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USING JET MIXING TECHNIQUES TO ENHANCE DIRECT FILTTERATION

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Abstract: The present study investigates the effect of jet mixing techniques performed with two types of coagulants (Aluminum sulfate hydrate $[Al_2(SO_4)_3.16H_2O]$ and Magnesium chloride $MgCl_2$) using the polyacrylamide PAM $(C_3H_5)_n$ as flocculent aid, on the flocculation. The study include two parts, the first one is the numerical analysis using ANSYS Fluent and CFX program. The second part included the experimental work in which Kaolin particles used to simulate the suspensions in natural resource water. The results indicated that the mixing process using jet mixing tank system produce uniform semi spherical shape. The image analysis provided indications that the floc with manganese chloride are compacted and dense so that it can be more suitable for direct filtration procedure.

Keywords: *jet mixing, flocculation, image analysis, direct filtration.*

استخدام تقنية الخلط بالبثق لتعزيز عملية الترشيح المباشر

الخلاصة: اختبرت هذه الدراسة تاثيرعملية الخلط باستخدام تقنية الخلط بالبثق على التلبد باستخدام نوعين من المواد المخثرة هما هيدرات كبريتات الالمنيوم $[Al_2(SO_4)_3.16H_2O]$ وكلوريد المغنيسيوم $MgCl_2$، بالاضافه الى بوليمر بولي اكريلامايد $(C_3H_5)_n$ كعامل مساعد للتلبد. تضمنت الدراسة جزئين: الاول هو الحل العددي والمحاكاة لعملية الخلط بالبثق باستخدام برنامج المحاكاة ANSYS Fluent and CFX program اما الجزء الثاني فتضمن الجزء العملي، اذ استخدمت دقائق الكاؤولين لمحاكاة الدقائق الموجودة في المياه الطبيعية. اظهرت النتائج ان عملية الخلط باستخدام تقنية البثق ينتج عنها ندف منتظمة الشكل شبه كروية واشارت نتائج التحليل الصوري الى ان الندف الناتجه باستعمال كلوريد المغنيسيوم كمادة مخثرة تكون متراصة وكثيفة وبالتالي تكون مناسبة لعملية الترشيح المباشر.

1. Introduction

In any water purification process or sewage treatment as well as industrial activity. The main objective of solid-liquid separation processes is the optimum removing of the suspended solids particles. Several sequential techniques can be applied for solids or particles removal such as filtration, flotation cyclone separation and settling [1].

In order to achieve efficiently removing of those suspended particles, it is important to collect adequately knowledge about their physical and often chemical properties. The most important physical characteristics of particles are size distribution, density, and

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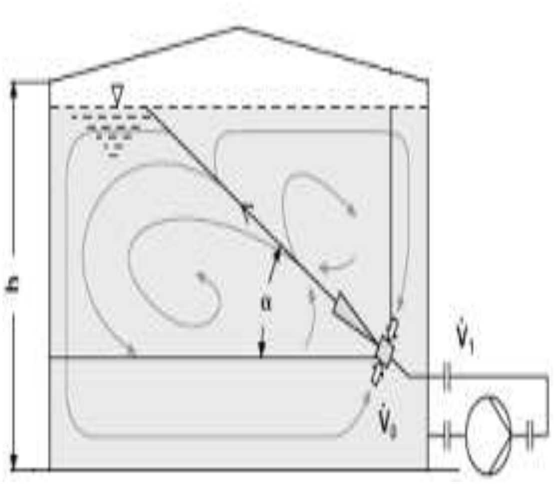
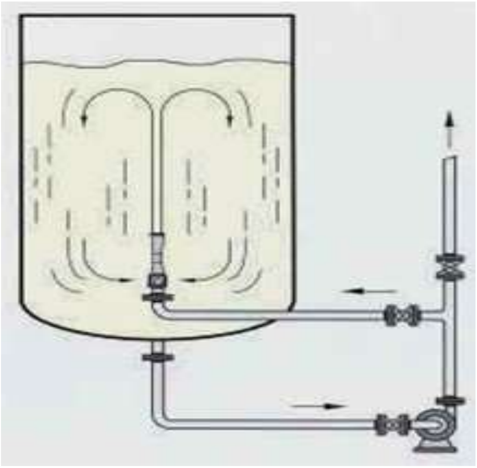
structure/shape. The surface charge or the chemistry falls under chemical nature of particles that has great influence of the efficient of their removal [2].

The aim of coagulation and flocculation process is to collect the suspended particles into large aggregate for improving separation. Fundamental utilization of flocculation application in water treatment is purification. As well as flocculation is also substantial in other operation deals with suspensions and emulsions, such as in pharmaceutical and paint industries, due to its effect on suspension rheology [3].

1.1 Jet mixing turbulent jet is very common method which used for mixing miscible liquids in the chemical process. In jet mixing a fast-moving stream of primary liquid is injected into the bulk or secondary liquid that stationary or in slow-motion. The jet enters the bulk liquid and expanded at the jet angle δ, which is variable between about 15º and 25º for Reynolds Re_J >100.

The most common types of jet mixer are the side jet mixer and the coaxial jet mixer as show in figure1 [4]. The velocity difference between the secondary liquid and injected primary liquid caused to create a mixing layer at the jet boundary. The mixing layer growth is directly proportional to the jet direction flow leading to entraining and mixing the jet with bulk liquid.





