WRPS-51528-FP
Revision 0

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Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC27-08RV14800

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# Full-Scale Testing Technology Maturation of a Thin Film Evaporator for High-Level Liquid Waste Management at Hanford - 12125

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## ABSTRACT

Simulant testing of a full-scale thin-film evaporator system was conducted in 2011 for technology development at the Hanford tank farms. Test results met objectives of water removal rate, effluent quality, and operational evaluation. Dilute tank waste simulant, representing a typical double-shell tank supernatant liquid layer, was concentrated from a 1.1 specific gravity to approximately 1.5 using a 4.6 $m^2$ (50 $ft^2$) heated transfer area Rototherm® evaporator from Artisan Industries. The condensed evaporator vapor stream was collected and sampled validating efficient separation of the water. An overall decontamination factor of 1.2E+06 was achieved demonstrating excellent retention of key radioactive species within the concentrated liquid stream. The evaporator system was supported by a modular steam supply, chiller, and control computer systems which would be typically implemented at the tank farms. Operation of these support systems demonstrated successful integration while identifying areas for efficiency improvement. Overall testing effort increased the maturation of this technology to support final deployment design and continued project implementation.

## INTRODUCTION

The Hanford tank farm facility utilizes evaporative technology to condense liquid wastes within its existing tanks to maximize storage capacity. A portion of this liquid directly derives from legacy plutonium production operations, but a major and growing segment of this stored liquid involves the material generated from retrieval of saturated saltcake and sludges. This saltcake and sludge waste are retrieved from single-shell storage tanks (SSTs) and then transferred to more environmentally secure double-shell tanks (DSTs). Retrievals and transfers involve the addition of water to the tank farm system, which then results in decreasing storage capacity. Waste volume reduction is performed through the 242-A Evaporator, a fixed facility housing a boiler vessel for water evaporation.

® Rototherm is a registered trademark of Artisan Industries, Inc.

The 242-A Evaporator facility was constructed in 1977 with an original design life of 20 years. Its mission need is to at least 2035 per the DOE Office of River Protection System Plan [1], to support continued SST retrievals and waste management within the DSTs while waste is being treated through the Hanford Waste Treatment and Immobilization (vitrification) Plant (WTP). Continued preventive and corrective maintenance, integrity assessments, and upgrades have successfully extended the facility life, however a critical failure that requires extensive maintenance downtime could delay retrievals and waste transfer operations to the WTP. This potential shutdown of the only waste concentrating system at Hanford is a key DOE risk.

A new thin-film evaporator system was identified to mitigate this risk. This system was further envisioned as a modular system which could be transported to any DST to provide waste management flexibility. The 242-A Evaporator operates batch-wise from a dedicated feed tank requiring transfer of waste throughout the tank farm complex to prepare its feed stream. An at-tank system would allow recovery of tank storage space without the logistic issues and cost associated with waste transfers.

This project was initiated by the tank farm operating contractor, Washington River Protection Solutions (WRPS), for the Office of River Protection/Department of Energy (ORP/DOE), through Columbia Energy and Environmental Services, Inc. (Columbia Energy). Funding for this effort was provided through the American Recovery and Reinvestment Act (ARRA) of 2009.

The project has completed two milestones under the ARRA program: multiple simulant testing on a pilot-scale system; and completion of simulant tests with a full-scale evaporator demonstration test system. This simulant testing is part of a project effort to develop this commercial evaporative technology for radioactive material processing under the DOE technology maturation program. [2] The evaporator subsystem was identified as a Critical Technology Element under this program, and its testing has concluded hardware-related technology readiness up to Technology Readiness Level 6 (general completion of engineering to full-scale prototypical systems in relevant environment). The overall actual project is at a lower technology readiness level, needing to qualify the full-scale system tests against application of final programmatic requirements, and completion of laboratory actual waste testing.

This evaporative system uses a commercial agitated thin-film evaporator technology, or wiped film evaporator (WFE). The WFE system will be located above a waste storage tank within a tank farm to receive supernatant solution pumped from a submersible pump, evaporate water from the solution, and feed the concentrated product back into the storage tank. Water is removed by evaporation at an internal heated drum surface exposed to high vacuum. The condensed water stream will be shipped to the site effluent treatment facility for final disposal. The general concept is depicted in Figure 1, showing a primary evaporation unit within the tank farm boundary, directly connected to a tank riser, with supporting systems located outside the tank farm.

