Pilot-scale Test Results of a Thin Film Evaporator System for Management of Liquid High-Level Wastes at the Hanford Site, Washington, USA - 11364

Robert A. Wilson*, Travis H. Beck*, and Jeff Larkin*
Allan R. “Rick” Tedeschi**, John E. Corbett**,
*Columbia Energy and Environmental Services, Inc., Richland, Washington 99354
**Washington River Protection Solutions, LLC, Richland, Washington 99352

ABSTRACT

A modular, transportable evaporator system, using thin film evaporative technology, is planned for deployment at the Hanford radioactive waste storage tank complex. This technology, herein referred to as a wiped film evaporator (WFE), will be located at grade level above an underground storage tank to receive pumped liquids, concentrate the liquid stream from 1.1 specific gravity to approximately 1.4 and then return the concentrated solution back into the 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. This operation provides significant risk mitigation to failure of the aging 242-A Evaporator facility; the only operating evaporative system at Hanford maximizing waste storage.

This technology is being implemented through a development and deployment project 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). The project will finalize technology maturity and install a system at one of the double-shell tank farms.

This paper summarizes results of a pilot-scale test program conducted during calendar year 2010 as part of the ongoing technology maturation development scope for the WFE.

INTRODUCTION

A modular, transportable, evaporative system is planned for development and deployment within the Hanford tank farms to supplement existing evaporative capacity. This evaporative system uses a commercial agitated thin-film evaporator technology, referred herein as a WFE. This WFE system will be located above a waste storage tank within the tank farm to receive supernatant solution pumped from a submerged pump, evaporate water from the solution, and feed the concentrated product back into the storage tank. 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 [1].

