Hanford WTP LAW Melter Startup and Tuning Feed Material Development - 17065

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ABSTRACT

The U.S. Department of Energy's (DOE) Hanford Site in southeast Washington state is home to 56 million gallons of chemical and radioactive waste stored in underground tanks, the result of more than four decades of plutonium production.

To address this challenge, the U.S. Department of Energy contracted Bechtel National, Inc., to design and build the world's largest radioactive waste treatment plant. The Hanford Tank Waste Treatment and Immobilization Plant (WTP) will use vitrification to immobilize most of Hanford's waste. Vitrification involves blending the waste with glass-forming materials, and heating it to high temperature to form molten glass, then pouring it into stainless steel containers. In this glass form, its radioactivity will decay over hundreds to thousands of years.

In advance of full operation of WTP, a sequential process of commissioning will be undertaken to ensure the plant operates safely and within design requirements. The first phase of WTP operations will focus on the Low-Activity Waste (LAW) Vitrification Facility and its supporting facilities and systems. Commissioning of the LAW Facility will employ a progressive approach to address the complexity of system operation and introduction of hazards. This approach starts with introduction of low hazard and simple testing configurations, and incrementally increasing the complexity and hazardous makeup of testing feed materials, culminating in fully integrated treatment of radioactive tank waste during hot commissioning.

Testing with simulants that are chemically similar to radioactive tank waste introduces significant chemical hazards into treatment systems in the form of nitrogen oxides (NOx) and anhydrous ammonia. A method of testing to allow tuning and demonstration of equipment and to develop operator proficiency prior to introducing these chemical hazards was deemed necessary. To that end, the development and testing of a new "tuning feed" material is in progress.

The tuning feed is important because its use will enable the first-time integration of all LAW Facility process systems. The tuning feed must include key physical and chemical characteristics that correspond to the commissioning simulant and low activity tank waste, without the inherently hazardous materials or toxic off-gas constituents that result from tank waste treatment. Tuning feed is being developed to provide representative melter feed rheology, glass chemistry, cold cap formation, and off-gas generation rate in order to predict system response to actual tank waste to the extent practical. The tuning feed must also be compatible with

process equipment and other process streams that will be encountered during the cold commissioning testing program.

INTRODUCTION

This paper provides a brief discussion of the WTP commissioning approach, a summary of the WTP LAW feed and melter systems, an explanation of why a tuning simulant is needed, and a summary of work planned to evaluate and select the nonhazardous tuning feed.

Commissioning of the WTP LAW Facility is a complex evolution that includes significant technical and schedule challenges. In order to safely and effectively demonstrate function and performance of LAW Facility systems, a commissioning approach has been developed to provide assurance of system performance and capability of operating staff while minimizing project cost and risk. Figure 1 provides a simplified graphic showing the commissioning scope within the overall WTP Project timeline. As shown, upon completion of commissioning with non-rad materials, a Contractor Readiness Review (CORR) and a DOE Operational Readiness Review (ORR) are performed prior to receiving authorization to begin commissioning with actual radioactive tank waste.