(a) (b)

Figure 1. Types of Jet Mixing Device: (a) - Side Jet Mixer, (b) - Coaxial Jet Mixer [4].

Patwardhan and Gaikwad 2003 [5] investigated the mixing time in side-entry jet mixer, various jet mixing parameters such as nozzle diameter, angle of inclination and jet velocity. In addition the energy efficiency comparison had been done with result from previous study in which mixing process accomplished by impeller. The experiments carried out in an acrylic tank of diameter D_T=0.5 m and height Z=0.75 m. the fluid height in all experiments was equal to tank diameter H=D_T. The tank outlet was d_{out}= 0.0381 m and sited at 0.05m from bottom of the tank. A centrifugal pump of 0.5 hp was equipped to recirculate part of the liquid from the tank and return it to the tank with high velocity through a nozzle. The inclination angles of the nozzles were (0º, 30º, 45º, and 60º). A large number of nozzles having different diameters were tested.

Masoud and Arsalan 2006 [6] studied the influence of jets layout on mixing time. A large storage tank of 19,000 m3 contain three types of crude oil with difference densities of height H=13m and a diameter D_T =44m was used in the study. The tank equipped with aside entry marine type, 3-blade impeller with a diameter D_i=0.65m. The jet out flow rate were 33, 66, 132 and 264 m^3/h corresponding to average velocity of 1.125, 2.25 4.5and 9 m/s in the jet nozzle of inner diameter was D_{noz}. =0.1 m. The position of impeller and the jet's suction was fixed in the model. The jet's nozzle was placed at angular way, around the tank wall in certain locations of 15º, 30º, 45º and 60º with respect to the impeller. **Kalaichelvi et. al. 2007**[7] investigated the effects of various parameters such as nozzle diameter, jet position, jet velocity and angle of inclination on jet mixing time. The experiments were carried out in metallic tank of diameter of D_T =0.28 m and height Z=0.45 m. The tap water was used as working fluid with constant level in all experiments at H=0.28 m. The suction of the tank was placed at 0.04m from the tank bottom. Part of water was recirculated from the tank and return with a high velocity through a nozzle into the tank by using 0.5 hp pump. Three nozzles were tested with diameter D_{noz}. = (0.005, 0.010, and 0.015 m) and average velocity of 4, 6, 8 and 10 m/s. Constant position for the suction and three different jet positions were examined as 0.28m, 0.186 m from the top and 0.03m from the bottom of the tank, these nozzles were arrangement at angles of inclination of 15º, 30º, 45º and 60º, which kept in all experiments. **Parvareh et. al. 2009** [8] examined the effect of the jet position on mixing implemented experimentally and theoretically. The experiments were accomplished in a cubical tank with volume of 125 lit. Both inlet and outlet of the tank were equal with a diameter of 0.04 m. The water was fed into the tank with a constant linear velocity at 0.045 m/s. Constant position for the suction with a diameter of D_{suc}. = 0.008 m. The nozzle diameter was equal to D_{noz}.= 0.006 m and induced a constant jet velocity of 4.35 m/s. Nozzles were tested in seven different positions and arrangement at constant angles of inclination at 22.5º with respect to the horizon. The tracer was 80 ml of the dark Nigrosine solution was injected from the top of tank, close to the inlet stream during 4 s, and its movement inside the tank was recorded by digital camera. The CFD code was performed the numerical solution of the conservation equation in the laminar and turbulent fluid flow regimes. Thus, the simulation predictions were estimated by simultaneous solution of the continuity and The RANS equations. **Grenville and Tilton 2011** [9] comprised the methods for predicting blend times in tall tank agitated by jet. The comparison deals with correlation of estimation the blend time data from previous study established with a large scale vessel up to 12000 m3. All experiments were carried out in vertical cylinders with flat bases. Three cylinder diameter were investigated; 0.61, 1.68 and 3.98 m. The ratio of fluid

Height to the diameter $H/D_T \leq 1$ for vessel of 1.68 and 3.98 m diameter, while for vessel of 0.61 m diameter the ration was $H/D_T \geq 1$. The sodium chloride solution was used as tracer and pulsed into the vessel through the jet nozzle. The change in the concentration was measured at three points in the fluid using conductivity probes. All experiments were carried out in the turbulent condition Re > 104.

2. Jet-Mixing Tank Design jet-mixing tank designed to be similar to a typical mixing tank as show in figure2. The bottom tank is flat with a diameter $D_T = 0.5$m and height of H = 0.6m. The diffuser of radius of $R_{df} = 0.241$m is mounted in vertical way at the tank base along the tank height slightly more than liquid level. The diffuser is designed to direct the injected flow to the curvature region in the vessel. The curvature zone consist of four quarters of hollow cylinder of radius $R_c = 0.055$m, each two quarter are assembly together to form one curvature zone which is fixed vertically and tangentially to the tank wall with the extension of diffuser radius. Two baffles with width $W_b = 0.05$m are mounted in adjacent to curvature zone to generate the small eddies zone. Four nozzles with diameter of $D_{noz.} = 0.004$m were used to inject the fluid into the mixing vessel. The nozzles arrangements in one plan each two adjacent to the other as show in figure 2. The nozzle height distribution at 0.1, 0.3m at right side and 0.2, 0.4m at the other side