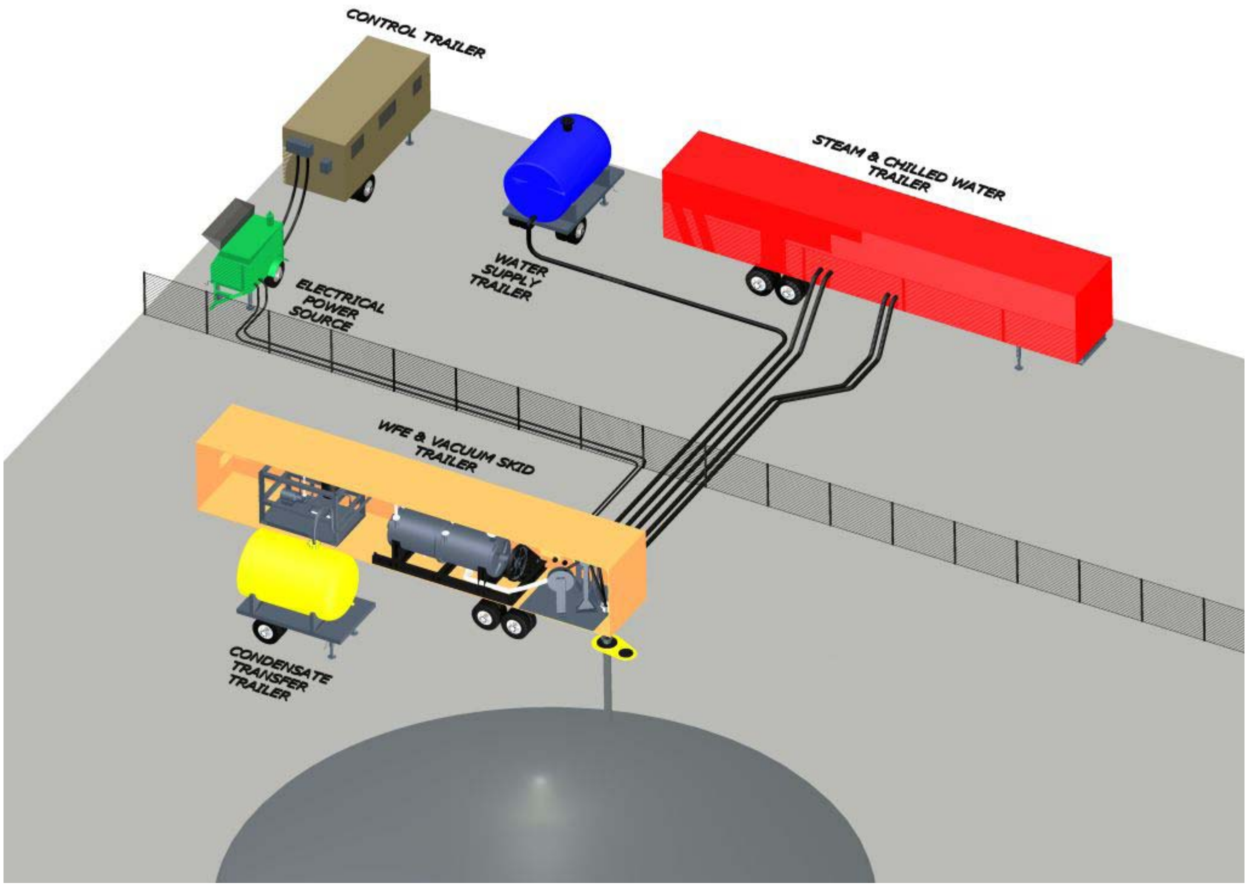

Fig. 1. Modular WFE concept.

The WFE system would supplement the current boiling evaporative capability through the Hanford 242-A Evaporator facility. A WFE system(s) would mitigate the risk of a 242-A facility critical failure and subsequent downtime that would negatively impact waste feed storage and feed delivery to the Waste Treatment and Immobilization Plant (WTP). The WFE system(s) would also increase the flexibility for waste feed management by providing evaporative capacity at the tank source, eliminating transfers to the 242-A facility, and minimizing secondary waste generation from these transfers.

There are two project phases. The first phase of this project, WFE Project Development, evaluates and develops the evaporative technology through Department of Energy (DOE) technology readiness level (TRL) 6, which generally qualifies an engineering/pilot scale system in a simulated environment. This will be achieved by testing tank waste simulants on a pilot-scale system. In addition, a full-scale system will be procured for testing simulants to qualify and resolve scale-up issues. This WFE Project Development phase is funded through the American Recovery and Reinvestment Act (ARRA) of 2009 through FY11and normal baseline funding during FY12 and 13.

The second phase, WFE Project Deployment, modifies the developed full-scale hardware, and/or procures new components, to allow testing with actual waste within a Hanford tank farm. This phase will also complete remaining project documentation, environmental permitting, nuclear safety protocols, necessary tank farm modifications, and training for tank farm operation.

The second phase takes the evaporative technology from TRL 6 to TRL 9, System Operations. The WFE Project Deployment phase, beginning in FY14, is funded from normal baseline funding [2]. The major activities per the two phases are noted below in Table I.

Table I. WFE Project Phase Approach.

PHASE	WFE PROJECT DEVELOPMENT					WFE PROJECT DEPLOYMENT				
Fiscal Year	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
Major Scope	Tech. Eval.	Pilot Scale Simulant Testing (DST/SST)	Full Scale Simulant Testing (DST)	Pilot-Scale Testing Secondary Wastes & Simulants		Final Design & Fabr. Const. Start	Final Fabr., Const. & Testing	Field Testing and Operation with Actual Waste		
Technology Readiness Level	TRL-2 TRL-3	TRL-4 → TRL-5 →	TRL-6 →				TRL-7 →	TRL-8 →		TRL-9 →
DOE 413.3 Stage	Initiation Pre-Conceptual Planning					Project Execution		Proj. Closeout & Mission Execution Commissioning and Operations		
Quality Assurance Level	Commercial Grade	Enhanced & Commercial				Enhanced / Full				
Funding Base	Recovery Act			Baseline						

