Chemical Engineering 140 **November 01, 2017**

Midterm Examination #2

[85 points] 1. Vapor Pressure of Liquid Ammonia

A laboratory thermometer is broken and mercury spills all over your bench. Since mercury is a liquid at room temperature and has a measurable vapor pressure, you are worried about breathing it in as mercury vapor is toxic and can cause damage to the nervous system at concentrations of 1.0 μg/L of blood and death at concentrations of 30. μg/L.

An inclined piston at ambient temperature measures the vapor pressure of mercury as shown in Figure 1b. Pure liquid mercury is loaded into a chamber and allowed to reach vapor/liquid equilibrium. The piston apparatus is initially horizontal with the piston is pushed against a backstop due to the pressure from the mercury vapor. The apparatus is slowly tilted as shown to the angle (θ = 6 degrees) where the piston is balanced by the pressure exerted by the vapor.

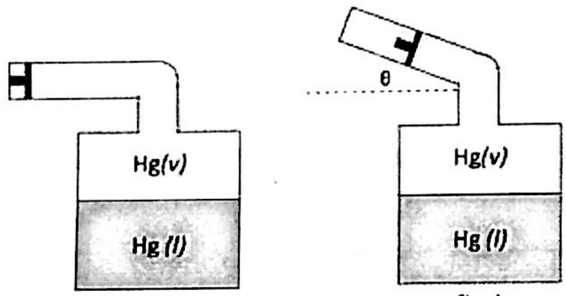


Figure 1. Inclined-Pistion Measurement of Hg vapor pressure

(a) **[25]** Determine the vapor pressure of mercury at room temperature (in Pascals) if the mass of the piston is 32.0 g with a corresponding cylinder diameter of 40. cm.

(b) **[25]** Assume that the mercury reached vapor/liquid equilibrium with the air in the classroom. Calculate the concentration of mercury in the air in μg/L, state all assumptions. (M_{Hg} = 201 g/mol, P=101325 Pa, T=298K)

(c) **[20]** Mercury absorbs into the blood stream very easily, especially when inhaled. At an initial time, you step into the room with the atmosphere described in part (b). Write an expression for the concentration of mercury in the blood, C_b[μg/L], as a function of time, t [min]. Let V_b[L] be the volume of blood in the body, Q [L/min] be the flowrate of air into the lungs from breathing, and C_a [μg/L] be the concentration of mercury in the air. Assume that any mercury vapor that is inhaled immediately is absorbed into the blood stream.

(d) [5] How long after you entered the room would you receive a lethal dose of mercury vapor, assuming the average person has 5.0 L of blood and breathes 7.0 L/min or air?

(e) [10] Explain why you wouldn't die from mercury-vapor poisoning if it took you longer than your answer to part (d) to clean the mercury spill.

[175] 2. A Membrane-Modified PFR with Recycle

Figure 2a. illustrates an isothermal and isobaric (constant T, P) PFR reactor with a recycle. In the figure, Q = total volumetric flow rate of stream, F_i = molar flow rate of species i and ρ = total molar density of stream. Only A and B flow through the entire system. As $\rho_A = \rho_B = \rho$, the molar density of the fluid at any point remains as a constant, ρ throughout the entire system.

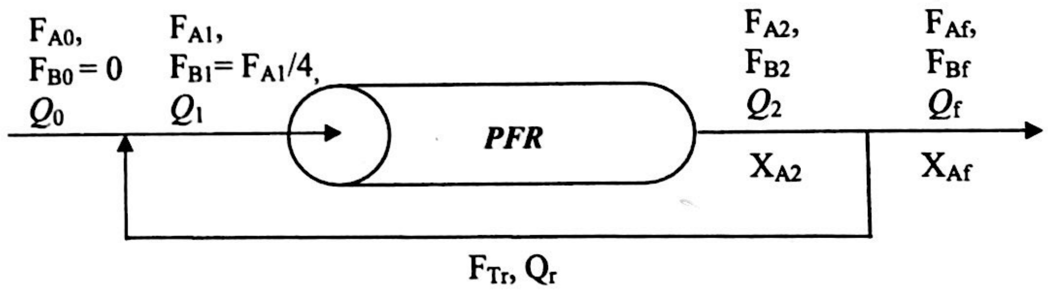


Figure 2a. Steady Process for PFR with recycle.

