Leak Testing with Simulated Waste of Hanford Tank Farm Valves Utilized for Double Valve Isolation – 16108

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ABSTRACT

The existing Hanford Tank Farms Waste Transfer System has several models of ball valves used for double valve isolation (DVI) that have been installed for 10 or more years. The safety function of the safety-significant valves is to limit leakage of waste past the valves in order to decrease the consequences of a fine spray release due to a transfer misroute. While previous leak testing of the valves has been conducted, the testing did not address concerns in the Documented Safety Analysis concerns about the impact on valve operation and service life of the potential abrasive/erosive properties of the tank waste on the valves when cycled. Pacific Northwest National Laboratory (PNNL) conducted DVI tests at their Multi-Phase Transport Evaluation Loop Facility. Testing evaluated the leak rate of safety-significant isolation valves for DVI as a function of simulated operating cycles. PNNL developed a performance-based simulant specifically for this test program. The test environment simulated the abrasive characteristics of the Hanford Tank Farms Waste Transfer System during single-shell tank retrieval and waste feed delivery to the Hanford Tank Waste Treatment and Immobilization Plant. The testing consisted of periodically measuring leak rates and maximum operational torques on the DVI valves after prescribed numbers of valve operational cycles (open and close). The test results from the simulant cycle tests provide Washington River Protection Solutions with performance characteristics that can be used to verify compliance with the Documented Safety Analysis limits for valve seat leakage.

INTRODUCTION

This paper describes testing performed to assess the leak rates and associated operating torques as a function of operational history for a sample of the safety-significant isolation valves used for double valve isolation (DVI) at the Hanford tank farms. Pacific Northwest National Laboratory (PNNL) tested the valves using an abrasive simulant developed to represent the Hanford waste. The suite of valves was made up of 2-way and 3-way valves and consisted of:

- 2-inch valves with ultra-high molecular weight polyethylene (UHMWPE) seats manufactured by Flow-Tek.

- 3-inch valves with Tefzel®[1] seats manufactured by Pittsburgh Brass Manufacturing (PBM) Inc.
- 3-inch valves with Kynar®[2] seats manufactured by PBM Inc.

The existing Hanford Tank Farms Waste Transfer System (WTS) contains DVI ball valves that have been installed for up to 10 years. The DVI valve seat materials were selected to be abrasion-resistant, based on the valve manufacturer's data, to provide additional wear protection from tank waste fluids that may be abrasive and erosive. Past operational valve testing performed by Washington River Protection Solutions (WRPS) evaluated wear performance characteristics utilizing representative (2-way and 3-way) DVI ball valves in wet cycling (valve flooded with water) and dry cycling (no liquid against the ball and seat) combinations. Following the operational cycling, the test valves were subjected to seat leak tests, which all passed.

A later evaluation by WRPS [1] concluded that the materials used for the DVI valves provide adequate capability to withstand the postulated failure modes due to operation in the Hanford Tank Farms WTS. However, this evaluation also concluded that the past WRPS DVI valve testing utilizing water did not address the Documented Safety Analysis (DSA) concern that valve life can be limited by valve seat exposure to abrasive particles in the waste. To address DSA valve life concerns regarding abrasive tank waste, PNNL conducted the additional DVI valve testing reported here.

The primary objective of the PNNL DVI valve test effort was to provide life cycle testing using waste simulants to determine whether valves in use for the WTS over extended periods and with repetitive cycling in abrasive service might develop excessive leak rates. Testing focused on evaluating a sample of newly purchased valves of the same makes and models as those currently installed in the WTS. Test operations included valve exposure to cycling conditions that include slurry transfer, water flushing to clean out remaining slurry transfer residuals, and gravity draining of fluids (slurry and water). For the DVI valves supplied by WRPS, the test program objectives were as follows:

- Measure leak rates and operating torques during prolonged cycling of the valves (up to 1500 operating cycles for PBM valves and 5000 cycles for Flow-Tek valves) in abrasive service.
- Identify differences in leak rates between valves that are flushed and valves that are not flushed prior to any rotation (actuation).
- Identify differences in leak rates for a given valve between normal (ambient temperature) and design conditions.
- Visually inspect for any indication of valve wear and solids migration within valve internals by performing post-test teardowns of valves.

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[1] Tefzel is a registered trademark of E.I. du Pont de Nemours and Company, Wilmington, Delaware.
[2] Kynar is a registered trademark of Arkema Inc., Philadelphia, Pennsylvania.