PILOT SCALE WFE TESTING

As part of the WFE Project Development activities in FY10, WRPS conducted a pilot-scale test program using a WFE pilot-scale system developed, owned, and operated by Columbia Energy. The WFE pilot-scale system consisted of a 1/50th-scale system, a WFE with a heat transfer area of 0.093 square meters (1 ft^2). The pilot-scale process is depicted in Figure 2. Major components included:

- Rototherm® E evaporator assembly with condenser; 9.3×10^{-2} m (1 ft^2)
- Delta-Therm® Ice T™ water chiller assembly; 8.9×10^7 joule/hr (7 ton)
- Tuthill® vacuum and blower systems liquid ring vacuum pumping system; 34 m^3/sec (20 cfm)
- Delta-Therm oil heater assembly; 24 kW
- Three Seepex® progressive cavity pumps (one each for the feed, bottoms, and condensate streams)
- Programmable logic control cabinet
- Pump and motor control panel
- Various flow transmitters, thermocouples, pressure transmitters, and level indicators
- Various manually operated valves.

® Rototherm is a regsitered trademark of Artisan Industries, Inc.
® Delta-Therm is a registered trademark of Delta-Therm Corporation.
™ Ice T is a trademark of Delta T Systems, Inc.
® Tuthill is a registered trademark of Tuthill Corporation.
® Seepex is a registered trademark of seepex Seeberger GmbH+Co.

