Study on Flow Behaviour in Rectangular Sedimentation Tank

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Abstract— The effect of baffles in a pilot rectangular settling tank system on the flow pattern was studied using trace analysis with Rhodamine B as a dye injection method. The operating variables were; baffle existence, baffle position, baffle height from bottom and the residence time inside the tank. The Morrill dispersion index for all experiments were predicted. The effect of baffle at a distance 10, 20 and 30 cm from the inlet at fixed baffle clearence from bottom of 9 cm were studied. On increasing the distance of baffle from inlet, a flattening of curve and increase in Morrill index was observed; i.e. a scatter from plug flow toward CSTR flow behaviour. The effect of clearence of the baffle of 6, 9, 12 cm from the bottom at each baffle position from inlet (10, 20, 30 cm) were also studied. It appears that the Morrill dispersion index (MDI) increases as the clearance of baffle from bottom was increased and hence the flow pattern will start to deviate from plug flow toward mix flow. It is also observed thate Morrill dispersion index (MDI) increased as the residence time decreased and hence the flow pattern will deviate from plug flow towards mixed flow pattern.

.**Index Terms**— Sedimentation, plug flow, mixed flow, Baffles, wastewater treatment, Sedimentation tank. Trace analysis

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1 INTRODUCTION

Sedimentation is applied in different chemical engineering operations and processes such as filtration, fluidization, two- phase flow and environmental engineering[1]. There are four types of settling: discrete, flocculation, hindered and compression settling [2].

Sedimentation tanks of various shapes and flow patterns are used for the separation of suspended solids in the treatment of water, sewage and industrial effluents.The principal configurations are rectangular tanks with flow from end to end, circular tanks giving radial flow outwards or a combination of radial and upward flow, and deeper tanks of cylindrical pyramidal or conical shape, in which the flow is upwards [3].

In rectangular tanks, flow pattern is much more unpredictable, heavily depending on the tank geometry and the characteristics of water inlets [4]. In general, two ideal flows can be defined for rectangular tanks: the “plug flow” and the “mixed flow”. In the “plug flow” there is no mixing or diffusion along the flow path and the maximal waste concentration is found in the outlet. In the “mixed flow” the exit stream from the tank has the same composition as the fluid within the tank [5].

Dead zones and short circuiting of the inlet to the outlet disturb the quietness of flow and leave negative influences on the performance of the tank. To prevent these phenomena, some baffles are used in different parts of the tank. By optimizing the application of the baffles in the tanks, the size of the recirculation zones is reduced and the plug flow percentage, which is the ideal flow for clarifiers, is increased. In fact, several parameters, e.g. location and type of inflow and effluent, location and size of baffle, and rate of sludge withdraw could influence the effeciency of settling tanks [6]. The construction of baffled sedimentation tanks in water treatment plants with no mechanical parts is considered to be more reliable, requires less maintenance and hence reduces the total cost [7].

In this study it is intend to study the effect of baffle in a pilot rectangular settling tank system on the flow pattern inside the tank using trace analysis by dye injection method. The operating variables will be ; baffle existence, baffle position, baffle height from bottom and the residence time inside the tank.

2 EXPERIMENTAL WORK

2.1 Equipment

The sedimentation apparatus and tank used in the experimental part are shown in Fig. 1 and 2 respectively.

Fig. 1 : Sedimentation apparatus

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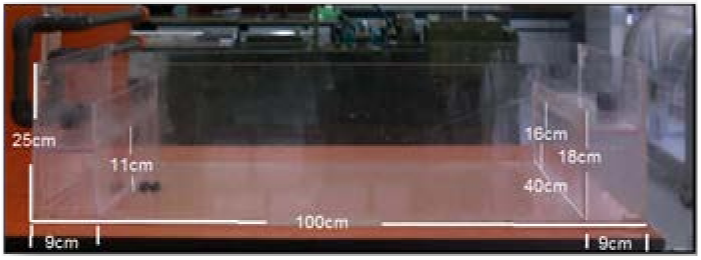

Fig. 2- Sedimentation tank.

Sedimentation apparatus consists mainly of Perspex rectangular settling tank, suspension flow meter, fresh water flow meter, suspension pump and suspension tank.

2.2 Procedure

The flow rate of water required to give the required residence time was recorded and set. Then a 60 ml was injected from stock dye solution of Rhodamine B (3 g/L) into the input weir. At the moment the colour approaches the outlet weir, the effluent samples are collected every two minutes for 10 minutes and then every 5 minutes for another 50 minutes. The concentration of the dye in the sample is determined by measuring OD of the dye with the help of Colorimeter device.