SIMULANT DESCRIPTION

The DVI simulant was developed by PNNL using a 10-metric basis [2]. The basis includes five primary metrics associated with valve wear from abrasive slurry; or more specifically the valve physical surface abrasion from particle interaction based on representative Hanford waste particulate characteristics (e.g., density, hardness, size) as well as the hardness of the valve body and seat surface exposed to abrasive slurry. Secondary metrics are related to pipeline slurry transfer and include erosion as the slurry is flowing through the piping, particle settling under conditions of no flow, and particle suspension for conditions of re-establishing flow. The different metrics were considered because they depend on various particle characteristics, and include the following:

1-5. Valve surface relative particle interaction and abrasive wear rate for two valve body materials (stainless steel, nickel plating, and three valve seat materials; Tefzel®, Kynar®, and UHMWPE)
6. Pipeline critical transport velocity
7. Pipeline erosion rate
8. Archimedes number
9. Settling velocity
10. Critical shear stress for erosion of non-cohesive particles

The composition and physical properties of the simulant developed for DVI valve testing are given in Table 1. The average undissolved solid density of this composition is approximately 3.17 g/mL. The composition of the simulant presented in Table 1 was modified slightly from the recommended simulant composition [2] because of material availability. For purposed of this report, the simulant will be referred to as slurry.

TABLE 1. Composition of the DVI Test Simulant.

Component	**Crystal Density (g/mL)**	**Mohs Hardness (VHN)[a]**	**Volume Fraction[b]**	**Mass Fraction[b]**	**Approximate Percentile Particle Size (μm)**	
					50th	**90th**
Gibbsite	2.42	3 (157)	0.240	0.185	80	158
Zeolite	2.15	3.75 (270)	0.182	0.125	53	309
Hydroxyapatite	3.14	5 (535)	0.115	0.116	4.7	12
Bismuth Oxide	8.9	4.5 (418)	0.021	0.060	8.7	24
Boehmite	3.01	4 (315)	0.221	0.212	8.5	21
Large Gibbsite	2.42	3.4 (213)	0.081	0.062	8.8	20

Component	Crystal Density (g/mL)	Mohs Hardness (VHN)[a]	Volume Fraction[b]	Mass Fraction[b]	Approximate Percentile Particle Size (μm)	
					50th	90th
Large Sand	2.65	6.5 (982)	0.030	0.025	394	592
Zirconium Oxide	5.7	8 (1567)	0.091	0.166	13	30
Stainless Steel[c]	8	5.5 (669)	0.02	0.051	59	152
			0.017	0.043		
			0.001	0.004		

a Different references provide similar but not equivalent conversions from Mohs to Vickers Hardness No. (VHN). Data provided at http://www.cidraprecisionservices.com/mohs-conversion.html in general agreement with the ranges provided in [3], was used for this analysis.
b Values differ slightly from those reported by Wells (2013) [2] due to difference between vendor-reported values for density and those of received material.
c Three stainless steel products were obtained to create stainless steel constituent equivalent to that defined by Wells (2013) [2].

TEST SETUP DESCRIPTION

An automated test system was configured for conducting the valve cycle operations at PNNL's Multi-Phase Transport Evaluation Loop Facility. The test system contained separate slurry and flush water delivery systems as well as a slurry recovery system. The test system was designed to provide four flow conditions through the valves that mimic the WTS operating conditions. The four flow conditions in order of occurrence during automated valve cycle operations consist of slurry flow, slurry drain, flush-water flow, and flush-water drain.

Valve operations were controlled and instrument readings were recorded using a PC-based data acquisition and control system. The test loop included instrumentation for recording test conditions associated with slurry and flush-water systems (flow rates, densities, temperatures, and pressures) as well as valve operating torques. Logging the valve rotation limits, which were used to maintain a cycle count during a test sequence, monitored the valve rotation. Valve operation was pneumatically or hydraulically actuated with specific valve orientations tightly controlled within set operating parameters ($\pm$ 2.5° ball alignment with ports). The test system was designed to allow the valve leak rates to be measured *in situ*. Leak rates were determined from measured mass of discharged fluid collected over the duration of applied pressure.

The ten DVI test valves, plumbed into one of three test manifolds, were each assigned a unique test valve number (TV#) along with an associated valve type (A through F) from Table 2. Multiple valves of types B, D, and E were tested. Fig. 1 provides a schematic of the test manifolds, associated TV numbers, designated valve types and indication of test loop hose connections (slurry, flush, and drain). The three test manifolds were plumbed in parallel to allow automated simultaneous testing of all ten test valves as well as ensuring that simulant degradation is uniform as a function of cycle operations for all valves tested. Each manifold contained valves of a single seat material.

