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FACILITY TITLE II DESIGN

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EXECUTIVE SUMMARY

Mixing tests were conducted in 1/25 and 1/10 scale test tanks with different slurry levels, solids concentrations, different jet mixers, and with simulated in-tank components. The test results concluded that:

1. The 1/25 test results support the scaling correlation derived previously in the Title I program. Namely, the mixing power requirement is approximately proportional to the second power of the tank diameter.
2. A partially filled tank requires less mixing power.
3. Horizontal and angled jets in combination (H/A mixer) are significantly more effective than the two horizontal jet mixer (H/H mixer) when used for mixing slurry with high solids concentration (23.2% to 28.3% solids by weight).
4. With the recommended H/A mixer the power requirement for uniformity mixing is rather independent of the solid concentration for the range tested (23.2% to 28.3% solids by weight).
5. In-tank components would cause some solids settlement behind them if they extend to the tank bottom. Therefore, it is recommended that in-tank components be elevated off the tank floor. The quality of settled solids, which is a function of component configuration and location can be determined only after these dimensions are final in the Title II design. For current in-tank

component configurations, 90% homogeneity can be achieved with the recommended mixer pump design.

6. The baseline design for the jet mixer recommended in the Title I design (Chang and Beaver 1993) remains unchanged. A single pump can adequately mix the tank waste. The recommended jet mixer for the Multi-Function Waste Tank Facility (MWTF) consists of two 2.2 inch diameter jets, of which one jet is aligned horizontally and the opposite jet is angled upward at 30 degrees. The minimum mixing power that satisfies the 90% homogeneity design goal is 14 horsepower (hp). This mixer configuration applies to both the centrally located mixer and to a mixer located up to 13 feet off-center.

ENGINEERING SCALE MIXING SYSTEMS TESTS FOR MULTI-FUNCTION WASTE TANK FACILITY TITLE II DESIGN

1.0 INTRODUCTION

The function of the Multi-Function Waste Tank Facility (MWTF) mixing system is to maintain the solid particles of the waste in suspension and keep them homogeneously distributed. The minimum homogeneity is specified at 90% for the mixing tests. The 90% homogeneity is so defined that anywhere in the tank the mixture should have a solids content (density) equal to or greater than 90% of the average density in the homogeneous mixture (i.e., perfectly mixed waste). The mixer is required to be operative during the tank filling and retrieval. Therefore the 90% homogeneity goal is effective for the partially filled tank.

The tank design requires placement of the transfer pump at the tank centerline. This requires the mixer pump to be placed off-center. The current MWTF design has two mixer pumps placed approximately 13 ft away from the tank center.

The main objective of the test program is to develop a mixing system for the MWTF that will:

1. Satisfy the design goal of maintaining 90% homogeneity.
2. Use the minimum number of mixer pumps (the goal is one pump) so that mixing system costs can be minimized.
3. Determine the minimum hydraulic power and mixer configuration for maintaining uniform mixing.
4. Verify the jet mixing effectiveness at off-center positions to be consistent with actual tank riser locations.

2.0 TITLE I MIXING TESTS

2.1 SUMMARY OF TITLE I MIXING TESTS

The main objective of the test program conducted during Title I design (Chang and Beaver 1993) was to establish a first level design of a mixing system for MWTF that properly accounted for the primary design parameters. The design goal is to use the minimum number of mixer pumps and use the minimum pump power necessary to satisfy the mixing requirements. Testing in scaled tanks was used as the main design tool for the mixing system development. A scaling correlation for scaling up from the smaller test tank data to the actual MWTF mixing design was derived from the test data.

Different mixing configurations were tested during the Title I program, which included mixers with two horizontal jets, four horizontal jets, jets with eductors and combinations of horizontal and upward angled jets. The test results showed that a mixing configuration with one horizontal jet and a 30° angled jet had the best performance for a given mixing power. The mixing requirement for MWTF was accomplished with one mixer pump at the tank center or one at a 13 ft off-center location. The scaling study was performed in three different size test tanks of 1/6.3, 1/10, and 1/15 of the diameter of MWTF. The test data indicated that the mixing power requirement is approximately proportional to the second power of the tank diameter. Under the Title I test conditions the required full scale hydraulic mixing power was determined to be 14 horsepower.

