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Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Evaluation of Flygt Mixers for Application in Savannah River Site Tank

Summary of Test Results from Phase A, B, and C Testing

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April 1999

Prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830

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(a) Oak Ridge National Laboratory
(b) Savannah River Site
(c) ITT Flygt Corporation

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Summary

Staff from the Savannah River Site (SRS), Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL), and ITT Flygt Corporation in Trumbull, Connecticut, are conducting a joint mixer testing program to evaluate the applicability of Flygt mixers to SRS Tank 19 waste retrieval and waste retrieval in other U.S. Department of Energy (DOE) tanks. This report provides the results of the Phase C Flygt mixer testing and summarizes the key findings from the Phase A and B tests.

Phase C Flygt mixer testing used full-scale, Model 4680 Flygt mixers (37 kW, 51-cm propeller) installed in a full-scale tank (25.9-m diameter) at SRS. Phase A testing used a 0.45-m tank and Flygt mixers with 7.8-cm diameter propellers. Phase B testing used Model 4640 Flygt mixers (3 kW, 37-cm propeller) installed in 1.8-m and 5.7-m tanks. Powell et al. (1999a, 1999b) provide detailed descriptions of the Phase A and B tests.

In Phase C, stationary submerged jet mixers manufactured by ITT Flygt Corporation were tested in the 25.9-m diameter tank at the SRS TNX facility. The Model 4680 mixers used in Phase C have 37-kW (50-hp) electric motors that drive 51-cm (20-in.) diameter propellers at 860 rpm. Fluid velocity was measured at selected locations with as many as four Model 4680 mixers operating simultaneously in the 25.9-m tank, which was filled with water to selected levels. Phase C involved no solids suspension or sludge mobilization tests.

An analysis of data collected during Phases A, B, and C provided the following key conclusions and recommendations.

- Based on the Phase A and B solids suspension tests and the Phase C velocity measurements, three stationary Model 4680 Flygt mixers are unlikely to provide sufficient mixing energy to either mobilize all of the Tank 19 heel or to maintain the rapidly settling zeolite solids in suspension so that the solids can be pumped from the tank.

- Continuously rotating (or oscillating) the Flygt mixers should improve their performance, but it is not known if the full-scale performance of such a system will be acceptable. The Phase C velocity measurements for mixers with extended shrouds imply that a rotating-mixer-based system may provide sufficient agitation to permit retrieval of the Tank 19 solids.

- Extending the shroud on the Model 4680 mixers significantly increases the downstream fluid velocities. It is recommended that extended shrouds be used for Flygt mixers that will be continuously or periodically reoriented. Further testing is planned to determine the optimum shroud length, but the Phase C tests show that a 50-cm-long shroud outperforms 20-cm- and 76-cm-long shrouds.

- Scale up of the Flygt mixers for the mixing of rapidly settling particles apparently follows a constant-power-per-unit-volume relationship over the range of tank sizes and simulant compositions tested. Whether this relationship holds for tanks as large as Tank 19 is not yet known.

- The sludge mobilization tests imply a correlation exists between sludge shear strength and required mixer thrust. This correlation cannot be directly applied to the Tank 19 sludge because the strength properties of the Tank 19 sludge are currently unknown. Further, it is not known if this correlation holds in tanks larger than those tested (i.e., 5.7-m diameter).

The Phase A, B, and C tests involved only stationary Flygt mixers. Substantial improvement is expected in mixing effectiveness when the Flygt mixers are continuously rotating or oscillating in the azimuthal plane so that the fluid jets periodically sweep over all regions of the tank floor. Azimuthal rotation of Flygt mixers will be studied as part of Phase D testing and additional full-scale oscillating-mixer-mast testing at SRS.

Acknowledgments

The authors gratefully acknowledge the support of ITT Flygt Corporation staff, in addition to Hanna Gladki, who participated in this test program. The authors thank Harry Langford, Mike Dillard, and David Robinson, who are affiliated with ITT Flygt Corporation. Their assistance during the tests is greatly appreciated.

Funding for this work was provided by the Tanks Focus Area, a program established by the U.S. Department of Energy's Environmental Management Office of Science and Technology to provide technical solutions for remediation and closure of radioactive waste storage tanks.

Nomenclature and Acronyms

DOE	U.S. Department of Energy
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
P/V	power per unit volume, W/m^3
SRS	Savannah River Site
TNX	full-scale tank (25.9-m diameter) test facility at SRS
τ_o	average wall shear stress, Pa

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1.0 Introduction

In the early 1980s two jet mixer pumps were used to dissolve and retrieve the saltcake in Tank 19 at the Savannah River Site (SRS). Not all of the waste was removed during this retrieval campaign, however, and roughly 125 m^3 (33 kgal) of waste solids remain. The solids are composed of sludge, zeolite, and salt. Based on the topography of the solids heel in Tank 19, it is suspected that the mixer pumps did not have sufficient power to maintain the faster settling solids in suspension or that the mixer 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 propeller mixers manufactured by ITT Flygt Corporation are one of the suggested alternatives. During fiscal year 1998, staff from Pacific Northwest National Laboratory (PNNL),[a] Oak Ridge National Laboratory (ORNL), SRS, and ITT Flygt Corporation conducted a joint mixer testing program to evaluate the applicability of Flygt mixers to Tank 19 waste retrieval and waste retrieval in other U.S. Department of Energy (DOE) tanks. This test program consisted of three phases. The first phase involved small-scale mixer testing at the ITT Flygt laboratory in Trumbull, Connecticut. The second phase involved larger-scale (about 1/4-geometrical scale) tests of Flygt mixers at PNNL. The third and final phase involved full-scale mixer testing at SRS. Testing in different tank sizes was needed to evaluate and validate scaling methods so the results of the relatively inexpensive small-scale tests could be used to make full-scale mixer performance predictions more cost-effective.

Flygt mixers consist of an electrically powered propeller surrounded by a close-fitting shroud. Figure 1.1 shows a Flygt mixer mounted to a vertical mast (ITT Flygt Corporation 1997). The 37-kW (50-hp) mixers being considered for use in Tank 19 have a propeller diameter of approximately 51 cm (20 in.) and operate at 860 rotations per minute (rpm). The rapidly spinning propeller creates a turbulent fluid jet with an average exit velocity approaching 6 m/s (see Figure 1.2) (ITT Flygt Corporation 1997).

This report summarizes the results of all three phases of the fiscal year 1998 Flygt mixer testing, but more emphasis is placed on the results of the Phase C tests because previous reports document the Phase A and B results (Powell et al. 1999a, 1999b).

Phase C testing used full-scale mixers in a full-scale diameter tank. Fluid velocity measurements were made at selected locations in the tank for three different liquid levels and various mixer orientations. Water was used for all the Phase C tests. No solids suspension or sludge mobilization tests were conducted.

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[a]PNNL is operated by Battelle for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

Section 2.0 of this report summarizes the key findings of the fiscal year 1998 Flygt mixer tests. The Phase C experimental protocol and results are provided in Section 3.0. Publications referenced in this report are listed in Section 4.0. Appendix A is a modified version of the Phase C test plan, and Appendix B provides the initial Phase C summary report and the extended shroud test report, which were prepared by SRS staff.

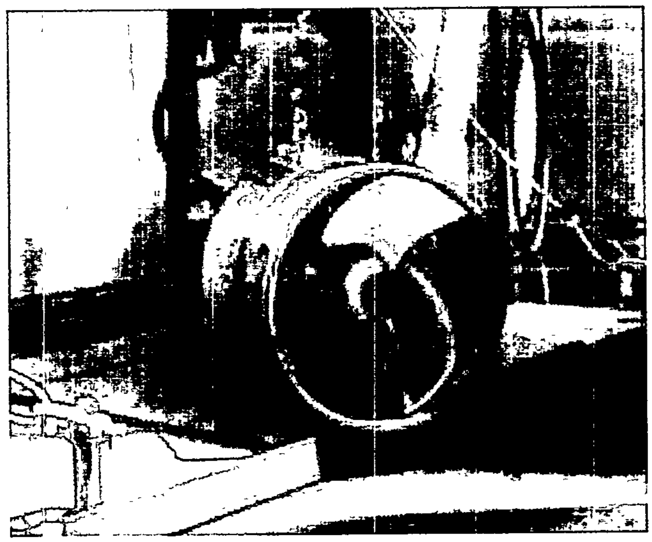

Figure 1.1. Flygt Mixer

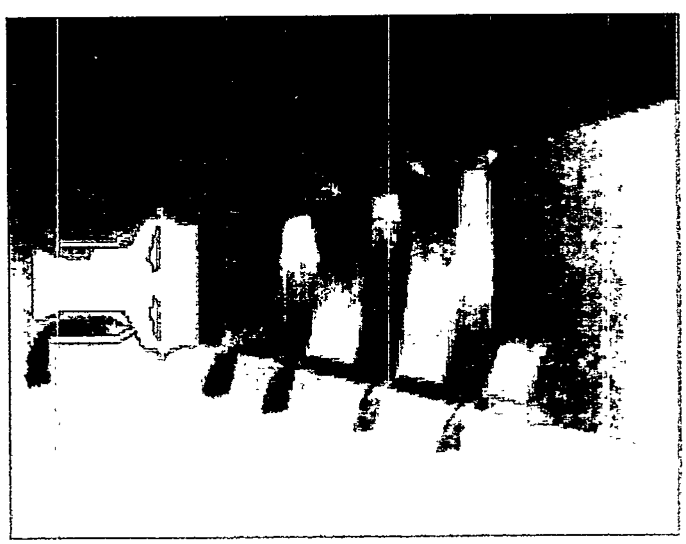

Figure 1.2. Flygt Mixer Jet Flow as Described by ITT Flygt

2.0 Fiscal Year 1998 Flygt Mixer Test Conclusions and Recommendations

Mixer tests were performed in 0.45-m, 1.8-m, 5.7-m, and 25.9-m diameter tanks using stationary Flygt mixers. These tests were designed to evaluate candidate scaling relationships for Flygt mixers used for sludge mobilization and particle suspension. These tests comprised a three-phase test program involving representatives from ITT Flygt Corporation, SRS, ORNL, and PNNL.

Although some of the Phase B tests in the 1.8-m tank were geometrically similar to selected Phase A tests (0.45-m tank), none of the Phase A or B tests were geometrically, kinematically, and/or dynamically similar to the proposed Tank 19 mixing system with stationary Model 4680 Flygt mixers. Therefore, the mixing observed during the Phase B tests is not *directly* indicative of the mixing expected in Tank 19 and some extrapolation of the data is required to make predictions for Tank 19 mixing. The implications of lack of geometric similarity, as well as other factors that complicate interpretation of the test results, are discussed in Powell et al. (1999b).

2.1 Conclusions

The key findings and implications of the fiscal year 1998 Flygt mixer tests are provided in this section. Refer to Powell et al. (1999a, 1999b) for detailed descriptions of the Phase A and B testing. Phase C testing is described in Section 3.0 of this report. The key findings from all three phases of testing are as follows:

- Fluid velocity measurements indicate that time-averaged velocities in the 30- to 50-cm/s range (measured 5 cm above the tank floor) are required to maintain 20x50-mesh zeolite particles suspended in water. If an all-particles-in-motion condition is to be met, the average fluid velocities near the tank floor (5 cm above) must exceed approximately 50 cm/s in all locations. This value may be somewhat lower if the supernate density and viscosity are significantly larger than those of water. The magnitude of this effect cannot be quantified without further testing.

- Fluid velocity measurements made at full scale confirm the Phase B prediction that three fixed-position Model 4680 Flygt mixers do not provide sufficient mixing intensity to achieve the required fluid velocities near the tank floor simultaneously in all regions of the tank.

- Extending the shroud on the Model 4680 mixers improves jet coherence and significantly increases the fluid velocities at all downstream locations in the direction of fluid jet flow.

Shroud lengths of 20, 50, and 76 cm were tested. Mixer performance was best using the 50-cm-long shroud. Further testing is planned to determine the optimum shroud length.

- The mixing intensity required to induce sludge mobilization can be estimated based on the sludge shear strength. The average wall shear stress[a] (τ_0) required to mobilize about 80% of the sludge in a tank is on the order of 5% to 15% of the sludge shear strength. Evidence exists that these percentages increase with increasing scale, but it is not known if this effect is real or an artifact of differences in the simulants tested. If the mixers are run for longer periods of time, 80% sludge mobilization may be achieved at τ_0 levels somewhat lower than implied by these percentages.

- Retrieval of the sludge portion of the solids, which is expected to be composed of slow-settling solids, is not expected to present difficulty if the sludge is mobilized. Once mobilized, the slowly settling solids are expected to be maintained in suspension with relatively gentle agitation.

- Constant-power-per-unit-volume mixer scaling is consistent with the Phase A and B experimental observations. Constant-power-per-unit-volume scaling predicts that significantly more than three stationary 37-kW (50-hp) Model 4680 Flygt mixers will be required in Tank 19 to achieve an all-particles-in-motion-on-the-tank-floor condition, although the accuracy of this prediction is uncertain because the effects of changing the number of mixers and the liquid-level-to-tank-diameter ratio are not well understood.

- The constant-wall-shear-stress method for predicting required mixing intensity (Gladki 1997) apparently does not apply to rapidly settling particles in large tanks (i.e., 1.8-m diameter and larger). Roughly 40% of the waste heel in SRS Tank 19 is expected to be rapidly settling zeolite, which was originally placed in the tank as 20x50-mesh zeolite particles (Goslen 1986).

- The SRS stationary mixer deployment mast successfully allowed the mixer to be installed through a simulated tank riser in a simple and timely manner. The mast maintained the Model 4680 Flygt mixer in a stable position on the tank floor during mixer operation. With external crane support, the mast allowed the mixer to be periodically lifted and redirected in a timely manner so that the mixer discharged in another direction.

- Measurements were made to characterize the velocity decay rate with distance of the fluid jets produced by Model 4680 Flygt mixers in a 25.9-m diameter tank. The velocities decay faster and the jet spreads wider than predicted by classical turbulent free jet correlations, but this result was not unexpected because the classical correlations do not

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[a]Average wall shear stress is defined as the total mixer thrust divided by the wetted surface area within the tank (Gladki 1997).

include the effects of the tank floor, the enclosed geometry of the tank, or the nonuniform velocity profile of the fluid jet produced by a propeller.

2.2 Recommendations

Based on the results of the Phase A and B Flygt mixer test programs, the following recommendations are made:

- The 37-kW (50-hp) Model 4680 Flygt mixers planned for installation in SRS Tank 19 should not be deployed without a mechanism for continuously (or periodically on a timescale of minutes) reorienting the mixers. Proceeding with the previously planned method to use three Model 4680 mixers with fixed orientation is likely to result in poor recovery of fast-settling waste components from Tank 19.

- Extended shrouds should be used on the Model 4680 Flygt mixers to improve jet coherence. Phase C testing implies the optimal shroud length is between 20 and 76 cm and may be near 50 cm. Further testing is planned to determine the optimum shroud length.

- A combination of numerical modeling, scaling analysis, and experimentation should be used to examine the potential effectiveness of Model 4680 Flygt mixers configured for continuously adjustable orientation.

- Efforts should be made to quantify the shear strength of the Tank 19 heel. Without these data, the number of mixers required to effect mobilization of the sludge cannot be predicted with sufficient accuracy. Accurate measurements of the Tank 19 waste heel particle size distribution and the supernate density and viscosity are also needed to improve the Tank 19 mixing predictions.

- Kaolin clay with a shear strength of about 400 Pa should be tested in the 0.45-m tank used previously for the Phase A tests in Trumbull, Connecticut. This test will allow a comparison of sludge mobilization using Flygt mixers and the same sludge simulant in 0.45-m, 1.8-m, and 5.72-m tanks.

- Improved slurry pump-down techniques should be explored, and an improved understanding of the pump-down process should be developed to help design and interpret pump-down tests. The Phase B testing implies that mixing intensity must be near (i.e., power per unit volume of at least half, perhaps three-quarters) that required to reach an all-particles-in-motion condition if slurry retrieval is performed without continuously reorienting the mixers and without systematically varying the mixer speeds during pump-down. Zeolite recovery may also be improved if the retrieval pump intake is positioned as close as is practical to the tank floor instead of 13 cm above the floor as was used in our 5.7-m tank tests. Further testing may be required to determine the extent of improvement that can be achieved and the relationship between applied mixing intensity, the number of mixers employed, the liquid-level-to-tank-diameter ratio, and the fraction of solids retrieved.

3.0 Phase C Testing

In Phase C, Model 4680 Flygt mixers were tested in a full-scale tank. Early in fiscal year 1998, three Model 4680 Flygt mixers were proposed for installation in Tank 19 to mobilize and mix the settled solids. Phase A and B testing used smaller mixers in smaller tanks. Phase C, however, was essentially a test of the proposed Tank 19 mixing system at full scale.

Phase C testing used only water. No solids or sludge simulants were employed. Therefore, the Phase C results cannot be used directly to determine the effectiveness of the proposed Tank 19 mixing system. Instead, the observed full-scale fluid velocities must be compared with the minimum required fluid velocities, which were determined as part of Phase A and B testing.

Section 3.1 provides a general description of the Phase C testing, and Section 3.2 discusses the test results. Section 3.3 provides the conclusions and recommendations from the Phase C tests. More complete descriptions of the tests and test results are provided in Appendixes A and B.

3.1 Description of Phase C Testing

Flygt Model 4680 mixers were used for the Phase C tests. These mixers consist of a 51-cm (20-in.) shrouded propeller driven by a 37-kW (50-hp) electric motor. Standard Flygt Model 4680 mixers use 30-kW motors and 76-cm propellers. Because the standard Model 4680 mixers are too large to fit in the 61-cm (24-in.) diameter tank risers at SRS, ITT Flygt Corporation developed a modified mixer design that uses a smaller propeller and more powerful motor. A wire-mesh screen was also added to the Model 4680 mixer suction to protect the propeller from debris known to be inside SRS Tank 19 and other DOE waste tanks. SRS developed a mixer deployment mast to install and orient the Model 4680 mixers in waste tanks such as SRS Tank 19. Figure 3.1 shows one of the Model 4680 mixers mounted on the SRS deployment mast. Figure 3.2 shows the mixer suspended from the mast above the full-scale TNX test tank.

Initial prototype tests of the modified Model 4680 mixer design were conducted by ITT Flygt Corporation at their Pewaukee, Wisconsin, test facility (ITT Flygt Corporation 1998). With the inlet screen installed and the mixer operating at full speed (860 rpm), the Model 4680 mixer is expected to generate a water flow rate of about 1.1 m^3/s (17,500 gpm). This flow rate corresponds to a mixer thrust of 6160 N, a hydraulic power of about 30 kW, and an average fluid exit velocity of 5.4 m/s (18 ft/s).

Four modified Model 4680 Flygt mixers were procured for the Phase C tests and eventual installation in Tank 19. A mixer-deployment mast was designed and constructed before Phase C

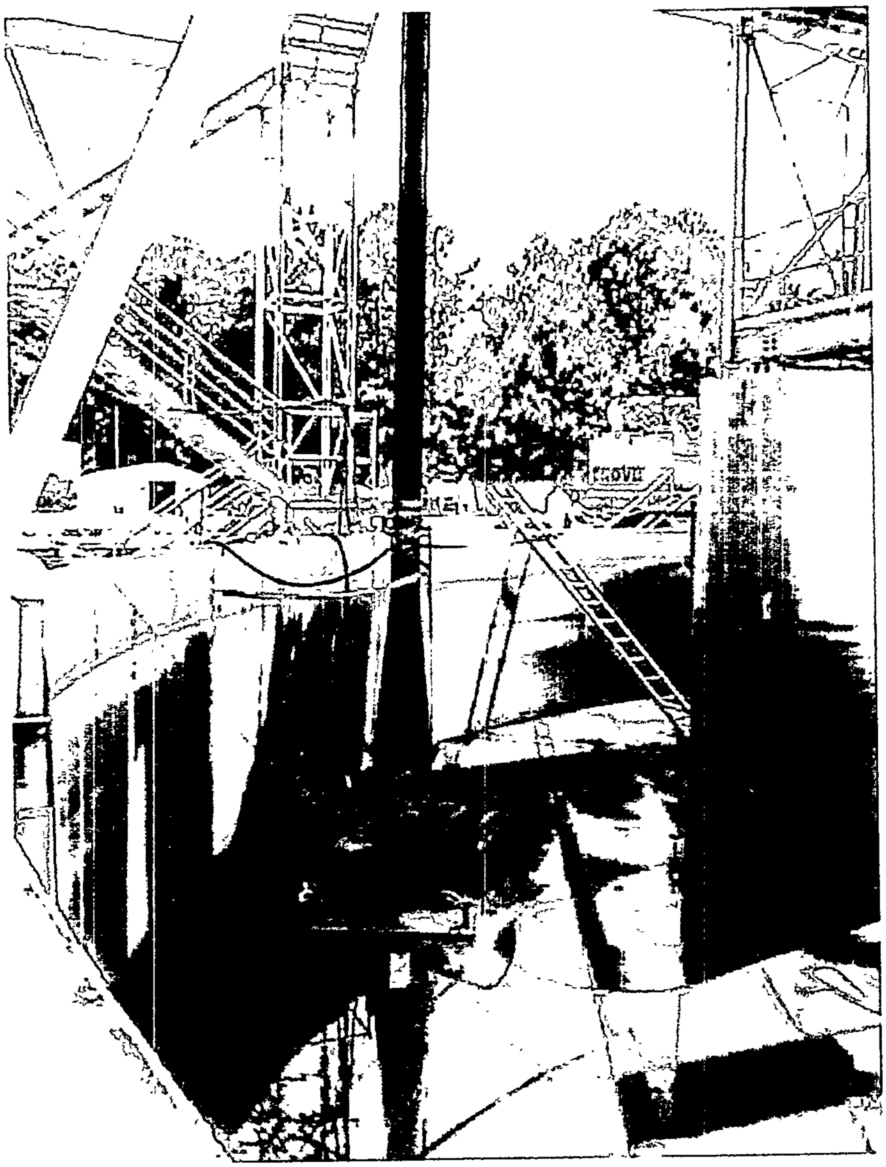

Figure 3.1. Model 4680 Mixer at SRS TNX Test Facility

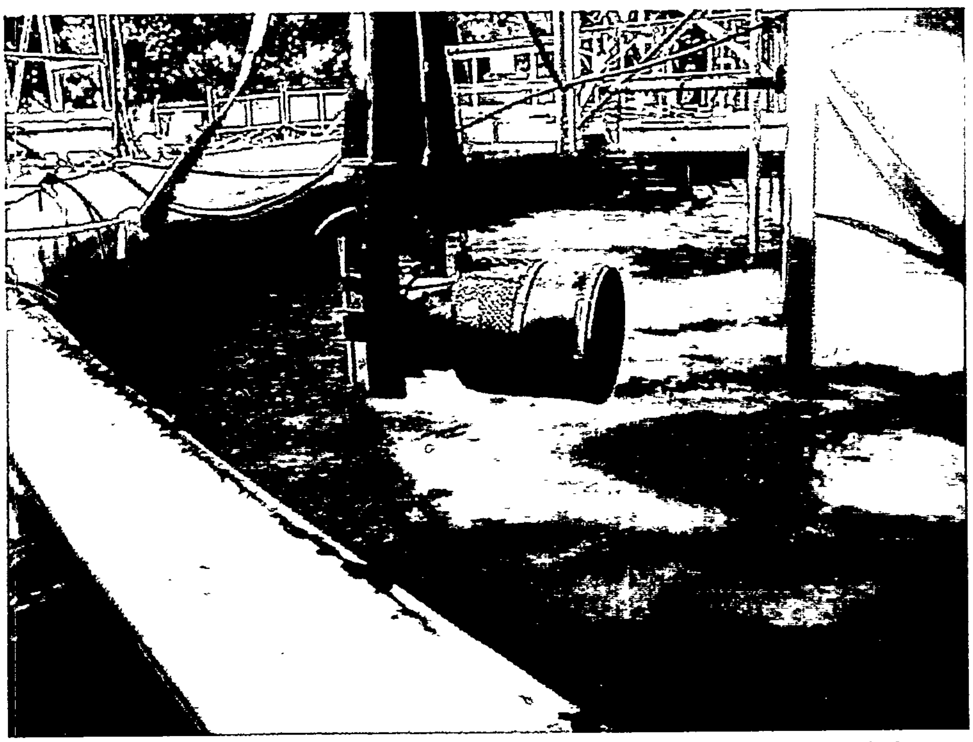

Figure 3.2. Model 4680 Flygt Mixer Supported by Deployment Mast

testing so that mixer deployment could be evaluated as part of the Phase C tests. The mast functioned as designed.

Phase C testing was performed at the full-scale tank test facility at SRS (TNX). The TNX tank is 25.9 m (85 ft) in diameter and 2.4-m (8-ft) deep. The TNX tank has the same diameter as Tank 19 and it can be filled to the same depth as the Tank 19 waste. The Model 4680 Flygt mixers were installed in the TNX tank in various positions (in most cases the positions correspond to Tank 19 riser locations) and orientations. Figures 3.3 and 3.4 show one of the mixers installed on the tank floor.

A 1.8-m (6-ft) diameter tank was previously installed in the TNX tank as part of another test program. The 1.8-m tank was not removed for the Phase C tests. This 1.8-m tank probably altered some of the water flow patterns during the Phase C tests, but efforts were made to avoid directing the mixers at the small tank. The 1.8-m tank can be seen in the right side of Figures 3.1 and 3.2 (its location is also shown on Figures 3.5 through 3.16).

Water velocities were measured at selected locations in the tank for each parametric variation of mixer position and water level. A Marsch-McBirney Model 511 electromagnetic velocity probe was used to collect the data. At each measurement location, the instantaneous water velocity was recorded for 2 to 5 minutes using a computer data-acquisition system at a sampling rate of 10 Hz. These data were used to calculate time-average and peak velocities for each location. The number of mixers and liquid level used for each test is given in Table 3.1. A more detailed description of the test protocols is provided in Appendix B.

Fluid velocity data were taken at the positions shown in Figures 3.5 to 3.16 (figures are to scale). In all cases except Tests 1, 19, 20, the velocity probe was positioned 5 cm above the tank floor, which is as close to the floor as the probe will allow. In Tests 1, 19, and 20, the probe was positioned at the same vertical height as the mixer centerline (i.e., 46 cm above the tank floor). In Tests 19 and 20, velocity data were also collected with the probe lowered to the tank floor (centerline of the probe is 5 cm above the floor) for all the positions in line with the mixer discharge (see Figures 3.15 and 3.16).

