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Extended Cold Testing of a Russian Pulsating Mixer Pump at the Oak Ridge National Laboratory, Oak Ridge, Tennessee

December 2002

Prepared by
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EXTENDED COLD TESTING OF A RUSSIAN PULSATING MIXER PUMP AT THE OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TENNESSEE

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ACRONYMS

AD	air distributor
ARES	American Russian Environmental Services
CS	control system
DOE	U.S. Department of Energy
DSR	decontamination spray ring
ECR	effective cleaning radius
GAAT	Gunite and Associated Tank
MCC	Mining and Chemical Combine
ORNL	Oak Ridge National Laboratory
PMP	pulsating mixer pump
PNNL	Pacific Northwest National Laboratory
PV	pressure/vacuum vessel
TC	transport cradle
TRI	tank riser interface
TTCTF	Tanks Technology Cold Test Facility
WSS	Work Smart Standards (ORNL)

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ABSTRACT

The effectiveness of a mixer is dependent on the size of the tank to be mixed, the characteristics of the waste, and the operating conditions. Waste tanks throughout the U.S. Department of Energy Complex require mixing and mobilization systems capable of (1) breaking up and suspending materials that are difficult to mix and pump, without introducing additional liquids into the tank; (2) complementing and augmenting the performance of other remotely operated and/or robotic waste retrieval systems; and (3) operating in tanks with various quantities of waste. The Oak Ridge Russian pulsating mixer pump (PMP) system was designed with the flexibility to permit deployment in a variety of cylindrical tanks. The PMP was installed at the Tanks Technology Cold Test Facility at the Oak Ridge National Laboratory (ORNL) to assess the performance of the system over an extended range of operating conditions, including supply pressures up to 175 psig. Previously conducted cold tests proved the applicability of the PMP for deployment in ORNL gunite tank TH-4. The previous testing and hot demonstrations had been limited to operating at air supply pressures of <100 psig.

The extended cold testing of the Russian PMP system showed that the system was capable of mobilizing waste simulants in tanks in excess of 20-ft diam. The waste simulant used in these tests was medium-grain quartz sand. The system was successfully installed, checked out, and operated for 406 pulse discharge cycles. Only minor problems (i.e., a sticking air distributor valve and a few system lockups) were noted. Some improvements to the design of the air distributor valve may be needed to improve reliability. The air supply requirements of the PMP during the discharge cycle necessitated the operation of the system in single pulse discharge cycles to allow time for the air supply reservoir to recharge to the required pressure. During the test program, the system was operated with sand depths of 2, 4, and 4.5 in.; at operating pressures from 100 to 175 psig; and elevations of 1 to 10 in. off the floor of the mock tank. The higher operating pressures resulted in larger values for the effective cleaning radius (ECR). The maximum observed ECR value, 144 in., occurred with the PMP elevated ~4 in. off the floor of the mock tank; a 2-in. layer of sand as the waste simulant, and 175-psig air supply pressure. Tests were conducted both within the confines of the 20-ft diam mock tank (confined) and with a portion of the tank wall removed (unconfined). The mixing mode during the confined tests changed from direct to indirect as the PMP was elevated above 4 in. off the floor of the mock tank. The direct mode of mixing pushes solids toward the wall of the waste tank, while the indirect mode tends to push solids toward the center of the tank. The mixing mode did not change during tests conducted in the unconfined tank. Changing the mode of mixing from direct to indirect should have a beneficial effect on the amount of solids mobilized and retrieved from a waste tank.

1. INTRODUCTION

The effectiveness of a mixer is dependent on the size of the tank to be mixed, the characteristics of the waste, and the operating conditions. Waste tanks throughout the U.S. Department of Energy (DOE) Complex require mixing and mobilization systems capable of (1) breaking up and suspending materials that are difficult to mix and pump, without introducing additional liquids into the tank; (2) complementing and augmenting the performance of other remotely operated and/or robotic waste retrieval systems; and (3) operating in tanks with various quantities of waste. The Oak Ridge Russian pulsating mixer pump (PMP) system was designed with the flexibility to permit deployment in a variety of upright cylindrical tanks, including the 50- and 20-ft-diam gunite tanks at Oak Ridge National Laboratory (ORNL). This technology may also be used in conjunction with other mixing technologies, to provide an efficient mixing system for even larger-diameter tanks. This report discusses the cold testing of a PMP under an extended range of operating conditions.

1.1 PURPOSE

The cold tests described in this document were conducted to assess the performance of the ORNL Gunite and Associated Tank (GAAT) Russian PMP over an extended range of operating conditions. An initial set of cold tests proved the applicability of the PMP for deployment in GAAT TH-4 at ORNL.[1] The testing described in this report was conducted to assess the performance of the Oak Ridge PMP at a variety of operating conditions, including air supply pressures up to 175 psig.

1.2 BACKGROUND

In FY 1996, technical exchanges between the DOE Tanks Focus Area Retrieval and Closure Program, the DOE Environmental Management International Programs, and delegates from Russia identified the Russian PMP as a technology that could be implemented in tank waste retrieval operations in the United States. The PMP is basically a jet mixer powered by a pressure/vacuum supply system. In FY 1997, a prototype PMP provided by the Russian Mining and Chemical Combine (MCC) was evaluated as a potential retrieval tool at Pacific Northwest National Laboratory (PNNL). Based on this evaluation, ORNL and DOE staff determined that a modified PMP would meet project needs for bulk mobilization of sludge from one or more of the gunite tanks at ORNL. In FY 1998, PMP technology was selected for deployment in one of the gunite tanks to mobilize settled solids. The Oak Ridge PMPs are functionally similar to the prototype mixer pump tested by PNNL; however, the Oak Ridge PMPs were designed to accommodate the unique constraints and requirements for operations in the GAATs. The GAAT PMP system consisted primarily of four major subsystems: (1) the PMP assembly, (2) the tank riser interface (TRI), (3) the decontamination spray ring (DSR), and (4) a transport cradle (TC). The MCC in Zheleznogorsk, Russia, fabricated the PMP under a contract with the Russian commercial firm RadioChem Services Company. A total of three PMPs and one control system (CS) were fabricated. A single TRI was fabricated by Battelle, Inc., to couple the PMP with the GAATs. Battelle also fabricated the DSR and TC. Both Battelle and RadioChem Services were under subcontract to American Russian Environmental Services, Inc. (ARES), which served as the integrating contractor responsible for fabrication and delivery of the PMP system to ORNL. The CS components were procured from U.S. vendors by ARES and shipped to Zheleznogorsk, Russia, for assembly and development of the CS algorithms.

Because the PMPs were fabricated in Russia, identification of and compliance with appropriate U.S. fabrication standards were significant issues during the initial cold testing and subsequent hot deployment. The ORNL Work Smart Standards (WSS) for engineering design applicable to industrial, radiological, and nonreactor nuclear facilities were the governing documents that identified the required codes and standards for the GAAT project. Because detail design and fabrication of the PMPs occurred in a Russian facility that did not operate under U.S. standards, compliance with the letter of the existing WSS was not feasible. As an alternative, the equipment was fabricated to the appropriate existing Russian standards, and steps were taken to ensure that the technical intent of the U.S. standards was met. The PMP is an adaptation of an existing design being used in Russia for radiochemical waste applications that were similar to those of the GAAT remediation project. The PMP was designed and fabricated by the Russian Federation Ministry for Atomic Energy MCC in Zheleznogorsk, which has extensive experience providing equipment for radiochemical service, using the appropriate Russian codes and standards. Pressure tests and inspections of the equipment were conducted in Russia and in the United States to ensure the integrity of the system prior to cold testing and deployment. Functional and performance tests of the equipment were conducted in the United States during FY 2000 to verify the operation of the system. After completion of cold testing of PMP unit 1, this system was deployed in GAAT TH-4 in January 2001. Operation of the PMP in tank TH-4 was completed during ~3 days of operation in which the PMP was effectively utilized in the mobilization and retrieval of >83 vol % of the sludge from the tank. Summary information on the hot deployment can be found in PNNL-SA-34056.[2] During FY 2001, PMP unit 1 was decommissioned and disposed of inside tank TH-4 as part of the tank closure operations. The TRI was returned to the Tanks Technology Cold Test Facility (TTCTF) for use in the extended cold testing of the remaining PMP units.

2. EQUIPMENT DESCRIPTION AND OPERATIONAL OVERVIEW

A schematic of the Oak Ridge PMP is shown in Fig. 1. The system consists primarily of an in-tank pressure/vacuum vessel (PV) coupled with pressurized air and vacuum sources. In addition to the PMP assembly, a TRI and a DSR were used to couple the PMP with GAAT TH-4. A DSR was used to provide a water rinse of the contaminated equipment as it was removed from tank TH-4. The TRI supported the PMP and permitted height adjustments and alignment with the tank riser. During hot deployment, the DSR was mounted to the central tank riser at TH-4 and was connected to the TRI by a flexible bellows to allow adjustment of the elevation of the PMP. The DSR and bellows were not used in this series of cold tests.

