

Saltstone Processing of 0.1 Ci/gal Waste at Savannah River Site

Aaron V. Staub, Jason L. Adams, and Chris H. Beheler
Savannah River Remediation, Aiken, SC 29808

ABSTRACT

Storage space constraints in the High Level Waste (HLW) Tank Farms at Savannah River Site (SRS) required the processing of several million gallons of salt solution in a cementitious waste treatment process that was originally designed to treat only fully decontaminated wastes with trace levels of residual radionuclides. The facility has been substantially modified from its baseline configuration to accommodate the higher curie waste streams (Cs-137 up to 1.0E+09 Bq/L [0.1 Ci/gal]). The new process has successfully treated most of the waste that drove the redesign, but process upsets experienced during operation and modifications to the HLW system plan at SRS will continue to drive changes to the manner in which waste is received and processed at Saltstone.

INTRODUCTION

The Saltstone Production and Disposal Facilities located at the Savannah River Site (SRS) in Aiken, SC were originally commissioned in 1990 for the purpose of immobilizing decontaminated low-level salt solutions in a cementitious grout form for long term storage in a near-surface landfill. However, problems with major upstream waste treatment operations greatly reduced the feed available for facility operations, and as a result the process operated only sporadically for much of the 1990s. Beginning in the early 2000s, the need to create space in the SRS High Level Waste (HLW) Tank Farms led to a series of projects that would fundamentally redesign the grout production facilities at Saltstone to allow for treatment of waste streams with gamma source strengths that were three orders of magnitude above the original design criteria. These physical modifications were coupled with several significant regulatory changes, and by early 2007 the Saltstone Facility initiated regular operations processing higher curie content wastes. This paper will briefly document the new process design, address several major process upsets that have occurred since restart, and look at potential changes as salt waste disposal activities at SRS accelerate in the next few years.

PROCESS DESIGN

The basic principle of operation at Saltstone requires only a few primary unit operations. Dry components (Portland cement, flyash, and slag) are received via truck into storage silos and batched into a weigh hopper. The current baseline mix is a 45% slag, 45% flyash, and 10% cement ratio by weight. The components are then fed to one of two air blenders and transferred to a feed bin on top of the main operations building. Here the process transitions from batch operation to continuous operation, as a loss-in-weight feeder meters the blended dry components to a mixer where the liquid feeds are then introduced. The fresh grout slurry is subsequently pumped to a disposal cell where cementitious reactions change the slurry from a free-flowing liquid to a free-standing monolith.

An overview of the Saltstone production process is shown in Figure 1.

