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EVALUATION OF TANK HYDRAULIC CHARACTERISTICS USING TRANSIENT TRACER TECHNIQUE

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Abstract. The hydraulic characteristics of three reactors were examined: completely mixed, plug flow and continuous flow with baffles. Flow patterns through these three type of reactors were analyzed by introducing a tracer dye into the fluid entering the reactor and observing the tracer output in the fluid effluent. The tracer was detected quantitatively and provided an impulse signal photometrically that led to the hydraulic analysis of each reactor employing Statistical Analysis System.

1 INTRODUCTION

The treatment of wastewater is basically carried out using tanks or basins of various configurations, and under controlled conditions. The products that yield from the reactions occurring within the reactors, either biologically or chemically, are separated typically in settling basins, Metcalf and Eddy [1]. The basis of reactor engineering and process design can be provided by analyzing the hydraulic characteristics of ideal reactor models. Emphasis is particularly placed on reaction kinetics and reactors selection. Several types of ideal reactor configurations are available, Weber [2]: (i) the completely mixed batch reactor, (ii) the completely mixed flow reactor,(iii) the plug flow reactor and (iv) the plug flow with longitudinal dispersion reactor.

In an ideal completely mixed reactor, the water or wastewater that enters the tank is immediately dispersed throughout the tank, and the concentration of reactant in the effluent is equal to that in the mixing liquid. As for an ideal plug flow system, the influent flows through a long tank at a uniform rate without intermixing. The concentration of reactant in this system decreases along the direction of flow, remaining within the imaginary plug of water moving through the tank, Hammer [3].

The extremes represented by the completely mixed flow reactor and the plug flow reactor are never fully realized in most full-scale process applications, although many designs closely approximate these ideals. In practice, the performance of the reactor does not nearly conform to the ideal behaviour due to the fact that the suspended particles and the flow characteristics are different from the assumed conditions. Some deviations from ideal conditions are always observed, and it is the precaution taken to minimize these effects that is really important.

Deviations can be caused by short-circuiting and intermixing caused by frictional resistance along the walls, by recycling, by eddy current and turbulent flow or by the presence of stagnant zones within the reactor. In such cases it may be necessary to determine the flow and mixing characteristics of the reactor, Levenspiel [4]. Usually the correction that

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is made for short-circuiting in plug flow reactors is by using submerged deflection baffles located at either the top or bottom of the tank. Alternatively, mechanical mixer or diffused air may be installed in the tank.

The methodology of this approach is to obtain information on how long individual fluid elements reside in the reactor. This results in information about the internal age distribution and exit age distribution functions for the fluid. The age distribution functions can be used to calculate directly the average extent of reaction when the kinetics are known, Aris [5]. This information, which must be determined experimentally, is most easily obtained by a stimulus-response technique using step or pulse inputs of a readily detectable tracer.

The extent of particle removal by settling or mixing tanks is governed by the settling properties of the suspended particles as well as the flow characteristics in the settling zone, Conner [6]. The design and performance of a given tank can be evaluated by measuring particle removal directly. Therefore tank or reactor efficiency provides the means by which particle removal can be assured. Reactor efficiency was calculated as the ratio of the actual to the "ideal" removal. Hence, the hydraulic efficiency, retention times, velocities, mixing and effective volumes can be determined.

2 OBJECTIVE

The objective of this experiment was to observe the hydraulic characteristics of three reactors using transient tracer techniques.

3 MATERIALS AND METHODS

The dynamics of the three different type of reactors were illustrated by setting up three tanks. The appropriate internal and external dimensions were noted for each tank, i.e volume, area and wetted surface area in the case of continuous flow. Calculations were required and made for flowrate (Q), average retention time and the appropriate tracer (dye) concentration.

Each reactor was connected to an inlet and outlet valve, and in order to allow for the appropriate retention times and volumes adjustment was made by varying the flowrate. A methylene blue (5 g/l) was prepared as a tracer source. After each tank was filled and the appropriate retention time determined the tracer was injected into each reactor. Effluent samples were withdrawn and collected into test tubes as the colour wave of the tracer approached the outlets. After collection all samples were analyzed using a spectrophotometer at a wavelength of 650 mu and % light transmission and absorbance obtained. The data was converted from absorbance to tracer concentrations, mg/l, incorporating previously prepared standard calibration curves (Figures 1, 2 and 3).

