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Comparison of Hydrodynamic Behavior of Jet Mixer for Newtonian and Non-Newtonian Fluids

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Abstract

Mixing is an important, even fundamental, operation in nearly all chemical industries. Mixing can usually be achieved by mechanical mixers and Jet mixers. Each of these mixers may be selected based on the operating and installation cost. However jet mixers are preferred, when compared to conventional mixers because they offer several advantages including lower costs of construction, maintenance and operation. Therefore investigation of effective operational parameters is important. In this article the hydrodynamic behavior of jet mixer was studied for Newtonian and non-Newtonian fluid. Experiments were conducted in a cylindrical tank with the shape factor of H/D=1.2. Nozzle diameter and nozzle position for the given geometry were optimized. Effect of nozzle diameter on fractional hold up as well as effect of nozzle position on fractional hold up were studied and compared for Newtonian fluid(tap water) and non-Newtonian fluid(CMC and Guar Gum). From the results, it can be seen that the fractional hold up increases with increase in liquid flow rate for both Newtonian and non-Newtonian fluids. Among the three fluids water shows more holdup than other two fluids at nozzle location 30 cm above the base of the tank for10 mm nozzle. Also the fractional hold up decreases with increase in concentration of the working fluid

Keywords: Jet mixer, fractional hold up, flow rate, hydrodynamics, nozzle diameter.

Introduction

Mixing in stirred tanks is a common practice in many chemical, oil and petrochemical industries. Stirred tanks are widely used in the process industries to carry out many different operations[1] including, blending of miscible liquids into a single liquid phase, suspension of solids, heat and mass transfer promotion, chemical reaction, etc.

Mixing by impellers and jets are two known methods for fluid homogenization in the liquid phase. The jet mixers are cheap and are easily installed relative to the impeller mixers. A jet needs just a pump for fluid circulating, a cheap nozzle and some simple piping works. In the jet mixing, a part of the liquid inside the tank is drawn through a pump and returned into the tank[2]. Therefore, similar to the mixing by an impeller, a circulating pattern is maintained in the tank by a jet which causes liquid homogenization. For the design of jet mixers, the detailed hydrodynamics of the mixing process is not properly understood[3]. Performance figures of free jets for mixing fluids in large circular tanks were reported[4-5] in the early work.

In this present work, hydrodynamic techniques are used to simulate jet mixing in a cylindrical tank. The flow circulation patterns with in the tank and the effect of liquid flow rate on fractional hold up for Newtonian and Non-Newtonian fluids are studied. An experiment was carried out to study the effects of various parameters such as nozzle diameter, jet position and liquid flow rate on fractional hold up. The effect of nozzle diameter was studied for jet mixer having diameter of 500mm and height of 600 mm, cylindrical vessel. For this purpose three different nozzles were designed and tested in the above tank. For all the studies nozzle was placed at an angle of 90^0. In order to compare the effectiveness of the nozzle, the end effect was compared based on the active area. The various nozzles studied in this work are 22mm, 15mm, and 10mm diameter

Material and Methods

Experimental Set Up: The schematic diagram of experimental set-up used in this present study is shown in figure 1 the mixing tank is made-up of a cylindrical borosilicate glass tank of 500 mm diameter and 600mm height in which a nozzle was installed at the centre of the tank. A centrifugal pump was used to withdraw fluid from the storage tank and deliver it through the nozzle with high velocity into the mixing tank as a jet stream. A U-Tube manometer was used to measure the pressure difference inside the mixing tank. The inlet flow rate was measured by pre-calibrated Rota meter (35-350 Lpm) and (10-100 LPM). Different type of nozzles used to study 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 fluid 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 has been noted. The inlet flow rate was varied then the corresponding variations in the liquid holdup and pressure difference were noted. The effect of jet position on mixing pattern was studied by changing the clearance between the nozzle and the bottom of the mixing tank. The angle of injection was fixed as 90^o throughout this study. The effect of geometrical properties on holdup was studied by changing the various diameters of (10mm, 15mm and 22mm diameter) nozzle placed at three different positions (21cm, 27cm, 30cm above from base of the tank) and the same experimental procedure was followed. From the experimental result, the optimization of nozzle diameter was done for the given tank geometry. The optimized nozzle was used to repeat the experiment for non-Newtonian fluid such as carboxyl methyl cellulose and guar gum.

Results and Discussion

Result shows that, for a given geometric arrangement, jet diameter is significantly more important in determining hydrodynamic aspects of jet mixer. Experimental results obtained on fractional hold up for various nozzle sizes (22 mm, 15 mm and 10 mm), different nozzle location (21 cm, 27 cm and 30 cm from bottom of the tank) have been analyzed for i. Effect of nozzle diameter on fractional hold up, ii. Effect of nozzle position on fractional hold up, and iii. Effect of power consumption on fractional hold up for Newtonian and Non-Newtonian fluids. An optimum nozzle diameter was obtained. The optimized nozzle was used to repeat the experiment with Non-Newtonian fluid such as carboy methyl cellulose (CMC) and guar gum as working fluid. Again the nozzle was placed at three positions cited above for confirmation of Jet length.