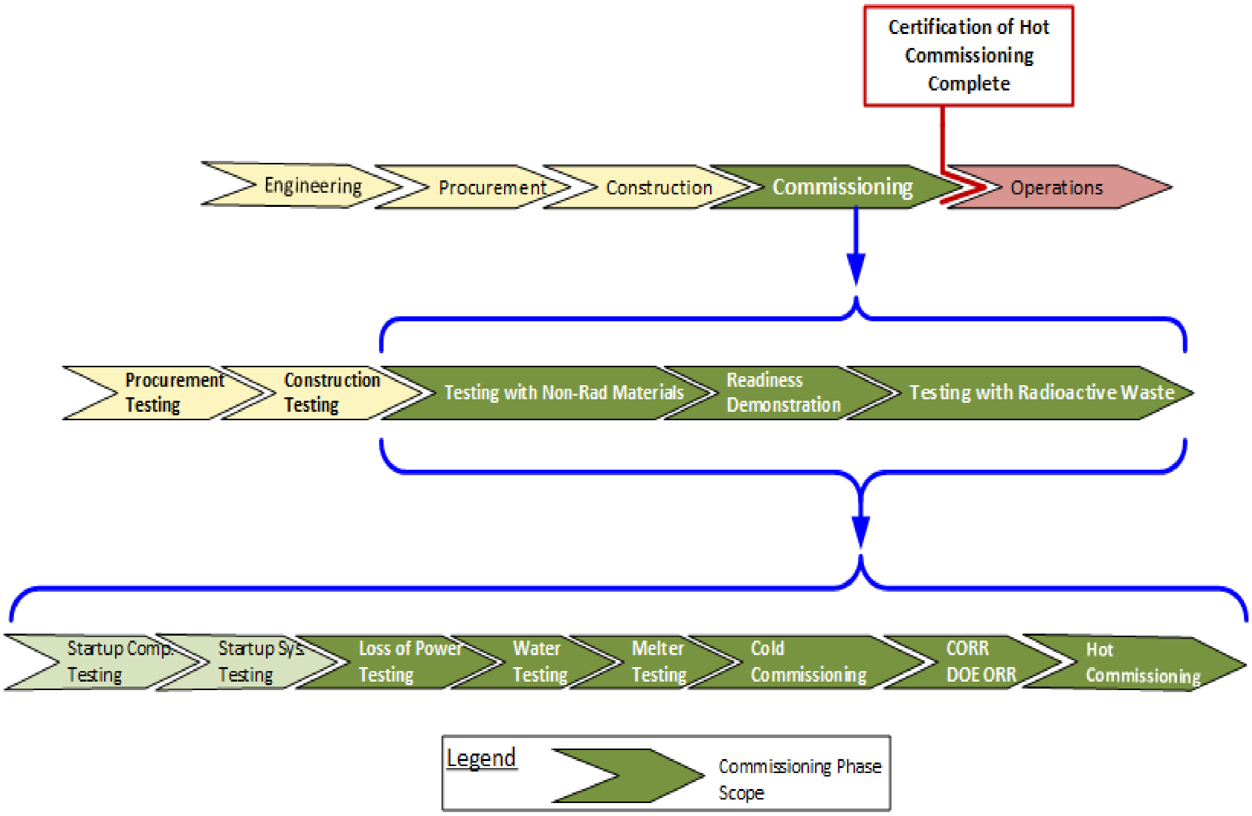

Figure 1 - Commissioning Scope

The WTP Project approach to commissioning incorporates the following priorities:

- Perform testing early to the extent practical
- Introduce complexity incrementally by testing individual systems before integrated systems, and simple feed materials before more complex feed materials
- Demonstrate system function to the extent practical prior to introducing high hazard materials
- Develop operator proficiency with systems prior to introducing high hazard materials.
- Protect capital investment in melters by testing a single melter prior to heating up the second melter.

Chemical simulants to be used to demonstrate system performance to chemical treatment criteria are high in nitrate and nitrite, resulting in the generation of significant concentrations of NOx in the offgas stream. In order to meet stack release criteria, the NOx component will be abated by using equipment that incorporates anhydrous ammonia. Anhydrous ammonia and NOx, at the concentrations involved, are highly hazardous chemicals that create major hazards to facility workers. Therefore, it is clearly preferable to optimize melter and offgas confinement system function and demonstrate operator proficiency prior to introducing these hazards. However, this approach requires a feed material that behaves similarly to actual waste for melter temperature and pressure control, but is absent the hazards associated with NOx or anhydrous ammonia.

A non-hazardous tuning feed would also enable hands-on operator proficiency training in feed systems control, melter control, off-gas system confinement, and immobilized LAW container handling and finishing before the full hazards of permitted operations are realized. Upon successful completion of a readiness management assessment and authorization from DOE, prototypical LAW simulants would be used to finish cold (non-active) commissioning, followed by the introduction and treatment of low activity waste during hot (active) commissioning.

COMMISSIONING STRATEGY

The LAW Facility and support systems are a complex, integrated radioactive waste processing system. While many components can be tested independently, some components (such as the melters and offgas systems) require the integrated system to be operational for functional demonstration. This fully integrated testing is performed relatively late in the commissioning sequence, with effectively all facility equipment on-line. Although necessary, fully integrated testing carries a higher cost and schedule risk, since any individual system or subsystem problem is likely to delay all testing and, correspondingly, overall Project completion. Additionally, the facility hazards introduced by fully integrated operation are significant, and it is appropriate to establish the functional capability of confinement systems and operations staff proficiency prior to introducing those hazards.