All tests were conducted with the mixers running at full speed (860 rpm).

Several other tests were performed as part of the Phase C testing. Currently, questions exist regarding the accuracy of the measurements made during those tests.[a] The data from the questionable tests are not included in this report.

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[a]Unusually high turbulent intensities and peak velocities were observed during some tests. The data from these tests were called into question because of these high values. Further review, and perhaps further testing, will be required before it is known whether the questionable data are valid.

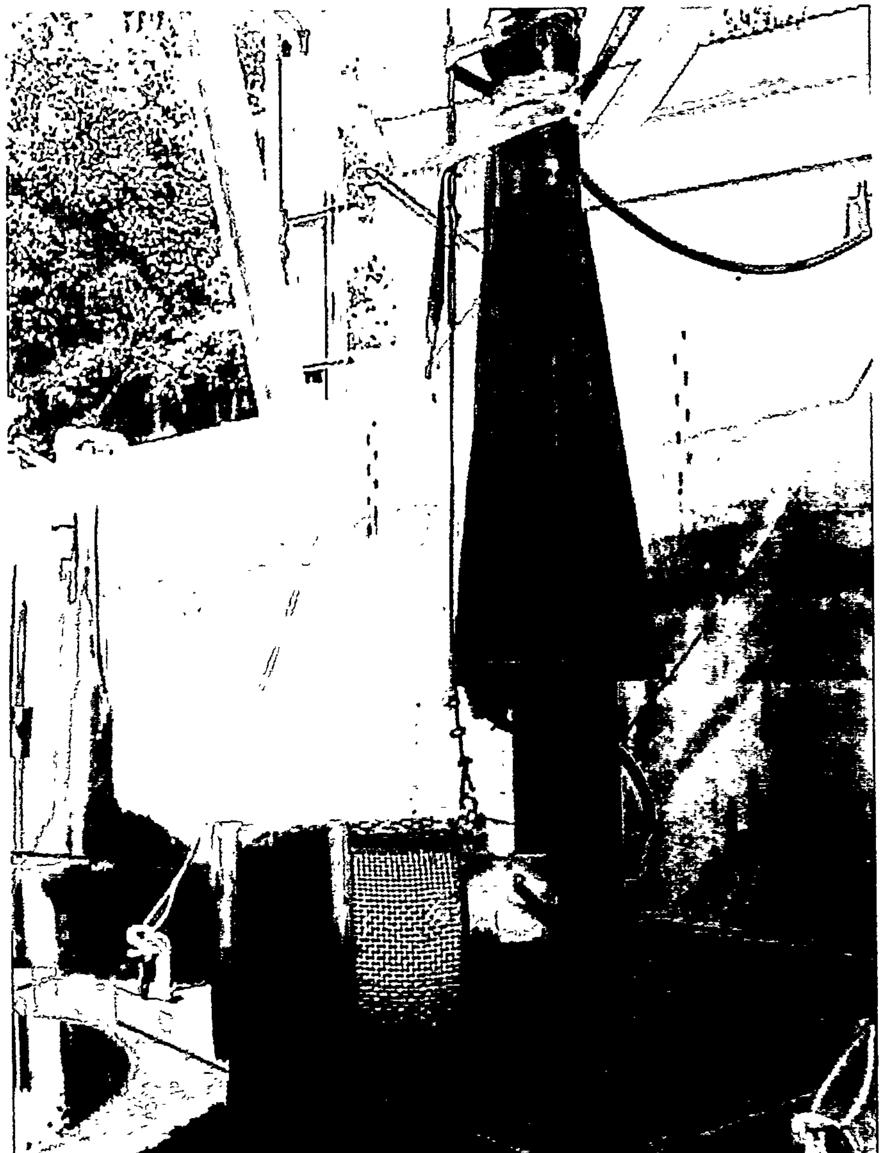

Figure 3.3. Side View of Model 4680 Flygt Mixer and SRS Mixer Deployment Mast

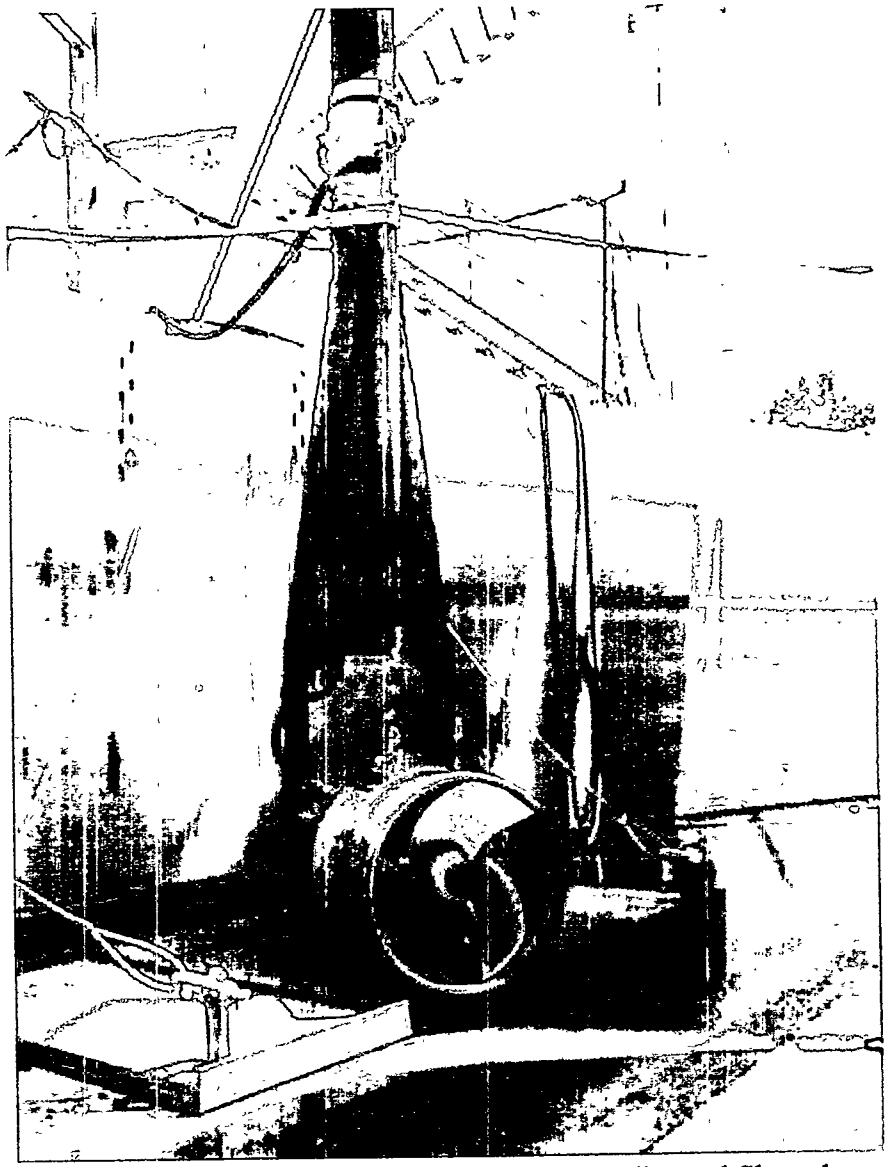

Figure 3.4. Model 4680 Flygt Mixer Propeller and Shroud

Table 3.1. Phase C Test Matrix

Test No.	No. of Mixers Used	Liquid Level (m)
1A	1	0.9
1B	1	1.2
1C	1	1.5
2	1	1.2
3	2	1.2
4	3	1.2
5	1	1.2
6	3	1.2
9B	4	1.2
11	2	1.2
19	1	1.2
20	1	1.2

