

ChE 433 BATCH AND CONTINUOUS REACTORS

BACKGROUND

Your team of consultants has been assigned to a project at a small dye plant which uses crystal violet. The plant manager, who is a mechanical engineer, has read a trade journal article stating that NaOH can be used to eliminate the dye color in the wastewater. Additionally, the state regulatory agency has placed a limitation of 1 ppm of crystal violet for the plant discharge.

This small dye plant produces a waste stream with crystal violet concentrations ranging from a minimum 2 ppm to a maximum of 8 ppm, and a daily average of 5 ppm. The flow ranges from a minimum of 20 GPM to a maximum of 75 GPM with an hourly average of 35 GPM. The plant operates 24 hours per day, 250 days per year. The wastewater temperature varies from 80°F to 95°F. Preliminary testing has shown that the reaction products of crystal violet hydrolysis by NaOH are nontoxic to the most sensitive aquatic organisms.

OBJECTIVES

1. Determine the size and cost of the wastewater treatment reactor required for NaOH hydrolysis of crystal violet. This will be done later as a part of ChE 453.

In addition to this principal objective, the engineer responsible for dye plant operations requests the following:

2. In support of your recommendations, **determine the kinetics** of crystal violet hydrolysis by NaOH. A batch reactor is available to determine the kinetics rate expression. The plant engineer is especially interested in a **statistical analysis** of these data showing the uncertainty of your rate parameters. Give your best estimate of the rate parameters along with a measure of error.
3. Using the available laboratory reactor, **compare the start-up and steady-state operations of a CSTR** to predictions based on the kinetic model determined previously. Explain any difference between the predicted steady-state concentration observed and that predicted from your batch data. Discuss how your results are dependent on hydroxide concentration. Is the change in hydroxide concentration negligible?
4. Submit before the experiment a preliminary report with a safety analysis and test plan. Your test plan should outline your experimental procedures including plans for data collection and flow settings for the CSTR.

SUGGESTIONS FOR SUPPORTING EXPERIMENTS

A batch reactor will be used to determine reaction order and the reaction rate constant. The same reaction will then be run in a continuous stirred tank reactor (CSTR). The chemical reaction used in this experiment is the hydrolysis of crystal violet dye by NaOH. See Merck Index under Gentian Violet for the structure and properties of this dye. The concentration of the dye can be followed by measuring the absorbency at 590 nm. The reaction is



The reaction mechanism is quite complex, but in the case of this experiment the reaction rate expression is simplified by using an excess of hydroxyl ion. The reaction rate can be expressed as

$$-\frac{dC_A}{dt} = kC_A^m C_B^n$$

Since C_B , the concentration of OH^- , is much greater than C_A , the dye concentration, C_B changes little during the reaction and

$$r_A = -\frac{dC_A}{dt} = k' C_A^m$$

For a CSTR, a material balance can be written as

$$v_0 C_{A0} - v C_A + r_A V = d(C_A V)/dt$$

Where v is the volumetric flow rate, V is the reactor volume, and the subscript 0 indicates inlet conditions. Solutions for this differential equation can be found in reference 3.

SUGGESTIONS FOR EXPERIMENTAL PROCEDURE

1. The stock dye solution has been prepared by dissolving approximately 0.01 g crystal violet per liter. The stock NaOH solution is 0.01N. These two solutions are stored in supply reservoirs above the CSTR. Before starting the experiment, determine the actual feed concentration of dye using the absorbance calibration curve. Then determine reaction order and reaction rate constant in a batch reactor. It is a good idea to check the feed concentration since it has previously been observed to decrease with time.
2. The CSTR has been calibrated to hold five gallons. Initially the reactor will be charged with 2.5 gal 0.01N NaOH and 2.5 gal water. Operate the CSTR to determine the time required to approach steady-state behavior.

DATA

Rotameter calibrations used to determine inlet flow rates to the CSTR will be provided. A calibration curve showing dye absorbance at 590 nm vs. dye concentration will be provided. Temperature for reactor operation will be assigned to each group. Temperatures will vary from approximately 80 to 95 °F.

REFERENCES

1. A.-F. A Asfour, An Improved Design of a Simple Tubular Reactor Experiment, *Chemical Engineering Education* 19: 84-87 (1985).
2. G. Corsaro, A Colorimetric Chemical Kinetics Experiment, *Journal of Chemical Education* 41: 48-50 (1964).
3. H. Scott Fogler, *Elements of Chemical Reaction Engineering*.