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Performance evaluation of helicoidal flow jet flocculator

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ABSTRACT

Potable and safe drinking water is an essential component of livelihood. The treatment plant performance suffers due to failure of various mechanical components; hence many researchers have proposed rapid mixing of coagulant and flocculation process assisted with jet flow as a promising unit. Dhabadgaonkar, (2008) had designed helicoidal flow jet floccu-clarifier but, the formation of helicoidal flow and actual performance in the basin is still not clear. To get better understanding of this unit, only flocculator was designed and tested by using CFD approach. The study was undertaken by designing single basin flocculator using dual tangential jet with different inlet positions. The performances were compared with non-tangential single jet flocculator. Performance indicators like Morrill index, percentage of dead space and plug/mixed flow were calculated and analyzed to understand its impact. Among the three types of inlet positions studied, the basin with non-tangential single jet flocculator performed better compared to tangential jet flocculator. This study corroborates the findings of Pani and Patil (2007).

***Keyword**: Jet flocculator, Retention time, Flocculation, Tracer study*

1. INTRODUCTION

The quest for robust, maintenance free and inexpensive flocculator, researchers led to the development of jet flocculators. Thus tangential and non-tangential jet system for flocculation has become popular research topic. In the past, many researchers have observed that the distribution of kinetic energy dissipation rate (ε) is highly uneven and getting nearly plug flow is difficult. To overcome these drawbacks, researchers have tried to create helicoidal flow in the flocculator basin. Helicoidal-flow flocculator imparts a rotational movement to the water, which may helps in reducing short circuiting of flow. In past (Schulz et al., 1984), studied the formation of helicoidal flow by allowing water tangentially into series of chambers, results were convincing but the series of basins were found to be uneconomical. Bhole (1993) studied the formation of helicoidal flow in various basins and calculated dead space, plug flow and mixed flow percentage using tracer study. Dhabadgaonkar et al., (1994) developed flocculator with helicoidal flow by directing jet tangentially at the bottom of bucket shape basin. It was found that conical shape causes decreasing upward velocity which was convincing. Many researchers like Haarhoff and van der Walt (2001); Patil and Pani (2005), have investigated the effect of helicoidal flow jet flocculator. Quite a few parameters affecting the turbidity removal was studied experimentally and numerically. Many old and new performance indices were proposed and used by the researchers for studying the performance of jet flocculator.

2. CONCEPT LITERATURE

Dhabadgaonkar (2008), designed small and large capacity floccu-clarifier units. The kinetic energy of incoming raw water is used to maintain the requisite velocity gradient. The author has suggested the few shape of floccu-clarifier unit based on his experience. In this floccu-clarifier, it is expected that helicoidal flow will get generated by directing a two jet nozzles at the bottom of the cylindrical tank facing in opposite direction (Fig 1)

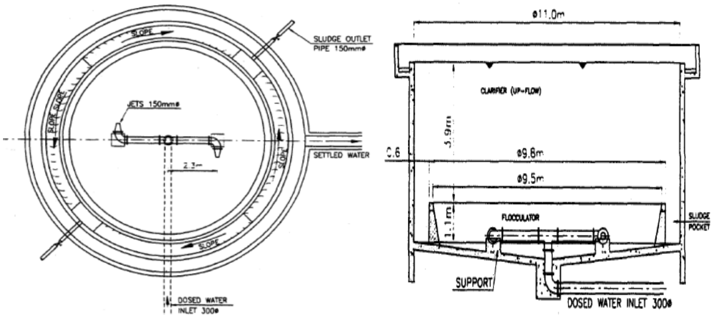

Fig. 1: 5MLD Floccu-Clarifier Unit

3. MOTIVATION

Previous researchers have conducted study on use of tangential jet flow in flocculation system. In the recent past, Dhabadgaonkar (2008) has designed multiple jet floccu-clarifier units. The idea looks to be convincing but how the entire unit actually behaves is still questionable. What will be the spread of velocity gradient and residence time distribution (RTD) in both flocculator part and clarifier part is really missing. As a prelude of the entire systemic study, it was decided to study only flow field in flocculator part and RTD. Whether actually reasonably acceptable helicoidal flow occurs or not is to be confirmed through numerical simulation. Above mentioned doubts can be clarified through present investigation.

