A First Course on Kinetics and Reaction Engineering

Example 28.2

Problem Purpose

This problem will help you determine whether you have mastered the learning objectives for this unit. It illustrates the use of a qualitative analysis to decide whether a CSTR or a PFR is a better reactor to use for a specific situation.

Problem Statement

Suppose a chemical process continually produces a byproduct stream that contains a small amount of a toxic, hazardous waste, A, dissolved in water. The decomposition of A is a first order reaction that is exothermic and irreversible. You have been asked to perform the preliminary design for a reactor to reduce the concentration of A to less than 0.1 ppm. From among the ideal reactor types, which would you choose and why?

Problem Analysis

In the absence of economic data, it will be assumed that operating costs will scale with reactor volume. According to the problem statement, the waste to be processed is produced continuously. Using a batch reactor would require intermediate storage of the waste, with no compelling reason for doing so. Therefore, the reactor of choice will be one of the flow reactors, either a CSTR or a PFR. A qualitative analysis will be performed to compare the merits of these two reactor types.

Problem Solution

The reaction is exothermic, but the reactant is present in a small amount dissolved in water. As such, it is likely that the amount of heat that will be released will be relatively small and the reaction can be run adiabatically. There are two competing factors in this case. By running adiabatically, the temperature will increase, which tends to increase the reaction rate, while the reactant concentration will decrease, tending to decrease the reaction rate. However, due to the high dilution, the adiabatic temperature rise will likely be small, and therefore the concentration effect is expected to predominate. The key point in this particular analysis is that the final reactant concentration will be extremely small. This means that the rate of reaction at the final conditions will be very low.

In a CSTR, the reaction only takes place at the final conditions where the rate will be very low. As a consequence, the reactor would need to be very large. In a PFR, the reaction rate at the inlet to the reactor will be greater than the rate in the CSTR because the reactant concentration will be greater. As one progresses through the PFR, the rate will decrease, but only at the very end of the PFR will the rate becomes as small as it is in the CSTR. Therefore, one expects that a smaller PFR would be needed. Assuming that operating costs will scale with reactor volume leads to the choice of a PFR for this process.