Study of Jet Mixing in Flocculation Process

P.S. Randive, Dr. D.P. Singh, Dr. V. Varghese, Dr. A.M. Badar

[1]Assistant Professor, [2,3,4]Professor
KDK College of Engineering, Nagpur

***Abstract* - Jet- mixing is widely used in various processing units for purposes as homogenization of physical properties of liquids in tanks, to ensure proper heat and mass transfer in various operations, prevention of stratification, and prevention of deposition of suspended particles. As Flocculation process is an important part of surface water treatment, use of jet in flocculation is an effective solution so as to remove turbidity in an efficient way. Most of the researchers have focused on experimental estimation and developed various mixing correlations, considering the effect of parameters like jet velocity, jet configuration, tank geometry. Recently, use of CFD simulation to predict parameters as well as flow patterns precisely that validates the experiments is on the rise. This review focuses on the study of various parameters used in experimental and CFD work on jet mixing and general conclusions have been drawn concerning the various parameters.**

***Keywords* - Flocculation, jet mixing, parameters, correlations.**

I. INTRODUCTION

The flocculation process plays is an important role in water treatment process. It has a direct impact on the reliability of plant operations and final water quality together with cost control. Mixing plays vital role in Flocculation process which can be achieved by various conventional techniques like mechanical stirrers, impellers or vanes. Due to various disadvantages of conventional mixers It is therefore necessary to explore and find other simpler devices free from various constraints. The jet flocculator seems to be a viable alternative.

Mixing systems approaches to jet mixing takes advantage of all the factors which includes easy installation, low maintainance cost as it dosent have any moving part inside, no requirement of any structural reinforcement of the tank, cheaper in cost as compared to conventional mixing devices. Dhabadgaonkar(2008) suggest the concept of jet flocculation for sustained satisfactory performance. Jet mixing is widely used for various purposes as for homogenation of physical properties of liquids in tanks, to prevent deposition of suspended particals, prevention of stratification. Jet mixers have become alternate to impellers for over 50 years in the process industry. The jet techniques have therefore been an active research area and found a wide range of industrial applications as absorption and desorption, extraction, chemical reaction, reaction injection molding, mixing etc. Bathija(1982) explains how an engineer can develop jet mixing preliminary design estimate for typical applications. In jet mixing, some part of liquid from the tank is circulated at high velocities into the tank with the help of pump through nozzles. The induced jet entrains some of the fluid in the chamber and creat a circulatory pattern, which leads to mixing in a tank. Jet mixing leaves fewer dead spots in a shallow or rectangular tank than does agitators. Terry L Engelhardt , (2010), Explained cursory information about the important units of water treatment plants as coagulation, flocculation and clarification. Dhabadgaonkar(2008) emphasizes the need to develop water treatment plant designs, which minimize the mechanical equipment as much as possible.

There have been many extensive studies on jet mixing for over 50 years. Researchers studied the effect of various parameters such as nozzle diameter, angle of inclination, position of jet, treatment device structures, as well as coagulant types and dosages. shape and size of jet, effect of power consumption on mixing time, effect of fluid property on mixing time to discuss the effective distribution of mixing energy and found that jet mixing method is very promising. studied the effect of the jet angle and the numbers of jets on the mixing time were studied by Zughbi et.al. (2004). Bhole(1994) and Armal (1997) reported the performance of the free jet flocculator is comparable to the actual performance, 69 to 74% turbidity removal efficiency.Number of experimental correlations were developed. So there is a dilemma in using correct experimental correlation from all those available correlations. So in this paper comprehensive review has done which can be explained different authors workdone on some parameters. An attempt is made to do critical analysis of the available literature.

Numerous investigation have carried out experimental studies on jet mixer tanks using different tank geometries, nozzle positions and diameter. The development from these arrangements has led many scientists to devise correlations which can determine the mixing time. Systematic studies of jet mixing are of fairly recent origin. In this paper, A review of the literature on jet- mixing is carried out.

II. VELOCITY GRADIENT ‘G’

Traditionally, flocculators have been characterized on the basis of the velocity gradient. Velocity gradient, G, is the relative velocity of the two fluid particles at a given distance. Velocity Gradient is very important parameter and used worldwide to characterize mixing. Camp and Stein in 1943 formalize an extension of Smoluchowski equation for a plane laminar flow to a general laminar or turbulent fluid motion. They defined the root-mean-square velocity gradient by “(2.1)”,

$$G = \sqrt{\frac{P}{\mu V}} \qquad (2.1)$$

For mechanical mixing, the equation for value of G was developed as “(2.2)”

(2.2) $(\ P = K_L n^2 D_i^3 \mu$

The work of Camp and Stein has been criticized by other authors. Cleasby (1984) discussed the validity of Camp and Stein approach for turbulent flows, especially for the particle size greater than kolmogoroff microscale. He also conclude that G may be an appropriate parameter for rapid mixing of small duration less than 30 sec. Clark (1985); Saatçi and Halilsoy (1985); Karmer and Clark (1997); Graber (1998) and Pedocchi and Piedra-Cueva(2005) criticize the Camp and Stein formalization and based their arguments on the lack of existance of the paticular frame where there particular frame of reference does not exist for a general three dimensional movement. If G is insufficient, adequate collisions will not occur and a proper floc will not be produced. If G is too great, excessive shear force will prevent the desired floc formation, for high shear rates breahup previously formed flocs, Reynolds & Richards (1996).