For the three manifolds containing the test valves, the operational valve positions within the manifolds are designated as follows:

- Slurry – upstream valve that controls slurry flow and does not experience flushing prior to cycling. For the configurations having a 3-way valve in this position, the valve also controls the flush water supply to the line. (TV1, TV4, and TV8)
- Drain – downstream 3-way valves that control the routing of the discharge fluid from the manifold (e.g., slurry, slurry drain, flush water, flush water drain) and experience flushing prior to cycling. (TV3, TV7, and TV10)
- Middle – Midline 2-way valve that experiences flushing prior to cycling. (TV2, TV6, and TV9)
- Flush – upstream 2-way valve that controls the supply of flush water and does not experience flushing prior to cycling. (TV5)

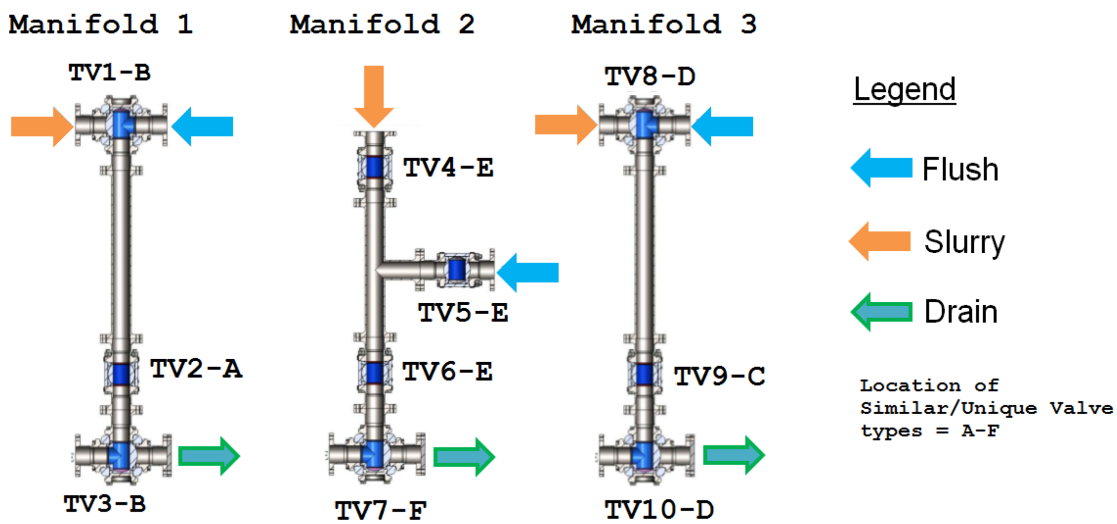

Fig. 1. Configuration of Test Manifolds with Indication of Flow Stream into and out of Manifolds as well as TV numbers Used to Define System Configuration.

Table 2. Description of Test Valve Types Presented in Fig. 1.

Valve Type	Manufacturer	Type	Seat Material	Ball Coating
A	PBM	3-in 2-Way	Tefzel®	Electroless nickel plating
B	PBM	3-in 3-Way	Tefzel®	Electroless nickel plating
C	PBM	3-in 2-Way	Kynar®	None
D	PBM	3-in 3-Way	Kynar®	None

Valve Type	Manufacturer	Type	Seat Material	Ball Coating
E	Flow-Tek	2-in 2-Way	UHMWPE	None
F	Flow-Tek	2-in 3-Way	UHMWPE	None

Test Matrix and Operating Conditions

Each test valve underwent a pretest teardown and inspection followed by an acceptance leak test (0 cycles) prior to being subjected to cycle testing with slurry. The allowable pretest (0 cycles) leakage was ≤ 4 mL/min (0.001 gpm) for the 2-inch Flow-Tek valves and ≤ 0.2 mL/min (5.3 x 10^{-3} gpm) for the 3-inch PBM valves.

Seat leakage testing was performed at normal conditions following valve cycle operation counts of 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000. For cycle counts beyond 1000, seat leakage tests at normal conditions were performed after every 100 cycles for PBM and 250 cycles for Flow-Tek valves.

Each seat leakage test consisted of differential pressures of 344 and 2760 kPa across the closed valve, with the pressure differential applied in both directions. Design condition (2760 kPa at 93°C for PBM valves and 2760 kPa at 82°C for Flow-Tek valves) leak tests were performed after 500 and 1000 cycles following the completion of the corresponding normal condition leak tests. For the 3-way valves, the design condition tests were only performed for the valve orientation that yielded the greatest leakage during the preceding normal condition leak tests.