In the reactor, $A \rightarrow B$ occurs as an elementary irreversible reaction with forward rate constant k. The recycle ratio is $R = F_{Tr}/F_{A0}$ where total molar flow rate in the recycle stream is given by: $F_{Tr} = F_{Ar} + F_{Br}$.

(a) **[40]** Directly using the PFR design equation, derive an expression for PFR volume (V) as a function of Q_0, R, k, and X_{A2}. The single pass conversion, X_{A2} = (moles of A fed to *PFR* - moles of A flowing out of *PFR*)/(moles of A fed to *PFR*)

(b) **[10]** Draw a sketch showing how F_A and F_B vary inside the reactor axially (along V). Also draw how F_A and F_B vary radially (along reactor radius).

(c) **[40]** Derive an expression for X_{Af} in terms of X_{A2} and R only. Note that overall conversion, X_{Af} = (moles of A fed to *entire system* - moles of A flowing out of *entire system*)/(moles of A fed to *entire system*).

(d) [10] A modification to the reactor is suggested in which a membrane is installed into the PFR that selectively removes all the B from the reactor as soon as it is produced (see Figure 2b. below). Which setup – that proposed in Figure 2a. or 2b. is a better design to increase the overall conversion of A for this particular reaction, i.e., is X_{Af} greater or lower than X'_{Af}? Explain your reasoning.

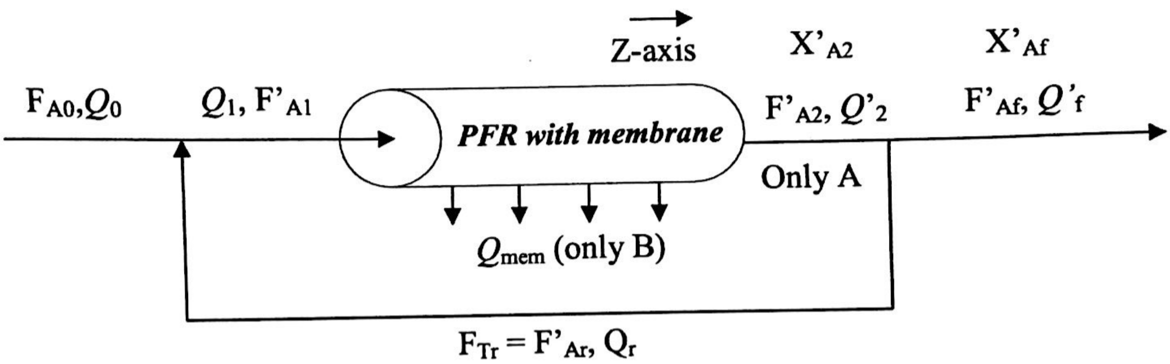
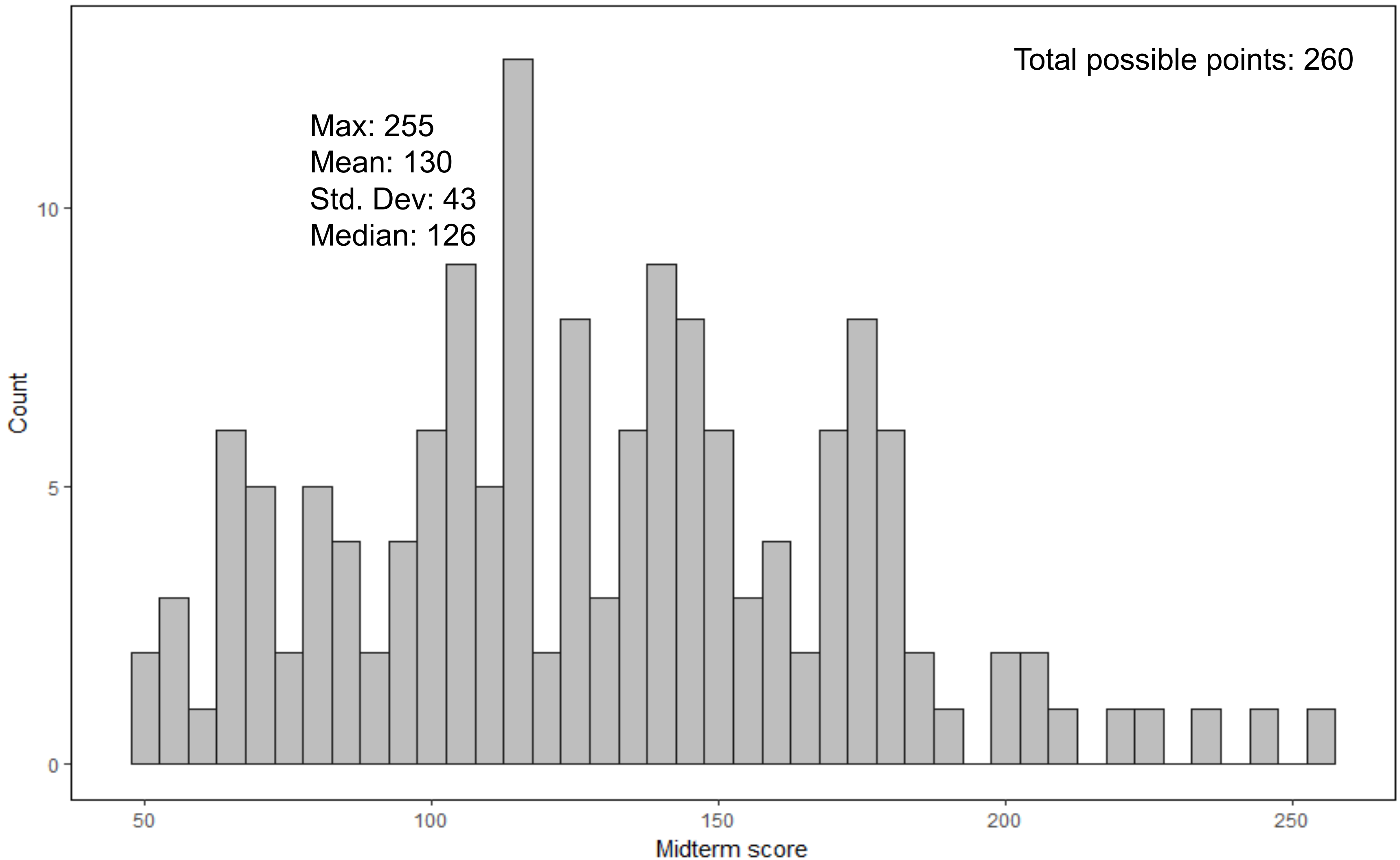