Comparison of Nozzle Diameter on Fractional Hold up: The effect of nozzle diameter on fractional hold up was compared[6] by plotting the graph between nozzle diameters vs. fractional hold up for a constant flow rate. The flow rate was fixed as 8 x 10^{-4} m^3/s (figure 2). From the graph it was observed that nozzle having 10 mm diameter located at 30 cm above the base of the tank shows more hold up.

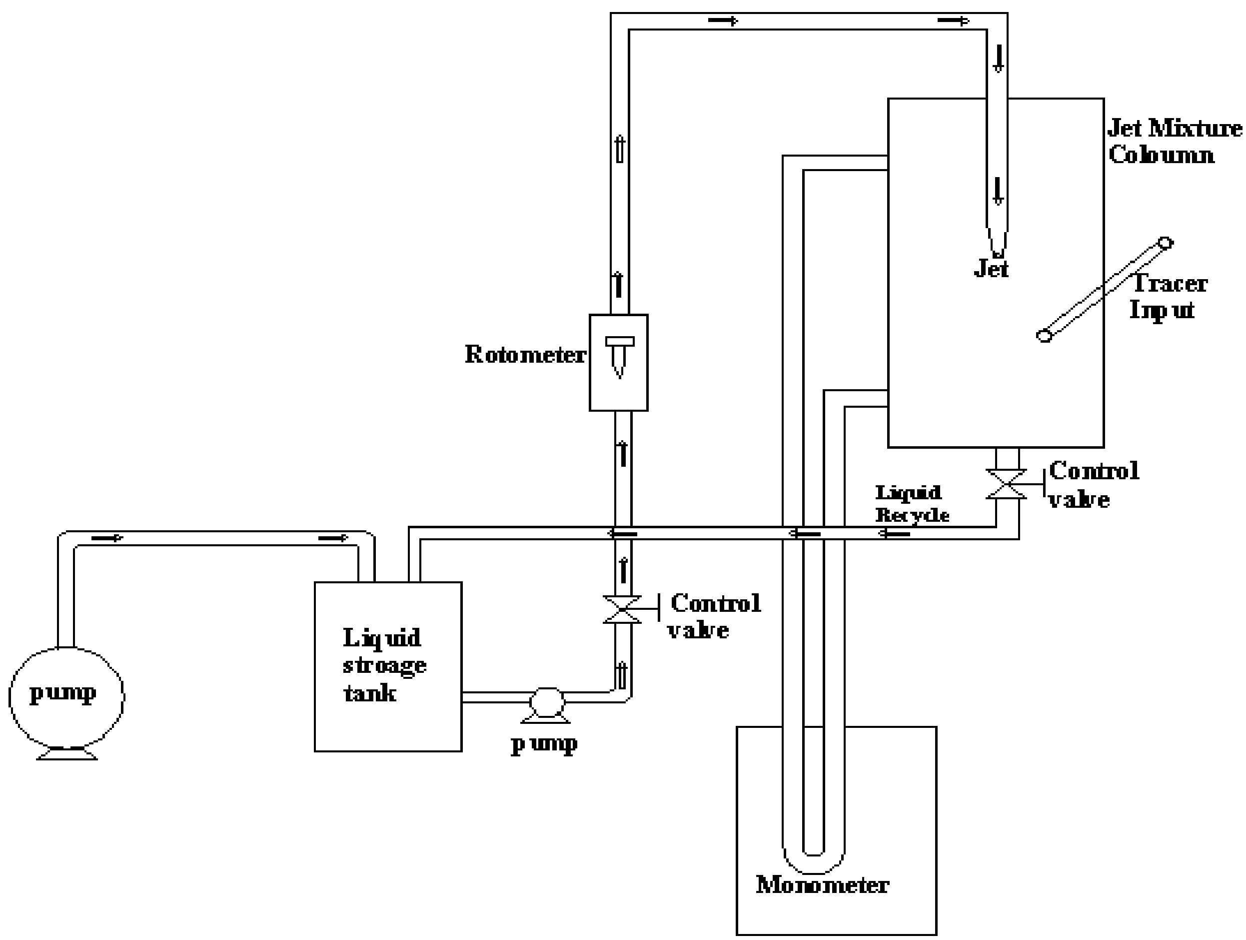

Figure 1
Schematic of Experimental Set Up

Comparison of Effect of Power Consumption on Fractional Hold up: The effect of power consumption on fractional hold up was compared[6] by plotting the graph between nozzle diameter vs. fractional hold up or for a constant power input. The power consumed was fixed as 0.37 watts (figure 3). From the graph it was observed that nozzle having 10 mm diameter located at 30 cm above the base of the tank shows more hold up.

