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Final Report: Support for DF LAW Flowsheet Development Report, VSL-17R4250-1, Rev 0

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Office of River Protection

P.O. Box 450
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Final Report: Support for DF LAW Flowsheet Development Report, VSL-17R4250-1, Rev 0

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Final Report

Support for Direct Feed LAW Flowsheet Development

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Test Plan: Support for Direct Feed LAW Flowsheet Development, VSL-16T4250-1, Rev. 0, 7/8/16; Rev. 1, 11/1/17.

This report describes the results of testing specified by the above Test Plan. The work was performed in compliance with the quality assurance requirements specified in the Test Plan. Results required by the Test Plan are reported. The test results and this report have been reviewed for correctness, technical adequacy, completeness, and accuracy.

I.L. Pegg: ________________ **Date:** 12/6/17
VSL Program Director/Principal Investigator

I. Joseph: Innocent Joseph **Date:** 12/6/17
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List of Abbreviations

ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BBI	Best-Basis Inventory
CEM	Continuous Emissions Monitoring
CUA	Catholic University of America
DCP-AES	Direct Current Plasma – Atomic Emission Spectroscopy
DF	Decontamination Factor
DM	DuraMelter
DOE	Department of Energy
DWPF	Defense Waste Processing Facility
EDS	Energy Dispersive X-ray Spectroscopy
EPA	Environmental Protection Agency
FTIR	Fourier Transform Infrared Spectroscopy
HEME	High Efficiency Mist Eliminator
HEPA	High-Efficiency Particulate Air (Filter)
HLW	High Level Waste
IHLW	Immobilized High Level Waste
IC	Ion Chromatography
ICP-MS	Inductively Coupled Plasma – Mass Spectroscopy
ILAW	Immobilized Low Activity Waste
ISE	Ion Selective Electrode
JHCM	Joule Heated Ceramic Melter
LAW	Low Activity Waste
NIST	National Institute of Standards and Technology
NQA	Nuclear Quality Assurance
ORP	Office of River Protection
QAPP	Quality Assurance Project Plan
SBS	Submerged Bed Scrubber
SEM	Scanning Electron Microscopy
TFCOUP	Tank Farm Contractor Operations and Utilization Plan
TSS	Total Suspended Solids
TWINS	Tank Waste Information Network System
VSL	Vitreous State Laboratory
WESP	Wet Electrostatic Precipitator
WTP	Hanford Waste Treatment and Immobilization Plant
WRPS	Washington River Protection *Solutions*, LLC
XRD	X-ray Diffraction
XRF	X-Ray Fluorescence

SECTION 1.0
INTRODUCTION

1.1 Background

About 50 million gallons of high-level mixed waste is currently stored in underground tanks at the United States Department of Energy's (DOE's) Hanford site in the State of Washington. The Hanford Tank Waste Treatment and Immobilization Plant (WTP) will provide DOE's Office of River Protection (ORP) with a means of treating this waste by vitrification for subsequent disposal. The tank waste will be separated into low- and high-activity waste fractions, which will then be vitrified respectively into Immobilized Low Activity Waste (ILAW) and Immobilized High Level Waste (IHLW) products. The ILAW product will be disposed in an engineered facility on the Hanford site while the IHLW product is designed for acceptance into a national deep geological disposal facility for high-level nuclear waste. The ILAW and IHLW products must meet a variety of requirements with respect to protection of the environment before they can be accepted for disposal.

The Office of River Protection is examining options to optimize the Low Activity Waste (LAW) Facility and LAW glass waste form. The Vitreous State Laboratory (VSL) at The Catholic University of America (CUA) and Atkins have evaluated several potential incremental improvements for ORP in support of its evaluation of WTP LAW facility optimization [1]. Many of these incremental improvements have been tested at VSL, including increasing the waste loading, increasing the processing temperature, and increasing the fraction of the sulfur in the feed that is partitioned to the off-gas (assuming that the present WTP recycle loop can be broken) [2-4]. These approaches successfully demonstrated increases in glass production rates and significant increases in sulfate incorporation at the nominal melter operating temperature of 1150°C and at slightly higher than nominal glass processing temperatures. Testing demonstrated further enhancement of glass formulations for all of the LAW waste envelopes, thereby reducing the amount of glass to be produced by the WTP for the same amount of waste processed [5, 6]. Subsequent testing determined the applicability of these improvements over the expected range of sodium and sulfur concentrations for Hanford LAW [7] and to a wider range of LAW wastes types, including those with high potassium concentration [8, 9]. Glasses were subsequently evaluated for the tendency to form secondary molten salt phases in response to variations in sulfur, halide, chromium, and phosphate concentrations in the melter feed [10, 11].

In the baseline WTP LAW flowsheet the majority of the radionuclides and other contaminants of concern that exit the melter in the off-gas stream are captured in the off-gas system and recycled to the pretreatment facility and, ultimately, to subsequent melter feed batches. Under the LAW direct feed option, the pretreatment facility is bypassed and LAW is fed to the vitrification facility with minimal in-tank or near-tank pretreatment, which will likely involve ion-exchange and solids removal. In some scenarios, without the pretreatment facility capability for evaporation and recycling, the secondary waste from off-gas treatment would either be stored or treated for disposal.

In addition, the LAW feeds to the vitrification facility could be of lower concentrations that those in the baseline flowsheet. For example, one of the projected early feeds for direct feed LAW is LAW from Tank AP-105, which is likely to be processed at a lower concentration of about 5.6 M Na as compared to about 8 M Na which would be expected for baseline WTP operations for LAW feeds with similar waste loading in the glass. Other consequences of the vitrification facility being delivered more dilute LAW feeds include lower processing rate, higher carryover of waste constituents into the off-gas system, and rheological changes in the melter feed [12]. In the tests described in this report, the effect of processing dilute LAW with the correspondingly low solids content and glass yield were evaluated to determine the impacts of low solids content on LAW glass production rates, melter emissions, and changes in feed rheology. In addition, the development of the direct feed LAW flowsheet was supported by the determination of the compositions of effluents from the off-gas system, particularly the Submerged Bed Scrubber (SBS) and wet electrostatic precipitator (WESP), in order to assess potential disposition strategies for those streams and the effects of lower LAW feed concentrations.

Previously, one of the two DM10 melter systems currently installed at VSL was modified to include key off-gas treatment system components prototypical of the WTP LAW primary off-gas system (SBS and WESP) [13-15]; this system provides an efficient and economical means to obtain information on the compositions of the primary off-gas system effluents. In a previous test, the compositions of primary off-gas system effluents were determined using a melter system that includes an SBS and WESP in the off-gas treatment system while processing an ORP LAW feed (ORPLA20) at two different feed solids contents [16] and while processing an ORP LAW feed (ORPLB4) at three different feed rhenium contents [17]. Testing was also performed using a WTP LAW feed that has been tested previously on the DM1200 HLW Pilot Melter so that a comparison could be obtained between data from the HLW Pilot Melter system and the DM10 system. A description of the tests conducted, feed compositions processed, test matrix, and data collected is given in the Test Plan for this work [18].

1.2 WTP Off-Gas Treatment

The baseline design for the WTP off-gas systems was developed by BNFL, Inc. under the privatization contract and includes a SBS, WESP, and a high efficiency mist eliminator (HEME) as the principal components [19]; a catalytic oxidation unit was added on the basis of test data that showed that the melter alone would not provide sufficient destruction of organics [20]. Essentially the same process train is also used for the LAW off-gas treatment system [21], but without the HEME. To test, optimize, and characterize the performance of this system a one-third scale HLW Pilot Melter system (DM1200) with prototypical off-gas treatment system was deployed at VSL. Since the commissioning of the DM1200 in January of 2001 [22, 23], the DM1200 off-gas system has been evaluated in the treatment of exhaust from a wide range of HLW and LAW simulated waste streams [23-38]. For DM1200 melter tests with LAW feeds, the HEME is valved out of the off-gas system.

Since the DM1200 melter and prototypical off-gas system was primarily intended for HLW testing, much more limited testing has been conducted with LAW feed streams [32-38] and only a smaller subset of those tests have extensive characterization of the effluents from the off-gas system components [33, 34, 37, 38]. Detailed characterization of the streams from the primary off-gas system components is critical for developing potential alternative disposition strategies. Analysis of solutions from the SBS from DM1200 tests shows the evolution in composition as the solution achieves steady state with respect to melter emissions and removal of solution from the SBS. The compositions of effluent solutions from the off-gas system are a function of the feed composition and the manner in which both the melter and off-gas system components are operated. The temperature of the SBS sump, for example, determines the amount of water that condenses in the SBS, which affects the elemental concentrations and rate of solution removal from the SBS.

Sugar, which is added to the feed to control foaming, reduces a large portion of nitrogen oxides to molecular diatomic nitrogen in the melter; ammonia is formed in reactions with sugar and nitrogen oxides and is removed from the exhaust stream in the primary off-gas system. The ratio of NO/NO_2 in the melter exhaust, and therefore the amount removed by the SBS, is determined by the plenum temperature, which in turn is determined by the extent of the melter cold cap and the manner in which the melter is fed. The pH of the off-gas solutions, which affects the partitioning between dissolved and particulate species, is influenced by several factors including the amounts and types of nitrogen species. The compositions of the solutions from the WESP are further determined by the frequency, duration, and volume of the deluge procedure used to clean the particle-collecting surfaces [16]. Radionuclides such as technetium (rhenium was used as a surrogate in DM1200 tests), iodine, and cesium partition to the off-gas system effluents to varying extents depending on feed and operational conditions [14, 15, 34, 38, 39]. Because of the complex interactions, the effects of feed composition and operational changes on off-gas system effluent compositions need to be determined from analysis of solutions generated by prototypical off-gas system components while vitrifying representative wastes and feeds under prototypical conditions.

1.3 Test Objectives

The primary objectives of this work were to develop a glass formulation for the direct feed LAW from Tank AP-105, collect data on primary off-gas system effluents to support the evaluation of potential direct feed LAW flowsheets, and determine the effect of the dilute direct feed LAW stream on processing rates and partitioning of waste components to the exhaust system. Development of a suitable glass formulation for the LAW Tank AP-105 composition made use of information from the ORP Enhanced LAW Glass Correlation that is currently under development [40-42]. Subsequently, melter feeds at low solids contents indicative of direct feed LAW waste streams were processed on the DM100 to determine glass production rates and bubbling rates required to process the high water content feed. Liquid effluent solutions generated from prototypical primary off-gas system components (SBS and WESP) were collected while processing the LAW Tank AP-105 composition at nominal conditions through the DM10. These solutions were analyzed to determine their steady state compositions and the effects of feed composition and feed water content at nominal processing conditions.

The objectives of this work were to:

- Develop a glass formulation for the direct feed LAW from Tank AP-105 by crucible scale testing to identify a high waste loading glass composition for this LAW stream.
- Prepare and characterize melter feeds containing direct feed LAW from Tank AP-105 at solids contents to be used in melter testing in order to assess the effect of solids content on feed physical properties, settling rate, and rheological properties.
- Conduct DM100 melter tests to demonstrate the processability of direct feed LAW from Tank AP-105 at feed solids contents corresponding to 4 M, 5.6 M, and 8M Na concentration in the waste.
- Determine glass production rates at prototypical WTP LAW plant operating conditions on the DM100 while processing direct feed LAW from Tank AP-105 at feed solids contents corresponding to 4 M, 5.6 M, and 8 M Na concentration in the waste.
- Determine the effect of feed solids content on solids carryover from the DM100 while processing direct feed LAW from Tank AP-105 at feed solids contents corresponding to 4 M, 5.6 M, and 8 M Na concentration in the waste.
- Perform a mass balance of the components around the DM100 melter using analysis of feed, melter exhaust, and glass samples.
- Conduct melter testing with the DM10 equipped with prototypical primary off-gas system components (SBS and WESP) to collect data on off-gas system liquid effluents while processing direct feed LAW from Tank AP-105 at feed solids content corresponding to 5.6 M Na concentration in the waste.
- Conduct melter testing with the DM10 equipped with prototypical primary off-gas system components (SBS and WESP) to achieve steady state sump and liquid effluent composition in the SBS (three turnovers) while processing direct feed LAW from Tank AP-105 at feed solids content corresponding to 5.6 M Na concentration in the waste.
- Determine the effect of feed solids content and glass formulation on off-gas emissions from the DM10 melter, SBS, and WESP while processing direct feed LAW from Tank AP-105 at feed solids content corresponding to 5.6 M Na concentration in the waste.
- Perform a mass balance of the components in the melter exhaust over the DM10 off-gas system effluents.

The glass formulation developed for the direct feed LAW from Tank AP-105 was subjected to testing on both the DM10 and DM100 melter platforms in order to collect data on processing characteristics and off-gas system effluent compositions. The larger scale DM100 is better suited to assessments of processing rate effects while the DM10 system includes prototypical SBS and WESP off-gas treatment components and generates data on off-gas system performance and off-gas system effluent composition. The DM100-WV melter system used for these tests was used for all of the initial LAW Envelope A, B, and C tests [43-54] prior to the subsequent tests on the larger LAW Pilot Melter [55-66]; tests to determine the effect of glass temperature on LAW glass production rates [3]; tests to demonstrate greater sulfur partitioning to the melter exhaust [4]; tests to demonstrate processing higher waste loading LAW glass formulations [5, 6]; tests to determine the effect of feed solids content on glass production rate [12]; and tests to determine the effect of feed additive form on glass production rate [67]. The DM100-WV melter was selected for the present tests in order to maintain comparisons between these data sets. Testing with a variety of LAW simulated waste streams has been previously performed on the DM10 melter system with prototypical off-gas system components [10, 11, 14-17].

1.4 Quality Assurance

This work was conducted under a quality assurance program compliant with applicable criteria of 10 CFR 830.120; the American Society of Mechanical Engineers (ASME) Nuclear Quality Assurance (NQA)-1 (2008) including NQA-1a-2009 addenda; and DOE Order 414.1 D, Quality Assurance. This program is supplemented by a Quality Assurance Project Plan (QAPP) for ORP work that is conducted at VSL [68]. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work [69]. Requirements of DOE/RW-0333P are not applicable to this work.

The waste simulants used in the tests were procured from Optima Chemicals according to VSL specifications. Optima Chemicals was required to provide completed batch sheets with identifications and weights of chemicals used in the preparation of each batch of simulant. The compositions of the simulants were confirmed by chemical analysis at VSL under the VSL QA program using VSL standard operating procedures.

1.5 DM100 Tests

1.5.1 Testing Overview

Melter tests were conducted to determine the effect of feed solids content on the glass production rates for the direct feed LAW AP-105 waste simulant and corresponding glass composition developed in the present tests. Sufficient blended feed (glass formers plus waste simulant) was procured from Optima Chemicals according to VSL specifications to make approximately one and a half metric tons of glass. Melter feeds with three different solids contents and rheological properties were processed to determine glass production rate as a function of feed solids content while processing the same LAW AP-105 waste simulant and glass composition. Sugar was added (at VSL) to the feed to achieve the equivalent of a stoichiometric ratio of 0.5 (1 mole sucrose per 16 moles NO_x) to the remaining nitrate after accounting for the redox reactions with carbon supplied by the waste organics (which are also assumed at a 0.5 stoichiometric ratio). Tests were conducted with feeds at the solids content associated with the current WTP baseline waste concentration of 8 M Na, the anticipated waste concentration in direct feed LAW of 5.6 M Na, and a lower waste concentration of 4 M Na. The initial test was conducted with feed at the nominal baseline solids content associated with 8 M Na while the feed and bubbling rates were adjusted to achieve a glass production rate of 2250 $kg/m^2/day$ (corresponds to the "stretch-goal" rate of 22.5 MT/day specified by ORP for the WTP meter) while maintaining a near-complete cold cap. In subsequent tests processing feed at two other solids contents, the bubbling rate was fixed at the rate used in the initial test to isolate the effect of feed solids content on production rate. All of the melter tests were performed at a nominal temperature of 1150°C. Key operating parameters such as the glass temperature (1150°C) and near complete cold cap coverage (90-100% of melt surface covered with feed) were held constant to investigate the effect of the feed solids content on the processing characteristics and, most notably, glass production rate. Quantitative measurements of glass production rates, melter operating conditions (temperatures, pressures, power, flows, etc.), and gaseous emissions by Fourier Transform Infrared Spectroscopy (FTIR) (i.e., NO_X, SO_2, CO, and acid halides) were made for each test. Stack sampling for particulates was conducted during each test to assess the effect of feed solids content on solids carryover from the melter. Discharged glass samples were inspected for secondary phases and analyzed for chemical composition.

1.5.2 DM100 Melter System Description

1.5.2.1 Feed System

A schematic diagram of the DM100 vitrification system is shown in Figure 1.1. The melter feed is introduced in batches into a feed container that is mounted on a load cell for weight monitoring. The feed is stirred with a variable speed mixer and constantly recirculated except for periodic, momentary interruptions during which the weight is recorded. The recirculation loop extends to the top of the melter where feed is diverted from the recirculation loop through a peristaltic pump and into the melter through a Teflon-lined feed line and vertical water-cooled feed tube.

1.5.2.2 Melter System

Cross-sectional diagrams through the DM100-WV melter are shown in Figures 1.2a-c. The DM100-WV unit is a ceramic refractory-lined melter fitted with a pair of opposing Inconel 690 plate electrodes as well as a bottom electrode. The melter can be operated with either three-phase or single-phase power. However, the standard mode of operation, which was used for these tests, is single-phase with voltage applied to the side electrodes only. The bubbler used for stirring the melt pool enters from the top and is removable. The glass product is removed from the melter by means of an air-lift discharge system. The DM100-WV has a melt surface of 12 × 14 inches, giving a melt surface area of 0.108 m^2. The nominal depth of the melt pool is about 19 inches, which gives a typical glass inventory of between 115 and 120 kg. The plenum height is 27.5 inches. Temperatures are monitored by means of a series of thermocouples located in the melt pool, the electrodes, the plenum space, and the discharge chamber.

1.5.2.3 Off-Gas System

For operational simplicity, the DM100-WV is equipped with a dry off-gas treatment system involving gas filtration operations only. Exhaust gases leave the melter plenum through a film cooler device that minimizes the formation of solid deposits. The film-cooler air has constant flow rate and its temperature is thermostatically controlled. Consequently, under steady-state operating conditions, the exhaust gases passing through the transition line (between the melter and the first filtration device) can be sampled at constant temperature and airflow rate. The geometry of the transition line conforms to the requirements of the 40-CFR-60 air sampling techniques. Immediately downstream of the transition line are cyclonic filters followed by conventional pre-filters and High Efficiency Particulate Air (HEPA) filters. The temperature of the cyclonic filters is maintained above 150°C while the temperatures in the HEPA filters are kept sufficiently high to prevent moisture condensation. The entire train of gas filtration operations is duplicated and each train is used alternately. An induced draft fan completes the system.

1.5.2.4 Sampling Points

A variety of sampling points are available on the DM100 system. The sampling points that were used in this work are as follows:

- *Melter Feed*: Samples of the melter feed were taken either from the parent feed batch or from the melter feed line to provide confirmation of the feed composition.

- *Glass Product:* Samples of the glass product were taken from glass that is air-lift discharged into steel cans.

- *Glass Pool:* Glass samples were also taken directly from the glass pool ("dip" samples).

- *Off-gas 1:* Isokinetic sampling of melter exhaust were conducted at a point located immediately downstream of the film cooler.

- *Off-gas 2:* A sampling point located down stream of the HEPA filter was used for continuous emissions monitoring (CEM) by FTIR of a wide variety of gaseous species including NO, NO_2, N_2O, CO, CO_2, NH_3, and SO_2.

1.6 DM10 Tests

1.6.1 Testing Overview

The direct feed LAW AP-105 waste composition and glass forming additives selected in the presents work was used to determine the effect of waste concentration on the amount and composition of effluents from the primary off-gas system. Key operating parameters such as the glass temperature (nominally 1150°C) was held constant to investigate the effect of the feed composition on off-gas effluent composition. The processing rate was maintained at a rate defined during DM100 testing as the normalized rate at which the feed based on LAW at 5.6 M Na was processed (see Section 3.0). This rate was less than 2250 kg/m^2/day of glass as a result of the higher feed water content. The bubbling rate was adjusted to achieve a near-complete cold-cap (90-100% of melt surface covered with feed). Primary off-gas system components were operated using prototypical WTP conditions as used in previous DM1200 [38] and DM10 tests [16, 17] including operating temperatures, WESP deluges, and transition line sprays. Quantitative measurements of glass production rates, melter and off-gas system operating conditions (temperatures, pressures, power, flows, etc.), gaseous emissions by FTIR, and particulate emissions into the off-gas system using Environmental Protection Agency (EPA) methods were made for each test. Discharged and melt pool glass samples were inspected for formation of any salt phases and analyzed for chemical composition. Samples of the process fluids from each of the off-gas treatment system components were quantified and analyzed. Sampling and analysis during testing were sufficient to support a mass balance for all constituents of interest and particularly those known to be concentrated in off-gas system effluents such as halides, sulfur, nitrogen oxides, and alkali metals.

1.6.2 DM10 Melter System

Test runs were performed using the DM10 melter system that was previously modified to include the key off-gas treatment components in the WTP LAW primary off-gas system (SBS and WESP). This melter and off-gas system was used in conjunction with an evaporator in previous tests to investigate the recycle of the SBS and WESP effluents back to the melter feed [13, 14]. The evaporator and recycle loop were not used in the present tests. All effluents from the primary off-gas system components were collected, analyzed, and their volumes determined.

1.6.2.1 DM10 Melter

The DM10 unit is a ceramic refractory-lined melter fitted with two Inconel 690 plate electrodes that are used for joule-heating of the glass pool and a bubbler for stirring the melt. A schematic diagram of the DM10 is provided in Figure 1.3. Thermocouples installed in a thermowell provide temperature measurements at various locations within the glass pool and in the plenum space. The glass product is removed from the melter by means of an air-lift discharge system. The DM10 unit has a melt surface area of 0.021 m^2 and a glass inventory of about 8 kg. The off-gas system maintains the melter under slight negative pressure (typically about 1 inch W.C) with respect to ambient. The melter feed is introduced in batches into a feed container that is mounted on a load cell for weight monitoring. The feed is constantly recirculated, providing continuous mixing except for periodic, momentary interruptions during which the feed tank is recharged. The feed is introduced into the melter by means of a peristaltic pump. The recirculation loop extends to the top of the melter where feed is diverted from the recirculation loop through the peristaltic pump and into the melter through a Teflon-lined feed line and water-cooled, vertical feed tube.

1.6.2.2 Off-Gas System

Exhaust gases leave the melter plenum through a film cooler device that minimizes the formation of solid deposits. The film-cooler input air has constant flow rate and its temperature is thermostatically controlled. Consequently, under steady-state operating conditions, the exhaust gases passing through the transition line (between the melter and the SBS) can be sampled at constant temperature and air flow rate. The geometry of the transition line conforms to the requirements of the 40-CFR-60 air sampling techniques. The transition line is periodically sprayed with water to remove particle buildup in a manner similar to that planned for the WTP LAW system. The sprayed solutions drain down the inclined transition line from the film cooler into the SBS. Figure 1.4 shows a flow diagram of the DM10 system from the melter through the SBS and WESP to final filtration and release to the stack. The SBS, WESP, and associated tanks and piping were added to the existing DM10 system. The layout of these components is shown in Figure 1.5; the internals are shown in cross-section in Figure 1.6; and a photograph of the system is shown in Figure 1.7. The off-gas system is equipped with a water treatment system to supply deionized water for all added makeup water, sprays, deluges, and rinses performed during the test. Downstream of the WESP are coarse particulate filters followed by conventional pre-filters and HEPA filters. The temperature of the filters is kept sufficiently high to prevent moisture condensation. The entire train of gas filtration stages is duplicated and each train is used alternately. An induced draft fan completes the system. The sampling location for gaseous species monitored by FTIR is immediately downstream of the fan.

1.6.2.2.1 Submerged Bed Scrubber

The SBS is the first unit operation in the DM10 off-gas system. The SBS serves multiple functions including: cooling the off-gas via contact with liquid water and condensing moisture in the gas; removing large particulates from the off-gas stream; scrubbing out soluble acid gases such as HCl and HF; and dissolving soluble particulates into the aqueous phase. The DM10 SBS consists of a vertically oriented, cylindrical, packed-bed column that is submerged in an outer tank that is partially filled with water. The water pool serves to quench the off-gas and collect particulates and soluble species. A gas plenum space above the packed bed serves as a disengagement volume to remove entrained liquid from the exiting gas stream.

The off-gas enters through a down-comer at the top of the column that passes through the gas plenum, the packed bed, and discharges into the water pool. The flow then bubbles up through a diffuser plate that supports the bed packing and evenly distributes the flow into the bed. The off-gas then flows through the plenum and exits through the top of the vessel. The water level and flow are controlled by an inlet nozzle and an outlet overflow nozzle located a few inches above the height of the packing. Water is filled to this level at the start of operation. As condensed water accumulates, it overflows from the SBS into an external collection tank. Water can also be added to the SBS at a controlled rate during testing to maintain the desired level of water in the SBS sump and simulate the amount of water condensed during processing on the DM1200 HLW Pilot melter. The level of water in the SBS during testing is monitored on an indicating tube, as shown in Figure 1.8.

The off-gas inlet temperature is typically 200-300°C and the off-gas outlet temperature is typically 30-50°C. To handle this thermal duty, the SBS employs a cooling jacket and a submerged coil in the water pool of the vessel. The cooling jacket and coil use water as the cooling medium and the temperature is adjusted to ensure stable liquid temperature in the SBS vessel. The DM10 SBS is constructed from 316 stainless steel.

The SBS tank was modified prior to the present test to include a taller headspace above the liquid overflow to prevent liquid being carried over into the WESP, which has been observed in some tests due to foaming [16, 17]. This larger plenum gives more volume for the off-gas to disengage from any foam that exists and allow more time for liquid droplets to lose momentum and fall back into the SBS prior to exiting the vessel. This does not affect the size of the liquid sump, the SBS residence time, or the expected particulate removal efficiency in the SBS liquid sump.

1.6.2.2.2 Wet Electrostatic Precipitator

The DM10 WESP treats the off-gas exiting the SBS. The WESP is particularly effective in capturing submicron particulates that pass through the SBS. The WESP is a vertical, 316 stainless steel vessel containing three rod electrodes that are surrounded by vertical grounded collection tubes that run the length of the vessel. A high voltage (20-30 kV) is applied to the electrodes forming an ionization corona, which generates a flow of electrons between the electrodes (shown in Figure 1.9) and the collection tubes. As the off-gas flows through the high electric field, any entrained particles are ionized and electrostatically attracted to the collector tube walls or the rod electrodes (depending on the charge on the particle). Power is supplied by a high-voltage power supply that maintains the voltage high but below the point of plasma discharge.

The off-gas enters through a port near the bottom of the unit and flows vertically through the three tubes and exits through the top. A water spray at the off-gas inlet ensures that the collection surfaces are coated in a wet film during operation that prevents the collected particulates from permanently adhering. The WESP can be flushed (deluged) with fresh water from the top in order to wash the particulate material that has built up on the electrodes into the vessel sump. A nozzle at the bottom allows for the transfer of the liquid effluent to an external collection tank.

1.6.2.3 Sampling Points

A variety of sampling points are included in the DM10 system to support a mass balance for all constituents of interest. The sampling locations (S1 – S9) are shown in Figure 1.4, except for S0 which is the drum of as-received feed. Additional information on the samples collected and analytical methods is provided in Section 1.7. The sampling points that were used for this work include:

- *Melter Feed*: Confirmation of the melter feed composition was based on samples of the melter feed from the drum of as-received feed (S0) and samples of the melter feed that were taken from the feed tank (S1).

- *Glass Product*: Samples of the glass product were taken from glass that is air-lift discharged into steel cans (S3).

- *Glass Pool*: Glass samples were also taken directly from the glass pool ("dip" samples, S2), particularly for detection of any molten salt phases.

- *Off*-gas 1: Isokinetic sampling of melter exhaust was conducted at a point located immediately downstream of the film cooler in the transition line (S4).

- *SBS Sump:* Liquid samples were collected from the SBS sump (S5) measuring the amount and composition of all solutions removed from the SBS.

- *Off*-gas 2: Isokinetic sampling of SBS exhaust was conducted at a point located immediately downstream of the SBS (S6).

- *WESP Sump:* Liquid samples were collected from the WESP sump (S7) measuring the amount and composition of all solutions removed from the WESP.

- *Off*-gas 3: Isokinetic sampling of WESP exhaust was conducted at a point located immediately downstream of the WESP (S8).

- *Off-gas 4*: A sampling point located downstream of the HEPA filter was used for CEM by FTIR of a wide variety of gaseous species, including NO, NO_2, N_2O, CO, and SO_2 (S9).

1.7 Summary of Experimental Methods

1.7.1 Glass Compositional Analysis

Sample preparation for chemical analysis typically involves size reduction and sieving. All samples were subjected to X-ray fluorescence spectroscopy (XRF) to determine the concentration of all elements except boron and lithium. A series of National Institute of Standards and Technology (NIST) reference materials were used for confirmation of the XRF data. Boron and lithium were determined by total acid dissolution of ground glass samples in HF/HNO_3 and subjecting the resulting solutions to direct current plasma-atomic emission spectroscopy (DCP-AES) analysis. The XRF detection limit for rhenium in powdered glass samples was reduced to about 0.001 wt% ReO_2 by employing element-specific analysis using a LiF220 crystal to measure the intensity of the Re Lβ1spectral line.

1.7.2 Melter Feed Analysis

Feed samples were taken directly from select drums of feed received from the vendor to confirm composition before use. Feed samples from feed drums were analyzed for general properties and oxide composition. Feed samples were placed into platinum/gold crucibles that were transferred into a programmed furnace for drying and fusion to form a glass. The glass samples produced from this fusion were ground to less than 200 mesh and sealed in 20-ml vials for subsequent analysis by XRF, or by acid digestion followed by DCP-AES on the resulting solution. The feed samples were also characterized for their density, pH, water content, and glass yield.

1.7.3 Anion Analysis of Liquid Samples

Ion chromatography (IC) was employed to measure the concentrations of inorganic anions in solutions. A Dionex DX-120 ion chromatograph was used. The DX-120 consists of a CDM-3 conductivity detector and an anion self-regenerating suppressor equipped with IonPac AS-14/AG-14 column/column guard for anion separation. Column elution was performed with a solution of $Na_2CO_3/NaHCO_3$. The instrument was controlled using the Chromeleon (version 6.50) data system software. Calibration standards for the analytes of interest were prepared with NIST traceable standards that were used to obtain a linear working range (typically 10 ppm). Separation of the common anions (e.g., F^-, Cl^-, and SO_4^{2-}) was normally completed within 15 minutes. Integrated peak areas for each separated analyte were used to calculate their respective concentrations.

1.7.4 Melter, SBS and WESP Emission Samples

Melter emission fluxes were measured from the DM100 to access the extent of feed component carryover from the melter for feeds of variable water content. Melter, SBS, and WESP emission fluxes were measured to perform a mass balance around the primary off-gas system components for the DM10 melter test. The WESP exhaust was sampled before and during the deluge of the WESP. The exhaust was sampled for metals/particles according to 40-CFR-60 Methods 1A, 2, 4, 5, 26, 29 at steady-state operating conditions during each test. The concentrations of off-gas species that are present as particulates and gaseous species that are collected in impinger solutions were derived from laboratory data on solutions extracted from air samples (filters and various solutions) together with measurements of the volume of air sampled. Particulate collection requires isokinetic sampling, which entails removing gas from the exhaust at the same velocity that the air is flowing in the duct (40-CFR-60, Methods 1-5). Typically, a sample size of 30 dscf is taken at a rate of between 0.5 and 0.75 dscfm. Total particulate loading is determined by combining gravimetric analysis of the standard particle filter and chemical analysis of probe rinse solutions. An additional impinger containing 2 N NaOH was added to the sampling train to ensure complete scrubbing of all acid gases. The collected materials were analyzed using DCP-AES for the majority of the constituents, Inductively Coupled Plasma–Mass Spectroscopy (ICP-MS) for low-level determination of select elements and particularly rhenium, and IC for anions.

At a sampling point located downstream of the HEPA for both melter systems, emissions were monitored in each test for a variety of gaseous components, most notably CO and nitrogen species, by FTIR. The off-gas system temperature is maintained well above 100°C prior to the sampling port downstream of the DM10 HEPA filter to prevent analyte loss due to condensation prior to monitoring. The data, therefore, represent the relative concentrations of volatile gaseous species in the WESP exhaust. There is no liquid scrubbing of gases in the DM100 system and therefore the monitored gases are indicative of the melter exhaust.

1.7.5 Rhenium Analysis

Rhenium concentrations in the feed were determined from the weights of perrhenic acid solutions of known concentration that were added to a known amount of as-received feed. This is the most accurate method for determining the Re concentration in the feed given the use of calibrated balances and the analysis of Re-containing solutions added to the feed. All reported rhenium concentrations in glass are based on the ICP-MS analysis of dissolved glass samples and by XRF analysis of powdered glass. Reported analysis of samples with rhenium concentrations $\geq$ 0.0019 wt% ReO_2 are from XRF analysis of powdered glass. The XRF was calibrated using a series of ICP-MS analyses of dissolved glass samples.

SECTION 2.0
WASTE SIMULANT, GLASS FORMULATION AND FEED TESTING

2.1 Hanford Tank AP-105 Waste Simulant

The direct feed LAW AP-105 simulant used in the present work was based on composition data for Hanford Tank AP-105 as given in the Tank Waste Information Network System (TWINS) Best-Basis Inventory (BBI) [70]. As shown in Table 2.1, the analytes reported in the BBI inventory were converted to concentrations in Mole/L and mg/L while fixing the sodium concentration at the anticipated direct feed LAW feed concentration of 5.6 M. The LAW AP-105 waste simulant composition given in Tables 2.2 was formulated in a manner similar to that previously used in the formulation of other LAW simulants used in the development of high waste loading ORP LAW glass compositions [2-9]. The component concentrations are based on the values given in Table 2.1, while eliminating minor constituents found at concentrations of less than 15 mg/L. Ni and Pb are included, as was the case with many prior LAW simulants used in vitrification studies at VSL. The waste simulant recipe uses metallic nitrites, nitrates, carbonates, and hydroxides of the main constituents, plus chloride, fluoride, sulfate, and phosphate salts of sodium. Components similar to those used in the formulation of LAW simulants for glass development studies for WTP and ORP were used in the formulation of the AP-105 simulant given in Table 2.2. The composition of the LAW AP-105 simulant is similar to that of LAW from Hanford tanks AN-105 and AP-101. The source of aluminum used in the simulant is aluminum nitrate, which provides almost half of the nitrate. The concentration of oxalate given in Table 2.1 of 426 mg/L is supplemented by a mixture of acetate and formate in order to reach the target TOC concentration, which is comparable to the concentrations used in the LAW simulant for Hanford tank AP-101 in previous tests at VSL.

2.2 Glass Formulation Development and Test Methods

One of the objectives of this work was to develop and evaluate a glass composition for the direct feed LAW AP-105 simulant that has high waste loading with acceptable durability and processing characteristics. The approach employed small-scale tests and crucible melts to identify high waste loading glass and feed formulations. The glass formulations for testing made use of information from the Enhanced LAW Glass Correlation that is under development [40-42]. LAW glass property-composition models [71, 72] and experience from previous work on high waste loading ORP LAW glass formulations were also utilized to identify suitable formulations for testing. The glass formulations were actively designed in that characterization data from the preceding set of crucible melts were used to design the next set of formulations. Crucible melts of the LAW glass formulations were prepared and characterized with respect to properties that affect processability and product quality (crystallization, salt formation, melt viscosity, melt electrical conductivity, refractory corrosion, VHT alteration, and PCT release). A total of eleven crucible melts were prepared and characterized to develop the glass and feed formulations. The first ten crucible melts were formulated based on the LAW simulant composition provided in Revision 0 of the Test Plan [73] while the last one was formulated based on the updated simulant composition provided in Revision 1 of the Test Plan [18]. Initial testing was limited to properties expected to be most constraining, which are VHT and K-3 refractory corrosion for high alkali glasses and sulfate solubility for high sulfate compositions. Finally, the glass composition selected for melter testing was characterized with respect to all properties relevant to processing and product quality for LAW glasses prior to melter testing.

Compositions of the eleven simulated direct feed LAW glass formulations are presented in Table 2.3. In the first series of glasses (AP105DLAW1 to AP105DLAW4), increasing Na_2O content was tested in four steps, each increasing Na_2O by 0.66 wt%, using the Enhanced LAW Glass Correlation that is currently under development [40-42] to define glass former additions. Since all four of these glasses met the property limits, subsequent composition variations were tested only at the two higher sodium contents of 23.26 and 23.92 wt% Na_2O. Boron oxide is fixed in the Enhanced LAW Glass Correlation but was tested here at two levels: at 11 wt% B_2O_3 in AP105DLAW1 to AP105DLAW4 as well as in AP105DLAW9 and AP105DLAW11, and at 10 wt% in AP105DLAW5 to AP105DLAW8. In addition, two different cases were tested for Cr_2O_3, which was tested as a decreasing linear function of SO_3 in seven out of the eleven glasses tested, and was kept at zero in AP105DLAW7 to AP105DLAW10. The best combination was found to be that at 11 wt% B_2O_3 and addition of Cr_2O_3 since it allowed the highest waste loading for a glass that met all glass property constraints, as discussed further in the following sections. Consequently, AP105DLAW11 was the final formulation designed at the maximum sodium content of 24 wt% Na_2O (or 28.75 wt% AP-105 waste). The formulations listed in Table 2.3 were designed according to the Enhanced LAW Glass Correlation and tested for various properties (Tables 2.3 to 2.9), as discussed below. For example, glass AP105DLAW11 was designed as follows:

1. The sodium content, set at the maximum of 24 wt%, defines the waste loading and also sets the values for the other waste constituents. Among them, the most abundant components in the AP-105 waste are 3.13 wt% Al_2O_3, 0.47 wt% K_2O, 0.51 wt% Cl, and 0.35 wt% SO_3. This sulfate content is not waste loading limiting.
2. Glass forming additives B_2O_3, MgO, and ZnO are held at fixed concentrations of 11.0, 1.0 and 3.0 wt%, respectively.
3. Al_2O_3 is defined as a function of ALK = Na_2O (wt%) + 0.66 K_2O (wt%) and is set at its maximum concentration of 10 wt% in the present case because ALK = 24.3 wt%. Since the waste composition contributes 3.13 wt%, the glass formers contribute 6.87 wt% Al_2O_3, as illustrated in Table 2.10.
4. CaO is increased linearly from 1.95 wt% as a function of SO_3 starting at 0.35 wt% SO_3. It is therefore set at the low value of 1.95 wt% CaO.
5. Cr_2O_3 additive is increased linearly as the SO_3 concentration decreases in the region of 1.0 to 0.1 wt% and is set at 0.46 wt% Cr_2O_3 for 0.35 wt% SO_3.
6. Fe_2O_3 and TiO_2 are both set at 0.67 wt%.

7. Li_2O is set at zero for any sulfate value below 1.11 wt% SO_3 (or for greater than 22.1 wt% ALK).
8. SnO_2 varies linearly between 0 and 1 wt% in the range of 23.33 to 24.33 wt% ALK; it is therefore close to its maximum, with a value of 0.98 wt% SnO_2 in AP105DLAW11 (for 24.3 wt% ALK).
9. No V_2O_5 is used in formulations if the SO_3 concentration is 0.4 wt% or less.
10. ZrO_2 is a function of ALK and close to its maximum at 6.01 wt% in this glass with an ALK value of 24.3 wt%.
11. Finally, SiO_2 is added to make up the remainder of the composition, once the concentrations of all other components are defined and summed; it is at 38.72 wt% in glass AP105DLAW11, with 38.70 wt% from the glass formers (Table 2.10).

The experimental procedures used in the preparation and characterization of the simulated LAW glasses are described below. The following subsections discuss the preparation of glass batches, crucible glass melting, glass composition analysis, and test procedures for PCT, VHT, melt electrical conductivity, melt viscosity, K-3 refractory corrosion, sulfate solubility, and secondary phase analysis. Testing was designed such that properties that were expected to be most constraining were measured first, so that glasses failing one property were not characterized further.

2.2.1 Glass Batching and Preparation

The target glass compositions (as percent oxides - see Table 2.3) were used to create the batching sheets providing information on the required starting materials and their weights for glass melting. These batch sheets include identification of the chemicals according to vendors and catalog numbers with the associated purity, and the amounts necessary to produce a batch size of approximately 450 to 480 g of glass. All glass samples were prepared using reagent grade or higher purity chemicals according to VSL standard operating procedures. A blender was used to mix and homogenize the starting materials before they were loaded into platinum-5% gold (Pt-Au) crucibles that are engraved with individual identification numbers.

The crucibles were placed inside a Deltech DT-29 furnace with a Eurotherm-2404 temperature controller. Glasses were melted for 75 minutes after the melt reaches a temperature of 1200°C. Mixing of the melt was accomplished mechanically using a platinum stirrer, beginning 15 minutes after the furnace reaches the target temperature and continuing for the next 60 minutes. At the end of melting, the molten glass was poured onto a graphite plate to cool. The glass sample was collected and analyzed for composition before distribution for property measurements.

2.2.2 Analysis of Glass Compositions

The compositions of the glasses were determined using XRF and DCP-AES, as described below.

The primary method used for glass composition analysis was XRF on powdered glass samples. Powdered samples of the glasses (–200 mesh) were analyzed with a PANalytical Axios^{mAX}-Advanced XRF spectrometer. The spectrometer was calibrated over a range of glass compositions using standard reference materials traceable to NIST, as well as waste glasses including the Argonne National Laboratory-Low Activity Waste Reference Material (ANL-LRM) [74], the Defense Waste Processing Facility-Environmental Assessment (DWPF-EA) glass [75], and Hanford WTP glasses. Analysis by XRF provides data for all glass components of interest except lithium and boron, which are analyzed by DCP-AES, as described below.

The glass samples were analyzed by DCP-AES after being subjected to microwave-assisted total acid dissolution in Teflon vessels according to VSL standard operating procedures. Twenty milliliters of a 1:5 mixture of concentrated HF:HNO_3 was diluted to 50 ml and used for the dissolution. This procedure is similar to the American Society for Testing and Materials (ASTM) Test Method C 1463-13, which also employs a mixture of concentrated HF and HNO_3 in microwave digestion of pulverized glass samples. However, supplemental use of HCl/H_3BO_3 is not included in the VSL procedure because boron is normally one of the analytes. The resulting solutions were analyzed by DCP-AES for all constituents except anionic species such as sulfur and halogens, which were determined by XRF.

XRF and DCP-AES (for B_2O_3 and Li_2O) analyzed compositions of the glasses are given in Table 2.3 together with the respective target compositions. The relative deviations from the target composition do not exceed 10% for any of the major oxides (those present at > 1 wt% target). With the exception of volatile components such as Cl and SO_3, the batched (target) glass compositions are expected to be more accurate than the analyzed compositions because the batched compositions are derived from simple weighings of pure chemicals. Hence, the target compositions for all major constituents, except SO_3, are believed to provide the best compositional representations of the tested glasses. All of the glasses were found to be on target compositionally and were accepted for subsequent testing.

2.2.3 Secondary Phases

The glasses collected from the crucible melt were visibly clear, generally lime to emerald green in color when chromium was used as an additive, or very pale yellow and nearly colorless when chromium was not used; less than 1 wt% V_2O_5 and small amount of Fe_2O_3 are not sufficient to yield much coloration. They showed no evidence of crystalline secondary phases.

All glass samples were also heat-treated for 20 hours at 950°C after a one-hour pre-melt at 1200°C and the results are presented in Table 2.4. All heat-treated samples remained clear and free of crystals under optical microscopy (up to 200 X magnification). All glass samples were further evaluated by scanning electron microscopy (SEM) coupled with energy dispersive X-ray spectroscopy (EDS) with no evidence of crystallization detected. One such evaluation is presented in Figure 2.1 for AP105DLAW11C950H20; all other samples appeared similar.

2.2.4 Sulfate Solubility

Sulfate solubility was determined by over-saturation tests on all AP105DLAW crucible glasses. In this method, sulfate solubility is determined by re-melting a small amount of the glass batch with an excess of sulfate such that a molten salt phase forms on the surface of the glass melt. The sulfate solubility is then determined by analyzing the chemical composition of the glass melt in equilibrium with the molten sulfate phase at the designated test temperature. The glass sample is ground and sieved to pass 40-mesh and then thoroughly mixed with reagent grade sodium sulfate. The amount of sulfate added was equivalent to 4 wt% SO_3 in the glass if all of the sulfur was retained in the glass. The glass/sulfate mixture was loaded into a Pt/Au crucible with a cover and re-melted at 1150°C for 1 hour. The crucible was then cooled naturally to room temperature and the glass recovered for examination. Washing of glass pieces to remove the salt phase was followed by grinding (<200 mesh) and then washing of the glass powder to ensure removal of all sulfate salts. Analysis of SO_3 in the powdered glass samples (denoted S4 after grinding and S4W after powder-washing) provides an estimate of sulfate solubility. Results are provided in Table 2.5. For all glasses, the solubility limit is found to exceed the value of 0.35 wt% SO_3 for waste AP-105 as defined by the maximum of 24 wt% Na_2O in the glass. As expected from the correlation design, this sulfate content is not waste loading limiting.

2.2.5 Melt Viscosity and Melt Electrical Conductivity

The melt viscosity (η) of each glass was measured using a Brookfield viscometer with a platinum-rhodium spindle and crucible. The relative torque of a rotating spindle immersed in molten glass was measured as a function of rotational velocity (revolutions per minute (RPM)) at temperatures around 950, 1050, 1150 and 1250°C. The viscosity of the molten glass was then calculated from the collected data of torque versus RPM. The equipment was calibrated using viscosity standard oils and checked periodically using a NIST traceable standard reference glass. To facilitate comparison, the viscosity data were interpolated to standard temperatures (e.g., from 950 °C to 1250°C) using the Vogel-Fulcher equation:

$$\ln \eta = [A/(T-T_o)] + B, \tag{2.1}$$

where A, B, and T_o are fitting parameters.

Per current WTP requirements, glass melts should satisfy the viscosity limits of 10 to 150 poise at 1100 ºC, with the preferred range being 40-80 poise at 1150ºC [76].

