide through a single-pass through the reactor, and an analysis of the ethylene glycol product shows that it has an ethylene glycol to water molar ratio of 10 and contains no ethylene oxide. If the flow rate of ethylene oxide into the process is 900 mole/min, determine:

- i) the flow rate of water entering the process,
- ii) the flow rate and composition of the product stream, and
- iii) the flow rate and composition of the stream exiting the reactor.

Problem 2 (25 points)

Ethylene oxide is produced by the partial oxidation of ethylene:



Both ethylene and oxygen are supplied to a reactor at 25 °C and 100 bar. Determine the relative *volumetric* flow rates for the two compressed gases (i.e., cm³ per second of ethylene / cm³ per second of oxygen) into the reactor required to supply a stoichiometric feed. At the given conditions, ethylene and oxygen do NOT behave as ideal gases. To receive full credit, your solution should yield a final numerical answer rather than leaving equations; however, answers assuming ideal gas behavior will receive no credit.

Problem 3 (25 points)

Ten moles of ethylene are to be compressed isothermally from their initial state (P = 21.7 bar, T = 25 °C, and V = 1000 cm³/mol) to 100 cm³/mol. Under these conditions, the behavior of the gas is well described by the van der Waals equation of state.

- i) Estimate the pressure at the final state.
- ii) Determine the work required to perform this compression.