3 THEORY

In all these sets of experiments for dye tracing technique, the exit age distribution curves were generated and plotted between the dimensionless concentration (C/C_o) with dimensionless time (t/t_{th}) , where:

C : the concentration of dye at exit from sedimentation basin
C_o: the weight of dye injected in gm per volume of active part of sedimentation basin in liter.
t : the time at which the concentration (C) of die is measured in minute.
t_{th}: residence time of water in the sedimentation basin (total flow/volume of active part of basin) in minute.

The hydraulic characteristics of sedimentation tank are also studied by obtaining coefficient of dispersion, using residence time distribution curves (RTD) [8].

To plot RTD curves we have to use the values of time and concentration for each experiments to calculate E(t) values using equation (1) and (2).

$$Area\ under\ C\ curve = \sum C\Delta t \quad (1)$$

$$E(t) = \frac{C}{\sum C\Delta t} \quad (2)$$

The E(t) values are correct by multiplying each one by the time step, and calculating the sum, the sum should be 1.00.

$$\sum E(t)\Delta t = 1 \quad (3)$$

The values for plotting the F(t) curve are obtained by summing cumulatively the (E(t) Δt) values to obtain the coordinates of the F curve. After plotting time verses F values curve, the dispersion index as proposed by Morrill (MDI) can be calculated using equation (4):

$$MDI = \frac{t_{90}}{t_{10}} \quad (4)$$

where t_{90} and t_{10} represented the time in min at which the cumulative total F(t) is equal to 0.9 and 0.1 respectively and can be obtained from the time verses F(t) curve [9]. A Morrill Index of 1 indicates pure plug flow and an index of 22 hours indicates complete mix where a Morrill index above 22 would suggest short circuiting in conjunction with a basin approaching complete mix [10].

4 RESULTS AND DISCUSSION

4.1 Effect of distance of the baffle from the inlet

In this set of experiments, our objective is to study the effect of baffle position from the inlet of the tank on the RTD curve as plotted between the dimensionless concentration ratio C/C_o and t/t_{th}. This set was conducted by collecting the tracer samples at the outlet of the sedimentation basin at different positions of the baffle namely 10 cm, 20 cm and 30 cm from the inlet. The curves for these baffle positions at a fixed baffle clearance of 9 cm from bottom are shown in Fig. 3, 4 and 5. The predicted values for Morrill dispersion index for all sets of experiments are shown in Table 1.

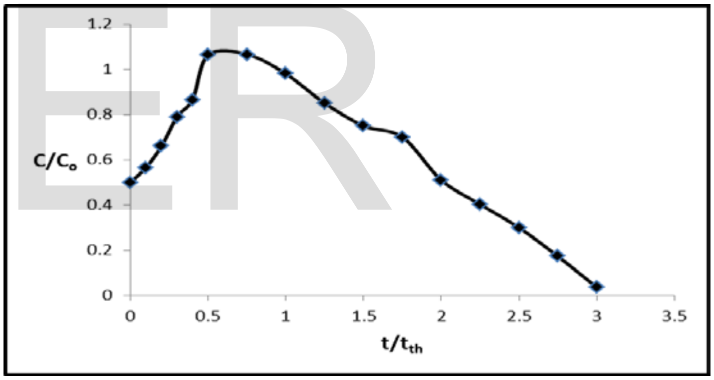

Fig. 3: RTD curve for a baffle position of 10 cm from entrance and baffle depth clearance of 9 cm from bottom (τ = 20 min).

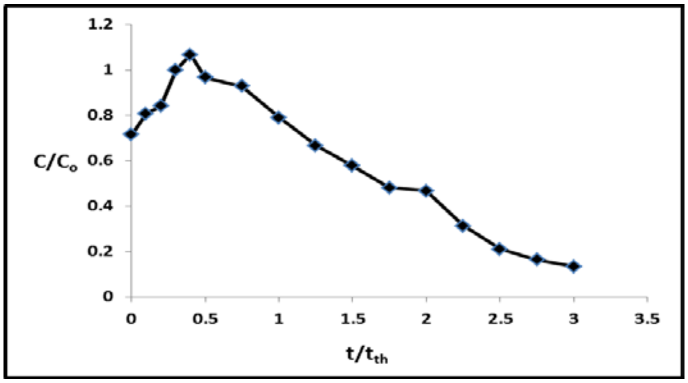

Fig. 4: RTD for a baffle position of 20 cm from inlet and baffle clearance of 9 cm from bottom (t_{th} = 20 min).