Clark (1985) and Karmer and Clark (1997) also discussed the root mean square velocity gradient utilization. Karmer and Clark (1997) presented an example to show that absolute velocity gradient (GA) varies considerably in the mixing tank and the root mean square velocity gradient (GRMS) creates a deficient estimation of coagulation rate so conclude that it is an inaccurate parameter to characterize complex nonuniform flows. Pedocchi and Piedra-Cueva (2005) reviewed Camp and Stein formalization and an alternative definition of the parameter GA was presented, and obtained a general expression for the collision rate as “(2.3)”

(2.3) $\beta ij = K\alpha Rij3GA$

With $K\alpha = k\alpha f\alpha$ and $GA = \sqrt{}\Phi/\mu$

Pani et al. (2007) introduced three new indices to explain the dependence of the performance of different flocculators on the kinetic and geometric properties. The velocity gradient is evaluated from “(2.4)”

$$G_u = \sqrt{\frac{\varepsilon_u \rho}{\mu}} \tag{2.4}$$

and the modified camp number is given as “(2.5)”

$$G_u T \tag{2.5}$$

The percent of the input energy to the flocculation is computed as “(2.6)”

$$E = \frac{\varepsilon_u \sum_{i=1}^{i=n} \Delta Vi}{\varepsilon_{av} V} \times 100 \tag{2.6}$$

Higher value of E is reflection that a more conductive environment for the formation of flocs exists in the chamber. Though this indices are useful for design purposes, but not able to explain the variations in the performance of the jet flocculator in terms of shape, nozzle diameter, L/d ratio etc.

III. Mixing Time & Correlations

Mixing time is an important design parameter in jet mixing. Many investigators in their studies conducted experiments to determine mixing time. Broadly measurement techniques can be classified in two types, such as visual observation techniques and tracer techniques. In the visual observation technique, the liquid in the tank is first made weakly acidic and an indicator is added. Strong base in a quantity just sufficient to neutralize the acid is then added. The mixing time is taken as the time from the moment of base addition to the time at which color of the indicator disappears. In tracer techniques, the tracer is usually injected into the tank. The tracer concentration is then measured with respect to time at a point or various positions in the tank using conductivity probe. Here various experimental correlations proposed by the researchers have been explained.

Some of the early work on mixing time was conducted by various investigators. The correlating equations for the mixing time have been proposed by Fox and Gex (1956), Fossett and Prosser (1951), Okita and Oyama (1963), Lane and Rice (1982). Fossett and Prosser assumed that the momentum of the jet was preserved in the tank and that the jet diameter and jet axis length at the termination (as cited in Wasewar 2006, Maruyama1982). Okita and Oyama (1963) based on their results concluded that mixing time does not depend on (Re>5000) in turbulent regime. Maruyama(1982) carried out experiment in the circulation flow regime (Re≥3x104) of mixing the dimensionless mixing time depends on liquid depth, nozzle height and nozzle elevation angle. Grenville and Tilton (1996) proposed that mixing time was controlled by the turbulent kinetic energy dissipation rate in the region away from the jet entrance. Grenville and Tilton(1997) reported that mixing time was proportional to the circulation time (estimated from the volume of liquid in the tank and flow rate entrained by the jet. Patwardhan A.W. (2002), predicted mixing behavior in jet mixed tanks, concentration profiles and mixing time have been compared over a large range of jet velocities, nozzle diameters and angles with the experimental measurements.

J.A. Denev et.al.(2005) investigate mixing process in a jet in a crossflow by means of LES. The TMD mixing index was evaluated for planes with increasing x/D coordinates. Hui Liu et. al.(2011) used numerical method adopting AUSM+ scheme and k-ω SST turbulence model with Wilcox compressibility correction is developed for the research on mixing of air and fuel gas in combustion chamber. They used mixing rate to measure the mixing degree between air and fluid. Perumal R. et. al.(2012) carried out experiment on Newtonian (water) and Non-Newtonian (Gaur Gum). Ultimately it indicates that when viscosity of the fluid increases the mixing time also increases, this was due to the diversion of flow path and circulation path. Mixing time correlation was developed for mixing time as a function of flow rate and nozzle diameter and found that mixing time for Newtonian fluid was found to be low as compared to Non Newtonian fluid. Sundararaj et.al.(2012) consider the effects of arbitrary injection angle and increasing inertia of flow and mixing of venture-jet mixer, using equation proposed by Jeon et al. for mixing efficiency. Liang Hong et. Al. (2017) used piston type synthetic jet which enhances the subsonic, heat temperature jet mixing.

Table I

Experimental correlations of jet mixing in tanks

Author	**Geometry**	**Dimensions**	**Correlation**	**Parameters**
Fosset (1951)	Inclined side entry jet and cylindrical tank	D = 1.524m H = 0.9144 m dj = 1.9 mm d0 = 2.54cm, θ = 40°	$t_{mix} = \frac{Cp\ D^2}{V_j\ d_j}$ Cp = 9, when t inj > tmin/ 2 Cp = 4.5, when t inj< tmin/ 2	t_{mix}= Mixing time D = Tank diameter v_j = Jet Velocity d_j = Jet Diameter Cp = Correlation constant
Fox & Gex (1956)	Side entry jet, Cylindrical jet	D=0.29 & 1.52m	$t_{mix} = f\ \frac{(H^{0.5} D)}{(V_j d_j)^6\ g^{1/6}}$	t_{mix}= Mixing time D = Tank diameter v_j = Jet Velocity d_j = Jet Diameter H = Tank Heignt g = gravity f = mixing time factor
Lane & Rice(1982)	Side entry jet, Axial jets & Cylindrical jet	For side entry jets D = 0.31–0.57m H/D = 0.9–1.1 m For axial jets D = 0.31–0.57 m H/D = 0.5–3.0 m Rej = 250–60,000	$t_{mix} = f\ \frac{(H^{0.5} D)}{(V_j d_j)^{0.667}\ g^{1/6}}$	t_{mix}= Mixing time D = Tank width v_j = Jet Velocity d_j = Jet Diameter H = Tank Heignt g = gravity f = mixing time factor
Maruyama et al. (1982)	Side entry jet, Cylindrical jet	D = 56,104cm H = 84, 125 cm hi,ho = 4,14,24,44,74,94 (D=104cm) hi,ho = 4.38, 20.5, 48.5 cm, (D = 56 cm) dj = 0.5,1,1.8	$\frac{t_{mix}}{t_r} \times \frac{L}{d_j} = 2.5 - 8.0$ Rej > 30000	t_{mix} = Mixing time t_r = Residence time d_j = Jet Diameter L = Jet path length g = gravity
Simon and Fonade(1993)	Two jets at H/2 and H/3 horizontally located	D,H = 490mm d_j = 10mm	$M = t_{mix}\,(gH)^{0.5}\,D\ \ J_s^{2/3} \sim 1$ $J_s = \frac{J}{\rho v_j g}, J = \rho A v_j^2$	t_{mix} = Mixing time vj = jet velocity, m s^{-1} *J* = momentum of jet, kg.m s^{-2} *Js* = specific jet momentum, dimensionless g = gravity
Orfaniotis et.al(1996)	Two jets at H/2 and H/3 horizontally located	D,H = 500mm d_j = 9, 15 mm	$M = \left[\frac{v_{mix}}{t_r}\right](J_s)^{0.41} = 11.3$ $t = \frac{D}{(gH)^{0.5}}$	*Js* = specific jet momentum, dimensionless g = gravity t_r = residence time, s M = Mixing factor
Grenville and Tilton (1996)	Cylindrical tank	D = 0.61–36 m H/D = 0.2–1.0 dj = 5.8–50 mm vj = 2.2–24.8 m	$t_{mix} = 3\ \frac{(L^2)}{(V_j d_j)}$	t_{mix} = Mixing time d_j = Jet Diameter L = Jet path length v_j = Jet Velocity
Grenville and Tilton (1997)	Cylindrical tank	D = 0.61–36 m H/D = 0.2–1.0 dj = 5.8–50 mm vj = 2.2–24.8 m	$t_{mix} = k\frac{D^2 H}{v_j d_j L}$ $k = 9.34, \theta > 15^0$ $k = 13.8, \theta < 15^0$	K = Correlation constant. d_j = Jet Diameter L = Jet path length v_j = Jet Velocity