During operation of the PMP, materials from the waste tank are pulled inside the PV through an inlet check valve when a vacuum is applied to the vessel. The inlet port is separated from the discharge line and is at a higher elevation relative to the bottom of the tank. The discharge outlet is typically positioned in the sludge layer, closer to the bottom of the tank, while the inlet remains in the supernatant. This orientation allows supernatant to be drawn into the PV and discharged into the sludge layer, which improves mixing performance. After the PV is full, the vacuum is turned off and air pressure is applied to close the inlet check valve and force the contents of the vessel out through four nozzles on the bottom of the discharge line. These operations are repeated using the fluidized waste material in the tank to break up and mix the solids in the bottom of the tank. Conventional pumping systems are then used to transfer the waste out of the tank. During mixing operations, the PMP can be automatically rotated through a 90-degree arc in alternating clockwise and counterclockwise directions to sweep the entire bottom of the tank.

Compressed air is used to create a vacuum using the in-tank eductor. Control valves are operated in conjunction with an electromechanical axial valve in the air distributor (AD) of the PMP to direct either the compressed airflow or vacuum to the pressure vessel. When vacuum is applied, tank waste is drawn into the PV through a coarse-screen and check-valve assembly on the bottom of the inlet to the vessel. In the event of a plug in the inlet screen, wash water can be admitted to clean the screen. A level sensor inside the PV is used to control the durations of the pressure and vacuum cycles. A spherical float containing a central magnet surrounds a sealed pipe inside the PV. A sensor located inside the sealed pipe is used to detect the high- and low-level positions of the float as the vessel is filled and discharged. The high-level signal is used to signal the CS to pressurize the PV, and the low-level signal is used to admit vacuum. The pressure/vacuum cycles can also be controlled either locally by using mechanical timers or remotely by using timers built into the computer-based CS.

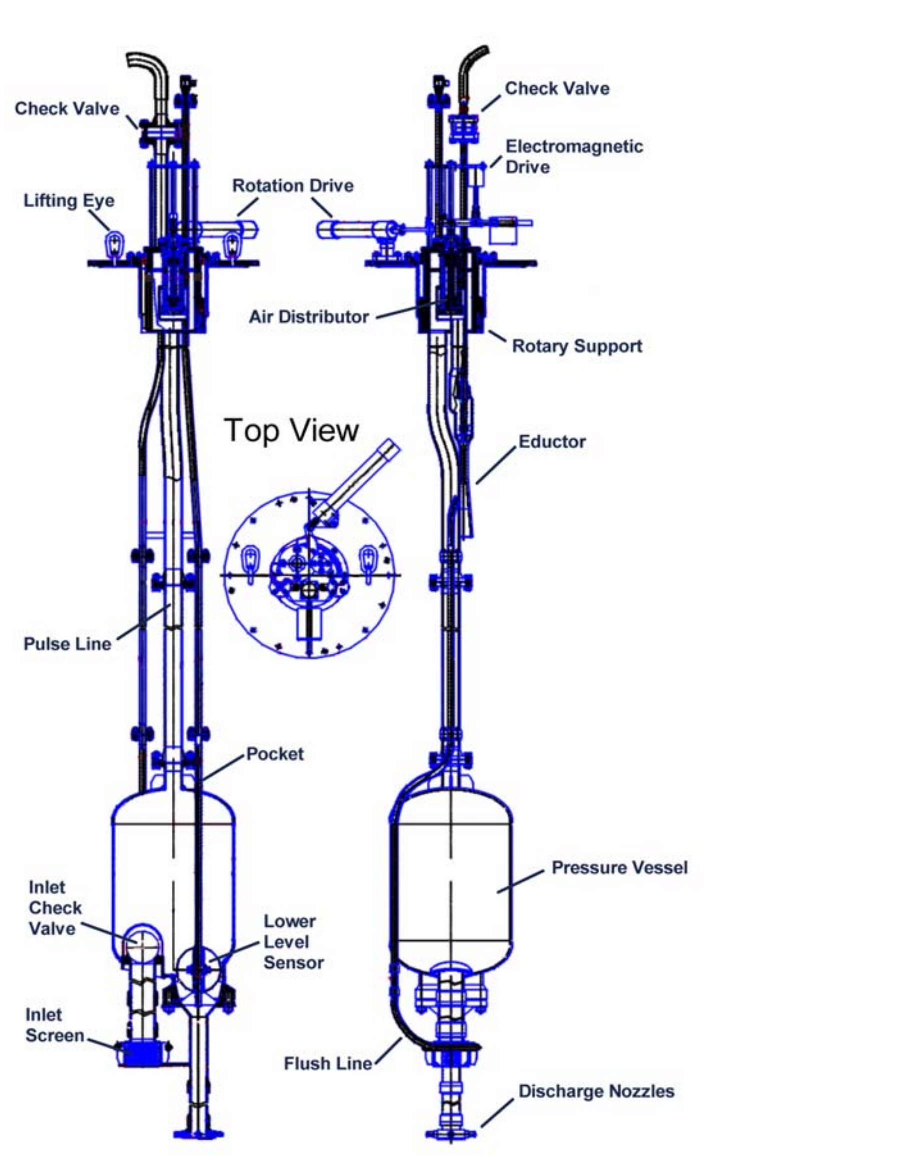


Fig. 1. Schematic of PMP assembly.

PMP units 2 and 3 are slightly different from unit 1. Unit 1 was delivered to ORNL from Russia in the summer of 1999, and units 2 and 3, in the spring of 2000. The design of PMP units 2 and 3 was modified to include a small hole in the bottom of the AD section to limit the vacuum applied and permit drainage of condensate. Units 2 and 3 also had an improved check-valve restraining system. PMP unit 2 was used in the extended cold tests described in this report.

3. OVERVIEW OF EXTENDED COLD TESTS

The extended cold tests conducted on the Russian PMP system were divided into two groups with common purposes and goals. The first group consisted of various functional tests designed to evaluate the operability and installation of the equipment. These tests included the following:

- TRI functionality — Verification of the TRI installation and the ability of the TRI to raise, lower, and hold the PMP at a selected elevation.
- Valves, actuator, sensors, and CS functionality — Verification of the installation of all valves, sensors, and actuators and the ability of the CS to communicate with and operate the system components.
- High-pressure air supply functionality — Verification of the ability of the air supply system to provide sufficient pressure and capacity for high-pressure operation (up to 175 psig).
- PMP functionality with water only — Observation of the operation of the mixer under manual and automatic control at various conditions.

The second group of tests was conducted to assess the mixing and operational performance of the PMP system. These tests included the following:

- Sand pile erosion — Observation of the ability of the PMP to erode a large pile of sand.
- Determination of PMP cleaning radius — Determination of the tank-cleaning radius using surrogate wastes at various extended operating conditions, waste simulant depths, and PMP elevations, as well as with one or more of the jet discharge nozzles plugged.

The general intent of these tests was to evaluate the performance of the PMP over an extended range of operating conditions. One of the two remaining PMPs was selected for this testing with surrogate sludge materials and at higher operating pressures than used in the previous cold test program.

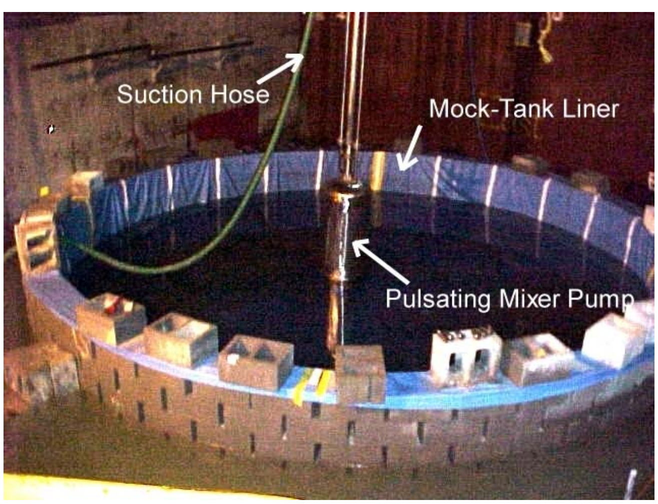


Fig. 2. Mock tank with pool liner at the TTCTF.

The TTCTF test pit and 20-ft-diam mock waste tank used in previous cold testing were used in these tests. A modification was made to the mock tank to add a 21-ft-diam heavy-duty pool liner to prevent leakage of waste simulants through the walls of the tank (see Fig. 2). The walls of the mock tank were constructed of stacked 12-in. cinder blocks that do not prevent the gradual loss of waste surrogate. This type of tank construction is relatively inexpensive and allows quick changes to the configuration. Thin plastic sheeting was used in the previous tests to minimize the leakage of waste surrogate. The suction hose shown in Fig. 2 leads to a diaphragm pump that was used to remove the water from the tank.