A sequential strategy to effectively manage worker hazards, while minimizing project cost and risk, has been developed. This strategy is listed here:

1. System level testing is performed as early as practical to establish the function of components and systems;
2. Initial integrated testing is performed using water and air to demonstrate integrated operation to the extent possible. Some equipment, such as melters and offgas treatment equipment cannot be effectively tested with air and water alone;
3. The first of two melters is heated up and tested using tuning feed to demonstrate feed, temperature, cold cap, pressure, and offgas flow control functions. This provides opportunity to identify any issues with the melter, operator performance, and procedures prior to heating up the second melter. This is important because once a melter is heated up it cannot be cooled back down for modification or repair and subsequently restored to operation;
4. The second melter is heated up and both melters are tested in parallel with tuning feed to establish performance of the combined offgas system that exhausts both melters. This configuration is used to complete management assessment of the effectiveness of hazard control programs prior to authorizing the introduction of NOx or anhydrous ammonia;
5. Chemical simulant feed that is representative of tank waste is introduced to the facility to allow tuning of the melter and offgas systems, including NOx abatement equipment, environmental permit compliance, and treatment capacity;
6. Hot commissioning testing uses actual tank waste to confirm that process control and confinement systems and operating staff meet requirements while processing radioactive feed.

This sequence meets key project objectives of 1) protecting workers from highly hazardous materials, while 2) completing required testing and demonstration requirements, and 3) minimizing project risk and cost.

FEED SYSTEM DESCRIPTION

The feed system is a complex arrangement of dry powder silos, hoppers, transport tubes, mixing tanks, and feed pumps designed to introduce a tailor-made feed into the melter. Figure 2 is a simplified representation of the feed system for the LAW Melters. Liquid waste will be pre-treated for removal of solids and cesium) and held in concentrate storage vessel located in a Low-Activity Waste Pretreatment System (LAWPS) facility, adjacent to the WTP complex. Pretreatment and operation of the LAWPS will be performed by the Hanford Tank Farms operating contractor.

The treated liquid waste is then transferred via underground piping to one of two concentrate receipt vessels (CRV) located within the WTP LAW facility, each for a given melter line. The primary mixing of feed destined for the melter occurs in the melter feed preparation vessel (MFPV), where dry glass forming chemicals (GFCs) are mixed with liquid waste to form a feed slurry. This feed slurry is then transferred to the melter feed vessel (MFV) for eventual pumping to the melter by air displacement slurry (ADS) pumps. The feed enters the melter through feed nozzles situated in the melter lid. There are six feed nozzles per melter, each supplied by a dedicated ADS pump within the MFV.