The following operating conditions were maintained for the cycle operations:

- Slurry conditions: bulk density – 1.08 to 1.13 g/mL, solids concentration – 13 to 18 wt%, temperature – 43°C to 49°C, volumetric flow for 2-inch valves – 341 to 417 L/min [2.6 to 3.2 m/s], volumetric flow for 3-inch valves – 530 to 795 L/min [1.8 to 2.7 m/s], flow duration – 160 to 200 sec
- Flush water conditions: temperature – ambient, volumetric flow for 2-inch valves – 341 to 417 L/min [2.6 to 3.2 m/s], volumetric flow for 3-inch valves –379 to 568 L/min [1.3 to 2.0 m/s], flow duration – 55 to 65 sec
- Valve rotation: 7.5 to 3.7 rpm (90° of rotation in 2 to 4 sec)
- Maximum allowable pressure 2760 kPa, no pressure requirements during cycle testing

The following operating conditions were maintained for leak testing:

- Normal leak test: temperature – ambient, low pressure condition – 310 to 379 kPag, high-pressure condition – 2620 to 2760 kPag, duration of applied pressure – minimum 5 min
- Design leak test: temperature Flow-Tek valves – 77°C to 82°C, temperature PBM valves – 88°C to 93°C, pressure – 2620 to 2760 kPa, duration of applied pressure – minimum 5 min
- Valve manifolds vented prior to valve rotation
- Threshold leak rate for valves in service: 379 mL/min (0.1 gpm)

PRELIMINARY TESTING

Two needs were identified for preliminary testing in support of developing and justifying the test approach to be used for the DVI cycle and leak rate test effort:

- Determine the life cycle of the test simulant and identify the parameters to be used for monitoring simulant degradation.
- Determine if slurry flow duration of approximately 3 minutes for slurry flow is sufficient to obtain representative conditions for evaluating valve cycle operations.

A critical factor in applying simulant for wear testing is assessing and monitoring degradation and attrition to ensure representative slurry conditions exist throughout the test duration. Prior to testing the suite of DVI valves, simulant degradation testing was conducted in a test configuration that used mockup DVI valves in a single manifold to determine degradation and attrition occurring in the test system as a function of valve cycle operations. Objectives for degradation testing were as follows:

- Obtain data for rate of solids attrition associated with a reduction in the bulk slurry density and attrition and degradation associated with shifts in the particle size distribution (PSD) as a function of cycle operations.
- Identify parameters (e.g., specific size percentiles) that yield the greatest resolution for indicating changes in the slurry characteristics (e.g., PSD).
- Select an acceptable simulant operating window defined by parameters exhibiting greatest resolution for indication of change in solids mixture.

Observation from degradation testing for 420 individual manifold cycles included the following:

- Bulk slurry density reduced from approximately 1.24 g/mL to 1.08 g/mL.
- The slurry density experiences a gradual and continual decline in density until solids captured by the solids recovery system are returned to the slurry system flow. Net reduction of slurry density was between 0.2% and 0.5% per operating cycle, with the larger values occurring at higher bulk densities. Re-introduction of solids at 25-cycle increments increases the slurry density flowing through the valves by approximately 3% to 14% of the slurry density operating range.
- d(50) of PSD corresponds closely with peak of modal associated with smallest particle sizes and reduces (i.e., shifts in particle size) from approximately 14 to 6 µm, while the size probability remains relatively constant (i.e., over reduction of bulk slurry density). This tended to indicate the reduction in particulate size for the distribution and increase the fines for material associated with the smaller modal.
- Modal of PSD associated with largest particle sizes has peak of approximately 500 µm, which initially corresponds to d(90). The particle size associated with the peak of the modal remained fairly constant while the corresponding

probability trended down, indicating a reduction in the relative volume of the larger-diameter particles.

- For a given cycle, the variation in the probability associated with the d(90) fluctuated on the order of 50% of the average magnitude of the size probability. This is expected due to the broad size distribution of the solids and the relatively low concentration of the larger particulate. The capture of a few less or few more large particles can significantly impact the probability associated with a large particle size or the value of the d(90).
- The modal associated with 100 µm was much more constant/stable than the corresponding larger and smaller modes.

During valve testing, slurry line samples drawn at start and end of each test run were evaluated for PSD to monitor change in the simulant condition (e.g., simulant degradation). A methodology was formulated, based on simulant degradation test results, for monitoring the simulant PSD based on key relative particle sizes (i.e., size percentiles d(50) and d(90)). The PSD of the initial simulant batch was characterized after 55, 83, 108, and 333 individual manifold operational cycles. The results (shown in Fig. 2) were evaluated along with the inline slurry density measurements for simulant degradation and constituent loss/dilution due to slurry drain and flush water operations. The cycle numbers presented in the legend of Fig. 2 correspond to passes through a single test manifold. Dividing by 3 provides an approximate cycle count for the entire three-manifold test loop.

The “Reference” (black dotted line in Fig. 2) is a benchtop-generated batch of simulant mixed under ideal conditions to eliminate uncertainties and impacts of material losses associated with multiple sub-batch mixtures and slurry transfers. “0 Cycle” represents the baseline sample drawn from the test loop after a full batch of simulant was loaded into the test loop.

The simulant material degradation was determined by observing the change in material size distributions of d(50) and d(90) and the density to the baseline reference after 333 individual manifold cycles. From this, criteria were developed to keep the simulant within acceptable parameters by either requiring periodic additions to the simulant to return it to its initial state or to replace the simulant batch.