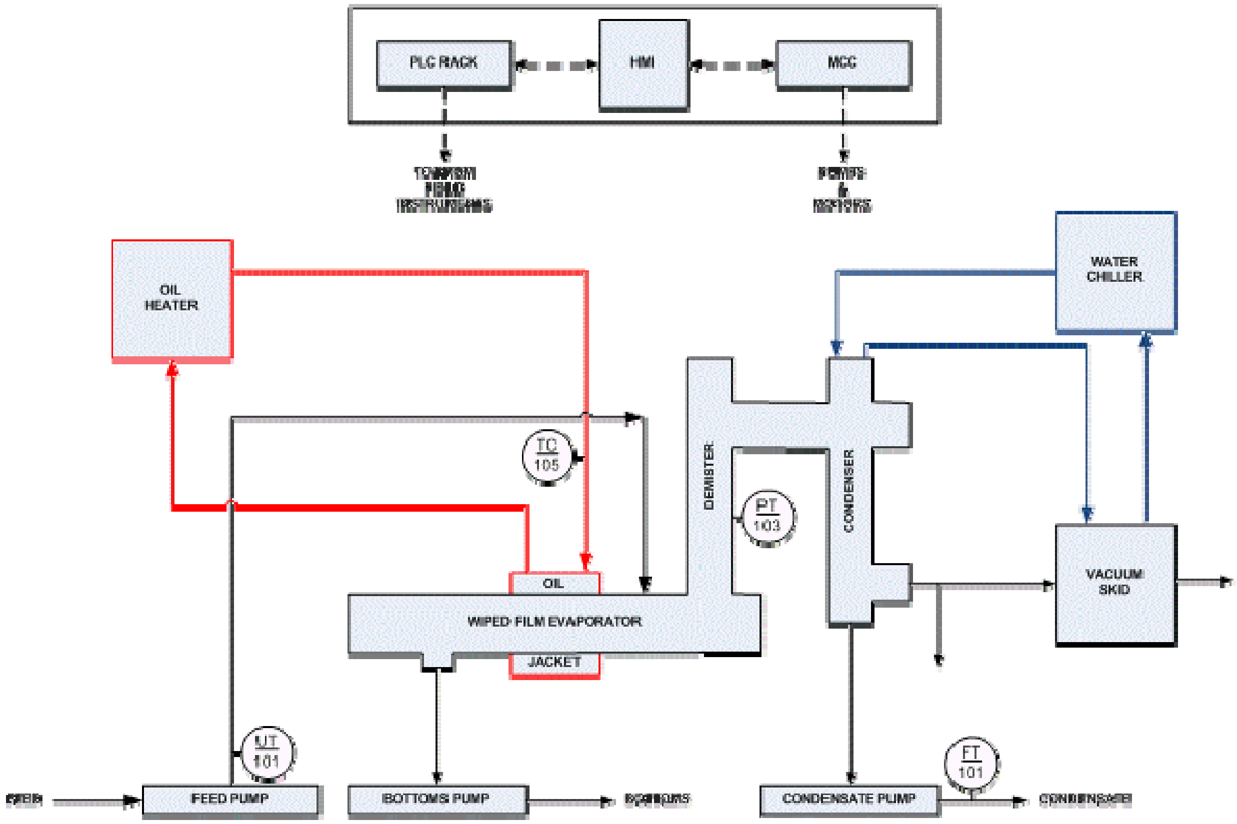

Fig. 2. Pilot Scale WFE System [3].

Pilot-scale WFE testing was conducted in three stages using non-radioactive simulants representative of DST and SST waste: 1) initial parameter and data gathering to support parameter optimization, 2) parameter optimization to determine the optimal process parameters, and 3) final data gathering using the optimized process parameters (Figure 3). Parameter optimization used a response surface methodology to design the experimental conditions and testing approach. Previous testing identified three variables having a significant influence on the WFE operation: process fluid feed rate, WFE operating pressure, and the heating medium inlet temperature [4]. The operating ranges for these parameters were based on expected operating ranges for the full-scale demonstration system and developed models based on pilot-scale results. The ranges were used as inputs into the response surface methodology for the test settings [5].

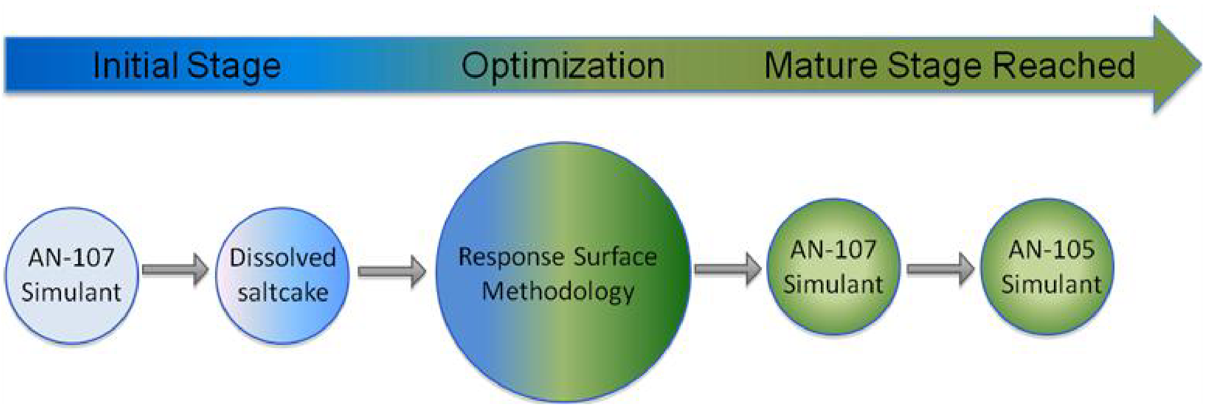

Fig. 3. Pilot Scale WFE Simulant Timeline.

SIMULANT SELECTION

Initial simulant selection was determined based on objectives identified for the pilot-scale tests [3]. Physical and chemical characteristics were derived from these objectives to narrow down the potential simulant cases. The simulants chosen were based on specific processing characteristics that best defined and enveloped the abilities of the WFE. The simulants selected were DST 241-AN-105 (AN-105), DST 241-AN-107 (AN-107), and the SST dissolved saltcake [6] [7].