J.A. Denev et.al.(2005)	---	θ = 90° Re No.=6930 Velocity ratio, $\frac{U_{jet}}{U_{cross}} = 3.3$	$TMD = Avg\left(\frac{\sqrt{<Y_1{}'Y_1{}'>}}{<Y_1>}\right)\times 100(\%)$ $SMD = \frac{RMS(<Y_1> - Avg(<Y_1>))}{Avg(<Y_1>)}\times 100(\%)$	$<Y_1{}^1Y_1{}^1>$ & $<Y_1>$= Variables represents the time averaged scalar fluctuations TMD=Temporal mixing deficiency. SMD= Spatial mixing deficiency RMS= Root mean square
Perumal R. et. al.(2012)	Cylindrical borosilicate glass tank	D = 500mm H = 600mm	$Mt=aQ^bD^c$, $M_t = 0.001806254346\ Q^{-1.77831}D^{0.802683}$	Mt = Mixing time in sec. D and H are Diameter and Height of the tank in meters respectively. a,b,c = empirical constants. Q = Liquid flow rate
Sundararaj et.al. (2012)	Transparent Plexiglas rod, in a shape on venturi, jet placed in a throat.	Diameter of jet = 1mm Throat dia = 10mm	$m_{eff} = \left[1 - \frac{\int_0^W \lvert c - c_{avg}\rvert dx}{\int_0^W \lvert c_0 - c_{avg}\rvert dx}\right]100\%$ $m_{idx} = m_{eff}\frac{\Delta p_{\max}}{\Delta p}$	m_{eff} – mixing efficiency, [–] m_{idx} – mixing index, [–] Δp – overall pressure drop in the mixer, [kPa] $\Delta p_{\max}$ – maximum pressure drop across the – mixer, [kPa] c = tracer concentration c_{avg} = concentration of a complete mixing.

IV. Parameters in Jet mixing

A. Effect of tank height

From various experimental correlations for mixing time proposed by number of investigators. Parvareh (2009), reported that optimal angle of injection is 30^0 at a height of 150mm which gives the shortest mixing time. Coldrey(1978), Grenville and Tilton (1997), Fox and Gex (1956), Lane and Rice (1982), Okita and Oyama (1963), Perumal R. et. al.(2012), from their relations it can be observed that mixing time is directly proportional to the tank height. While keeping other parameters constant mixing time increases with increase in tank height.

B. Effect of tank diameter

From most of the experimental correlations given by authors , it is observed that for constant set of other parameters mixing time increases with increase in diameter of the tank and vice versa. Subramani et.al.(2012) reported that by adopting larger diameter nozzles the efficiency of turbidity removal can be enhanced.

C. Effect of tank geometry

Researchers have used various types of geometries to get the better mixing time, such as cylindrical tanks, rectangular tanks. Lane and Rice in 1981, 1982 used cylindrical tank with hemispherical base, and proposed a correlation showing strong dependence on jet Reynolds number in the laminar regime, but weak function in turbulent regime, and achieve short mixing time. Jayanthi(2001), considered conical, spherical, ellipsoidal, flat bottom for mixing and concluded that circular pattern created by a jet is specific to the geometry of the vessel and circular pattern strongly affects the mixing time .Also used CFD code to find the optimum shape needed for reduction in mixing time. Zughbi et.al (2004), considered a jet mixed tank with a flat bottom equipped with four curved baffled .

Althaus et al.(2011) carried out physical experiments in a rectangular tank to investigate the influence of a circular jet arrangement on the circulation, sediment release and sediment behavior Subramani et.al.(2012) conducted experiments on rectangular and circular flocculation chamber for different jet sizes and noted that rectangular basin is marginally superior compared to circular basin and efficiency of turbidity removal in case of the rectangular basin is higher by 0.5%.

