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Experimental Investigation on Mixing time Analysis of Jet Mixer

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Abstract

Fluids mixing can usually be achieved using mechanical mixers and jet mixers. Each of these mixers may be selected and used in order to provide optimal operative condition. However the jet mixing system is more effective than other mixing methods because they are very expensive for large storage tanks and underground tanks. Jet mixers are used in industrial applications primarily in unit processes where liquid blending, solids suspension, flow generation or chemical reactions are key process parameters. Mixing of reactants, catalysts etc. in a chemical and bio-chemical reactor can be achieved using a jet mixer, which offers the advantages of having no moving parts inside the reactor. For the design of jet mixers much experimental work has been done and many correlations have been proposed. However these correlations are case specific and not valid for generic mixer. The work reported in this paper are based on the use of hydrodynamic techniques to simulate jet mixing in a cylindrical tank with an aspect ratio (H/D) of 1.2. The flow circulation pattern within the tank and the effect of liquid flow rate on mixing of a soluble salt are studied. It can be seen that the nozzle diameter having 11% active area (10mm diameter) and jet position 30 cm above, from bottom of the tank shows shortest mixing time for Newtonian and non Newtonian fluids. An increase in the nozzle diameter was found to increase the mixing time at a given level of power consumption. The optimum nozzle diameter and jet position are not universal, it varies with tank geometry. The nozzle was placed at an angle of 90^0 throughout the studies. An empirical correlation has been developed

Keywords: Jet mixer, mixing time, flow rate, nozzle diameter, nozzle clearance.

Introduction

Mixing Systems approach to jet mixing takes advantage of all the factors which increase mass transfer rates while lowering operating costs. In large storage tanks, the conventional top entry agitator may not be suitable for mixing or blending purposes[1]. Usually small side entry mixers are used, but they require mechanical seals and contain rotating equipment inside the tank. In such situations, mixing induced by jet of liquid can be advantages. In jet mixers a part of liquid from the tank is withdrawn and returned through a nozzle at high velocity with help of a centrifugal pump. The velocity difference between jet and bulk liquid creates a turbulent mixing layer at jet boundary[2]. This causes entrainment of surrounding liquid; as a result the jet grows in diameter and centerline velocity reduces in magnitude. A circulation pattern is created within the tank, which causes mixing. Jet mixers are easy to install; there is no requirement of any structural reinforcement of the tank and they are normally cheaper in cost as compared to conventional mixing devices. The maintenance of jet mixer is easier as they are no moving parts inside the tank[3]. Systematic studies of jet mixing are of fairly recent origin. The early work in this area was reported[4-5]to discuss about the performance figure of free jets for mixing fluids in large circular tanks, the studies having been conducted for the war-time purpose of utilizing existing underground storage tanks for blending aviation petrol.

The work reported in this paper are based on the use of hydrodynamic techniques to simulate jet mixing in a cylindrical tank. The flow circulation pattern with in the tank and the effect of liquid flow rate on mixing of a soluble salt were studied. An experiment was carried out to study the effects of various parameters such as nozzle diameter, jet clearance on mixing time. Three different diameter (10 mm, 15 mm and 22 mm) nozzles were designed for this purpose. These nozzles were placed at 21 cm, 27 cm and 30 cm above from base of the tank. The optimizations of nozzles were done by analyzing the holdup study. NaCl was used as a tracer, and the response to a step input was noted to calculate the mixing time[4]. Mixing time was calculated as the time required to achieve 80% fully mixed concentration, the effect of nozzle diameter and nozzle clearance on mixing time, effect of Power consumption on mixing time and effect of fluid property on mixing time were studied to discuss the effective distribution of mixing energy. The nozzle angle was fixed as 90^0 to horizontal throughout the experiment.

Material and Methods

Experimental Set up: The experimental setup used in this present study is shown schematically in figure-1 it consists of a cylindrical borosilicate glass tank of 500 mm diameter and 600mm height in which a nozzle is installed at the centre of the tank. A centrifugal pump is used to maintain recycling condition which withdraw fluid from the storage tank and deliver it through the nozzle into the mixing tank as a jet stream. A U-Tube manometer with carbon tetrachloride as a manometer fluid is used to measure the pressure difference inside the mixing

tank. The inlet flow rate is measured by pre-calibrated Rota meter of range (35-350) lpm and (10-100) lpm. The nozzles are specified by its active area and it is defined as the ratio of area of the jet to the area of the pipe.

