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EWG-RPT-028, Rev. 0.0
PNNL-30141, Rev. 0.0

Vitrification of High-Cr Glass in Research-Scale Melter

August 2020

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99354

Executive Summary

This test report describes the experimental results from a small-scale test using the research-scale melter (RSM) at Pacific Northwest National Laboratory to demonstrate processing of a high-Cr simulated feed stream, designated HLW-HCr-16.

The RSM is a small, joule-heated melter capable of processing melter feed continuously. The melter is equipped with Inconel® 693 electrodes, Monofrax® K-3 refractory, and an Inconel 690 pour spout. An electric kiln surrounds the melter body and minimizes heat loss from the melter body during operation. The RSM is equipped with an offgas treatment system that employs quenching, wet scrubbing, and high-efficiency mist elimination. The glass-discharge section is heated to facilitate pouring of the glass. The melter is fitted with a melt cavity that is ~25 cm (10 in.) in diameter with a nominal glass depth of 8.9 cm (3.5 in.). The melter was operated with a target glass temperature of 1150°C and target plenum temperature between 550°C and 700°C for this test. The air bubbling rate was 4.2 L/min. Overall, during the continuous operation of the melter for ~ 103 hours, ~ 141 kg of glass was produced.

At the conclusion of the test, the melter and exhaust lines were visually inspected for particulate deposition and corrosion. Entrained material had adhered to the underside of the melter lid and to the exhaust piping. Enrichments in elements such as Cl, F, B, K, Li, P, Na, and S were measured in these deposits through inductively coupled plasma–optical emission spectroscopy and X-ray fluorescence analysis. When the melter electrodes and air bubbler tube were removed from the glass in the RSM, the electrodes appeared discolored, but no significant loss of metal was observed.

The processing of a high-Cr simulant, HLW-HCr-16, in the RSM produced glass at an average rate of 1.36 kg/h, equaling a melter-surface-area normalized glass generation rate of 654 kg/day/m^2. The resulting glass met the toxicity characteristic leaching procedure requirement. Test results of crystallinity, electrical conductivity, and viscosity showed good processing properties of this high-Cr high-level waste glass. RSM offgas was also sampled and analyzed at periodic intervals during steady-state operating conditions. The total decontamination factor averaged by four sampling periods was 134. The concentrations of CO and NO_x in emissions were 237 to 422 and 69 to 94 parts per million by volume, respectively.

Acknowledgments

The authors gratefully acknowledge the financial support provided by the U.S. Department of Energy Office of River Protection Waste Treatment and Immobilization Plant Project, managed by Tom Fletcher, with technical oversight by Albert Kruger.

The authors thank Charmayne Lonergan (PNNL) for her technical review, Matt Wilburn (PNNL) for the editorial review, and Renee Russell, David MacPherson, Hans Brandal, and Veronica Perez (PNNL) for programmatic support during the conduct of this work.

Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
BNI	Bechtel National, Inc.
CCC	canister centerline cooling
DAC	data acquisition and control
DF	decontamination factor
DOE	U.S. Department of Energy
dscf	dry standard cubic feet
dscfm	dry standard cubic feet per minute
DWPF	Defense Waste Processing Facility
EC	electrical conductivity
EDS	energy dispersive X-ray spectroscopy
EPA	U.S. Environmental Protection Agency
EVS	ejector venturi scrubber
EWG	enhanced waste glass
HASQARD	Hanford Analytical Services Quality Requirements Document
HDI	PNNL's standards-based management system — "*How Do I*?"
HEME	high-efficiency mist eliminator
HLW	high-level waste
HX	heat exchanger
IC	ion chromatography
ICP-OES	inductively coupled plasma–optical emission spectroscopy
JHM	joule-heated melter
LSM	laboratory-scale melter
NA	not applicable
ND	not detected
NDIR	nondispersive infrared
NIST	National Institute of Standards and Technology
NM	not measured
NQAP	Nuclear Quality Assurance Program
OD	outer diameter
ORP	Office of River Protection
PM	particulate matter
PNNL	Pacific Northwest National Laboratory
ppm	parts per million
ppmvd	dry parts per million by volume
QA	quality assurance
RSM	research-scale melter
sccm	standard cubic centimeters per minute
SEM	scanning electron microscopy
SRM	Standard Reference Material
SwRI	Southwest Research Institute
TAP	Test/Analytical Procedure

TCLP	toxicity characteristic leaching procedure
VSL	Vitreous State Laboratory
WTP	Waste Treatment and Immobilization Plant
wscfm	wet standard cubic feet per minute
XRD	X-ray diffraction
XRF	X-ray fluorescence

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1.0 Introduction

The U.S. Department of Energy (DOE), Office of River Protection (ORP), has contracted with Bechtel National, Inc. (BNI) to design, construct, and commission the Waste Treatment and Immobilization Plant (WTP) at the Hanford Site (DOE 2000). This plant is designed to operate for ~40 years and treat millions of gallons of radioactive waste stored in 177 underground tanks at the Hanford Site. Vitrification technology was chosen to treat a portion of the tank waste at the DOE's Hanford and Savannah River sites. Joule-heated melters (JHMs) are being used at the Defense Waste Processing Facility (DWPF) at Savannah River Site and will be used at the WTP to vitrify tank waste fractions.

A JHM developed by Pacific Northwest National Laboratory (PNNL), referred to as the research-scale melter (RSM), is used for small-scale tests, which are intended to provide programmatic guidance to the WTP mission for efficient vitrification of a variety of Hanford waste streams. The RSM configured for the test includes Inconel® 693 plate electrodes and Monofrax® K-3 as the glass contact refractory. The melt cavity is 25.4 cm (10 in.) in diameter and 8.9 cm (3.5 in.) deep. The results described here are from a test performed in fiscal years 2013-2014 as part of ORP validation tests for melters used by PNNL and the Vitreous State Laboratory (VSL) at The Catholic University of America (Matlack et al. 2014).

This test report describes the experimental results from processing simulated high-Cr high-level waste (HLW) feed using the RSM. A high-Cr glass composition developed by VSL (Matlack et al. 2014) was prepared in a single batch by NOAH Technologies Inc. and shipped to testing facilities at PNNL and VSL to be tested concurrently. The tests measured process rates, crystal formation, and retention of constituents in the glass.

Requirements for this assessment included, but were not limited to, successful production of a durable, compliant glass with an acceptable waste loading at design production rates without causing excessive corrosion of JHM components or operating instability. The specific objectives of the study were to (1) obtain steady-state operations to determine processing rate and melter operating characteristics; (2) collect and analyze samples from feed, glass, and offgas; (3) verify composition and quality of glass produced through inductively coupled plasma–optical emission spectroscopy (ICP-OES), X-ray diffraction (XRD), and microscopic analyses; (4) measure processing properties, viscosity, and electric conductivity of the produced glasses; and (5) conduct sampling of the melter exhaust to characterize particulate and major gas emissions.

Test objectives and goals were satisfied; however, operational issues related to plugging of melter feed lines limited the collection data over time periods typical of vitrification tests. This report discusses the challenges presented to the operations staff during the run and considerations for future melter tests.

1.1 Quality Assurance

Activities supporting the research contained in this report has been ongoing since 2012. From 2012 through 2016, this work was performed in accordance with PNNL's laboratory-level Quality Management Program, which is based upon the requirements as defined in the United States Department of Energy (DOE) Order 414.1D, Quality Assurance, and 10 CFR 830, Nuclear Safety Management, Subpart A, Quality Assurance Requirements. PNNL implements these requirements with a graded approach using the consensus standard ASME NQA-1-2000, Quality Assurance Requirements for Nuclear Facility Applications, graded on the approach presented in NQA-1-2000, Subpart 4.2, Guidance on Graded Application of Quality Assurance (QA) Standard for Nuclear-Related Research and Development.

Since 2017, work has been performed in accordance with the PNNL Nuclear Quality Assurance Program (NQAP) Quality Assurance Manual (NQAP-2012) and associated QA procedures. The NQAP is based on the requirements of NQA-1-2012, Quality Assurance Requirements for Nuclear Facility Application, graded on the approach presented in NQA-1-2012, Subpart 4.2.1, Guidance on Graded Application of Nuclear Quality Assurance (NQA) Standard for Research and Development. The NQAP works in conjunction with PNNL's laboratory-level Quality Management Program.

All analytical project work was performed following the Hanford Analytical Services Quality Assurance Requirements Document (HASQARD; DOE 2014).

2.0 RSM System

This section describes the RSM processing system used to support this study. The Process Development Laboratory East building, located at PNNL in Richland, Washington, housed the RSM system, for which a schematic is shown in Figure 2.1. The liquid lines are shown in blue and the gas lines are shown in black.

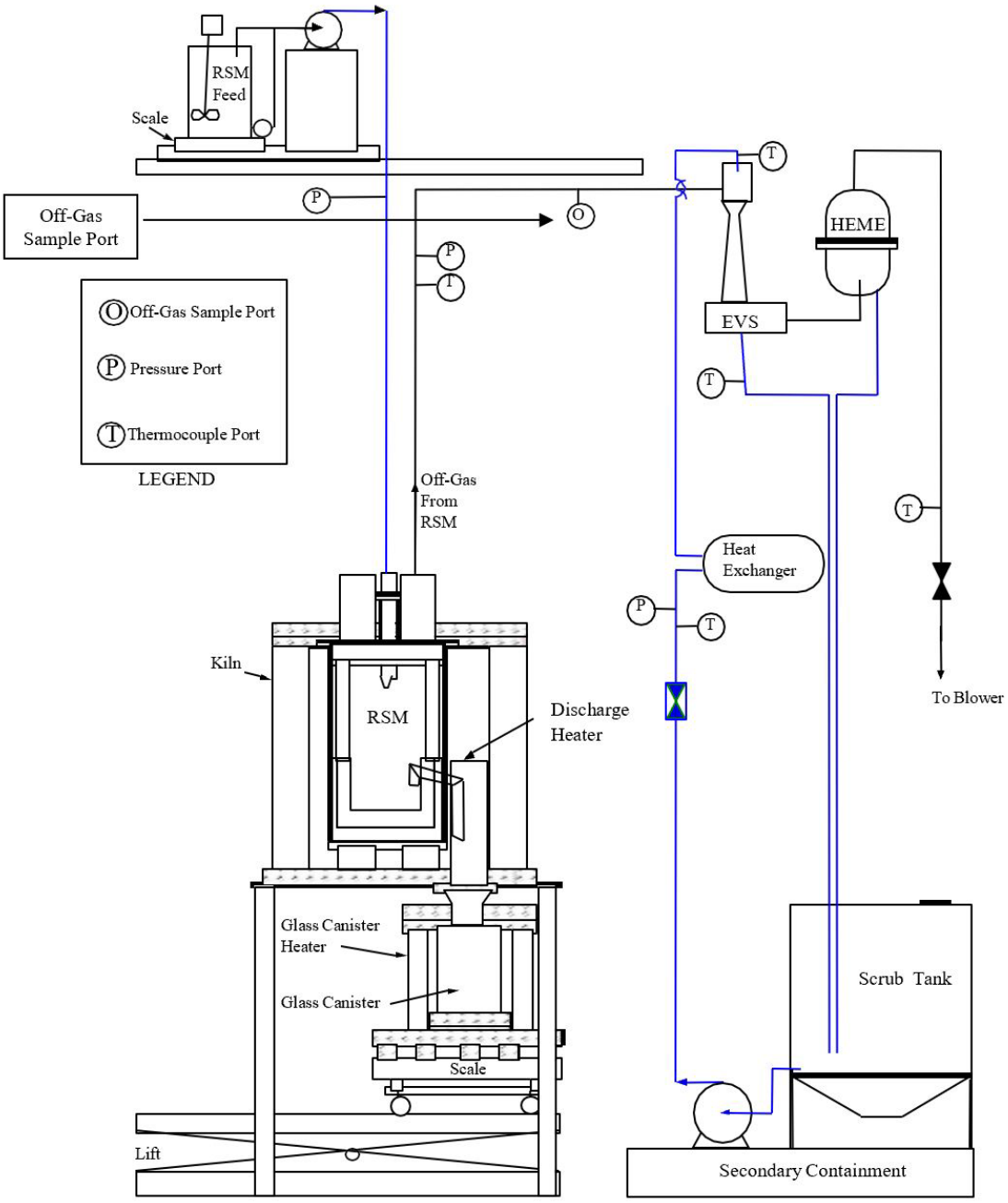


Figure 2.1. Research-Scale Melter Configuration

The RSM is a small JHM capable of processing melter feed continuously, which is a key capability that is needed for the melter to be representative of a full-scale melter system at the WTP. Testing in the RSM allows parametric studies to be conducted in a relatively short time.

The RSM processing system provides unit offgas treatment operations of quenching, wet scrubbing, and high-efficiency mist elimination. The offgas port contains a simple film cooler fabricated from a sintered metal filter that allows injected air to pass from the outside of the filter through the sintered metal into the offgas line while melter exhaust gas passes through the middle of the filter, combining with the injected air. The aqueous quench scrubber is an ejector venturi scrubber (EVS), previously shown to be functionally equivalent to the WTP submerged bed scrubber technology (Goles and Schmidt 1992). The exhaust of the RSM EVS is treated by a high-efficiency mist eliminator (HEME) which efficiently removes sub-micron aerosols and particulate matter penetrating the EVS. Table 2.1 provides RSM dimensions and other operational features.

Table 2.1. RSM Dimensions and Operational Features

Parameter	RSM
Melter cavity diameter	25.4 cm
Melt surface area	500 cm^2
Melter cavity height	17 cm
Melter internal volume	8.6 L
Nominal glass melt depth	8.9 cm
Nominal glass melt volume	4.5 L
Maximum operating temperature	1200°C
Nominal operating temperature for borosilicate glass	1150°C
Bubbler dimensions	1/4-in. OD[(a)] tubing
Bubbler material	Inconel 690
Electrode dimensions (W × H × T)	11 × 10 × 0.9 cm
Electrode material	Inconel 693
Electrode distance from bottom	0 cm[(b)]
Electrode current (average)	90 A
Electrode voltage (average)	60 V
Electrode current density (average/maximum)	0.5/2.0 A/cm^2

(a) OD = outer diameter.
(b) Electrodes rest on the bottom of the RSM cavity.

The body of the RSM is an Inconel 625 closed-ended cylinder lined with Alfrax® refractory that contains a Monofrax K3 refractory melt cavity. An Inconel pour spout tube discharges molten glass into a stainless-steel canister. Two Inconel 693 electrodes enter the melter through ports in the lid and are suspended in the glass to supply joule-heating power to the RSM. An electric kiln surrounds the melter body to heat the melter during startup and to minimize heat loss from the melter body during operation by decreasing the temperature gradient across the melt chamber walls. The discharge section is heated to facilitate pouring of the glass. The stainless-steel canister, for receiving poured glass, sits inside a smaller kiln maintained between 700°C and 900°C to promote uniform canister filling. Accounting for the areas displaced by the electrodes and air bubblers (used to promote mixing), the melt surface area of the RSM is 500 cm^2, with a nominal glass depth of 8.9 cm. This results in a corresponding glass inventory of 11 kg, assuming a glass density of 2.5 g/cm^3 at 1150°C. The melter is controlled using a data acquisition and control (DAC) system (hardware and software from Allen-Bradley/Rockwell Automation, Milwaukee, WI), which allows temperature and power control. Temperature control was typically employed during

these tests, with alarms set to alert the operators if temperature or power strayed outside of its pre-defined range.

2.1 RSM Feed System

During the test, feed was delivered from the conical bottom of the 55-gallon feed tank to the RSM melter with two peristaltic pumps (Figure 2.2). One pump recirculated the slurry in a 1/2-in. line to a point near the melter to keep solids in the feed line suspended, and the second pump provided slurry in a 1/4-in. line to the water cooled melter feed nozzle. An agitator in the feed tank kept the slurry well mixed. The feed tank was mounted on a scale that was monitored by the computer DAC system. The speed of the second pump was used to control the feed rate to the melter. While the feed system performed well in prior tests, during this test, frequent plugging by undissolved NaOH pellets was observed in the 1/4-in. line.

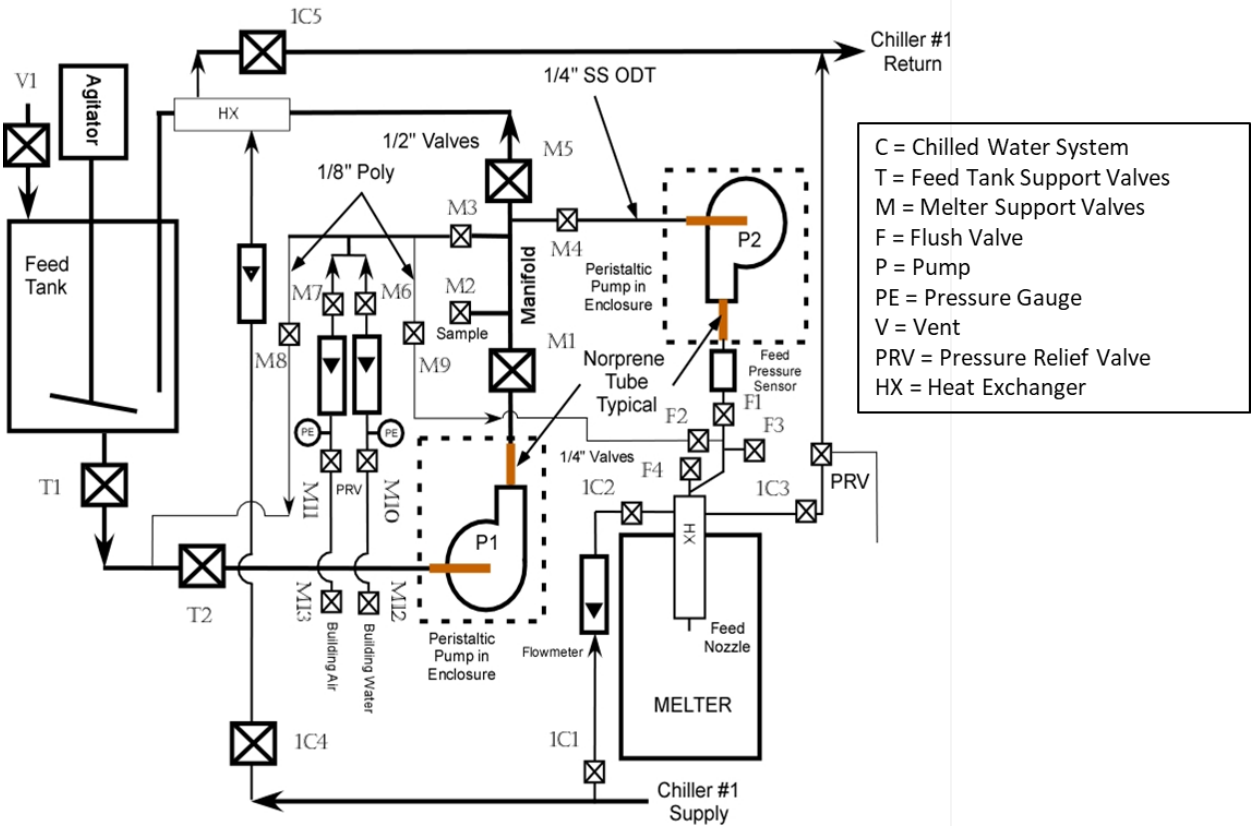


Figure 2.2. RSM Feed System Diagram

2.2 EVS

The EVS sprays scrubber solution through a nozzle for direct contact with the melter exhaust. At the beginning of a melter run, the scrubber solution consists only of water. As the melter operates, the EVS condenses water from the melter exhaust and removes particulates and some acid gases. The resulting two-phase stream travels through a separator chamber and the scrubber solution returns to the scrub tank under the force of gravity. The scrubber solution is recirculated from a tank with a pump located adjacent to the RSM platform and through a heat exchanger (HX) to remove the heat transferred from the melter

exhaust. From the scrubber, the exhaust passes through a HEME to remove condensed-phase aerosols. Quench-scrubber samples were collected periodically during the test for chemical analysis.

2.3 Process Conditions

The process conditions maintained during the feeding/pouring period of the test are described in this section. The process conditions targeted during testing are described below and are given in Table 2.2.

Table 2.2. Target RSM Operating Conditions

Parameter	RSM
Glass inventory[(a)]	11 kg
Glass melt temperature	1150°C
Plenum temperature range	550–700°C
Plenum vacuum	~0.5 to ~ 3.0 in. water
Post-film-cooler temperature range	150–350°C
Melt bubbling rate	4.2 L/min
Initial scrub solution volume	50 L
Melt condensate pH	> 3

(a) Assuming a glass density of 2.5 g/cm^3 at 1150°C.

The major process conditions that were controlled were glass pool temperature, melter vacuum, melt pool bubbling rate, processing rate, plenum temperature, offgas temperature, and quench-scrubber condensate temperature. Strategies for maintaining baseline conditions are discussed in the following subsections.

2.3.1 Glass Pool Temperature

The 1150°C target temperature was automatically controlled by the RSM DAC system. The electrode current density was constrained to ≤2 A/cm^2 (~190 A for the RSM) to prevent excessive corrosion of the electrodes. If the electrode current density was to become a constraint in maintaining the target glass temperature, the kiln temperature could be adjusted to mitigate heat loss from the melt. The thermocouples monitoring the melt temperature were located within the melter electrodes.

2.3.2 Melter Vacuum

The RSM blower was able to provide up to 28-in. water gauge vacuum (at 200 cubic feet per minute). The RSM vacuum was automatically controlled at a set point, nominally between 0.5- and 2-in. water gauge below ambient conditions. The vacuum pressure was adjusted to instigate and postpone glass pours.

2.3.3 Melt Pool Bubbling Rate

Glass pool agitation using subsurface air injection was employed to enhance melter feed processing rates. To accomplish this, a flow meter delivered air into the RSM at 4.2 L/min divided between two tubes that entered the melt from the top of the melter. The accuracy of the flow meter was such that the bubbling rates in the RSM were within ± 0.05 L/min of the rates indicated by the flow meter.

2.3.4 Processing Rate

Steady-state feed processing rates for the melter were controlled based on cold-cap conditions, which were visually observed through a view port in the lid of the melter at least once every hour and obliquely

monitored by tracking the plenum temperature. Changes in feed rate were required to maintain target cold-cap coverage of 80% to 90%. During the test, to achieve the target glass processing rate of ~1.0 MT/day/m^2, a feed rate of ~4.1 L/h was necessary.

2.3.5 Plenum Temperature

The targeted plenum temperature range was 550°C to 700°C during periods when maximum feeding rates were sustained. While plenum temperature was not directly controlled, in-leakage, melter kiln temperature, and bubbling rate all influenced it under steady-state processing conditions (80% to 90% cold-cap coverage).

2.3.6 Offgas Temperature

The post-film-cooler offgas temperature was constrained to <350°C to prevent the offgas lines from becoming plugged by particulate deposition. The temperature was controlled by a valve adjusting the film-cooler air injection rate.

2.3.7 Quench-Scrubber Solution Temperature

The expected EVS solution temperature was ~30°C to 40°C. If there was a need to increase or decrease this temperature, the cooling flow rate of the condensate HX was adjusted appropriately.

After changes in operating parameters, some operating time was needed to allow the glass melt to approach a new equilibrium. After changes to the bubbling rate, a significant amount of time was required to find the appropriate feed rate for reaching steady-state conditions. Stability can be difficult to assess because plenum temperatures have normal fluctuations and cold-cap observations are subjective. For the present test, conditions were required to be stable for >5 h to declare the system at steady state. Many feed rates were tested to determine the maximum sustainable rate.

2.4 Data Collection and Process Controls

The collection of process, operational, and control data was performed primarily by the RSM DAC system, which monitors, controls, and electronically logs key system variables at 1-s intervals. Process data not electronically logged by this system and selected parameters of most interest were recorded manually on operator datasheets every hour (shown in Appendix A).

Table 2.3 identifies the process information that was electronically logged by the RSM DAC system and/or manually logged on RSM operation datasheets. The data documented important operational conditions associated with the melter, offgas system, feed, glass, and secondary waste streams.

Table 2.3. RSM Process Data Logged Electronically (1-s intervals) or Manually (~1-h intervals)

Parameter	Units	Electronic Log	Manual Log
Melt temperature (T1, T2)	°C	X	X
Melt (electrode) set-point temperature	°C		X
Plenum temperature	°C	X	X
Feed pump setting (power output %)	%	X	
Feed tank weight	kg	X	
Glass poured	g		X
Electrode potential	volt	X	X
Electrode current	amp	X	X
Electrode power	kW & %	X	X
Electrode power control mode	auto or manual		X
Melt resistance	Ω		X
Kiln power	kW & %		X
Kiln set-point temperature	°C		X
Kiln actual (middle) temperature	°C		X
Kiln top/bottom temperatures	°C/°C		X
Pour spout heater set-point temperature	°C		X
Pour spout heater temperature	°C		X
Pour spout heater power output	kW & %		X
Feed nozzle temperature	°C		X
Offgas temperature	°C		X
Post-EVS offgas temperature	°C		X
Scrub liquid EVS inlet temperature	°C		X
HX temperature	°C		X
Post HEME temperature	°C		X
Plenum vacuum	in. H_2O	X	X
Bubbling rate	sccm	X	X

3.0 Simulated Waste and Melter Feed

This section describes the preparation and analysis of the melter feed. The feed was originally formulated based on a high-Cr glass, HLW-HCr-16 (Matlack et al. 2014). The high-Cr glass composition is summarized in Table 3.1, which also shows the relative proportions of the glass formers used and the resulting target glass composition. The feed composition was prepared in a batch by the supplier (NOAH Technologies Inc., San Antonio, TX) and split into two to be tested concurrently in this run and in VSL melters. The high-Cr melter feed was shipped from the supplier to PNNL in 55-gallon drums. However, due to an errant formula in the spreadsheet that was used to calculate the batch, an insufficient amount of sodium was present in the feed received from the supplier. Therefore, both VSL and PNNL had to mix additional Na into the feed. After receiving the prepared feed at PNNL, NaOH pellets were added directly to the 55-gallons drums that the feed was shipped in to restore the Na concentration to target levels [20.43 g of reagent grade (97%) NaOH per kg of as-received feed]. The adjusted feed was then mixed within the drums for several hours and transferred to the melter feed tank. During the test, samples of the melter feed stream were collected for post-test analytical validation of feed composition. The feed samples were taken from the feed tank during the RSM operation. The sampling log is shown in Appendix B and summarized in Table 5.1 of Section 5.0.

During the test, it was observed that the NaOH pellets had not fully dissolved. The recirculation line was able to pass the pellets but the feed injection line to the melter frequently plugged. The plugs were cleared by water flushes, air blowdowns, and “rodding” out the melter feed nozzle with a wire. The line was also replaced occasionally during the test.

Table 3.1. HLW-HCr-16 Glass Composition in wt% (Matlack et al. 2014)

Component	Waste Composition	Waste in Glass	Glass-Forming and Modifying Additives in Glass	Target Glass HWL-HCr-16
Al_2O_3	44.07	19.83	–	19.83
B_2O_3	0.13	0.06	15.00	15.06
Bi_2O_3	2.03	0.91	–	0.91
CaO	2.18	0.98	–	0.98
Cr_2O_3	4.04	1.82	–	1.82
F	0.14	0.06	–	0.06
Fe_2O_3	11.20	5.04	–	5.04
K_2O	0.86	0.39	6.00	6.39
Li_2O	0.00	0.00	4.00	4.00
MnO	2.87	1.29	–	1.29
Na_2O	23.76	10.69	–	10.69
NiO	0.56	0.25	–	0.25
P_2O_5	0.84	0.38	–	0.38
PbO	0.70	0.31	–	0.31
SiO_2	6.42	2.89	30.00	32.89
WO_3	0.19	0.09	–	0.09
Sum	100.0	45.00	55.00	99.99[(a)]

(a) The sum does not equal 100.00 because of rounded decimals.

One feed sample was analyzed at Southwest Research Institute (SwRI) by ICP-OES, while another sample was analyzed at PNNL using only ion chromatography (IC). At SwRI, samples were digested using hydrochloric and nitric acids in an open vessel. The resulting digestates of the feed samples

contained residue. The remaining residues were separated, dried, and fused with a lithium metaborate/tetraborate mixture. The feed samples were also digested using concentrated nitric, perchloric, hydrofluoric, and hydrochloric acids in an open vessel. All digestions were analyzed. To ensure against false positives, blanks were analyzed intermittently. Calibrations were performed using NIST SRM[1] 278 Obsidian Rock and NIST SRM 688 Basalt Rock laboratory control samples. At PNNL, a subsample of each slurry feed supernate was analyzed directly by IC after filtering the slurry feed through a 0.2-micron filter.

As shown in

[1] NIST SRM = National Institute of Standards and Technology Standard Reference Material.

Table 3.2, the SwRI analysis agreed very well with the target composition, as expected. The IC analysis by PNNL was applied to several anion components, F^-, NO^{2-}, and NO_3^- in the supernate after filtering the slurry feed. The PNNL IC results were consistent among samples and with targets. As shown in Table 3.3, the densities of feed samples were consistent among samples, varying only between 1.41 and 1.43 g/mL.