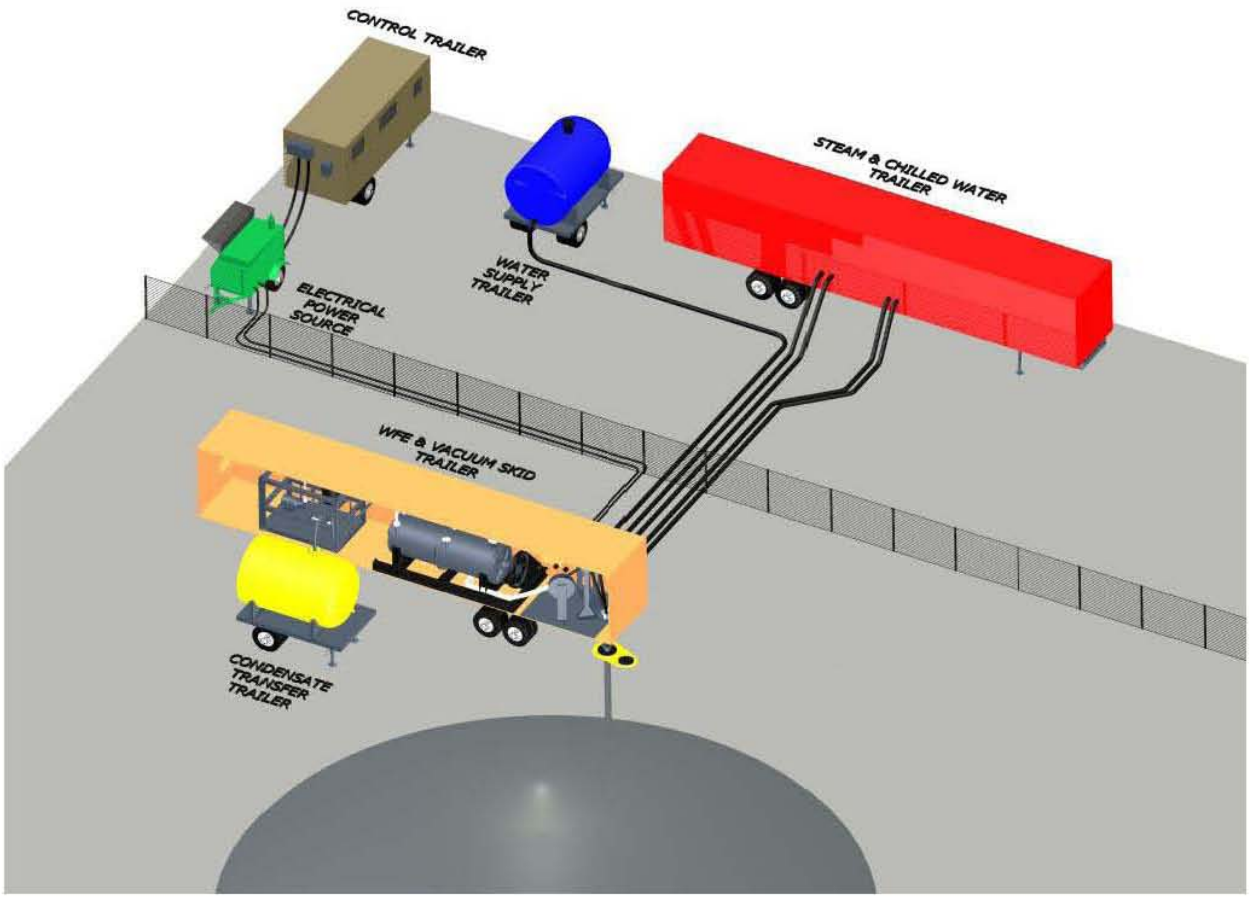

Fig. 1. Modular WFE Concept

## TEST DEVELOPMENT

Full-scale system testing in 2011 proceeded from two key activities: prior small-scale simulant testing in 2010 and full-scale system design.

### Prior Pilot-Scale Testing

Pilot-scale testing was performed in 2010 on Columbia Energy's 9.2E-02 $m^2$ (1 $ft^2$) heat transfer area Rototherm® evaporator unit from Artisan Industries, as part of ARRA scope.[3] Three simulants were tested representing processing characteristics of supernatant wastes that bounded conditions expected for deployment: DST 241-AN-105 (AN-105), DST 241-AN-107 (AN-107), and the SST dissolved saltcake. The AN-105 simulant allows fast solubility response as concentrations change. The AN-107 simulant was selected for its high organic carbon content, representing organic complexants common at the Hanford site. The SST dissolved saltcake simulant contained the highest concentration of phosphate which limits the endpoint specific gravity from gelling and solid precipitation following evaporation.

This pilot-scale testing provided data on key performance characteristics including condensate production of 16.8 – 22.5 lb/hr. This data verified the base sizing assumption of 20 lb/hr per $ft^2$ of heat transfer area. Pilot-scale testing successfully met its four primary objectives.

- *Verify Performance Characteristics:* The condensate production rate exceeded the nominal production goal of 20 lb/hr ranging from an initial 16.8 lb/hr to a high of 22.5 lb/hr while maintaining a "clean" condensate suitable for treatment by the onsite Effluent Treatment Facility (ETF).
- *Assess Discharge Vapor Quality*: The quality of the off-gas generated during pilot-scale testing demonstrated that the vapor discharge of the full-scale system will not exceed permitted DST ventilation system requirements.
- *Assess Condensed Vapor Quality*: Condensate produced by the pilot-scale WFE system is acceptable for receipt at ETF; the condensate produced during testing was below the more stringent ETF waste discharge limits.
- *Assess Process Stream Discharges*: Secondary process streams, such as WFE seal water, chiller water, and vacuum seal water, met the criteria for disposal using existing Hanford facilities.