Optimum Condition for Tank Geometry: The optimum nozzle design for the geometry was confirmed by plotting the graph (figure 4a - c) between power consumption and nozzle diameter for constant fractional hold up and repeated for all the three locations, the fractional hold up was fixed as 0.1, 0.2, and 0.3. From all the graphs, it was observed that the nozzle having diameter 10mm, is optimum irrespective of jet position. The power consumption was less for 10mm nozzle. The optimum nozzle design is not universal, and varies with the geometry of system[6] the power consumption was found to be shortest for fractional hold up 0.1in all the cases. The power consumption for 10 mm diameter nozzle placed at 30 cm above from the base of the tank was found to be 0.22 watts corresponding to 0.1 fractional hold up. Power consumption for 15 mm, and 22mm nozzle at same location was found to be 0.26 and 0.33 watts respectively for same hold up. The optimum nozzle for the given geometry was fixed as 10 mm diameter nozzle and the position was fixed as 30 cm above from the base. This implies longer jet length gives better result[7].

Effect of Viscosity on Fractional Hold Up: The efficiency of mixing in a Jet Mixer has significant importance on the viscosity of the working fluid[8-9]. The effect of viscosity was on fractional hold up was analyzed for the optimized diameter nozzle placed at all the three position. In order to study the effect of viscosity test fluid namely carboxyl methyl cellulose (CMC) and Gaur gum were employed[10]. The concentrations of CMC were varied in the range of 0.2 to 0.5 % (vol.). The effect of flow rate on holdup for various concentrations (0.2%, 0.3% and 0.5%) of CMC were plotted to emphasize the effect of fractional hold up for various flow rate ranging from 0.00067-0.0011 m^3/s.

Also the effect of fractional hold up on flow rate was studied for various concentrations on Guar Gum (0.2%, and 0.3%). The effect of fractional hold up on various flow rates ranging from 0.00067-0.0011 m^3/s. were plotted and compared with that of Newtonian fluid as shown in figure 5a-c. From these figures it can be seen that the holdup decrease as concentration of fluid increases. This may be due to the reduction in jet velocity[11]. Also the flow path and circulation path is minimized when concentration of fluid is increased with respect to water.