4. METHODOLOGY

Computational Fluid Dynamics (CFD) technique was used to understand the complex fluid dynamics present in the flocculator. The performance of flocculator unit was also adjudged indirectly by conducting numerical trace study.

FLUENT CFD software (based on finite volume method) is a powerful tool for solving the governing equations of fluid flow in the flocculator basin. The same has been used by many investigators in the past. CFD is the art of replacing the differential equations governing the fluid flow, with a set of algebraic equations. The commercially available ANSYS FLUENT CFD code was used for simulation. Reynolds Averaged Navier-Stokes equations namely continuity and momentum equation are given below.

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho\, \bar{u}_i) = 0 \qquad (1)$$

$$\rho \frac{D\bar{u}_i}{Dt} = -\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial \bar{u}_i}{\partial x_i}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u'_i u'_j}\right)$$

As a closer, the k-epsilon turbulence model was used in the study. The computational domain was divided in small computational cells and the above mentioned equations were solved for each cell with appropriate boundary conditions.

5. NUMERICAL METHOD

The designing is preceded considering 0.5MLD capacity of the flocculator tank.
Detention time = 20min, thus discharge in flocculator tank Q = 0.006m^3. Accordingly, volume of the flocculator tank 7.2 m^3. Flocculator tank was of 2m diameter with a considered height of 2m. The outflow was from the top of the tank. The height for the outflow was 0.2m, to maintain the velocity at the outflow. The large outflow height was considered to avoid the breaking of the flocs generated during the process of flocculation. The inlet nozzle diameter was remained constant of 0.06m. Jet inlets were placed at height of 0.2m from bottom considering formation of proper jet development in the basin. Jet velocity found = 1m/s , Velocity gradient G = 21s^{-1} and GT = 25,678 for retention time T= 20min. The resulting flocculator basin is similar to that of the tank designed by Dhabadgaonkar (2008). The velocity, G and GT for different retention time were as follows:

Table 1: Value of G, GT and velocity

Retention Time	Velocity	G	GT
10min	2.1m/s	63s^{-1}	38,144
15min	1.4m/s	34s^{-1}	31,480
20min	1m/s	21s^{-1}	25,678

To understand the effect of position of jet nozzle, two more alternative positions of jet nozzle were considered. The position of inlet nozzle is presented in fig. 02, 03 and 04.

- Two opposite facing jet inlets are placed on either side of the vertical axis of cylindrical basin. Their distance from axis and height from the bottom are taken as 0.5m and 0.2m respectively.
- The placing of dual jets is exactly similar to case 1 but inlet is located on the side surface of the cylindrical basin. This alternative was considered to increase the availability of jet development length which indirectly may help in achieving proper distribution of velocity gradient and helicoidal flow field.
- Single inlet nozzle of diameter at the top center surface with diameter 0.084m was considered.

