DP-MS-89-80
CONF 891113 - 13

Mixing and Solid Suspension
of Up-Down Agitators in a Slab Tank

DP-MS--89-80

DE91 005146

Chris J. Ramsey
Mechanical Engineering Department
Texas A&M University
College Station, Texas 77843

Edward A. Kyser, III, and Gary B. Tatterson*
Actinide Technology Division
Savannah River Laboratory
Aiken, SC 29808-0001

Keywords: Mixing, Homogenization, Solid Suspension, Up-down Agitation,
Up-Down Mixing

* Author to whom correspondence should be addressed.

ABSTRACT

Seven different up-down agitators were studied for their ability to produce mixing and solid suspension in a slab tank. Mixing times were measured as the time needed to disperse injected dye. The solid suspension studies determined the minimum stroke frequency of the agitators needed for complete off-bottom suspension. The effects of stroke frequency, n ; amplitude, a ; blade width, w ; blade clearance, c ; and liquid depth, h , and weight percent solids, X , were studied. The most effective geometry, in terms of mixing, solid suspension and design simplicity, was a single flat blade with minimum off-bottom clearance and a blade width/tank thickness ratio, w/T , of 0.74 at the maximum stroke amplitude studied.

INTRODUCTION

At SRP, slab tanks, shown in Fig. 1, are routinely used as the tank geometry for many processes including dissolution, precipitation, crystallization, blending, and solid suspension. Typical slab tanks are rectangular with length-height-width proportions of 7-4-1. The geometry is a result of nuclear safety requirements. Impeller designs, used in up-down agitation, can closely match the slab tank geometry. As a result, up-down agitation could be used for process applications in slab tanks if sufficient documentation is obtained.

The up and down motion of the impeller and shaft in Fig. 1 was caused by a crank wheel located above the tank. The stroke frequency of the up-down motion was analogous to the impeller rotational speed in rotary mixing. The major geometric variables of the impeller were the amplitude,

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
MASTER

a, of the up-down motion, the blade width, w, and the general shape of the impeller. Secondary geometric variables included the blade clearance, c, off the tank bottom, the liquid height, h, and the blade length.

The objective of this study (Ramsey, 1988) was to document mixing and solid suspension capabilities of up-down impellers. The effects of impeller design, stroke frequency, n; amplitude, a; blade width, w; and liquid depth, h, were studied. Ancillary objectives of the work were to investigate the similarities between up-down agitation and rotary agitation and to study the use of full tank impellers, typical of laminar mixing designs, in turbulent mixing applications.

BACKGROUND

Mixing Times: In mixing studies where an effective impeller is used, the product of impeller rotational speed, N, and mixing time, θ , is the number of revolutions to mix a tracer injection throughout a vessel:

$$N\theta = H_o$$

1

where H_o is the homogenization number. H_o varies from 20 to 80 for efficient rotary geometries. For a fixed geometry, H_o is constant under either laminar or turbulent rotary mixing conditions. In studies of different geometries, H_o is a function of geometry. In the transition regime, H_o is dependent upon geometry, the fluid mechanics and fluid properties.

Studies involving the mixing capabilities of up-down agitators include Bates et al. (1966) which discussed an perforated reciprocating plate. Effective mixing at high stroke frequencies was obtained but no quantitative results were given. Nagata et al., (1972), working with high viscosity fluids, showed that up-down agitation provided mixing times comparable to those obtained with the best rotary designs. Murakami et

al.(1980) combined up-down and rotary motion through a crank-gear system and measured mixing times for different impellers. The addition of up-down motion led to improvements in mixing performance. Nagata et al. (1972) and Murakami et al.(1980) found Eq. 1 to hold for up-down designs in the laminar regime.