Using these two distributions, a functional particle population model of how simulant loss and degradation would influence the size distribution was generated. This model was used to assess the shift in the size distribution caused by particle attrition and the shift in the size probability caused by variations associated with sampling or changes in concentration due to loss or gain of the large (i.e., 500-µm) particles. The results of the PSD evaluation were only applied within the narrow window of acceptable slurry density. The assessment of the shifts in the PSD as well as an evaluation of the impact to the metrics identified for simulant development allowed slurry size distribution criteria to be defined that provided parameters to be monitored.

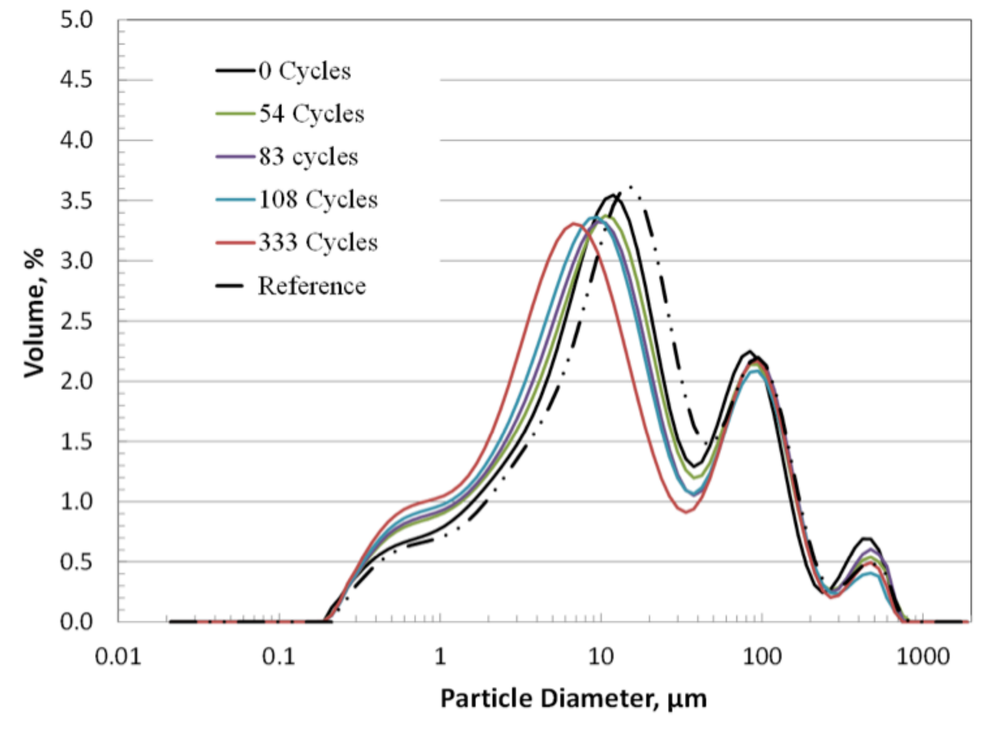

Fig 2. Changes in Volume Percent Solids as a Function of Particle Size Observed During Initial Assessment of Simulant Degradation and Attrition.

An analysis was performed that applied the model in conjunction with the size distribution criteria to obtain acceptance checks used for two size percentiles, the d(50) and d(90), for monitoring the size distribution. From the analysis, simplified simulant bounding conditions were established. Specifically, the simulant was considered acceptable for continued cycle testing if 8 µm ≤ d(50) ≤ 16 µm, 110 ≤ µm d(90) ≤ 170 µm, and bulk density at 20°C is between 1.095 and 1.139 g/mL (between 1.085 and 1.130 g/mL at 46°C). The continually monitored parameter was the slurry density, which terminated testing if out-of-bounds conditions were detected. Failure to meet these criteria indicated the need to restore simulant materials lost to their original ratios or to completely change out the simulant.

Waste transfers occur over several hours. However, the test program used 3-minute duration of slurry flow between each sequence of drain, flush, and valve cycle operation. A basis had not previously been established for using a 3-minute slurry flow to provide a representative amount of accumulated material within the valve body during testing prior to cycling the valve. This is most relevant to the upstream 3-way valves in each test manifold that are not flushed prior to rotation from the slurry position to the flush position. A pretest assessment was conducted with the mockup DVI valves to determine if a 3-minute duration for slurry flow is sufficient to evaluate valve wear or if significantly more slurry accumulates on the interior of the valves during an extended (2-hour) period of slurry flow. The test results revealed that the solids film on the inside of the pipe wall and the buildup of material at the interface between the ball and valve body were indistinguishable between slurry runs of 3 min. and 120 min.