In addition, parameter optimization testing refined the overall process parameters for both the pilot- and full-scale WFE systems by performing test runs at various points for the 3 key parameters: feed rate, WFE operating pressure (vacuum), and heat transfer medium inlet temperature. Analyzing the results from parameter optimization testing provided valuable process control information. For example, as expected, the relative quality of the condensate is most sensitive to vacuum, followed by feed rate and heat transfer medium inlet temperature. Accordingly, the condensate conductivity and contaminant concentrations are lowest when the WFE is operated at lower vacuum pressures (i.e., higher absolute pressures). Finally, pilot-scale testing successfully identified key lessons learned for full-scale design and testing.

Overall, the pilot-scale WFE testing demonstrated that the technology is capable of concentrating waste simulant up to expected operational specific gravity values (1.4 to 1.55). Although minor precipitation was observed during the first test run with AN-107 simulant, refined process parameters and improved test methods prevented precipitation from re-occurring in subsequent test campaigns, including an additional test run with AN-107 simulant.

**Full-Scale Test System Construction**

Pilot-scale testing confirmed the commercial design assumption relating heat transfer area and condensate production. This was a major component in performing design scale-up for a full-scale system. The full-scale demonstration system was labeled as WFE-D to differentiate it from the pilot-scale system.

A Value Engineering session was performed to qualify impacts of key conditions affecting scale-up: notably, weight - since the unit was projected to be installed over existing underground domed tanks; size - since material holdup affects dose consequences within the tank farm and safety hazards from accident scenarios; basic dimensions - since these affect the practicality of installation in mobile, modular containers; and basic throughput - to match existing commercial productions units from the same manufacturer, Artisan Industries.

A 50 $ft^2$ heat transfer area was selected as the optimum unit size. Support systems (steam, chiller, power, and pumps/piping) were then selected to interface with this unit's process flowsheet. The basic process flow diagram for the full-scale demonstration test unit is shown below in Figure 2.