Table 3.2. Feed Sample Compositions (wt%) Measured by ICP-OES and IC

Measured by:		PNNL		SwRI
Sample #:	Target	RSM-EWG8-001[a]	RSM-EWG8-059[a]	RSM-EWG8-041
Al_2O_3	7.11	NM	NM	7.26
B_2O_3	5.40	NM	NM	5.83
Bi_2O_3	0.33	NM	NM	0.340
CaO	0.35	NM	NM	0.371
Cr_2O_3	0.65	NM	NM	0.421
F[b]	0.02	0.0201	0.0179	0.0157
Fe_2O_3	1.81	NM	NM	2.02
K_2O	2.28	NM	NM	1.90
Li_2O	1.43	NM	NM	1.43
MgO	–	NM	NM	0.0282
MnO	0.46	NM	NM	0.489
Na_2O	3.83	NM	NM	3.50
NiO	0.09	NM	NM	0.0895
P_2O_5	0.14	NM	NM	0.150
PbO	0.11	NM	NM	0.108
SO_3	–	NM	NM	0.0592
SiO_2	11.79	NM	NM	9.33
TiO_2	–	NM	NM	0.0115
WO_3	0.03	NM	NM	0.0267
CO_3[b]	4.26	NM	NM	3.18
NO_2[b]	0.09	0.0936	0.0943	0.0736
NO_3[b]	0.25	0.364	0.357	0.242
C_2O_4[b]	3.68	NM	NM	3.06
Total, no water	44.11	NM	NM	39.93
Formulated water	55.89	NA	NA	NA

(a) Sample was only analyzed with IC.
(b) Measured by IC.
NM = not measured; NA = not applicable.
MgO, SO_3, and TiO_2, are not target components.

Table 3.3. Feed Densities

Sample #:	RSM-EWG8-001	RSM-EWG8-004	RSM-EWG8-013	RSM-EWG8-053	RSM-EWG8-059
Density (g/mL)	1.41	1.43	1.42	1.41	1.41

4.0 Run Description

This RSM test was run over a period of 103.4 h, 9/9/2013 0548 – 9/13/2013 1312, processing ~360 kg of slurry feed and producing ~140.8 kg of glass. The melter operated with continuous feeding, and the glass was sampled periodically. This section describes the melter operation as well as the inspection of the melter after operation was completed.

Prior to melting in the RSM, a preliminary melt of the HLW-HCr-16 feed was performed in a laboratory-scale melter (LSM) at 1150°C to evaluate the melting characteristics and resulting glass product. The LSM consists of a 10-cm-diameter quartz melting chamber that is top-loaded into a laboratory furnace (Kim et al. 2011). Unlike the RSM, there is no bubbler to agitate the melt in the LSM. Before placing the melt chamber into the furnace, the bottom of the chamber was covered with a layer of HLW-HCr-16 glass. After the chamber was lowered into the furnace and the starter glass had melted, the high-Cr feed was introduced into the quartz chamber at rates between 3.0 and 6.5 mL/min using a peristaltic pump. The feed rates of the peristaltic pump were calibrated by operating the pump over a wide range of rotational speed settings and measuring the average feed rate at each setting. The melt was completed with no difficulties, and examination of the resulting glass under an optical microscope found little to no crystallization.

4.1 Melter Operation

The glass was melted under operational targets that are discussed in Section 2.3. Several charts are provided in Appendix C to graphically present actual operating conditions that were achieved during testing. The manual log of temperature and electrical data is provided in Appendix A as a reference and supplemental material to the electronically logged data. A summary of the main operating parameters is given in Table 4.1.

Table 4.1. Summary of RSM Operations

Start date	9/9/2013
Start time	0548
Total hours of normal operation (h)	103.4
Total hours of feeding (h)	91.9
Feeding interruptions (h)	11.5
Glass Temperature (°C)	
Min. [a]	958
Max. [a]	1177
Avg. glass temperature	1137
Plenum Temperature (°C)	
Min.	320
Max.	972
Avg.	598
Steady-State[b] Plenum Temperature (°C)	
Min.	515
Max.	622
Avg.	569
Melter Vacuum (in. H_2O)	
Min.	-1.1
Max.	2.8
Avg.	0.9
Average electrode power (kW/m^2)	109.2
Average glass resistance (ohms)	8.5
Bubbling rate (L/min)	4.2
Target feed rate (L/h)[c]	4.1
Avg. overall feed rate, including feed outages (L/h)	2.65
Avg. stable processing feed rate(L/h)	2.98
Avg. glass pour rate (kg/h)	1.36
Avg. glass pour rate, by melt surface area (kg/day/m^2)	654
Steady-state production rate (L/h)	3.33
Steady-state production rate (kg/day/m^2)[d]	822
Max. sustained production (kg/day/m^2)[e]	964

(a) Averaged by two thermocouples measuring glass pool temperature simultaneously at different locations in the melter.
(b) Selected “steady-state” is a 5-h period from 9/10 1505 to 9/10 2004.
(c) Converted by target glass processing rate of ~1.0 MT/day/m^2.
(d) Rate calculated from feed rate data.
(e) Rate calculated from feed data based on surface area of the melt and best > 5-h period.

Before the actual feed processing was initiated, the melter was loaded with 6.4 kg of previously melted HLW-HCr-16 glass and heated by gradually increasing the set points for the melter kiln and pour spout heaters. The middle kiln thermocouple measured 862°C and the melter electrode thermocouple measured 747°C before joule heating was started at 0155 hours on Monday, September 9, 2013. The melter reached the targeted glass temperature of 1150°C at 0524 hours on Monday, September 9, 2013. Testing operations were initiated at 0548 hours, although refinements to the processing conditions continued during testing, which produced a total of 140.8 kg of glass. During testing, erroneously fluctuating temperature readings were observed on several of the thermocouples, including the pour spout, kiln, HX, and process water thermocouples. This was corrected by providing a steady ground for all affected thermocouples. Plots of melter power, melter feed rate, plenum temperature, and glass temperature are shown in Figure 4.1 and Figure 4.2.

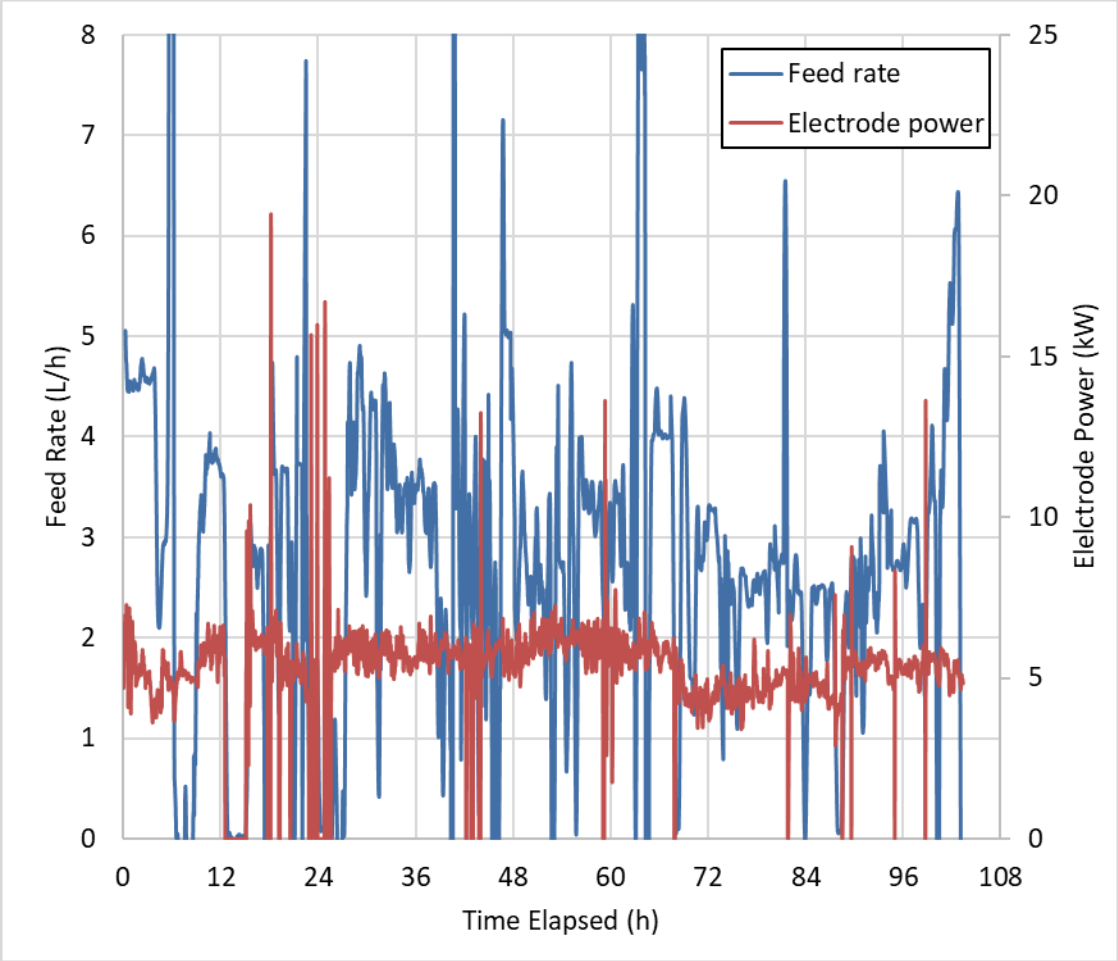


Figure 4.1. Feed Rate (30-min average) and Electrode Power

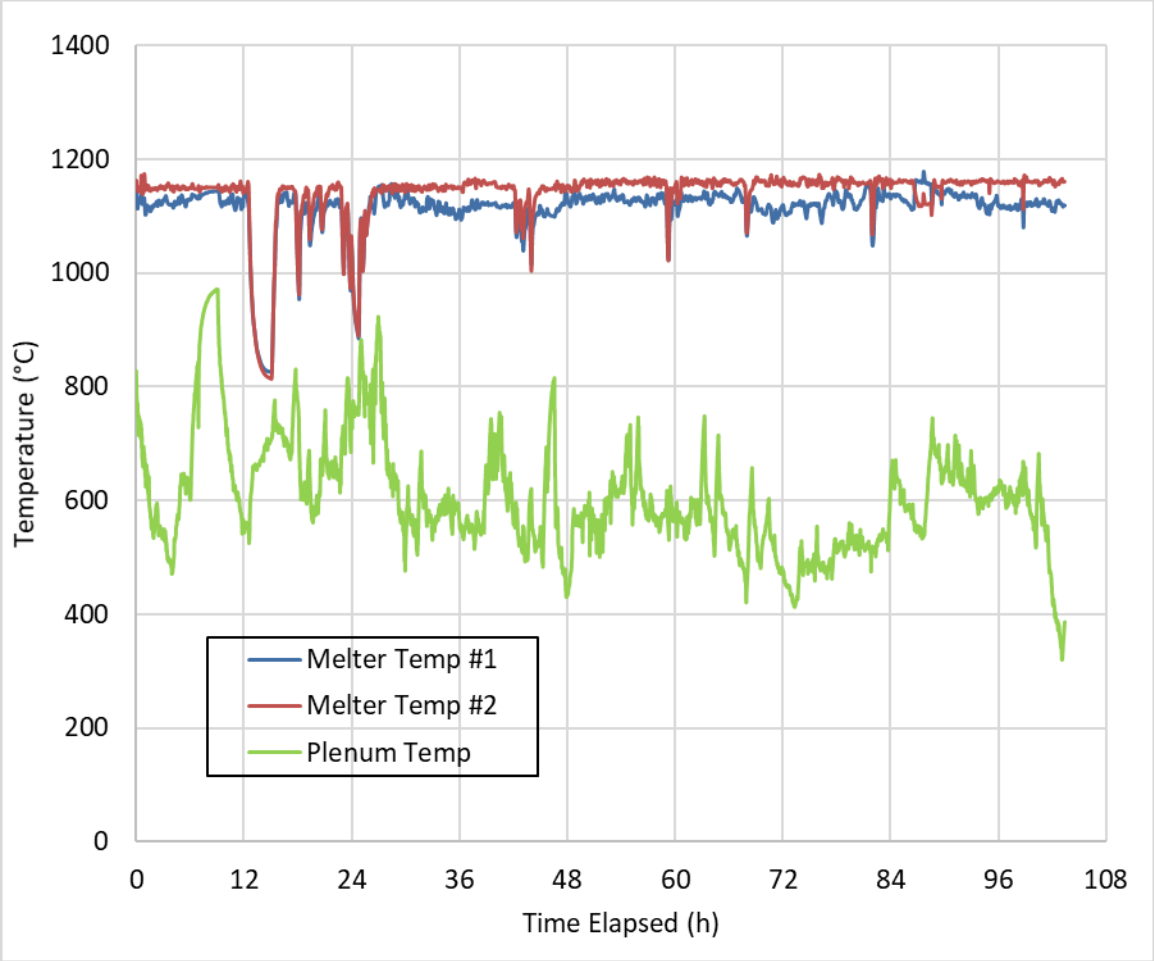


Figure 4.2. Melter Glass and Plenum Temperatures

The operation of the RSM was successful and enabled collection of basic operational data, albeit less than ideal due to short steady-state periods. The plenum temperatures ranged between 515°C and 622°C during steady-state operation, in keeping with the 550°C to 700°C target range. The maximum steady-state feed rate was attempted early in the melter run but was not optimized due to feed line plugging and limited durations of steady state cold cap coverage. The temperatures of the bulk glass and electrodes were relatively stable throughout the test, with no electrode temperature data having a standard deviation greater than 17°C over the course of normal operation during the test. Likewise, the standard deviation of the supplied power data was less than 1 kW during the test, meaning good temperature control was maintained without large swings in electrode power.

Feed-line and feed-nozzle plugging problems were the primary cause of disruption during processing and the main obstacle to obtaining a steady equilibrium melt rate. In one case, while clearing a plugged feed nozzle, power to the electrodes was lost due to a loose fuse. Toward the end of the test, cold cap bridging led to a couple of brief pauses in feeding. Interruptions in feeding to resolve these issues totaled around 12 h over the course of the test (~ 103 h) and did not prevent steady-state conditions from being achieved. There was no foaming in the glass discharge or on the melt pool surface. The cold-cap coverage was continuously changing throughout the tests and can roughly be related to plenum temperature trends. However, during most of the testing, it remained within the target range of 80% to 90%. In the feed tank, there was some settling of NaOH pellets that did not completely dissolve. These undissolved pellets contributed to most of the feed line plugging issues that were experienced during the test, which caused

subsequent interruptions to cold cap coverage, plenum temperatures, glass temperatures, glass pouring, and glass chemistry.

The RSM test commenced on September 9, 2013, at 0548 hours with an initial feed rate of 5.0 L/h. The bubbling rate was 4.2 L/min for the duration of the test. Several hours after beginning the test, at 1202 hours, feeding was interrupted for 2 h and 50 min to remove a blockage in the feed nozzle that had to be bored out with a drill. A few hours later, at 1824 hours, another interruption in feeding was initiated to remove another blockage in the feed nozzle. The electrode power was turned off to allow entry into the plenum space and could not be turned back on after the blockage was cleared. While troubleshooting the loss of power, feed remaining in the nozzle solidified and the nozzle had to be removed from the melter to clear the plug. Meanwhile, it was found that a fuse had become loose, causing the loss of power. Normal operation was restored after this second 2-h and 50-min interruption. A little over 2 h later, it was found that the feed recirculation line was plugged and that there was no feed going into the melter. The lines and nozzle were cleared, and feeding was restored after 33 min.

A little less than an hour later, on September 10, 2013 at 0053 hours, feeding was again halted due to a plug in the line from the feed pump. The line and nozzle were cleared and feeding started after an 11-min interruption. After a little more than an hour, feeding was stopped again to clear feed plugs at 0214 hours and reinitiated after 38 min. Slightly over an hour and a half later, the chiller tripped, causing the feed in the nozzle to bake and solidify. Another feed outage began at 0434 hours, during which the feed nozzle was removed and drilled out. The outage ended after 3 h and 9 min. During this outage, the power output was unstable, and the glass temperature dropped below 950°C for several minutes. It should be noted power loss was observed during each of the feed outages (see Appendix C, Figure C.5) due to the low glass level, and the two major interruptions, September 9, 2013 at 1824 to 2115 hours and September 10, 2013 at 0434 to 0744 hours, glass temperature was < 950°C intermittently (Figure 4.2). Temperature data measured from those two periods were not included in the summary in Table 4.1. There was no significant power loss after those two interruptions.

Normal operation was maintained for over 12.5 h before it was found that a hose had to be replaced on September 10, 2013 at 2021 hours. This outage only took 4 min. A 1-min feed interruption was required almost 12 h later, on September 11, 2013 at 0819 hours, to knock down a stalactite that had formed in the melter. Almost 4 h later, at 1214 hours, a 14-min feed outage occurred to remove a feed plug. There was not another feed stoppage for over 33 h, when, on September 12, 2013 at 2133 hours, feeding was interrupted because the cold cap was bridging. After 55 min, the cold cap had dissipated enough to start feeding again. Feeding then continued uninterrupted until the test was concluded on September 13, 2013, at 1312 hours.

As shown in Figure 4.3, with the exception of brief interruptions and two successive data points when the bubbler set points were recorded as 2100 followed by 5000 standard cubic centimeters per minute (sccm), the bubbling rates were steady, oscillating around the 4200 sccm target value without trending higher or lower. The average surface-area-specific bubbling rate, calculated by dividing the bubbling rate of 4200 sccm or 4.2 L/min by the melter surface area of 500 cm^2 or 0.05 m^2, was 84 L/min/m^2. There wasn't an entry in the lab record book to suggest that the bubbler set point was intentionally changed or that the change was recognized.

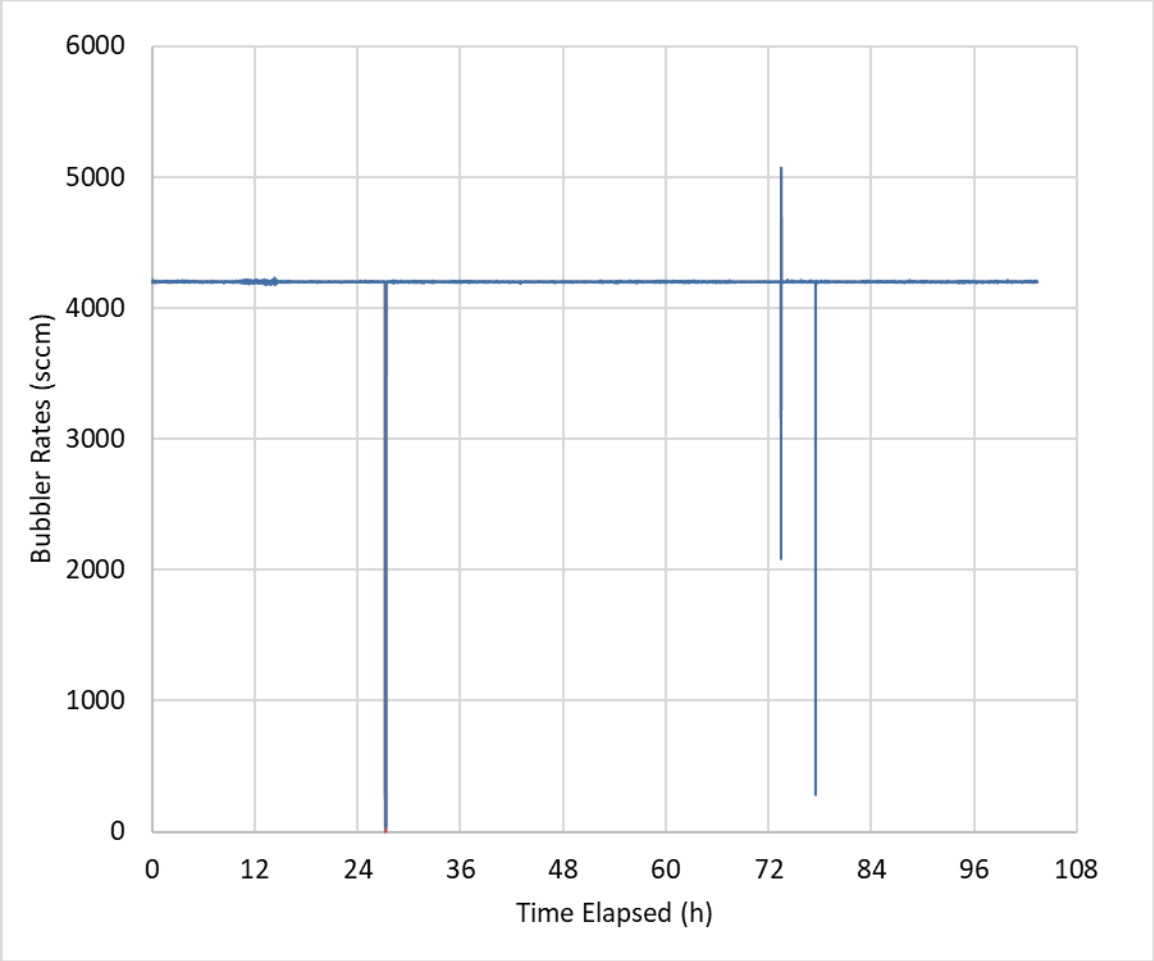


Figure 4.3. Bubbler Flow Rates

4.2 Melter System Inspection

At the conclusion of the test, the melter and exhaust lines were inspected. The melter electrodes were removed from the melt while the glass was hot. After the glass cooled, the melter lid and the first section of the exhaust line were disassembled. There was no significant corrosion damage observed. The electrodes were discolored, but it did not appear that a significant amount of metal had been removed. The edges of the electrodes were sharp, as shown in Figure 4.4, although there was evidence of heavy oxidation and very small pits on the surface. The bubbler flow in the RSM was split into two bubbler tubes, which were made from Inconel 690 tubing with a 0.05-in. wall thickness. One of them had been used in previous melter runs, and both were heavily oxidized but not structurally damaged after this melter run. Inspection of the melter lid showed that some entrained material adhered to the underside and to the exhaust piping. The deposits appeared to be entrained feed or glass. The inside of the melt chamber after testing is shown in Figure 4.5. The yellow spots in the melter chamber (Figure 4.5) are likely Cr-containing salts/oxide crystals, which are not observed in output glass samples.

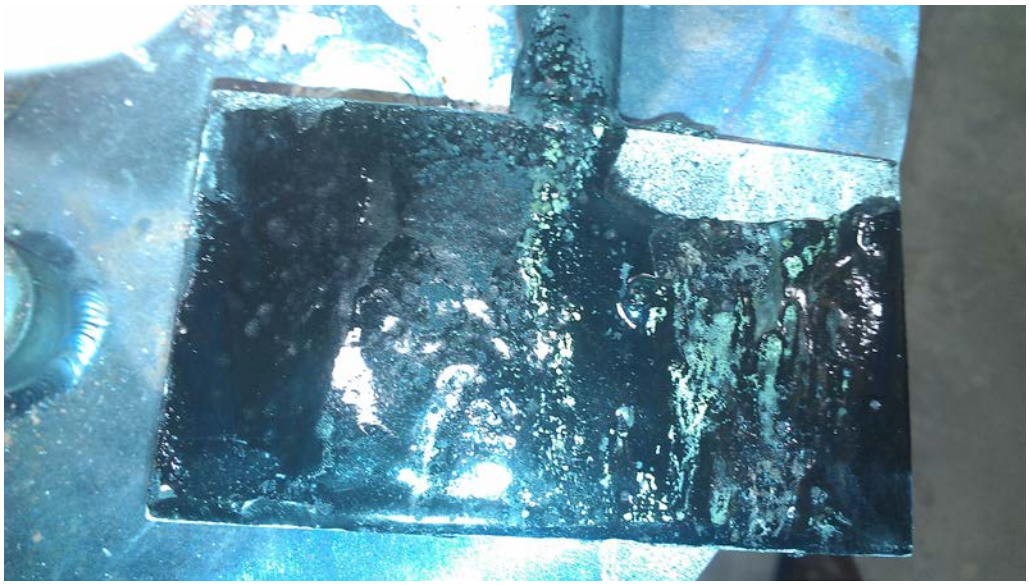


Figure 4.4. Melter Electrode Pulled from the Glass Melt

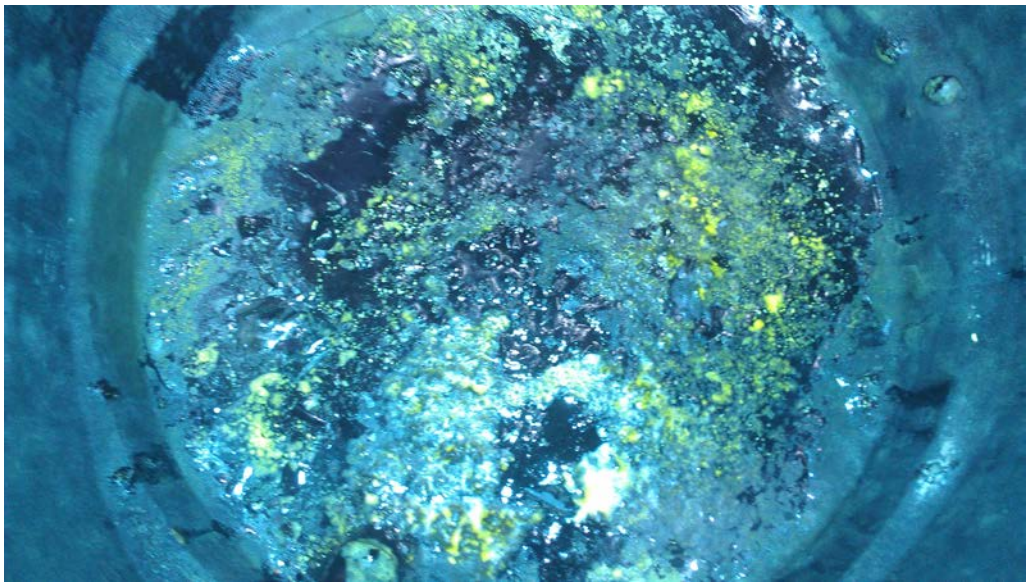


Figure 4.5. Inside of the Melt Chamber after Testing

Samples of deposits in the offgas line were collected from the RSM after the test. One was taken from the film cooler, one from the 90° bend above the melt chamber, and one from the long tube downstream from the 90° bend. These areas of the offgas line are labeled in Figure 4.6. The collected samples were analyzed using X-ray fluorescence (XRF), ICP-OES, and IC for the given ions and metals provided in Table 4.2. All the elements expected in the target glass composition were detected in the offgas line deposits except Bi, Ni, Pb, and W, each of which was a minor constituent representing less than 1 wt% of the glass recipe on an oxide basis. Some elements found in the chemical analysis were not in the target composition, such as Cl, MgO, SO_3, and ZrO_2. Total mass recovery was lower than 100% because some components were not measured (e.g., Bi_2O_3). In addition to XRF, Cl and F were measured by IC. F is important for emission analysis, which will be used in mass balance analysis.

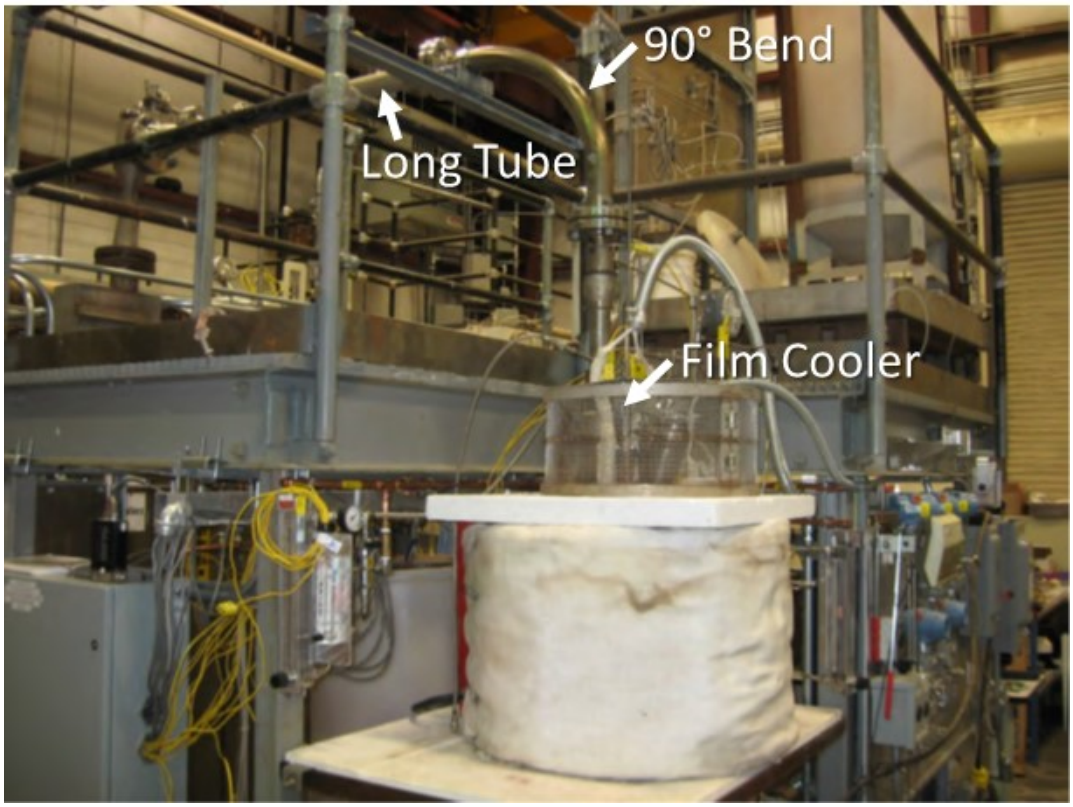


Figure 4.6. Areas in Offgas Line from which Samples of Deposit Material Were Collected

Table 4.2. Plenum and Exhaust Line Deposit Composition (wt%) Measured by XRF and IC

Compound	Film Cooler	Long Tube	90° Bend
Al_2O_3	13.61	11.27	8.89
B_2O_3	18.50	13.20	10.00
CaO	0.71	0.82	0.79
Cl[(a)]	0.22	0.39	0.33
Cr_2O_3	1.80	1.49	1.46
Fe_2O_3	5.44	4.58	4.33
F[(a)]	0.49	0.45	0.64
K_2O	7.33	6.48	6.45
MgO	0.06	0.04	0.04
MnO	1.42	0.91	0.88
Na_2O	11.06	9.14	8.05
P_2O_5	0.38	0.93	0.87
SO_3	0.34	0.00	0.28
SiO_2	21.35	17.82	14.75
ZrO_2	0.05	0.24	0.32
Total[(b)]	83.97	68.33	58.44

(a) Cl and F were analyzed by IC. Others were all analyzed by XRF.