4 RESULTS

From the results obtained in the first reactor which was a completely mixed flow reactor, the initial tracer concentration was found to be 0.0. An increase in tracer concentration was observed until its highest concentration of 0.18 mg/l was reached whereby the concentration slowly decreased back to near 0.0 (Figure 4). The equation used to illustrate the completely mix flow reactor from the experimental work was:

$$C_0 = C_i \times e^{-t/T}$$

where

C_o = concentration of reactant
C_i = initial concentration of the tracer in reactor
T = mean residence time in the reactor
t = time

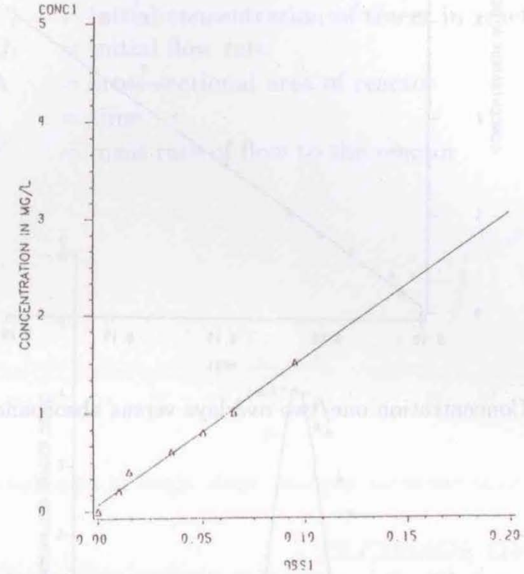

Fig. 1 Concentration one versus absorbance one

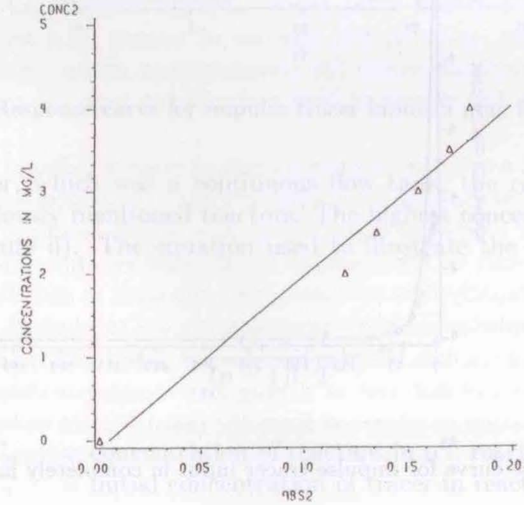

Fig. 2 Concentration two versus absorbance two

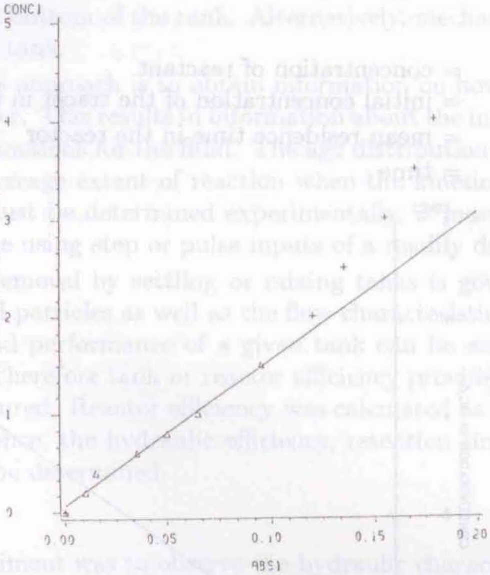

Fig. 3 Concentration one/two overlays versus absorbance one/two

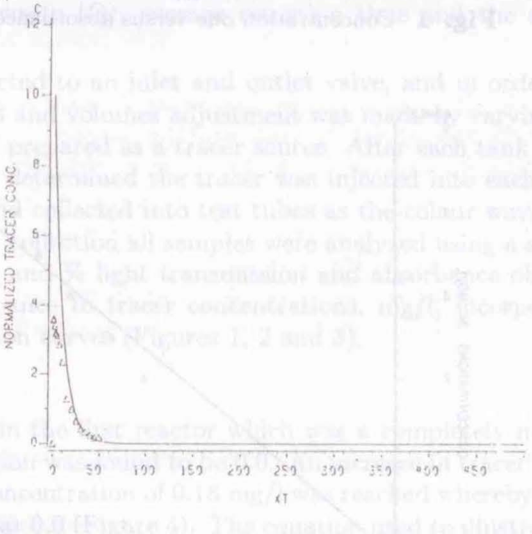

Fig. 4 Response curve for impulse tracer input in completely mixed flow reactor

The response in the second reactor was approximately a plug flow reactor was that of an abrupt response immediately to its highest concentration of 0.195 mg/l (Figure 5). After the tracer concentration reached its highest point the response input was found to be similar to that of the output concentration. The equation used to illustrate the plug flow reactor was:

$$C_i = \frac{Q_i}{At} \times F$$

C_i = initial concentration of tracer in reactor
Q_i = initial flow rate
A = cross-sectional area of reactor
t = time
F = mass rate of flow to the reactor

