10.213 Chemical Engineering Thermodynamics
Spring 2001

Practice Tests and Problems

Annnouncement: Test 1 (open book/open notes) will be on Wednesday, March 7 from 10-11 am in 2-190. Coverage will be class materials covered through and including Wed, February 28: materials balances, ideal gas processes, PVT of real gases, enthalpies for ideal systems, etc.

Scheduling conflicts for Test 1 due to athletics or other courses must be cleared with Professor Laibinis (pel@mit.edu) BEFORE Monday, March 5, 2001.

Office Hours for Kristin and Jiehyun to be announced.

Spring 2000, Test 1 (2/25/2000)—to be covered in Monday's recitation

Problem 1 (40 points)

A frictionless piston-and-cylinder system shown in Figure A is subjected to 1.013 bar of external pressure. The piston mass is 200 kg, it has an area of 0.1 m^2, and the initial volume of the entrapped gas (40 mol % CO_2 and 60 mol % O_2) is 0.15 m^3. The piston and cylinder do not conduct heat, but heat can be added to the gas by a heating coil. The blocks in Figure A are removed so the piston can move freely.

a) If heat is added so to raise the temperature from 35 to 400 °C, determine the amount of added heat, the amount of work done by the piston, and the change in internal energy of the gas. You may assume that nitrogen and oxygen gas behave ideally under these conditions. (25 points)
b) If the operation were to be repeated and fresh gases were to be added to an empty chamber, determine what volumes of CO_2 and O_2 would need to be removed from compressed gas cylinders at 3650 psia that each contain a pure gas and are stored at 35 °C. Note that CO_2 and O_2 are not ideal gases as 3650 psia. (15 points)

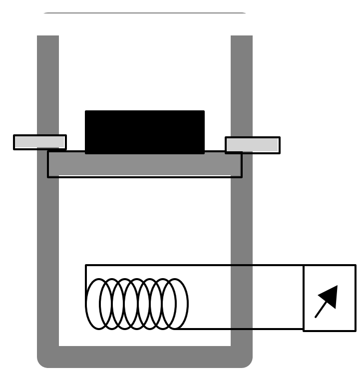


Figure A

Problem 2 (30 points)

The process for making nitrobenzene is shown in Figure B. Benzene and a mixture of nitric and sulfuric acids in water are fed to a reactor where the following reaction goes to completion:

$$C_6H_6 + HNO_3 \rightarrow C_6H_5NO_2 + H_2O$$

Benzene and nitric acid in the feed streams are in a stoichiometric ratio. Effluent from the reaction is phase separated and the acid solution, containing 70 wt % H_2SO_4, 30 wt % H_2O and no HNO_3, is re-concentrated in an evaporator. The resulting 93 wt % H_2SO_4 solution is recycled, mixed with fresh 64 wt % HNO_3 (36 wt % H_2O) and fed to the reactor. Calculate the values of B (the benzene input stream), S (the dilute sulfuric acid stream), W (the water output stream), C (the concentrated sulfuric acid recycle stream), and N (the nitric acid feed stream), each expressed in tons per ton of nitrobenzene produced. Note: the molecular weights are C_6H_6 (78), HNO_3 (63), $C_6H_5NO_2$ (123), H_2O (18), H_2SO_4 (98).

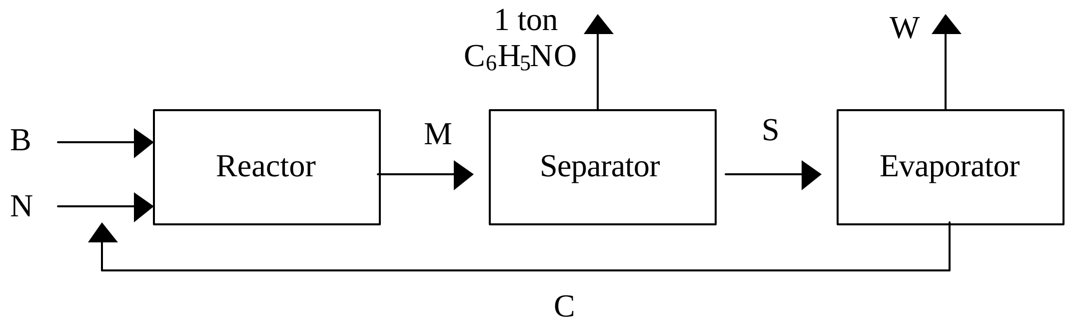


Figure B

Problem 3 (30 points)