(b) The XRF concentrations sum to less than 100% because some elements could not be analyzed.

5.0 Sample Collection and Analysis Methods

Routine sampling of the feed, glass, and offgas streams was conducted throughout the test. The melter feed recirculation loop allowed for direct sampling of the feed stream just before it entered the melter. Glass samples were collected from the melter pour spout stream with rectangular graphite boats. Because the newly formed glass bar could shatter and create a sharp projectile hazard, glass samples were shielded while cooling. These samples were used as the rapidly cooled "quenched" samples for toxicity characteristic leaching procedure (TCLP) tests. The EVS condensate samples were directly extracted from a valve on the condensate recirculation line. The HEME runoff was manually recycled back to the EVS recirculation tank. Accumulated undissolved solids in the quench scrubber's condensate tank were collected; however, the amount was negligible and was not used in mass balance evaluations. The collection and analysis of the RSM offgas is discussed in Section 8.0.

Process samples collected for analysis included the feed slurry, glass product, and EVS scrubbing liquid samples (Appendix B)[2]. In general, process samples were collected at least once per day and for every identified "stable" operating condition except for offgas line deposits and the EVS undissolved solids, which were collected only at the conclusion of testing. Sample analyses were conducted to characterize the quantities, compositions, and properties of these process streams following the protocol called out in the HASQARD (DOE 2014).

Process and offgas samples were analyzed, as applicable, for elemental composition, durability, and density. Some analyses were contemporaneous with test operations. Other analyses required preparations of several hours or days, depending on the analysis performed, the sample preparation required prior to analysis, and the location of the analytical equipment. Table 5.1 briefly describes the different analyses included in this test program. Table 5.2 lists the collected feed, glass, and EVS solution samples for analysis together with the analyses that were performed. For glass samples, the analyses were performed on an as-cooled or quenched glass, while one canister centerline cooling (CCC)-treated sample was prepared by further heat-treating part of the RSM-EWG8-044 quenched sample following the CCC heating profile (Section 6.1). The quenched and CCC samples were compared to investigate the crystallinity under different cooling conditions.

[2] In the sampling log (Appendix B), a white residue sample in glass canister and two glass samples from melt pool surface were also collected but not used for analysis.

Table 5.1. Sample Analysis Methods for Process (feed slurry, glass, and EVS) and Offgas Samples

Analysis	Sample Matrix	Analysis Method	Analysis Description
Cations	Solid or liquid	ICP-OES, XRF	Analysis of total amount of element, regardless of speciation
Anions	Liquid	IC	Br^-, Cl^-, NO_3^-, NO_2^-, PO_4^{3-}, SO_4^{2-}, F^-
Durability	Solid (glass)	TCLP	ASTM and EPA procedures (ASTM C 1285-02(2008); EPA 1992)
Density	Liquid (feed)	Mass/Volume	Mass/Volume

Table 5.2. List of Feed, Glass, and EVS Solution Samples Analyzed

Sample Type	ID	Analyses
Feed	RSM-EWG8-001	IC, Density
	RSM-EWG8-004	Density
	RSM-EWG8-013	Density
	RSM-EWG8-053	Density
	RSM-EWG8-059	IC, ICP-OES, Density
Glass	RSM-EWG8-003	XRF
	RSM-EWG8-014	XRF
	RSM-EWG8-018	IC, ICP-OES, TCLP
	RSM-EWG8-032	XRF
	RSM-EWG8-035	IC, ICP-OES
	RSM-EWG8-044[(a)]	η[(b)], SEM, XRD, Liquidus Temperature
	RSM-EWG8-048	XRF
	RSM-EWG8-057	XRF, ICP-OES
	Mixture of Samples	EC[(b)]
EVS Solution	RSM-EWG8-002	IC, ICP-OES
	RSM-EWG8-019	IC, ICP-OES
	RSM-EWG8-029	IC, ICP-OES
	RSM-EWG8-045	IC, ICP-OES
	RSM-EWG8-058	IC, ICP-OES

(a) A CCC-treated specimen was also prepared and analyzed by scanning electron microscopy (SEM) and XRD.
(b) Viscosity (η) and electrical conductivity (EC) were measured on glass melts by re-melting of the listed samples.

6.0 Glass Characterization

This section describes the test results for the chemical composition, crystallinity, TCLP, electrical conductivity, and viscosity for the RSM-produced glass.

Over the course of the test, 140.8 kg of glass was produced. Quenched glass samples were collected in the manner described in Section 5.0, and were used for most of the characterizations. In addition, selected quenched samples were heat treated for crystallinity analysis.

6.1 Canister Centerline Cooling Heat Treatment of Glass

One selected glass sample, RSM-EWG8-044, was heat treated following the HLW CCC profile per CCN 074851.[3] Glass samples were placed in a Pt-10%Rh crucible, covered with a lid, and placed in a high-temperature furnace at 1050°C for 1 h. They were then cooled using a programmable furnace controller following the CCC schedule shown in Table 6.1 and Figure 6.1. Some of the samples from the CCC heat treatment were characterized by SEM, XRD, and product consistency test.

Table 6.1. Temperature Schedule for CCC Treatment

Segment	Time (min)	Start Temp. (°C)	Rate (°C/min)
1	0–45	1050	−1.556
2	45–107	980	−0.806
3	107–200	930	−0.591
4	200–329	875	−0.388
5	329–527	825	−0.253
6	527–707	775	−0.278
7	707–1776	725	−0.304

[3] Memorandum, “Canister Centerline Cooling Data,” CCN 074851, Rev. 1, RPP-WTP, Richland, WA, October 29, 2003.

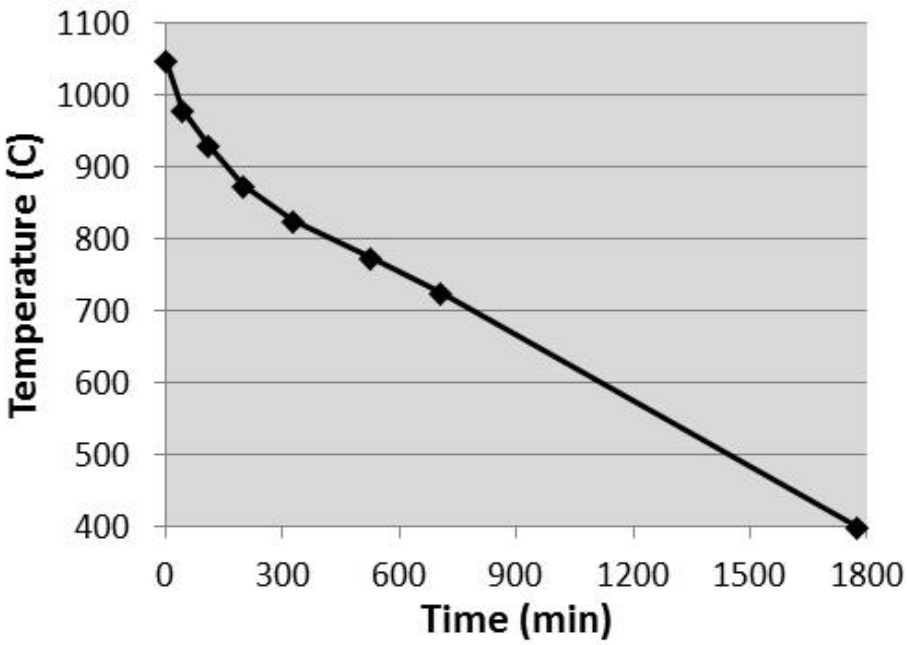


Figure 6.1. Graph of CCC Heat Treatments of HLW Glass

6.2 Analyses of Glass for Chemical Composition

To confirm that the fabricated glass composition agreed with the target, quenched glass samples RSM-EWG8-018 and RSM-EWG8-035 were chemically analyzed at SwRI and sample RSM-EWG8-057 was analyzed at PNNL. At SwRI, the samples were prepared for analysis using three techniques. The first technique was a closed vessel digestion using concentrated nitric, hydrochloric, and hydrofluoric acids. Boron and silicon were reported from this digestion. The second technique was a lithium metaborate/tetraborate fusion. Aluminum, calcium, chromium, iron, and sodium were reported from this fusion. The third technique used concentrated nitric, perchloric, hydrofluoric, and hydrochloric acids in an open vessel. The remaining metals were reported from this digestion. Blanks were run to ensure that no analytes were falsely detected above SwRI's reporting limits. Two solid laboratory control samples (NIST SRM[4] 278 Obsidian Rock and NIST SRM 688 Basalt Rock) were used during all sample preparation techniques. Aqueous laboratory control samples were also digested for calibration.

Additionally, SwRI performed IC analysis on the samples. Approximately 0.25 g of the sample was extracted with 50 mL of deionized water. The extract was analyzed for fluoride, chloride, nitrate, nitrite, phosphate, oxalate, and sulfate. Another ~0.20 g of the sample was fused using sodium carbonate and analyzed for total fluorine, chlorine, and sulfur. The fusion was diluted to 50 mL using deionized water. Due to the high sodium carbonate concentration, it was diluted an additional 10× prior to analysis. IC analyses followed SW-846 Method 9056 (EPA 1994) and SwRI procedure TAP 01-0406-042, Rev. 6.[5]

At PNNL, samples were prepared by finely grinding ~0.1 g of glass with an agate mortar and pestle and digesting the resulting powder in 9 mL of concentrated nitric acid, 3 mL of concentrated hydrofluoric acid, and 2 mL of concentrated hydrochloric acid at 210°C for 30 min. After cooling, 30 mL of 5% boric acid solution was added and further digestion took place at 180°C for 25 min. Each sample was poured

[4] NIST SRM = National Institute of Standards and Technology Standard Reference Material.
[5] SWRI. 2012. *Inorganic Anions and Disinfection Byproducts using Ion Chromatography*. Test/Analytical Procedure (TAP) 01-0406-042, July 2012, Rev. 6. Southwest Research Institute, San Antonio, TX.

into a 50-mL centrifuge tube and the digestion vessel was rinsed three times with a 1-mL aliquot of deionized water to ensure the entire sample had been transferred. The centrifuge tube was then capped and shaken to homogenize the solution. The tube was weighed, and a 10-mL sample was removed and filtered using a 0.45-µm polyvinylidene fluoride or polyvinylidene difluoride syringe filter and analyzed by ICP-OES. Three 1-mL samples were taken from the remaining solution and weighed to determine density so that the final weight of the solution could be density corrected.

The ICP-OES results from the two labs are summarized in Table 6.2, which provides the measured composition of the glass together with the targeted composition and the relative differences between the measured and targeted values for major components (those with target concentrations >2 wt%). Although PNNL did not measure as many of the constituent elements as SwRI, the measured concentrations of the major components measured by PNNL were similar to those measured by SwRI and within error of the target composition. The major glass components measured at PNNL were within ±7% of the target concentration, indicating that the glass was very close to the target composition. The two major components not measured by PNNL, SiO_2 and B_2O_3 (as the use of hydrofluoric acid and boric acid preclude analysis of SiO_2 and B_2O_3, respectively), were also within 7% of their target concentrations in the samples measured at SwRI.

Five of the melter glass samples were also analyzed by XRF (Table 6.3). The results of the major components show good agreement with the target composition. Light elements such as boron and lithium cannot be detected by XRF. All samples from early to late stages of the melter run have very similar compositions, which demonstrates consistency of the glass production during the melter operation.

Table 6.2. Composition of HLW-HCr-16 Glass Samples Analyzed by ICP-OES at SwRI and PNNL

Measured by:		SwRI				PNNL	
	Sample ID:	RSM-EWG8-018		RSM-EWG8-035		RSM-EWG8-057	
Oxide	Targeted (wt%)	Measured (wt%)	% Diff	Measured (wt%)	% Diff	Measured (wt%)	% Diff
Al_2O_3	19.83	19.07	-3.8	18.84	-5.0	20.03	1.0
B_2O_3	15.06	14.42	-4.3	14.12	-6.3	NM	NA
Bi_2O_3	0.91	0.63	-30.6	0.55	-39.1	0.63	-31.1
CaO	0.98	0.96	-2.1	0.95	-3.4	0.95	-2.6
Cr_2O_3	1.82	1.62	-10.8	1.64	-10.2	1.64	-10.1
F	0.06	ND	NA	ND	NA	NM	NA
Fe_2O_3	5.04	4.66	-7.5	4.68	-7.1	5.02	-0.4
K_2O	6.39	5.67	-11.2	5.76	-9.9	5.94	-7.1
Li_2O	4.00	3.78	-5.6	3.80	-5.0	3.81	-4.8
MgO	–	<0.01	NA	0.02	NA	0.09	NA
MnO	1.29	1.20	-7.1	1.19	-7.8	NM	NA
Na_2O	10.69	9.40	-12.1	9.34	-12.6	10.14	-5.2
NiO	0.25	0.28	10.0	0.25	-0.8	0.21	-17.5
P_2O_5	0.38	0.28	-25.8	0.26	-30.5	NM	NA
PbO	0.31	0.24	NA	0.22	NA	0.26	NA
SiO_2	32.89	34.72	5.6	34.94	6.2	NM	NA
SO_3	–	0.06	NA	0.06	NA	NM	NA
TiO_2	–	0.03	NA	0.03	NA	NM	NA
WO_3	0.09	0.09	3.0	0.09	4.7	NM	NA
ZnO	–	0.01	NA	<0.01	NA	NM	NA
ZrO_2	–	0.01	NA	0.01	NA	NM	NA
Sum	100	97.10	-2.9	96.66	-3.3	NA	NA

% Diff = % difference of measured vs. targeted.
NM = not measured; NA = not applicable; ND = not detected.
MgO, SO_3, TiO_2, ZnO, and ZrO_2 are not target components.

Table 6.3. Composition of HLW-HCr-16 Glass Samples Analyzed by XRF at PNNL

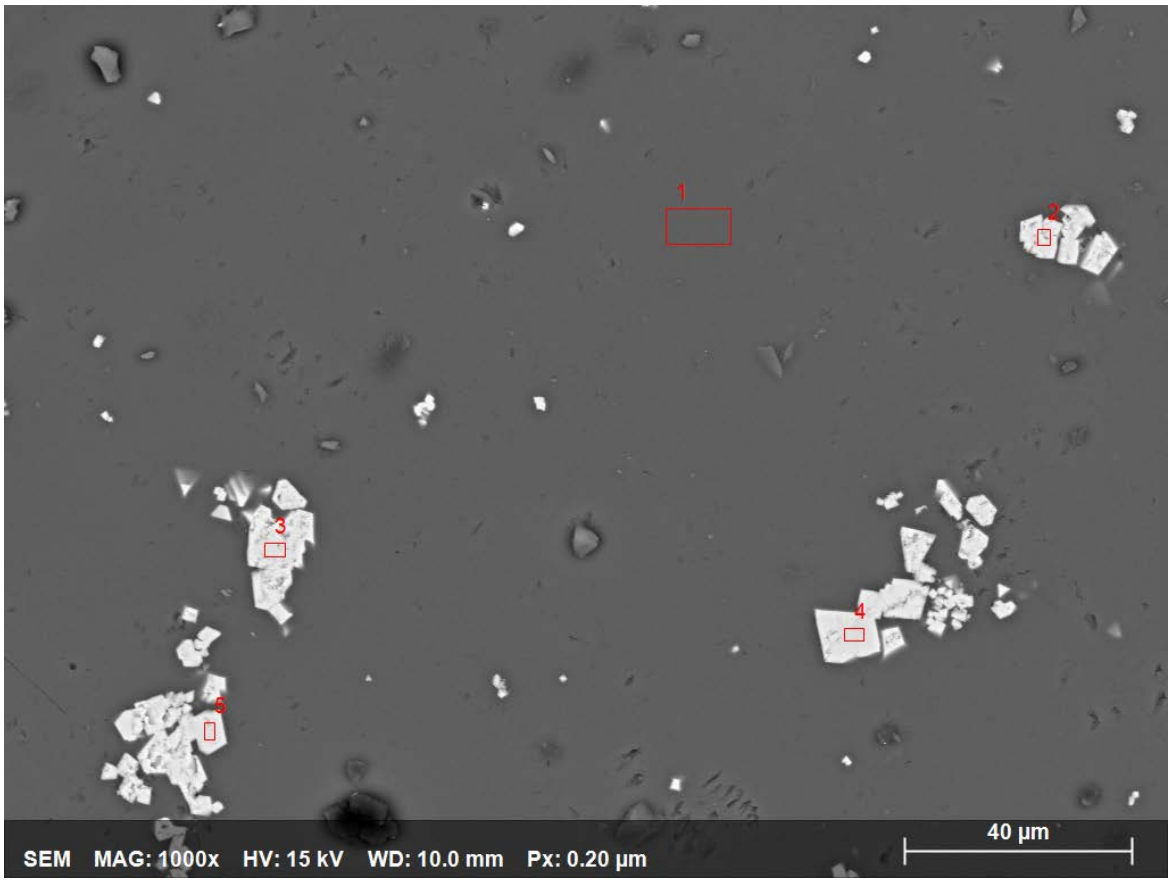
	Sample ID:	RSM-EWG8-003		RSM-EWG8-014		RSM-EWG8-032		RSM-EWG8-048		RSM-EWG8-057	
Oxide	Targeted (wt%)	Measured (wt%)	% Diff	Measured (wt%)	% Diff	Measured (wt%)	% Diff	Measured (wt%)	% Diff	Measured (wt%)	% Diff
Al_2O_3	19.83	20.50	3.4	21.70	9.4	20.32	2.5	21.70	9.4	21.47	8.3
B_2O_3	15.06	NM	NA	NM	NA	NM	NA	NM	NA	NM	NA
Bi_2O_3	0.91	0.74	-18.7	0.79	-13.2	0.73	-19.8	0.80	-12.2	0.69	-24.3
CaO	0.98	1.23	25.5	1.11	13.3	1.06	8.2	1.02	4.1	0.99	1.2%
Cr_2O_3	1.82	1.61	-11.5	1.77	-2.7	1.68	-7.7	1.69	-7.4	1.67	-8.5
F	0.06	NM	NA	NM	NA	NM	NA	NM	NA	NM	NA
Fe_2O_3	5.04	5.35	6.2	5.54	9.9	5.41	7.3	5.35	6.2	5.26	4.3
K_2O	6.39	6.21	-2.8	6.63	3.8	6.51	1.9	6.45	1.0	6.53	2.2
Li_2O	4.00	NM	NA	NM	NA	NM	NA	NM	NA	NM	NA
MgO	–	ND	NA	0.04	NA	0.05	NA	0.09	NA	ND	NA
MnO	1.29	1.40	8.5	1.53	18.6	1.52	17.8	1.49	15.5	1.51	16.8
Na_2O	10.69	9.80	-8.3	10.00	-6.5	9.70	-9.3	9.79	-8.4	9.99	-6.5
NiO	0.25	0.30	20.0	0.30	20.0	0.28	12.0	0.26	4.4	0.26	3.6
P_2O_5	0.38	0.45	18.4	0.41	7.9	0.41	7.9	0.37	-2.6	0.39	2.4
PbO	0.31	0.39	25.8	0.40	29.0	0.40	29.0	0.37	18.7	0.36	17.4
SiO_2	32.89	34.40	4.6	36.64	11.4	35.65	8.4	36.20	10.1	36.38	10.6
SO_3	–	0.06	NA	0.07	NA	0.08	NA	0.08	NA	0.06	NA
WO_3	0.09	NM	NA	NM	NA	NM	NA	NM	NA	NM	NA
ZnO	–	0.02	NA	0.01	NA	0.00	NA	0.00	NA	0.01	NA
ZrO_2	–	0.04	NA	0.00	NA	0.00	NA	0.00	NA	0.00	NA
Sum	100	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

% Diff = % difference of measured vs. targeted.
NM = not measured; NA = not applicable; ND = not detected.
MgO, SO_3, ZnO, and ZrO_2 are listed as impurities.

6.3 Crystallinity by Scanning Electron Microscopy and X-Ray Diffraction

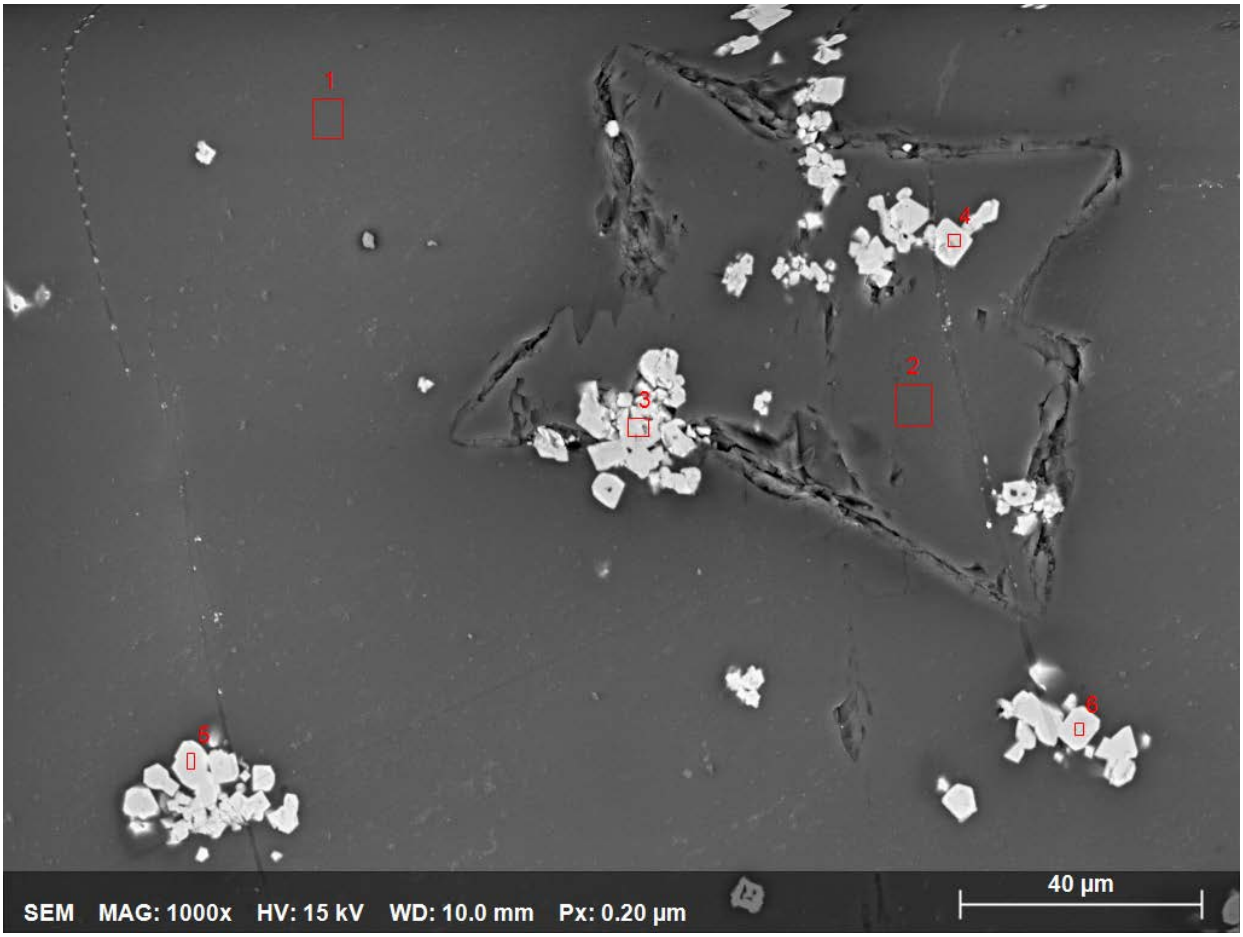
Figure 6.2 is an SEM back-scattered electron micrograph of a cross-section of a quenched specimen (glass sample ID: RSM-EWG8-044) together with the results of the energy dispersive X-ray spectroscopy (EDS) analysis of designated regions. The micrograph reveals a few clusters of crystals ranging in size up to ~10 µm (EDS regions 2-5) and several smaller isolated crystals that are on the order of 1 µm in the surrounding glass matrix (EDS region 1). The crystals in regions 2-5, while very similar in composition to one another, were enriched in Fe, Ni, Mg, Mn, and Cr, which are the major constituents of spinel phases typically detected in waste glass (Barnes and Larson 1981; Matlack et al. 2009; Rose et al. 2011) as compared to the glass matrix composition in region 1.

The micrograph in Figure 6.3 shows a cross section of a specimen from the same sample (RSM-EWG8-044) that underwent CCC heat treatment. After CCC heat treatment, the crystal formations (regions 3-6) were very similar to those in the quenched specimen described above. The relative difference in chemical composition as compared to the surrounding glass matrix (region 1) was also similar with the same elements, showing increased or decreased concentrations in the crystals. As compared to the crystalline phase composition in the quenched glass, the crystals present after CCC generally exhibited lower Cr and Mn concentrations and higher levels of Na, Al, and Si. The main difference in morphology between the quenched and CCC glasses was the presence of what appears to be a large, ~80-µm faceted crystal that has the same dark gray contrast as the glass matrix and that appeared to encapsulate some of the smaller, lighter-colored crystals. EDS shows that this area contains higher concentrations of Na, Al, and Si, which are the major constituents of nepheline, and lower concentrations of K, Ca, Mn, and Fe than the glass matrix.



Spectrum	1	2	3	4	5
O	63.85	55.37	56.16	55.55	55.38
Na	8.40	0.48	0.02		0.39
Mg		0.34	0.22	0.28	0.42
Al	9.19	2.19	2.12	2.17	2.25
Si	12.39	0.60	0.30	0.02	0.30
K	3.98	0.18	0.14		0.13
Ca	0.56				
Cr		25.34	24.75	26.53	25.74
Mn	0.28	4.80	4.48	4.68	4.61
Fe	1.36	9.11	9.80	9.24	9.29
Ni		1.59	2.01	1.54	1.49

Figure 6.2. Back-Scattered Electron Micrograph and EDS of Quenched Glass Analysis of a Polished Cross-Section of a Quenched Specimen from Sample RSM-EWG8-044



Spectrum	1	2	3	4	5	6
O	67.88	60.64	62.61	60.53	63.07	62.78
Na	8.34	11.36	1.02	3.33	3.88	2.10
Mg			0.31	0.15	0.30	0.27
Al	8.01	11.23	1.83	3.61	4.17	2.85
Si	11.11	13.78	0.86	2.30	3.39	1.67
K	3.22	2.44	0.12	0.34	0.50	0.37
Ca	0.43	0.00				
Cr			15.88	15.72	12.15	15.37
Mn	0.26	0.06	3.95	3.53	2.87	3.55
Fe	0.74	0.48	11.87	9.21	8.58	9.88
Ni			1.54	1.29	1.08	1.16

Figure 6.3. Back-Scattered Electron Micrograph and EDS of CCC Glass Analysis of a Polished Cross-Section of a CCC Specimen from Sample RSM-EWG8-044

XRD patterns were collected using a Bruker D8 X-ray diffractometer by scanning over the range of 5–80° 2θ with a step size of 0.015° and a 53.1-s dwell at each step. Data were analyzed using EVA v.14 and TOPAS v.4.2 software (Bruker AXS, Karlsruhe, Germany) for phase identification. For the purposes of semiquantitative analysis, 5 wt% CaF_2 was added to each sample as an internal standard. The crystalline content was determined by Rietveld refinement of the XRD patterns using TOPAS software.