The following limitations applied to the Title I test results:

1. The Title I tests were conducted exclusively with a full tank. No partially filled tanks were tested.
2. Only one solids concentration was tested in Title I. The effect of solids concentration on mixing power was not examined.
3. The Title I tests were conducted in test tanks without in-tank components such as other pumps and instrument trees. Previous experience reveals that in-tank components can significantly reduce mixing effectiveness (Chang 1993).

2.2 CONCLUSIONS OF TITLE I MIXING TESTS

2.2.1 Full Scale Mixing System

Based on the scaling correlation derived from the test data, the mixing jets for the full size tank require approximately 14 hydraulic horsepower to maintain the required homogeneity of the actual waste in a MWTF tank. This power requirement projection is derived from the test data correlation that indicates mixing power increases by approximately the second power of the linear dimension ($HP_{mix} \sim L^{2.0}$). The required pump head would be 22.3 psig at a flowrate of 1111 gpm.

2.2.2 Off-Center Jet Locations

The current MWTF tank design places the transfer pump at the tank centerline. This requires that the mixer pumps be placed at off-center locations. The location for the mixer pumps for the current MWTF design is approximately 13 ft away from the tank center. Mixing jets at off-center locations were tested to satisfy this design constraint. The test result showed that the off-center mixer has the same mixing effectiveness as the mixer located at the tank center.

2.2.3 Nozzle Configuration

Among the jet mixer configurations tested, the most power efficient configuration includes two jet nozzles located 180° apart with one jet horizontal and the other angled upwards at 30°. However this configuration bears the concern of the jet breaking the surface and generating waste aerosol at low liquid depths. Also, it requires full circle indexing compared to the half circle indexing with two horizontal jets. A mixing configuration with two horizontal jets has been tested extensively during Title II design (see Section 4.3.2). The final recommendation for nozzle configuration has not changed from that of the Title I report (Chang and Beaver 1993).

Table 1. Jet Mixer Configurations.

Tank Scale	Nozzle Diameter	Nozzle Height	Tank Diameter	Off-Center Dis.
1/15	5/32"	1.0"	60"	0"
1/10	7/32"	1.5"	92"	0"
1/6.3	0.35"	2.4"	143"	25"
Recommended MWTF	2.2"	15"	900"	156"

2.2.4 Operating Procedures

An operating procedure that increments the angular position of the mixer jets in the horizontal plane is required. The recommended increment for indexing the nozzles is 30°, which is based on the subscale test procedure and the spreading angle for a free jet. The running time at each 30° indexed angle is recommended to be 30 minutes. The running time is estimated based on the test results that uniformity was maintained in the 1/6.3 scale tank with 5 minutes running time at each 30° indexed angle. The distance and time for particle settling are proportional to the linear scale of the tank. The full scale running time is therefore estimated to be $5 \times 6.3 \sim 30$ minutes.

It is recommended that a variable speed drive motor be coupled to the MWTF pump so that it can be initially run at a speed that provides 14 hydraulic horsepower to satisfy the baseline mixing operation. The homogeneity should be monitored continuously and pump rpm readjusted to a higher speed if greater homogeneity is required.

2.2.5 Instrumentation for Monitoring Homogeneity

Instrumentation that continuously monitors the density of MWTF tank slurry during the mixing operation is recommended. Azimuthal location is not important but density measurement at a minimum of two elevations (near surface and near bottom) should be provided. From our laboratory experience and the experience with instrumentation in tank 101-SY, we believe simplicity of

design is the key to instrument reliability. As a case in point, the current test program did not use any sophisticated electronics or complicated technology yet it proved that the desired measurement can be accomplished by a simple, reliable, and straightforward instrument.

3.0 SCOPE AND OBJECTIVES OF TITLE II MIXING TESTS

The Title II Mixing Tests include the following test cases:

A. Testing to extend the range of the scaling correlation.

The objective is to further verify the scaling method concluded from the Title I program by conducting tests in a 1/25 scale tank.

B. Testing with horizontal jets.

The objective is to establish the qualitative relative performance of angled and horizontal jets for different slurry parameters, such as height and concentration.