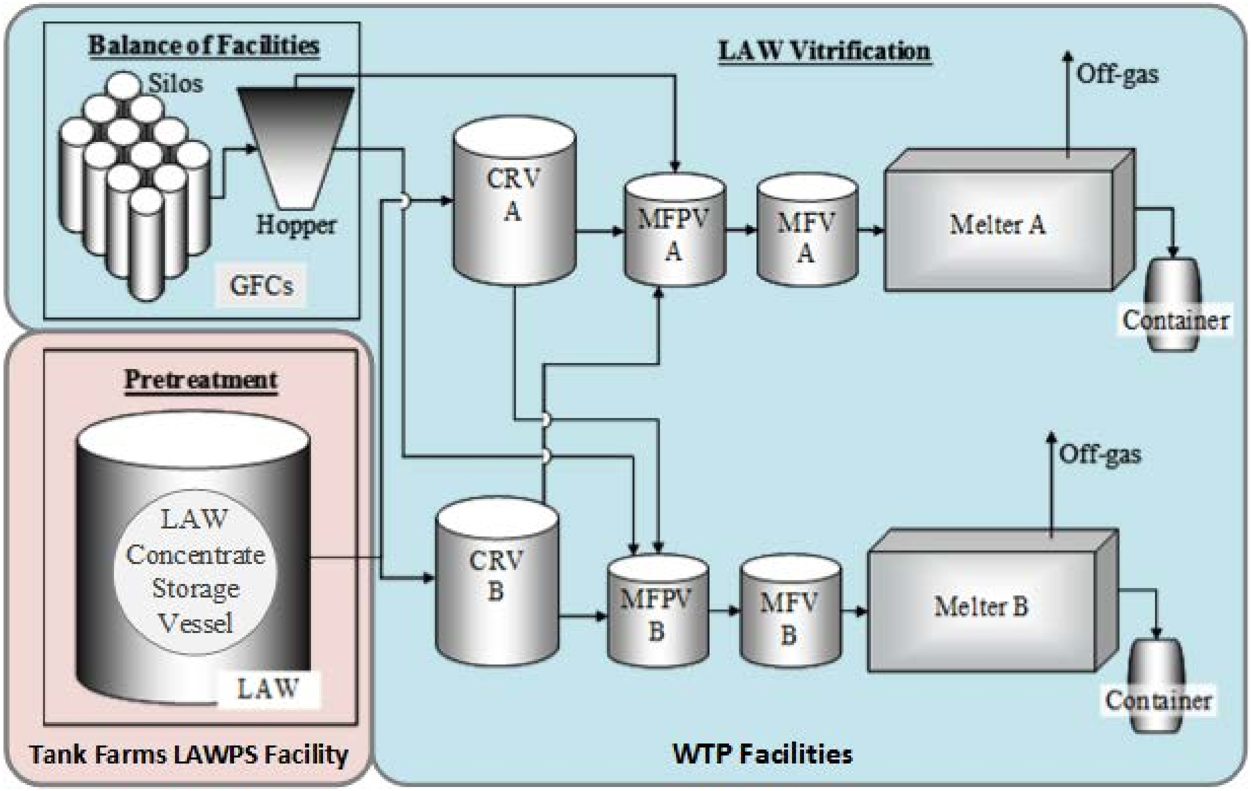

Figure 2 - LAW Melter Feed System

During the commissioning phase with tuning feed, GFCs would be metered in and mixed within the glass former storage facility and transferred to the MFPV, where they would be combined with a non-radioactive liquid slurry. This slurry is expected to be composed of sodium hydroxide and water, and is called the tuning surrogate. This tuning surrogate takes the place of liquid radioactive or simulated waste, and is transferred to the MFV after mixing with GFCs. Six ADS pumps then transfer the tuning feed to the melter via water-cooled melter feed tubes.

MELTER OPERATION TESTING

The melter is the heart of the LAW Facility and drives many of the process conditions for the rest of the facility (such as for the offgas system). During melter operation, feed enters the melter through the lid and forms a layer of unmelted material, called a cold cap, on top of the molten glass pool. Water in the feed evaporates and other components decompose or volatilize. Steam and offgases are then treated in the melter offgas system. Nonvolatile components react to form oxides and are incorporated into the glass matrix. Bubblers inserted into the glass pool agitate the glass to increase the rate at which the cold cap is incorporated into the glass pool. The feed rate to the melter is adjusted based on melter plenum temperature, typically between 300 – 600 °C. Feed rate to the melter is controlled to maintain an optimum layer of cold cap on the melt surface, such that a sufficient processing rate is maintained, while simultaneously ensuring the melter plenum space remains sufficiently hot by not adding excessive feed, which acts as an insulating layer on the melt surface.

Cold Cap Formation

From an operations standpoint, it is important to determine how to properly start melter feeding and achieve steady state operation with complete cold cap coverage of the glass pool. At one extreme, high feed rates could be used to achieve the cold cap as quickly as possible, but this runs the risk of overfeeding the melter and dropping the plenum temperature well below the desired set point. At the other extreme, cold cap formation could be achieved by using a low feed rate over an extended period of time, but this condition tends to generate significant quantities of particulate matter because the feed slurry vigorously boils and reacts when it contacts molten glass instead of the cold cap. Determining the optimum parameters for establishing the cold cap after a period of melter idling is a sensitive process that must be completed before cold commissioning. The tuning feed affords this opportunity.

A desired characteristic for the tuning feed is that it be able to form a cold cap that will spread to cover the entire glass pool while generating sufficient gas quantity to challenge the offgas system. Based on preliminary investigation, it is expected that the tuning feed can be formulated with similar rheological and melting properties as the actual LAW feeds. As a result, the formation of the cold cap and its dispersion over the glass pool surface should be very similar to that expected in the LAW Melter during normal treatment operations. Plenum temperatures, feed rates, and gas loading to the offgas system should mimic production values, which will help define and validate the commissioning requirements.

