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Research Article

To study the performance of the ozone contactor using numerical tool

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Abstract

Ozone is mostly used as disinfect in water treatment. To determine the performance of purify stage in waste water treatment; computational fluid modeling can be a useful aid. Contactor tanks are designed to take help of the contact time between ozone and pathogens before the water are release to clients. Thus the design plan is to exploit on the time that it takes for water to travel from the tank influent to the effluent. In present analysis Tracer studies can be used to determine the hydraulic characteristics of the ozone contactor tank. Residence Time Distribution (RTD) analysis is a very efficient analysis tool that can be used to inspect the malfunction of ozone contactor tank. The result from tracer studies can used to obtain precise estimate of the efficient contact time. The effects of opposing tank flow condition and different geometry arrangement are studies using CFD.

Keywords: *CFD; Residence Time Distribution; Contact tank; Tracer; Hydraulic.*

1. Introduction

The ozonation process has been used as an effective method for removing residual pollutants such as pesticides and other hazardous chemicals from raw water during drinking water treatment (Jian-Ying Hu *et al* 2000). Worldwide, over 3000 ozone contactors are used in drinking water treatment plants, primarily for disinfection purposes (Wols, B.A *et al* 2008). The performance of ozone disinfection processes is affected by reactor design and operating conditions as well as source water characteristics. Understanding the role played by these factors is important for optimizing the ozone disinfection process and ensuring adequate control of pathogens such as Cryptosporidium parvum oocysts and disinfection by-products (DBPs) such as bromated (Wols, B.A *et al* 2010). The most important hydraulic characteristic of an ozone contactor is its residence time distribution (RTD). Under the US EPA Interim Enhanced Surface Water Treatment Rule (IESWTR) the physical removal or the inactivation of waterborne pathogens during disinfection of drinking water is specified in terms of CT which is the numeric product of the residual ozone outlet concentration (C) and a characteristic contact time (CT) (Jae-Hong Kim *et al* 2007). The value of CT is dependent on the target species and the disinfectant. The effective contact time is taken to be T_{10} rather than the mean hydraulic retention time. T_{10} is the time required for 10% of a pulse of a tracer introduced at the disinfectant dosing point to have reached the residual sampling point. Thus T_{10} can be derived from the RTD of a contactor, which in turn, is affected by its geometry and operating conditions. The disinfection efficiency of the ozone systems depends on the ozone dose (or CT value) distribution. The low ozone doses are very critical for the disinfection due to the high extent of removal required (for example, 3 log or 99.9%). Therefore, hydraulic optimizations that increase the lowest ozone doses are very beneficial for the disinfection. An accurate prediction of the disinfection is therefore of major interest, so that the required ozone dosage can be determined precisely. Present study is to simulate the performance of multi-chambered bubble-diffuser ozone contactors with variation in the number of the baffle and then change the flow condition. It is important to know the mixing level and residence time in reactors, since they both affect the degree of process reaction that occurs while the fluid usually water and its components often pollutants pass through the ozone contactor tank. Fluid flows are inherently complex and governed by equally complex equations. This is certainly the case for many fluid flow problems seen in the water & waste water treatment industry.

The rapid acceleration of computer technology in recent decades has resulted in computer hardware and software that is now capable of numerically solving these equations and problems to time scales that fit within project schedules. The purpose of this article is to summaries the results of the CFD modeling analysis of ozone contactor tank. The analysis considered three different condition low, average and high inflow for different arrangement of tank geometry mainly baffle named as Scenario-1, Scenario-2 and Scenario-3.

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2. Ozone contact tank

A recent three-dimensional laser induced fluorescence (3DLIF) Investigating multi-chamber ozone contactor using 3D laser induced fluorescence conducted tracer studies for several hanging baffle designs based on a down scaled ozone contactor model and found that an efficient baffle arrangement would have a significant enhancement in tracer residence time on physical experiments on a tank that has been numerically modeled in this study (USEPA *et al* 1999). The laboratory scale contactor consisted of 12 chambers. A truncated version consisting of 4 chambers was considered in the computations (Kim *et al* 2010b) and was also considered for the present computations. The section formed by the 4 chambers (chamber width is 0.113m) is 0.473 m long in the streamwise (X) direction, height is 0.21m in the (Z) direction and 0.23 m wide in the span wise (Y) direction. The rest of the dimensions of the contactor including the dimensions of the baffles are given in Fig 1. The other two contactors studied in the present computations have the same dimensions except with twice and thrice the number of chambers, respectively, corresponding to approximately half (0.053m) and quarter (0.033m) chamber widths of the original contactor. The geometries of the three contactors are shown in Fig 1, Fig 2 and Fig 3. Henceforth, the original contactor is denoted as Scenario-1 (for normal chamber width), the second contactor is denoted as Scenario-2 (for half chamber width) and the third contactor as Scenario-3 (for quarter chamber width).

