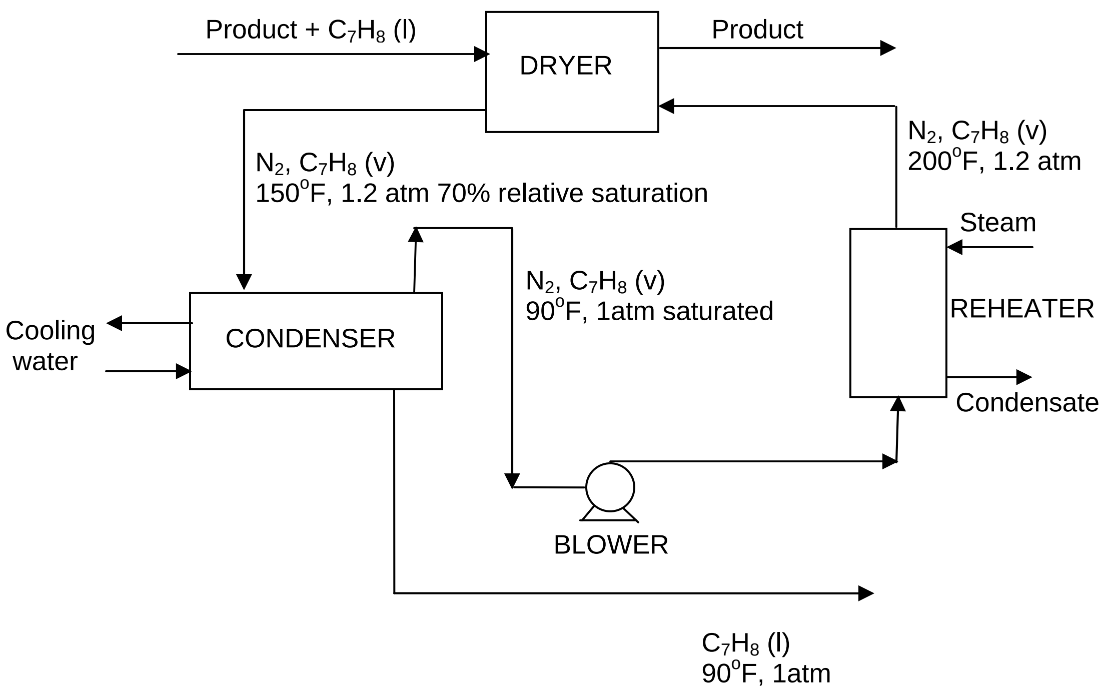
Homework 5 (Group) Due date: 14-Feb-2007

1. (Chapter 6, Prob. 6.36) In the final stage of the manufacturing process for a solid product, the product is cleaned with liquid toluene and then dried in a process whose flowchart is shown below.

   The wet product enters the dryer at a rate of 300 lb_m/h containing 0.200 lb_m toluene/lb_m dry solids. A stream of N_2 at 200°F, 1.2 atm and containing a small amount of toluene vapour also enters the dryer. (A higher temperature would cause the product to soften and degrade). Heat is transferred in the dryer from the gas to the wet solids, causing most of the toluene to evaporate. The final product contains 0.020 lb_m toluene/lb_m dry solids. Gas leaves the dryer at 150°F and 1.2 atm with a relative saturation of 70% and passes through a water-cooled condenser. Gas and liquid streams leave the condenser in equilibrium at 90°F and 1 atm. The gas is reheated to 200°F and reenters the dryer.

a) Briefly explain the process in your own words. In your explanation, include the purposes of the condenser and nitrogen reheater and a likely reason that nitrogen rather than air is used as the recirculating gas. What would happen to the liquid toluene leaving the condenser?



b) Calculate the compositions (component mole fractions) of the gas streams entering and leaving the dryer, the circulation rate of dry nitrogen (lb_m/h), and the volumetric flow rate of gas entering the dryer (ft^3/h). Antoine equation for estimating vapour pressure of toluene is: $\log_{10} p^* = 6.95805 - \frac{1346.773}{T + 219.693}$, where T is in °C and p^* is in mm Hg.