D. Effect of angle of jet

Investigations have been carried out considering various angles of jet and from comparision it has been found that for different assembly optimum jet angle is different. Okita and Oyama(1963) suggested in their work that the angle of the jet, relative to the base of the tank, does not affect mixing time. Coldrey(1978) propounded a theory that the configuration with the longest jet length, inclined at 450, gives shortest mixing time. Greenville and Tilton(1997) propounded two correlations based on the angle of inclination of jet. This coincides with Coldrey (1978) but contradicts Maruyama et al.(1982,1984). Maruyama(1982) investigated the mixing time cannot be made less than the minimum value for horizontal nozzle by tilting the nozzle upwards and consequently decreasing the mean circulation time. Joseph et al.(1986) studied the mixing behavior of a 450 two dimensional buoyant jet in a linearly stratified fluid and their results can be used for outfall design of for the verification of detailed numerical models of turbulent buoyant jet in stratified fluid. Patwardhan and Gaikwad (2003) also observed the effect of nozzle orientation, i.e., 0^0, 30^0, 45^0, & 90^0, producing results showing that 45^0mixes slightly better. K. Sendilkumar(2007), said angles of inclination of 30^0 and 45^0 gives better flow pattern but the shortest mixing time is observed for the angle of 30^0 which coincides with the results of Zughbi et.al.(2002). Zughbi et.al(2005) used Computational Fluid dynamics to study the effect of angle and elevation of mixing in a fluid jet agitated tank. They showed that the angle of injection is significant in determining the time required for mixing. Kalaichelvi et al.(2007) in their study made conclusion that, optimum angle is not universal. In their study injection angle of 300 for jet located either at two-third of the volume of the tank or top and bottom of the tank, gives the shortest mixing time. Parvareh (2009) outcome also coincides with Kalaichelvi et.al .(2007) result which states that jet induced from a 10mm nozzle at bottom with angle of inclination 300 gave an optimum mixing time for the preferred geometry. Hamid Rafiei et.al(2012) conduct experiments on angles 0^0,35^0,45^0, for 35^0 two circulation streams are created that cause circulation of fluid all over the tank that lead to improve mixing and decrease in mixing time. They compared results with simulation models. Sundararaj et.al.(2012) investigate the trajectory of jet and mixing performance by numerical method and also experimentally using concentration dilution and pressure drop measurements and concluded that improved mixer performance can be achieved with lower pressure drop for initial injection angle $\theta0\geq900$. Manjula P. et al. (2012) considered double jet mixer and found that a jet2 inclination between 400 and 450 give the minimum mixing time which shows that mixing time decreases as the length of the jet2 increases.

E. Effect of jet velocity

From the maximum of experimental correlations it is observed that mixing time decreases with increase in velocity and vice versa. With other parameters to kept constant. Corelations given in table I shows relation between jet velocity and mixing time with consideration of other parameters.

F. Effect of jet diameter

In all experimental correlations of mixing time jet diameter appears and it is observed in most of the correlations that as the nozzle diameter increases it leads to reduction in the mixing time, hence good flow patterns inside the tank. Contradictory to it from Coldrey(1978) correlation it is observed that mixing time is directly proportional to jet diameter under constant tank dimensions and at constant flow rate. Kalaichelvi et al.(2007) state that the optimum diameter could be between 5 to 10 for their geometry relating to the mixing time and power consumption. K. Sendilkumar et.al(2007) and Perumal R. et. al.(2012) with their experiments on three different sized nozzle diameter conclude that, 10mm nozzle placed at 30cm above base of the chamber was fixed as an optimum nozzle size and nozzle clearance for the geometry of the system. H. Syazwani et.al. (2015) studied the effect of nozzle length, inlet angle, diameter, flow rate and wate pressure so as to minimize the nozzle wear and suggest the porous lubricated nozzle to reduce wear rate and improve nozzle life.

G. Effect of location of jet

The past studies explained that, the nozzle size and nozzle location are extensively important in estimating the mixing time. However the optimum position is not universal and varies with the geometry of the tank. Maruyama et.al. ((1982, 1986), extensively did experiments to find the optimum location of the nozzle in the circulation regime(Re> 30000). Kalaichelvi et al.(2007) found that when the jet was placed at the bottom position it gives optimum mixing time for their geometry of the tank. Parvareh et.al.(2009) examined the nozzle location at various positions around the bottom of rectangular tank, additional CFD work has advanced the work on the basis of nozzle position. Saravanan et al.(2010) in their study said that among the nozzle design studied nozzle with active area of 20% shows more holdups with less power consumption also jet position (from bottom of the vessel) of T/1.8 shows more hold up. Stephen Kennedy (2018) consider Submerged recirculating jet mixing systems which enhances the capability of designing mixing tanks, also found that it is an efficient and economical method of agitating large tanks with a high hydraulic residence time.

H. Effect of multiple jets

It was observed that not much experimental studies has taken place in past considering multiple jets and no particular experimental correlation is developed. Fossett (1951) has mentioned that multiple jets may give better mixing times but did not support by experimental results. Imam et.al. (1988) and Perona et.al.(1998) used multiple jets in finding mixing time and conclude double jets gave less mixing time and consistently more efficient than single jet. Manjula P. et al. (2012) considered double jet mixer and describes the effect of jet2 angle, jet2 location and radial angle on mixing time using DOE based on experimental mixing time which results into increasing the radial angle of jet2 with respect to jet1 increases the mixing time. Subramani et.al.(2012) report that the flow distribution in a double jet nozzle flocculator is superior to single jet flocculator but the turbidity removal rate remained same as that of single jet. Chen et.al. (2014) presents an experimental study of flow visualization on free jets and jets in hypersonic crossflow. Results show that the multiple jet spatial interaction region and surface interaction region expand with the increment of pressure ratio. It was observed that under the same mass flow rate ratio, single jet configuration has larger interaction region and smaller wake region than multiple jet configurations. In the couple of years before some investigators consider multiple jets for their studied but no correlations were reported.

I. Effect of jet configuration

Position of the poor mixed regions in the tank definitely depends on the jet configuration. If the best jet configuration is provided, which can eliminate poorly mixed regions ultimately mixing time can be reduced to a greater extent. Many experiments have been conducted with different jet configurations such as side entry jet, jets provided at bottom, side of the tank, downward and upward pointing jet. Coldrey in 1978 reported that for the used geometry longer jet length gives shorter mixing time. Assume that the mixing time is inversely proportional to the liquid entrained through jet, an equation was proposed on mixing time. Broadwell et.al.(1984), studied a tranverse jet and observe that, minimun in flame chord length at a velocity ratio of about "(4.1)"