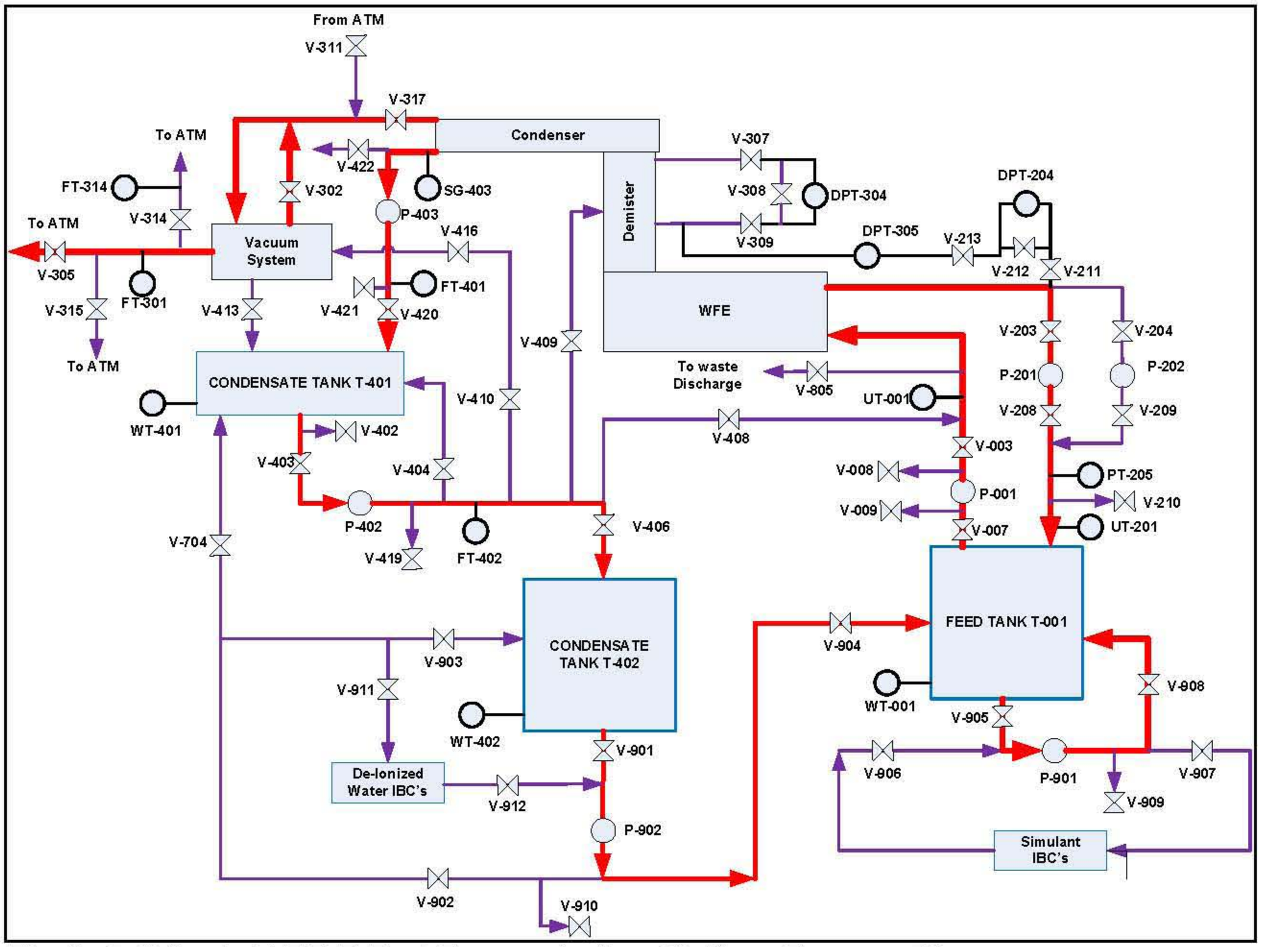


Fig. 2. Full-Scale WFE-D Test Demonstration Platform Process Diagram

FT = Flow Transmitter
CT = Conductivity Transmitter
V = Valve
P = Pump
UT = Multivariable Transmitter
WT = Weight Transmitter
ATM = Atmosphere
DPT = Differential Pressure Transmitter
PT = Pressure Transmitter
SG = Sight Glass
IBC's = Intermediate Bulk Containers

Major components and their design characteristics of the WFE-D full-scale test system are noted below in Table 1.

Table 1. Major Full-Scale WFE-D Test Demonstration Platform Components

| Equipment | Characteristics |
| --- | --- |
| Evaporator System | • Artisan Industries 50 $ft^2$ Rototherm® WFE assembly<br>  o 40 HP drive<br>  o Steam jacketed pressure vessel<br>• Demister (stainless steel housing with mesh pad and spray back-flushing capability)<br>• Condenser (shell and tube) |
| Vacuum Pump | • Gardner Denver Nash®[1] liquid ring<br>• 5 horsepower (HP) motor<br>• 60 acfm maximum off gas flowrate |
| Boiler | • Cleaver Brooks[2] Packaged Boiler from Boiler Masters (propane fired, 125 boiler HP) |
| Chiller | • 130 Ton Air Cooled Screw Chiller Package from Carrier Rental Services<br>• Cooling Fluid – 50/50 mix of propylene glycol and de-ionized water. |
| Feed Pump | • Goulds 1 HP Centrifugal Pump (13 gpm maximum flow) |
| Condensate Pump | • Goulds 3/4 HP Centrifugal Pump (25 gpm maximum flow) |
| Bottoms Pumps (2) | • Moyno®[3] 1 HP Progressive Cavity Pump (9.5 gpm maximum flow) |
| Condensate Pump | • Seepex® Progressive Cavity Pump (2.55 gpm maximum flow) |
| Motorized Control Steam Valve | • Flow Coefficient ($C_v$) 0.2 to 52.9<br>• Linear actuated valve. |
| Process Condensate Tank | • 750 gallon stainless steel horizontal tank with sight glass |
| Data Acquisition System | • Asea, Brown, and Boveri (ABB®[4]) Programmable Logic Controller |
| Feed Recirculation Pump | • Goulds 1 HP Centrifugal Pump (25 gpm maximum flow) |
| Condensate Collection Transfer Pump | • Goulds 3/4 HP Centrifugal Pump (10 gpm maximum flow) |
| Off Gas Analyzers | • Thermo Fisher Scientific 42i NOx (0-1000 ppb)<br>• Thermo Fisher Scientific 43i SOx (0-1000 ppb) |

The WFE-D test system was constructed at the Columbia Energy Test Facility. The evaporator and vacuum/condensate systems were laid out in the general arrangement

[1] Gardner, Denver, Nash® is a registered trademark of Gardner, Denver, Nash, Number 18 Weiwu Road, Zibo Economic Development Zone, Boshan, 255213, China
[2] Cleaver Brooks® is a registered trademark of Cleaver Brooks, 221 Law Street, Thomasville, GA 31792
[3] Moyno® is a registered trademark of Moyno Pumps, 1895 W. Jefferson, Springfield, OH 45506
[4] ABB® is a registered trademark of Asea Brown Boveri, Ltd., Corporate Communications, Affolternstrasse 44, CH-8050 Zurich, Switzerland

of a single transportable module as conceptualized for deployment. These primary components are shown below in Figure 3.