4. TEST RESULTS AND OBSERVATIONS

4.1 FUNCTIONALITY TESTS

Near the end of FY 2001, the TRI was removed from the TH-4 site and installed at the TTCTF. A photograph of the TRI at the TTCTF is shown in Fig. 3. After relocation of the TRI to the TTCTF, an extended delay in the startup of operation was experienced because of an unexpected facility upgrade that disconnected the electrical service from the TTCTF for several months. Once the electrical service was restored, the reconnection of the system was completed and functionality tests were performed to verify the operation of component operators, sensors, the TRI, the high-pressure air supply system, process valves, and the associated CS. Any problems with the equipment were noted and repaired as necessary to continue the testing or to enhance the performance of the PMP.

Fig. 3. TRI installed at the TTCTF.

4.1.1 TRI Functionality Tests

The ability of the TRI to raise and lower the PMP assembly was verified during this test. The overall length of the PMP installed in the TRI was determined to be ~313.12 in. from the base of the discharge nozzles to the top side of the PMP support platform inside the TRI. The distance between the floor of the mock tank and the centerline of the lowest discharge nozzle was ~1.06 in. This amount of separation allowed sufficient clearance between the base of the PMP and the plastic liner on the floor of the tank to permit trouble-free pump operation. Because of imperfections in the tank floor, the distance to the centerline of each nozzle varied. Measured distances were 1.06, 1.31, 1.19, and 1.19 in.

The drive motor for the PMP support platform performed as required to support and hold the PMP in place. The drive motor was able to raise and lower the support table without difficulty throughout its full length of travel.

4.1.2 Functionality Tests of Valves, Actuators, Sensors, and CS

The operation of the valves, actuators, sensors, and process control software was verified during this test. The functionality of the various components comprising the CS was checked to ensure that the components were properly installed and operational. During installation of PMP unit 2, minor modifications were made to the pipe connectors for the air supply lines to allow the use of more traditional four-bolt flanges in place of the original nonstandard connections, which included integral check-valve and screw-type connectors. The nonstandard connectors were cut from the PMP, and four-bolt flanges were then welded to the pipe stubs. The flange piping connections are shown in Fig. 4.

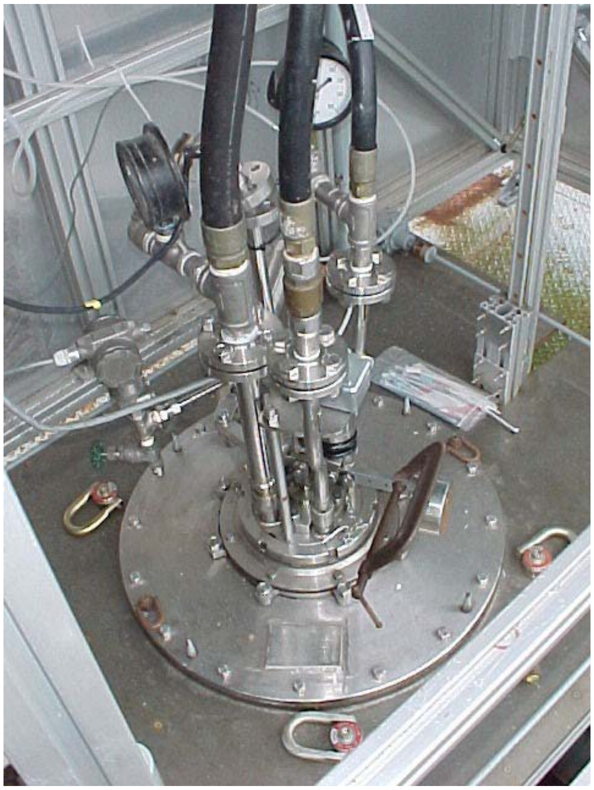


Fig. 4. Top of PMP, showing the new four-bolt flanges.

The PMP CS comprised four Jamesbury™ electrically actuated valves, one Bimba™ position feedback pneumatic cylinder (model PFC-50 12-P), a Trombetta™ solenoid valve (model P/Q 515), a Rosemont™ pressure sensor (model 3051TA), a level sensor, a Micron™ laptop computer, FieldPoint™ computer interface hardware, and LabView™ control software.

The PMP system uses a pneumatic actuator that is capable of rotating the PMP assembly through a 90-degree arc. The actuator, supplied by Bimba, Inc., uses two small solenoid valves to supply and exhaust air to and from the unit. The CS software is configured to use the actuator's feedback positioning sensor to specify the range of motion of the Bimba. As a signal is received from the CS to move the actuator to a predetermined position, air is supplied to the actuator and the feedback sensor provides the necessary position information to the CS. After the actuator reaches the desired position, the CS turns off the solenoid valves, effectively trapping the supplied air in the actuator. The air is released upon command of the CS to open the solenoid valves and return the PMP to its starting position. The small solenoid valves are three-way ported valves, which supply air to the actuator and release it to the atmosphere. The arrangement allows air to be used to drive the actuator forward or backward. While one solenoid is applying pressure, the other is exhausting. After minor modifications were made to extend the air supply and control lines, the Bimba actuator successfully operated through the required 90-degree arc.

The PMP is equipped with two primary sensors. One sensor is used to measure the absolute pressure in the PV, and the other, to measure the fluid level inside the PV. The absolute pressure sensor is mounted on top of the PMP's AD. This sensor provides a signal to the CS for monitoring purposes only. The signal from the pressure sensor is processed by the CS and is displayed as a pressure readout. The pressure signal data are also used to produce on-screen graphs of the fill and discharge pressure cycles for the PMP. The functionality of the sensor was tested, and the appropriate signal was received at the CS monitor. The readout from the pressure sensor was checked in both a horizontal and vertical orientation.

The PV is equipped with a level sensor to provide high- and low-level indications for the contents of the PV. Magnetic sensors, separated by spacers and weights that are attached to a steel support cable, comprise the level sensor. This cable is attached to an end cap located on top of the PMP. The end cap and cable support the sensor elements and reduce the load on the electrical cable running from the sensor elements to an interface connector in the end cap. The length of the sensor is predetermined based upon the particular application. A sealed conduit running from the top of the PMP to the bottom of the PV houses the level sensor and provides protection from contamination and contact with the contents of the PV. A stainless steel float with a central magnetic core surrounds the level-sensor conduit inside the PV. The float is free to rise and lower as the level of material inside the PV changes. When the float passes over the area of the conduit containing a sensor element, an electrical signal is transmitted to the CS to indicate either a high- or low-level condition. The level sensor and magnetic float performed reliably.

A Trombetta solenoid valve is used to operate the linear-actuated AD valve on the top of the PMP. The valve stem is lowered into the AD during the vacuum fill cycle and raised during the pressurized discharge cycle. The initial operations of the PMP showed that the AD valve stem was sticking and not properly engaging and disengaging. A two-bolt flange is used to hold a seal around the AD valve stem. Loosening this flange and maximizing the counterweight on the lever arm of the Trombetta reduced the occurrence of this problem. A similar problem was noted during hot deployment of the PMP at tank TH-4. Similar adjustments were made; however, because of a slightly different design for the AD on PMP unit 1 and adverse weather conditions, the problem during hot deployment was more severe. A design change was implemented for PMP units 2 and 3 to provide a small weep hole in the bottom of the AD to prevent the accumulation of condensate inside. The near-freezing weather conditions in January 2001 and the absence of a weep hole in the AD for PMP unit 1 were thought to have been the major factors contributing to the problems experienced with the sticking of the AD valve stem during hot deployment.

The CS performed as required, with only minor modifications to allow longer discharge times. Tests conducted with one or more plugged nozzles required longer discharge times. A minor modification to one of the control constants was made to allow discharge times up to 60 s or more. A second modification was made to the tank pressure display to indicate a higher-pressure operating range than in previous tests. The data collection system was successfully verified to ensure that data files were properly stored and retrieved from the CS laptop computer.

4.1.3 Functionality Tests of High-Pressure Air Supply

An Ingersoll-Rand T30 model 2340 two-stage air compressor was used as a source of pressurized air up to 175 psig. The air compressor included a pressure relief valve to prevent overpressurization and an adjustable electropneumatic shutoff switch. The 5-hp electric-motor-driven air compressor, which included a 60-gal supply tank, has an output capacity of ~14.7 ft^3/min (cfm) at 175 psig. An additional 80-gal air reservoir was placed in-line with the air compressor to provide increased capacity during operation of the PMP. The air compressor and additional reservoir did not have sufficient capacity to allow continuous operation of the PMP; however, the capacity was sufficient to allow single pulse operation with an acceptable drop in the initial applied pressure. The system volume included the ~140-gal total reservoir volume plus ~4 gal in the interconnecting 1.5-in.-diam hoses. The time required to recharge this volume from 90 to 175 psig was ~7.5 to 8 min. The air supply system included a connection to the facility's 90-psig supply system, which could be valved in to precharge the PMP to 90 psig. The 90-psig air supply system was then valved out, and the 175-psig air compressor was used to pressurize the PMP supply system to the desired pressure. The 90-psig facility air supply was not typically used during this test program.