Figure 6.4 is an XRD pattern of quenched glass taken from the same sample as the SEM-EDS sample shown in Figure 6.2. The XRD pattern confirmed the microscopy results, identifying that the spinel crystal structure was indeed present in a concentration of 2.46 wt% (calculated by the 4.99 wt% CaF_2 standard). The best match in the XRD pattern database was trevorite ($NiFe_2O_4$), but based on the EDS results discussed above, the spinel crystals are likely a solid solution of trevorite, chromite ($FeCr_2O_4$), nichromite ($NiCr_2O_4$), manganochromite ($MnCr_2O_4$), and magnesiochromite ($MgCr_2O_4$) all of which are forms of spinel.

Figure 6.5 is an XRD pattern of CCC-treated glass taken from the same sample as the SEM-EDS sample shown in Figure 6.3. A spinel phase was again detected, this time at a slightly higher concentration of 3.40 wt% (calculated based on the 4.99 wt% CaF_2 standard). Nepheline was also detected, at a concentration of 2.56 wt% (calculated based on the 4.99 wt% CaF_2 standard). This likely represents the large crystal found microscopically in Figure 6.3.

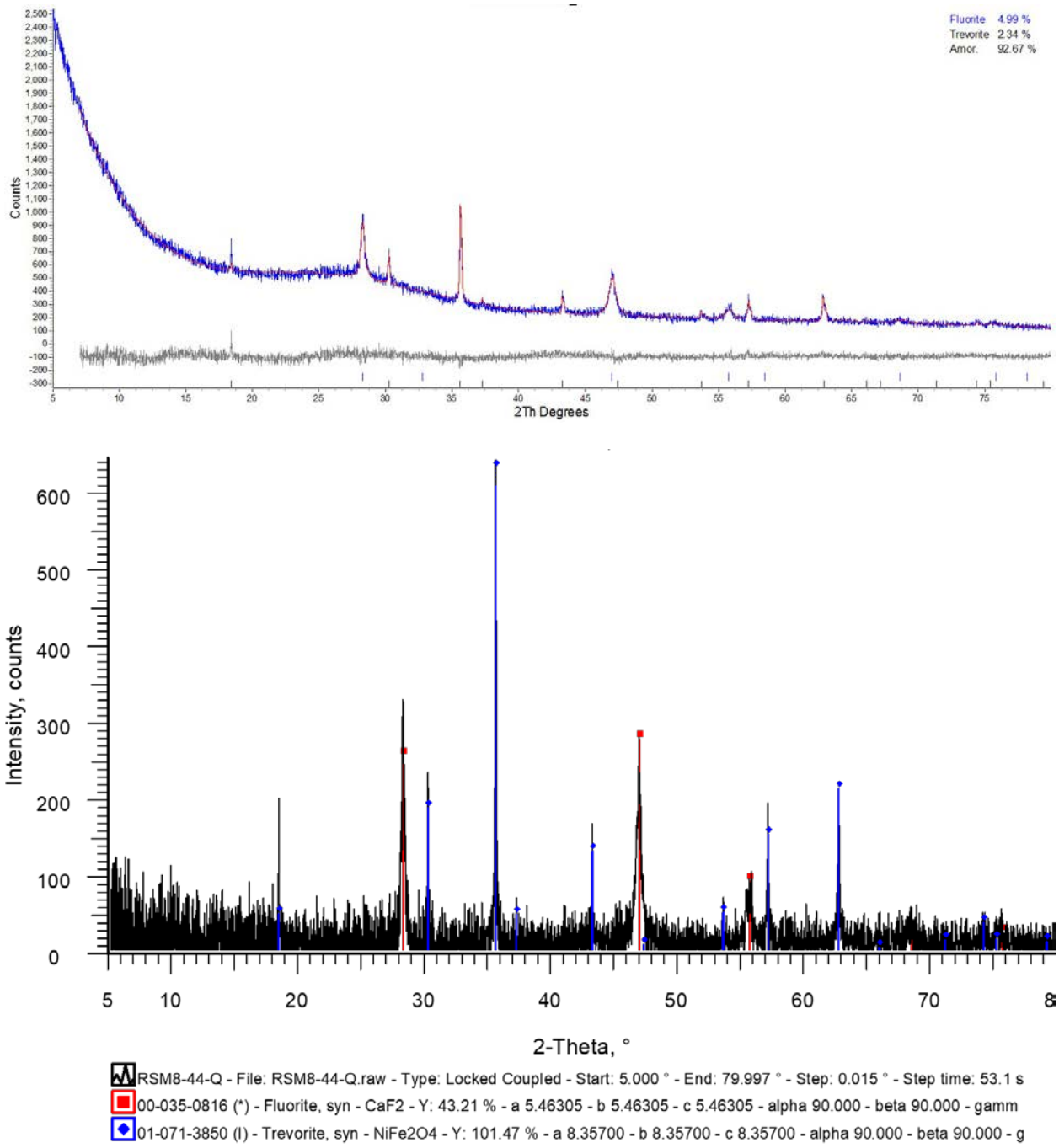


Figure 6.4. XRD Pattern of Quenched Glass (sample ID RSM-EWG8-044) Examined microscopically in Figure 6.2

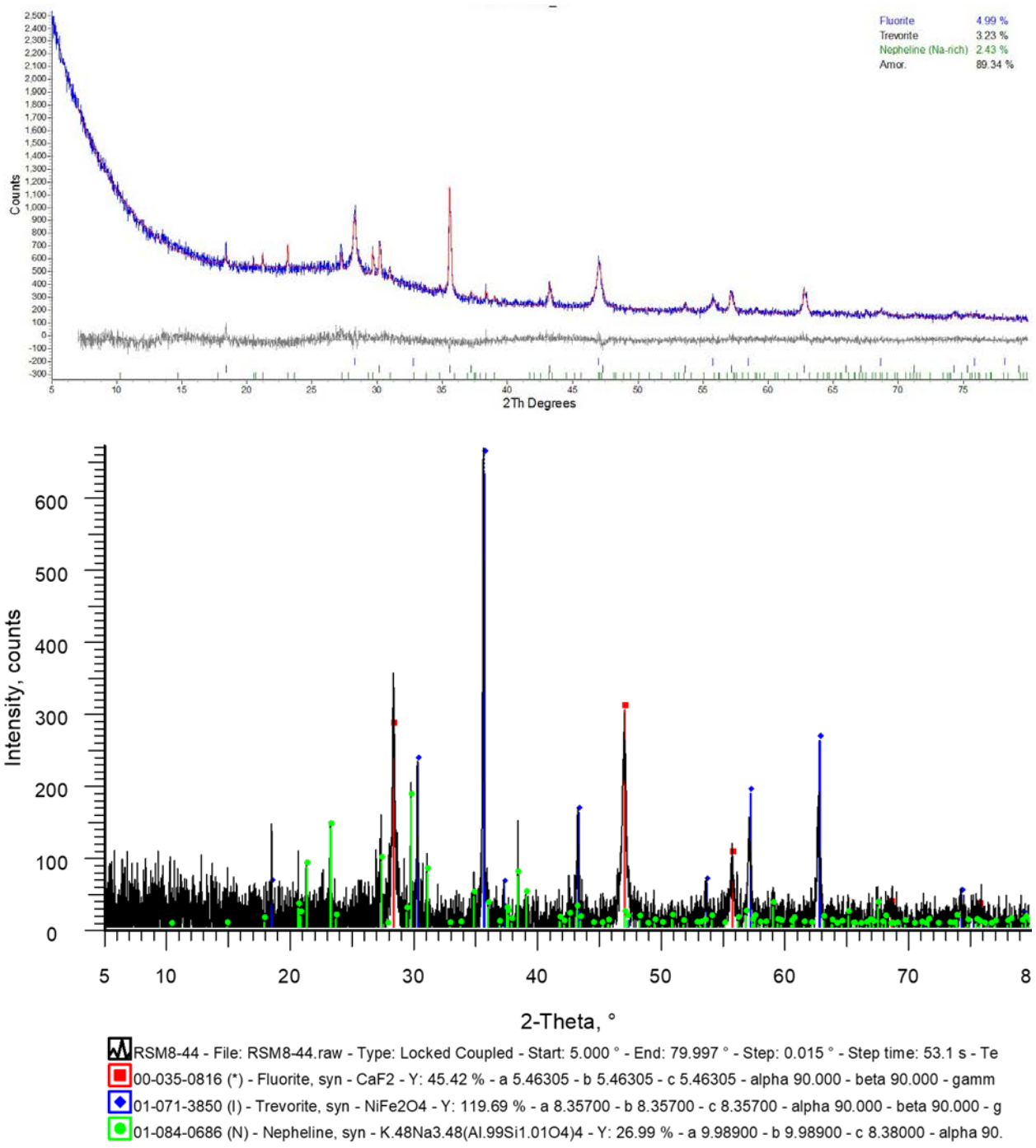


Figure 6.5. XRD Pattern of CCC Glass (sample ID RSM-EWG8-044) Examined Microscopically in Figure 6.3

6.4 Liquidus Temperature

XRD analysis of sample RSM-EWG8-044 was used to determine the liquidus temperature of crystalline content as a function of temperature. XRD patterns were collected after the glass had been heat treated at 950°C, 1000°C, and 1050°C for 20 h. The resulting data are shown in Figure 6.6. From extrapolation of the linear fit of temperature versus crystal wt%, the estimated liquidus temperature was 2075°C. The temperature at 1 vol% spinel was 1786°C. It should be noted that a fourth data point at 1100°C was removed as an outlier; the liquidus temperature by fitting three data points was for reference only.

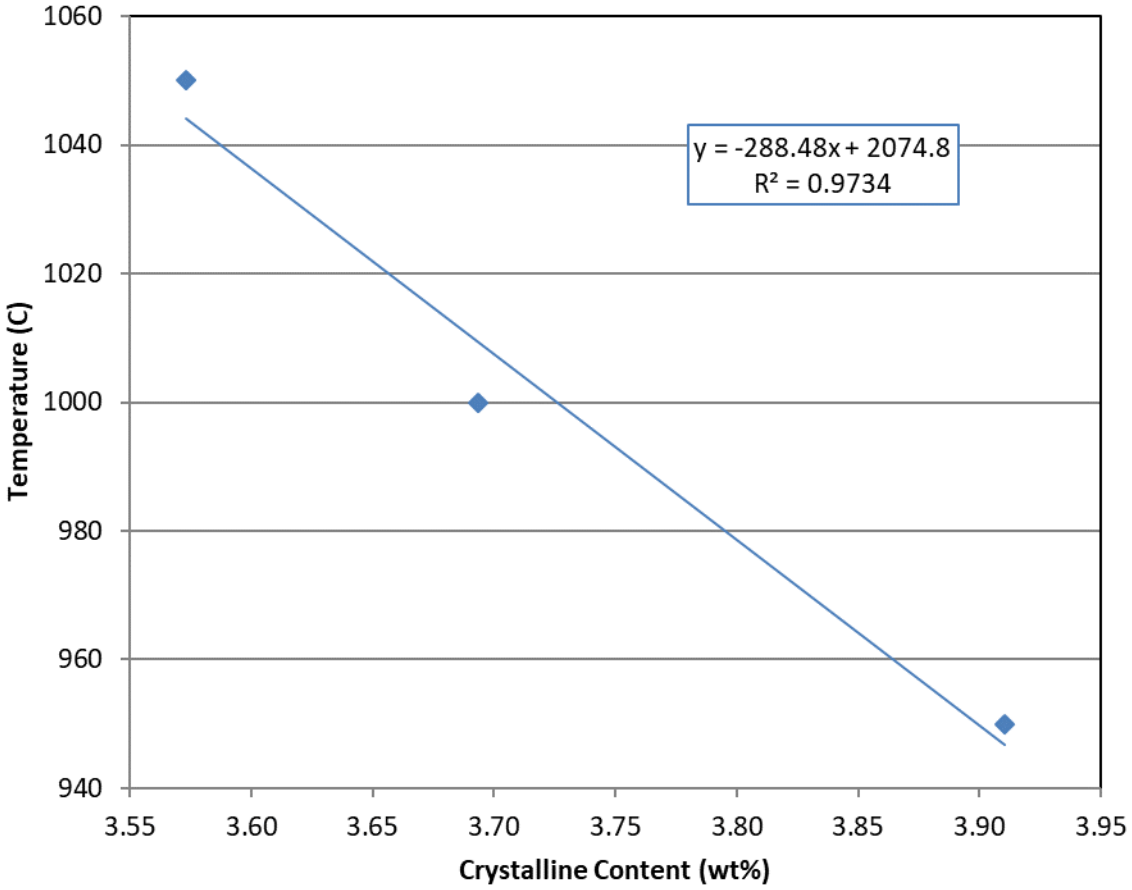


Figure 6.6. Temperature vs. Spinel Content for HLW-HCr-16 Glass Melted at PNNL

6.5 Toxicity Characteristic Leaching Procedure

A quenched sample of HLW-HCr-16 glass with sample ID RSM-EWG8-018 was sent to SwRI for TCLP analysis, following EPA Test Method 1311 (EPA 1992). Table 6.4 shows that the quenched glass is well below EPA regulatory limits for all regulated elements. However, the CCC glass with the extra crystallization was not tested.

Table 6.4. TCLP Concentrations for HLW-HCr-16 Glass (sample ID RSM-EWG8-018)

CAS No.	Analyte	Concentration (ppb)	EPA Regulatory Limits[(a)] (ppb)
7440-38-2	As	20	5000
7440-39-3	Ba	50	100000
7440-43-9	Cd	5	1000
7440-47-3	Cr	17.6	5000
7439-92-1	Pb	329	5000
7439-97-6	Hg	0.20	200
7782-49-2	Se	10.0	1000
7440-22-4	Ag	10.0	5000

(a) 40 CFR 261.25, 1997.

6.6 Electrical Conductivity

The electrical conductivity of the high-Cr glass was measured at temperatures between 940°C and 1240°C on a mixture of glass collected from several pours during the melter run that were crushed together. Impedance spectroscopy was performed using a Solartron 1470E potentiostat/galvanostat coupled with a Solartron 1400 frequency analyzer (Solartron Analytical, Oak Ridge, TN) while cooling through the temperature range.[6] Measurements were performed with the glass in a Pt-10% Rh crucible inside a DT-31-RS furnace (Deltech, Denver, CO). The impedance probe used for these measurements consisted of two paddles made of Pt-10% Rh (7 mm wide × 12.7 mm long) spaced 9.32 mm apart. Duplicate or triplicate impedance measurements were performed at several temperatures. Prior to the measurements, the cell constant for the impedance analyzer was determined with 0.1 M and 1 M KCl reference solutions at room temperature. The conductivity results for the HLW-HCr-16 glass are presented in Table 6.5 and Figure 6.7 together with the conductivities measured for the DWPF Environmental Assessment Standard Reference Material glass. The electrical conductivity of the HLW-HCr-16 glass is slightly lower than that of the DWPF reference but has a very similar activation energy. At 1140°C (slightly off from target temperature of 1150°C), the electrical conductivity is ~22.3 S/m.

[6] Crum JV. 2012. *PNWD Procedure: High-Temperature Electrical Conductivity*. GDL-Elec-Test-01, Rev. 0, Pacific Northwest National Laboratory, Richland, WA.

Table 6.5. Electrical Conductivity of HLW-HCr-16 Glass and DWPF Reference Glass

Glass	Temperature (°C)	Impedance, 1 kHz (ohms)	EC (S/m)
DWPF	1187	0.926	28.64
	1187	0.922	28.77
	1188	0.92	28.83
	1089	1.293	20.51
	1089	1.297	20.45
	1089	1.299	20.42
	990	1.989	13.34
	990	2.049	12.95
HLW-HCr-16	1236	0.946	29.55
	1236	0.944	29.59
	1140	1.255	22.26
	1042	1.726	16.19
	1041	1.726	16.19
	983	2.685	10.40
	983	2.69	10.39

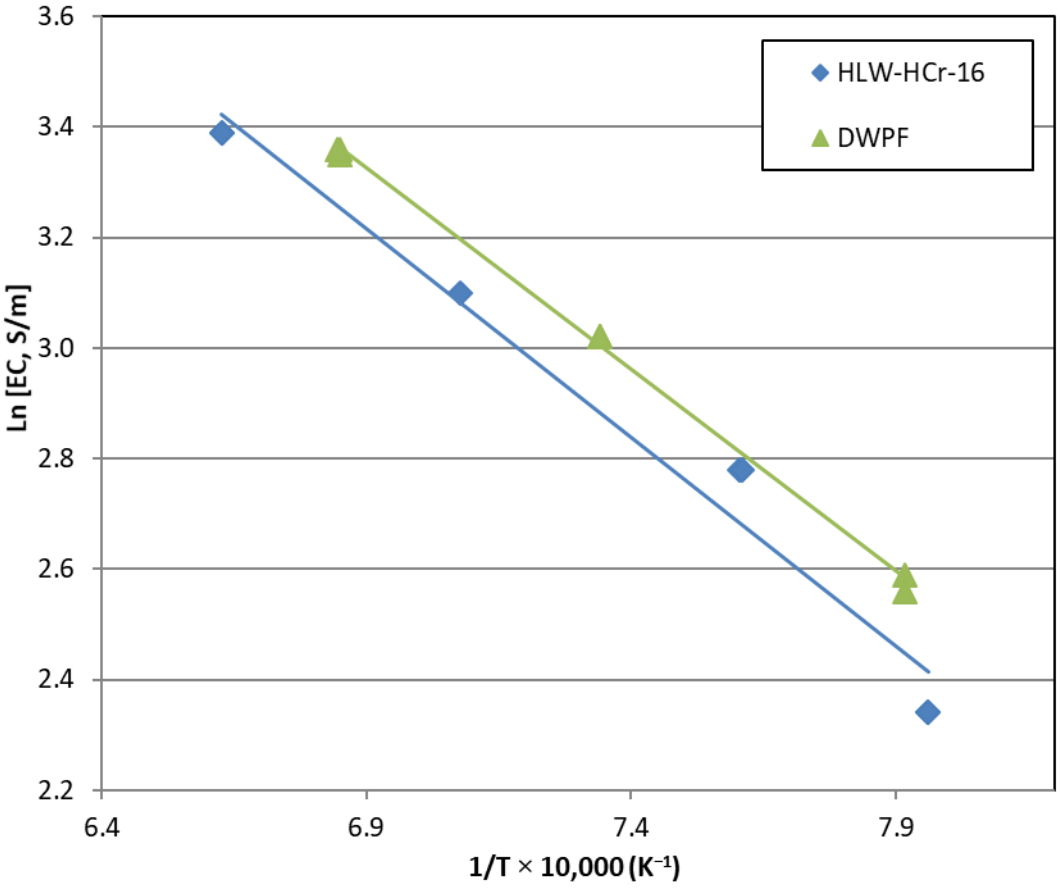


Figure 6.7. Electrical Conductivity of HLW-HCr-16 Glass and DWPF Reference Glass

6.7 Viscosity

Viscosity (η) of the glass was measured as a function of temperature using a rotating-spindle digital viscometer according to PNNL procedure GDL-Visc-Test-01.[7] Prior to viscosity measurements, the instrument was calibrated using DWPF startup frit (Crum et al. 2012) and PNNL procedure GDL-Visc-Test-01. GDL-Visc-Test-01 complies with ASTM C965 Method A such that the spindle was rotated, and the crucible was fixed. A total of 50 mL of glass from the sample labeled RSM-EWG8-044 was heated to ~1150°C in a Pt-10% Rh crucible and maintained until thermal equilibrium was reached. An initial torque reading at a constant spindle speed was taken at 1150°C, with measurements taken after the glass was cooled to 1050°C and again at 950°C. The glass was then heated back to 1150°C and further to 1250°C, then cooled back to 1150°C, with additional measurements made at each temperature. The ramp rates were 10°C/min. The measured viscosities at the different temperatures are shown in Table 6.6. The viscosity data are plotted in logarithmic scale as a function of 1/T in Figure 6.8. Arrhenius equation was applied to fit the data. Calculated by the fitting parameter, the viscosity at 1150°C is 5.8 Pa-s (fitted by Arrhenius equation as shown in Figure 6.8), which is within the acceptable range of 4 to 6 Pa-s for HLW glass (Vienna et al. 2013).

Table 6.6. Viscosity of HLW-HCr-16 Glass (sample ID RSM-EWG8-044)

Set Temperature (°C)	Measured Temperature (°C)	Viscosity (Pa-s)
1150	1126	6.576
1050	1032	17.087
950	935	55.002
1150	1115	6.948
1250	1219	3.496
1150	1150	6.443

[7] Crum JV. 2012. *PNWD Procedure: High-Temperature Viscosity Measurement.* GDL-Visc-Test-01, Rev. 0, Pacific Northwest National Laboratory, Richland, WA

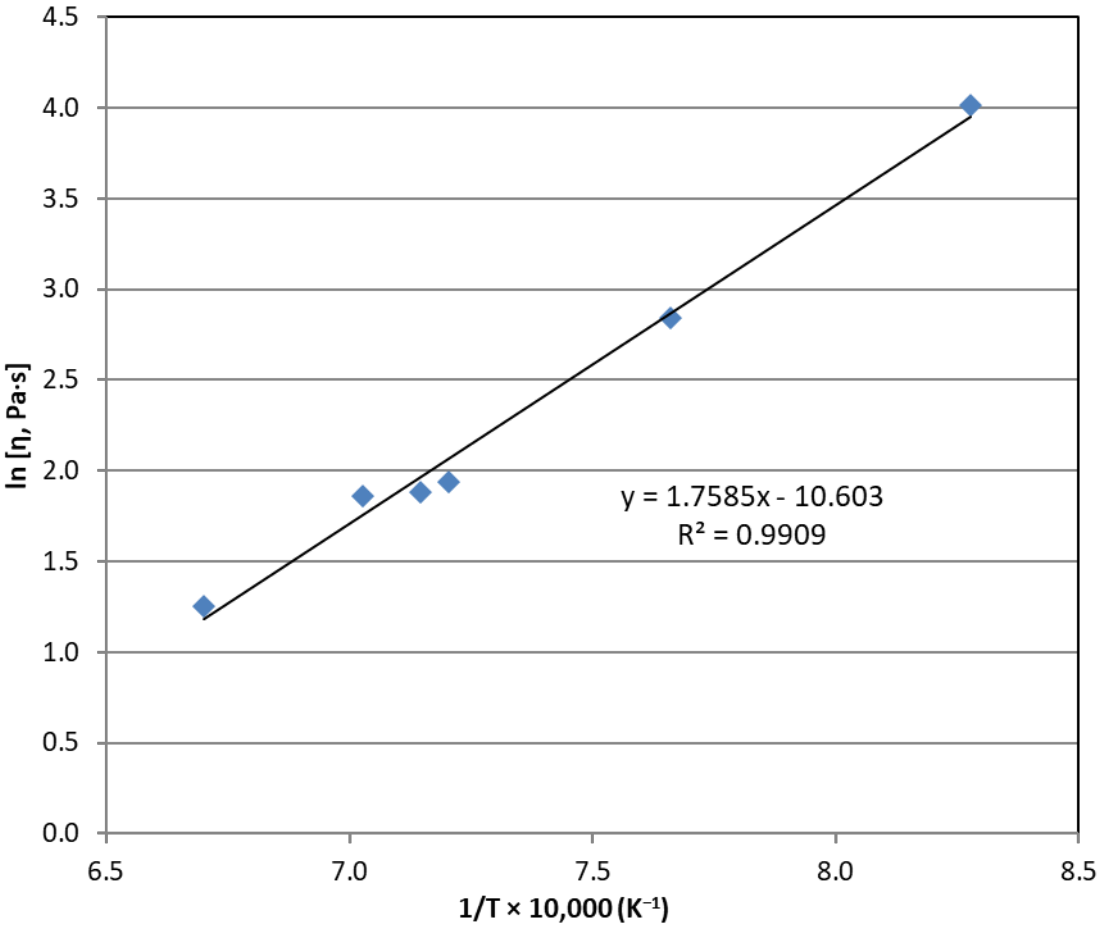


Figure 6.8. Viscosity of HLW-HCr-16 Glass as a Function of Temperature (Sample RSM-EWG8-044)

7.0 Scrubber Solution Analysis

As described in Section 2.2 and shown in the flow diagram in Figure 2.1, the EVS condenses water from the melter exhaust and samples were collected. This section summarizes chemical analysis results of scrubber solution or EVS solution samples.

Like the feed samples, EVS samples were analyzed by ICP-OES and IC at SwRI and PNNL. At SwRI, samples were digested using hydrochloric and nitric acids in an open vessel. The digestates for the scrub solution samples did not contain residues. At PNNL, the samples were filtered with a 0.2-micron filter and analyzed directly.

The results of ICP-OES and IC analyses of five EVS solution specimens at PNNL and one specimen at SwRI are given in Table 7.1 and show that the concentrations of most of the measured elements in the scrubber solution were less than 10 parts per million (ppm). Only F, Bi, B, Li, K, Na, and S were detected at levels above this threshold, and their concentrations increased with time due to accumulation in the scrubber tank, as expected. There was agreement between most of the concentrations measured for sample RSM-EWG8-058 at PNNL and SwRI.

Table 7.1. EVS Solution Sample Compositions (ppm) Measured by ICP-OES

Measuring Lab:	PNNL					SwRI
Sample ID:	RSM-EWG8-002	RSM-EWG8-019	RSM-EWG8-029	RSM-EWG8-045	RSM-EWG8-058	RSM-EWG8-058
Al	0.247	0.445	0.369	0.369	0.604	ND
Bi	ND	ND	ND	ND	ND	85.2
B	25	139	160	193	216	222
Cd	0.233	ND	ND	ND	ND	0.4
Ca	19.6	8.51	4.68	5.23	2.14	4.88
Cr	0.587	1.58	1.5	1.65	1.95	2.98
$F^{(a)}$	ND	58.5	70.5	65.5	78.5	68.3
Fe	ND	ND	ND	ND	ND	10
Pb	ND	ND	ND	ND	ND	2.84
Li	4.51	18.8	20.3	23.8	25.7	28.4
Mg	6.77	4.81	4.14	3.45	2.95	3.15
Mn	ND	0.101	0.115	0.115	0.104	2.85
Mo	0.219	0.234	0.258	0.245	0.26	ND
Ni	ND	0.519	0.592	0.682	0.728	1.23
$NO_2^{(a)}$	ND	ND	ND	ND	ND	78.5
K	4.36	105	122	156	180	182
Si	3.92	5.02	4.44	3.88	4.08	13.9
Na	38.7	107	113	131	141	162
Sr	0.186	ND	ND	ND	ND	ND
S	10.1	38	44	51.6	59.1	63.4
W	NM	NM	NM	NM	NM	0.95

(a) Measured by IC.
ND = not detected; NM = not measured.

8.0 Offgas Sample Analysis

Section 7.0 reports the RSM exhaust processed by the EVS system. The melter offgas was also directly sampled and analyzed. The offgas sampling port within the RSM system is shown in Figure 2.1 and Figure 8.1. This section presents analyses of particulate matter (PM) and gas species in the RSM offgas.

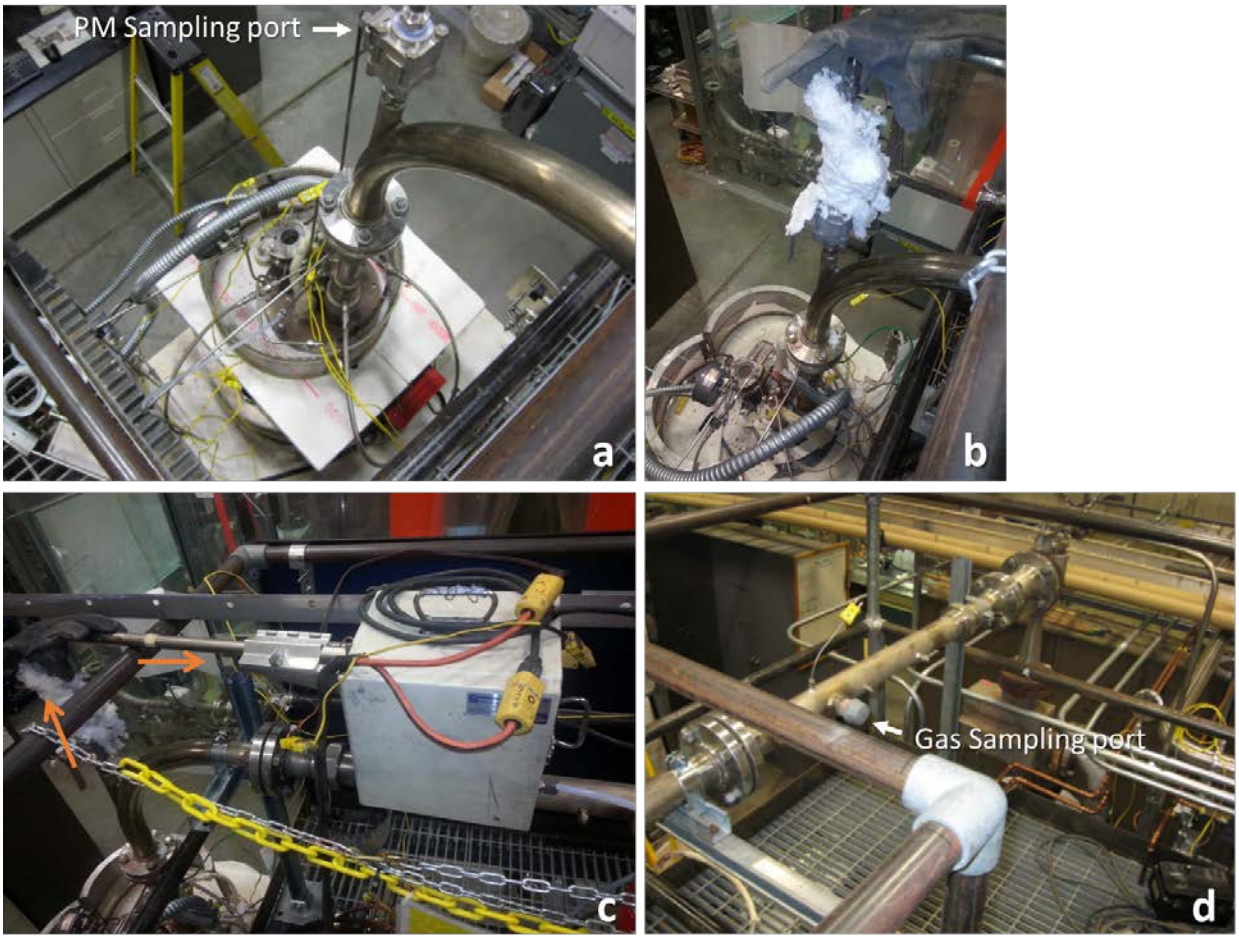


Figure 8.1. Sampling Locations. (a) PM sampling port on top of the RSM (next to the 90º bend in exhaust pipe); (b) PM sampling port with PM filter installed; (c) PM filter, the orange arrows mark the PM sampling Line, with the main exhaust pipe on the bottom; (d) gas sampling port in horizontal section of exhaust pipe

8.1 Sampling and Analytical Procedures

AmTest Air Quality (Auburn, WA) was contracted by PNNL to perform offgas sample analysis of the RSM exhaust. Testing was performed in accordance with test methods outlined in 40 CFR 60, Appendix A, and the Emission Measurement Technical Information Center's website, Test Methods section.[8] The following equipment and analytical methods were used during the analysis.