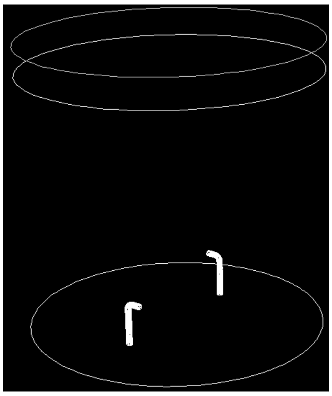

Fig. 2: Inlet 1

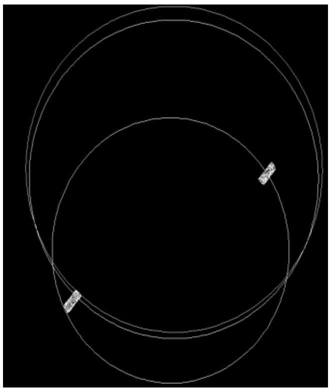

Fig. 3: Inlet 2

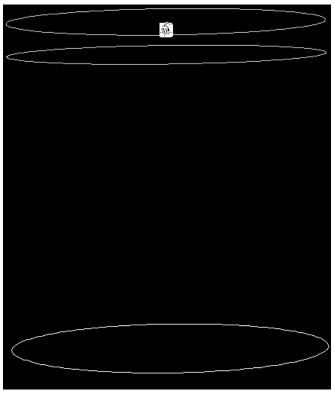

Fig. 4: Inlet 3

Meshing was undertaken using tetrahedral and hexahedral mesh shapes with the view of acquiring satisfactory results. Total number of cell in the geometry were 7,52,386 and the nodes were 1,25,328. After meshing, the geometry was transferred to ANSYS FLUENT. The model was run in steady state using Realizable k-epsilon model. The water-liquid was used as the fluid material in the tank. The appropriate inlet, outlet and outflow boundary condition were assigned at the prescribed location. For all the simulation trials the convergence criteria i.e., residuals for continuity, x-velocity, y-velocity, z-velocity components, k and ε were set as 0.0001. The set up was run in steady state for 15000 iteration to reach the convergence value of the residuals. In the present study the local velocity gradients G_L were calculated by using the following equation (Haarhoff and van der Walt, 2001; Jones et al., 2002).

Where

$$G_L = \sqrt{\frac{\varepsilon\rho}{\mu}} \qquad (2)$$

ε = turbulent kinetic energy dissipation rate at the cell centre, $m^2.\ s^{-3}$
μ = dynamic viscosity of water, kg. $m^{-1}.\ s^{-1}$
ρ = density of water, kg. m^{-3}

Typical contour plots of G_L over the plane of symmetry are presented to understand each inlet type performance. After the steady simulation a tracer of mass fraction of 0.03 was injected for a very small time period (i.e. 1 second) as per the requirement of slug dosage procedure and was run under transient state to get the idea of tracer distribution in the basin.

6. RESULT AND DISCUSSION

To get an idea about the spread of local velocity gradient, custom field functions were generated in the software. From the G_L distribution the performance of inlets were studied. The decision of better inlet position type for enhancing the performance of flocculation was investigated using two performance factor viz. Morrill Index and the percent of plug flow/mixed flow and dead space.

6.1 Numerical Analysis

G_L distributions were plotted over the chosen planes for T=15min. These plots are presented in Fig.5, 6, 7

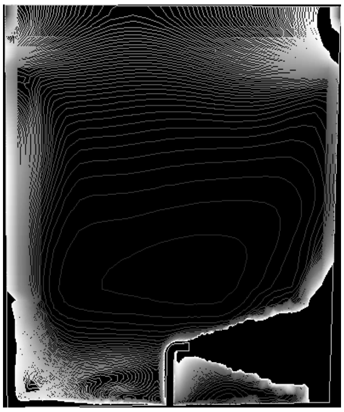

Fig. 5: Inlet Type 01

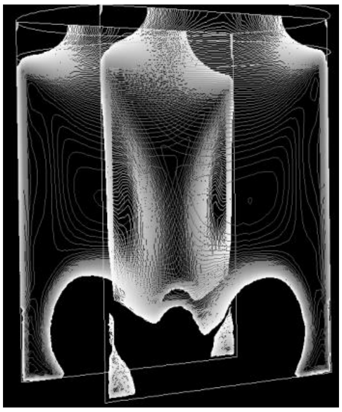

Fig. 6: Inlet type 02

Fig. 7: Inlet Type 03

6.1.1 For inlet type 01: The velocity gradient contours for inlet type 1 are not evenly distributed above the nozzle inlet showing less performance of the flocculator. Thus from the plot we can see that the formation of dead space is high in the middle region of the basin. The region in front of inlet nozzle has very high local velocity gradient, which does not assist in flocculation but may help in mixing process (coagulation).

