RUSSIAN TECHNOLOGY ADVANCEMENTS FOR WASTE MIXING AND RETRIEVAL

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ABSTRACT

Engineers at the Mining and Chemical Combine nuclear facility, located in Zheleznogorsk, Russia, have developed a pulsating mixer/sluicer to mobilize a layer of consolidated, hardened sludge at the bottom of their 12-m-diameter by 30-m-high nuclear waste tanks. This waste has resisted mobilization by conventional sluicing jets. The new pulsating mixer/sluicer draws tank liquid into a pressure vessel, then expels it at elevated pressure either through a set of submerged mixing jets or a steerable through-air jet. Four versions (or generations) of this technology have been developed.

Following testing of three other Russian mobilization and transfer systems at Pacific Northwest National Laboratory, a first generation of the new pulsating mixer/sluicer was identified for possible waste retrieval applications in U.S. high-level waste tanks (1). A second-generation pulsating mixer/sluicer was developed and successfully deployed in Tank TH-4 at the Oak Ridge Reservation, located in Tennessee, United States (2). A third-generation pulsating mixer/sluicer with a dual nozzle design was developed and is being tested for possible use by the Hanford Site's River Protection Project to retrieve waste from Tank 241-S-102, a single-shell tank containing radioactive saltcake and sludge. In cooperation with the U.S. Department of Energy Tanks Focus Area, the Mining and Chemical Combine is conducting cold (that is, nonradioactive) tests and demonstrations of the third-generation system in 2001 and 2002. This work is being conducted through the Tank Retrieval and Closure Demonstration Center, which is sponsored by the National Nuclear Safety Administration's Office of Arms Control and Nonproliferation (NN-40). A fourth-generation dual-nozzle pulsating mixer/sluicer is undergoing cold testing for use at the Mining and Chemical Combine to retrieve radioactive sludge there in 2004.

INTRODUCTION

Removing consolidated, hardened radioactive sludge from tanks is a problem for waste site managers in Russia and the United States. Advancements in Russian mixing and retrieval technologies, such as a new pulsating mixer/sluicer, may be applicable to retrieving radioactive waste from storage tanks in the United States (1). A new pulsating mixer/sluicer, developed at the Russian Mining and Chemical Combine, draws tank liquid into a pressure vessel, then expels it at elevated pressure either through a set of submerged mixing jets or a steerable through-air jet. Four versions (or generations) of this technology have been developed. A first generation of the mixer/sluicer was identified for possible waste retrieval applications in U.S. high-level waste tanks. A second generation was developed and successfully deployed in Tank TH-4 at the U.S. Department of Energy's Oak Ridge Reservation (2). A third-generation pulsating mixer/sluicer with a dual nozzle design was developed and is being tested for possible use in a U.S. Department of Energy Hanford Site single-shell tank containing radioactive saltcake and sludge. A fourth-generation dual-nozzle pulsating mixer/sluicer is undergoing cold testing for use at the Mining and Chemical Combine to retrieve radioactive sludge there in 2004. This paper discusses the four generations of the technology, briefly discusses several other Russian retrieval technologies, and provides conclusions on the possible benefits of the dual-nozzle pulsating mixer pump.

FIRST-GENERATION RUSSIAN RETRIEVAL SYSTEMS

Radioactive waste resulting from Russian plutonium-uranium extraction processes (PUREX) is stored in a series of tanks at the Mining and Chemical Combine nuclear facility in Zheleznogorsk, Russia. These tanks were constructed of stainless steel and placed in vaults mined out of the rock floor of the complex. Each tank is approximately 30 m in height and 12 m in diameter, with a capacity of approximately 3,200 m^3 (3). The original tank design does not have sufficient provisions for retrieving waste, requiring new access ports for retrieval and transfer equipment. Because the tanks are inside a tunnel, retrieval equipment can be used without regard for the weather; however, with only a 4-m overhead clearance, large-scale equipment cannot be used unless it can be installed in sections.

The first tank to be addressed for retrieval is Tank 8301/3. The objective is to remove enough waste to reach maintenance levels (5 mR/hr) for the tank (4). Once the waste is removed, the tank can be decontaminated and used to store materials generated by other activities.

