National Exams December 2003

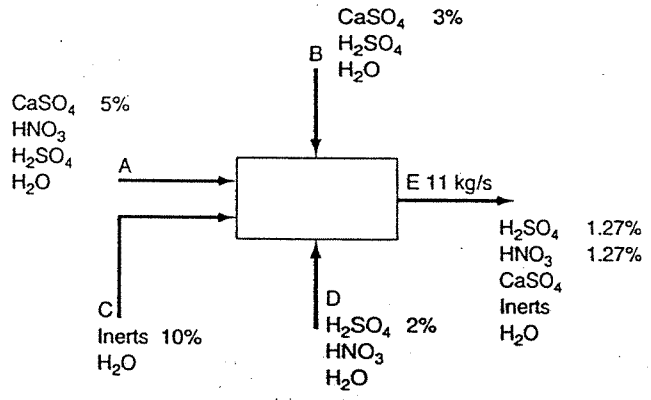
98-Chem-A1 Process Balances and Chemical Thermodynamics

Three Hours Duration

NOTES:

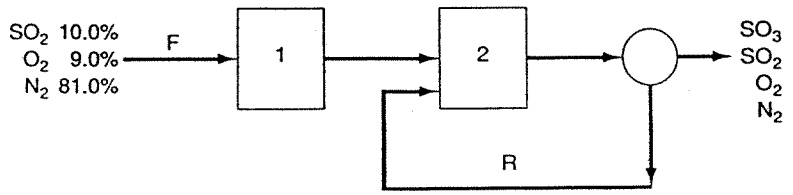
1. If doubt exists as to the interpretation of any question, you are urged to submit with the answer paper, a clear statement of any assumptions made.
2. Property data required to solve a given problem are provided in the problem statement or are available in the recommended texts. If you are unable to locate the required data, do not let this prevent you from solving the rest of the problem. Even in the absence of property data, you still have the opportunity to provide a solution methodology.
3. This is an open-book exam.
4. Any non-communicating calculator is permitted.
5. Any **FIVE** questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.
6. All questions are of equal value. Individual parts of multi-part questions are also of equal value.

1. (a) Effluent from a fertilizer plant is processed by the non-reactive system shown below (with stream flow rates and mass percentages given where they are known). Perform a degree-of-freedom analysis for this system. Explain the significance of your answer for the number of degrees of freedom.



(b) Sludge (wet solids that result from processing in municipal sewage systems) has to be dried before it can be composted or otherwise handled. If a sludge containing 70 mass % water and the remainder solids is passed through a drier operating at steady state, and the resulting product contains 25 mass % water, how much water is evaporated per kilogram of sludge sent to the drier? What quantity of dried sludge (sludge containing 25 mass % water) would be produced if 100 kg of wet sludge (sludge containing 70 mass % water) were fed to the drier?

2. Sulfur dioxide may be converted to sulfur trioxide by reaction with oxygen. A gas stream (F) having the molar composition shown in the figure below is passed through a two-stage converter. The single-pass conversion of SO_2 to SO_3 in the first stage is 75 % and in the second stage 65 %. To boost the overall conversion to 95 %, some of the exit gas from stage 2 is recycled (R) back to the inlet of stage 2. How much must be recycled per 100 mol of inlet gas (F) to stage 1?



3. Calculate the adiabatic flame temperature of methane at 1 atm when burned with 10 % excess air. The air and methane both enter the furnace at 25 °C and complete combustion is achieved in the furnace.

4. Dry ice (solid CO_2) has been used as a mine explosive in the following manner. A hole is drilled into the mine wall, filled with dry ice plus a small charge of gunpowder, and then plugged. The gunpowder is lit with a fuse, vaporizing the CO_2 and building up an explosively high pressure within the hole. You have been asked to estimate the pressure that will develop if 5 g of dry ice is placed in a 50-mL hole and heated to 1000 K. Demonstrate quantitatively that an ideal gas assumption in this case will underestimate the pressure.

5. A portable power supply consists of a 28-L cylinder of compressed helium, charged to 13.8 MPa at 300 K, connected to a small turbine. During operation, the He drives the turbine continuously until the pressure in the gas cylinder drops to 0.69 MPa. The turbine exhausts at 0.1 MPa. Neglecting heat transfer, calculate the maximum possible work from the turbine. Assume helium to be an ideal gas with $C_p = 20.9$ J/(mol)(K).

6. Because they are members of the same chemical family, benzene and toluene are expected to form ideal liquid solutions. Calculate the data needed to construct a *Txy* diagram for this system at a pressure of 1 bar.

7. A heat pump is being used to heat a house in the winter and to cool it in the summer. The heat transfer rate through the house exterior is 0.75 kJ/s for each °C of temperature difference between the inside and outside of the house year-round. The heat pump motor is rated at 1.5 kW. Under these conditions, the minimum outside temperature for which the house can be maintained at a comfortable temperature during the winter is about -4 °C.
   (a) Calculate this "comfortable temperature".
   (b) Calculate the maximum temperature outside the house in the summer at which the above comfortable temperature could be maintained by the heat pump.

8. The water-gas shift reaction to produce hydrogen, $H_2O + CO \rightarrow CO_2 + H_2$, is to be carried out at 1000 K and 10 atm. For an equimolar mixture of water and carbon dioxide, calculate the equilibrium conversion. You may assume the components behave as ideal gases.
   Data: At 1000 K and 10 atm, the Gibbs free energies of formation are -47,860 cal/mol for CO, -94,630 cal/mol for CO_2, and -46,040 cal/mol for H_2O.