ISSN:2348-2079

Volume-6 Issue-1

International Journal of Intellectual Advancements and Research in Engineering Computations

Investigation of mixing time for Newtonian fluids in jet mixer

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Abstract

Mixing is one of the common unit operation employed in chemical industries. Conventional mixers are equipped with impellers but are expensive for mixing in large storage tanks and underground tanks. Jet mixers have become an alternative to impellers for over 50 years in the process industry. For the design of jet mixers, the detailed hydrodynamics of the mixing process is not properly understood. In the present paper, hydrodynamic techniques are used to simulate jet mixing in a cylindrical tank. The flow circulation patterns with in the tank and their effect on mixing of a soluble salt are studied. An experiment was carried out to study the effects of various parameters such as nozzle diameter, jet position and jet velocity on mixing time. Results show that, for a given geometric arrangement, jet dia is significantly more important in determining mixing time of jet mixer for Newtonian fluids. The optimum jet was found to be the jet dia of 15 mm for jet located at various positions at the top of the tank which gave the shortest mixing time for Newtonian fluids. An increase in the nozzle diameter was found to reduce the mixing time at a given level of power consumption and in turn in the energy efficiency can be improved. The results obtained shows a good understanding of hydrodynamic aspects of mixing process in jet mixed tanks

Key words: *Jet mixing, liquid hold up, Newtonian Fluids, Mixing time, Jet diameter, Jet position.*

1. Introduction

Mixing is one of the common unit operations employed in chemical industries. Mixing is usually carried out in order to produce a uniform mixture and it can be achieved using mechanical mixers, fluid jet mixers, static mixer or pipe line with tees. It can be used for a variety of purposes. Eg, homogenization of physical properties and composition prevention of stratification or deposition of suspended particles, for and improved rates of heat, mass transfer and chemical reaction. Examples of mixing operations include dissolution, leaching gas, absorption, crystallization and liquid-liquid extraction. Depending on the specific application and process mixing may be done in batch wise or in continuous mode and the content may be stirred either by rotating turbines and propellers or by jets of liquid. Impellers are the conventional devices used for mixing purpose industries. But they are very expensive for large storage tanks and underground tanks. Jet mixers have become an alternative to impellers for over 50 years in the process industry in jet mixing; a part of the liquid in the tank is drawn through a pump and returned as a high velocity jet through a nozzle into the tank. This jet entrains some of the surrounding liquid and creates a circulation pattern within the vessel thus leading to mixing of the content. In jet mixers, a fast moving jet stream of liquid is injected into a slow moving or stationary bulk liquid. The relative velocity between the jet and the bulk liquid creates a turbulent mixing layer at the jet flow, entraining and mixing the jet liquid with the bulk liquid. Jet mixers have several advantages over conventional impellers. It has no moving parts as in conventional agitators, there by reducing maintenance costs, and it is easy to install when compared with impellers. Agitators require support at the top of the tank, implying a pre-requisite for thicker walls of stronger materials. Mechanical agitators show disadvantages at an industrial scale with regard to investment and energy costs, and also sterilization and maintenance in biochemical processes and jet mixers are preferable in such situations. Jet mixers are used for the following applications as well: blending the inhibitor into the monomer storage tank to stop violent runway exothermic polymerization reactions (Hoffman,1996); Mewes and Renz 1991), emergency cooling systems of chemical reactors in case of breakdown in operations (Schmetzek, 1995), bio chemical applications (Simon and Fonade 1993) and fast competitive consecutive reactions having a mixing sensitive reactions having a mixing sensitive product distribution (Baldyga, 1994).

Jet mixers are more appropriate for mixing processes involving chemically sensitive liquids, eg, preparation of food stuffs (Lane 1981) and acids mixing (Harnby 1985), crude oil storage tanks (Masoud Rahimi 2007) water storage tank (Michael Marek 2007) cross flow filtration using an unsteady jet (C.Maranges 1997), Electric desalting units in refineries (S.Sh. Gershuni 1981), Industrial furnace with a cross-flow-jet combustion system (L. Wang 2007) jet mixing in a slot has the potential to be applied for cooling in various components in gas turbines (Ting wang 2000). In the jet mixer, jet injected at the top of the tank. Jet mixers are easy to install. They are normally cheaper compared with conventional mixing devices. In large storage tanks the conventional top entry mixer may not be suitable. 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 a jet of liquid can be advantageous. Jet mixers can be used for sludge suspension processes where the particles are of fairly small size. The issues that need to be addressed are (i) effect of nozzle diameter (ii) The effect of jet position (iii) The effect of change in fluid properties. From a process point of view the various nozzle configurations need to be compared on the basis of different power input. The various factors that influence the energy efficiency, mixing time have to be studied.