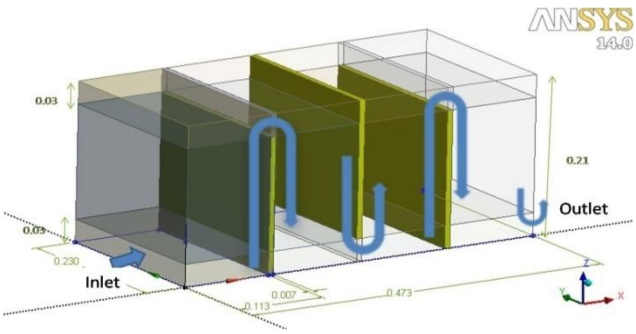

Fig. 1 Three dimensional view of the model generated for ozone contactor Scenario-1

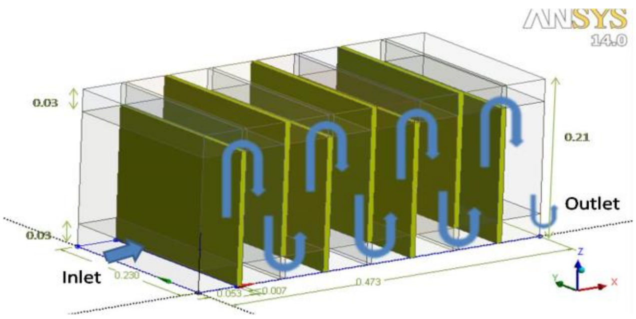

Fig.2 Three dimensional view of the model generated for ozone contactor Scenario-2

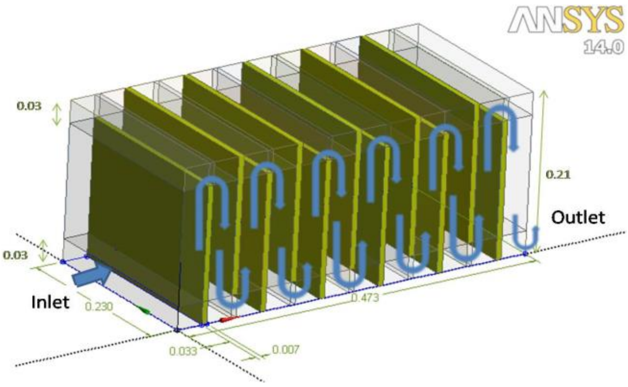

Fig.3 Three dimensional view of the model generated for ozone contactor Scenario-3

3. Modeling Strategy

There are diverse techniques existing within CFD modelling platforms by which this flow condition can be simulated. Considering the little variation in the free surface of the water, the water surface was considered to be steady for the analysis purpose. The software code 'Fluent v14.0' was used for this analysis. To predict the behaviour of the ozone contactor tank, Residence Time Distribution (RTD) analysis was carried out.

The following assumptions were made while studying the performance of the ozone contactor tank. Water is considered to be isothermal, and none of its properties change during the simulation. The inflow to the ozone contactor and outflow from the contact is continuous and steady. Three flow condition consider are 0.1 kg/s, 0.2 kg/s and 0.4 kg/s.

4. Results and Discussion

The velocity contours along with velocity vector are plotted at vertical plane located in water levels in order to understand the flow patterns in the ozone contact tank. Fig 4 to Fig 12 shows the velocity contour along with velocity vector at plane in vertical plane location in the ozone contactor tank at different flow condition. From the Fig 13 to Fig 21, Shows streamline coloured by velocity magnitude in the ozone contactor tank.