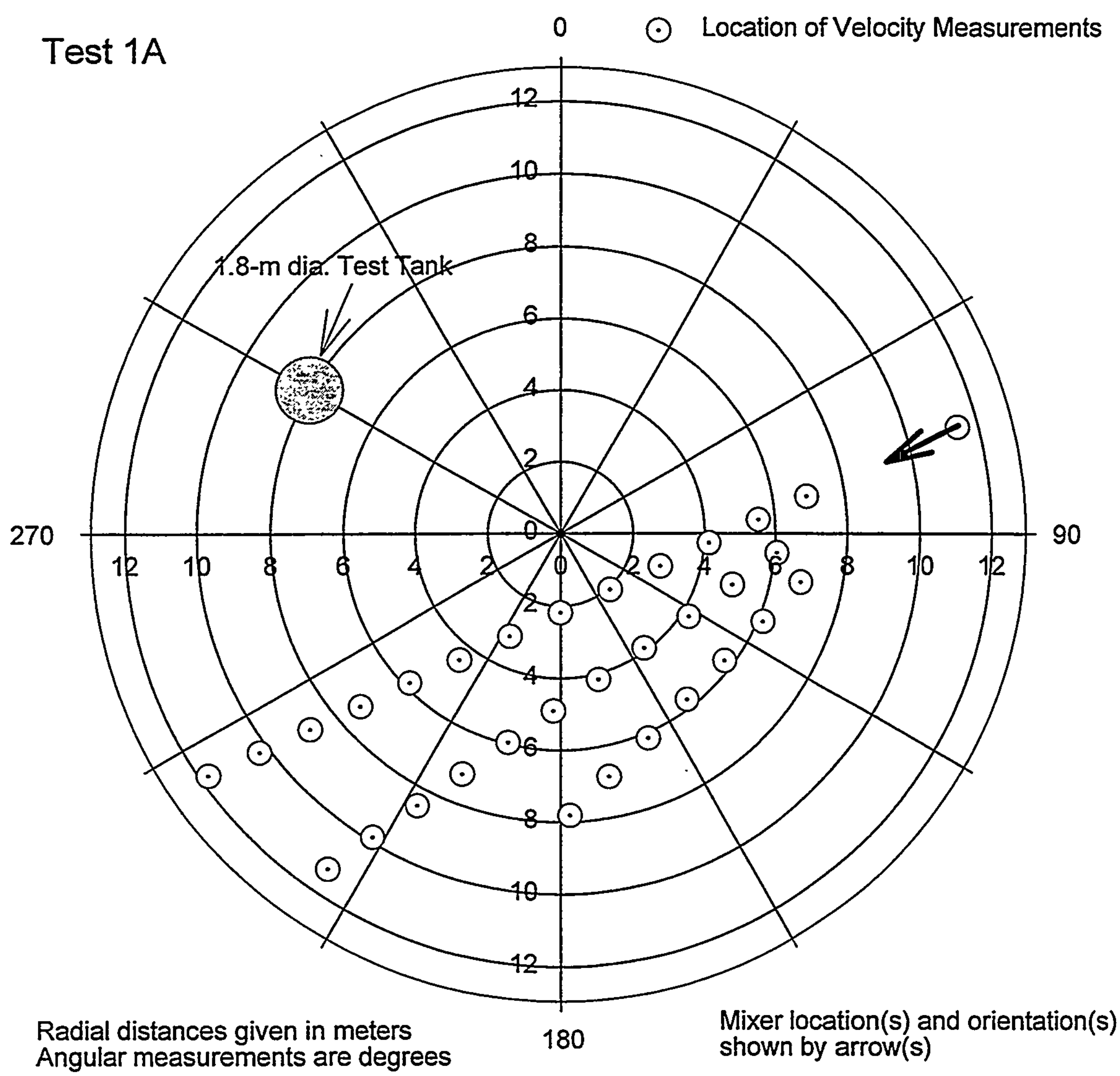

Figure 3.5. Velocity Measurement Locations for Test 1A

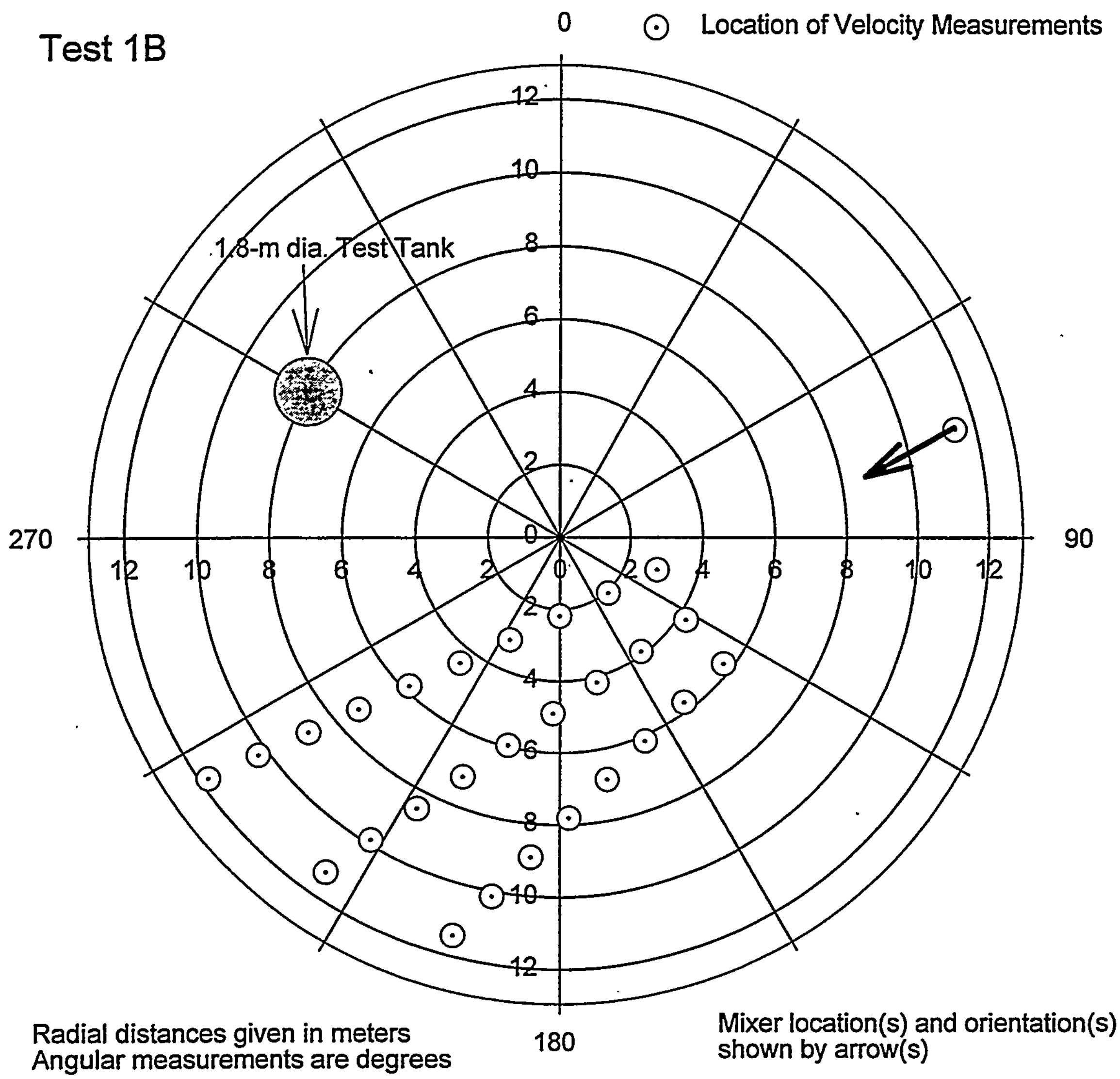

Figure 3.6. Velocity Measurement Locations for Test 1B

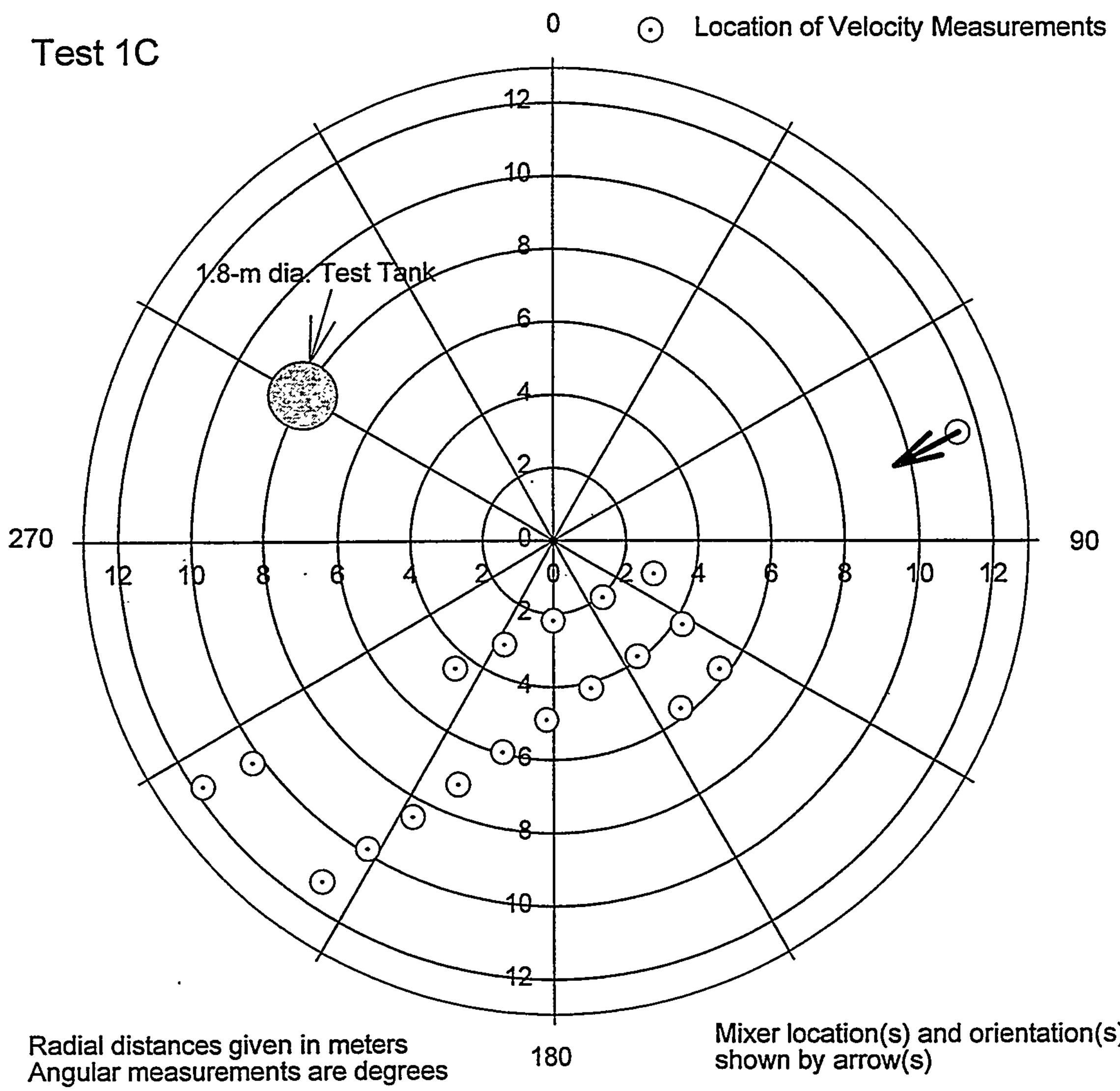

Figure 3.7. Velocity Measurement Locations for Test 1C

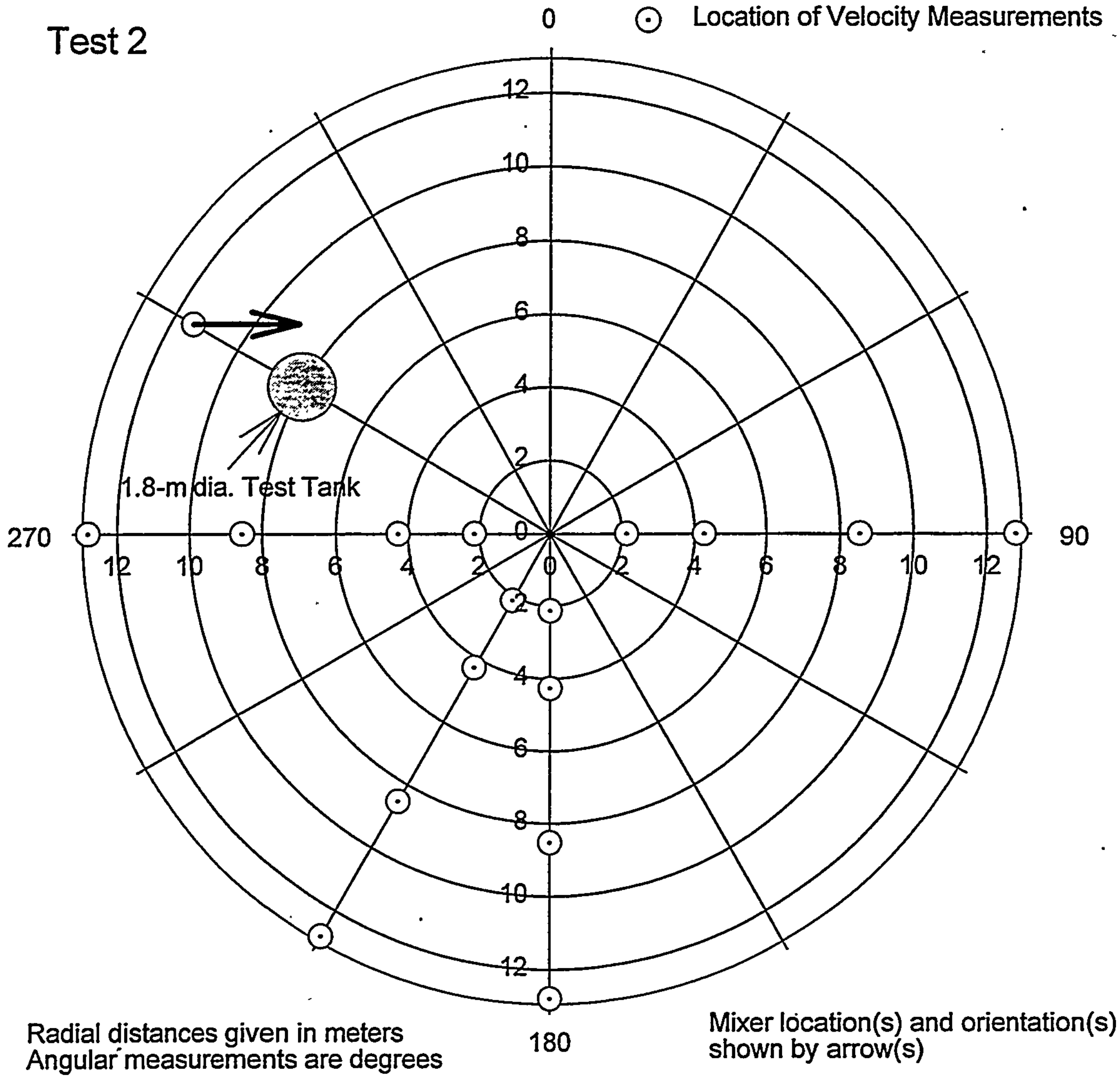

Figure 3.8. Velocity Measurement Locations for Test 2

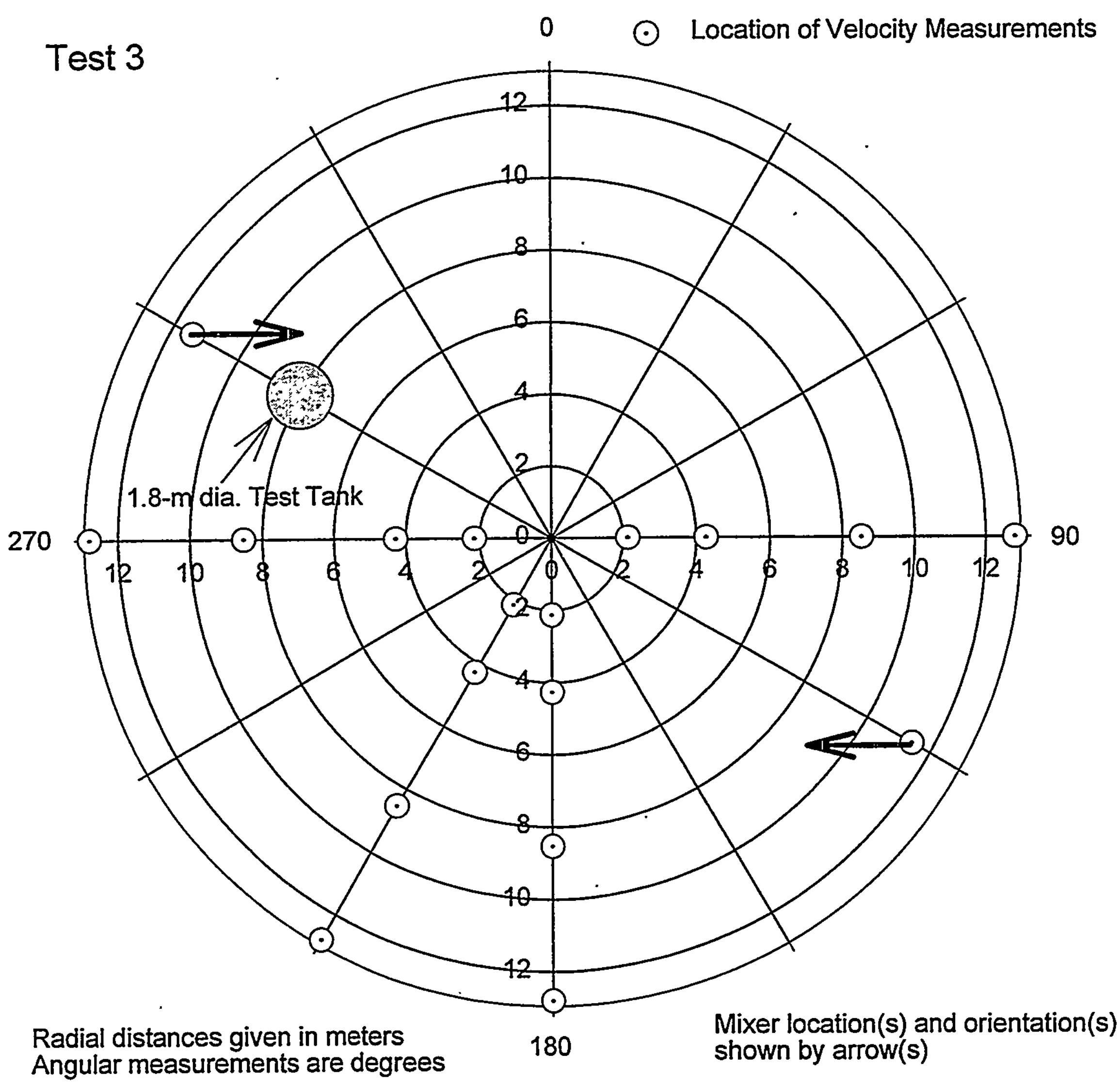

Figure 3.9. Velocity Measurement Locations for Test 3

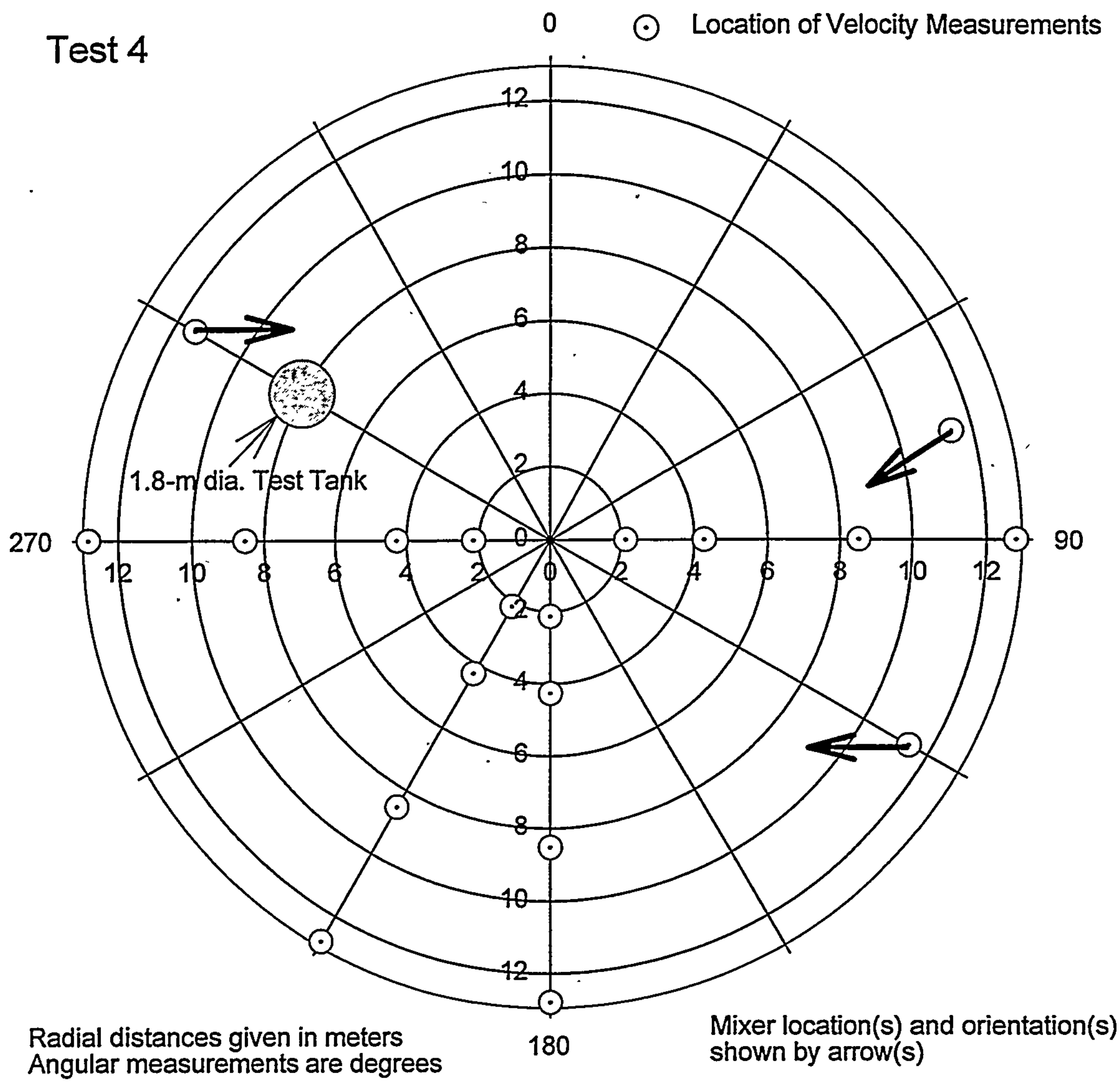

Figure 3.10. Velocity Measurement Locations for Test 4

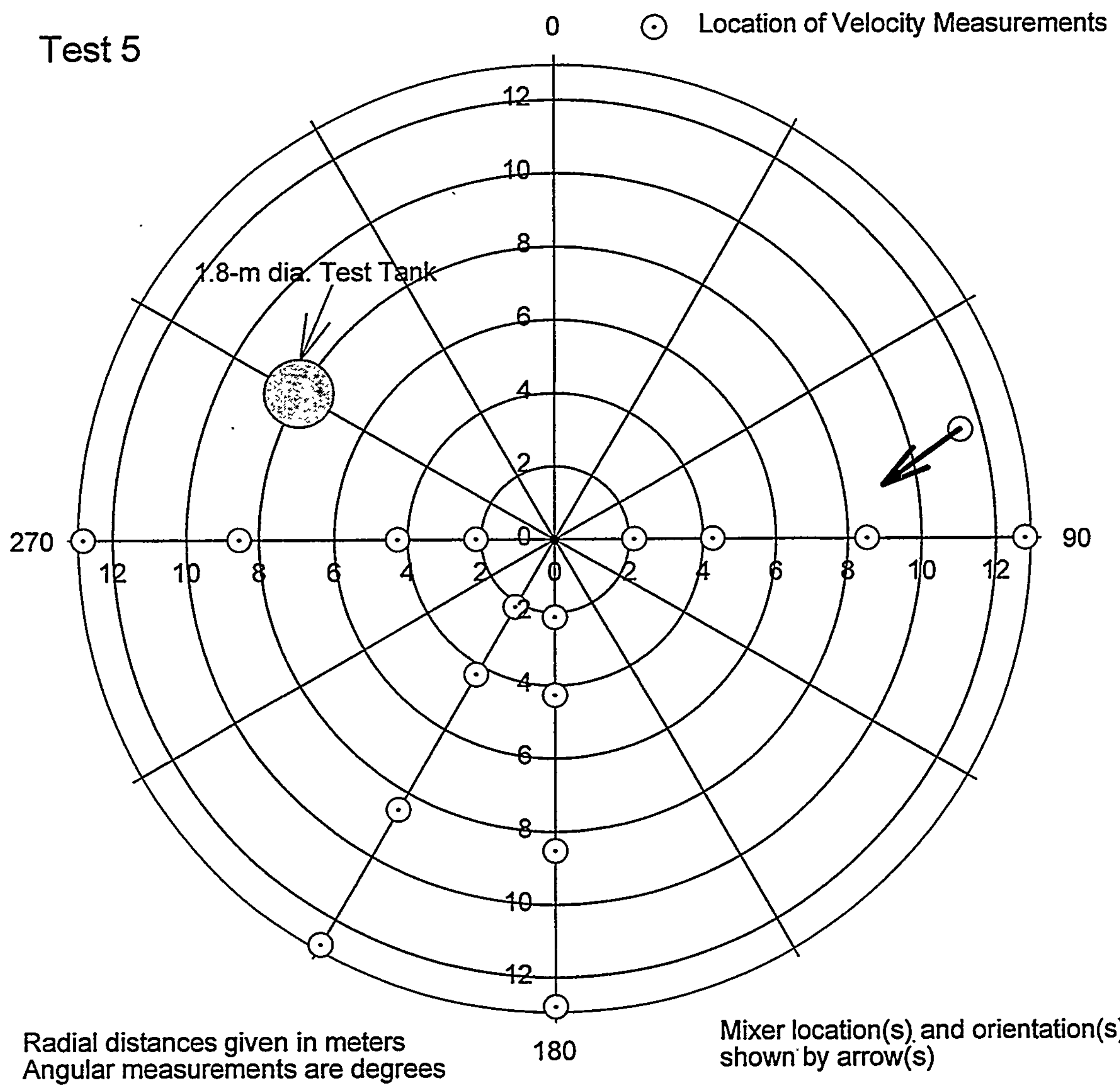

Figure 3.11. Velocity Measurement Locations for Test 5

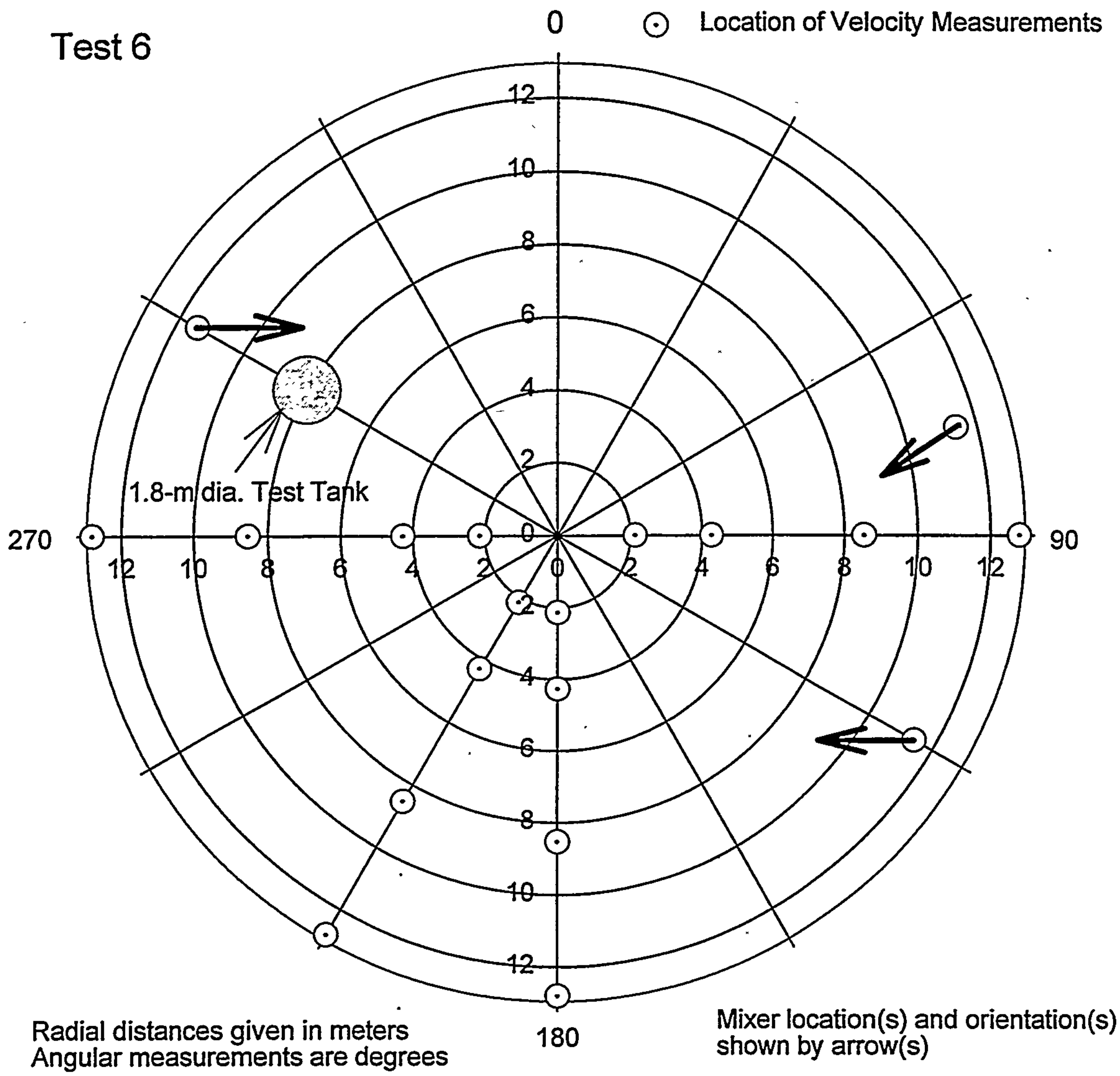

Figure 3.12. Velocity Measurement Locations for Test 6

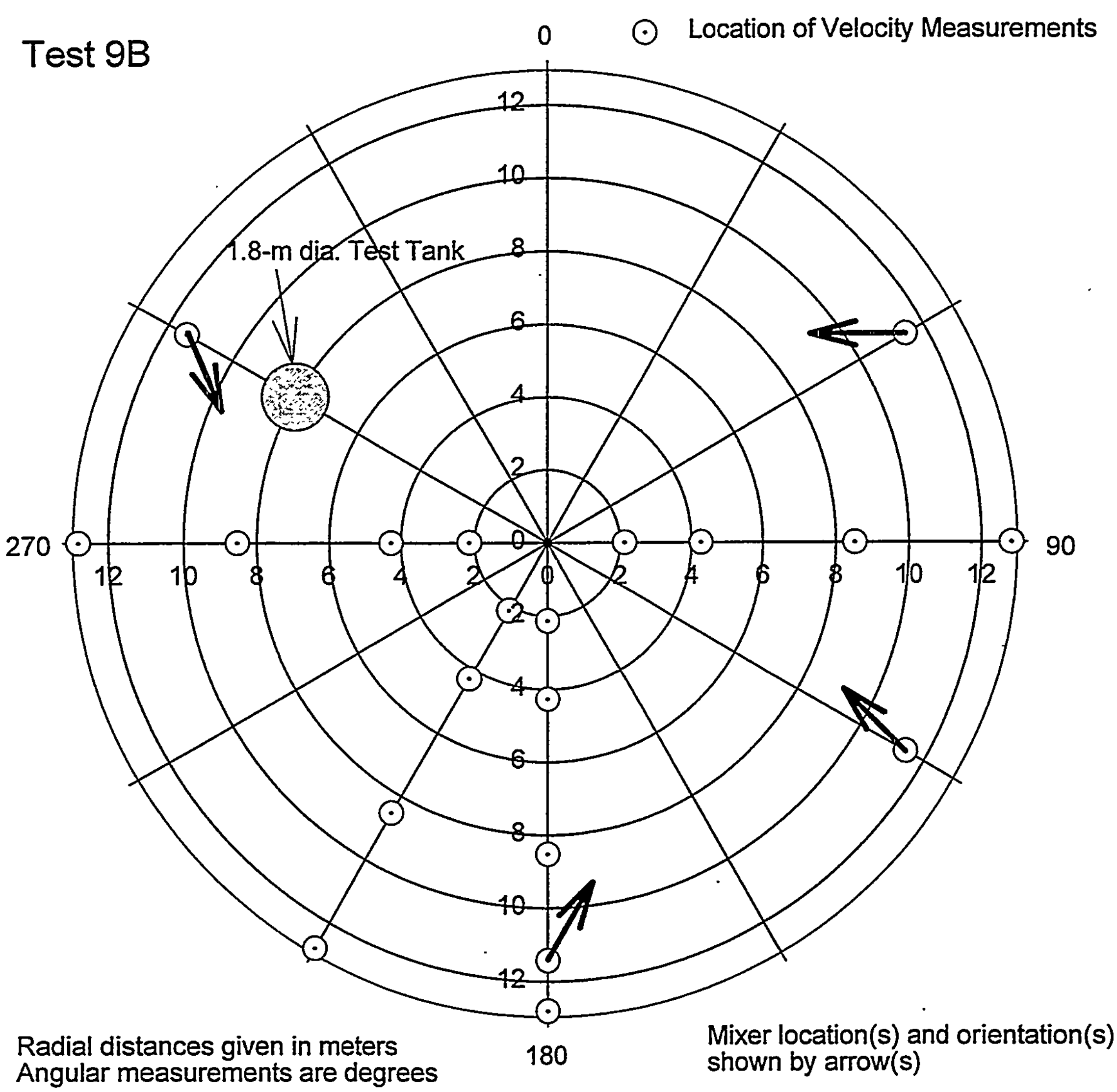

Figure 3.13. Velocity Measurement Locations for Test 9B

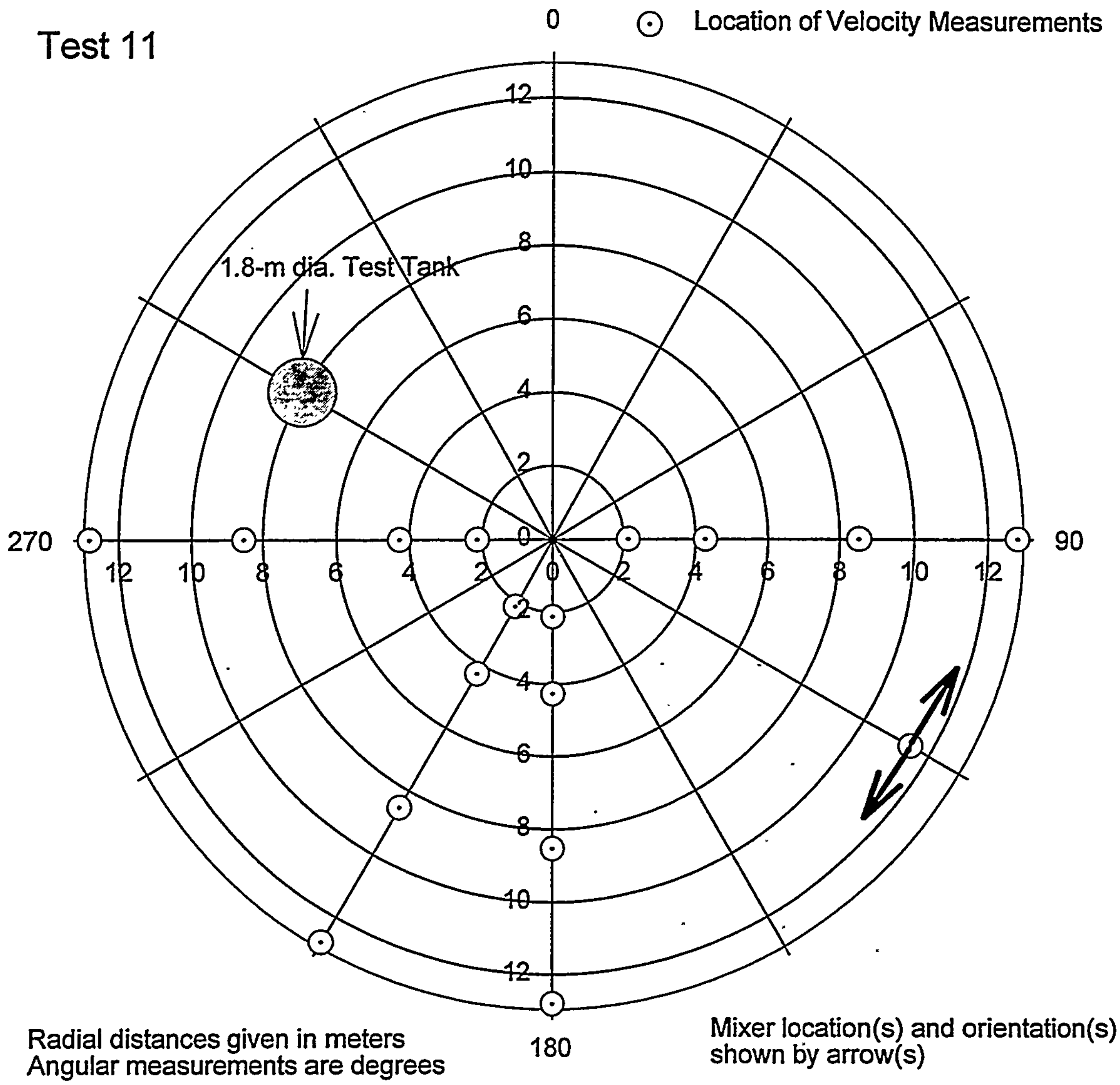

Figure 3.14. Velocity Measurement Locations for Test 11

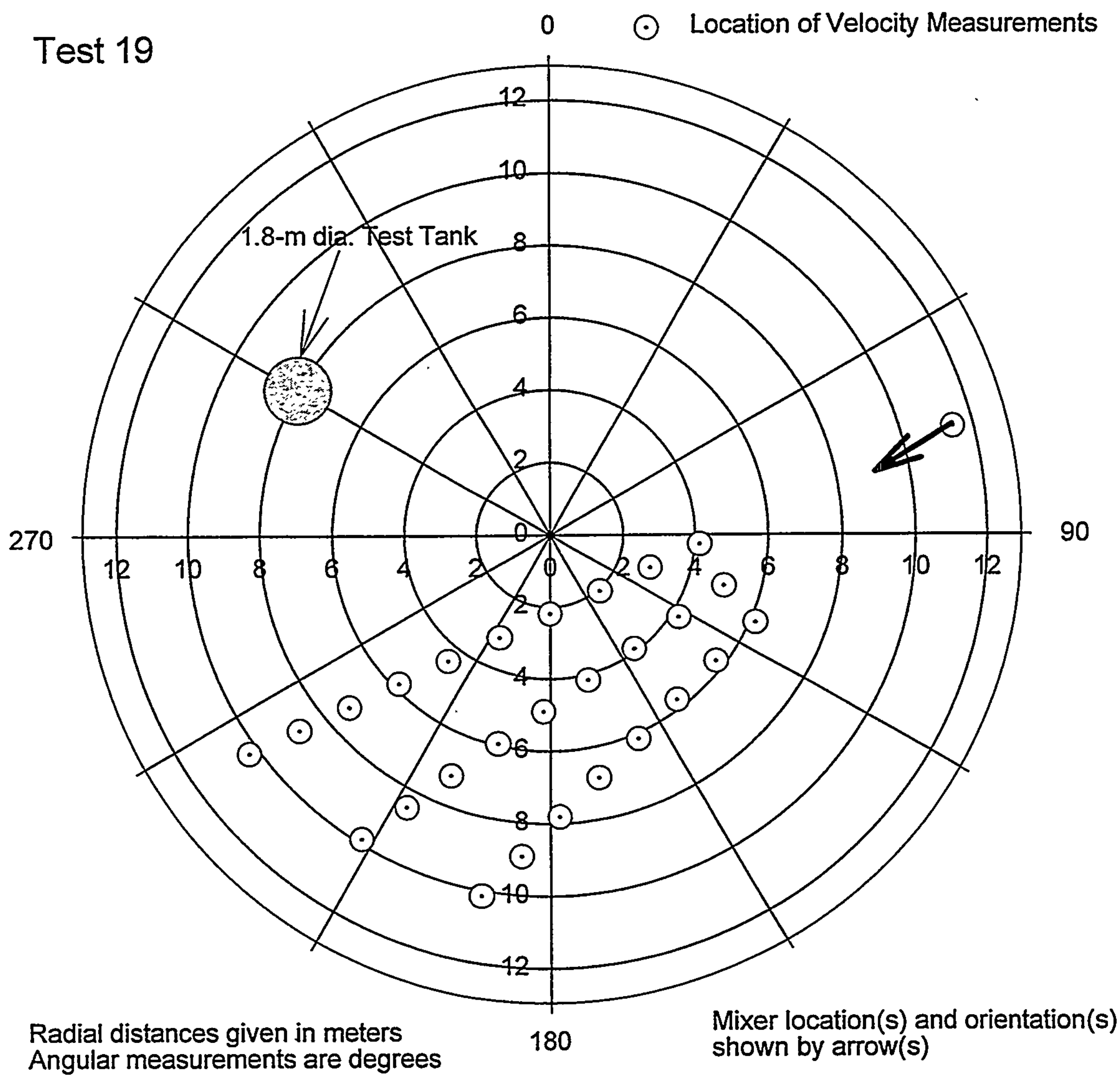

Figure 3.15. Velocity Measurement Locations for Test 19

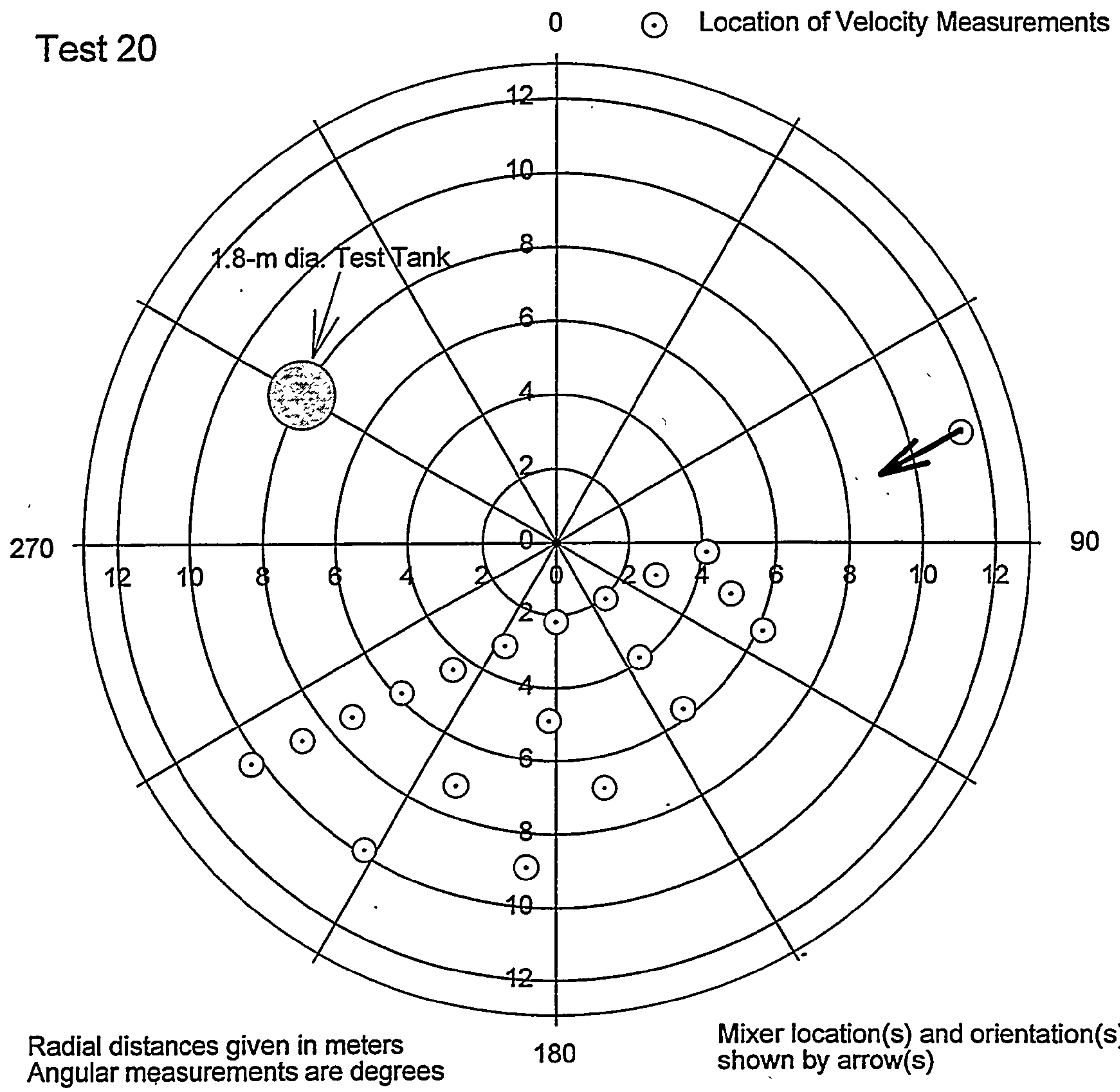

Figure 3.16. Velocity Measurement Locations for Test 20

3.2 Phase C Test Results

The Phase C test results are consistent with the scale-up predictions made based on the Phase A and B tests. The water velocities near the tank floor, in some places, did not comfortably exceed the 40 ± 10-cm/s critical velocity for zeolite suspension, which was determined in the Phase A and B tests. Because settling will likely occur in regions where the critical velocity is not maintained, the previously planned three-stationary-mixer arrangement must be modified. Two modifications are suggested. First, the mixers must be rotated in the azimuthal plane so all areas on the tank floor are periodically exposed to the high fluid velocities present in the direction of the mixer discharge. Second, the mixer shrouds should be extended to improve the coherence of the jet, thereby increasing the jet velocities at all downstream distances.

