Suspending Insoluble Solids in Waste Tanks with Shrouded Axial Impeller Mixers

M. R. Poirier (WSRC), M. R. Powell (PNNL), H. Gladki (ITT Flygt)

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Summary

The Savannah River Site (SRS) is in the process of removing waste (sludge and salt cake) from million gallon waste tanks. The current practice for removing waste from the tanks is adding water, agitating the tanks with long shaft vertical centrifugal pumps, and pumping the sludge/salt solution from the tank to downstream treatment processes. This practice has left sludge heels (~ 30,000 gallons) in the bottom of the tanks. SRS is evaluating shrouded axial impeller mixers for removing the sludge heels in the waste tanks.

The authors conducted a test program to determine mixer requirements for suspending sludge heels using shrouded axial impeller mixers. Tests were performed in geometrically-scaled tanks which have diameters of 1.5, 6.0, and 18.75 feet. The tests were performed with zeolite and limestone. The mixer speeds required to suspend the insoluble solids were measured at each scale. The data were analyzed with various scaling methods to compare their ability to describe the suspension of insoluble solids with the mixers and to apply the data to a full-scale waste tank.

The conclusions of the work are: Scaling of the suspension of fast settling particles (i.e., zeolite and limestone) was best described by the constant power per unit volume method. Increasing the zeolite particle concentration increased the required mixer power needed to suspend the particles. Decreasing the zeolite particle size from 0.7 mm – 0.3 mm decreased the required mixer power needed to suspend the particles. Increasing the number of mixers in the tank decreased the required mixer power needed to suspend the particles.

Introduction

In the early 1980s, two jet mixer pumps were used to dissolve and retrieve the salt cake in Tank 19 at the Savannah River Site. After the salt cake dissolution and retrieval, approximately 33,000 gallons of waste solids remained in the tank. The solids are composed of sludge, zeolite, and salt. Based on the topography of the solids heel in the tank, it is suspected that the long shaft vertical centrifugal pumps did not have sufficient power to maintain the faster settling solids in suspension, or that the pump jets pushed the larger, settled solids out beyond the reach of the jets.

Efforts are now being made to identify and design alternative waste retrieval techniques for the Tank 19 waste. Shrouded axial impeller mixers manufactured by ITT Flygt Corporation are one of the suggested alternatives (Figure 1). A test program was conducted to determine whether the shrouded axial impeller mixers will effectively remove the solids heel from the tank.

The shrouded axial impeller mixers consist of an electrically powered propeller surrounded by a close-fitting shroud. The 50 hp mixer being considered for use in SRS Tank 19 has a propeller diameter of approximately 20 inches and runs at 860 rpm. The rapidly spinning propeller creates a turbulent fluid jet with an average exit velocity of 20 ft./sec.

The test program consists of mixer tests being performed in a 1.5 ft. diameter tank, a 6.0 ft. diameter tank, and an 18.75 ft. diameter tank. The 1.5 ft. diameter tank was mixed with a single

0.4 hp mixer, the 6.0 ft. diameter tank was mixed with a single 4.0 hp mixer, and the 18.75 ft. diameter tank was mixed with three 4.0 hp mixers. Tests were performed with different size tanks so that scaling methods can be developed and used to determine whether the mixers can adequately suspend and retrieve the solids heel in SRS Tank 19.

One scaling method evaluated was the constant shear stress method developed by Gladki.[1] This method involves determining the magnitude of the average wall shear stress (τ_o) required to maintain solids in suspension for a given tank geometry and type of solids. The magnitude of the wall shear stress is computed by dividing the mixer thrust by the tank wetted surface area (bottom and sides). According to this method, the average wall shear stress required is independent of scale provided the same materials are used and the tanks are geometrically scaled.

Power per unit volume is another method for mixing system scaleup. This method is described by equation [1].

$$\frac{T_2}{T_1} = \left[\frac{(P/V)_2}{(P/V)_1}\right]^a \qquad [1]$$

where T is the tank dimension, P is the hydraulic horsepower, V is the tank volume, and a is a constant. The value of a is a function of the mixing application.

This program collected and evaluated data on mixer requirements to suspend zeolite and limestone in 1.5, 6.0, and 18.75 foot diameter tanks in order to determine which scaling methods are most appropriate for this application.

Experiments

Tests were performed in three different sized tanks: a 1.5 ft. diameter tank, a 6.0 ft. diameter tank, and an 18.75 ft. diameter tank. The 1.5 ft. diameter tank was filled to liquid levels of 7 inches and 10 inches. The mixer contained a 3-bladed propeller with a diameter of 3 inches and a pitch of 2 inches. The blade angle was 12 degrees. The mixer had a variable speed drive and a maximum speed of 2500 rpm. The mixer did not contain a shroud. However, because the mixer thrust was measured directly, the lack of a jet ring does not affect the results.

The 6.0 ft. diameter tank was approximately a 4:1 geometric scaleup of the 1.5 ft. diameter tank. The tank was filled to liquid levels of 28 inches and 41 inches. The mixer was a 4 hp Model 4640 Flygt mixer. The mixer contained a 3-bladed propeller with a diameter of 14 inches. The mixer had a variable speed drive and a maximum speed of 860 rpm.

