New Methods to Remove Stubborn Tank Heels Using Agitation and Continuous Recirculation - 11207

Jason. R. Vitali
Savannah River Remediation, LLC – Aiken, SC 29808

ABSTRACT

The Department of Energy (DOE) at the Savannah River Site (SRS) intends to remove from service and operationally close 22 waste tanks within 8 years that do not meet current containment standards. The ability to remove residual solids is vital to accelerate closure of these highly radioactive storage tanks. SRS is retrieving waste as part of an accelerated tank closure program. Previous methods of waste removal included the addition of large volumes of water in a batch process followed by mixing and transfer from the waste storage tank. Following this mechanical cleaning approach, chemical cleaning, consisting of bulk oxalic acid additions to the tank, was used to remove remaining solids from the tanks.

Previous mechanical and chemical cleaning methods to remove the solids residue did not meet expectations (i.e., excessive amounts of radioactive material remained in the tanks). The insoluble solids remaining in the tanks were large, fast-settling particles that proved difficult to remove using previous methods. This, along with storage space constraints within the waste tanks, is a significant limitation when attempting to remove the solids. Recently, a new mechanical cleaning operation was used on two tanks targeted for closure (Tanks 5F and 6F), which involved a feed and bleed or continuous recirculation transfer method.

The method was designed and implemented in two phases. During the first phase, fresh water was introduced into Tank 5F while a transfer pump was simultaneously removing liquid out of Tank 5F at approximately the same flow rate (i.e., a feed and bleed process). During this operation, three mixing pumps were used to suspend the residual solids to increase the likelihood of transferring the solids from the tank before settling. While this process proved to be successful at removing residual solids from the tank, storage space constraints continued to be an operational issue, as the feed and bleed process created approximately 375,000 gallons of additional waste volume.

The second phase to remove residual solids was deployed on Tank 6F and consisted of agitation and continuous recirculation. Removal is accomplished by agitating the contents using three mixing pumps while simultaneously pumping the Tank 6F contents suspension to a receipt tank. The receipt tank is unmixed (tranquil) and serves as a settling basin allowing the particles to sink. A temporary waste transfer and pumping system recirculates the clarified supernatant liquid to Tank 6F at a rate nearly equal to that of the Tank 6F transfer pump. This arrangement allows for the greatest mixing and transfer turnover rate in the shortest operation time while adding no additional volume to the high level waste storage system. Through the use of the recirculation transfer line, space constraints were eliminated as an operational limitation during this phase of the process.

INTRODUCTION

As part of an accelerated tank closure program, the Department of Energy (DOE) at the Savannah River Site (SRS) intends to remove from service and operationally close 22 waste tanks within 8 years that do not meet current containment standards. This is aggressive considering that in the more than 50 years of operation of SRS, only two tanks have been operationally closed and grouted.

The single shell High Level Waste tanks targeted for closure were constructed from commercial grade carbon steel in the mid-1950's to the early 1960's. In general, their dimensions range from 23 to 26 meters in diameter, 7 to 10 meters high, and the volumetric capacity ranges from 2.8 to 4.9 million liters. Typically, each tank contains an internal labyrinth of cooling coils made from carbon steel, which further complicates waste removal, cleaning, and closure.

The ability to remove residual solids is vital to accelerate closure of these highly radioactive storage tanks. Previous methods of waste removal that have been utilized and presented at the Waste Management Symposia included the addition of large volumes of water in a batch process followed by mixing and transfer from the waste storage tank [1]. Following this mechanical cleaning approach, chemical cleaning, consisting of bulk oxalic acid additions to the tank, was used to remove as much of the remaining solids from the tanks as possible [2].

Previous mechanical and chemical cleaning methods to remove the solids residue did not meet closure targets (i.e., excessive amounts of radioactive material remained in the tanks). The insoluble solids remaining in the tanks were large, fast-settling particles that proved difficult to remove using previous methods. Additionally, due to mixing pump capabilities, mixing operations are suspended at low volumes during the waste removal process. During operations, pump speed is decreased at tank levels below approximately 44 inches, and pump operations are suspended at levels below approximately 36 inches [3]. Furthermore, storage space constraints within the tank farms significantly impact the ability to maximize waste removal utilizing batch operations due to the inability to store excessive amounts of new liquid into the system. As shown in Figure 1, available tank space is limited in the liquid waste system. Available tank space has been declining since the 1980's due to waste removal activities and preparation of sludge batches to feed to the Defense Waste Processing Facility (DWPF). As waste removal efforts continue, space will continue to be a constraint on liquid waste operations.