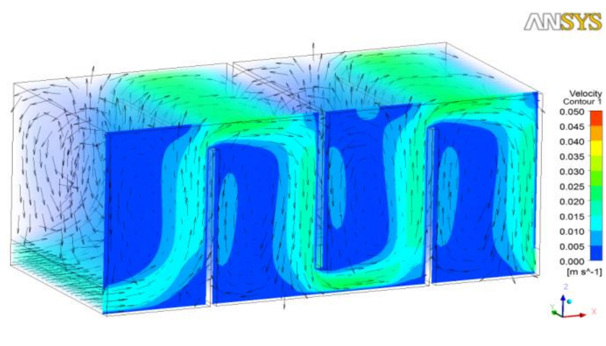

Fig. 4 Velocity contour for 0.1 kg/s inflow Scenario-1

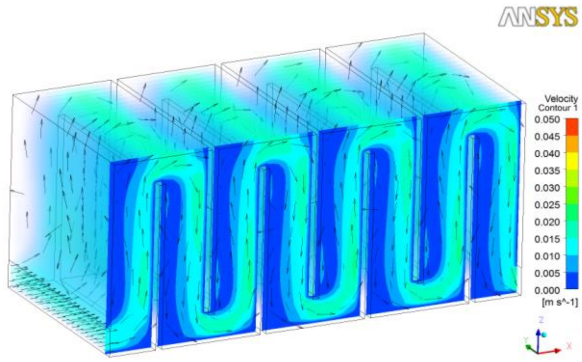

Fig. 5 Velocity contour for 0.1 kg/s inflow Scenario-2

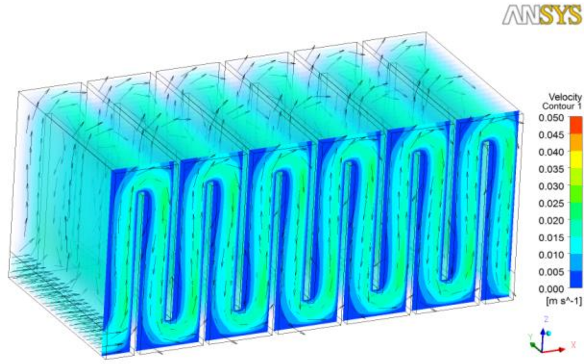

Fig. 6 Velocity contour for 0.1 kg/s inflow Scenario-3

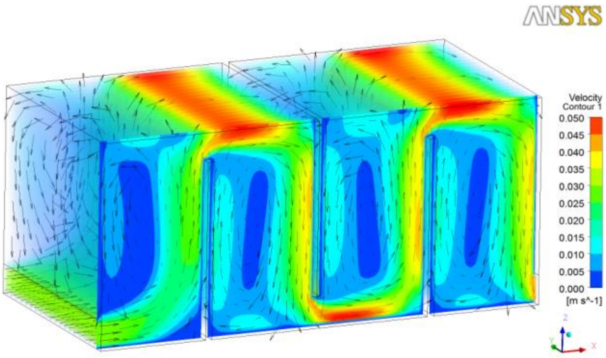

Fig. 7 Velocity contour for 0.2 kg/s inflow Scenario-1

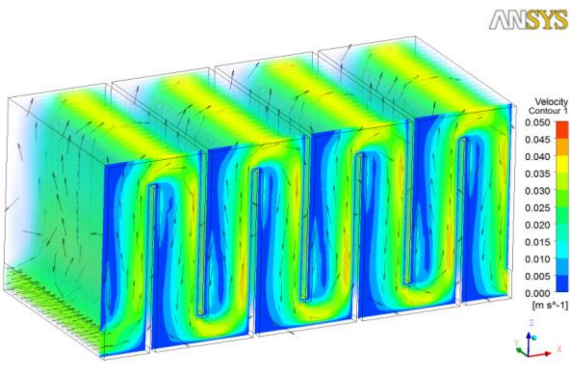

Fig. 8 Velocity contour for 0.2 kg/s inflow Scenario-2

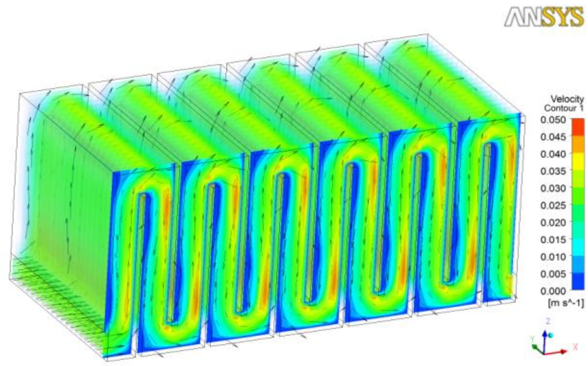

Fig. 9 Velocity contour for 0.2 kg/s inflow Scenario-3

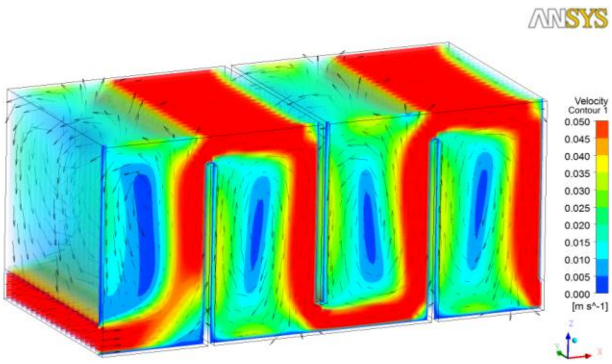

Fig. 10 Velocity contour for 0.4 kg/s inflow Scenario-1

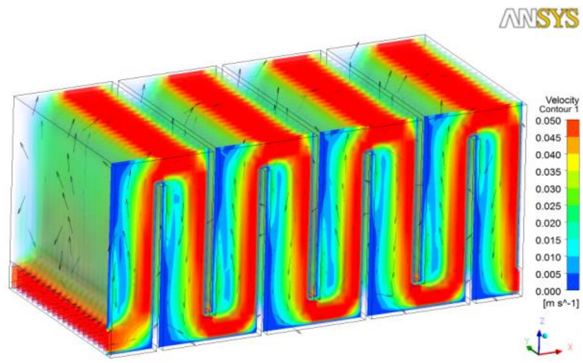

Fig. 11 Velocity contour for 0.4 kg/s inflow Scenario-2