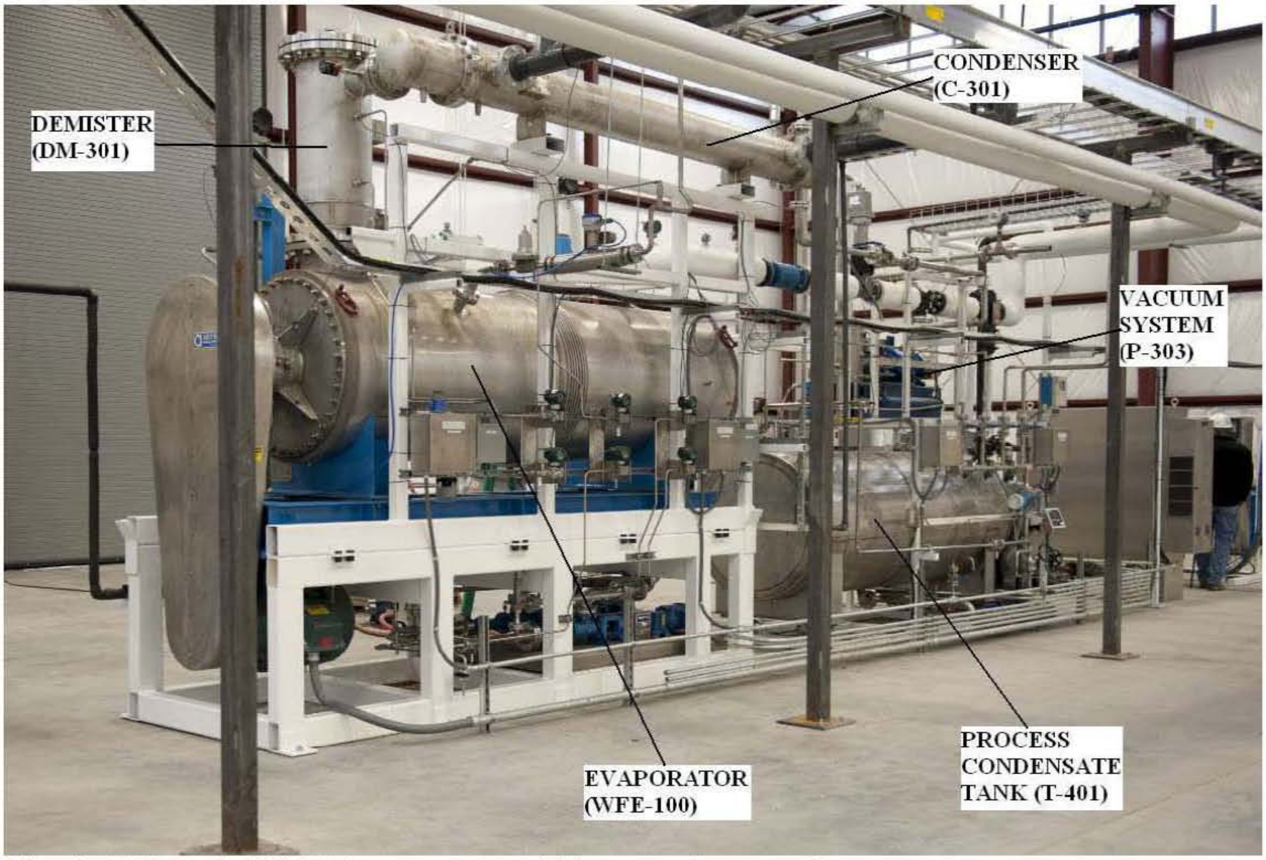


Fig. 3. Full-scale WFE Evaporator and Vacuum System Components

### Full-Scale Test Objectives

The five primary test objectives for full-scale testing are listed below.

- *Simulant Concentration.* The WFE-D system shall demonstrate that the simulant can be concentrated to a specific gravity as high as 1.5 as measured in the WFE bottoms (concentrate discharge) stream.
- *Condensate Production Rate*. The WFE-D system shall demonstrate that water can be removed from the simulant feed at a rate of 1.5 to 2.5 gallons per minute (gpm) (750 to 1,250 pounds mass per hour [lbm/hr]) as measured by the condensate production.
- *Operating Parameter Scale-Up Validation*. The WFE-D system shall be tested over the range of operating parameters established during pilot-scale testing. Operating parameters to be demonstrated include simulant feed rate, steam temperature, WFE operating pressure, and condensate production rate.

- *Evaluate Liquid Effluent.* Compare process water stream discharges to Effluent Treatment Facility (ETF) waste acceptance criteria and Treated Effluent Disposal Facility (TEDF) waste acceptance criteria per HNF-3172, *Liquid Waste Processing Facilities Waste Acceptance Criteria*. Demonstrate that the condensate, the water in the WFE seal water reservoirs, vacuum seal water reservoir, chiller water, and boiler blow down can be discharged at Hanford site effluent disposal facilities.
- *Evaluate Vapor Effluent.* Demonstrate vapor discharge characteristics are within the DST ventilation limits. Values will be compared to Washington Administrative Code (WAC)-173-460-150, "Washington State Air Pollution Control Regulations," for toxic air pollutants.

Two secondary test objectives were developed.