Flow rate:	Hot wire anemometer supplied by PNNL
CO_2 and O_2:	EPA Method 3A [nondispersive infrared (NDIR) and paramagnetic analyzers]
Moisture:	EPA Method 4 (incorporated w/ isokinetic sampling method)
PM:	EPA Method 5 (filterable PM; single point isokinetic sampling)
NO_x:	EPA Method 7E (chemiluminescent analyzer)
CO:	EPA Method 10 (gas filter correlation NDIR analyzer)

Offgas emissions in the RSM exhaust were analyzed for nine separate 70- to 100-min sample periods. The EPA Method 5 sampling rate (ΔP) was back-calculated using cubic feet per minute data from PNNL's mass flow meter, which reported wet standard cubic feet per minute (wscfm) corrected to 70°F. The average flow rate during each test period was corrected to dry standard cubic feet per minute (dscfm) at 68°F to be consistent with EPA test methods. The stack gas velocity was back-calculated in feet per second and converted to airflow in actual cubic feet per minute. The back-calculated ΔP and measured gas temperature were used to calculate the percent isokinetics for each run. Because of the complexity of the back-calculations, the percent isokinetics for these tests may not be as meaningful as traditional EPA Method 5 sampling performed in larger area stacks. Since this testing was performed with the nozzle inserted into a 2-in. duct, the normal acceptance criterion for isokinetics (100 ± 10%) should be less stringent. The percent isokinetics for each test period is shown in Table 8.1. This table also summarizes average feed rate and stack gas moisture, and lists data analyzed for each test. Feed rate of the nine tests is plotted in Figure 8.2. Feed rate shows large variations during the test periods; however, the average feed rates of all tests are in a reasonable range as listed in Table 8.1.

Test periods #1 and #2 were considered trial runs because the team was fine-tuning how the back-calculations for the isokinetics would be performed and the RSM was experiencing clogging issues with the feeder system during this time. The offgas samples taken during test period 3 also may not be representative since the RSM was not feeding product during portions of the test period due to continuing feed clogging issues. As shown in Figure 8.2, tests 4 and 5 show large fluctuations of feed rate. After examining the offgas analysis data, tests 4 and 5 were only used for comparing averaged NO_x and CO with averaged feed rate in the following Section 8.2.

Samples taken during test periods 6 through 9 were determined to be the most appropriate for the gas analysis and PM chemical analysis because the RSM was operating in a stable condition during this time. Approximately 31 dry standard cubic feet (dscf) of melter exhaust gas was sampled at a rate between 0.31 and 0.38 dscfm during these four test periods. Particulate emissions are particularly sensitive to cold-cap coverage in the melt cavity, and the feed rate and bubbler flow rates were adjusted as necessary to control cold-cap coverage. The cold-cap coverage ranged from 75% to 85% during the four test periods, which was reasonably close to the target cold-cap coverage of 80% to 90% as desired for continuous melter operation.

[8] https://www.epa.gov/emc/emc-promulgated-test-methods

Table 8.1. RSM PM Sampling Conditions

Test Period #	Date/Time			Test Period (min)	Average feed rate (g/min)	Isokinetics (%)	Gas Moisture (%)	Data analyzed
	Test Date	Start	End					
1	9/10/2013	1313	1423	70	78.78	187	21.01	None
2	9/10/2013	1513	1633	80	78.40	152	22.62	None
3	9/11/2013	0837	0957	80	56.57	93	19.82	None
4	9/11/2013	1032	1147	75	38.54	111	18.66	Offgas[(a)]
5	9/11/2013	1244	1414	90	68.62	99	17.18	Offgas[(a)]
6	9/11/2013	1446	1616	90	77.97	89	17.55	Offgas, PM
7	9/12/2013	0754	0934	100	49.53	88	14.65	Offgas, PM
8	9/12/2013	1003	1123	80	58.08	98	13.76	Offgas, PM
9	9/12/2013	1155	1320	85	57.87	100	14.99	Offgas, PM

(a) Only average NO_x and CO concentration was used for Test 4 and 5.

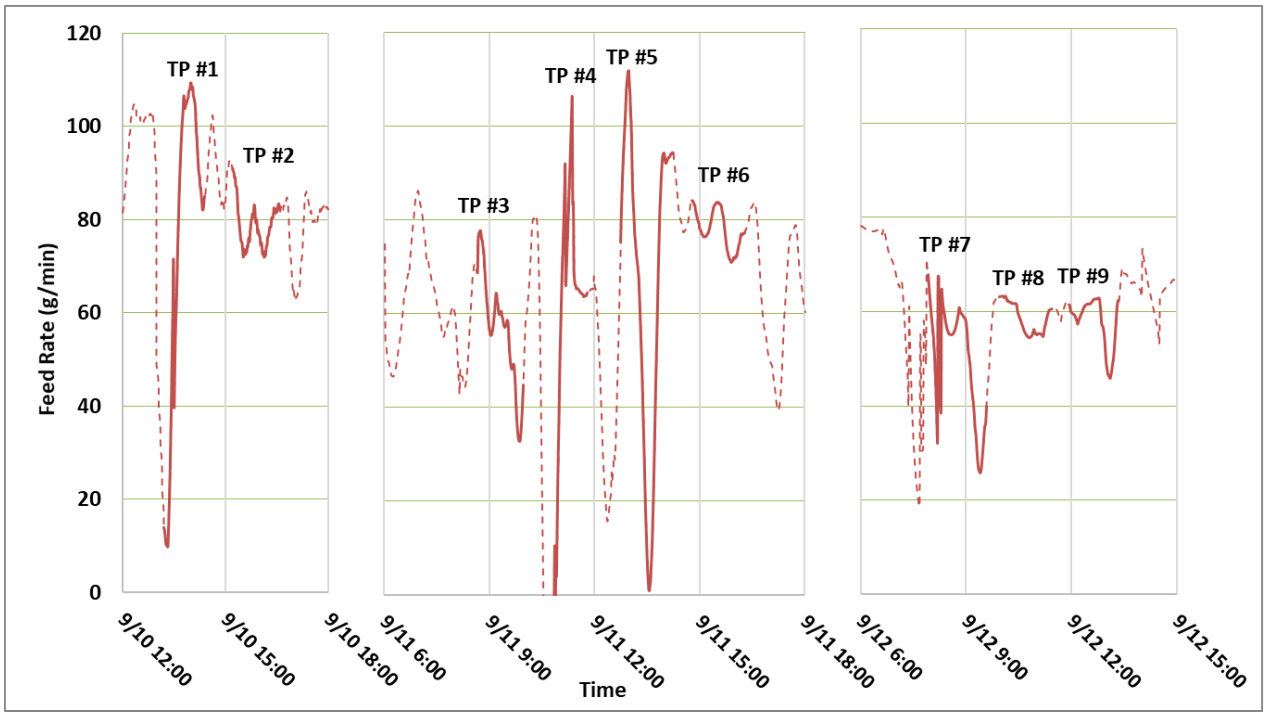


Figure 8.2. Feed Rate (30-min average, sections of Figure 4.1) of Offgas Test Periods (TPs)

8.2 NO_x and CO Emissions

EPA Methods 3A, 7E, and 10 (see Section 8.1) were performed on the RSM exhaust gas during nine sample periods, lasting 70 to 100 min each, to quantify O_2, CO_2, NO_x, and CO concentrations. Airflow data collected during concurrent PM sampling test periods were used to calculate NO_x and CO emission rates. NO_x and CO emission concentrations in dry parts per million by volume (ppmvd) were measured using a chemiluminescent analyzer and a gas filter correlation NDIR analyzer, respectively. Oxygen and CO_2 concentrations in dry percent were measured using a paramagnetic analyzer and NDIR analyzer, respectively. The data were recorded using an automated data acquisition system and the concentrations were recorded once per minute during each test period. A schematic of the NO_x and CO sampling system is shown in Figure 8.3.

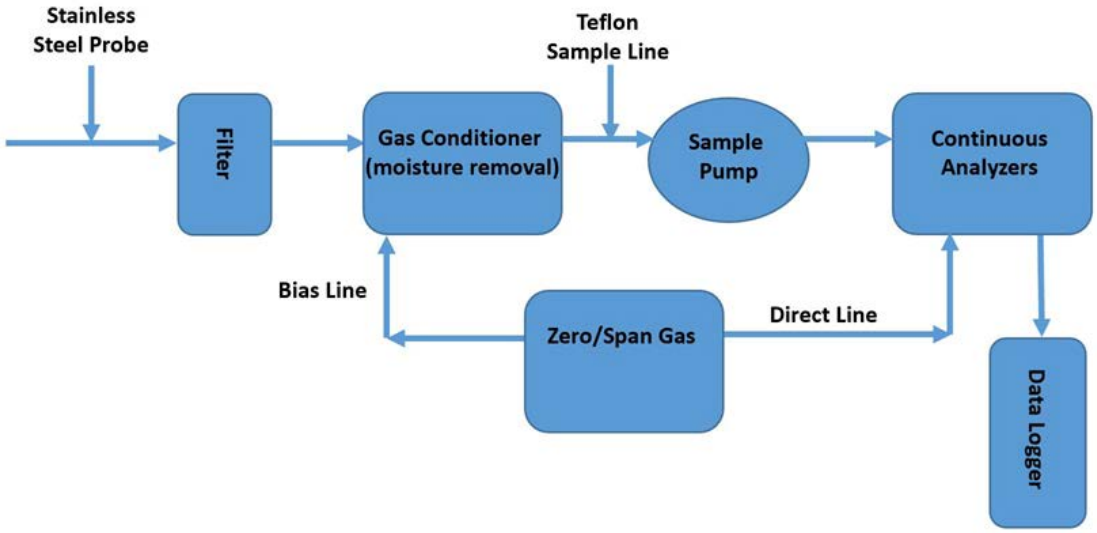


Figure 8.3. EPA Methods 3A, 7E, and 10 Analyzer Sample System Diagram

Data collected during test periods 1 through 3 were not analyzed because of the melter feed clogging issues mentioned earlier. Feed rate was unstable for test periods 4 and 5. Gaseous emissions rates of NO_x and CO for test periods 6 through 9 represented the most reliable set of data and are shown in Table 8.2. CO emissions are considerably higher than NO_x emissions during all test periods. Average gaseous emissions of NO_x and CO increased with increasing feed rate, as shown in Figure 8.4 and Figure 8.5.

Table 8.2. Gaseous Emissions Rates for Test Periods 6 through 9

	Test Period 6			Test Period 7		
	09/11/13, 1446 – 1616, Avg. Feed Rate 77.97 g/min			09/11/13, 0754 – 0934, Avg. Feed Rate 49.53 g/min		
	Avg.	Min.	Max.	Avg.	Min.	Max.
NO_x (ppmvd)	94.19	56.12	160.58	70.21	33.52	127.13
CO (ppmvd)	421.55	288.86	758.83	268.93	126.49	496.20
H_2O vol%[(a)]	17.55	–	–	14.65	–	–
CO_2 vol%	0.98	0.88	1.10	0.59	0.30	0.90
	Test Period 8			Test Period 9		
	09/12/13, 1003 – 1123, Avg. Feed Rate 58.08 g/min			09/12/13, 1155 – 1320, Avg. Feed Rate 57.87 g/min		
	Avg.	Min.	Max.	Avg.	Min.	Max.
NO_x (ppmvd)	68.70	39.98	156.32	91.68	40.46	146.64
CO (ppmvd)	236.53	120.35	511.14	400.97	211.61	604.78
H_2O vol%[(a)]	13.76	–	–	14.99	–	–
CO_2 vol%	0.56	0.42	0.86	0.77	0.48	1.09

(a) Only average vol% of H_2O was obtained.

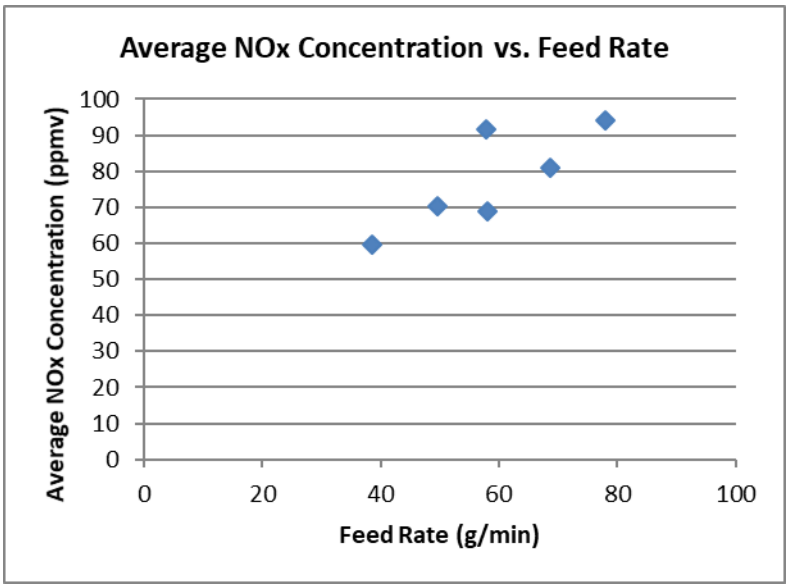


Figure 8.4. Feed Rate vs. NO_x Concentration in RSM Offgas

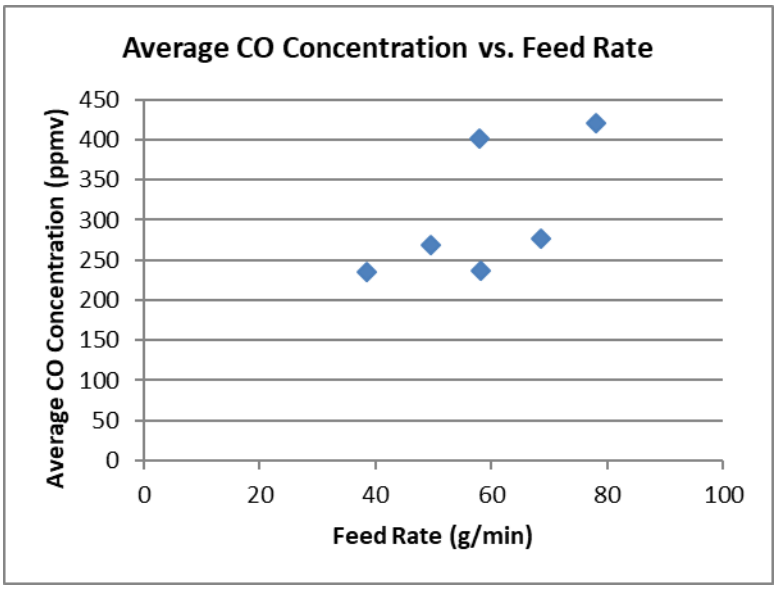


Figure 8.5. Feed Rate vs. CO Concentration in RSM Offgas

8.3 Particulate Matter Emission Analysis

For each test period, PM was withdrawn isokinetically from the source gas within the RSM exhaust pipe and collected on a fiber filter maintained at a temperature of 120 ± 14°C (248 ± 25°F). The mass of PM during each test period was determined gravimetrically after the removal of uncombined water from the material accumulated on the filter. PM emission rates were calculated in milligrams per minute using the percent isokinetics and sample nozzle/exhaust stack ratio information. A schematic of the PM sample train is shown in Figure 8.6. It should be noted that the flow meter used during the test was a PNNL installed device not provided by the offgas sampling contractor.

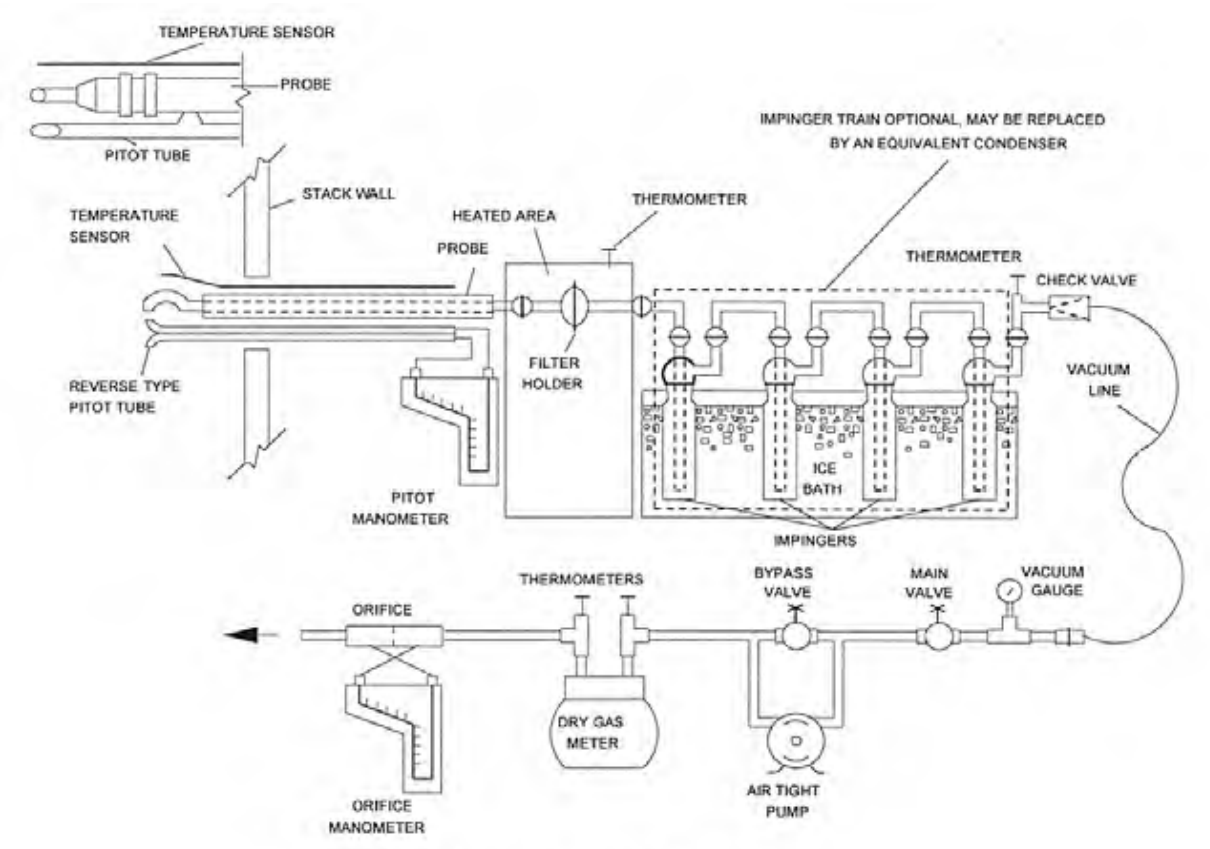


Figure 8.6. EPA Method 5 Particulate Sample Train Diagram

PM filter materials were analyzed by Antech (Corbett, OR) using ICP-OES for test periods 6 through 9, and the results are shown in Table 8.3. Particulate emissions contained an average of 0.74% of feed solids for the detected elements. The average decontamination factor (DF) during the four test periods was determined to be 134 with an average slurry feed rate of 60.7 g/min (2.57 L/h, lower than the stable processing feed rate of 2.98 L/h). Bismuth, potassium, sulfur, and lead exhibited the highest emission rates of the elements measured.

Table 8.3. RSM PM Emissions Summary

	Test Period 6				Test Period 7			
	09/11/13 1446 – 1616, 17.55% Moisture, 89% Isokinetics				09/12/13 0754 – 0934, 14.65% Moisture, 88% Isokinetics,			
	Feed Solids Rate (mg/min)	Emissions Rate (mg/min)	% Feed	DF	Feed Solids Rate (mg/min)	Emissions Rate (mg/min)	% Feed	DF
Total	13874	99.64	0.72	139	8813	49.82	0.57	177
Al	2994	ND	NC	NC	1902	ND	NC	NC
Bi	238	53.75	22.60	4.4	151	15.18	10.05	10.0
Ca	207	0.19	0.09	1083	131	0.04	0.03	3385
Cr	225	0.37	0.17	602	143	0.48	0.34	295
Fe	1099	2.29	0.21	480	698	1.56	0.22	449
K	1232	22.58	1.83	55	783	18.02	2.30	43
Li	518	1.69	0.33	307	329	1.34	0.41	246
Mg	13.3	0.36	2.72	37	8.4	0.03	0.33	303
Mn	296	0.49	0.17	600	188	0.38	0.20	501
Na	2027	10.78	0.53	188	1288	8.62	0.67	149
Ni	55	0.11	0.21	478	35	0.07	0.21	473
P	51	0.14	0.28	356	32	0.09	0.29	349
Pb	78	1.68	2.16	46	49	0.66	1.33	75
S	18	5.16	27.93	3.6	12	3.32	28.31	3.5
Si	3400	ND	NC	NC	2160	ND	NC	NC
	Test Period 8				Test Period 9			
	09/12/13 1003 – 1123, 13.76% Moisture, 98% Isokinetics				09/12/13 1155 – 1320, 14.99% Moisture, 100% Isokinetics			
	Feed Solids Rate (mg/min)	Emissions Rate (mg/min)	% Feed	DF	Feed Solids Rate (mg/min)	Emissions Rate (mg/min)	% Feed	DF
Total	10334	116.17	1.12	89	10298	61.74	0.60	167
Al	2230	7.50	0.34	297	2222	ND	NC	NC
Bi	177	19.83	11.19	8.9	177	19.48	11.04	9.1
Ca	154	0.05	0.03	3155	153	0.06	0.04	2769
Cr	167	0.69	0.41	241	167	0.56	0.34	296
Fe	819	3.49	0.43	235	816	1.53	0.19	533
K	918	25.31	2.76	36	914	22.49	2.46	41
Li	386	2.21	0.57	175	384	1.59	0.41	242
Mg	9.9	1.88	18.99	5	9.8	ND	NC	NC
Mn	220	0.79	0.36	278	219	0.38	0.17	581
Na	1510	13.74	0.91	110	1505	10.31	0.69	146
Ni	41	0.15	0.37	268	41	0.09	0.21	466
P	38	0.18	0.48	208	38	0.07	0.17	574
Pb	58	0.92	1.58	63	58	0.96	1.66	60
S	14	5.14	37.33	2.7	14	4.23	30.86	3.2
Si	2532	24.28	0.96	104	2523	ND	NC	NC

ND = not detected; NM = not measured; NC = not calculated.

Comparison of PM and offgas line deposit samples are shown in Table 8.4. As shown in Figure 4.6, solid deposits from the melter were collected from the offgas line. The three analyzed samples showed similar chemical compositions (Table 4.2). The averaged composition was calculated and compared with the composition of filter PM samples. It should be noted that small amounts of Cl and F are not included in the comparison.

The average PM emission rate during test periods 6 through 9 was used to estimate the total PM emissions generated during the entire RSM test. The average feed rate of the four selected PM test periods was 60.7 g/min (2.57 L/h) which is lower than the stable processing feed rate is 70.4 g/min (2.98 L/h, Table 4.1). Considering the large variation of the feed rate over the entire run, this difference is fairly small; and the PM emission rate averaged in a short period can be used to compare with other data averaged based on the entire run (e.g. averaged feed rate, glass pour rate, and EVS emission rate) for the mass balance calculation.

There are some components that were not included in the analysis, such as Bi_2O_3 for offgas line deposits and B_2O_3 for PM, which caused the sum of the concentrations to be less than 100 mass%. Al_2O_3, Na_2O, K_2O, and SiO_2 are other major components were analyzed in the samples. PM samples were collected by filters down-stream which should be finer particles. The composition of PM samples is high in K_2O and SO_3. On the other hand, offgas line deposits are larger particles from the melter, which contain higher Al_2O_2, and Na_2O. The total mass of samples are small fractions of the total feed processed. The total mass of PM was calculated by measured mass emission rate during sample periods and overall feed rate; while the total mass of the offgas line deposits was measured from the collected samples of the whole run. The total emission from the melter, including offgas line deposits, PM, and EVS solution will be discussed in Section 9.0.

Table 8.4. Comparison of PM and Offgas Line Deposits

Compound, mass%	Offgas Line Deposits				PM
	Film Cooler	Long Tube	90° Bend	Average	
Al_2O_3	13.61	11.27	8.89	11.20	4.59
B_2O_3	18.50	13.20	10.00	13.75	NM
Bi_2O_3	NM	NM	NM	NM	14.43
CaO	0.71	0.82	0.79	0.78	0.06
Cr_2O_3	1.80	1.49	1.46	1.57	0.37
Fe_2O_3	5.44	4.58	4.33	4.75	1.49
K_2O	7.33	6.48	6.45	6.72	12.63
Li_2O	1.90	1.41	1.36	1.54	1.73
MgO	0.06	0.04	0.04	0.05	0.52
MnO	1.42	0.91	0.88	1.05	0.31
Na_2O	11.06	9.14	8.05	9.36	6.92
NiO	NM	NM	NM	NM	0.06
P_2O_5	0.38	0.93	0.87	0.75	0.13
PbO	NM	NM	NM	0.00	0.54
SO_3	0.34	ND	0.28	0.19	5.28
SiO_2	21.35	17.82	14.75	17.88	16.84
SrO	NM	NM	NM	NM	0.02
TiO_2	NM	NM	NM	NM	0.16
ZrO_2	0.05	0.24	0.32	0.21	0.02
Total mass%[(a)]	83.97	68.33	58.44	69.80	66.10
Total sample weight, g	56.55	72.29	61.12	189.96	74.13

(a) Concentrations sum to less than 100% because some elements could not be analyzed.
ND = not detected; NM = not measured.

9.0 Process Mass Balance

During the RSM operation, offgas streams including deposits in the exhaust line, PM emission, and scrubber (EVS) solution were characterized for completeness. The compositional data of process streams previously discussed and summarized were combined.

Total water mass in the feed was calculated and compared with the mass of water accumulated in the EVS tank (Table 9.1). It should be noted that there are two reference values of the water mass% in the slurry feed (target and analyzed). The analyzed water content in the feed sample is ~7% higher than the target water content of the feed formulation, which should be caused by experimental error. As expected, the water mass% calculated by EVS vs. feed basically matches the reference values, which indicates that the EVS solution accumulated all water- and water-soluble components in the offgas stream (expect the offgas line deposits).

Table 9.1. Water Mass Calculation

Feed processed, kg	388.01
EVS solution accumulated in tank, kg	228.85
Water mass% recovered by EVS[(a)]	59.0
Reference water mass%, Target[(b)]	*55.9*
Reference water mass%, Analyzed feed sample[(c)]	*60.1*

(a) Calculated by EVS solution mass (ignore mass of soluble component in the solution) divided by feed mass.
(b) Calculated by feed formulation, including water from hydroxides.
(c) Calculated by an analyzed feed sample (sample ID, RSM-EWG8-041,
(d) Table 3.2), by subtracting total dry mass of analyzed components from total mass of the slurry feed sample
Italics are reference water mass%.

The mass balance is measured by comparing input and output of the RSM. The results for the overall RSM run are summarized in Table 9.2. For each element, the mass from the slurry feed was the input, and the output mass included the poured glass, the offgas line deposit, and EVS solution. For the feed and glass samples, analytical compositional data from SwRI were used whenever possible; otherwise, PNNL data were used.