The PUREX waste in Tank 8301/3 settled into three distinct sludge layers. The top layer was somewhat "thin" with a solid phase concentration of 60 g/L. The second layer, having the consistency of fruit jam, was more dense and viscous with a solid phase concentration of 120 g/L. The final (bottom) layer was strongly dehydrated and structured, with a solid phase concentration of 600 to 800 g/L (3). The liquid fraction of the waste had a pH of 12 (5). The temperature at the solid-liquid interface was 75 to 108°C, depending on the depth of the upper layer of sludge (3). Over the past five years, the top two layers have been removed from Tank 8301/3, leaving the dense sludge layer to be retrieved.

Ten hydro-monitors (sluicers using two opposing sluicing jets mounted on the lower end of a vertical shaft as close to the tank floor as possible) and four hydro-elevators (axial flow jet pumps) were installed as an array at the bottom of Tank 8301/3 to remove sludge (1, 6). Shielded access ports, each 10 cm in diameter, were added to the top of the tank. In addition, shielded transfer lines were arranged on the hall floor (6). To remove the waste, supernate from an adjacent tank was pumped through the immersed jets on the hydro-monitor agitating the waste in a circle approximately 4 m in diameter (in the fashion of a submerged mixer pump). Periodically, the waste was pumped out using the hydro-elevators. After the upper layer of sludge was removed, one of the hydro-monitors was removed and replaced with a hydro-monitor with four horizontal jets at the lower end. The jets were effective near the hydro-monitor but left hard sludge several feet deep in the tank.

To soften the hard sludge, 0.5 M nitric acid was added to the tank through a hydro-monitor at 5 to 6 atm pressure. The nitric acid reacted with the sludge, breaking down its structure so that the jets could form a slurry that could be pumped out of the tank. The solids were transferred to another location; the liquid was returned to the tank with additional acid. This process was repeated over the course of a year or more.

Approximately 70 m^3 of aged and hardened sludge remained in the tank after the mixing and retrieval campaigns. The specialists at the Mining and Chemical Combine plan to use an organic acid, produced as a waste from caprolactam production (the raw material for the production of nylon fiber), to soften and mobilize the remaining hardened sludge. However, before that campaign begins, a series of experiments was conducted in cooperation with the Tank Retrieval and Closure Demonstration Center Project for their Savannah River Site client. First, oxalic acid was introduced into the tank. Second, a mixture of oxalic and citric acid was introduced. These tests succeeded in mobilizing and removing an additional 20 m^3 of sludge. The results of these experiments in support of chemical cleaning of residual waste at the Savannah River Site will be reported in a future paper.

RUSSIAN EQUIPMENT PROVIDED FOR TESTING AT PACIFIC NORTHWEST NATIONAL LABORATORY

Many of the waste retrieval technologies developed, tested, and deployed by Russian specialists were identified as having potential application in the retrieval of supernate and sludge from U.S. Department of Energy radioactive waste storage tanks. Four of these technologies were designed, fabricated, and cold tested at one-quarter scale in Russia. Then, the four technologies were sent to Pacific Northwest National Laboratory, a U.S. Department of Energy multiprogram national laboratory, for testing and evaluation in the Hanford Quarter-Scale Test Facility. The four technologies sent were a hydro-elevator, a hydro-monitor, and air-operated vacuum and pressure pulsating transfer and pulsating mixer pumps. The Tanks Focus Area and Pacific Northwest National Laboratory team along with the Russian specialists conducted performance testing and demonstrations of the pulsating pump and the pulsating mixer pump (a.k.a. pulsating monitor) at the Hanford Quarter-Scale Test Facility. The hydro-monitor and hydro-elevator were deemed sufficiently similar to existing sluicers and jet pump transfer systems to not warrant testing at the quarter-scale facility. The Tanks Focus Area in conjunction with the U.S. Department of Energy Office of Environmental Restoration and Waste Management International Programs (Joint

Coordinating Committee for Environmental Management or JCCEM) sponsored the design, fabrication, and testing of the Russian retrieval technologies.