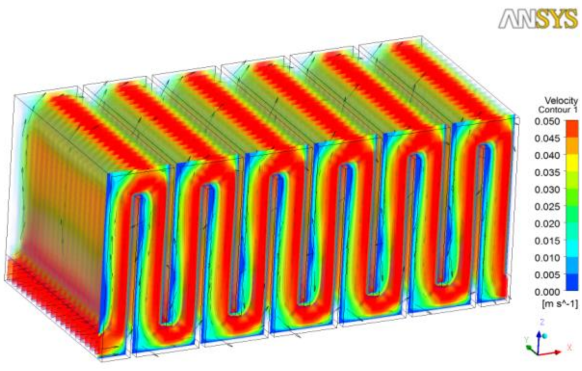

Fig. 12 Velocity contour for 0.4 kg/s inflow Scenario-3

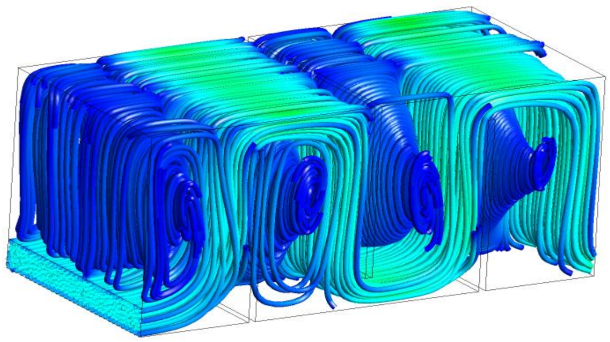

Fig. 13 Streamline for 0.1 kg/s inflow Scenario-1

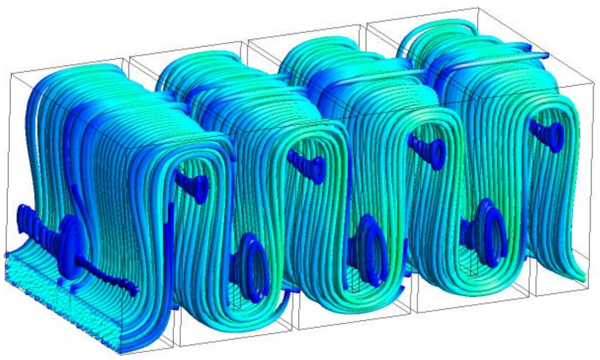

Fig. 14 Streamline for 0.1 kg/s inflow Scenario-2

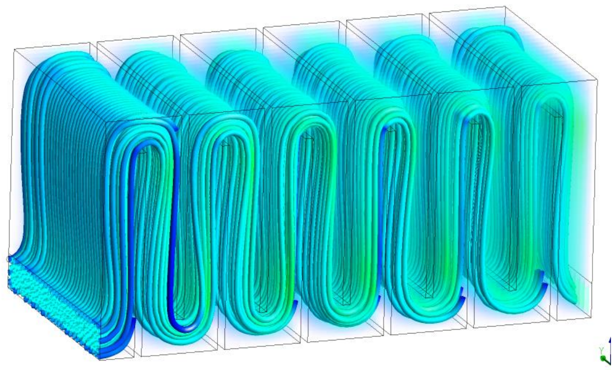

Fig. 15 Streamline for 0.1 kg/s inflow Scenario-3

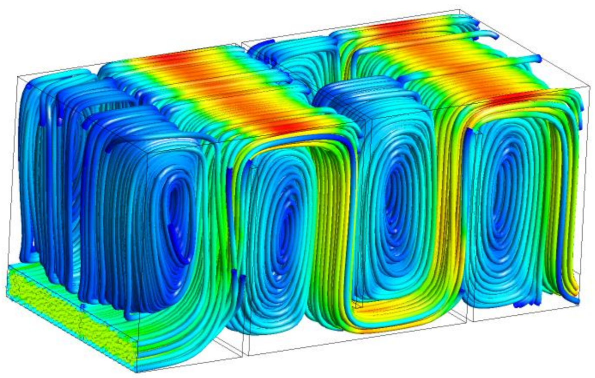

Fig. 16 Streamline for 0.2 kg/s inflow Scenario-1

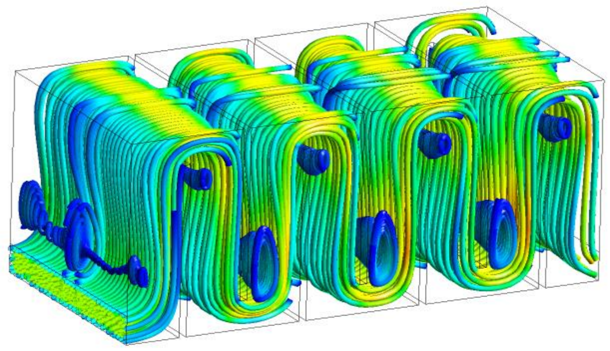

Fig. 17 Streamline for 0.2 kg/s inflow Scenario-2

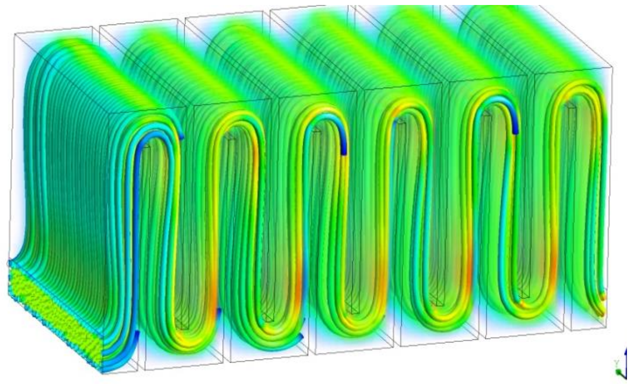

Fig. 18 Streamline for 0.3 kg/s inflow Scenario-3

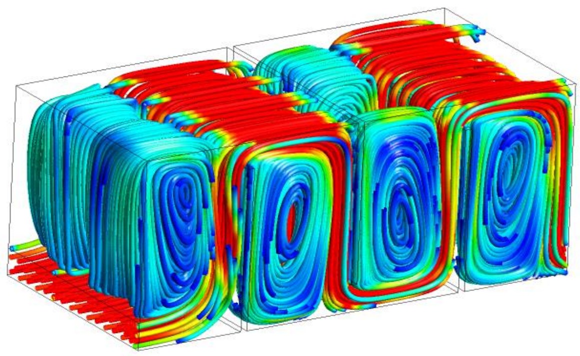

Fig 19 Streamline for 0.4 kg/s inflow Scenario-1

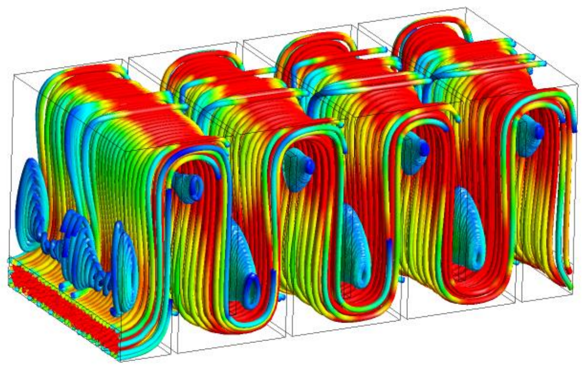