The electrical conductivity (EC) of each glass was determined by measuring the impedance of the glass melt at temperatures around 950, 1050, 1150 and 1250ºC as a function of AC frequency using a calibrated platinum-rhodium electrode probe attached to a Hewlett-Packard model 4194A impedance analyzer. The collected impedance data were analyzed to obtain the DC electrical conductivity. The probe (analyzer along with the crucible to assure that the geometry is replicated) was calibrated and checked periodically using NIST traceable standard reference materials. To facilitate glass to glass comparison, the electrical conductivity data were interpolated to standard temperatures (e.g., 1150ºC) using the Vogel-Fulcher equation:

$$\ln \mathrm{EC} = [A/(T-T_o)] + B \qquad (2.2)$$

where A, B, and T_o are fitting parameters.

The current WTP requirement is that glass melt EC be in the range of 0.1 - 0.7 S/cm at 1100 – 1200 ºC [76].

The measured values of viscosity and electrical conductivity interpolated to standard temperatures from 950ºC to 1250ºC are given in Table 2.6 for nine AP105DLAW glasses. Values predicted using the enhanced LAW glass property-composition models [71, 72] and measured values show good agreement. The melt viscosity at the melter operating range varies from 53 poise at 1150ºC to 90 poise at 1100ºC for AP105DLAW11, and up to 162 poise at 1100ºC for AP105DLAW1. These melt viscosity values are within the WTP limits, and within the preferred range (40-80 poise at 1150ºC) for the selected glass AP105DLAW11. EC values range from 0.393 S/cm at 1100°C for AP105DLAW1 to 0.679 S/cm at 1200°C for AP105DLAW2. All of the measured EC values are also within acceptable ranges for WTP operations [76] and well within the limits for the selected formulation AP105DLAW11.

2.2.6 Product Consistency Test (PCT)

The PCT was conducted using 4 g of crushed glass (100-200 mesh, 75-149 μm) placed in 40 ml of test solution (de-ionized water) inside 304L stainless steel vessels. These test conditions result in a ratio of the glass surface area to the solution volume of about 2000 m^{-1}. The PCT was performed at 90ºC for 7 days according to ASTM C 1285 [77], in accordance with the current WTP contract requirement [78]. All tests were conducted in triplicate, in parallel with the ANL-LRM glass standard for LAW glasses [74] included in each test set. Leachates were sampled after seven days: one milliliter of sampled leachate was mixed with 20 ml of 1M HNO_3 and the resulting solution analyzed by DCP-AES. Another 3 ml of sampled leachate was used for pH measurement.

PCT results are summarized in Table 2.7 and shown in Figure 2.2. From the figure, it is clear that all of the normalized PCT releases are well below the contractual limit of 2 g/m^2 [78]. These results are generally consistent with predictions from PCT models [72] and found to be very close to or a little below the predicted values.

2.2.7 Vapor Hydration Test

The vapor hydration tests were run in Parr series 4700 screw-cap pressure vessels made of 304L stainless steel and having either 22 or 45 ml capacity, in accordance with the corresponding VSL procedure which conforms to ASTM C 1663 [79]. Glass coupons were cut and polished, dimensional measurements were taken to permit calculation of the area, and the coupons were weighed before and after the VHT on a balance having a resolution of 100 μg. Coupons were suspended from a hanger in the pressure vessel and enough de-ionized water was added to the vessel to saturate the volume at the test temperature of 200ºC and to allow for a non-dripping layer covering the coupon. The pressure vessels were sealed, weighed on a high capacity balance having a resolution of 1 mg, and placed in an oven held at 200ºC. The temperature was monitored continuously with an independent calibrated thermocouple. At the completion of the test, the pressure vessels were removed and immediately partially immersed in an ice/water bath to condense the water vapor near the bottom of the vessel. Once cool and dry, the vessel was weighed. If the difference in the mass of the sealed pressure vessel before and after the test indicated a water loss in excess of 50% of the original amount, the test results were discarded (none were discarded in the set reported here). If the weighing indicated an acceptable test, the pressure vessel was then opened and if the coupon had not fallen from its hanger during the test, it was removed and weighed. Post-VHT coupons were placed on an optical scanner and the scanned images examined and stored for future reference. Coupons were mounted whole in epoxy in a standard 1-inch diameter SEM mounting cup with the broad surfaces supported vertically so that subsequent grinding and polishing would produce a representative cross-section of the reacted layer and the remaining glass for SEM examination and measurement. For consistency with existing data, the nominal test duration was 24 days.

For an average reacted layer thickness greater than 100 microns, the layer thickness (which can be uneven) was determined by measuring the remaining glass thickness at ten points throughout the cross-section of the coupon and subtracting the average remaining thickness from the original thickness of the coupon and dividing that value by 2. For average layer thickness less than or equal to about 100 microns, the thickness of the altered layer was measured directly at 3 points in each of 6 evenly spaced regions of the coupon using the digital caliper in the SEM software package and the resulting set of 18 measurements was averaged.

WTP Contract Specification 2 [78] requires that the VHT alteration rate determined from tests of seven days or longer duration be below 50 g/m^2/day. If it is assumed that the altered layer density is not appreciably different from that of the glass, the mean glass alteration rate over the test interval (r in g/m^2/d) is related to the measured altered layer thickness D in microns by:

$$r = \rho D/t, \tag{2.3}$$

where ρ is the glass density in g/cm^3 and t is the test duration. Under this assumption, for a typical glass density of 2.65 g/cm^3, a layer thickness of 453 microns in a 24-day VHT would correspond to a mean glass alteration rate of 50 g/m^2/day.

The VHT alteration depths (in µm) and alteration rates (in g/m^2/d) are given in Table 2.8 for the AP105DLAW glasses (eleven predicted and nine measured). The model-predicted alteration rates [72] are given in the last column of the table for all formulated glasses and compared to the measured values in Figure 2.3. Both the predicted values and the VHT alteration rates measured for these glasses were below 50 g/m^2/d. The highest measured VHT alteration rate of 32.2 g/m^2/d for glass AP105DLAW8 is close to, but slightly lower than the predicted alteration rate of 38.9 g/m^2/d. For the selected glass AP105DLAW11, the measured VHT alteration rate is 26.5 g/m^2/d, also lower than the predicted value of 32 g/m^2/d. The difference is well within the variability in the VHT alteration rate measurement estimated from multiple replicates at 40% RSD [72]. Even with the variability shown by the error bar in the graph, the selected glass meets the glass alteration rate limit of 50 g/m^2/day.

Examination of the alteration layers on the VHT coupons with SEM showed large crystals of Na-aluminosilicate (likely analcime) on top of sodium-depleted alteration layers.

2.2.8 Refractory Corrosion

The Monofrax™ K-3 refractory corrosion tests were conducted using a modified ASTM refractory corrosion test procedure (ASTM C621 [80]), building on experience gained from extensive refractory corrosion tests at the VSL. The primary modification is the addition of gas bubbling during testing in order to better represent the conditions in the bubbled WTP melters.

For this test, K-3 test coupons are cut from K-3 refractory bricks. Since the material that forms fused-cast K-3 varies from the surface of the brick to its interior (e.g., the interior material tends to contain larger and more numerous pores), the test coupons are cut from material within one inch of the brick surface. All sides of the K-3 coupons are ground parallel with a precision of better than 2 mil (0.002”). A typical K-3 coupon measures 0.6 × 0.4 inches in cross-section and is long enough (~ 3 inches) to be immersed in the molten glass to a depth of one inch.

For each test, the K-3 test coupon is first cemented to a crucible cover made of Zirmul and baked. Before starting the corrosion test, the baked coupons are preheated and then positioned in a 200-ml platinum crucible containing 170 grams of pre-melted glass. A platinum sheet covers the glass to ensure that it cannot be contaminated by Zirmul. The platinum crucible containing the K-3 coupon and molten glass is set inside a quartz crucible holder, which is then placed in a box furnace preheated to about 800°C. After the furnace reaches the designated test temperature (nominally 1208°C), a platinum bubbling tube is introduced into the molten glass from above through a slot in the Zirmul/platinum cover. Dry, room temperature air is bubbled through the molten glass at a constant rate of 8 cc/minute controlled by a precision flow meter. The bubbling rate, i.e., the number of gas bubbles generated inside the melt per minute, is monitored using a pressure transducer interfaced to a computer via an A/D converter. The temperature of the furnace is monitored using an S-type thermocouple positioned above the crucible inside the furnace and checked before each test against a calibrated S-type thermocouple. The standard glass-contact corrosion test is run for six days at 1208°C with continuous air bubbling. All K-3 corrosion tests are performed at the same *refractory surface area (S) / melt volume (V)* ratio of about 0.20 cm^{-1}, which is 74% less than the S/V ratio specified by the ASTM C-621-84 for static glass contact corrosion tests. Fresh K-3 test coupons are used for each corrosion test. At the end of each test, the K-3 coupon is removed from the melt and cooled to room temperature in a clean quartz crucible. The coupon is then sectioned lengthwise to facilitate measurement of dimensional changes. Per ASTM C-621, the dimension losses at the "neck" (the glass-air interface) and the "half-down" (half of the immersed length of the coupon below the neck) locations are reported.

The acceptability of the corrosion characteristics of a glass composition is somewhat subjective because a glass composition that shows slightly higher K-3 corrosion, but which allows higher waste loading, may be a more economical choice than one with lower K-3 corrosion and lower waste loading. However, for WTP LAW glass formulation development, a neck corrosion of 0.035 inches on a 6-day K-3 coupon corrosion test at 1208°C has been used as an acceptance limit. A temperature about 50°C higher than the nominal melter operating temperature of 1150°C was selected for these tests so that a measurable amount of corrosion will be observed on a 6-day test. For the ORP LAW glass formulations, since higher waste loading compositions are being explored, a slightly higher neck corrosion value of 0.040 inches has been used as a guide for acceptable refractory corrosion characteristics. The corrosion limits were adopted based on the observations given below.

The K-3 corrosion limits specified for the LAW glasses can be correlated to the observed refractory corrosion in the one-third scale LAW Pilot Melter, in which more than 15 LAW glass compositions were processed. These glasses had neck corrosion losses ranging from about 0.009 to 0.0334 inches with a mean of about 0.025 inches per the modified ASTM procedure. After nearly five years of operations, K-3 refractory loss at the neck region in the LAW Pilot Melter ranged from 4 to 5 inches through a combination of uniform corrosion and spalling [81]. Similar results regarding contact K-3 refractory corrosion rates were obtained from the M-Area melter operated by Atkins at SRS, even though it was operated for only about one year. With a total K-3 refractory thickness of 17 inches for the WTP LAW Melter (12-inch glass contact K-3 refractory with 5-inch backup K-3 brick) the proposed corrosion rate limits are adequate for the melter design life of five or more years. With the proposed K-3 refractory corrosion rate limits, the melter failure mechanism is highly unlikely to be the glass contact refractory.

K-3 corrosion tests were conducted on seven AP105DLAW glasses, and the results are given in Table 2.9, along with model predicted values [81] for all formulations. The corrosion is generally higher when chromium is not used, particularly at the higher waste loading (AP105DLAW8 or AP105DLAW10 for which the neck loss was predicted to be above the limit of 0.040"). The measured values were somewhat lower than predicted, with AP105DLAW11 showing a measured neck corrosion value of 0.026” (predicted 0.030”), as shown in Figure 2.4.

2.3 Glass Formulation Selection

The above crucible scale testing on selected glass formulations for the direct feed LAW from Tank AP-105 permitted identification of a high waste loading glass composition, AP105DLAW11, which meets all the WTP product quality and processing requirements. A summary description of the glass composition showing the respective contributions of waste and glass former additives is given in Table 2.10 along with key glass properties and their respective contractual limits. This formulation was used as the basis for feed tests at various concentrations, and as feed for melter tests.

2.4 Effect of LAW Concentration on Feed Properties

Prior to conducting the melter tests, a series of melter feeds were subjected to physical and rheological characterization to investigate the effects of LAW concentration on these properties over the concentration range of interest. Melter feeds were prepared at three solids contents by blending the LAW AP-105 simulant with glass former additives targeting the AP105DLAW11 glass composition, as shown in Table 2.11. Three simulant concentrations were tested: the WTP baseline concentration of 8 M Na, the projected direct feed concentration of 5.6 M Na, and a diluted concentration of 4 M Na. The waste component types and masses are given in the upper section of Table 2.11. The additive types, which remained the same for each feed, and amounts, are listed in the lower part of Table 2.11. On a per-kilogram of glass basis, the feeds differ only in the amount of water, which affects the total volume produced for each. Each feed is distinguished by the molarity of sodium as an expression of the waste concentration. Each feed was produced using reagent grade chemicals, and the same glass forming additives planned for use at the WTP, with the exception of chromium and tin, which are new additives used in AP105DLAW11. The three feed concentrations, with sodium molarities in the LAW simulant set at 4 M, 5.6 M, and 8 M, were analyzed for viscosity, yield stress, and settling rate to provide data to document the rheological behavior of each feed to be processed through the DM10 and DM100 melters. The measured apparent viscosity is also compared to bounding conditions for LAW melter feeds defined for the WTP [83-86]. In this report, any reference to a feed of a specific sodium molarity is a reference to the feed made from a LAW simulant of that particular molarity. For example, a feed prepared from a 4 M Na LAW AP-105 simulant is referred to as a 4 M AP105DLAW11 feed; the nomenclature used for the feed samples is AP105DFL4, AP105DFL5p6, and AP105DFL8 for the feed samples prepared from waste simulants at 4 M, 5.6 M, and 8 M, respectively.

2.5 Analytical Methods for Feed Analysis

2.5.1 Feed and Waste Simulant Density

Densities were measured by weighing a known volume (ranging from 100 to 1000 ml) of the material. Slurry samples were thoroughly mixed and homogenized before being placed in pre-weighed graduated cylinders for these measurements. Bulk density of the slurry feeds only was measured in this work.

2.5.2 Feed and Waste Simulant pH

Waste simulants and feed slurry samples were thoroughly mixed before pH measurement with an Accumet Research pH meter (AR15 or AR50) calibrated with buffer standards and equipped with an automatic temperature compensation probe.

2.5.3 Feed Total Solids Content and Glass Yield

Feed solids contents were determined by drying (110°C for 24 hours) and weighing of the resulting solids. Homogenized slurry samples were placed in pre-weighed beakers or platinum/gold crucibles and weighed before drying in an oven at 110°C for at least 24 hours. Dried samples were allowed to cool to room temperature in a desiccator before weighing to determine the solids content. The dried solids were then melted in a furnace at 1150°C for 1 hour before cooling and weighing. The difference between the weight of the original wet slurry samples and the final weight of the glass were used in the calculation of glass yield.

2.5.4 Feed Solids Settling Rate and Settled Solids Volume Percent

Settling rates were measured after re-suspending the slurries. The measurements were made using a 1.3 liter settleometer cylinder as well as smaller volume Imhoff cones according to VSL procedures [69]. Observations and recordings of the location of the solid-liquid interface continued periodically over a period of up to three days or until the settling appeared to be complete. The settled solids volume percents were calculated by dividing the settled solids volume by the total sample volume. Sample measurements were conducted at room temperature.

2.5.5 Feed Rheological Properties

Melter feeds were characterized using a Haake RS6000 rheometer, which can be equipped with multiple sensors (Z41, Z40, Z35) for viscosity measurements or an FL16 sensor with Z40 cup for yield stress determination. A typical set of measurements consists of identifying the flow characteristics of the slurry by measuring the shear stress on the slurry at controlled shear rates and temperature (25°C). In these measurements, the shear rate values are preset and are increased stepwise from 0.01 s^{-1} to 1000 s^{-1}, with a sufficient delay (typically 15 to 30 seconds) between steps to ensure that shear stress is allowed to fully relax, and, therefore, is measured at equilibrium. The apparent viscosity of the sample as a function of the shear rate is then calculated as the ratio of the shear stress to the shear rate. The yield stress data were measured using a torque maximum method in which the yield stress is calculated from the maximum torque obtained from the torque versus time curve [87].

2.6 Properties of Melter Feeds at Three Solids Contents

2.6.1 Preparation and Characterization of Waste Simulants

LAW AP-105 simulants were prepared at sodium molarities of 4, 5.6, and 8 using the recipes provided in Table 2.11. To reach the concentrations of 4 and 5.6 M Na, a simple dilution of the 8 M recipe was required, but the amount of water needed to reach the exact final volume was verified in laboratory tests to account for deviation from ideal solutions. Densities of waste simulants were measured by weighing a known volume of the simulant (1000 ml). The water addition was adjusted after the simulant mixture was left to cool overnight because the simulant temperature rises considerably, up to about 40°C, during mixing. The measured densities are given in Figure 2.5 and Table 2.12. As shown in Figure 2.5, the densities measured on LAW AP-105 simulants at three dilutions compare well to the results from tests conducted previously at VSL for various dilutions of simulated LAW from tank AN-105[12].

2.6.2 Feed density

Melter feeds were prepared at three dilutions for LAW AP-105 simulants described above by addition and mixing of glass formers (Table 2.11). The measured feed densities are presented in Figure 2.6, showing that the density increases linearly with the sodium molarity in the waste [Na], as was previously noted with the AN-105 feed, ORPLA20 [12].

2.6.3 Feed and Waste Simulant pH

The measured pH values of feed samples are given in Table 2.11. The pH values increase slightly with sodium molarity, ranging from 11.51 to 11.94, as the sodium concentration increases from 4 M to 8 M. These are lower than previously measured feed pH values [12], which is expected since the present feed contains a higher amount of boric acid (11 wt% B_2O_3 in glass, versus ~9 wt% in previous tests [12]).

2.6.4 Feed Total Solids Content and Glass Yield

Feed total solids contents determined by drying and weighing of the resulting solids are given in Table 2.12. The water contents of the feeds are presented in Figure 2.7. From these, the total solids contents in g/kg of feed and, based on the measured feed density, in g/L of feed were calculated (Table 2.12). As expected, the solid content increases with the concentration of the simulant. A very small offset in the water content places the AP-105 feed series about 3 to 4% above from the previous tests for AN-105 likely due to the differences in the waste compositions and glass former additives.

Measured glass yields are given in Table 2.12, both on a per kg of feed and per liter of feed basis. These values are compared to those obtained in previous tests for LAW AN-105 and formulation ORPLA20 in Figure 2.8.

2.6.5 Feed Solids Settling Rate and Settled Solids Volume Percent

Data on the settling behavior of the AP105DFL feeds at the three concentrations are given in Table 2.13. Tests were initiated on slurry feeds that were re-suspended about one day after their preparation, at room temperature, in triplicate (one larger sample was tested in settleometer cylinder and two more samples in 10 ml Imhoff tubes noted A and B in Table 2.13). The results shown in Figure 2.9 show large differences in the settling behavior as the concentration changes, with as much as a factor of five difference in settling rates between the highest (8 M Na) and lowest (4 M Na) concentrations tested. At 4 M Na, settling is rapid, with a rate as high as 40 vol% per hour at the onset (within the first hour), while for the highest concentrations (8 M) the settling rate is about 8 vol% per hour, for the first three hours. Feeds of all three concentrations tested mostly settled to steady state values within 5 hours. The effect of feed concentrations on settling is evident with the settled volumes ranging from 40% to 70% for feeds with sodium molarities ranging from 4 M to 8 M.

It is clear from these results that feeds with higher sodium concentrations remain better suspended and are slower settling. If the direct feed LAW flowsheet uses feed at the lower concentrations it will be necessary to determine whether these high settling rates are an issue and, if so, potential mitigation methods.

2.6.6 Feed Rheological Properties

Rheological testing, consisting of shear stress (σ) vs. shear rate (γ) and yield stress determination, were conducted at 25°C within three days of feed preparation at the three concentrations described above. The measured apparent viscosities were also compared to the bounding conditions for LAW melter feeds defined for the WTP [83-86], partly to verify that the 5.6 M Na feed could be used for the subsequent melter tests.

The shear stress versus shear rate data presented in Figure 2.10 show close to a linear relationship, indicating a near Newtonian behavior for feeds at all three concentrations; although not noticeable on the figure, at the lowest shear rates, the feeds exhibit shear-thinning, which is better seen in the plot of viscosity in Figure 2.11. As is evident from Figure 2.10, all of the feeds show shear stress values that are well within the WTP operational limit. Similarly, effective feed viscosities as a function of shear rate given in Table 2.14 and Figure 2.11 show significant changes in viscosity with shear rate up to about 50 s^{-1} but remain essentially constant at higher shear rates.

The yield stress values that can be estimated from extrapolation to zero shear rate in Figure 2.10 (nearly zero) agree with the very low values measured at maximum torque and presented in Table 2.15. The yield stress values for all of the feeds are close to zero and thus well below the operational limits for the WTP.

2.7 Sugar Additions

With high nitrate feeds, the addition of reductants is necessary in order to control melt foaming. Sugar, which was used for this purpose at West Valley, has also been selected as the baseline reductant for the WTP. The amount of sugar required increases with the amount of nitrates present in the feed and decreases with the amount of waste organics present in the feed, which themselves act as reductants. Excessive additions of reductants can be deleterious, leading to over-reduction of the melt and formation of sulfides and molten metals. Consequently, the oxidants and reductants in the feed must be suitably balanced. The basis for achieving this balance was developed by VSL and Atkins for the vitrification of high-sodium-nitrate feeds at Savannah River's M-Area and has been successfully applied to the processing of a wide variety of simulated WTP feeds. In developing this approach, we elected to conservatively adopt the most reducing potential reaction as the basis for the *definition* of a "sugar" or stoichiometric ratio of 1.0 as a result of concerns for over-reducing the melt. Such a reaction, using sodium salts as an example, is:

$$C_{12}H_{22}O_{11} + 8NaNO_3 = 8CO_2 + 4CO + 4N_2 + 11H_2O + 4Na_2O$$

Fundamentally, the basis that is selected is simply a convention, since the precise stoichiometry of the reactions involved is neither known nor constant under the conditions prevailing in the melter. However, with this convention, a sugar ratio of 1.0 corresponds to one mole of sucrose per eight moles of nitrate or, more generally, 1.5 moles of organic carbon per mole of nitrate. It is then expected that significantly less sugar than this will be required in practice. The empirically determined amount required to successfully control melt foaming without significantly reducing the glass melt was found to correspond to a ratio of 0.5 when any nitrites present were counted as nitrates (i.e., 0.75 moles of organic carbon per mole of nitrate + nitrite). This approach has been employed for all WTP melter testing [33-37, 43-66]. It is, however, expected that slight variations around the nominal value of 0.5 may be necessary to account for differences in the reducing power of waste organics in comparison to sugar, particularly for LAW streams that are high in organics.

As an example, the calculation of the amount of sugar needed for the present LAW AP-105 feed to achieve a sugar ratio of 0.5 proceeds as follows:

- One liter of 5.6 molar sodium simulant contains 1.1499 moles of nitrite and 1.7106 moles of nitrate, giving a total of 2.8605 moles of NOx (see Table 2.2)
- The required total amount of organic carbon for a sugar ratio of 0.5 is 2.8605 × 0.75 = 2.145 moles
- One liter of simulant contains 0.2327 moles of organic carbon (see Table 2.2)
- Therefore, 2. 145 – 0.2327 = 1.913 moles of organic carbon must be added.

Since the molecular weight of sucrose is 342 g, 1.913 × 342/12 = 54.51 g sugar must be added per liter of simulant, as shown in Table 2.11 for the 5.6 molar waste stream.

2.8 Preparation of Melter Feed

The feed used for melter testing was augmented to account for the recycle of volatile constituents back to the melter feed. Radioactive waste vitrification systems are typically designed in such a way that a significant fraction of the radionuclides and other contaminants of concern that exit the melter in the off-gas stream is captured in the off-gas system and recycled back to the melter feed. This is the case for the WTP melter systems, where the liquid waste streams from the primary off-gas system components are recycled back to the pretreatment facility and, ultimately, to subsequent melter feed batches. Such a recycle loop results in increased concentrations of volatile constituents such as halides and sulfur in the waste feed, which are ultimately fed to the melter. In previous tests processing high alkali LAW waste simulants [44, 48, 50], sulfate, chlorine, and fluorine were increased by 17.65%, 111%, and 19%, respectively, based on projections at steady state using measured melter decontamination factors to account for the contribution from the recycled stream [88]. Sulfur, chlorine, and fluorine from recycle streams were added as the respective sodium salts. Subsequently, a DM10 equipped with prototypical primary off-gas system components and the capacity to concentrate and recycle primary off-gas system effluents has been operated and tested at VSL [13-15, 89]. Enrichments of sulfate, chlorine, and fluorine while processing high alkali LAW waste simulants were measured as 2.5%, 59.7%, and 0.7%, respectively [89]. These enrichment factors were used for determining sulfate and halide concentrations in the simulated waste streams processed in the present tests, as shown in Table 2.16. The sodium concentration was not increased in response to recycle.

Sufficient feed was prepared to conduct all of the testing reported herein as a single batch of 8 M sodium feed. Optima Chemicals, which has supplied all of the LAW simulants for the previous DM10, DM100, DM1200, and LAW Pilot Melter studies, prepared the simulants and added the glass forming chemicals before shipment to VSL in 55-gallon drums. The feed was sampled by Optima Chemicals and the sample sent to VSL to verify solids chemical composition prior to shipment of the entire batch to VSL. The glass former additives shown in Table 2.11 are the same as those planned for use at the WTP, with the exception of chromium and tin, which would be new additives. Feed produced by Optima was complete except for the rhenium spikes and sugar which were added to the feed at VSL prior to testing. In a manner analogous to previous tests [10, 14-17, 38-42], perrhenic acid solutions (50 wt% Re metal) were spiked into the melter feed corresponding to 0.01 wt% ReO_2 if all were retained in the glass. Tap water was added to the 8 M sodium feed to produce the 5.6 and 4 M sodium feeds.

SECTION 3.0
DM100 MELTER OPERATIONS

A series of three tests were conducted on the DM100-WV melter between 2/22/17 and 3/17/17 to determine glass production rates over a range of feed water contents. The AP105DLAW11 glass composition, LAW AP-105 waste simulant, and corresponding glass forming additives, which are all described in Section 2.0, were processed in each test at the nominal glass pool temperature of 1150°C. These three tests conducted in nominally 50-hour test segments produced nearly two and a half metric tons of glass from approximately five metric tons of feed. Summaries for all of the tests are provided in Table 3.1. The tests were divided as follows:

- 8 M Na waste simulant and glass formers processed with bubbling adjusted to achieve a glass production rate of 2250 kg/m^2/day. The steady state average bubbling rate of 14 lpm measured in this test was then used in all subsequent tests.

- 5.6 M Na waste simulant and glass formers processed with bubbling fixed at 14 lpm.

- 4 M Na waste simulant and glass formers processed with bubbling fixed at 14 lpm.

Attempts were made to replicate the melter configuration and operating conditions used in previous LAW Sub-Envelope [2-6, 12, 38, 40-54] tests on the DM100-WV melter. These conditions include a near complete cold cap, which is between 80-95% melt surface coverage for the DM100 since a 100% cold cap tends to lead to "bridging" in smaller melters. Cold cap conditions were mostly similar to those experienced in previous DM100 tests with LAW simulants. The target glass production rate of 2250 kg/m^2/day was approximated over the majority of the initial test, as depicted in Figure 3.1.a. Melt pool bubbling flow rate averaged 14 lpm during steady processing in this test and therefore the bubbling rate was held constant at this rate in all subsequent tests. This was the same level of bubbling required to achieve the production rate of 2250 kg/m^2/day with the 8 M Na AN-105 simulant and the ORPLA20 glass composition [12]. Deposits formed along the walls of the melter after discharging glass, which lowered the glass level in the melter leaving material adhering to the walls out of contact with the molten glass. Manual methods used on average every six to ten hours (or every 3 to 8 discharges) readily dislodged these soft deposits from the walls onto the cold cap surface. This frequency was less than when processing other high sodium compositions, which required deposit removal as frequently as every glass discharge [12, 40, 41]. Occasionally, liquid would pond on the cold cap surface and abruptly flow to the melt pool surface causing minor excursions in melter pressure. Short, routine interruptions were required during testing to transfer feed to the feed tank. No foamy glass was observed in any of the glass discharges.

Glass production rates calculated by the amount of glass discharged, and slurry feed rate using both the target and measured glass conversion ratios are provided in Table 3.1. Glass production rates as moving hourly and cumulative averages while processing the AP105DLAW11 glass composition and three different feed water contents are illustrated in Figures 3.1.a – 3.1.c. Cumulative production rates based on the amounts of materials fed and the target glass conversion ratios are compared for the three tests in Figure 3.1.d. The measured glass conversion ratios were about six percent lower than the target and therefore glass production rates calculated with the measured conversion ratios are correspondingly lower than those calculated from target ratios. The average production rate calculated from the amount of glass discharged was closer to the glass production rates calculated using the measured glass conversion ratio suggesting that the actual conversion ratio is closer to the measured value. Steady state processing rates approximate the average processing rates for much of the three tests as a result of the consistent operation over the course of each test. Production rates increased with increasing feed solids content from 1600 kg/m^2/day with 4 M Na waste, to 1900 kg/m^2/day with 5.6 M Na waste, to 2250 kg/m^2/day with 8 M Na waste. Steady state glass production rates from the present tests are compared to rates obtained while processing the ORPLA20 composition at multiple solids content [12] in Figures 3.1.e and 3.1.f. Both sets of results confirm expectations that glass production rates increase with decreasing feed water over most of the range of solids contents tested; only at the highest solids content associated with 12 M Na waste was a decrease in production rate observed [12]. The amount of bubbling required for processing both 8 M Na wastes with about 40% water at 2250 kg/m^2/day was similar, suggesting that feed solids and water content are important determinants for processing rate. Production rate increases were 45 and 33 kg/m^2/day for each percentage of feed water decrease for the ORPLA20 and AP105DLAW11 compositions, respectively. Similarly, production rate increases were about 160 and 110 kg/m^2/day for each mole increase in sodium waste concentration for the ORPLA20 and AP105DLAW11 compositions, respectively. The differences in the processing rate increase between the two compositions is possibly because the testing with the AP105DLAW11 composition covers a larger range of water contents at lower solids contents, while the testing with the ORPLA20 composition covered a larger range of waste Na molarities at higher solids contents.

The results of various operational measurements that were made during these tests are given in Table 3.2. Melt pool bubbling rates are shown in Figures 3.2.a – 3.2.c, glass temperatures in Figures 3.3.a – 3.3.c, plenum temperatures in Figures 3.4.a – 3.4.c, electrode temperatures and melt pool resistance in Figures 3.5.a – 3.5.c; electrode power is included in Figures 3.4.a – 3.5.c. The target bubbling rate of 14 lpm was maintained while processing 4 and 5.6 M Na wastes, as intended. Test segment average bulk glass temperatures, as indicated by the thermocouples located at four and ten inches from the bottom of the melt pool, averaged within four and ten degrees of the target glass temperature of 1150°C, respectively. Glass temperatures near the top of the melt pool, at sixteen inches from the melter floor, were about 100°C colder as a result of gradients near the cold cap and therefore are not reliable indicators of bulk glass temperatures. The glass level in the melter is maintained below eighteen inches from the melter floor; therefore, temperatures measured in the thermowell at nineteen inches above the floor are actually above the glass pool and thus reflect the temperature within the cold cap or plenum space and not the molten glass. Plenum temperatures typically ranged from 450 to 600°C once the cold cap was established indicating near complete coverage of the melt pool surface with melter feed. Higher plenum temperatures occurred during the first ten to fifteen hours of each test as the cold cap was being established and the upper melter refractories cooled down. Plenum temperatures measured by the exposed thermocouple were about

10°C higher than those measured in the thermowell due to more direct exposure to the glass surface during the first two tests; temperatures measured by the exposed thermocouple in the last test were on average 5°C lower than in the thermowell, indicating that the exposed thermocouple was partially shielded from the glass surface. The west electrode temperatures averaged between 1080 – 1093ºC, which was about 100ºC higher than the east electrode temperature. The difference in temperature between the side electrodes is probably due to the sensitivity to the placement of thermocouples in the electrodes and therefore not reflective of an overall temperature difference between the sides of the melter.

A significant fraction of the power supplied to the electrodes is used to evaporate water and thus the amount of power used in each test varied with the amount of water in the feed and the processing rate. The highest test average power consumption was 27.2 kW while processing the 4 M Na waste, which has the highest water content; the lowest test average power consumption was 23.9 kW while processing the 8 M Na waste, which has the lowest water content. Power consumption while processing the 5.6 M Na waste was almost as high as while processing the 4 M Na waste due to the higher processing rate offsetting the higher water content of the more dilute feed. The power typically varied within 3 kW from the average values once steady state processing conditions were established during each test. As expected, melt pool resistance decreased from 0.075 ohms over the initial test in response to the increasing sodium and decreasing calcium concentrations in the glass. Due to uniform operating conditions and the lack of significant compositional change in the glass pool, the glass resistance varied within the narrow range of 0.04 to 0.05 ohms from the midpoint of the initial test to the end of the last test.

The gas temperature at the film cooler averaged between 296 and 298°C and depended on the plenum temperature, the amount of added film cooler air, and the temperature of the added film cooler air. A small drop of about fifteen to twenty degrees in gas temperature was observed across the (insulated) transition line; the high temperature is maintained in order to prevent condensation in the downstream filtration units.

SECTION 4.0
DM10 MELTER OPERATIONS

A melter test was conducted with the LAW AP-105 5.6 M Na simulant and AP105DLAW11 glass composition on the DM10 system with prototypical primary off-gas system components (SBS and WESP) from 3/28/17 to 3/31/17. This test investigated the retention of rhenium and other volatiles in glass and generated off-gas effluent solutions from prototypical melter off-gas system components. The test produced nearly 100 kg of glass from 270 kg of feed. Table 4.1 provides summaries of the DM10 test, including run times and dates, the percent of rhenium and other volatiles measured in the glass product, the amount of glass discharged, and the amount of feed processed.

4.1 DM10 Tests

For this test, the nominal melter operating conditions for testing were an 1150°C glass pool temperature and air bubbled through the glass pool at a rate to achieve target glass production rate of 1900 kg/m^2/day, producing nearly 100 kg of glass during the test. The targeted glass production rate of 1900 kg/m^2/day was taken from the DM100 test with the same feed (see Section 3.0). The test was conducted with the same LAW AP-105 5.6 M Na simulant and AP105DLAW11 glass composition, waste/feed solids content, glass forming additives, and sugar as an organic reductant at a stoichiometric sugar ratio of 0.5 as was processed on the DM100. The feed was spiked with perrhenic acid targeting 0.01 wt% ReO_2 in the product glass assuming total retention of the amount in the feed. Sufficient feed was processed in the test to pass a volume of water greater than three times the SBS sump volume of 135 liters (i.e., to reach three turnovers of the SBS sump) through the SBS as either blow down solutions or moisture carried downstream. The same prototypical operating conditions for the off-gas system components such as SBS operating temperature of 45°C, transition line spraying every 12 hours, and daily deluge of the WESP were used. A mass balance for rhenium and other feed constituents of concern was measured across the glass pool, discharge glasses, melter exhaust, off-gas system component effluent solutions, and WESP exhaust over the course of the test.

At the end of the test, dip samples were taken to provide samples for analysis of the glass pool, to detect the presence of separated sulfur phases on the glass pool surface, and to provide an indication of the amount of glass in the melter (via a rod extended to the melt pool floor). All discharge and dip glass samples were analyzed by XRF for composition. No sulfate layer was detected on the melt surface. Also, at the end of the test the WESP was deluged and the transition line was washed prior to draining and quantifying the amounts of liquid in each reservoir.

4.2 DM10 Test Melter Conditions

Nominal target processing conditions, including bubbling rate adjusted to maintain the target glass production rate of 1900 kg/m^2/day, a melt pool temperature of 1150°C, and a complete cold cap were targeted and achieved throughout the majority of the melter test. Slurry feed and glass production rates calculated from feed tank data are shown in Figure 4.1. The 4.4 kg/hr feed rate corresponded to 1.6 to 1.7 kg/hr glass, depending on the glass conversion ratio for the feed. Small deviations are observed between the glass production rates calculated from the feed consumed and glass discharged data due to minor low biases in actual glass conversion ratios from target values. Feed interruptions were confined to short periods to transfer feed at regular planned intervals.

The cold cap was monitored visually throughout the tests and controlled by varying the bubbling rate while keeping the feed rate fixed. Bubbling was decreased if the cold cap was observed to cover less than the majority of the melt pool surface and bubbling was increased if the cold cap was observed to cover the entire surface. Deposits formed along the walls of the melter after discharging glass, which lowered the glass level in the melter leaving material adhering to the walls out of contact with the molten glass. Manual methods were used on average after every other discharge, and readily dislodged these deposits from the walls onto the cold cap surface. This frequency is six times higher than while processing the same feed on the DM100 due to the much higher relative surface area of the melter walls in the smaller melter.

Temperatures across the melter system were measured and logged electronically every minute. Test average measured temperatures and ranges are given in Table 4.2; glass temperatures for each test are shown in Figure 4.2, electrode and discharge chamber temperatures in Figure 4.3, and plenum temperatures in Figure 4.4. The measured test average glass temperatures were 1146 and 1140°C, indicating that the target glass temperature of 1150°C was approximated and maintained throughout most of the test. Glass and discharge chamber temperatures were lower during the first twenty hours of the test due to an incomplete seal of the discharge can on the bottom of the discharge chamber. Also, brief downward spikes in discharge chamber, and to a lesser degree glass temperatures, correspond to glass discharging. The discharge chamber temperature was maintained at around 1120°C to facilitate pouring when the discharge can is fully seated. The glass temperatures measured at two and four inches from the melt floor typically varied by about five degrees, indicating uniform temperatures over the bulk of the glass pool. The East electrode temperatures averaged about 15°C lower than the glass pool temperature; the West electrode temperature was about 100°C lower due presumably to the thermocouple not being as deeply inserted. Test average plenum temperatures were 467 and 544°C measured by the exposed and thermowell thermocouples, indicating that a complete cold cap covered the melt pool surface throughout the tests. Plenum temperatures decreased from about 800°C at the start of each test as the cold cap insulating the plenum space from the glass pool developed. Temperatures measured by the exposed thermocouple were up to 100°C less than plenum temperatures measured in the thermowell during the latter half of the test, suggesting that the exposed thermocouple is partially shielded by cold cap from the glass surface. Melter exhaust from the plenum is diluted by film cooler air, which reduced the temperature to 270°C.

In addition to temperature, a variety of other melter system data are measured and recorded during testing, including glass melt pool bubbling rate, electrode power, glass electrical properties and melter vacuum; test average values and ranges are given in Table 4.2. Bubbling used to agitate the melt pool is displayed in Figure 4.5; power supplied to the electrodes and glass pool resistance are shown in Figure 4.6. The amount of bubbling increased from about 1 lpm during the first day of testing to about 2 lpm as steady state conditions were achieved over the remainder of the test. This level of bubbling is less than that used on DM100 while processing the same feed when scaled to melter surface area (95 vs. 130 lpm/m^2). Total power to the electrodes is calculated from the electrode voltage and current that are electronically recorded every minute during testing. Test average power usage was 6.1 kW, which is higher than the 4.8 kW for the ORPBL4 composition [17] and 5.1 kW for the ORPLA20 composition [16] due to the higher water content of the feed used in the present tests. The amount of power used in the DM10 test is comparable to that used on DM100 while processing the same feed when normalized to glass production rate (3.8 vs 3.4 kW per kg glass produced per hour). Melt pool resistance decreased from about 0.12 ohms at the onset of testing to 0.08 ohms after half a day of testing and remained relatively constant over the remainder of the test.

A melter vacuum of about one and a half inches of water was maintained for most of the testing, with the instantaneous spikes toward ambient pressure associated with sampling in between tests and manual dislodging of deposits in the upper plenum area. “Bridging” of feed material between the melter walls (which can result in separation of the cold cap from the melt surface) tends to occur more frequently in melters with small surface areas and is mitigated as necessary by manual dislodging. For this purpose, the DM10 is equipped with a tool that allows removal of deposits without opening the viewports or flanges on the melter lid.

4.3 Off-Gas System Test Results

The off-gas treatment system, shown schematically in Figure 1.4, consists of a SBS, WESP, and a HEPA. Data on the off-gas system performance collected over the course of the three tests are presented and discussed in this section. Data for each of the off-gas system components, logged by the LabVIEW data acquisition and control software, were imported into MS Excel files for data analysis and plotting. Time “0” on the axis of each data plot corresponds to the start of feed into the melter at the beginning of each test. The timing for operational events discussed below is measured from this time “0”. The test start and stop dates and times are listed in Table 4.1. Where indicated, data were smoothed by time averaging instantaneous measurements logged at one-minute intervals to reduce data scatter and the number of data points for the plots. The average, minimum, and maximum values of the measured off-gas system parameters are given in Table 4.3. Plots of the average off-gas temperatures and the off-gas flows throughout the DM10 off-gas system are shown in Figure 4.7. Air exits the melter around 550°C and is diluted with heated air through the film cooler to about 270°C before passing through the insulated transition line. The off-gas system parameters, performance, and key operational events are discussed below.

4.3.1 Transition Line

After the melter film cooler, the first component of the off-gas system is the transition line, which is exposed to the highest exhaust temperatures, particle loading and concentrations of gaseous components. Solids accumulation has been observed in the transition line during previous tests [14, 16] and therefore the transition line was modified to include a flush with city water to minimize particulate accumulations in this portion of the off-gas system. A fixed mass of water (2.0 kg) is sprayed over 20 seconds every 12 hours and drains directly into the SBS sump. By design, this flush water raised the level in the SBS, which overflowed into an accumulation tank for blow down after the flush. The addition of this spray water to the transition line quenched the off-gas temperature entering the SBS every twelve hours. These temperature depressions can be seen in Figure 4.8. At the end of the test the transition line was flushed again to remove particulate buildup.

4.3.2 SBS

The SBS is the first component in the primary off-gas system and is designed to quench melter exhaust, remove particulate from the exhaust stream, and provide liquids with constituents removed from the melter exhaust to be recycled back to melter feed or sampled and discarded as they were in the present tests. The SBS liquids overflowed into a blow down tank, (which was monitored visually during the tests), and were removed, quantified, and sampled on an as-needed basis and after each transition line rinse. Monitored and electronically recorded parameters from the SBS during testing were the temperature of the inlet and outlet exhaust streams, as shown in Figure 4.8, the temperature of the sump fluids and cooling water, as shown in Figure 4.9, the inlet pressure and pressure drop across the SBS, as shown in Figure 4.10, and the liquid flow rate into the SBS, as shown in Figure 4.11. The SBS effectively quenched the melter exhaust to the bed liquid temperature; no blockages occurred over the course of the tests. The operating temperature for the SBS was set to the prototypic operating temperature of 45°C [16, 17, 88], similar to the SBS in the DM1200 system. Throughout testing this temperature was maintained without incident. Some periodic temperature spikes can be seen in SBS sump temperatures corresponding to the transition line flushes that were performed every 12 hours. The pressure drop across the SBS of about twenty inches of water is consistent with the packed bed height.

In addition to temperature, for data comparisons, it is desirable to operate the SBS with the same liquid accumulation rate as the DM1200 system. However, the dilution air through the film cooler in the DM10 is larger relative to the off-gas flow rate than that in the DM1200 system. This results in a larger fraction of the water in the gas stream leaving as saturated vapor versus condensing in the SBS. Prior testing with the DM1200 melter resulted in roughly 2/3 of the of the nominal water content in the melter feed accumulating in the SBS. In order to achieve the same accumulation rate, it was calculated that 2.0 lpm of makeup water would have to be added during the present tests. The 2.0 lpm makeup water flow rate was maintained using a rotameter and although there was some drift in the flow, which can be seen in Figure 4.11, the average flow rate was 2.2 lpm. Since there was no active control, manual adjustments were made as necessary. During the test there were no interruptions of the makeup water flow.

4.3.3 WESP

The WESP is the second component in the primary off-gas system and is designed to remove fine particulate from the exhaust stream. A water spray into the gas stream at the inlet ensures that the walls of the collection plates are wetted to keep particulate from adhering to them. The WESP liquids overflow into a blow down tank, (which was monitored visually during the tests), and are removed, quantified, and sampled on an as-needed basis and after each WESP deluge. The blower (P-200) that provides vacuum for the melter and primary off-gas system immediately follows the WESP in the exhaust train and therefore is evaluated in conjunction with the WESP. To prevent condensation in the downstream exhaust system hot dilution air is added to the off-gas downstream of the blower. The temperature of the gas leaving the blower is measured after this mix point and is elevated by about 40 °C as a result. This can be seen in Figure 4.12, which also shows the SBS outlet/WESP inlet temperature, and the spray water inlet temperature. Additional monitored and electronically recorded parameters from the WESP during testing were the WESP inlet pressure, differential pressure across the WESP, and the blower discharge pressure, as shown in Figure 4.13; WESP spray water flow rate, as shown in Figure 4.14; and WESP voltage and current, as shown in Figure 4.15. The average voltage to the WESP was 17.6 kV and the average current was 1.0 mA.

A deluge was performed once a day at 12:00 pm in order to remove any accumulated particulate from the collection plates. To perform the deluge, the water spray and WESP power supply were secured. Then, deionized water was deluged into the top of the WESP for 1 minute at a flow rate of 4 lpm. Afterwards, the WESP voltage was raised back to its set point and then the water spray was turned back on. The operating procedure called for the WESP to operate at 20,000 volts, or as high as possible without arcing, and to allow the current to fluctuate with process conditions. The time required to fully recover from the first deluge was significant. The WESP was stable at ~12 kV after about 30 minutes, but increasing the voltage to the nominal condition was not possible until roughly five and a half hours after the deluge (at test time 23.5 hours).

The long delay in power restoration is assumed to be the result of residual water in the WESP creating a path to ground for the high voltage. As shown in Figure 4.12, the WESP outlet temperature is several degrees cooler in the hours immediately following the first deluge. The temperature then rises several degrees at a test time of ~23 hours, which corresponds with the ability to maintain the higher voltage. Additionally, there is a concurrent decrease in the exhaust flow rate, as shown in Figure 4.16, which is the result of a decrease in speed of the P-200 blower downstream of the WESP and the exhaust blower after the HEPA filters at a test time of 22.7 hours. The operational change in flow increased the temperature in the WESP, allowing the residual water to evaporate, and the WESP voltage to be restored. The time for the WESP to recover after the second deluge was much shorter. Within 20 minutes the voltage was stable at ~15 kV and was fully restored in about 45 minutes. The WESP outlet temperature after the second deluge was not as significantly decreased. Except for the deluges the WESP performance was stable and no operating issues were encountered. The average water spray flow rate for the test was 3.1 lph and was shut off during the deluges. The spray water flow rate was otherwise constant throughout the testing.