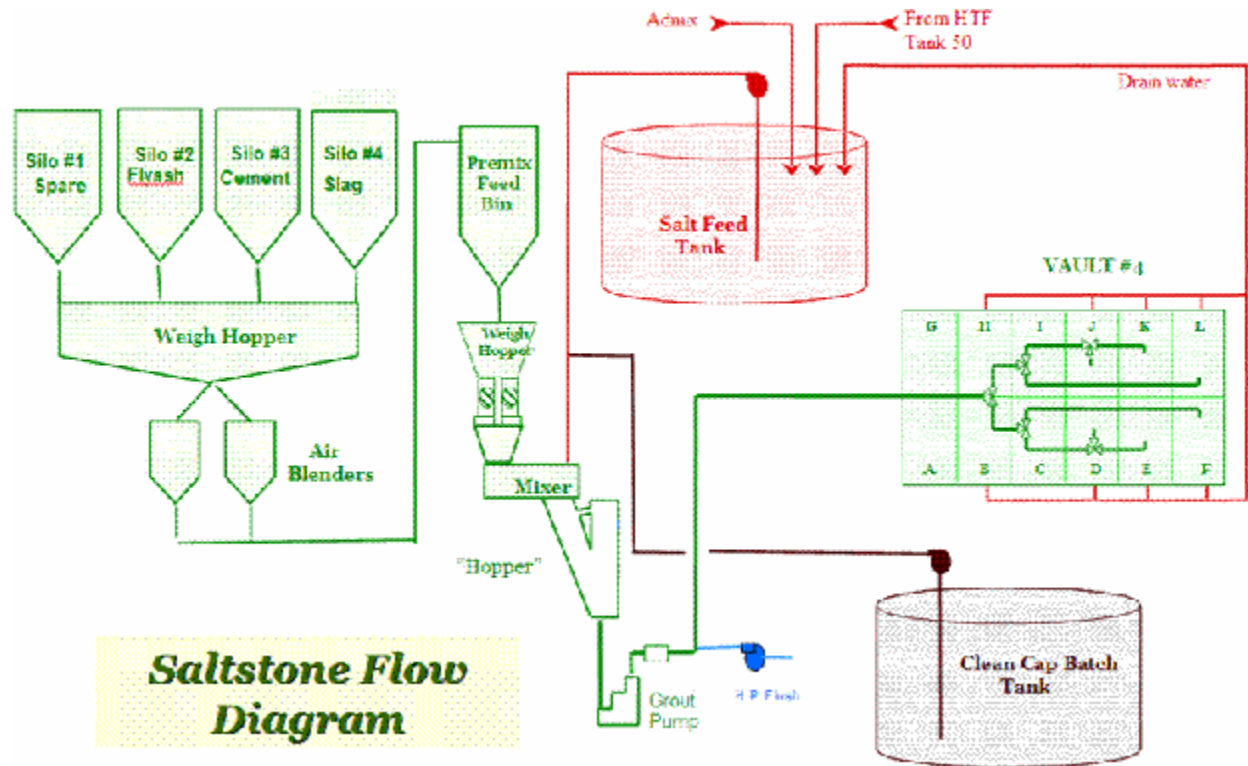


Figure 1: Process overview of grout production activities at Saltstone

The major components involved in the receipt, weighing, and blending of dry feed components (shown at left) have not changed significantly over time, but almost all of the equipment downstream of the grout mixer was replaced in an effort to lower the radiological dose potential of the process. In some cases this meant little more than volume reductions to minimize source terms, in others it meant complete overhauls to use more reliable equipment or decrease the duration of maintenance activities associated with the equipment. A description of the major process components is provided below.

Saltstone Mixer

The saltstone mixer is a twin-shaft, ten inch Readco Continuous Processor that operates at a nominal dry feed rate of 8.8 kg/s (35 ton/hr). The dry feed is mixed with waste salt solution fed from the Salt Feed Tank (SFT) at a rate of approximately 5.7 L/s (90 gpm). The resulting grout mixture is sheared for 10-15 seconds before discharging at a rate of 8.5 L/s (135 gpm) to a small tank upstream of the grout pump. The saltstone mixer has been a fairly constant design throughout the life of the facility; however, in 2003 the internal shafts were replaced with new paddle assemblies that imparted higher shear rates to the mixture to improve homogeneity of the product. No major changes to address the higher curie waste streams were required as a part of the project.

Grout Pump Hopper

The small tank beneath the mixer, called the grout pump hopper, was a significant change from the original design. Previously, grout fed from the mixer was collected in the Saltstone Hold Tank (SHT), a 750 L (200 gal) vessel that contained a small agitator and used a rodded bubbler assembly to measure tank level. The roughly 60-70 second residence time in the SHT provided for additional mixing time and the tank provided much needed suction head to the pumping system, which at the time consisted of two parallel trains of two centrifugal pumps in series (four pumps total, two operating and two spare). The size of this tank was a stumbling block due to shielding requirements for the higher gamma source, and as a result the grout pump hopper has an operating level in the 50-75 L range (15-20 gal). Level information is now provided by a radar instrument, which offers the advantage of eliminating contact with the cementitious product and the inherent cleanliness issues that the bubbler assembly experienced. A video camera was later added as an enhancement to allow operators to observe processing and flushing activities and to monitor the potential for grout accumulation in the hopper

Grout Pump

The 90% reduction in holdup volume between the mixer and pumping system had serious consequences on the performance and reliability potential for the original centrifugal pumps. Given the constraints of the smaller volume, it was essential to specify a pump that has low suction head requirements, self-lubrication, and a history of proven reliability. The project selected a Watson Marlow SPX-100 pump, which is a dual-head peristaltic pump capable of delivering over 11 L/s (185 gpm) of throughput under a wide variety of operating conditions. The pump, shown in Fig. 2, is of robust construction and is routinely used in industry for the transport of heavy slurries.