The 18.75 ft. diameter tank contained 3 Flygt model 4640 mixers. The mixers were placed in the 90°, 225°, and 270° positions approximately 1.5 feet from the tank wall. The 90° and 270° mixers were directed 30 degrees to the left of the tank center. The 225° mixer was pointed toward the tank center.

The tests were performed in the following manner: The tank was filled with zeolite or limestone. Water was added to the specified level. The mixers were turned on and the speed increased until the solids were suspended. In the 1.5 and 6.0 ft. diameter tanks, the solids were visually determined to be suspended when all particles were found to be in motion on the tank bottom. In the 18.75 ft. diameter tank, the solids suspension was determined by measured fluid density at various points in the tank with a coriolis flow meter (Krohne model #300P). The required thrust was measured in the 1.5 foot diameter tank and determined from the affinity laws for the 6 and 18.75 foot diameter tanks. The mixer hydraulic horsepower was determined from the affinity laws in all of the tanks.

Table 1 shows the test conditions.

Table 1. Mixer Test Conditions

Test#	Tank Diameter (ft)	Liquid Level (in)	Material (zeolite/limestone)	Concentration (vol. %)	Particle Diameter (mm)
1	1.5	7	zeolite	1.5	.7
2	1.5	10	zeolite	1.1	.7
3	1.5	10	zeolite	1.5	.7
4	1.5	7	zeolite	6	.7
5	1.5	10	zeolite	4.3	.7
6	1.5	10	zeolite	6	.7
7	1.5	7	zeolite	1.5	.3
8	1.5	10	zeolite	1.1	.3
9	1.5	10	zeolite	1.5	.3
10	1.5	7	zeolite	6	.3
11	1.5	10	zeolite	4.3	.3
12	1.5	10	zeolite	6	.3
13	1.5	7	limestone	1.5	.2
14	6	28	zeolite	1.5	.7
15	6	40	zeolite	1.1	.7
16	6	40	zeolite	1.5	.7
17	6	28	limestone	1.5	.2
18	18.75	39	limestone	1.5	.2
19	18.75	39	zeolite	1.5	.7

Following the mixing tests, the authors performed pump down tests in which the solid-liquid slurry was pumped from the tank while the mixers operated, and the fraction of solids removed measured. As the fluid level in the tank decreased, the mixer speed was reduced, and eventually stopped.

Results

Table 2 shows the test results. The table shows the tank diameter, the type of solid, the number of mixers, the required shear stress (τ_o, mixer thrust divided by wetted surface area), and the required mixer power per unit tank volume (P/V).

Table 2. Test Results

Test #	Tank Diameter (ft)	Material (zeolite/limestone)	Number of Mixers	τ_o (Pa)	P/V (W/m^3)
1	1.5	Z	1	16.5	530
2	1.5	Z	1	16.3	510
3	1.5	Z	1	16.1	501
4	1.5	Z	1	21.1	736
4a	1.5	Z	2	21.1	545
5	1.5	Z	2	20.0	490
6	1.5	Z	2	21.5	530
7	1.5	Z	1	11.0	285
8	1.5	Z	1	11.8	311
9	1.5	Z	1	10.8	276
10	1.5	Z	1	14.7	431
11	1.5	Z	1	13.8	392
12	1.5	Z	1	14.9	438
13	1.5	L	1	15.9	492
14	6	Z	1	86	760
15	6	Z	1	62	510
16	6	Z	1	89	890
17	6	L	1	89	890
18	18.75	L	3	> 55	> 280
19	18.75	Z	3	> 55	> 280

Table 3 shows the effect of liquid level on the required mixer thrust and power. The results from the 1.5 and 6.0 foot diameter tanks showed minimal change in required shear stress or power per unit volume when the liquid level was increased. The power per unit volume required to suspend the zeolite is expected to decrease with increasing tank volume.[3] The absence of a measurable effect could be due to the small change in liquid level or to the effect being smaller than the experimental uncertainty.

Table 3. Effect of Liquid Level on Required Mixer Power

Diameter (ft)	Conc. (vol%)	Particle Diam. (mm)	Level (in)	τ_o (Pa)	P/V (W/m^3)	Level (in)	τ_o (Pa)	P/V (W/m^3)
1.5	1.5	.7	7	16.5	530	10	16.1	501
1.5	6.0	.7	7	21.1	545	10	21.5	530
1.5	1.5	.3	7	11.0	285	10	10.8	276
1.5	6.0	.3	7	13.8	392	10	15.9	492
6.0	1.5	.7	28	86	760	40	89	890

Table 4 shows the effect of particle concentration on the required mixer thrust and power. Increasing the zeolite concentration from 1.5 vol. % to 6.0 vol. % increased the required shear stress by approximately 25% and the required power per unit volume by approximately 45%. Previous research[2] has shown the required mixer speed is related to particle concentration by equation [1]

$$N_{js} \propto c^{a} \qquad [1]$$

Where N_{js} is the speed required to just suspend all of the particles, c is the particle concentration, and a is a constant. Typical values of a are 0.12. If a is equal to 0.12, increasing the solids concentration from 1.5 vol% to 6.0 vol% would increase the minimum required mixer thrust by 40% and the required hydraulic horsepower by 65%.