TEST RESULTS

At the start of the PNNL test program, some setbacks occurred that required resolution before continuing and included pre-test (0 cycle) leak test failures, failure to meet leakage criteria after 25 operating cycles, and insufficient valve actuator torque capacity to cycle some of the Tefzel®-seated valves within first 25 operating cycles. These setbacks were determined to be the result of inadequate manufacture assembly procedures. Assessment of the manufacturer's assembly procedures identified issues such as the following:

- Assembly instructions that allowed angular misalignment of the ball and/or prevented concentric alignment of the ball branch port with the valve side fitting port.
- Missing, inconsistent, or incorrect assembly torque setting information

Recommendations for revising the assembly procedures were presented to the manufacturers through WRPS. Updated manufacturer procedures resulted in all future assembled valves passing the pre-test leak check and operating successfully through the prescribed cycles without exceeding the allowable leak rate or exceeding the torque capacity of the test actuators (except for one valve; see below).

Most of the initial failure issues were associated with the 3-way valves and especially the PBM Tefzel®-seated valves. Some Tefzel®-seated valves seized due to the need for operating torques greater than the capacity of the actuators. The Tefzel®-seated valves with an electroless nickel-plated ball appeared to be less forgiving and require greater operating torques than the Kynar®-seated valves once in service. The valves have the same geometric design except for the valve stem packing. The increased operating torques for the 3-way PBM valves with Tefzel® seats are suspected of being associated with the relative hardness of the ball material. While Kynar® (Vicker hardness ≈627) is harder than Tefzel® (Vicker hardness ≈511), the difference is not considered large enough to fully account for the observed differences in performance. In comparison, the Kynar® seats are paired with stainless steel (Vicker hardness ≈175) balls while the Tefzel® seats are paired with nickel-plated (Vicker hardness ≈990) balls. The difference in ball hardness is suspected of significantly increasing the friction resulting when the interface is contaminated with solids, as the harder material is less likely to absorb/deform from hard particulate that migrates into the interface, and instead is more likely to allow the particles to act as a wedge, binding movement between the sliding surfaces. In addition, the hardness of the ball relative to the seats is inverted for these two valve types, which can affect the mechanisms associated with wear/abrasion [2].

The UHMWPE-seated slurry valve (TV4) was replaced after 500 cycles due to valve stem deformation. Review of the test events and the operating procedure resulted in speculation that the valve may have been rotated when one side of the valve remained pressurized to 400 psig.

The limited number of valves tested prevented statistical analysis of combined valve results. However, opportunistic repeat test results were obtained for TV4 and TV8, which yielded good agreement for leak rates and operating torques.

The most common use of 3-way valves in industry is to route flow, which results in an internal pressure condition that results in the ball being pushed against the sealing seat. A less common application of 3-way valves is to block or terminate flow, which results in an external pressure condition that reduces the contact pressure between the ball and the sealing seat. The measured leak rates for the 3-way valves were greater for test configurations corresponding to external pressurization of the ball compared to those measured for internal pressurization of the ball.

The 3-way slurry valves (TV1 and TV8) have flow passing through all legs (i.e., welded flange stems) of the valve during a cycle operation. In comparison, the 3-way drain valves (TV3, TV7, and TV10) have a dead leg (refer to Fig. 1) that is exposed to flow but does not experience a flow stream passing through it, which allows deposited solids to accumulate and be present when the valve cycles. Settled solids layers on the order of 3 to 7 mm thick were observed in the dead legs at the start of leak testing.

In comparing all the operating torque measurements for the full duration of testing, the data indicate that the cycle-to-cycle variations are small and the scatter in the data observed was the result of rising and falling trends in the measurements rather than large cycle-to-cycle variations. This is believed to be the result of particle migration and size reduction within the tight clearances associated with the rotating ball. The operating torque increases as larger particles are wedged into the space and then decreases as the particles are broken down or embedded into the soft valve components.

Results for UHMWPE-Seated (Flow-Tek) Valves

The normal condition leak rates for the 2-way Flow-Tek valves (TV4, TV5, and TV6) for all conditions are relatively low, with a maximum leak rate of 1.5 mL/min, which is less than 0.5% of the allowable rate. Increased leak rates were measured for the design condition. However, the maximum leak rate of 11.0 mL/min, obtained for the slurry valve (TV4) after 1000 cycles, is less than 3% of the allowable rate.

The 2-way Flow-Tek valves displayed a slight increase in operating torque over the entire test duration, with values for torque ranging between approximately 41 and 115 N-m. As expected, the slurry valve (TV4), which is not flushed, experienced the higher operating torque over the duration of operations.