4.3.4 Dry Off-Gas System

The dry off-gas exhaust system provides coarse filtration and HEPA filtration before release through the stack. Additional vacuum is drawn on the system and there is air dilution through the blower. The exhaust is monitored downstream of the final blower for gaseous species and stack flow rate which is shown in Figure 4.16. Monitored and electronically recorded parameters in the system are cyclone outlet temperatures, HEPA filter inlet and outlet temperatures, exhaust blower outlet temperature, and exhaust blower outlet air flow rate. Test average, minimum and maximum values for these parameters are provided in Table 4.3. The system contains a redundant line of cyclone and HEPA filtration units and therefore the temperature of one set of filters is indicative of ambient room temperature rather than the exhaust flow stream. As mentioned above, heated exhaust air is added downstream of blower P-200 to prevent condensation. This raised the average temperature of the gas entering the dry off-gas system to 99.8 °C. The average temperature of the gas leaving the HEPA filters was 50.9 °C, which is above the dew point for the system. The temperature profile for the dry off-gas system during the test can be seen in Figure 4.18.

4.4 SBS and WESP Process Fluids

All liquids drained from the SBS and WESP were quantified and sampled. Samples were subjected to total suspended solids (TSS) determination by gravimetric analysis of filtered material. The filtered solids and filtrate were subjected to complete chemical analysis, which included pH determination, DCP-AES analysis for metals, IC for anions, and ion specific electrode (ISE) for ammonia; the dried filtered solids underwent microwave-assisted acid dissolution prior to chemical analysis. Tables 4.4 and 4.5 list the SBS and WESP samples as well as the total mass of solution removed from each sump, pH, and solids content; the first letter in the sample name is “S” or “W” for the SBS and WESP, respectively.

A summary of water entering and exiting the primary off-gas system is provided in Table 4.6. Water is introduced into the off-gas system through the melter exhaust, which contains water evaporated from the feed, makeup water added to the SBS, the transition line rinse spray which drains into the SBS, the inlet spray into the WESP, and the WESP deluge. Water leaves the primary off-gas system in the WESP exhaust as well as in blow-down solutions from the SBS and WESP. Illustrated in Figure 4.18 are the cumulative amounts of water introduced from the SBS makeup water (2.2 kg/hr), WESP inlet spray (3 kg/hr), and SBS and WESP blow-downs. The amount of water originating from melter feed matched the 135 kg required to turn over the 45 kg of liquid in the SBS sump three times for the test. Three times more water enters the SBS from the melter exhaust and makeup water than exits the SBS in blow-down solutions; the difference being attributable to moisture in the SBS exhaust stream, which is in equilibrium with the temperature of the SBS sump solution. A higher proportion of the water entering the SBS exited as blow-down solutions than in previous tests [16, 17] due to a lack of liquid droplet carryover from the SBS to the WESP as a result of the extended plenum space (see Section 1.6.2.2.1]. The approximate 1:2 ratio of SBS to WESP blow-down solutions in the present test is very different than the 3:1 ratio observed for DM1200 tests due to the lower ratio of WESP spray rate to process air flow and the relative lack of liquid carryover from the SBS to the WESP in the DM1200 tests.

A good water mass balance was measured across the primary off-gas system with a surplus of less than four percent. The water content values measured in one-hour duration melter and WESP exhaust samples (see Section 6.1) were used to calculate the total amount of water entering the primary off-gas system. Notice that the total amount of water measured in the melter exhaust is over 70 kg more than the amount in the feed processed during the test as a result of moisture in the process air. Also worth noting is that the amount of water entering the primary off-gas system in the melter exhaust is less than the amount of water exiting the primary off-gas system in the WESP exhaust.

The pH and solids content of the sump solutions are affected by constituents removed from the exhaust, by dilution from the makeup and spray water, and carryover from upstream unit operations. Measured pH and solids content values for SBS and WESP solutions are shown in Figures 4.19 and 4.20, respectively. The SBS sump solution pH varied from 8.2 at the start of the test and decreased by a pH unit about half way through the test to a steady state value. The pH of the SBS solutions decreased over the initial portion of the test due to the increasing concentration of acid anions, most notably nitrite generated by scrubbing of nitrogen oxides from the melter exhaust. Measured pH values are comparable to those for SBS solutions collected while processing the ORPLA20 and ORPLB4 compositions on the DM10 melter system [16, 17], as a result of the feeds containing high concentrations of nitrates/nitrites, sodium, and sugar as a reductant as well as the use of the same operating parameters for the melter and off-gas system components. The pH values of the WESP solutions were more variable, ranging from 6.4 to 8.2 due to the low concentration of dissolved constituents. The WESP solution pH is lower than in previous tests processing the ORPLA20 composition [16] due in part to the use of deionized water for the 3 kg/hr spray and deluge. The total suspended solids content of SBS solutions reached a steady state concentration of about 300 mg/l during each test and spiked by factors of up to six in response to transition line washing. Higher solids concentrations were also measured in WESP solutions sampled at the beginning of the test due presumably to clearing of residual material from the preceding tests. In WESP solutions, the total suspended solids content was low (< 50 mg/l) except for samples taken immediately after deluges and after instances of high liquid carryover from the SBS.

The chemical composition was measured for all solutions and the results are provided in Tables 4.7 and 4.8. The chemical composition is divided into suspended and dissolved fractions for two SBS samples (before and after transition line wash) and two WESP samples (before and after deluge) as shown in Tables 4.9 and 4.10. The dissolved fraction constitutes over 95% and 99% of the chemical species measured in the SBS solutions associated and not associated with transition line rinsing, respectively. The amount of suspended solids measured in SBS solutions from previous tests on the DM1200 and DM10 with LAW feeds [16, 17, 33-35, 38] were typically higher at around 5% of total solids. Higher proportions of suspended solids of up to thirteen percent of total solids were also measured in SBS solutions sampled immediately after transition line rinses during DM10 tests with ORPLB4 composition [17]. Suspended solids constituted less than one percent of the chemical species measured in most WESP solutions during nominal operations and after deluges, in contrast to previous tests which had suspended solids as high as ten percent of total solids in some solutions sampled immediately after some WESP deluges [17]. The lower proportion of suspended solids in SBS and WESP samples suggests less carryover from the melter of insoluble mineral additives than in previous melter tests. Nearly all of the most abundant elements measured by DCP/ICP, particularly boron and alkali metals, were detected in the dissolved fraction, as well as more than ninety nine percent of the rhenium. This is consistent with the most volatile elements from vitrification being water soluble and therefore present as dissolved species in off-gas effluent solutions. The measured distribution between dissolved and suspended solids also indicates that the behavior of constituents such as rhenium and alkali metals can be understood by analysis of the filtered off-gas effluents alone.

Total compositions of SBS and WESP solutions as well as solids from SBS solutions from each test are depicted in Figures 4.21 – 4.23. As expected, the most abundant species in the SBS solutions were soluble constituents, with nitrite, ammonia, chlorine, and sodium constituting ninety percent of the dissolved and suspended species. These species are readily volatilized from the glass and cold cap in the melter as soluble salts or gaseous compounds such as nitrogen oxides and ammonia. The suspended solids, which constitute a very small fraction of the total solids in the SBS solutions, are composed mostly of silicon, aluminum, and zinc with significant amounts of zirconium, iron, calcium, and sodium originating from entrainment of minerals in the feed into the exhaust stream. The WESP solutions contain an even lower proportion of suspended solids and more volatile salts (alkali nitrites, nitrates, halides, and sulfates as well as ammonia) as fine particulate not removed by the SBS.

The relative abundance of nitrate versus nitrite is a function of solution pH; acidic solutions favor nitrate and basic solutions favor nitrite. Since the processing of this feed result in mildly basic SBS and WESP solutions, the most abundant nitrogen form in DM10 SBS and WESP solutions is nitrite, not nitrate. The compositions of SBS solutions sampled before and after the transition line rinse, displayed in Figure 4.24, shows increases in the concentrations of insoluble elements aluminum, silicon, zirconium, and zinc after the rinse. Conversely, ammonia shows a significant decrease in concentration after the transition line wash, indicating minimal deposition of ammonium compounds in the transition line. The lack of other differences in solutions sampled before and after transition line washes is attributable to the dilution of wash solution in the 45 liter SBS sump and only minor accumulations of minerals from the feed deposited in the transition line. The WESP deluge had a significant effect on WESP solution chemistry, particularly with respect to nitrogen oxides, rhenium, chloride, sulfate, and alkali, as shown in Figure 4.25. Notice the higher concentrations of rhenium, chloride, sulfate, nitrate, and alkali present in the WESP post-deluge samples, indicating that these constituents were present in deposits removed from the internal WESP components. Concentrations of ammonia and nitrite were lower in samples after the deluge because these compounds are incorporated into solutions by scrubbing nitrogen oxides and ammonia gases from the exhaust stream as opposed to the removal of particulate salts from the exhaust stream.

The evolution of the SBS and WESP solution chemistry during testing is illustrated for some of the most abundant dissolved constituents, nitrite, sodium, fluoride, chloride, sulfate, ammonia, boron, and nitrate, in Figures 4.26 – 4.29. Rhenium concentrations over the course of the test are compared to those in solutions generated while processing the ORPLB4 composition at the same rhenium target concentration in Figures 4.30. All sumps were rinsed prior to the test and the SBS was completely exchanged with deionized water; thus, the only constituents present in the solution at the start of the test were residual contamination of the sampling system from previous tests [90] (which was observed for most elements in the initial SBS sample). Concentrations of the soluble species in the SBS increase over the course of the test with most constituents not reaching a steady state plateau most notably nitrite, sodium, ammonia, chloride, and boron. Rhenium does appear to approach steady state by the end of the current test in contrast to testing with the ORPLB4 composition. It is interesting to note that the most abundant dissolved species in SBS solutions do not approach steady state concentrations while suspended solids quickly attain a steady state at about 300 mg/l, suggesting a different mechanism for removal from the exhaust stream than for sodium, nitrate, and most other dissolved constituents. Also note in Figures 4.26 and 4.27 that there is no clear effect of the transition line rinse (conducted every twelve hours) on the concentrations of the displayed constituents, as opposed to the spikes in solids content shown in Figure 4.19. Concentrations of many soluble species in WESP solutions are affected by the daily deluge: sodium, chloride, rhenium, nitrate, and sulfate spike and ammonia and nitrite drop in concentration in response to the deluge. Rhenium concentrations in WESP solutions appear to reach a steady-state plateau at about 6 mg/l for both the present and the previous tests, as shown in Figure 4.30.

SECTION 5.0
FEED AND GLASS PRODUCTS

5.1 Analysis of Melter Feed Samples

5.1.1 General Properties

Melter feed samples were analyzed to confirm the physical properties and chemical composition during each test. A feed sample from the beginning and end of each test was taken from the line into the melter to again verify the composition of the feed for most inorganic components. Sample names, sampling dates, and measured properties are provided in Table 5.1. The measured glass yield for all of the feed sampled during melter testing deviated by less than eight percent from the target values and on average were 5.6 percent below the target values (on a mass per unit mass basis). The feed sample analysis shows the intended decrease in glass yield and density with decreasing waste simulant sodium molarity. The analysis also shows an increase in water content from about forty to sixty percent with decreasing waste simulant sodium molarity, as intended. A decrease of a quarter of a pH unit was also observed with waste simulant dilution. The measured parameters show the consistency of the feed for each of the simulant concentrations tested. Collectively, the measured values support the use of the target value for calculating glass production rates (this criterion is the same as was used extensively in all previous melter testing performed for the WTP and was adopted here for consistency); however, production rates were also calculated using the measured feed solids content for comparison.

5.1.2 Chemical Composition

The chemical compositions of the feed samples were determined by first making a glass from the feed sample via crucible melt. The glass was subsequently crushed and analyzed directly by XRF. All vitrified feed samples were also dissolved in acid (HF/HNO_3) with the aid of a microwave oven and the resulting solutions analyzed by DCP-AES. The measured boron and lithium values from the DCP-AES analysis were used for normalizing the XRF data since their concentrations were not determined by XRF. The low target value of 0.01 wt% for fluorine was also used for normalizing the XRF data. The analyzed compositions of feed samples are provided in Table 5.2. The results show good agreement between the AP105DLAW11 target composition and the melter feed samples. The measured values had relative deviations that were significantly less than 10% for all the oxides with target concentrations of greater than one weight percent oxide. Magnesium oxide, which is targeted at one weight percent, was collectively twenty-six relative percent below target in the feed sample analysis but much closer to the target concentration in the discharge glasses (see Section 5.2). Magnesium is present in the feed as the mineral olivine which readily settles out of the feed during sample preparation and therefore many feed analysis show deficits in magnesium. Tin in the form of stannic oxide is prone to the same behavior. Boron values averaged within two percent of the target concentrations and therefore the target values were used to normalize the XRF values for the discharge glasses. The concentration of the volatile element sulfur determined by XRF is slightly above target with no indication of loss during crucible melting of the feed samples, suggesting that the actual concentration of sulfur in the feed is marginally above the target concentration. Chloride, which is more volatile than sulfur, was measured at less than half the target concentration in the vitrified feed samples, consistent with previous tests [e.g., 14, 16]. Rhenium, also a very volatile element, was measured at about thirty percent of the target value due to loss during crucible melting of the melter feed samples. Small amounts of lithium and manganese were detected in feed samples, despite their absence from the feed recipes, due to the presence of these elements as impurities in bulk chemicals. Similarly, chromium, iron, and nickel, which are targeted at only 0.005 to 0.66 wt% in the product, were on average 0.05, 0.07, and 0.02 wt% oxide above the target concentrations in the feed samples due to the presence of these elements as impurities in bulk chemicals. The consistency of analysis between the melter test feed samples and product glass (see Section 5.2) collectively demonstrate the consistency of the composition delivered to the melter throughout the tests for the vast majority of the constituents in the AP105DLAW11 composition.

5.2 Compositional Analysis of Discharged and Dip Glass Samples

Over twelve hundred kilograms of glass was produced during the three DM100 and single DM10 tests. The glass was discharged periodically using air lift systems into 5-gallon carbon steel pails from the DM100 and into square steel cans from the DM10. The discharged product glass was sampled by removing sufficient glass from the top of each pail for total inorganic analysis. Product glass masses and discharge date are given in Tables 5.3 and 5.4. Glass samples were also taken by inserting a threaded metal rod directly into the glass pool before and after each test. These "dip" were closely examined to assess the presence or absence of sulfate salt secondary phases, to provide samples for chemical analysis, and to document the depth of glass in the melter. No macroscopic secondary phases were observed in any of the discharged glasses or dip glass samples.

All discharge glass samples were crushed and analyzed directly by XRF. Since boron and lithium are not determined by XRF, boron and lithium concentrations were calculated from the target concentrations, the initial concentrations measured in the melt pool, and the nominal glass volume of the melters. The low target value of 0.01 wt% for fluorine was also used for normalizing the XRF data. All dip samples were dissolved in acid (HF/HNO_3) with the aid of a microwave oven and the resulting solutions were analyzed by DCP-AES primarily for boron and lithium determination; powdered samples were subjected to XRF analysis. The XRF analyzed compositions of discharged and dip glass samples are provided in Tables 5.5 - 5.9 and the test average analyzed compositions are compared to the target composition in Tables 5.10 – 5.13. The vast majority of the XRF analysis results compare favorably to their corresponding target values and feed sample analyses (see Section 5.1). All oxide values with a target concentration greater than one weight percent in glass discharged at the end of each test showed less than 10% deviation from the target values, except for calcium at the end of the first two DM100 tests. All test average oxide values with a target concentration greater than one weight percent showed less than 10% deviation from the target values, except for surpluses of calcium oxide in all but the last DM100 test and deficits of zirconium in initial samples from the

DM100 and the DM10 test. These deviations are attributable to the glass pool containing four times the target calcium and half the target zirconium at the onset of the DM100 and DM10 tests. Boron concentrations measured by DCP-AES on solutions generated from glass pool samples generally corroborate the feed sample analysis and validate the use of analyzed feed sample boron concentrations for normalizing the XRF data. Manganese was measured in the product glass at low concentrations despite not being included in the target composition as a result of its presence in the feed as a contaminant. Lithium in the DM100 and DM10 as well as vanadium in the DM100 were present at the start of testing at concentrations exceeding two percent oxide and therefore were detected in significant quantities in discharge glasses. Consistent with the feed sample analysis, chromium, iron, and nickel, which are present in the target composition at low concentrations, were measured throughout the tests at higher concentrations as a result of their ubiquity as a contaminant in chemicals used to produce the melter feed as well as being imparted to the melt pool by corrosion of melter refractories and Inconel components. Measured chlorine and rhenium concentrations in discharged and melt pool glasses are well below target concentrations due to volatilization from the melt pool and cold cap, as expected.

Compositional trends for selected constituents shown in Figures 5.1 - 5.9 for DM100 tests illustrate the approach of the majority of the glass constituents to the target composition over the initial portions of testing and the consistency over the remaining course of the tests. The DM100 contained the ORLEC48 composition [42] at the onset of testing, which is very different from the AP105DLAW11 composition with most notably lithium and vanadium, no tin or titanium, four times the calcium and sulfur, eight absolute percent less soda, and half the zirconia. In response to the differences between the glass compositions, sodium, aluminum, zirconium, titanium, and tin increased in concentration at the expense of calcium, silicon, vanadium, sulfur, and lithium as the glass pool transitioned to the AP105DLAW11 composition. Most of the transition was complete by the conclusion of the first test (494 kg glass production or 4.5 turnovers of the glass pool); however, calcium, vanadium, and lithium concentrations continued to decrease through 879 kg glass production or 8 turnovers of the glass pool. Concentrations of zinc, iron, potassium, phosphorus, magnesium and chromium are relatively constant over the course of the DM100 tests. Variability in measured concentrations of zirconium, magnesium, zinc, and tin oxides are attributable to variability in feed concentrations due to the settling out of dense additive minerals in the feed tank. The relationship between measured concentrations of the volatile constituents, rhenium, sulfur, and chlorine depend on the element, target concentration, the water content of the feed, and the concentration in the glass pool at the onset of testing. All volatile constituents were measured at below target values for all but sulfur due to the excessive amount (three times higher than the target concentration) in the glass pool at the start of testing. The concentrations of chlorine increase over the course of each test, often followed by the measured concentrations reaching a plateau characteristic of steady state. Decreases of up to 0.15 absolute weight percent chlorine were observed during idling periods between the tests. The amount of chlorine lost during feeding increased with feed water content; the chlorine concentration decreased with feed sodium molarity as follows: 0.40 wt% at 8 M, 0.34 wt% at 5.6 M, and 0.31 wt% at 4 M. Similar behavior was observed for rhenium although the increase in concentration at the onset is obscured by the close proximity of the measured steady state concentrations to the detection limit (0.0019 wt% ReO_2). The amount of rhenium lost during feeding increased with feed water content; the rhenium concentration decreased with feed sodium molarity as follows: 0.0026 wt% at 8 M, 0.0023 wt% at 5.6 M, and 0.0022 wt% at 4 M. The amount of sulfur in the glass also decreased with increasing feed water content from the target concentration to 0.33 wt% SO_3; however, the effect is obscured by the high level of sulfur in the glass pool at the start of testing.

Compositional trends for selected constituents shown in Figures 5.10 – 5.17 for the DM10 test illustrate the approach of the majority of the glass constituents to the target composition over the initial portions of testing and the consistency over the remaining course of the tests. The DM10 contained the WDFL2 composition [90] at the onset of testing, which is very different from the AP105DLAW11 composition with most notably lithium, no tin, six times more iron, twice the calcium and titanium, ten absolute percent less soda, and half the zirconia. In response to the differences between the glass compositions, sodium, aluminum, zirconium, and tin increased in concentration at the expense of calcium, silicon, iron, titanium, and lithium as the glass pool transitioned to the AP105DLAW11 composition. Most of the transition was complete after 4 turnovers of the glass pool (28 kg glass production); however, calcium, vanadium, and lithium concentrations continued to decrease through 6 turnovers of the glass pool (42 kg glass production). Concentrations of zinc, potassium, phosphorus, magnesium, sulfur, and chromium are relatively constant over the course of the DM10 tests. Variability in measured concentrations of zirconium, magnesium, zinc, and tin oxides are attributable to variability in feed concentrations due to the settling out of dense additive minerals in the feed tank. Readily apparent is the volatilization of rhenium, sulfur, and chlorine from the glass over the course of the tests; all measured concentrations in discharge glasses were below target values. The concentrations of the volatiles typically increase over the course of each test, often followed by the measured concentrations reaching a plateau characteristic of steady state. These plateau concentrations were used to estimate the steady-state retention in glass by dividing by the target concentrations; the percent retentions were 27, 52, and 93 for rhenium, chlorine, and sulfur, respectively, as listed in Table 4.1. These levels of retention are typical for chlorine and sulfur but about half the amount for rhenium measured in previous tests with the ORPLA20 [16] and ORPLB4 [17] compositions. The differences in rhenium retention is presumably due to differences in the feed composition and particularly the waste organic content since melter operating conditions were the same for all three test series.

SECTION 6.0
MONITORED OFF-GAS EMISSIONS

6.1 Exhaust Particulate and Gas Sampling

The D100 melter exhaust was sampled for metals/particles/acid gases according to 40-CFR-60 Methods 3, 5, 26, and 29 at steady-state operating conditions during each test. Similarly, the DM10 melter, SBS, and WESP exhaust were sampled for metals, particles, and acid gases during each test using the procedures described in Section 1.7.4. DM100 melter emission fluxes are compared to feed fluxes in Table 6.1. DM10 melter, SBS, and WESP emission fluxes are compared to feed fluxes in Tables 6.2 – 6.4. Notice the distinction that is made between constituents sampled as particles and as "gas". The "gaseous" constituents are operationally defined as those species that are scrubbed in the impinger solutions after the air stream has passed through a 0.3 μm heated filter. All samples are well within the 90 – 110% limits for isokinetic sampling. The purpose of the emissions data is to determine the amounts of key volatile components (chlorine, sulfur, and rhenium) that escape the primary off-gas system, to complete the elemental mass balances (see Section 7.0), to provide scaling data between the DM10 and DM100 melters, to provide data for calculating elemental decontamination factors (DFs) across the primary off-gas system (SBS and WESP), and to determine the effect of the WESP deluge on decontamination factors across the primary off-gas system.

The melter exhaust was sampled once for each of the DM100 tests. Sampling times of only five and twenty-six minutes instead of the planned one hour occurred while processing the 5.6 and 4 M Na feeds due to heavy accumulations of particulate on the sampling filter. Solids carryover from the DM100 melter ranged from 0.82 percent of feed solids at the lowest feed water content (8 M Na waste) to 2.34 percent of feed solids at the highest feed water content (4 M Na waste). Most of this nearly threefold increase with increasing water content occurred after the initial dilution of the 8 M Na waste since 2.24 percent of feed solids were carried over while processing the 5.6 M Na waste. Increases in carryover with increasing feed water content were previously shown as two-fold increase while processing 6 and 12 M Na wastes with ORPLA20 composition on the DM100 [12] and a thirty five percent increase while processing 6 and 8 M Na wastes with ORPLA20 composition on the DM10 [16]. Carryover increases with increasing feed water content have also been observed while processing HLW wastes on the DM10, DM100, and DM1200 [25, 91-93]. Increasing carryover with increasing feed water content is attributable to the entrainment of solids during boiling since the increase affects both soluble and insoluble feed components. The most abundant elements in the exhaust stream while processing the AP105DLAW11 and ORPLA20 compositions were sodium and chlorine, which constitute well over half the elements measured in the exhaust stream and define carryover when comparing different compositions processing under the same conditions. While processing both formulations at an 8 M Na concentration carryover for AP105DLAW11 with a chlorine target of 0.82 wt% was 0.82% and for ORPLA20 with chlorine target of 0.68 wt% it was 0.65%. Most glass forming constituents in the melter feed are represented in the melter exhaust either as entrainment of feed particles directly into the exhaust stream or volatilization from either the cold cap or molten glass. As expected, the feed elements emitted at the lowest melter decontamination factor (DF), in ascending order, were rhenium, chlorine, fluorine, sulfur, potassium, sodium, chromium, and boron. The proportion of non-volatile elements in the exhaust increased with increasing water content due to more entrainment of solids during boiling. Emissions of chlorine and sulfur were exclusively particulate, consistent with previous tests conducted at high sodium contents [12, 94, 95]. Boron was the only element detected in the impinger solutions collected downstream of the heated particle filter in the sampling train, which constitute the "gas" fraction of the melter emissions. Increasing feed water content did not result in an increase in the amount of gaseous species in the exhaust.

Two melter exhaust samples were taken during the DM10 test once steady-state processing was established. Solids carryover from the melter was 1.09 and 1.11 percent of feed solids, half the amount measured while processing the same 5.6 M Na waste on the DM100. The measured DM10 carryover is considered more indicative of the actual carryover for this feed under nominal conditions since the results are based on one hour replicated samples as opposed to the DM100 results based on a five-minute sampling period. Carryover in the present DM10 test was higher than with other LAW high sodium wastes with lower feed water contents: LAWE4H composition at 0.28 percent of feed solids [16], ORPLB4 composition at 0.88 percent of feed solids [17], and ORPLA20 composition at 0.88 percent of feed solids [16]. Volatile feed elements that were emitted at the lowest melter DF, in ascending order, were rhenium, chlorine, fluorine, potassium, sulfur, sodium, chromium, and boron, the same as in the DM100 tests with the same composition, similar to preceding tests on the DM10 with the ORPLA20, LAWE4H and ORPLB4 feeds [16, 17], and generally similar to tests with high alkali feeds [2-7, 33, 34, 38-41, 43-45, 47-50, 94, 95]. Melter emissions of chlorine and sulfur were exclusively particulate, consistent with many previous tests conducted at high sodium contents [3, 4, 6, 94, 95]. No elements from the feed were detected in the impinger solutions collected downstream of the heated particle filter in the sampling train, which constitute the "gas" fraction of the emissions.

Two SBS exhaust samples were taken during the DM10 test once steady-state processing was established. Unlike previous attempts to directly sample the SBS exhaust [17], no difficulties were encountered in measuring stack flow rates due to water droplets impinging on the pitot tube and liquid accumulations in sampling lines and the heated filter holder. Also, the moisture content measured in the SBS exhaust was indicative of saturated air at the SBS exhaust temperature of 45°C as opposed to the 61 volume percent measured in previous tests [17]. These differences in sampling results are attributable to modification of the SBS tank before testing to include a taller headspace above the liquid overflow (see Section 1.6.2.2.1) to prevent liquid being carried over into the WESP. Solids carryover from the SBS was 0.44 and 0.53 percent of feed solids or about half the particulate in the melter exhaust. The SBS achieved a DF of only about 2 because much of the particulate emissions from the melter were alkali halide salts which by design are not fully scrubbed by the SBS and have to be treated by the WESP [33, 34, 37, 38]. The particulate in the SBS exhaust is almost entirely alkali halide and about half the rhenium fed into the melter with most of the other elements present in the melter exhaust detected at much lower concentrations including aluminum, boron, calcium, chromium, magnesium, sulfur, silicon, and zinc. No elements from the feed were detected in the impinger solutions collected downstream of the heated particle filter in the sampling train, which constitute the "gas" fraction of the emissions.

Two WESP exhaust samples were taken during the DM10 test, one during the deluge and one after the deluge during nominal operations. An additional WESP exhaust sample was subsequently taken during nominal operating conditions when it was discerned that the WESP was not fully recovered from the deluge when the initial nominal operation sample was taken (see Section 4.3.3). Sampling during the deluge was conducted to determine the effect of the deluge procedure on the overall particulate removal from the exhaust stream. In the latter sample taken during nominal operation, the measured particulate emission rate from the WESP was 2.74 mg/min, corresponding to a feed carryover through the melter and primary off-gas system of 0.01% (DF of nearly 13000). This removal efficiency is greater than in previous tests conducted with the same off-gas system components while processing ORPLA20 and LAWE4H compositions (4.9 to 7.2 mg/min, corresponding to 0.01 and 0.02% or DF from 5000 to 8500) [16] and a range of LAW compositions (4 to 6 mg/min and feed carryover through the melter and primary off-gas system of 0.01%) [14], but slightly less than while processing the ORPLB4 composition (0.5 to 2.7 mg/min, corresponding to 0.001 and 0.01% or DF from nearly 14000 to 70000) [17]. Particulate carryover from the WESP during nominal processing was calculated from less than 2 mg weight gain over the course of the sample, which approaches the detection limit of the method. Comparable DF values on the DM1200 for high alkali LAW streams were considerably higher at about 500,000 [33, 34, 38]; this is likely due in part to the longer sampling times (24 hours vs. 1 hour), which improves the resolution for determination of high DF values due to larger sample size. Measured particulate emission rate sampled during the WESP deluge was 34.1 mg/min, corresponding to a feed carryover through the melter and primary off-gas system of 0.10 % (DF of 1037) with emission rates twelve times higher than during nominal operation. Lower DF across the WESP is expected during the deluge since the inlet spray is turned off and power to WESP electrodes is deactivated, resulting in no exhaust treatment during this procedure [15]. The measured particulate emission rate sampled after the initial WESP deluge was 56.9 mg/min, corresponding to a feed carryover through the melter and primary off-gas system of 0.16 % (DF of 623) with emission rates twenty times higher than during nominal operation, and 60% higher than during the deluge. During a five and a half hour period after the initial deluge power was not fully restored to the WESP elements due to arcing of the wet internal elements. As a result, the ability of the WESP to remove particulate was compromised during this time period. The most abundant constituents in the emissions sampled during the WESP deluge procedure are alkali halides and sulfates; therefore, feed containing high concentrations of these constituents has the highest emission rates during the deluges. The only constituents present in the WESP exhaust during nominal operation were very low concentrations of alkali chlorides, sulfates, and perrhenates. Aside from a small amount of boron in the sample taken while the WESP power could not fully be restored, no elements from the feed were detected in the impinger solutions collected downstream of the heated particle filter in the sampling train, which constitute the "gas" fraction of the emissions. Also of note is that the measured rhenium concentration in the WESP exhaust during nominal operation was 48 times lower than during the deluge procedure and 70 times lower than during the period after the initial deluge when power could not fully be restored. In addition, that level of rhenium which was not detectable in a preceding test during nominal WESP operation [16] was detectable in the present test as a result of the improved analytical sensitivity by using ICP-MS.

6.2 Particulate Sampled from the DM100 Off-Gas System

Material accumulated in the cyclones downstream of the DM100 film cooler (Figure 1.1) was removed, quantified, and analyzed after each test. The amounts of material removed, mineral phases detected, and chemical analysis of the cyclone deposits are provided in Table 6.5. The amount of material removed from the cyclone is not indicative of the total amount of particulate emitted from the melter since much of the material emitted is fine particulate, which is not captured in the cyclones. Pre-filters for HEPA filters downstream of the cyclones required periodic replacement over the course of these tests. This finding is consistent with tests processing high alkali LAW on the DM1200 in which significant amounts of fine alkali salts are captured downstream of the submerged bed scrubber in the wet electrostatic precipitator, which is designed to remove fine particulate from the exhaust stream [33, 34, 37, 38]. Analysis of material accumulated in the cyclones shows all of the feed components in similar proportions to the feed for most of the elements, enrichments over feed for volatile elements, most notably chlorine, rhenium, and sulfur, as well as depletions of non-volatile silicon and aluminum, and contamination with lithium, iodine, and vanadium from earlier tests. Chlorine, rhenium, and sulfur, which had the lowest measured DFs across the melter, have the greatest enrichment (6-7X, 6.5-11.5X, and 3-10X) in the cyclone powders over their respective amounts in the target glass. The mineral phases detected by X-ray diffraction (XRD) analysis show carryover of feed additives quartz, zircon, wollastonite, kyanite, rutile, and zincite, as well as halite volatilized from the glass pool and cold cap. This enrichment of volatile elements along with other feed components in the cyclone particulate indicates loss of volatile components from the glass pool and cold cap as well as some bulk carryover of feed from the melter. The proportions of the volatile elements and minerals would be even higher if particulates passing through the cyclones were included.

6.3 Gases Monitored by FTIR

Melter emissions were monitored in each test for a variety of gaseous components, most notably CO and nitrogen species, by FTIR spectroscopy, at locations described in Sections 1.5.2.3 and 1.6.2.3. The DM10 sampling location is downstream of the primary and dry off-gas systems and therefore the measured concentrations are affected by any dilutions in the off-gas system and removal of constituents by wet scrubbing. There is no liquid scrubbing of gases in the DM100 system and therefore the monitored gases are indicative of the melter exhaust. A summary of average and range of concentrations monitored during each test is provided in Table 6.6. The analytes listed in Table 6.6 are those that were thought likely to be observed during the tests based on previous work; no other species were detected in the off-gas stream by FTIR. Intermittent decreases in the output of the FTIR laser during the latter portions of the DM100 test processing the 5.6 and 4 M Na simulants resulted in exclusions in some of the data generated during these tests. Concentrations of various monitored species during the DM100 and DM10 tests are plotted in Figures 6.1 – 6.10.

The measured emissions during the DM100 tests were, as expected, reflective of the composition of the feeds and the relative processing rates achieved during the tests. The most abundant nitrogen species monitored was NO, which is consistent with previous tests [2-12, 33-54, 67, 89, 93, 94] in which nitrates and nitrites were present in the feed. The NO_2 concentration was about 15-27 times less than the NO concentration, in keeping with many previous DM100 tests with LAW simulants containing high concentrations of nitrates. As expected, concentrations of nitrogen oxides and by-products of incomplete organic combustion, such as ammonia and carbon monoxide increased with waste processing and glass production rate. Water is unique among the analytes monitored by FTIR in that the concentration in the feed varied over the course of the tests and therefore measured concentrations do not increase with increasing glass production rates but increase instead with increasing feed water content. The measured water contents were typically 7 to 10%, which is about half the amount measured by the Method 5-type sampling discussed earlier as a result of air in-leakage between the two sampling points. The variations in emissions over the course of each test, which may be over an order of magnitude, are due in part to changes in the melt pool cold cap. Little or no HF or HCl was observed by FTIR, in keeping with the gaseous emission rates measured by the Method 5-type sampling.

The measured emissions during the DM10 test were consistent with the DM100 test processing the same feed and the removal of some gaseous species due to wet scrubbing. The most abundant nitrogen species monitored was NO, which is consistent with previous tests [2-11, 33-54, 67, 89, 93, 94] in which nitrates and nitrites were present in the feed. The NO_2 concentration was about seven times less than the NO concentration, a ratio less than from the DM100 tests due to the lower temperatures throughout the DM10 off gas treatment system and the partial scrubbing of NO_2 in the wet off-gas system. As expected, concentrations of by-products of incomplete and complete organic combustion, such as carbon monoxide and carbon dioxide, were observed throughout the tests. Ammonia was also observed in the WESP exhaust showing incomplete removal in the SBS and WESP despite the high concentrations of ammonia measured in the SBS and WESP effluent solutions, similar to previous tests with the ORPLB4 composition [17]. This observation is in contrast to previous tests processing the ORPLA20 composition in which no ammonia was detected in the WESP exhaust, which showed complete scrubbing of ammonia from the exhaust stream [16] and higher pH of SBS solutions. The water contents as measured by the Method 5-type sampling were about 6.6% at the WESP outlet and 3.5% at the blower outlet as a result of variable amounts of air dilution between the two sampling points. The variations in NO, NO_2, CO, and CO_2 emissions over the course of each test, which may approach an order of magnitude, are due in part to changes in the melt pool cold cap. The variations in water and ammonia concentrations over the course of each DM100 test were not observed during the DM10 test due to the damping effect of the SBS sump. No HCl was observed by FTIR, in keeping with the gaseous emission rates measured by the Method 5-type sampling trains at the WESP outlet.

SECTION 7.0
MASS BALANCE FOR VOLATILE CONSTITUENTS

7.1 Mass Balance of Volatile Constituents

The amounts of rhenium, sulfur, and chlorine fed into the melter were compared to the respective total amounts measured in the discharged glass, off-gas system solutions, and WESP exhaust streams. The amounts of rhenium, chlorine, and sulfur fed to the melter are calculated from the target concentrations and the total amount of feed processed during each test. At the end of the test, the WESP was deluged, the lines flushed, all of the sumps were drained and flushed, the contents were quantified, and samples were taken for analysis. The amount of volatiles in the WESP exhaust was calculated as the weighted average from a one-hour sample taken during nominal operating conditions, a one hour sample taken to include the WESP deluge procedure, and a one hour sample taken while the WESP was recovering from the initial deluge. The percentage reported in the glass is the steady state concentration (see Section 5.1), which for most of the analytes in most of the tests is the same as the test average concentration. The results from analysis of this suite of samples enable the calculation of mass balance around two different parts of the vitrification process: across the melter and off-gas system using the analysis of the glass, off-gas system effluents, and WESP emissions, as shown in Table 7.1; and across the melter using the analysis of the glass and melter emissions, as shown in Table 7.2. This approach also permits comparison of measured volatile distributions in glass and melter exhaust for tests conducted on the DM10 and DM100 melters with the AP105DLAW11 composition in Table 7.2. Distributions of measured volatile distributions in glass and DM10 off-gas system effluents are compared with results from the preceding test on the DM10 with the ORPLB4 composition in Table 7.1.

7.1.1 Rhenium

The total recovery for rhenium in glass, off-gas solutions, and WESP emissions was 90%, which is comparable to results for the ORPLB4 composition, below the 105 and 109% measured for previous tests with the LAWE4H and ORPLA20 compositions [16], and at the low end of the 90.5 to 119.6% range measured in previous tests conducted with the same off-gas system [14]. The lower total recovery in the present test and the test with the ORPLB4 composition is attributable to the uncertainty associated with the lower rhenium target concentration that was used (0.01 vs. 0.05 wt% ReO_2). Note that the rhenium concentrations measured in the discharge glasses from the present tests were marginally above the 0.0019 wt% ReO_2 limit for the ICP-MS calibrated XRF method. The sum of rhenium in the glass and melter exhaust gives higher total rhenium recoveries, between 102.2 and 117.7% for the DM100 and DM10 tests with the AP105DLAW11 composition. The high total recovery for the 5.6 M Na test is likely the result of the melter exhaust sample not being representative of the entire test. The total amount of rhenium reporting to the glass ranged from 22 to 27%, which is on the lower end of the range measured for most LAW glasses processed on the

DM10 and DM100 melter systems [38, 39, 89] and about half the amount measured in the preceding tests with the ORPLB4 [17] and ORPLA20 compositions [16]. About half of the rhenium fed into the melter was detected in the SBS solutions, which is considerably more than in the preceding tests with the ORPLB4 composition due to much lower retention in the glass. Similar proportions of rhenium were detected in WESP solutions during the two tests, at 13 to 15% of the amount fed. The amount of rhenium determined to be in the WESP exhaust during the present DM10 test was higher than in previous tests (2.1 vs. < 0.8 [16]– 0.18% [17]) due to the inclusion of emissions during the deluge and inclusion of the five-hour period in which power was not fully restored to the WESP. During nominal operating conditions, rhenium was detected in the WESP emissions at 0.01 percent of feed rhenium; this is lower than the 0.09% measured while processing the ORPLB4 composition [17] and lower than the detection-limit values of less than 0.7 to 0.8 percent in previous tests [16], which did not have the benefit of ICP-MS analysis of the liquid from the dissolved particulate sampling filter. Rhenium emission rates during the deluge were about 50 times higher than during nominal operation.

7.1.2 Sulfur

Mass balance closure for sulfur across the DM10 melter and off-gas system as well as across the DM10 melter alone was excellent at 99.1 and 101.6%, respectively. Conversely, mass balance closure across the DM100 melter of between 115.5 and 125.9% showed excess sulfur due to the high levels of sulfur in the melter at the start of testing and some of the melter exhaust samples not being fully representative of the entire test. The vast majority of feed sulfur reported to the glass at 91 - 100%, similar to the ORPLB4 composition at 94 – 96% [17] and more than the ORPLA20 composition at 84 - 86% [16] due to differences in the glass and waste composition. These levels of retention are well within the range measured in previous DM10 tests with these compositions [7]. The small amounts of sulfur in the off-gas system effluents are in the ratio of roughly 3:1 for SBS and WESP solutions. Emissions of sulfur from the WESP were minimal, at 0.1% or less of feed sulfur.

7.1.3 Chlorine

Good mass balance closure was obtained for chlorine across the DM10 melter and off-gas system at 87.5%, as well as across the DM10 and DM100 melters alone at 97 and 112%, respectively. Numerous melter tests with LAW feeds and chlorine have shown chlorine retentions of about half the feed chlorine in glass [2-6, 48-51, 94, 95], consistent with the glass discharged during the present DM10 and DM100 tests. Excesses of chlorine are often observed due to the ubiquity of chlorine as a contaminant in chemicals and additives [14, 16, 94, 95] and, in the case of tests conducted on the DM10 with the prototypical off gas system components, chlorine in the tap water used as makeup water, rinses, and sprays [14-17]. The present test used deionized water for makeup water, rinses, and sprays, which is one of the reasons for the improved chlorine balance across the DM10 melter and off-gas system as compared to the preceding tests with the ORPLB4 composition (87.5 vs, 184%). Also, the relatively high target chlorine concentration and the lack of observed contamination in feed samples (see Section 5.1) resulted in little excess measured chlorine in the present tests, in contrast to many previous tests. About a third of the chlorine fed to the melter was detected in the off-gas effluents with three quarters of that being measured in the SBS. Emissions of chlorine from the WESP were only 0.59% of the chlorine fed to the melter during nominal operation but increased by over seven times during the deluge procedure and seventeen times during the period in which power could not fully be restored to the WESP.

7.2 Distribution of Components in Primary Off-gas System Effluents

One of the objectives of this work was to quantify the amount of waste constituents in off-gas system solutions that would either be recycled back to the melter feed or require an alternate form of disposition. The elemental amounts in the waste and feed additives processed are compared to the total amounts measured in SBS and WESP solutions in Table 7.3. The amounts fed are calculated from the waste simulant composition in Table 2.2, target feed composition, and the total amount of feed processed in Table 4.1. The amounts in SBS and WESP solutions are the sum of the products of the amounts measured in SBS and WESP (Tables 4.7 and 4.8) and the amounts of fluid removed from each reservoir (Tables 4.4 and 4.5). Note that the concentrations given in Tables 4.7 and 4.8 are total concentrations of both suspended and dissolved constituents even though most of the waste components are dissolved and elements from additives comprise the vast majority of the suspended solids. Although nitrite is the most abundant species in the off-gas solutions, the total amount of nitrogen oxides present in the primary off-gas system effluents is less than two and a quarter percent of the amount in the melter feed. At the nominal levels of reductant, approximately half the nitrites and nitrates are converted to N_2, with most of the balance converted to gaseous NO and NO_2 [38, 39, 94, 95], the latter of which is partially scrubbed into SBS and WESP fluids [33-38]. The second most abundant constituent in the off-gas effluents is ammonia, which is not a waste component or feed additive, but a byproduct of reactions between nitrates/nitrites and sugar. Contrary to the preceding tests with the ORPLA20 and ORPLB4 compositions [16, 17], more than sixty percent of the rhenium present in the feed is observed in the primary off-gas system effluents due primarily to the low single-pass retention of rhenium in the glass. Similar proportions of fluorine are detected in off-gas solutions at 57% while 36% of feed chlorine was measured in the off-gas solutions. Sulfur and potassium are measured in the off-gas effluents at eight percent of the amounts in feed in response to the volatility of these elements. One to two percent of the sodium (the most abundant element in the waste), boron, chromium, lead, and tin fed to the melter were measured in off-gas effluents, mostly in the SBS solutions. Minimal amounts of most of the other feed components were measured in off-gas effluents, primarily as suspended solids in SBS solutions.

SECTION 8.0
SUMMARY AND CONCLUSIONS

Tests were conducted to develop a glass formulation for the LAW from Tank AP-105, collect data on primary off-gas system effluents to support the evaluation of potential direct feed LAW flowsheets, and determine the effect of the dilute direct feed LAW stream on processing rates and partitioning of waste components to the exhaust system. Development of a suitable glass formulation for the LAW Tank AP-105 composition made use of information from the ORP Enhanced LAW Glass Correlation that is currently under development [40-42]. Subsequently, melter feeds at various dilutions (4, 5.6, and 8 M Na), including those anticipated for direct feed LAW waste streams, were processed on the DM100 to determine glass production rates, bubbling rates required to process feeds with different water contents, and to determine feed carryover into the off-gas as a function of feed water content. Liquid effluent solutions generated from prototypical primary off-gas system components (SBS and WESP) were collected while processing the same LAW Tank AP-105 composition at a concentration of 5.6 M Na through the DM10 melter system. These solutions were analyzed to determine their steady state compositions and the effects of feed composition and feed water content at nominal processing conditions.

Glass formulations for LAW from Tank AP-105 were designed using information from the Enhanced LAW Glass Correlation that is under development [40-42]. LAW glass property-composition models [71, 72] and experience from previous work on high waste loading ORP LAW glass formulations were also utilized to identify suitable formulations for testing. Crucible melts of the LAW glass formulations were prepared and characterized with respect to properties that affect processability and product quality (crystallization, sulfate salt formation, melt viscosity, melt electrical conductivity, refractory corrosion, VHT alteration, and PCT release). A total of eleven crucible melts were prepared and characterized to develop the glass and feed formulations. Initial testing was limited to properties expected to be most constraining, which are VHT and K-3 refractory corrosion for high alkali glasses. Finally, the glass composition selected for melter testing was characterized with respect to all properties relevant to processing and product quality for LAW glasses prior to melter testing. The composition of the AP105DLAW11 glass selected for melter tests along with the waste contribution, glass former additives, and measured properties are given in Table 2.10. The glass has a waste loading of 28.75 wt% with 24 wt% Na_2O from the waste. Since the SO_3 loading in the glass is only 0.35 wt%, waste loading is limited by the alkali content ($Na_2O + K_2O$) of 24.47 wt%. As evident from Table 2.10, all the measured properties of glass AP105DLAW11 are well within the WTP processing and product quality requirements for LAW glasses.