Experimental Procedure: The water from storage tank was pumped in to the mixing tank through a nozzle; the output flow rate was adjusted to maintain the initial liquid holdup. After attaining the steady state the initial hold up was noted. The inlet flow rate was varied and then a small amount of sodium chloride was added into the mixing tank as a tracer. The concentration of the tracer was measured in terms of conductivity with respect to time and pressure drop was noted. The experiment was repeated for various flow rates. The effect of nozzle diameter and effect nozzle clearance on mixing pattern was studied by changing the nozzle size and nozzle position respectively by repeating the experiment.

Results and Discussion

The data obtained from the experiment was analyzed and discussed for effect of nozzle diameter on mixing time, effect of power consumption on mixing time, and effect of fluid properties on mixing time.

Effect of Nozzle Diameter on Mixing Time: Figure -2 a -2 c shows the plot between flow rate and mixing time for 10 mm, 15 mm, and 22 mm nozzles placed at 21 cm, 27 cm, and 30 cm above from bottom of the tank. From the graph it can be seen that the mixing time decreases with increasing flow rate irrespective of the nozzle diameter. Among the three nozzles employed for the experiment 10 mm nozzle (active area 11%) shows shortest mixing time compared to 15 mm (active area 20%) and 22 mm (active area 30%) nozzles. When 15 mm and 22 mm nozzles were used the mixing time found to be increased, this implies that the travelling path of the flow was disturbed and there is formation of secondary loop which result in increasing mixing time. The nozzle placed at 30 cm above from base of the tank shows the shortest mixing time for all the three nozzles. This implies that the increase in jet length decreases the mixing time. Hence 10 mm nozzle placed at 30 cm above base of the tank was fixed as optimum nozzle size and nozzle clearance for the geometry of the system.

Effect of power consumption on mixing time: Figure-3 a -3 c shows the plot between power consumption and mixing time for 10 mm, 15 mm, and 22 mm nozzles placed at 21 cm, 27 cm, and 30 cm above from bottom of the tank. From the graph it can be seen that the mixing time decreases with increasing power consumption irrespective of the nozzle diameter. Among the three nozzles employed for the experiment, 10 mm nozzle shows shortest mixing time compared to 15 mm and 22 mm nozzles. When 15 mm and 22 mm nozzles were used the mixing time found to be increased for same power input, also the nozzle placed at 30 cm above from base of the tank shows the shortest mixing time for all the three nozzles. Hence 10 mm nozzle placed at 30 cm above base of the tank was fixed as optimum nozzle size and nozzle clearance for the geometry of the system.

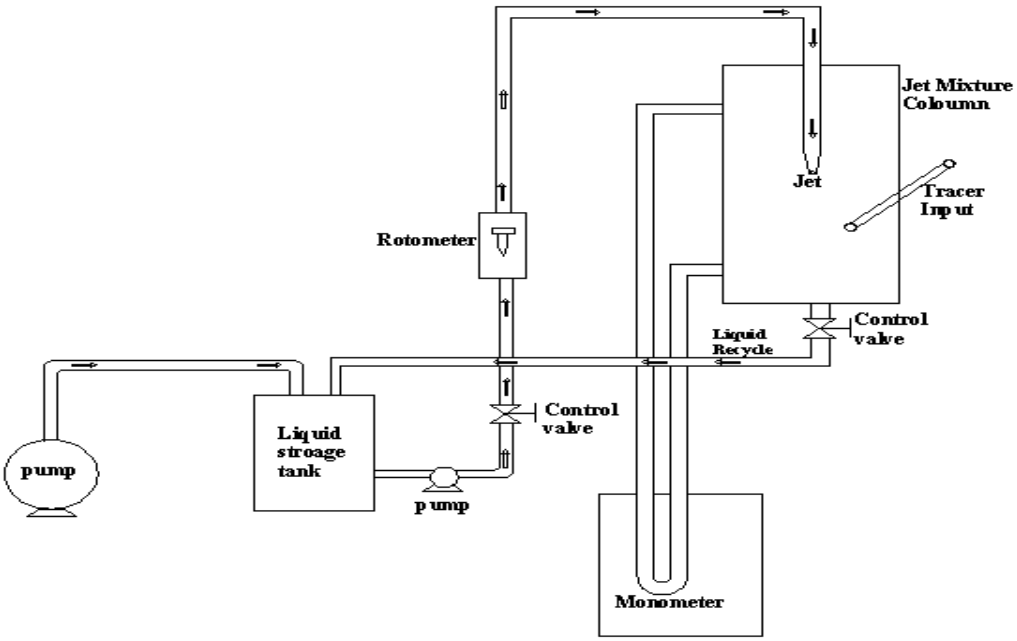

Figure 1
Schematic of Experiment set up

Comparison of performance of jet mixer for Newtonian and non –Newtonian fluid: The performance of jet mixer for Newtonian and non- Newtonian fluid was compared[12] by plotting the graph between flow rate and mixing time for 10 mm nozzle placed at C = 0.30 M. From figure-6 it can be seen that the mixing time was found to be minimum for water and increases for CMC and Gaur Gum with increase in concentration of the fluid. Ultimately it indicates the importance of the effect of fluid property on mixing time.