4.1.4 Noise Assessment and Tests of Test Pit Liner Durability

Compressed air is fed to an eductor to generate the vacuum used to refill the PMP pressure vessel. An extension to the discharge of the eductor was added to direct the exhausted air into the TTCTF pit. Air flowing through the eductor produces significant noise levels as it exhausts into the pit. Sound measurements were made to determine the level of hearing protection and setback limits needed for workers in the vicinity of the PMP during operation. Conservative measurements of sound levels indicated that hearing protection would be needed within ~4 ft of the work platform (based on 8-h exposure) when the PMP is operating. The peak noise level, which was measured near the discharge area of the eductor in a space that is seldom occupied, was 104–106 dBA for ~2 s during eductor operation.

This test was performed during the first full operation of the PMP in the mock tank. During actual deployment of the PMP in tank TH-4, sound levels were such that hearing protection was not required. The noise from the eductor exhaust was contained within the waste tank.

The 21-ft-diam heavy-duty pool liner that was placed in the mock tank to better contain waste surrogate materials during testing was proven to be sufficiently durable to withstand the mixing action of the PMP. Routine operation of the PMP at the maximum supply pressure of ~175 psig and with the discharge nozzles positioned ~1.06 in. from the liner did not disturb or damage the liner. The liner was placed in the mock tank and draped over the top of the concrete block wall. Cinder blocks were then placed on top of the wall to hold the liner in place. Fig. 2 shows the mock tank with the liner in place.

4.1.5 Observations with Water Only

The PMP was initially operated with only water present in the mock tank. The PMP was installed near the center of the tank, with the bottom of the discharge manifold for the jet nozzles positioned within ~0.63 in. of the tank floor. Because of imperfections in the floor of the test pit, the distance to the centerline of each nozzle varied from 1.06 to 1.31 in. Water was added to the mock tank to a depth of ~24 in.

4.1.5.1 Tests with Four Open Nozzles

The four largest-diameter nozzles (16-mm diam) available with the PMP were installed for the initial tests. The PMP was operated at various discharge supply pressures ranging from 60 to 158 psig using a combination of both automatic and timed pressure/vacuum cycles. A pressure regulator, with a maximum setting of 160 psig, was placed in the PMP air feed line to control the air pressure to the pump. For tests at pressures above 90 psig in which the auxiliary high-pressure air supply was used, the pressure inside the pump chamber rapidly decreased during the discharge operation and, at the end of the discharge cycle, significant amounts of air were expelled from the jet nozzles. Discharge times as low as 1 s were used during these tests. This observation indicated that the capacity of the auxiliary air compressor used to supply the high-pressure air to the system was insufficient.

The 16-mm-diam nozzles were replaced by 10-mm-diam nozzles and tests conducted at supply pressures of 100 and 153 psig. Fig. 5 compares the pressure recovery performance of the PMP at supply pressures of 100 and 153 psig during consecutive operating cycles with four 10-mm-diam jet nozzles. The pressure readings recorded by the data collection system were in absolute units (psia) and are reported as such in Fig. 5. Gage pressure units (psig) are used in the figure legend to refer to specific particular tests. This convention is used throughout this report. Because of the large open area from the four jet nozzles and therefore the minimal resistance to flow, the maximum pressure achieved during each discharge operation was similar and significantly lower than the maximum supply pressure. The discharge rate and cycle times were too short to allow the auxiliary air supply to recover.

4.1.5.2 Tests with Two Open Nozzles

For this test, two adjacent 10-mm-diam nozzles were removed from the PMP and the outlets for those nozzles plugged. The conditions used in the four-nozzle tests were repeated to observe the pressure response of the PMP with two plugged nozzles. Fig. 6 shows a pressure decay pattern similar to that observed in the four-nozzle test but with a higher overall operating pressure range. No adverse effects were noted on the operation of the PMP with two plugged nozzles.

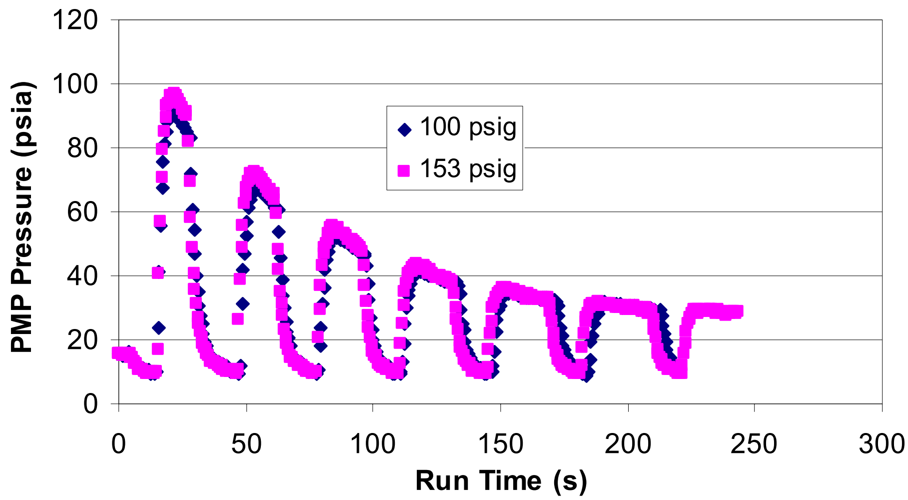


Fig. 5. Comparison of PMP fill and discharge pressure cycles for 100- and 153-psig air supply pressure using four 10-mm-diam nozzles.

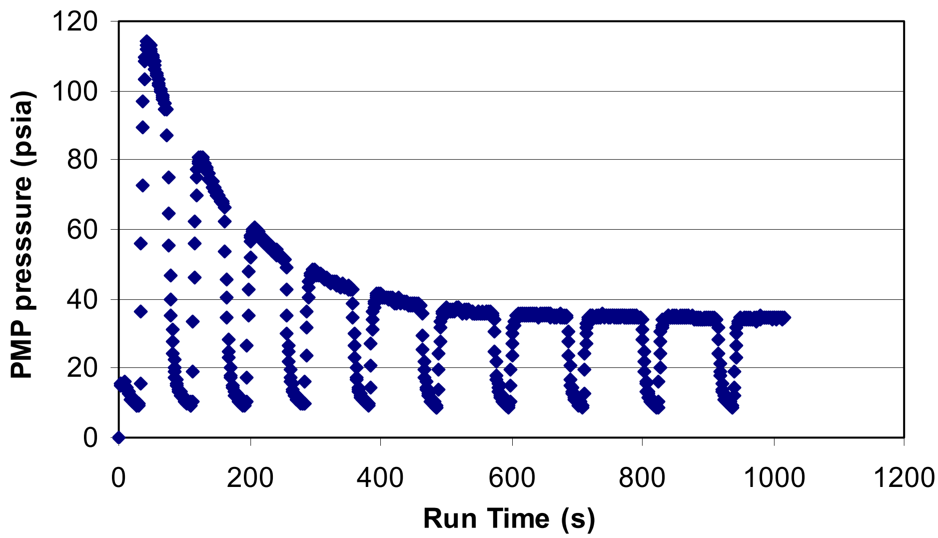


Fig. 6. Fill and discharge pressure cycles with two plugged 10-mm-diam nozzles and a 156-psig air supply pressure.

4.1.5.3 Tests with One Open Nozzle

For this test, all but one of the jet nozzles were removed from the PMP and the outlets for those nozzles plugged. To increase the supply of pressurized air, an 80-gal reservoir was added to the auxiliary air supply system. Fig. 7 shows the pressure decay pattern with three plugged nozzles. The pattern is similar to that for two plugged nozzles but with extended cycle times and much higher overall operating pressure. The pressure decrease during the initial discharge cycle was ~20 psi.

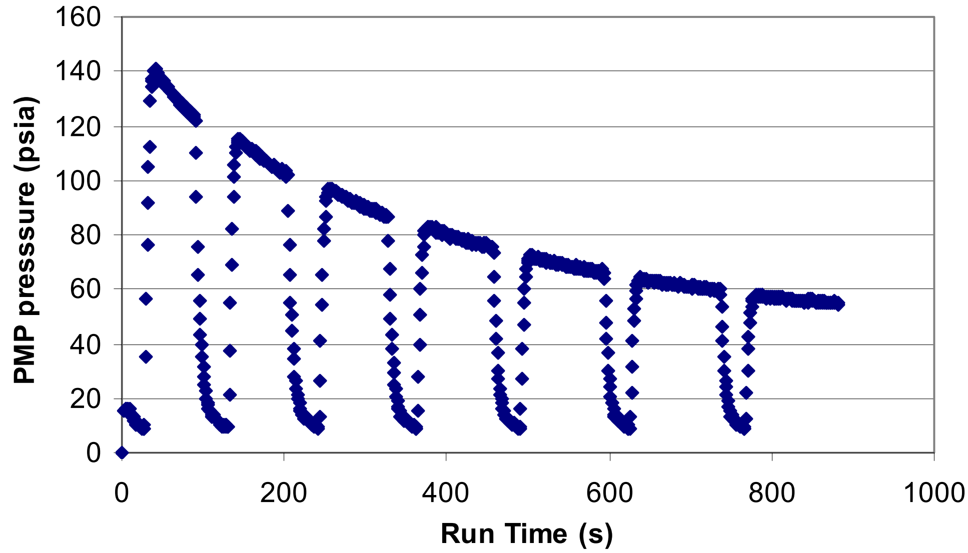


Fig. 7. Fill and discharge pressure cycles with three plugged 10-mm-diam nozzles and a 155-psig air supply pressure.