A two-stage separator is shown in Figure C. The stream to be extracted flows at a constant flow rate F moles/hr through the system. The solute concentration in the feed is x_0 moles solute per mole of solvent. The total flow of extractant is 2S moles/hr, and the feed concentration is y_3 moles per mole of extractant. Half of the extractant is fed to stage 2. The other half is mixed with the extractant effluent from stage 2 and fed to stage 1. The equilibrium relationship at each stage is

$$y_i = Kx_i$$

Determine an expression for x_2 that is a function of x_0, x_3, and B, where $x_3 = y_3/K$ and $B = SK/F$.

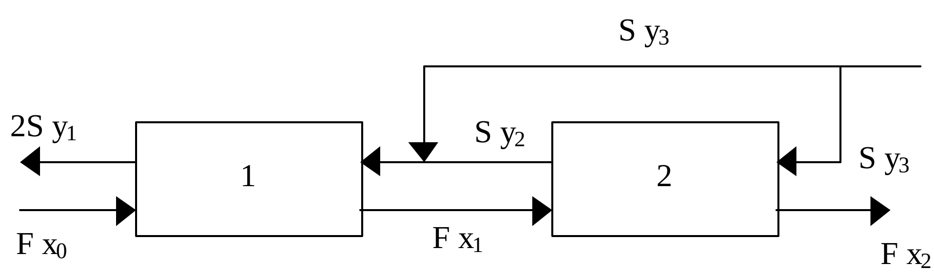


Figure C

Additional Practice Problems:

Problem P1

a) Strawberries contain about 15 wt% solids and 85 wt% water. To make strawberry jam, crushed strawberries and sugar are mixed in a 45:55 mass ratio, and the mixture is heated to evaporate water until the residue contains one-third water by mass. Draw and label a flowchart of this process, and, calculate how many pounds of strawberries are needed to make a pound of jam.
b) A paint mixture containing 25 % of a pigment and the balance water sells for \$18/kg, and a mixture containing 12 % pigment sells for \$10/kg. If a paint retailer produces a blend containing 17 % pigment, for how much (\$/kg) should it be sold to yield a 10 % profit?

Spring 2000, Test 1 (2/26/1999)

Problem 1 (40 points)—*Covered in 2/12/2001 recitation*
A mixture containing 50 wt% methanol and 50 wt% ethanol undergoes a process involving two unit operations and is separated into two product streams that each contain 90 wt% of one of the components (referred to as the "methanol-rich" and "ethanol-rich" products) and a third waste stream of unknown composition. In the first unit, the mixture is separated into the above methanol-rich phase that is collected and another stream that has twice the mass flow rate of the methanol-rich phase. This second stream enters a second separation unit that produces the ethanol-rich product and another stream of unknown composition with twice the mass flow rate of the ethanol-rich stream.

a) Determine the relative mass flow rates of the methanol-rich product, the ethanol-rich product, the waste product stream, and the stream flowing between the two separation units.
b) Determine the compositions of the waste stream and the stream flowing between the two separation units.

Problem 2 (30 points)
A catalytic reactor generates ethylene from butene by the reaction:

$$C_4H_8\ (g) \rightarrow 2\ C_2H_4\ (g)$$

In the process, the reactor produces an equilibrium mixture that contains 20 mol% ethylene and 80 mol% butene.

a) Determine the moles of ethylene produced per mole of butene entering the reactor.
b) If the ethylene is separated from the butene by distillation after the reactor, and the unreacted butene is recycled back to the reactor where it is combined with a feed of butene, determine the relative molar flow rates of the entering butene and exiting ethylene streams and the recycled butene stream.