Off-gas Behavior

If the cold cap performance exhibited while using the tuning feed is similar to that expected during routine operations, offgas surging is also expected to be similar. Offgas surging occurs when the cold cap shifts or breaks up, allowing fresh feed to come directly into contact with the molten glass surface. Water in the feed immediately flashes to steam, which produces a short term surge in gases, impacting both the melter vacuum and operation of the offgas system.

The offgas stream generated during normal operation consists of air (from controlled air addition and in-leakage), steam (evaporation of feed slurry water and hydroxide decomposition), gases (e.g., carbon dioxide, nitrogen oxides, sulfur oxides), and other aerosols and particulate.

During offgas generation, the plenum pressure increases, requiring a controller response from the offgas system to restore the melter vacuum to the desired set point. If the tuning feed is shown to mimic the generation of these gases, then the offgas system control loops can be tuned and the operators properly trained.

Film Cooler and Transition Line

The film cooler, located in the lid of the melter, is used to prevent the buildup of entrained feed material at the inlet to the offgas system. Within the film cooler is a sleeve that directs an added air stream (compressed air) toward the center of the film cooler. This air cools the melter offgas and decreases the rate of solids buildup inside the piping. The film cooler air injection rate is also the primary method for control of the melter plenum pressure. As the plenum pressure becomes more positive (closer to ambient pressure) relative to the pressure setpoint, the injection air flow is reduced. Conversely, as melter pressure drops below the setpoint, the control air flow is increased.

Proper film cooler operation is important to control the buildup of particulate matter. Therefore, it is important that the tuning feed be capable of generating particulate matter that is similar to what would be produced during normal operations. As discussed previously, the surrogate “waste” portion of the melter feed slurry will be made up of sodium hydroxide and water, and the same GFCs planned for normal operations will be used in the tuning feed. Therefore, it is anticipated that particulate generation from the tuning feed will be quite similar to normal operation and to previous testing performed on the LAW pilot melter [3] [4].

During normal operations, the film cooler and transition line temperature will be approximately 250 – 350 °C. The film cooler transition line temperature is directly controlled by the plenum temperature and the film cooler air addition flow rate. The temperature within the film cooler and transition line is very important as it defines the type of solids which will be deposited within the system. If the temperature is too high, then the deposits can become crusty and glassy and be difficult to remove. It is anticipated that at the 250 – 350 °C temperature, the particulate generated from the tuning feed will be some type of alkali compound which is similar to that expected during normal operation.

Similarly, the type of particulate, as well as the temperature, is important to the cleaning operation of the film cooler and transition line. Tuning feed development testing, described later, will include a comparison of particulate deposition in the film cooler against previously measured deposition during LAW waste simulant vitrification. The alkali solids from the tuning feed will be water soluble so that they are easily removed during flushing of the film cooler and transition line. Cleaning of the film cooler and transition line is very important since the buildup of solids could clog the film cooler and transition line, which would likely require shutdown of feeding operations until the film cooler and associated lines were cleaned. Early experience using a non-hazardous tuning feed will enable optimization of the film cooler operating parameters.

Offgas Systems Operation Testing

The offgas systems are designed to collect, cool, and treat the offgas from the LAW Melters so that the offgas effluent conforms to relevant federal, state, and local air emissions requirements at the point of discharge from the facility exhaust stack.

The system includes ALARA design features and the best available radionuclide control technologies (BARCT and BACT).

The primary offgas system contains two parallel trains, one for each melter, with each train consisting of a submerged bed scrubber (SBS) and a wet electrostatic precipitator (WESP). The two primary train flows are then combined in the secondary treatment portion of the offgas system, which includes HEPA filtration, thermal catalytic reduction (for NOx removal) and caustic scrubbing.

The main purposes of the SBS are to condense the steam in the offgas and remove coarse particulate matter. The WESP further treats the offgas by removing sub-micron particulate matter and mist. These systems must be challenged during commissioning, so it is important that the melter offgas contain both condensable gases and particulate matter.