PM samples were not counted in the output mass. The PM sampling process was performed for a total of 355 min (Table 8.1), and the sampling stream was ~2% of the total offgas stream (PM filter run fraction was ~ 2%, calculated based on the ratio of sampling nozzle area and the main line area), which means most emission from the melter went to the offgas line deposit and the EVS. Thus, the mass of PM samples was negligible for the overall mass balance. However, the PM results are used to estimate the element emissions in terms of emission rate later in this section.

The volatile NO_x, CO, and CO_2 were directly measured by continuous gas monitors as described in Section 8.2; they were not included in the mass balance calculation because of that 100% of the output was in the gas emission.

The recovery of elements throughout the RSM system was calculated for the targeted components as elements. There are some elements measured in the feed and glass samples as impurities (not in the target

formulation). Some of those impurities, Mg, S, Sr, Ti, Zn, and Zr, are included in the mass balance calculation.

Overall, the tracked elements show good recovery as shown in Table 9.2. Major components such as Al, B, Na, and K had about 90% to 110% recoveries. The recoveries of Fe and Si were 84% and 135% respectively, which is likely due to experimental error. Fluorine was lower than the detection limit in the produced glass samples; however, the recovery was estimated by the ICP-OES detection limit. The estimated F recovery was below 65.2%; this low mass balance closure is related to the larger relative errors for the components with lower concentration. It should be noted that some components were not analyzed in collected samples, such as Bi in offgas deposits, which led to lower recovery percentages.

Furthermore, the feed rate and emission rate of the elements were calculated by the masses and feeding time, and the proportion of emission were estimated (Table 9.3). F and S show over 10% total emission. Considering that F was not analyzed in PM, its total emission percentage might be underestimated. The percentage of volatile F and S can be used to compare with other melter studies. The total emission of elements from the melter is 0.39%.

The PM filter was effective in collecting solids from the emission, which can be approximately used as the total deposits of the offgas system. As shown in Table 9.3, the total offgas line deposits were calculated by subtracting the EVS emission rate from the PM emission rate. As expected, most of the analyzed components show that the calculated masses exceed the masses recovered from the three offgas line deposit samples (film cooler, the 90° bend, and the long tube) except for Ca, which was likely caused by experimental error. Comparing the calculated and measured total offgas line deposits rates in mg/min, the source of differences is deposits in the offgas system outside of the three sampling locations (Figure 4.6). The value of Mg (an impurity) is very low and is likely due to experiment error in the chemical analyses.

In PM samples, a significant amount of Bi, 12.59% of total Bi from feed, was found; however, Bi was not measured in the offgas line deposits. This shows Bi emission might be under-estimated by the analytical result of EVS solution. Bi was found in filtered solid samples of EVS solution (data not reported, because sample mass could not be determined precisely).

In summary, the melter emission could not be 100% recovered by offgas line deposit samples and EVS samples; the unrecovered proportion was investigated by comparing with PM results. Even though it is more effective, PM still has downsides. First, the film cooler and 90° bend deposits could not be collected by PM filter. Also, the PM sampling periods were intermittent, which was affected by the changes of feeding rate and bubbling rate. The comparison results of different emission samples provide important information of undetected emissions from (1) offgas line deposits that were hard to collect and (2) probable precipitates not collected in the bottom of the EVS tank.

Table 9.2. Mass Balance Calculation

Element	Feed[a], 388.01 kg		Offgas Line deposit[b], 0.190 kg		EVS Solution[c], 228.85 kg		Glass[d], 140.81 kg		% of mass accounted for
	mg/kg	mass, kg	mg/kg	mass, kg	mg/kg	mass, kg	mg/kg	mass, kg	
Al	38400	14.900	59272	0.01126	0.41	0.00009	100350	14.130	94.9%
B	18100	7.023	42697	0.00811	221.50	0.05069	44300	6.238	89.7%
Bi	3050	1.183	–	–	85.15	0.01949	5315	0.748	64.9%
Ca	2650	1.028	5561	0.00106	4.88	0.00112	6815	0.960	93.5%
Cr	2880	1.117	10763	0.00204	2.98	0.00068	11150	1.570	140.7%
F[e]	157	0.061	5227	0.00099	68.30	0.01563	< 164	< 0.023	< 65.2%
Fe	14100	5.471	33235	0.00631	10.00	0.00229	32650	4.597	84.2%
K	15800	6.131	55795	0.01060	181.50	0.04154	47450	6.681	109.8%
Li	6640	2.576	7171	0.00136	28.35	0.00649	17600	2.478	96.5%
Mg[f]	170	0.066	272	0.00005	3.15	0.00072	143	0.020	31.7%
Mn	3790	1.471	8139	0.00155	2.85	0.00065	9250	1.302	88.7%
Na	26000	10.088	69432	0.01319	161.50	0.03696	69500	9.786	97.5%
Ni	703	0.273	–	–	1.23	0.00028	2055	0.289	106.2%
P	656	0.255	3266	0.00062	–	–	1190	0.168	66.1%
Pb	998	0.387	–	–	2.84	0.00065	2155	0.303	78.5%
S[f]	237	0.092	773	0.00015	63.40	0.01451	245	0.034	53.5%
Si	43600	16.917	83591	0.01588	13.90	0.00318	162500	22.882	135.4%
Sr[f]	4.87	0.002	–	–	–	–	8	0.001	58.1%
Ti[f]	69.1	0.027	–	–			162	0.023	84.8%
W	212	0.082	–	–	0.95	0.00022	741	0.104	127.1%
Zn[f]	15.6	0.006	–	–	–	–	42	0.006	98.5%
Zr[f]	16.8	0.007	–	–	–	–	84	0.012	181.2%
Total	NA	69.163	NA	0.072	NA	0.1952	NA	72.335	105.0%

(a) Feed Solids analysis from RSM-EWG8-041 (
(b) Table 3.2).
(c) Offgas line deposits analysis by XRF and ICP-OES (Table 4.2).
(d) EVS Solution from analysis of sample RSM-EWG8-058 except Al, which was averaged by four samples (Table 7.1).
(e) Glass composition from average of ICP-OES analysis of two samples, RSM-EWG8-018 and RSM-EWG8-035 (Table 6.2).
(f) Used detection limit to estimate the maximum concentrating in glass.
(g) Impurities.
"–" = not measured or not detected; NA = not applicable.

Table 9.3. Total Estimated Cation and Anion Emissions (Offgas Line Deposits, PM, and EVS Solution Analyses Combined)

Element	Feed	Offgas Line Deposits, measured		EVS		SUM		PM		Offgas Line Deposits, calculated[a]		% measured vs calculated offs-gas line deposits[b]	% recovered emission[c]
	mg/min	mg/min	% feed	mg/min	%feed	mg/min	% feed	mg/min	% feed	mg/min	% feed		
Al	2703	2.04	0.08	0.017	0.001	2.06	0.08	7.50	0.28	7.48	0.28	27.3%	27.5%
B	1274	1.47	0.12	9.19	0.72	10.66	0.84	–	–	–	–	–	–
Bi	215	–	–	3.53	1.65	3.53	1.65	27.04	12.59	23.50	10.95	–	13.1%
Ca	187	0.19	0.10	0.20	0.11	0.39	0.21	0.08	0.04	–	–	–	–
Cr	203	0.37	0.18	0.12	0.06	0.49	0.24	0.52	0.26	0.40	0.20	93.1%	94.8%
F	11	0.18	1.63	2.83	25.65	2.83	27.28	–	–	–	–	–	–
Fe	992	1.14	0.12	0.42	0.04	1.56	0.16	2.17	0.22	1.76	0.18	65.2%	71.8%
K	1112	1.92	0.17	7.53	0.68	9.46	0.85	21.89	1.97	14.36	1.29	13.4%	43.2%
Li	467	0.25	0.05	1.18	0.25	1.42	0.30	1.68	0.36	0.51	0.11	48.9%	84.6%
Mg	12	0.01	0.08	0.13	1.09	0.14	1.17	0.69	5.73	0.56	4.64	1.7%	20.4%
Mn	267	0.28	0.11	0.12	0.04	0.40	0.15	0.50	0.19	0.38	0.14	73.5%	79.8%
Na	1830	2.39	0.13	6.70	0.37	9.09	0.50	10.73	0.59	4.02	0.22	59.5%	84.8%
Ni	49	–	–	0.05	0.10	0.05	0.10	0.11	0.21	0.05	0.11	–	48.4%
P	46	0.11	0.24	–	–	0.11	0.24	0.12	0.26	–	–	–	93.9%
Pb	70	–	–	0.12	0.17	0.12	0.17	1.05	1.49	0.93	1.33	–	11.2%
S	17	0.03	0.16	2.63	15.77	2.66	15.93	4.42	26.47	1.78	10.70	1.5%	60.2%
Si	3069	2.88	0.09	0.58	0.02	3.46	0.11	24.28	0.79	23.71	0.77	12.1%	14.2%
W	15	–	–	0.04	0.26	0.04	0.26	–	–	–	–	–	–
Total	12547	13.09	0.10	35.40	0.28	48.487	0.39	103.13	0.82	79.44	0.63	16.5%	47.0%

(a) Calculated offgas line deposits by subtracting EVS masses from PM masses.
(b) Measured offgas line deposit mass rates (three collected samples in Table 4.2) divided by calculated mass rates offgas line deposit.
(c) Calculated by total measured masses rates (offgas line deposits and EVS) divided by PM mass rates.
"–" = not measured or not detected.

10.0 PNNL RSM and VSL DM100 Comparisons

The HLW-HCr-16 glass was produced in the RSM operated by PNNL (this work) and the DM100 melter operated by the VSL (Matlack et al. 2014). The SY101/102 simulants used by PNNL and VSL were produced by the same supplier from the same batch and were below the target value for sodium (detailed description in Section 3.0). VSL and PNNL made batch adjustments to increase sodium in the melter feed. PNNL made adjustments by adding NaOH pellets. It was not indicated in the corresponding report (Matlack et al. 2014) how the adjustments were made.

Melter testing by VSL included two melter runs totaling 100 h of feed time, 580 kg of glass, and feeding over 1600 kg of melter feed. PNNL melter testing, by comparison, consisted of 92 hours of feed time, 140.8 kg of glass, and feeding 388 kg of melter feed. The glass production average reported by VSL for the DM100 was nearly 100% greater (1100 and 1550 kg/day/m^2 for DM100 and 654 kg/day/m^2 for the RSM). However, the peak steady state production in the RSM was 822. The two runs in the DM100 were distinguished by optimized processing parameters to increase production, namely bubbling rates. In VSL's DM100 test 1, the goal was optimized bubbling to achieve greater production with a bubbling flux of 144 L/min/m^2, which resulted in a production rate of 1550 kg/day/m^2. In VSL's DM100 test 2, bubbler air flow was held at a constant value with a bubbling flux of 83 L/min/m^2 and a glass production rate of 1100 kg/day/m^2 (Matlack et al. 2014).

Table 10.1. Production Value Comparison, PNNL-RSM and VSL-DM100 (Matlack et al. 2014)

	RSM	DM100 test 1, Optimized Bubbling[(a)]	DM100 test 2, Fixed Bubbling[(b)]
Melt surface area, m^2	0.05	0.108	0.108
Average glass temperature, °C	1137	1140	1142
Average plenum temperature, °C	598	492	444
Average bubbling rate, L/min	4.2	15.6	9.0
Average bubbling rate, L/min/m^2	84	144	83
Feeding duration, h	92	50	50
Feed processed, kg	388	982	697
Glass produced, kg	140.8	327.3	253.3
Feed rate, average (steady state), L/h[(c)]	2.98(3.33)	13.8	9.8
Glass production rate, average (steady state), kg/day/m^2[(d)]	654(822)	1550	1100
Total DF	134	143	162

(a) Data for optimized production run with enhanced bubbling.
(b) Data for baseline production run.
(c) Based on feed density of 1.416 g/cm^3.
(d) Due to feeding problems, the average glass production rate of PNNL RSM is lower than the steady-state glass production rate.

HLW-HCr-16 VSL glass compositions, shown in Matlack et. al. 2014 (Table 4.7), were comparable with the PNNL glass (Table 6.2 and Table 6.3 of this report) in terms of the major glass-forming components of Al_2O_3, B_2O_3, Na_2O, and SiO_2 (Table 10.2). It is noticeable that Bi is much lower in the PNNL glass, and evidence of Bi emission was observed. On the other hand, loss of Bi was not as significant in the VSL glass. Sodium in the PNNL glass was below target and below VSL numbers. This is thought to be

related to undissolved NaOH pellets that were removed from the system when resolving frequent line plugs.

Table 10.2. Glass Composition Comparison, HLW-HCr-16 Produced in PNNL-RSM and VSL-DM100 (Matlack et al. 2014)

Component	Target (mass%)	PNNL[a] (mass%)	VSL[b] (mass%)
Al_2O_3	19.83	18.955	17.09
B_2O_3	15.06	14.27	14.34
Bi_2O_3	0.91	0.59	1.00
CaO	0.98	0.955	0.92
Cr_2O_3	1.82	1.63	1.42
F	0.06	< 0.016	0.01
Fe_2O_3	5.04	4.67	5.88
K_2O	6.39	5.715	4.95
Li_2O	4.00	3.79	3.82
MgO	–[c]	0.02	0.15
MnO	1.29	1.195	1.04
Na_2O	10.69	9.37	10.32
NiO	0.25	0.265	0.41
P_2O_5	0.38	0.27	0.46
PbO	0.31	0.23	0.23
SO_3	–[c]	0.03	0.09
SiO_2	32.89	34.83	37.12
TiO_2	–[c]	0.03	0.04
WO_3	0.09	0.09	0.10
ZnO	–[c]	0.01	0.20
ZrO_2	–[c]	0.01	0.42
Total	100	96.88	100.00

(a) Average of two PNNL RSM samples, RSM-EWG8-018 and RSM-EWG8-035, from Table 6.2.
(b) Averaged of three VSL DM100 samples, MBL-D-39A, MBL-D-78A, and MBL-D-97A, reported in Matlack et al. 2014.
(c) MgO, SO_3, TiO_2, ZnO, and ZrO_2 are not target constituents.

The analytical results from EPA Method 5 sampling were also comparable. VSL reported an overall melter DF of 143 and 162 for tests 1 and 2, respectively. PNNL reported an overall DF of 134 averaged for the four test periods. Notable exceptions were DFs for Al, Ca, Cr, and Si, which were significantly higher in the DM100, and Fe, Mn, and Li, which were significantly lower. The reasons for these differences are unclear.

Gaseous emissions from the melter were also sampled and analyzed by PNNL and VSL, with the results given in Table 8.2 of this report and Table 5.2 of Matlack et. al. 2014, respectively. Notable differences were the higher levels of NO_x (81.2 vs. 35.5 ppmv) and CO (331.9 vs. 138.1 ppmv) during the PNNL RSM run. This can be explained by the higher plenum temperatures and larger variations in cold cap coverage during the RSM offgas testing period compared to the larger DM100 melter.

11.0 Conclusions

The RSM tests in this study provided glass samples and basic operational data while processing a high-Cr waste simulant feed composition, HLW-HCr-16. It was demonstrated that acceptable processing rates and characteristics could be achieved when the RSM was operated under parameters that were generally aligned with those of larger melters on a melt-surface-area-adjusted basis. The tests demonstrated the process flowsheet through a small-scale integrated process which provided feedback and data and during operations.

Steady-state processing is essential in a vitrification process to maintain glass quality and reduce the challenges to the offgas system from particulate, aerosols, and noxious gasses. During this test, undissolved NaOH pellets frequently plugged the feed injection line to the melter. As would be expected, stopping feed to the melter reduced the durations for collecting steady state data as well as impacting glass chemistry results. As a result, it was difficult to make firm conclusions about the data and make fair comparisons with other melter tests.

This test was carried out in a period of ~103 h; several interruptions caused by plugging of the feeding system were resolved in the first 24 h. The RSM was operated with a target glass temperature of 1150°C and target plenum temperature between 550°C and 700°C. The average glass melt temperature measured in the RSM was 1137°C. Measured plenum temperatures ranged from 515°C to 622°C during steady-state operation and the average surface-area-specific bubbling rate was 84 L/min/m^2. The average glass production rate was 1.36 kg/h in the RSM, resulting in an overall average melter surface-area-normalized glass generation rate of 654 kg/day/m^2. During periods of steady-state operation in the RSM, the production rate as calculated from the feed rate was 822 kg/day/m^2. The average power use for glass production was 109.2 kW/m^2. Overall, 140.8 kg of glass was produced during operation of the RSM.

One glass (RSM-EWG8-044) was subsampled and isothermally heat treated at different temperatures as well as following the HLW CCC profile. The crystal phases in the quenched and heat-treated samples were analyzed by SEM-EDS and XRD. Some spinel crystals were identified in the quenched glass and also in the heat-treated glasses. The crystal fraction of spinel in the glass increased slightly after heat treatments. Nepheline was also identified in the heat-treated glass. The temperature at 1 vol% spinel determined by the isothermal heat-treatment tests was estimated to be 1786°C. The resulting glass product had TCLP responses below the regulatory limits. At ~1150°C, viscosity and electrical conductivity of the glass were 5.8 Pa-s and 22.3 S/m, respectively. The viscosity was within the acceptable range and the electrical conductivity was close to the DWPF reference glass.

Offgas sample analysis determined the H_2O, CO_2, NO_x, and CO concentrations in the emission gas. H_2O and CO_2 were 13.76 – 17.55 vol% and 0.56 – 0.98 vol% in the emission gas respectively, with the rest being bubbled air. NO_x and CO, as minor components of interest in the emission, were 68.70 – 94.19 ppmvd and 236.53 – 421.55 ppmvd respectively. The total DF for the RSM test was determined to be 134 by the PM analysis results.

Process mass balance was investigated focusing on the emission of various elements. Bi, F, and S are the three elements that had significant levels of emission during the melter run. Combination of offgas line deposits and EVS solution recovered 27.28% of F and 15.93% of S; while PM method recovered 12.59% of Bi and 26.47% of S. Emission ratios of the elements other than Bi, F, and S were all less than 2% (disregarding data from some impurities, which had low concentration and large uncertainties, such as Mg). Only a portion of the offgas line deposit samples was collected, and the unrecovered deposits were

estimated by PM results. EVS captured majority of alkalis, B, Cr, F, and S, while Si, Al, and Pb are found mainly in the solid deposits in the offgas line.

Comparing the RSM and VSL DM100, RSM is smaller and has a slower glass production rate. The analytical results from offgas systems of the two melters were very similar and the glass samples from the two melter tests were both reasonably close with the target composition, as expected. Improvements can be made to the RSM feeding and bubbling operations.

Overall, this work demonstrates that the smaller-scale RSM can be used to support and supplement waste vitrification research, providing comparable experimental results while requiring less material and shorter turnaround times than the larger melters. In future tests, consideration should be given to validating the prepared feed before commencing operations.

12.0 References

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Appendix A – Manual Log (Melter Operating Parameter)

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Temperature and Electrical Data (HMI)	Operator (initials):		JJ	MJ	MLL	DGL	DGL	DGL	MLL	JL
	Date:		09.09.13	9.9.13	9-9-13	9/9/13	9/9/13	9/9/13	9/9/13	9/9/13
	Start time:		0529	0629	0736	0828	0938	1036	1136	1247
DESCRIPTION	UNITS	RANGE								
Melt Temperature (T1)	°C	1125-1175	1148	1121	1115	1126	1120	1121	1129	1131
Melt Temperature (T2)	°C	1125-1175	1157	1144	1148	1152	1150	1149	1147	1149
Melt (Electrode) Temp Setpoint	°C	1150	1160	1150	1150	1150	1150	1150	1156	1150
Secondary Electrode Current	Amps		102.9	102	98.8	98.9	92.4	94.8	98.1	97.4
Secondary Electrode Potential	Volts		48.1	61	53.2	53.3	44.1	47.6	52.5	48.2
Secondary Electrode Power (calc)	kW (V×A)		4.95	6.22	5.26	5.27	4.07	4.51	5.15	4.64
Melt Resistance (calc)	Ω (V/A)		0.468	0.598	0.538	0.53	0.48	0.50	0.54	0.495
Electrode Power Output	%		57.9	60.1	55.6	55.8	52.7	53.9	54.5	53.0
Electrode Power Control	A or M		A	A	A	A	A	A	A	A
Melter Temperature Control		T1 or T2	T2	T2	T2	T2	T2	T2	T2	T2
Kiln Monitored (Middle) Temp	°C		849	740	743	771	784	776	775	798
Kiln Top Temp	°C		811	659	685	714	724	731	726	751
Kiln Bottom Temps	°C		897	714	877	930	965	925	933	958
Kiln Temp Setpoint	°C		800	800	800	800	800	off	780	780
Kiln Power	kW		226	1.3	3.9	3.9	3.86	↓	387	0
Kiln Power Output	%		6.6		93.0	93.0	93.0	↓	93.4	0
Kiln Control	A or M		A	A	A	A	A	↓	A	A
Discharge Canister Temp	°C	750 - 850	↓	↓	off	off	off	↓	off	off
Discharge Canister Temp Setpoint	°C		↓	↓	↓	↓	↓	↓	↓	↓
Discharge Canister Power	kW		↓	↓	↓	↓	↓	↓	↓	↓
Discharge Canister Power Output	%		↓	↓	↓	↓	↓	↓	↓	↓
Pourspout Heater Actual Temp	°C	1000-1100	1089	1124	1097	1095	1083	985	1055	1048
Pourspout Heater Temp Setpoint	°C		1100	1100	1100	1100	1100	off	1050	1050
Pourspout Heater Power	kW		1.67	3.4	2.18	1.77	1.78	↓	1.53	1.87
Pourspout Heater Power Output	%		36.2	53	45.7	42.5	38.5	↓	39.7	43.9
Plenum Temperature	°C	500-700	576	665	547	543	483	599	619	851
Feed Nozzle Temp (FNT)	°C	<50	43	34	32	31	31	32	33	39
Off-Gas Temp (OGT_1)	°C	<350	374	269	269	282	249	244	266	215
Off-Gas Temp (OGT_#2)	°C		271	145	226	245	208	202	215	186
Scrub Liquid Temp (SLT)	°C	<40	27	37	32	34	34	31	91	28
Post EVS Off-Gas Temp	°C	<50	29	36	38	38	39	34	34	29
Heat Xfer Temp	°C	<30	?		12	29	24	25	25	24
Post HEME Temp	°C		25	36	31	32	39	30	29	27
Bubbler Flow Rate (total)	sccm		4200	4200	4209	4202	4201	4197	4203	4200
Plenum Vacuum	in. H_2O	0.1 - 2.5	1.3	.4	1.0	1.0	0.9	0.4	1.0	.3 .2 JL 9/9/13
		Finish time:	0536	0646	0741	0834	094	1044	1145	1249

Reviewed by: Dan Lindsey Date: 10-21-13

pps 9/9/13 No rounds taken due to electrode power outage.

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Temperature and Electrical Data (HMI)		Operator (initials):	JC	MLK	PPS	PPS	PPS	PPS	PPS	AJJ
		Date:	9/9/13	9/9/13	9/9/13	9/9/13	9/9/13	9/9/13	9/9/13	9/10/13
		Start time:	13:45	1507	16:03	17:04	18:03	22:01	23:02	1205
DESCRIPTION	UNITS	RANGE								
Melt Temperature (T1)	°C	1125-1175	1141	1124 ~~1148~~	1129	1131	1139	1147	1124	1075
Melt Temperature (T2)	°C	1125-1175	1150	1148	1148	1152	1144	1150	1150	1106
Melt (Electrode) Temp Setpoint	°C	1150	1150	115	1150	1150	1150	1150	1150	1150
Secondary Electrode Current	Amps		98.2	97.2	103.9	102.7	110.7	111.6	106.6	88
Secondary Electrode Potential	Volts		45.7	50.1	51.5	50.3	52.9	51.6	51.9	49
Secondary Electrode Power (calc)	kW (V×A)		4.49	4.86	5.35	5.17	5.86	5.76	5.53	4.31
Melt Resistance (calc)	Ω (V/A)		0.47	0.52	0.496	0.49	0.48	0.46	0.49	0.557
Electrode Power Output	%		55.5	54.5	58.5	58.3	62.5	62.6	60.0	49.9
Electrode Power Control	A or M		A	A	A	A	A	A	A	A
Melter Temperature Control		T1 or T2	T2	T2	T2	T2	T2	T2	T2	T2
Kiln Monitored (Middle) Temp	°C		837	855	805	756	727	787	759	760
Kiln Top Temp	°C		801	819	764	711	679	747	714	715
Kiln Bottom Temps	°C		832	830	812	787	770	788	772	756
Kiln Temp Setpoint	°C		799.9	854	805	756	727	787	759	760
Kiln Power	kW		0	0	0	0	0	0	0	0
Kiln Power Output	%		0	0	0	0	0	0	0	0
Kiln Control	A or M		A	Off	off	off	off	off	off	M
Discharge Canister Temp	°C	750 - 850	Off	Off	off	off	off	off	off	
Discharge Canister Temp Setpoint	°C									
Discharge Canister Power	kW				N/A	N/A	N/A	N/A	N/A	
Discharge Canister Power Output	%									
Pourspout Heater Actual Temp	°C	1000-1100	1050	1050	1053	1050	1050	1049	1051	1080
Pourspout Heater Temp Setpoint	°C		1050	1050	1050	1050	1050	1050	1050	1050
Pourspout Heater Power	kW		1.97	1.97	2.12	2.22	2.36	2.06	2.10	2.28
Pourspout Heater Power Output	%		44.9	45.0	46.5	47.8	49.0	44.0	46.4	46.2
Plenum Temperature	°C	500-700	955	825	682	612	560	727	679	601
Feed Nozzle Temp (FNT)	°C	<50	48	40	35	33	32	38	36	32
Off-Gas Temp (OGT_1)	°C	<350	147	350	326	315	276	331	330	244
Off-Gas Temp (OGT_#2)	°C		117	249	262	253	248	266	257	251
Scrub Liquid Temp (SLT)	°C	<40	25	27	31	33	33	29	31	30
Post EVS Off-Gas Temp	°C	<50	26	30	35	37	37	32	34	34
Heat Xfer Temp	°C	<30	23	24	28	25	25	24	25	25
Post HEME Temp	°C		26	26	25	31	31	25	27	26
Bubbler Flow Rate (total)	sccm		4201	4202	4204	4193	4195	4200	4197	4201
Plenum Vacuum	in. H_2O	0.1 - 2.5	.3	1.0	1.1	1.0	1.0	1.0	1.1	0.9
		Finish time:	1350	1514	16:08	17:07	18:08	22:04	23:05	1211

Reviewed by: Dary Serrigny

Date: 9-11-13

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Temperature and Electrical Data (HMI)	Operator (initials):		MJ	CL	MJ	CL	MJK	JL	SL	MJK
	Date:		9/10/13	9/10/13	9/10/13	9/10/13	9/10/13	9/10/13	9/10/13	9/10/13
	Start time:		0112	02:03	0310	04:17	0730	0915	1016	1115
DESCRIPTION	UNITS	RANGE								
Melt Temperature (T1)	°C	1125-1175	1054 *	1123	1124	1128	1090	1142	1154	1117
Melt Temperature (T2)	°C	1125-1175	1076	1147	1138	1100	1081	1153	1143	1151
Melt (Electrode) Temp Setpoint	°C	1150	1150	1150	1150	1150	1150	1150	1150	1150
Secondary Electrode Current	Amps		96.3	103.3	109	90.5	96.9	103.6	99.6	97.2
Secondary Electrode Potential	Volts		57.3	53.4	53	47.1	57.3	52.4	53	54.4
Secondary Electrode Power (calc)	kW (V×A)		5.52	5.516	5.78	4.26	5.55	5.43	5.11	5.29
Melt Resistance (calc)	Ω (V/A)		0.595	0.517	0.486	0.520	0.591	0.506	0.515	0.559
Electrode Power Output	%		54.0	58.7	60.9	50.8	54.6	59.3	56.3	55.2
Electrode Power Control	A or M		A	A	A	A	A	A	A	A
Melter Temperature Control		T1 or T2	T2	T2	T2	T2	T2	T2	T2	T2
Kiln Monitored (Middle) Temp	°C		719	802	801	800	847	826	769	733
Kiln Top Temp	°C		671	768	764	767	814	791	731	689
Kiln Bottom Temps	°C		741	834	827	834	835	822	792	769
Kiln Temp Setpoint	°C		—	800	800	800	850	826	768	731
Kiln Power	kW		—	2.87	1.34	1.65	1.99	0	0	0
Kiln Power Output	%		—	86.1	55.1	60.4	65.8	0	0	0
Kiln Control	A or M		M	A	A	A	A	M	M	M
Discharge Canister Temp	°C	750 - 850					off	off	off	off
Discharge Canister Temp Setpoint	°C									
Discharge Canister Power	kW									
Discharge Canister Power Output	%									
Pourspout Heater Actual Temp	°C	1000-1100	1051	1051	1047	1051	1053	1052	1050	1051
Pourspout Heater Temp Setpoint	°C		1050	1050	1050	1050	1050	1050	1050	1050
Pourspout Heater Power	kW		2.23	1.83	2.08	1.89	1.96	1.75	1.96	2.11
Pourspout Heater Power Output	%		47	43.2	44.6	44.0	44.5	41.8	44.9	46.7
Plenum Temperature	°C	500-700	592	594	655	641	775	735	640	561
Feed Nozzle Temp (FNT)	°C	<50	32	31	32	32	35	35	31	30
Off-Gas Temp (OGT_1)	°C	<350	278	290	316	264	302	301	237	228
Off-Gas Temp (OGT_#2)	°C		229	244	246	201	242	243	194	185
Scrub Liquid Temp (SLT)	°C	<40	30	32	31	32	29	33	33	34
Post EVS Off-Gas Temp	°C	<50	34	37	35	35	32	37	37	38
Heat Xfer Temp	°C	<30	26	26	25	25	25	25	26	26
Post HEME Temp	°C		27	28	27	27	24	29	30	30
Bubbler Flow Rate (total)	sccm		4205	4200	4202	4200	4200	4204	4199	4207
Plenum Vacuum	in. H_2O	0.1 - 2.5	1.0	1.0	0.5	0.3	1.1	.7	.3	0.4
		Finish time:	0116	02:07	0315	04:21	0757	0920	1022	1125

Reviewed by: _____ * low flow to feed pump..