Based on previous studies [6-12] the melter feed for a glass with 24 wt% Na_2O from the waste would be prepared at a feed sodium concentration of 8 M under the WTP baseline melter feed concentration requirements. However, since the direct feed LAW flowsheet is not expected to have an evaporator, the waste will be delivered at a concentration of 5.6M Na or less. Therefore, melter feeds were prepared at LAW simulant concentrations of 8, 5.6, and 4 M Na and tested for their properties including density, pH, solids settling rate, viscosity, and yield strength. All of the measured properties were within acceptable limits, except for settling rates of lower dilution (5.6 and 4 M Na) feeds, which could be an issue. The direct feed LAW flowsheet incorporation of feeds at or near the lowest sodium concentration tested (4 M Na) would necessitate the determination of the solids settling rate, and if rapid settling is found, corresponding mitigating strategies.

A series of three tests were conducted on the DM100-WV melter to determine glass production rates over a range of feed water contents with the simulated LAW from Tank AP-105 and AP105DLAW11 glass composition developed in this work. Melter configuration and operating conditions used in previous LAW tests [2-6, 40-54, 94, 95] were replicated, including a nominal glass temperature of 1150°C and a near complete cold cap, which is between 80-95% melt surface coverage for the DM100 since a 100% cold cap tends to lead to “bridging” in smaller melters. The target glass production rate of 2250 kg/m^2/day was approximated over the majority of the initial test while processing the nominal 8 M sodium waste simulant; the 14 lpm melt pool bubbling flow rate averaged during steady processing of this test was held constant in all subsequent tests. The production rates of 1900 kg/m^2/day and 1600 kg/m^2/day that were achieved while processing the 5.6 M Na and 4 M Na simulants confirmed expectations that glass production rates decrease with increasing feed water content. Production rate decrease with increasing feed water content was comparable to that measured for the ORPLA20 composition in tests with waste simulant concentrations of between 6 and 10 M Na [12]. Also, similarly observed with increasing feed water content was increasing solids and volatile constituent carryover from the melter into the exhaust stream.

A melter test was conducted with the LAW AP-105 5.6 M Na simulant and AP105DLAW11 glass composition on the DM10 system with prototypical primary off-gas system components (SBS and WESP) to investigate the retention of rhenium and other volatiles in glass and generated off-gas effluent solutions from prototypical melter off-gas system components. The nominal melter operating conditions for testing were an 1150°C glass pool temperature and air bubbled through the glass pool at a rate to achieve target glass production rate of 1900 kg/m^2/day (taken from the DM100 test with the same feed). The test was conducted with the same feed used in the DM100 test, including sugar as an organic reductant at a stoichiometric sugar ratio of 0.5 and spiking with perrhenic acid targeting 0.01 wt% ReO_2 in the product glass assuming total retention of the amount in the feed. Sufficient feed was processed in the test to pass a volume of water greater than three times the SBS sump volume of 135 liters (i.e., to reach three turnovers of the SBS sump) through the SBS as either blow down solutions or moisture carried downstream. Prototypical operating conditions for the off-gas system components, such as SBS operating temperature of 45°C, transition line spraying every 12 hours, and daily deluge of the WESP, were used. A mass balance for rhenium and other feed constituents of concern was measured across the glass pool, discharge glasses, melter exhaust, off-gas system component effluent solutions, and WESP exhaust over the course of the test.

Analysis of SBS and WESP solutions showed the effect of processing this LAW composition and off-gas system cleaning methodologies on the chemistry of the sump solutions over the course of the test. Similar to SBS solutions generated while processing the ORPLA20 and ORPLB4 compositions [16, 17], dissolved species constituted about 95% and 99% of the chemical species in SBS and WESP solutions, which were primarily nitrite, ammonia, chloride, alkali metals, sulfate, boron, and rhenium during nominal operation. Transition line rinsing was performed successfully during these tests, resulting in the introduction of additional feed solids into the SBS every 12 hours. Solutions sampled from the SBS after the transition line wash were very similar to other SBS solutions, with higher amounts of sodium and insoluble material (aluminum, silicon, and zinc) and lesser amounts of ammonia and nitrite. Steady state appeared to be achieved for pH and some minor constituents over the course of the test; however, the more abundant constituents such as nitrite, ammonia, chloride, sodium, boron, and rhenium increased in concentration over the entire test. Solutions from the WESP contained mostly soluble species, sodium chloride, and ammonium nitrite, with lesser amounts of potassium, nitrate, and sulfate, and less than one percent of solids being suspended. Deluging of the WESP once a day was successfully performed during the test, which rinsed soluble alkali, chloride, sulfate, rhenium, and nitrate salts from the internal WESP elements; however, difficulty recovering power after the initial deluge resulted in diminished effectiveness of the WESP for a five-hour period.

The DM100 melter and the DM10 melter, SBS, and WESP exhaust were sampled for metals, particles, and acid gases during testing and continuous monitoring of the stack exhaust for volatile species was performed. A melter exhaust sample was taken during each DM100 test and two melter exhaust samples were taken during the DM10 test once steady-state processing was established. Solids carryover from the DM100 melter ranged from 0.82 percent of feed solids while processing 8 M Na waste to 2.34 percent of feed solids while processing 4 M Na waste. Solids carryover from the DM10 melter was 1.1 percent of feed solids and decreased to 0.49 percent across the SBS. Volatile feed elements that were emitted at the lowest melter DF, in ascending order, were rhenium, chlorine, fluorine, potassium, sulfur, sodium, chromium, and boron. The composition of the SBS exhaust was very similar to the composition of the melter exhaust, but without the carried-over insoluble feed additives elements such as Al, Si, and Zn. The SBS achieved a DF of only about 2 because much of the particulate emissions from the melter were alkali halide salts, which are not fully scrubbed by the SBS and are treated by the WESP [33, 34, 37, 38]. Two WESP exhaust samples were taken during the DM10 test, one during the deluge and one after the deluge during nominal operations. An additional WESP exhaust sample was subsequently taken during nominal operating conditions when it was discerned that the WESP was not fully recovered from the deluge when the initial nominal operation sample was taken. The measured particulate emission rate from the WESP was 2.74 mg/min, corresponding to a feed carryover through the melter and primary off-gas system of 0.01% (DF of nearly 13000) during nominal operation. The measured particulate emission rate sampled during the WESP deluge was 34.1 mg/min, corresponding to a feed carryover through the melter and primary off-gas system of 0.10 % (DF of 1037) with emission rates twelve times higher than during nominal operation. The measured particulate emission rate sampled after the WESP deluge during difficulties restoring full power to the WESP was 56.9 mg/min, corresponding to a feed carryover through the melter and primary off-gas system of 0.16 % (DF of 623) with emission rates twenty times higher than during nominal operation, and 60% higher than during the deluge. This lack of WESP performance underscores the importance of a fully functioning

WESP in order to achieve the required level of particulate removal. The most abundant constituents in the emissions sampled during the WESP deluge procedure are alkali halides and sulfates; therefore, feed containing high concentrations of these constituents has the highest emission rates during the deluges. The only constituents present in the WESP exhaust during nominal operation were very low concentrations of alkali chlorides, sulfates, and perrhenates. Typical of the vitrification of LAW feeds with nitrates, nitrites, and sugar, gaseous species monitored in the DM100 and DM10 exhaust streams were NO (the most abundant nitrogen species monitored) with lower concentrations of NO_2 and by-products of incomplete and complete organic combustion, such as carbon monoxide and carbon dioxide, and ammonia generated from reaction between nitrates/nitrites and sugar. Ammonia was also observed in the WESP exhaust, indicating incomplete removal in the SBS and WESP despite the high concentrations of ammonia measured in SBS and WESP effluent solutions.

Mass balance distributions for rhenium, sulfur, and chlorine were calculated across the melter, off-gas system effluents, and WESP exhaust stream for the DM10 test. Volatile distributions across the DM10 and DM100 melters were calculated using glass and melter exhaust analysis. The total recovery of rhenium across the glass, off-gas solutions, and WESP emissions, as well as the melters alone, ranged from 90% to 118%. The proportion of target feed rhenium retained in the glass was 22 to 27 percent, which is on the lower end of the range measured for most LAW glasses processed on the DM10 and DM100 melter systems [38, 39, 89] and about half the amount measured in the preceding tests with the ORPLB4 [17] and ORPLA20 compositions [16]. The amount of rhenium retained in the glass decreases with increasing feed water content in the DM100 tests. The proportion of target feed rhenium in the melter exhaust ranged from 76 to 95%, with the higher value not deemed indicative of steady state processing. About half of the rhenium fed to the DM10 melter was detected in SBS solutions and over two percent was emitted from the WESP, mostly during the deluges and the period when the WESP was not fully powered. Rhenium was detected in the WESP emissions at 0.01 percent of feed rhenium during nominal operating conditions. Mass balance closure for sulfur across the DM10 melter and off-gas system as well as across the DM10 melter alone was excellent at 99.1 and 101.6%. Conversely, mass balance closure across the DM100 melter of between 115.5 and 125.9% showed excess sulfur due to the high levels of sulfur in the melter at the start of testing and some of the melter exhaust samples not being fully representative of the entire test. The vast majority of feed sulfur reported to the glass at 91 - 100%. Good mass balance closure was obtained for chlorine across the DM10 melter and off-gas system at 87.5%, as well as across both melters alone at 97 and 112%. About half the chlorine fed to the melter was retained in the glass at the higher feed solids content, with the amount retained decreasing with increasing feed water content. Similar to rhenium, emissions of chlorine from the WESP were less than one percent of feed during nominal operation but increased significantly during the deluge procedure and the period during which power could not fully be restored to the WESP.

The amount of waste constituents in off-gas system solutions that would either be recycled back to the melter feed or require an alternate form of disposition was quantified from the analysis of off gas effluents from the DM10 test. Although nitrite is the most abundant species in the off-gas solutions, the total amount of nitrogen oxides present in primary off-gas system effluents is less than two and a quarter percent of the amount in the melter feed. The second most abundant constituent in the off gas effluents is ammonia, which is not a waste component or feed additive, but a byproduct of reactions between nitrates/nitrites and sugar. Contrary to the preceding tests with the ORPLA20 and ORPLB4 compositions [16, 17], more than sixty percent of the rhenium present in the feed is observed in the primary off-gas system effluents due primarily to the low single-pass retention of rhenium in the glass. Similar proportions of fluorine are detected in off-gas solutions at 57% while 36% of feed chlorine was measured in the off-gas solutions. Sulfur and potassium are measured in the off-gas effluents at eight percent of their amounts in the feed in response to the volatility of these elements. One to two percent of the sodium (the most abundant element in the waste), boron, chromium, lead, and tin fed to the melter were measured in off-gas effluents, mostly in the SBS solutions. Minimal amounts of most of the other feed components were measured in off-gas effluents, primarily as suspended solids in SBS solutions.

SECTION 7.0
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Table 2.1. AP-105 Supernatant Inventory Based on BBI [70], Converted to Solution Concentrations at 5.6 Molar Sodium for Simulant Development.

Analyte	Inventory (kg)	Mol. Weight	Mole/L	mg/L
Al	8.91E+04	26.98	4.43E-01	11,962
Ca	3.08E+02	40.08	1.03E-03	41
Cl	2.77E+04	35.45	1.05E-01	3,719
TIC as CO$_3$	4.89E+04	60.01	1.09E-01	6,565
Cr	2.16E+03	52	5.58E-03	290
F	4.78E+02	19	3.38E-03	64
K	2.08E+04	39.098	7.14E-02	2,792
Na	9.59E+05	22.99	5.60E+00	128,744
Ni	1.98E+02	58.69	4.54E-04	27
Pb	1.08E+02	207.20	7.00E-05	14
NO$_2$	3.94E+05	46	1.15E+00	52,894
NO$_3$	7.90E+05	62	1.71E+00	106,056
Oxalate	3.17E+03	88.00	4.84E-03	426
PO$_4$	1.41E+04	94.97	1.99E-02	1,893
Si	4.80E+02	28.09	2.29E-03	64
SO$_4$	2.24E+04	96.06	3.13E-02	3,007
TOC	2.08E+04	12	2.33E-01	2,792
Other minor analytes not included in simulant (<15 mg/L)				
Bi	103.00	208.98	6.62E-05	14
U TOTAL	22.9	238.03	3.34E-05	8
Mn	8.23	54.938	3.20E-05	2
Fe	34.3	55.85	2.39E-05	1
La	8.67	138.90	9.20E-06	1
Zr	5.79	91.22	9.92E-06	1
Sr	2.95	87.62	6.27E-06	1
Hg	0.02	200.59	2.46E-08	0

Table 2.2. LAW AP-105 Waste Simulant Recipe at 5.6 Molar Sodium.

Constituents	Simulant AP-105 For Direct Feed		Glass Oxides	Simulant as Oxides (wt%)	Source in Simulant	Order for Addition	Formula Weight	Assay*	Target Weight (g)
-	mg/L	Molarity	Loading	100%	In 544 ml water add following compounds in the order listed below				
Al	11,962	0.4433	Al_2O_3	10.87	$Al(NO_3)_3.9H_2O$, 60% sol.	1	375.14	0.607	274.04
Ca	41	0.0010	CaO	0.03	$Ca(NO_3)_2.4H_2O$	2	236.16	0.998	0.24
Cr	290	0.0056	Cr_2O_3	0.20	$Na_2CrO_4.4H_2O$	8	234.04	0.995	1.31
K	2,792	0.0714	K_2O	1.62	KOH	7	56.10	0.908	4.41
Na	128,744	5.6000	Na_2O	83.48	NaOH, 50% sol. d=1.53	6	40.00	0.501	274.94
Ni	27	0.0005	NiO	0.02	$Ni(OH)_2$	3	92.72	1.000	0.04
Pb	14	0.0001	PbO	0.01	PbO	4	223.20	1.000	0.02
Si	64	0.0023	SiO_2	0.07	SiO_2	5	60.09	0.990	0.14
Cl	3,719	0.1049	Cl	1.79	NaCl	10	58.45	0.994	6.17
F	64	0.0034	F	0.03	NaF	11	42.00	1.005[&]	0.14
PO_4	1,893	0.0199	P_2O_5	0.68	$Na_3PO_4.12H_2O$	9	380.12	1.006[&]	7.53
SO_4	3,007	0.0313	SO_3	1.21	Na_2SO_4	12	142.06	0.998	4.46
NO_2	52,894	1.1499	-	-	$NaNO_2$	14	69.00	0.995	79.74
NO_3	106,056	1.7106	-	-	$NaNO_3$	15	84.99	0.990	32.49
CO_3	6,565	0.1094	-	-	Na_2CO_3	16	105.99	1.000	11.60
Org. Carbon	2,792	0.2327	-	-	-	-	-	-	-
Acetate[$]	3,978	0.0673	-	-	Sodium Acetate ($C_2H_9NaO_5$)	13	136.08	1.001	9.15
Formate[$]	3,978	0.0884	-	-	Sodium Formate (HCO_2Na)	14	68.01	1.013	5.93
Oxalate	426	0.0048	-	-	Sodium Oxalate ($Na_2C_2O_4$)	13	134.00	0.990	0.65
-	-	-	SUM	100.0	Total simulant Weight (g)				1257

- Empty data field.

* Assay refers to the purity of the raw material as specified by the vendor.

[$] Oxalate content is complemented by equal weight fractions of acetate and formate to meet the target TOC**.**

[&] Assay value greater than one for any raw material containing sodium is based on the sodium content of that raw material.

Table 2.3. Target and Analyzed Compositions (wt%) of AP105DLAW Crucible Glasses.

Glass	**AP105DLAW1**		**AP105DLAW2**		**AP105DLAW3**		**AP105DLAW4**		**AP105DLAW5**		**AP105DLAW6**	
Oxides	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*	Target	Analyzed*
Al_2O_3	8.34	7.99	8.92	8.57	9.51	9.16	10.00	9.58	9.51	9.53	10.00	9.83
B_2O_3	11.00	10.87	11.00	11.04	11.00	11.45	11.00	11.11	10.00	10.07	10.00	10.03
CaO	1.95	2.04	1.95	2.03	1.95	2.07	1.95	1.94	1.95	2.09	1.95	2.10
Cr_2O_3	0.36	0.36	0.35	0.36	0.34	0.37	0.33	0.37	0.34	0.36	0.33	0.39
Fe_2O_3	0.20	0.22	0.20	0.24	0.20	0.22	0.20	0.22	0.20	0.22	0.20	0.22
K_2O	0.56	0.55	0.58	0.58	0.60	0.59	0.61	0.57	0.60	0.56	0.61	0.57
MgO	1.00	0.87	1.00	0.89	1.00	0.93	1.00	0.87	1.00	0.82	1.00	0.80
Na_2O	21.94	21.18	22.60	22.81	23.26	22.97	23.92	23.87	23.26	23.32	23.92	23.59
NiO	0.004	0.006	0.004	0.000	0.004	0.000	0.004	0.008	0.004	0.010	0.004	0.000
PbO	0.002	0.000	0.002	0.006	0.002	0.000	0.002	0.000	0.002	0.000	0.002	0.000
SiO_2	45.51	46.84	43.47	43.80	41.43	42.15	39.48	40.59	42.43	42.57	40.48	40.73
V_2O_5	0.76	0.77	0.83	0.84	0.90	0.94	0.96	0.97	0.90	0.92	0.96	1.00
ZnO	3.00	2.85	3.00	2.87	3.00	2.91	3.00	2.84	3.00	2.92	3.00	3.03
ZrO_2	4.01	3.93	4.68	4.68	5.36	5.20	6.03	5.74	5.36	5.28	6.03	6.23
Cl	0.38	0.30	0.40	0.29	0.41	0.31	0.42	0.29	0.41	0.31	0.42	0.30
F	0.03	NA	0.03	NA	0.04	NA	0.04	NA	0.04	NA	0.04	NA
P_2O_5	0.39	0.42	0.40	0.15	0.41	0.41	0.42	0.42	0.41	0.42	0.42	0.45
SO_3	0.57	0.54	0.58	0.49	0.60	0.59	0.62	0.55	0.60	0.51	0.62	0.57
Sum	100.0	99.9	100.0	99. 7	100.0	100.3	100.0	99.9	100.0	99.9	100.0	99.9

* Analyzed by XRF except for boron and lithium which were measured by DCP
NA = Not Analyzed.

Table 2.3. Target and Analyzed Compositions (wt%) of AP105DLAW Crucible Glasses (continued).

Glass	**AP105DLAW7**		**AP105DLAW8**		**AP105DLAW9**		**AP105DLAW10**		**AP105DLAW11**	
Oxides	Target	XRF	Target	XRF	Target	XRF	Target	XRF	Target	XRF
Al_2O_3	9.51	9.50	10.00	9.87	9.51	9.59	10.00	10.02	10.00	10.01
B_2O_3	10.00	10.07	10.00	9.99	11.00	10.68	11.00	10.92	11.00	10.94
CaO	1.95	2.05	1.95	2.00	1.95	2.01	1.95	2.02	1.95	2.09
Cr_2O_3	–	–	–	–	–	–	–	–	0.46	0.47
Fe_2O_3	0.20	0.22	0.20	0.24	0.20	0.23	0.20	0.21	0.67	0.71
K_2O	0.60	0.61	0.61	0.61	0.60	0.58	0.61	0.62	0.47	0.47
MgO	1.00	0.84	1.00	0.83	1.00	0.87	1.00	0.82	1.00	0.81
Na_2O	23.26	23.09	24.00	24.20	23.26	22.25	23.92	23.27	24.00	23.73
NiO	0.004	0.000	0.004	0.009	0.004	0.008	0.004	0.006	0.005	0.000
PbO	0.002	0.000	0.002	0.007	0.002	0.000	0.002	0.000	0.002	0.000
SiO_2	42.77	42.75	40.82	40.88	41.77	42.76	39.82	40.59	38.72	38.92
SnO_2	–	–	–	–	–	–	–	–	0.98	0.91
TiO_2	–	–	–	–	–	0.04	–	0.05	0.67	0.74
V_2O_5	0.90	0.96	0.96	0.98	0.90	0.95	0.96	0.99	–	–
ZnO	3.00	3.00	3.00	2.92	3.00	2.92	3.00	2.90	3.00	3.01
ZrO_2	5.36	5.58	6.03	5.98	5.36	5.42	6.03	6.06	6.01	6.06
Cl	0.41	0.29	0.42	0.31	0.41	0.29	0.42	0.32	0.51	0.40
F	0.04	NA	0.04	NA	0.04	NA	0.04	NA	0.01	NA
P_2O_5	0.41	0.43	0.42	0.42	0.41	0.43	0.42	0.44	0.20	0.20
SO_3	0.60	0.52	0.62	0.55	0.60	0.55	0.62	0.54	0.35	0.31
Sum	100.0	99.9	100.0	99.8	100.0	99.6	100.0	100.0	100.0	99.8

[*] Analyzed by XRF except for boron and lithium which were measured by DCP
NA = Not Analyzed
– Empty data field.

Table 2.4. Descriptions of AP105DLAW Crucible Glasses after Heat-Treatment.

Sample ID	**Observation (Optical microscopy)**
AP105DLAW1C950H20	Clear peridot-to-emerald green glass; free of crystallization in SEM evaluation
AP105DLAW2 C950H20	
AP105DLAW3 C950H20	
AP105DLAW4 C950H20	
AP105DLAW5 C950H20	
AP105DLAW6 C950H20	
AP105DLAW7 C950H20	Clear very pale yellow - nearly colorless glass; free of crystallization in SEM evaluation
AP105DLAW8 C950H20	
AP105DLAW9 C950H20	
AP105DLAW10 C950H20	
AP105DLAW11 C950H20	Clear emerald green glass; free of crystallization in SEM evaluation

Table 2.5. Measured Sulfate Solubility by Batch Saturation for AP105DLAW Crucible Glasses.

Sample ID	**SO_3 Content (wt%) in As-Melted Glass**	**SO_3 Content (wt%) After Acid Wash**
AP105DLAW1	0.52	0.48
AP105DLAW2	0.57	0.54
AP105DLAW3	0.77	0.59
AP105DLAW4	0.79	0.57
AP105DLAW5	0.65	0.59
AP105DLAW6	0.63	0.60
AP105DLAW7	0.64	0.65
AP105DLAW8	0.67	0.59
AP105DLAW9	0.65	0.58
AP105DLAW10	0.59	0.59
AP105DLAW11	0.42	0.43

Table 2.6. Viscosities and Electrical Conductivities for AP105DLAW Crucible Glasses.

Glass ID			AP105D LAW1	AP105D LAW2	AP105D LAW3	AP105D LAW4	AP105D LAW5	AP105D LAW6	AP105D LAW7	AP105D LAW8	AP105D LAW11
Viscosity (P)	Predicted at 1100°C		142	126	111	98	132	116	138	122	95
	Predicted at 1150°C		86	76	67	59	79	70	83	73	56
	Interpolated	950°C	1197	966	883	741	963	778	972	848	699
		1000°C	569	446	401	332	450	367	461	399	321
		1050°C	293	229	204	168	232	190	240	207	163
		1100°C	162	127	114	94	129	107	134	116	90
		1150°C	95	76	68	57	77	64	80	69	53
		1200°C	59	48	44	36	49	41	50	44	33
		1250°C	38	32	29	25	32	27	33	29	22
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.501	0.540	0.582	0.629	0.567	0.611	0.562	0.607	0.644
	Interpolated	950°C	0.214	0.266	0.239	0.257	0.269	0.279	0.287	0.303	0.266
		1000°C	0.268	0.330	0.297	0.321	0.336	0.345	0.346	0.362	0.333
		1050°C	0.328	0.404	0.363	0.393	0.409	0.417	0.411	0.428	0.405
		1100°C	0.393	0.486	0.437	0.472	0.487	0.494	0.483	0.499	0.482
		1150°C	0.463	0.578	0.519	0.558	0.568	0.576	0.561	0.575	0.563
		1200°C	0.536	0.679	0.608	0.650	0.651	0.662	0.645	0.658	0.647
		1250°C	0.613	0.789	0.705	0.749	0.736	0.751	0.734	0.745	0.733

Table 2.7. Results of 7-day PCT (at 90ºC) for AP105DLAW Crucible Glasses.

Glass ID	AP105DLAW3	AP105DLAW5	AP105DLAW6	AP105DLAW7	AP105DLAW8	AP105DLAW11
7-Day PCT, Stainless Steel Vessel; S/V=2000 m^{-1} (ppm)						
B	43.61	29.36	36.36	27.76	32.31	47.42
Na	172.11	158.89	184.8	154.16	176.92	195.86
Si	48.67	54.46	52.81	54.26	52.46	54.2
Normalized Concentrations (g/L)						
B	1.28	0.94	1.17	0.89	1.04	1.39
Na	1.00	0.92	1.04	0.89	1.00	1.10
Si	0.25	0.27	0.28	0.27	0.27	0.30
pH	11.16	11.22	11.34	11.23	11.34	11.32
7-Day PCT Normalized Mass Loss (g/m^2)						
B	0.64	0.47	0.58	0.45	0.52	0.69
Na	0.50	0.46	0.52	0.45	0.50	0.55
Si	0.13	0.14	0.14	0.14	0.14	0.15

Table 2.8. Results of VHT (at 200ºC for 24 Days*) for AP105DLAW Crucible Glasses.

Glass ID	Alteration Depth (µm)	Rate (g/m^2/d) Calculated for Estimated Average Density of 2.65 g/cc	Comparison to Limit of 50 g/m^2/d	Predicted Rate (g/m^2/d)
AP105DLAW1	107.0	11.8	24%	13.4
AP105DLAW2	150.5	16.6	33%	20.1
AP105DLAW3	220.5	24.3	49%	30.7
AP105DLAW4	255.0	28.2	56%	46.9
AP105DLAW5	218.0	24.1	48%	27.3
AP105DLAW6	279.6	30.9	62%	41.5
AP105DLAW7	215.5	23.8	48%	25.6
AP105DLAW8	292.1	32.2	64%	38.9
AP105DLAW9	–	–	–	28.9
AP105DLAW10	–	–	–	43.9
AP105DLAW11	247.3	26.5*	55%	32.0

– Empty data field.

*Glass AP105DLAW11 tested for 24.7 days; all others tested for 24.0 days.

Table 2.9. Results of K-3 Corrosion Testing for AP105DLAW Crucible Glasses.

Glass ID	Predicted Neck loss (inches) [82]	Measured Neck loss (inches)	Measured Depth of altered zone (inches)	Measured Half-down loss (inches)
AP105DLAW1	0.022	–	–	–
AP105DLAW2	0.025	0.007	0.025	0.000
AP105DLAW3	0.029	0.012	0.025	0.000
AP105DLAW4	0.033	0.018	0.024	0.000
AP105DLAW5	0.026	–	–	–
AP105DLAW6	0.030	0.02	0.021	0.000
AP105DLAW7	0.034	0.021	0.026	0.001
AP105DLAW8	0.039	0.032	0.026	0.001
AP105DLAW9	0.037	–	–	–
AP105DLAW10	0.042	–	–	–
AP105DLAW11	0.030	0.026	0.028	0.0005

– Empty data field.

Table 2.10. Property Summary for Selected Glass Formulation AP105DLAW11.

	AP-105	**Glass Formers**	**AP105DLAW11**
Waste loading	28.75%	71.25%	28.75%
Al_2O_3	3.13	6.87	10.00
B_2O_3	–	11.00	11.00
CaO	0.01	1.94	1.95
Cr_2O_3	0.06	0.41	0.46
Fe_2O_3	–	0.67	0.67
K_2O	0.47	–	0.47
MgO	–	1.00	1.00
Na_2O	24.00	–	24.00
NiO	0.01	–	0.01
PbO	0.00	–	0.00
SiO_2	0.02	38.70	38.72
SnO_2	–	0.98	0.98
TiO_2	–	0.67	0.67
ZnO	–	3.00	3.00
ZrO_2	–	6.01	6.01
Cl	0.51	–	0.51
F	0.01	–	0.01
P_2O_5	0.20	–	0.20
SO_3	0.35	–	0.35
Sum	28.75	71.25	100.00

Property	**Requirements [76, 78]**	**Measured on AP105DLAW11**
SO_3-Sat (S4-W)	0.35 wt% SO_3 from waste AP-105	0.43
K3 Neck Loss (inch)	For WTP LAW glass formulation development, a neck corrosion of 0.035 inches on 6-day K-3 coupon corrosion test at 1208°C has been used as an acceptance limit. For the current LAW glass formulation development work for ORP, since higher waste loading compositions are being explored, a slightly higher neck corrosion value of 0.040 inches was used as a guide for acceptable corrosion characteristics.	0.026
Viscosity (P)-1100°C*	10 to 150 P	90
Viscosity (P)-1150°C*	20-80P	53
Conductivity (S/m)-1100°C	0.1 to 0.7 S/cm	0.482
B-PCT (g/m^2)	$< 2.0\ g/m^2$	0.69
Na-PCT (g/m^2)	$< 2.0\ g/m^2$	0.55
VHT (g/m^2/day)	$< 50\ g/m^2$/day	26.5

* The listed viscosity requirements are from [76]. Per another document "Preliminary ILAW Formulation Algorithm Description" 24590-LAW-RPT-RT-04-0003, Rev. 1, viscosity requirements are ≤ 150 poise at 1100°C and 20 - 80 poise at 1150°C.

Table 2.11. Description of the AP105DFL Feeds Prepared to Test the Effects of Solids Content (per One Liter of Simulant).

Sodium Molarity		**4**	**5.6**	**8**
Simulant (1L)	$Al(NO_3)_3.9H_2O$, 60% sol.	195.75	274.04	391.49
	$Ca(NO_3)_2.4H_2O$	0.17	0.24	0.35
	$Na_2CrO_4 \cdot 4H_2O$	0.94	1.31	1.87
	KOH	3.15	4.41	6.30
	NaOH, 50% sol. d=1.53	196.38	274.94	392.77
	$Ni(OH)_2$	0.03	0.04	0.06
	PbO	0.01	0.02	0.02
	SiO_2	0.10	0.14	0.20
	NaCl	4.41	6.17	8.81
	NaF	0.10	0.14	0.20
	$Na_3PO_4.12H_2O$	5.38	7.53	10.76
	Na_2SO_4	3.18	4.46	6.37
	$NaNO_2$	56.96	79.74	113.91
	$NaNO_3$	23.21	32.49	46.42
	Na_2CO_3	8.28	11.60	16.57
	Sodium Acetate ($C_2H_9NaO_5$)	6.54	9.15	13.08
	Sodium Formate (HCO_2Na)	4.24	5.93	8.47
	Sodium Oxalate ($Na_2C_2O_4$)	0.47	0.65	0.94
	Added Water , ml	675	544	333
	Simulant Weight	1185	1257	1352
	Simulant density	1.19	1.26	1.35
Feed	Kyanite (Al_2SiO_5) 325 Mesh (g)	62.14	87.00	124.29
	H_3BO_3 Technical Granular (g)	101.02	141.42	201.83
	Wollanstonite NYAD-325 (g)	22.07	30.90	44.14
	Cr_2O_3 oxide – Alfa Aesar	2.14	2.99	4.20
	Fe_2O_3 oxide – Alfa Aesar	2.29	3.21	4.59
	Olivine (Mg_2SiO_4) 325 Mesh (g)	10.49	14.68	20.98
	SiO_2 (Sil-co-Sil 75) (g)	142.67	199.74	285.35
	SnO_2 - Stannic Oxide - Belmont	5.08	7.12	10.10
	Rutile Sand – Premium airfloated	2.48	3.47	4.87
	ZnO – Kadox 920 (g)	15.50	21.69	30.99
	Zircon $ZrSiO_4$ (Flour) (g)	47.27	66.18	94.54
	Sucrose as Reductant (g)	38.94	54.51	77.87
	Sum of Additives with sugar (g)	452.08	632.92	903.74
	Sum of complete batch (g)	1637	1890	2255
	Measured Feed Density	1.35	1.47	1.64
	Measured Feed pH	11.51	11.83	11.94
	Expected Glass yield (g) starting from 1L simulant	517	723	1033
	Calculated Glass Yield (g/kg of Feed)	320	394	470

Table 2.12. Total Solids Content, Glass Yield, and Density for AP105DFL Feeds.

Sodium Molarity	**4**	**5.6**	**8**
Sample ID	AP105DFL4	AP105DFL5p6	AP105DFL8
Measured by Drying			
Measured % Water	60.6%	52.0%	40.8%
Feed Total Solid Content (g/kg of Feed)	395	480	592
Measured Density (g/cm^3)	1.35	1.47	1.64
Total Solids (g/l of Feed)	533	705	970
Measured by Melting			
Glass Yield (g/kg of Feed)	307	372	470
Glass Yield (g/l of Feed)	414	547	771
Sodium Content (g Na/kg of Feed)	56	68	82

Table 2.13. Settling Behavior of AP105DFL Feeds.

4 M Na						5.6 M Na						8 M Na					
Sample ID AP105DFL4		Sample ID AP105DFL4A		Sample ID AP105DFL4B		Sample ID AP105DFL5p6		Sample ID AP105DFL5p6A		Sample ID AP105DFL5p6B		Sample ID AP105DFL8		Sample ID AP105DFL8A		Sample ID AP105DFL8B	
Time (hrs)	Settled Solids (vol.%)	Time (hrs)	Settled Solids (vol.%)	Time (hrs)	Settled Solids (vol.%)	Time (hrs)	Settled Solids (vol.%)	Time (hrs)	Settled Solids (vol.%)	Time (hrs)	Settled Solids (vol.%)	Time (hrs)	Settled Solids (vol.%)	Time (hrs)	Settled Solids (vol.%)	Time (hrs)	Settled Solids (vol.%)
0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
0.1	89.0	0.2	89.0	0.2	95.0	0.1	98.0	0.0	98.0	0.0	98.0	0.2	99.0	0.5	96.0	0.5	97.0
0.3	76.0	0.5	67.0	0.5	69.0	0.4	88.0	0.3	89.0	0.3	89.0	0.7	95.0	0.8	95.0	0.8	94.0
0.6	66.0	0.8	54.0	0.8	56.0	0.6	84.0	0.5	82.0	0.5	85.0	1.0	92.0	1.1	91.0	1.1	92.0
0.8	58.0	1.0	46.0	1.0	47.0	0.8	80.0	0.8	76.0	0.8	77.0	1.3	90.0	1.8	77.0	1.8	79.0
1.1	54.0	1.2	43.0	1.2	44.0	1.1	74.0	1.0	67.0	1.0	69.0	2.0	84.0	2.3	75.0	2.3	76.0
1.3	48.0	1.5	42.0	1.5	43.0	1.6	70.0	1.5	58.0	1.5	56.0	2.5	80.0	2.6	74.0	2.6	75.0
1.6	44.0	1.7	41.0	1.7	42.0	1.8	67.0	1.8	54.0	1.8	53.0	2.8	78.0	3.5	72.0	3.5	73.0
4.3	40.0	4.5	41.0	4.5	42.0	2.1	64.0	2.0	53.0	2.0	53.0	3.7	74.0	3.8	71.0	3.8	72.0
19.7	40.0	19.8	41.0	19.8	42.0	4.8	60.0	4.8	53.0	4.8	53.0	4.0	72.0	4.3	71.0	4.3	72.0
30.7	40.0	30.8	41.0	30.8	42.0	20.2	52.0	20.1	53.0	20.1	53.0	4.5	72.0	5.6	70.0	5.6	71.0
44.1	40.0	44.3	41.0	44.3	42.0	31.2	52.0	31.1	53.0	31.1	53.0	5.8	70.0	7.6	70.0	7.6	71.0
–	–	–	–	–	–	44.6	52.0	44.5	53.0	44.5	53.0	7.7	68.0	23.6	70.0	23.6	70.0
–	–	–	–	–	–	–	–	–	–	–	–	23.8	68.0	31.6	70.0	31.6	70.0
–	–	–	–	–	–	–	–	–	–	–	–	31.7	68.0	47.6	70.0	47.6	70.0
–	–	–	–	–	–	–	–	–	–	–	–	47.8	68.0	–	–	–	–

- Empty data field

Table 2.14. Viscosity of the AP105DFL Feeds (Poise).

Sodium Molarity of Feed	**Shear Rate (s^{-1})**					
	1	**10**	**100**	**377**	**900**	**1000**
4	1.05	0.15	0.07	0.04	0.05	0.06
5.6	1.40	0.47	0.15	0.11	0.09	0.09
8	6.32	0.40	0.25	0.23	0.21	0.21

Table 2.15. Yield Stress of the AP105DFL Feeds.

Feed ID	**Yield Stress (Pa)**
AP105DFL4	<0.06(a)
AP105DFL5p6	<0.06(a)
AP105DFL8	0.3
Operational Limit [84]	**15 Pa**

(a) Values less than 0.2 Pa are below instrument measurement limit.

Table 2.16. Target Glass Formulation AP105DLAW11 Including Recycle for DM100 Tests.

	AP-105 Crucible work	**Recycle**	**AP-105 with Recycle**	**Glass Former**	**AP105DLAW11 Feed for DM100**
Waste Loading	28.75%	0.31%	29.06%	70.94%	28.75%
Al_2O_3	3.13	–	3.13	6.87	10.00
B_2O_3	–	–	–	11.00	11.00
CaO	0.01	–	0.01	1.94	1.95
Cr_2O_3	0.06	–	0.06	0.41	0.46
Fe_2O_3	–	–	–	0.67	0.67
K_2O	0.47	–	0.47	–	0.47
MgO	–	–	–	1.00	1.00
Na_2O	24.00	–	24.00	–	24.00
NiO	0.01	–	0.01	–	0.01
PbO	0.00	–	0.00	–	0.00
SiO_2	0.02	–	0.02	38.39*	38.41
SnO_2	–	–	–	0.98	0.98
TiO_2	–	–	–	0.67	0.67
ZnO	–	–	–	3.00	3.00
ZrO_2	–	–	–	6.01	6.01
Cl	0.51	0.30$	0.82	–	0.82
F	0.01		0.01	–	0.01
P_2O_5	0.20		0.20	–	0.20
SO_3	0.35	0.01#	0.35	–	0.35
Sum	28.75	0.31	29.06	70.94	100.00

$ Recycling of 59.7% applied to Cl
# Recycling of 2.5% applied to SO_3
*Silica decreased to compensate for recycle additions

Table 3.1. Summary of Test Conditions and Results for DM100 Tests with AP105DLAW11 Glass Composition.

Test/ Waste Simulant Concentration		8 M Na	5.6 M Na	4 M Na
Operational Strategy		Bubbling Adjusted to achieve 2250 kg glass/m^2/day	Bubbling fixed at 14 lpm	Bubbling fixed at 14 lpm
Avg. Bubbling Rate (lpm)		13.6	14.0	14.1
Time	Feed Start	2/22/17 10:35	3/7/17 11:00	3/15/17 12:00
	Feed End	2/24/17 15:00	3/9/17 13:00	3/17/17 10:07
	Water Feeding (hr)	1.3	1.7	1.8
	Net Slurry Feeding (hr)	51.1	48.3	44.3
	Total (hr)	52.4	50	46.1
	Interruptions (min)	15	16	14
Feed	Target Glass Yield (kg/kg)	0.460	0.383	0.316
	Measured Glass Yield (kg/kg)	0.431	0.359	0.297
	Used (kg)	1118	1088	989
Glass Discharged (kg)		494	385	291.5
Avg. Production Rate based on feed consumed and target glass yield (kg/m^2/day)		2234	1869	1568
Avg. Production Rate based on feed consumed and measured glass yield (kg/m^2/day)		2094	1798	1473
Avg. Production Rate based on glass discharged (kg/m^2/day)		2148	1771	1462
Steady State Production Rate based on feed consumed and target glass yield (kg/m^2/day)		2250	1900	1600

Table 3.2. Summary of Measured Melter Parameters for DM100 Tests.

Test			8 M Na			5.6 M Na			4 M Na		
			AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (C)	Electrode	East	949	903	961	968	914	991	965	920	979
		West	1080	1031	1101	1090	1054	1122	1093	1053	1126
	Glass	19” from bottom	745	289	963	589	242	953	553	182	998
		16” from bottom	1076	953	1136	1024	834	1171	1038	760	1151
		10” from bottom	1150	1116	1173	1145	1099	1199	1141	1060	1187
		4” from bottom	1153	1119	1175	1154	1112	1207	1154	1091	1198
	Plenum	Exposed	510	399	797	583	485	782	516	396	796
		Thermowell	500	423	783	570	479	756	521	429	781
	Discharge Chamber		1049	1009	1072	1055	993	1085	1045	1023	1078
	Film Cooler Outlet		296	279	308	298	279	310	298	281	309
	Transition Line Outlet		282	270	293	283	272	293	278	265	292
Lance Bubbling (lpm)			13.6	1.3	15.2	14.0	1.3	14.7	14.1	1.4	14.2
Melter Pressure (inches water)			-0.90	-4.22	1.02	-0.85	-5.06	0.85	-0.78	-4.53	1.52
Electrode Voltage (V)			35.5	32.6	45.8	34.6	26.8	40.5	34.8	31.6	37.8
Total Power (kW)			23.9	21.0	28.8	27.1	17.8	33.9	27.2	23.1	32.0
Glass Resistance (ohms)			0.053	0.046	0.073	0.044	0.040	0.049	0.045	0.041	0.050

Table 4.1. Summary of Test Conditions and Results for the DM10 Test with AP105DLAW11 Glass Composition.

Test		**5.6 M Na**
Time	Feed Start	3/28/17 18:00
	Feed End	3/31/17 7:15
	Interval	61.3 hr
	Feed Interruptions	14 min
Glass	Target ReO_2 wt%	0.01
	Mass Poured	97.8 kg
	Average Glass Production Rate	1823 kg/m^2/day
Feed	Target Glass Yield	0.383 kg/kg
	Measured Glass Yield	0.369 kg/kg
	Mass Fed	270 kg
	Average Feed Rate	4.4 kg/hr
	Average Glass Production Rate calculated using Target Glass Yield	1930 kg/m^2/day
	Average Glass Production Rate calculated using Measured Glass Yield	1860 kg/m^2/day
Measured % Feed in Glass	Rhenium	27
	Chlorine	52
	Sulfur	93

Table 4.2. Measured DM10 Melter Parameters.

Test		**5.6 M Na**		
		Avg.	Min.	Max.
Temperature (°C)	Glass Pool (2" from floor)	1146	1086	1170
	Glass Pool (4" from floor)	1140	1078	1166
	Plenum (exposed)	467	318	560
	Plenum (thermowell)	544	345	613
	East Electrode	1133	1094	1157
	Discharge Chamber	1112	1062	1129
	West Electrode	1064	1043	1079
Melter Pressure (inches water)		-1.61	-3.06	2.99
Bubbling (lpm)		1.8	0.5	4.0
Electrode Voltage (Volts)		22.8	0.3	46.6
Electrode Current (Amps)		266	179	299
Total Power (kW)		6.1	0.1	13.1
Melt Resistance (ohms)		0.086	0.001	0.172

Table 4.3. Off-Gas System Measured Parameters.

		Avg.	Max.	Min.
SBS	Inlet Pressure ("WC)	-1.8	2.8	-5.0
	Differential Pressure ("WC)	17.6	25.4	13.9
	Inlet Gas Temperature (°C)	261.9	312.6	61.3
	Outlet Gas Temperature (°C)	45.2	47.3	43.6
	Sump Temperature 4" depth (°C)	45.0	47.6	43.1
	Sump Temperature 10" depth (°C)	45.2	48.4	43.4
	Makeup Water Inlet Temperature (°C)	25.3	27.9	22.3
	Makeup Water Flow into SBS (LPH)	2.2	5.5	0.3
WESP	Spray Water Inlet Temp (°C)	24.8	27.4	21.5
	WESP Off-gas Outlet Temp (°C)	64.0	67.0	44.6
	Blower (P-200) Discharge Temp (°C)	99.8	104.4	94.0
	SBS / WESP Transition Line Temp (°C)	44.3	45.7	39.4
	Off-gas dP across WESP (" WC)	1.7	2.4	1.2
	Blower (P-200) Suction Pressure ("WC)	-21.1	-15.8	-30.0
	Blower Discharge Pressure("WC)	-0.6	0.0	-5.0
	Spray Water Flow into WESP (LPH)	3.1	7.5	0.0
	WESP Current (Amps)	1.0	9.0	0.0
	WESP Voltage (kV)	17.6	22.4	0.0
EXHAUST	Cyclone Filter 1 Outlet Temp. (°C)	66.9	78.5	27.4
	Cyclone Filter 2 Outlet Temp. (°C)	39.8	77.6	29.1
	HEPA Filter 1 Inlet Temperature (°C)	50.4	57.1	27.2
	HEPA Filter 2 Inlet Temperature (°C)	38.8	65.1	31.3
	HEPA Filter Outlet Temperature (°C)	50.9	55.5	38.3
	Exhaust Blower Outlet Temp. (°C)	49.7	54.8	44.4
	Exhaust Flow Rate (SCFM)	108.5	127.3	92.6

Table 4.4. Listing of SBS Effluents.