Fig.20 Streamline for 0.4 kg/s inflow Scenario-2

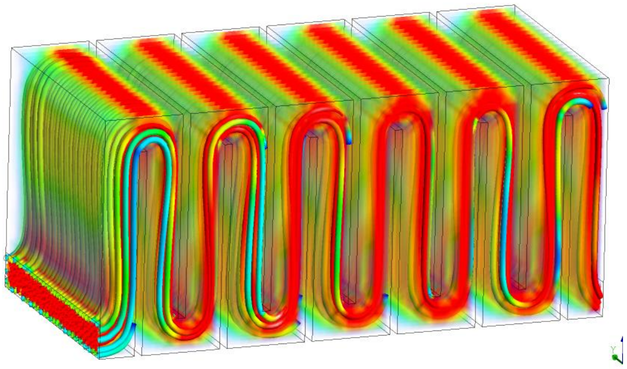

Fig.21 Streamline for 0.4 kg/s inflow Scenario-3

The residence time distribution (RTD) is one of the ways to characterize the non-ideal flow in ozone contactor tanks. The Tracer CFD Simulation reproduces the passage of a tracer through the ozone contactor tank.

To model real reactors which deviates from the ideal reactors various models are available to represent the behavior of fluid flow and mixing in the process equipments. The model assumes diffusion like process superimposed on plug flow. The dispersion coefficient represents the spreading of the tracer which is injected at the inlet in the reactor.

We evaluate D or $\frac{D}{uL}$ by recording the shape of the tracer curve as it pass the exit of the vessel.