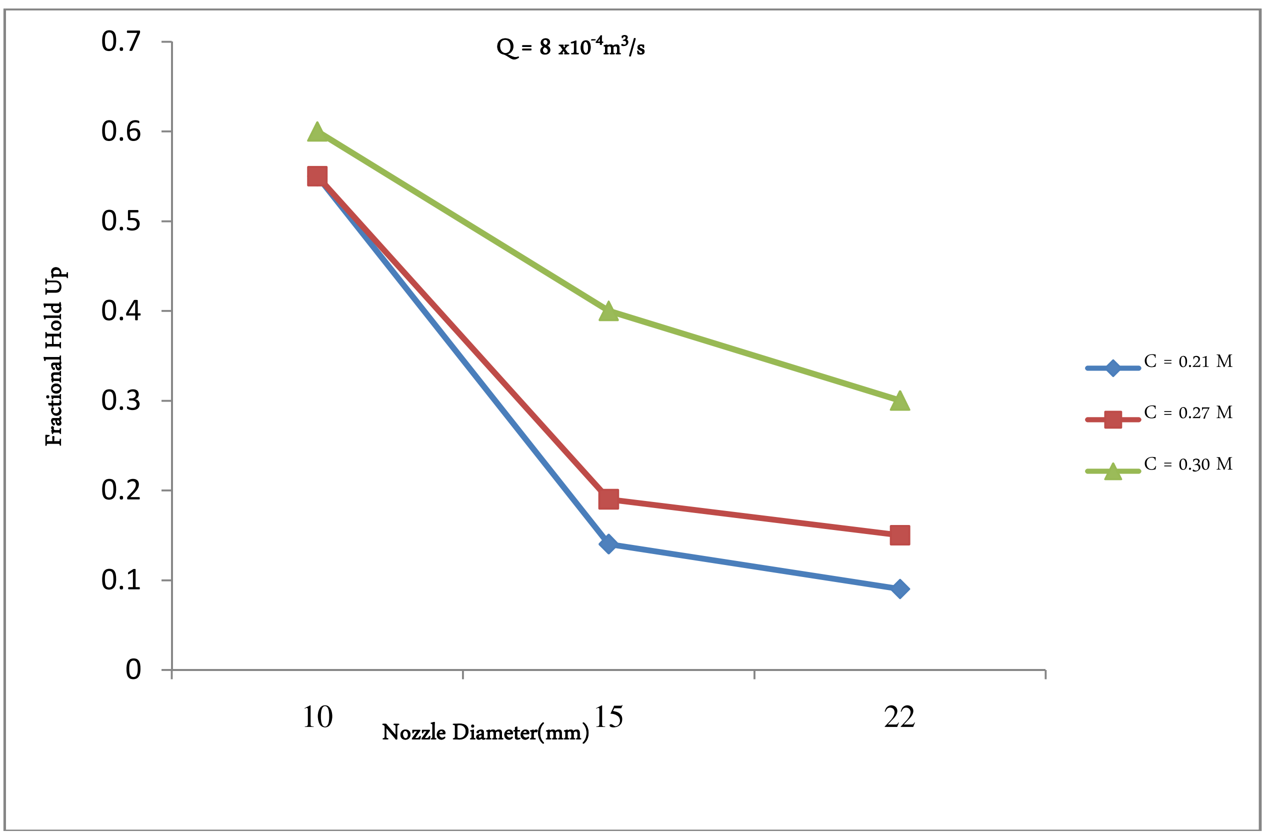

Figure 2
Comparison of Fractional Hold Up

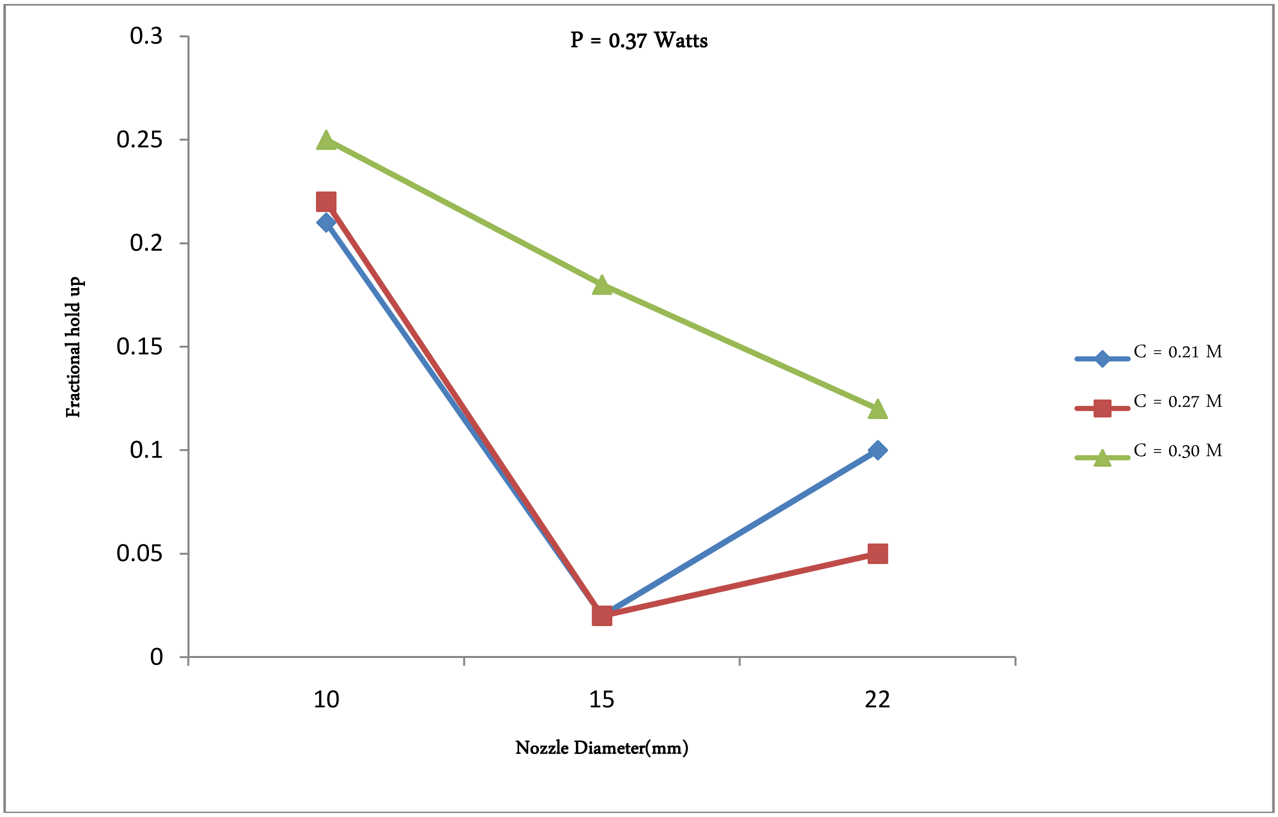

Figure 3