Table 4. Effect of Particle Concentration on Required Mixer Power

Diameter (ft)	Liquid Level (in)	τ_o (1.5 vol%) (Pa)	τ_o (6 vol%) (Pa)	P/V (1.5 vol%) (W/m^3)	P/V (6 vol%) (W/m^3)
1.5	7	16.5	21.1	530	736
1.5	7	11.0	14.7	285	431
1.5	10	11.8	13.8	311	392
1.5	10	10.8	14.9	276	438

Table 5 shows the effect of particle size on the required mixer thrust and power. Decreasing the particle size from 0.7 mm to 0.3 mm, decreased the required shear stress by approximately 30% and the required power per unit volume by approximately 35%. This result is expected. Previous research[2] has shown the required mixer speed is related to particle concentration by equation [2]

$$N_{js} \propto d_p^{\,b} \qquad [2]$$

Where N_{js} is the speed required to just suspend all of the particles, d_p is the particle diameter, and b is a constant. Typical values of b are 0.15 – 0.20. If b is equal to 0.15 – 0.20, decreasing the particle size from 0.7 mm to 0.3 mm would decrease the minimum required mixer thrust by 22 - 29% and the required hydraulic horsepower by 32 - 40%.

Table 5. Effect of Particle Size on Required Mixer Power

Diameter (ft)	Liquid Level (in)	Conc. (vol%)	τ_o (.7mm) (Pa)	τ_o (.3mm) (Pa)	P/V (.7mm) (W/m^3)	P/V (.3mm) (W/m^3)
1.5	7	1.5	16.5	11.0	530	285
1.5	10	1.5	16.3	11.8	512	311
1.5	10	1.5	16.1	10.8	501	276
1.5	7	6	21.1	14.7	736	431

Table 6 shows the effect of the number of mixers on the required mixer thrust and power. Increasing the number of mixers in the 1.5 foot diameter tank from one to two decreased the required power per unit volume by 25%. Multiple mixers in a tank would provide a more even distribution of energy, and therefore, a lower average energy in the tank.

Table 6. Effect of Number of Mixers on Required Mixer Power

# of Mixers	Diameter (ft)	Liquid Level (in)	Conc. (vol%)	τ_o (Pa)	P/V (W/m^3)
1	1.5	7	6	21.1	736
2	1.5	7	6	21.1	545

Table 7 shows the effect of tank diameter on the mixer shear stress required to suspend zeolite and limestone. Increasing the tank diameter caused an increase in the required shear stress to suspend zeolite and limestone. The increase in required shear stress is approximately a factor of 5, which suggests scaling based on tank volume rather than wetted surface area. These results disagree with the constant shear stress model, and suggest it does not apply to suspension of fast settling solids such as zeolite and limestone.

Table 7. Effect of Tank Size on Required Mixer Shear Stress

Test #s	1.5 ft Tank Required τ_o (Pa)	6.0 ft Tank Required τ_o (Pa)
1, 14	16.5	86
2, 15	16.3	62
3, 16	16.1	89

Table 8 shows the effect of tank diameter on the mixer power required to suspend zeolite and limestone. Increasing the tank diameter had a small effect on the power per unit volume required to suspend the zeolite and limestone. The differences in required power per unit volume measured are most likely due to experimental uncertainty.

Table 8. Effect of Tank Size on Required Mixer Power

Test #s	1.5 ft Tank Required P/V (W/m^3)	6.0 ft Tank Required P/V (W/m^3)
1, 14	530	760
2, 15	512	510
3, 16	501	890
13, 17	725	890

Following the mixing tests, pump down tests were performed in which the solid-liquid slurry was pumped from the tank with mixers operating, and the fraction of solids removed from the tank measured. Table 9 shows the results of the pump down tests. When the mixer speed was sufficient to have all particles in motion, about 90% of the solid particles were removed. When the mixer power was insufficient to suspend the solid particles, less than 40% of the particles were removed.

Table 9. Pump Down Test Results

Test#	Tank Diameter (ft)	Material	Mixing Effectiveness	% Removed
16	6	Z	successful	90%
17	6	L	successful	89%
18	18.75	L	unsuccessful	36%
19	18.75	Z	unsuccessful	15%

Conclusions

The conclusions of the work are:

- Scaling of the suspension of fast settling particles (i.e., zeolite and limestone) was best described by the constant power per unit volume method.
- Increasing the zeolite particle concentration increased the required mixer power needed to suspend the particles.
- Decreasing the zeolite particle size from 0.7 mm – 0.3 mm decreased the required mixer power needed to suspend the particles.
- Increasing the number of mixers in the tank decreased the required mixer power needed to suspend the particles.

References

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Figure 1. Shrouded Axial Impeller Mixer (ITT Flygt)