$$\frac{V_\infty}{V_j} = 0.06 \qquad (4.1)$$

While the existence of such a minimum is anticipated from the analysis, the corresponding transformation in the flow structure remains unclear. Imam et.al. (1988) said optimum configuration should yield to the minimum mixing time. They consider several feasible jet mixing configuration in order to identify an optimum configuration. From their experimental studies they consider a double jet consists of one tangential jet and another one 450 inward jet at 0.4 of the tank radius and found that with this arrangement 95% uniformity of an injected substance could be achieved by recirculating only 5% of the basin volume. Ranade(1996) predicted results of the mixing time agree with published experimental data for various jet configuration. Gholamreza - Kashi(2008) compared the turbulent structure of a rectangular surface jet to that of the three dimentional free and wall jets. The velocity ratio for the far field behavior of the surface jet is given as "(4.2)"

$$(4.2) \qquad \frac{U_{\max}}{U_o} = \frac{K}{x / A^{1/2}}$$

Ashery et.al.(2012) studied the efficiency of water treatment by using a spiral clari-flocculator. Sundararaj et.al.(2012) consider Venturi jet mixer for five different angles, for all experimental cases indicates that lower the cross flow velocity v and Reynolds number Recf, more the jet entrains into the mixer and higher the velocity ratio R for 450≤ θ0 ≤ 1350. The correlatrion is obtained for jet trajectory by multivariate-linear regression analysis using power law as z/ Rd = (0.614- 0.0047 (900 - θ0)) (x/ Rd)0.502 R0.333 Recf0.0187 Rej0.0176. Althaus et.al (2011) determined the sediment release ratio in order to compare and evaluate the different experiments and to identify the most efficient jet configuration composed by the optimal parameter combination as "(4.3)"

$$(4.3) \qquad \frac{P_{out}}{P_{in}} = \frac{\sum c_{s,i}[g/l].Q_{out}[l/s].\Delta t[s]}{P_{s,in}[g]}$$

J. Effect of Reynolds number

Some of the researchers consider dependence of Reynolds number in their correlation and some do not consider it. In the previous studies Reynolds number was predefined below which mixing is not effective. Fox and Gex(1956) found that mixing is not effective above reynolds number of 80000. Maruyama et.al. (1982) found that for Reynolds number greater than 30000 and in a circulation flow regime of mixing there exist an optimum nozzle depth for rapid mixing, that ranges from the liquid surface level to three quarters of the depth of liquid when the depth of liquid is same to the diameter of tank. Zughbi D. et.al.(2005), considered symmetrical and an asymmetrical jet arrangement for their studies. Reynolds number greater than 25000 mixing times for both the arrangements was nearly the same, and for Reynolds number less than 25000 the side pump around tank geometry required less time to achieve 95% mixing. The asymmetry of the jet was found to reduce the mixing time. Hamid Rafiei et.al.(2012), concluded that by the rise of volumetric flow rate, mixing time falls and low Reynolds causes more notable changes in mixing time as compare to high Reynolds.

K. Effect of Viscosity, density

Researchers consider different fluid medium for their experimental researches and ultimately it indicated the importance of the effect of fluid property on mixing time. Saravanan et al.(2010) investigate the effect of viscosity for the optimized nozzle design and location. Saravanan et al.(2010) and Perumal R. et. al.(2012) consider water, CMC and Gaur Gum for their experiment. Perumal R. et. al.(2012) implies that when viscosity of the fluid increases the mixing time also increases, this was due to the diversion of flow and circular path.

L. Effect of tracer injection

Yianneskis(1991) also observed that mixing time increases almost linearly with tracer injection time. So to get good idea about mixing time, tracer injection time should be less. Grenville et al. (1996) investigated the mixing process by giving pulse of tracer(electrolyte) through a jet nozzle and proposed that turbulent kinetic energy controlled the mixing process far away from the jet entrance. The power consumed in mixing process through the nozzle was calculated using the kinetic energy of the jet as follows "(4.4)"

$$(4.4) \qquad P_j = (\Pi / 8) * \left(\rho 8 dj^2 * Uj^3\right)$$

Sundararaj et.al.(2012) used a tracer solution of potassium-di-chromate with 0.3% concentration. Digital spectrophotometer is used to measure local scalar concentration and found that the centerline concentration decay is rapid up to x=15d for $\theta_0 \leq 90^0$ and x=20d for $\theta_0 > 90^0$.

M. Effect of outlet location

Location of outflow plays a minor role in the overall efficiency of turbidity removal. Fox and Gex(1956) pointed that outlet is the place from where liquid is taken out from tank and sent to the nozzle. He also suggest, that the location of outlet should not be near the jet location otherwise feed from the jet is taken directly entering into suction of the outlet system. Pani et al. (2007) and Subramani et.al.(2012) in their study explained that the outflow section could be located at a convenient spot on the periphery of the chamber based on prevailing conditions on site .

N. Effect of power consumption

Yianneskis(1991) proposed correlation relating mixing time and power consumption. Result indicate a straight line variation with a negative slope. The power 'P' imparted to the liquid by impellers may be determined (Reynolds & Richards 1996) for laminar flow (Reynolds number, Re.< 10to 20), the power imparted by an impeller is given as $P = K_L n^2 D_i^3 \mu$. Saravanan et al.(2010) state that power consumption increase with increase in concentration of the fluid. Subramani et.al.(2012) calculated the power input from the relationship $G = \sqrt{\frac{P}{\mu V}}$ Perumal R. et. al.(2012), consider Newtonian and Non Newtonian fluid and found that mixing time decreases with increase in liquid flow rate and power consumption.

V. CFD IN JET MIXING

Several areas are their which requires further study to facilitate their accurate representation using CFD. In particular, use of CFD models in population balance modeling for flocculation process in water treatment process remains a key challenge. There are various principal turbulence models which are generally packaged with commercially available CFD packages are the standard k-ε model, the renormalized group k-ε model(RNG k-ε), the low Reynolds number k-ε model (LRN k-ε), the realizable k-ε model, the standard k-ω model, the shear-stress transport (SST) k-ε model, and the Reynolds stress model (RSM). Also most codes provide the Large Eddy Simulation (LES) model, and the Spalart- Allmaras model. J. Bridgeman et.al. (2009) gives the descriptive comparision chart of the most commonly used turbulence models and with their formulation.