Figure 2: Saltstone Grout Pump

Saltstone Disposal Facility

The Saltstone Disposal Facility (SDF) currently consists of two above-ground storage units designed to receive and hold the fresh slurry until the waste form becomes a free-standing monolith. The existing disposal units, called Vault 1 and Vault 4, are broken up into an array of 30 m x 30 m x 7.6 m (100 ft x 100 ft x 25 ft) cells that are filled separately. Vault 1, which is no longer used for waste operations, is a 6 x 1 arrangement and Vault 4, the currently active disposal location, is a 6 x 2 arrangement with the capacity to store about 4.5 E+07 L (12M gal) of treated waste. When the vaults were originally constructed, the exterior walls were not intended to support more than 1.5 m (5 ft) of liquid slurry at a given time. Due to a small amount of shrinkage in the final product and the generation of bleed water after placement, the walls can experience much larger hydrostatic loads when the bleed water fills the interstitial space between the vault wall and the grouted waste form. This phenomenon has required the retrofit installation of a bleed water collection and drain system to prevent damage to the bottom of the vault walls. The bleed water is returned to the SFT for reprocessing in the mixer. Future vaults are being designed to accommodate larger hydrostatic loads and will have an improved bleed water collection system.

PROCESS UPSETS

Since startup of the newly designed process in early 2007, the facility has treated nearly 1.1 E+07 L (3M gal) of salt solution from the SRS Tank Farms. This inventory is nearly equivalent to the entire volume of waste processing performed from facility commissioning in 1990 through the completion of the process redesign in 2007. Given the regularity of operation, the facility has experienced several process upsets that have led to significant improvements in the reliability and performance of the mixing and transfer systems.

SFT Pump

The SFT pump is a Goulds 3796 series centrifugal pump that supplies a continuous flow of salt solution from the SFT to the saltstone mixer. In August 2006, a facility shutdown was required when a plug of grout lodged at the outlet of the saltstone mixer which was not free to flow into the grout pump hopper. While facility maintenance personnel worked to recover the affected equipment, a review of data trends showed a significant transient in liquid flow fed to the mixer immediately prior to formation of the grout plug. Subsequent troubleshooting of the liquid feed system showed that air in-leakage to the suction of the pump likely broke the pump prime and caused the loss in flow at the mixer. The SFT pump is installed on top of the tank due to access restrictions and is required to operate under suction lift. As a result of this event, facility engineering and operations reviewed other factors which could impact pump performance and increased the rigor of system health monitoring to detect any degradation in pumping performance.

Grout Pump Suction Piping

In March 2009, a leak was observed during operation of the grout pump which required that processing be suspended and the facility shutdown for maintenance. Upon inspection of the pump suction and discharge piping, examination of the affected pump hose, and discussions with the pump vendor, it was determined that a relatively large piece of solidified grout had been held up in the piping upstream of the pump and had broken loose and been pulled into the pump suction. This piece of grout evidently then wedged at the pump outlet causing an almost instantaneous pressure spike which damaged the hose. The pump apparently managed to clear the blockage, but process data indicates a decrease in pump efficiency, and shortly thereafter the hose failed completely and lost containment.

Because the process is remotely operated and there is no simple way to inspect the cleanliness of all the system internals, flushing and shutdown of the process is critical to avoiding these types of issues. Figure 3 shows an area of grout accumulation inside the grout pump hopper. Almost all of the piping and equipment downstream of the pump can be pigged to remove grout, but the mixer, hopper, pump, and associated piping can only be flushed to remove residual grout. Previous reviews had been performed to ensure that fluid velocity would prevent settlement of cementitious solids during operation in the process lines. As a result of this incident, an evaluation was performed to consider the effectiveness and proper sequencing of the shutdown procedure and process flushes. Only a limited amount of operation has occurred since this incident so it remains an area of scrutiny and observation.