The simulant representing AN-105 was selected based on its relation to the sodium aluminate boundary on the Barney Diagram (Figure 4). This simulant is located close to the gibbsite phase boundary meaning that a short processing time (relative to the others) results in crossing this boundary [8]. The AN-107 simulant was selected for its high organic carbon content, present as organic complexants [9]. These complexants are common at the Hanford site. The SST dissolved saltcake simulant was selected based on the need for a SST simulant and this one provided representative characteristics [10]. This simulant contained the highest concentration of phosphate which limited the endpoint specific gravity. High concentrations of phosphates in tank waste are known causes of gelling and solid precipitation following evaporation [11].

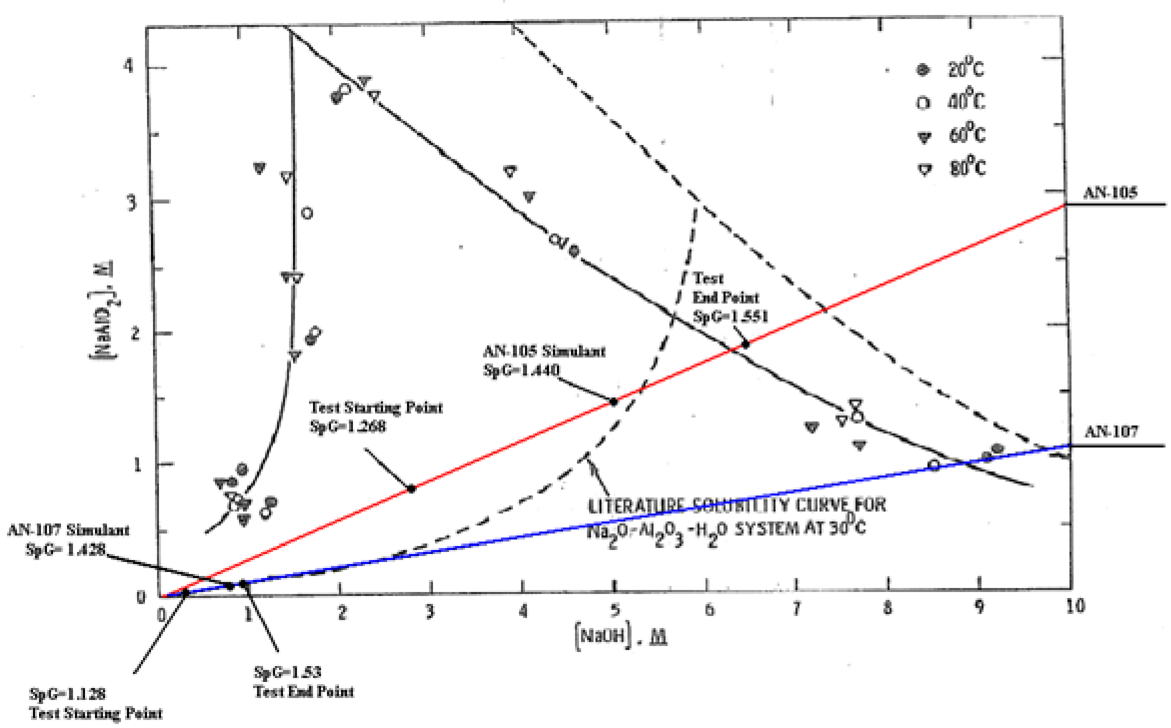

Fig. 4. Sodium Aluminate Solubility of AN-105 and AN-107 Simulants (Barney Diagram).

TEST OBJECTIVES

The goal of pilot-scale WFE testing was to mature the technology from its initial TRL of 3 through TRL 4 and 5 by addressing the open, testing-related lines of inquiry for technology readiness [3]. To accomplish this goal, four primary test objectives were developed, each supported by a detailed matrix linking test objectives to lines of inquiry to specific instruments or data collected. The four primary test objectives were: 1) verify performance characteristics of the

WFE, 2) assess the quality of non-condensable vapor against applicable discharge requirements, 3) assess the quality of condensable vapor against applicable discharge requirements, and 4) assess process stream discharges against waste acceptance criteria for receipt at existing Hanford treatment facilities. Table II lists the overall test objectives for simulant testing on DST and SST simulants.