- *Obtain Process Upset Condition Response Data.* Identify and demonstrate the WFE-D system parameter response during process upset conditions.
- *Obtain Operational Data for Future Deployment.* Collect operational data that can be used to support the planning for the field deployment.

To accomplish these goals, WFE-D testing was divided into three separate test phases:

1. Off gas blank testing to measure baseline values for vapor and condensate production,
2. Validation testing to demonstrate waste simulant concentration from 1.16 to 1.55 specific gravity,
3. Parametric testing to demonstrate condensate production at the minimum and maximum operating setpoints for the 3 key process parameters.

The WFE-D system was tested with a modified AN-105 simulant. This simulant was selected for WFE-D testing based on successful testing during the pilot scale campaign and to remove a degree of variability between pilot-scale and full-scale test comparisons. This was the only simulant tested during the WFE-D test campaign because of limited cost and time to meet ARRA project planning.

## RESULTS

Testing commenced June 23, 2011 and finished June 28, 2011. All test objectives were achieved. A summary of the overall results are noted below and in Table 2.

- *Simulant Concentration.* The WFE-D system was able to concentrate Tank AN-105 simulant to a specific gravity of 1.55 producing a waste volume reduction factor (WVRF) of 0.683.
- *Condensate Production Rate.* The WFE-D system demonstrated that water can be removed from the simulant feed at a rate of 1.5 to 2.5 gpm (750 to 1,250 lbm/hr) as measured by the condensate production. The evaporation rate exceeded the nominal requirements of 2.0 gpm (1,000 lbm/hr) in all tests.

- *Operating Parameter Scale-Up Validation.* The WFE-D system was tested over the range of operating parameters established during pilot scale testing (feed rate, steam temperature [energy transferred], WFE operating pressure, and condensate production rate). Production rates ranged from 3.6 to 11.6% higher than heat transfer model predictions.
- *Evaluate Liquid Effluent*. Sample results showed that WFE process condensate (condensed liquid from evaporated water vapor), and seal water meets the published effluent criteria for the Hanford site effluent disposal facilities.[5] The chiller water and boiler blowdown water do not meet all the effluent criteria and thus would need to be compared to the influent acceptance criteria for TEDF. During field deployment actual waste streams from the field-deployed system must be sampled to confirm waste acceptance.
- *Evaluate Vapor Effluent.* The off gas emissions were below Washington Administrative Code (WAC) for toxic air pollutants.[6] Based on the DST ventilation system requirements for pressure and moisture control, there are no observed issues with the flow or moisture content of the discharged off-gas from the WFE.
- *Obtain Process Upset Condition Response Data.* Response data was obtained for loss of feed, loss of bottoms control, and flooded WFE chamber. All upset condition experience was recoverable with no system damage.
- *Obtain Operational Data for Future Deployment.* The boiler and chiller were reliable and the feed rate, WFE operating pressure, and steam temperature remained stable during testing; all requiring very little need for adjustments. The human machine interface (HMI) and control system were adequate to provide data and control for remote operation. During field deployment, one operator would be sufficient to operate the system from the HMI.

Table 2. Full-Scale WFE-D Process Test Results

| | Phase 1: Off Gas Blank Test | Phase 2: Validation Testing | Phase 3: Parametric Testing |
|---|---|---|---|
| Feed Rate (gpm) | 8.65 | 8.65 | 8-10 |
| WFE Operating Pressure (torr absolute) | 100 | 100 | 90-110 |
| Steam Pressure (psig) | 28 | 28 | 24-37 |
| Condensate Production Rate (lb/hr) | N/A | 1094 | Ranged from 1051 to 1276 |
| Overall (Cesium) Decontamination Factor | N/A | 1,200,000 | N/A |
| Simulant Concentration | N/A | 1.17 to 1.55 | N/A |
| Waste Volume Reduction Factor (WVRF) | N/A | 0.683 | N/A |

## DISCUSSION

Full-scale WFE testing met each of the four primary test objectives and accomplished the goal of maturing the technology. Demonstration testing confirmed the details (e.g., sizing, throughput, and process parameters) necessary to finalize a field deployable design. Overall, the WFE-D testing demonstrated that a full-scale system using steam as the heating medium is capable of concentrating waste simulant up to expected operational specific gravity values (1.55), while producing a condensate and secondary process streams acceptable for receipt at existing Hanford treatment facilities.

### Simulant Concentration

During validation testing the WFE-D was able to concentrate 22,073 lbs of modified AN-105 simulant from a starting specific gravity of 1.17 to 8,732 lbs with a final feed tank value of 1.46. Testing ended when the bottoms specific gravity leaving the WFE reached 1.55. The WVRF (initial feed volume minus ending feed volume divided by starting feed volume) achieved was 0.683. Figure 4 shows the relationship of the specific gravity of the feed and bottoms during validation testing.