Generation of particulate matter using the tuning feed benefits early testing since it challenges the SBS solids removal system and the water deluge operation for cleaning the inside of the WESP in a manner that closely resembles intended operation. However, since all of the nitrate and nitrite will be removed from the feed material, the WESP sump will not be acidic from acid gases and mist that it will capture from the SBS effluent during normal operations. Since a higher pH effluent solution has been shown in previous melter offgas testing to enhance solids removal, the solids removal of the water deluge operation in tuning feed testing may not be as efficient as during normal operations, thereby producing somewhat more conservative test results relative to normal operations.

Control Loop Description

The molten glass and cold cap activity within the melter results in a highly variable offgas generation rate with frequent pressure surges. To compensate, multiple feedback loops are used to balance the system pressure and flow. Starting at the melter, air inleakage, ADS, and bubbler flow provide a baseline non-condensable gas flow through the melter plenum. At the film cooler, air is injected for plenum pressure control. This injection flow is monitored and controlled by adjusting a flow control valve. Insufficient vacuum within the melter plenum would be corrected by reducing injection flow, while excessive melter vacuum would be addressed by increasing injection air. Required control margin is maintained in the control air loop by modulating a differential pressure control valve at the exit of the wet electrostatic precipitator. This control slowly returns the pressure control air flow to a predetermined value following changes in control air flow to ensure that operating range is maintained in the control air valve position for transient response.

Changes to the plenum pressure and offgas flow impact the secondary offgas system as well as the main exhauster fan speed control. The control systems for the primary and secondary offgas systems and exhauster fan contain multiple inputs that must be tuned properly to operate efficiently. This need for control system tuning and demonstration of the effectiveness of the confinement system provides additional impetus for use of a tuning feed early in the commissioning process.

Melter offgas tuning exercises will start with simple water additions to the melter. The pulse of steam generation from the melter will cause a pressure change which must be mitigated by the pressure control system. A rapid response without much overshoot is desired and initial adjustments will be made to attain this response. The pressure control system mitigates the step change in steam flow by reducing air flow to the offgas system. Conversely, when the steam is stopped, the air addition will increase, so that as the steam is condensed in the SBS, the entire offgas system must respond to the changes in air flow. Water addition provides for these simple step changes in flow to exercise the system.

The next step in tuning the system is mitigation of pressure spikes caused by a short burst of steam production. The spikes are caused as pockets of liquid contact hot glass. The water boils away, leaving the solids to decompose to oxides and enter the glass.

Following pressure control testing with water alone, testing with tuning feed to establish cold cap performance and water to induce transients will be performed. Testing will also include testing of system response to loss of power and other upset events.

TUNING FEED DEVELOPMENT

Ideally, a tuning feed should have a composition that resembles the waste and GFC mixture to be processed. Selection of a non-hazardous feed for tuning started with well-defined LAW feed and glass compositions that were used in previous developmental testing. Simple elimination of the hazardous components of the feed results in only aluminum and sodium remaining. Glass properties, feed properties, and processing behavior all need to conform to the range of operability of the melter.

The feed proposed is based on a “LAW A44” glass, which was formulated to a particular WTP waste composition. This glass was extensively evaluated in a pilot melter testing program, and it exhibits the glass properties needed for processing through the WTP LAW Melter. Glass development for WTP has been the subject of several previous papers [2] [3] [4].

Table I lists all the constituents removed from the nominal LAW A44 feed, as well as the additives and solutions remaining that constitute the tuning feed. Removed from the LAW feed are nitrates, nitrites, organic compounds simulating those in the waste, and sucrose (added to the production feed in proportion to nitrates and nitrites in the feed). The remaining constituents in the proposed LAW tuning feed are the standard WTP glass forming chemicals, and sodium hydroxide and water. The tuning feed will contain no nitrogen compounds, sulfur, halides, or organic carbon.

