IMPROVING WALL VELOCITY IN NON-NEWTONIAN MIXING TANKS

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Abstract

The aim of this project was to determine a retrofit impeller design for tanks for non-Newtonian slurries, such that an increased tank wall velocity (and hence reduced scale growth) could be achieved within the constraint of the existing motor power.

The study was carried out using a scaled-down model mixing tank at CSIRO Fluids Engineering laboratory. The tank was fully instrumented for torque and speed measurements. The non-Newtonian viscous slurry flow in the de-silication tanks was modelled with a clear Carbopol solution with similar non-Newtonian rheology to the industrial material. Velocity profiles near the tank wall were measured at several vertical heights in the tank using Laser Doppler Velocimetry via a fibre optic probe mounted on an industrial robot. Tanks studied included those with multiple Lightnin A310 impellers as the original configuration.

Several different modified agitator configurations were tried with the best results for the wall velocity being for the case where the agitators were adjusted to increase the operating speed without changing the power. It is thought that this is due to the shear thinning nature of the slurry allowing a reduction in the effective viscosity (and hence tank resistance) due to increased shear rate as the agitator speed is allowed to increase. Improved agitator designs were found which could provide median velocity increases of the order of 20-30% near the tank wall without extra agitator power as demonstrated by velocity measurements.

1 Introduction

The problem of scale build-up in minerals processing equipment is a common one leading to much expense in scale removal during scheduled maintenance. If possible it would be desirable to design the flow and chemical systems such that scale did not occur in the first place i.e. prevention rather than cure.

One possible way of preventing scale is to increase the velocity adjacent to the wall. This leads to a reduced tendency for material to remain in the vicinity of the wall and hence grow scale. There is also an increased shear stress on the wall which could also inhibit scale growth.

The alumina industry (as well as other minerals processing industries) has mixing tanks where the slurry behaves essentially as a non-Newtonian fluid, for example de-silication tanks. These tanks can have a scale problem; hence there would be interest in determining a means of reducing scale growth. If possible this should be done without using any excess power over the present setups.

One approach to this goal is to consider whether the impeller arrangements are optimised for the tank and the fluid. Most impellers are typically designed for water rather than non-Newtonian fluids and hence may not be optimised for other fluids. It is expected that a generalised solution will not be found due to the widely differing rheologies found in practice; however a general principle may be able to be determined.

This paper describes an experimental program carried out at CSIRO to determine if it is possible to improve wall velocity of non-Newtonian fluids in mixing tanks by optimising the impeller arrangements. The basic philosophy of the tests was to measure tank near wall velocities for a typical benchmark case and compare these measurements with the modified impeller configurations.

2 Experimental equipment

2.1 *Mixing tanks*

Two mixing tanks were used for this work, simulating full scale tanks with differing aspect ratios. One tank had an internal diameter of 1.07 m and height of 1.8 m and the other 1.0 m internal diameter and height 3 m. Both tanks were made from clear acrylic tube and were mounted inside square cross section glass tanks to minimise optical distortion. The impellers are driven by a three-phase electric motor and controlled by variable frequency drives. Both tanks are fully instrumented for shaft torque and speed with the sensors being between the motor and the impeller shaft. Figure 1 shows a photograph of the 1.0 m tank together with the robot mounted LDV system described in the next section.

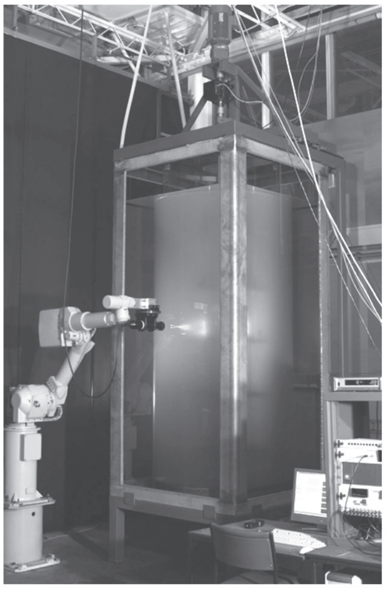

Figure 1. View of 1.0 m diameter 3.0 m tall tank (high aspect ratio) and robot mounted LDV system.

A set of 508 mm (20 inch) A310 impellers with adjustable pitch angles was available for these tests. They were modified to allow the fitting of extension tips to test the option of increasing the blade diameter. A range of impellers of smaller diameters were also available.

2.2 *LDV system*

Velocity measurements are made within the near wall region of the tanks by laser-Doppler velocimetry. This is a technique for non-invasive velocity measurements using intersecting laser beams and is described in considerable detail by Durst et al (1981). A brief description of the simplified principle of operation is included here.