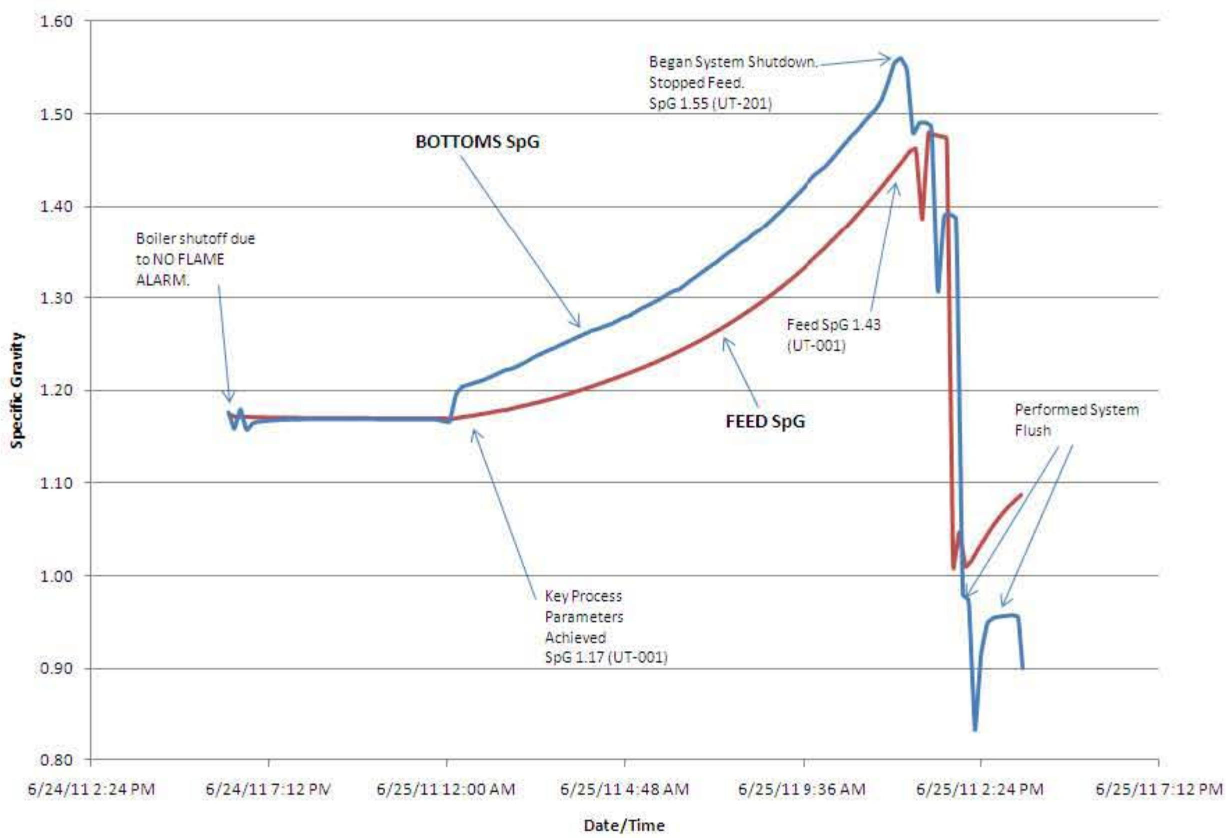


Fig. 4. Full-Scale WFE-D Testing Feed and Bottoms Specific Gravities

## Condensate Production

During validation testing, the feed rate was 8.65 gpm, WFE operating pressure was 100 torr absolute, and steam pressure was 28 psig, the condensate production rate ranged from 1.85 to 2.3 gpm with an average rate of 2.185 gpm (1,094 lbm/hr). The condensate production for the eight parametric test runs is shown in Table 3. For each of the parametric test runs the condensate production rate exceeded the nominal production rate requirement (2.0 gpm [1,000 lbm/hr]). The table lists the key process parameters, starting and ending specific gravities, temperature, and condensate production rate observed for each test run during parametric testing.

Table 3. Full-Scale WFE-D Testing Parametric Test Results

| Test Run | Average Feed Rate [UT-001] (gpm) | Average WFE Operating Pressure [DPT-305] torr absolute | Average Steam Pressure [PT502] (psig) | Feed Starting Specific Gravity [UT-001] | Feed Starting Temperature [UT-001] (°F) | Feed Ending Specific Gravity [UT-001] | Feed Ending Temperature [UT-001] (°F) | Average Condensate FT-401 Flow Rate (gal/min) [lb/hr] |
|---|---|---|---|---|---|---|---|---|
| 1 | 8.6 | 110 | 24 | 1.17 | 77 | 1.23 | 116.4 | 2.071 [1037] |
| 2 | 10 | 110 | 24 | 1.17 | 100 | 1.25 | 126.1 | 2.185 [1094] |
| 3 | 10 | 90 | 24 | 1.17 | 102.3 | 1.27 | 121.8 | 2.363 [1183] |
| 4 | 8 | 90 | 24 | 1.17 | 100.9 | 1.28 | 118.0 | 2.312 [1157] |
| 5 | 8 | 110 | 37 | 1.17 | 96.9 | 1.28 | 124.1 | 2.514 [1258] |
| 6 | 10 | 110 | 33 | 1.17 | 100.2 | 1.28 | 126.0 | 2.479 [1241] |
| 7 | 10 | 90 | 31 | 1.17 | 102.4 | 1.31 | 120.7 | 2.599 [1301] |
| 8 | 8 | 90 | 29 | 1.17 | 97.1 | 1.27 | 118.3 | 2.473 [1238] |