The Phase C data used to arrive at these recommendations are discussed in Sections 3.2.1 through 3.2.5. Section 3.2.1 provides the data showing that the critical velocities for zeolite suspension are not achieved simultaneously in all areas of the tank when stationary mixers are used in the configurations tested. Section 3.2.2 examines the beneficial effect of extending the mixer shroud. Section 3.2.3 provides data showing the effect of liquid level on water velocities, and Section 3.2.4 gives a comparison of the Phase B and C velocity data. Section 3.2.5 examines the effects of long-term flow circulation.

3.2.1 Comparison of Phase C Velocities with Critical Velocity for Zeolite Suspension

Tests 4, 6, and 9B had mixer positions similar to that proposed for Tank 19 and studied in Phase B. Therefore, the velocities observed in these tests are indicative of the velocities that are expected to be seen in Tank 19 using three or four stationary Flygt mixers. Figures 3.17 through 3.19 give the average velocities versus radial and angular position. Many of the locations have average velocities higher than the 40 ± 10-cm/s critical velocity for zeolite suspension,[a] but to ensure effective solids suspension with stationary mixers, the velocities in *all* locations must comfortably exceed the critical suspension velocity. Solids will accumulate in any location with an average velocity less than the critical velocity.

Because many of the locations have average velocities of 40 cm/s or less, three (Tests 4 and 6) or four (Test 9B) stationary Model 4680 Flygt mixers are not expected to provide adequate solids suspension in SRS Tank 19. Mixing performance should improve if the mixers

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[a]The critical velocity for zeolite suspension was estimated in Phases A and B using 20x50-mesh zeolite particles in water. The Tank 19 supernatant liquid has a higher density (1.23 g/mL) and viscosity (2.4 cP) than water, so the required velocities in Tank 19 may be different. Correlations for unidirectional flow in channels (e.g., Graf 1976) imply the Tank 19 liquid properties may reduce the critical velocity by 10% to 20%, but the applicability of these correlations to tank mixing is questionable. Tests are required to accurately quantify the effect.

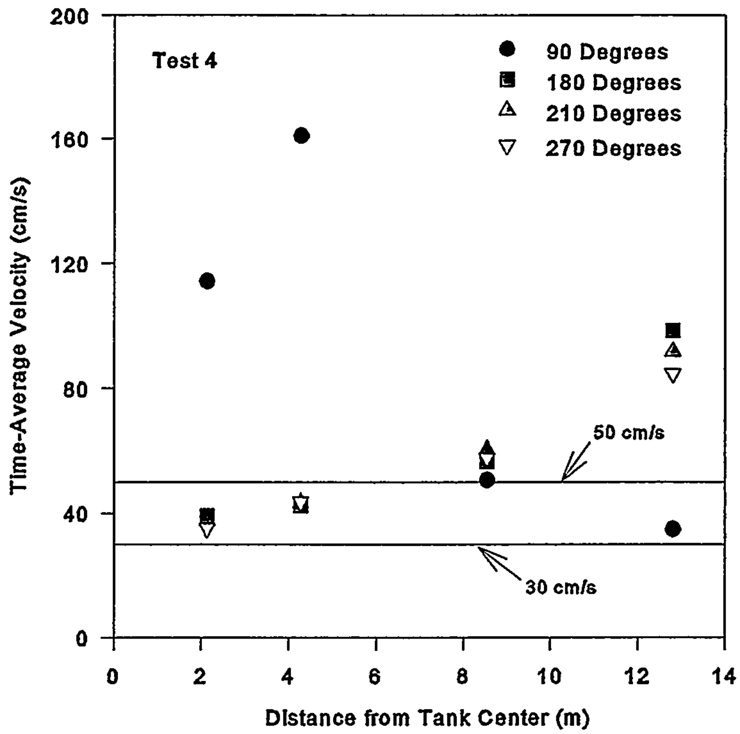

Figure 3.17. Average Velocity Data for Test 4

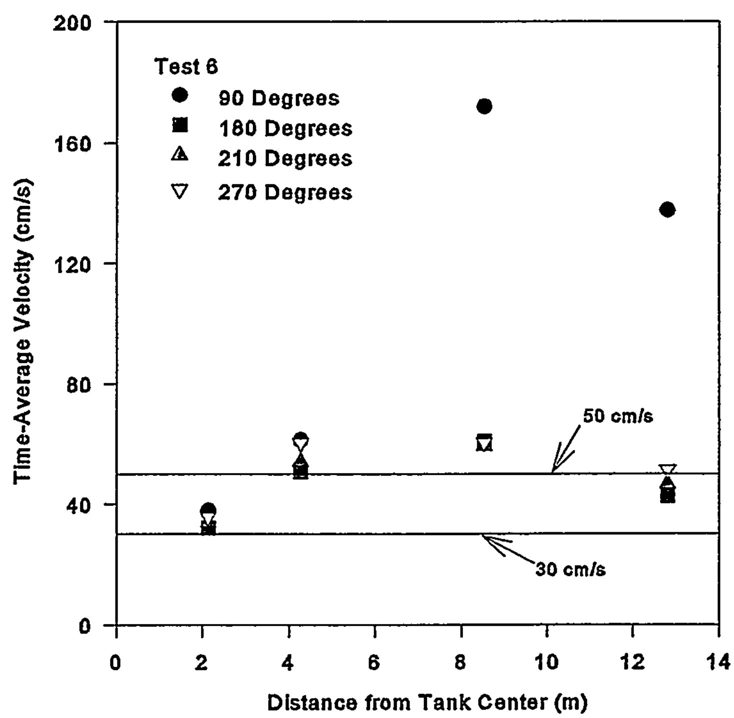

Figure 3.18. Average Velocity Data for Test 6

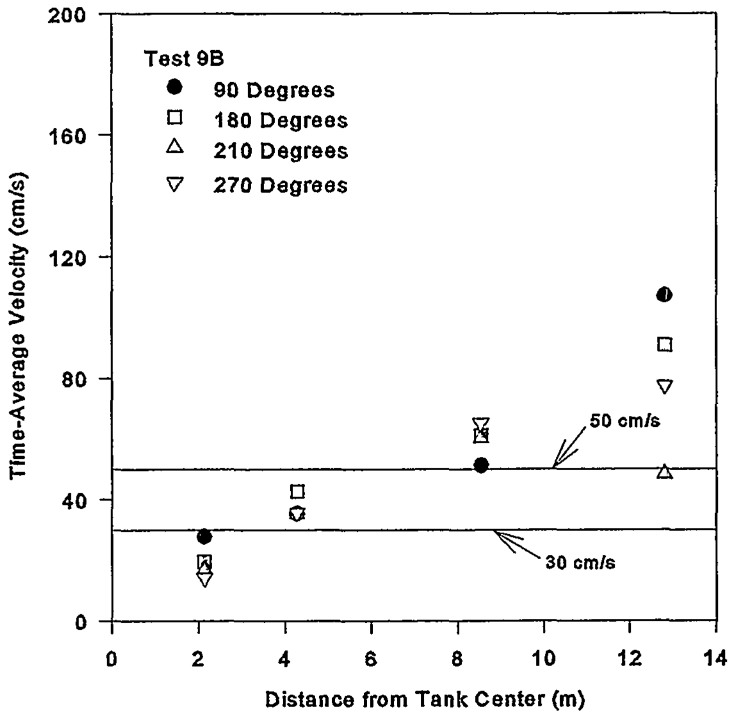

Figure 3.19. Average Velocity Data for Test 9B

are rotated or oscillated azimuthally. Phase D tests are planned to examine proposed rotating-mixer-operation scenarios for Tank 19 solids retrieval.

The interactions between mixers must be considered for effective mixing. In particular, selection of mixer positions and orientations need to account for the circulation patterns induced by the additive effects of all the mixers. Figures 3.18 and 3.19 illustrate this point. Test 6 (Figure 3.18) used three mixers while Test 9B (Figure 3.19) used four mixers, yet the velocities near the tank center are lower in Test 9B than in Test 6. This result may have been partly due to the fact that the mixer positions are shifted with respect to the velocity measurement points. The potential for beneficial and adverse mixer interaction effects needs to be considered when the rotating-mixer waste retrieval system for Tank 19 is designed.

3.2.2 Effect of Extended Mixer Shroud

The rapidly spinning propeller of the Flygt mixer produces a horizontal fluid jet with both axial and angular momentum. The angular momentum, also known as swirl, tends to increase the rate at which surrounding fluid is entrained by the jet. This increased entrainment results in lower downstream velocities compared with a nonswirling jet (Rajaratnam 1976). In some mixing applications, jet swirl is advantageous, but to maximize the downstream jet velocities swirl must be minimized.

The standard mixer shroud, which is 20-cm long, was extended by 30 cm (12 in.) in an effort to improve the coherence of the jet. Velocity measurements made with the 20-cm shroud and with the 50-cm shroud demonstrate that the extended shroud significantly improves the downstream water velocities. Based on this encouraging result, it was decided to further extend the shroud to 76 cm and then measure the resultant fluid velocities. The 76-cm shroud test is referred to as Test 20. A photograph of the Test 20 mixer is provided in Figure 3.20.

Figure 3.21 shows the results from Tests 1B, 19, and 20. At downstream distances of greater than about 15 m, the water velocities produced by the mixer with the 50-cm long shroud are more than 50% higher than those produced by the mixer with the standard 20-cm shroud. Further, the velocities produced using the 50-cm shroud are higher than those from the 76-cm shroud.

Figure 3.22 shows a comparison of the velocities near (5 cm above) the tank floor for mixers using the 50- and 76-cm shrouds. Again, the 50-cm shroud results in higher downstream velocities. Measurements near the tank floor were not made in Test 1B (20-cm shroud).

Based on these results, it is recommended that extended shrouds be installed on the Model 4680 Flygt mixers for applications where downstream velocities must be maximized, such as the rotating-mixer-based Flygt mixer system planned for use in Tank 19. The optimal shroud length will be determined by further testing, but the Phase C results imply the optimum length may be around 50 cm.

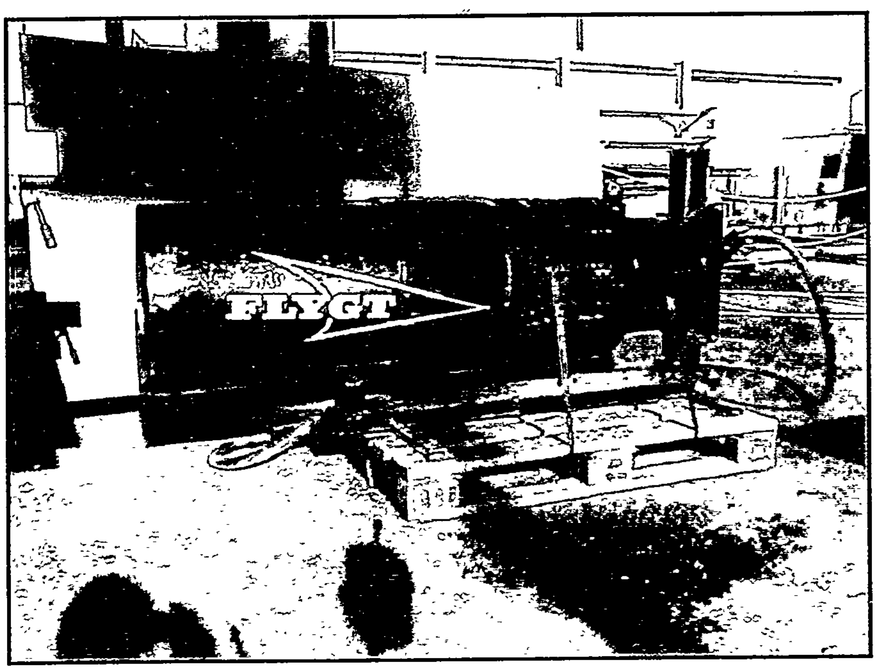

Figure 3.20. 76-cm Shroud Used for Test 20

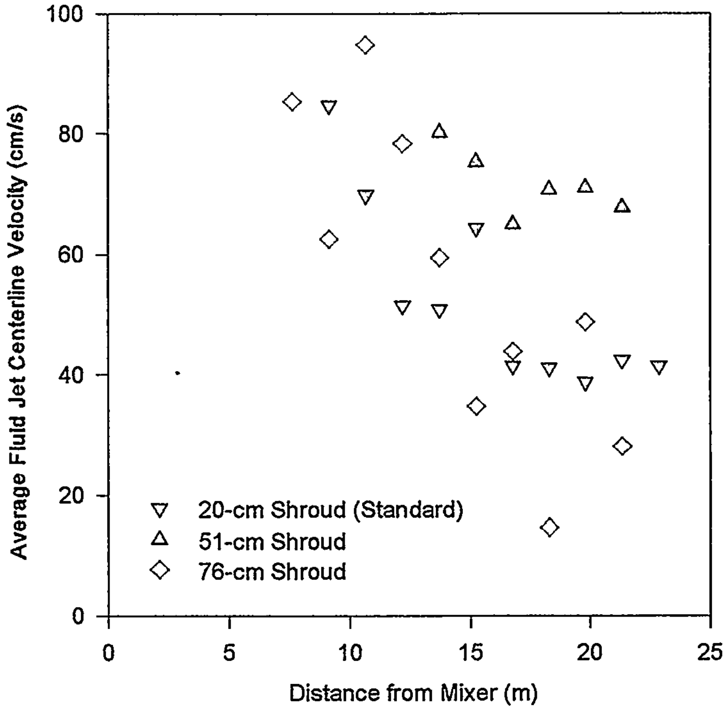

Figure 3.21. Effect of Shroud Length on Centerline Jet Velocities for Tests 1B, 19, and 20

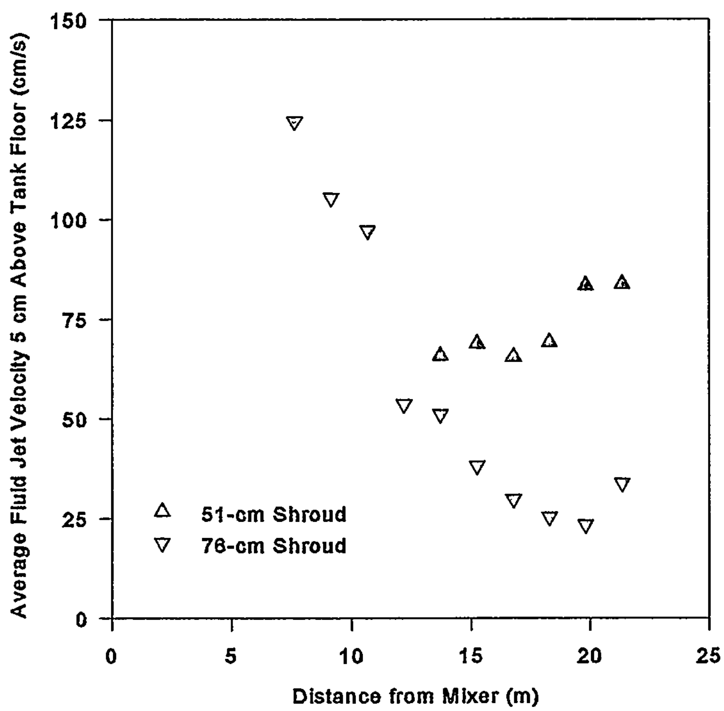

Figure 3.22. Effect of Shroud Length on Velocities Near Floor for Tests 1B, 19, and 20

3.2.3 Effect of Liquid Level

Liquid level was varied in Test 1. Reduced liquid level is expected to increase the average velocities because with a lower liquid level there is less liquid to mix and the same available mixing power (i.e., approximately 30 kW per mixer). Figure 3.23 shows the increase in average velocities with decreasing liquid level.

Considerable scatter exists in the data, but there is a trend of increasing velocity with decreasing liquid level. This trend does not necessarily imply that retrieval of solids from Tank 19 will be improved by decreasing the liquid level because the required velocities may increase with decreasing liquid level. Liquid level effects on the required mixing intensity are discussed in the Phase B report (Powell et al. 1999b).

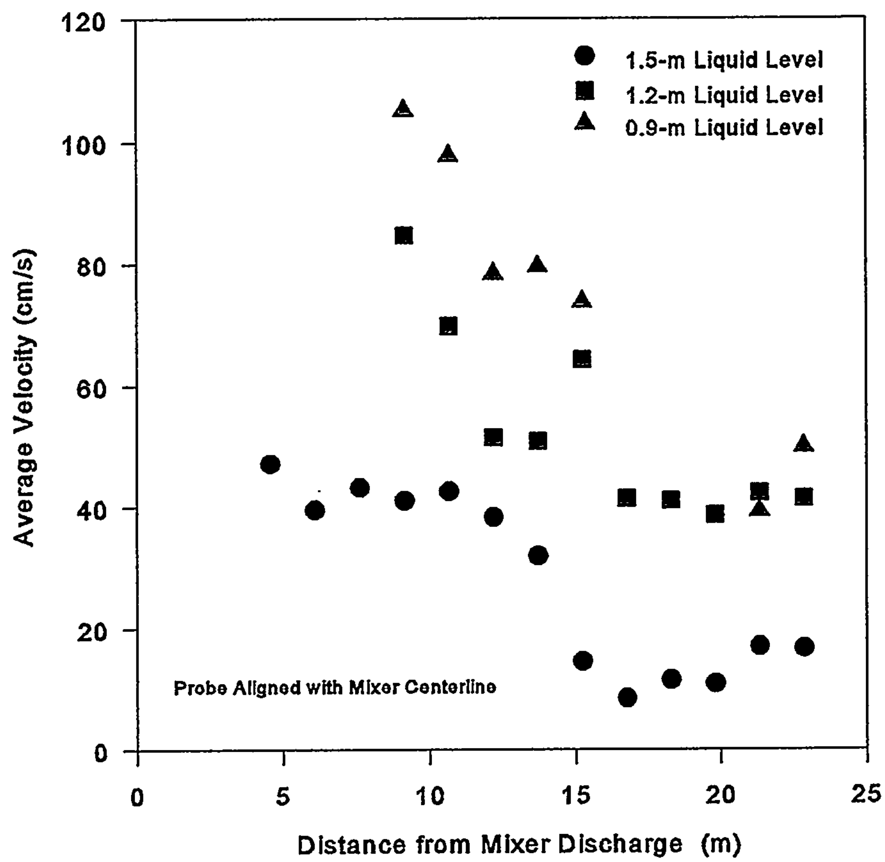

Figure 3.23. Effect of Liquid Level on Fluid Velocity

3.2.4 Comparison of Phase B and C Velocity Data

Water velocity measurements were made as part of Phase B testing. Three Model 4640 Flygt mixers were installed in a 5.7-m tank in an arrangement similar to that used for Phase C Test 4. Tests were run with these mixers operating in water with liquid levels of both 1 m and 2 m and at multiple mixer speeds.

Direct comparisons can be made between the appropriate Phase B Test 7 data and Phase C Tests 3 and 4. Comparison plots are given in Figures 3.24 and 3.25. The data plotted are in roughly the same geometrically scaled positions. All the measurements were made with the probe positioned 5 cm above the tank floor. Both comparison plots show higher velocities for the Phase B tests. This difference is not surprising given that the mixing-power-per-unit-volume in the Phase B test was roughly twice that in Phase C Tests 3 and 4. Further, differences in the relative liquid heights, mixer diameters, mixer centerline heights, and velocity probe heights may have contributed to the observed differences in velocities.

The fact that the velocities in the Phase B tests were higher provides further evidence that three stationary Model 4680 mixers will not provide adequate solids suspension in Tank 19. The mixing intensity in the Phase B tests was insufficient, so solids retrieval from a three-stationary-mixer Tank 19 retrieval system is also expected to be inadequate. The Phase C results confirm the scale-up predictions made based on the Phase A and B particle suspension tests. Based on those predictions and on the Phase C data, it is not recommended that three *fixed-position* Model 4680 Flygt mixers be installed in Tank 19 for the purpose of mixing and retrieving the waste heel.

3.2.5 Long-Term Flow Circulation Effects

As part of Test 20 (76-cm shroud test), a long-term velocity measurement was conducted in which the velocity probe was positioned 5 cm above the tank floor at a distance of 35 ft from the mixer discharge and 20 degrees off the jet centerline. The velocity was monitored for more than 20 minutes. A plot of the temporal velocity data is provided in Figure 3.26.

During this test, the velocity magnitude varied considerably. Between about 5 and 15 minutes, the velocity rarely exceeds 20 cm/s, but sustained velocities higher than 50 cm/s are evident at around 2 to 3 minutes and after about 18 minutes. This behavior illustrates the complexity in turbulent flow systems. From visual observations made during the test, the jet path was initially straight across the tank in the direction of the mixer discharge. Over a period of about 10 minutes, however, a large-scale circular flow pattern was established on one side of the tank. As this flow pattern developed, the jet path curved progressively more in the direction of the circular flow. Once the jet path curvature reached a visibly apparent limit, the circular flow pattern dissipated and a straight-line jet path was reestablished. This process was observed to repeat multiple times with a frequency of about once every ten minutes.

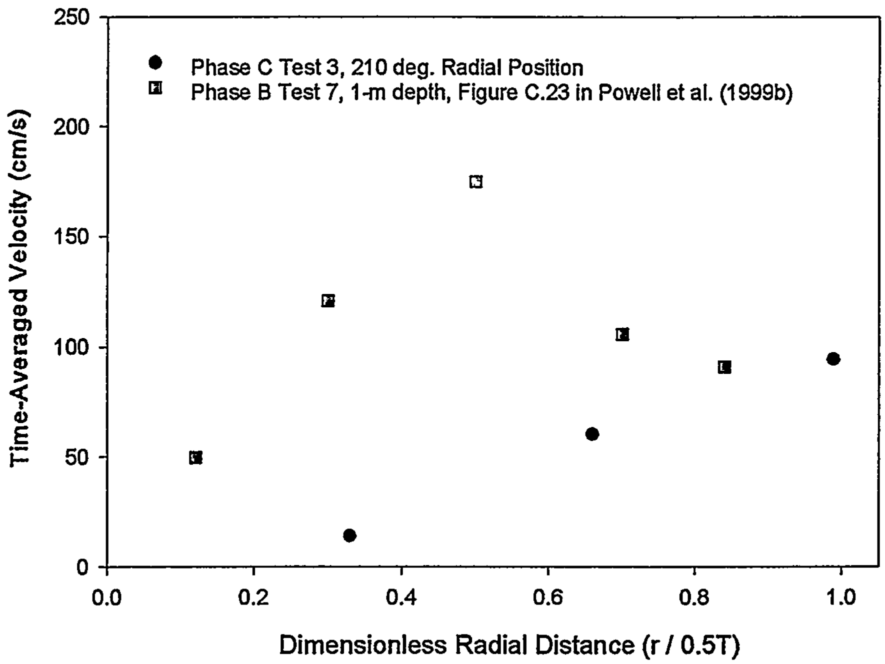

Figure 3.24. Comparison of Phase B and C: Two Mixers at 860 rpm

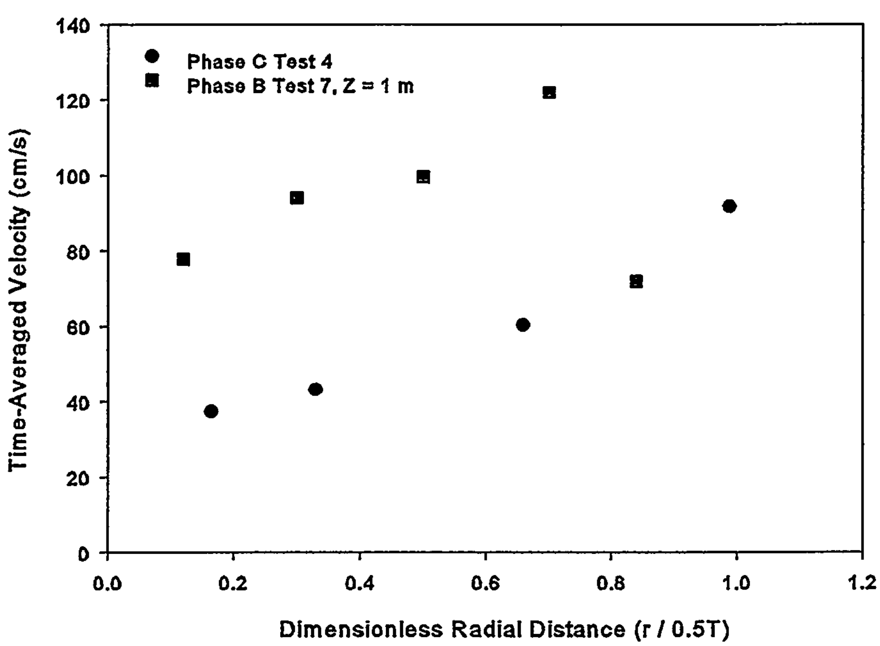

Figure 3.25. Comparison of Three Mixers at 860 rpm

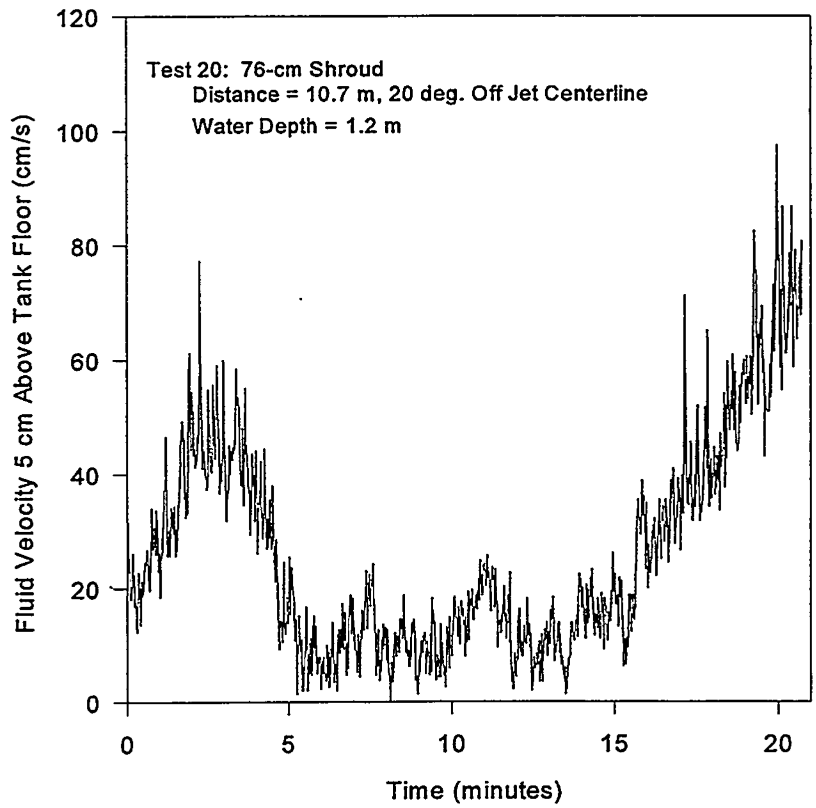

Figure 3.26. Test 20 Long-Term Velocity Measurement

The changing jet path meant that the velocity probe, which was stationary for this test, was not always positioned within the bulk of the jet flow. During the high-velocity periods, the velocity probe was within or near the jet flow, but during the low-velocity periods, the probe was outside the direct influence of the jet.

