Measurement of Thoroughness of Mixing

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Perfectly mixed continuous stirred tank reactor systems have the following characteristics. The concentration in the vessel is uniform throughout its contents and is, therefore, equal to the outlet concentration. The molecules of the feed stream to the vessel are uniformly dispersed almost instantaneously, and some of them appear immediately in the effluent stream and are lost from the vessel while others may be retained in the vessel for extremely long periods of time.

In practice, many systems do not conform to the assumption of perfect mixing. It is the purpose of this work to determine the residence time distribution for an actual continuous stirred tank reactor, to measure the magnitude of the deviation, and to investigate the variables that cause the deviation.

PREVIOUS WORK

One of the first mathematical relationships derived to allow comparison of the continuous stirred tank reactor system to batch systems was presented by Ham and Coe (*6*) in 1918. The formulas derived were to determine the detention or treatment period which different percentages of the material have on leaving a continuous agitation system. MacMullin and Weber (*10*) were the first to extend the mathematical analysis to the problems of homogeneous chemical reactions being carried out in a series of stirred tank reactors. Kirillov (*8*) extended the analysis for first-order reactions to include the transient starting-up period as well as the steady state condition of operation.

Mason and Piret (*11*) applied the Laplace transform method of solving linear constant coefficient-differential difference equations to solve, in a relatively simple manner, the rate equations of the continuous systems for a wide variety and number of conditions. Eldridge and Piret (*5*) extended theoretical equations for the performance of a series of continuous flow reaction vessels having uniform mixing to higher order unidirectional reactions.

Cholette, Blanchet, and Cloutier (*1*) approached the problem of nonperfect mixing by assuming various combinations of tubular flow and perfect mixing regions to describe a continuous flow system.

ANALYTICAL PROCEDURE

The analysis of the dye containing effluent from the continuous stirred tank reactor was performed continuously by use of spectrophotometry.

APPARATUS

The data reported in this study of a continuous stirred tank reactor was obtained using a 9⅝ in. I.D. flat bottom glass tank as the reaction vessel. The agitator, which was supported by the glass tank, was an ELB Experimental Agitator.

EXPERIMENTAL PROCEDURE

All runs were initiated in the same manner to insure reproducibility of data. The system geometry was set and then operated by feeding and withdrawing tap water at the desired flow rate and tank volume. The geometry of the system was left unchanged after steady state flow conditions were reached.

The effluent line was then closed off at the dip-leg by means of a screw clamp. The desired weight of dye was added to the tank, the walls of the tank washed down, and the tank agitated for a minimum of 30 min. to insure a homogeneous solution. A run was initiated by setting the agitator dial at the desired reading, and then starting the feed and effluent pumps. Flow was initiated by removal of the pinch clamp on the feed and effluent lines.

The variables investigated were flow rate, rpm, impeller size and type, inlet and outlet positions, L/D ratios and viscosity.

TREATMENT OF DATA

The data were calculated in final form as graphs of C/C_o vs. t/θ in order to compare the results with the ideal residence time distribution curve presented in the introduction. In order to establish the accuracy of the experimental work, an evaluation of the experimental error was made.

DISCUSSION

The light transmittal measurement was necessarily at a point downstream of the inside vessel wall. Thus, an inadvertent time lag was incorporated into the measurement. One method of correcting for this would be to plot the value of C/C_o vs. time and integrate from zero to infinity, thus giving a value of θ consistent with the data. This corrected value of holding time was then used.

CONCLUSIONS

The residence time distribution data were not affected by feed rate, length to diameter ratio, amount of agitation, viscosity (within a narrow range), position of inlet and outlet, or type or size of impeller.

Of course, it must be recognized that the type of measurement, since it measured an average tracer concentration over the outlet stream, determined the gross mixing characteristics only and did not attempt to distinguish between micro and macromixing or to determine the degree of segregation.

LITERATURE CITED

1. Cholette, A., J. Blanchet, and L. Cloutier, *Can. J. of Chem. Engr.*, **38**, 1 (1960).
2. Dankwertz, P. V., *Chem. Engr. Sci.*, **2**, 1 (1953).
3. Denbigh, K. G., *Trans. Faraday Soc.*, **40**, 352 (1944).
4. *Ibid.*, **43**, 648 (1947).
5. Eldridge, J. W., and E. L. Piret, *Chem. Engr. Prog.*, **46**, 290 (1950).
6. Ham, A., and H. S. Coe, *Chem. Met. Eng.*, **19**, 663 (1918).
7. Jordan, D. G., *Pet. Refiner.*, 129 (June, 1956).
8. Kirillov, N. I., *J. Applied Chem. USSR*, (English Transl.) **13**, 978 (1940).
9. *Ibid.*, **18**, 381 (1945).
10. MacMullin, R. B., and M. Weber, Jr., *Trans. Am. Inst. Chem. Engrs.*, **31**, 409 (1935).
11. Mason, D. R., and E. L. Piret, *Ind. Eng. Chem.*, **42**, 817 (1950).

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