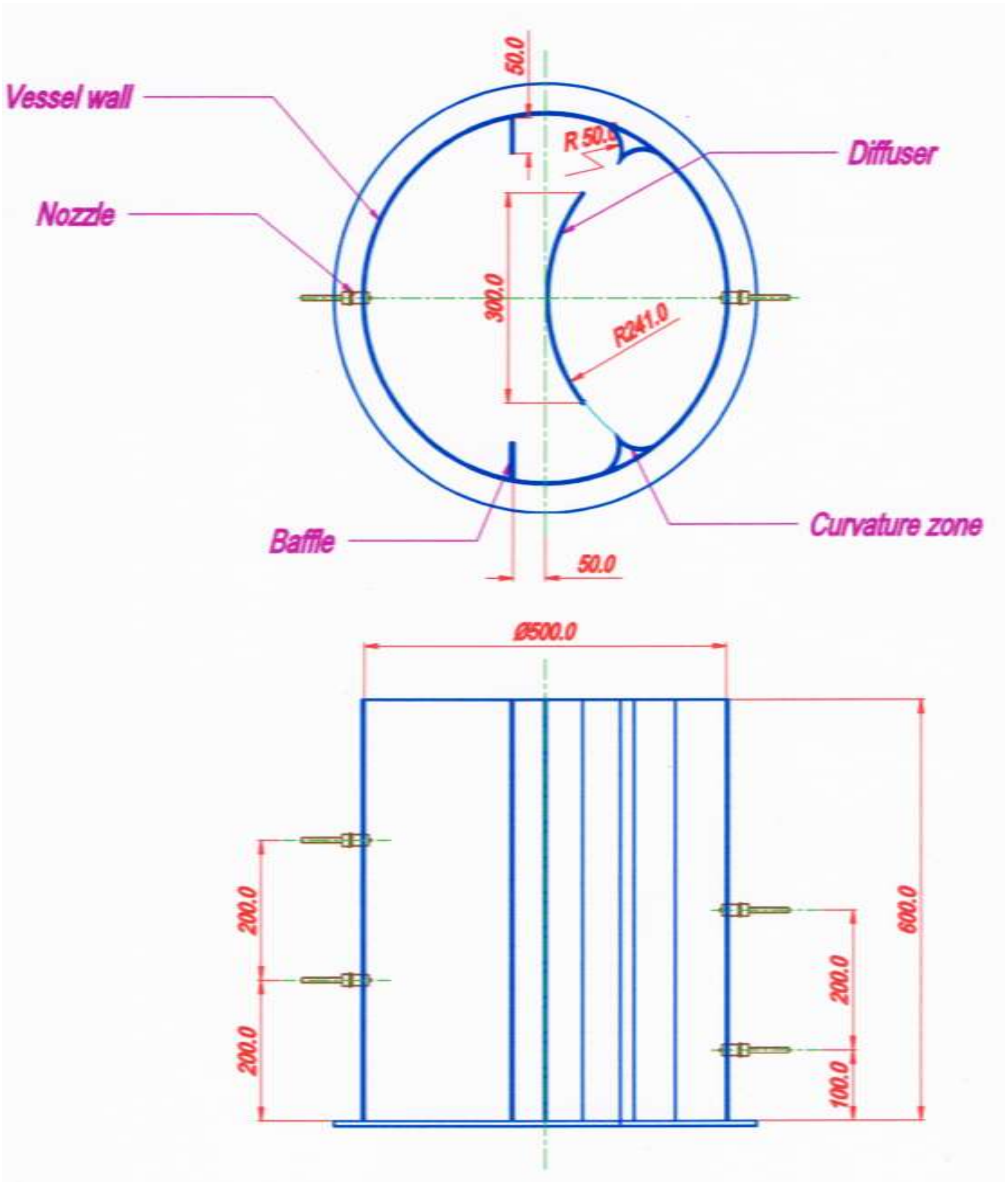


Figure 2. Jet-Mixing tank and Nozzles Layout Arrangement

3. Governing Equations

In order to analysis the fluid hydrodynamic in the mixing tank, the mass (continuity) equation and the momentum equation in additional to the renormalized group version of (k-ε) turbulent model equation by considering the infinite control volume with cylindrical coordinate.

3.1. Continuity Equation the continuity equation writes as conservation of mass equation with the following form: -

$$\frac{\partial}{\partial z}(\bar{u})+\frac{1}{r}\frac{\partial}{\partial r}(r\bar{v})+\frac{1}{r}\frac{\partial}{\partial \theta}(\bar{w})=0 \qquad (2\text{-}1)$$

3.2. Momentum Equation momentum equations can be written in terms of shear stress τ governing the fluid motion for three dimensions in cylindrical coordinate [56] as:

In z – direction:

$$\rho\left[\bar{u}\frac{\partial}{\partial z}\left(\bar{u}-\mu_{eff}\frac{\partial\bar{u}}{\partial z}\right)+\bar{u}\frac{1}{r}\frac{\partial}{\partial r}\left(r\bar{v}-\mu_{eff}\,r\frac{\partial\bar{u}}{\partial r}\right)+\bar{u}\frac{1}{r}\frac{\partial}{\partial\theta}\left(\bar{w}-\mu_{eff}\frac{1}{r}\frac{\partial\bar{u}}{\partial\theta}\right)\right]=source_{z} \qquad (2\text{-}2)$$