4.1.5.4 Comparison of Pressure Profiles with One or More Open Nozzles

In Fig. 8 the pressure profiles for the PMP with one or two plugged nozzles are compared with that for no plugged nozzles. Tests were conducted with ~2 ft of water present and the PMP jet nozzles positioned to within ~1 in. of the floor of the tank. The air supply pressure regulator was set to 159, 158, and 160 psig for the two-plugged-nozzle, one-plugged-nozzle, and no-plugged-nozzle tests, respectively. Figure 8 shows the effect of the increased resistance to flow when one or two nozzles are plugged.

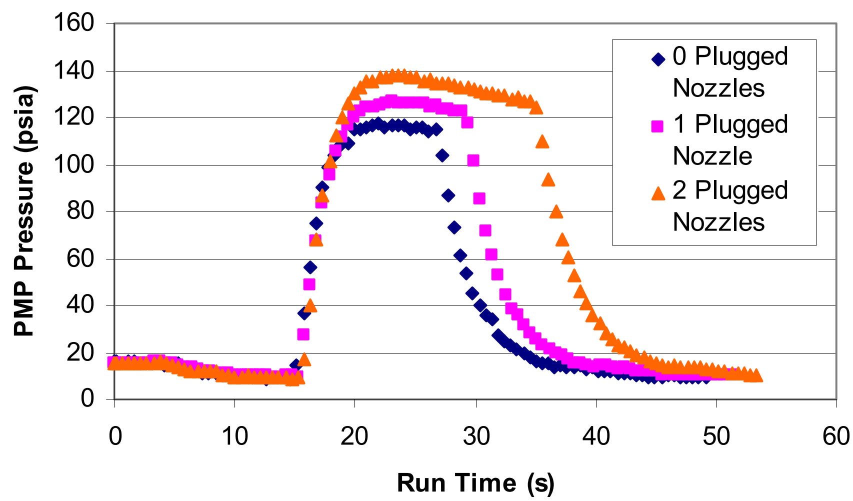


Fig. 8. Comparison of single pressure cycles with zero, one, and two plugged nozzles.

To further increase the maximum available air pressure delivered to the PMP, the pressure regulator was removed from the feed line to the system. In general, this change allowed the PMP to be operated at air supply pressures up to ~160 psia with three plugged nozzles. Fig. 9 represents a typical pressure cycle for the PMP with three plugged nozzles. The auxiliary air compressor was set to provide up to 172-psig air supply for this test.

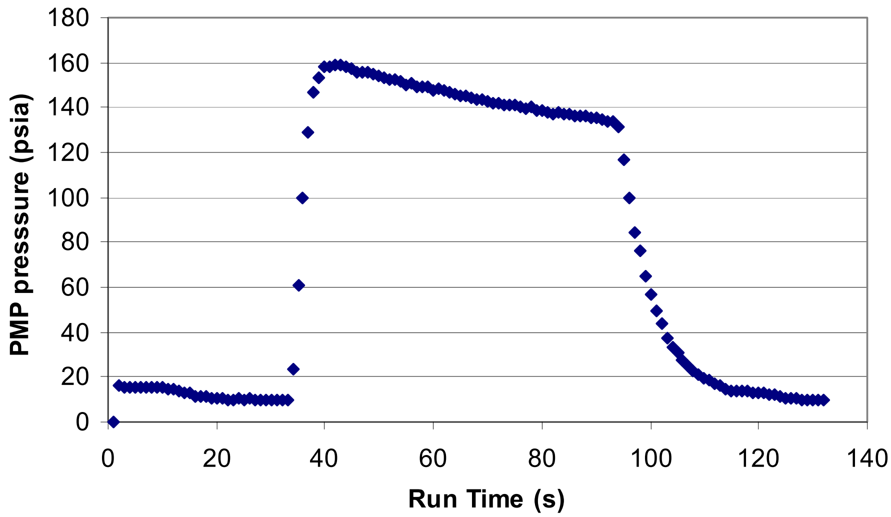


Fig. 9. Typical pressure response curve with three plugged nozzles.

Based on the observations from the various tests conducted with only water, the decision was made to primarily operate the PMP with three plugged nozzles in order to maintain the maximum pressure possible throughout its initial discharge cycle. It was further decided that testing would be conducted by operating the PMP for one discharge cycle and then shutting down the system to allow time for the auxiliary air compressor to recharge the supply tanks.

4.2 PERFORMANCE TESTS

Performance tests were conducted using medium-grain quartz sand (play sand) in water as a waste surrogate. A settling test was conducted by placing 100 mL of sand in a graduated cylinder that was then filled with ~500 mL of water. The sand and water combination was mixed by upending the cylinder 20 times and then allowing the sand to settle. The majority of the sand settled after 6 s; however, the slurry was still cloudy after 19.5 h. The size distribution for the sand waste surrogate, determined by dry-sieve analysis, is shown in Fig. 10.

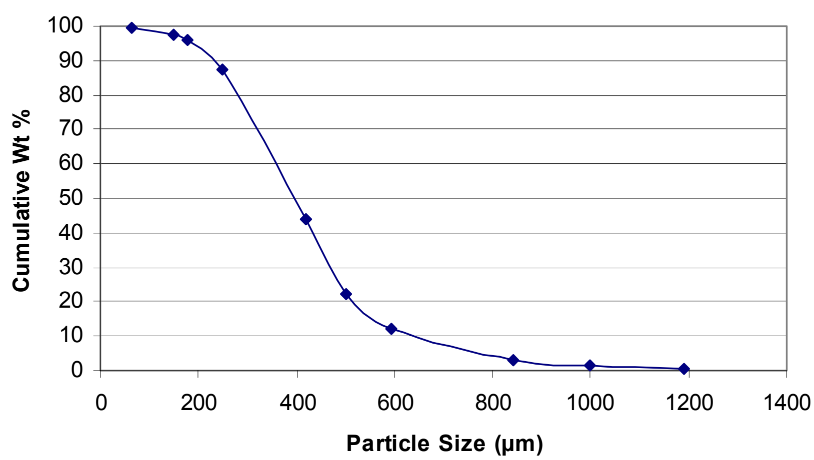


Fig. 10. Particle size distribution for sand waste surrogate.

4.2.1 Sand Pile Erosion Test

During this test, the ability of the PMP to erode the large sand pile (shown in Fig. 11) was observed. A total of 8300 lb of sand was added to the mock tank in one pile on one side of the tank. The edge of the sand pile was ~2 ft from the outside wall of the PMP PV and extended over a 105-degree arc of the tank wall. The apex of the pile, which was ~103 in. from the PV, was ~46 in. tall. Approximately 25.5 in. of waste was added to the tank. Fig. 11 is a view of the PMP and sand pile prior to the start of the initial erosion test.

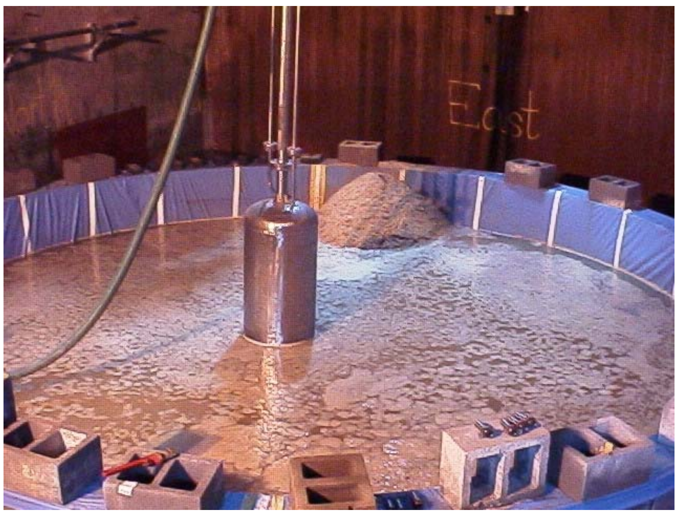


Fig. 11. Sand pile before the erosion tests were conducted .

Multiple series of single pulse cycle operations were conducted using the PMP with three plugged nozzles. The pressure regulator in the feed line to the PMP was removed and the air supply pressure to the PMP was set in the range of 168 to 176 psig. An initial series of ten consecutive pulses was performed with the open nozzles directed slightly to one side of the center of the sand pile and the PMP stationary. Inspection of the sand pile at the end of the first ten pulse cycles showed an indentation of ~3 ft into the pile and the formation of a small valley in the side of the pile.

The position of the PMP was adjusted to better align the open discharge nozzle with the center of the sand pile, and a second series of ten pulse cycles was then conducted. After the first pulse cycle, the position of the PMP was adjusted again to better direct the discharge from the jet nozzle at the center of the sand pile. The PMP was repositioned a total of four times during this series of pulse cycles. The sand pile was visibly eroded during this series of tests, as indicated by the significant amount of sand that slid into the water in the mock tank.