For this purpose, the experiments were conducted in 500mm diameter, 600mm height column. Five different nozzles have been employed and it is optimized based on the holdup characteristics. In order to study the effect of viscosity non Newtonian fluid such as Carboxyl Methyl Cellulose (CMC), Guargum was employed. Finally, a correlation has been developed for holdup, mixing time based on the experimental studies.

2. Materials and Methods

2.1 Experimental set-up

The experimental setup is shown in figure 2.1.1. It consists of a cylindrical borosilicate glass tank of 500mm diameter and 600mm height in which a nozzle is installed at the centre of the tank. A centrifugal pump is used to maintain a recycling condition which withdraw fluid from the storage tank and deliver it through the nozzle where the fluid is ejected to the mixing tank as a jet stream. The borosilicate tank is equipped with sensors which are used to measure pH, conductivity, dissolved oxygen and temperature. A U-Tube manometer with carbon tetrachloride as a manometric fluid is used to measure the pressure difference inside the mixing tank. The inlet flow rate is measured by precalibrated rotameter (35-350lpm) and (10-100lpm).
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.

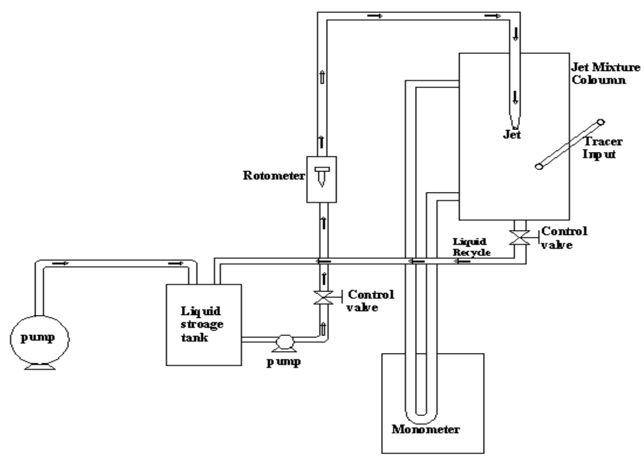

Fig.2.1.1 Experimental Set-up

2.2 Experimental procedure

The fluid from storage tank is pumped in to the mixing tank through a nozzle; the output flow rate is adjusted to maintain the initial liquid holdup. After attaining the steady state the initial hold up is noted. The inlet flow rate is varied then the corresponding variations in the liquid holdup and pressure difference are noted. The effect of jet position on mixing pattern is studied by changing the clearance between the nozzle and the bottom of the mixing tank.

The effect of geometrical properties on holdup is studied by changing the various diameters of nozzle and the same experimental procedure is followed.
From the observations obtained, the optimization of nozzle diameter is done and a correlation for liquid holdup is derived. To find out the Mixing Time in jet Mixed tank, Nozzle size 15mm (N3) Mixing Time was considered as the time required attaining 85% of the fully mixed concentration. A correlation for mixing time is derived.

3. Results and Discussion

3.1 Effect of Nozzle Diameter on Mixing Time for Newtonian Fluid

The effect of Nozzle diameter on mixing time for Newtonian fluid, jet mixer having diameter of 500mm and height of 600mm. For this purpose three different Nozzles were used and tested. In order to analysis the effect of Nozzle diameter on mixing time, the Nozzle positioned at the centre of the tank. The fluid was taken to be water. The effect of Nozzle diameter on mixing time was shown in figures 3.1.1. From this graph Nozzle diameter increased mixing time also increased. When jet dia increased the Reynolds No decreased. The effect was compared for three different jet Dias.

3.2 Effect of Jet Velocity on Mixing Time for Newtonian Fluid

Effect of jet velocity on mixing time for Newtonian fluid, jet mixer having diameter of 500mm and height of 600mm. For this purpose three different Nozzles were used and tested. In order to analysis the effect of jet velocity on mixing time, the nozzle positioned at the centre of the tank. The fluid was taken to be water. The effect of jet velocity on mixing time was shown in figure 3.1.1. From this graph, the Nozzle N2,N3,N4 is used, when velocity increased, the mixing time decreased when jet dia increased, the velocity increased. The effect was compared for three different jet Dias.