6.1.2 For inlet type 02: The velocity gradient contours in the mid region are more evenly spread as compared with the inlet type 1. Thus inlet type 2 can be predicted to yield slightly better performance compared to that of inlet type 1

6.1.3 For inlet type 03: From the velocity gradient display plot of inlet type 3 we can see that the contours are evenly distributed in the whole basin. The small dead space region is created near the inlet nozzle, but as the jet flow develops, it tries to entrain flow from the ambient, therefore the dead zone becomes an active zone and thus the whole volume of the basin contributes in the process of flocculation. Thus inlet type 3 functioning is better as compared to the inlet position 1 and 2.

6.2 Tracer analysis for the alternative three inlet positions with MI value calculation

After tracer simulation the graph of tracer concentration at outflow for each inlet position for retention time of 20min, 15min, 10min were compared.

The tracer concentration at outlet for inlets with T=10min is very high indicating the short circuiting and hence performance of flocculator is expected to drop at T=10min.

For T=15min and T=20min the small peak formation with gradual decrease in the graph show that the tracer is uniformly distributed and received at the outlet position. This shows that better flow conditions would prevail with T=15 and 20 min compared to T=10min in all inlet conditions. Comparing inlet 1 and 2 high peak for inlet 1 shows short circuiting while there is low peak for inlet 2 depicting lesser short circuiting and marginally better performance. Inlet type 3 for T=15min has low peak compared to the above two inlet positions predicting better performance. T=20min and T=10min curve are linearly decreasing which shows good slow mixing condition in the basin. Thus a good flocculation performance is expected in this type of arrangement compared to above two inlet alternatives. To determine the flocculator performance, indicator Morrill Index has been calculated studying the procedure by previous studies.