A third series of ten pulse cycles was conducted by using automatic rotation of the PMP during the discharge portion of the pulse cycle. During this series the PMP was rotated through a 90-degree arc at a rate of either 15 degrees/s or 3 degrees/s during each discharge cycle. At the end of this series of tests, the water was drained from the mock tank and the sand pile was then inspected (see Fig. 12). A significant quantity of the sand pile had been eroded as a result of the cumulative effects from the 30 pulse discharge cycles with the PMP. Additional sand could have been eroded from the pile had the system been operated longer.

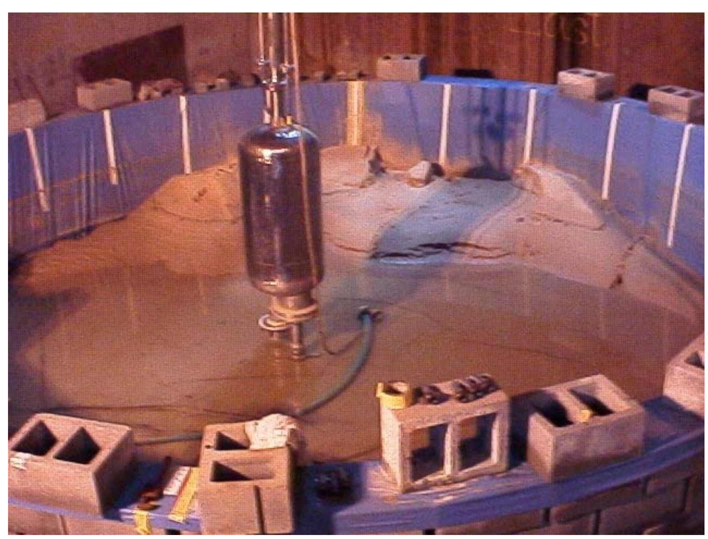


Fig. 12. Sand pile after the erosion tests were conducted.

4.2.2 Tests to Determine the Effective Cleaning Radius

The effective cleaning radius (ECR) is a measurement of the clear space between the tip of the jet nozzles on the PMP and the waste surrogate. ECR measurements were made by first operating the PMP for a set number of pulse cycles, then shutting down the system, next draining the water from the mock tank using a diaphragm pump, and then physically measuring the clear space beyond the discharge from the jet nozzles. All tests to determine the ECR in this work were conducted while the PMP remained stationary. The initial tests were conducted within the confines of the mock tank, which limited the ECR to a maximum of ~120 in. Later tests were conducted with a portion of the wall of the mock tank removed to provide an unconfined area for determination of the maximum ECR. A variety of measurements were made to describe the ECR. These included the following:

- Inside ECR — Distance from the tip of the jet nozzle to the most distant edge of the waste surrogate. Throughout this report, the term "inside ECR" is used interchangeably with the term "maximum ECR."
- Outside ECR — Distance from the tip of the jet nozzle to the top of the waste surrogate ridge at the position where the inside ECR was determined.
- Inside width — Maximum width of the cleared space in front of the jet nozzle.
- Outside width — Distance between waste surrogate ridges at the position where the inside width was determined.
- Depth at tip — Maximum waste surrogate depth at the point where the outside ECR was determined.

4.2.2.1 ECR Measurements in Confined Space

A series of tests was conducted to determine the number of pulse discharge cycles required to develop the maximum ECR for a given set of operating conditions and within the confined space of the mock tank. The following operating conditions were used for this series of tests:

Water depth	~26 in.
Nominal sand depth	~4.5 in.
Nominal elevation	1.06 in. from floor of mock tank
Air compressor supply pressure	171 to 179 psig
Confinement distance	10 ft
Nozzle diameter	10 mm

Fig. 13, a plot of the progression to steady-state operation of the PMP during 25 pulse discharge cycles, shows that the inside ECR continues to increase while the outside ERC appears to be at steady state. Furthermore, as the sand was cleared all the way to the mock-tank wall, the depth-at-tip measurement decreased while piles of sand accumulated on both sides of the cleared area near the tank wall. Fig. 14 shows the sand pattern on the floor of the mock tank after the first pulse cycle and at the end of the series of 25 cycles. The sand piles on either side of the cleared area near the tank wall were 15 to 16 in. deep.

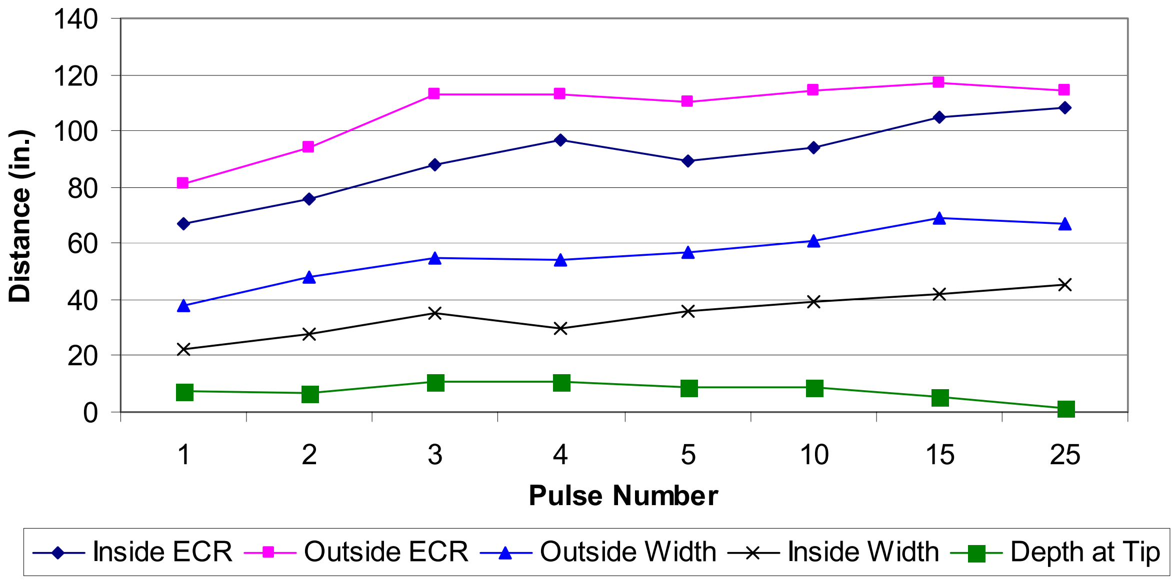
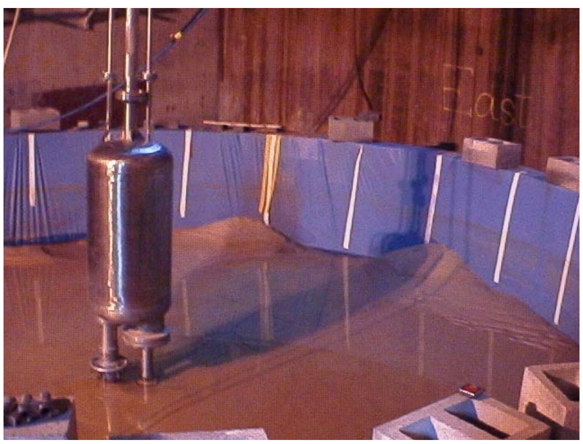


Fig. 13. Progression to steady-state operations with 4.5-in. sand depth.



After 1 Pulse

After 25 Pulses

Fig. 14. View of sand pattern after 1 pulse (left) and 25 pulses (right) with a 4.5-in. sand depth.

4.2.2.2 Effect of Nozzle Elevation on Mixing Performance

A series of tests was conducted to observe the effect on mixing performance of changes in elevation of the PMP jet nozzles relative to the floor of the mock tank. The following operating conditions were used for this series of tests:

Water depth	24 in.
Nominal sand depth	2 in.
Nominal elevation	Various (1, 2, 3, 4, 6, and 10 in.)
Air compressor supply pressure	175 psig
Confinement distance	10 ft
Nozzle diameter	10 mm

Each test consisted of 15 consecutive pulse discharge cycles at each elevation. At the end of each test, the water was removed from the test pit. Measurements and photographs were then made of the resulting cleared area in the sand on the bottom of the mock tank. Although the sand was cleared from the outer wall of the mock tank in each test, the cleared pattern in the sand varied with nozzle height. Fig. 15 shows photographs of the resulting sand patterns for nozzle elevations of 1, 3, 4, 6, and 10 in. Although it is difficult to see in some of the photographs, the width of the cleared area near the mock-tank wall increased from ~2.5 ft at 1-in. elevation to over 10 ft at the 10-in. elevation. The general shape of the sand pattern also changed from elliptical at the 1-in. elevation to tee-shaped at the 10-in. elevation. At the latter elevation, the pattern exhibited a beach area immediately beyond the discharge from the jet nozzle and extending ~2.5 ft toward the mock-tank wall. This type of pattern suggests a change in the mode of mixing from direct displacement by the jet discharge to indirect displacement by reflection of the jet off the mock-tank wall. The indirect displacement mixing mode tends to push the sand away from the tank wall to clear a path back toward the PMP at the center of the mock tank, while the direct mixing mode pushes the sand toward the mock-tank wall and deposits piles near the wall. Sand piles up to 12.5 in. deep formed at the mock-tank wall for nozzle elevations up to 4 in., as shown in Fig. 16. The sand piles at the 6- and 10-in. nozzle elevations were flatter, with maximum depths of only 9 and 7 in., respectively. This observation also supports a change in mixing mode. This result is pertinent to waste retrieval operations in that changing the elevation of the PMP could be beneficially used to push waste either toward the tank wall or away from the wall, with an end result of mobilizing more of the waste for transfer out of the tank.