Pulsating Transfer Pump

This pump consists of an upright cylindrical reservoir; a foot-check valve with an inlet screen; a working air supply pipe; a discharge pipe; and a back flush/check valve at the riser head. In operation, the supply pipe is valved to a vacuum source, and the waste is drawn into the reservoir through the foot-check valve. The supply pipe is then valved to a pressurized air source to expel the waste up the discharge pipe through the discharge check valve and into the downstream balance of plant pipe. This unit is rugged, simple, and able to pump heavy slurry; however, it is comparable in function to commercially available systems in the United States and therefore did not warrant further development.

Pulsating Mixer Pump

This pump, also referred to as a pulsating monitor, is a second-generation air-actuated jet sluicing system. It consists of an upright cylindrical reservoir; a foot-check valve; a working air supply pipe; a discharge manifold; and nozzle head (7). In operation, the supply pipe is valved to a vacuum source drawing the waste into the reservoir through the foot-check valve. The supply pipe is then valved to a pressurized air source to expel the waste through the manifold and nozzles located near the tank floor. A riser cover plate on a swivel bearing/seal allows operators to manually turn it to direct the nozzle jets in different directions and supports the pulsating mixer pump. The working air supply is delivered by a hose connected to a swivel 90° elbow fitting at the top of the monitor (7). This system uses existing tank liquid as the working fluid. Separate intake and jet nozzles allow the use of higher-pressure jets than other similar systems and as such is a good candidate for follow-on testing for possible use in U.S. high-level waste tanks (see Fig. 1).

Fig. 1. Cleaning footprint of initial test with sand of the pulsating mixer pump in Pacific Northwest National Laboratory's quarter-scale test tank

Hydro-monitor

The hydro-monitor is a sluicing device composed of two diametrically opposed 10-mm jet nozzles inclined 30° down from horizontal axis. The nozzles are mounted at the lower end of a vertical pipe stem just above the tank floor. The pipe stem is inserted through a small riser and can be rotated about the vertical axis. The working fluid connection is made to a 90° elbow swivel fitting. The unit is designed for operation at 1.2 mPa (175 psia). This system was not tested because of its similarity to available sluicing jets.

Hydro-elevator

The hydro-elevator is a conventional axial jet pump (1). With a large axial motive jet, it would be categorized as a high-volume, low-pressure pump. The rated output of combined water and slurry (for slurry of specific gravity = 1.4) is 8 to 12 m^3/hr while consuming 6 to 9 m^3/hr of water. Therefore unless supernate is used as the working fluid, the dilution ratio is unattractive. The hydro-elevator was set up for an optional demonstration, but it was not tested because of time constraints.

The pulsating transfer pump and pulsating mixer pump showed promise of applicability in the U.S. Department of Energy tanks. The pulsating mixer pump was selected for hot demonstration at the Oak Ridge Reservation, located in Tennessee, United States, as part of the Gunite Tank Remediation Project.

SECOND-GENERATION RETRIEVAL SYSTEM USED AT OAK RIDGE RESERVATION

In 1998, based on the results of the Pacific Northwest National Laboratory demonstration, Oak Ridge Reservation and U.S. Department of Energy staff determined that a second-generation pulsating mixer pump--capable of discharge pressures of 15 atm--could be used for sludge mobilization in Tank TH-4. This tank is 6.1 m in diameter, with a working capacity of 52,996 L. The tank has a vertical sidewall height of 2.0 m and a dome height of 0.8 m. The tank contained 20,800 L of radioactive settled sludge covered by a 1-m layer of aqueous liquid with a vaporous air space above the liquid. The pH of the waste ranged from 7 to 11. The average sludge depth was 0.9 m (7).

The Mining and Chemical Combine fabricated the pulsating mixer pump in Russia. American Russian Environmental Services Inc. was the integrating contractor responsible for fabrication and delivery to Oak Ridge National Laboratory. The Tanks Focus Area funded installation, checkout, and deployment of the system (7). A single tank riser interface system was fabricated by Battelle Pacific Northwest Division to mate the pump with the tank infrastructure. Battelle also fabricated the decontamination spray ring housing and pulsating mixer pump transport cradle (2).

Compliance with appropriate U.S. fabrication standards was an important consideration and proved to be the most difficult aspect of the project. The "Work Smart" Standards for Engineering Design applicable to industrial, radiological, and nonreactor nuclear facilities identified the required codes and standards for the project. Because design and fabrication of the pulsating mixer pump occurred in a Russian facility that does not work to U.S. standards, the equipment was fabricated to the appropriate Russian standards, and steps were taken to ensure that the technical intent of U.S. standards was achieved. Pressure tests and inspections of the equipment were conducted in Russia and the United States to ensure the integrity of the system before deployment (2).

