ECHE 260: FINAL EXAM

Units 1-7: Material and energy balances

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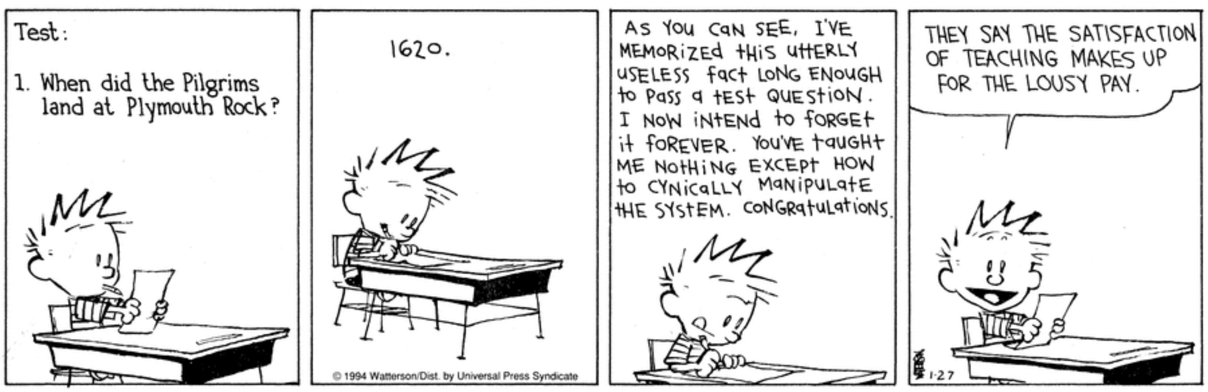
Due by Wednesday, December 20 at 11AM Eastern

Directions:

i. Quantitative Question: SHOW ALL WORK. Write neatly.
ii. Write the values for all physical property and tabulated data on your solution. I should be able to calculate a numerical answer to the problem using your solution and without having to look up any additional values. **This does not apply to a Z value (see notes after problem statement).
iii. Upload your PDF solution to Canvas in the Final Exam submission portal
iv. Take the course evaluation.
v. Enjoy the winter break! ☺



Quantitative Questions: SHOW ALL WORK. WRITE NEATLY.

Tetrachloroethylene (TCE, C_2Cl_4) is a common chemical used in dry cleaning. It is synthesized by chlorinating 1,2-dichloroethane (DCE, $C_2H_4Cl_2$) in the presence of a catalyst according to the following chemical reaction:

$$C_2H_4Cl_2\ (l) + Cl_2\ (g) \rightarrow C_2Cl_4\ (l) + 2H_2\ (g) \qquad \textit{Reaction 1}$$

An undesired side reaction can occur in which the hydrogen produced from reaction 1 reacts with the dichloroethane (DCE) to create ethyl chloride (EC, C_2H_5Cl) according to reaction 2:

$$C_2H_4Cl_2\ (l) + H_2\ (g) \rightarrow C_2H_5Cl\ (g) + HCl\ (g) \qquad \textit{Reaction 2}$$

The continuous production and purification process involves several process units. First of all, the reactor operates at a temperature of 30 °C. The feeds to the reactor are a stream of containing liquid DCE and a pure stream of gaseous Cl_2. Both feeds to the reactor have a temperature of 30 °C and a pressure of 3 atm. The Cl_2 (g) is bubbled through the reactor. The molar flowrate of Cl_2 to the reactor is 1.5 times higher than the molar flowrate of DCE to the reactor. All gaseous species exit through the top of the reactor while the liquids exit through the bottom of the reactor. The fractional conversion of DCE is 0.62 and the selectivity for TCE over EC is 5.

The liquid effluent stream from the reactor is fed to a distillation unit which operates at 87 °C. To achieve the separation, heat is supplied to the distillation unit at a rate of 100 kJ/min. Pure, liquid TCE is recovered from the distillation unit at a flowrate of 8 L/min. The vapor phase leaving the distillation unit has a molar flowrate of 54 mol/min and the vapor phase mole fraction of TCE is 0.17. After exiting the distillation unit, the vapor phase passes through a total condenser which operates at 30 °C before mixing with the fresh feed of DCE.

The vapor stream leaving the reactor can be considered an ideal gas. It is then fed to an isothermal compressor which increases the pressure to 50 atm. The entire process operates at steady state. <u>The entire process is not isobaric</u>. In the distillation unit, TCE is the only species in vapor-liquid equilibrium.

Using the general procedure for material and energy balances from ECHE 260, explain how to answer the questions below. A complete answer will include a fully labeled PFD, material balances, energy balances, and an explanation of how you would solve for the desired unknowns. You are encouraged to do a DOF analysis and write theoretical paths, but they are <u>optional</u>. The values of all thermodynamic and tabulated data needed for the calculations should be explicitly written and sources of that data should be cited. **Tables A, C, and D (below)** contain some useful thermodynamic data. The remaining data can be found in Tables B.1, B.2, and B.4 in your book.

- What is the volumetric flowrate of the compressed gas leaving the compressor (L/min)?
- How much heat is evolved (released) by the reactor (kJ/min)?

Additional Instructions:

- DO NOT solve for final numerical answers.
- <u>Your solution must include all units and be dimensionally homogenous.</u>
- If you need a Z value, you do not need to read it from the compressibility charts. Just write the equations for the reduced properties using process variables from your PFD.
- Integrate one of the indefinite integrals for Cl_2 to demonstrate you know how, but do not evaluate. Ex: $\int_{P_1}^{P_2} \ln(x) = (x\ln(x) + x)\Big|_{P_1}^{P_2}$

USEFUL THERMODYNAMIC INFORMATION ON THE NEXT PAGE

TABLE A: Select thermodynamic and physical property data. Naming conventions are consistent with Tables B.1 and B.2.

Species	ΔH_f^o (kJ/mol)	ΔH_c^o (kJ/mol)	$\Delta H_v^o(T_b)$ (kJ/mol)	T_b (°C)	MW (g/mol)	SG (20°/4°)	Tc (K)	Pc (atm)
TCE	-167 (g)	-1236	35	121	165.83	1.62	620	46.9
DCE	-132 (g)	-1230	35	83	98.96	1.25	561	53

TABLE C: Additional Antoine Equation Constants which can be used with the Antoine Equation shown in Table B.4. Note the units for pressure and temperature.

Species	Formula	Range (K)	A	B	C	Pressure units	Temperature Units
TCE	C_2Cl_4	301 -381	4.18	1440.82	-49.17	Bar	K
DCE	$C_2H_4Cl_2$	242 – 372	4.58	1521.79	-24.67	Bar	K

TABLE D: Additional heat capacities.

Species	State	C_p (kJ/mol °C)
TCE	Liquid	0.15
	Gas	0.07
DCE	Liquid	0.13
	Gas	0.05
EC	Liquid	0.10
	Gas	0.06