The basic instrument consists of two intersecting laser beams focussed to a region known as the measuring volume typically 1mm long x 0.2mm diameter. The intersecting beams form a region of interference fringes (alternating light and dark stripes). The flow requiring measurement is seeded with small particles (typically 2–5 microns), small enough to follow the flow. As a seed particle passes through the measuring volume, it scatters light with a modulation due to the fringes. The scattered light is picked up by a photo-detector and the frequency measured by the electronics system. The particle and hence fluid velocity is then calculated by using the frequency and geometry of the optical arrangements.

Commercial LDV systems used for the present work were fibre optic based systems where the laser transmitting and receiving optics are housed in a probe which is connected to the water cooled laser and electronics by means of optical fibres. The probes are mounted on industrial robots as shown in Figure 1 and traversing and data collection is automated using a PC. The LDV systems were manufactured by TSI and Aerometrics and the robots by Fanuc.

Rheology measurements were made with a Bohlin CVO50 controlled stress rheometer using cone and plate geometry

2.3 *Fluid rheology*

It was desired to model a typical industrial slurry (bauxite slurry), the rheology of which was described by the Herschel-Bulkley model i.e. a fluid with a yield stress which is shear thinning. In this case it was assumed that the solids were sufficiently fine to be included in the fluid i.e. the slurry was considered homogeneous. It was also required that the fluid be transparent to allow the LDV velocity measurements. A solution of Carbopol 980 (0.15% w/w) supplied by B.F. Goodrich was made up with deionised water to simulate the rheological behaviour of the slurry. The viscosity behaviour of the slurry as measured by an alumina refinery together with typical data is shown in Figure 2.

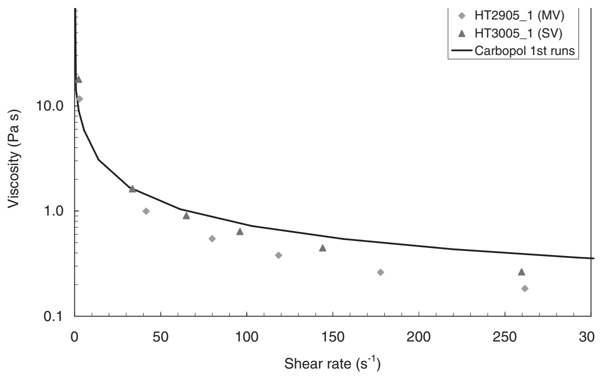

Figure 2. Comparison between Carbopol used for initial tests and rheology of typical bauxite slurry. Viscosity vs shear rate.

3 Operating parameters for benchmark case

The mixing flow pattern in a tank is a function of the generalised Reynolds number. A dynamic similarity is assumed at the laboratory scale tank at the same Reynolds number. For the present case the approach used was to operate the model tank with the same Power Number as a full–scale tank, which was 1.39 for a full scale tank studied by the authors. The impellers used in the model tank were the same as often used in full scale, Lightnin A310. The operating speed for this condition was determined by running the model tank at varying speeds to determine the Power Number as a function of speed. The speed to use in the model was then determined as that speed which gave the same power number for the agitator assembly as for full scale. The result of this test is shown in Figure 3 for the 1.07 m tank with the resulting speed being 95 rpm. The same speed was used for the 1.0 m tank work.

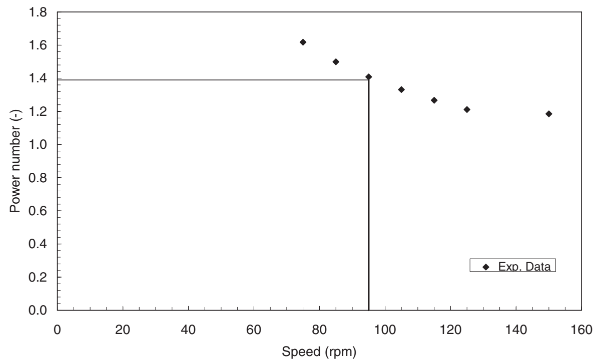

Figure 3. Power number versus speed for Carbopol in 1.07 m tank. 95 rpm selected as operating speed in the physical model to give the same power number as a full size tank.

4 Results and discussion

4.1 *1.07 m diameter low aspect ratio tank*

This tank used 4 standard 508 mm (20 inch) A310 impellers as its benchmark configuration as shown in Figure 4. Several agitator configurations and operating speeds were tried to find one which would give a higher wall velocity than the current configuration at a given power input. The lengths and angles of the impellers were modified but the spacing on the shafts was not altered.

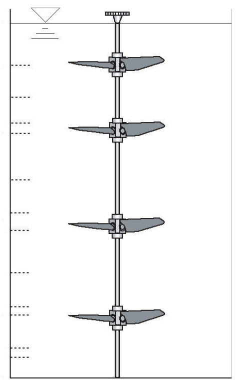

Figure 4. Benchmark case impellers with dashed lines showing where LDV measurements made.