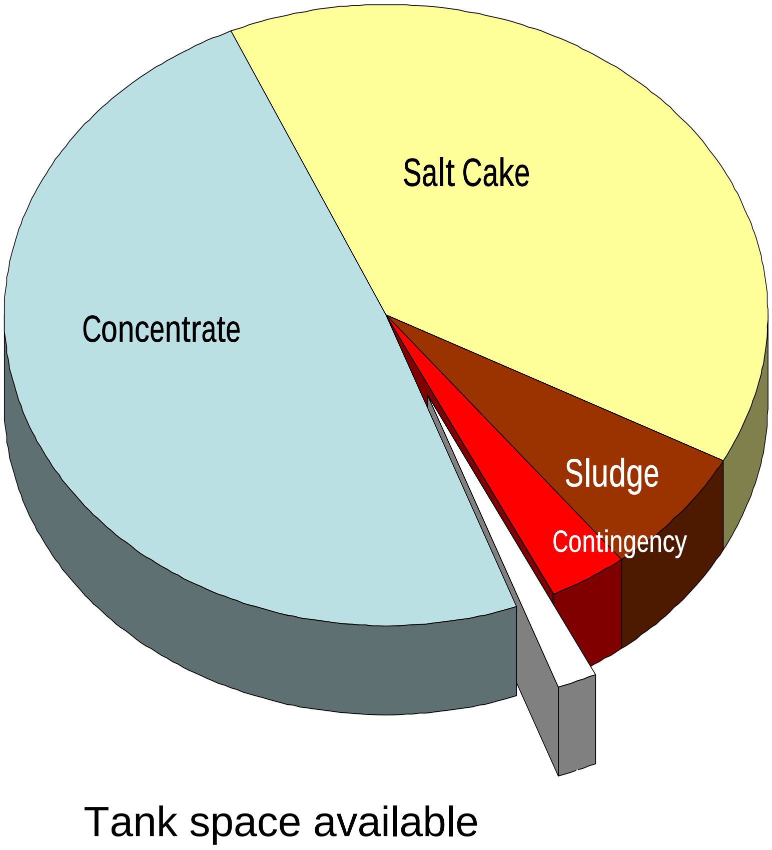

Fig. 1. Available tank space in the SRS liquid waste system.

Recently, a new mechanical cleaning operation was used on two tanks targeted for closure (Tanks 5F and 6F), which involved a feed and bleed or continuous recirculation transfer method. This method was deployed specifically to address the limiting effect on mixing during batch operations, and to address the space constraints within the tank farms.

The method was designed and implemented in two phases. During the first phase, fresh water was introduced into Tank 5F while a transfer pump was simultaneously removing liquid out of Tank 5F at approximately the same flow rate (i.e., a feed and bleed process). Tank 5F was completed using fresh water to test the feed and bleed theory. During this operation, three mixing pumps were used to suspend the residual solids to increase the likelihood of transferring the solids from the tank before settling. While this process proved to be successful at removing residual solids from the tank, storage space constraints continued to be an operational issue, as the feed and bleed process created approximately 380,000 gallons of additional waste volume.

The second phase of the feed and bleed process to remove residual solids was deployed on Tank 6F and consisted of agitation and continuous recirculation. Removal is accomplished by agitating the contents using three mixing pumps while simultaneously pumping the Tank 6F contents to a receipt tank. The receipt tank is unmixed (tranquil) and serves as a settling basin allowing the particles to sink. A temporary waste transfer and pumping system recirculates the clarified supernatant liquid to Tank 6F at a rate nearly equal to that of the Tank 6F transfer pump. This arrangement allows for the greatest mixing and transfer turnover rate in the shortest operation time while adding minimal additional volume to the high level waste storage system. Through the use of the recirculation transfer line, space constraints were minimized as an operational limitation during this phase of the process.