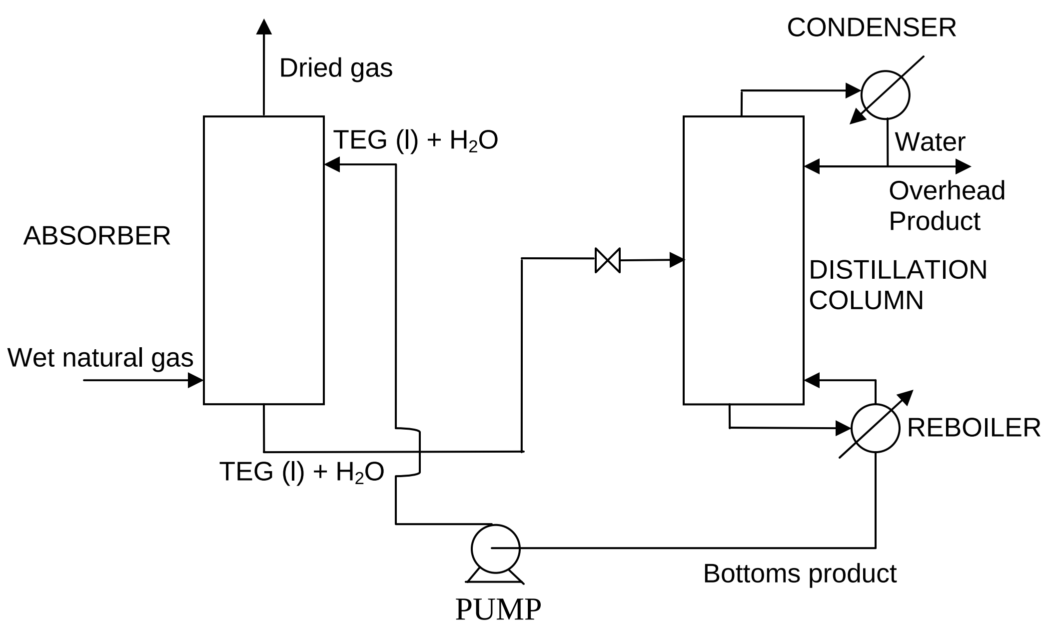
2. (Chapter 6, Prob. 6.39) A mixture of propane and butane is burned with air. Partial analysis of the stack gas produces the following dry-basis volume percentages: 0.0527% C_3H_8, 0.0527% C_4H_{10}, 1.48% CO, and 7.12% CO_2. The stack gas is at an absolute

pressure of 780 mm Hg and the dew point of the gas is 46.5°C. Calculate the molar composition of the fuel. Antoine equation for calculating vapour pressure is:

$\log_{10} p^* = 8.10765 - \frac{1750.286}{T(^oC) + 235.000}$, where T is in °C and p^* is in mm Hg.

3. (Chapter 6, Prob. 6.91) Acetone is t be extracted with *n*-hexane from a 40.0 wt% acetone—60.0 wt% water mixture at 25°C. The acetone distribution coefficient (mass fraction of acetone in the hexane-rich phase/ mass fraction of acetone in water-rich phase) is 0.343. Water and *n*-hexane may be considered immiscible. Three different processing alternatives are to be considered: a two-stage process and two single-stage processes.
   a. In the first stage of the two-stage process, equal masses of the feed mixture and pure hexane are blended vigorously and then allowed to settle. The organic phase is withdrawn and the aqueous phase is mixed with 75% of the amount of hexane added in the first stage. The mixture is allowed to settle and the two phases are separated. What percentage of the acetone in the original feed solution remains in the water at the end of the process?
   b. Suppose all of the hexane added in the two-stage process in part a is instead added to the feed mixture and the process is carried out in a single equilibrium stage. What percentage of the acetone in the feed solution remains in the water at the end of the process?
   c. Finally, suppose a single-stage process is used but it is desired to reduce the acetone content of the water to the final value of part a. How much hexane must be added to the feed solution?

4. (Chapter 6, Prob. 6.72) Dehydration of natural gas (mostly CH_4) is necessary to prevent the formation of gas hydrates, which can plug valves and other components of a gas pipeline, and also to reduce the potential corrosion problems. Water removal can be accomplished as shown in the following schematic diagram.



Natural gas containing 80 lb_m $H_2O/10^6$ SCF gas [SCF = ft^3 (STP)] enters the bottom of an absorber at a rate of 4.0 x 10^6 SCF/day. A liquid stream containing triethylene glycol (TEG, molecular weight = 150.2 g/gmol) and a small amount of water is fed to the top of the absorber. The absorber operates at 500 psi (absolute) and 90^{o}F. The dried gas leaving the absorber contains 10lb_m $H_2O/10^6$ SCF gas. The solvent leaving the absorber, which contains all the TEG-water mixture fed to the column plus all the water absorbed from the natural gas goes to a distillation column. The overhead product stream from the distillation column contains only liquid water. The bottoms product stream, which contains TEG and water, is the stream recycled to the absorber.

a. Calculate the mass flow rate (lb_m/day) and volumetric flow rate (ft^3/day) of the overhead product from the distillation column.
b. The greatest possible amount of dehydration is achieved if the gas leaving the absorber is in equilibrium with the solvent entering the column. If the Henry's law constant for water in TEG at 90^{o}F is 0.398 psi (absolute)/mole fraction, what is the maximum allowable mole fraction of water in the solvent fed to the absorber?
c. A column of infinite height would be needed to achieve equilibrium between the gas and the liquid at the top of the absorber. For the desired separation to be achieved in practice, the mole fraction of water in the entering solvent must be less than that calculated in part b. Suppose it is 80% of that value and the flow rate of TEG in the recirculating solvent is 37 lb_m TEG/lb_m water absorbed. Calculate the flow rate (lb_m/day) of the solvent stream entering the absorber and the mol fraction of water in the solvent stream leaving the absorber.
d. What is the purpose of the distillation column in the process? (*Hint:* Think about how the process would operate without it.)