The implications of this result for the rest of the Phase C velocity data are not clear. Figure 3.26 demonstrates that cycles in the fluid velocities *can* occur on a time scale as large as 10 minutes in a large tank such as the 25.9-m TNX Test Facility – or in Tank 19. Based on this result, it appears that to accurately characterize the average velocity at a specific location, the measurement must be continued for perhaps 30 minutes or more. This length of time would have been impractical to implement for the rest of the Phase C testing because of the large number of mixer configurations that needed to be tested.

Possibly, the jet behavior noted during the Test 20 long-term velocity measurement was not representative of the flow patterns present during most of the other Phase C tests. In most cases, velocity data were collected at each position for about 3 minutes. Over selected 3-minute periods, Figure 3.26 shows, in some cases, readily apparent upward or downward trends in the measured velocity. If the behavior evident in Figure 3.26 was prevalent during the rest of the Phase C tests, it would be expected that a significant number of the 3-minute-long velocity measurements taken during *other* Phase C tests would exhibit obvious upward or downward trending velocities when plotted vs. time. A review of the Phase C velocity-vs.-time data did not reveal any clear indications of upward or downward trending velocities, implying that the Test 20 long-term result may be somewhat anomalous.

Regardless of whether the phenomenon evident in Figure 3.26 was a significant effect in the other Phase C tests, the principal conclusion of the Phase C velocity measurements remains unchanged; i.e., the mixer configurations tested do not provide sufficient fluid velocity near the tank floor at all times to ensure 20x50-mesh zeolite will remain in motion on the tank floor. Zeolite in this size range settles very quickly–at about 5 cm/s (Powell et al. 1999b). The time-scale for zeolite settling through a 1-m liquid depth is, therefore, about 20 seconds. So accumulations of zeolite can reasonably be expected on the tank floor in regions where the velocity falls below the zeolite critical suspension velocity[a] for periods on the order of about 10 seconds.

Most of the Phase C velocity measurements were continued for about 180 seconds (3 minutes), which is long enough to identify at least some of the regions where zeolite accumulation is expected. The 3-minute-long velocity measurements were probably too short to accurately quantify the long-term average or peak velocities, but they *were* long enough to satisfy the needs of the test program with respect to zeolite settling and resuspension.

3.3 Conclusions and Recommendations from Phase C Tests

The principal conclusions from the Phase C tests are included in the Summary and in Section 2.0 of this report. This section provides all the significant findings and recommendations that resulted from the Phase C tests.

3.3.1 Phase C Test Conclusions

The Phase C Flygt mixer tests in the 25.9-m TNX Test Facility yielded the following conclusions:

- As predicted by Phase A and B tests, three or four stationary Model 4680 Flygt mixers, in the configurations tested, do not appear to provide sufficient mixing intensity to ensure suspension of the Tank 19 zeolite particles. None of the Phase C mixer configurations

[a]The critical suspension velocity is actually the velocity required to suspend particles from an initially settled state. Phase A and B tests showed that, for 20x50-mesh zeolite particles, the critical suspension velocity was essentially equal to the critical saltation velocity, which is the velocity required to *maintain* the solids in suspension. Thus, the 40 ± 10-cm/s critical velocity for zeolite suspension, which was determined via Phase A and B testing, can be used as a direct measure of the critical saltation velocity.

used for testing resulted in all average velocities being higher than the 50-cm/s target velocity for zeolite suspension. In most tests, the average velocities near the tank center ranged from 10 to 40 cm/s. Average velocities near the tank wall ranged from 35 to 140 cm/s.

- The SRS stationary-mixer deployment mast successfully allowed the mixer to be installed through a simulated tank riser in a simple and timely manner. The mast maintained the Model 4680 Flygt mixer in a stable position on the tank floor during mixer operation. With external crane support, the mast allowed the mixer to be periodically lifted and redirected in a timely manner so that the mixer discharged in another direction.

- Extending the standard 20-cm-long shroud on the Model 4680 Flygt mixers to 50 cm results in significantly higher (up to 50% higher) downstream velocities. Further extending the shroud to 76-cm degrades mixer performance.

- The Model 4680 Flygt mixers with 50-cm shrouds were found to give velocities greater than 60 cm/s out to distances of more than 21 m. Using the 20- and 76-cm shrouds gave velocities of only about 40 cm/s at 21 m.

- Velocity measurements made 10 and 20 degrees off the jet centerline imply that the 76-cm shroud provided a more focused jet, but water flow through the mixer was probably reduced by the increased backpressure caused by the long shroud. This reduction in flow through the mixer resulted in lower downstream velocities than those given using the 50-cm shroud.

- For each set of Phase C velocity measurements included in this report, the turbulent intensity was calculated.[a] Typically, the values ranged from about 0.1 to 0.7. This range is consistent with that observed in Phase B fluid velocity tests and with published values for turbulent jets and flow in agitated tanks.

- Test 1 demonstrates that, as expected, the measured velocities increase as the liquid level decreases (provided the mixer speed and orientation is not changed).

- The Flygt Model 4680 mixer jet velocities decay faster and the jet spreads wider than predicted by classical turbulent free jet correlations, but this result was not unexpected because the classical correlations do not include the effects of the tank floor, the free-moving liquid surface, the enclosed geometry of the tank, and the nonuniform velocity profile of the fluid jet produced by the propeller.

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[a]Turbulent intensity is defined as the root-mean-square fluctuating velocity divided by the average velocity.

3.3.2 Phase C Test Recommendations

The Phase C Flygt mixer tests in the 25.9-m TNX Test Facility yielded the following recommendations:

- Mechanisms for continuously rotating or oscillating (azimuthally) the Flygt mixers should be developed and tested. If Flygt mixers are to be used in Tank 19, they must be rotated to avoid accumulation of solids in some regions of the tank.
- The Model 4680 Flygt mixers planned for use in Tank 19 should be fitted with extended shrouds to improve jet coherence and increase downstream velocities.
- Further mixer testing should be conducted to determine the optimal shroud length.
- If additional fluid velocity measurements are taken, the data should be collected for a sufficient time to ensure that the measured average velocity is representative of the true average.

4.0 References

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Appendix A

Phase C Test Plan

The following document (SRT-WHM-98-11) dated July 27, 1998, was prepared and cleared for release by staff at the U.S. Department of Energy's Savannah River Site. This document served as the test plan for Phase C.

OSR 31-688 (Rev 11-20-97)
Stores: 26-8910.00

WESTINGHOUSE SAVANNAH RIVER COMPANY
INTEROFFICE MEMORANDUM

BNFL

July 27, 1998

SRT-WHM-98-11

To: W. B. Van Pelt, 679-T
P. O. Rodwell, 742-6G

From: M. R. Poirier, 679-T

FLYGT MIXER PHASE C TEST PLAN

Introduction

SRS is identifying and investigating techniques to remove sludge heels from waste tanks such as Tank 19. Shrouded axial propeller mixers manufactured by ITT Flygt Corporation are one of the suggested alternatives. The mixers consist of an electrically powered propeller surrounded by a close-fitting shroud. The 50 hp mixers being considered for waste retrieval in Tank 19 have a propeller diameter of 20 inches and a maximum speed of 860 rpm. The rapidly spinning propeller creates a turbulent jet with an average exit velocity of approximately 20 ft/sec.

SRS, PNNL, ORNL, and ITT Flygt are conducting a mixer test program to evaluate the ability of Flygt mixers to retrieve waste from SRS Tank 19, and other DOE site waste tanks. The team performed the first phase of tests at the ITT Flygt laboratory in Trumbull, CT with a 1.5 ft diameter tank. The second phase of tests was performed with PNNL's pilot-scale mixing tanks (6 ft diameter and 18.75 ft diameter) in Hanford, WA. The third test phase will be performed with the TNX Full Tank (85 ft diameter) at SRS. Tests are performed with different size tanks so scaling methods can be developed to apply the test results to real waste tanks.

This test plan describes the tests to be performed at the TNX Full Tank with Flygt mixers.

Test Outline

Because of cost and waste disposal issues, tests will only be performed with water in the TNX full tank. Water will be added to the tank and mixed with the Flygt mixers. Fluid velocities will be measured throughout the tank and compared with predictions from smaller scale tests. The purpose of the tests will be to determine whether the mixers provide sufficient velocity throughout the tank to suspend zeolite and sludge.

Table 1 and Figures 1 - 12 show the mixer configurations to be tested. In the table, CW indicates the mixer will be discharging fluid at an angle 30° off the tank centerline and in the clockwise direction. CCW indicates the mixer will be discharging fluid at an angle 30° off the tank centerline and in the counterclockwise direction. T indicates the mixer will be positioned to discharge fluid transverse (approximately 10° off the center of the tank). The mixer positions are given in polar coordinates, with zero degrees being the position of the center of the support structure located on the south side of the tank which holds slurry pumps in the tank. In tests 1 - 10, the mixers will be placed approximately 5 feet from the tank wall (37.5 feet from the tank center). In tests 11 and 12, two mixers will be placed back-to-back to determine the agitation produced by this configuration. In test 11, the mixers will be placed approximately 5 feet from the tank wall. In test 12, the mixers will be placed at the tank center.

The liquid level in the tank during testing will be 4 feet. During tests 1 and 4, additional velocity data will be collected with tank levels of 3 feet and 5 feet.

The mixer located at 37.5 ft. and 300° will be inserted into the tank through a riser to test deployment of the insertion mast and mixer operation from that mast.

The tests will be performed by operating the mixers at full speed and measuring the fluid velocity at various positions in the tank. Fluid velocities will be measured with the Marsh-McBirney probe used in Phase B testing and recorded with a Strawberry Tree data acquisition system at a rate of 10 Hz for 2 minutes. During test 1, the velocity will be measured at distances of 20-75 feet from the mixer discharge, along the jet centerline, and at 10 and 20 degrees off the centerline. Table 2 shows the positions at which the fluid velocities will be measured during tests 2 - 12. The probe will be oriented so the y-axis is south and the x-axis is west. The purpose of the tests is to validate the computational fluid dynamics modeling performed by ITT Flygt, and to determine whether the fluid velocity in the tank exceeds the minimum velocity required to suspend zeolite and sludge which was identified in the Phase A and Phase B tests.

Additional tests may be performed with a 50 hp Porta-Clens mixer located at the center of the tank, with rotating Flygt mixers, or with a simulant containing kaolin clay. The test plan will be revised prior to performing any of these tests.

Table 1. Mixer Configurations

Test	(37.5', 300°)	(37.5', 120°)	(37.5', 75°)	(37.5', 60°)	(37.5', 180°)	(0', 0°)
1*			T			
2*	CW					
3*	CW	CW				
4*	CW	CW	T			
5			T			
6	CW	CW	CW			
7	CCW	CCW	T			
8	CCW			CCW	CCW	
9*	CCW	T		CCW	CCW	
10	CCW	CCW		CCW	CCW	
11		back-to-back				
12*						back-to-back

* critical tests which must be performed

Table 2. Velocity Measurement Positions

Radius	Angle	Angle	Angle	Angle
0 ft	270°	90°	180°	210°
14 ft	270°	90°	180°	210°
28 ft	270°	90°	180°	210°
42 ft	270°	90°	180°	210°