The 3-way Flow-Tek valve in the drain position (TV7) exhibited the maximum leak rate for a UHMWPE seated valve at 13.8 mL/min after 5500 cycles with external pressurization at 2760 kPa, which is 4% of the allowable rate. Other than one other measurement at 800 cycles (12.5 mL/min), with external pressurization at

2760 kPa, the normal condition leak rates were less than 1% of the allowable rate through 4000 cycles. As was the case for the 2-way valves, the design condition leak rates for the 3-way valve were not greater than all the normal condition leak rates. No significant differences were observed between the leak rates obtained for the high- and low-pressure conditions for any of the Flow-Tek valves.

The trend in operating torque for the 3-way Flow-Tek valve (TV7) was reverse that observed for the 2-way valves (i.e., decreasing torque) with torques ranging between 40 and 190 N-m.

Results for Kynar®-Seated (PBM) Valves

The leak rates for the 2-way, PBM, middle (TV9) valve are relatively low (<9% of allowable), with the bulk of the leak leaks rates measured for the 344-kPag condition (32.2 mL/min) being several factors greater than those obtained at the higher design pressure of 2760 kPag (10.3 mL/min). This suggests that the force applied to the floating ball against the ambient side seats at higher pressures consistently limits the amount of leakage. Lower pressure, which generates less force against the seats, appears to be a more challenging test for the 2-way valve configuration. The operating torque for the 2-way valve was observed to rise rapidly over the first 50 cycles to 362 N-m and then steadily declined over the next 1400 cycles to 188 N-m, 50% of the peak value.

The relatively small leak rates (order magnitude less than failure criterion) measured for the 2-way Kynar®-seated valve and the observed trend in the data over 1500 cycle operations leads to high confidence that the valve design life is greater than 1500 cycles. The small leak rates that yield no definitive trend toward failure do not support making any prediction for extended design life beyond 1500 cycles tested. The steady decrease in operating torque is expected to be a better indication of valve wear as the clearances between the ball and the seats are increased with material wear, resulting in a reduced torque required for valve rotation. The initial rise in operating torque at the start of cycle operations is believed to be the result of particulate migrating into the interfaces between the ball and the soft components. The continual wear of the soft components will eventually eliminate the sealing integrity of the seats, which is predicted to be preceded by a rapid rise in the leak rate. Evaluation of seat wear (clearances) as a function of cycle operations and determination of the clearances that results in the allowable leak rate being exceeded would be required to predict design life based on trends in the operating torque measurements.

The maximum leak rates for the 3-way, Kynar®-seated valve were obtained at 700 cycles, 73.8 mL/min for TV8 and 98.2 mL/min for TV10, which are less than 26% of the allowable limit. No definitive trends were observed in the torque measurements for the Kynar®-seated 3-way valves with the approximate range between 447 and 814 N-m.

For the Kynar®-seated valves, the design condition leak rates were not the maximum observed. The design condition rates at 500 cycles (16.4 mL/min) were less than 5% of the allowable, and at 1000 cycles (48.8 mL/min) were less than 13%.

The performance of the Kynar®-seated 3-way valves, based on the measured test parameters, provided no indication that the valves were significantly degrading over the course of the 1500 cycles tested. As with the 2-way valve, the design life of the 3-inch, 3-way PBM valves with Kynar® seats is predicted to exceed 1500 cycles. However, the spread in the data and the occurrence of greater leak rates between 500 and 1000 cycles do not allow for reliable trending of the leak rate or operating torque data. Indication of valve wear was only observed based on the post-test teardown inspection.

Results for Tefzel®-Seated (PBM) Valves

The leak rates for the 2-way, PBM, middle (TV2) valve are relatively low, with a maximum of 5.7 mL/min for normal condition tests, which is 1.5% of the allowable rate, and 13.0 mL/min (3.4% of allowable rate) for the design condition. Only a slight difference was observed between the low- and high-pressure conditions, with the low-pressure condition yielding greater leak rates after the first 500 cycles. The operating torque rose gradually over the first 200 cycles to approximately 150 N-m and then appeared steady up until 600 cycles. Following 600 cycles, the operating torque trended upward again, reaching a peak of 247 N-m at approximately 900 cycles, and then trended downward over the course of the following 600 cycles to 152 N-m. The torque required for actuation of the 2-way valve was significantly lower (at least 678 N-m) than that required for a 3-way valve with Tefzel® seats.

Over the 1500 cycles tested for the 3-way Tefzel®-seated valves, the maximum normal (ambient) leak rates measured were 24.0 mL/min (6.4% of allowable rate) and 51.1 mL/min (13.5% of allowable rate) for TV1 and TV3, respectively. The maximum design condition rates were similar at 29.1 and 28.8 mL/min for TV1 and TV3, respectively, which are both less than 8% of the allowable leak rate. Comparison of the low- and high-pressure conditions for the two valves did not reveal a significant difference in leak rates.

