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.

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
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 μm 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:

\[ C_0 = C_i e^{-t/T} \]
where

\[ C_0 = \text{concentration of reactant} \]
\[ C_i = \text{initial concentration of the tracer in reactor} \]
\[ T = \text{mean residence time in the reactor} \]
\[ t = \text{time} \]

Fig. 1 Concentration one versus absorbance one

Fig. 2 Concentration two versus absorbance two
is made by short-circuiting to any line reactor is by using submersed diffusion tubes located at either the top or the bottom of the tank. Alternatively, mechanical stirrer(s) may be installed at the same.

The methodology of this approach is based on the assumption that the individual fluid elements make up the residence time distribution of the tank. The age distribution function can be used to calculate directly the extent of reaction if the residence times are known. Arai [8] has determined experimentally, whereas we can easily obtain the residence time distribution function using step or pulse inputs of a readily detectable tracer.

The solute removal efficiency of settling or raising tanks is governed by the settling properties of the suspended particles as well as by their characteristics in the settling zone. Conrey et al. [27] have developed a model to predict the behavior of the tank by which particle removal can be ensured. Reactor efficiency was calculated as the ratio of the removal to the "ideal" removal. Hence, the volume efficiency, retention times, velocities, settling and effective volumes can be evaluated.

3 OBJECTIVE

The objective of this experiment was to observe and study hydraulically characterized or nonreacting systems using transient tracer input.

3 MATERIALS AND METHODS

For each of the three different types of reactors were constructed by setting up three stacks. The appropriate inhalation and egress dimensions were used. For each tank, the volume, area and wetted-surface area in the case of continuous flow. Calculations were performed to find the hydraulic characteristics for the appropriate tracer transport concentration.

Each reactor was connected to an inlet and outlet valve, and in order to allow for the appropriate retention time, the volume adjustment was carried by varying the reactor. A solution of basic tracer (0.1% NaCl) was prepared as the tracer source. After each tank was filled and the appropriate retention times determined, the tracer was injected into each reactor. Samples were withdrawn from the reactor effluent and placed into test tubes as the chemical properties of the tracer approximated the solution. After filtration, all samples were analyzed using a spectrophotometer as a wavelength of 580 nm. A high transmission of light was obtained. The data was converted from absorbance to concentrations of the tracer solutions (Figures 1, 2 and 3). The results obtained were used to illustrate the completely mixed flow reactor.

4 RESULTS

From the results obtained in the first reactor which was a completely mixed flow reactor, the initial tracer concentration was observed until 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.
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to that of the output concentration. The equation used to illustrate the plug flow reactor was:

\[ C_t = \frac{Q_t}{A} \times F \]

where:
- \( C_t \) = initial concentration of tracer in reactor
- \( Q_t \) = 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](image)

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:

\[ C_n = \frac{C_t}{(n-1)!} \left( \frac{t}{T} \right) e^{-t/T} \]

where:
- \( C_n \) = concentration of reactant in \( n^{th} \) reactors
- \( C_t \) = 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 was found 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

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