Table 1 shows a list of impeller configurations tried where the agitator power was the same as the benchmark case together with the change in the near wall velocity compared with the benchmark. A sample of vertical velocity profiles taken at 297 mm from the base of the tank is shown in Figure 5, 960 mm above the tank base in Figure 6 and 1352 mm above the base in Figure 7. These results show that the best improvement in the velocity profile overall was given by test 1.7. These results suggest that the case where four impellers are retained but arranged so that the speed can be increased by the greatest amount would give the best chance of success. A version of the most successful impeller configuration in the model tests is undergoing a full scale trial at the time of writing.

Table 1. Cases with same power as benchmark case. Wall velocity comparison is made 40 mm into the tank.

Test No.	Configuration	Wall velocity compared to base case (% change)	Speed (rpm)	Power (W)
1.1	Benchmark case (4 A310)	0	95	182
1.2	Original length 10 deg less blade angle	10.85	110	186
1.3	Longest tips 10 deg less blade angle	-48.23	80	187
1.4	Longest tips	–69.73	66	186
1.5	Middle length tips	–45.99	74	186
1.6	3 impellers 10 deg less blade angle	-56.75	124	185
1.7	Final modified (details are confidential)	29.83	115	185

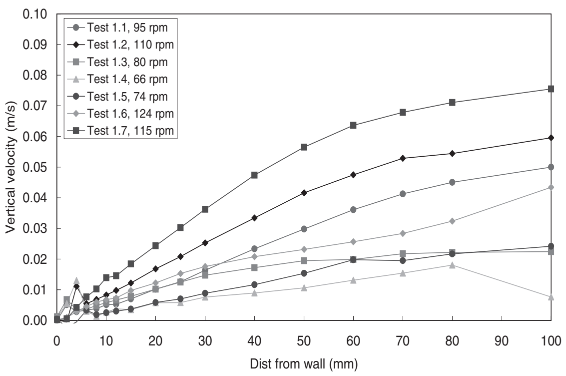

Figure 5. Vertical component modified and original configurations 297 mm above base. Same power as benchmark case.

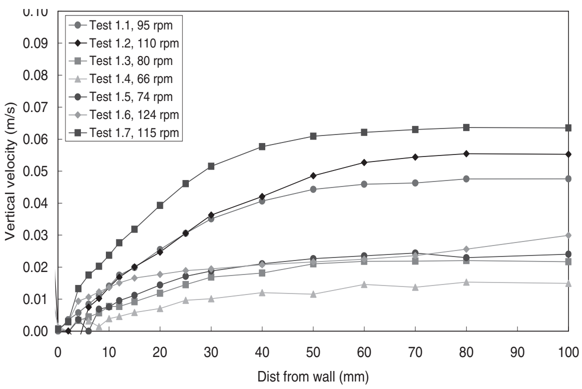

Figure 6. Vertical component modified and original configurations 960 mm above base of tank. Same power as benchmark case.

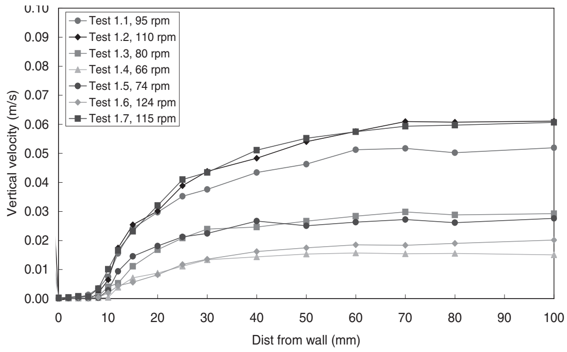

Figure 7. Vertical component modified and original configurations 1352 mm above base. Same power as benchmark case.

4.2 *1.0 m diameter high aspect ratio tank*

Two different impeller configurations were tested for this tank. One consisted of the standard configuration and the other used a modified configuration. The modified configuration was based on the experience with the low aspect tank reported in the previous section.

LDV measurements were made in the near wall region and a sample set of these is shown in Figure 8 to Figure 10. These results showed that the velocity is increased with the modified configuration over the whole tank. As for the previous case the rotational speed for the modified case is increased but the power is unchanged.

It is useful to have a single number for comparative purposes. The median of the percentage differences in the velocity (for every measured data point) between the modified case and the existing case was selected as being representative of the improvement of the wall velocity over the whole tank. Table 2 shows the comparison between the benchmark and modified case where a median improvement of about 20% in the wall velocity is shown.