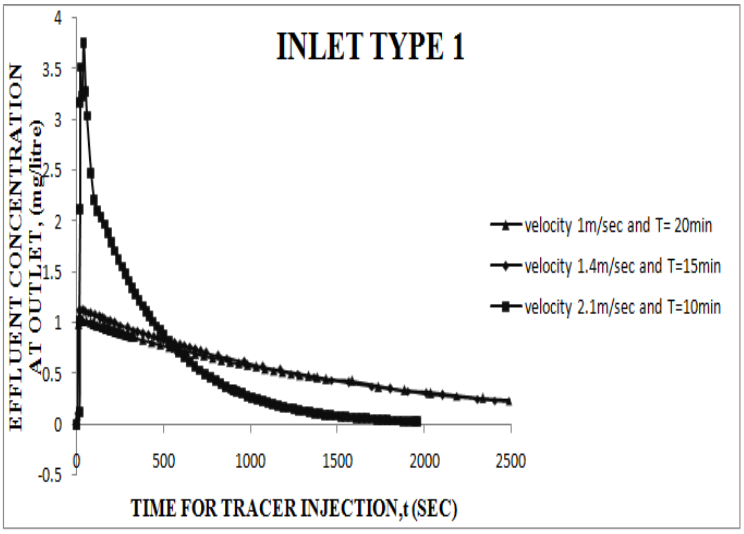

Fig. 8: Tracer concentration at outlet for Inlet1

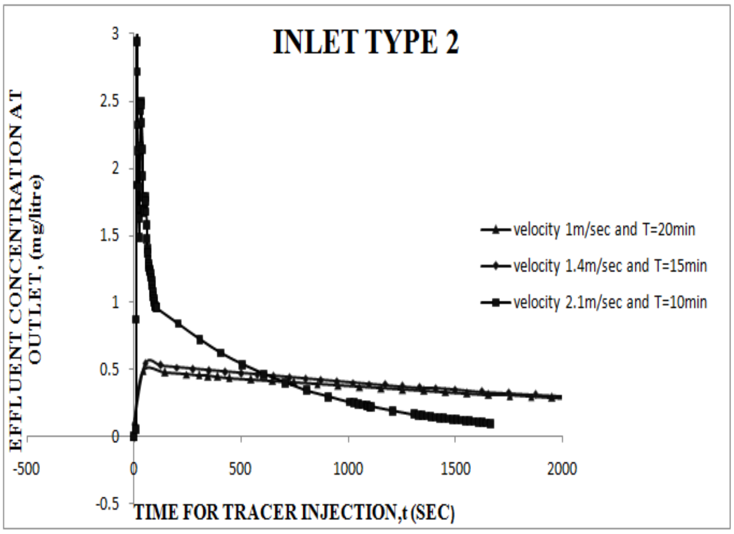

Fig. 9: Tracer concentration at outlet for Inlet 2

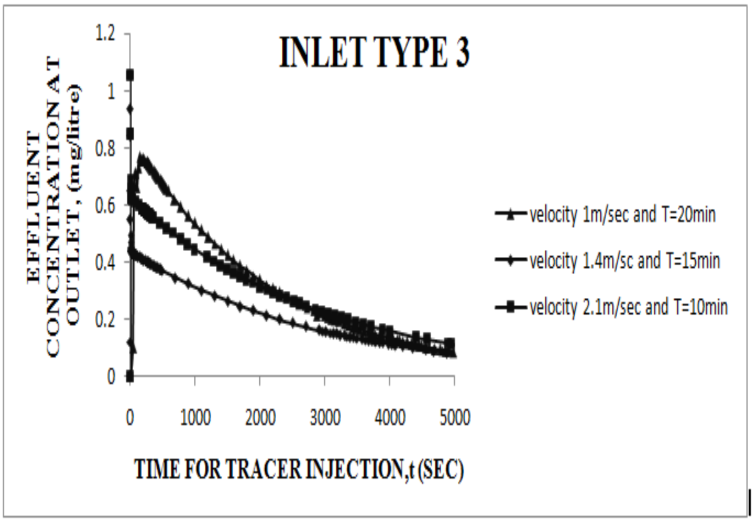

Fig. 10: Tracer concentration at outlet for Inlet 3

$$\text{Morrill Index is defined as, } MI = \frac{t_{90}}{t_{10}} \qquad (3)$$

Where, t_{10} = time required to collect 10% of total tracer quantity
t_{90} = time required to collect 90% of total tracer quantity

Table 2: Result of Tracer Study with the value of MI

Inlet	Detention Time (T)	Velocity (v)	Velocity Gradient (G)	GT	MI
Inlet 1	20min	1 m/s	21 s^{-1}	25,678	19.4
	15min	1.4m/s	34 s^{-1}	31,480	16.2
	10min	2.1m/s	63s^{-1}	38,144	24
Inlet 2	20min	1 m/s	21 s^{-1}	25,678	16.0
	15min	1.4m/s	34 s^{-1}	31,480	17.3
	10min	2.1m/s	63s^{-1}	38,144	18.4
Inlet 3	20min	1 m/s	21 s^{-1}	25,678	17.1
	15min	1.4m/s	34 s^{-1}	31,480	16.2
	10min	2.1m/s	63s^{-1}	38,144	20.1

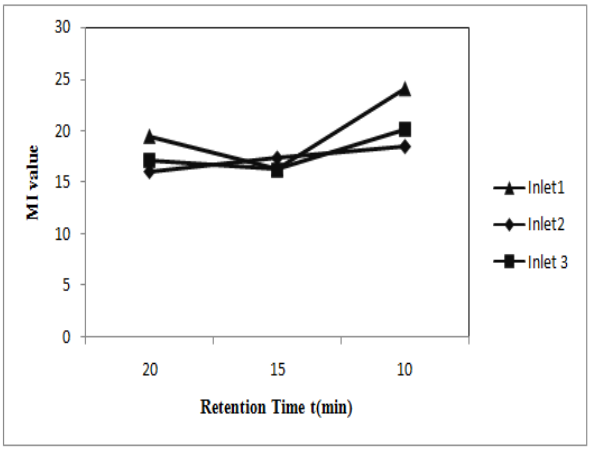

Fig. 11: Curve of MI v/s T

From the computed MI values it was found that, for inlet1 and inlet 2 the basin behaves more like a continuously stirred tank reactor. Whereas inlet type 3 gives marginally good MI value. Hence it is expected that the inlet type 3 is a better alternative compared to other tested alternatives