Mixer Locations for Phase C Tests

Figure 1. Test 1 Mixer Configuration

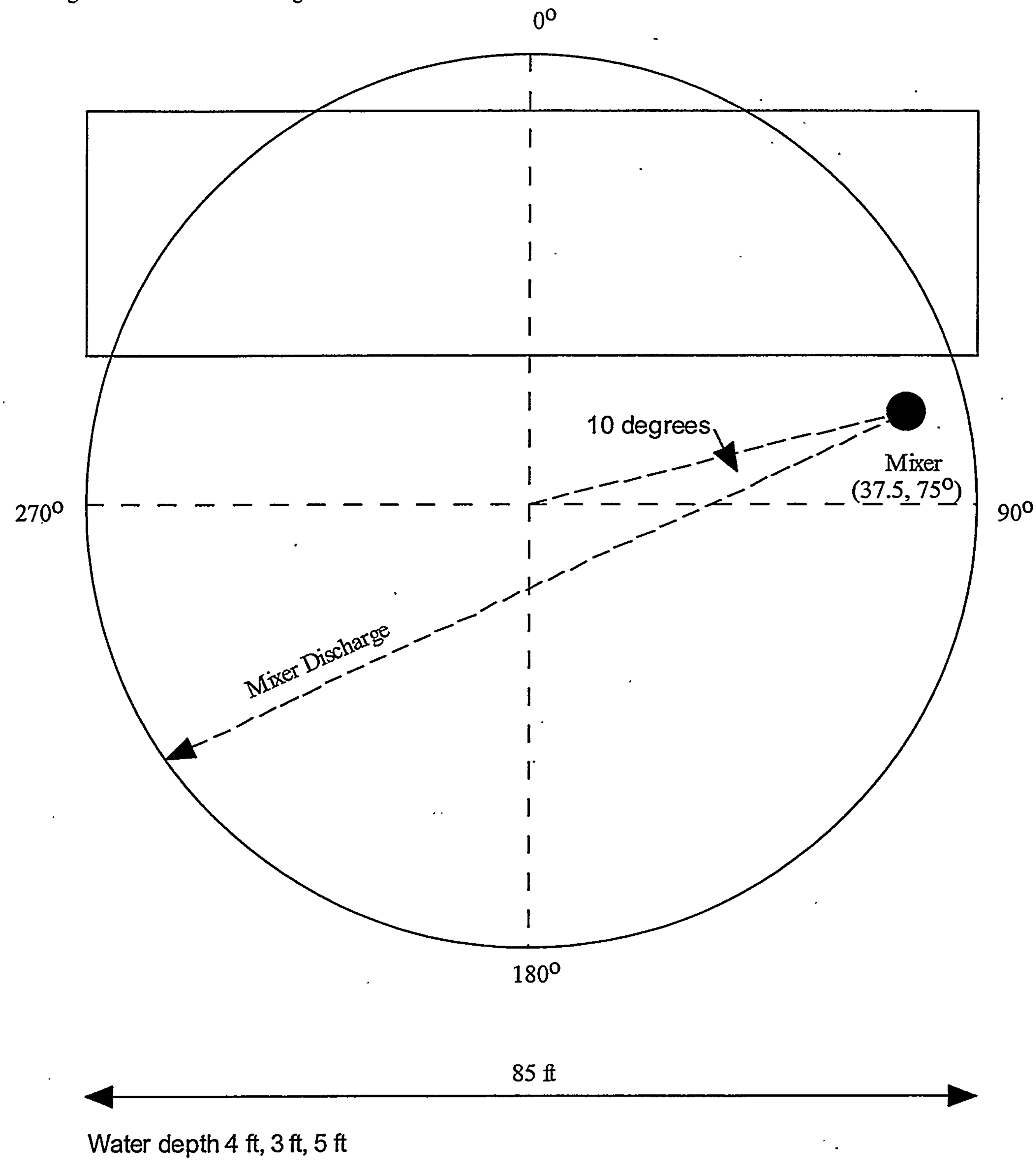


Figure 2. Test 2 Mixer Configuration

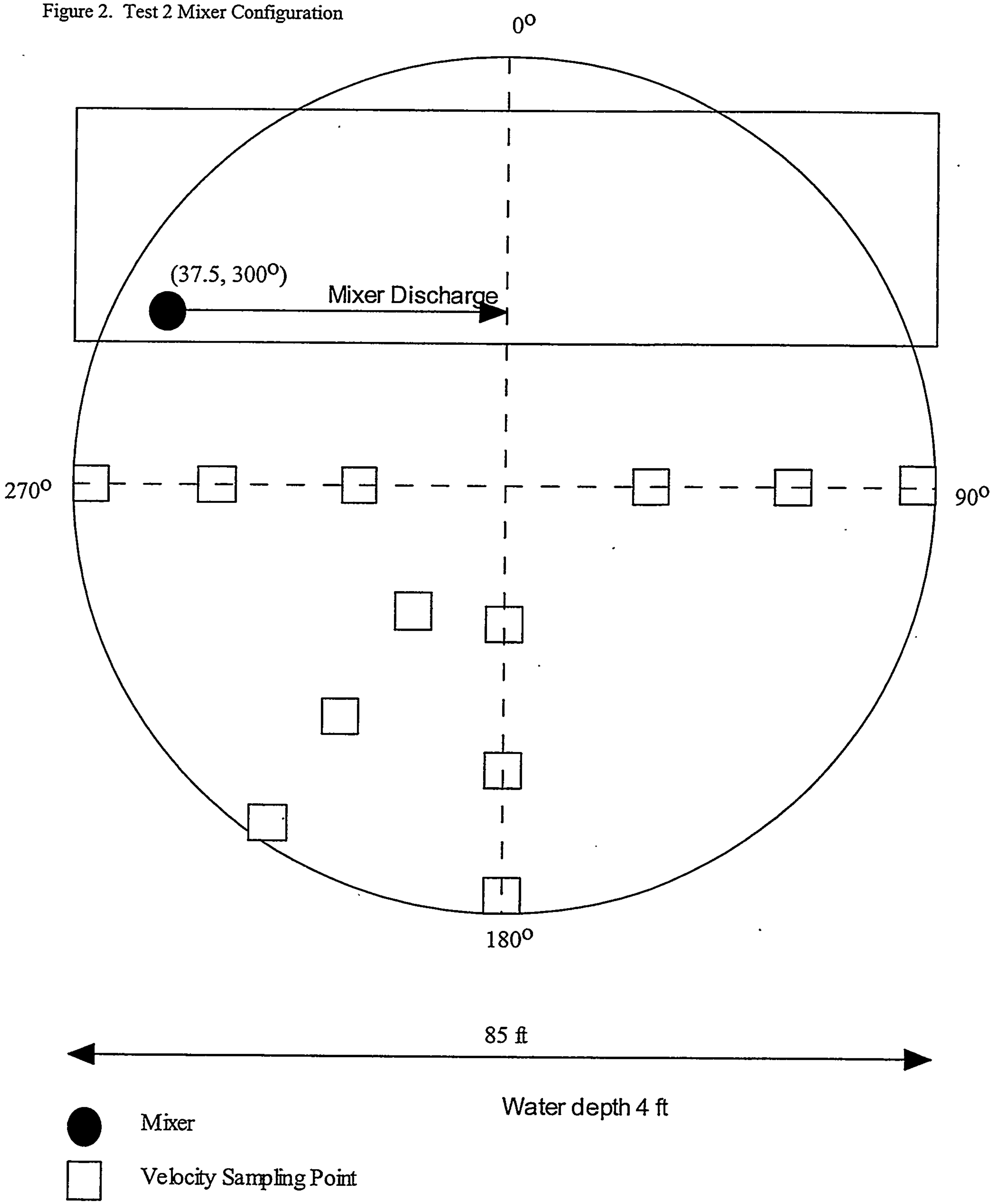


Figure 3. Test 3 Mixer Configuration

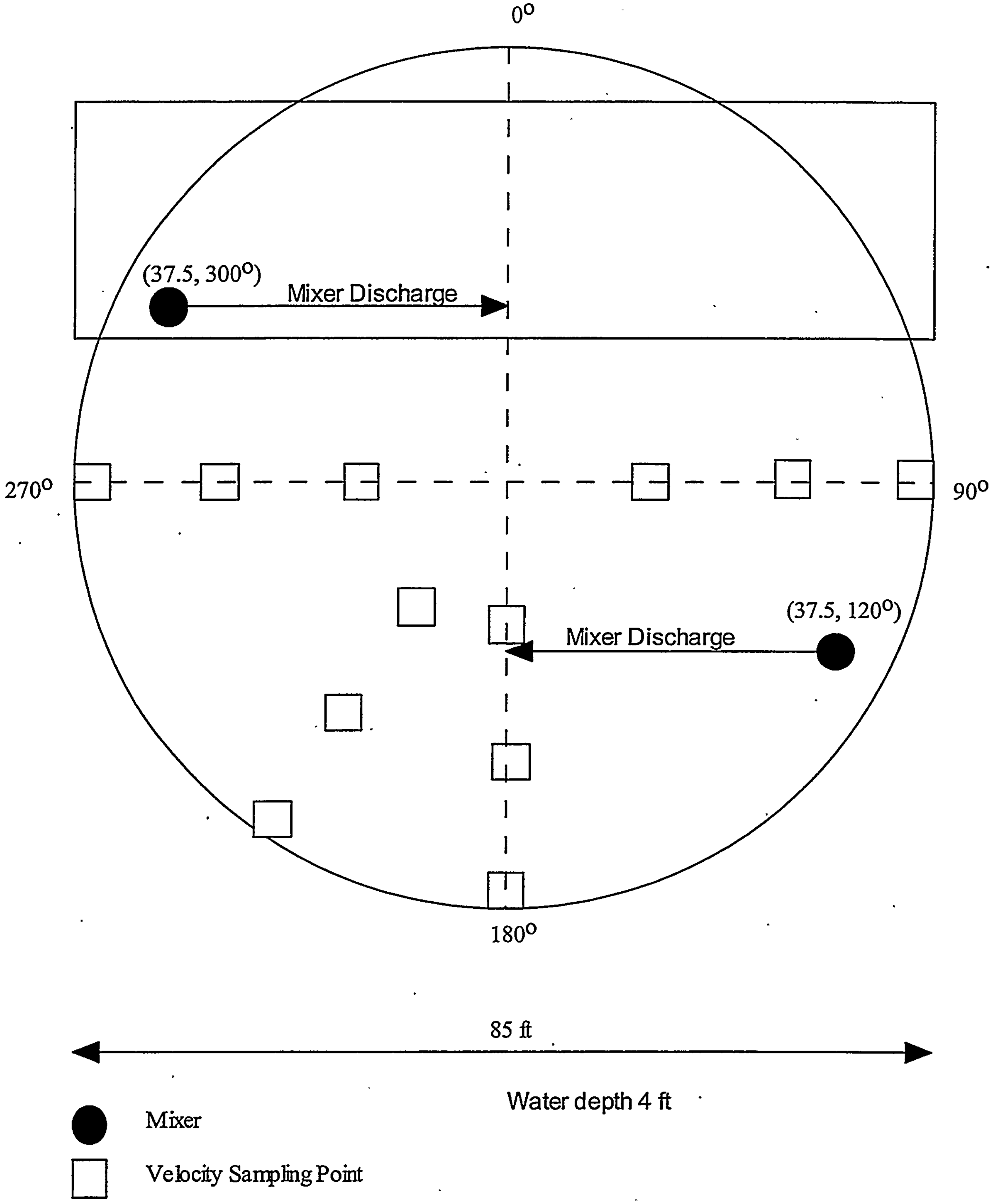


Figure 4. Test 4 Mixer Configuration

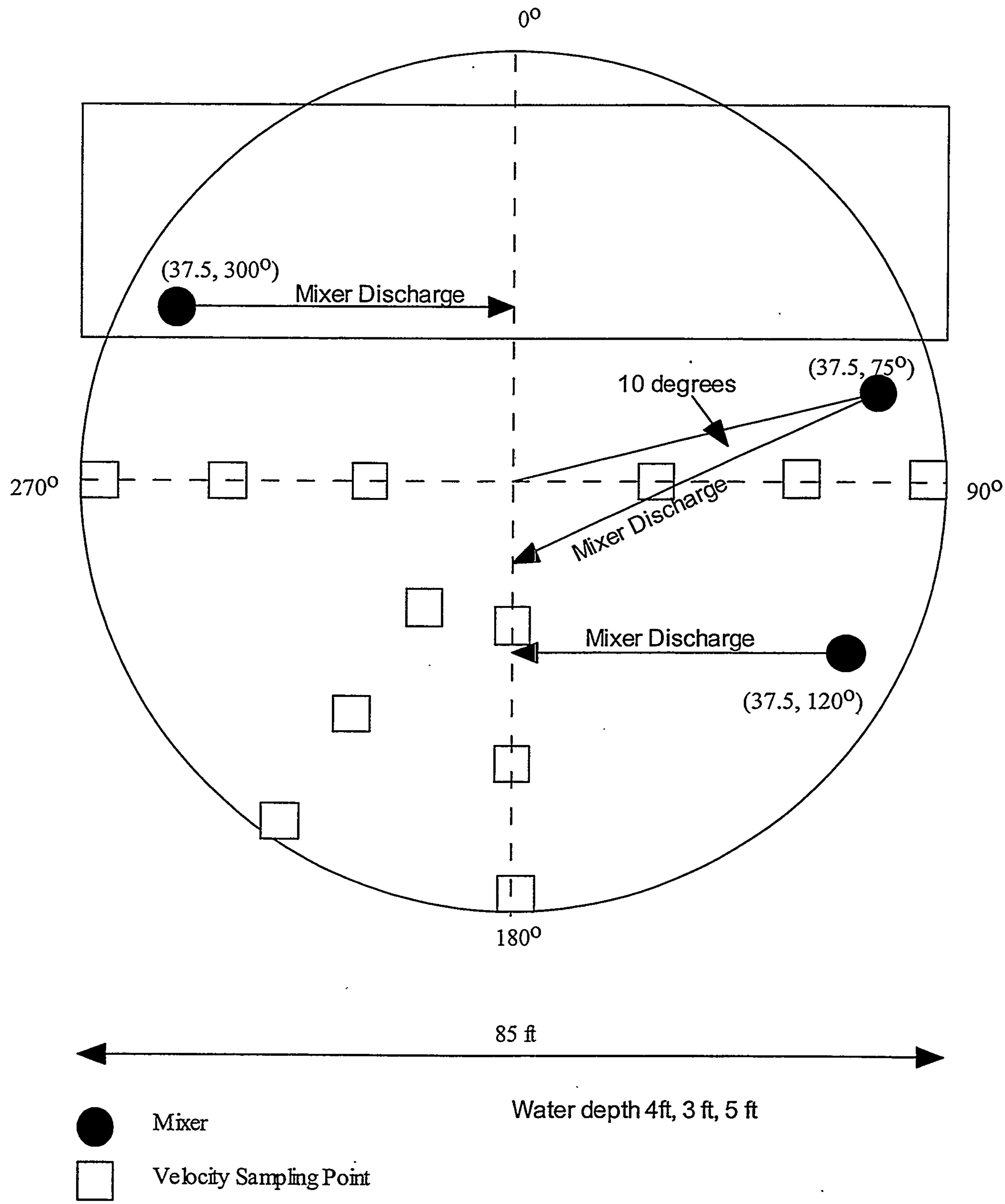


Figure 5. Test 5 Mixer Configuration

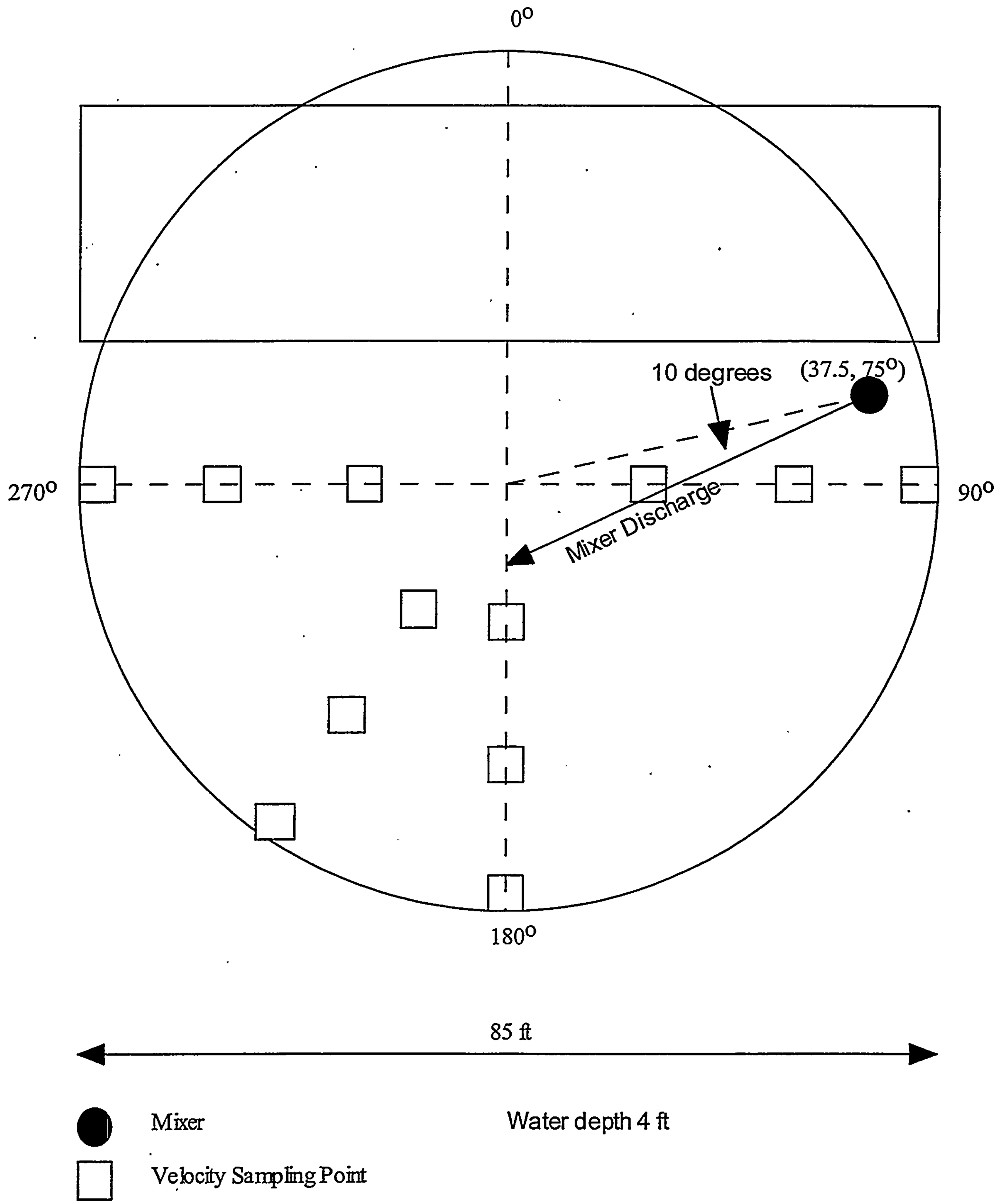


Figure 6. Test 6 Mixer Configuration

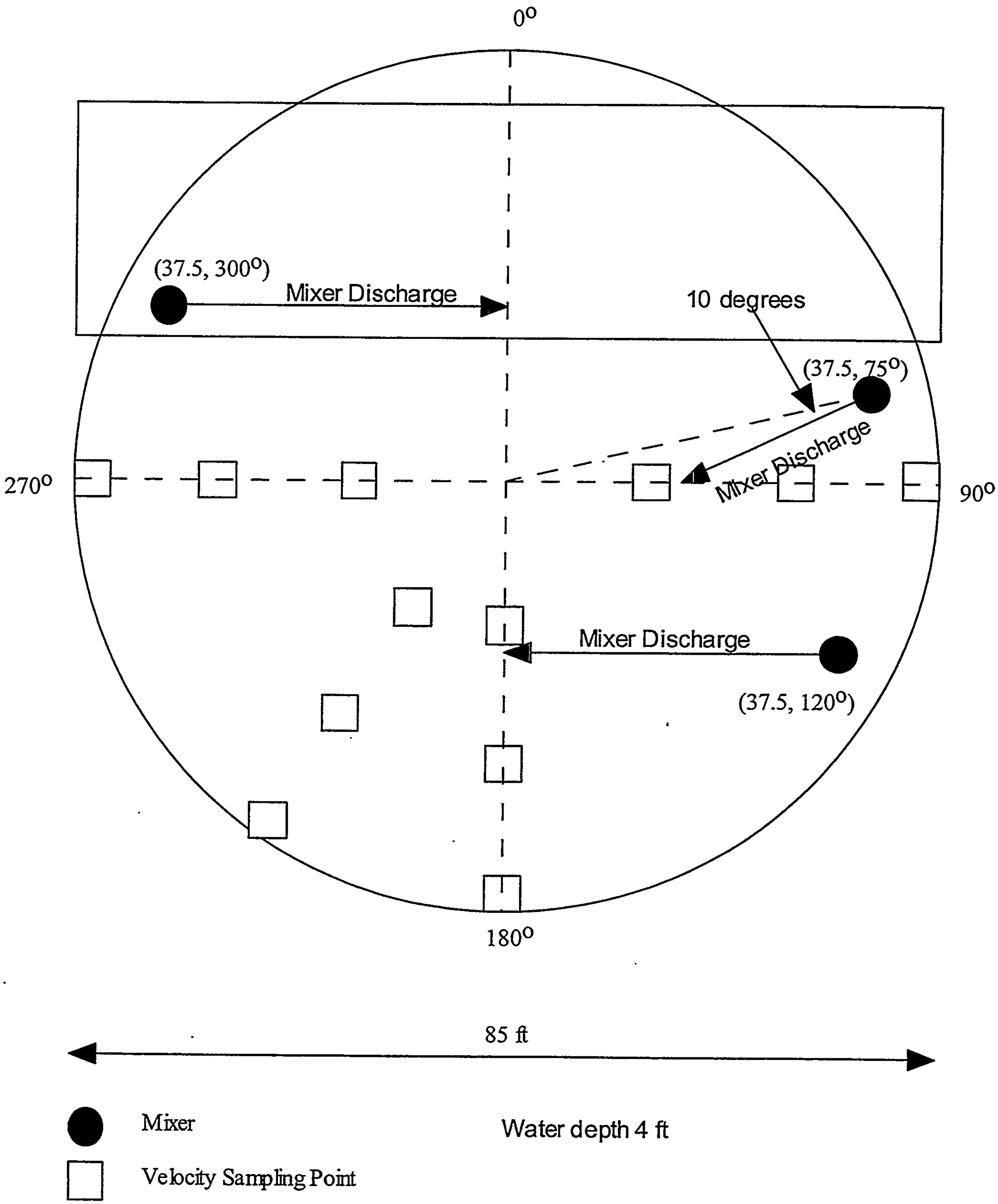


Figure 7. Test 7 Mixer Configuration

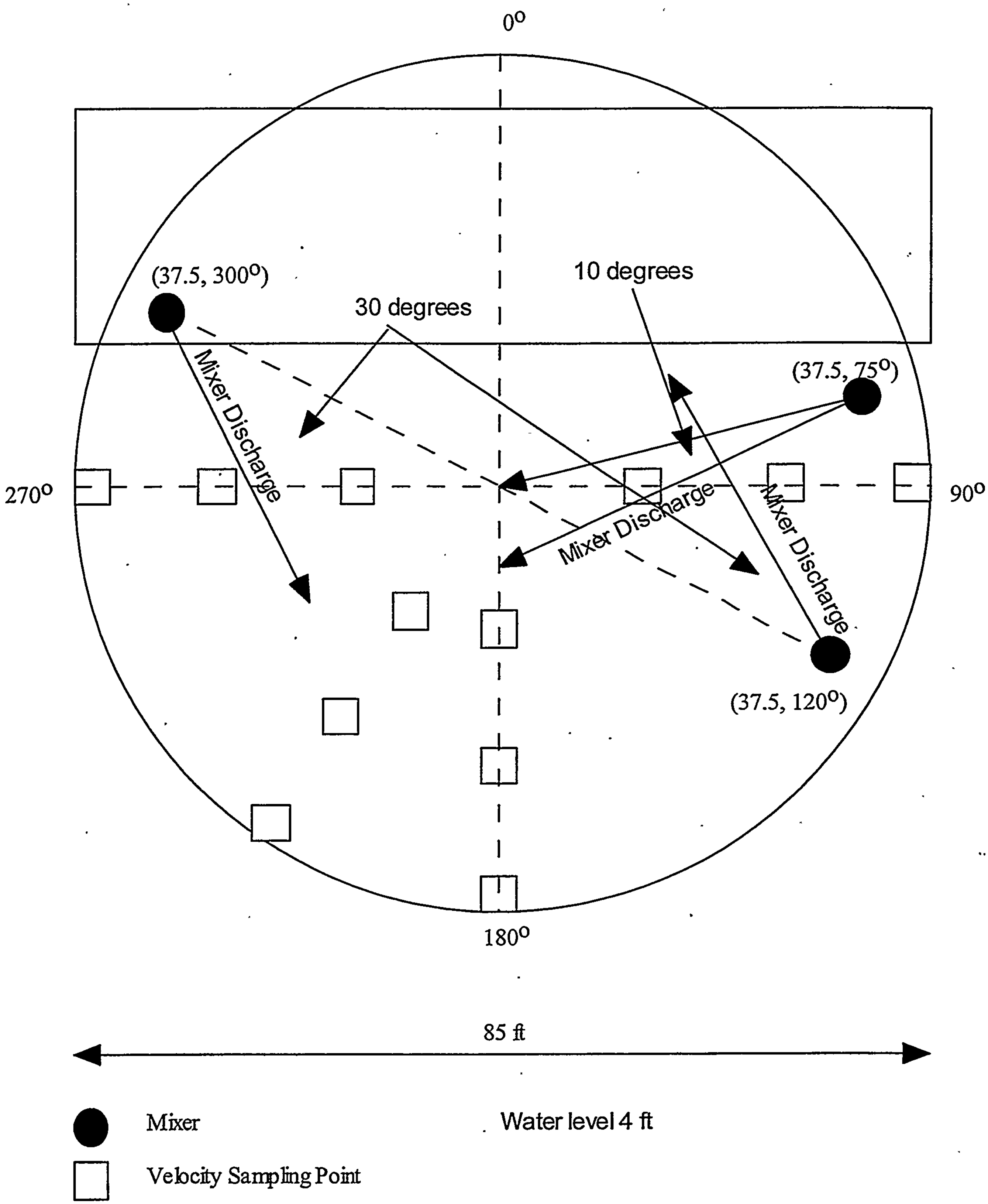


Figure 8. Test 8 Mixer Configuration

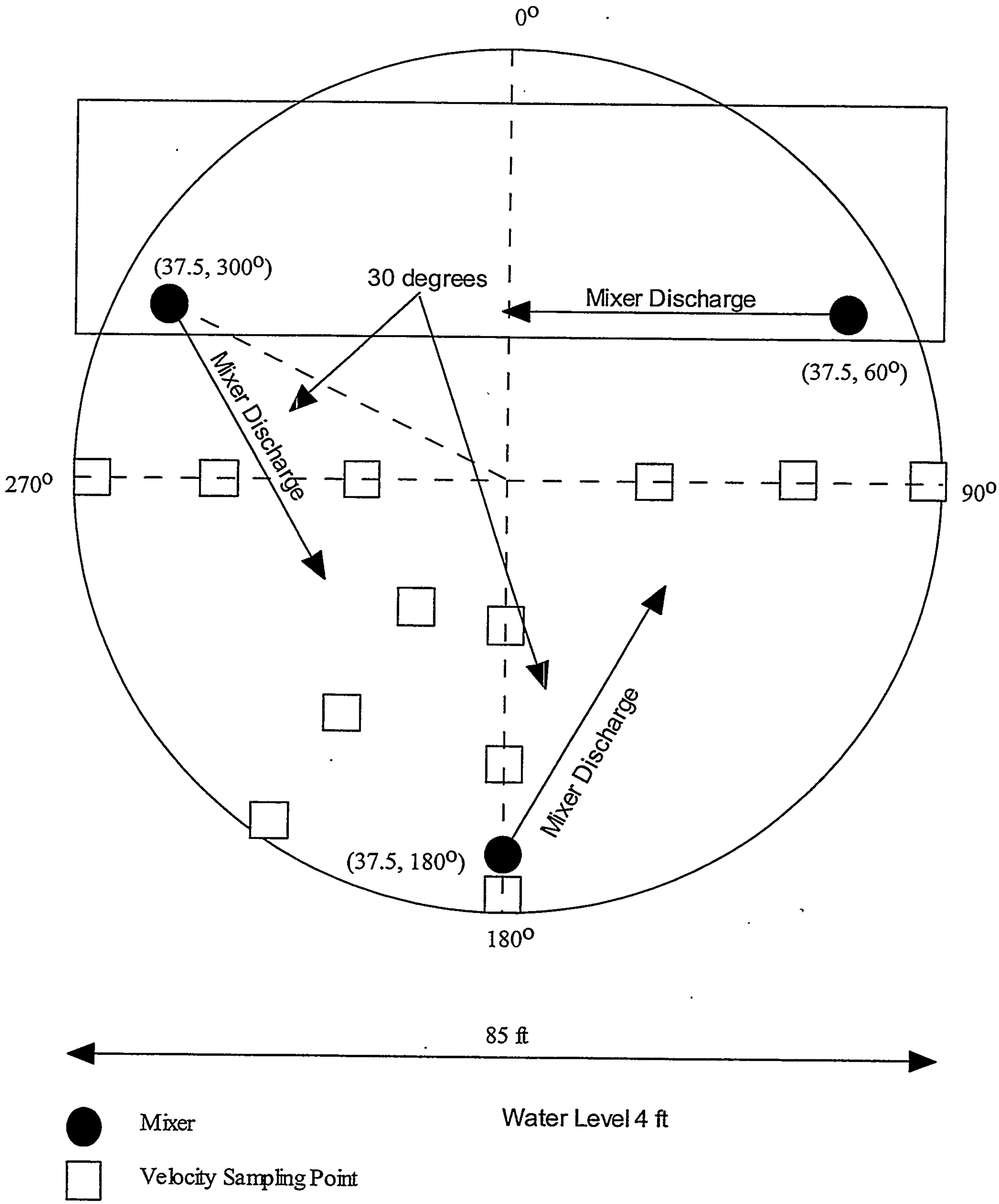


Figure 9. Test 9 Mixer Configuration

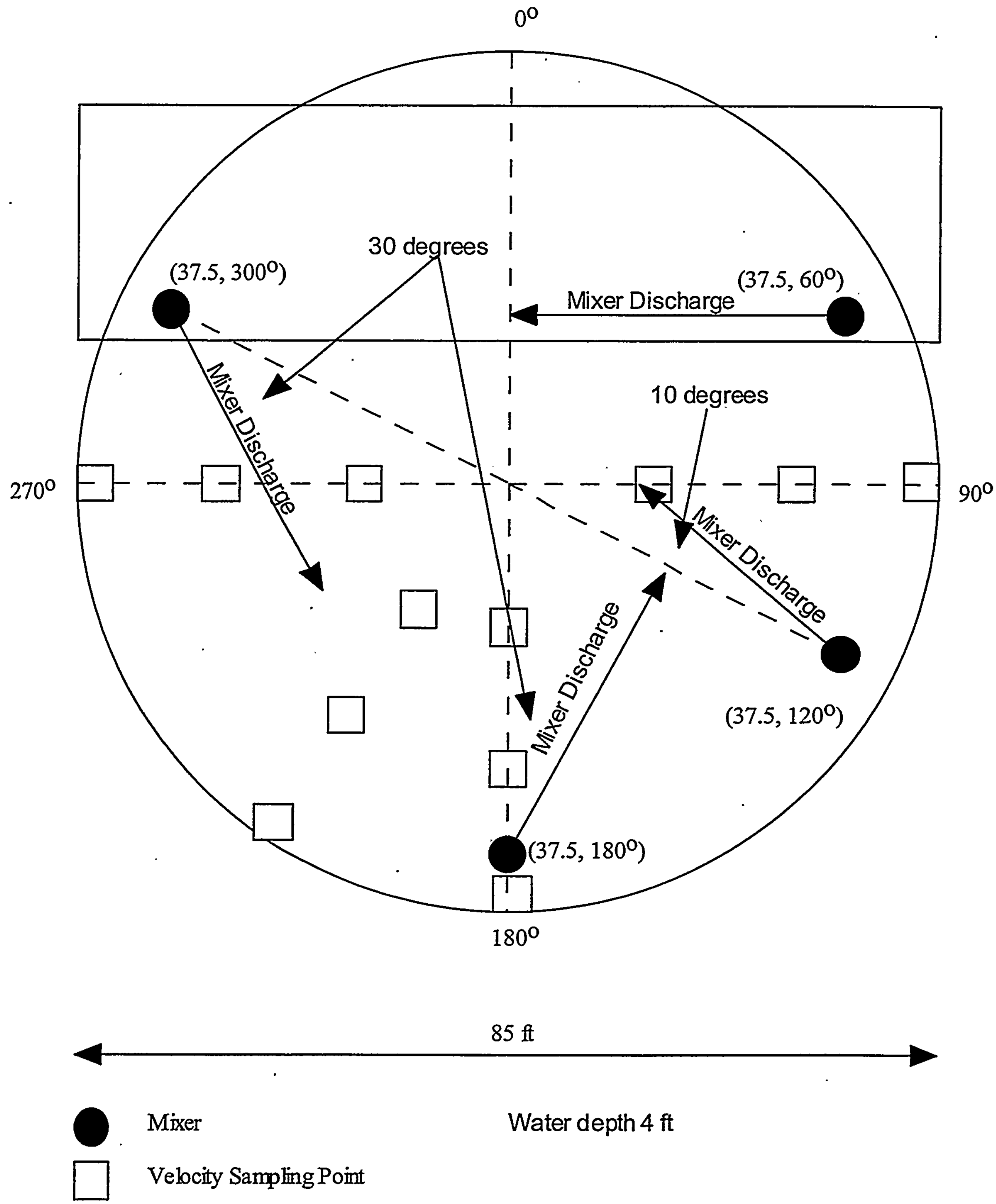


Figure 10. Test 10 Mixer Configuration

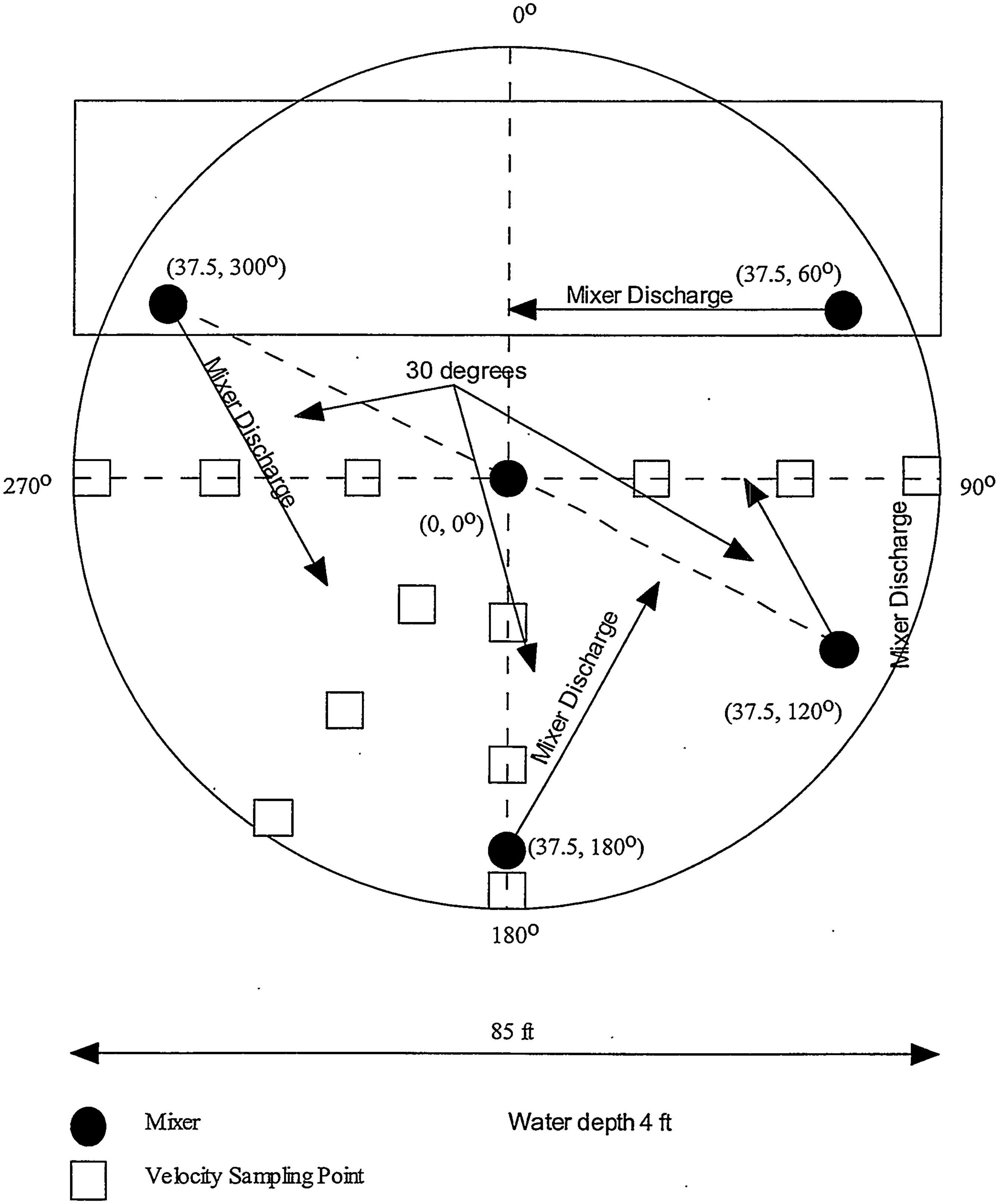


Figure 11. Test 11 Mixer Configuration

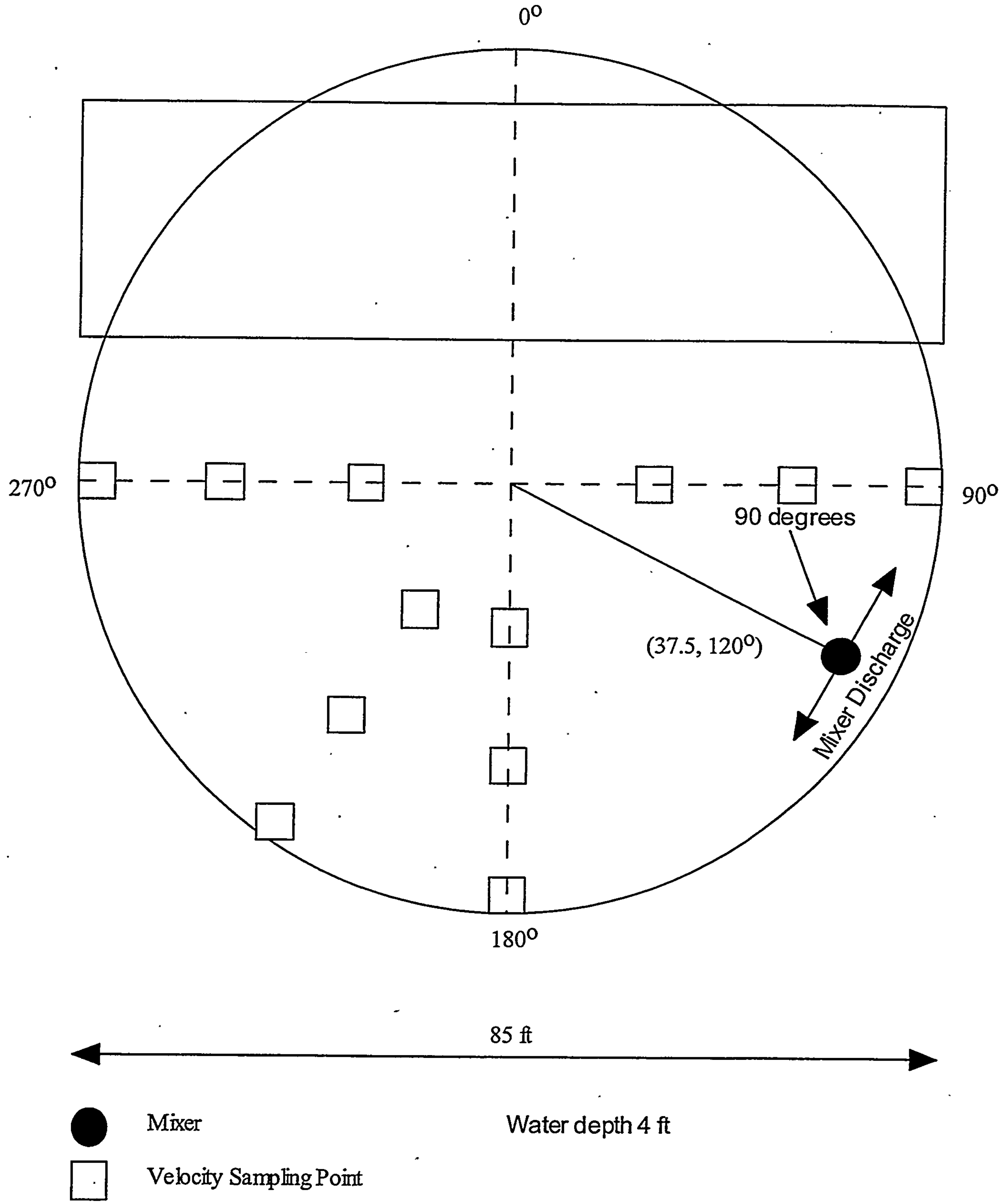
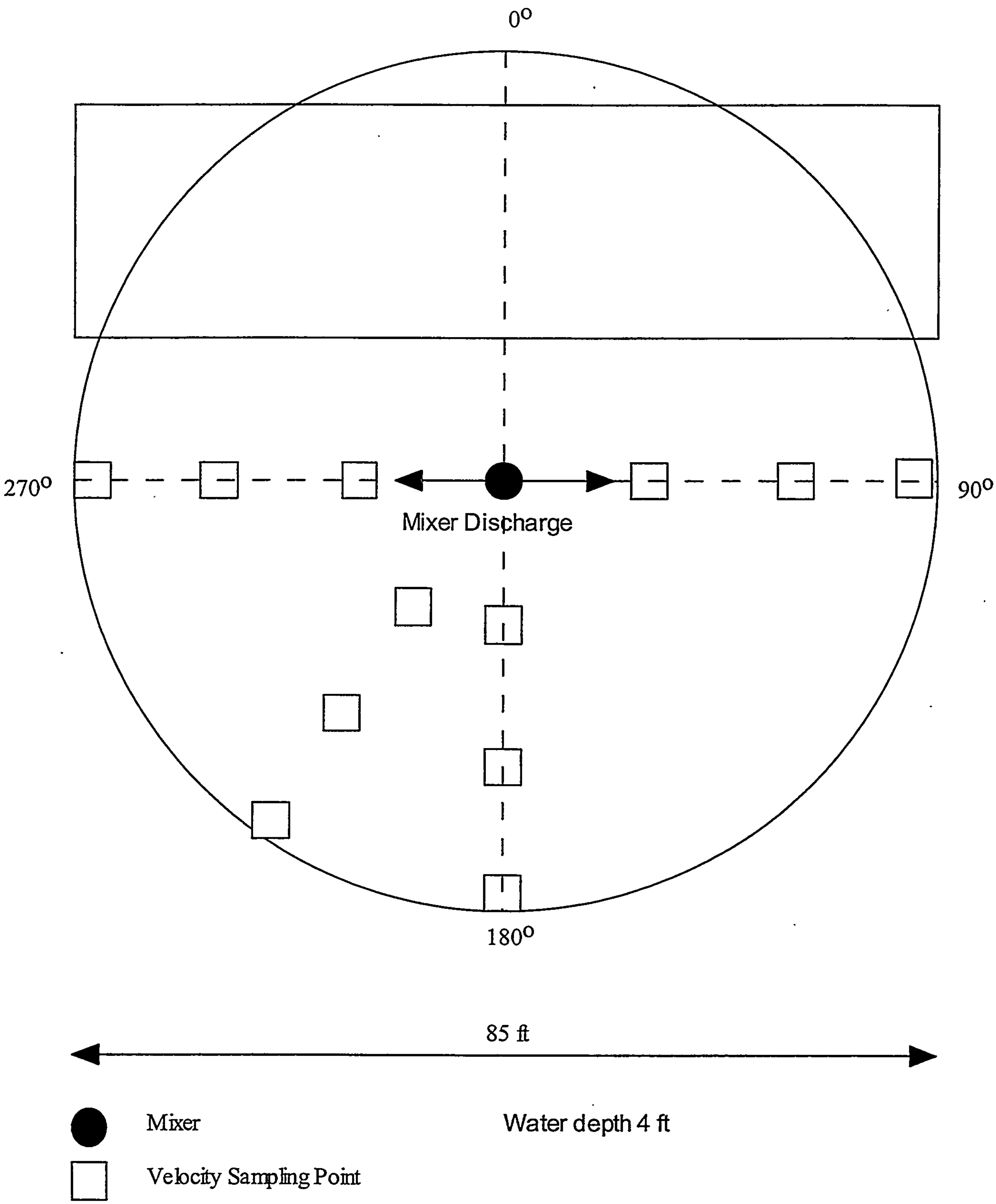


Figure 12. Test 12 Mixer Configuration



Appendix B

Phase C Test Results

The following document (WSRC-TR-99-00097) dated March 26, 1999, was prepared and cleared for release by staff at the U.S. Department of Energy's Savannah River Site. This document provides the data used to prepare Section 3.0 of this report

WSRC-TR-99-00097

KEYWORDS: Waste Removal, Flygt mixer, Tank 19

RETENTION: Permanent

Phase C Flygt Mixer Test Results (U)

M. R. Poirier
P. O. Rodwell

March 26, 1999

SAFETY • RESPONSIBILITY • SECURITY
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SAVANNAH RIVER SITE

Summary

The Savannah River Site (SRS) teamed with the Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL), and ITT Flygt Corporation to conduct a test program evaluating shrouded axial propeller mixers (Flygt mixers) for heel removal in SRS Tank 19. The team performed tests with 50 hp mixers in the 85 ft diameter Full Tank at SRS. The significant results and conclusions of this test are:

- The SRS stationary mixer deployment mast testing was successful in allowing simple, efficient mixer installation through the riser opening. Once within the tank, the mixer manually reoriented to its horizontal operating position. The mast kept the 50 hp mixer stable on the tank floor during operation. With external crane support, the mast was lifted and redirected to discharge in another direction.
- Three stationary Flygt mixers will not successfully suspend zeolite in an SRS waste tank.
- The test results indicate that three mixers should successfully suspend zeolite and lighter sludge components in SRS waste tanks provided the mixers can rotate from horizontal positions on the tank floor and are equipped with modified shrouds to focus the mixer discharge.
- Typical average fluid velocities at the center of the tank (measured 7 feet from center) were 0.35 – 1.28 feet/second.
- Typical average velocities at the tank wall were 1.1 – 4.5 feet/second.
- The jet produced by the Flygt mixer spreads wider and decays faster than a classical turbulent jet.
- The measured fluid velocities increased when the tank liquid level was decreased.

Introduction

SRS is identifying and investigating techniques to remove sludge heels from waste tanks such as Tank 19. Shrouded axial propeller mixers manufactured by ITT Flygt Corporation are one of the suggested alternatives. The mixers consist of an electrically powered propeller surrounded by a close-fitting shroud (see Figure 1). The 50 hp mixers being considered for waste retrieval in Tank 19 have a propeller diameter of 20 inches and a maximum speed of 860 rpm. The rapidly spinning propeller creates a turbulent jet with an average exit velocity of approximately 20 ft/sec.

SRS, PNNL, ORNL, and ITT Flygt are conducting a mixer test program to evaluate the ability of Flygt mixers to retrieve waste from SRS Tank 19, and other DOE site waste tanks. The team performed the first phase of tests at the ITT Flygt laboratory in Trumbull, CT with a 1.5 ft diameter tank.[1] The second phase of tests was performed with PNNL's pilot-scale mixing tanks (6 ft diameter and 18.75 ft diameter) in Hanford, WA.[2] The third test phase was performed with the TNX Full Tank (85 ft diameter) at SRS. Tests are performed with different size tanks so scaling methods can be developed to apply the test results to real waste tanks.

Test Description

Because of cost and waste disposal issues, tests were performed with water in the TNX full tank. Water was added to the tank and mixed with the Flygt mixers. Fluid velocities were measured throughout the tank and compared with predictions from smaller scale tests. The purpose of the tests was to determine whether the mixers provide sufficient velocity throughout the tank to suspend zeolite and sludge.

Table 1 shows the mixer configurations tested. In the table, CW indicates the mixer was discharging fluid at an angle 30° off the tank centerline and in the clockwise direction. CCW indicates the mixer was discharging fluid at an angle 30° off the tank centerline and in the counterclockwise direction. T indicates the mixer was positioned to discharge fluid transverse (approximately 10° off the center of the tank). The mixer positions are given in polar coordinates, with zero degrees being the position of the center of the support structure located on the south side of the tank which holds slurry pumps in the tank. Figure 2 shows the mixer layout from Test 4.

Table 1. Mixer Configurations

Test	(37.5', 300°)	(37.5', 120°)	(37.5', 75°)	(37.5', 60°)	(37.5', 180°)	(0', 0°)
1			T			
2	CW					
3	CW	CW				
4	CW	CW	T			
5			T			
6	CW	CW	CW			
7	CCW	CCW	T			
8	CCW			CCW	CCW	
9	CCW	T		CCW	CCW	
10	CCW	CCW		CCW	CCW	
11		back-to-back				
12						back-to-back
13	T*	T	T			
14						Porta-Cleans
15	CW	CW	CW			Porta-Cleans
16	CW	CW	CW			Porta-Cleans
17#	90°	270°		240°		270°
18&	180°	240°		285°		240°
19^			T			
20<			T			

* mixer located at 255° rather than 300°
# Referred to as Flygt #1
& Referred to as Flygt #3
^ Mixer located at 70° rather than 75° - Mixer with 20 inch shroud
<Mixer with 30 inch shroud

The liquid level in the tank during testing was 4 feet, except during tests 1, 9, 15, and 16. During tests 1 and 9, velocity data was collected with tank levels of 3 feet, 4 feet, and 6 feet. During tests 15 and 16, the water level was 5.5 feet.

The mixer located at 37.5 ft. and 300° (see Figure 2) was inserted into the tank through a riser to test deployment of the insertion mast and mixer operation from that mast.

The tests were performed by operating the mixers at full speed and measuring the fluid velocity at various positions in the tank. Fluid velocities were measured with the Marsh-McBirney model 511 electromagnetic velocity probe used in Phase B testing[2] and recorded with a Strawberry Tree data acquisition system at 10 Hz for 2 - 5 minutes. During test 1, the velocity was measured at distances of 15-75 feet from the mixer discharge, along the jet centerline, and at 10 and 20 degrees off the centerline (at same height as jet centerline). Table 2 shows the positions at which the fluid velocities were measured during tests 2 - 18. In tests 2 – 18, the velocity was measured 2 inches above the tank bottom. During tests 19 and 20, the velocity was measured at distances of 25-70 feet from the mixer discharge, along the jet centerline, 2 inches above the tank bottom, and at 10 and 20 degrees off the centerline (at same height as jet centerline). The probe was oriented so the y-axis is parallel to the cat walk and the x-axis is perpendicular to the cat walk. The purpose of the tests is to validate the computational fluid dynamics modeling performed by ITT Flygt, and to determine whether the fluid velocity in the tank exceeds the minimum velocity required to suspend zeolite and sludge which was identified in the Phase A and Phase B tests.[1,2]

Table 2. Velocity Measurement Positions for tests 2 - 18

Radius	Angle	Angle	Angle	Angle
0 ft	270°	90°	180°	210°
14 ft	270°	90°	180°	210°
28 ft	270°	90°	180°	210°
42 ft	270°	90°	180°	210°

Results

Appendix A contains the velocity data from the tests. The data shows the time averaged velocity, the turbulent intensity, and the location of the reading. The velocity is the square root of the sum of the squares of the x and y components of the velocity. The turbulent intensity is the fluctuating component of the velocity divided by the average velocity. In some of the tests, the turbulent intensities and peak velocities measured were much higher than expected and appear to indicate some type of problem with the velocity probe or data acquisition system. The data from these tests are being evaluated and are not discussed further in this report. The following observations and conclusions were made from the data in this test:

Mixer discharge profile

- The average discharge velocity measured with a standard shroud was about 20% of the value predicted based upon turbulent jet theory.