Date	Time	Event	Mass (kg)	Sample Name	Solids (mg/l)	pH
3/28/17	20:59	Blow Down Over Flow Tank	0.220	S-10P-84A	3142	8.23
	21:11	Transition Line Flush	2.680	S-10P-84B	1348	8.28
	22:10	Blow Down Over Flow Tank	4.260	S-10P-85A	642	8.28
	22:56	Blow Down Over Flow Tank	3.088	S-10P-85B	372	8.22
3/29/17	0:16	Blow Down Over Flow Tank	3.560	S-10P-86A	266	8.23
	1:38	Blow Down Over Flow Tank	4.138	S-10P-86B	276	8.15
	3:16	Blow Down Over Flow Tank	3.126	S-10P-87A	218	8.13
	4:45	Blow Down Over Flow Tank	2.346	S-10P-87B	232	8.07
	6:38	Blow Down Over Flow Tank	3.496	S-10P-87C	206	8.03
	7:02	Transition Line Flush	0.190	S-10P-93A	1328	7.91
	7:48	Blow Down Over Flow Tank	4.082	S-10P-93B	356	8.02
	10:54	Blow Down Over Flow Tank	3.994	S-10P-95A	204	7.85
	12:59	Blow Down Over Flow Tank	2.884	S-10P-95B	246	7.71
	15:33	Blow Down Over Flow Tank	4.048	S-10P-97A	228	7.68
	18:55	Blow Down Over Flow Tank	4.340	S-10P-97B	330	7.41
	19:09	Transition Line Flush	0.808	S-10P-103A	1854	7.46
	20:47	Blow Down Over Flow Tank	5.286	S-10P-103B	235	7.46
	22:39	Blow Down Over Flow Tank	3.696	S-10P-105A	298	7.31
3/30/17	0:40	Blow Down Over Flow Tank	3.776	S-10P-105B	390	7.35
	2:48	Blow Down Over Flow Tank	3.900	S-10P-107A	262	7.32
	4:48	Blow Down Over Flow Tank	3.750	S-10P-107B	237	7.35
	6:00	Blow Down Over Flow Tank	2.346	S-10P-107C	307	7.22
	6:51	Blow Down Over Flow Tank	1.482	S-10P-107D	385	7.30
	7:03	Transition Line Flush	0.350	S-10P-113A	867	7.39
	8:26	Blow Down Over Flow Tank	3.290	S-10P-113B	275	7.45
	10:43	Transition Line Flush	3.840	S-10P-113C	605	7.28
	12:50	Blow Down Over Flow Tank	3.432	S-10P-114A	252	7.20
	15:31	Blow Down Over Flow Tank	4.832	S-10P-114B	298	7.01
	18:38	Blow Down Over Flow Tank	5.006	S-10P-117A	263	7.11
	19:06	Transition Line Flush	2.076	S-10P-117B	852	7.28
	21:08	Blow Down Over Flow Tank	4.424	S-10P-122A	245	7.28
	23:31	Blow Down Over Flow Tank	4.070	S-10P-124A	428	7.30
3/31/17	1:52	Blow Down Over Flow Tank	3.840	S-10P-124B	368	7.10
	3:58	Blow Down Over Flow Tank	3.752	S-10P-124C	352	7.12
	6:48	Blow Down Over Flow Tank	4.450	S-10P-130A	347	7.16
	7:00	Transition Line Flush	1.300	S-10P-130B	1552	7.41
	7:48	Blow Down Over Flow Tank	4.000	S-10P-130C	597	7.69
	8:20	Post Test Drain of SBS	38.970	S-10P-130D	330	7.74

Table 4.5. Listing of WESP Effluents.

Date	Time	Event	Mass (kg)	Sample Name	Solids (mg/l)	pH
3/28/17	19:16	Blow Down	9.440	W-10P-84A	46.0	6.88
	21:50	Blow Down	8.750	W-10P-84B	2.0	6.67
3/29/17	0:22	Blow Down	9.900	W-10P-86A	2.0	7.79
	3:21	Blow Down	10.782	W-10P-87A	2.0	8.07
	4:49	Blow Down	5.152	W-10P-87B	6.0	7.88
	7:11	Blow Down	8.576	W-10P-93A	5.0	8.2
	9:50	Blow Down	8.392	W-10P-93B	6.7	8.07
	11:56	Blow Down	7.699	W-10P-95A	5.0	7.93
	12:06	WESP Deluge	4.650	W-10P-95B	25.0	7.74
	14:50	Blow Down	9.220	W-10P-97A	1.7	8.15
	17:30	Blow Down	9.464	W-10P-97B	5.0	7.9
	19:57	Blow Down	8.070	W-10P-103A	8.3	7.31
	22:13	Blow Down	8.156	W-10P-103B	26.7	6.59
3/30/17	0:46	Blow Down	9.334	W-10P-105A	30.0	7.08
	3:10	Blow Down	8.532	W-10P-107A	45.0	7.09
	6:05	Blow Down	10.674	W-10P-107B	31.7	6.83
	8:30	Blow Down	8.788	W-10P-113A	56.7	7.44
	11:51	Blow Down	12.080	W-10P-113B	31.7	7.06
	12:03	WESP Deluge	4.646	W-10P-114A	36.7	6.64
	14:46	Blow Down	9.052	W-10P-114B	5.0	6.39
	17:11	Blow Down	8.682	W-10P-117A	8.3	6.73
	20:30	Blow Down	12.170	W-10P-122A	18.3	7.15
	23:21	Blow Down	10.216	W-10P-124A	26.7	7.29
3/31/17	2:35	Blow Down	11.906	W-10P-124B	18.3	6.64
	5:55	Blow Down	12.410	W-10P-124C	18.3	6.86
	7:41	Blow Down	6.028	W-10P-130A	28.3	7.66
	8:00	WESP Deluge	4.434	W-10P-130B	127	8.16

Table 4.6. Water Balance Across the Primary Off-Gas System.

Input, kg	Melter Exhaust (from feed)	206.8 (135)
	Makeup Water into SBS and transition line flush	147
	Spray into WESP and WESP deluge	198
	Total Water Introduced into Primary Off-gas system	551.8
Output, kg	Liquid Blown down from SBS	116.2
	Liquid Blown down from WESP	226.7
	WESP Exhaust	229
	Total Water removed from Primary Off-gas system	572
% Deviation		3.7

Table 4.7. DCP, ICP, Ion Chromatography, and Ion Specific Electrode Analysis of SBS Effluents (mg/l).

	S-10P-84A	S-10P-84B	S-10P-85A	S-10P-85B	S-10P-86A	S-10P-86B	S-10P-87A	S-10P-87B	S-10P-87C
Al	160	62.9	32.5	21.5	17.9	18.8	16.4	17.2	15.9
B	129	112	110	110	121	131	153	158	163
Ca	85.5	33.9	15.9	9.9	7.5	7.8	7.1	7.8	7.5
Cr	16.7	8.7	6.4	6.2	6.4	7.2	7.9	8.4	9.1
Fe	143	50.8	23.2	11.1	7.5	7.3	5.4	6.2	4.7
K	24.1	21.5	21.6	26.3	32.3	39.3	47.6	53.7	63.3
Li	3.5	2.4	2.0	2.1	2.4	2.7	3.0	3.0	3.1
Mg	5.5	2.0	1.0	0.6	0.4	0.4	0.4	0.5	0.4
Na	471	349	370	404	451	517	590	644	688
Ni	3.6	1.3	0.5	0.3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
P	5.1	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
Pb	4.1	1.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Re	29.5	7.6	7.0	7.6	9.3	10.5	12.0	12.9	14.2
Si	554	235	110	60.9	40.2	43.0	33.4	36.1	30.8
Sn	6.3	3.5	2.2	1.6	1.4	1.7	1.1	1.1	1.3
Ti	6.9	2.6	1.3	0.9	0.6	0.7	0.6	0.6	0.6
Zn	144	65.7	36.4	27.3	21.8	23.6	21.4	22.1	21.6
Zr	35.4	16.2	8.6	6.2	4.6	5.1	4.4	4.4	3.9
Chloride	163	129	142	192	250	333	400	485	553
Fluoride	106	64.7	45.7	37.0	35.6	32.3	33.2	32.5	31.3
Nitrite	183	191	230	330	427	586	707	857	1034
Nitrate	133.7	11.2	7.1	7.4	5.7	5.8	7.1	8.0	9.9
Sulfate	82.9	71.3	72.3	79.0	88.8	96.6	107	111	117
Ammonia	74.8	37.3	43.4	64.5	76.5	114	139	175	229

Table 4.7. DCP, ICP, Ion Chromatography, and Ion Specific Electrode Analysis of SBS Effluents (mg/l) (continued).

	S-10P-93A	S-10P-93B	S-10P-95A	S-10P-95B	S-10P-97A	S-10P-97B	S-10P-103A	S-10P-103B	S-10P-105A
Al	76.7	28.6	16.0	18.2	16.8	23.8	96.6	18.1	22.5
B	170	174	184	192	201	233	249	243	246
Ca	30.0	10.7	8.8	9.6	9.8	11.9	42.3	10.8	11.5
Cr	13.8	11.0	11.7	13.1	13.7	16.7	22.0	16.7	18.8
Fe	36.2	8.4	4.3	5.2	4.5	6.1	52.8	4.5	4.9
K	65.1	67.4	80.7	92.5	104	132	146	142	151
Li	3.4	3.0	3.1	3.1	3.0	3.0	3.4	2.7	2.7
Mg	1.8	0.6	0.5	0.6	0.6	0.7	2.4	0.6	0.7
Na	758	776	855	1003	1021	1273	1303	1293	1472
Ni	0.7	0.1	< 0.1	0.1	0.1	0.1	1.0	0.1	< 0.1
P	4.3	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
Pb	0.1	0.1	0.1	0.1	0.1	0.2	1.5	0.2	0.7
Re	14.6	15.1	17.4	19.3	20.7	23.9	25.4	25.2	25.3
Si	214	60.6	34.6	40.3	37.8	55.0	326	38.7	49.7
Sn	4.4	1.5	1.1	1.1	1.1	1.3	4.8	0.9	1.1
Ti	3.2	1.1	0.6	0.7	0.6	0.9	4.0	0.6	0.7
Zn	98.6	31.1	20.8	25.4	24.3	34.0	115	24.7	32.1
Zr	20.2	6.1	3.5	4.2	3.9	5.3	22.1	3.6	4.4
Chloride	553	568	723	793	967	1205	1295	1297	1370
Fluoride	39.1	32.0	30.7	30.1	27.9	27.8	35.5	27.5	26.0
Nitrite	1061	1053	1333	1379	1669	1954	2012	2034	2183
Nitrate	16.7	15.6	21.4	21.5	23.1	28.7	31.3	31.5	34.6
Sulfate	108	109	118	120	130	147	149	150	151
Ammonia	251	258	326	364	497	528	526	486	571

Table 4.7. DCP, ICP, Ion Chromatography, and Ion Specific Electrode Analysis of SBS Effluents (mg/l) (continued).

	S-10P-105B	S-10P-107A	S-10P-107B	S-10P-107C	S-10P-107D	S-10P-113A	S-10P-113B	S-10P-113C	S-10P-114A	S-10P-114B
Al	27.8	20.7	18.7	23.3	29.6	51.8	23.9	37.3	21.5	25.3
B	264	274	277	279	281	303	288	312	321	350
Ca	13.2	11.0	10.4	11.4	12.6	22.9	11.0	18.3	11.1	11.5
Cr	20.6	21.1	22.4	22.9	22.5	23.6	21.6	23.7	24.3	26.3
Fe	7.1	4.1	3.2	4.4	6.1	19.2	3.7	12.0	3.6	3.7
K	164	166	169	169	164	181	173	181	189	201
Li	2.7	2.5	2.3	2.2	2.0	2.2	1.9	1.8	1.7	1.7
Mg	0.8	0.7	0.6	0.7	0.8	1.3	0.7	1.1	0.7	0.7
Na	1514	1652	1613	1672	1689	1796	1766	1806	2056	2082
Ni	< 0.1	< 0.1	< 0.1	0.1	0.1	0.4	0.1	0.4	< 0.1	0.1
P	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
Pb	0.7	0.7	0.2	0.9	0.2	0.8	0.8	0.2	0.2	0.2
Re	26.6	27.5	27.7	28.2	28.4	29.8	28.6	29.6	30.0	31.6
Si	66.3	43.1	38.2	48.8	63.0	144	40.7	98.1	39.0	45.9
Sn	1.2	1.0	1.0	1.0	1.4	2.7	1.1	1.8	1.0	1.0
Ti	0.9	0.6	0.5	0.7	0.9	2.2	0.8	1.4	0.7	0.8
Zn	37.0	31.3	27.7	36.4	40.7	67.1	30.4	50.3	33.0	40.9
Zr	5.3	3.8	3.3	4.2	5.1	12.1	4.5	8.4	4.4	5.3
Chloride	1479	1524	1526	1543	1598	1689	1623	1661	1783	1893
Fluoride	27.3	26.7	25.8	25.1	26.0	29.2	26.5	28.6	26.8	26.7
Nitrite	2353	2468	2616	2636	2699	2894	2808	2830	3030	3161
Nitrate	36.3	37.8	41.4	44.8	45.4	50.8	51.0	51.8	51.7	51.4
Sulfate	160	163	161	162	164	175	166	175	182	195
Ammonia	731	741	1646	1937	1911	2101	1911	1963	1802	1818

Table 4.7. DCP, ICP, Ion Chromatography, and Ion Specific Electrode Analysis of SBS Effluents (mg/l) (continued).

	S-10P-117A	S-10P-117B	S-10P-122A	S-10P-124A	S-10P-124B	S-10P-124C	S-10P-130A	S-10P-130B	S-10P-130C	S-10P-130D
Al	23.0	59.4	20.9	34.2	31.1	30.9	30.3	107	44.3	27.3
B	378	382	383	387	401	391	430	433	431	441
Ca	11.8	19.5	11.5	14.0	13.2	12.9	12.7	31.0	16.7	12.4
Cr	28.4	31.9	27.3	28.5	28.9	29.1	29.3	34.8	30.7	30.0
Fe	3.2	11.0	2.9	5.4	4.3	3.9	3.8	20.0	6.9	3.3
K	205	208	206	208	213	212	220	219	217	221
Li	1.6	1.5	1.4	1.3	1.2	1.2	1.0	1.0	1.1	1.1
Mg	0.7	0.9	0.7	0.8	0.7	0.7	0.7	1.3	0.8	0.7
Na	2102	2081	2087	2045	2103	2101	2205	2301	2327	2315
Ni	0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.5	0.3	0.1
P	< 0.6	2.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	5.4	< 0.6	< 0.6
Pb	0.2	0.2	0.2	0.2	0.2	0.2	0.6	0.2	0.2	0.2
Re	32.6	32.1	32.0	31.9	33.0	32.9	32.8	33.0	33.2	34.0
Si	42.0	130	38.7	68.2	56.4	55.8	55.6	256	95.4	48.7
Sn	1.0	2.7	1.1	1.7	1.7	1.7	1.4	4.4	1.8	1.4
Ti	0.7	2.3	0.7	1.2	1.0	1.3	1.0	4.2	1.7	0.9
Zn	36.9	76.3	30.3	45.9	46.3	43.1	41.6	116	49.2	31.8
Zr	4.8	13.5	4.3	7.1	6.1	5.9	5.8	20.8	8.7	5.0
Chloride	1952	1878	1922	1920	1995	1995	2034	2039	2036	2044
Fluoride	28.1	28.2	28.2	27.9	27.3	27.4	28.0	31.1	32.3	33.4
Nitrite	3244	3149	3134	3177	3340	3363	3397	3364	3330	3329
Nitrate	49.4	48.1	47.5	46.7	47.9	47.3	46.8	48.0	50.9	55.4
Sulfate	207	197	197	199	207	209	212	212	216	220
Ammonia	2238	2158	1876	562	2148	1999	2668	1851	2044	2035

Table 4.8. DCP, ICP, Ion Chromatography, and Ion Specific Electrode Analysis of WESP Effluents (mg/l).

	W-10P-84A	W-10P-84B	W-10P-86A	W-10P-87A	W-10P-87B	W-10P-93A	W-10P-93B	W-10P-95A	W-10P-95B
Al	1.2	0.1	0.1	0.1	0.2	0.4	0.3	0.3	1.1
B	2.1	3.1	13.4	10.5	13.4	8.0	9.3	10.2	17.0
Ca	1.8	0.6	0.7	0.5	0.6	0.5	0.4	0.4	0.6
Cr	0.2	0.3	2.1	2.0	2.7	1.8	2.1	2.0	6.7
Fe	3.0	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.3	< 0.1	1.4
K	1.6	2.1	16.6	16.5	22.9	17.9	21.1	20.4	56.0
Li	0.1	0.1	1.0	0.7	0.8	0.5	0.4	0.3	1.9
Mg	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Na	12.5	19.1	130	127	167	124	151	147	411
Ni	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.2
P	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
Pb	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Re	2.6	0.9	5.0	3.8	4.9	3.7	4.7	4.3	13.7
Si	10.9	0.9	0.7	0.7	1.1	1.3	1.9	1.4	5.3
Sn	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ti	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Zn	2.2	0.4	0.2	0.1	0.2	0.1	0.2	0.2	0.5
Zr	0.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1	0.1
Chloride	9.7	16.2	157	177	244	189	235	225	659
Fluoride	0.9	0.7	3.2	2.3	2.7	1.7	1.8	1.8	16.1
Nitrite	30.3	108	256	272	335	304	308	267	168
Nitrate	39.4	28.1	44.8	37.3	44.1	43.6	39.6	32.8	122
Sulfate	7.2	9.5	46.7	28.5	29.2	19.0	21.5	20.9	87.8
Ammonia	12.9	31.8	70.2	87.2	102	105	96.0	82.5	48.6

Table 4.8. DCP, ICP, Ion Chromatography, and Ion Specific Electrode Analysis of WESP Effluents (mg/l) (continued).

	W-10P-97A	W-10P-97B	W-10P-103A	W-10P-103B	W-10P-105A	W-10P-107A	W-10P-107B	W-10P-113A	W-10P-113B
Al	0.0	0.1	0.5	0.7	0.8	1.0	0.8	1.2	0.9
B	1.8	2.3	11.6	13.3	20.1	14.0	15.1	20.2	22.3
Ca	0.1	0.2	0.5	0.6	0.9	1.0	0.7	1.2	0.7
Cr	0.2	0.3	2.1	2.7	4.6	3.2	3.6	4.8	5.2
Fe	0.0	0.2	0.3	1.2	1.5	2.6	1.5	2.9	1.7
K	1.6	2.5	20.1	24.6	37.1	25.2	32.8	38.9	37.5
Li	< 0.1	< 0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Mg	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1
Na	10.6	18.2	148	163	248	179	223	274	275
Ni	< 0.1	< 0.1	< 0.1	< 0.1	0.2	< 0.1	< 0.1	< 0.1	< 0.1
P	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
Pb	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Re	0.4	0.6	3.9	4.5	5.8	4.4	5.6	6.1	5.9
Si	1.3	1.5	2.9	7.4	8.3	13.3	8.4	13.9	8.4
Sn	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ti	< 0.1	< 0.1	0.1	0.2	0.2	0.3	0.2	0.3	0.2
Zn	0.1	0.1	0.8	1.2	1.2	1.3	1.3	1.4	1.3
Zr	< 0.1	< 0.1	0.1	0.1	0.2	0.4	0.2	0.4	0.3
Chloride	11.7	26.6	228	262	378	283	346	411	390
Fluoride	0.3	0.0	0.4	1.0	2.7	2.0	2.0	3.3	3.3
Nitrite	146	163	268	293	465	353	357	611	539
Nitrate	29.0	39.2	65.8	83.6	83.5	81.0	126	73.7	64.5
Sulfate	1.5	2.5	19.7	23.4	36.5	23.5	28.8	38.5	39.8
Ammonia	55.3	65.8	92.3	80.7	133	98.5	116	186	138

Table 4.8. DCP, ICP, Ion Chromatography, and Ion Specific Electrode Analysis of WESP Effluents (mg/l) (continued).

	W-10P-114A	W-10P-114B	W-10P-117A	W-10P-122A	W-10P-124A	W-10P-124B	W-10P-124C	W-10P-130A	W-10P-130B
Al	3.0	0.3	0.5	0.6	0.7	0.8	0.7	1.0	4.2
B	23.8	13.6	21.9	17.5	14.3	25.8	24.9	23.5	28.6
Ca	0.7	0.2	0.4	0.4	0.6	0.5	0.5	0.7	2.1
Cr	11.6	2.4	4.1	3.0	2.7	5.1	4.9	4.3	11.0
Fe	2.0	0.0	0.2	0.7	1.2	0.9	0.8	1.5	6.6
K	98.4	18.9	32.8	28.0	22.8	39.9	38.9	34.6	85.5
Li	0.6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3
Mg	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Na	695	156	249	206	175	289	280	257	635
Ni	0.3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	0.4
P	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6	< 0.6
Pb	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Re	17.4	3.8	5.4	4.9	3.8	6.0	6.0	5.3	14.3
Si	7.5	0.9	1.9	4.5	6.1	5.0	4.3	7.0	25.9
Sn	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ti	0.2	< 0.1	< 0.1	0.1	0.2	0.2	0.1	0.2	0.6
Zn	1.9	1.0	1.0	0.8	1.1	1.4	1.3	1.3	3.5
Zr	0.3	< 0.1	< 0.1	0.1	0.2	0.2	0.1	0.2	0.8
Chloride	1066	188	340	282	236	400	402	347	973
Fluoride	17.2	1.3	2.6	2.0	0.7	3.6	3.4	3.5	19.2
Nitrite	269	321	397	360	354	469	532	513	217
Nitrate	297	62.5	60.1	55.3	55.9	68.3	54.0	59.4	163
Sulfate	100.8	21.8	34.4	27.9	24.2	38.6	36.7	33.5	96.8
Ammonia	62.7	86.1	105	105	96.0	127	138	132	29.8

Table 4.9. Analytical Results for Dissolved and Suspended Solids in SBS Sump Solutions (mg/l).

	S-10P-130A (blowdown before transition line wash)				S-10P-130B (blowdown after transition line wash)			
	Dissolved	Suspended	Total	% Dissolved	Dissolved	Suspended	Total	% Dissolved
Al	1.0	29.3	30.3	3.4	0.6	106	107	0.6
B	428.3	1.4	430	99.7	426	7.5	433	98.3
Ca	9.2	3.5	12.7	72.1	9.8	21.2	31.0	31.5
Cr	26.8	2.5	29.3	91.5	26.6	8.2	34.8	76.4
Fe	< 0.1	3.8	3.8	0.0	< 0.1	20.0	20.0	0.0
K	219.3	0.9	220	99.6	216	3.6	219	98.3
Li	1.0	< 0.1	1.0	100.0	1.0	< 0.1	1.0	100.0
Mg	0.6	0.1	0.7	88.9	0.7	0.6	1.3	54.5
Na	2201.3	3.5	2205	99.8	2286	15.3	2301	99.3
Ni	0.1	< 0.1	0.1	100.0	0.1	0.4	0.5	16.9
P	< 0.6	< 0.6	0.0	ND	< 0.6	5.4	5.4	0.0
Pb	0.2	0.4	0.6	36.4	0.2	< 0.1	0.2	100.0
Re	32.8	0.020	32.8	99.9	32.9	0.086	33.0	99.7
Si	6.3	49.3	55.6	11.3	4.6	252	256	1.8
Sn	0.2	1.3	1.4	10.5	0.2	4.2	4.4	3.6
Ti	< 0.1	1.0	1.0	2.0	< 0.1	4.2	4.2	0.5
Zn	15.4	26.3	41.6	36.9	8.3	108	116	7.1
Zr	< 0.1	5.8	5.8	0.0	< 0.1	20.8	20.8	0.0
Chloride	2034	NA	2034	NA	2039	NA	2039	NA
Fluoride	28.0	NA	28.0	NA	31.1	NA	31.1	NA
Nitrate	46.8	NA	46.8	NA	48.0	NA	48.0	NA
Nitrite	3397	NA	3397	NA	3364	NA	3364	NA
Sulfate	212	NA	212	NA	212	NA	212	NA
Ammonia	2668	NA	2668	NA	1851	NA	1851	NA
Sum	11328	129	11457	99	10558	577	11135	95

NA- Not analyzed
ND- Not defined

Table 4.10. Analytical Results for Dissolved and Suspended Solids in WESP Sump Solutions (mg/l).

	W-10P-113B (blowdown before deluge)				W-10P-114A (blowdown after deluge)			
	Dissolved	Suspended	Total	% Dissolved	Dissolved	Suspended	Total	% Dissolved
Al	0.3	0.6	0.9	32.4	2.2	0.8	3.0	74.1
B	22.3	< 0.1	22.3	100.0	23.8	< 0.1	23.8	100.0
Ca	0.3	0.4	0.7	45.9	0.4	0.3	0.7	57.1
Cr	5.0	0.2	5.2	95.8	10.7	0.8	11.6	93.0
Fe	< 0.05	1.7	1.7	0.0	< 0.05	2.0	2.0	ND
K	37.5	< 0.1	37.5	100.0	98.4	< 0.1	98.4	100.0
Li	0.1	< 0.1	0.1	100.0	0.6	< 0.1	0.6	100.0
Mg	0.0	< 0.1	< 0.1	100.0	0.1	< 0.1	0.1	100.0
Na	275	0.3	275	99.9	694	0.3	695	100.0
Ni	< 0.04	< 0.1	< 0.1	ND	0.1	0.3	0.3	19.5
P	< 0.6	< 0.1	< 0.1	ND	< 0.6	< 0.1	< 0.1	ND
Pb	< 0.1	< 0.1	< 0.1	100.0	0.1	< 0.1	0.1	100.0
Re	5.9	0.0014	5.9	100.0	17.4	0.0040	17.4	100.0
Si	0.9	7.5	8.4	10.6	0.9	6.7	7.5	11.4
Sn	< 0.01	< 0.1	< 0.1	ND	< 0.03	< 0.1	< 0.1	ND
Ti	< 0.02	0.2	0.2	ND	< 0.02	0.2	0.2	ND
Zn	1.0	0.3	1.3	77.5	1.5	0.4	1.9	77.5
Zr	< 0.02	0.3	0.3	ND	< 0.02	0.3	0.3	ND
Chloride	390	NA	390	NA	1066	NA	1066	NA
Fluoride	3.3	NA	3.3	NA	17.2	NA	17.2	NA
Nitrate	64.5	NA	64.5	NA	297	NA	297	NA
Nitrite	539	NA	539	NA	269	NA	269	NA
Sulfate	39.8	NA	39.8	NA	101	NA	101	NA
Ammonia	138	NA	138	NA	62.7	NA	62.7	NA
Sum	1523	11	1535	0.7	2663	12	2675	0.5

NA- Not analyzed
ND- Not defined

Table 5.1. Characteristics of Melter Feed Samples from Tests with the AP105DLAW11 Glass Composition.

Waste Simulant Concentration	Source	Date	Name	% Water	pH	Density (g/ml)	Glass Yield			
							(g/l)	Measured (kg/kg)	Target (kg/kg)	%Dev.
8 M Na	DM100	2/22/2017	SWV-F-35A	39.4	11.47	1.60	688	0.430	0.460	-6.50
	DM100	2/24/2017	SWV-F-56A	43.6	11.56	1.58	681	0.431	0.460	-6.24
5.6 M Na	DM100	3/7/2017	SWV-F-76A	51.7	11.33	1.46	517	0.354	0.383	-7.52
	DM100	3/9/2017	SWV-F-100A	54.0	11.41	1.42	517	0.364	0.383	-4.96
	DM10	3/28/2017	F-10P-72A	52.5	11.40	1.45	525	0.362	0.383	-5.51
	DM10	3/31/2017	F-10P-130A	49.9	11.30	1.46	549	0.376	0.383	-1.78
4 M Na	DM100	3/15/2017	SWV-F-115A	60.3	11.29	1.33	401	0.302	0.316	-4.59
	DM100	3/17/2017	SWV-F-136A	60.5	11.23	1.35	393	0.291	0.316	-7.91

Table 5.2. XRF Analyzed Compositions for Vitrified Feed Samples from Melter Tests (wt%).

	Target	DM100						DM10		Avg.	% Dev.
		SWV-F-35A	SWV-F-56A	SWV-F-76A	SWV-F-100A	SWV-F-115A	SWV-F-136A	F-10P-72A	F-10P-130A		
Al_2O_3	10.00	9.63	9.63	9.68	9.53	9.82	9.60	9.75	9.50	9.64	-3.56
$B_2O_3^{\#}$	11.00	10.46	10.44	10.68	11.16	10.29	11.60	10.94	10.80	10.80	-1.84
CaO	1.95	2.11	2.05	2.05	2.06	1.95	1.98	2.06	1.96	2.03	4.04
Cl	0.82	0.40	0.40	0.36	0.37	0.37	0.33	0.38	0.43	0.38	NC
Cr_2O_3	0.46	0.47	0.53	0.52	0.55	0.47	0.54	0.47	0.57	0.51	NC
$F^{\%}$	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	NC
Fe_2O_3	0.66	0.69	0.71	0.64	0.78	0.71	0.69	0.71	0.92	0.73	NC
K_2O	0.46	0.54	0.54	0.50	0.54	0.50	0.51	0.49	0.49	0.51	NC
$Li_2O^{\#}$	&	0.01	0.01	0.01	0.03	0.01	0.03	0.05	0.04	0.02	NC
MgO	1.00	0.65	0.62	0.59	0.81	0.89	0.66	0.81	0.87	0.74	-26.22
MnO	&	< 0.01	0.01	0.01	0.02	0.01	< 0.01	0.01	0.02	0.01	NC
Na_2O	24.00	25.49	26.11	26.04	25.37	24.70	26.71	24.32	23.83	25.32	5.51
NiO	0.005	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	NC
P_2O_5	0.20	0.22	0.26	0.25	0.22	0.22	0.25	0.22	0.23	0.23	NC
PbO	0.002	< 0.01	< 0.01	< 0.01	0.01	0.01	0.01	< 0.01	< 0.01	< 0.01	NC
$ReO_2^{\$}$	0.0100	0.0033	0.0031	0.0030	0.0034	0.0030	0.0028	0.0033	0.0034	0.003	NC
SO_3	0.35	0.35	0.37	0.38	0.35	0.35	0.39	0.37	0.32	0.36	NC
SiO_2	38.43	39.19	37.60	38.59	38.17	40.02	36.52	39.46	38.52	38.51	0.20
SnO_2	0.98	0.73	0.74	0.73	0.90	0.83	0.87	0.88	0.97	0.83	NC
TiO_2	0.66	0.59	0.64	0.60	0.63	0.60	0.60	0.60	0.82	0.64	NC
ZnO	3.00	2.85	2.90	2.87	2.91	2.65	2.81	2.80	2.67	2.81	-6.42
ZrO_2	6.01	5.58	6.40	5.47	5.57	5.57	5.87	5.65	7.01	5.89	-1.96
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	

- DCP Analysis
& - Not a target constituent
% Target value.

Table 5.3. List of Glass Discharged and Masses During DM100 Tests.

Waste Simulant Concentration	Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
8M Na	2/22/2017	SWV-G-35A	24.62	24.62
		SWV-G-35B		
		SWV-G-36A	23.02	47.64
		SWV-G-36B		
		SWV-G-36C	25.66	73.30
		SWV-G-37A		
		SWV-G-37B	16.30	89.60
		SWV-G-37C		
		SWV-G-39A	30.10	119.70
	2/23/2017	SWV-G-39B		
		SWV-G-39C	23.88	143.58
		SWV-G-39D		
		SWV-G-42A	18.86	162.44
		SWV-G-42B		
		SWV-G-42C	24.96	187.40
		SWV-G-42D		
		SWV-G-42E	27.70	215.10
		SWV-G-45A		
		SWV-G-45B	26.54	241.64
		SWV-G-45C		
		SWV-G-45D	25.30	266.94
		SWV-G-45E		
		SWV-G-48A	21.58	288.52
		SWV-G-48B		
		SWV-G-48C	23.50	312.02
		SWV-G-49A		
		SWV-G-49B	24.56	336.58
		SWV-G-49C		
	2/24/2017	SWV-G-49D	21.42	358.00
		SWV-G-49E		
		SWV-G-49F	17.62	375.62
		SWV-G-54A		
		SWV-G-54B	27.94	403.56
		SWV-G-54C		
		SWV-G-54D	23.98	427.54
		SWV-G-54E		
		SWV-G-56A	23.94	451.48
		SWV-G-56B		
		SWV-G-56C	20.22	471.70
		SWV-G-56D		
		SWV-G-56E	22.32	494.02
		SWV-G-61A		

Table 5.3. List of Glass Discharged and Masses During DM100 Tests (continued).

Waste Simulant Concentration	Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
5.6M	3/7/2017	SWV-G-77A	19.30	19.30
		SWV-G-77B		
		SWV-G-77C	22.26	41.56
		SWV-G-78A		
		SWV-G-78B	25.34	66.90
		SWV-G-78C		
		SWV-G-80A	22.70	89.60
	3/8/2017	SWV-G-80B		
		SWV-G-83A	24.04	113.64
		SWV-G-83B		
		SWV-G-83C	23.16	136.80
		SWV-G-83D		
		SWV-G-84A	28.82	165.62
		SWV-G-84B		
		SWV-G-89A	21.17	186.79
		SWV-G-89B		
		SWV-G-89C	26.64	213.43
		SWV-G-89D		
		SWV-G-89E	19.32	232.75
		SWV-G-91A		
		SWV-G-91B	27.48	260.23
		SWV-G-91C		
		SWV-G-92A	30.00	290.23
	3/9/2017	SWV-G-92B		
		SWV-G-92C	17.96	308.19
		SWV-G-95A		
		SWV-G-95B	25.06	333.25
		SWV-G-95C		
		SWV-G-95D	26.10	359.35
		SWV-G-95E		
		SWV-G-95F	25.74	385.09
		SWV-G-95G		

Table 5.3. List of Glass Discharged and Masses During DM100 Tests (continued).

Waste Simulant Concentration	Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
4 M Na	3/15/2017	SWV-G-116A	24.98	24.98
		SWV-G-116B		
		SWV-G-116C	24.58	49.56
		SWV-G-116D		
		SWV-G-117A	27.66	77.22
	3/16/2017	SWV-G-117B		
		SWV-G-117C	21.16	98.38
		SWV-G-117D		
		SWV-G-117E	30.92	129.30
		SWV-G-121A		
		SWV-G-121B	24.06	153.36
		SWV-G-121C		
		SWV-G-125A	21.08	174.44
		SWV-G-125B		
		SWV-G-125C	23.7	198.14
		SWV-G-127A		
		SWV-G-127B	32.06	230.20
	3/17/2017	SWV-G-129A		
		SWV-G-129B	26.38	256.58
		SWV-G-129C		
		SWV-G-132A	34.92	291.50
		SWV-G-132B		
		SWV-G-136A		

Table 5.4. List of Glass Discharged and Masses During the DM10 Test.

Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
3/28/2017	G-10P-84A	2.96	2.96
	G-10P-84B		
	G-10P-85A	4.16	7.12
	G-10P-85B		
3/29/2017	G-10P-86A	2.76	9.88
	G-10P-86B		
	G-10P-86C	2.44	12.32
	G-10P-86D		
	G-10P-87A	3.08	15.40
	G-10P-87B		
	G-10P-87C	3.12	18.52
	G-10P-87D		
	G-10P-93A	3.60	22.12
	G-10P-93B		
	G-10P-93C	3.50	25.62
	G-10P-95A		
	G-10P-95B	3.50	29.12
	G-10P-95C		
	G-10P-97A	3.78	32.90
	G-10P-97B		
	G-10P-97C	3.92	36.82
	G-10P-97D		
	G-10P-103A	3.98	40.80
	G-10P-103B		
	G-10P-105A	3.66	44.46
	G-10P-105B		
3/30/2017	G-10P-105C	4.02	48.48
	G-10P-105D		
	G-10P-107A	3.34	51.82
	G-10P-107B		
	G-10P-107C	3.84	55.66
	G-10P-107D		
	G-10P-113A	3.66	59.32
	G-10P-113B		
	G-10P-113C	4.12	63.44
	G-10P-113D		

Table 5.4. List of Glass Discharged and Masses During the DM10 Test (continued).

Date	Sample Name	Mass (kg)	Cumulative Mass (kg)
3/30/2017	G-10P-113E	4.30	67.74
	G-10P-114A		
	G-10P-114B	4.24	71.98
	G-10P-117A		
	G-10P-117B	4.56	76.54
	G-10P-117C		
	G-10P-122A	4.02	80.56
	G-10P-122B		
	G-10P-122C	3.64	84.20
	G-10P-122D		
3/31/2017	G-10P-124A	3.84	88.04
	G-10P-124B		
	G-10P-124C	3.80	91.84
	G-10P-124D		
	G-10P-124E	4.00	95.84
	G-10P-124F		
	G-10P-130A	2.00	97.84

Table 5.5. XRF Analyzed Compositions for Glass Samples Discharged During DM100 Melter Test with AP105DLAW11 Glass Composition and 8 M Na Simulant (wt%).

	Glass (kg)	24.62	47.64	73.3	89.6	119.7	143.58	162.44
	Target	SWV-G-35B	SWV-G-36B	SWV-G-37A	SWV-G-37C	SWV-G-39B	SWV-G-39D	SWV-G-42B
Al_2O_3	10.00	8.22	8.40	8.54	8.73	8.94	9.04	9.11
$B_2O_3^{\#}$	11.00	9.73	9.93	10.11	10.20	10.35	10.43	10.49
CaO	1.95	7.66	6.84	6.42	5.77	5.20	4.76	4.44
Cl	0.82	0.09	0.15	0.19	0.24	0.28	0.31	0.31
Cr_2O_3	0.46	0.34	0.38	0.40	0.40	0.43	0.48	0.44
$F^{\%}$	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	0.63	0.63	0.67	0.67	0.67	0.67	0.71
K_2O	0.46	0.54	0.55	0.55	0.52	0.55	0.53	0.53
$Li_2O^{\#}$	&	1.80	1.46	1.16	1.01	0.77	0.62	0.53
MgO	1.00	0.96	0.98	1.01	0.91	0.96	0.95	0.95
MnO	&	0.03	0.03	0.02	0.03	0.02	0.01	0.02
Na_2O	24.00	17.08	18.04	18.31	19.34	20.53	20.46	21.24
NiO	0.005	0.60	0.56	0.50	0.43	0.36	0.33	0.29
P_2O_5	0.20	0.16	0.17	0.17	0.17	0.19	0.18	0.18
PbO	0.002	0.02	0.00	0.01	0.01	< 0.01	< 0.01	0.01
$ReO_2^{\$}$	0.0100	< 0.0019	< 0.0019	0.0019	0.0020	0.0023	0.0023	0.0025
SO_3	0.35	1.02	0.93	0.84	0.78	0.66	0.67	0.61
SiO_2	38.43	42.19	41.71	41.47	41.55	40.99	40.93	40.85
SnO_2	0.98	0.09	0.19	0.28	0.32	0.37	0.49	0.50
TiO_2	0.66	0.20	0.25	0.33	0.34	0.40	0.43	0.44
V_2O_5	&	2.28	2.04	1.80	1.59	1.25	1.12	0.92
ZnO	3.00	2.68	2.73	2.86	2.70	2.69	2.78	2.69
ZrO_2	6.01	3.68	4.01	4.36	4.28	4.36	4.78	4.72
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SWV-D-34A) and target concentration using a simple well-stirred tank model;

& - Not a target constituent.

% Target value.

$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.5. XRF Analyzed Compositions for Glass Samples Discharged During DM100 Melter Test with AP105DLAW11 Glass Composition and 8 M Na Simulant (wt%) (continued).

	Glass (kg)	187.4	215.1	241.64	266.94	288.52	312.02	336.58
	Target	SWV-G-42D	SWV-G-45A	SWV-G-45C	SWV-G-45E	SWV-G-48B	SWV-G-49A	SWV-G-49C
Al_2O_3	10.00	9.18	9.20	9.25	9.32	9.37	9.32	9.69
$B_2O_3^{\#}$	11.00	10.55	10.61	10.65	10.68	10.70	10.72	10.73
CaO	1.95	4.10	3.95	3.56	3.46	3.28	3.04	2.83
Cl	0.82	0.35	0.37	0.38	0.38	0.39	0.38	0.37
Cr_2O_3	0.46	0.46	0.47	0.49	0.52	0.52	0.50	0.49
$F^{\%}$	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	0.71	0.69	0.74	0.76	0.75	0.79	0.71
K_2O	0.46	0.51	0.55	0.56	0.54	0.50	0.54	0.51
$Li_2O^{\#}$	&	0.43	0.34	0.27	0.22	0.18	0.15	0.13
MgO	1.00	0.99	0.90	0.94	0.91	0.99	0.95	0.94
MnO	&	0.02	0.02	< 0.01	0.02	0.01	0.02	< 0.01
Na_2O	24.00	21.92	22.05	22.20	22.53	22.79	23.14	23.55
NiO	0.005	0.27	0.25	0.21	0.18	0.17	0.16	0.14
P_2O_5	0.20	0.20	0.18	0.20	0.20	0.21	0.21	0.22
PbO	0.002	< 0.01	0.01	< 0.01	< 0.01	0.02	< 0.01	0.01
$ReO_2^{\$}$	0.0100	0.0023	0.0024	0.0027	0.0025	0.0025	0.0025	0.0026
SO_3	0.35	0.56	0.49	0.50	0.45	0.44	0.44	0.41
SiO_2	38.43	40.22	40.18	40.26	39.88	39.84	39.41	40.39
SnO_2	0.98	0.54	0.54	0.58	0.64	0.63	0.73	0.53
TiO_2	0.66	0.45	0.49	0.50	0.53	0.55	0.54	0.50
V_2O_5	&	0.85	0.78	0.61	0.55	0.47	0.42	0.34
ZnO	3.00	2.78	2.84	2.82	2.84	2.85	2.91	2.63
ZrO_2	6.01	4.89	5.10	5.26	5.40	5.33	5.62	4.87
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SWV-D-34A) and target concentration using a simple well-stirred tank model;

& - Not a target constituent.

% Target value.

$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.5. XRF Analyzed Compositions for Glass Samples Discharged During DM100 Melter Test with AP105DLAW11 Glass Composition and 8 M Na Simulant (wt%) (continued).

	Glass (kg)	358	375.62	403.56	427.54	451.48	471.7	494.02
	Target	SWV-G-49E	SWV-G-54A	SWV-G-54C	SWV-G-54E	SWV-G-56B	SWV-G-56D	SWV-G-61A
Al_2O_3	10.00	9.73	9.59	9.50	9.58	9.64	9.57	9.51
$B_2O_3^{\#}$	11.00	10.74	10.75	10.76	10.77	10.77	10.78	10.78
CaO	1.95	2.68	2.70	2.78	2.53	2.58	2.45	2.50
Cl	0.82	0.37	0.37	0.41	0.40	0.41	0.42	0.40
Cr_2O_3	0.46	0.49	0.47	0.54	0.52	0.51	0.54	0.57
$F^{\%}$	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	0.72	0.70	0.81	0.73	0.74	0.79	0.75
K_2O	0.46	0.49	0.49	0.55	0.53	0.53	0.56	0.54
$Li_2O^{\#}$	&	0.11	0.10	0.08	0.07	0.06	0.05	0.05
MgO	1.00	0.97	0.91	0.88	0.87	0.85	0.84	0.82
MnO	&	0.01	0.01	0.02	0.01	0.02	0.01	< 0.01
Na_2O	24.00	24.12	23.81	23.57	24.25	24.39	24.60	24.63
NiO	0.005	0.13	0.12	0.11	0.11	0.10	0.09	0.09
P_2O_5	0.20	0.22	0.21	0.23	0.21	0.22	0.23	0.26
PbO	0.002	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01
$ReO_2^{\$}$	0.0100	0.0023	0.0025	0.0026	0.0024	0.0026	0.0028	0.0027
SO_3	0.35	0.40	0.41	0.39	0.39	0.38	0.38	0.36
SiO_2	38.43	39.97	40.15	39.26	38.96	38.85	38.63	38.75
SnO_2	0.98	0.52	0.62	0.67	0.74	0.69	0.70	0.72
TiO_2	0.66	0.53	0.53	0.57	0.57	0.59	0.55	0.54
V_2O_5	&	0.33	0.28	0.26	0.25	0.22	0.18	0.16
ZnO	3.00	2.65	2.71	2.96	2.89	2.88	2.91	2.92
ZrO_2	6.01	4.82	5.05	5.63	5.61	5.57	5.70	5.64
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SWV-D-34A) and target concentration using a simple well-stirred tank model;

& - Not a target constituent;

% Target value.

\$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.6. XRF Analyzed Compositions for Glass Samples Discharged During DM100 Melter Test with AP105DLAW11 Glass Composition and 5.6 M Na Simulant (wt%).

	Glass (kg)	513.32	535.58	560.92	583.62	607.66	630.82
	Target	SWV-G-77B	SWV-G-78A	SWV-G-78C	SWV-G-80B	SWV-G-83B	SWV-G-83D
Al_2O_3	10.00	9.77	9.61	9.76	9.81	9.79	9.71
$B_2O_3^{\#}$	11.00	10.78	10.79	10.79	10.79	10.79	10.79
CaO	1.95	2.48	2.46	2.36	2.27	2.32	2.25
Cl	0.82	0.25	0.25	0.28	0.27	0.31	0.31
Cr_2O_3	0.46	0.56	0.57	0.58	0.54	0.55	0.57
$F^{\%}$	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	0.79	0.80	0.79	0.76	0.79	0.88
K_2O	0.46	0.56	0.49	0.51	0.48	0.51	0.48
$Li_2O^{\#}$	&	0.04	0.04	0.04	0.03	0.03	0.03
MgO	1.00	0.85	0.88	0.91	0.89	0.90	0.94
MnO	&	0.02	0.02	0.02	< 0.01	0.02	0.02
Na_2O	24.00	24.26	24.59	23.88	24.34	24.19	24.02
NiO	0.005	0.16	0.13	0.13	0.10	0.11	0.10
P_2O_5	0.20	0.25	0.22	0.24	0.24	0.23	0.21
PbO	0.002	0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01
$ReO_2^{\$}$	0.0100	0.0020	0.0021	0.0022	0.0022	0.0023	0.0021
SO_3	0.35	0.42	0.41	0.40	0.37	0.37	0.37
SiO_2	38.43	38.85	39.02	39.78	39.68	39.50	39.20
SnO_2	0.98	0.80	0.73	0.69	0.69	0.77	0.79
TiO_2	0.66	0.58	0.54	0.58	0.61	0.58	0.62
V_2O_5	&	0.17	0.16	0.13	0.12	0.10	0.10
ZnO	3.00	2.82	2.79	2.75	2.70	2.71	2.87
ZrO_2	6.01	5.59	5.47	5.38	5.29	5.43	5.72
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 and Li_2O concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SWV-D-34A) and target concentration using a simple well-stirred tank model;

& - Not a target constituent;

% Target value.

$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.6. XRF Analyzed Compositions for Glass Samples Discharged During DM100 Melter Test with AP105DLAW11 Glass Composition and 5.6 M Na Simulant (wt%) (continued).