Extensive cold testing was conducted at the Oak Ridge Reservation Gunite Tank Cold Test Facility to evaluate all aspects of operations, procedures, and operator training. The cold test facility also served as the stage for the operational readiness review. The tests evaluated the effective cleaning radius for the pulsating mixer pump nozzles using different nozzle sizes and various simulated waste types. The effective cleaning radius was 200 to 240 cm with the pulsating mixer pump operating with a 6-atm air supply in a stationary position. The effective cleaning radius using oscillating jets was approximately the same as the cleaning radius achieved with a stationary jet. In addition to the effective cleaning radius tests, mixing and pumping tests were conducted using simulated sludge and various water depths. Very little sludge remained in the tank after the pumping operation was completed (see Fig. 2b)(7).

In January 2001, the pulsating mixer pump was deployed in Tank TH-4 (2). Following the first retrieval campaign, the tank was deemed clean enough for closure because of the relatively low radioactivity of the sludge. A ring of residual sludge remained at the edges of the tank (see Figs. 2a and 2b). This deployment became the first hot deployment of Russian tank retrieval technology in the U.S. Department of Energy radioactive waste complex.

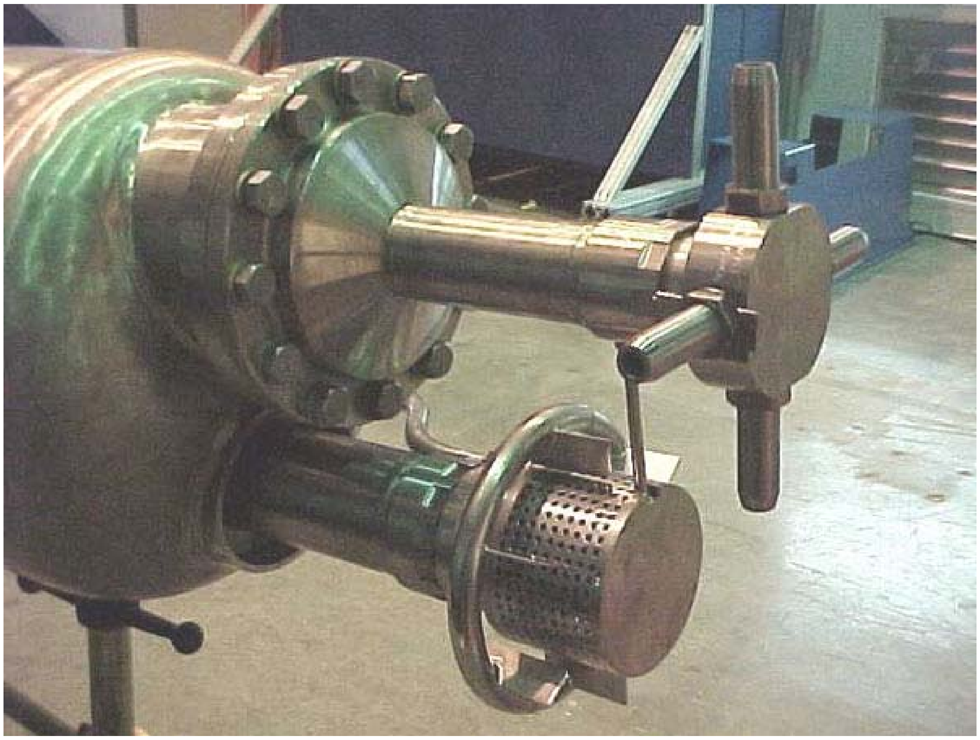

Fig. 2a. Suction strainer and discharge nozzles for Oak Ridge Reservation pulsating mixer pump

Fig. 2b. Pulsating mixer pump installed in Oak Ridge Tank TH-4 following one retrieval campaign (mixing and pump down)

THIRD- AND FOURTH-GENERATION RETRIEVAL SYSTEMS

The success of the pulsating mixer pump in removing hardened sludge has led to the development of two additional pumps. A third-generation unit with an additional nozzle that operates through the air, above the liquid level as well as the lower, submerged nozzles was developed for the Mining and Chemical Combine. Due to the extreme height of the tanks at Mining and Chemical Combine, this third-generation unit has a remote upper jet nozzle suspended from a second mast. A fourth-generation, only slightly different from the third-generation model with the upper nozzle directly attached, was developed as a candidate for use in retrieval of waste from the Hanford Site's Tank 241-S-102.