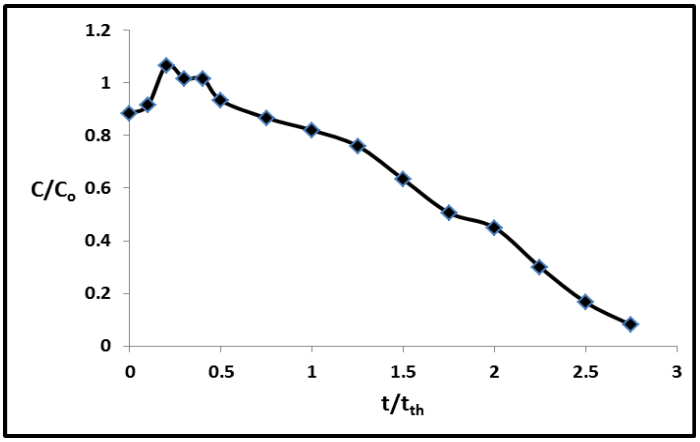

Fig. 5: RTD curve for a baffle position of 30 cm from inlet and baffle clearance of 9 cm from bottom (t_{th} = 20 min).

Table 1: Morrill dispersion for different configuration and flow

Flow (L/min)	Baffle position from inlet (cm)	Depth of baffle (cm)	Morrill Dispersion Index
3	--------	---------	11.1
4	--------	--------	12.6
5	--------	-------	14.2
3	10	6	5.63
3	10	9	8.07
3	10	12	8.73
3	20	6	8.80
3	20	9	10.5
3	20	12	13.6
3	30	6	11.75
3	30	9	12.1
3	30	12	15.2

From Fig. 3, it clearly appeared that initially the concentration ratio C/C$_o$ increased with time to reach a maximum at t/t$_{th}$ equal to about 0.75 (represent a time of 15 min) and then the concentration ratio decrease to zero. The same trend was obtained in Fig. 4 and 5 but the maximum concentration ratio C/C$_o$ is at a t/t$_{th}$ equal to 0.4 and 0.2 respectively which which represent a time of 8 & 4 minutes respectively. It appears from Table 1 that the Morrill dispersion index (MDI) increases as the distance of baffle from the inlet increases and hence the flow pattern will start to deviate from plug flow toward mixed flow.

4.2 Effect of clearance of the baffle from bottom

The effect of the different clearences of the baffle from the bottom at each different baffle position from the inlet of the tank on RTD curve were studied. Three different clearences from the bottom (6, 9, 12 cm) were used for each three different baffle positions (10, 20, 30 cm) from the inlet of the tank at a residence time of 20 min (Fig. 6, 7 and 8).

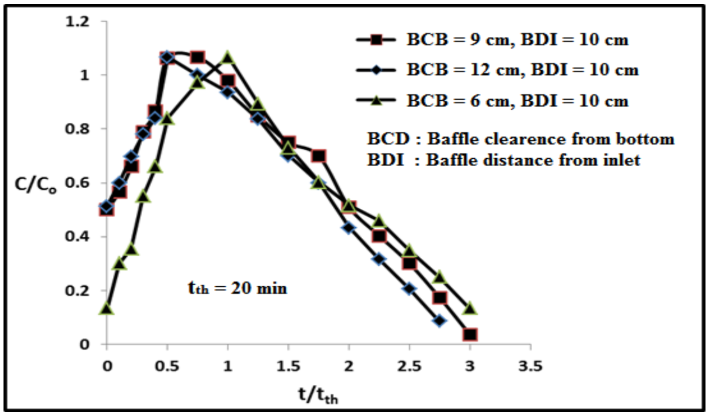

Fig. 6: Effect of clearance of baffle at 10 cm from inlet on RTD.

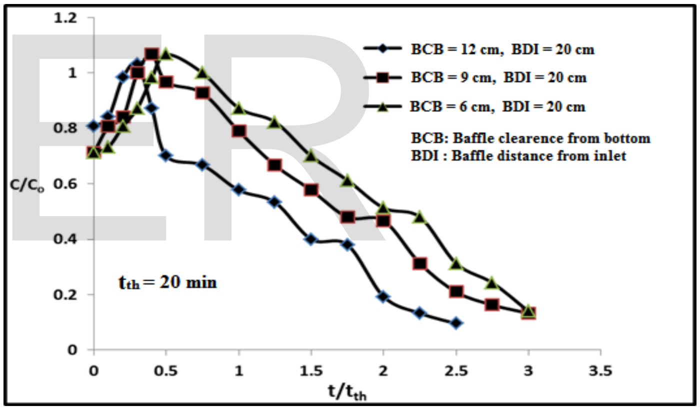

Fig. 7: Effect of clearance of baffle at 20 cm from inlet on RTD.