Comparison of Effect of power on fractional hold up

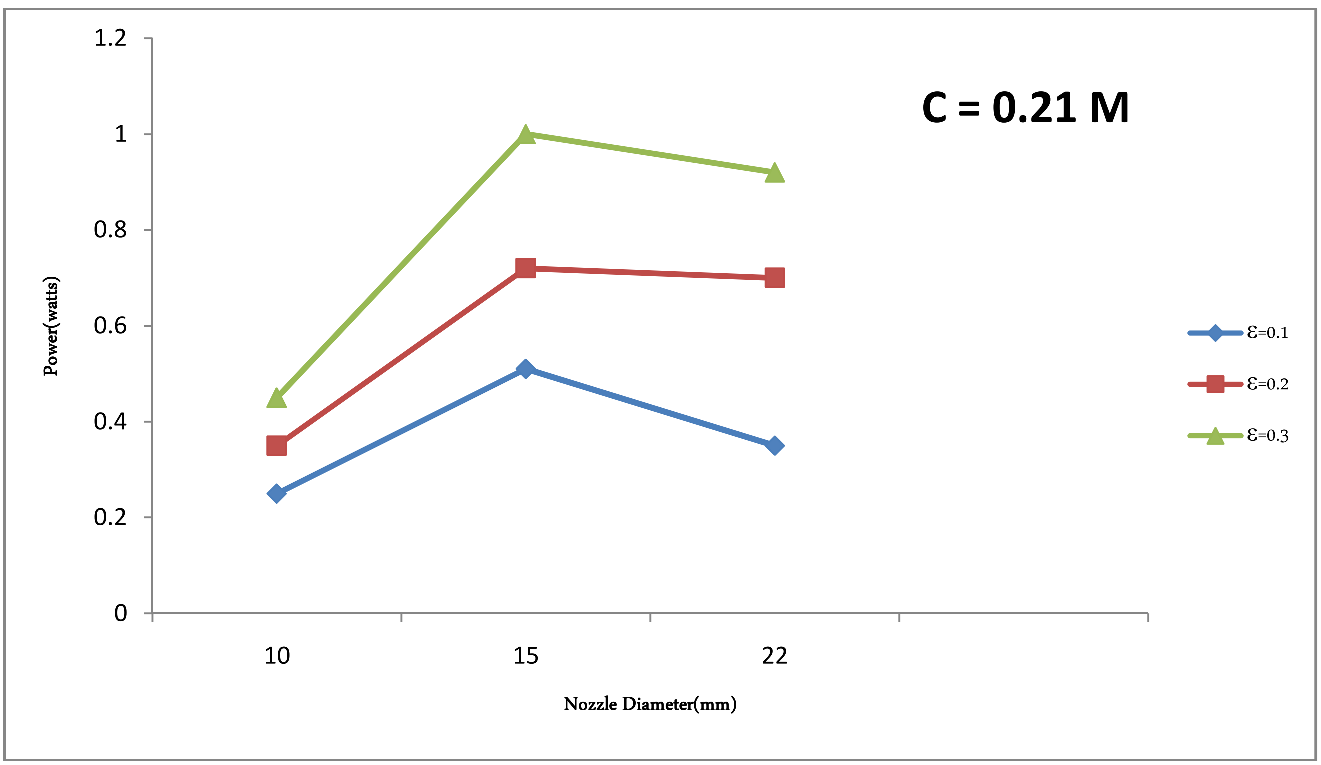

Figure 4 a
Nozzle Diameter Vs Power