PROCESS IDENTIFICATION

Throughout the history of SRS, a number of tanks have undergone mechanical waste removal operations and/or chemical cleaning operations. Most recently, mechanical and chemical waste removal efforts have been completed in Tanks 5F and 6F. At the completion of mechanical cleaning of Tanks 5F and 6F, a residual solids volume of approximately 3,500 gallons and 6,000 gallons, respectively, remained in the tanks [4, 5]. It is worth noting that 3 mixing pumps were used in Tank 5F, whereas 2 mixing pumps were used in Tank 6F. This is likely the reason that Tank 6F resulted in almost twice as many solids remaining after mechanical cleaning. Following chemical cleaning of Tanks 5F and 6F, a residual solids volume of approximately 3,300 gallons and 3,500 gallons, respectively, remained in the tanks [6, 7]. Refer to Tables I and II for the residual solids volume remaining after each waste removal campaign from Tanks 5F and 6F.

Table I: Solids Volume Remaining after Mechanical and Chemical Cleaning Campaigns for Tank 5F [6].

Cleaning Method	Phase	Date	Approximate Solids Volume (gal)
Mechanical	0	Initial Vol.	34,000
	1	11/5/2005	18,000
	2	12/10/2005	16,000
	3	2/25/2008	14,000
	4	3/15/2008	N/A[a]
	5	4/12/2008	4,800
	6	4/25/2008	3,500
	7	5/9/2008	3,500
Chemical	1	6/23/2008	2,700
	2	10/11/2008	3,600
	3	12/23/2008	3,300

[a] Fourth mechanical run was terminated due to a tornado warning, and no volume estimate was obtained.

Table II: Solids Volume Remaining after Mechanical and Chemical Cleaning Campaigns for Tank 6F [7].

Cleaning Method	Phase	Date	Approximate Solids Volume (gal)
Mechanical	0	Initial Vol.	25,000
	1	6/10/2006	N/A[a]
	2	7/9/2006	17,000
	3	8/12/2006	14,000
	4	9/2/2006	12,000
	5	9/22/2006	8,600
	6	12/8/2006	7,000
	7	3/23/2007	6,900
	8	4/29/2007	6,600
	9	5/9/2007	5,800
	10	5/29/2007	5,400
	11	8/5/2007	6,000
Chemical	1	7/14/2008	2,400
	2	10/11/2008	3,300
	3	11/12/2008	3,500

[a] Final liquid volume was not low enough to map and estimate the solids volume.

Based on the operating experience during mechanical sludge removal and chemical cleaning campaigns in Tanks 5F and 6F, it was observed that the primary difficulty in removing the residual solids material from the tanks was the inability to maintain the material in suspension until it is captured by the suction of the transfer pump. It was determined that there were two factors that significantly impacted the ability to remove the remaining solids [8]:

1) Tank configuration and the number of mixing devices utilized resulted in limited mixing zones within the tank which allowed suspended material to settle, and

2) No mixing occurs at low levels (typically < 30 inches) during the transfer which allows time for suspended material to settle. Mixing pump design limitations and Safety Basis Requirements [9] prohibit mixing device operation at low tank levels.

Tables I and II provide the solids volume remaining after each mechanical and chemical cleaning campaign in Tanks 5F and 6F. These results show the importance of an adequate number of mixing devices on the solids removal effectiveness. The use of three mixing pumps in Tank 5F resulted in a marked improvement in the volume of solids remaining at the end of the mechanical cleaning campaigns. This was observed even though Tank 6F mechanical cleaning was completed over 11 campaigns versus the 7 campaigns completed for Tank 5F. Additionally, the remaining solids volumes after each campaign show that a point of diminishing returns is observed during the mechanical sludge removal batch process due to the limitations on the design of the mixing pumps. This was noticeable as the last two campaigns for Tank 5F resulted in approximately 3,500 gallons of solids remaining in the tank, and the last three campaigns for Tank 6F resulted in approximately 6,000 gallons of solids remaining in the tank.