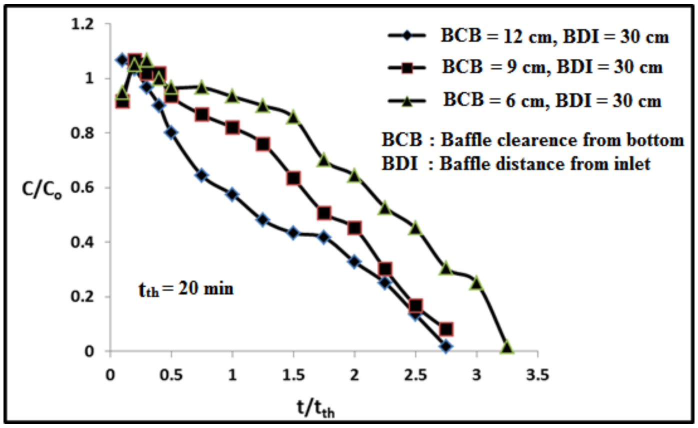

Fig. 8: Effect of clearance of baffle at 30 cm from inlet on RTD.

For better judgment, in the three curves the lower value of dispersion index can be recommended for better design.

From Fig. 6 we notice the baffle at three clearences (6, 9, 12 cm) have relatively small amount of axial dispersion flow with an optimum condition at 6 cm clearence. According to this curve, when the baffle is placed near the inlet (10 cm from inlet) at suitable clearence from the bottom give an enhancement for the overflow of the primary tank. That's mean dead zones and short circuiting problems between the inlet and outlet of the tank are reduced. As a result, the baffle at 6 cm clearance from the bottom is cut the circulating streamline to give uniform flow field. As the investigation was done in literature, we find this result confirms the work of Tamayol et al. [11].

It appears from Fig. 7 that when the baffle at a clearance of 6, 9, 12 cm and at a distance of 20 cm from inlet, the flow is try to move toward mixed with relatively large amount of axial dispersion. Therefore; clearence of the baffle have no great affect on the dead zones which are reduced the effective volume of the tank. So, some part of the flow is exited without any sedimentation. But, it can see that when the baffle is placed closer to the bottom give acceptable dispersion of the flow as we notice from the curve at 6 cm clearence.

It obsereved from Fig. 8 that when the baffle at a clearance of 6, 9, 12 cm and at a distance of 30 cm from inlet, the flow is moving toward mixed flow. In this case, the performance is poor due to the size of dead zone. Regions are created with high turbulence intensity, which reduces the possibility of particle deposition. From the Fig. 8, it also appeared that when the baffle is placed at wrong height and position affecting the performance of the tank negatively due to the size of circulation zones is increased.

If the Morrill dispersion index (MDI) is checked using Table 1, it appeared that MDI increases as the clearence of baffle from bottom increases for a baffle position of 10, 20 and 30 cm from inlet and hence the flow pattern will start to deviate from plug flow to mix flow. A 6 cm baffle clearence from the bottom of the tank at a baffle location of 10 cm from the inlet gave the lower MDI value as shown in Table 1.

4.3 Effect of residence time:

The hydraulic design has traditionally been based on the assumption that the contact time for all fluid elements corresponds to the theoretical hydraulic residence time (t_{th}) of a given tank [12], which can be estimated as $\tau = V/Q$. In chemical reaction engineering, this assumption has been associated with the theoretical/idealized flow pattern, known as "Plug Flow", in which all elements of fluid passing through a flow reactor do so uniformly, in parallel paths from the inlet to the outlet sections of the tank, i.e. without undergoing longitudinal or axil dispersion [13]. The other theoretical/idealized flow pattern is known as 'Complete Mixing' and its characterizing assumption is the instantaneous mixing of all incoming fluid elements with the fluid already in the reactor, thereby representing maximum dispersion.