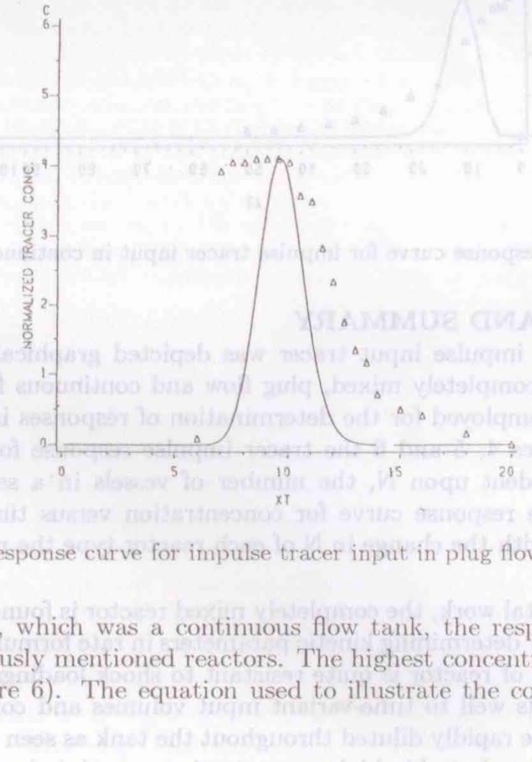

Fig. 5 Response curve for impulse tracer input in plug flow reactor

In the third reactor, which was a continuous flow tank, the response was an impulse between the two previously mentioned reactors. The highest concentration was 0.065 mg/l with N being 15 (Figure 6). The equation used to illustrate the continuous flow reactor was:

$$C_n = \frac{C_i}{(n-1)!}(\frac{t}{T})e^{-t/T}$$

C_n = concentration of reactant in n^{th} reactors
C_i = initial concentration of tracer in reactor
n = number of reactors
T = mean residence time in the reactor
t = time

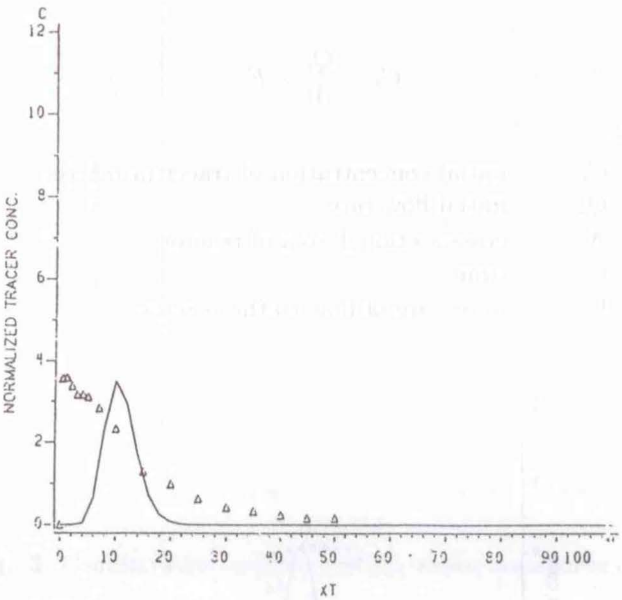

Fig. 6 Response curve for impulse tracer input in continuous flow reactor

5 DISCUSSION AND SUMMARY

The response of an impulse input tracer was depicted graphically for all three types of hydraulic reactors, completely mixed, plug flow and continuous flow. Statistical Analysis System (SAS) was employed for the determination of responses in the three tanks [7]. As illustrated by Figures 4, 5 and 6 the tracer impulse response for each reactor was quite different and dependent upon N, the number of vessels in a series. As N increases to infinity, the impulse response curve for concentration versus time wasfound to be more abrupt. Therefore with the change in N of each reactor type the reaction equation changes accordingly.

From the experimental work, the completely mixed reactor is found to be a valuable experimental apparatus for determining kinetic parameters in rate formulations. As observed from the graph, this type of reactor is quite resistant to shock loadings. The completely mixed reactor also responds well to time-variant input volumes and concentrations because the influent reactants are rapidly diluted throughout the tank as seen from the result obtained. Therefore regions of undesirably high concentration are minimized.

As for plug flow reactor models, they are useful for describing many water quality control processes. Because the influent end of a plug flow reactor is characterized by regions of high reactant concentration as observed from the disturbances caused during slug injection of tracer, this type of reactor does not respond well to time variant or shock inputs.

REFERENCES

[1] Metcalf and Eddy, Inc., *Wastewater Engineering: Treatment Disposal Reuse, 3rd Edition*, McGraw-Hill, New York, 1991.

[2] W. J. Weber, *Physio-Chemical Processes for Water Quality Control*, John Wiley and Son Inc., New York, 1992.

[3] M. J. Hammer, *Water and Wastewater Technology*, John Wiley and Son Inc., New York, 1986.

[4] O. Levenspiel, *Chemical Reaction Engineering 2nd Edition*, John Wiley and Son Inc., New York, 1972.

[5] R. Aris, *Introduction to the Analysis of Chemical Reactors*, Prentice-Hall Inc., Englewood Cliffs, New York, 1965.

[6] J. T. O'Conner, *Environmental Engineering Unit Operations and Unit Processes Laboratory Manual. Association of Environmental Engineering Professors* (1975), II-1 - II-5.

[7] SAS/Graph User's Guide, *SAS Institute* (1981), Cary N.C..