In r – direction:

$$\rho\left[\bar{v}\frac{\partial}{\partial z}\left(\bar{u}-\mu_{eff}\frac{\partial\bar{v}}{\partial z}\right)+\bar{v}\frac{1}{r}\frac{\partial}{\partial r}\left(r\bar{v}-\mu_{eff}\,r\frac{\partial\bar{v}}{\partial r}\right)+\bar{v}\frac{1}{r}\frac{\partial}{\partial\theta}\left(\bar{w}-\mu_{eff}\frac{1}{r}\frac{\partial\bar{v}}{\partial\theta}\right)\right]=source_{r} \qquad (2\text{-}3)$$

In θ - direction:

$$\rho\left[\bar{w}\frac{\partial}{\partial z}\left(\bar{u}-\mu_{eff}\frac{\partial\bar{w}}{\partial z}\right)+\bar{w}\frac{1}{r}\frac{\partial}{\partial r}\left(r\bar{v}-\mu_{eff}\,r\frac{\partial\bar{w}}{\partial r}\right)+\bar{w}\frac{1}{r}\frac{\partial}{\partial\theta}\left(\bar{w}-\mu_{eff}\frac{1}{r}\frac{\partial\bar{w}}{\partial\theta}\right)\right]=source_{\theta} \qquad (2\text{-}4)$$

4. Jet Mixing Unit numerous arrangements of jet mixing tanks with different dimensions and operation parameters were studied by changing the number of jet nozzles and nozzles distribution layout. A number of shapes have been created using solid work software, which are exported to ANSYS 15.0 (CFX) to study the hydrodynamics of the flow in each design for floc formation. The jet mixing tank with a flat bottom cylindrical tank of diameter D_J = 0.5m and height H_J = 0.6m its made from Plexiglas material of thickness 8mm as show in figures 3 & 4.

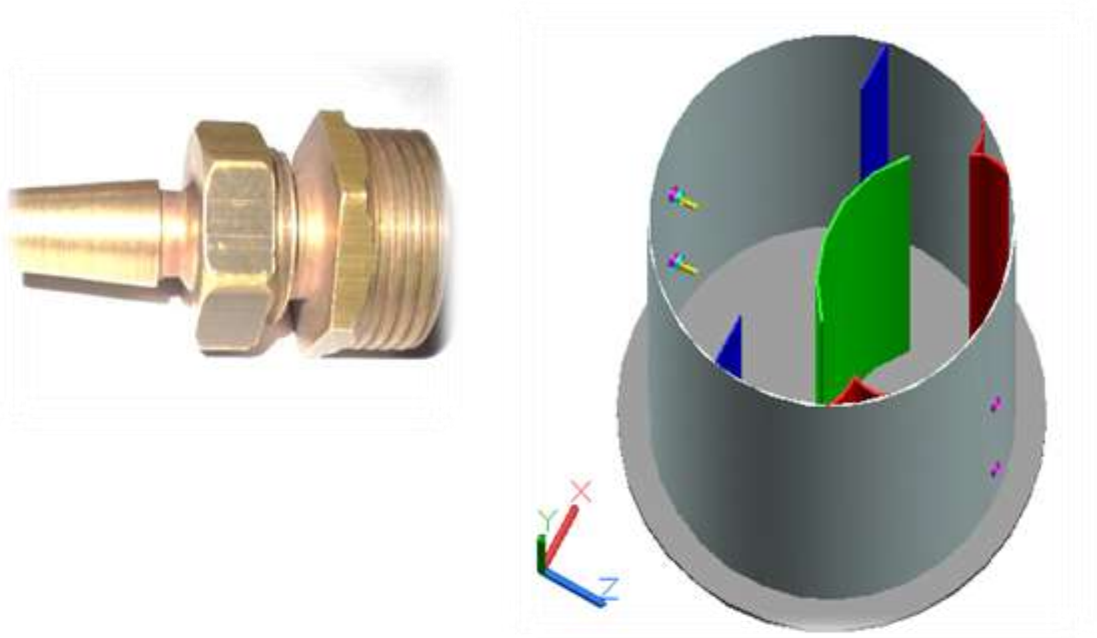
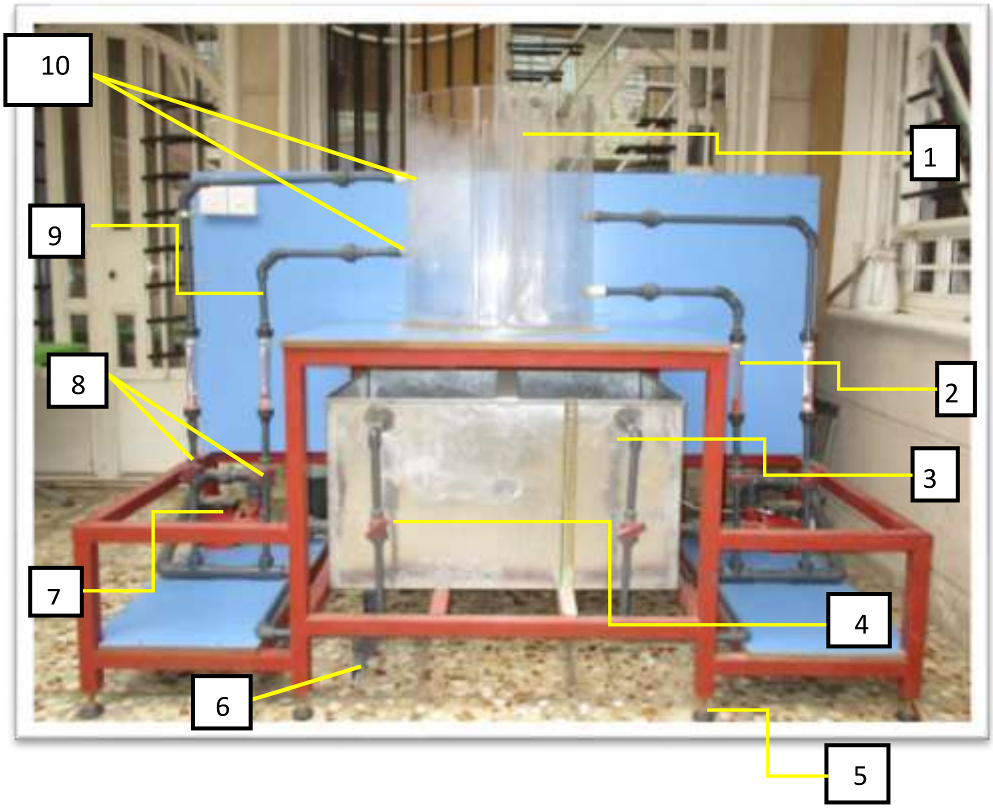