Retrieval System for Use at the Mining Chemical Combine

A third-generation pulsating mixer pump is being developed to have better effect on the hardened sludge. The unit consists of an integral pulsating pump that discharges either through lower, submerged nozzles or through an upper, steerable sluicing nozzle located above the liquid level. This version of the pulsating mixer pump is referred to as the Dual-Nozzle Pulsating Mixing Pump. The upper nozzle has a greater effective range and specific energy than the submerged nozzles when the sludge is exposed. The upper jet is expected to be capable of dislodging sludge across the full extent of the tank bottom while the lower jet mixes the slurry for pumping. A dual-nozzle pump will be tested in the next tank to be retrieved at Mining and Chemical Combine.

Retrieval System Testing for Hanford Application

The fourth-generation mixing pump, which also has a dual nozzle configuration, was cold tested at the Mining and Chemical Combine according to specifications developed for potentially leaking Hanford Site single-shell tanks. The Dual-Nozzle Pulsating Mixing Pump is being considered for use in potentially leaking tanks for two reasons. First, the pump operates with a minimum amount of liquid (15 cm is feasible) in the tank relative to baseline high-volume sluicing methods (1 to 2 m). This would keep standing liquid away from the highly stressed tank wall knuckles in tanks with a 33-cm eep dish-shaped bottom. Second, the sluicing jets utilize existing liquid in the tank as the working fluid, thus reducing secondary waste volumes.

The fourth-generation pump complied with the requirement to be deployed through a 33-cm (12-in.) riser. The pump consisted of a 200-L cylindrical chamber with a working volume of 160 L. The design of the inlet screen allowed for stable operation of the pump with a liquid level of 12 cm. A set of four sluicing nozzles is located near the bottom of the tank with an angular spacing of 90°. A single, through-air sluicing nozzle is located at the top of the chamber, approximately 2.5 m above the lower nozzles. The entire pump assembly could be rotated through an angle of 90°, which provides for rotation of the lower nozzles. The upper sluicing jet can be rotated independently through a horizontal angle of 360° and a vertical angle of +/- 45°. The dual-nozzle pump was designed for operating pressures up to 12 atm, although the tests were conducted with pressures of 4 to 6 atm (see Fig. 3).