Solid Suspension: Most research on solid suspension in rotary mixing concerns the minimum impeller rotational speed, n_s , necessary to produce complete off-bottom suspension. The minimum rotational speed permits particles to remain on the tank bottom for only 1 to 2 seconds. An accepted correlation for n_s can be written in a power law form:

$$n_s = S \nu^{0.1} d_p^{0.2} (g\Delta\rho/\rho_L)^{0.45} X^{0.13} D^{-0.85} \quad 2$$

where S is a significant function of the D/T and C/T ratios(Zwietering, 1958). The S parameter accounts for the relative size of the impeller to the tank and the proximity of the impeller to the tank bottom. With an increase in the impeller to tank diameter ratio (D/T), the impeller is relatively more effective at solid suspension which causes a decrease in n_s . A decrease in the impeller clearance to tank diameter ratio (c/T) usually causes a decrease in n_s since the impeller is relatively closer to the vessel bottom. The exponent on weight fraction, X , is not fixed and is known to vary between 0 and 0.3 (Tay et al., 1984).

In up-down agitation for solid suspension, Tojo et al. (1981) assumed that the mechanism responsible for suspension in both rotary and up-down systems was the same. They assumed that the energy imparted by the rotating impeller or vibrating disk induced an axial velocity which suspended the particles. Tojo et al. found roughly the same effects of liquid viscosity, particle diameter and density difference as stated in Eq. 2 but obtained a -1.6 exponent for the impeller diameter.

Studies of up-down agitation which couple solid suspension and mixing times in a non-standard geometry are unavailable.

EXPERIMENTAL PROGRAM

Seven different blade geometries, shown in Fig. 2, were studied. Blade width was varied between 36 to 85 mm. The blade thickness, the projected horizontal blade length and tank width were fixed at 9.53mm, 454mm, and 102mm, respectively. The minimum off-bottom blade clearance was 20mm measured from the tank centerline. Blade number, blade angles (i.e., pitch and roll), blade spacing and off-bottom clearance were varied as shown in Fig. 2.

Mixing times were obtained by dispersing dye. A device injected an equal volume ratio (0.2ml/l) of dye at the same location for each test. No substantial momentum was added to the liquid in the tank during injection. The process fluid was tap water which remained at a constant temperature during the experiments. Mixing times from dye injection on either side of the tank were equivalent.

The full cycle stroke frequency, n , ranged from 0.7 to 2.6 Hz and the stroke amplitudes were 25, 38, and 51mm. The stroke length of the impeller in the slab tank was twice the amplitude. The impeller Reynolds Number was defined as $4naw/\nu$ and ranged from 2,500 to 45,000. In most tests, the flow contained a variety of length scales and was turbulent at high Reynolds numbers. The transition mixing regime occurred at low Reynolds numbers. The majority of tests were conducted with a tank volume of 29 liters at a liquid depth, h , of 400 mm measured from the tank centerline. The effect of liquid depth was studied for the two different blade geometries at the depths of 300mm and 480mm. The tank was considered mixed when the dye concentration was uniform throughout the tank as recorded on the

videotape. This was verified by a visual inspection. The standard deviations in H_o were usually less than 10% of the mean value.

Solid Suspension: These studies were performed using sand and tap water. The density and mean particle size of the sand were 2.63 g/cm^3 and $160\mu\text{m}$, respectively. Particle sizes ranged from $75\mu\text{m}$ to $300\mu\text{m}$. All solid suspension studies had one flat blade at the minimum off-bottom clearance of 20mm measured at the tank centerline. Two blade widths, 47 and 74 mm, and the same amplitudes and liquid height as above were studied. The frequency at which no particle remained on the tank bottom longer than 1 second was recorded as the complete suspension frequency, n_s . The solids concentration was varied from 0.1 to 20.0 weight percent for a liquid volume of 29 liters. The effect of liquid depth was studied by lowering the liquid level to 180mm. The depth change increased the maximum solids concentration to 57.2wt%. This weight percent posed no difficulties in solid suspension since the flat blades were always started at minimum clearance. The maximum height which the slurry obtained was recorded (Ramsey, 1988) but is not reported in this work.

RESULTS

Mixing Time Studies: The bulk motion of the dye, shown in Fig. 3, was the same for all geometries studied. The bulk motion was not discernible after one stroke (step 1), but became obvious as mixing progressed. The mixing depended upon the number of strokes. The design and operational effects on mixing times will be expressed in terms of their effect on this bulk motion and the homogenization number, H_o .