## Operating Parameter Scale-Up Validation

Pilot-scale testing (RPP-RPT-47442) identified three key process parameters having a significant influence on the WFE operation: process fluid feed rate, WFE operating pressure, and the heating oil inlet temperature. A heat transfer model was developed to determine the ranges of these parameters to be used for pilot scale testing. The information gathered from pilot scale testing confirmed the heat transfer coefficients developed in the model were accurate. The heat transfer coefficient for full-scale WFE-

D AN-105 simulant testing was then derived from pilot scale testing results. The heat transfer model was used to predict the values of the key process parameters. A change from pilot scale testing is that steam was used in place of hot oil. The heat transfer coefficients of steam are greater than hot oil resulting in lower operating temperatures for steam as opposed to hot oil. Hot oil also requires a high Reynolds number (i.e., high flow) to achieve a sufficient heat transfer coefficient.

Feed rates, operating vacuum, and steam pressures were changed through eight parametric test runs. All parametric runs generated a final specific gravity value of 1.2 to 1.3. with an average condensate flow of 2.1 to 2.5 gal/min. Table 5 shows the high agreement for predicted condensate rate versus actual using this heat transfer model. Full-scale testing validated this model for deployment design and operation.

Table 5. Condensate Production Comparison

| Test | Condensate Production Rate FT-401 gpm | Predicted Rate gpm | Delta (%) |
|---|---|---|---|
| Validation Test | 2.185 | 2.108 | 3.7 |
| Parametric Test Run #1 | 2.071 | 1.922 | 7.8 |
| Parametric Test Run #2 | 2.185 | 2.107 | 3.7 |
| Parametric Test Run #3 | 2.363 | 2.217 | 6.6 |
| Parametric Test Run #4 | 2.312 | 2.258 | 2.3 |
| Parametric Test Run #5 | 2.514 | 2.426 | 3.6 |
| Parametric Test Run #6 | 2.479 | 2.384 | 4.0 |
| Parametric Test Run #7 | 2.599 | 2.291 | 13.4 |
| Parametric Test Run #8 | 2.473 | 2.330 | 6.1 |

Further test results may be found in the Wiped Film Evaporator Full-Scale Demonstration System Test Report. [4]

## Lessons Learned

The major components were evaluated for suitability in field deployment. As expected, the Rototherm® performed well and the post-test inspection verified that the unit was clean and there was no holdup of waste. The boiler, steam system, and chiller performed well and would be suitable for field deployment. The vacuum system did not function as planned (would not accept additional seal water from condensate) and was modified to pull only the non-condensed vapor through the system. Condensate was routed directly to the condensate tank instead of going to the vacuum system. With the modification in place, the vacuum system operated without incident and was able to maintain the WFE operating pressure specified for each test. The pumps worked adequately during testing. For field deployment a bottoms pump with flow capacity equal to or slightly greater than the feed pump would be desired to ensure the bottoms flowrate could always keep up with the feed flowrate. The 750 gallon process condensate tank worked adequately during testing and with an interlock to prevent the tank from overflowing and removal of the sight glass, the tank would be suitable for field deployment.

Although feed reconstitution is not to be used during field deployment, the use of feed reconstitution was beneficial for WFE-D testing. Feed reconstitution consisted of mixing the condensate produced with the remaining feed/bottoms that was present at the end of testing to create a new batch of feed. This allowed for feed to be re-used and for the starting feed properties to be similar during each of the parametric tests. Employing feed reconstitution reduced the potential time frame to accomplish testing along with the extraordinary cost of purchasing, handling, and disposing of extra simulant.

In comparing the performance of the WFE-D system to the WFE pilot scale unit, the system performed as expected. In some cases WFE-D exceeded expectations, such as higher condensate production rate and lower air in-leakage. Overall the testing demonstrated that the full-scale design is capable of concentrating waste simulant up to expected operational specific gravity values while producing condensate that meets the production and quality requirements. Based on the test results, the WFE-D provided valuable information for development and operation of the field deployable design.

## CONCLUSION

Mobile, modular thin-film evaporation is a viable alternative technology for concentration of Hanford tank supernatant. Besides providing risk mitigation for a critical 242-A Evaporator component failure that results in a lengthy repair, this technology can provide flexible at-tank treatment for retrieval operations, waste blending, and tank freeboard space improvement. Further effort should be expended to mature this technology for full-scale deployment and processing of actual tank waste, while continuing to analyze mission applications.

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