In order to address these issues (i.e., the number of mixing pumps and the restricted operation of the mixing pumps at low levels in the tank), a group completed a System Engineering Evaluation (SEE) to identify the optimal way to effectively remove the residual solids in Tanks 5F and 6F [8]. Based upon the weighting criteria used in the SEE, utilization of three mixing pumps during "feed and bleed" operations was identified as the preferred method for removing the stubborn heels remaining in the tanks. The feed and bleed process is commonly used throughout commercial industry, and the process follows the solution to the 1st order differential equation shown in Equation 1 [10].

$$C(t) = C_0*((V-r)/V)^t \qquad (1)$$

Where: $C(t)$ = solids concentration at any time (t)
C_0 = initial solids concentration when t = 0
r = pump rate
V = mixed volume

It was identified that this method would directly address the two issues previously discussed. That is, the process would allow the mixing pumps to remain in operation without shutting down due to low tank levels, and mixing would be maximized through operation of three mixing pumps and introduction of the feed through a submerged downcomer directed toward zones of limited mixing. Based on Equation 1, ideal curves were generated based on the planned operating strategies for Tanks 5F and 6F. Assuming successful suspension of all remaining residual solids during mixing pump operation, Figure 2 was generated to show the anticipated solids concentration during the feed and bleed process. Note that the Tank 6F assumed starting solids volume is increased to 5,500 gallons to account for the transfer of solids from Tank 5F to Tank 6F during mechanical waste removal.

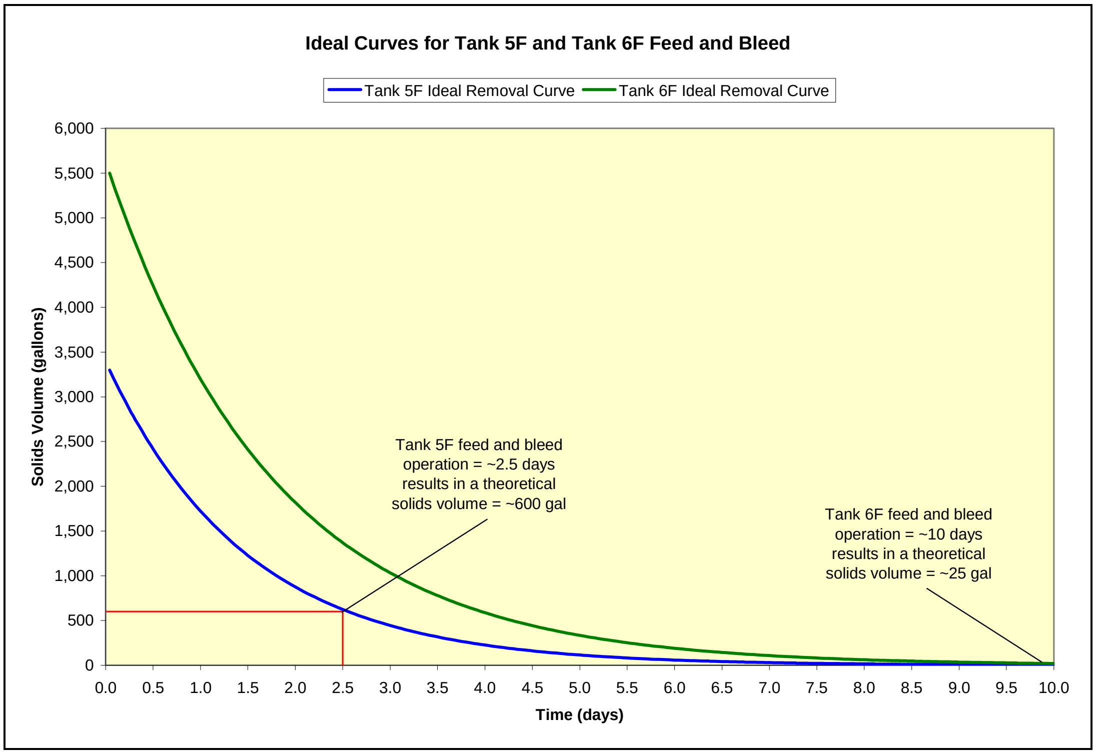

Fig. 2. Ideal solids concentration curves for Tank 5F and Tank 6F feed and bleed operations.

The engineering evaluation also identified two options for supplying the feed to the mixing tank during transfer:

1) Feed supplied from the well water system via a downcomer.

2) Feed will be supplied by setting up a recirculation loop between the receipt tank and the mixing tank.