$\bar{t}$ = mean time of passage, or when the curve passes by the exit

The mean, for continuous or discrete data, is defined as

$$\bar{t} = \frac{\int_0^\infty tCdt}{\int_0^\infty Cdt} = \frac{\sum t_i C_i \Delta t_i}{\sum C_i \Delta t_i}$$

Fig 22 to Fig 27 Show the tracer results obtained for the different inflow for scenario-1, Scenario-2 and Scenario-3. From the Fig 28 to Fig 32 it can be seen that the effect of for the different inflow for scenario-1, Scenario-2 and Scenario-3.

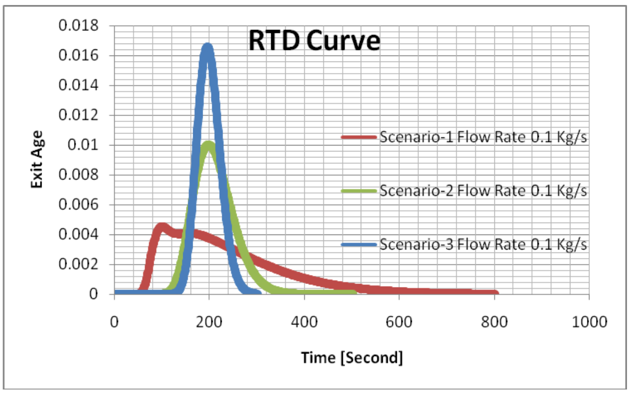

Fig.22 RTD Curve for 0.1 kg/s inflow Scenario-1, 2 & 3

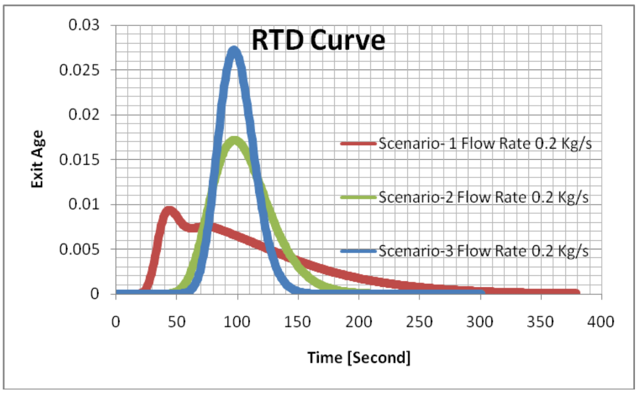

Fig.23 RTD Curve for 0.2 kg/s inflow Scenario-1, 2 & 3

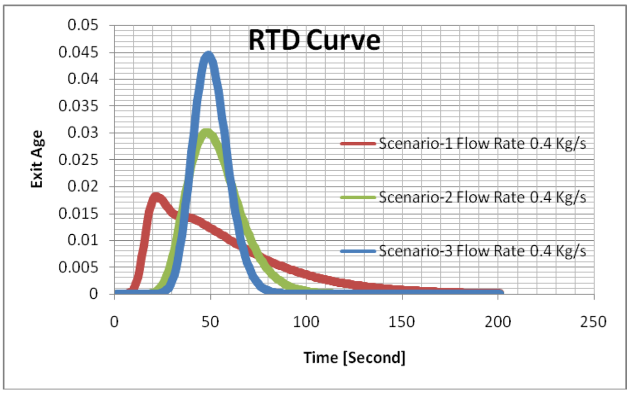

Fig.24 RTD Curve for 0.4 kg/s inflow Scenario-1, 2 & 3

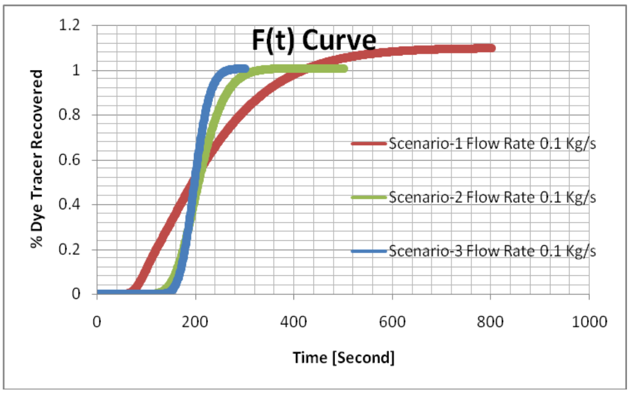

Fig. 25 Cumulative distribution curve for 0.1 kg/s inflow Scenario-1, 2 & 3

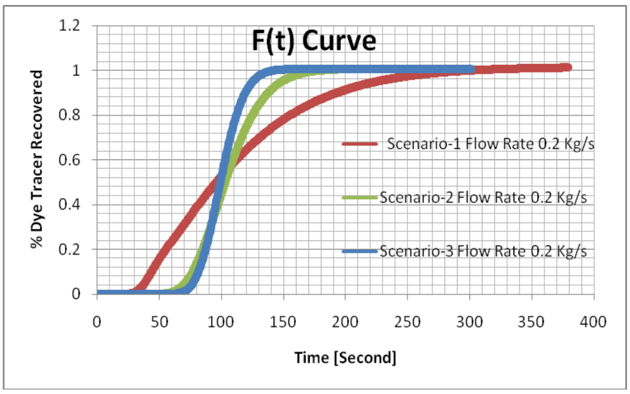

Fig. 26 Cumulative distribution curve for 0.2 kg/s inflow Scenario-1, 2 & 3

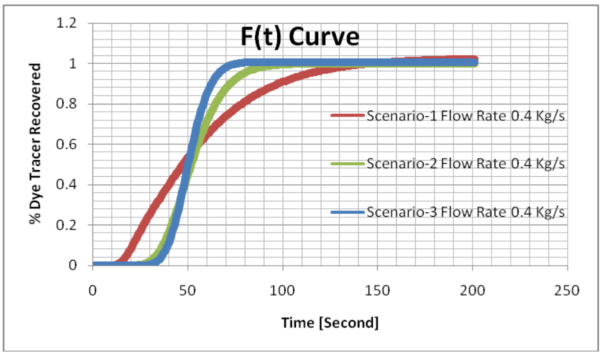

Fig.27 Cumulative distribution curve for 0.4 kg/s inflow Scenario-1, 2 & 3

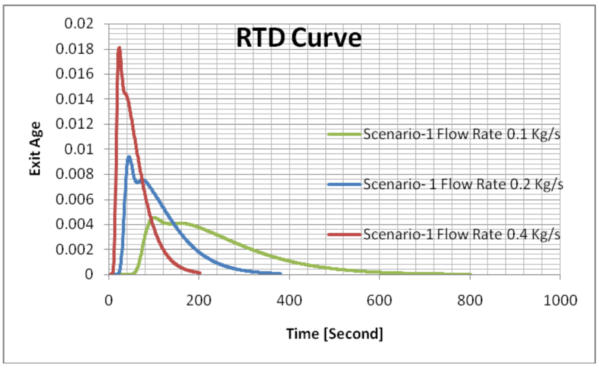

Fig.28 RTD Curve for Scenario-1 inflow 0.1, 0.2 & 0.4 kg/s

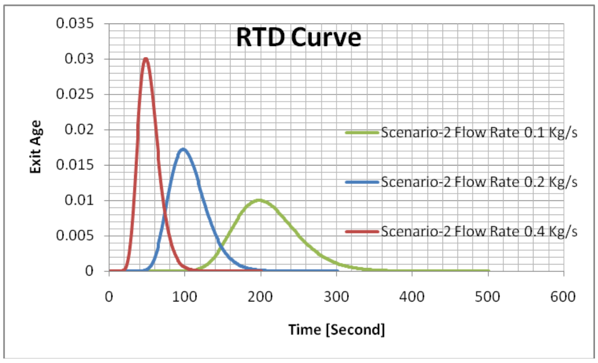

Fig.29 RTD Curve for Scenario-2 inflow 0.1, 0.2 & 0.4 kg/s

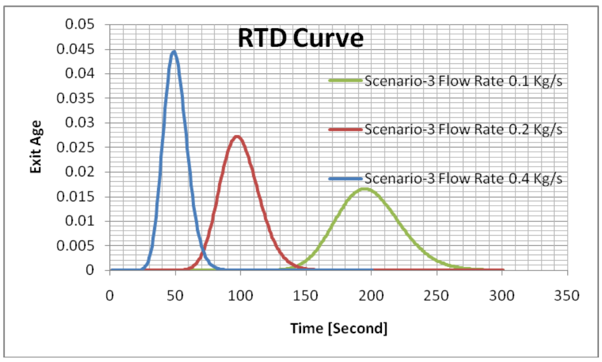