Date: 9-11-13

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Temperature and Electrical Data (HMI)	Operator (initials):		SL	SL	SL	SL	SL	SL	PPS	PPS
	Date:		9/10/13	9/10/13	9/10/13	9/10/13	9/10/13	9/10/13	9/10/13	9/10/13
	Start time:		1245	1322	1417	1524	1603	1720	18:01	19:03
DESCRIPTION	UNITS	RANGE								
Melt Temperature (T1)	°C	1125-1175	1124	1107	1134	1120	1107	1110	1095	1117
Melt Temperature (T2)	°C	1125-1175	1155	1152	1151	1147	1150	1149	1149	1158
Melt (Electrode) Temp Setpoint	°C	1150	1150	1150	1150	1152	1150	1150	1150	1160
Secondary Electrode Current	Amps		92.0	96.1	102.2	99.8	99.2	95.5	95.1	103.3
Secondary Electrode Potential	Volts		51.3	48.1	53.1	52.2	54.2	52.7	51.6	53.9
Secondary Electrode Power (calc)	kW (V×A)		4.72	4.62	5.42	5.21	5.38	5.03	4.91	5.57
Melt Resistance (calc)	Ω (V/A)		0.558	0.5075	0.516	0.523	0.546	0.552	0.543	0.522
Electrode Power Output	%		52.2	54.4	57.8	56.8	56.1	54.1	54.6	58.7
Electrode Power Control	A or M		A	A	A	A	A	A	A	A
Melter Temperature Control		T1 or T2	T2	T2	T2	T2	T2	T2	T2	T2
Kiln Monitored (Middle) Temp	°C		709	695	707	704	710	710	703	696
Kiln Top Temp	°C		664	649	663	659	663	664	655	648
Kiln Bottom Temps	°C		750	740	741	747	749	745	738	739
Kiln Temp Setpoint	°C		709	694	707	703	709	710	703	696
Kiln Power	kW		0	0	0	0	0	0	0	0
Kiln Power Output	%		0	0	0	0	0	0	0	0
Kiln Control	A or M		M	M	M	M	M	M	M	M
Discharge Canister Temp	°C	750 - 850	off	off	off	off	off	off	off	off
Discharge Canister Temp Setpoint	°C									
Discharge Canister Power	kW									
Discharge Canister Power Output	%									
Pourspout Heater Actual Temp	°C	1000-1100	1049	1050	1051	1049	1051	1051	1051	1055
Pourspout Heater Temp Setpoint	°C		1050	1050	1050	1050	1050	1050	1050	1050
Pourspout Heater Power	kW		2.32	2.32	2.27	2.22	2.16	2.37	2.37	2.20
Pourspout Heater Power Output	%		48.9	48.5	47.8	52.5	50.5	48.9	49.4	47.7
Plenum Temperature	°C	500-700	574	639	570	565	587	549	553	547
Feed Nozzle Temp (FNT)	°C	<50	29	31	30	30	30	30	30	30
Off-Gas Temp (OGT_1)	°C	<350	258	199	239	231	239	261	247	258
Off-Gas Temp (OGT_#2)	°C		214	165	206	199	208	240	232	228
Scrub Liquid Temp (SLT)	°C	<40	33	32	32	32	32	33	33	33
Post EVS Off-Gas Temp	°C	<50	37	33	36	36	36	37	37	37
Heat Xfer Temp	°C	<30	~~30~~ 26	26	25	26	26	26	26	26
Post HEME Temp	°C		30	30	30	31	31	31	31	31
Bubbler Flow Rate (total)	sccm		4196	4200	4199	4203	4199	4199	4196	4204
Plenum Vacuum	in. H_2O	0.1 - 2.5	~~4196~~ -4	-5	-3	-4	-4	-9	1.0	0.6
		Finish time:	1249	1325	1420	1527	1603	1602	18:05	19:06

Reviewed by: Dary Jerigan Date: 9-11-13

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Temperature and Electrical Data (HMI)	Operator (initials):		PPS							
	Date:		9/10/13	9/10/13	9/11/13	9/11/13	9/11/13	9/11/13	9/11/13	9/11/13
	Start time:		20:02	23:15	00:40	02:22	03:16	05:00	10:09	07:27
DESCRIPTION	UNITS	RANGE								
Melt Temperature (T1)	°C	1125-1175	1115	1119	1077	1102	1099	1118	1117	1133
Melt Temperature (T2)	°C	1125-1175	1161	1152	1107	1137	1149	1149	1150	1156
Melt (Electrode) Temp Setpoint	°C	1150	1160	1150	1150	1150	1150	1150	1150	1160
Secondary Electrode Current	Amps		98.9	100.3	628	97.6	99.8	100.7	100.4	101.7
Secondary Electrode Potential	Volts		51.7	44.8	43.5	52.1	48.7	52.2	46.9	49.8
Secondary Electrode Power (calc)	kW (V×A)		5.11	4.99	2.73	5.08	4.80	5.26	4.71	5.36
Melt Resistance (calc)	Ω (V/A)		0.523	0.497	0.69	0.534	0.484	0.518	0.467	0.462
Electrode Power Output	%		56.2	56.3	39.3	55.0	55.8	56.6	56.4	57.5
Electrode Power Control	A or M		A	A	A	A	A	A	A	A
Melter Temperature Control		T1 or T2	T2	T2	T2	T2	T2	T2	T2	T2
Kiln Monitored (Middle) Temp	°C		693	738	705	696	695	718	679	675
Kiln Top Temp	°C		642	690	656	637	644	672	630	627
Kiln Bottom Temps	°C		737	764	743	720	734	745	730	724
Kiln Temp Setpoint	°C		693	—	—	—	—	—	—	—
Kiln Power	kW		0	0	—	0	—	0	—	—
Kiln Power Output	%		0	0	—	0	—	0	—	—
Kiln Control	A or M		M	M	M	M	M	M	M	M
Discharge Canister Temp	°C	750 - 850	off						—	off
Discharge Canister Temp Setpoint	°C								—	
Discharge Canister Power	kW								—	
Discharge Canister Power Output	%		↓	↓	↓	↓	↓	↓	—	—
Pourspout Heater Actual Temp	°C	1000-1100	1048	1051	1050	1050	1046	1030	1050	1051
Pourspout Heater Temp Setpoint	°C		1050	1050	1050	1050	1050	1050	1050	1050
Pourspout Heater Power	kW		2.50	2.42	2.40	2.45	3.07	3.40	2.47	2.27
Pourspout Heater Power Output	%		50.8	49.6	57.3	49.7	50.3	62.2	49.5	48.0
Plenum Temperature	°C	500-700	548	534	512	519	528	580	472	574
Feed Nozzle Temp (FNT)	°C	<50	30	31	28	28	31	28	28	28
Off-Gas Temp (OGT_1)	°C	<350	246	271	232	232	271	230	209	254
Off-Gas Temp (OGT_#2)	°C		232	246	219	220	247	219	205	232
Scrub Liquid Temp (SLT)	°C	<40	33	32	33	32	31	33	33	32
Post EVS Off-Gas Temp	°C	<50	37	36	36	36	34	38	36	36
Heat Xfer Temp	°C	<30	26	26	26	15	25	26	25	25
Post HEME Temp	°C		32	30	30	28	27	38	30	29
Bubbler Flow Rate (total)	sccm		4197	4201	4200	4203	4202	4201	4200	4202
Plenum Vacuum	in. H_2O	0.1 - 2.5	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0
		Finish time:	20:06	23:18	00:54	02:22	03:37	05:04	10:22	10:36

Reviewed by: Dana Swanberg

Date: 9-11-13

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Temperature and Electrical Data (HMI)	Operator (initials):		MJL	JL	JL	JL	JL	JL	JL	DSH
	Date:		9/4/13	9/4/13	9/4/13	9/4/13	9/4/13	9/4/13	9/4/13	9/4/13
	Start time:		0824	0931	1030	1134	1243	1345	1454	1556
DESCRIPTION	UNITS	RANGE								
Melt Temperature (T1)	°C	1125-1175	1129	1124	1128	1135	1126	1132	1126	1131
Melt Temperature (T2)	°C	1125-1175	1162	1158	1159	1159	1159	1161	1156	1164
Melt (Electrode) Temp Setpoint	°C	1150	1160	1160	1160	1160	1160	1162	1160	1160
Secondary Electrode Current	Amps		102.7	106.6	106.9	111.2	107.8	110.2	110.2	99.9
Secondary Electrode Potential	Volts		49.9	53.4	54.3	51.2	50.7	50.1	53.1	49.5
Secondary Electrode Power (calc)	kW (V×A)		5.124	5.692	5.804	5.693	5.411	5611	5.851	4.945
Melt Resistance (calc)	Ω (V/A)		.485	.5009	.508	.460	.466	.455	0.482	0.495
Electrode Power Output	%		57.4	60.3	62.4	62.8	60.8	61.9	62.4	55.9
Electrode Power Control	A or M		A	A	A	A	A	A	A	A
Melter Temperature Control		T1 or T2	T2	T2	T2	T2	T2	T2	T2	T2
Kiln Monitored (Middle) Temp	°C		691	687	693	710	711	723	711	710
Kiln Top Temp	°C		640	637	644	660	674	675	675	662
Kiln Bottom Temps	°C		728	729	730	735	746	749	755	751
Kiln Temp Setpoint	°C		off	off	off	off	off	off	off	off
Kiln Power	kW		0	0	0	0	0	0	0	0
Kiln Power Output	%		0	0	0	0	0	0	0	0
Kiln Control	A or M		M	M	M	M	M	M	M	M
Discharge Canister Temp	°C	750 - 850	N/A	NA	NA	NA	NA	NA	NA	NA
Discharge Canister Temp Setpoint	°C		—	—	—	—	—	—	—	—
Discharge Canister Power	kW		—	—	—	—	—	—	—	—
Discharge Canister Power Output	%		—	—	—	—	—	—	—	—
Pourspout Heater Actual Temp	°C	1000-1100	1052	1050	1051	1051	1050	1050	1051	1050
Pourspout Heater Temp Setpoint	°C		1050	1050	1050	1050	1050	1050	1050	1050
Pourspout Heater Power	kW		2.34	2.35	2.38	2.37	2.36	2.28	2.27	2.32
Pourspout Heater Power Output	%		48.5	48.7	49.1	49.1	49.1	48.3	48.4	48.7
Plenum Temperature	°C	500-700	573	557	609	670	678	665	581	575
Feed Nozzle Temp (FNT)	°C	<50	29	30	30	31	33	37	30	30
Off-Gas Temp (OGT_1)	°C	<350	242	249	260	266	289	291	265	249
Off-Gas Temp (OGT_#2)	°C		221	230	231	230	265	265	272	236
Scrub Liquid Temp (SLT)	°C	<40	33	33	33	33	31	32	34	34
Post EVS Off-Gas Temp	°C	<50	36	37	37	36	36	37	38	38
Heat Xfer Temp	°C	<30	25	25	25	25	25	25	26	30
Post HEME Temp	°C		28	29	30	30	30	30	32	33
Bubbler Flow Rate (total)	sccm		4201	4198	4207	4201	4201	4202	4202	4200
Plenum Vacuum	in. H_2O	0.1 - 2.5	1.0	1.1	.9	.9	1.1	1.0	1.0	1.0
		Finish time:	0833	0934	1032	1136	1236	1348	1436	1531
OG Flow			—	—	—	21.16	22.08	20.42	19.19	21.13

Reviewed by: Dawn Kurtz

Date: 10-21-13

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Temperature and Electrical Data (HMI)	Operator (initials):									
	Date:		9-11	9-11	9-11	9/11	9/11	9/11	9/11	9/11
	Start time:		1610	1725	1804	1859	2007	2109	2201	2308
DESCRIPTION	UNITS	RANGE								
Melt Temperature (T1)	°C	1125-1175	1136	1106	1101	1134	1129	1132	1130	1134
Melt Temperature (T2)	°C	1125-1175	1150	1134	1122	1161	1162	1160	1152	1163
Melt (Electrode) Temp Setpoint	°C	1150	1150	1140	1130	1160	1160	1160	1160	1160
Secondary Electrode Current	Amps		112	105	101.3	101.1	99.5	103.9	113.5	107.7
Secondary Electrode Potential	Volts		54.3	53.6	56.0	51.2	50.4	50.0	53.4	51.0
Secondary Electrode Power (calc)	kW (V×A)		6.08	5.63	5.67	5.18	5.01	5.20	6.06	5.50
Melt Resistance (calc)	Ω (V/A)		0.485	0.510	0.55	0.51	0.51	0.48	0.47	0.47
Electrode Power Output	%		63.4	59.2	57.6	57.8	56.5	58.8	63.8	60.6
Electrode Power Control	A or M		A	A	A	A	A	A	A	A
Melter Temperature Control		T1 or T2	T2	T2	T2	T2	T2	T2	T2	T2
Kiln Monitored (Middle) Temp	°C		705	696	692	685	694	706	710	717
Kiln Top Temp	°C		656	648	643	636	645	656	662	667
Kiln Bottom Temps	°C		748	735	732	728	733	735	744	749
Kiln Temp Setpoint	°C		OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Kiln Power	kW		0	0	0	0	0	0	0	0
Kiln Power Output	%		0	0	0	0	0	0	0	0
Kiln Control	A or M		M	M	M	M	M	M	M	M
Discharge Canister Temp	°C	750 - 850	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Discharge Canister Temp Setpoint	°C									
Discharge Canister Power	kW									
Discharge Canister Power Output	%		OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Pourspout Heater Actual Temp	°C	1000-1100	1052	1053	1051	1050	1050	1050	1053	1059
Pourspout Heater Temp Setpoint	°C		1050	1050	1050	1050	1050	1050	1050	1050
Pourspout Heater Power	kW		~~3.27~~ 3.27	~~3.03~~ 2.20	2.34	2.29	2.29	2.33	2.33	2.10
Pourspout Heater Power Output	%		48.3	48.1	48.8	48.5	48.5	48.9	48.9	44.5
Plenum Temperature	°C	500-700	569	572	567	537	555	656	544	582
Feed Nozzle Temp (FNT)	°C	<50	30	29	30	30	29	32	29	30
Off-Gas Temp (OGT_1)	°C	<350	256	231	224	221	240	254	243	236
Off-Gas Temp (OGT_#2)	°C		245	235	232	226	240	259	238	229
Scrub Liquid Temp (SLT)	°C	<40	34	33	33	34	33	31	34	33
Post EVS Off-Gas Temp	°C	<50	37	27	37	37	37	35	38	37
Heat Xfer Temp	°C	<30	30	25	26	25	25	25	26	26
Post HEME Temp	°C		33.0	32	33	32	32	30	32	31
Bubbler Flow Rate (total)	sccm		4203	4200	4201	4196	4206	4198	4196	4193
Plenum Vacuum	in. H_2O	0.1 - 2.5	0.9	1.0	1.1	0.9	1.0	1.0	1.0	1.1
		Finish time:	1615	1730	1806	1907	2014	2111	2203	2311
	OG Flow		20.6	25.4	23.80	25.71	22.31	28.02	27.7	23.44

Reviewed by: Marcia K

Date: 10-7-13

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Temperature and Electrical Data (HMI)	Operator (initials):										
	Date:		9/12/13	9/12/13	9/12/13	9/12/13	9/12/13	9/12/13	9/12/13	9/12/13	9/12/13
	Start time:		0008	0112	0225	0513	0411	0510	0611	0730	
DESCRIPTION	UNITS	RANGE									
Melt Temperature (T1)	°C	1125-1175	1125	1129	1125	1111	1120	1096	1102	1127	
Melt Temperature (T2)	°C	1125-1175	1157	1165	1149	1163	1157	1166	1158	1153	
Melt (Electrode) Temp Setpoint	°C	1150	1160	1160	1160	1160	1160	1166	1160	1160	
Secondary Electrode Current	Amps		106.8	104.2	104.7	87.3	94.8	81.7	88	110.2	
Secondary Electrode Potential	Volts		46.4	45.5	46.5	42.3	43.9	41.2	41	42.5	
Secondary Electrode Power (calc)	kW (V×A)		4.955	4.741	4.868	3.69	4.15	3.37	3.608	4.683	
Melt Resistance (calc)	Ω (V/A)		0.4345	0.437	0.444	0.485	0.465	0.504	0.466	0.386	
Electrode Power Output	%		60.2	58.8	58.7	48.2	55.3	46.0	49.8	61.6	
Electrode Power Control	A or M		A	A	A	A	A	A	A	A	
Melter Temperature Control		T1 or T2	T2	T2	T2	T2	T2	T2	T2	T2	
Kiln Monitored (Middle) Temp	°C		688	675	718	700	691	681	656	649	
Kiln Top Temp	°C		641	628	665	652	641	632	615	598	
Kiln Bottom Temps	°C		740	734	872	774	745	735	724	717	
Kiln Temp Setpoint	°C		—	—	700	—	—	—	—	—	
Kiln Power	kW		0	—	62	—	—	—	—	—	
Kiln Power Output	%		0	—	29.6	—	—	—	—	—	
Kiln Control	A or M		M	M	A*	M	M	M	M	M	
Discharge Canister Temp	°C	750 - 850		—				—			
Discharge Canister Temp Setpoint	°C			—				—			
Discharge Canister Power	kW										
Discharge Canister Power Output	%			—				—			
Pourspout Heater Actual Temp	°C	1000-1100	1031	1050	1052	1048	1049	1049	1049	1053	
Pourspout Heater Temp Setpoint	°C		1050	1050	1050	1050	1050	1049	1049	1049	
Pourspout Heater Power	kW		3.4	2.25	1.74	2.13	2.34	2.32	2.38	2.37	
Pourspout Heater Power Output	%		45.7	48.2	42.5	50.2	49	48.6	49.2	49.5	
Plenum Temperature	°C	500-700	547	490	601	493	603	490	452	474	
Feed Nozzle Temp (FNT)	°C	<50	29	28	29	28	29	27	27	27	
Off-Gas Temp (OGT_1)	°C	<350	237	226	253	218	239	223	207	193	
Off-Gas Temp (OGT_#2)	°C		224	221	236	209	222	210	196	185	
Scrub Liquid Temp (SLT)	°C	<40	34	34	32	33	31	31	32	32	
Post EVS Off-Gas Temp	°C	<50	38	38	36	36	31	35	35	33	
Heat Xfer Temp	°C	<30	26	26	25	26	26	26	25	25	
Post HEME Temp	°C		31	32	30	30	29	29	29	29	
Bubbler Flow Rate (total)	sccm		4206	4205	4205	4203	4199	4203	4204	4202	
Plenum Vacuum	in. H_2O	0.1 - 2.5	1.1	1.0	1.1	1.0	1.0	1.0	1.0	0.9	
		Finish time:	0011	0115	0230	0315	0416	0513	0613	0738	
	OG FLOW		23.42	22.86	24.03	22.4	22.16	21.43	22.70	17.09	

9/12/13 JL

Reviewed by: [signature]

* turn kiln off

Date: 10-7-13

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Temperature and Electrical Data (HMI)	Operator (initials):		MLK	JEH	JC	JC	JC	JC	MLK	JC
	Date:		9-12-13	9/12/13	9/12/13	9/12/13	9/12/13	9/12/13	9/12/13	9/12
	Start time:		0824	0935	1032	1133	1234	1339	1441	1626
DESCRIPTION	UNITS	RANGE								
Melt Temperature (T1)	°C	1125-1175	1097	1118	1126	1139	1116	1123	1130	1146
Melt Temperature (T2)	°C	1125-1175	1164	1160	1158	1150	1162	1159	1160	1169
Melt (Electrode) Temp Setpoint	°C	1150	1160	1160	1160	1160	1160	1160	1160	1160
Secondary Electrode Current	Amps		86.8	93.1	93.7	111.7	89.1	92.3	96.4	91.4
Secondary Electrode Potential	Volts		43.4	43.4	41.5	47.9	43.9	48.4	44.8	44.5
Secondary Electrode Power (calc)	kW (V×A)		3.77	4.05	3.89	5.35	3.91	~~4.37~~	4.32	4.07
Melt Resistance (calc)	Ω (V/A)		0.5	0.466	0.443	0.479	0.493	0.536	0.465	0.487
Electrode Power Output	%		48.7	53.8	52.4	62.6	50.6	51.2	54.3	51.6
Electrode Power Control	A or M		A	A	A	A	A	A	A	A
Melter Temperature Control		T1 or T2	T2	T2	T2	T2	T2	T2	T2	T2
Kiln Monitored (Middle) Temp	°C		659	678	681	682	693	681	692	703
Kiln Top Temp	°C		608	626	627	630	639	634	641	650
Kiln Bottom Temps	°C		717	727	728	735	736	730	733	741
Kiln Temp Setpoint	°C		off	off	off	off	off	off	off	OFF
Kiln Power	kW									
Kiln Power Output	%									
Kiln Control	A or M		M							
Discharge Canister Temp	°C	750 - 850	1370	off	off	off	off	off	off	
Discharge Canister Temp Setpoint	°C		off							
Discharge Canister Power	kW									
Discharge Canister Power Output	%									
Pourspout Heater Actual Temp	°C	1000-1100	1049	1099	1101	1102	1100	1099	1100	1104
Pourspout Heater Temp Setpoint	°C		1100	1100	1100	1100	1100	1100	1100	1100
Pourspout Heater Power	kW		3.28	3.23	2.90	3.07	2.84	2.86	2.86	3.14
Pourspout Heater Power Output	%		92	55.2	53.9	55.3	53.5	53.5	53.7	56.0
Plenum Temperature	°C	500-700	488	541	480	529	506	535	521	534
Feed Nozzle Temp (FNT)	°C	<50	28	28	27	27	28	29	28	28
Off-Gas Temp (OGT_1)	°C	<350	215	201	198	190	218	241	223	226
Off-Gas Temp (OGT_#2)	°C		207	158	192	181	214	236	220	221
Scrub Liquid Temp (SLT)	°C	<40	32	32	32	32	32	32	32	33
Post EVS Off-Gas Temp	°C	<50	35	35	35	35	35	36	37	36
Heat Xfer Temp	°C	<30	25	25	25	25	25	25	25	25
Post HEME Temp	°C		29	36	29	30	30	31	31	32
Bubbler Flow Rate (total)	sccm		4200	4201	4201	4195	4201	4203	4201	4204
Plenum Vacuum	in. H_2O	0.1 - 2.5	1.0	1.0	0.9	.3	1.1	1.5	1.4	1.0
		Finish time:	0837	0939	1035	1135	1236	1342	1446	1629
OG Flow	OG Flow				19.59	14.57	20.98	28.14	26.05	23.75

Reviewed by: [signature] Date: 10-2-13

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Temperature and Electrical Data (HMI)	Operator (initials):									
	Date:		9/12	9/12	9/12	9/12	9/12	JL 9/12/13	JL 9/13/13	JL 9/13/13
	Start time:		1741	1830	2001	2058	2201	2303	2414	0107
DESCRIPTION	UNITS	RANGE								
Melt Temperature (T1)	°C	1125-1175	1139	1138	1115	1160	1150	1140	1148	1139
Melt Temperature (T2)	°C	1125-1175	1158	1159	1158	1118	1121	1137	1163	1163
Melt (Electrode) Temp Setpoint	°C	1150	1160	1160	1160	1160	1160	1160	1160	1160
Secondary Electrode Current	Amps		95.8	98.6	93.0	92.1	93.9	100.9	99.2	94.4
Secondary Electrode Potential	Volts		45.5	46.0	47.6	41.6	42.7	50.5	47.1	47.3
Secondary Electrode Power (calc)	kW (V×A)		4.36	4.54	4.43	3.93	3.54	5.095	4.672	4.465
Melt Resistance (calc)	Ω (V/A)		0.475	0.467	0.512	0.463	0.401	0.5005	0.475	0.501
Electrode Power Output	%		53.8	56.0	52.8	52.0	52.9	56.8	55.8	56.1
Electrode Power Control	A or M		A	A	A	A	A	A	A	A
Melter Temperature Control		T1 or T2	T2	T2	T2	T1	T1	T2	T2	T2
Kiln Monitored (Middle) Temp	°C		715	730	725	711	701	741	745	752
Kiln Top Temp	°C		661	677	674	660	648	689	695	709
Kiln Bottom Temps	°C		749	752	754	747	738	754	764	770
Kiln Temp Setpoint	°C		OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Kiln Power	kW									
Kiln Power Output	%									
Kiln Control	A or M									
Discharge Canister Temp	°C	750 - 850								
Discharge Canister Temp Setpoint	°C									
Discharge Canister Power	kW									
Discharge Canister Power Output	%									
Pourspout Heater Actual Temp	°C	1000-1100	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Pourspout Heater Temp Setpoint	°C		1110	1101	1100	1100	1100	1107	1103	1104
Pourspout Heater Power	kW		1100	1100	1100	1100	1100	1100	1100	1100
Pourspout Heater Power Output	%		3.15	2.79	2.74	2.74	2.80	2.78	2.76	2.90
Plenum Temperature	°C	500-700	56.6	53.1	52.6	52.5	52.9	52.9	52.7	53.7
Feed Nozzle Temp (FNT)	°C	<50	598	640	577	550	649	680	665	680
Off-Gas Temp (OGT_1)	°C	<350	30	31	29	29	30	32	31	31
Off-Gas Temp (OGT_#2)	°C		241	261	252	231	246	274	306	306
Scrub Liquid Temp (SLT)	°C	<40	236	244	238	216	224	249	247	251
Post EVS Off-Gas Temp	°C	<50	32	31	33	32	30	31	32	32
Heat Xfer Temp	°C	<30	34	34	36	35	31	34	35	35
Post HEME Temp	°C		26	25	25	26	25	25	26	25
Bubbler Flow Rate (total)	sccm		32	31	31	30	29	29	29	29
Plenum Vacuum	in. H_2O	0.1 - 2.5	4197	4200	4194	4200	4195	4202	4201	4197
			0.8	1.0	0.9	1.1	1.1	1.0	1.0	0.9
		Finish time:	1744	1832	2003	2100	2205	2307	2416	0113
	OG FLOW		18.68	21.20	25.49	18.6	17.82	19.58	21.16	19.57

Reviewed by: Marie Kinn

Date: 10/7/13

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Temperature and Electrical Data (HMI)	Operator (initials):		JL	JL	JL	JL	JL	JL	MJK	MJK
	Date:		9/13/13	9/13/13	9/13/13	9/13/13	9/13/13	9/13/13	9/13/13	9/13/13
	Start time:		0200	0304	0400	0502	0601	0700	0800	0913
DESCRIPTION	UNITS	RANGE								
Melt Temperature (T1)	°C	1125-1175	1138	1135	1129	1113	1115	1116	1111	1124
Melt Temperature (T2)	°C	1125-1175	1162	1159	1166	1163	1160	1161	1158	1161
Melt (Electrode) Temp Setpoint	°C	1150	1169	1160	1163	1160	1160	1162	1160	1160
Secondary Electrode Current	Amps		101.2	104.8	94.0	96.1	98.3	98.3	97.6	102.0
Secondary Electrode Potential	Volts		49.1	49.4	46.8	47.8	48.2	48.7	47.0	49.6
Secondary Electrode Power (calc)	kW (V×A)		4.969	5.177	4.399	4.593	4.738	4.787	4.587	5.06
Melt Resistance (calc)	Ω (V/A)		0.485	0.471	0.479	0.497	0.490	0.495	0.482	0.486
Electrode Power Output	%		56.8	59.0	52.8	54.0	55.4	55.1	56.0	57.4
Electrode Power Control	A or M		A	A	A	A	A	A	A	A
Melter Temperature Control		T1 or T2	T2	T2	T2	T1	T2	T2	T2	T2
Kiln Monitored (Middle) Temp	°C		748	759	758	736	734	732	725	741
Kiln Top Temp	°C		697	707	703	686	685	683	676	690
Kiln Bottom Temps	°C		768	784	786	769	764	765	760	769
Kiln Temp Setpoint	°C		off	off	off	off	off	off	off	off
Kiln Power	kW									
Kiln Power Output	%									
Kiln Control	A or M									
Discharge Canister Temp	°C	750 - 850								
Discharge Canister Temp Setpoint	°C									
Discharge Canister Power	kW									
Discharge Canister Power Output	%									
Pourspout Heater Actual Temp	°C	1000-1100	off	off	off	off	off	off	off	off
Pourspout Heater Temp Setpoint	°C		1101	1100	1100	1100	1100	1103	1100	1098
Pourspout Heater Power	kW		1100	1100	1100	1100	1100	1100	1100	1100
Pourspout Heater Power Output	%		2.79	3.25	3.08	2.68	2.70	2.71	2.71	3.24
Plenum Temperature	°C	500-700	52.5	56.5	53.3	51.7	60.1	52.0	52.1	55.8
Feed Nozzle Temp (FNT)	°C	<50	630	655	595	602	627	608	666	590
Off-Gas Temp (OGT_1)	°C	<350	30	31	29	30	30	30	31	30
Off-Gas Temp (OGT_#2)	°C		282	309	249	235	261	245	232	283
Scrub Liquid Temp (SLT)	°C	<40	241	255	209	210	224	214	196	240
Post EVS Off-Gas Temp	°C	<50	33	33	33	33	33	35	33	33
Heat Xfer Temp	°C	<30	37	37	37	36	36	36	36	37
Post HEME Temp	°C		26	26	26	26	26	26	26	26
Bubbler Flow Rate (total)	sccm		30	30	30	30	29	30	29	29
Plenum Vacuum	in. H_2O	0.1 - 2.5	4196	4200	4196	4202	4201	4198	4196	4201
			0.8	1.1	0.7	0.7	0.7	0.5	.5	1.0
		Finish time:	0209	0306	0407	0504	0603	0704	0838	0913
	06 Flow		20.29	18.82	16.27	19.06	20.28	16.11	16.61	18.28