Figure3. Nozzle and Jet Mixing tank



No.	*Item*	*Quantity*
1	Mixing vessel	1
2	Flow meter	4
3	Storage tank	1
4	Feedback valve	2
5	Level adjustment	8
6	Drain	1
7	pump	2
8	Control valve	4
9	Pipe network	-
10	nozzle	4

Figure 4. Jet mixing unit

5. RESULTS AND DISCUSSION

Four nozzles arrangement at different height at the tank bottom used to provide the fluid flow motion. The fluids hydrodynamics in jet mixing tank are numerically are analyzed by ANSYS 15.0 –CFX- and Fluent. In order to cover and trace the fluid behavior in the tank, many sections in the tank are analyzed and studied. One is at a vertical plane and extends along the center of the tank. The others are nine sections in horizontal plane at heights of 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, and 0.55 m from the tank bottom. Figure 5 shows the velocity vectors in the vertical plane. It can be observed that fluid flow in all the zones of the tank, which is different from the stirred mixing tank. Therefore, eddies generated everywhere in tank as the fluid circulation in all direction. This can be considered as a significant improvement of the jet-mixing tank over the impeller-mixing tank as it increases the mixing efficiency.

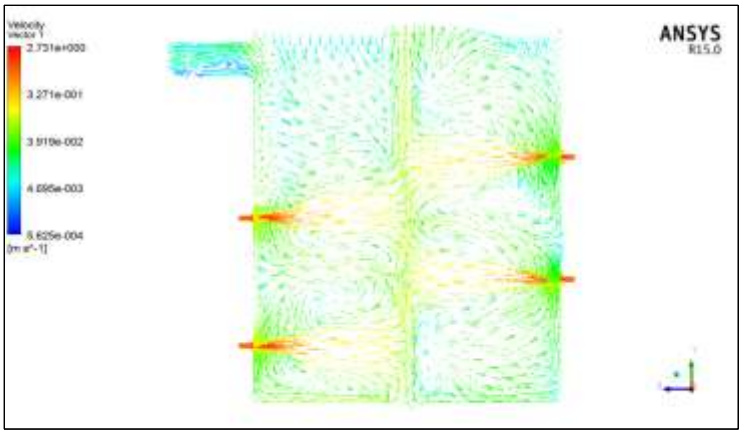


Figure 5. Velocity vectors induced in jet-mixing tank at vertical plane extended along the center of tank

Figure 6 illustrates the velocity contour at a vertical plane. It is obvious that there is very small poor mixing zones are located in the upper part of tank near the exit, where the flowing out of the mixing tank. It is useful that the low velocity zones existed at the upper zone because the floc do not exposed to a high shear stress and that may breaks them to smaller particles.

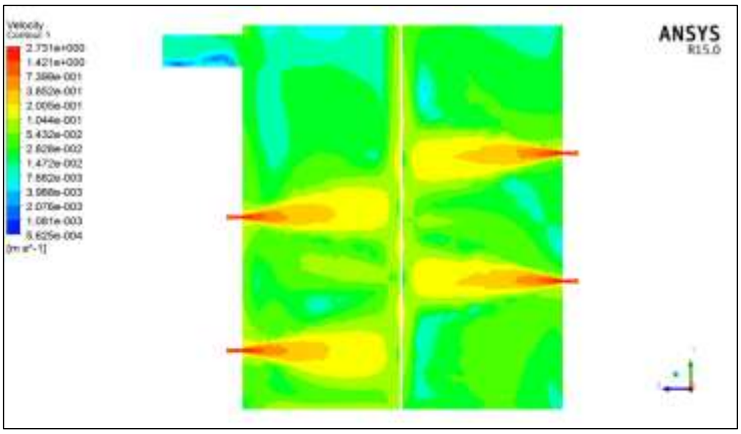


Figure 6. Velocity contours in jet-mixing tank at vertical plane extended along the center of tank.