Utilizing the information presented during the SEE, a phased approach was taken with regards to the implementation of the feed and bleed process. The process was initially implemented in Tank 5F utilizing the well water system as the feed for the process (refer to Figure 3). This phase would allow the theory to be tested in a 750,000 gallon waste tank with an internal labyrinth of cooling coils. This phase of the feed and bleed process does impact the overall volume of waste stored in the liquid waste system, as it would add an appreciable amount of new liquid to the tank farms (approximately 380,000 gallons of water). This creates a significant integration issue within the liquid waste system, as space constraints are one of the major obstacles in accelerating the closure of the high level waste tanks. If this method were utilized on each of the remaining 17 old-style tanks to undergo heel removal, the tank farms would have to store or process ~6.5 million gallons of generated waste. Additionally, ~0.5 million gallons of chemicals and space would be required to perform chemical adjustment of the waste stream from a corrosion perspective.

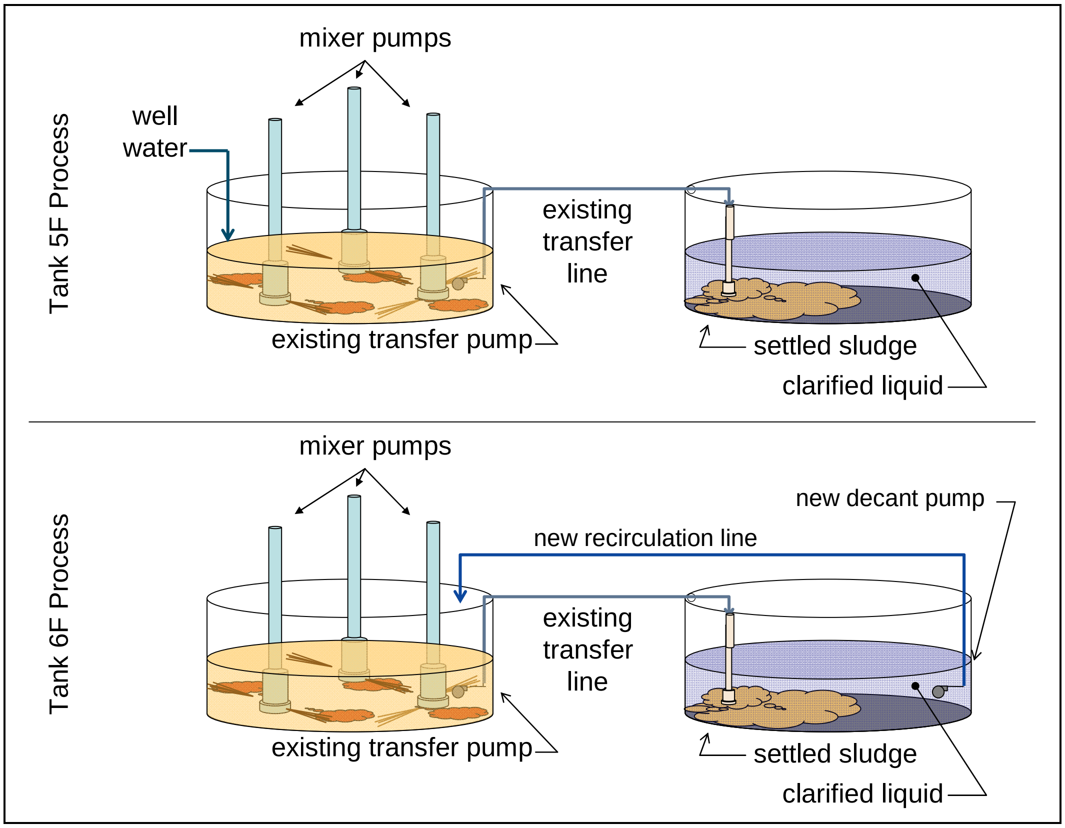

Fig. 3. Feed and bleed process overview utilizing a single pass through the system (Tanks 5F) and utilizing a recirculation loop (Tank 6F).

Thus, the second phase of the feed and bleed process was implemented in Tank 6F. This phase of the process used a recirculation loop between the receipt tank and Tank 6F to provide the feed for the waste removal effort (refer to Figure 3). The use of the recirculation loop allowed for the process to be completed over a longer period of time with an indefinite transfer volume with no appreciable impact on the available space in the tank farms. Heel removal using continuous recirculation employs a technique commonly found in the chemical process industry and in storage tanker cleaning [11]. Commercial methods encourage the reuse of agitation liquid and the minimization of secondary waste streams [12].