Reviewed by: Adam Heroy

Date: 10-21-13

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Temperature and Electrical Data (HMI)	Operator (initials):		DTR	MLK	RGH	DO				
	Date:		9/13/13	9/13/13	9/17/13	9/18/13				
	Start time:		1022	1117	1216	1336				
DESCRIPTION	UNITS	RANGE								
Melt Temperature (T1)	°C	1125-1175	1127	1119	1126	1115				
Melt Temperature (T2)	°C	1125-1175	1155	1162	1157	1157				
Melt (Electrode) Temp Setpoint	°C	1150	1160	1160	1160	1160				
Secondary Electrode Current	Amps		105.8	100.2	103.3	108				
Secondary Electrode Potential	Volts		48.8	49.9	45.2	48.2				
Secondary Electrode Power (calc)	kW (V×A)		5.15	5.00	4.76	5.21				
Melt Resistance (calc)	Ω (V/A)		0.46	0.50	0.44	0.44				
Electrode Power Output	%		59.9	56.5	58.4	61.3				
Electrode Power Control	A or M		A	A	A	A				
Melter Temperature Control		T1 or T2	T2	T2	T2	T2				
Kiln Monitored (Middle) Temp	°C		734	733	697	695				
Kiln Top Temp	°C		682	682	646	640				
Kiln Bottom Temps	°C		771	773	761	757				
Kiln Temp Setpoint	°C		off	off	off	off				
Kiln Power	kW									
Kiln Power Output	%									
Kiln Control	A or M									
Discharge Canister Temp	°C	750 - 850								
Discharge Canister Temp Setpoint	°C									
Discharge Canister Power	kW									
Discharge Canister Power Output	%									
Pourspout Heater Actual Temp	°C	1000-1100	1091	1103	1095	1100				
Pourspout Heater Temp Setpoint	°C		1100	1100	1100	1100				
Pourspout Heater Power	kW		3.23	2.84	2.90	2.89				
Pourspout Heater Power Output	%		67.0	53.3	53.0	53.8				
Plenum Temperature	°C	500-700	628	536	388	646				
Feed Nozzle Temp (FNT)	°C	<50	30	29	26	31				
Off-Gas Temp (OGT_1)	°C	<350	274	263	198	204				
Off-Gas Temp (OGT_#2)	°C		238	232	179	174				
Scrub Liquid Temp (SLT)	°C	<40	33	35	37	33				
Post EVS Off-Gas Temp	°C	<50	37	40	41	39				
Heat Xfer Temp	°C	<30	26	26	26	29				
Post HEME Temp	°C		31	33	41	32				
Bubbler Flow Rate (total)	sccm		4200	4201	4203	4200				
Plenum Vacuum	in. H_2O	0.1 - 2.5	1.0	1.0	0.9	0.6				
		Finish time:	1027	1121	1221	1340				

MLK 10/1/13

Reviewed by: Danny Reamyo

Date: 10-2-13

Appendix B – Sample Log Sheet

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Attachment A

Sample Log Sheet

Sample Number	Operator	Date:	Start time:	Description
RSM-EWG8-#sequence	initials	e.g., 11/29/10	e.g., 1400 h	e.g., Glass, melter feed, EVS condensate, HEME
RSM-EWG8-01	CDL	9/9/13	05:07	feed
RSM-EWG8-02	JST	9/9/13	0510	Scrub Soln
RSM-EWG8-03	MLK	9/9/13	10:10	glass
RSM-EWG8-04	DEQ	9/9/13	1520	Feed
RSM-EWG8-05	MLK	9/9/13	1520	Scrub soln
RSM-EWG8-06	PPS	9/9/13	15:55	glass pour
RSM-EWG8-07	PPS	9/9/13	18:06	glass cen, ~ 18.25 kg
RSM-EWG8-08	PPS	9/9/13	21:54	glass pour
RSM-EWG8-09	WCB	9/9/13	2310	EVS
RSM-EWG8-10	PPS	9/9/13	23:37	Feed sample
RSM-EWG8-11	CDL	9/10/13	02:24	GLASS SAMPLE
RSM-EWG8-12	JL	9/10/13	07:45	scrub
RSM-EWG8-13	JL	9/10/13	07:45	Feed
RSM-EWG8-14	DEQ	9/10/13	1015	Glass
RSM-EWG8-15	MLK	9/10/13	0224	Glass canister ~ 6.82 kg
RSM-EWG8-16	MLK	9/10/13	1020	Glass canister
RSM-EWG8-17	MLK	9/10/13	1425	Glass canister
RSM-EWG8-18	MLK	9/10/13	1450	Glass Canister ~ 0.98 kg
RSM-EWG8-19	MLK	9/10/13	1515	Scrub Soln
RSM-EWG8-20	DEQ	9/10/13	1515	Feed
RSM-EWG8-21	PPS	9/10/13	18:27	glass pour GW 90.25 g
RSM-EWG8-22	PPS	9/10/13	20:10	Glass canister ~ 10.3 kg
RSM-EWG8-23	PPS	9/10/13	22:54	glass pour Gross wt: 87.69 g
RSM-EWG8-24	WCB	9/10/13	23:02	EVS
RSM-EWG8-25	PPS	9/10/13	23:02	feed sample

15:47 9/9/13 samples collected by Ben Williams

* BLD Taken 9/10

Reviewed By: [signature] Date: 10-2-13

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Attachment A

Sample Log Sheet

Sample Number RSM-EWG8-#sequence	Operator initials	Date: e.g., 11/29/10	Start time: e.g., 1400 h	Description e.g., Glass, melter feed, EVS condensate, HEME	
RSM-EWG8-26	DL	9/11/13	01:08	GLASS CANISTER 5.14 KG	*
RSM-EWG8-27	DL	9/11/13	04:35	GLASS SAMPLE GW: 74.7 g	*
RSM-EWG8-28	MK	9-11-13	0656	Feed Sample	*
RSM-EWG8-29	MK	9-11-13	0657	EVS scrub Slu Sample pH=8	*
RSM-EWG8-30	MK	9-11-13	0750	Glass can ~10kg	✓
RSM-EWG8-31	MK	9-11-13	0835	Glass can ~1 kg sample. Mass = 1.79kg	*
RSM-EWG8-32	MK	9-11-13	0840	Glass Sample GW 73.17	*
RSM-EWG8-33	MK	9-11-13	MK 1030	Glass Canister mass not taken 24kg	*
RSM-EWG8-34	SL	9-11-13	1450	Glass Sample	*
RSM-EWG8-35	WCB	9-11-13	1735	Glass canister	
RSM-EWG8-36	WCB	9-11-13	2000	Glass sample	
RSM-EWG8-36	MK	9-11-13	2330	feed sample	
RSM-EWG8-37	WCB	9-11-13	2330	EVS Rinse Solution	
RSM-EWG8-38	DL	9/12/13	01:22	GLASS CANISTER	
RSM-EWG8-39	MK	9-12-13	0238	Glass sample	
RSM-EWG8-40	DL	9-12-13	0656	EVS SCRUB SAMPLE PH 8.5	
RSM-EWG8-41	DL	9-12-13	0656	FEED SAMPLE	
RSM-EWG8-42	MK	9-12-13	0730	Glass Sample	
RSM-EWG8-43	MK	9-12-13	1003	GLASS CANISTER	
RSM-EWG8-44	MK	9-12-13	1140	Glass Sample (large) 1.2kg	
RSM-EWG8-45	MK	WCB 9/12/13	1225	EVS Scrub Sample	
RSM-EWG8-46	WCB	9/12/13	1615	Glass sample	
RSM-EWG8-47	WCB	9/12/13	1740	Glass can GW = 11.067 kg	
RSM-EWG8-48	WCB	9/12/13	2000	Glass Sample	
RSM-EWG8-49	WCB	9/12/13	2300	Scrub (EVS)	

Reviewed By: [signature] Date: 10-7-13

[signature] 10/31/13

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Attachment A

Sample Log Sheet

Sample Number	Operator	Date:	Start time:	Description
RSM-EWG8-#sequence	initials	e.g., 11/29/10	e.g., 1400 h	e.g., Glass, melter feed, EVS condensate, HEME
RSM-EWG8-50	WCB	9/12/13	2310	Melter feed
RSM-EWG8-51	JL	9/13/13	2405	Glass sample
RSM-EWG8-57	JL	9/13/13	2405	Glass Sample
RSM-EWG8-53	[illegible]	9.13.13	0559	feed sample
RSM-EWG8-54	[illegible]	9-13-13	0559	Scrubs slu sample pH = 8.5
RSM-EWG8-55	JL	9-13-13	0650	Glass canister 15,10 kg (nk) 9/13/13
RSM-EWG8-56	DTER	9/13/13	0830	white residue on Glass Canister
RSM-EWG8-57	MLK	9/13/13	0850	Glass sample
RSM-EWG8-58	MLK	9/13/13	1235	Scrubber sample pH = 7
RSM-EWG8-59	DTER	9/13/13	1240	Feed
RSM-EWG8-60	[illegible]	9/13/13	1530	~~Melt sample 9/13/13~~ Large glass container 12,158 kg glass
RSM-EWG8-61	[illegible]	9/13/13	1300	Melt surface sample (glass) < 10 g
RSM-EWG8-62	JL	10/7/13	1300	Melt surface sample (glass) < 50 g
			10/23/13	

Reviewed By: Dary Swanson 10/23/13 Date: 10-2-13

Appendix C – Operating Parameter Data Plots from RSM Tests

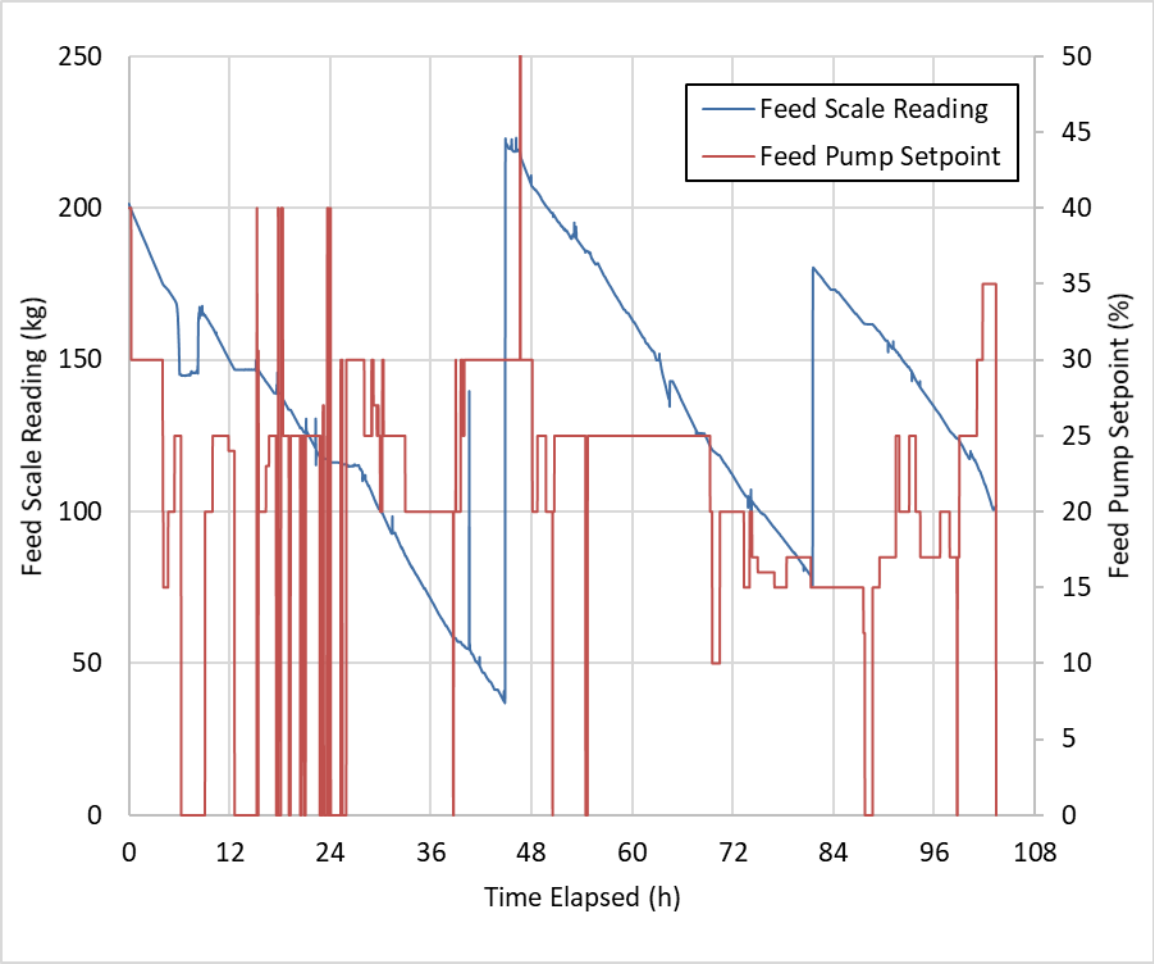

Figure C.1. Simulant Feed Pump Set Point and Balance Reading

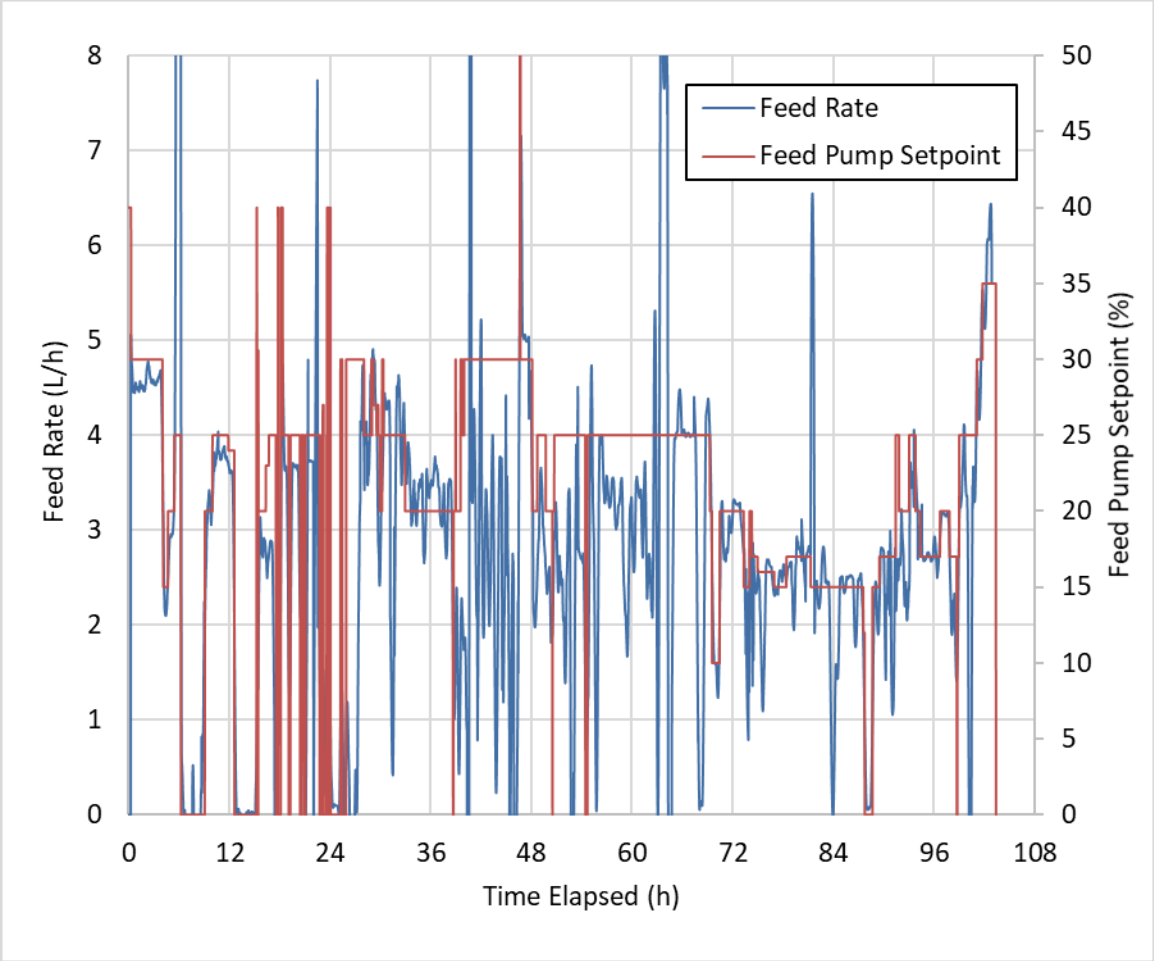

Figure C.2. Simulant Feed Pump Set Point and Calculated Feed Rate

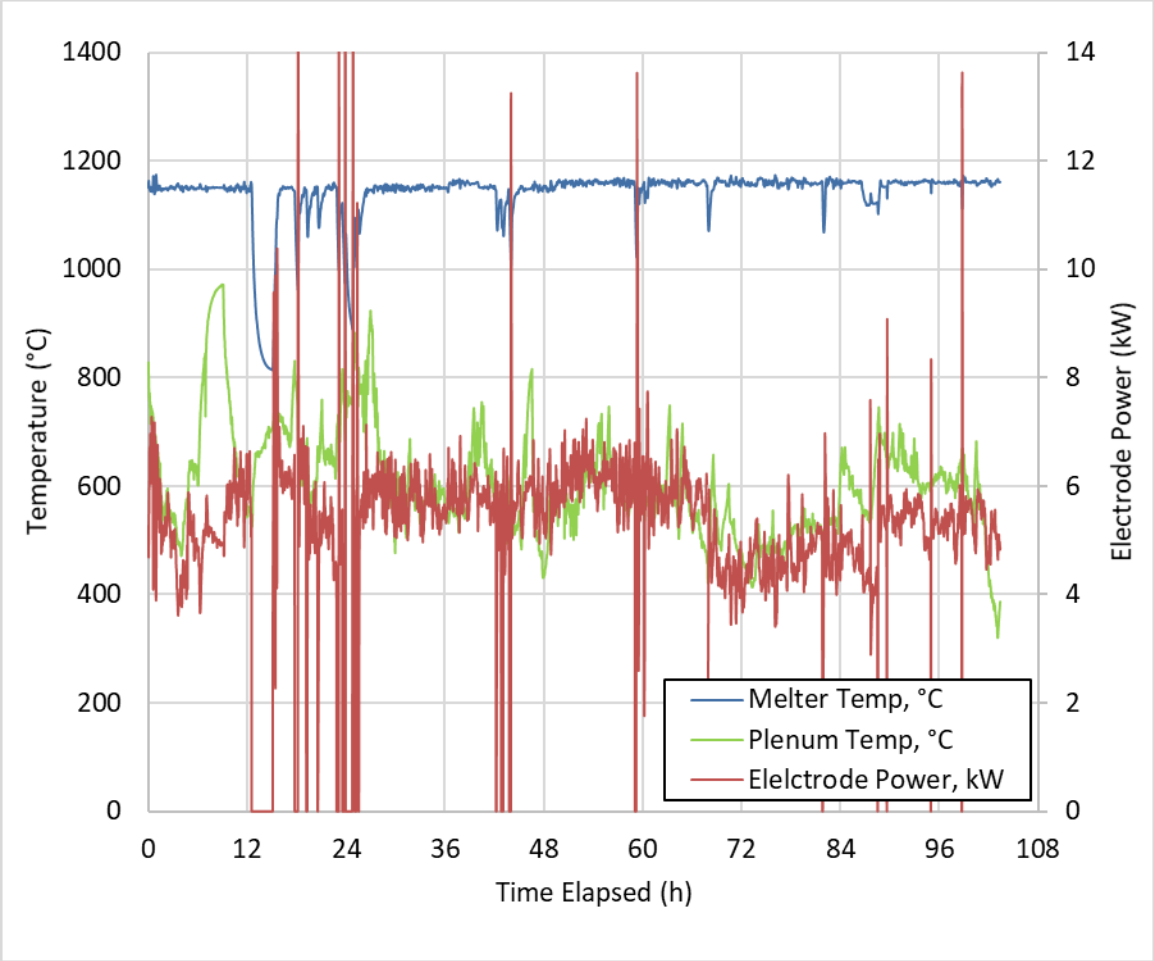

Figure C.3. Melter and Plenum Temperatures and Electrode Power

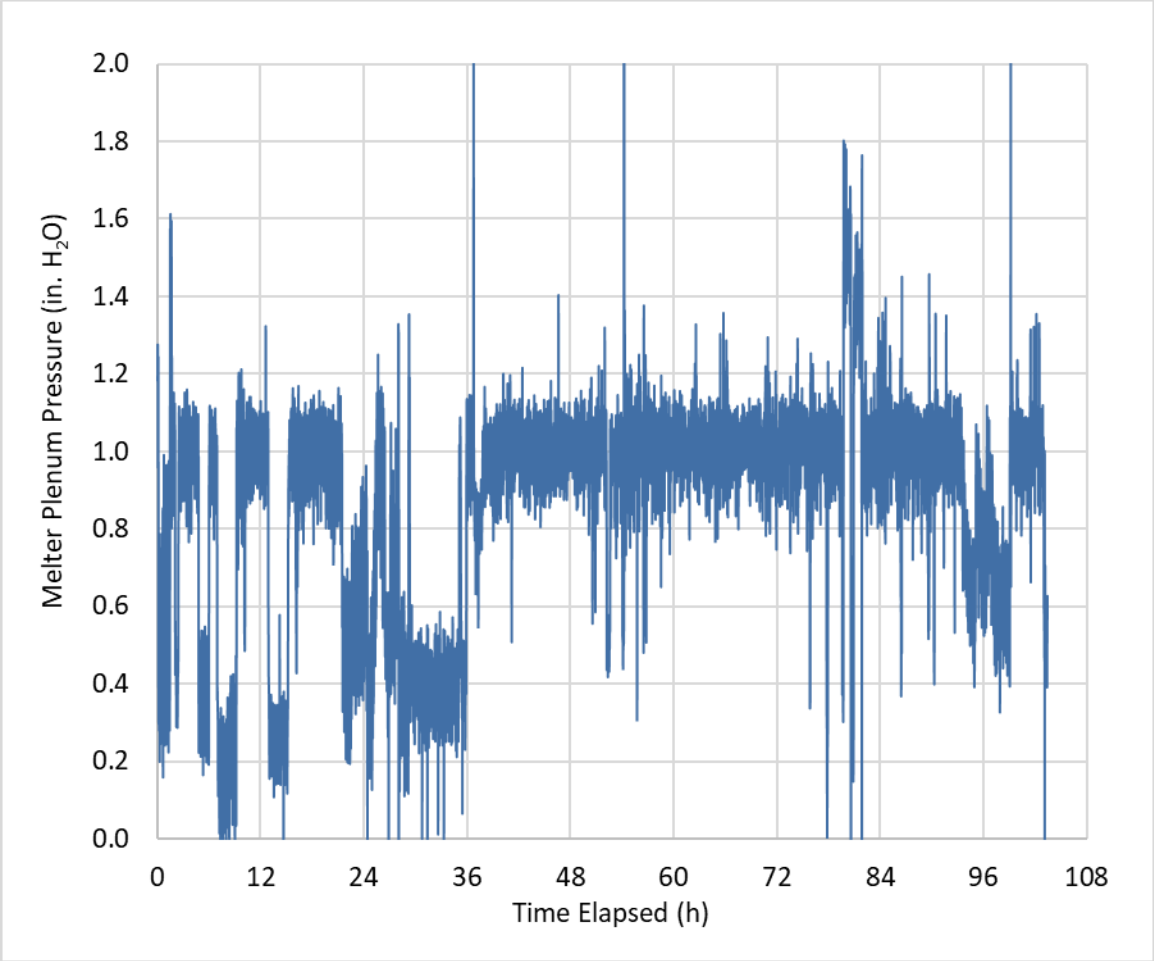

Figure C.4. Melter Vacuum

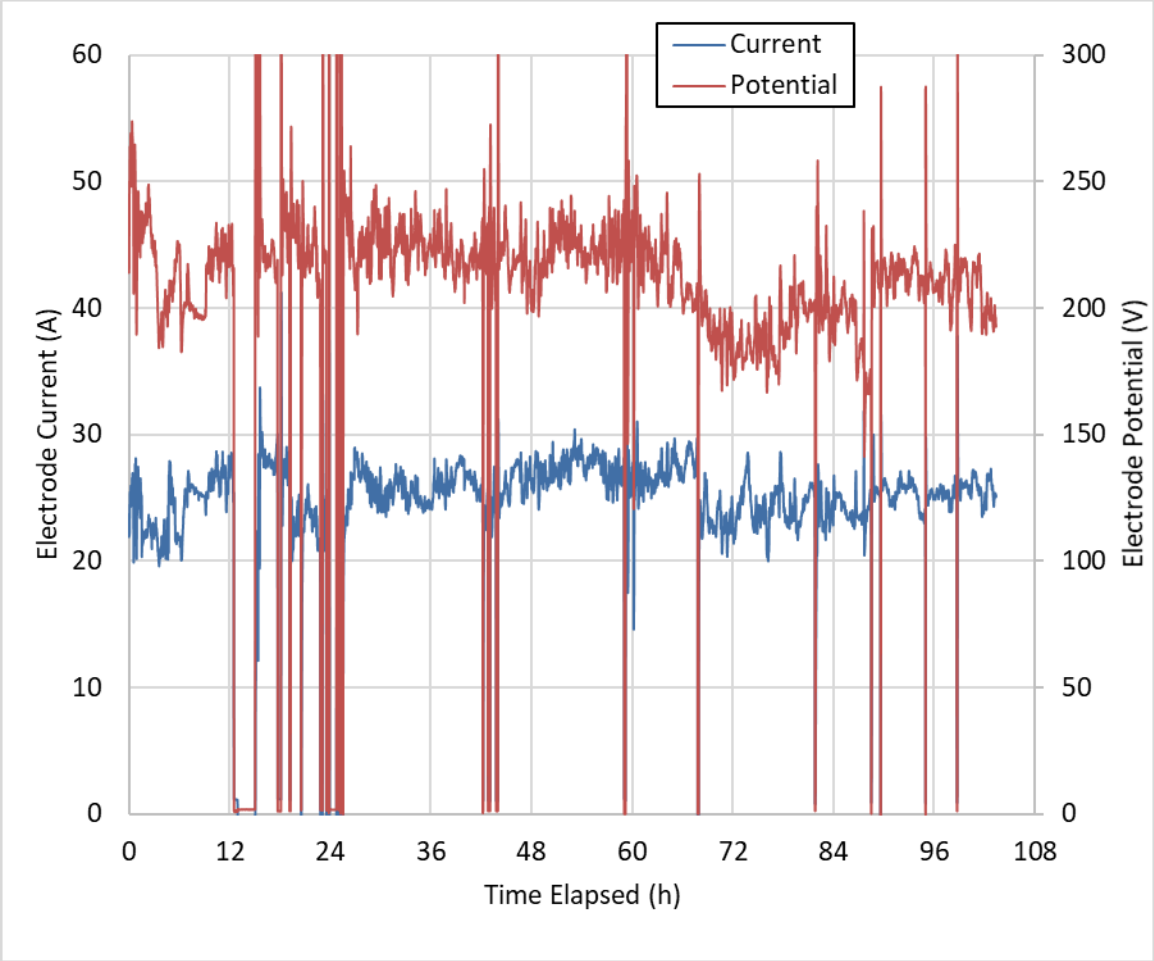

Figure C.5. Electrode Current and Potential

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