Simplest Geometry: A single flat blade at minimum clearance was the simplest geometry. The blade width and amplitude were the most important lengths and fixed the major geometric features of the up-down agitator. H_o

data for this system are shown in Fig. 4. The minimum in Ho at a dimensionless blade width, w/T , of 0.75 was caused by two opposing effects. Below w/T of 0.75, increasing the blade width increased the bulk circulation which caused lower Ho values. Above w/T of 0.75, wall effects and wall friction became significant and reduced the bulk circulation. As the blade width approached the tank thickness, circulation approached zero and the homogenization number became very large. Minimums in Ho are common in mixing when full tank impellers are used (Takahashi et al. 1982, Kappel, 1979). In terms of the hydrodynamics, the minimum probably occurred because of a size balance between the blade vortices forming and shedding from behind the blade, the size of the flow into these vortices and the draft flow of the blade.

The data in Fig. 4 also show that, as the stroke amplitude increases, the effect of the amplitude becomes less. Although further data are needed, the effect of increasing stroke amplitude reaches an asymptotic limit where the mixing effectiveness of long strokes becomes independent of the stroke length. Practical considerations of machine design restrict the use of high amplitudes.

The data in Fig. 4 also show that, as mixing becomes turbulent, the variation of Ho with geometry becomes less. This effect occurs in cylindrical geometries which have efficient mixing configurations.

Ho Correlation: From Fig. 4, operations at low amplitude or above w/T of 0.75 were considered undesirable. The low amplitude data were in the transition mixing regime which is undesirable for mixing. Wall effects and high friction were undesirable. Operation at the minimum was also considered too restrictive. In the region of choice: $0.35 < w/T < 0.75$ and $0.090 < a/h < 0.13$, the homogenization number was correlated by:

$$Ho = 2.13(w/T)^{-2/3}(a/h)^{-1.0}$$

3

This correlation has the same basis as correlations for cylindrical tanks reported by Prochazka and Landau (1961, 1961), Hiraoka and Ito, (1977), Shiue and Wong (1984) and Sano and Usui (1985). The homogenization number is proportional to the ratio of the volume being mixed, i.e., $T^2/3h$, to the volume of the mixer, i.e., $w^2/3a$.

The effect of liquid height was not be as clear as Eq. 2 indicates. Marr and Johnson (1961) in cylindrical systems showed that Ho changed abruptly with changes in liquid height because of changes in flow patterns. These same effects as well as compartmentalization were observed in this study.

Blade widths above w/T of 0.75 were not studied further because of the substantial wall effects.

Ho Data in More Complicated Geometries: The homogenization numbers in Fig. 5 were obtained for different blade geometries as a function of a/T at $w/T = 0.725$ just below the minimum. (The ratio of T/H was 0.255 in this study.) The lowest homogenization number, $Ho=18$, was obtained using a single blade with the widest blade width (i.e. $w/T = 0.725$) at the largest blade amplitude studied.

The effects of geometry on Ho in Fig. 5 can be explained in terms of the effect of geometry on bulk circulation. Increasing amplitude decreased Ho . For a given geometry, an increase in amplitude produced stronger bulk motion in the tank. An increase in the off-bottom blade clearance, c , produced an increase in Ho (poorer mixing). With the blade set at the lowest clearance, the bulk flow was forced upwards in the middle of the tank. When the clearance was increased, the flow was forced upwards not only in the middle, but also up and down along the curved sides of the

tank, resulting in weaker bulk circulation. An increase in blade number to two blades (blade spacing = blade width) caused an increase in H_o (poorer mixing). A weaker circulation was produced by an increase in blade number since the upper blade disrupted with the flow produced by the motion of the lower blade. An increase in the distance between the two blades produced an increase in H_o (poorer mixing). An increase in blade spacing caused an increase in blade interference with bulk circulation.