Table II. Pilot-Scale WFE Test Objectives for DST and SST Simulants [3]

Test Objective
Verify Performance Characteristics – Verify pilot-scale WFE test system to support the evaporation of 15 to 25 pounds (lb) of water per hour per square foot (hr/ft^2) of heat transfer area.
Assess Discharge Vapor Quality – Compare air quality of the discharged vapor to the Hanford Site air operating permit [12].
Assess Condensed Vapor Quality – Compare condensed vapor with the Effluent Treatment Facility (ETF) waste acceptance criteria (WAC) [13].
Assess Process Stream Discharges – Compare WFE Seal Water to the ETF WAC.
Assess Process Stream Discharges – Compare Vacuum Seal Water to the ETF WAC.
Assess Process Stream Discharges – Compare chiller water to the Treated Effluent Disposal Facility WAC.

RESULTS

Pilot-scale WFE testing was performed starting February 8, 2010 and finished June 14, 2010. During this time, four separate test campaigns and one parameter optimization campaign were conducted to mature the WFE technology. The testing began with dilute AN-107 simulant and dilute SST simulant. Data gathered from these two tests were used to define the key process parameters (feed rate, WFE operating pressure, and heating medium inlet temperature) used in the parameter optimization testing. Data from the parameter optimization testing was used to define the key process parameters for retesting AN-107. The final test performed was on dilute AN-105 simulant using the same key process parameters that were used for the AN-107 second test evolution. Table III summarizes the results from pilot-scale WFE testing on each of the simulants.

Successful completion of testing met the four primary test objectives:

- ***Verify Performance Characteristics***: Testing allowed the development and refinement of process parameters to evaporate 20 pounds of water per hour per square foot of heat transfer area. After refining the test parameters following the first test campaign, the condensate production rate exceeded the nominal production goal of 20 lb/min for the remaining tests. The condensate production rate ranged 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 ETF.

Table III. Summary of Pilot-scale WFE Testing

	AN-107 Simulant (First Test Evolution)	**SST Simulant Testing**	**AN-107 Simulant (Second Test Evolution)**	**AN-105 Simulant Testing**
Test Date (MM/DD/YY)	2/8/10 and 2/9/10	2/25/10	6/8/10	6/14/10
Test Duration (Hrs)	12	7.5	7	6.75
Key Process Parameters				
Feed Rate (gpm)	0.480	0.480[(a)]	0.172	0.172
WFE Operating Pressure (torr abs)	67	100	80	80
Oil Inlet Temperature (°F)	325	380	358	358
Condensate Characteristics				
Condensate Production Rate (lb/hr)	16.8	21.2	22.5	20.5
Cesium Decontamination Factor [(b)]	5.5×10^4	3.7×10^4	7.0×10^4	5.5×10^5
Condensate Conductivity (µS/cm)	N/T	N/T	1.7	2 - 42
Compatible with ETF WAC [13]	Yes	Yes	Yes	Yes
Feed/Bottoms Characteristics				
Waste Volume Reduction Factor	0.795	0.731	0.729	0.482
Starting Feed SpG	1.128	1.120	1.128	1.268
Ending Feed SpG	1.528	1.432	1.463	1.470
Peak Bottoms SpG	1.528	1.469	1.533	1.551
Vacuum Off Gas Characteristics				
Issues w/Hanford Air Permit [12]	None	None	None	None
Cesium Partition Factor [(b)]	N/T	N/T	2.1×10^7	2.4×10^8
Mass Flow (lb/min)	0.0017	0.0015	0.0010	0.0010
Pressure (torr)	N/T	N/T	760	762
Temperature (°F)	N/T	N/T	81	78
Relative Humidity (%)	95	75	88-97	88-92
Concentration of NOx (µg/L)	<200	N/T	N/T	N/T
Concentration of SOx (µg/L)	<15	N/T	N/T	N/T
WFE Seal Water Characteristics				
Compatible with ETF WAC [13]	Yes	Yes	Yes	Yes
Chiller Water Characteristics				
Compatible with TEDF WAC [13]	Yes	Yes	Yes	Yes
Compatible with ETF WAC [13]	Yes	Yes	Yes	Yes
Vacuum Seal Water Characteristics				
Compatible with ETF WAC [13]	Yes	Yes	Yes	Yes

(a) This campaign was conducted at fixed mass flow rate. Consequently, the volumetric flow rate continually changed.