- Turbulent jet theory predicts the fluid velocity measured 10 degrees off the jet centerline should be less than 50% of the velocity at the centerline. In the tests with standard shrouds, the measured velocities 10 degrees and 20 degrees off the centerline were approximately equal to and in some cases exceeded the centerline velocity. The results indicate the jet produced by the Flygt mixer spreads wider than a classical turbulent jet. Visual observations of the mixer discharge support this conclusion.
- In the test with the extended shrouds, the fluid velocity measured 2 inches above the tank bottom was approximately equal to the fluid velocity measured at the jet centerline.
- The measured fluid velocities increased when the tank liquid level was decreased.

- The turbulent intensity (fluctuating velocity divided by average velocity) was measured. Many of the readings were in the range of 0.30 – 0.60. Typical turbulent intensities for turbulent jets are approximately 0.30. Measured intensities in agitated tanks are approximately 0.35. These intensities are slightly higher than expected. The differences could be due to the waves circulating around the tank, the variations in flow caused by the rotating propellers, or surface agitation.
- If the mixers are to be rotated to improve solids suspension, the mixer shrouds should be modified to narrow the jet, reduce the axial velocity decay, and increase the cleaning radius.
- Tests performed after extending the shroud on the Flygt mixer to 20 inches showed the centerline velocity increased approximately 50%. Increasing the shroud length to 30 inches caused a decrease in the jet velocity. This decrease is most likely due to the increased resistance of the shroud. Additional work should be performed to optimize the shroud design.

Tank velocity with multiple mixers

- Typical average fluid velocities at the center of the tank (measured 7 feet from center) were 0.35 – 1.28 feet/second. The one large reading at the center (test #4) was due to the velocity probe being in the mixer discharge.
- Typical average velocities at the tank wall were 1.14 – 4.51 feet/second. The low velocity readings at the wall in test #5 are because only a single transverse mixer was used.
- Turbulent intensities in most tests were 0.09 – 0.68.

Conclusions

- The SRS stationary mixer deployment mast testing was successful in allowing simple, efficient mixer installation through the riser opening. Once within the tank, the mixer manually reoriented to its horizontal operating position. The mast kept the 50 hp mixer stable on the tank floor during operation. With external crane support, the mast was lifted and redirected to discharge in another direction.
- Three stationary Flygt mixers will not successfully suspend zeolite in an SRS waste tank.
- The test results indicate three mixers should successfully suspend zeolite and lighter sludge components in SRS waste tanks provided the mixers can rotate from horizontal positions on the tank floor and are equipped with modified shrouds to focus the mixer discharge.

The full Phase C test report will provide a more complete evaluation of test program results and conclusions.

References

1. M. R. Powell, J. R. Farmer, H. Gladki, B. K. Hatchell, M. R. Poirier, and P. O. Rodwell, "Evaluation of Flygt Mixers for Application in Savannah River Site Tank 19 Test Results from Phase A: Small-Scale Testing at ITT Flygt", PNNL-12094, March 1999.
2. M. R. Powell, W. H. Combs, J. R. Farmer, H. Gladki, B. K. Hatchell, M. A. Johnson, M. R. Poirier, and P. O. Rodwell, "Evaluation of Flygt Mixers for Application in Savannah River Site Tank 19 Test Results from Phase B: Mid-Scale Testing at PNNL", PNNL-12093, March 1999.

Appendix A
Test Data

Velocity is average velocity
Turbulent intensity is fluctuating velocity component divided by average velocity (u'/U)
Axial distance is distance from mixer discharge to velocity probe along the centerline
Angle is the angle between the discharge centerline and the line between the mixer and the velocity probe
Water level is 4 ft except for 1a (6 ft) and 1c (3 ft)

Test #1a

Velocity	Turbulent Intensity	Axial Distance	Angle
1.55 ft/s	.33	15 ft	0 degrees
1.30	.40	20	0
1.42	.42	25	0
1.35	.36	30	0
1.40	.32	35	0
1.26	.45	40	0
1.05	.50	45	0
0.48	.58	50	0
0.28	.58	55	0
0.38	.62	60	0
0.36	.40	65	0
0.56	.37	70	0
0.55	3.34	75	0
1.36	.67	20	10
1.29	.38	25	10
1.26	.42	30	10
1.07	.44	35	10
0.92	.50	40	10
0.54	.56	45	10
0.32	.57	50	10
0.31	.48	55	10
0.26	.51	60	10
0.42	.66	65	10
0.46	.55	70	10
2.70	.36	20	20
2.23	.41	25	20
1.90	.39	30	20
1.62	.40	35	20
1.05	.58	40	20
1.01	.47	45	20
0.43	.73	50	20

Test#1b

Velocity	Turbulent Intensity	Axial Distance	Angle
2.78 ft/s	.20	30 ft	0 degrees
2.29	.32	35	0
1.69	.55	40	0
1.67	.58	45	0
2.11	.48	50	0
1.36	.45	55	0
1.35	.63	60	0
1.27	.42	65	0
1.39	.69	70	0
1.36	.95	75	0
2.34	.46	30	10
2.57	.34	35	10
1.87	.47	40	10
1.85	.53	45	10
1.88	.57	50	10
1.79	.61	55	10
1.55	.76	60	10
1.39	.79	65	10
1.58	.97	70	10
2.34	.55	30	20
2.03	.62	35	20
2.05	.46	40	20
1.15	.65	45	20
0.66	.87	50	20
0.71	.85	55	20
0.41	.84	60	20
0.35	.61	65	20

Test #1c

Velocity	Turbulent Intensity	Axial Distance	Angle
3.45 ft/s	.35	30 ft	0 degrees
3.21	.38	35	0
2.57	.68	40	0
2.61	.55	45	0
2.42	.48	50	0
1.29	.70	70	0
1.64	.73	75	0
3.29	.44	30	10
2.75	.59	35	10
1.74	.61	40	10
2.63	.67	45	10
2.62	.55	50	10
2.13	.39	55	10
2.04	.47	60	10
1.95	.65	65	10
1.88	.57	70	10
2.38	.65	30	20 degrees
1.61	.66	35	20

Test#2

Velocity (ft/s)	Turbulent Intensity	Distance From Tank Center	Angle
1.61	.16	14	90
1.24	.18	28	90
2.95	.16	42	90
1.50	.12	14	180
1.27	.10	28	180
2.70	.10	42	180
1.42	.11	14	210
1.22	.12	28	210
2.57	.15	42	210
1.27	.15	14	270
1.30	.46	28	270
1.86	.09	42	270
0.46	.35	7	270

Test#3

Velocity (ft/s)	Turbulent Intensity	Distance From Tank Center	Angle
.61	.53	7	90
.98	.32	14	90
1.45	.38	28	90
3.18	.21	42	90
.35	.43	7	180
.40	.38	14	180
1.58	.2	28	180
		42	180
		7	210
.46	.41	14	210
1.98	.16	28	210
3.10	.10	42	210
.35	.41	7	270
.53	.36	14	270
1.90	.13	28	270
2.91	.09	42	270

Test#4

Velocity (ft/s)	Turbulent Intensity	Distance From Tank Center	Angle
3.75	.14	7	90
5.28	.26	14	90
1.66	.14	28	90
1.14	.31	42	90
1.28	.24	7	180
1.39	.19	14	180
1.85	.19	28	180
3.23	.14	42	180
1.23	.25	7	210
1.42	.15	14	210
1.98	.12	28	210
3.01	.11	42	210
1.15	.23	7	270
1.43	.25	14	270
1.89	.10	28	270
2.78	.12	42	270

Test#5

Velocity (ft/s)	Turbulent Intensity	Distance From Tank Center	Angle
.56	.55	7	90
.97	.54	14	90
5.08	.26	28	90
.57	.45	42	90
.39	.41	7	180
.34	.53	14	180
.65	.36	28	180
1.43	.21	42	180
.47	.30	7	210
.34	.29	14	210
.96	.22	28	210
1.24	.24	42	210
1.02	.24	7	270
.93	.15	14	270
.81	.17	28	270
1.07	.18	42	270

Test#6

Velocity (ft/s)	Turbulent Intensity	Distance From Tank Center	Angle
1.24	.45	7	90
2.01	.13	14	90
5.64	.22	28	90
4.51	.35	42	90
1.05	.30	7	180
1.66	.29	14	180
1.99	.17	28	180
1.40	.49	42	180
1.11	.24	7	210
1.77	.14	14	210
1.94	.13	28	210
1.53	.27	42	210
1.17	.31	7	270
1.98	.13	14	270
1.98	.11	28	270
1.68	.17	42	270

Test#9b

Velocity (ft/s)	Turbulent Intensity	Distance From Tank Center	Angle
.91	.57	7	90
1.16	.32	14	90
1.68	.38	28	90
3.51	.17	42	90
.64	.52	7	180
1.40	.24	14	180
2.00	.15	28	180
2.98	.39	42	180
.55	.68	7	210
1.15	.26	14	210
1.97	.17	28	210
1.58	.38	42	210
.46	.47	7	270
1.17	.33	14	270
2.14	.12	28	270
2.54	.16	42	270

Test#11

Velocity (ft/s)	Turbulent Intensity	Distance From Tank Center	Angle
1.73	.81	7	90
1.51	.21	14	90
3.94	.45	28	90
1.95	.44	42	90
.44	1.07	7	180
.54	.87	14	180
.82	.50	28	180
1.91	.23	42	180
.48	.56	7	210
.50	.66	14	210
1.45	.21	28	210
1.97	.15	42	210
.79	.17	7	270
.75	.38	14	270
1.23	.18	28	270
2.04	.13	42	270

Test #19 (20 inch shroud)

Velocity (ft/s)	Turbulent Intensity	Max Velocity (ft/s)	Axial Distance (ft)	Angle (degrees)
2.75	.36	9.52	25	0
3.93	.69	23.41	25	Bottom
3.98	.66	26.60	25	Bottom
2.48	.58	9.84	30	0
3.13	.55	18.82	30	Bottom
3.11	.64	17.95	30	Bottom
2.70	.50	20.83	35	0
4.12	.99	32.49	35	Bottom
3.37	.88	30.14	35	Bottom
2.05	.46	7.62	40	0
3.40	.99	33.29	40	Bottom
2.63	.46	7.48	45	0
2.16	.64	13.23	45	Bottom
2.47	.54	9.95	50	0
2.26	.62	9.02	50	Bottom
2.13	.47	7.04	55	0
2.15	.53	9.27	55	Bottom
2.32	.47	9.35	60	0
2.27	.52	9.10	60	Bottom
2.33	.50	7.22	65	0
2.74	.39	8.34	65	Bottom
2.22	.66	8.78	70	0
2.75	.48	9.04	70	Bottom
3.33	.35	8.38	25	10
3.19	.42	12.00	30	10
2.86	.37	7.89	35	10
2.15	.59	8.29	40	10
2.46	.51	7.85	45	10
2.14	.59	8.36	50	10
2.10	.60	8.85	55	10
2.52	.56	8.92	60	10
2.14	.54	8.08	65	10
3.83	.22	8.50	25	20
3.47	.27	8.65	30	20
2.80	.46	9.13	35	20
2.71	.55	13.45	40	20
2.13	.63	7.43	45	20
2.37	.68	11.33	50	20
2.35	.64	9.09	55	20
2.33	.63	9.87	60	20

Test 20 (30 inch Shroud)

Average Velocity (ft/sec)	Turbulent Intensity	Maximum Velocity (ft/sec)	Distance (ft)	Angle (degrees)
2.80	.26	4.42	25	0
4.09	.12	5.45	25	Bottom
2.05	.43	4.15	30	0
3.46	.13	5.36	30	Bottom
3.11	.13	4.48	35	0
3.19	.13	4.43	35	Bottom
2.57	.17	3.75	40	0
1.76	.33	3.07	40	Bottom
1.95	.19	2.98	45	0
1.68	.22	3.21	45	Bottom
1.14	.36	2.29	50	0
1.25	.33	2.49	50	Bottom
1.44	.24	2.66	55	0
0.98	.50	2.92	55	Bottom
0.48	.53	1.61	60	0
0.83	.56	3.24	60	Bottom
1.60	.54	3.77	65	0
0.77	.55	2.30	65	Bottom
0.92	.35	2.66	70	0
1.11	.33	2.13	70	Bottom
1.43	.27	3.24	25	10
0.77	.29	2.13	35	10
1.18	.29	2.24	45	10
1.68	.18	2.64	55	10
1.90	.25	3.42	65	10
0.79	.30	1.32	25	20
1.81	.52	3.88	35	20
1.51	.12	2.07	45	20
2.20	.18	3.37	55	20