C. Testing with variable tank levels.

The objective is to test mixing systems at different waste levels to determine the mixing requirements during anticipated filling and emptying conditions.

D. Testing with different solids concentrations.

The objective is to provide data for high solids concentration to determine the effect on mixing power requirements.

E. Testing with in-tank components.

The objective is to establish the severity of non-homogeneous mixing that results from the presence of in-tank components.

F. Testing with non-rotational jets.

Testing with non-rotational jets was included in the test plan but not performed. Upon re-examination of cost savings, non-rotational jets were not considered as a good design option.

The test parameters of Title II tests are summarized in Table 2, where Test Classes are as defined above.

Table 2. Mixing Test Parameters.

Test #	Test Class	Mixer Type	Liquid Height (in.)	% of Solids Weight	Specific Gravity	Jet Pressure (psi)	Jet Flow (gpm)	Hydraulic Power (hp)	Fig. #
#A	A,B	H/H	20	21.4	1.065	15	2.17	0.019	Fig. 1
#B	C,B	H/H	18	17.6	1.053	10	8.2	0.048	Fig. 3
#C	C,B	H/H	12	15.7	1.047	9.9	8.0	0.046	Fig. 4
#D	C,B	H/H	24	15.7	1.048	9.5	7.7	0.043	Fig. 5
#E	C,B	H/H	38	14.8	1.044	8.7	7.4	0.037	Fig. 6
#F	D,B	H/H	49	5.2	1.015	16	10	0.093	Fig. 7
#G	D,B	H/H	49	19.5	1.059	15	9.6	0.084	Fig. 8
#H	D,B	H/H	49	21.4	1.065	14	9.3	0.075	Fig. 9
#I	D,B	H/H	49	21.4	1.065	13	9	0.068	Fig. 10
#J	D,B	H/H	49	22.6	1.069	15	9.6	0.084	Fig. 11
#K	D,B	H/H	49	22.6	1.069	23	12	0.16	Fig. 12
#L	D	H/A	49	27.4	1.083	15	9.6	0.084	Fig. 13
#M	D	H/A	49	28.3	1.088	13	9	0.068	Fig. 14
#N	D	H/A	49	28.3	1.088	17	10.3	0.102	Fig. 15
#O	D	H/A	49	28.3	1.088	13	9	0.068	Fig. 16
#P	E	H/A	49	28.3	1.088	16	10	0.093	Fig. 17
#Q	NA	H/A	49	23.2	1.071	10.3	8	0.048	Fig. 18

Notes:

1. Mixer Type

H/H - Two horizontally opposed nozzles.

H/A - One horizontal nozzle and one angled upward at 30°.

2. Specific gravity refers to the specific gravity at the completely mixed slurry.

3. All tests were conducted in the 1/10th scale tank except Test #A that was performed in the 1/25 size tank.

4. Percent of solid weight refers to the percentage of the centrifuged solids weight, which is calculated based on that the specific gravity of the centrifuged solids is 1.40 (Chang and Beaver 1993).

4.0 TITLE II TEST RESULTS

4.1 TESTS IN THE 1/25 SCALED TANK

4.1.1 Tests Description

Performing tests in the 1/25 scaled tank were more difficult than expected and the quality of the data was only marginal with the exception of Test #A. The difficulty was mainly caused by the small jet nozzles, which were frequently plugged by the slurry particles. In order to test with the required low flow for the 1/25 scale, the control valve must be set at a highly throttled position. The control valve tended to collect particles in the valve seat area, that reduced the pressure and flow of the mixing jet. Frequent manual adjustments were needed to maintain the desired test condition during the mixing test.

4.1.2 Test Results of 1/25 Scale Test

The test was conducted with a slurry containing 21.4% solids. Test data are presented in Figure 1. The mixing configuration of this test had the combination of a 3/32 in. horizontal nozzle and a 3/32 in. 30° upward nozzle (3/32 in. H/A mixer). The densitometer probe is 9 in. tall and it was installed just submerged in the test slurry. Therefore the specific gravity measurement indicated the average density of the top half (9 in. out of 20 in.) layer of the slurry. The slurry was first mixed with excessive power (45 psi) as shown in Figure 1, to ensure a completely uniform mixture. The jet pressure was then reduced to 15 psi. The data showed that 15 psi jet pressure was able to maintain nearly uniform mixing. The mixer was then shut off to allow the solids to settle for two hours. The mixer was turned on at the same operating conditions to resume mixing for another hour. The solids concentration recovered to within 5% of that of the completely mixed slurry under this mixing condition. The percentage of the uniformity of the top layer is so defined that supernate is zero and uniformly mixture is 100%.