Table 1. Constituents Removed from LAWA44 Feed Composition and WTP Additives Used to Produce the Proposed LAW Tuning Feed

Description	Constituent
Waste Simulant Constituents Removed or Substituted	Al(NO3)3.9H2O, 60% sol.
	Al(OH)3
	Ca(NO3)2*4H2O
	Na2CrO4.4H2O
	NaOH, 50% sol. d=1.53
	CsNO3
	Fe(NO3)3*9H2O
	KOH
	KI
	Ni(NO3)3*6H2O
	NaCl
	NaF
	Na3PO4.12H2O
	Na2SO4
	NaNO2
	NH4NO3
	Na2EDTA.2H2O
	Na3HEDTA 41% sol.
	Sodium Acetate
	Sodium Formate
	Sodium Oxalate
	Glycolic Acid
Additive Removed	Sucrose as Reductant
WTP Additives and Constituents Used to Formulate LAW Tuning Feed	Kyanite (Al2SiO5) 325 Mesh (Kyanite Mining)
	H3BO3 (US Borax – Technical Granular)
	Wollanstonite NYAD 325 Mesh (NYCO Minerals)
	Fe2O3 (97% Alfa)
	Olivine (Mg2SiO4) 325 Mesh (#180 Unimin)
	Na2CO3 (Technical grade)
	SiO2 (Sil-co-Sil 75 US Silica)
	TiO2 (Rutile Airfloated Chemaloy)
	ZnO (KADOX – 920 Zinc Corp. of America)
	Zircon ZrSiO4 (Flour) Mesh 325 (AM. Mineral)
	5 Molar NaOH Solution (Membrane or reagent grade; < 0.01 wt% NaCl)
	Water

Team members from Atkins Engineering and the Vitreous State Laboratory at Catholic University have been contracted by the Project to perform two phases of testing, described in the following paragraphs.

Phase 1 Testing: Laboratory Characterization

The feed properties will initially be measured in a laboratory environment. Small quantities of the tuning feed will be produced with five different hydroxides to carbonate ratios for characterization. Critical feed properties will be measured for each ratio, including density, pH of the waste and final feed, total solids content and glass yield, feed solids settling rate, settled solids volume percent, and rheology.

Variations in the feeds that will be tested will primarily involve the ratio of sodium hydroxide and sodium carbonate used as the sodium source. Higher concentrations of sodium carbonate will more closely represent the effect of the sodium nitrate that is being removed from the simulant; however, excessive sodium carbonate in the feed can result in foaming of the melt pool.

Quantifying pH provides an indication of the stability of the slurry; a high pH feed can dissolve oxides and thicken the feed. In addition, pH of the feed can directly impact material handling considerations. Total solids content and glass yield impact production rate and slurry transport considerations. Feed solids settling rate, settled solids volume percent, and rheology effect feed slurry pumpability and its ability to distribute over the melt pool surface. Each of these variables will be quantified and evaluated to determine an optimum feed formulation.

Phase 2 Testing: Scaled Melter Operation

Adding feed to an operating melter is necessary to determine cold cap behavior. Although the final glass is targeted to achieve a known composition, the behavior of the intermediary compounds is not known. It is the combination or fluxing of the various oxides, eventually into the glass, along with the production of decomposition gases, that will determine cold cap behavior. Most of the glass former oxides melt at higher temperatures than the 2100 °F processing temperature and rather than melt, they actually dissolve into the glass pool during processing. Feeding of the proposed tuning feed formulation(s) will be performed in a scale prototypic melter to provide empirical data on cold cap behavior.

Projected Schedule

Team members from Atkins Engineering and the Vitreous State Laboratory at Catholic University have been contracted by the Project to complete bench scale crucible testing by the spring of 2017, followed by small scale melter testing and final reporting by late 2017.

CONCLUSION

Startup and commissioning of the LAW Facility will utilize a progressive approach, starting with simple tests and progressing to full integrated testing. Each successive step in the commissioning sequence will introduce additional complexity of integration and increasing hazards. Development of a non-hazardous tuning feed for use in the initial startup and integrated testing of the LAW Facility is currently underway. The tuning feed will enable integrated testing of the feed receipt system, glass former chemical metering and blending systems, melter feed preparation and melter feed systems, as well as tuning of pressure and flow control loops for the primary and secondary offgas treatment systems, all without generating hazardous or toxic offgas. Key chemical and performance characteristics have been identified to ensure compatibility with LAW Facility process equipment and process streams. Scale melter testing of candidate tuning feeds for the LAW Facility is planned for completion in 2017. Successful development of this tuning feed material is a key step in the WTP approach to safe and efficient commissioning of its vitrification facilities.

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