	Glass (kg)	659.64	680.81	707.45	726.77	754.25
	Target	SWV-G-84B	SWV-G-89B	SWV-G-89D	SWV-G-91A	SWV-G-91C
Al_2O_3	10.00	9.63	9.94	9.70	9.83	9.62
B_2O_3#	11.00	10.79	10.79	10.79	10.79	10.79
CaO	1.95	2.27	2.26	2.23	2.21	2.18
Cl	0.82	0.32	0.32	0.30	0.34	0.32
Cr_2O_3	0.46	0.55	0.55	0.54	0.53	0.58
F%	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	0.83	0.83	0.81	0.77	0.85
K_2O	0.46	0.47	0.50	0.51	0.52	0.49
Li_2O#	&	0.03	0.03	0.03	0.03	0.03
MgO	1.00	0.97	1.00	0.95	1.01	1.01
MnO	&	0.02	0.02	< 0.01	0.01	0.02
Na_2O	24.00	23.77	24.06	24.12	24.05	23.94
NiO	0.005	0.10	0.09	0.09	0.08	0.08
P_2O_5	0.20	0.24	0.23	0.23	0.23	0.22
PbO	0.002	< 0.01	0.01	< 0.01	0.01	< 0.01
$ReO_2$$	0.0100	0.0022	0.0024	0.0022	0.0023	0.0024
SO_3	0.35	0.33	0.33	0.34	0.34	0.35
SiO_2	38.43	39.46	38.95	39.06	39.36	39.13
SnO_2	0.98	0.86	0.81	0.82	0.82	0.90
TiO_2	0.66	0.60	0.59	0.59	0.63	0.60
V_2O_5	&	0.10	0.07	0.08	0.07	0.07
ZnO	3.00	2.88	2.88	2.93	2.83	2.93
ZrO_2	6.01	5.78	5.73	5.87	5.53	5.88
Sum	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SWV-D-34A) and target concentration using a simple well-stirred tank model;
& - Not a target constituent.
% Target value.
$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.6. XRF Analyzed Compositions for Glass Samples Discharged During DM100 Melter Test with AP105DLAW11 Glass Composition and 5.6 M Na Simulant (wt%) (continued).

	Glass (kg)	784.25	802.21	827.27	853.37	879.11
	Target	SWV-G-92B	SWV-G-95A	SWV-G-95C	SWV-G-95E	SWV-G-95G
Al_2O_3	10.00	9.74	9.73	9.62	9.77	9.66
$B_2O_3^{\#}$	11.00	10.80	10.80	10.80	10.80	10.80
CaO	1.95	2.07	2.14	2.17	2.13	2.15
Cl	0.82	0.31	0.31	0.33	0.32	0.34
Cr_2O_3	0.46	0.56	0.56	0.54	0.55	0.53
$F^{\%}$	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	0.79	0.83	0.82	0.79	0.79
K_2O	0.46	0.49	0.50	0.47	0.50	0.51
$Li_2O^{\#}$	&	0.03	0.03	0.02	0.02	0.02
MgO	1.00	1.03	0.99	1.00	1.03	1.00
MnO	&	0.01	0.02	0.02	0.01	0.02
Na_2O	24.00	24.08	23.96	24.02	24.14	23.87
NiO	0.005	0.08	0.10	0.08	0.07	0.07
P_2O_5	0.20	0.23	0.22	0.21	0.21	0.20
PbO	0.002	< 0.01	0.01	0.02	< 0.01	< 0.01
$ReO_2^{\$}$	0.0100	0.0022	0.0022	0.0023	0.0024	0.0024
SO_3	0.35	0.32	0.32	0.31	0.34	0.34
SiO_2	38.43	39.89	39.61	39.41	39.12	39.30
SnO_2	0.98	0.81	0.84	0.84	0.89	0.97
TiO_2	0.66	0.60	0.61	0.62	0.63	0.63
V_2O_5	&	0.05	0.05	0.04	0.03	0.03
ZnO	3.00	2.76	2.81	2.92	2.88	2.91
ZrO_2	6.01	5.35	5.55	5.73	5.77	5.88
Sum	100.00	100.00	100.00	100.00	100.00	100.00

\# - B_2O_3 concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SWV-D-34A) and target concentration using a simple well-stirred tank model;

& - Not a target constituent;

% Target value.

$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.7. XRF Analyzed Compositions for Glass Samples Discharged During DM100 Melter Test with AP105DLAW11 Glass Composition and 4 M Na Simulant (wt%).

	Glass (kg)	904.09	928.67	956.33	977.49	1008.41	1032.47
	Target	SWV-G-116B	SWV-G-116D	SWV-G-117B	SWV-G-117D	SWV-G-121A	SWV-G-121C
Al_2O_3	10.00	9.71	9.73	9.83	9.70	9.56	9.80
B_2O_3#	11.00	10.80	10.80	10.80	10.80	10.80	10.80
CaO	1.95	2.18	2.15	2.05	2.08	2.18	2.13
Cl	0.82	0.24	0.25	0.21	0.23	0.28	0.30
Cr_2O_3	0.46	0.62	0.59	0.63	0.59	0.58	0.56
F%	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	0.88	0.90	0.88	0.79	0.87	0.81
K_2O	0.46	0.48	0.53	0.51	0.53	0.52	0.51
Li_2O#	&	0.02	0.02	0.02	0.02	0.02	0.02
MgO	1.00	1.02	1.04	1.14	1.08	1.09	1.03
MnO	&	0.02	0.02	0.01	0.03	0.02	0.01
Na_2O	24.00	23.61	23.50	23.57	23.60	23.82	24.08
NiO	0.005	0.13	0.12	0.15	0.14	0.10	0.11
P_2O_5	0.20	0.23	0.22	0.22	0.22	0.21	0.22
PbO	0.002	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
$ReO_2$$	0.0100	0.0021	0.0020	0.0020	0.0019	0.0021	0.0022
SO_3	0.35	0.36	0.33	0.31	0.34	0.33	0.34
SiO_2	38.43	38.96	38.98	39.60	39.66	39.04	39.18
SnO_2	0.98	1.00	1.05	0.98	1.02	0.94	0.86
TiO_2	0.66	0.61	0.65	0.60	0.62	0.63	0.61
V_2O_5	&	0.05	0.04	0.04	0.03	0.03	0.03
ZnO	3.00	2.97	2.96	2.77	2.84	2.96	2.87
ZrO_2	6.01	6.10	6.10	5.67	5.69	6.02	5.72
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SWV-D-34A) and target concentration using a simple well-stirred tank model;

& - Not a target constituent;

% Target value.

$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.7. XRF Analyzed Compositions for Glass Samples Discharged During DM100 Melter Test with AP105DLAW11 Glass Composition and 4 M Na Simulant (wt%) (continued).

	Glass (kg)	1053.55	1077.25	1109.31	1135.69	1170.61
	Target	SWV-G-125B	SWV-G-127A	SWV-G-129A	SWV-G-129C	SWV-G-136A
Al_2O_3	10.00	9.77	9.68	9.79	9.94	9.78
$B_2O_3^{\#}$	11.00	10.80	10.80	10.80	10.80	10.80
CaO	1.95	2.07	2.16	2.04	2.08	2.12
Cl	0.82	0.29	0.31	0.25	0.23	0.33
Cr_2O_3	0.46	0.58	0.57	0.68	0.64	0.56
$F^{\%}$	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	0.81	0.84	0.76	0.79	0.78
K_2O	0.46	0.52	0.52	0.50	0.49	0.52
$Li_2O^{\#}$	&	0.02	0.02	0.02	0.02	0.02
MgO	1.00	0.93	0.88	0.92	0.89	0.89
MnO	&	0.01	0.02	< 0.01	0.01	0.02
Na_2O	24.00	23.91	24.32	24.56	24.03	25.09
NiO	0.005	0.09	0.09	0.12	0.12	0.08
P_2O_5	0.20	0.23	0.23	0.23	0.24	0.22
PbO	0.002	0.01	0.01	0.01	< 0.01	0.01
$ReO_2^{\$}$	0.0100	0.0021	0.0022	0.0019	0.0020	0.0023
SO_3	0.35	0.30	0.28	0.31	0.35	0.33
SiO_2	38.43	39.20	38.86	39.55	39.59	38.51
SnO_2	0.98	0.97	0.96	0.87	0.93	0.90
TiO_2	0.66	0.61	0.60	0.58	0.59	0.62
V_2O_5	&	< 0.01	0.03	0.02	< 0.01	< 0.01
ZnO	3.00	2.97	2.97	2.71	2.76	2.88
ZrO_2	6.01	5.90	5.86	5.28	5.48	5.54
Sum	100.00	100.00	100.00	100.00	100.00	100.00

- B_2O_3 concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SWV-D-34A) and target concentration using a simple well-stirred tank model;

& - Not a target constituent.

% Target value.

$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.8. XRF Analyzed Compositions for Glass Samples Discharged During DM10 Melter Test with AP105DLAW11 Glass Composition (wt%).

	Glass (kg)	2.96	7.12	9.88	12.32	15.40	18.52	22.12
	Target	G-10P-84B	G-10P-85B	G-10P-86B	G-10P-86D	G-10P-87B	G-10P-87D	G-10P-93B
Al_2O_3	10.00	6.69	7.80	8.17	8.53	8.72	8.81	9.07
$B_2O_3^{\#}$	11.00	10.02	10.33	10.47	10.55	10.63	10.69	10.73
CaO	1.95	4.70	3.84	3.42	3.10	2.94	2.79	2.65
Cl	0.82	0.15	0.26	0.34	0.39	0.39	0.43	0.48
Cr_2O_3	0.46	0.29	0.39	0.38	0.41	0.41	0.49	0.54
$F^{\%}$	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	4.88	3.48	2.96	2.49	2.09	1.86	1.64
K_2O	0.46	0.60	0.60	0.54	0.53	0.57	0.55	0.58
$Li_2O^{\#}$	&	1.43	0.86	0.62	0.46	0.32	0.22	0.15
MgO	1.00	1.30	1.18	1.14	1.07	1.01	1.04	0.96
MnO	&	0.03	0.02	0.02	0.01	0.02	0.01	0.01
Na_2O	24.00	16.93	19.42	20.68	21.28	22.38	22.92	22.50
NiO	0.002	0.19	0.14	0.14	0.13	0.11	0.10	0.09
P_2O_5	0.20	0.23	0.23	0.22	0.23	0.20	0.22	0.23
PbO	0.002	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
$ReO_2^{\$}$	0.0100	0.0020	0.0022	0.0025	0.0026	0.0026	0.0030	0.0032
SO_3	0.35	0.30	0.29	0.33	0.32	0.34	0.33	0.33
SiO_2	38.43	44.24	43.06	42.36	42.28	41.17	40.23	40.10
SnO_2	0.98	0.15	0.33	0.42	0.48	0.60	0.63	0.70
TiO_2	0.66	1.42	1.12	1.00	0.91	0.83	0.82	0.80
ZnO	3.00	3.17	2.94	2.84	2.76	2.82	2.96	3.11
ZrO_2	6.01	3.28	3.70	3.94	4.05	4.44	4.86	5.32
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- Values calculated from B_2O_3 and Li_2O analysis by DCP-AES of glass pool sample (D-10P-72A), analyzed feed lithium content, and target boron concentration using a simple well stirred tank model.

& - Not a target constituent

% Target value.

$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.8. XRF Analyzed Compositions for Glass Samples Discharged During DM10 Melter Test with AP105DLAW11 Glass Composition (wt%) (continued).

	Glass (kg)	25.62	29.12	32.90	36.82	40.80	44.46	48.48
	Target	G-10P-95A	G-10P-95C	G-10P-97B	G-10P-97D	G-10P-103B	G-10P-105B	G-10P-105D
Al_2O_3	10.00	9.23	9.31	9.31	9.56	9.57	9.68	9.82
$B_2O_3^{\#}$	11.00	10.75	10.77	10.78	10.78	10.79	10.79	10.79
CaO	1.95	2.45	2.37	2.34	2.21	2.20	2.03	2.06
Cl	0.82	0.48	0.45	0.50	0.44	0.43	0.45	0.44
Cr_2O_3	0.46	0.52	0.52	0.58	0.55	0.55	0.52	0.55
$F^{\%}$	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	1.40	1.22	1.24	1.03	0.98	0.93	0.85
K_2O	0.46	0.54	0.52	0.53	0.51	0.52	0.48	0.52
$Li_2O^{\#}$	&	0.11	0.08	0.06	0.04	0.04	0.03	0.03
MgO	1.00	1.05	1.11	1.03	1.01	1.02	0.97	1.03
MnO	&	0.02	0.02	0.01	0.02	0.01	0.01	0.01
Na_2O	24.00	23.15	23.39	23.35	23.82	23.98	24.38	24.32
NiO	0.002	0.10	0.08	0.09	0.08	0.08	0.08	0.08
P_2O_5	0.20	0.21	0.22	0.22	0.23	0.21	0.22	0.22
PbO	0.002	< 0.01	< 0.01	0.02	< 0.01	0.01	< 0.01	0.01
$ReO_2^{\$}$	0.0100	0.0029	0.0027	0.0028	0.0028	0.0028	0.0028	0.0027
SO_3	0.35	0.32	0.33	0.32	0.34	0.33	0.33	0.33
SiO_2	38.43	39.96	39.62	39.26	39.37	39.20	39.81	39.65
SnO_2	0.98	0.75	0.85	0.76	0.85	0.85	0.75	0.71
TiO_2	0.66	0.73	0.66	0.75	0.66	0.64	0.59	0.60
ZnO	3.00	2.93	2.94	3.10	2.88	2.86	2.72	2.74
ZrO_2	6.01	5.29	5.53	5.73	5.60	5.72	5.21	5.23
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- Values calculated from B_2O_3 and Li_2O analysis by DCP-AES of glass pool sample (D-10P-72A), analyzed feed lithium content, and target boron concentration using a simple well stirred tank model.

& - Not a target constituent

% Target value.

$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.8. XRF Analyzed Compositions for Glass Samples Discharged During DM10 Melter Test with AP105DLAW11 Glass Composition (wt%) (continued).

	Glass (kg)	51.82	55.66	59.32	63.44	67.74	71.98	76.54
	Target	G-10P-107B	G-10P-107D	G-10P-113B	G-10P-113D	G-10P-114A	G-10P-117A	G-10P-117C
Al_2O_3	10.00	9.87	9.68	9.77	9.77	9.49	9.96	9.70
B_2O_3#	11.00	10.79	10.80	10.80	10.80	10.80	10.80	10.80
CaO	1.95	2.03	2.09	2.02	2.13	2.11	2.09	1.98
Cl	0.82	0.43	0.41	0.44	0.41	0.44	0.42	0.43
Cr_2O_3	0.46	0.56	0.54	0.55	0.54	0.55	0.57	0.54
F%	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	0.92	0.89	0.88	0.88	0.87	0.82	0.85
K_2O	0.46	0.49	0.51	0.49	0.51	0.55	0.54	0.51
Li_2O#	&	0.03	0.03	0.02	0.02	0.02	0.02	0.02
MgO	1.00	1.05	1.07	1.09	1.13	1.04	0.95	1.10
MnO	&	0.02	0.02	0.01	0.01	0.01	< 0.01	< 0.01
Na_2O	24.00	23.89	24.09	23.84	23.78	23.68	24.10	24.41
NiO	0.002	0.09	0.07	0.07	0.08	0.07	0.06	0.07
P_2O_5	0.20	0.23	0.22	0.21	0.23	0.21	0.23	0.21
PbO	0.002	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01
$ReO_2$$	0.0100	0.0027	0.0028	0.0026	0.0027	0.0027	0.0025	0.0027
SO_3	0.35	0.32	0.34	0.33	0.32	0.33	0.33	0.32
SiO_2	38.43	39.74	39.40	39.51	39.36	39.33	39.09	39.16
SnO_2	0.98	0.73	0.86	0.85	0.81	0.93	0.83	0.85
TiO_2	0.66	0.60	0.62	0.62	0.63	0.62	0.59	0.60
ZnO	3.00	2.79	2.80	2.86	2.88	2.95	2.90	2.86
ZrO_2	6.01	5.42	5.56	5.62	5.71	6.01	5.67	5.58
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- Values calculated from B_2O_3 and Li_2O analysis by DCP-AES of glass pool sample (D-10P-72A), analyzed feed lithium content, and target boron concentration using a simple well stirred tank model.

& - Not a target constituent

% Target value.

$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.8. XRF Analyzed Compositions for Glass Samples Discharged During DM10 Melter Test with AP105DLAW11 Glass Composition (wt%) (continued).

	Glass (kg)	80.56	84.20	88.04	91.84	95.84	97.84
	Target	G-10P-122B	G-10P-122D	G-10P-124B	G-10P-124D	G-10P-124F	G-10P-130A
Al_2O_3	10.00	9.60	9.77	9.91	9.83	9.76	9.78
$B_2O_3^{\#}$	11.00	10.80	10.80	10.80	10.80	10.80	10.80
CaO	1.95	2.06	2.13	1.99	2.06	1.99	2.02
Cl	0.82	0.42	0.42	0.40	0.41	0.42	0.42
Cr_2O_3	0.46	0.56	0.60	0.51	0.54	0.54	0.57
$F^{\%}$	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	0.88	0.92	0.85	0.87	0.81	0.84
K_2O	0.46	0.49	0.49	0.49	0.55	0.48	0.50
$Li_2O^{\#}$	&	0.02	0.02	0.02	0.02	0.02	0.02
MgO	1.00	1.09	1.16	1.12	1.16	1.03	0.95
MnO	&	0.02	< 0.01	0.02	0.02	0.01	0.02
Na_2O	24.00	23.72	23.38	24.20	24.10	24.60	24.40
NiO	0.002	0.07	0.07	0.07	0.06	0.06	0.06
P_2O_5	0.20	0.21	0.23	0.21	0.22	0.21	0.22
PbO	0.002	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01
$ReO_2^{\$}$	0.0100	0.0024	0.0027	0.0025	0.0028	0.0026	0.0026
SO_3	0.35	0.31	0.33	0.32	0.33	0.31	0.34
SiO_2	38.43	39.24	39.10	39.57	39.36	38.79	38.58
SnO_2	0.98	1.06	0.89	0.83	0.79	1.00	0.92
TiO_2	0.66	0.64	0.64	0.60	0.62	0.61	0.64
ZnO	3.00	2.92	3.06	2.74	2.83	2.79	2.94
ZrO_2	6.01	5.89	5.97	5.35	5.42	5.73	5.97
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- Values calculated from B_2O_3 and Li_2O analysis by DCP-AES of glass pool sample (D-10P-72A), analyzed feed lithium content, and target boron concentration using a simple well stirred tank model.

& - Not a target constituent

% Target value.

$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.9. XRF Analyzed Compositions for Melt Pool Samples from DM100 and DM10 Melter Tests (wt%).

Target		DM100							DM10	
		Prior to 8 M Na test	After 8 M Na test		Prior to 5.6 M Na test	After 5.6 M Na test	Prior to 4 M Na test	After 4 M Na test	Prior to 5.6 M Na test	After 5.6 M Na test
		SWV-D-34A	SWV-D-61A	SWV-D-61B	SWV-D-61C	SWV-D-100A	SWV-D-100B	SWV-D-136A	D-10P-72A	D-10P-130A
Al_2O_3	10.00	8.19	9.74	9.55	9.67	9.82	9.82	9.68	6.09	9.71
$B_2O_3^{\#}$	11.00	9.46	10.36	10.38	9.76	10.00	10.25	10.31	9.67	10.74
CaO	1.95	7.91	2.43	2.41	2.58	2.11	2.15	2.15	5.35	2.03
Cl	0.82	0.02	0.45	0.42	0.24	0.35	0.29	0.31	0.03	0.43
Cr_2O_3	0.46	0.33	0.65	0.60	1.23	0.55	0.70	0.57	0.23	0.53
$F^{\%}$	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fe_2O_3	0.66	0.80	0.72	0.74	0.85	0.79	0.90	0.82	6.05	0.83
K_2O	0.46	0.55	0.51	0.54	0.53	0.51	0.54	0.52	0.63	0.46
$Li_2O^{\#}$	&	2.24	0.19	0.19	0.26	0.05	0.08	0.03	2.06	0.06
MgO	1.00	1.00	0.82	0.82	0.83	0.98	1.01	0.83	1.43	1.00
MnO	&	0.06	0.01	< 0.01	0.03	0.03	0.02	0.01	0.02	0.01
Na_2O	24.00	15.90	24.93	25.32	24.15	24.59	23.69	24.85	14.11	24.49
NiO	0.005	0.57	0.12	0.11	0.22	0.07	0.15	0.08	0.22	0.06
P_2O_5	0.20	0.15	0.25	0.22	0.23	0.22	0.23	0.22	0.23	0.21
PbO	0.002	0.01	0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01
$ReO_2^{\$}$	0.0100	< 0.0019	0.0030	0.0028	0.0021	0.0024	0.0020	0.0024	< 0.0019	0.0027
SO_3	0.35	1.07	0.40	0.37	0.47	0.34	0.34	0.32	0.32	0.34
SiO_2	38.43	42.09	39.05	38.40	38.86	39.41	39.09	38.96	45.54	39.19
SnO_2	0.98	0.07	0.65	0.73	0.71	0.91	0.93	0.95	< 0.01	0.90
TiO_2	0.66	0.18	0.55	0.59	0.56	0.60	0.64	0.63	1.70	0.62
V_2O_5	&	2.44	0.16	0.17	0.24	0.03	0.04	0.02	< 0.01	< 0.01
ZnO	3.00	3.76	2.81	2.86	3.14	2.87	3.06	2.97	3.29	2.78
ZrO_2	6.01	3.19	5.20	5.57	5.45	5.76	6.07	5.75	3.03	5.59
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- DCP Analysis
& - Not a target constituent
% Target value.
$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

Table 5.10. Comparison of XRF Analyzed Compositions for Average and Terminal Discharged Glass from DM100 Test with 8 M Na Simulant to the Target Composition (wt%).

	Target	Avg.	% Dev.	SWV-G-61A	% Dev.
Al_2O_3	10.00	9.21	-7.89	9.51	-4.91
$B_2O_3^{\#}$	11.00	10.54	-4.21	10.78	-1.98
CaO	1.95	3.98	104.00	2.50	27.98
Cl	0.82	0.33	NC	0.40	NC
Cr_2O_3	0.46	0.47	NC	0.57	NC
$F^{\%}$	0.01	0.01	NC	0.01	NC
Fe_2O_3	0.66	0.72	NC	0.75	NC
K_2O	0.46	0.53	NC	0.54	NC
$Li_2O^{\#}$	&	0.46	NC	0.05	NC
MgO	1.00	0.93	-6.84	0.82	-17.9
MnO	&	0.02	NC	< 0.01	NC
Na_2O	24.00	22.03	-8.22	24.63	2.62
NiO	0.005	0.25	NC	0.09	NC
P_2O_5	0.20	0.20	NC	0.26	NC
PbO	0.002	0.01	NC	0.01	NC
$ReO_2^{\$}$	0.0100	0.0024	NC	0.0027	NC
SO_3	0.35	0.55	NC	0.36	NC
SiO_2	38.43	40.21	4.63	38.75	0.82
SnO_2	0.98	0.53	NC	0.72	NC
TiO_2	0.66	0.47	NC	0.54	NC
V_2O_5	&	0.79	NC	0.16	NC
ZnO	3.00	2.80	-6.79	2.92	-2.63
ZrO_2	6.01	4.99	-17.00	5.64	-6.03
Sum	100.00	100.01	-	100.00	-

- B_2O_3 concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SWV-D-34A) and target concentration using a simple well-stirred tank model;
& - Not a target constituent.
% Target value.
$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.
NC- Not calculated

Table 5.11. Comparison of XRF Analyzed Compositions for Average and Terminal Discharged Glass from DM100 Test with 5.6 M Na Simulant to the Target Composition (wt%).

	Target	Avg.	% Dev.	SWV-G-95G	% Dev.
Al_2O_3	10.00	9.73	-2.69	9.66	-3.44
B_2O_3#	11.00	10.79	-1.88	10.80	-1.85
CaO	1.95	2.25	15.28	2.15	10.26
Cl	0.82	0.31	NC	0.34	NC
Cr_2O_3	0.46	0.55	NC	0.53	NC
F%	0.01	0.01	NC	0.01	NC
Fe_2O_3	0.66	0.81	NC	0.79	NC
K_2O	0.46	0.50	NC	0.51	NC
Li_2O#	&	0.03	NC	0.02	NC
MgO	1.00	0.96	-4.08	1.00	0
MnO	&	0.02	NC	0.02	NC
Na_2O	24.00	24.08	0.35	23.87	-0.54
NiO	0.005	0.10	NC	0.07	NC
P_2O_5	0.20	0.23	NC	0.20	NC
PbO	0.002	0.01	NC	< 0.01	NC
$ReO_2$$	0.0100	0.0022	NC	0.0024	NC
SO_3	0.35	0.35	NC	0.34	NC
SiO_2	38.43	39.33	2.34	39.30	2.25
SnO_2	0.98	0.81	NC	0.97	NC
TiO_2	0.66	0.60	NC	0.63	NC
V_2O_5	&	0.08	NC	0.03	NC
ZnO	3.00	2.84	-5.49	2.91	-2.97
ZrO_2	6.01	5.62	-6.41	5.88	-2.18
Sum	100.00	100.01		100.00	

- B_2O_3 concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SWV-D-34A) and target concentration using a simple well-stirred tank model;
& - Not a target constituent.
% Target value.
$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.
NC- Not calculated

Table 5.12. Comparison of XRF Analyzed Compositions for Average and Terminal Discharged Glass from DM100 Test with 4 M Na Simulant to the Target Composition (wt%).

	Target	Avg.	% Dev.	SWV-G-136A	% Dev.
Al_2O_3	10.00	9.76	-2.43	9.78	-2.14
$B_2O_3{}^{\#}$	11.00	10.80	-1.84	10.80	-1.84
CaO	1.95	2.11	8.36	2.12	8.82
Cl	0.82	0.26	NC	0.33	NC
Cr_2O_3	0.46	0.60	NC	0.56	NC
$F^{\%}$	0.01	0.01	NC	0.01	NC
Fe_2O_3	0.66	0.83	NC	0.78	NC
K_2O	0.46	0.51	NC	0.52	NC
$Li_2O^{\#}$	&	0.02	NC	0.02	NC
MgO	1.00	0.99	-1.05	0.89	-11.0
MnO	&	0.02	NC	0.02	NC
Na_2O	24.00	24.01	0.05	25.09	4.56
NiO	0.005	0.11	NC	0.08	NC
P_2O_5	0.20	0.23	NC	0.22	NC
PbO	0.002	0.01	NC	0.01	NC
$ReO_2{}^{\$}$	0.0100	0.0021	NC	0.0023	NC
SO_3	0.35	0.33	NC	0.33	NC
SiO_2	38.43	39.19	1.98	38.51	0.20
SnO_2	0.98	0.95	NC	0.90	NC
TiO_2	0.66	0.61	NC	0.62	NC
V_2O_5	&	0.03	NC	< 0.01	NC
ZnO	3.00	2.88	-4.02	2.88	-3.97
ZrO_2	6.01	5.76	-4.13	5.54	-7.79
Sum	100.00	100.02		100.00	

- B_2O_3 concentrations calculated from DCP-AES analysis of glass in the melt pool prior to the tests (SWV-D-34A) and target concentration using a simple well-stirred tank model;
& - Not a target constituent.
% Target value.
$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.
NC- Not calculated

Table 5.13. Comparison of XRF Analyzed Compositions for Average and Terminal Discharged Glass from DM10 Test with 5.6 M Na Simulant to the Target Composition.

	Target	Avg.	% Dev.	G-10P-130A	% Dev.
Al_2O_3	10.00	9.30	-6.97	9.78	-2.23
B_2O_3#	11.00	10.71	-2.61	10.80	-1.84
CaO	1.95	2.44	24.94	2.02	3.58
Cl	0.82	0.41	NC	0.42	NC
Cr_2O_3	0.46	0.51	NC	0.57	NC
F%	0.01	0.01	NC	0.01	NC
Fe_2O_3	0.66	1.42	NC	0.84	NC
K_2O	0.46	0.53	NC	0.50	NC
Li_2O#	&	0.18	NC	0.02	NC
MgO	1.00	1.07	6.85	0.95	-5.13
MnO	&	0.01	NC	0.02	NC
Na_2O	24.00	23.14	-3.59	24.40	1.69
NiO	0.002	0.09	NC	0.06	NC
P_2O_5	0.20	0.22	NC	0.22	NC
PbO	0.002	< 0.01	NC	0.01	NC
$ReO_2$$	0.0100	0.0027	NC	0.0026	NC
SO_3	0.35	0.32	NC	0.34	NC
SiO_2	38.43	40.02	4.13	38.58	0.37
SnO_2	0.98	0.75	NC	0.92	NC
TiO_2	0.66	0.72	NC	0.64	NC
ZnO	3.00	2.89	-3.61	2.94	-2.12
ZrO_2	6.01	5.25	-12.57	5.97	-0.65
Sum	100.00	100.00		100.00	

\# - Values calculated from B_2O_3 and Li_2O analysis by DCP-AES of glass pool sample (D-10P-72A), analyzed feed lithium content, and target boron concentration using a simple well stirred tank model.

& - Not a target constituent

% Target value.

$ Determined by single-element rhenium XRF analysis with increased sensitivity calibrated against ICP-MS; values < 0.0019 wt% from ICP-MS analysis of dissolved glass samples.

NC- Not calculated

Table 6.1. Results from DM100 Melter Off-Gas Emission Samples.

		8M Na 2/23/2017 12:47 – 13:47 14.3 % Moisture, 102.5% Isokinetic				5.6 M Na 3/8/2017 13:17 – 13:22 17.2% Moisture, 102.5% Isokinetic			
		Feed# (mg/min)	Output (mg/min)	% Emitted	DF	Feed# (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total$	214076	1756	0.82	122	175428	3937	2.24	44.6
	Al	8904	8.22	0.09	1083	7538	42.4	0.56	178
	B	5746	56.2	0.98	102	4864	214	4.39	22.8
	Ca	2346	2.22	0.09	1055	1986	14.4	0.73	138
	Cl*	1397	756	54.1	1.85	1183	842	71.2	1.40
	Cr	534	7.53	1.41	70.9	452	17.7	3.92	25.5
	F*	15.1	9.63	63.6	1.57	12.8	2.22	17.3	5.79
	Fe	790	0.60	0.08	1328	669	4.57	0.68	146
	K	650	65.1	10.0	10.0	550	102	18.6	5.38
	Mg	1015	0.21	0.02	4919	859	0.81	0.09	1060
	Na	29971	525	1.75	57.1	25372	1111	4.38	22.8
	Ni	6.19	< 0.10	< 1.62	> 62	5.24	0.23	4.36	22.9
	P	144	0.34	0.24	425.5	122	< 0.10	< 0.08	> 1219
	Pb	3.37	0.12	3.61	27.7	2.86	1.16	40.6	2.46
	Re	14.4	10.9	76.2	1.31	12.2	11.5	94.7	1.06
	S*	234	39.1	16.7	5.99	198	57.2	28.9	3.47
	Sn	1295	2.58	0.20	502	1096	5.14	0.47	213
	Si	30241	14.5	0.05	2086	25600	116	0.45	221
	Ti	678	0.35	0.05	1957	574	2.08	0.36	276
	Zn	4057	8.15	0.20	498	3434	47.5	1.38	72.3
	Zr	7485	1.91	0.03	3921	6336	10.4	0.16	610
Gas	B	5746	9.98	0.17	576	4864	< 0.10	< 0.00	> 48642
	Cl	1397	< 0.10	< 0.01	> 13972	1183	< 0.10	< 0.01	> 11828
	F	15.1	< 0.10	< 0.66	> 151	12.8	< 0.10	< 0.78	> 128
	S	234	< 0.10	< 0.04	> 2341	198	< 0.10	< 0.05	> 1981

$ - From gravimetric analysis of filters and particulate nitric acid rinses.
# - Feed rate calculated from target composition and steady state production rate.
*- Calculated from water dissolution of filter particulate and direct analysis of rinse solutions.

Table 6.1. Results from DM100 Melter Off-Gas Emission Samples (continued).

		4M Na 3/16/2017 13:22 – 13:48 18.8 % Moisture, 105% Isokinetic			
		Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total[$]	150380	3521	2.34	42.7
	Al	6348	57.8	0.91	110
	B	4096	195	4.77	21.0
	Ca	1672	16.0	0.95	105
	Cl*	996	586	58.8	1.70
	Cr	380	16.0	4.20	23.8
	F*	10.8	10.2	94.2	1.06
	Fe	563	5.19	0.92	108
	K	463	79.5	17.2	5.83
	Mg	723	0.82	0.11	884
	Na	21366	921	4.31	23.2
	Ni	4.41	0.32	7.31	13.7
	P	103	1.48	1.44	69.6
	Pb	2.41	0.35	14.7	6.80
	Re	10.2	8.70	84.9	1.18
	S*	167	35.9	21.5	4.64
	Sn	923	11.94	1.29	77.3
	Si	21558	121	0.56	178
	Ti	483	2.55	0.53	189
	Zn	2892	59.0	2.04	49.0
	Zr	5336	17.2	0.32	310
Gas	B	4096	< 0.10	< 0.00	> 40961
	Cl	996	< 0.10	< 0.01	> 9960
	F	10.8	< 0.10	< 0.93	> 108
	S	167	< 0.10	< 0.06	> 1669

[$] - From gravimetric analysis of filters and particulate nitric acid rinses.

[#] - Feed rate calculated from target composition and steady state production rate.

*- Calculated from water dissolution of filter particulate and direct analysis of rinse solutions.

Table 6.2. Results from DM10 Melter Emission Samples.

		3/30/2017 12:01 – 13:01 8.77 % Moisture, 101% Isokinetic				3/30/2017 13:33 – 14:33 9.54% Moisture, 100% Isokinetic			
		Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF	Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total[$]	35400	387	1.09	91.4	35400	392	1.11	90.4
	Al	1470	1.89	0.13	779	1470	1.59	0.11	927
	B	948	18.7	1.97	50.7	948	18.9	2.00	50
	Ca	387	0.62	0.16	627	387	0.48	0.12	809
	Cl*	228	123	54.1	1.85	228	140	61.3	1.63
	Cr	88.1	1.75	1.98	50.4	88.1	1.89	2.15	46.6
	F*	2.50	1.54	61.5	1.63	2.50	1.65	65.9	1.5
	Fe	130	0.19	0.15	672	130	0.10	0.07	1349
	K	107	13.2	12.4	8.10	107	13.6	12.6	7.91
	Mg	168	0.07	0.04	2416	168	0.03	0.02	5640
	Na	4947	109	2.20	45.6	4947	108	2.17	46.0
	Ni	1.02	< 0.01	< 0.98	> 102	1.02	< 0.01	< 0.98	> 102
	P	23.8	0.10	0.41	243	23.8	< 0.01	< 0.04	> 2377
	Pb	0.56	0.04	7.58	13.2	0.56	0.03	5.68	17.6
	Re	2.37	1.91	80.5	1.24	2.37	1.96	82.8	1.21
	S*	38.6	3.91	10.1	9.89	38.6	4.18	10.8	9.25
	Sn	214	0.57	0.27	373	214	0.57	0.26	378
	Si	5029	4.11	0.08	1225	5029	3.28	0.07	1534
	Ti	112	0.08	0.07	1431	112	0.08	0.07	1468
	Zn	670	2.29	0.34	292	670	1.93	0.29	346
	Zr	1235	0.37	0.03	3311	1235	0.31	0.03	3941
Gas	B	948	< 0.10	< 0.01	> 94837	948	< 0.10	< 0.01	> 94837
	Cl	228	< 0.10	< 0.01	> 22782	228	< 0.10	< 0.01	> 22782
	F	2.50	< 0.10	< 0.40	> 250	2.50	< 0.10	< 0.40	> 250
	S	38.6	< 0.10	< 0.03	> 3863	38.6	< 0.10	< 0.03	> 3863

[$] - From gravimetric analysis of filters and particulate nitric acid rinses

[#] - Feed rate calculated from target composition and actual feed rate during sampling

* - Calculated from analysis of filter particulate by water dissolution and direct analysis of particulate rinse

Table 6.3. Results from SBS Outlet Emission Samples and Corresponding Feed Carryover Calculated Across the Melter and SBS.

		3/29/2017 9:16 - 10:16 8.92 % Moisture, 105% Isokinetic				3/29/2017 10:32 – 10:52 10.3% Moisture, 101% Isokinetic			
		Feed$^{\#}$ (mg/min)	Output (mg/min)	% Emitted	DF	Feed$^{\#}$ (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total$^{\$}$	35400	154	0.44	230	35400	188	0.53	189
	Al	1470	0.13	0.01	11691	1470	0.33	0.02	4494
	B	948	2.35	0.25	403	948	1.02	0.11	933
	Ca	387	0.19	0.05	2003	387	0.75	0.19	513
	Cl*	228	72.9	32.0	3.13	228	81.5	35.8	2.80
	Cr	88.1	0.58	0.66	151	88.1	0.64	0.72	138
	F*	2.50	0.70	28.1	3.56	2.50	<0.01	< 0.40	> 250
	Fe	130	< 0.01	< 0.01	> 13044	130	< 0.01	< 0.01	> 13044
	K	107	5.76	5.37	18.6	107	6.89	6.43	15.6
	Mg	168	0.07	0.04	2320	168	0.29	0.17	579
	Na	4947	46.8	0.95	106	4947	57.6	1.16	85.9
	Ni	1.02	< 0.01	< 0.98	> 102	1.02	< 0.01	< 0.98	> 102
	P	23.8	< 0.01	< 0.04	> 2377	23.8	< 0.01	< 0.04	> 2377
	Pb	0.56	< 0.01	< 1.80	> 56	0.56	< 0.01	< 1.80	> 56
	Re	2.37	1.11	46.7	2.14	2.37	1.28	54.1	1.85
	S*	38.6	1.88	4.86	20.6	38.6	3.24	8.38	11.9
	Sn	214	< 0.01	< 0.01	> 21376	214	< 0.01	< 0.01	> 21376
	Si	5029	1.40	0.03	3603	5029	5.58	0.11	901
	Ti	112	< 0.01	< 0.01	> 11183	112	< 0.01	< 0.01	> 11183
	Zn	670	0.14	0.02	4810	670	0.17	0.03	3999
	Zr	1235	< 0.01	< 0.01	> 123540	1235	< 0.01	< 0.01	> 123540
Gas	B	948	< 0.10	< 0.01	> 94837	948	< 0.10	< 0.01	> 94837
	Cl	143	< 0.10	< 0.01	> 22782	142.8	< 0.10	< 0.01	> 22782
	F	2.50	< 0.10	< 0.40	> 250	2.50	< 0.10	< 0.40	> 250
	S	38.6	< 0.10	< 0.03	> 3863	38.6	< 0.10	< 0.03	> 3863

$^{\#}$ - Feed rate calculated from target composition and the average glass production rate
* - Calculated from the direct analysis of the particulate rinse

Table 6.4. Results from WESP Outlet Emission Samples and Corresponding Feed Carryover Across the Melter and Primary Off-Gas System.

		3/29/2017 11:55 – 12:55 6.76 % Moisture, 97.6% Isokinetic				3/29/2017 13:16 – 14:16 6.80% Moisture, 97.7% Isokinetic			
		Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF	Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total[$]	35400	34.1	0.10	1037	35400	56.9	0.16	623
	Al	1470	0.03	< 0.01	46836	1470	0.06	< 0.01	23467
	B	948	0.30	0.03	3129	948	0.69	0.07	1371
	Ca	387	0.06	0.01	6791	387	0.12	0.03	3194
	Cl*	228	9.68	4.25	23.5	228	23.2	10.2	9.84
	Cr	88.1	0.14	0.16	615	88.1	0.24	0.27	373
	F*	2.50	<0.01	< 0.40	> 250	2.50	<0.01	< 0.40	> 250
	Fe	130	< 0.01	< 0.01	> 13044	130	< 0.01	< 0.01	> 13044
	K	107	1.49	1.39	72.1	107	2.16	2.02	49.6
	Mg	168	0.02	0.01	10605	168	0.04	0.03	3883
	Na	4947	12.1	0.24	409	4947	18.3	0.37	271
	Ni	1.02	< 0.01	< 0.98	> 102	1.02	< 0.01	< 0.98	> 102
	P	23.8	< 0.01	< 0.04	> 2377	23.8	< 0.01	< 0.04	> 2377
	Pb	0.56	< 0.01	< 1.80	> 56	0.56	< 0.01	< 1.80	> 56
	Re	2.37	0.29	12.4	8.09	2.37	0.42	17.6	5.70
	S*	38.6	0.37	0.97	103	38.6	0.84	2.16	46.2
	Sn	214	< 0.01	< 0.01	> 21376	214	< 0.01	< 0.01	> 21376
	Si	5029	0.42	0.01	11854	5029	0.86	0.02	5835
	Ti	112	< 0.01	< 0.01	> 11183	112	< 0.01	< 0.01	> 11183
	Zn	670	0.04	0.01	17426	670	0.05	0.01	12569
	Zr	1235	< 0.01	< 0.01	> 123540	1235	< 0.01	< 0.01	> 123540
Gas	B	948	< 0.10	< 0.01	> 94837	948	0.22	0.02	4307
	Cl	142.8	< 0.10	< 0.01	> 22782	143	< 0.10	< 0.01	> 22782
	F	2.50	< 0.10	< 0.40	> 250	2.50	< 0.10	< 0.40	> 250
	S	38.6	< 0.10	< 0.03	> 3863	38.6	< 0.10	< 0.03	> 3863

[$] - From gravimetric analysis of filters and particulate nitric acid rinses

[#] - Feed rate calculated from target composition and the average glass production rate

* - Calculated from the direct analysis of the particulate rinse

Table 6.4. Results from WESP Outlet Emission Samples and Corresponding Feed Carryover across the Melter and Primary Off-Gas System (continued).

		3/30/2017 14:54 – 15:54 6.39 % Moisture, 102% Isokinetic			
		Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total[$]	35400	2.74	0.01	12933
	Al	1470	< 0.01	< 0.01	> 146964
	B	948	< 0.01	< 0.01	> 94837
	Ca	387	0.01	< 0.01	34600
	Cl*	228	1.35	0.59	169
	Cr	88.1	< 0.01	< 0.01	> 8809
	F*	2.50	<0.01	< 0.40	> 250
	Fe	130	< 0.01	< 0.01	> 13044
	K	107	0.02	0.02	5626
	Mg	168	< 0.01	< 0.01	> 16751
	Na	4947	0.35	0.01	14212
	Ni	1.02	< 0.01	< 0.98	> 102
	P	23.8	< 0.01	< 0.04	> 2377
	Pb	0.56	< 0.01	< 1.80	> 56
	Re	2.37	0.006	0.270	371
	S*	38.6	0.06	0.15	680
	Sn	214	< 0.01	< 0.01	> 21376
	Si	5029	< 0.01	< 0.01	> 502860
	Ti	112	< 0.01	< 0.01	> 11183
	Zn	670	< 0.01	< 0.01	> 66956
	Zr	1235	< 0.01	< 0.01	> 123540
Gas	B	948	< 0.10	< 0.01	> 94837
	Cl	143	< 0.10	< 0.01	> 22782
	F	2.50	< 0.10	< 0.40	> 250
	S	38.6	< 0.10	< 0.03	> 3863

[$] - From gravimetric analysis of filters and particulate nitric acid rinses
[#] - Feed rate calculated from target composition and the average glass production rate
* - Calculated from the direct analysis of the particulate rinse

Table 6.5. XRF Analyzed Composition of Solids from Cyclone Filter.

		8 M Na	5.6 M Na	4 M Na
Amounts removed		450 g	682 g	545 g
Mineral phases detected		Quartz, Halite, Zircon, Wollastonite, Kyanite, Zincite	Quartz, Halite, Zircon, Wollastonite, Kyanite, Zincite, Hematite, Rutile	Quartz, Halite, Zircon, Wollastonite, Kyanite
	Target	SWV-O-61A	SWV-O-100A	SWV-O-136A
Al_2O_3	10.00	5.68	7.56	7.74
$B_2O_3^{\#}$	11.00	15.56	13.06	14.21
CaO	1.95	4.09	2.98	2.81
Cl	0.82	6.06	4.50	5.05
Cr_2O_3	0.46	0.53	0.65	0.73
$F^{\%}$	0.01	NM	NM	NM
Fe_2O_3	0.66	0.53	0.64	0.63
I	&	0.03	0.04	0.04
K_2O	0.46	1.06	1.11	1.14
$Li_2O^{\#}$	&	0.74	0.10	0.13
MgO	1.00	0.05	< 0.01	< 0.01
MnO	&	0.02	< 0.01	< 0.01
Na_2O	24.00	27.45	28.42	28.94
NiO	0.005	0.02	0.01	0.01
P_2O_5	0.20	0.19	0.22	0.21
PbO	0.002	0.01	0.01	0.01
$ReO_2^{\$}$	0.0100	0.115	0.065	0.071
SO_3	0.35	3.64	1.16	1.22
SiO_2	38.43	22.62	26.55	25.05
SnO_2	0.98	0.70	1.12	1.16
TiO_2	0.66	0.41	0.67	0.53
V_2O_5	&	1.45	0.20	0.24
ZnO	3.00	3.71	3.78	3.98
ZrO_2	6.01	5.34	7.15	6.10
Sum	100.00	100.00	100.00	100.00

- DCP analysis
& - Not a target constituent

Table 6.6. Concentrations [ppmv] of Selected Species in Off-Gas Measured by FTIR Spectroscopy.

	DM100						DM10	
	8 M Na		5.6 M Na		4 M Na		5.6 M Na	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
H_2O (%)	7.3	4.17 – 16.5	8.5	< 1.0 - 12.5	10.2	2.8 - 19.1	3.5	2.8 - 4.5
CO	70.8	1.1 – 423	62.4	< 1.0 – 218	55.3	< 1.0 - 459	15.8	< 1.0 - 87.4
CO_2	4699	603 –24221	3265	< 1.0 -3591	3339	396 - 19449	1498	458 - 8847
HCN	< 1.0	< 1.0 – 2.0	< 1.0	NA	< 1.0	< 1.0 - 1.6	< 1.0	NA
HF	1.3	< 1.0 – 2.6	< 1.0	< 1.0 - 1.4	1.0	< 1.0 - 2.6	4.2	< 1.0 - 25.5
HCl	< 1.0	< 1.0 - 1.1	< 1.0	NA	< 1.0	< 1.0 - 1.0	< 1.0	< 1.0 - 2.8
NH_3	52.2	9.9 – 507	42.2	< 1.0 - 329	47.5	1.7 - 618	3.1	< 1.0 - 10.8
HNO_3	< 1.0	NA	< 1.0	NA	< 1.0	NA	< 1.0	< 1.0 - 3.1
NO	1829	86.7 - 5846	1546	< 1.0 -3947	1496	1.7 - 5557	408	31.1 - 1502
NO_2	118	7.8 - 774	63.4	< 1.0 - 326	54.6	< 1.0 - 638	61.3	1.6 - 603
HNO_2	< 1.0	< 1.0 – 3.1	< 1.0	< 1.0 - 1.9	< 1.0	< 1.0 - 3.1	1.4	< 1.0 - 17.0
N_2O	158	5.3 -767	141	< 1.0 - 564	118	< 1.0 - 814	47.4	1.3 - 431

Table 7.1. Measured Volatile Distributions in Glass and DM10 Off-gas System Effluents (%).