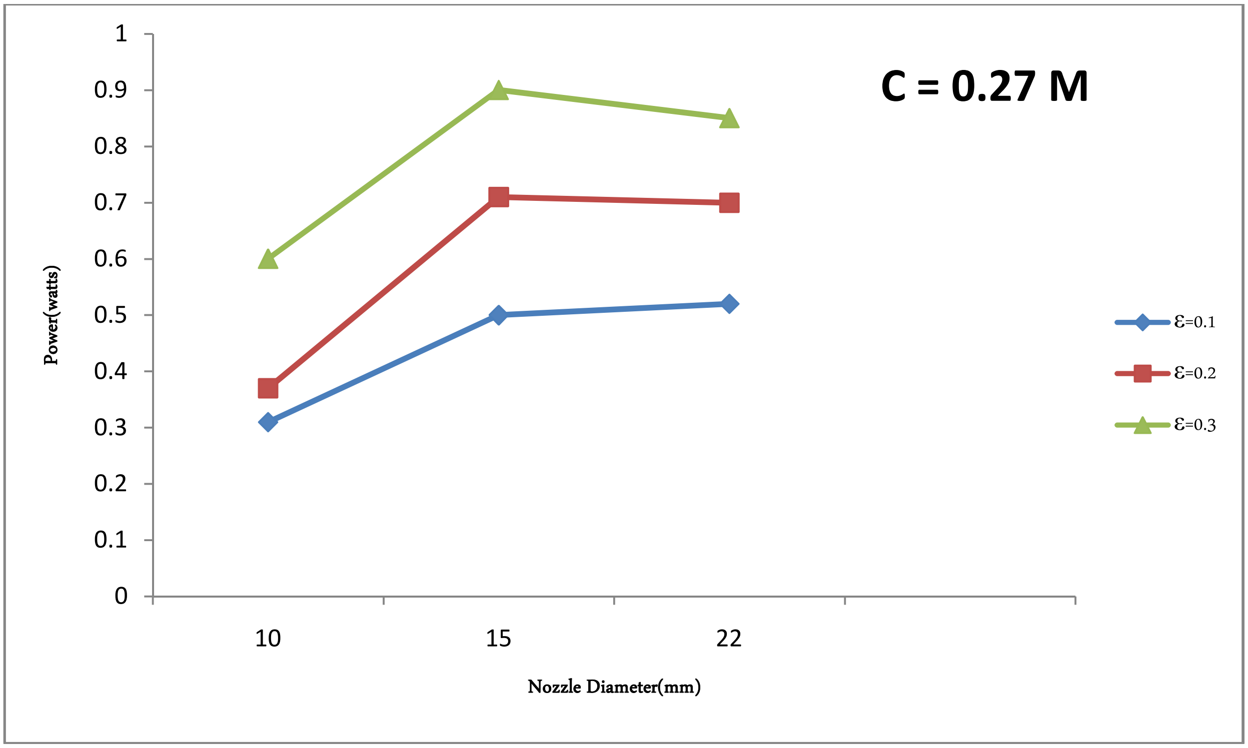

Figure 4 b
Nozzle diameter Vs power

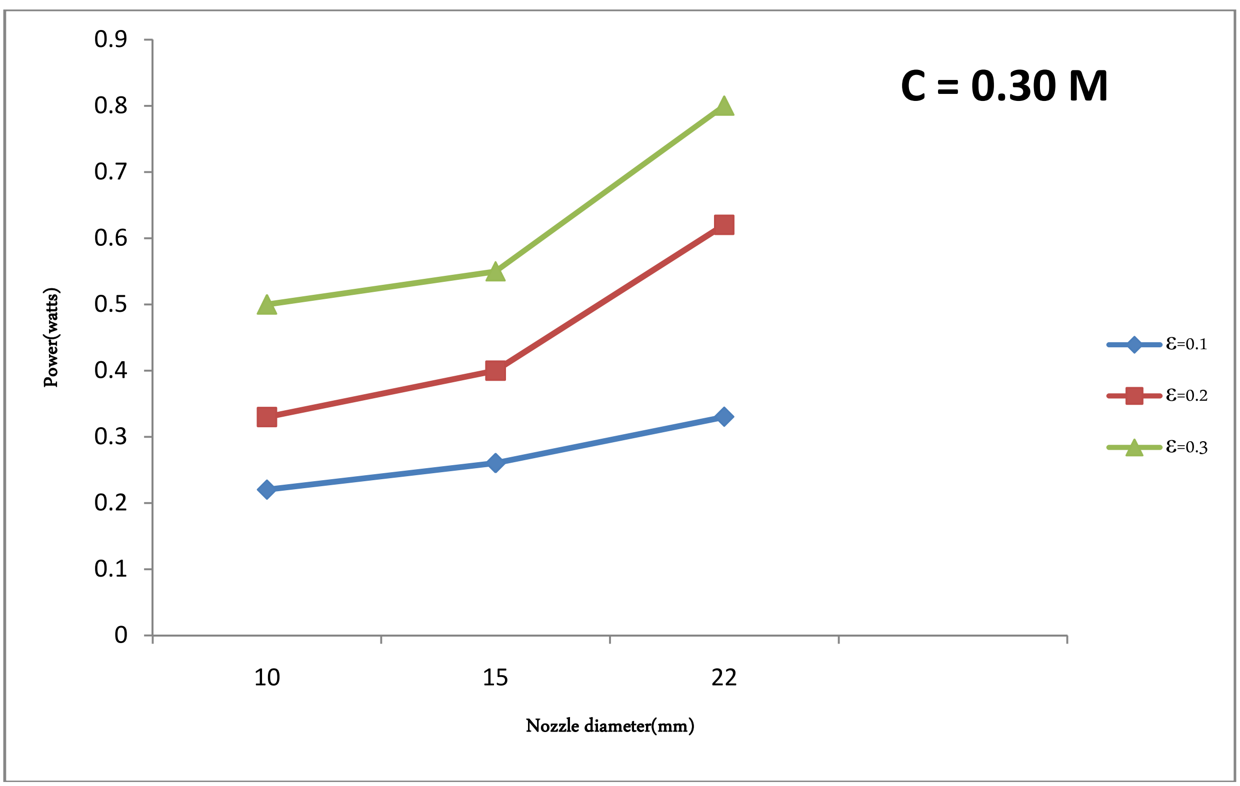

Figure 4 c
Nozzle Diameter Vs Power