Fig.30 RTD Curve for Scenario-3 inflow 0.1, 0.2 & 0.4 kg/s

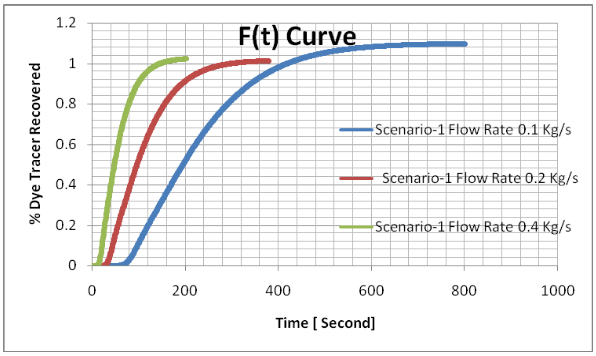

Fig.31 Cumulative distribution Curve for Scenario-1 inflow 0.1, 0.2 & 0.4 kg/s

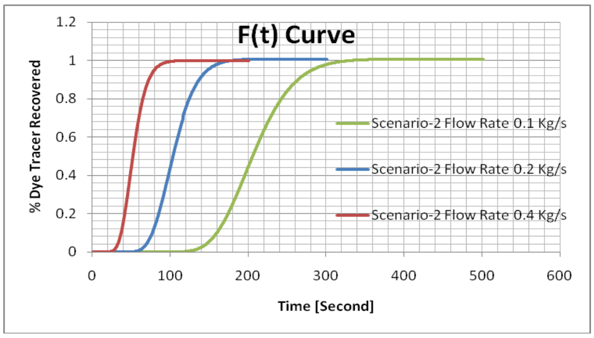

Fig.32 Cumulative distribution Curve for Scenario-2 inflow 0.1, 0.2 & 0.4 kg/s

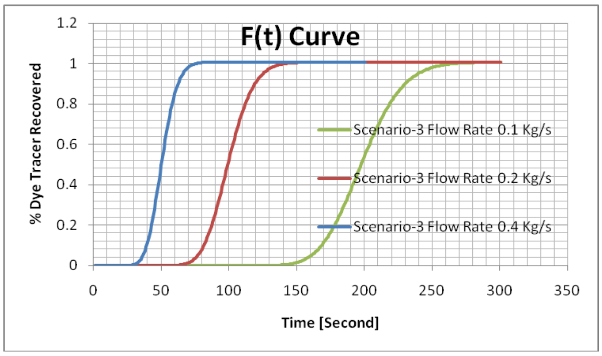

Fig. 33 Cumulative distribution Curve for Scenario-3 inflow 0.1, 0.2 & 0.4 Kg/s

Table 1 Parameters obtained from CFD analysis

S. No	Parameters	Scenario-1		
		Low Flow	Average Flow	High Flow
1	Mass flow rate (kg/s)	0.10	0.20	0.40
2	HRT (Second)	219.77	109.88	54.94
3	CFD(MRT) (Second)	255.83	111.71	56.87
4	T10 (Second)	71.00	31.00	14.00
5	T90 (Second)	340.00	193.00	98.00
6	Baffling factor T10/HRT	0.32	0.28	0.25

Table 2 Parameters obtained from CFD analysis

S. No	Parameters	Scenario-2		
		Low Flow	Average Flow	High Flow
1	Mass flow rate (kg/s)	0.10	0.20	0.40
2	HRT (Second)	208.17	104.09	52.04
3	CFD(MRT) (Second)	211.37	106.18	52.82
4	T10 (Second)	131.00	61.00	28.00
5	T90 (Second)	264.00	137.00	73.00
6	Baffling factor T10/HRT	0.63	0.59	0.54

Table 3 Parameters obtained from CFD analysis

S. No	Parameters	Scenario-3		
		Low Flow	Average Flow	High Flow
1	Mass flow rate (kg/s)	0.10	0.20	0.40
2	HRT (Second)	196.58	98.29	49.15
3	CFD(MRT) (Second)	199.62	100.22	50.64
4	T10 (Second)	168.00	69.00	31.00
5	T90 (Second)	199.62	119.00	62.00
6	Baffling factor T10/HRT	0.85	0.70	0.63

Conclusion