Constituent	-	**AP105DLAW11**	**ORPLB4 [17]**
Rhenium	*Target Mass fed, g*	*8.72*	*12.33*
	Glass	27	42
	SBS Solutions	48	34
	WESP Solutions	13	15
	WESP Emissions*	2.1	0.18
	Total	90.1	91.2
Chlorine	*Target Mass fed, g*	*526*	*181*
	Glass	50	100
	SBS Solutions	28	48
	WESP Solutions	8.0	36
	WESP Emissions*	1.5	0.3
	Total	87.5	184.3
Sulfur	*Target Mass fed, g*	*142*	*1015*
	Glass	91	94
	SBS Solutions	6.4	1.2
	WESP Solutions	1.7	1.0
	WESP Emissions*	< 0.1	< 0.1
	Total	99.1	96.2

NA – Not Applicable
*- Weighted average of deluge and nominal operations exhaust samples.

Table 7.2. Measured Volatile Distributions in Glass and Melter Exhaust for Tests Conducted with AP105DLAW11 Composition (%).

-		**DM100**			**DM10**
Constituent	Na Waste Molarity	**8**	**5.6**	**4**	**5.6**
ReO_2	*Target Glass Concentration, wt%*	*0.01*	*0.01*	*0.01*	*0.01*
	Glass	26	23	22	27
	Melter Exhaust	76.2	94.7	84.9	81.7
	Total	102.2	117.7	106.9	108.7
Chlorine	*Target Glass Concentration, wt%*	*0.82*	*0.82*	*0.82*	*0.82*
	Glass	49	41	38	50
	Melter Exhaust	54.1	71.2	58.8	52.7
	Total	103.1	112.2	96.8	102.7
Sulfur	*Target Glass Concentration, wt% SO_3*	*0.35*	*0.35*	*0.35*	*0.35*
	Glass	100	97	94	91
	Melter Exhaust	16.7	28.9	21.5	10.6
	Total	116.7	125.9	115.5	101.6

NA – Not Applicable

Table 7.3. Measured Distributions of Melter feed Constituents in Off-gas System Effluents.

	Feed	SBS		WESP	
	g	g	%	g	%
Al	5407	4.38	0.08	0.16	< 0.01
B	3487	49.3	1.42	3.49	0.10
Ca	1423	2.01	0.14	0.15	0.01
Cl	839	233	27.8	67.3	8.0
Cr	324	3.48	1.08	0.77	0.24
F	9.20	4.98	54.1	0.69	7.46
Fe	478	1.08	0.23	0.24	0.05
K	394	25.4	6.45	6.38	1.62
Mg	618	0.12	0.02	< 0.01	< 0.01
Na	18195	262	1.44	46.3	0.25
Ni	3.75	0.02	0.57	0.01	0.18
P	88	0.02	0.02	< 0.01	< 0.01
Pb	2.06	0.04	2.10	0.01	0.34
Re	8.72	4.19	48.1	1.17	13.4
S	142	9.02	6.35	2.38	1.68
Sn	787	9.51	1.21	1.25	0.16
Si	18497	0.23	< 0.01	< 0.01	< 0.01
Ti	412	0.16	0.04	< 0.01	< 0.01
Zn	2464	5.62	0.23	0.22	0.01
Zr	4542	0.91	0.02	0.03	< 0.01
Nitrite	7556	387	1.73	78.8	0.42
Nitrate	15151	6.15		15.6	
Sulfate	430	27.1	6.30	7.13	0.05
Ammonia	0	208	NC	22.7	NC

NC – Not Calculated

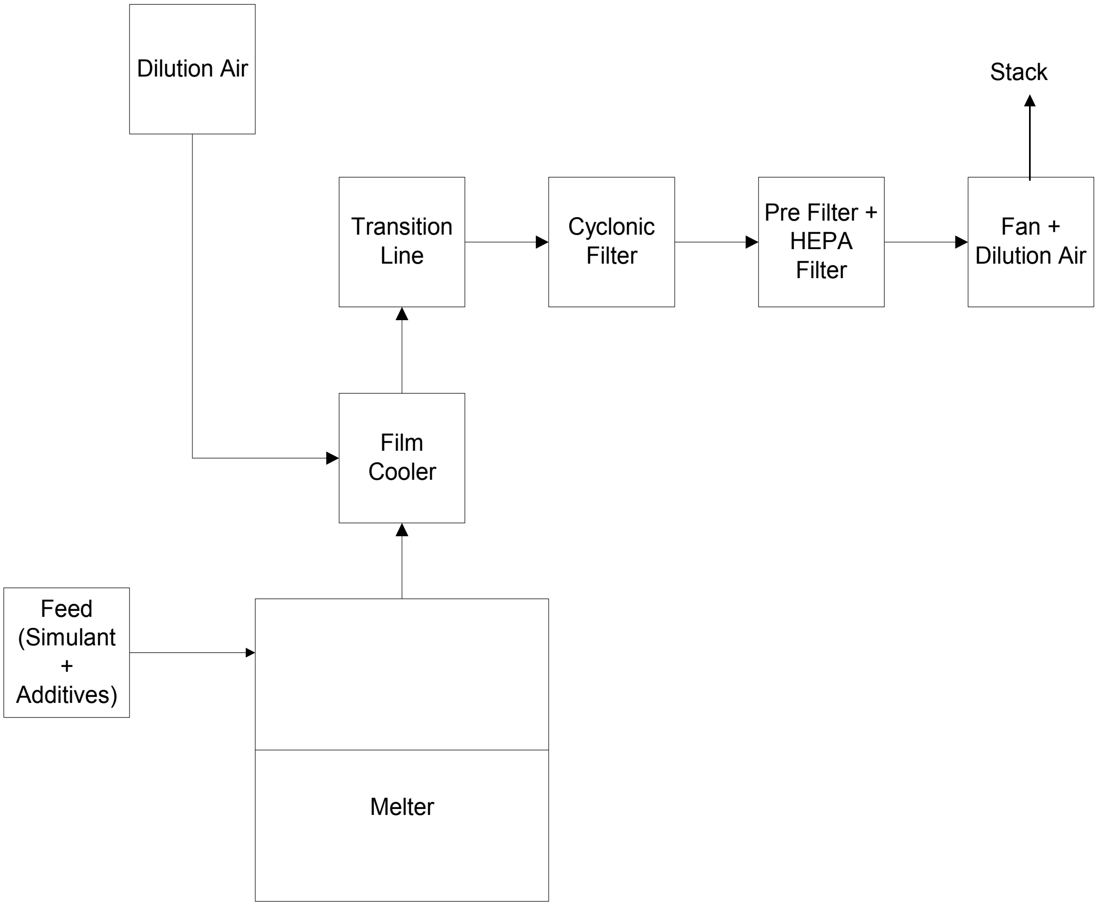

Figure 1.1. Schematic diagram of DuraMelter 100-WV vitrification system.

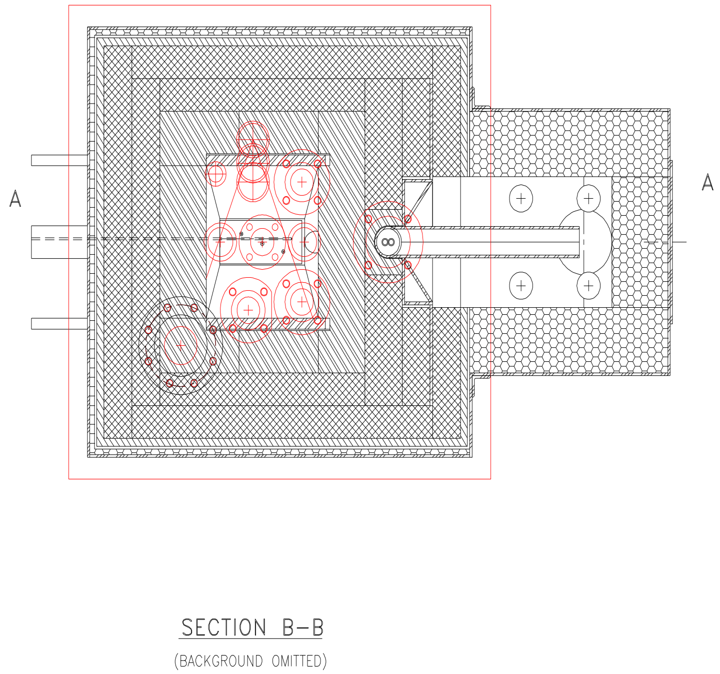

Figure 1.2(a). Cross-section through the DM100-WV melter—Plan View.

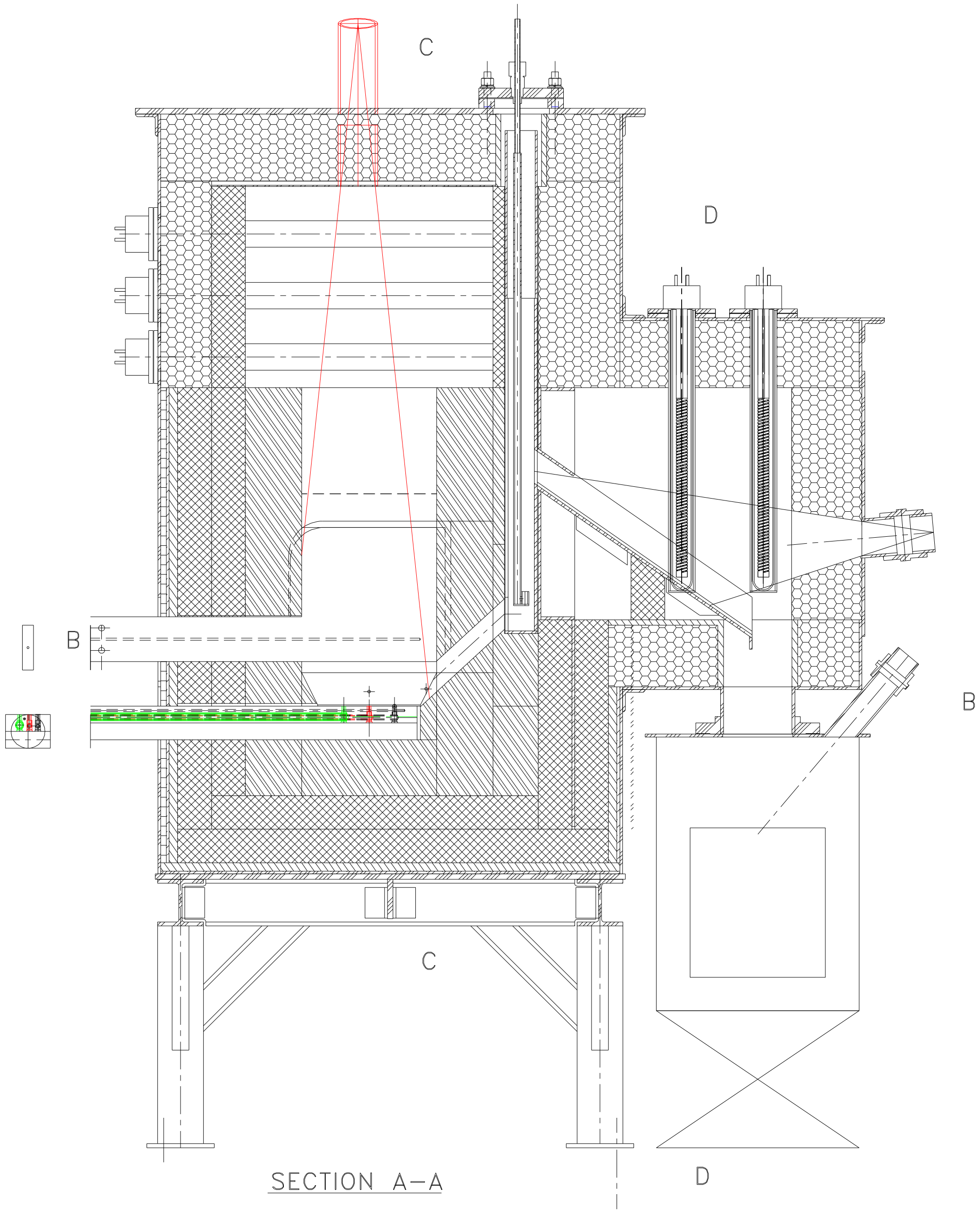

Figure 1.2(b). Cross-section through the DM100-WV melter—Section AA.

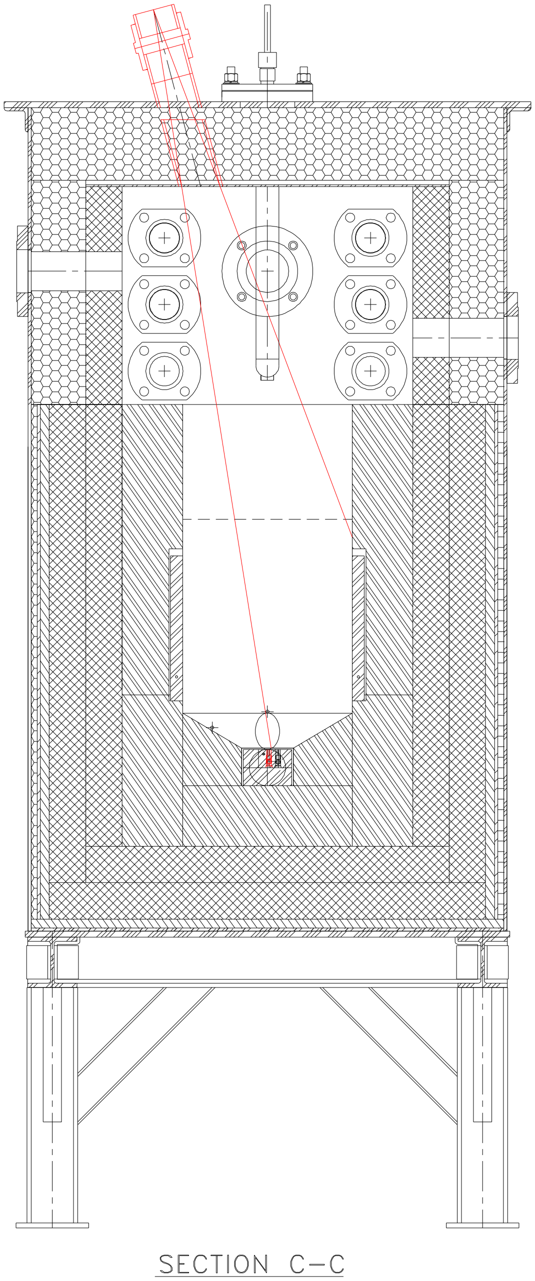

Figure 1.2(c). Cross-section through the DM100-WV melter—Section CC.

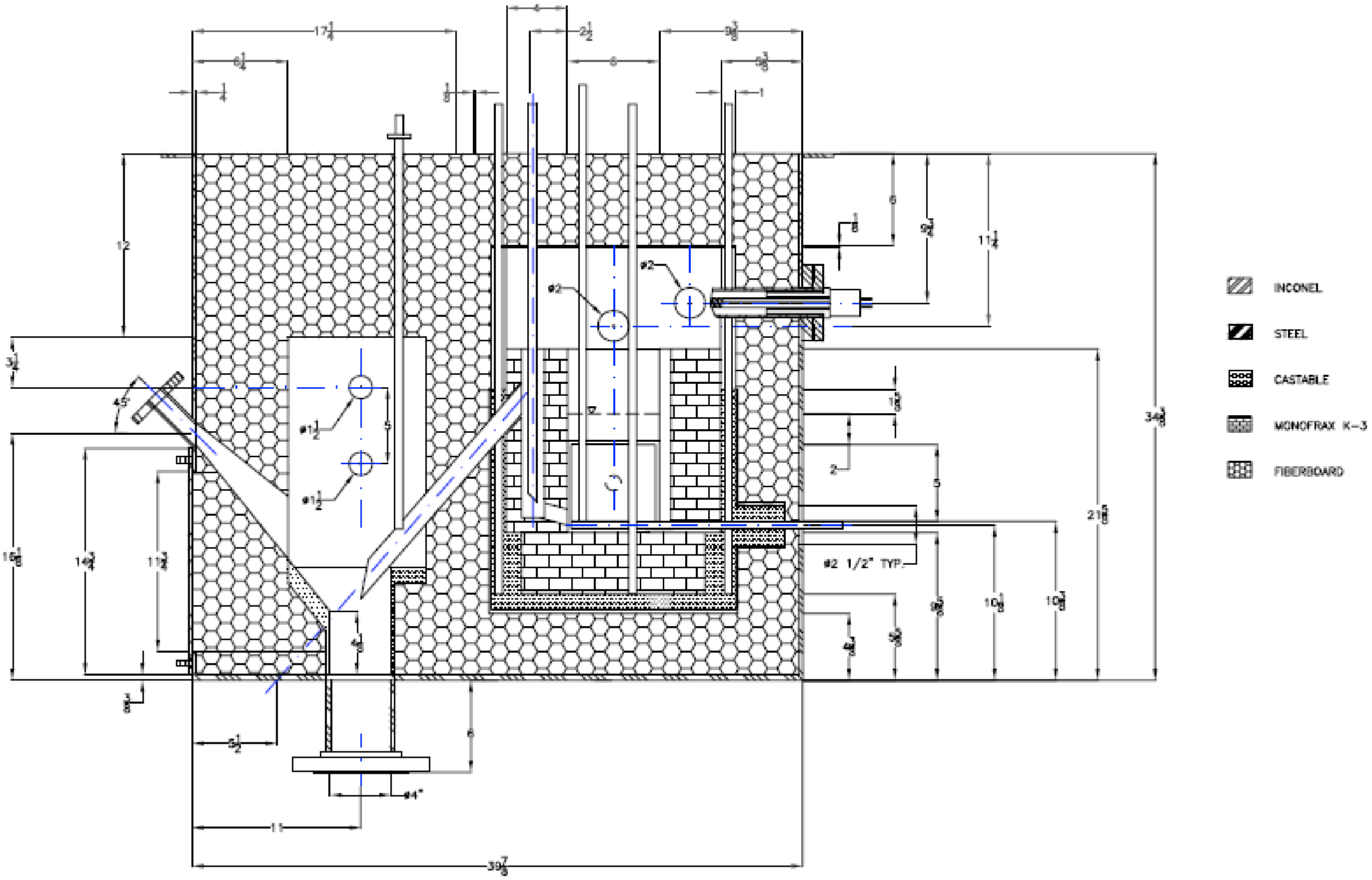

Figure 1.3. Schematic diagram showing cross-section through the DM10 melter.

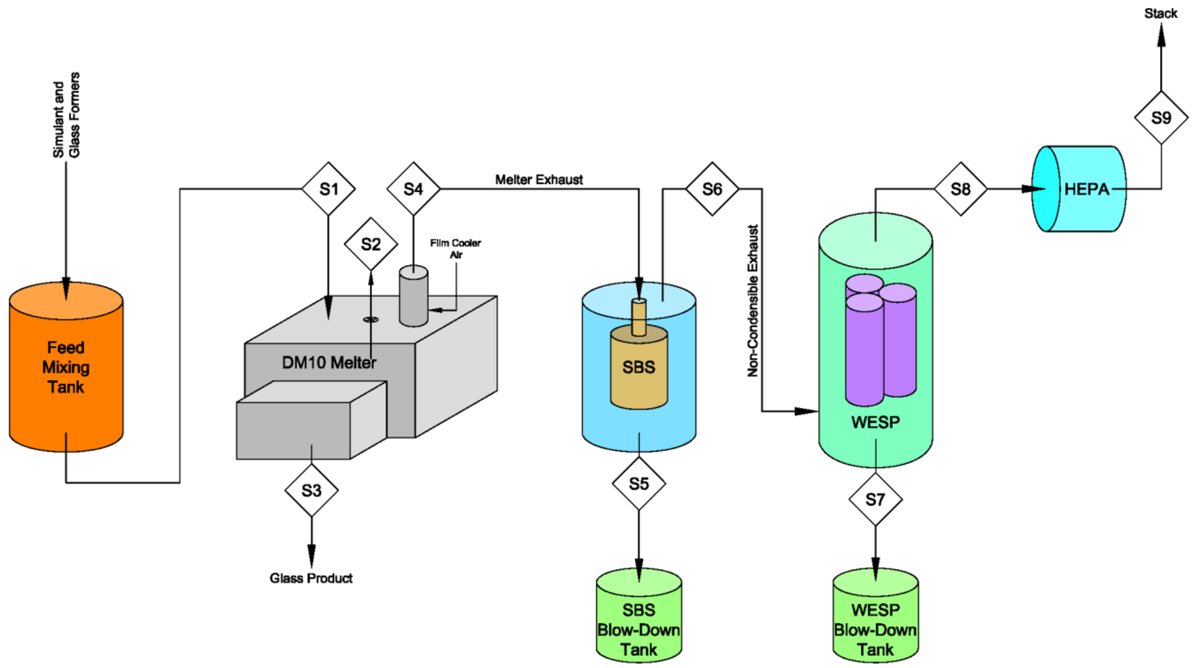

Figure 1.4. Schematic diagram showing DM10 system components and process flows. Also shown are the sampling points (S1 – S9).

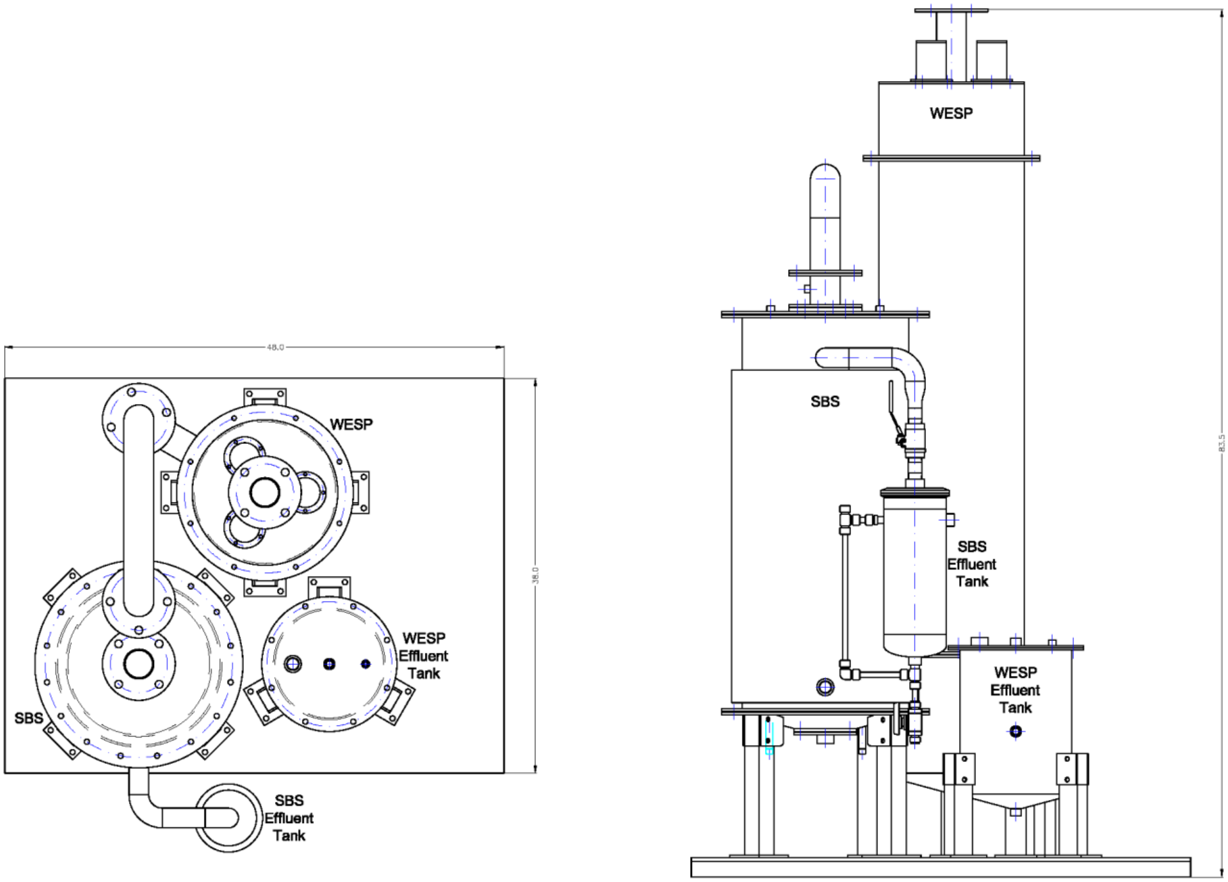

Figure 1.5. Plan and elevation views of arrangements of new DM10 off-gas system components. SBS is on the left, WESP is in the center, and the smaller vessels in front are the effluent collection tanks.

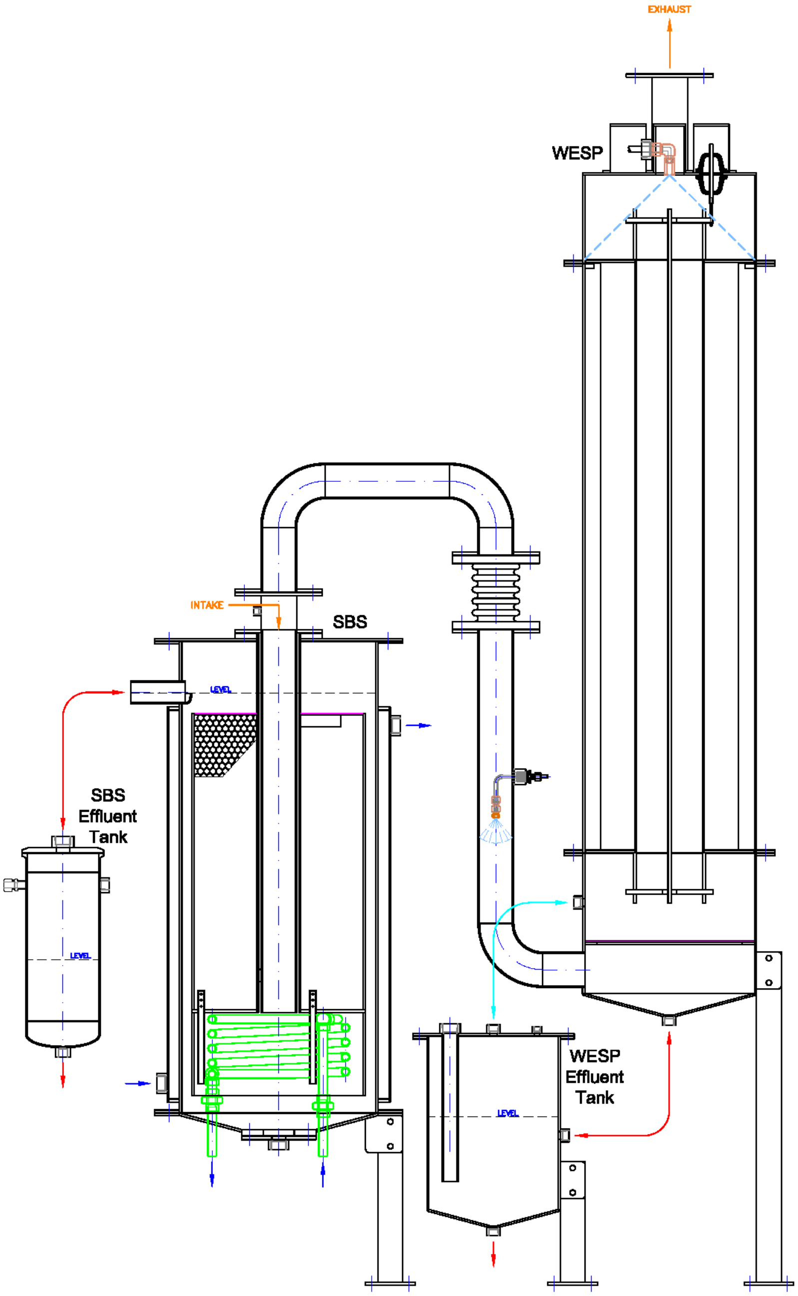

Figure 1.6. Cross-section through the DM10 off-gas system components showing internals; SBS, WESP, and effluent tanks.

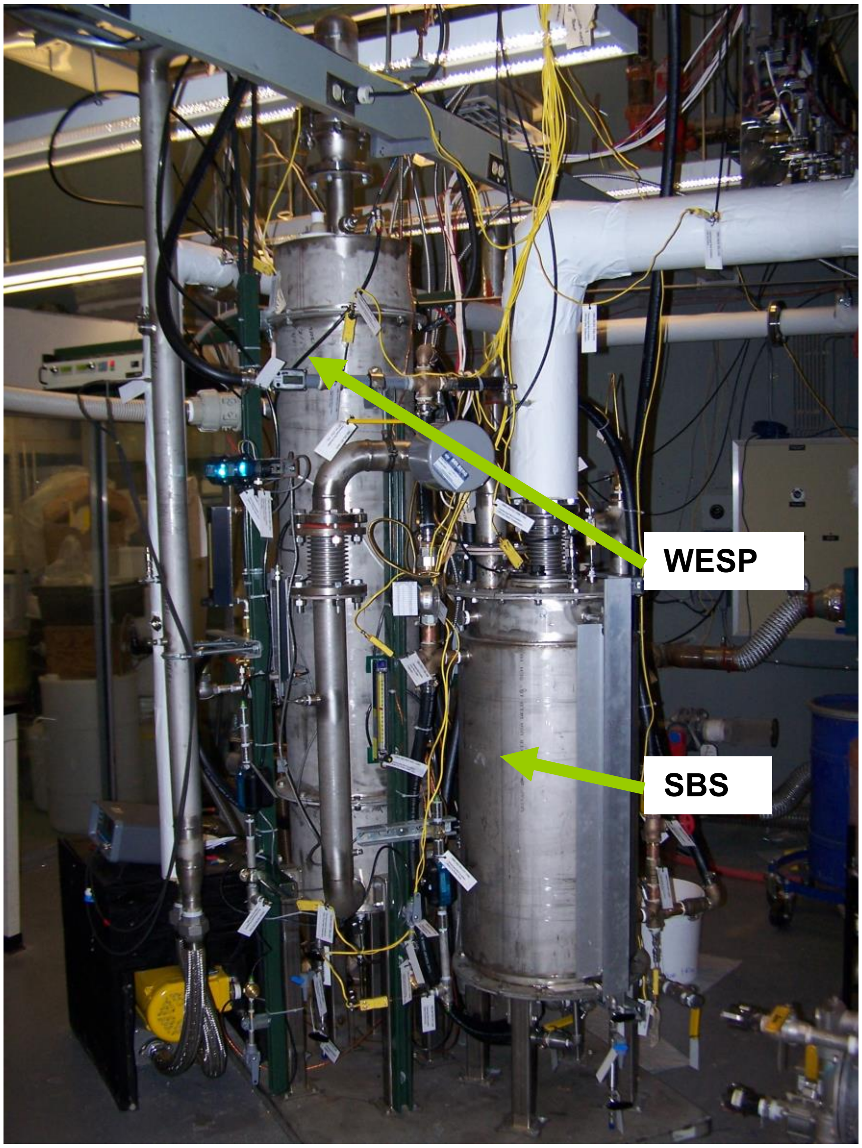

Figure 1.7. Photograph of the wet off-gas system skid.

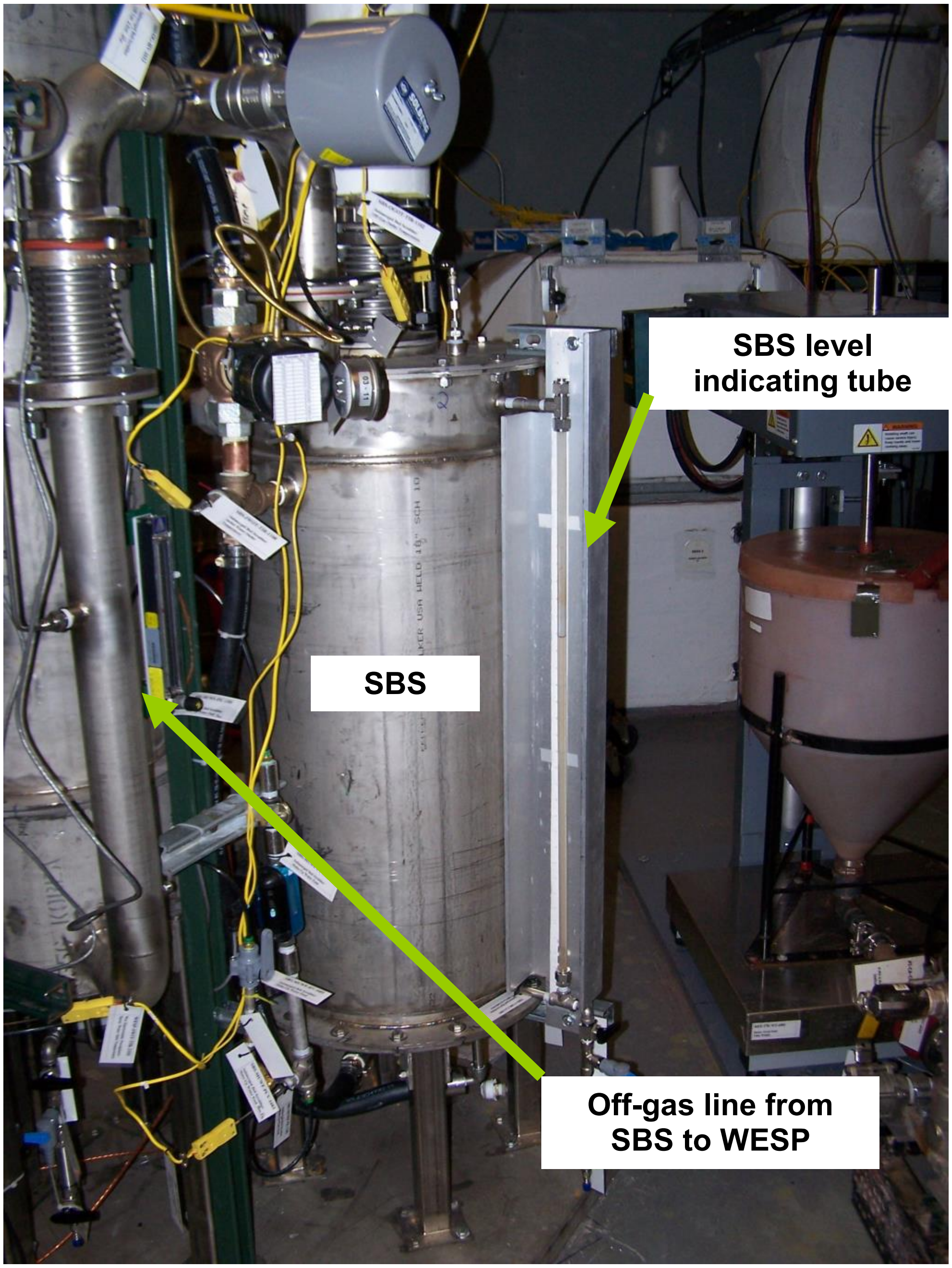

Figure 1.8. Photograph of the SBS.

Figure 1.9. Photograph looking down into the WESP from the top. The three channels with electrodes are visible.

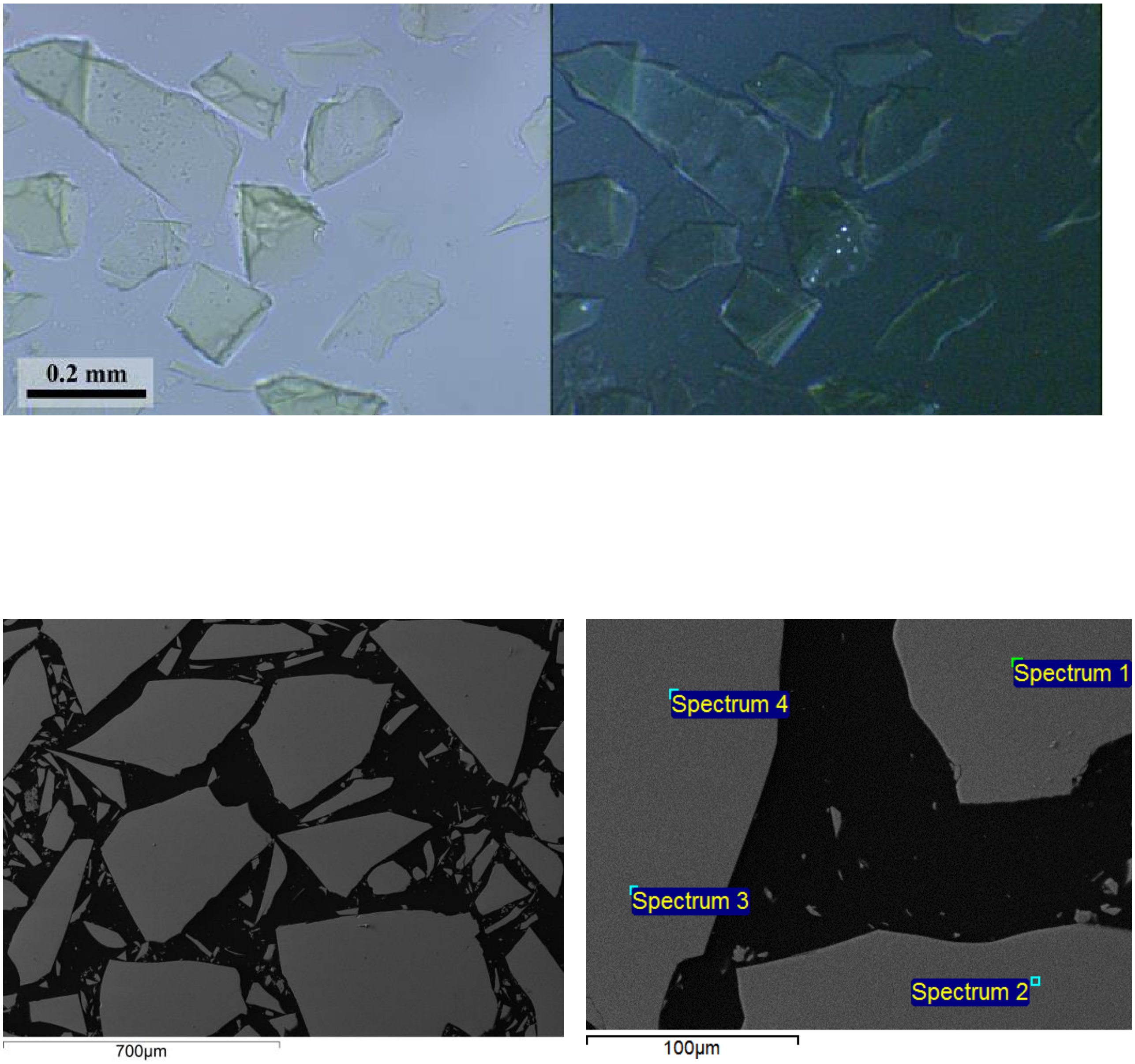

Figure 2.1. Optical micrograph (top) and SEM micrograph (bottom) of glass sample AP105DLAW11C950H20 after isothermal heat-treatment at 950°C for 20 hours.

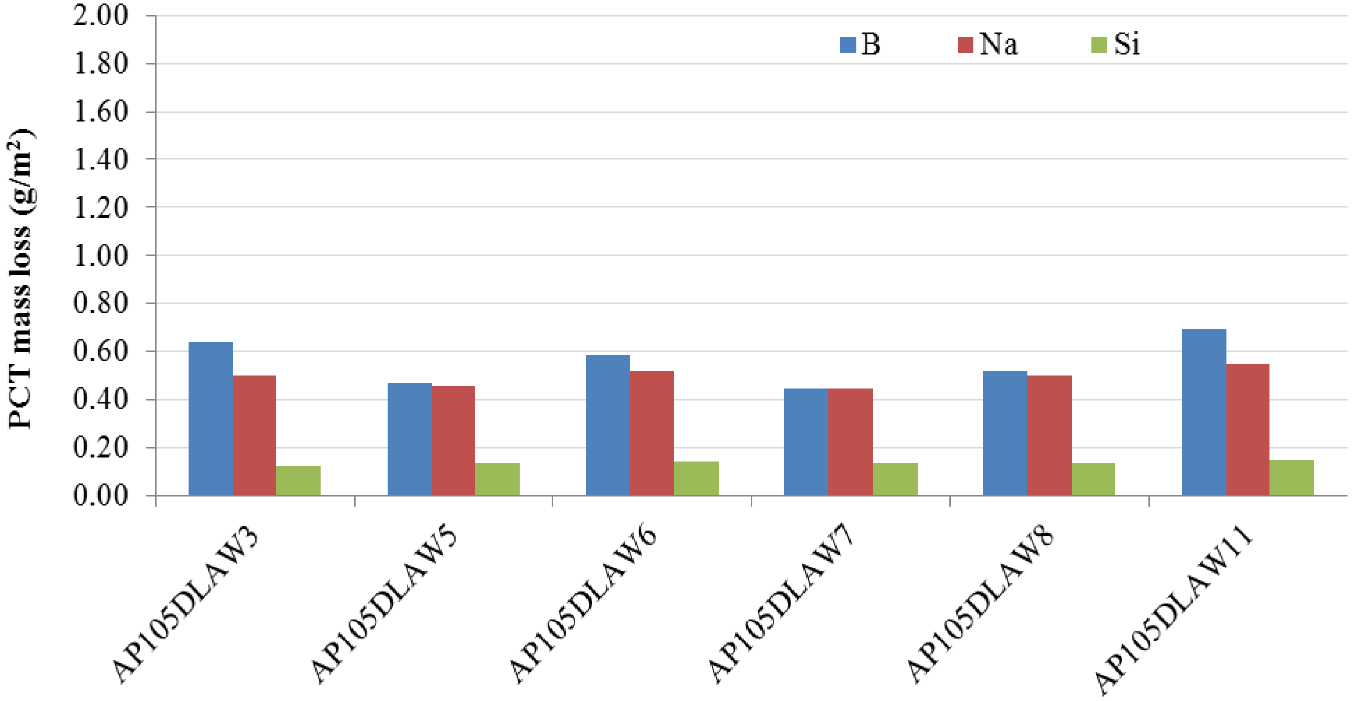

Figure 2.2. Normalized PCT mass loss for AP105DLAW crucible glasses (contractual limit = 2 g/m^2 [78]).

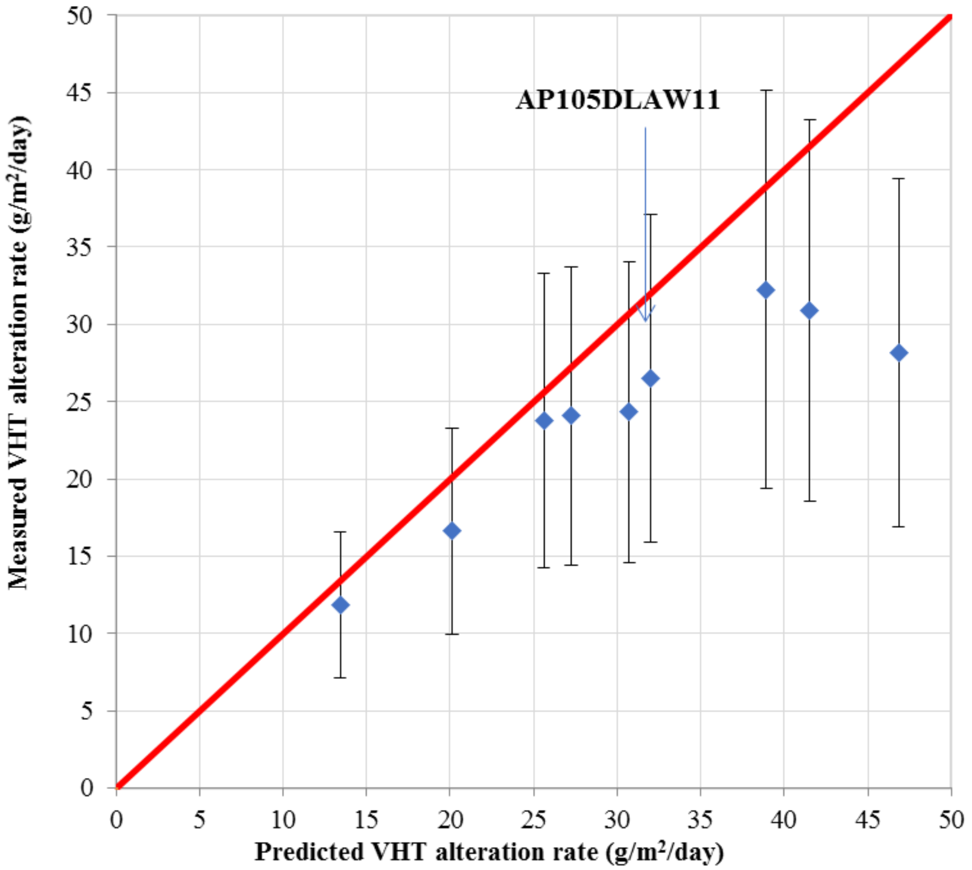

Figure 2.3. Comparison of predicted and measured VHT alteration rates for AP105DLAW crucible glasses. (Percent relative standard deviation (%RSD) of VHT measurement is estimated to be 40% [72]).

