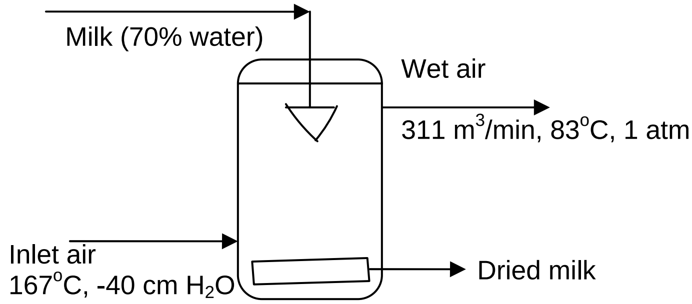
Homework 4 (Group) **Due date: 7-Feb-2007**

1. (Chapter 5, Prob. 5.17) **Spray drying** is a process in which a liquid containing dissolved or suspended solids is injected into a chamber through a spray nozzle or centrifugal disk atomizer (creates minute droplets). The resulting mist is contacted with hot air, which evaporates most or all of the liquid, leaving the dried solids to fall to a conveyor belt at the bottom of the chamber.

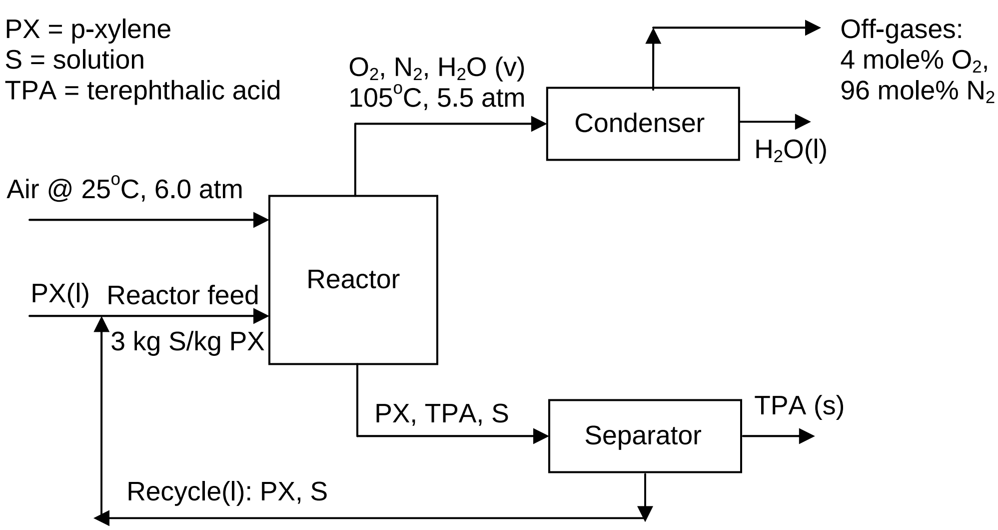


Powdered milk is produced in a spray drier 6 m in diameter by 6 m high. Air enters at 167°C and -40 cm H_2O. The milk fed to the atomizer contains 70% water by mass, all of which evaporates. The outlet gas contains 12 mole% water and leaves the chamber at 83°C and 1 atm (absolute) at a rate of 311 m^3/min.

a) Calculate the production rate of dried milk and the volumetric flow rate of the inlet air. Estimate the upward velocity of air (m/s) at the bottom of the drier (volumetric flow rate = cross-sectional area x velocity)
b) What problem would you guess would occur if the velocity is too high?

2. (Chapter 5, Prob. 5.53) Terephthalic acid (TPA), a raw material in the manufacture of polyester fiber, film and soft drink bottles, is synthesized from p-xylene (PX) in the process shown below

$$C_8H_{10} + 1.5\ O_2 \longrightarrow C_8H_6O + 2H_2O$$



A fresh feed of pure liquid PX combines with a recycle stream containing PX and a solution (S) of a catalyst (a cobalt salt) in a solvent (methanol). The combined stream, which contains S and PX in a 3:1 mass ratio, is fed to a reactor in which 90% of the PX is converted to TPA. A stream of air at 25^oC and 6.0 atm absolute is also fed to the reactor. The air bubbles through the liquid and the reaction given above takes place under the influence of a catalyst. A liquid stream containing unreacted PX, dissolved TPA, and all the S that entered the reactor goes to a separator in which solid TPA crystals are formed and filtered out of the solution. The filtrate, which contains all the S and PX leaving the reactor, is the recycle stream. A gas stream containing unreacted oxygen, nitrogen, and water formed in the reaction leaves the reactor at 105^oC and 5.5 atm absolute and goes through a condenser in which essentially all the water is condensed. The uncondensed gas contains 4.0 mole% oxygen.

a) Taking 100 kmol TPA produced/h as a basis of calculation, draw and label a flowchart for the process.
b) What is the require fresh feed rate (kmol PX/h)?
c) What are the volumetric flow rates (m^3/h) of air fed to the reactor, the gas leaving the reactor, and the liquid water leaving the condenser? Assume ideal gas behaviour for the two gas streams. Report volumetric flow rate to the reactor in SCMH (standard cubic meters per hour) also.
d) What is the mass flow rate (kg/h) of the recycle stream?
e) Briefly explain in your own words the functions of oxygen, nitrogen, catalyst and the solvent in the process.
f) In the actual process, the liquid condensate stream contains both water and PX. Speculate what might be done with the latter stream to improve the economics of the process.

3. (Chapter 5, Prob. 5.78) Methanol is produced by reacting CO and hydrogen at 644 K over a $ZnO\text{-}Cr_2O_3$ catalyst. A mixture of CO and H_2 in a ratio of 2 mol H_2/1mol CO is compressed and fed to the catalyst bed at 644 K and 34.5 MPa (mega Pascal). A single pass conversion of 25% is achieved. The product gases are passed through a condenser in which the methanol is liquefied. T_c and P_c for CO are 133.0 K and 34.5 atm and those for H_2 are 33.3 K and 12.8 atm.
    a) You are deigning a reactor to produce 54.5 kmol methanol/h. Estimate the volumetric flow rate that the compressor must be capable of delivering if no gases are recycled. (Use Kay's rule in P-V calculations).
    b) If (as is done in practice) the gases from the condenser are recycled to the reactor, the compressor is required to deliver only the fresh feed. What volumetric flow rate must it deliver assuming all the methanol is completely liquefied in the condenser?

4. (Chapter 5, Prob. 5.72) Approximately 150 SCFM (standard cubic feet per minute) of N_2 is required by a process facility. Plans call for supplying the facility from a tank of liquid N_2 (SG = 0.81) at its normal boiling point (-350^oF) and 1 atm. N_2 vapour leaves the tank and is compressed and heated to obtain the desired conditions, 150^oF and 600 psi (absolute).
    a) Using the generalized compressibility charts, determine the volumetric flow rate of N_2 delivered from the heater.
    b) What would the required minimum tank size be if deliveries are made to the site no more frequently than every two weeks?