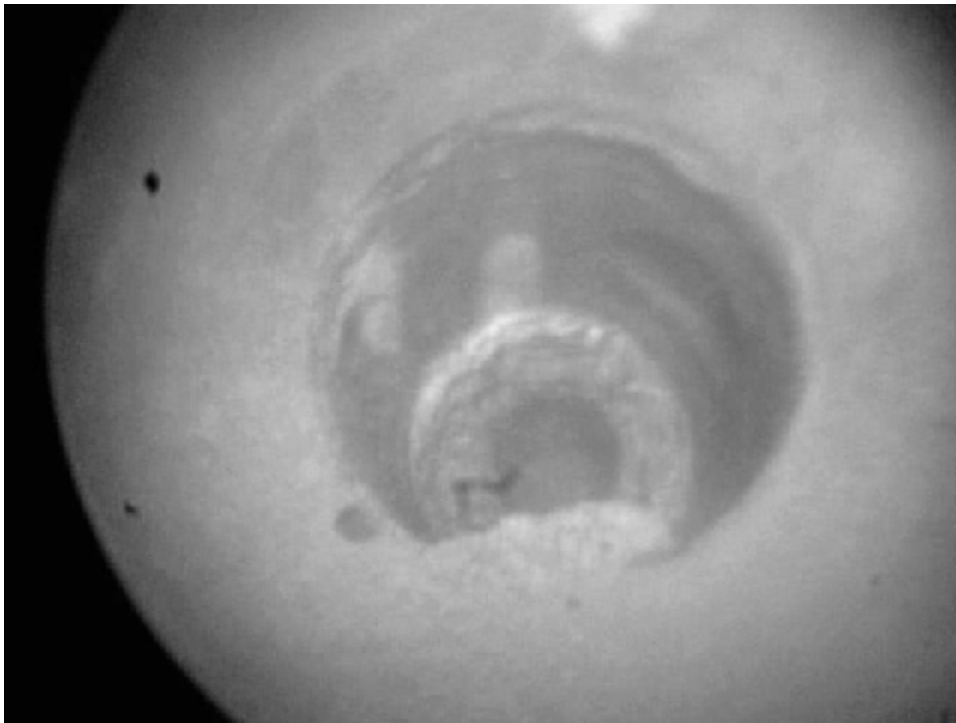


Figure 3: Image of grout buildup in hopper. Incoming feed enters at top right and exits at center.

Mixer Operation

A series of pluggage events experienced during the summer and fall of 2009 has recently been attributed to problems correctly sequencing dry material and liquid flows to the mixer. Although the production of Saltstone is generally a steady-state, continuous process, there are several occasions when transient conditions are unavoidable. Startup and shutdown activities require that liquid and dry material flows to the mixer change over time. The operating philosophy of the facility dictates that dry material feed is only initiated after full liquid flow is established, and dry material flow is secured prior to shutdown of liquid feeds.

Despite this design, the facility underwent several process pluggages in succession this year after two years of successful operation. Camera observation of the grout hopper indicated the dry feed was exiting the mixer without having been contacted with liquid feed, and this discovery led to a wholesale review of how the facility deals with transient conditions. An independent review team determined that several small changes to the process which were intended to improve the performance of particular system components led to a loss in reliability of the overall process.

A series of corrective actions was implemented to guarantee that dry material cannot be fed to the mixer without an already existing flow of liquid. The potential remains for catastrophic equipment failure to create similar conditions (e.g., a complete failure of the salt solution pump), but routine startup and shutdown transients are now constrained to prevent recurrence.

Vault Bleed Water Collection System

One of the most challenging issues has been the management and operation of the disposal vault. While a tremendous amount of attention was paid to the redesign of the grout production facility, the disposal vault was expected to be ready to receive feed once the bleed water collection manifold and return pump was installed. The system is comprised of a sheet drain (porous fabric over a corrugated plastic backing attached to the interior wall) which allows bleed water to fall to the bottom of the cell and collect in a pipe that runs the entire perimeter. A discharge pipe penetrates the cell wall and supplies a pump which returns the bleed water to the facility for reprocessing.

In some of the cells, the efficiency of the system has been significantly degraded as grout was placed into the cells. The system performed exactly as expected for the first 20-25% of the total height, but shortly thereafter indications appeared that suggested parts of the system were becoming plugged. By the time 60-70% of the cell was filled the system was seriously degraded and required significant corrective maintenance to restore to partial operability. Not only does this reintroduce the risk of damage to the integrity of the vault walls, but a constant holdup of liquid against the exterior vault wall will allow for salt solution to weep through small cracks and expansion joints in the wall and become exterior wet spots that pose a transferable contamination risk to the facility.

Because no personnel access to an operating vault cell is feasible, the facility has been forced to mitigate the issue by using exterior coatings and shields to prevent the spread of contamination.

A series of Radiological Control hut and collection troughs were installed at Vault 4 for this purpose. A typical installation is shown in Figure 4.



Figure 4: Radiological control hut and rain deflector installed to mitigate wet spots on Vault wall.

It was previously mentioned that future vault designs would accommodate the hydrostatic head of bleed water which collected between the monolith and vault wall. Part of the design change includes a full inner liner that will ensure the vault is leaktight during grout placement and curing.