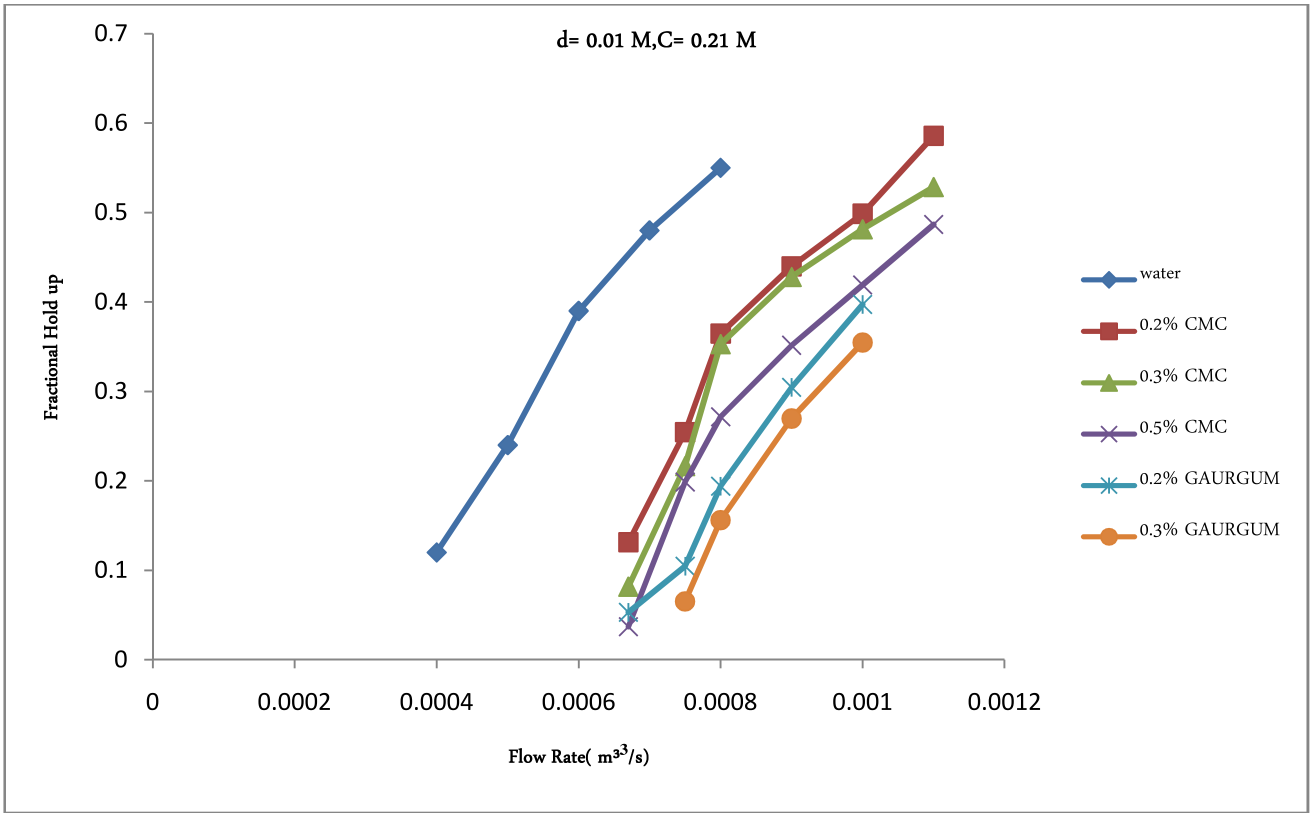

Figure 5 a
Comparison of Fractional Hold Up For Newtonian and Non-Newtonian Fluid