When implemented in Tank 6F, this phase of the process used low-activity supernatant as the transfer media (versus well water) to minimize the generation of new waste and to support greater suspension of material in the tank. During Tank 6F residual heel removal, a pump run strategy was employed to increase the suspension time of any particle (to improve the chance of being captured by the transfer pump and being moved to the settling tank) and to prevent the formation of low flow (quiet) zones [13]. As time progresses, the concentration of suspended particles becomes lower (asymptotically approaches zero) and eventually reaches a point of negligible removal.

RESULTS AND DISCUSSION

From March 11, 2010 – March 13, 2010, approximately 150,000 gallons of well water was added to Tank 5F to increase the waste level to greater than 60 inches to maximize the operating speed of the 3 mixing pumps inserted into the tank. Upon completion of the water addition, the mixing pumps were operated for approximately 7 hours to suspend the solids prior to initiating the transfer from Tank 5F to the receipt tank (i.e., Tank 6F). On March 14, 2010, the Tank 5F to Tank 6F transfer was initiated, and well water additions were resumed to Tank 5F. Both the transfer from Tank 5F and the water addition to the tank were maintained at approximately 110 gpm. Once approximately 230,000 gallons of well water had been fed to Tank 5F, the well water additions were suspended, while mixing pump operation and the transfer to Tank 6F continued. When the Tank 5F level reached approximately 52 inches, operation of the 3 mixing pumps was suspended, while the transfer to Tank 6F continued. On March 16, 2010, the transfer from Tank 5F to Tank 6F was terminated when the waste level in Tank 5F was approximately 1.5 inches from the tank bottom.

Following chemical cleaning activities in Tank 5F, the solid volume was determined to be approximately 3,300 gallons. After the feed and bleed operations in Tank 5F, it has been preliminary determined that the final solids volume has been reduced to between 1,500 – 2,000 gallons. Approximately 380,000 gallons of waste was generated during the feed and bleed process. Based on the theoretical curves generated for the removal of solids, had all solids been suspended, the remaining solids in the system should have been approximately 600 gallons. Due to physical obstructions in the tank (e.g., cooling coils), limitations of the mixing pumps (i.e., operating restrictions at low tank levels), and the large size of the particles, the feed and bleed process was not as effective as theoretically postulated. Based on measurements obtained from an electronic personal dosimeter (EPD) located in the valve box on the Tank 5F to Tank 6F transfer path, the solids reduction does follow an exponential curve, as expected based on the theoretical model (refer to Figure 4). Based on this information, the feed and bleed process was determined to be successful at removing additional residual solids that could not be removed during previous mechanical and chemical cleaning operations. The single most important benefit obtained by using this method was the ability to keep the solids suspended until they were captured by the transfer pump. Use of this method did not minimize / eliminate the impact on the overall waste storage system, as the process generated a significant volume of secondary waste that must be stored or processed within the tank farms.