Roll and pitch blade angles for the impellers shown in Fig. 6 can affect H_o . The two pitched geometries had lower H_o values than the single flat blade geometry for the same blade width and stroke amplitude. The addition of a pitched angled blade did not disrupt the bulk circulation, but enhanced it by increasing mixing in both the vertical and horizontal directions. Rolling or tilting a top horizontal blade led to higher H_o values than a single flat blade geometry. A second horizontal blade disrupted the bulk circulation.

The bulk circulation of dye in the tank and the homogenization number remained the same at lower liquid depths in other data. Partitions divided the slab tank in half under these conditions, causing compartmentalization. The effect was similar to that reported by Marr and Johnson (1961). At higher liquid depths, an increase in the homogenization number occurred for a given stroke amplitude. Longer circulation paths gave rise to longer mixing times. There was no effect of dye injection location on H_o which is common in cylindrical mixing data.

Solid Suspension: In all cases, the sand was carried upward in the middle of the tank and spread from side to side by the strong bulk circulation in a manner similar to dye mixing. A correlation for the minimum complete suspension frequency, n_s , was obtained as:

$$n_s = 0.314(w/T)^{-0.84}(a/h)^{-0.6}X^{0.10}$$

4

for $0.46 < w/T < 0.725$, $0.06 < a/h < 0.13$ and $0.7 < X < 20$ from data shown in Fig. 7. No data were taken above $w/T = 0.75$ since n_s will increase as w/T approaches one. The correlation is very similar to Eq. 2 cited above and the effects of geometry on n_s are roughly the same as on Ho . The -0.84 exponent on blade width is similar to the -0.85 exponent on the impeller diameter in the Zwietering correlation. Blade width is the characteristic length of up-down suspension in a slab tank. The exponents on weight fraction are essentially the same.

An increase in blade width pulled more fluid upward in its wake, producing higher velocities at the tank bottom. The flow velocity in the wake of the blade increased with increasing stroke amplitude. n_s remained constant or decreased with a decrease in liquid depth.

CONCLUSION

Effects of geometry on mixing and solid suspension reported for rotary agitation have been observed in up-down agitation as well. The information about mixing and solid suspension is more universal than is typically assumed.

ACKNOWLEDGEMENTS

This work was performed under SRL Contract No.: AX 0798886. The help and support of E.W. Holtzscheiter and C.R. Goetzman of SRL and T.P.K. Chang of E.I. du Pont are gratefully acknowledged.

NOMENCLATURE

a	amplitude
C	rotary impeller clearance
c	off-bottom blade clearance
D	rotary impeller diameter
d_p	particle diameter
g	gravity
h	liquid height
Ho	homogenization number, stroke or revolutions for mixing
N	impeller rotational speed
n	stroke frequency
n_s	complete off-bottom suspension in up-down and rotary

	configuration
T	tank thickness or tank diameter
w	blade width
X	weight percent solids (wt%)
y	blade spacing
Greek Symbols	
$\Delta\rho$	density difference between solid and liquid
ρ_L	density of liquid
θ	mixing time
ν	kinematic viscosity