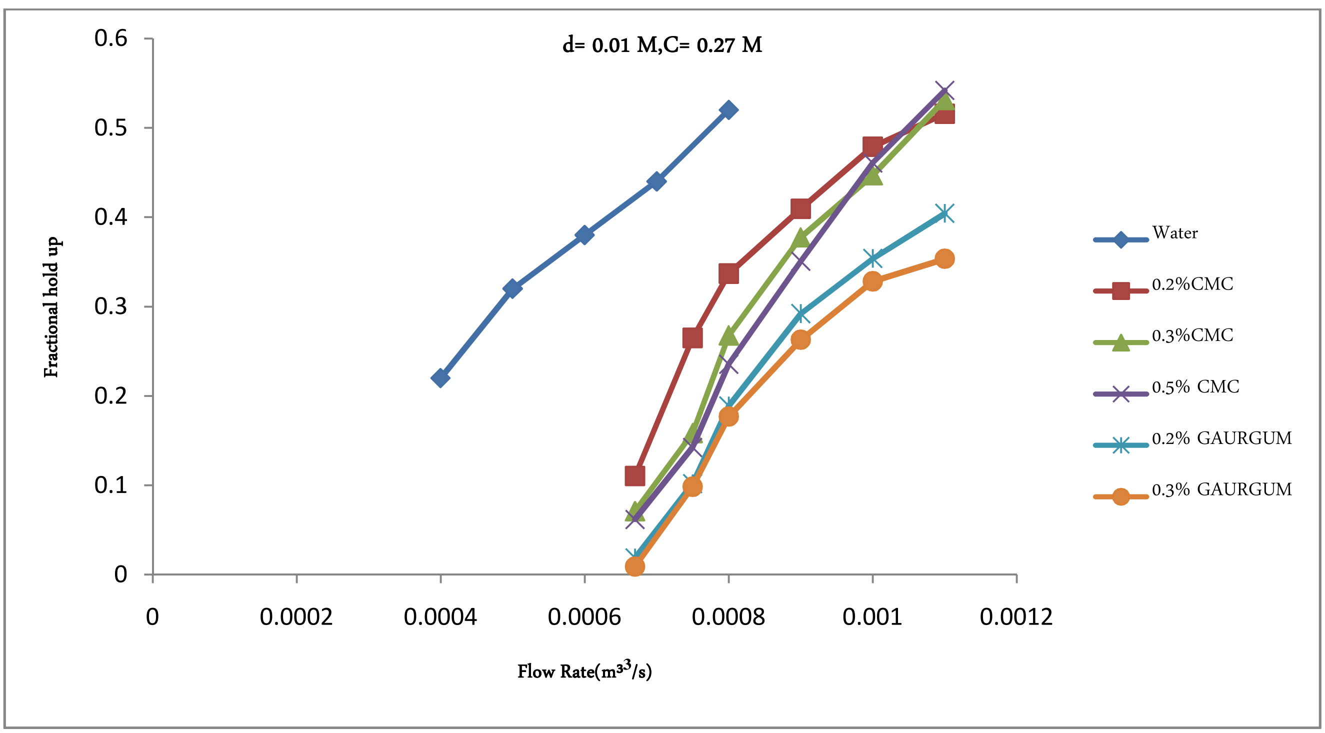

Figure 5 b
Comparison of Fractional Hold Up For Newtonian and Non-Newtonian Fluid

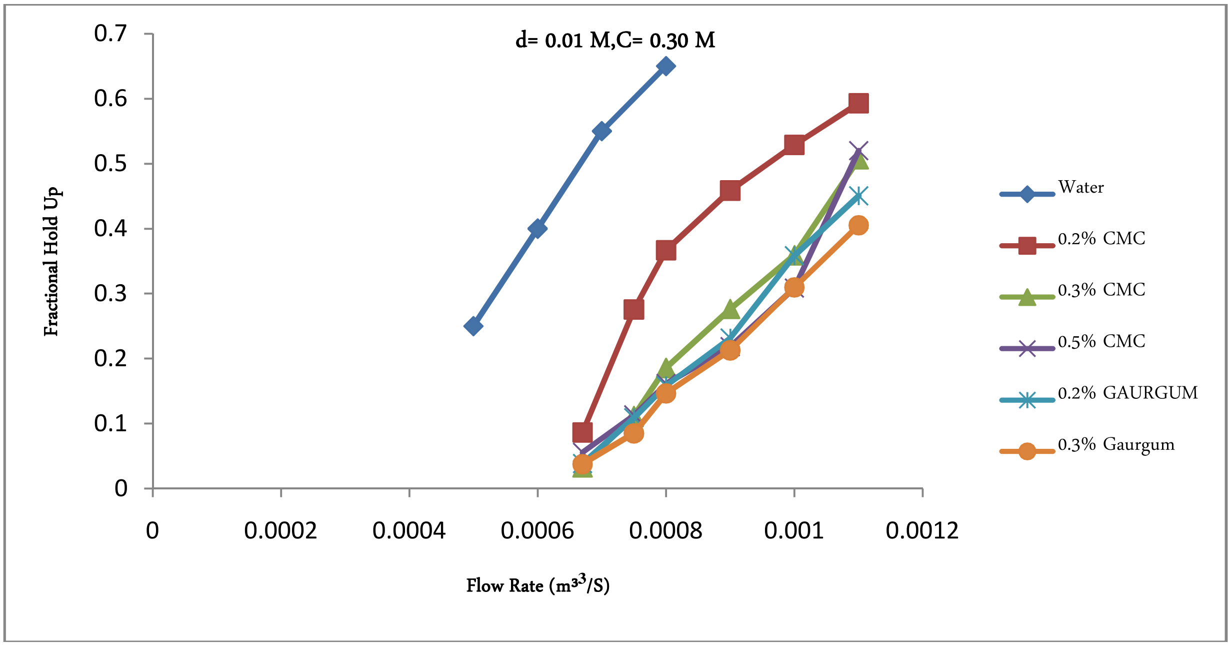

Figure 5 c
Comparison of Fractional Hold Up For Newtonian and Non-Newtonian Fluid

Conclusion

Experiments were carried out by varying parameters like jet diameter and jet position to study their effects on fractional hold up as well as power consumption for Newtonian (water) and Non-Newtonian fluids (carboxyl methyl cellulose, gaur gum) Fractional hold up increases with increase in liquid flow rate and power consumption. The effect of viscosity on fractional hold up studied by using carboxyl methyl cellulose and Gaur gum as working fluid. Among the three fluids water shows more holdup than other two fluids at nozzle location 30 cm above the base of the tank for10 mm nozzle. Also the fractional hold up decreases 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 optimum nozzle diameter was found to be the nozzle having 10mm diameter, located at 30 cm above the base of the mixing tank. The optimum nozzle design is not universal, and varies with the geometry of system.

Nomenclature: H/D = ratio of tank height to diameter, Q = volumetric flow rate in m^3/sec, P = power in watts, C= clearance between nozzle and tank bottom, d = nozzle diameter ε = fractional hold Up, M = meter.

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