The results show that these hydrodynamic deficiencies could be partially prevented by decreasing the chamber width. Nevertheless, this study showed that CFD can be a useful tool for new plant design as well as retrofitting existing contactor for better process efficiency. The performance of diverse flow condition and different scenario has been checked using computational fluid dynamics and the results were analyzed to determine mixing and residence time distribution. Results of the low flow, average flow and high flow were obtained for Scenario-1, Scenario-2 and Scenario-3. Table 1, 2 and 3 summaries the output of CFD analysis. From Table 1, 2 and 3 it can be seen that low flow Scenario-3 provides an improved performance over the low, average and high flow in Scenario-1, Scenario-2 with a lower tracer concentration at the outlet and a T_{10} time of 168 second.

Nomenclature

$\bar{t}$	Mean time of passage, Second
HRT	Hydraulic Residence Time, Second
MRT	Mean Residence Time, Second
T10	10% of the flow passed, Second
T90	90% of the flow passed, Second
D	Diffusion coefficient, m^2/s
U	Velocity, m/s
L	length of the reactor, m
C	Concentration of Tracer, kg/m^3
C (t)	Concentration function of time, kg/m^3
C_i	Tracer concentration at time i, kg/m^3
k	Turbulence kinetic energy, m^2/s^2
Δt_i	Time increment, Second
ε	Dissipation rate, m^2/s^3

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