Ranade (1996), carried out CFD simulations using standard k-e model for turbulence with an alternating jets. However, the CFD model was not validated by comparison with experimental measurements. Foster et.al.(1977) showed that a power law form of the forcing function could produce a kolmogorav k-5/3 energy spectrum, an inertial range where k is a wave number. He applied the RNG model to hydrodynamics. Jayanthi(2001), used a CFD code CFX to find the optimum shape required to reduce the mixing time. He discovered that omitting dead zones in reactor and using conical bottom reduces mixing time. H.D. Zughbi et.al. (2004), and Hamid Rafiei et.al.(2012), used RNG k-ε model, both investigator showed that the angle of injection is important in determining the time required for mixing as Nozzle angle reduces mixing time effectively. H.D. Zughbi et.al. (2004), investigated the effect of elevation and angle of mixing in a fluid jet agitated tank using CFD. For an angle of injection of 450, it does not gives the shortest time but for 300 it gives the shortest mixing time. T. Raja et.al. (2007), in their work employed a standard k-ε model to close the Reynolds transport equations and said that, CFD model in FLUENT6.1 enables the solution of Reynolds transport equation with a turbulence model to close the set of equations.

C. Shanawaskhan et.al.(2009), considered a jet mixer in three dimensional view consisting of a cylindrical vessel with a flat bottom has been modeled using Fluent 6.2.16. This modeled geometry was used for simulation at various nozzle configurations and angles. They concluded that, as air jet velocity increases mixing time decreases considerably. The effect of jet position on mixing process for a rectangular pilot scale tank using the commercial CFD package, FLUENT6.2, has been investigated experimentally and theoretically by A. Parvareh et.al. (2009). Among the studied jet positions, the best performance is obtained at an angle of 900, also they conclude that the CFD can be used as a good theoretical tool for studying mixing in continuous flow stirred tanks equipped with a jet.

B.S.Pani et.al.(2011) , compares and contrasts the results for different types of turbulent jets using the point- source method and the standard k-ε CFD simulation. Hamid Rafiei et.al(2012) RNG k-ε model is used as the turbulent model for the prediction of the pattern of turbulent flow inside the cylindrical tank. They compared results from experiments and CFD and found that CFD liquid dynamic calculation is substantially able to predict mixing. Manjula. P et.al(2012), studied the statistical design of experiments were carried out using Design Expert Software (version 6.0) using the predicted experiments mixing times. Lyutsia S. Dautova et.al. (2012), considered jet-stirred cylindrical tank for symmetric and asymmetric jet placement configurations and assess the performance of Spalart-Allmaras (SA), k-ω (k-ω SST) and Reynolds Stress (RS) turbulent models. The best mixing results were obtained at the jet offset r/D = 16/3. They also suggest the use of structured grid, refinement of the grid overlapping with shear layer, and recommended the study of other turbulence models such as k-ε and V2F RANS is for further studies. Kathiresan et.al. (2014), designed and analyzed two-dimensional coaxial jet profiles of different area ratios. The models were designed in ANSYS Design Modeler and the numerical simulation was done in ANSYS FLUENT 14.5 using the two dimensional density based energy equation and k- ε turbulence model with primary supersonic flow and secondary subsonic flow. The results of this study indicate that analysis employing linear two-equation turbulence modeling can predict the effect of spreading rates of high-speed coaxial jets reasonably well. Bumrungthaichaichan et.al.(2016) developed CFD model and studied effect of jet nozzle angle on mixing time considering various H/D ratios and observed that 45^0 nozzle angle exhibited the shortest mixing time regardless of H/D ratios. The knowledge gained in the computational approach enabled the examination of turbulent kinetic energy in the developing jet. Most of the researchers said that CFD liquid dynamic calculation is substantially able to predict mixing.

VI. CONCLUSION

Flocculation is one of the important unit in water treatment process. For better flocculation , mixing plays an important role. Better the mixing in flocculation higher the rate of turbidity removal, ultimately lesser load on consequent units of Water Treatment Plant. Jet mixing is the best alternative of mechanical agitators. In this paper, Jet mixing process in flocculation , various experimental studies are explained briefly. It also explains the need of review on jet mixing. The comprehensive study is given by Wasewar(2006). The various parameters like tank geometry (height, diameter), jet diameter, jet configuration (side entry jets, vertical jets etc, number of jets), jet velocity, jet flow rate and fluid properties, such as viscosity are studied which affects mixing time. Many experimental correlations given by various researchers are listed in this review. CFD studies on jet mixing have been covered. There are number of papers published to date which present the experimental, correlation and CFD simulation of liquid flow with single and multi-jets, whereas as the significant effects and interactions of each variable involved in the process on mixing time were not studied. This shows that there is a strong need to investigate the interaction effects of operating parameters.

Notations

P = power induced in the tank.
V = volume of fluid
μ= viscosity of fluid.
KL = impeller constant for laminar flow
n = rotational speed (rpm)
Di = impeller diameter (m)
Re_{cf} = Cross flow Reynolds number
Re_j = Jet Reynolds number
Δp = Pressure drop
ε_u = Dispersion rate
ε_{av} = Volume averaged turbulent kinetic energy dispersion rate.
T = Diameter of column,m
U_o = Initial velocity
U_{max} = maximum velocity
A = Jet exit area
K = Constant for free and wall jets.