(b) Factors for the overall pilot-scale WFE test system.

%	=	percent	gpm	=	gallons per minute	SpG	=	specific gravity
°F	=	degrees Fahrenheit	Hrs	=	hours	SST	=	single-shell tank
µS/L	=	microSiemen per liter	lb/hr	=	pounds per hour	TEDF	=	Treated Effluent Disposal Facility
ETF	=	Effluent Treatment Facility	N/T	=	not tested	WAC	=	waste acceptance criteria

- ***Assess Discharge Vapor Quality***: As expected, the quality of the off-gas generated during pilot-scale testing demonstrated that the vapor discharge of the full-scale system will not exceed the DST ventilation system conditions under the Hanford Air Permit [11]. Based on the DST ventilation system requirements for pressure and moisture control, there are no observed issues with the flow or moisture content of discharged off-gas from the WFE.
- ***Assess Condensed Vapor Quality***: Analytical results from the condensate collected during testing demonstrated that the condensate produced by the pilot-scale WFE system is acceptable for receipt at ETF, although the actual waste stream must be sampled to confirm waste acceptance. ETF does not publish influent criteria for waste acceptance because the criteria are subject to change, but, when compared against the ETF waste discharge limit, that is, the limits after treatment, the condensate produced during testing was below the more stringent 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 such as the 200 Area TEDF and ETF. As with condensate, actual waste streams from full-scale field campaigns will require analysis of the respective water streams prior to receipt, but based on the results of pilot-scale testing the secondary process streams may be treated using existing treatment facilities.

CONCLUSIONS

Pilot-scale WFE testing met each of the four primary test objectives and accomplished the goal of maturing the technology from its initial TRL of 3 through TRL 4 and 5 by addressing the open, testing-related lines of inquiry for technology readiness. As a result of the structured testing approach, the pilot-scale WFE testing met each of the open lines of inquiry for TRL 4 and all but one for TRL 5.

As part of the technology maturation process, pilot-scale testing confirmed the design details (e.g., sizing, throughput, and process parameters) necessary to finalize design and procure full-scale components. This allows the closeout of the single, remaining open line of inquiry for TRL 5 (TRL Line of Inquiry 5-2, "Plant size components available for testing" [3]) at the beginning of full-scale demonstration testing.

Pilot-scale WFE testing also addressed design-related lines of inquiry for TRL 6, furthering the understanding of the technology and providing directly-applicable information for the parallel full-scale design activity. By advancing the maturity of the technology at pilot-scale, design of the full-scale WFE system benefited from the data collected and, as a result, specific process parameters and design features were validated and incorporated into the full-scale demonstration system design.

In addition to the four primary test objectives, parameter optimization testing refined the overall process parameters for both the pilot- and full-scale WFE systems. Analyzing the results from parameter optimization testing provided valuable process control information. For example, the heat transfer medium (i.e., oil during pilot-scale testing and steam for full-scale testing) inlet temperature has the greatest impact on the production of condensate, followed by WFE operating pressure and feed rate. 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 1.5). Although precipitation was observed during the AN-107 first test evolution, refined process parameters and improved test methods prevented precipitation from re-occurring in subsequent test campaigns. Based on pilot-scale testing results, the WFE technology is a suitable alternative for reducing liquid waste streams at Hanford and a solid foundation for full-scale system design and demonstration testing has been established.