Effect of Viscosity on Mixing Time: Figure 5 shows the plot between liquid flow rate and mixing time for non – Newtonian fluid. The optimized nozzle size (10 mm) and nozzle clearance (C =0.30 M) have been used to study the effect of viscosity on mixing time. 0.2% and 0.3% carboxyl methyl cellulose and 0.2% and 0.3% Gaur Gum were used[10] as non-Newtonian fluid. From the graph it can be seen that the mixing time decreases with increasing flow rate for all the concentration of CMC and Gaur Gum. But the mixing time was found to be shortest for CMC compared to Gaur Gum; this implies that when viscosity of the fluid increases the mixing time also increases[8-9], this was due to the diversion of flow path and circulation path[11].

Comparison of nozzle performance: The performances of the entire three nozzles were compared by plotting the graph[6] between nozzle diameter and mixing times for a constant flow rate of 8 x 10^{-4} m³/s. From figure-4 it can be seen that the 10 mm nozzle shows the shortest mixing time for all the three nozzle position. When the nozzle was placed at C = 0.30 M position, the mixing time was found to be minimum when compared to C = 0.21 M and C = 0.27 M position. This emphasize that the nozzle size and nozzle location are extensively important in estimating the mixing time[7].

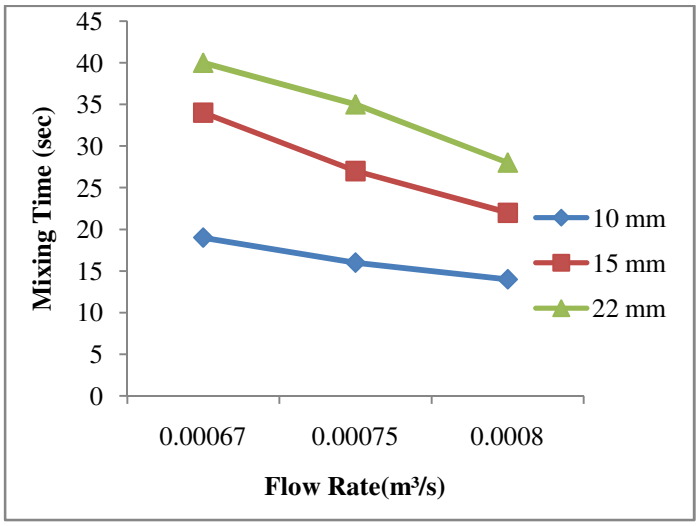

Figure-2 a
Effect of Flow Rate on Mixing Time C= 0.21 M

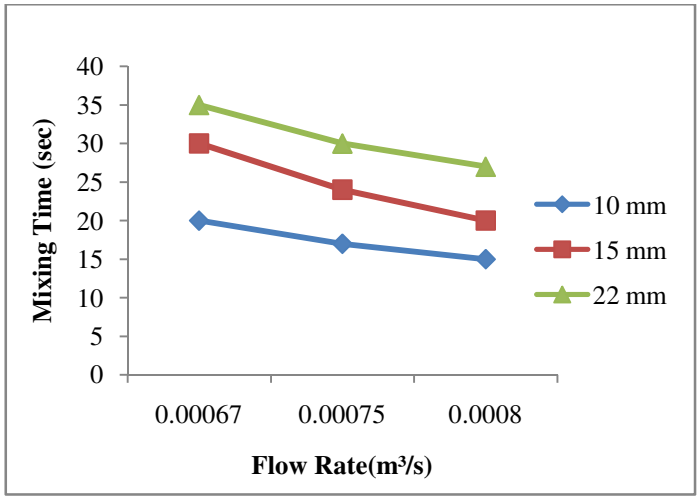

Figure-2 b
Effect of Flow Rate on Mixing Time C= 0.27 M

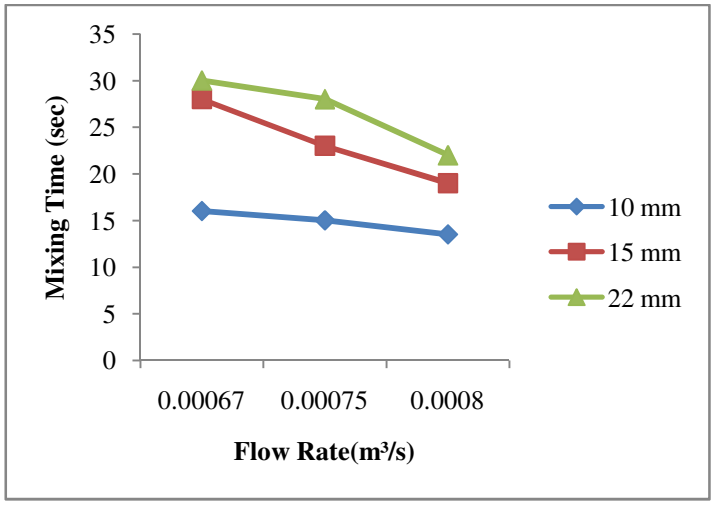

Figure-2 c
Effect of Flow Rate on Mixing Time C= 0.30 M

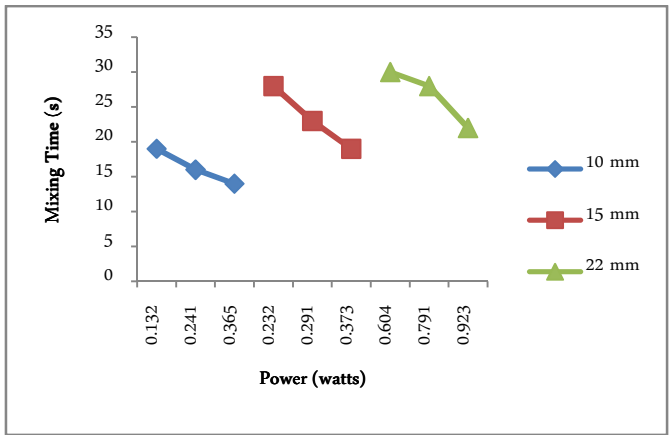

Figure-3 a
Effect of Power Consumption on mixing time C = 0.21 M

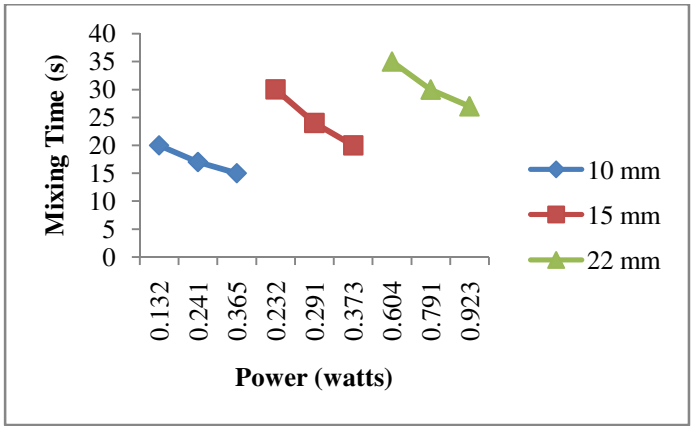

Figure-3 b
Effect of Power Consumption on mixing time C = 0.27 M

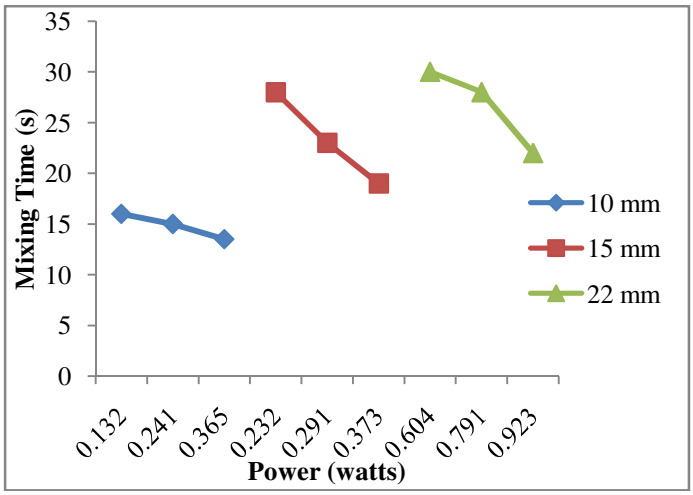

Figure-3 c
Effect of Power Consumption on mixing time C = 0.30 M

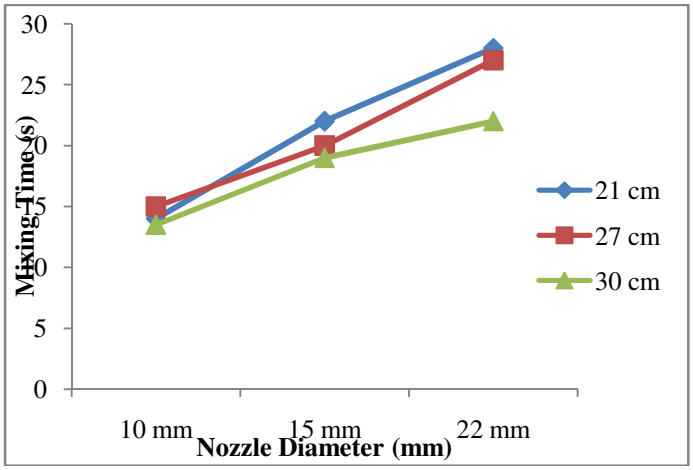

Figure-4
Comparison of nozzle performance Q = 0.0008 m³/s

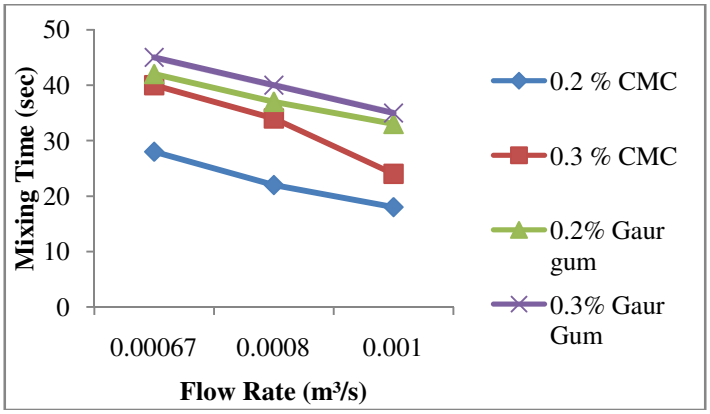

Figure-5
Effect of Mixing Time on Flow rate for non- Newtonian fluid

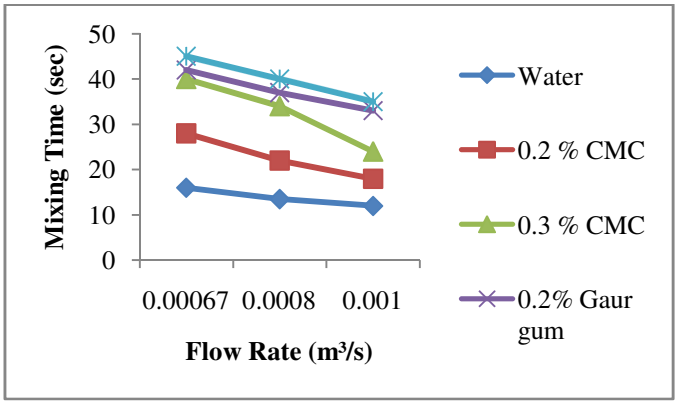

Figure-6
Comparison of Mixing Time for Newtonian and non-Newtonian fluid

Conclusion

Experiments are carried out by varying parameters like jet diameter and jet clearance to study their effects on mixing time for Newtonian (water) and Non-Newtonian fluids (carboxyl methyl cellulose, and Gaur Gum). Mixing time decreases with increase in liquid flow rate and power consumption. The effect of viscosity on mixing time was studied by using carboxyl methyl cellulose and Gaur Gum as working fluid. Results show that the mixing time increases with increase in concentration of the working fluid, this may be due to drop in jet velocity and minimization of circulation path and flow path with respect to water. The Mixing time for Newtonian fluid was found to be low when compared to non-Newtonian fluid. The optimum nozzle diameter was found to be the nozzle having 10 mm diameter, located at 30 cm above the base of the mixing tank[13]. The optimum nozzle design is not universal, and varies with the geometry of system

Correlation: An empirical correlation was developed for mixing time as a function of flow rate and nozzle diameter: $M_t = a\, Q^b\, D^c$, $\mathrm{M_t} = 0.001806254346\, \mathrm{Q}^{-1.77831}\, D^{0.802683}$

Notations D = diameter of the tank in meters, H = height of the tank in meters, Lpm = Liter per minute, C = clearance between nozzle and tank bottom in meters, P = power in watts, M_t = mixing time in seconds, Q = liquid flow rate in m³/s, M = meter, a, b, c = empirical constants.

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