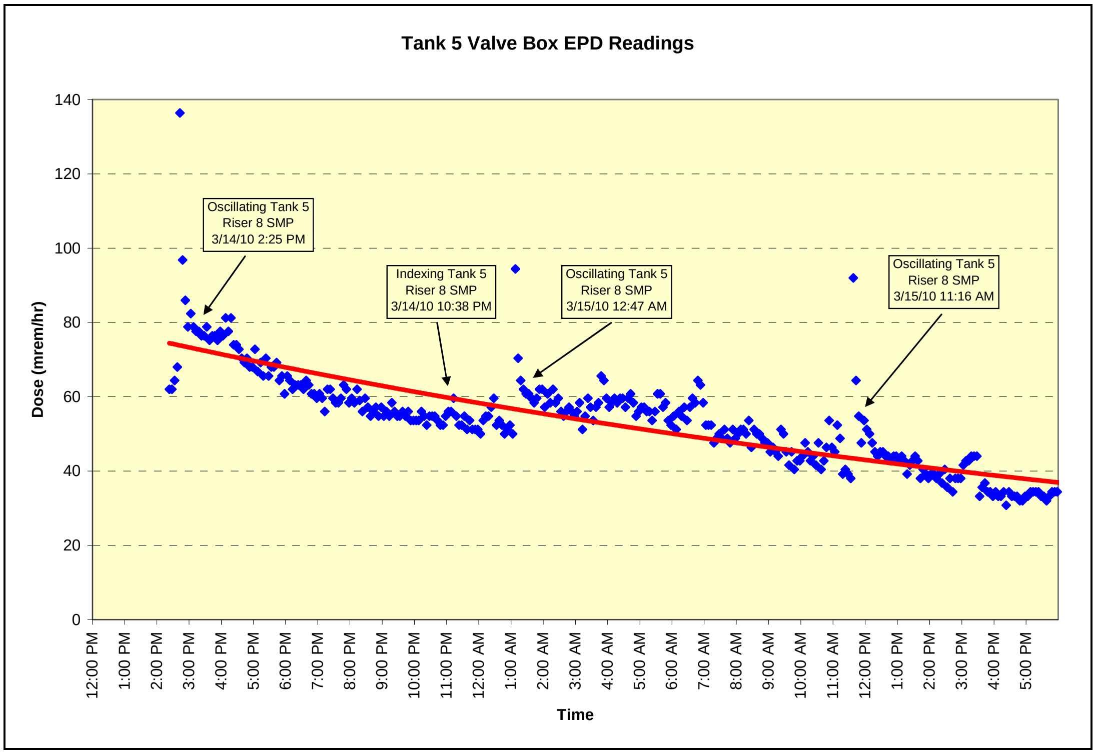

Fig. 4. Tank 5F Electronic Personal Dosimeter (EPD) on the Tank 5F to Tank 6F transfer line.

After successfully deploying the feed and bleed concept in Tank 5F, the next step was to initiate additional heel removal from Tank 6F. The data obtained from Tank 5F was considered, and the team addressed the issue of the volume of waste generated during the process by including a recirculation loop from the receipt tank to the treatment tank during the implementation of the feed and bleed process in Tank 6F. Residual heel removal was completed on Tank 6F using predominantly supernatant with a low activity (i.e., <1.5 Ci/gal Cs-137) and a combination of well water and 50 wt% sodium hydroxide in order to attain desired tank operating levels and ensure compliance with the Liquid Waste Operations Corrosion Control Program [14]. The waste removal campaign from Tank 6F used Tank 7F as the receipt tank for the suspended solids. Tank 7F acted as a settling basin for the entrained solids allowing the fast-settling particles to sink as the clarified supernatant is recirculated back to Tank 6F via an above-grade transfer line. During the process, the recirculation line transfer pump and the Tank 6F transfer pump were operated at approximately 110 gpm. Three recirculation “campaigns” were completed from Tank 6F over a 3-week period of time. The total operating time of the recirculation process was approximately 10 days.

Following chemical cleaning activities in Tank 6F, the solid volume was determined to be approximately 3,500 gallons. It was estimated that the solids volume was approximately 5,500 gallons after receipt of solids from Tank 5F. After the recirculation operations in Tank 6F, it has been preliminary determined that the final solids volume has been reduced to between 1,500 – 2,000 gallons. Approximately 10,000 gallons of chemicals were utilized during the process to adjust for corrosion. Through the use of the recirculation process that beneficially re-used exiting tank farm supernatant, the secondary waste stream generated during the Tank 6F waste removal effort was minimized. Based on the theoretical curves generated for the removal of solids, had all solids been suspended, the remaining solids in the system should have been <100 gallons. As seen in Tank 5F, due to physical obstructions in the tank (e.g., cooling coils), limitations of the mixing pumps (i.e., operating restrictions at low tank levels), and the large size of the particles, the feed and bleed process was not as effective as theoretically postulated. Based on this information, the feed and bleed process was determined to be successful at removing additional residual solids that could not be removed during previous mechanical and chemical cleaning operations. The largest benefit observed through use of the recirculation process over the traditional feed and bleed process was that the secondary stream volume was minimized. Thus, the impact on the overall waste storage system was reduced.

CONCLUSION

A feed and bleed method for removing stubborn residual solids from Tanks 5F and 6F was implemented in two stages. First, a traditional feed and bleed process was utilized in Tank 5F in which well water was continuously added to the tank at approximately the same rate the slurried material was transferred from Tank 5F. A total of 3 mixing pumps were used during this stage of the process. This process resulted in reducing the residual heel volume to approximately 1,500 – 2,000 gallons from the original solids volume of approximately 3,300 gallons that remained after chemical cleaning operations. A total of approximately 380,000 gallons of new waste was generated as a result of this process being run for 2.5 days.