Figures 7 and 8 show the velocity vectors and velocity contours for horizontal plane at height of 0.1m (nozzle level) from the tank bottom. It can be observed that the high velocity of fluid flow leaving from the nozzle at 2.734 m/s hits the diffuser wall inside the tank lead to the flow propagated in all direction along the diffuser wall. Most of the fluid propagates in the left, right side, and to lower directions according to the stagnation point. As the fluid flow aligned to the diffuser wall in the left and right direction until reached the distributor tip. Where it splits the flow into two parts: i) the first part moves alignment with the tank wall toward the jet injected from cylinder wall and mixed with incoming fluid. ii) The second part of the fluid will mix with the fluid coming from the adjacent side of tank in the zone between the distributer and the baffle. As a results of this type of motion eddies are generation in different zones and the turbulent kinetic energy dissipated in these eddies. The arrangement of diffuser and distributer provided to get better mixing conditions with less poor mixing zones as shown in the figure 8.

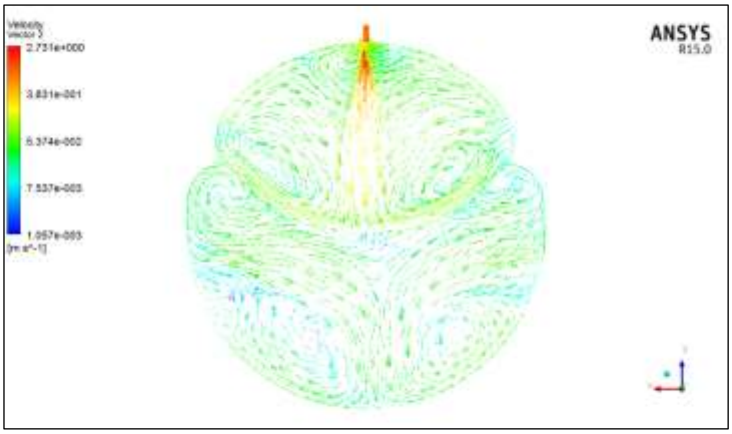


Figure7. Velocity Vectors generated in Jet-Mixing Tank at Horizontal Plane at Height of 0.1m from the Tank Bottom.

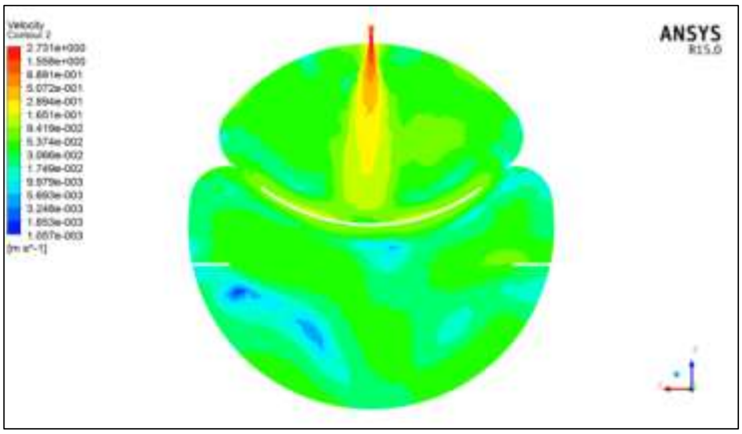


Figure8. Velocity contours in Jet-Mixing Tank at Horizontal Plane at Height of 0.1m from the Tank Bottom.

5.1. Floc and aggregate induced with aluminum sulfate hydrate coagulant [Al_2 (SO_4).14 H_2O].

Figure 9 shows the image of aggregates as well as calibrated and analyzed images induced after 120s of the start of mixing process. It can be observed that the formed aggregate is compacted and tends to have spherical shape and less porosity. Therefore, it has a high specific weight that lead to and faster settling in the mixing tank.

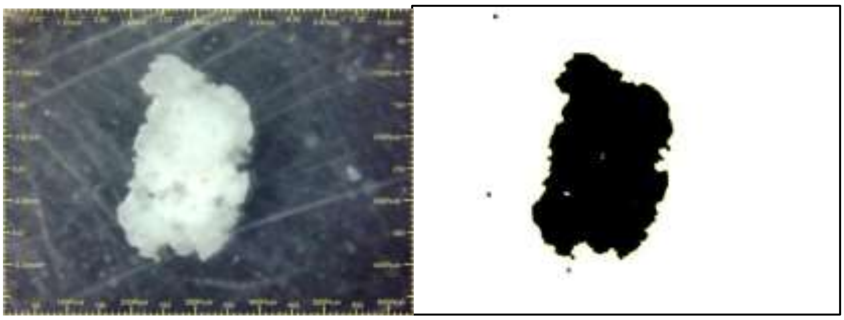


Figure 9. Images of flocculation process with alum after 120s of mixing.

Figure10. shows the settled aggregates at the end of mixing process. It is obvious that the settled aggregates are compacted, dense and some of them are agglomerated aggregates. The number of small parts and particles is very small because of the majority of these particles are tends to forms aggregates rather than affected with the flow in jet mixing tank.

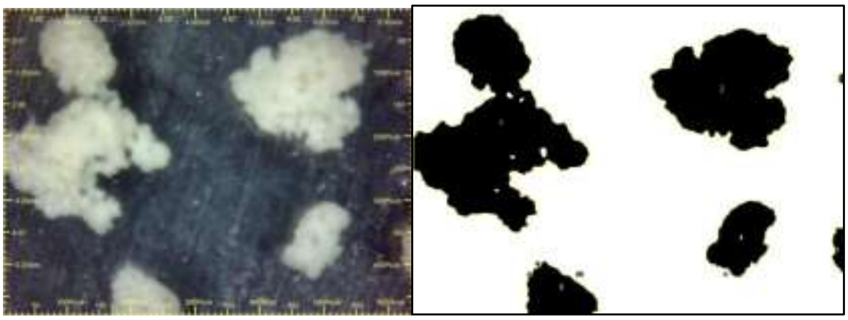


Figure 10. Images of flocculation process with alum after 600s of mixing.