The flow rate in this test was too low for the existing flowmeter and it could not be measured continuously as in the other tests. The flowrate was determined manually by a stopwatch and a measuring cylinder. The measured flow at 15 psi was 2.174 gpm.

Figure 1 shows large density fluctuations in some portions. These occur while the jet is operating, and is the effect of dynamic forces acting on the probe in this small tank. While the jet is off, the trace is stable.

4.1.3 Mixing Power and Scaling Correlation

The hydraulic power can be calculated by the following formula:

$$\text{Power (in hp)} = \text{flow rate (in gpm)} \times \text{pressure (in psi)} / 1714$$

Therefore the mixing hydraulic power of this test is

$$Hp_{\text{mixing}} = 2.174 \times 15 / 1714 = 0.019 \text{ hp}$$

Figure 2 presents the scaling correlation of the present 1/25 scale test together with the data obtained from Title I tests. Although one test is not conclusive proof, the present test result supports the Title I program finding that the mixing power requirement is approximately proportional to the second power of the tank diameter.

4.2 TESTING WITH PARTIALLY FILLED TANK

4.2.1 Test Description

Uniformity mixing tests were performed with a partially filled tank at different levels. The objective was to verify that the same or less power is required to maintain uniform mixing at lower liquid levels so that no additional mixing power would be needed for mixing during low level operation. This series of test were performed with a jet mixer with two horizontal nozzles (H/H mixer). The tests were performed in the 1/10 scale tank.

The test procedure used in this series of tests is the same as in the Title I uniformity test. The densitometer was installed so that the top of the 9 in. probe was about 1 in. submerged in the liquid. A jet mixer with two horizontal jets (H/H mixer) was used for this series test.

The following steps were performed with the appropriately scaled final mixer configuration mounted on the centerline in each of the test tanks. Tests were performed to determine the minimum jet velocity and associated pump power necessary to maintain a 90% mixture uniformity.

1. Before the start of the mixing test record the density of the clear supernate. Mix the tank liquid thoroughly with excessive mixing power to obtain 100% homogeneity. Record the local bulk density of the mixed slurry.
2. Select a test condition (pump power) and run the mixer for a predetermined time to determine whether homogeneity can be maintained by the selected condition. Homogeneity is determined by monitoring the local density variation during the test.
3. Stop the mixer for a predetermined time to allow the solids to settle for a predetermined period.
4. Repeat Step 2 with the same test parameters to determine whether the selected mixing condition can recover the homogeneity.
5. Analyze the data and determine the test condition for the next test. If mixing was satisfactory, reduce the jet velocity. Otherwise increase the jet velocity.
6. Repeat steps 1-5 until the jet velocity is just able to maintain 90% homogeneity and recover the settled condition to within 90%.

The tests were conducted with a fixed scale height of the nozzles above the tank floor.

4.2.2 Test Results

Figure 3 presents the measured specific gravity, pressure and flowrate as a function of time for Test #B. The liquid level was 18 inches, which represents a 37% filled tank.

The slurry was first mixed by using full pump power (33 psi as indicated in Figure 3). Then the uniformity mixing test was run with 14 psi. The use of 14 psi was the minimum jet pressure for uniformity mixing of a full tank slurry from Title I tests. Figure 3 shows that the specific gravity was nearly constant during the mixing with 14 psi, which indicates that uniformity of the mixture was maintained under this mixing condition.

Then, the jet pressure was further reduced to 10 psi. The specific gravity of the top layer appears relatively constant during this period of mixing. The mixing power with 10 psi is about $(10/14)^{1.5} = 60\%$ of that with 14 psi. The test result verifies that the partially filled tank with 18 in. liquid requires less mixing power than that for a full tank.

