**Chemical Engineering 140** **November 6, 2013**

## Midterm Examination #2

(145) 1. **Production of Urea**

Urea, an organic nitrogen-containing compound with the formula $(NH_2)_2CO$, is an important fertilizer. Figure 1 illustrates a continuous process for producing urea. The feed contains only ammonia and carbon dioxide. In the reactor, Reactions 1 and 2 occur in the gas phase at 2 bar and 500 K.

$$2NH_3(g) + CO_2(g) \longleftrightarrow CH_6O_2N_2(g) \qquad (1)$$

$$CH_6O_2N_2(g) \longleftrightarrow (NH_2)_2CO(g) + H_2O(g) \qquad (2)$$

The reactor residence time is long enough for each of the above reactions to reach equilibrium. A complete separation of the water and urea from the ammonia, carbon dioxide, and ammonium carbamate is achieved prior to recycle.

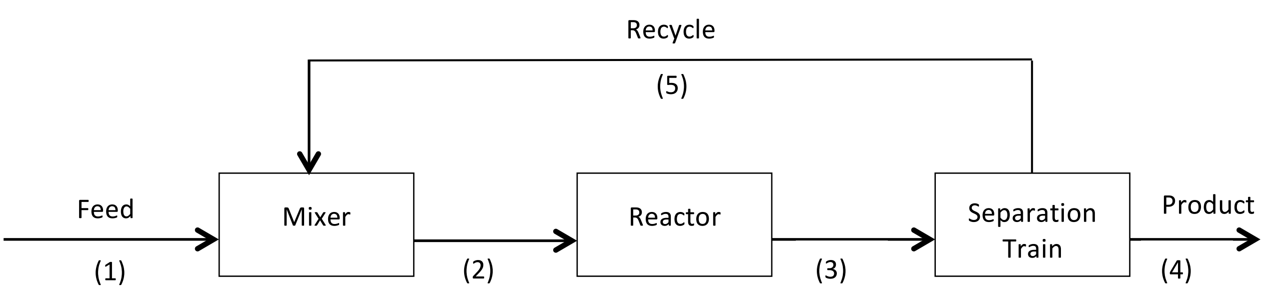


Figure 1. Steady production of aqueous urea from ammonia and carbon dioxide

200 mol/s of ammonia, 100 mol/s of $CO_2$ and 50 mol/s of ammonium carbamate are fed to the reactor in stream 2. The equilibrium extent of reaction for Reaction 1 is 80 mol/s. It is important to note that there is no purge so that ammonium carbamate does not exit the process.

(30) a.) Express the equilibrium constants for the reactions, $K_1$ and $K_2$, respectively, in terms of the extents of reaction.

(30) b.) What are the values for the two equilibrium constants?

(20) c.) Calculate the species molar flow rates in stream 3.

(20) d.) Calculate the recycle ratio on a molar basis.

(20) e.) What is the overall conversion of this process?

(25) f.) To increase production of urea should the reactor be run at higher or lower pressure? Explain.

(145) 2. **Batch Distillation of Styrene**

Polystyrene is a synthetic aromatic polymer made from the styrene (nbp = 145 °C), a liquid petrochemical. It is one of the most widely used plastics with a production scale of several billion kilograms per year. Common applications include protective packaging, containers, lids, bottles, trays, tumblers, and disposable cutlery. The Segalman Laboratory (Gabriel) synthesizes polystyrene-based membranes for use in solar-fuel generators. During the synthesis steps, the styrene monomer can be contaminated with cyclohexane (nbp = 80.7 °C). Purification of the contaminated styrene is achieved by batch distillation as shown in Figure 2

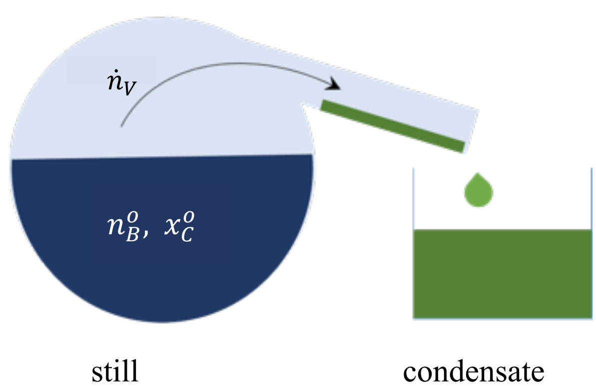


Figure 2. Transient batch distillation process

The batch still is initially charged with $n_B^o$ moles of contaminated liquid styrene, a mixture of styrene (i.e., vinyl benzene) and cyclohexane of initial cyclohexane mole fraction $x_C^o$, and heated to vaporize the bottoms liquid. The more volatile species is preferentially vaporized producing a constant vapor molar flow rate $\dot{n}_V$ into the condenser where liquid product is collected. The distillation rate is slow enough that the still vapor and liquid are in equilibrium.

(20) a). Which species is more volatile and why? Where will the purified styrene be collected?

(10) b). What will be the composition of the condensed liquid after the still is completely emptied (you need no calculation to answer this question).

(10) c). Should you run the still until the entire initial charge is vaporized? Why or why not?

(40) d). Derive an expression for how long it takes the still to empty (i.e., you are to prove your answer using mass conservation!)

(40) e). Let $K_C$ denote the K-factor for cyclohexane. Derive an expression for how the mole fraction of cyclohexane in the still depends on time.

(25) f). Explain quantitatively how to establish the time at which distillation is stopped to obtain the most amount of high purity styrene. Do not do the calculation.

(15)3. **Extra Credit**

State the location on campus of the confluence of the south and north forks of Strawberry Creek.