References

[1] Fossett, H. and L. E. Prosser: Proc. I. Mech. E., 160, 224. (1949), idem: Trans. Instn. Chem. Engrs., 29, 322 (1951).
[2] Fox, E.A. andV.E. Gex: AIChE/.,2, 539 (1956).
[3] Okita, N., Oyama, Y., Japanese Journal of Chemical Engineers 31(9) (1963) 92.
[4] Foster D, Nelson D.R. & Stephen M.J, “Large distance and long time properties of a randomly stirred fluid”, Physical review, A-16, 732-749 (1977).
[5] Coldrey, P. W., Paper to I.Chem.E.Course, Univ. of Bradford,England, July, (1978).
[6] A.G.C Lane, P. Rice, “An Experimental investigation of liquid jet mixing employing a vertical submerged jet”, Ind. Chem. Engg. Symposium series, Vol 64, pp. K1-K14, 1981.
[7] T. Maruyama, Y. Ban, T. Mizushina, “Jet mixing of fluids in tanks”, Journal of Chemical
[8] Engineering, Japan, 15, 342-348, 1982 .
[9] Prakesh R. Bathiji, "Jet mixing design and application," Chemical Engingeering Desember 13, 1982.
[10] Lane, A. G. C., Rice, P., Poster v, 4th European Conf. On Mixing, Leeuwenhorst, Netherlands 27–29 April 1982.
[11] Maruyama, T., Kamishima, N., Mizushina ,T., J. Chem. Eng. Japan, 17, (1984) 20.
[12] John L. Cleasby, "Is Velocity Gradient a valiad Turbulant. Flocculation Parameter? A.J. Environ. Eng.110:875-897, 1984.
[13] Mark M. Clark, 1 A.M. ASCE, " Critique of camp and Steins RMS Velocity Gradient", J. Hydraul. Eng. 111:741-754, 1985.
[14] J. E. Broadwell and R. E. Breidenthal, "Structure and mixing of a transverse jet in incompressible flow", Find Mech. of 148,p p. 40& 412, 1984.
[15] A.M. Saatci, M. Halilsoy, "Critique of camp and Stein's RMS Velocity Gradient." J. Hydraul. Eng. 113:975-678, 1985.
[16] Maruyama, T., Jet mixing of fluids in vessels. In N P Cheremesinoff, Encyclopedia of fluid mechanics. Vol 2. chapter 2, Gulf Publishing Company, Houston, TX, pp. 544–562, 1986.
[17] Joseph H. W. Lee,1 A.M. ASCE and Valiant W.L. Cheung2," Inclined Plane Buoyant Jet in Stratified Fluid," J.Hydraul. Engg., 112:580-589, 1986.
[18] Emad H. IMAM, 1 Abdelkawi Khalifa, 2 and John A. McCorquodale, 3 Member, ASCE, "Optimal Jet-Mixer for shallow basins ", J.Hydraul. Engg., 114:1398-1415, 1988.
[19] Yianneskis, M., 7th European Conf. on Mixing, Kiav, Brugge, Sept 18–20, Belgium, 121,1991.
[20] Swaminathan Tanjore, Vikramghavan, T and Bhole A.G., “Significance of tapered flocculation in water treatment processes.” Journal of Indian Water Works association, 26(1), 15-19, 1994 .
[21] V.V.Ranade, Towards better mixing protocols by designing spatially periodic flows: The case of a jet mixer, Chemical Engineering Science, 51, 2637-2642, 1996.
[22] Grenville, R. K., Tilton, J. N., Tran. Inst. of Chem. Engrs.74A, 390, 1996.