Figures 4, 5, and 6 present the test results with liquid levels of 12 in., 24 in. and 38 inches (24%, 48% and 78%), respectively. In each case the test results show that 10 psi was sufficient to maintain the slurry uniformity within 90% of the completely mixed condition. (Note, Figure 4 shows a density greater than 100% due to dynamic effects.) The test results show that the required mixing power for uniformity mixing are lower for a partially filled tank than that of a full tank. No additional mixing power nor special requirement in equipment design are needed for mixing a partial filled tank.

4.3 TESTING WITH DIFFERENT SOLIDS CONCENTRATIONS

4.3.1 Test Description

In order to understand the mixing power requirement for uniformity as a function of solids concentration, a series of tests were conducted in the 1/10 scaled tank with solids concentration as a variable (see Table 2). This test series started with a low concentration of solids and then gradually increased the solids concentration. The density of the uniformly mixed slurry was determined by weighing a sample of a measured volume. The densitometer was then calibrated against the measured slurry density. The top of the densitometer was installed about 1 in. below the free surface of the liquid. The two horizontal jets (H/H mixer) and the horizontal/angled jet combination (H/A mixer) were tested in the series. The test procedure was the same as in the uniformity tests (Section 4.2.1).

4.3.2 Test Results with Two Horizontal Jets (H/H) Mixer

Test #F was performed with H/H mixer and very low solids concentration, 5.2% solid concentration. The specific gravity of the completely mixed slurry was 1.0145. Figure 7 shows that the uniformity was maintained within 90% with 13 psi mixing pressure. After 2 hours settling, the mixture uniformity was almost completely recovered by one hour of mixing with 13 psi mixing pressure. The test results show that the uniformity mixing of this low solids

concentration requires slightly less power than that required for higher concentrations.

Test #G was also run with a H/H mixer but in a slurry of a higher solids concentration (19.5%). The specific gravity of the slurry was 1.059. As shown in Figure 8, jet mixing pressure of 15 psi maintained uniformity within 90%. This mixing pressure is only slightly higher than that of Test #F, 13 psi. It appears that in this regime of solids concentration the required power is not sensitive to the solids concentration of the slurry.

The solids concentration was further increased in Tests #H and #I (Figures 9 and 10). The solids concentration was 21.4% and the specific gravity of the slurry was 1.065. The test results show that 15 psi mixing pressure was more than adequate to maintain uniformity within 90% (Test #H) and 13 psi pressure was marginal (Test #I).

The slurry specific gravity in Test #J (Figure 11) was 1.069, and the solid concentration was 22.6%, which represents a slight increase from that of Test #I. When the slurry was mixed with 15 psi, the specific gravity stayed nearly constant, which indicated that the mixing power was sufficient to maintain a uniform mixing. However, after two hours of settling, 15 psi mixing pressure could not regain the uniformity. Instead, the specific gravity continue to reduce at an even faster rate. This unexpected result is extremely interesting from a theoretical point of view. However, it is important to note that this fast solids settling phenomenon occurred only with H/H jet mixing at high solid concentrations (above 22.6% solids). Since the H/A jet mixer, not the H/H jet mixer, is recommended for the MWTf design after the Title II testing, this phenomenon has no practical implication.

Test #K (Figure 12) was run with a higher mixing pressures. The data in Figure 12 show that after 1.5 hours settling, mixing with 17 psi could not recover the slurry uniformity. Uniformity was finally recovered by mixing with 23 psi. The flowrate was measured to be 11.5 gpm and the hydraulic mixing power is calculated to be 0.154 hp.

The tests with a horizontal nozzle mixer revealed that the power requirement for maintaining uniform mixing depends only weakly on the solids concentration when the specific gravity of the slurry was less than 1.065. However, the power requirement for establishing a uniform mixture from a partially settled slurry increases drastically for mixtures of higher solids concentrations.

4.3.3 Test Results with Horizontal/Angled Nozzle (H/A) Mixer

Following the finding from testing with horizontal nozzle mixer, we determined to switch to a horizontal/angled nozzle (H/A) mixer for higher solids concentration tests because we expected better performance with the H/A mixer. A plausible reason was that the angled nozzle would provide a stronger upward momentum that would help to overcome the density gradient between the supernate layer and the partially settled slurry layer.