5.2. Floc and aggregate induced with magnesium chloride coagulant $MgCl_2$.

. Figure11 shows the aggregates formation after 120s of the start of mixing process with magnesium chloride. In figure11, it can be observed that the agglomerates are formed by jointing several compacted aggregates at the outer boundary as noted by the red circles. Theses agglomerates are compacted, dense and have high specific weight. In addition, they tend to form another agglomerates.

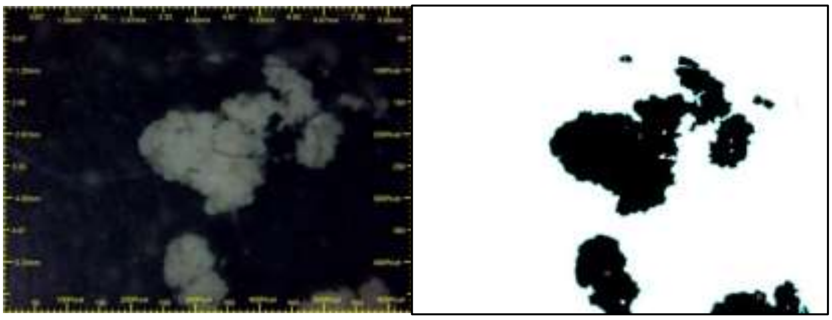


Figure 11. Images of flocculation process with magnesium chloride after 240s of mixing.

Figure 12 shows the evolution of flocculation process after 240s of the start of jet mixing process. It is obvious that the aggregates tend to grown up by jointing with other small floc. The aggregates are withstanding the shear stress after 240s of mixing because of the aggregate size is small and tend to spherical shape therefore it easily transport through flow stream in same velocity of stream. This behavior referred to the slow effect of magnesium chloride to enhance the particles to form floc. Figure (11) shows the calibrated image the analyzed image to estimate the average surface area of aggregates.

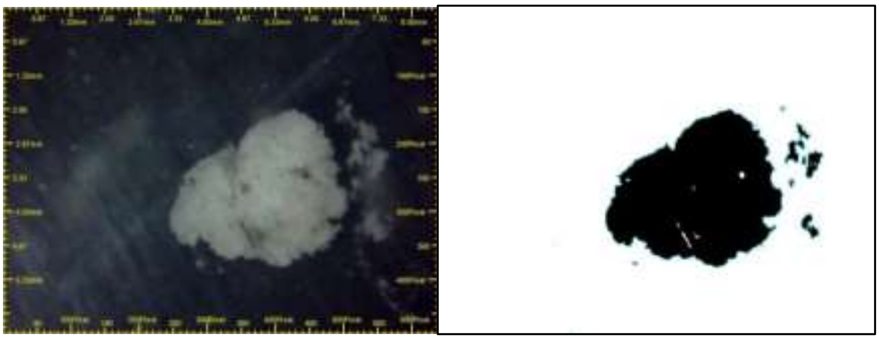


Figure12.
Image analysis of flocculation and aggregation process occurred in jet mixing tank with magnesium chloride as coagulant material after 240s of mixing process.

Figure 13 shows the flocculation evolution after 600s of the start of mixing process. In The newborn aggregates have less tendency to re-flocculation a again because they are more stable in this stage of mixing process, or in other words it reaches steady state condition.

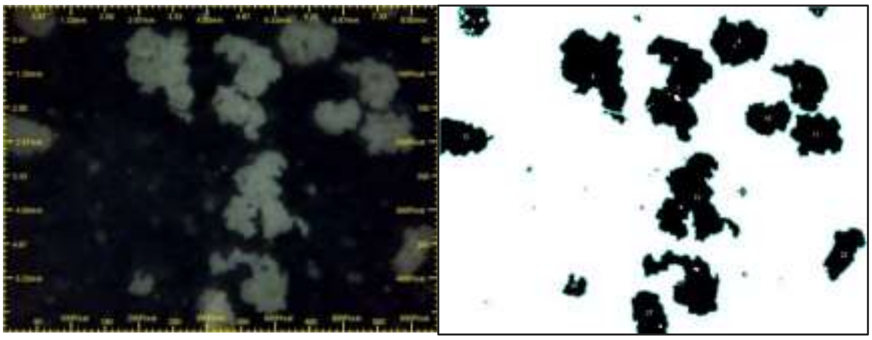


Figure 13. image analysis of flocculation and aggregation process occurred in jet mixing tank with magnesium chloride as coagulant material after 600s of mixing process.

5.3. Comparison with Floc and aggregate induced with aluminum sulfate hydrate and magnesium chloride coagulant.

Figure 14 shows the flocculation evaluation in jet mixing tank with two types of coagulants. It can observe the alum coagulant is faster effect in flocculation so the larger agglomerates induced after 120 second of mixing process while the coagulant manganese chloride is slower active so that the aggregates surface area induced with alum is larger than that induced with magnesium chloride. In drinking water treatment plant the sequence of purification process is chemical additive (coagulation) then flocculation and after that sedimentation process and the last procedure is filtration. Therefore, the alum coagulant is more suitable for flocculation process followed by sedimentation process.