Next, the feed and bleed process was implemented in Tank 6F utilizing agitation and a continuous recirculation transfer line. As with Tank 5F, 3 mixing pumps were used during this process. The stage of the process resulted in reducing the residual heel volume to approximately 1,500 – 2,000 gallons from the original solids volume of approximately 5,500 gallons that remained after Tank 5F residual solids were transferred to Tank 6F. A total of approximately 10,000 gallons of chemicals were added to the tank for corrosion control purposes, and the process was performed for a total operating time of approximately 10 days.

Based on the results of the residual solids removal campaigns in Tanks 5F and 6F, it was determined that the processes were successful in reducing the radiological dose in the tanks adequately to meet closure targets. It was also determined that excessive operation of the process (i.e., 10 days versus 2.5 days) did not result in significantly more solids being removed from the tanks. From this information, it was determined that the tank obstructions (e.g., cooling coils) are the limiting factor in being able to remove the remaining residual solids from the tanks. Though a marked improvement on the volume of solids removed was not observed through the use of the recirculation line, the volume of secondary waste streams generated was appreciably reduced. This significantly reduces the total space needs in the tank farms to support accelerated closure operations, which has historically proven to be a limiting factor in waste removal operations.

The results of the additional mechanical cleaning completed in Tanks 5F and 6F was evaluated for future use of the feed and bleed process in the tank farm. Based on the minimal change running the process for 10 days versus 2.5 days, future feed and bleed operations will be performed for approximately 80 hours. The process will be completed utilizing a recirculation line and existing supernatant in the tank farms to minimize the generation of secondary waste streams.

REFERENCES

1) R.C. JOLLY, JR., "Status of Mechanical Sludge Removal and Cooling Coil Closure at the Savannah River Site – F-Tank Farm Closure Project - 9225," LWO-LWE-2008-00268, Waste Management Symposia, March 1-5, 2009, Savannah River Site (2009).
2) G.D. THAXTON IV, G.B. CLENDENEN, W.E. GORDON, M.R. POIRIER, and S.D. FINK, "Status of Chemical Cleaning of Waste Tanks at the Savannah River Site – F-Tank Farm Closure Project – 9114," Waste Management Symposia, March 1-5, 2009, Savannah River Site (2009).
3) G.B. CLENDENEN, "Tank 5 (241-905F) Waste Removal and Closure Operating Plan (U)," U-ESR-F-00024, Savannah River Site (2010).
4) W.C. LUDWIG, "Tank 5 Sludge Volume Estimation after the Seventh Phase of Mechanical Sludge Removal," M-ESR-F-00147, Savannah River Site (2008).
5) W.C. LUDWIG, "Estimation of Tank 6 Sludge Volume after Phase 11 Bulk Sludge Removal," M-ESR-F-00132, Savannah River Site (2007).
6) V.A. CHANDER, "Tank 5 Solids Volume Estimation after the Chemical Cleaning and Final Wash (U)," M-ESR-F-00160, Savannah River Site (2008).
7) W.C. LUDWIG, "Tank 6 Solids Volume Estimation after the Chemical Cleaning and Final Wash," M-ESR-F-00165, Savannah River Site (2009).
8) G.B. CLENDENEN, "Strategy for Tanks 5 and 6 Phase II Mechanical Sludge Removal," SRR-CES-2009-00022, Savannah River Site (2009).
9) "Concentration, Storage, and Transfer Facility Documented Safety Analysis," WSRC-SA-2002-00007, Savannah River Site (2010).
10) W.B. FURMAN, Continuous Flow Analysis: Theory and Practice. Volume 3. New York: Marcel Dekker, Inc. (1976).
11) "Military Handbook Cargo Tank Cleaning," MIL-HDBK-291(SH), U.S. Department of Defense, Department of the Navy, Naval Sea Systems Command, Washington, D.C. (1986).
12) Guidelines and Procedures for Entering and Cleaning Petroleum Storage Tanks. ANSI/API Recommended Practice 2016, American Petroleum Institute (2001).
13) T.B. CALDWELL, "Tank 6F Phase II Mechanical Sludge Removal (MSR): A Heel Removal Technique using Agitation and Continuous Recirculation," SRR-CES-2010-00031, Savannah River Site (2010).
14) C.M. COLE, "CSTF Corrosion Control Program," WSRC-TR-2002-00327, C. M. Cole, Savannah River Site (2007).