6.3 Determination of mixed/plug flow and dead space in the basin

The hydraulic behavior of a basin can be judged based upon the values of dead space fraction of the tank basin volume, plug flow fraction of effective basin volume and perfect mixing fraction of the effective basin volume. These parameters were calculated using Rebhun and Argaman (1965) method.

The residence time distribution curve for the three basin were plotted. With the use of the graph the percent of plug flow, mix flow, and dead space is determined which helps to understand the mixing capacity of each flocculator basin at different detention time.

Table 3: Result of numerical tracer study

Inlet Position	Detention Time (T)	Velocity (v)	Velocity Gradient (G)	GT	MI	Plug Flow (%)	Mixed Flow (%)	Dead Space (%)
Inlet 1	20min	1 m/s	21 s^{-1}	25,678	19.4	10	89	17
	15min	1.4m/s	34 s^{-1}	31,480	16.25	16	83.8	6.4
	10min	2.1m/s	63s^{-1}	38,144	24	22.2	77.7	15.5
Inlet 2	20min	1 m/s	21 s^{-1}	25,678	16	10.5	89.4	17.6
	15min	1.4m/s	34 s^{-1}	31,480	20.3	16.1	83.8	9.9
	10min	2.1m/s	63s^{-1}	38,144	20.4	22.2	77.7	5.9
Inlet 3	20min	1 m/s	21s^{-1}	25,678	15.62	5	94.9	11.9
	15min	1.4m/s	34s^{-1}	31,480	18.3	10.5	89.4	8.29
	10min	2.1m/s	63s^{-1}	38,144	18.5	22.2	77.7	7.4

For Inlet 1 from the above table we can say that the high dead space value compared to other inlet positions, depict less volume of water contributing in the process of flocculation.

Inlet 2 has low dead space for T 15min and T 10min and has large plug flow for the same indicates good contribution in the flocculation performance. Thus Inlet 2 type was found to be good for flocculation of small water treatment plant in comparison with inlet 1.

For Inlet 3 the dead space was low. The retention time T=15min has a reasonable plug flow and the percent of dead space is also slight. The greater plug flow at the retention time T=10min gives good performance. The dead space fraction is very small for the cases of T=15min. This indicates that the entire volume of the basin will contribute to the flocculation process.

From the result of all the three basin it was found that inlet type 3 has least dead space and greater mixed flow and plug flow. Using this inlet position the performance of the flocculator can be increased. Inlet type 2 has a greater jet development length compared to the inlet type 1 and the results were found to better compared to the inlet type 1.

7. CONCLUSION

- Tracer study result shows that the modal time increases with increase in retention time.
- For inlet nozzles where the dual jets are located on the side surface of the cylindrical basin and the height from bottom is 0.2m found to give better performance compared with the inlets placed at the either side of the cylindrical axis at a distance of 0.5m at height of 0.2m from bottom.
- The availability of jet development length which indirectly may help in achieving proper distribution of velocity gradient and helicoidal flow field.
- The single inlet jet nozzle at the top centre surface of the basin have the high plug flow with less dead space and uniform velocity gradient contours. Hence single jet (with no helicoidal flow) is expected to give better flocculator performance.
- Construction of flocculator basin with single jet inlet at top centre surface has advantages like easy of construction and desludging.
- Helicoidal flow jet flocculator performance is expected to be inferior in comparison to non-helicoidal flow jet flocculator.

8. ACKNOWLEDGEMENT

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