Figure 2b. Steady Process for Membrane-Modified PFR with Recycle.

[75] Consider the membrane-modified PFR design shown in Figure 2b. You are given that volumetric flow inside the PFR varies due to the presence of the membrane as, $Q(z) = Q_1\left(1 - \frac{z}{2L}\right)$ where L is the reactor length and z is the variable axial length along the PFR. The area of cross-section of the PFR tube is a constant and equal to A_c. Write a local differential mole balance on species A (for F_A) over a small reactor volume element of length Δz and take the limit as Δz approaches zero. Use this mole balance to derive a new design equation for the membrane-modified PFR describing how c_A varies along the length of the reactor. Write your final ODE expression for $\frac{dc_A}{dz}$ as a function of c_A, z, k, R, L, A_c, and Q_0. Then, explain how you would solve for $c_{A',2}$. Do not actually solve for $c_{A',2}$.

Midterm 2 Histogram



Comments

- Time management is critical on exam: do problems you know first, write your material balances and "CBE 140 Toolkit Fundamentals" to maximize credit!

- Unless the reaction is at equilibrium, we cannot use LeChatlier's principle. If reaction is not at equilibrium, then look at rate law (kinetics) for reactor conversion. If $r=kc_a$ then conversion should increase if c_a increases (which happens when membrane pulls B out of PFR, concentration of A increases in reactor – more chance for it to convert to B)

- PFR assumptions: no radial variation (plug flow), only axial variation

- Recycle stream contains both A and B in PFR without membrane. Many points lost due to not reading question carefully