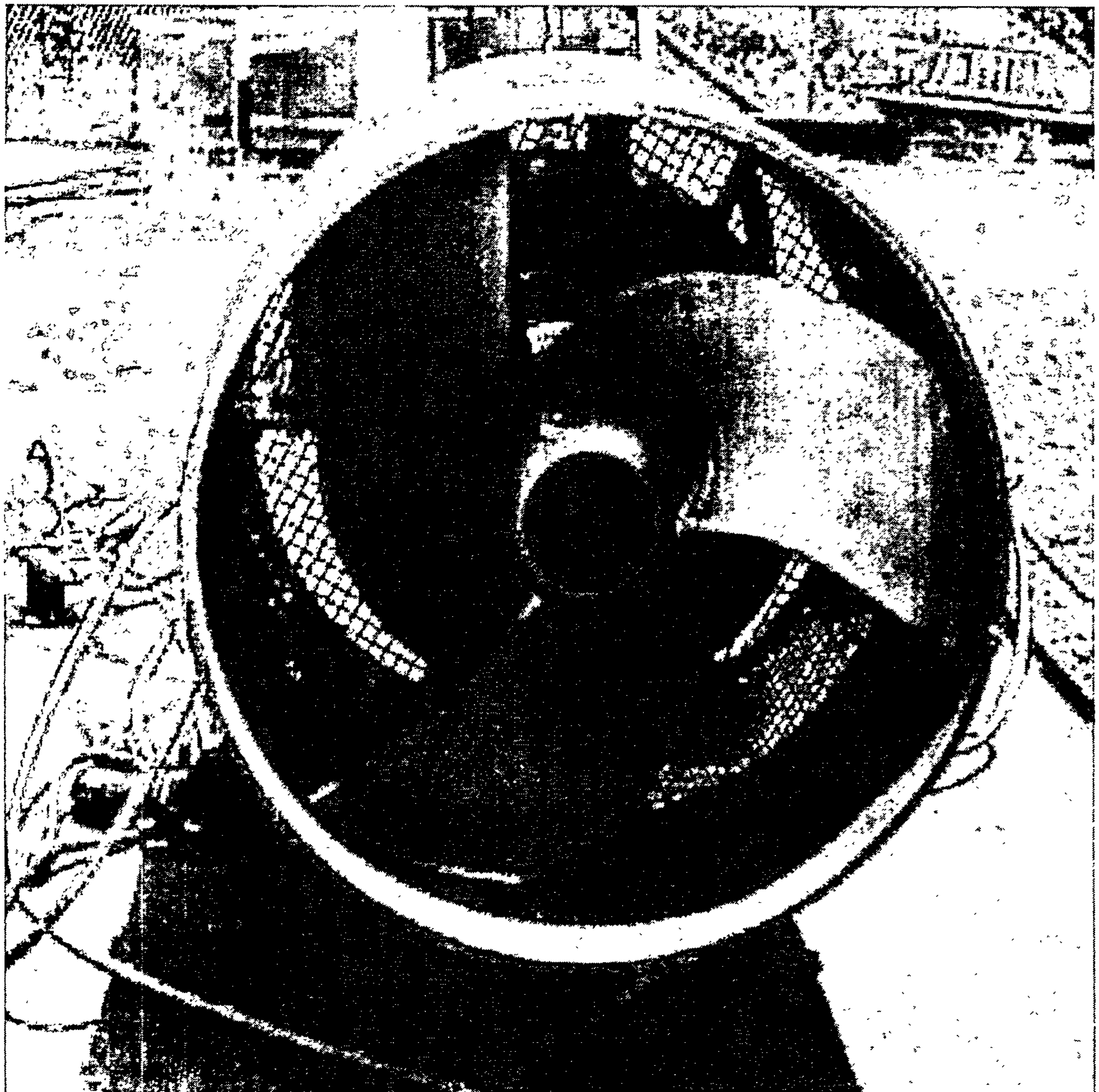

Figure 1. 50 hp Flygt Mixer

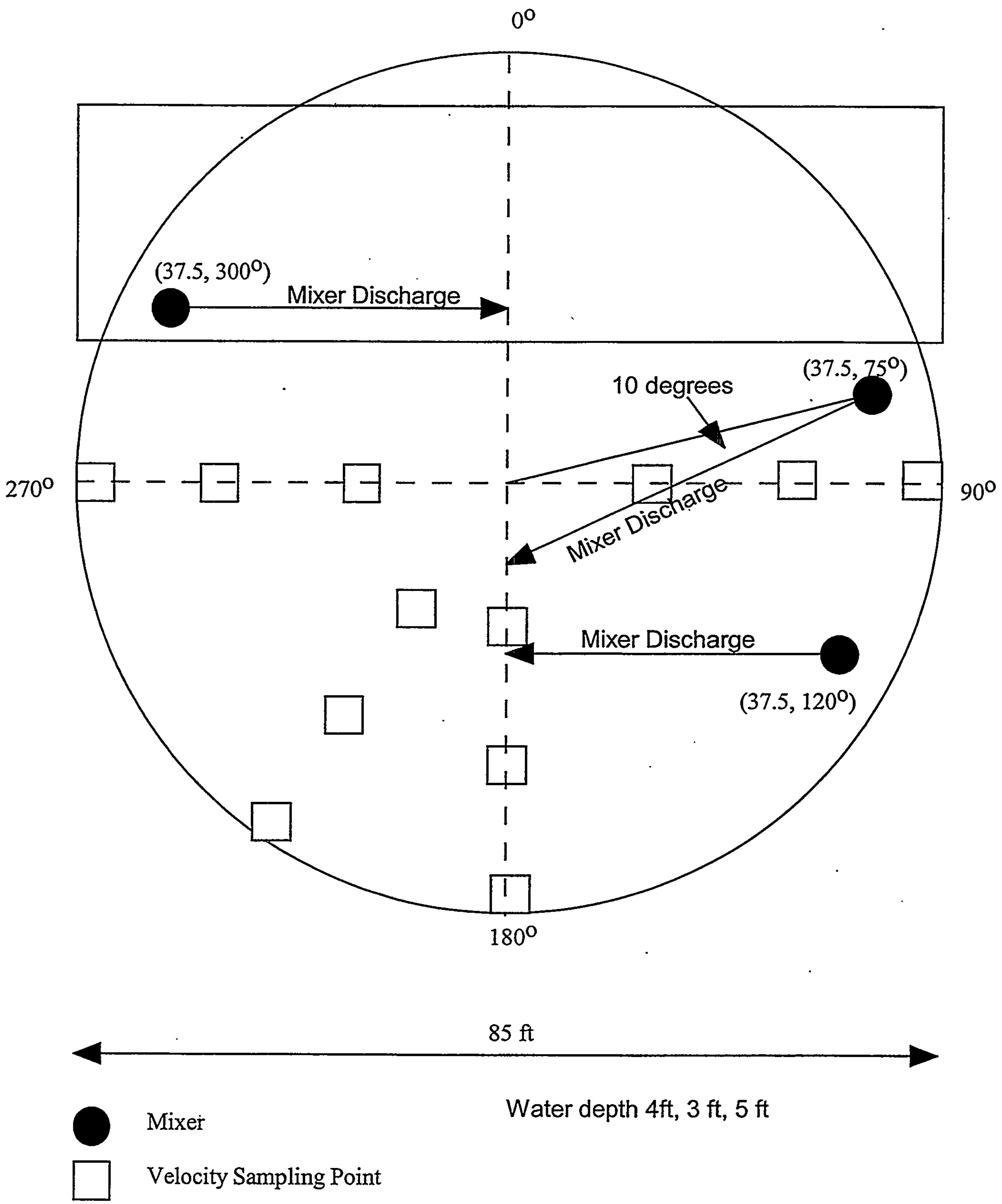

Figure 2. Mixer Layout for Test 4

Appendix C

Long Shroud Flygt Mixer Velocity Profiles

The following document (SRT-WHM-99-002) dated February 4, 1999, was prepared and cleared for release by staff at the U.S. Department of Energy's Savannah River Site.

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Savannah River Company
Aiken, SC 29808

BNFL

February 4, 1999 **SRT-WHM-99-002**

To: W. B. Van Pelt, 679-T
W. E. Stevens, 773-A
H. M. Handfinger, 704-71S
B. A. Martin, 742-4G
WHMP File, 679-T

From: M. R. Poirier, 679-T
P. O. Rodwell, 742-6G

Long Shroud Flygt Mixer Velocity Profiles

Introduction

SRS is identifying and investigating techniques to remove sludge heels from waste tanks such as Tank 19. Shrouded, axial propeller, submersible mixers, manufactured by ITT Flygt Corporation are one of the suggested alternatives. The mixers consist of an electrically powered propeller surrounded by a close-fitting shroud. The 50 hp mixers being considered for waste retrieval in Tank 19 have a propeller diameter of 20 inches and a maximum speed of 860 rpm. The rapidly spinning propeller creates a turbulent jet with an average exit velocity of approximately 20 ft/sec.

SRS, PNNL, ORNL, and ITT Flygt are conducting a mixer test program to evaluate the ability of Flygt mixers to retrieve waste from SRS Tank 19, and other DOE site waste tanks. The team performed the first phase of tests at the ITT Flygt laboratory in Trumbull, CT with a 1.5 foot diameter tank. The second phase of tests was performed with PNNL's pilot-scale mixing tanks (6 feet diameter and 18.75 feet diameter) in Hanford, WA. The third test phase was performed with the TNX Full Tank (85 feet diameter) at SRS.[1] Tests are performed with different size tanks so scaling methods can be developed to apply the test results to real waste tanks.

During the tests performed in the 85 foot diameter tank, the authors observed the average centerline velocity of the jet produced by the Flygt mixers was much less than predicted for a turbulent free jet. Additional testing showed the centerline velocity could be increased if the mixer shroud was extended. The purpose of this test was to determine if increasing the shroud length to 30 inches would increase the discharge jet velocity and improve its ability to suspend sludge and zeolite in waste tanks.

Test Description

The tests were performed by operating the mixers at full speed and measuring the fluid velocity at various positions in the tank. Fluid velocities were measured with the Marsh-McBirney probe used in Phase B and C testing and recorded with a Strawberry Tree data acquisition system at 10 Hz for approximately 3 minutes. The velocity was measured at distances of 25 - 70 feet from the mixer discharge, along the jet centerline (18 inches above the tank bottom), 2 inches above the tank bottom, and at 10 and 20 degrees off the centerline (at same height as jet centerline). The probe was oriented so the y-axis is parallel to the cat walk and the x-axis is perpendicular to the cat walk. The water level in the tank was 4 feet. The purpose of the tests was to determine the effect of increasing the shroud length on mixer discharge velocity.

Results

Table 1 shows the measured average velocities, turbulent intensities, and maximum velocities. The average velocities ranged from 4.09 to 0.48 ft/sec. The turbulent intensities were 0.12 – 0.56 with an average of 0.30. Typical turbulent intensities of turbulent jets are 0.30, and typical turbulent intensities in agitated tanks are 0.35. Peak velocities ranged from 1.32 to 5.36 ft/sec.

Figure 1 shows the average velocity plotted as a function of distance from the mixer. The centerline velocity is less than the theoretical average predicted velocity for a turbulent free jet. The probable reason for this result is the jet is close to the tank bottom and behaves as a combination turbulent free jet – turbulent wall jet. The fluid velocity 2 inches above the tank bottom is approximately equal to the centerline velocity. Since at distances of 25 – 70 feet the sample locations are 1° – 3° off the centerline, the velocities measured at the tank bottom should be within 10% of the velocities measured at the centerline. The testing did show a drop in fluid velocity as the probe was moved 10° – 20° off the centerline which indicates this jet was better focused than the jets produced by the Flygt mixers with standard shrouds (~ 4 inches) and 20 inch shrouds.

Figure 2 compares the velocity of the jet produced by the mixer with a 30 inch shroud against other mixers tested. At distances of 25 – 40 feet, the Flygt mixers with 20 and 30 inch shrouds produced approximately the same velocity. Beyond 40 feet, the Flygt mixer with the 20 inch shroud produced a higher velocity. These results are surprising and suggest the longer shroud may have restricted the flow rate of water through the mixer.

Figure 3 shows a plot of the peak velocities measured in these tests. The figure shows the peak velocities can be much larger than the average velocities measured.

While performing the tests, the authors noticed low frequency (~ 0.1/min) variations in the fluid velocities measured at fixed points in the tank over an extended period. Figure 4 shows an example of the variation. The data were collected 35 feet from the mixer discharge and 20° off the discharge jet centerline for approximately 20 minutes. These variations may affect the solids suspension process and will be evaluated further to determine their impact on Flygt mixer operations in a High Level Waste Tank.

Conclusions

Testing in the Joint Mixer Test Program determined that average fluid velocities of 1.6 ft/sec, 2 inches above the tank bottom are needed to mobilize and maintain fast settling particles such as IE95 Zeolite (a constituent of SRS Tank 19 and other waste tanks) in suspension. These tests (Figures 1 and 2) indicate the 30 inch shroud would produce these velocities at distances of 40 feet from the mixer. Beyond 40 feet, the velocities would drop below this value. The standard shroud would be expected to perform similarly. Based on these tests, the 20 inch shroud would be expected to produce average fluid velocities greater than 2 ft/sec at distances of 70 feet from the mixers.

References

1. M. R. Poirier and P. O. Rodwell, "Phase C Flygt Mixer Test Results", SRT-WHM-98-0015, September 25, 1998.

Table 1. 30" Shroud Flygt Mixer Velocity Profile

Average Velocity (ft/sec)	Turbulent Intensity	Maximum Velocity (ft/sec)	Distance (ft)	Angle (degrees)
2.80	.26	4.42	25	0
4.09	.12	5.45	25	Bottom
2.05	.43	4.15	30	0
3.46	.13	5.36	30	Bottom
3.11	.13	4.48	35	0
3.19	.13	4.43	35	Bottom
2.57	.17	3.75	40	0
1.76	.33	3.07	40	Bottom
1.95	.19	2.98	45	0
1.68	.22	3.21	45	Bottom
1.14	.36	2.29	50	0
1.25	.33	2.49	50	Bottom
1.44	.24	2.66	55	0
0.98	.50	2.92	55	Bottom
0.48	.53	1.61	60	0
0.83	.56	3.24	60	Bottom
1.60	.54	3.77	65	0
0.77	.55	2.30	65	Bottom
0.92	.35	2.66	70	0
1.11	.33	2.13	70	Bottom
1.43	.27	3.24	25	10
0.77	.29	2.13	35	10
1.18	.29	2.24	45	10
1.68	.18	2.64	55	10
1.90	.25	3.42	65	10
0.79	.30	1.32	25	20
1.81	.52	3.88	35	20
1.51	.12	2.07	45	20
2.20	.18	3.37	55	20

Table 2. Effect of Shroud Length on Flygt Mixer Discharge Centerline Velocity

Distance from Mixer (ft.)	Standard Shroud (ft/sec)	20" Shroud (ft/sec)	30" Shroud (ft/sec)
25	2.78	2.75	2.80
30	2.29	2.48	2.05
35	1.69	2.70	3.11
40	1.67	2.05	2.57
45	2.11	2.63	1.95
50	1.36	2.47	1.14

55	1.35	2.13	1.44
60	1.27	2.32	0.48
65	1.39	2.33	1.60
70	1.36	2.22	0.92

(The velocity data values summarized in this report reflect average values developed from larger data sets. Copies of the larger source data sets are available upon request.)

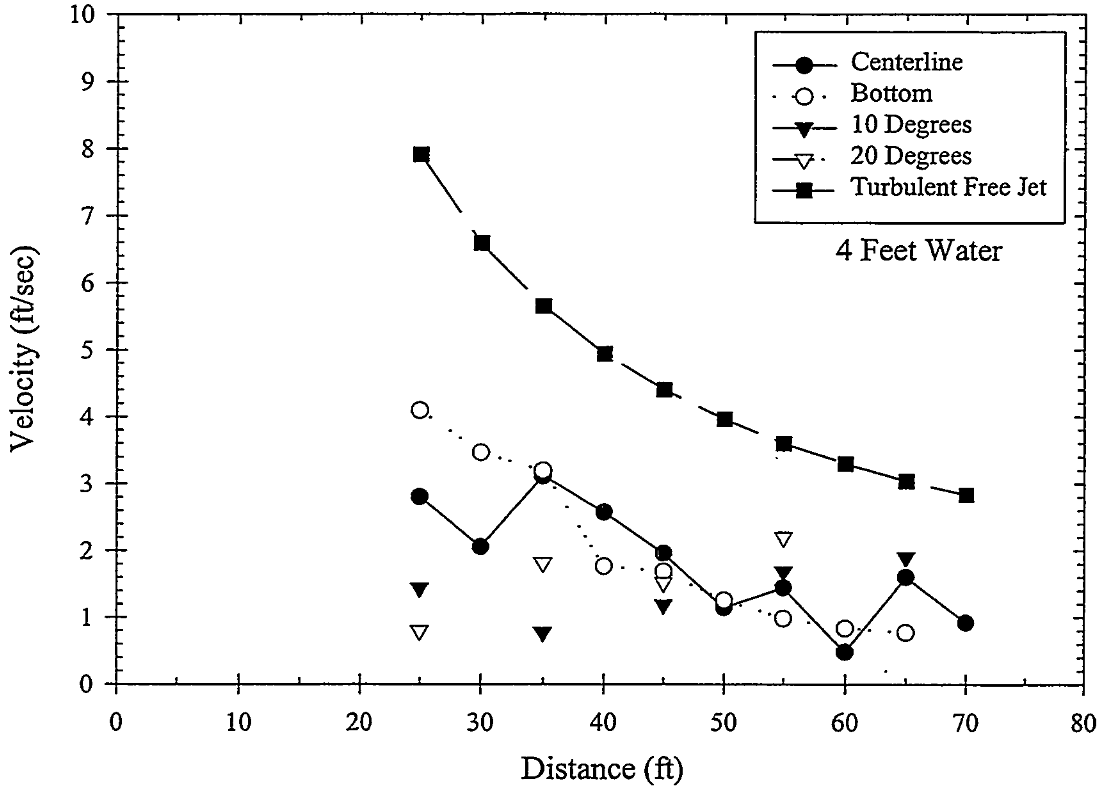

Figure 1. 30" Shroud Flygt Mixer Velocity Profile

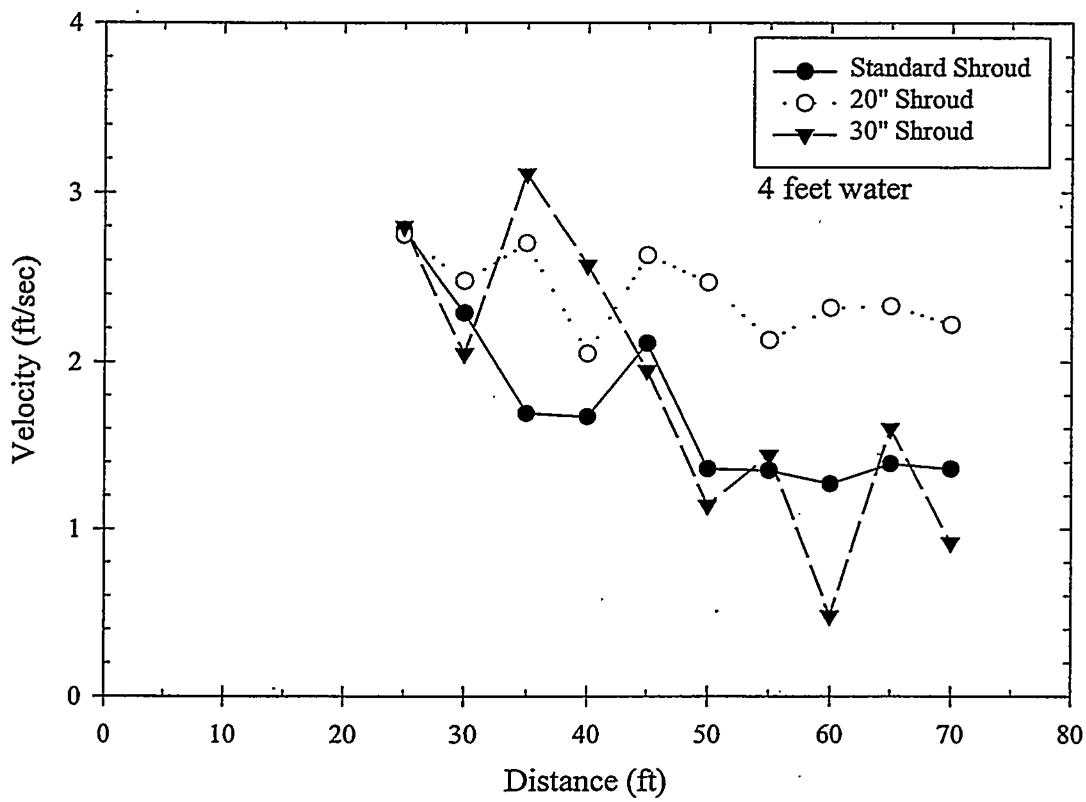

Figure 2. Effect of Shroud Length on Flygt Mixer Discharge Centerline Velocity

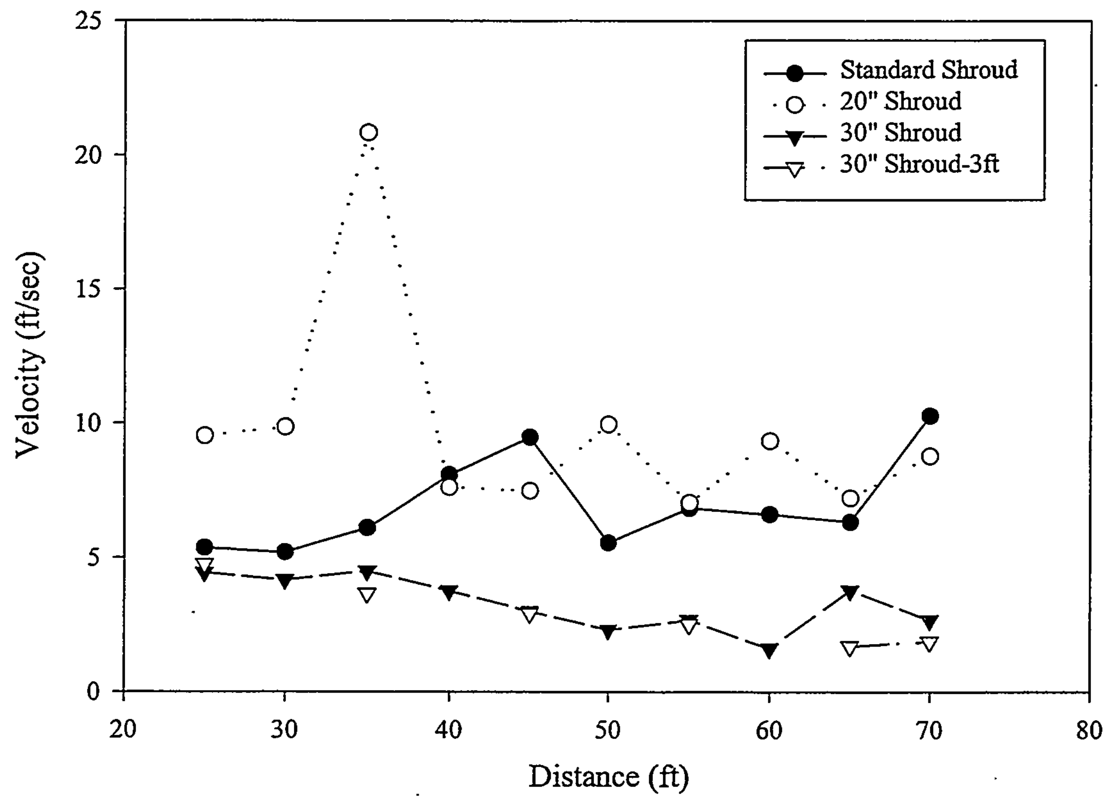

Figure 3. Peak Velocities of Jets Produced by Flygt Mixers

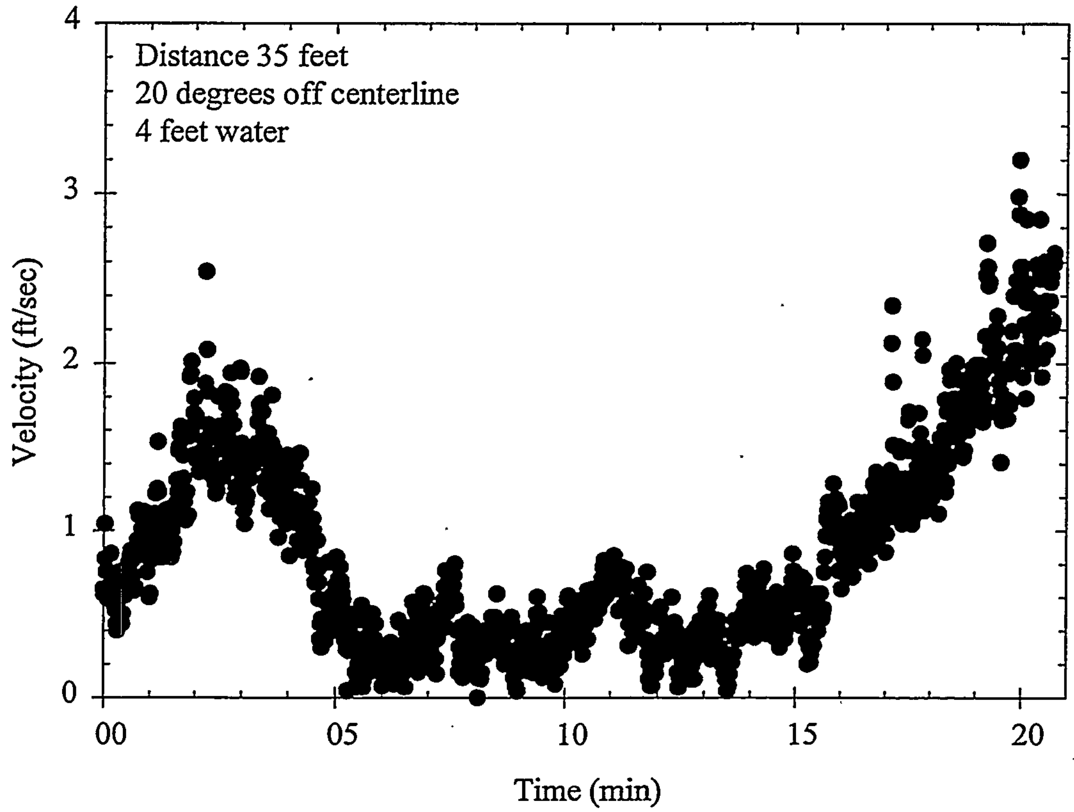

Figure 4. Mixer Discharge Velocity as a Function of Time

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