In this work, the effect of the residence time (t_{th}) without baffle on the sedimentation tank performance was investigated, using tracer technique. Three different values for residence time were applied, namely 12, 15 and 20 min as shown in Fig. 9, 10 and 11 respectively. It observed that the curves will be flatterned as the residence time increases from 12 to 20

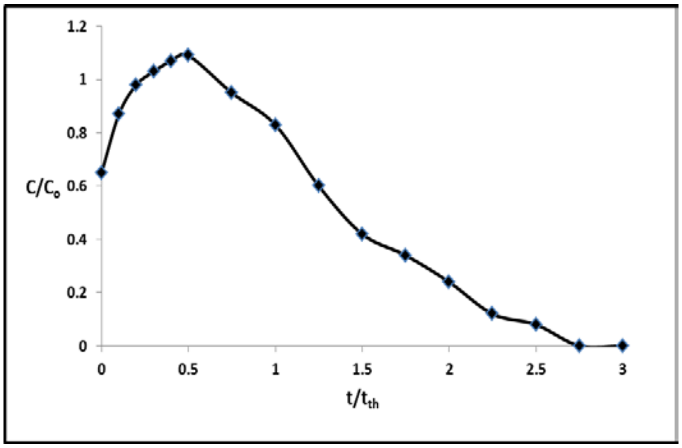

Fig. 9: RTD for t_{th} = 20 min (without baffles).

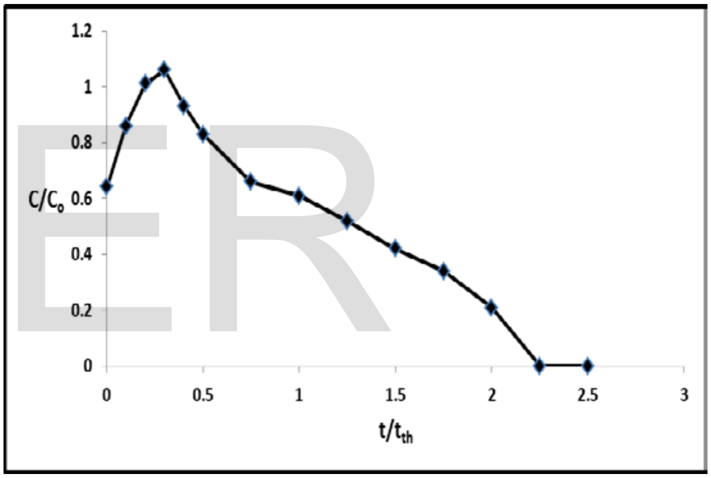

Fig. 10: RTD for t_{th} = 15 min (without baffles).

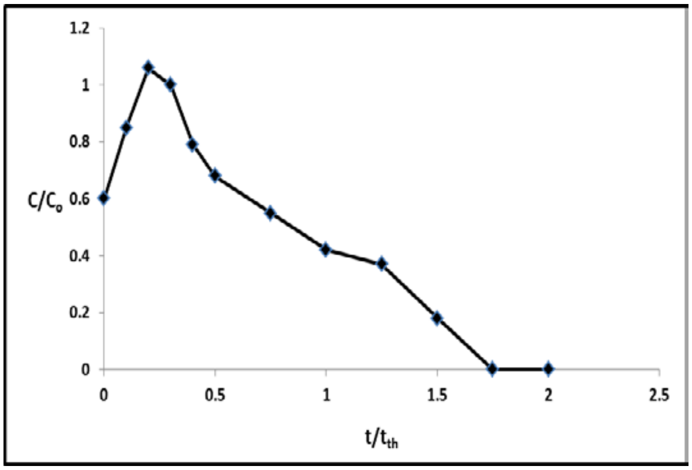

Fig. 11: RTD for t_{th} = 12 (without baffles).

minutes. It means that as the residence time increases the flow is moving toward plug flow. This approach is supported by comparing the MDI values as appears in Table 1 which indicated that the Morrill dispersion index (MDI) decreases as the residence time increases and hence the flow pattern will deviate from mixed flow towards plug flow pattern.

5 CONCLUSIONS

A series of laboratory experiments were conducted to study the effects of distance of the baffle from the inlet, clearance of the baffle from the bottom and residence time on the performance of rectangular sedimentation tank as indicated by RTD curve and Morrill dispersion index (MDI).

The following conclusions can be extracted from this study:

- The effect of baffle at a distance 10, 20 and 30 cm from the inlet at fixed baffle clearence from bottom of 9 cm were studied. With increasing the distance of baffle from inlet, a flattening of curve and increase in Morrill index was observed; i.e. a scatter from plug flow toward CSTR flow behaviour.
- The effect of clearence of the baffle of 6, 9, 12 cm from the bottom at each baffle position from inlet (10, 20, 30 cm) were also studied. It appears that the Morrill dispersion index (MDI) increases as the clearance of baffle from bottom was increased and hence the flow pattern will start to deviate from plug flow toward mix flow.
- It is also obsereved thate Morrill dispersion index (MDI) increased as the residence time decreased and hence the flow pattern will deviate from plug flow towards mixed flow pattern

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