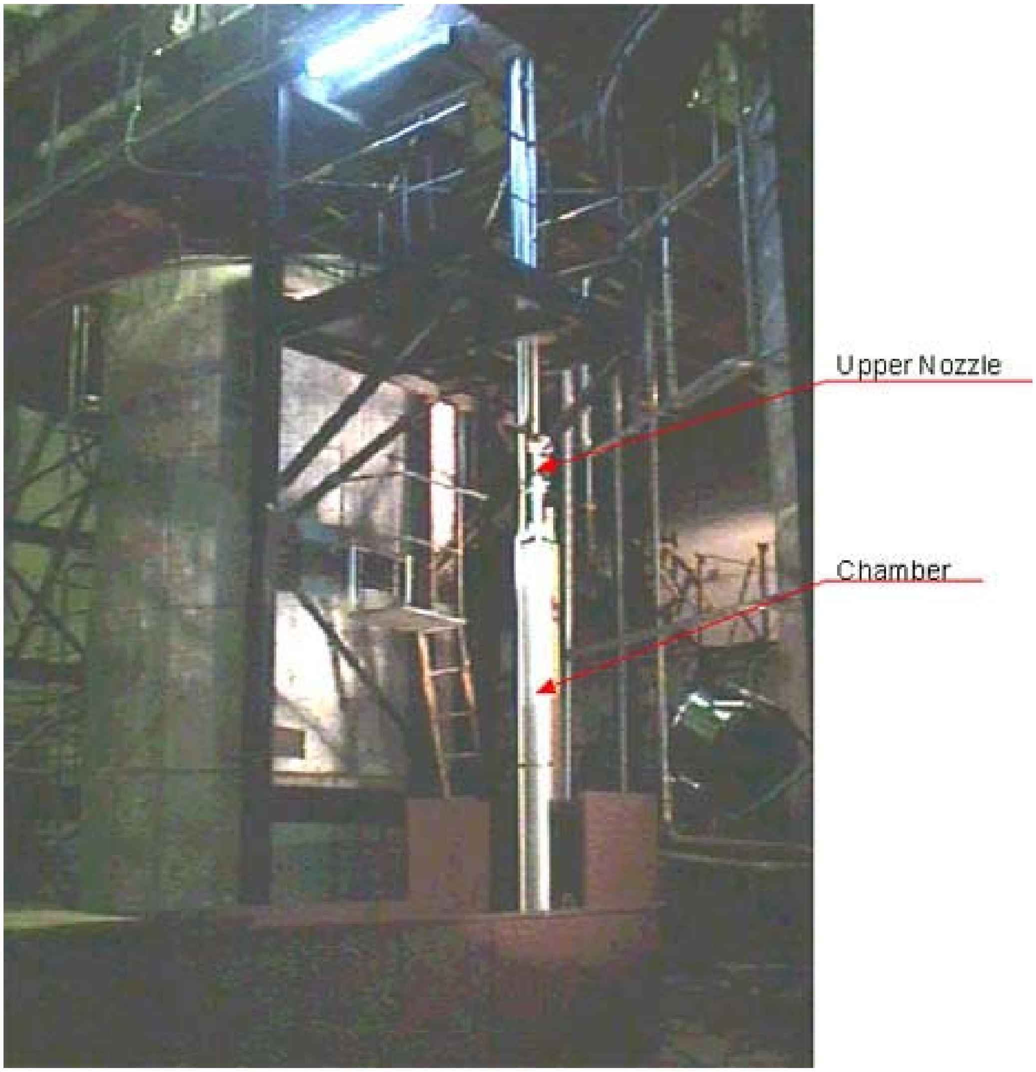

Fig. 3. Dual-Nozzle Pulsating Mixing Pump set up for testing at Mining and Chemical Combine's Cold Test Facility in Zheleznogorsk, Russia

The Dual-Nozzle Pulsating Mixing Pump electronic control system provides a remote interface control of all system functions through a personal computer interface. The control system provides for all of the automatic operational cycles of the Dual-Nozzle Pulsating Mixing Pump such as startup, normal operational cycles, and shutdown, as well as operator-selected functions, such as selection of upper or lower nozzles and all nozzle-positioning controls.

The test specifications provided by CH2M HILL Hanford Group, Inc. were designed to test the functionality of the Dual-Nozzle Pulsating Mixing Pump for potential deployment in Hanford Tank 241-S-102, a single-shell tank with high salt/sludge fraction. Test simulants representative of the range of waste composition in Tank 241-S-102 were specified. The principal objectives of the tests were as follows: 1) determine the ability of the Dual-Nozzle Pulsating Mixing Pump to mobilize and wash back to the tank center the sludge simulant at a distance of 13 m, and 2) determine the minimum level of liquid required for operation of the system. A secondary objective was to determine the pump's ability to operate in the presence of potentially fouling debris.

CONCLUSIONS AND FUTURE RETRIEVAL SYSTEM PLANS

Because tank penetrations are expensive and usually limited in number, the ability to perform multiple functions with a single device is expected to be beneficial. The dual-nozzle mixing pump combines the functions of a mixing pump and a sluicing jet. Future designs will include the ability for the same device to operate as a lifting pump, mixing pump, or sluicing jet. Testing of the Dual-Nozzle Pulsating Mixing Pump and deployment of earlier generations of pulsating mixer pumps show that the dual-nozzle configuration is a viable candidate for use in Hanford's single-shell tanks where minimizing standing water while providing for waste mobilization throughout a 23-m-diameter tank without the expense of a remote-controlled crawler or long-reach arm deployment system. The Russian Mining and Chemical Combine nuclear complex is a valuable and unique resource for testing mechanical and chemical processes and equipment in cold test conditions and hot conditions, with plutonium-uranium extraction sludge in laboratory-scale arrangements and in full-scale storage tanks.

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