**Chemical Engineering 140** **September 27, 2017**

## Midterm Examination #1

### (145) 1. Flue-Gas Reactive Cleaning with $NH_3$-Selective Catalytic Reduction (SCR)

Flue gas released from a coal-fired power plant gas has been analyzed to contain the following composition: 3% $NO_2$, 7% $O_2$, and remaining amounts of an unknown inert gas, I. Local regulations require emissions of $NO_2$ be less than 50 ppm as $NO_2$ contributes to smog. An economic method to denitrify flue gas is $NH_3$-based selective catalytic reduction (SCR). The irreversible reaction occurring in the SCR reactor removes $NO_2$ by converting it into $N_2$ as shown:

$$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$$

Assume that the conversion of $NO_2$ is 100% and that the composition of inerts leaving the SRC reactor is 78.3 %.

A stream of pure ammonia ($NH_3$) and the flue-gas stream are first sent to a mixer, after which the resulting mixed stream is fed to the SCR reactor. $NH_3$ is fed to the mixer in 75 % excess of the stoichiometric requirement of the given reaction.

(25) a. Construct a process flow diagram of the proposed system. Label each stream with numbers and also with the species that are present. Fill out the diagram with all of the information that is specified about this process.

(50) b. Calculate the compositions of $O_2$ and I (inert gas) in the stream entering the SCR reactor.

(50) c) Calculate the compositions of $O_2$ and $H_2O$ in the product stream exiting the SCR reactor.

(20) d) Explain how it might be possible for this process not to meet the $NO_2$ 50 ppm design limit.

### (125) 2. Inert Atmosphere in a Glovebox

When working with particularly reactive materials, a high purity inert atmosphere is desired. Consider a rigid glovebox of volume V, initially open to the atmosphere. To render the glovebox operational, the box is sealed and the inlet valve is connected to a stream of pure nitrogen of $\rho_{N2}$ (units of moles per volume) at a constant volumetric flow rate Q. The outlet valve is open to the atmosphere with a molar flow rate out of the box proportional to its difference in pressure. The proportionality constant is $\alpha$.

(15) a. What are the units of the proportionality constant $\alpha$?

(35) b. Assuming ideality of gas species and constant temperature, establish a differential equation for P(t) in terms of relevant constants. State initial conditions and classify the ode.

(20) c. Find an expression for the steady pressure in the glove box.

(20) d. Solve for the $P(t)$. For all $t > 0$, show that $P > P_{atm}$. Explain why this result is desired.

(30) e. Establish a differential equation for the composition change of oxygen in the glove box. Do not attempt solution. List the initial condition and the steady mole fraction of oxygen in the glove box.