FUTURE CHALLENGES

While the basic unit operations involved in the operation of the Saltstone Production and Disposal Facilities are relatively constant, the integration of these facilities into the overall system plan for waste disposal at SRS will present several challenges in the near future. These challenges will require significant effort on the part of both facility engineering and operations to ensure that HLW tank closure milestones are consistently met. Several of the impacted areas are described separately below.

Introduction of Flammable Organics to Disposal Facility

The original removal technology for cesium from the SRS salt solution stored in the Tank Farm was precipitation followed by filtration and treatment of the solids through a HLW processing facility. The new technology is a solvent extraction using an isoparaffin carrier to transport the active components. Some carryover of this solvent into the salt solution is unavoidable, and the heat evolved by hydration reactions in the curing saltstone will tend to drive this solvent into the vapor space above the grout. Since the quantity of material stored in a vault is enormous, the consequences of a vault explosion must be carefully considered however unlikely the accident. The vaults were not designed with the expectation that an explosion was a credible event, and as a result several controls have been identified to prevent the accumulation of flammable gases in the vault vapor space.

These controls include high temperature interlocks which stop the production process if vault temperatures become too hot for safe operation. The control of vault temperature is a key strategy for suppressing the vapor pressure of the solvent. Additionally, a portable ventilation system has been developed which will allow Operation to evacuate any flammable gases from the vault and a flammable vapor monitoring system will be installed that will regularly sample the vapor space to ensure that the vault remains below 60% CLFL.

The installation and operation of these systems, and the administrative programs associated with ensuring compliance with these safety requirements is a significant impact to the traditional engineering and operations programs at Saltstone.

Lag Storage

Currently the SRS HLW Tank Farms have an underground storage tank with a 3.8E+06 L (1M gal) capacity dedicated as a low level waste feed tank for Saltstone. This vessel is of sufficient capacity to significantly separate the operation of waste treatment activities upstream of Saltstone with grout production activities at the facility. However, this tank space will be required in the future for HLW service and at that point it will no longer be available to serve as a feed supply to Saltstone.

This need has driven the development of a new project to build a feed facility for Saltstone. The current projections indicate that the new feed facility will have a total volume of 4.5E+05 L (120k gal) and a working level of about half that volume. The impacts of such close coupling between facilities are significant for a facility that is expected to support up to 8.7E+05 L (230k gal) per week of processing. Any significant downtime for maintenance has an almost immediate impact on upstream facilities, which will require significant coordination in outage planning and transfer strategies.

There is also a potential impact to the process chemistry of the facility. With a large underground waste tank available, Saltstone is able to aggregate feeds from all of its upstream suppliers. As a result, the composition of the bulk waste changes only slowly over time. With the new, but much smaller, feed facility, it is more likely that Saltstone will need to accommodate a larger variety of waste compositions than have been anticipated in the past.

Product Quality and Monitoring

Part of the regulatory changes associated with the processing of higher curie waste streams at Saltstone includes the introduction of the Nuclear Regulatory Commission (NRC) into an advisory role. While not acting in a direct oversight capacity, the NRC has been given the authority to routinely survey the technical basis for waste form compliance with performance objectives and they have identified a series of focus areas in which additional research and development is being performed.

While some of the effort is being directed specifically into modeling improvements, there is a considerable amount of scope that covers the expansion of understanding the impacts of variability on product performance and degradation. Basic mix proportioning plays a large role in defining waste form properties, but physical conditions play a role as well. Cure temperature profiles have been demonstrated to impact performance, and the microstructure of the grout has been observed to change as the material dries. The presence of elevated levels of aluminate and free hydroxide impact the extent of reaction, and the proportioning of the individual dry feed components will affect the reductive capacity of the grout and its ability to stabilize heavy metals in the waste.

Proper understanding of these relationships will allow for better mix design and should provide insight on how best to improve product quality. This will be critical as the variability of the feed is expected to increase in the future.

CONCLUSIONS

Grouting of low level waste solutions has proven to be a cost-effective and durable method of disposal at Savannah River Site. The need to accommodate higher curie wastes required a significantly different design concept than the original construction, but project teams were able to specify equipment that would meet the strict radiological dose constraints while also supporting a robust processability window. Three years of regular operation have been sufficient to identify likely failure modes, and the facility is addressing those vulnerable areas in a disciplined and focused manner. This trend is likely to extend out for the foreseeable future given the system plan changes that are anticipated over the next several years.