Problem 3 (30 points)
a) Calculate the pressure in a 0.45 m^3 vessel when it is charged with 8 kg of CO_2 at 40 °C?
b) Determine the mass of ethane contained in a 0.3 m^3 cylinder at 60 °C and 130 bar.
c) If problem a) noted the mass, volume, and pressure but not the temperature, how would you solve for temperature?

The molecular weights for CO_2 and ethane are 44.0 and 30.0 g/mol, respectively.)
NOTE: Answers using the ideal gas law will not be accepted.

Additional Practice Problems:
Problem P2
A rigid vessel, filled to one-half its volume with liquid nitrogen at its normal boiling point (-195.8 °C) is allowed to warm to 25 °C. What pressure is developed? The molar volume of liquid nitrogen at its normal boiling point is 34.7 cm^3/mol. You can select any of a variety of methods for solving this problem *except using the ideal gas law*. Compare your answer with the pressure obtained from http://webbook.nist.gov/chemistry/fluid/ for nitrogen at 25 °C and the molar volume of interest.

Problem P3

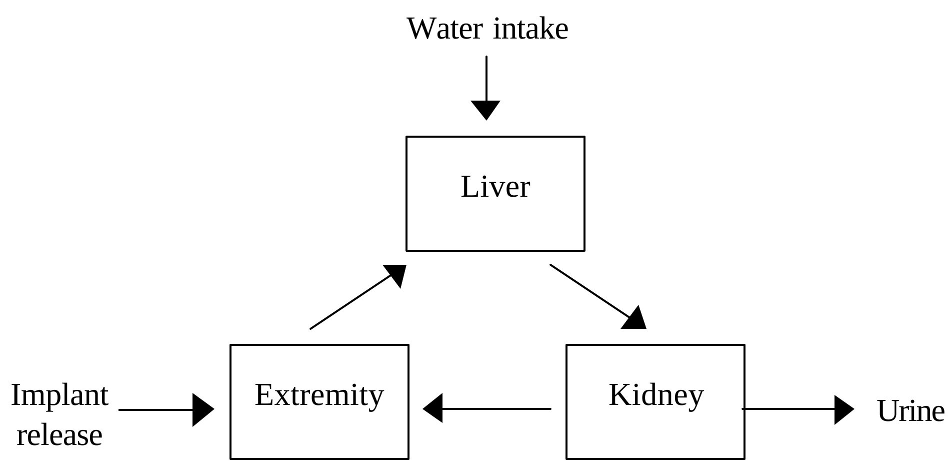
What is the final temperature when heat in the amount of 10^6 BTU (1.055×10^6 kJ) is added to a 40 lbmol (18.14 kg mol) mixture of 50 mol% ethylene/50 mol% ethane initially at 500 °F (260 °C) in a steady-flow heat exchanger operating at approximately atmospheric pressure?

Problem P4

Implants for the delivery of drugs are frequently implanted under the skin at an arm or leg (i.e., an extremity). The concentration of the drug in these regions is difficult to measure due to problems associated with the collection of sufficient amounts of blood from these areas as the capillaries that carry the blood are small.

As an indirect method for obtaining this information, a radioisotopic label is added to the drug used in the implant and the amount of radioactivity in the urine is measured. In this analysis, we assume that no radiolabel is lost, the body is in homeostasis (there is no accumulation of drug or degraded products), and only degraded product is eliminated through the kidneys.

The following grossly simplified flow chart applies:



In this flow chart, the blood flows through the extremities where it picks up drug from the implant, then to the liver where half of the drug is degraded into degradation products, and finally to the kidneys where 10% of the degraded products are excreted. The total blood flow between the liver and kidney is estimated to be 6600 cc/hour. The measured output of urine is 30 cc/hr and contains 99.9 vol % water and 0.1 vol % degraded products.

a) Estimate the rate at which the implant releases drug into the extremities.
b) Estimate the volume of drug in the flow between the kidneys and the extremities.