4.2.2.3 Effect of Nozzle Elevation on the ECR in Unconfined Space

Two series of tests were conducted (at sand depths of 2 and 4 in.) to measure the change in ECR with changes in elevation of the PMP jet nozzles in the absence of the confines of the mock-tank wall. For these tests a portion of the mock-tank wall was removed and the plastic liner cut and laid on the floor of the test pit. Without the mock-tank wall, the distance from the discharge of the jet nozzle on the PMP to the nearest permanent wall varied from 189 to 259 in. The following operating conditions were used for these tests:

Water depth	24 in.
Nominal sand depth	2 and 4 in.
Nominal elevation	Various (1, 2, 3, 4, and 6 in.)
Air compressor supply pressure	175 psig
Confinement distance	Unconfined
Nozzle diameter	10 mm

Each test consisted of 15 or 30 consecutive pulse discharge cycles at each elevation. At the end of each test, the water was removed from the test pit. Measurements and photographs were then made of the resulting cleared area in the sand on the bottom of the mock tank. Fig. 17 is a photograph of the resulting sand pattern for the 4-in. elevation test with a 2-in. sand depth after 15 pulse discharge cycles. The shapes of the sand patterns produced by each test were similar and this general consistency is indicative of the direct mixing mode. Because the jet discharge was not confined by a tank wall in these tests, no obstructions were present to cause reflection of the jet. Consequently, no change in the mode of mixing was noted. The variation of the ECR with nozzle elevation for the 2- and 4-in. sand depths and for the extended number of pulse discharge cycles is illustrated in Fig. 18. In these tests, the ECR increased to a maximum of ~144 in. at the 4-in. elevation and began to decrease when the elevation was changed to 6 in. for the tests conducted at 2-in. sand depth.

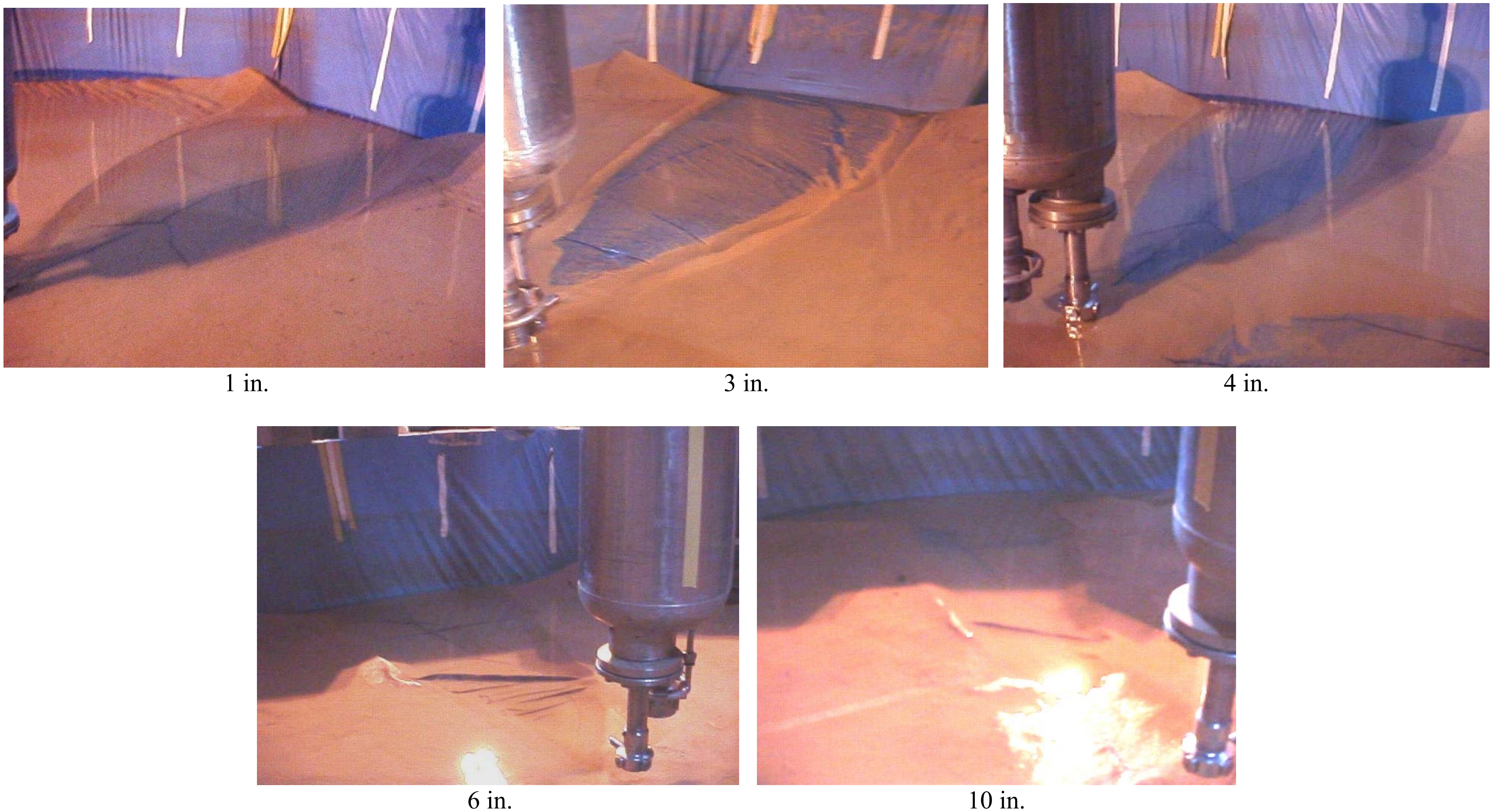


Fig. 15. Variation of sand patterns with changes in PMP elevation.

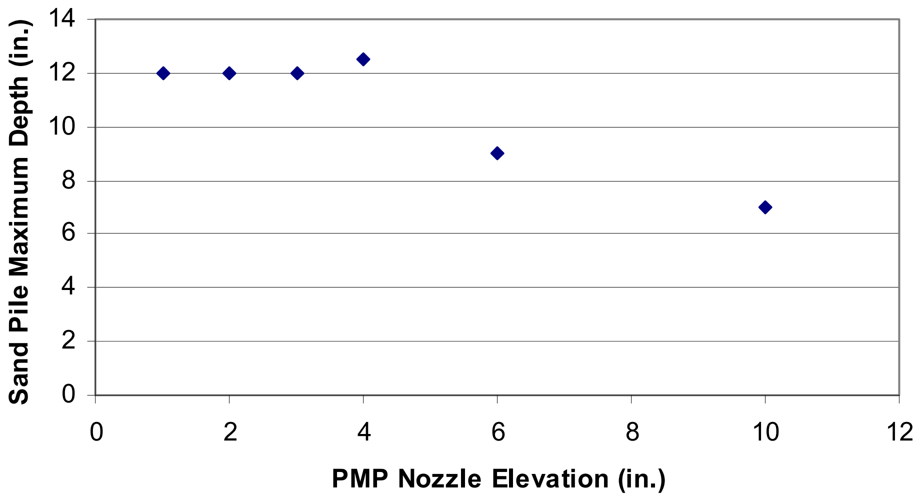


Fig. 16. Variation of sand-pile depth with PMP nozzle elevation.

Fig. 17. Sand pattern during the unconfined ECR test series produced by 4-in. nozzle elevation with 2-in. sand depth.

The tests with the extended number of pulse discharge cycles were conducted using a total of 30 pulse discharge cycles for elevations of 1, 3, and 4 in. These tests were accomplished by refilling the test pit with water after performing a test of 15 pulse discharge cycles and then operating the PMP for 15 additional cycles. The test pit was drained and measurements made of the resulting cleared area in the sand on the bottom of the mock tank. As expected, the 4-in.-depth tests exhibited higher ECR values with the increase in the number of pulse discharge cycles, as shown in Fig. 18. Fig. 19 presents photographs of the sand patterns after 15 and 30 pulse discharge cycles for the 4-in. sand depth test.