The trends in operating torque measurements for both 3-way Tefzel®-seated valves display a rise in torque up to approximately 500 operating cycles, whereupon a design temperature and pressure test was performed. After 500 cycles, the operating torque reached 1395 N-m for TV1 and 969 N-m for TV3. Following 500 cycles, a gradual downward trend is observed through the remaining 1000 cycles, where values of torque reach 727 and 560 N-m for TV1 and TV3, respectively. The trends for each valve also indicate a shift in the operating torque measurements corresponding to the 500- and 1000-cycle design leak tests. The final torques measured at 1500 cycles for TV1 and TV3 were 914 and 766 N-m, respectively.

Based on the relatively small leak rates (an order of magnitude less than the allowable limit), the design life for the 3-inch, 2-way and 3-way PBM valves with Tefzel® seats is predicted to significantly exceed 1500 cycles based on the testing completed. As with the Kynar®-seated valves, the trend in operating torques does not allow for definitive predictions for design life.

CONCLUSIONS

A technically justifiable simulant as well as test setup, methodology, and procedures were developed to perform abrasive wear testing on safety-significant isolation valves used for DVI at the Hanford tank farms. Test results provide WRPS with data to establish the performance characteristics and verify compliance with the DSA for aging mechanisms resulting from valve cycling. These results also provide a technical basis to define and plan maintenance and equipment replacement schedules. The following conclusions were drawn based on the outcomes of the test program:

- No valves exceeded the allowable leak rate of 379 mL/min (0.1 gpm) during any normal or design leak tests provided they were assembled per the updated manufacturer's procedure.
  - All four of the 2-inch Flow-Tek valves with UHMWPE seats were successfully operated through at least 5000 cycles.
  - The two 3-inch, 3-way PBM valves with Kynar® seats were successfully operated for 1500 cycles.
  - The 3-inch, 2-way PBM valve with Kynar® seats was successfully operated for 1475 cycles.
  - The two 3-inch, 3-way PBM valves with Tefzel® seats were successfully operated for 1500 cycles.
  - The 3-inch, 2-way PBM valve with Tefzel® seats was operated for 1500 cycles.
- The procedure used for assembling the PBM 3-way valves, including revisions identified by this test program, is considered critical to obtaining a centered ball and ensuring that the ported ball is concentrically aligned with the side ports, which is necessary for adequate sealing in order to meet the pretest leak test criterion (i.e., leak rate less than 0.2 mL/min [5.3 x 10^{-3} gpm]) and achieving extended life valve operation. As a result of this test program and the associated feedback to the valve manufacturers, PBM revised their installation, operation, and maintenance valve procedure.
- Opportunistic conditions allowed for repeat testing of two valve types through 500 cycles, which demonstrated that repeatable measurements were obtainable over an extended duration of valve cycles.
- Leakage of valves was evaluated at both ambient temperature and design temperatures (82°C for UHMWPE seats and 93°C for Kynar® and Tefzel® seats). All of the measured leak rates were far below the allowable limit for all test conditions.
  - Leak rates for the UHMWPE 2-way valves were greatest at design temperatures but still less than 3% of the allowable rate. The 3-way UHMWPE had higher leak rates at ambient temperature compared to the design temperature tests, with all leak rates less than 4%. Design temperature conditions yielded higher leak rates for the corresponding valve orientation evaluated.

  - o For the Kynar®-seated valves, the design temperature leak rates were not the maximum leak rates observed. The maximum normal leak rate measured for the Kynar®-seated valves was approximately 26% of the allowable. The design leak rates at 500 cycles were all less than 5% of the allowable, and at 1000 cycles they were all less than 13%.
  - o Normal and design leak rates for the Tefzel®-seated valves were similar. The maximum leak rates measured were less than 4% and 14% of the allowable rate for the 2-way and 3-way valves, respectively.
- The leak rate measurements obtained for the various 3-way valves indicated that the leak rate was nearly an order of magnitude lower for conditions that applied an internal pressure to the valve ball as opposed to an applied external pressure.
- Current waste transfer system operating practices at Hanford, where valves evaluated as part of this test program are installed, call for setting the transfer valve line-up (i.e., configuration) to be used prior to introducing pressurized slurry at elevated temperatures. While slurry temperatures of tank waste to be transferred to the waste treatment plant can reach 66°C current standard operating practices would not require the manipulation of DVI valves at these temperatures.
- The design life of the Flow-Tek valves with UHMWPE seats tested is predicted to exceed 5000 cycles by a significant amount, and for the PBM valves with Kynar® or Tefzel® seats, the design life is predicted to exceed 1500 cycles. The design life predictions are limited by the number of operating cycles completed during testing rather than any observed trend in the measured leak rates or valve operating torques.

The multi-manifold automated test setup assembled for this test effort allows head-to-head comparative testing and extensive test procedures have been developed that should be considered for any future valve testing to assure a standardized approach and corresponding results.

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