REFERENCES

- Bates, R.L., Fondy, P.L., and Fenic, J.G., "Impeller Characteristics and Power", Mixing, Vol. 1, Uhl, V.W., and Gray, J.B., eds., Academic Press, New York, NY, Chap. 3, 112-176, 1966.
- Hiraoka, S., and Ito, R., "Simple Relationship Between Power Input and Mixing Time in Turbulent Agitated Vessel", J. Chem. Eng. Japan, 10, 75-77, 1977.
- Kappel, M., "Development and Application of a Method for Measuring the Mixture Quality of Miscible Liquids. III. Application of the New Method for Highly Viscous Newtonian Liquids", Intern. Chem. Eng., 19, 571-590, 1979.
- Landau, J., and Prochazka, J., "Experimental Methods for Following the Homogenization of Miscible Liquids by Rotary Mixers", Coll. Czech. Chem. Commun., 26, 1976-1990, 1961.
- Marr, G.R., and Johnson, E.F., "The Dynamical Behavior of Stirred Tanks", Chem. Eng. Progr. Sym. Ser., 36, 109-118, 1961.
- Murakami, Y., Hirose, T., Yamato, T., Fujiwara, H., and Ohshima, M., "Improvement in Mixing of High Viscosity Liquid by Additional Up-Down Motion of a Rotating Impeller", J. Chem. Eng. Japan, 13, 318-323, 1980.
- Nagata, S., Nishikawa, M., Katsube, T., and Takaishi, K., "Mixing of Highly Viscous Non-Newtonian Liquids", Intern. Chem. Eng., 12, 175-182, 1972.
- Prochazka, J., and Landau, J., "Homogenization of Miscible Liquids in the Turbulent Region", Coll. Czech. Chem. Commun., 26, 2961-2973, 1961.
- Ramsey, C.J., "An Investigation of the Mixing and Solid Suspension Capabilities of Vibratory Agitators in a Slab Tank", MS Thesis, Mechanical Engineering Dept., Texas A&M Univ., College Station, TX, 1988.
- Sano, Y., and Usui, H., "Interrelations Among Mixing Time, Power Number and Discharge Flow Rate Number", J. Chem. Eng. Japan, 18, 47-52, 1985.
- Shiue, S.J., and Wong, C.W., "Studies on Homogenization Efficiency of Various Agitators in Liquid Blending", Canad. J. Chem. Eng., 62, 602-609, 1984.
- Takahashi, K., Sasaki, M., Arai, K., and Saito, S., "Effects of Geometrical Variables of Helical Ribbon Impellers on Mixing of Highly Viscous Newtonian Liquids", J. Chem. Eng. Japan, 15, 217-224, 1985.

Tay, M., Deutschlander, B., and Tatterson, G.B., "Suspension Characteristics of Large Cylinders in Agitated Tanks," Chem. Eng. Commun., 29, (1-6), 89-97, 1984

Tojo, K., Miyanami, K., and Mitsui, H., "Vibratory Agitation in Solids-Liquid Mixing," Chem. Eng. Sci., 36, 279-284, 1981

Zwietering, Th.N., "Suspending of Solid Particles in Liquid by Agitators" Chem. Eng. Sci., 8, 244-253, 1958.

List of Figure Titles

Figure 1: Slab Tank Geometry With a Single Flat Blade Impeller

Figure 2: Different Impeller Configurations Studied

Figure 3: Idealized Dye Dispersion for Stroke Frequencies of: (A) 1.1Hz and (B) 2.1Hz with Stroke Amplitude = 38mm, Liquid Height = 400mm

Figure 4: The Effect of Blade Width upon the Homogenization Number for Different Amplitudes for a Single Flat Blade Geometry, Liquid Height = 400mm, Minimum Off-Bottom Clearance

Figure 5: Change in Homogenization Number with Amplitude for Different Geometries, Liquid Height = 400mm, Blade Width = 74mm

Figure 6: A Comparison between Flat and Angled Blade Geometries, Blade Width = 47mm, Liquid Height = 400mm

Figure 7: Change in n_s with Blade Width, Amplitude, and Solids Concentration (wt%), Liquid Height = 400mm, Minimum Off-Bottom Clearance, $c = 20\text{mm}$

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Figure 2: Different Impeller Configurations Studied

Figure 3: Idealized Dye Dispersion for Stroke Frequencies of: (A) 1.1 Hz and (B) 2.1 Hz with Stroke Amplitude = 38mm, Liquid Height = 400mm

Figure 4: The Effect of Blade Width upon the Homogenization Number for Different Amplitudes, Liquid Height = 400mm, Minimum Off-Bottom Clearance $c = 20\text{mm}$.

Figure 5; Homogenization Number versus Dimensionless Amplitude for All Geometries, Liquid Height = 400mm.

Figure 6: A Comparison between Flat and Angled Blade Geometries, Blade Width = 47mm, Liquid Height = 400mm.

Figure 7: Change in n_s with Blade Width, Amplitude and Solids Concentration (wt%),
 Liquid Height = 400mm, Minimum Off-Bottom Clearance, $c = 20\text{mm}$

END

DATE FILMED

03 / 01 / 91