Test #L was performed with a H/A mixer in a slurry having a specific gravity of 1.083. The data are presented in Figure 13. The result clearly shows that 15 psi was sufficient to maintain a uniform mixture. After two

hours settlement the measured uniformity dropped from 100% to 40%. It is interesting to notice that the H/A mixer had re-established a uniform mixture in two hours, when operated at the same 15 psi pressure. The flowrate was measured to be 9.7 gpm and the mixing power is calculated to be 0.085 hp.

The specific gravity of the slurry in Tests #M, #N, and #O was increased to 1.088. The tests show (Figures 14, 15, and 16) that the marginal operating pressure was close to 15 psi. Therefore the required hydraulic mixing power is practically the same as that in Test #L. The required mixing power for a slurry with 1.076 specific gravity was determined to be 0.089 hp from Title I tests. It appears that all power requirements for maintaining uniformity different solids concentrations were very close and within the test error band for power determination. This indicated that the power requirement of the tested H/A mixer configuration is rather independent of the solids concentration even at high solids concentrations.

We observed that the H/H mixer requires more power for a less concentrated slurry (specific gravity of 1.065) than does the H/A mixer. This lead to the conclusion that mixing with the H/A mixer is significantly more efficient than the H/H mixer. Another difference in performance is that the power requirement of the tested H/H mixer was highly dependent on solids concentration when the specific gravity of the slurry was greater than 1.065.

4.4 TESTING WITH IN-TANK COMPONENTS

4.4.1 Test Description

The in-tank component of the current MWTF design was simulated by a linearly scaled model installed in the 1/10 scale tank at the proper location. The major in-tank component that may affect mixing operation would be the transfer pump, that is located at the center of the tank. However, at the present time, the dimensions of the pump have not been determined. In the present test a 4.5 in. vertical cylinder that extended to the tank bottom was used to simulate the pump structure, which is equivalent to a 45 in. diameter pump in the actual waste tank. The jet mixer was located 15.6 in. off center, which simulates a 13 ft. off-center position in the actual tank. The tests were conducted with H/A mixer.

4.4.2 Test Results

The result of the in-tank component test is given in Figure 17. The specific gravity drops slightly (from 1.088 to 1.082) when mixing with 15 psi pressure. It was noticed that some solids were settled in the back side of the simulated transfer pump during the mixing. Although the quantity of the settled solids is small, it could be a concern if there is a significant increase in the number and size of the in-tank components considered in this tank. It is also reasonable to believe that the quantity of settled solids is a function of the dimension and installation of the components. Solid settlement can be eliminated by installation off the tank floor to allow the jet stream to penetrate underneath the in-tank components.

4.5 TEST SENSITIVITY

Test #H and Test #I were run with the same mixer configuration (H/H nozzles) and the same solids content (1.065 specific gravity). Test #H shows (Fig. 9) that a total jet flow of 9.8 gpm could maintain the uniformity at 97% and it recovered to 95% uniformity after two hours settling. In Test #I (Fig. 10) the total flow was 9.3 gpm. This reduced flow could maintain the uniformity at 95% and it recovered to 90% of uniformity after one hour settling.

Test #Q (Fig. 18) was conducted for the sensitivity study with the H/A jet configuration. The test results show that when the total jet flow was reduced from 8.3 to 7.9 gpm, the uniformity dropped from 98% to 88%. This indicated that a 5% reduction in flow caused about a 10% drop in uniformity.

5.0 REFERENCES

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Figure 1. Test #A.

Figure 2. Mixing Scaling Correlation.

Figure 3. Test #B.

Figure 4. Test #C.

Figure 5. Test #D.

Figure 6. Test #E.

Figure 7. Test #F.

Figure 8. Test #G.

Figure 9. Test #H.

Figure 10. Test #I.

Figure 11. Test #J.

Figure 12. Test #K.

Figure 13. Test #L.

Figure 14. Test #M.

Figure 15. Test #N.

Figure 16. Test #0.

Figure 17. Test #P.

Figure 18. Test #Q.

Figure 19. Test Loop Configuration.