LESSONS LEARNED

There were a number of improvements made during the progression of the pilot-scale WFE test campaigns. The key lessons learned were:

1. Using a lower feed rate. Following the AN-107 first test evolution and SST testing, the feed rate was reduced from 0.480 gpm to 0.172 gpm. With the higher feed rate, more sensible heat was required to raise the temperature of the feed to cause evaporation. Thus the system was more efficient with the lower feed rates. As a result, the pilot-scale WFE system was able to produce a more stable condensate production rate from start to finish. The feed rate used during pilot-scale testing will be scaled to the full scale demonstration unit.

2. Since the WFE operating pressure is based on an absolute pressure, a barometer was incorporated into testing following the AN-107 simulant first test evolution and SST simulant testing. When changes to the atmospheric pressure were indicated, the vacuum pump was adjusted to maintain the WFE operating pressure at a constant absolute pressure. Atmospheric pressure needs to be monitored during full-scale demonstration testing.

3. Confirmation of feed not requiring a cooling jacket. The first two pilot-scale WFE tests were performed with an external cooling jacket attached to the outside of the feed tank. Chiller water was supplied to the cooling jacket in an attempt to maintain the feed temperature to below 100 °F.

   Columbia Energy developed a calculation to determine the temperature response inside of the DST, which would not have an external cooling jacket [14]. As a result, subsequent pilot-scale WFE tests were performed without the external cooling jacket. The calculated temperature response was comparable to the results of pilot-scale testing without cooling the feed.

4. Consider taking additional condensate samples at a more frequent interval on the full-scale demonstration system to quantify when steady-state conditions are reached.

REFERENCES

1. A. R. TEDESCHI, "Application of a Thin Film Evaporator System for Management of Liquid High-Level Wastes at Hanford", Waste Management Symposia (2010).
2. "Wiped Film Evaporator Project Execution Plan", RPP-PLAN-41513, Rev. 1, Washington River Protection Solutions (2010).
3. "Wiped Film Evaporator Technology Maturation Plan", RPP-PLAN-43339, Rev. 0, Washington River Protection Solutions (2009).
4. "Pilot-Scale Thin Film Evaporator Test Report", CEES-0393 Rev. 0, Columbia Energy and Environmental Services, Inc., (2008).
5. "Pilot-Scale Wiped Film Evaporator Test Report," RPP-RPT-47442, Rev. 0, Washington River Protection Solutions (2010).
6. "Hanford Waste Simulants Created to Support the Research and Development on the River Protection Project – Waste Treatment Plant", WSRC-TR-2000-00338, Rev. 0, Westinghouse Savannah River Company (2001).
7. "Cold Dissolved Saltcake Waste Simulant Development, Preparation, and Analysis", PNNL-14194, Rev. 1, Pacific Northwest National Laboratory (2003).
8. "Pilot-Scale Wiped Film Evaporator Test Plan for Dilute AN-105 Simulant", CEES-0734, Rev. 0, Columbia Energy and Environmental Services, Inc. (2010).
9. "Pilot-Scale Wiped Film Evaporator Test Plan for Double-Shell Tank Supernatant Simulant AN-107", CEES-0643, Rev. 0, Columbia Energy and Environmental Services, Inc. (2010).
10. "Pilot-Scale Wiped Film Evaporator Test Plan for Dilute SST Simulant", CEES-0641, Rev. 0, Columbia Energy and Environmental Services, Inc. (2010).
11. "Waste Transfer, Dilution, and Flushing Requirements", TFC-ENG-STD-26, Rev. A-8, Washington River Protection Solutions (2010).
12. *Hanford Site Air Operating Permit*, AOP 00-05-06, Washington State Department of Ecology (as amended).
13. "Liquid Waste Processing Facilities Waste Acceptance Criteria", HNF-3172, Rev. 3, Fluor Hanford (2005)
14. "Full-Scale Demonstration Unit Double-Shell Tank Temperature Response Calculation", CEES-CALC-221-P-002, Rev. 0, Columbia Energy and Environmental Services, Inc. (2010).