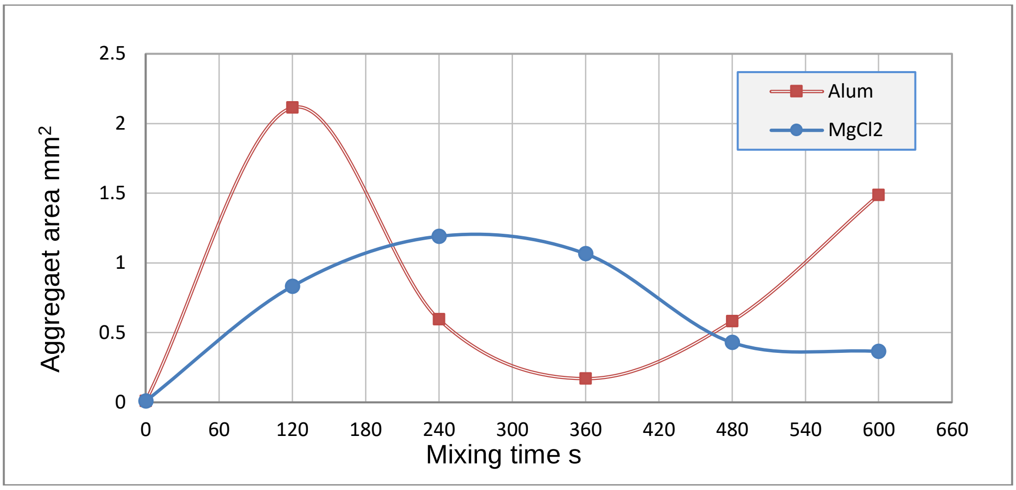


Figure 14 the flocculation evaluation in jet mixing tank with the time for two types of coagulant.

6. Conclusions

1) The jet-mixing technique produces floc and aggregates have physical characteristics are suitable direct filtration process in water treatment plant.

2) The coagulant aluminum sulphate hydrate [$Al_2(SO_4)_3.14H_2O$] is faster indication in flocculation and produce floc with large surface area that is suitable for sedimentation process as next stage after flocculation process in drinking water treatment plant.

3) The coagulant manganese chloride [$MgCl_26H_2O$], although is not faster effected in flocculation process but, the floc induced is small, more dense, tends to have spherical shape, and compacted, that is more suitable for direct filtration process.

7. Symbols

Symbols	Description	SI Unit
D_I	Impeller diameter	m
D_T	Diameter of mixing tank	m
$D_{noz.}$	Nozzle diameter	m
$d_{out.}$	Mixing tank outlet diameter	m
$d_{suc.}$	Diameter of suction in jet mixing tank	m
H_J	Height of jet mixing tank	m
H	Liquid height in mixing tank	m
R_c	Radius of curvature baffles	m
R_{df}	Radius of diffuser	m
r	Radius of mixing tank	m

S_z	Source term in z-direction of momentum equation	S_z
S_r	Source term in r-direction of momentum equation	S_r
S_θ	Source term in θ-direction of momentum equation	S_θ
W_b	Width of baffles	m
$\bar{u}$	Velocity in z-direction	m/s
$\bar{v}$	Mean velocity in θ-direction	m/s
$\bar{w}$	Velocity vector in R direction	m / s
μ_{eff}	Effective viscosity	Pa.s
Re_j	Reynolds number of jet	

8. References

1. G. Selomulya, 2001, "*The Effect of Shear on Flocculation and Floc Size / Structure* ". Ph.D. Thesis, university of New South Wales, Australia.

2. S. Ladislav, 2000, " *Solid – liquid separation* ", Butterworth – Heinemann, fourth edition.

3. D. Letterman, Raymond, Appiah, Amirtharajah and Charles, R. O. Melia, 2004 "*Coagulation and Flocculation*", separation technology, Article 8, vol. RP3.

4. N.Rajaratnam, 1976, "*Turbulent Jets*", Elsevier Scientific publishing Company.

http://www.milonic.com/bookZZ.org

5. A. W. Patwardhan and S. G. Gaikwad, February 2003, "*Mixing in Tanks Agitated by Jets*" Trans IChemE, vol.81, part A, pp.211-220,.

6. M. Rahimi, A. Parvareh, 2007, "*CFD Study on Mixing by Coupled Jet-Impeller Mixer in A large Crude Oil Storage Tank*", Elsevier, Computer and Chemical Engineering, vol.31, pp.737-744.

7. P. Kalaichelvi, Y. Swarnalatha and T. Raja, October 2007, "*Mixing Time Estimation and Analysis in a Jet Mixer*". Asia Research Publishing Network, Journal of Engineering and Applied Sciences, vol.2, No.5, pp.35-44.

8. A. Parvareh, M. Rahimi and A. A. Alsairafi, 2009, "*Experimental and CFD Studies on The Effect of The Jet Position on Mixing Performance*", Iranian Journal of Chemical Engineering, vol.6, No.3.

9. R. K. Grenville, J. N. Tilton, 2011, "*Jet Mixing in Tall Tanks: Comparison of Methods for Predicting Blend Times*", Elsevier, Chemical Engineering Research and Design, vol.89, pp.2501-2506.