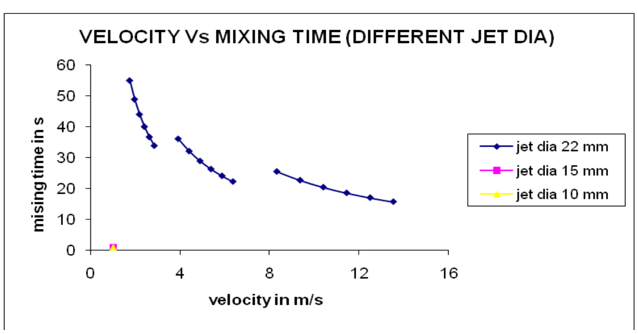

Fig 3.1.1. Effect of velocity vs mixing time for Newtonian fluid water (Nozzle dia : 22,15,10 mm)

3.3 Effect of Jet Reynolds Number on Mixing Time for Newtonian fluid

Effect of jet Reynolds No. on mixing time for Newtonian fluid, jet mixer having diameter of 500mm and height of 600mm. For this purpose three different Nozzles were used and tested. In order to analysis the effect of jet velocity on mixing time, the nozzle positioned at the centre of the tank. The fluid was taken to be water. The effect of jet velocity on mixing time was shown in figure 3.3.1.From this graph, the Nozzle N2,N3,N4 is used, when jet Reynolds No. increased mixing time decreased. When jet dia increased, jet Reynolds No. decreased. The effect was compared for three different jet Dias.

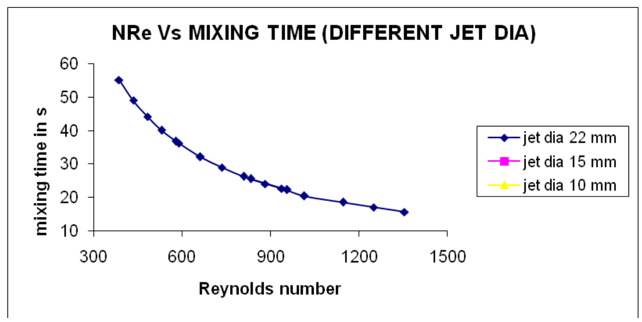

Fig 3.3.1. Effect of Reynolds number vs mixing time for Newtonian fluid

3.4 Effect of Power Requirement on Mixing Time for Newtonian Fluid

Effect of power on mixing time, this section deals with energy efficiency of jet mixer for Newtonian fluid. Previous researches have shown that the jet mixers are less energy efficient as compared with the top energy agitators, but are economically attractive. Grenuille and Tilton (1996) investigated the mixing process by giving pulse of tracer (electrolyte) through the jet Nozzle and by monitoring the conductivity at three locations with in the tank. They have propsed that the mixing process was controlled by the turbulent kinetic energy dissipation rate in the region far away from the jet entrance. They have taken the energy dissipation rates in the region far away from the Nozzle to be proportional to jet velocity and the jet diameter at the location.

The power requirement on mixing time for Newtonian fluid was calculated using the formula in chapter 3.8. Various correlations available in literature (Fossett and Prosser 1949, Okita and Oyama 1963, Grenuille and Tilton 1996, 1997) used to predict the mixing time show that the mixing time is inversely proportional to the jet velocity and the Nozzle. The correlation reported Grenuille and Tilton (1996,1997) are valid over a very wide range of the tank diameter.

The effect of power requirement on mixing time for Newtonian fluid at different jet diameter was shown in figure 3.4.1. From this graph, thus for a given level of power consumption, an increase in the nozzle diameter would reduce the mixing time.

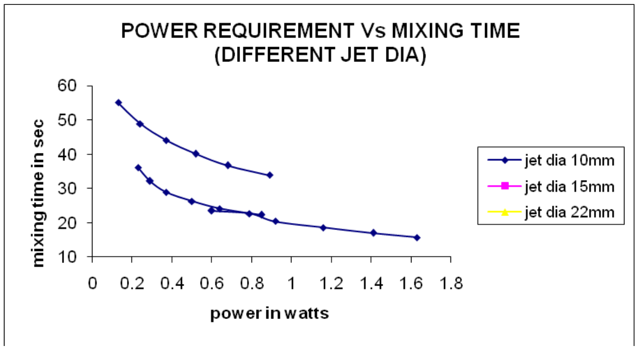

Fig 3.4.1. Effect power requirement vs mixing time for Newtonian fluid

4. Conclusions

Jet mixers can be suitably replaced in place of conventional mixers for large tanks. Among the nozzle design studied nozzle with active area of 20 % shown more holdup with less power consumption. Jet position (from bottom of the vessel) of 27 cm shows more hold up. The power consumption increase with an increase in concentration of the fluid. Correlation has developed for holdup with an error +/-27 %. The optimum Nozzle position, the mixing time for different jet velocity at different jet dia, increases in jet velocity, mixing time decreased. Increase in jet Reynolds No. Mixing time decreased. In this study, increase in the nozzle diameter was found to reduce the mixing time at given level of power consumption and in turn the energy efficiency can be improved for Newtonian fluid.

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