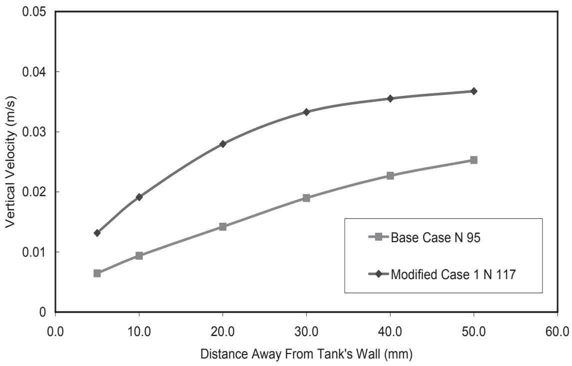

Figure 8. Velocity profiles for original and modified cases. 400 mm from bottom for liquid level 2350 mm.

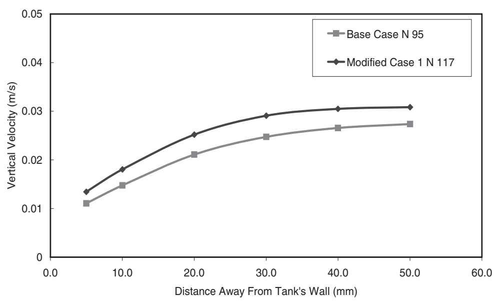

Figure 9. Velocity profiles for original and modified cases. 900 mm from bottom for liquid level 2350 mm.

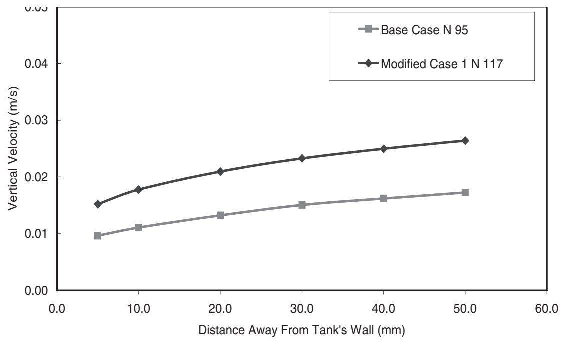

Figure 10. Velocity profiles for original and modified cases. 2000 mm from bottom for liquid level 2350 mm.

Table 2. Comparison of near wall velocities for existing and modified impellers for the high aspect ratio. Comparison is based on median % velocity difference over all data points.

Configuration	Wall velocity compared to base case (median % change)	Speed (rpm)	Power (W)
Existing	0	95	237
Modified overall	20	117	237
Modified 5mm from wall (model scale)	17.8	117	237

4.3 *Scale up to full scale*

In the physical model the power number for the modified case is determined from torque and speed measurements. The speed required for full scale operation can now be determined by using the same power number as for the modified case at model scale assuming that the rheology of the model fluid is the same as full scale. The full scale speed can then be calculated using the following equation:

$$N = \left(\frac{P}{P_n \rho D^5} \right)^{1/3}$$

where:
N is the speed in revolutions/second
D is the impeller diameter
ρ is the slurry density
P is the power in Watts
Pn is the dimensionless power number from the model tests of the modified configuration.

5 Conclusions

Tests were carried out on two tanks with differing aspect ratios to determine an impeller configuration or configurations which give an increase in the near wall velocity with the object of reducing scale growth in full scale installations. The results showed that the slurry velocity in the vicinity of the tank wall could be increased without increasing the agitator power. The best results were obtained by modifying the impellers so that a higher operating speed could be used at the same power as currently used. This is most likely due to the higher speed (and hence a higher local shear rate) reducing the apparent viscosity of the slurry. This reduces the tank resistance and hence allows an increased velocity for the same power input. Those impeller cases where the operating speed had to be reduced to maintain the same power input were not successful most likely due to the shear rate being lower and hence the average viscosity would be higher. The details of the final version of the impeller modifications are confidential.

A further possible improvement would be to adjust the pitch angle of the lowest impeller to put more power at the bottom of the tank. This would increase the flow at the bottom of the tank and may be useful in case of scale or solids settling problems at the bottom of the tank.

The rheology of the Carbopol used in these tests is not thixotropic or time dependent[1]. If the real slurries are thixotropic it may be possible to increase the operating speed further taking advantage of the time dependent behaviour.

As yet it is unclear as to the universality of the impeller configuration for different slurry rheologies however the authors consider that the approach of attempting to increase the average shear rate of the tank by increasing the impeller operating speed could be useful over a range of shear thinning rheologies.

Acknowledgements

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References

Durst, F, Melling, A. and Whitelaw J, 1981. Principles and practice of laser-Doppler Anemometry., Academic Press, London.

[1] This refers to the case where the slurry viscosity reduces with time at a constant shear level. Typically the material recovers its viscosity when the shear is removed. If this recovery time is longer than the time scale of motion in the tank this will lead to increased velocity for the same power.