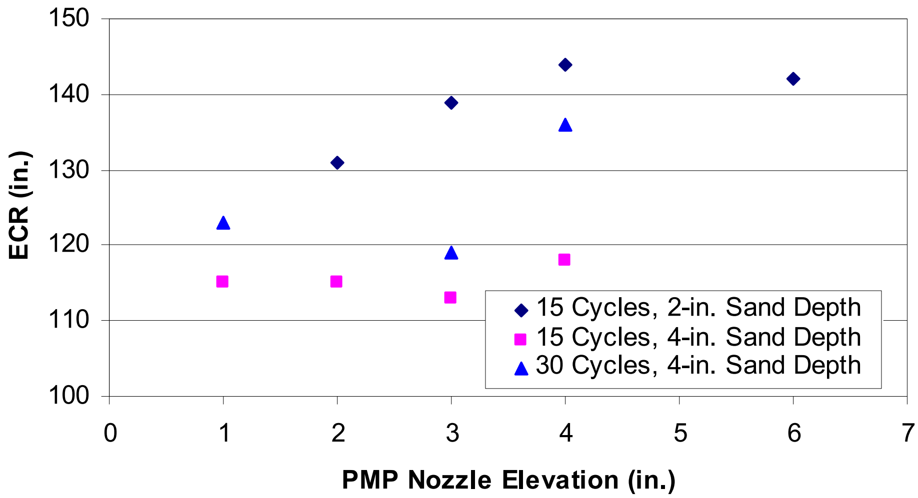


Fig. 18. Variation of ECR with nozzle elevation, sand depth, and number of pulse discharge cycles for the unconfined ECR tests.

15 Cycles 30 Cycles

Fig. 19. Sand pattern during the unconfined ECR test series for the 4-in. nozzle elevation test with 4-in. sand depth.

4.2.2.4 Variation of ECR Measurements with Supply Pressure

Two additional tests were conducted to observe the change in ECR with changes in the air supply pressure for the discharge cycle in the unconfined test pit. The tests were conducted in a manner similar to the previous tests using 15 pulse discharge cycles. The following operating conditions were used for these tests:

Water depth	24 in.
Nominal sand depth	2 in.
Nominal elevation	1 in.
Air compressor supply pressure	150 and 125 psig
Confinement distance	Unconfined
Nozzle diameter	10 mm

The observations from these tests are summarized in Table 1. Air supply pressures above ~150 psig appear to be sufficient to provide the maximum cleaning of the floor of the 20-ft-diam mock tank.

Table 1. Observations from reduced-pressure tests

Air supply pressure (psig)	ECR (in.)	Maximum width (in.)	Maximum sand depth (in.)
125	113	44	8
150	119	44	9

4.2.3 Comparison of Pressure Profiles

Tests were conducted to compare the discharge pressure profiles for the PMP with 2 in. of sand present on the floor of the mock tank and one or more plugged discharge nozzles. These tests are similar to those conducted during the functionality tests but were conducted at a higher operating pressure and in the presence of a sand waste surrogate. The pressure profiles from these tests are shown in Fig. 20. These tests were conducted with ~2 ft of water present and the PMP jet nozzles positioned to within ~1 in. of the floor of the tank. An air supply pressure of 175 psig was used in all these tests. All the tests except the one using three plugged nozzles were conducted in the unconfined mock tank with a portion of the tank wall removed. The test with three plugged nozzles was conducted with the mock-tank walls intact. The pressure drops during typical pulse cycles were 26.6, 20.2, 15.6, and 12.4 psi and the durations of the discharge cycles were 35.0, 17.8, 13.0, and 10.7 s during the tests with 3, 2, 1, and 0 plugged nozzles, respectively. The discharge portion of the cycle is labeled in Fig 20. The ramp up to maximum discharge pressure never achieves the air supply pressure, because the limited capacity of the air supply reservoir must first overcome the vacuum before the PV can begin to pressurize. This process depletes a portion of the available air supply and reduces the maximum achievable pressure for the discharge cycle. The process continues as the slurry in the PV is discharged by the pressurized air supply. When the slurry in the PV reaches a preset low level, the discharge cycle is terminated and the PV is vented to a vacuum source during the refill cycle. The PV is then refilled while the vacuum is applied. Once the slurry reaches a preset high level, the refill cycle is complete and the discharge cycle begins.

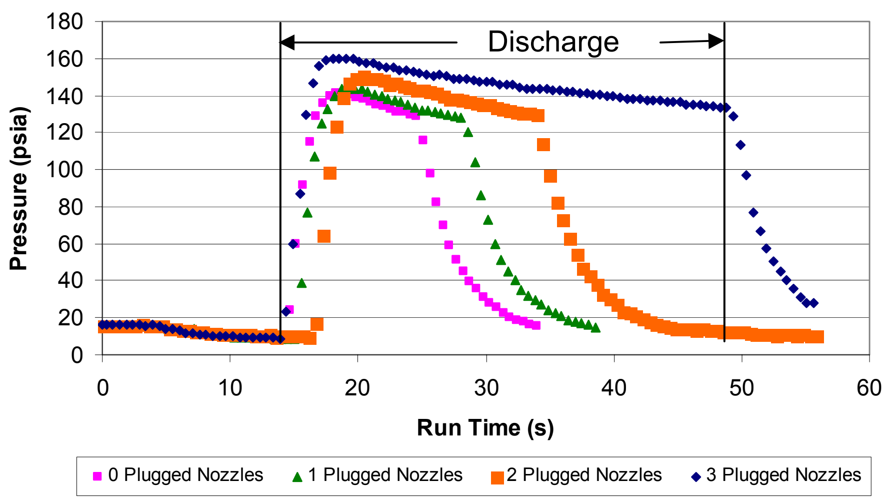


Fig. 20. Comparison of pressure profiles.

5. CONCLUSIONS AND RECOMMENDATIONS

One of the two remaining Russian PMPs originally designed for use in the GAAT remediation was installed at the TTCTF at ORNL to assess the performance of the system while operating at supply pressures up to ~175 psig. Previous testing and hot demonstrations had been limited to operations at air supply pressures of <100 psig. The TRI used in previous cold testing and hot deployment operations at tank TH-4 was used in these tests. The results from the extended cold tests showed that the Russian PMP system is capable of mobilizing wastes in tanks in excess of 20-ft diam, which improves the range of applicability for the PMP.

5.1 CONCLUSIONS

Based on the results of the extended cold tests, the following conclusions were reached:

1. The PMP was successfully installed and operated for 406 pulse discharge cycles, with only minor problems with a sticking AD valve and infrequent system lockups. The sticking AD valve was most prevalent during checkout of the system and near the end of the test program.
2. The air supply requirements of the PMP during the discharge cycle necessitated the operation of the system in single pulse discharge cycles to allow time for the air supply reservoirs to recharge to the required pressure.
3. The maximum observed unconfined ECR was 144 in. with the PMP elevated ~4 in. off the floor of the mock tank, a 2-in. layer of sand as the waste stimulant, and 175-psig air supply pressure.
4. The maximum observed confined ECR was 119 in., which was the distance from the tip of the PMP discharge nozzle to the mock-tank wall.
5. Higher air supply pressures during the pulse discharge cycle resulted in larger ECR values.
6. The depth of sand affected the number of pulse discharge cycles needed to achieve the maximum ECR. For a 2-in. sand depth, 15 cycles were sufficient to achieve the maximum ECR. However, for a 4.5-in. sand depth, over 30 cycles were needed to achieve the maximum ECR.
7. The mixing mode during tests conducted within the confines of the 20-ft-diam mock tank changed from direct to indirect as the PMP was elevated more than 4 in. off the floor of the tank. These tests were conduced with a 2-in. layer of sand on the tank floor. The direct mode of mixing pushes solids toward the wall of the waste tank, while the indirect mode tends to push solids toward the center of the tank.
8. The mixing mode did not change during tests conducted with a portion of the mock-tank wall removed. This type of operation does not confine the jet discharge from the PMP.
9. Additional testing to expand the range of data collected would allow the development of correlations for the variation of the ECR with discharge pressure, elevation, surrogate depth, and number of pulse discharge cycles.

5.2 RECOMMENDATIONS

Based on the conclusions and observations from this work, the following recommendations are made:

1. Review of the design and operation of the PMP AD valve is needed to improve the long-term reliability of the system.
2. Changing the mode of mixing from direct to indirect should have a beneficial effect on the amount of solids mobilized and retrieved from a waste tank. The mode of mixing with the PMP

can be changed by modifying the elevation of the discharge nozzles off the floor of the tank. The depth of waste in the tank may have an effect on the elevation needed to change the mixing mode.

3. The PMP should be operated at the highest pulse discharge pressure available (up to the system's maximum allowable working pressure) to maximize the ECR. The ORNL PMPs were designed for a maximum allowable operating pressure of 230 psig.

REFERENCES

1. B. E Lewis and J. D. Randolph, *Cold Testing of a Russian Pulsating Mixer Pump at the Oak Ridge National Laboratory, Oak Ridge, Tennessee*, ORNL/TM-2001/141, UT-Battelle LLC, Oak Ridge National Laboratory, Oak Ridge, Tenn., January 2002.

2. B. Hatchell, B. Lewis, J. Randolph, and M. Johnson, *Russian Pulsating Mixer Pump Deployment in the Gunite and Associated Tanks at ORNL*, PNNL-SA-34056, Battelle Memorial Institute, Pacific Northwest National Laboratory, Richland, Wash., March 2001.

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