[23] Reynolds T.D, Richards P.A., Unit operations and process in Environmental Engineering, 2nd edition, PWS Publishing Company 1996.
[24] Grenville, R. K., Tilton, J. N., Progress en Genie desProcedes 11(51)**,** 67, 1997.
[25] Armal,S.D, “Peripheral inlet tapered velocity gradient flocculator. J. Indian water works Ass, 29(1), 43-50, 1997.
[26] Kramer, T.A., and Clark, M.M. “ Influence of strain-rate on coagulation kinetics.” J. Environ. Eng., 123(5), 444-452, 1997.
[27] Perona, J. J., Hylton, T. D., Youngblood. E. L., Cummins, R. L., Ind. Eng. Chem. Res. 38,1478, 1998 .
[28] Graber, S.D. “ Discussion of ‘Influence of strain-rate on coagulation kinetics.” By , T.A. Kramer and M.M. Clark , J. Environ. Eng., 124(10), 1028-1028, 1998.
[29] S. Jayanthi, Hydrodynamics of jet mixing in vessels, Chemical Engineering Science, 56, 2001, 193-210.
[30] Patwardhan, A. W., Chem. Eng. Sci. 57,1307, 2002.
[31] Zughbi, H. D., Rakib, M. A., Chem. Eng. Comm.189 ,1038, 2002.
[32] Patwardhan, A. W., Gaikwad, S.G. , Mixing in tanks agitated by jets. Inst. Chem. Eng., 211-220, 2003.
[33] H.D. Zughbi, M.A. Rakib,” Mixing in a fluid jet agitated tank: effects of jet angle and elevation and number of jets,” Chemical engineering science, vol. 59, pp. 829-842, doi:10.1016/j.ces.2003.09.044, Feb. 2004
[34] D. Zughbi and IqtedarAhmad “Mixing in Liquid Jet Tanks: Effect of Jet Asymmetric,” Industrial and Engineering Chemistry Research, American Chemical Society, 44, pp 1502-1066, 2005.
[35] Francisco Pedocchi 1 and Ismael Piedra-Cueva 2, "Camp and Stein's Velocity Gradient Formalization," J.Environ. Eng.,131:1369-1376, 2005.
[36] J A Denev, J Frohocchi, H Bockhorn, "Evalution of mixing & chemical reaction within a jet in crossflow by means of LES", Proccding of the European combustion meeting 2005.
[37] K. L. WASEWAR, A Design of Jet Mixed Tank, Chem. Biochem. Eng. Q. 20 (1) 31–46, 2006.
[38] B.S.Pani, L.G. Pani, “ Single- Basin jet flocculators”, Journal of Hydro-environment Research, 2007/1/1/20-29, 2006.
[39] T Raja, P Kalaichelvi, N. Anantharaman, “ Development of CFD model for optimum mixing in jet mixed tanks”, Jr. of Scientific & Industrial Research Vol. 66, pp. 522-527, July 2007.
[40] K. Sendilkumar,P.Kalaichelvil, M. Perumalsamy, A.Arunagiri and T. Raja, “Computational Fluid Dynamic Analysis of Mixing Characteristics inside a Jet Mixer for Newtonian and Non Newtonian Fluids. Revised on ^ August 2007. Unpublished.
[41] P.Kalaichelvil, Y. Swarnalath 1 and T. Rajal 1," Mixing time Estimating and analysis in a jet mixing", ARPN Journal of Engineering and Applied Sciences , Vol. 2, No. 5, October 2007.
[42] Soheil Gholamreza-Kashil J. Martinuzzi, M. ASCE and Raouf E. Baassour, M.ASCE, " Comparison of Far-Field Turbulent Structure of a Rectangular Surface Jet to Three-Dimensional Free and all Jets", J.Eng. Mech.,134:224-233, 2008.
[43] S.M. Dhabadgaonkar, "Jet Clarifiers: Appropriate Technology for water Tretment in India", Journal of Indian Water Work Association Jan March 2008.
[44] C. Shanawaskhan, P. Kalaichelvi, M. Perumalsamy, A. Arunagiri, "Computational Fluid Dynamic Analysis of two phase jet Mixer", Journal of the university of chemical Techology and Metallurgy, 44, 3, 262-266, 2009.
[45] J. Bridgeman, B. Jefferson, S.A. Parsons, “Computational Fluid Dynamic Modelling of Flocculation in water treatment: A Review", Engineering Applications of Computational Fluid Merchanics, Vol 3, No.2, pp220-241, 2009.
[46] J Bridgeman B. Jefferson , S A Parson, "Computational Fluid Dynamics Modelling of Flocculation in water tretment A Reviews", Engg Applications of Computational Fluid Mechanics. Vol 3, No.2, pp. 220-241 2009.
[47] A.Parvareh 1, M. Rahimi 1* and Ammar Abdulaziz Alsairafi 2,"Experimental and CFD Studies on the Effects the Jet Position on Mixing Performance", Iranian Jouranal of Chemical Engg. Vol 6, No. 3 (summer) , IAChE, 2009.
[48] Terry L.Engelhardt ,Coagulation,Flocculation and Clarification of Drinking Water , April 2010.
[49] Prof. Dr. K. Saravanan, N. Sundaramoorthy, G. Mohanumar, N. Subramanin, "Studies on Some Aspects of jet mixer I: Hydrodynamics" Modern Applied Sciecen, Vol-4, No-3. March 2010.
[50] J.M.I. Jenzar Althaus , "Influence of a circular jet arrangement in a rectanular tank on flow and suspended sediment release", 34th IAHR Word Congress, Brisbane, Australia, 26 june-1 july 2011.
[51] Hui Liu, Yuming Xing,"Unsteady flow and the mixing efficiency in transverse Jets", IEEE 2011.
[52] Bidya Sagar Pani*1, Lai A.C.H. 2 and wong C.K.C., "Turbulent jets : Point-Source and CFD Simulation Results", Journal of Environmental Research and Development and Vol. 5 No. 4, April-June 2011.
[53] Subramanian Sundararaj a* and Velappan Selladurai "The Effects of Arbitary Injection Angle and Flow Conditions on Venturi jet Mixer" Thermal Scicence, Vol. 16, No. 1, pp. 207-221, 2012.
[54] Hamid Rafiei, Reza Janamiri, Mohammad Hossein Sedaghat, and Amir Hatampour, “Experimental and CFD Investigation of Nozzle Angle in Jet Mixer”, World Academy of Science, Engineering and Technology, Vol:6 , 12-28, 2012.
[55] Manjula P. Kalaichevi. P Annsdurai. G and Dheenathayalan K, "Optimum Configuration of a Double Jet Mixer Using DOE", (ICBEE 2012) December 14-15, 2012 Singapore.
[56] T. Subramani 1 Suraja Nair 2, "Experimental Analysis on Horizantal For Small Water Supply Schemes", International Journal of Modern Engg. Research (IJMER) Vol 2, Issue.4, July -Aug 2012 pp-1534-1539 ISSN: 2249-6645.
[57] Perumal R. Saravanan K, "Experimaental Investingtion on mixing time analysis of jet mixer", Research Journal of Engg. Sciences, Vol.1(5), 7-11, November 2012.
[58] Hamid Rafiei, Zeza Janamiri, Mohammad Hossein Sedaghat, and Amir Hatampour, " Experimental and CFD Investigation of Nozzle Angle in Jet Mixer", Word Academy of Science, Engg and Technology Vol:6 ,12-28, 2012.
[59] Lyutsia S. Dautoval, Ivana Milanovic 2, Khaled J. Hammad 3,"CFD Studay of the Effect of Jet Placement of Flow Patterns Inside a Jet Stirred Tank, "2012 ASEE Norheast Section Conference, April 27-28, 2012.

[60] K. Kathiresan, A. Balamani, M. Karthik, P. Gogulanathan, D. Thanikaivel Murugan, S.Ilakkiya, " CFD Analysis of Supersonic Coaxial Jets on Effect of Spreading Rates", Int. Journal of Engineering Research and Applications www.ijera.com ISSN : 2248-9622, Vol. 4, Issue 4(Version 1), pp.29-35, April 2014 .

[61] Pei Chen, Suxun Li, Shijie Luo, Zhaoyong Ni, "Flow Visualization on Lateral Multiple Jet Interaction with

[62] Freestream" Journal of Flow Control, Measurement & Visualization, 2014, 2, 7-11 Published Online January 2014.

[63] H. Syazwani, G. Mebrahitom, A. Azmir, "A review on nozzle wear in abrasive water jet machining application", IOP Conf. Series: Mateials Science and Engineering 114, 012020, 2015.

[64] Eakarach Bumrungthaichaichan, Nattawat Jaiklom, Apinan Namkanisorn and Santi Wattananusorn, "On the computational fluid dynamics (CFD) analysis of the effect of jet nozzle angle on mixing time for various liquid heights", Academic Journals, Vol. 11(4), pp. 42-56, DOI: 5897/SRE2015.6353, 29 February, 2016 .

[65] Liang Hong , Rubing Zhang , Zheng Liu, "Numerical Simulations of Jet Mixing Enhancement in a Round Jet Exhaust Using SJA", IOP Conf. Series: Materials Science and Engineering 187 (2017)

[66] Stephen Kennedy, Pradipto K. Bhattacharjee, Sati N. Bhattacharya, Nicky Eshtiaghi, andRajarathinam Parthasarathy, "Control of the mixing time in vessels agitated by submerged recirculating jets", Royal Society Open science, 5(1) 171037, Jan 2018.