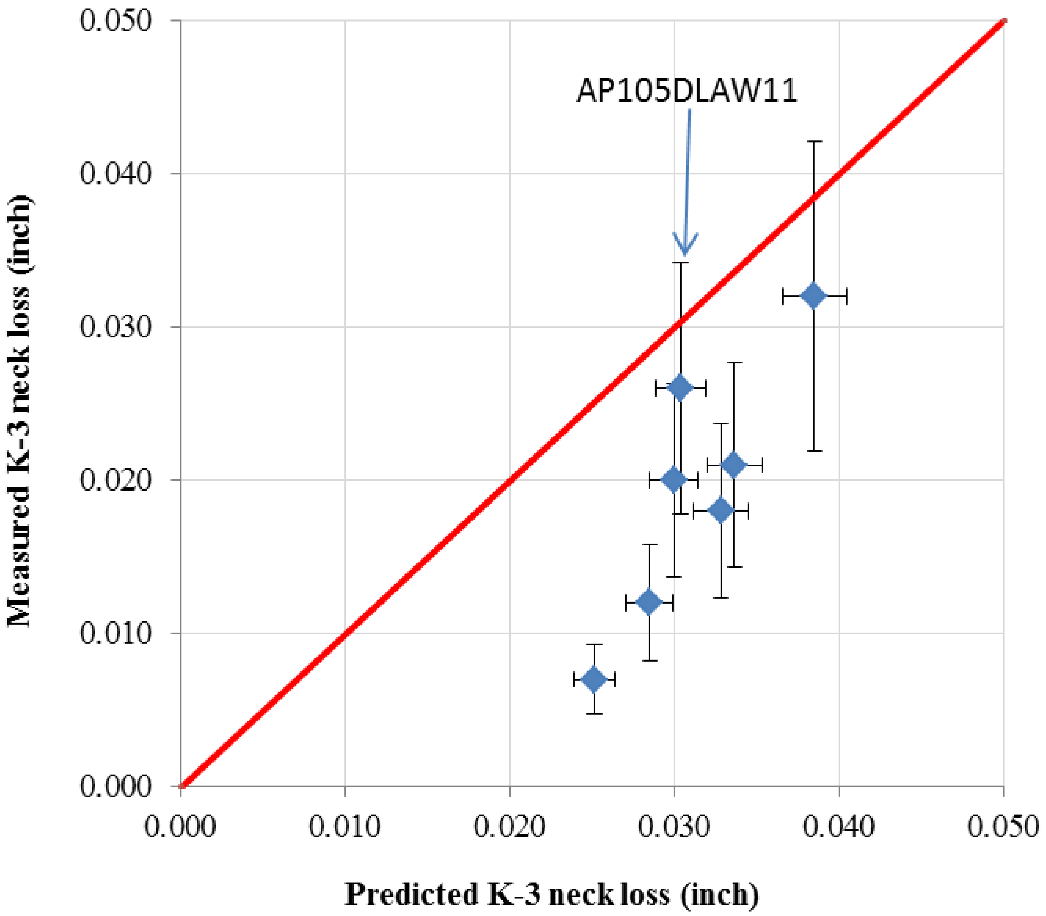

Figure 2.4. Comparison of predicted and measured K-3 neck losses for AP105DLAW crucible glasses.

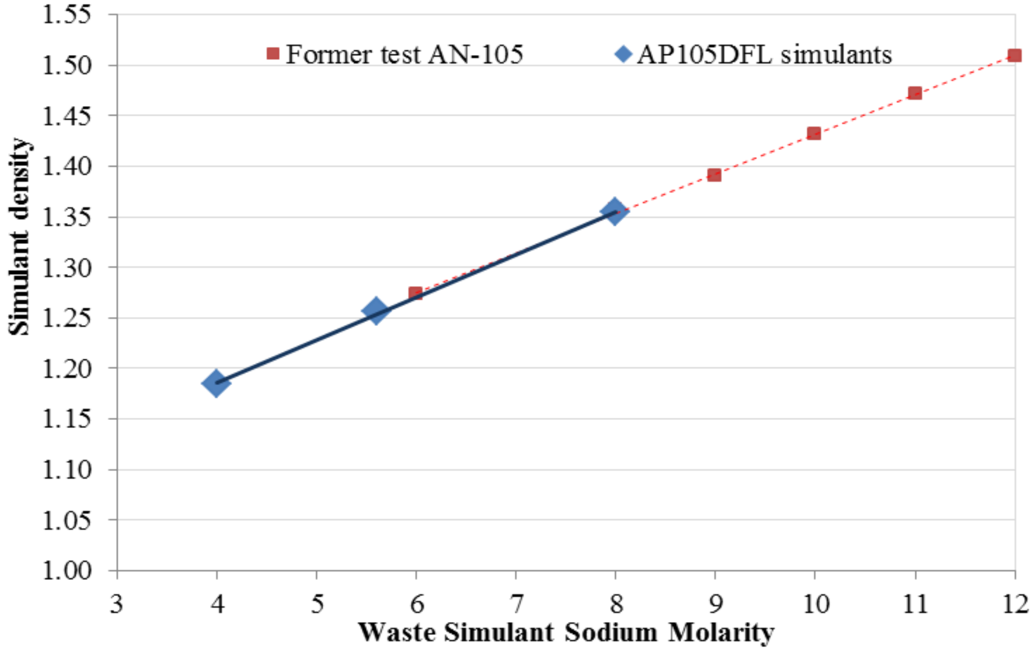

Figure 2.5. Dependence of AP-105 simulant density (g/cm^3) on sodium molarity and comparison to previous VSL test for AN-105 simulant [12].

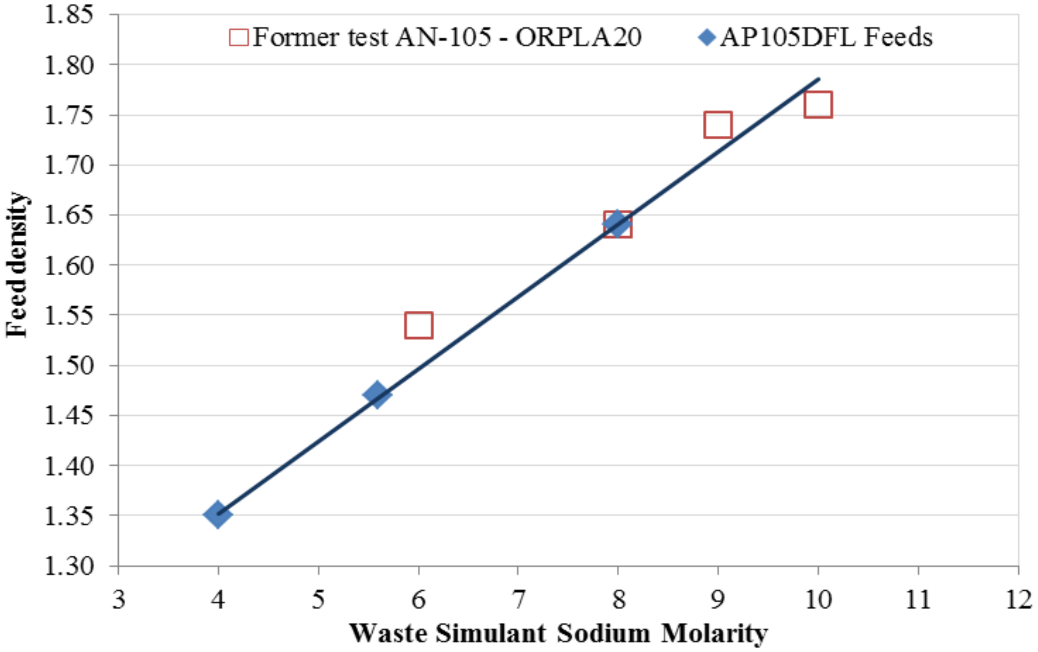

Figure 2.6. Dependence of AP105DFL feed density (g/cm^3) on sodium molarity of AP-105 simulant and comparison to selected feeds for AN-105 (glass formulation ORPLA20) [12].

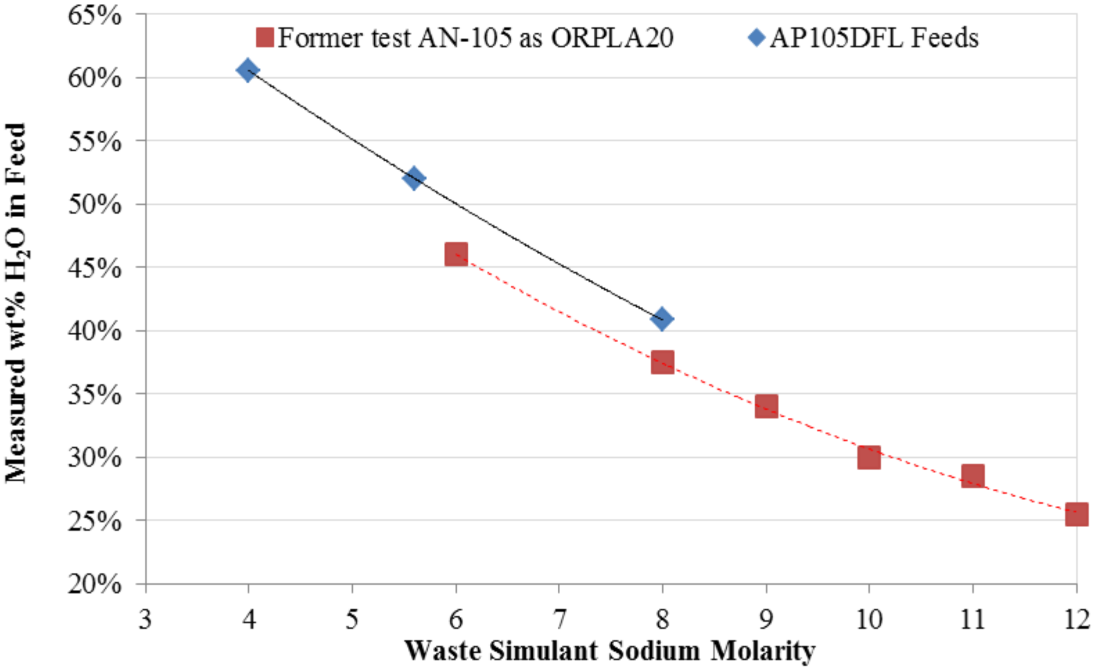

Figure 2.7. Measured water content in AP105DFL feeds as a function of sodium molarity in AP-105 simulant and comparison to formerly tested ORPLA20 feeds [12].

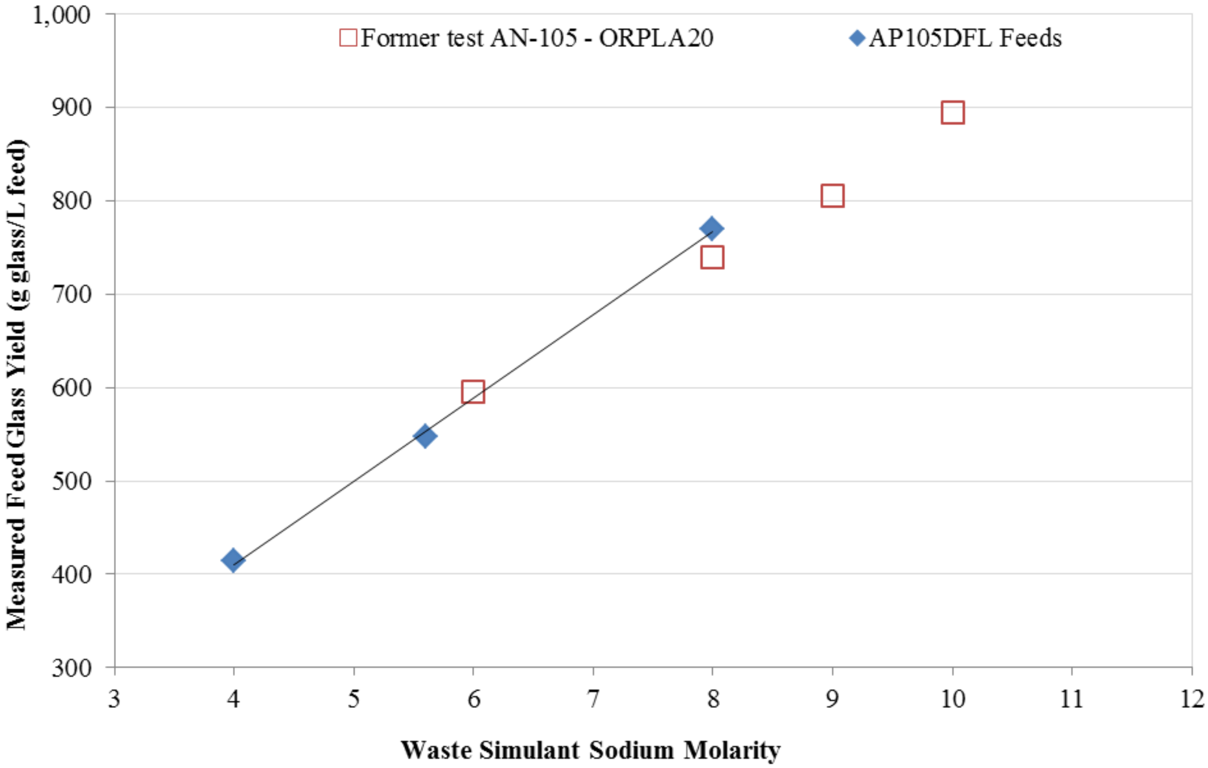

Figure 2.8. Dependence of glass yield on sodium molarity of AP-105 simulant and comparison to formerly tested ORPLA20 feeds [12].

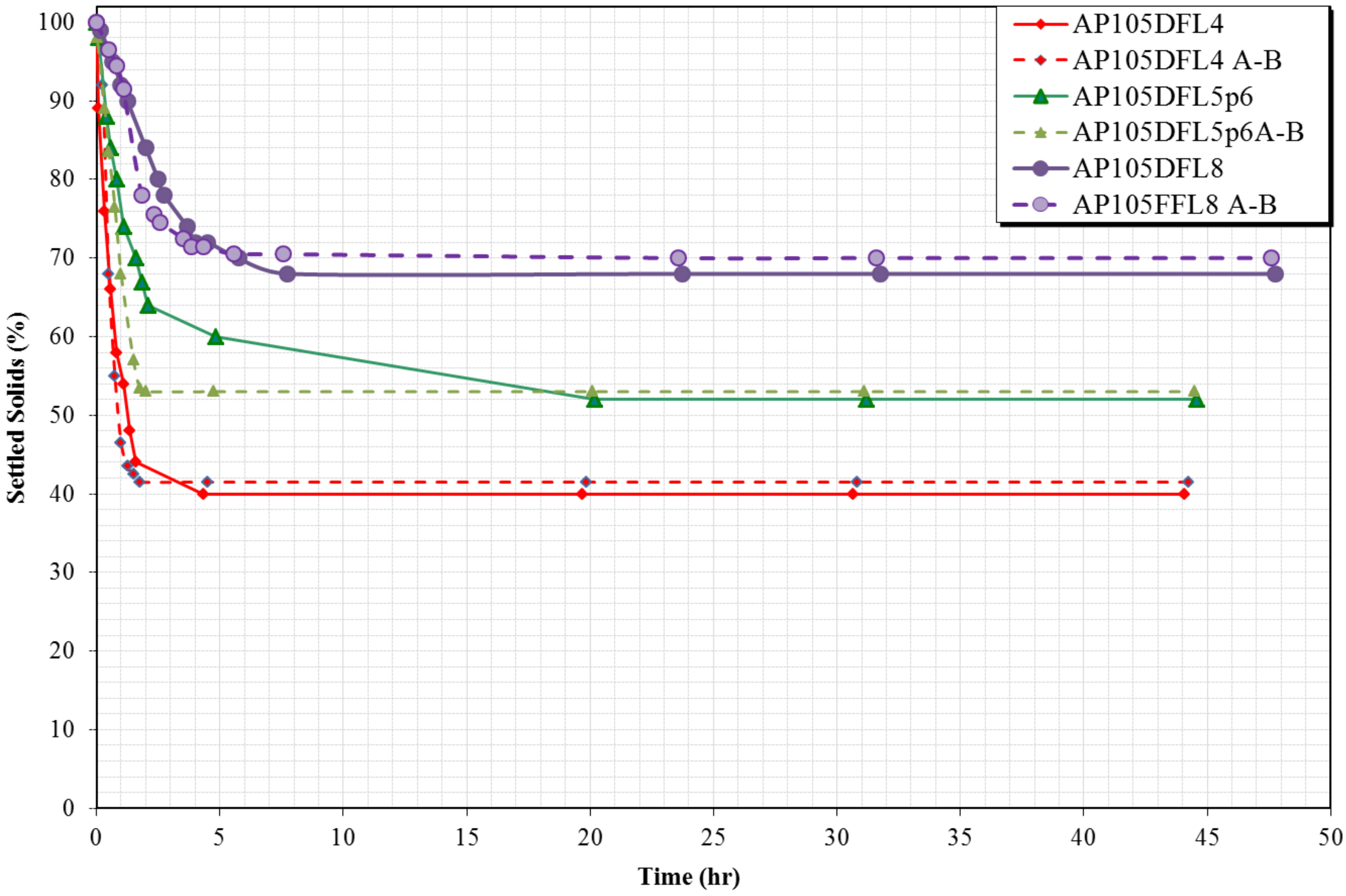

Figure 2.9. Settling rate curves for AP105DF feeds at various concentrations after 1-day aging (data noted A-B is the average of duplicate Imhoff tubes testing).

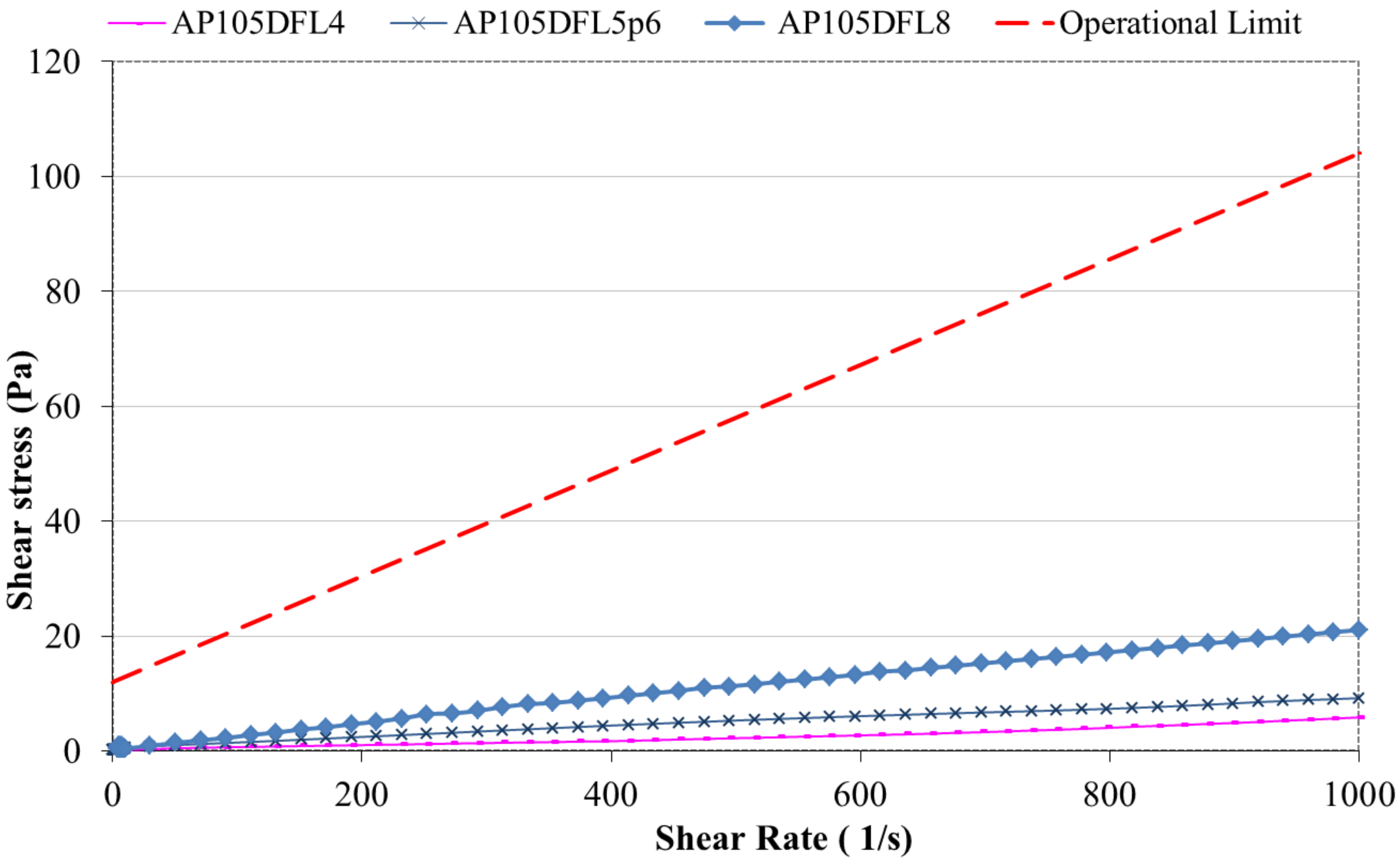

Figure 2.10. Plot of shear stress versus shear rate for the three AP105DFL feeds compared to the WTP operational limits for LAW feeds [84].

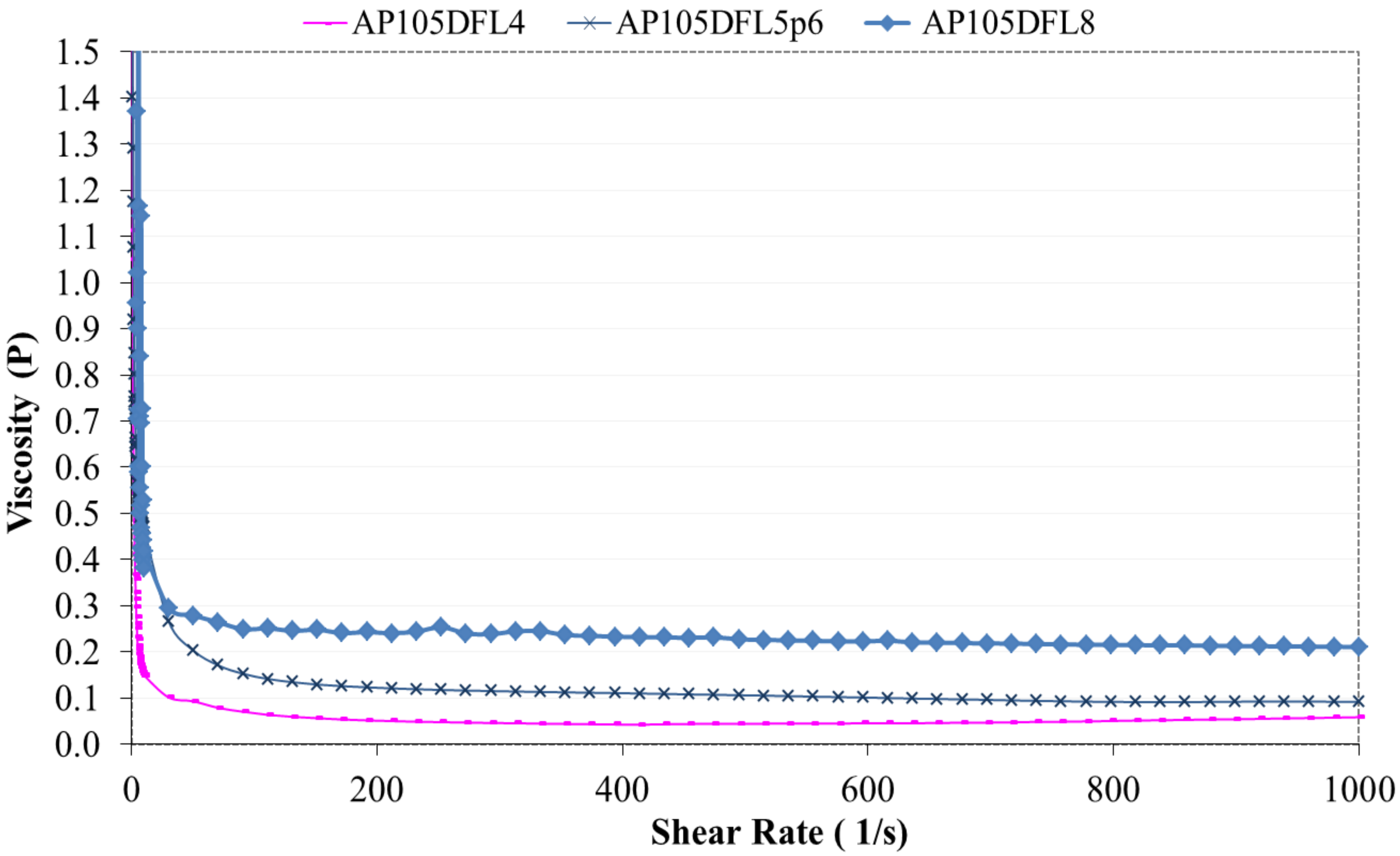

Figure 2.11. Plot of viscosity versus shear rate for AP105DFL feeds.

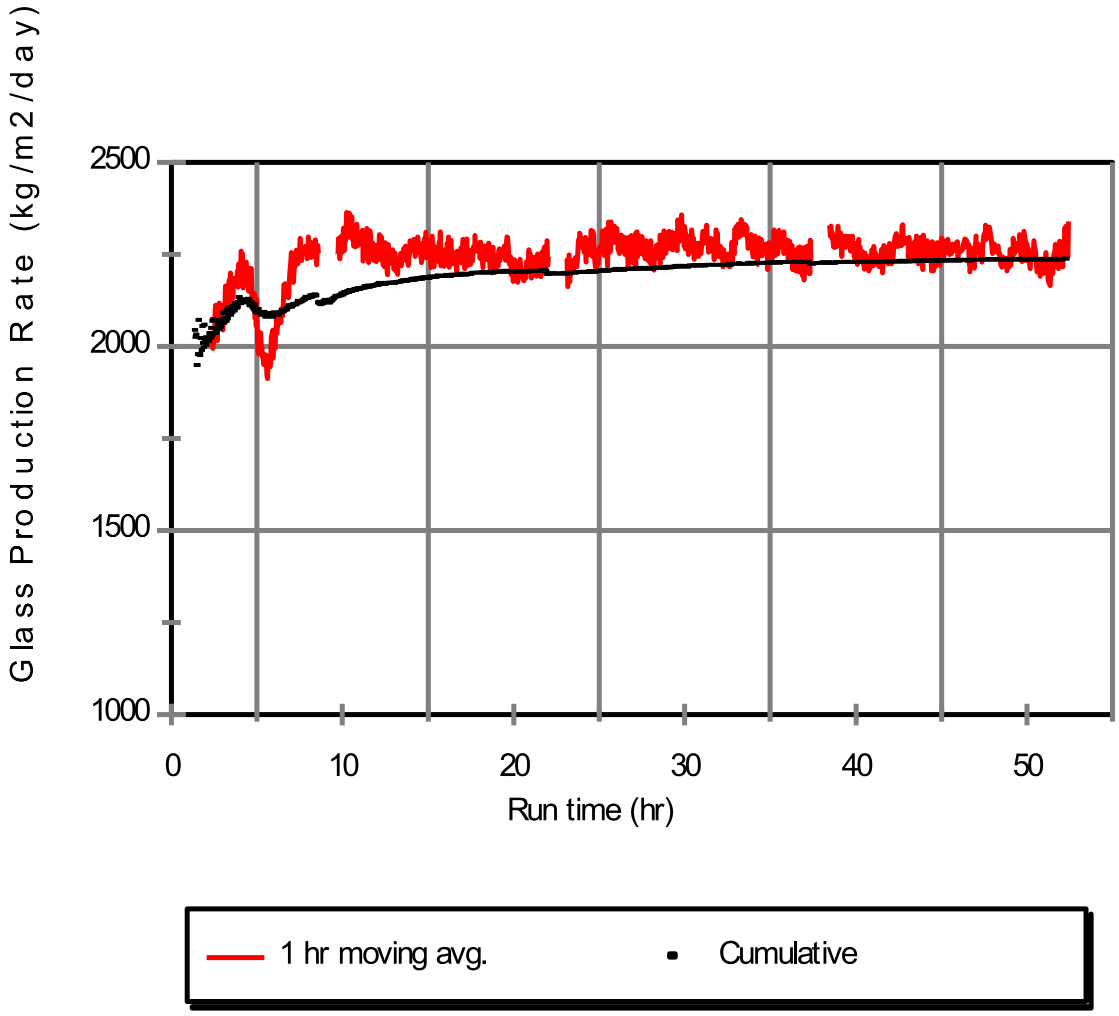

Figure 3.1.a. Glass production rates during DM100 tests with 8 M Na simulant.

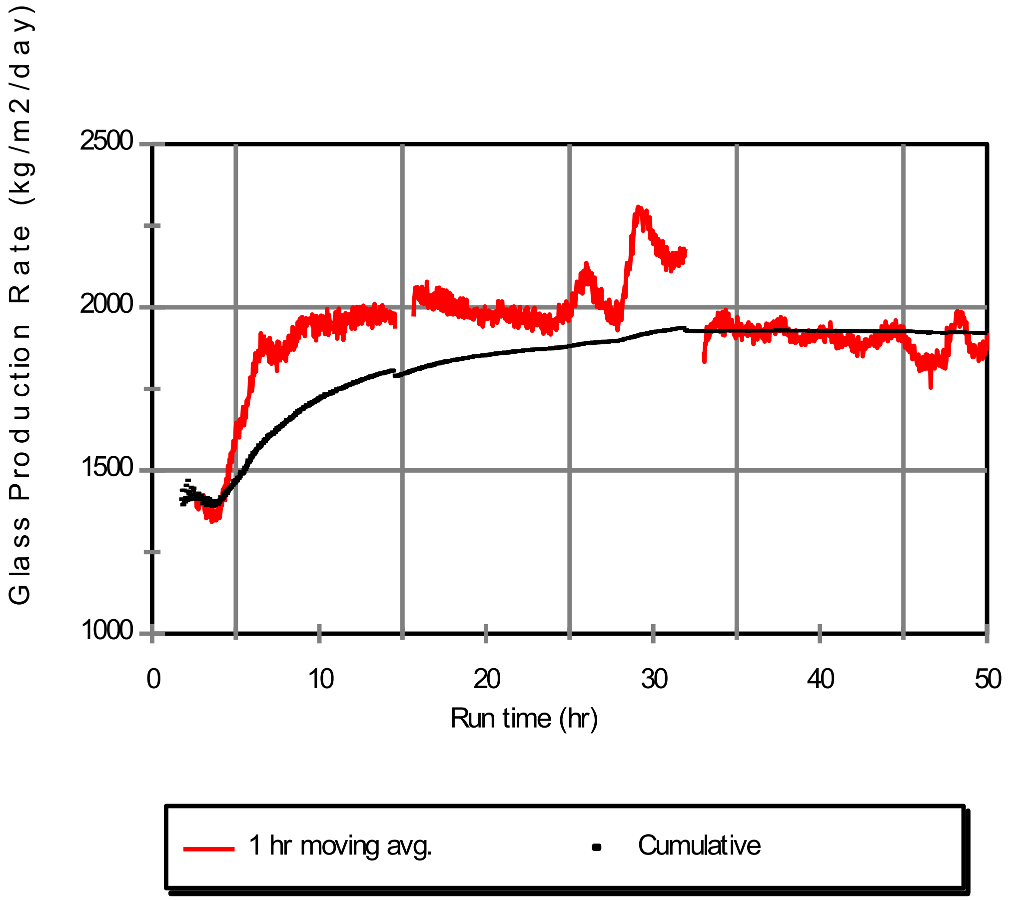

Figure 3.1.b. Glass production rates during DM100 tests with 5.6 M Na simulant.

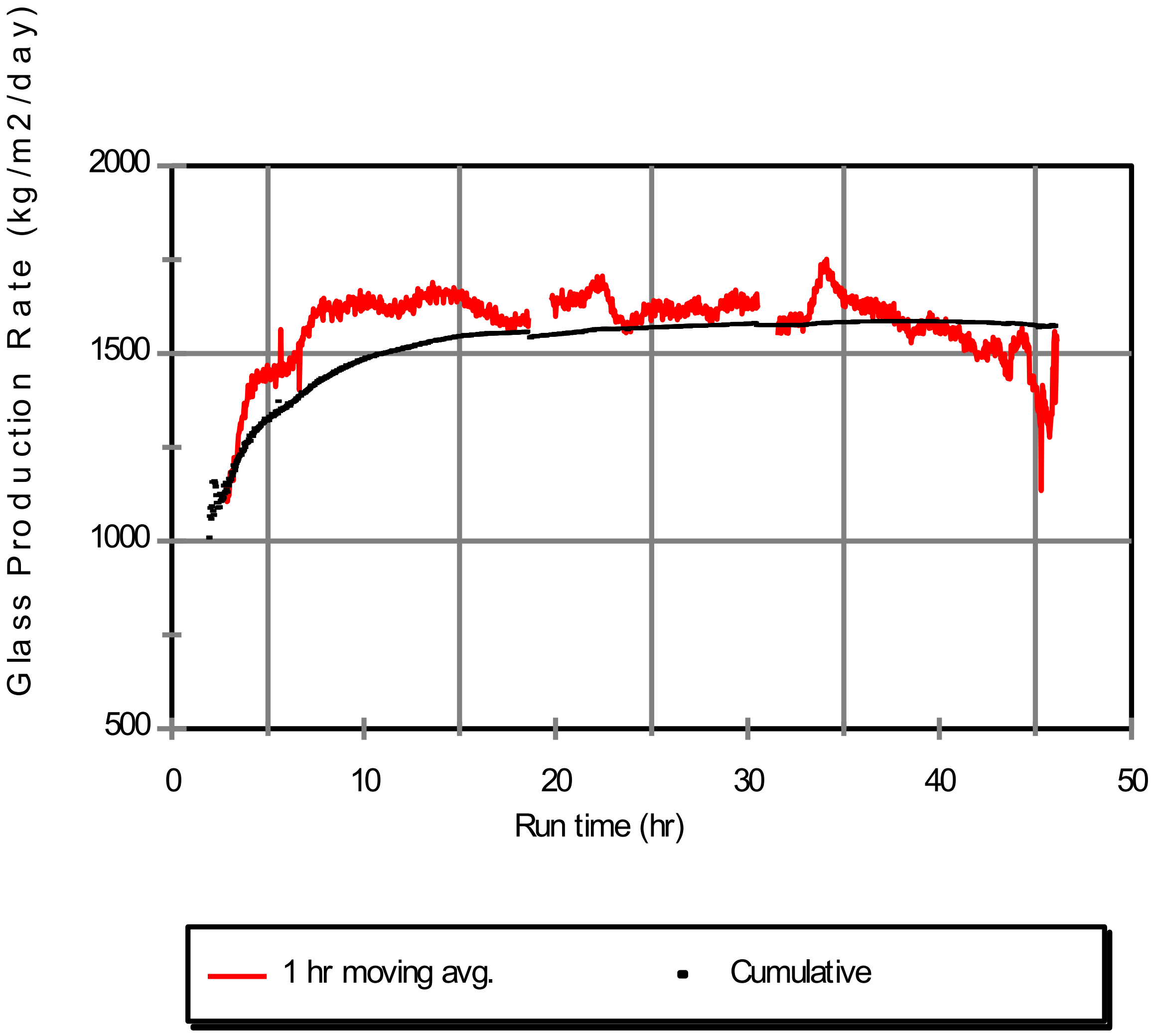

Figure 3.1.c. Glass production rates during DM100 tests with 4 M Na simulant.

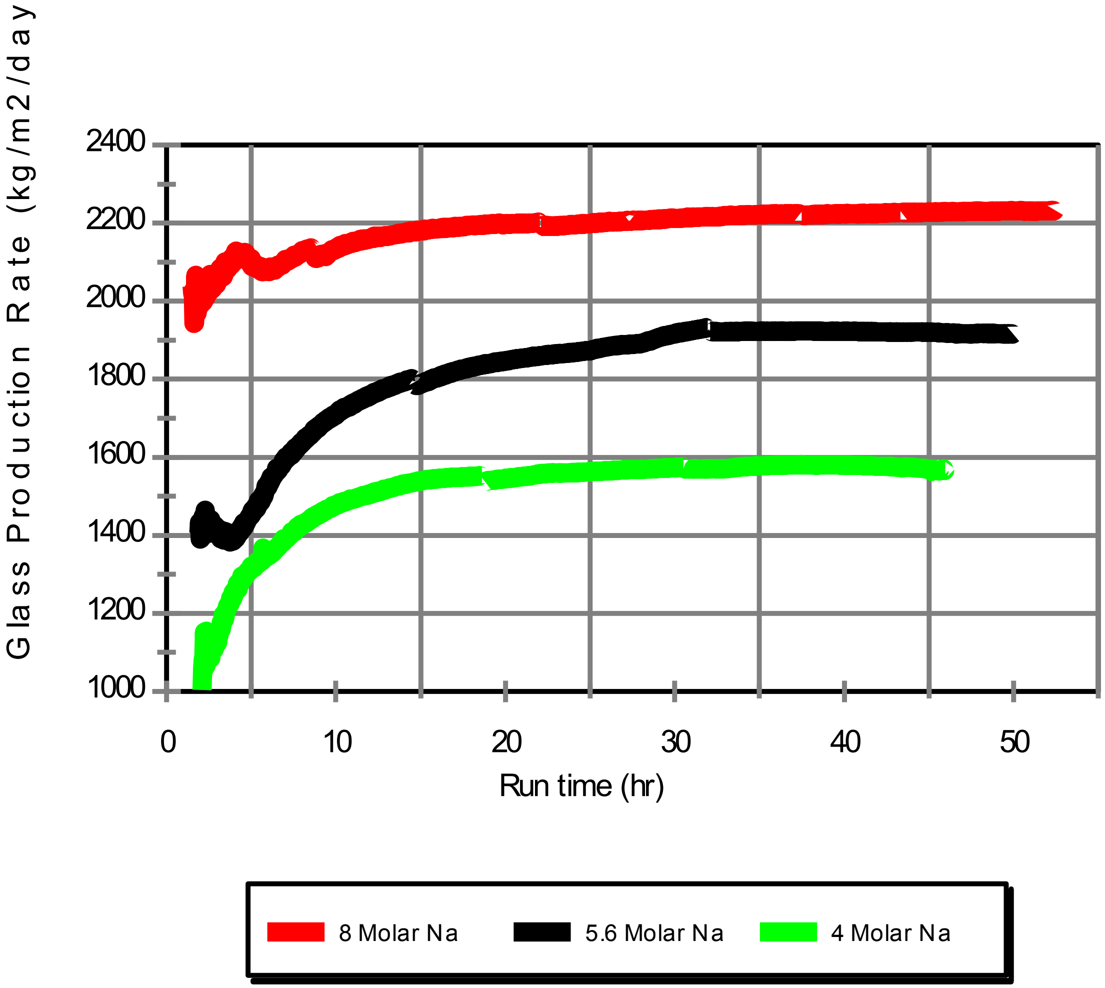

Figure 3.1.d. Cumulative glass production rates during DM100 tests.

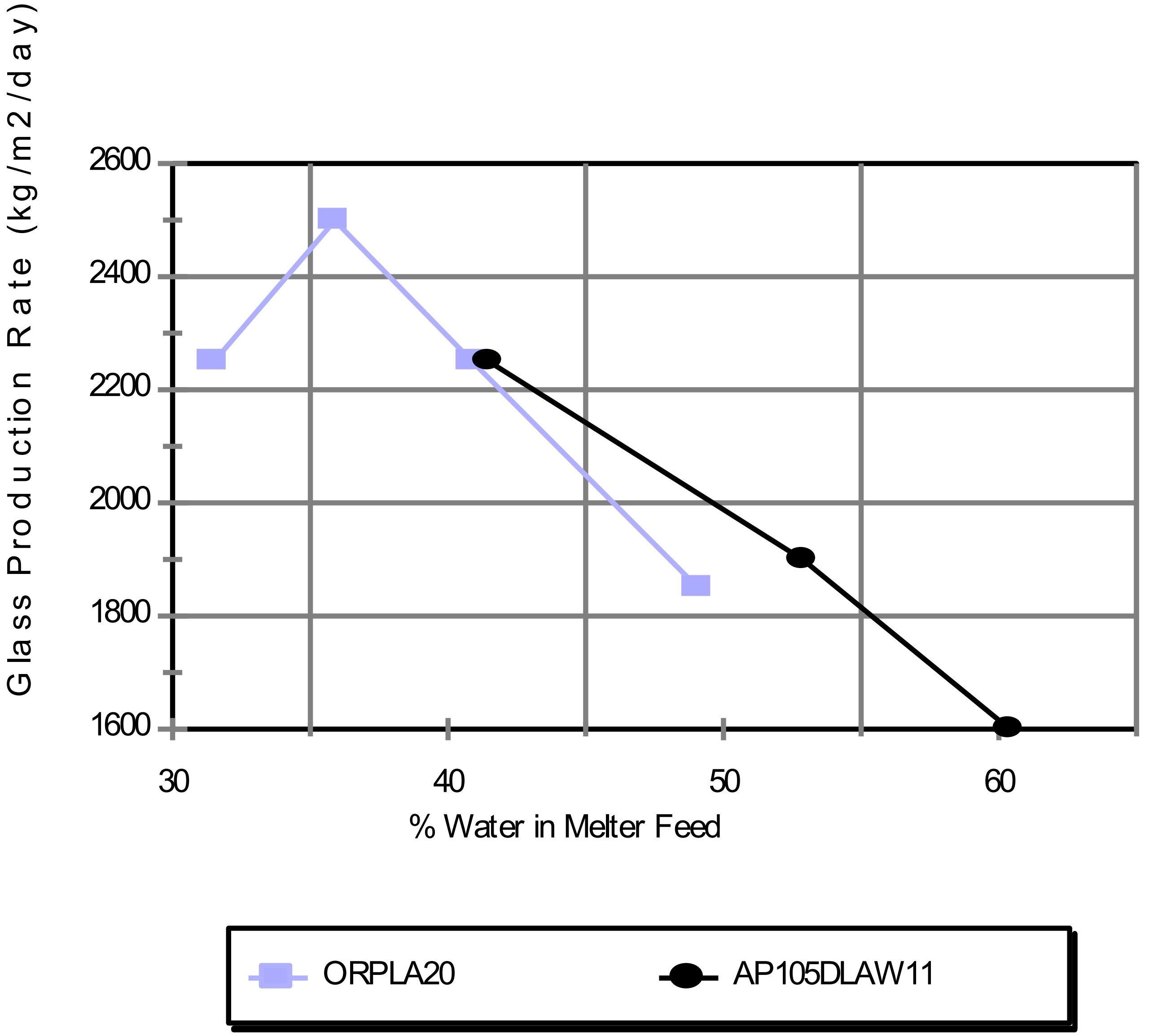

Figure 3.1.e. Steady state glass production rates during current and previous [12] DM100 tests at variable feed water contents.

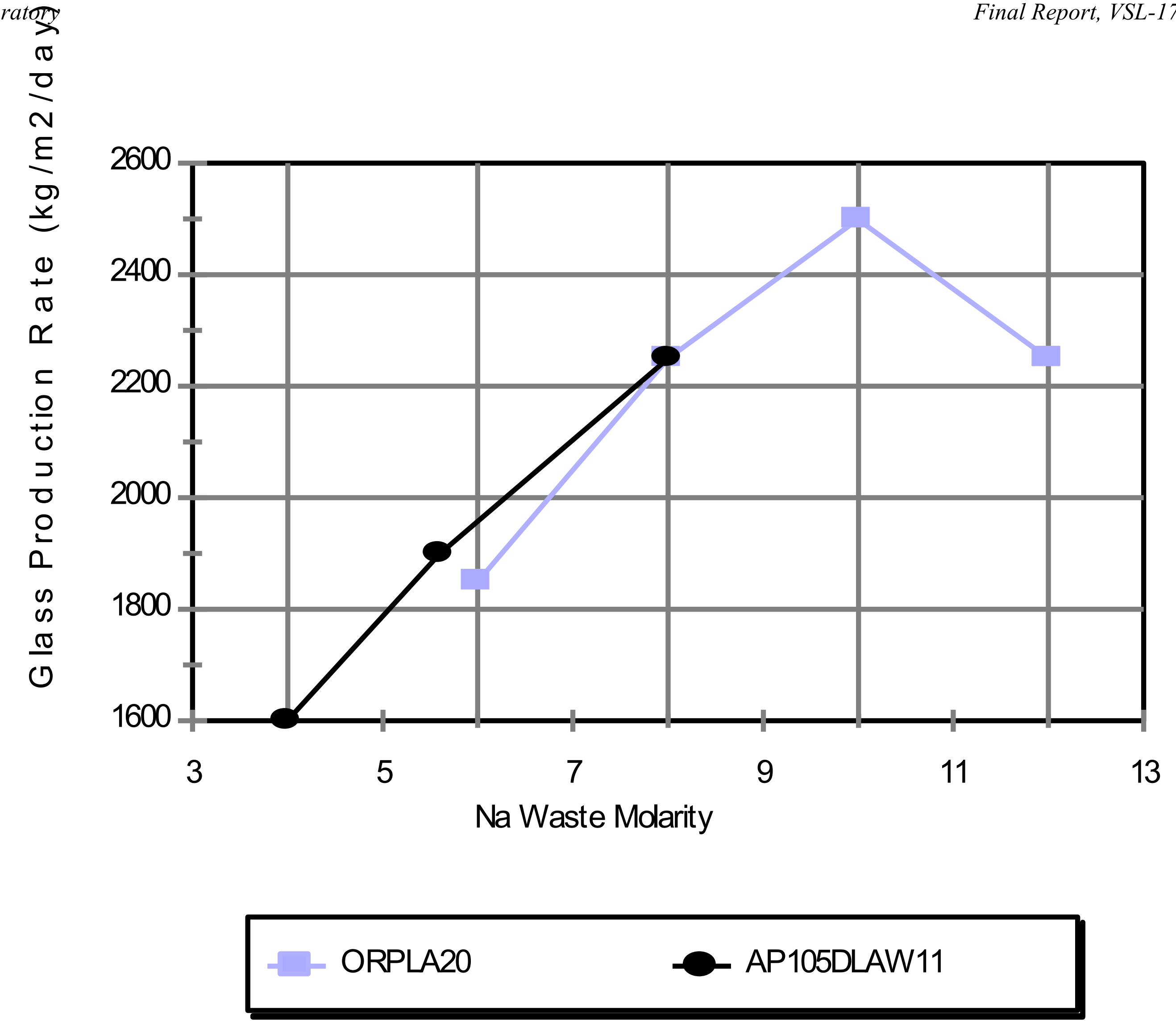

Figure 3.1.f. Steady state glass production rates during current and previous [12] DM100 tests at variable Na waste concentrations.

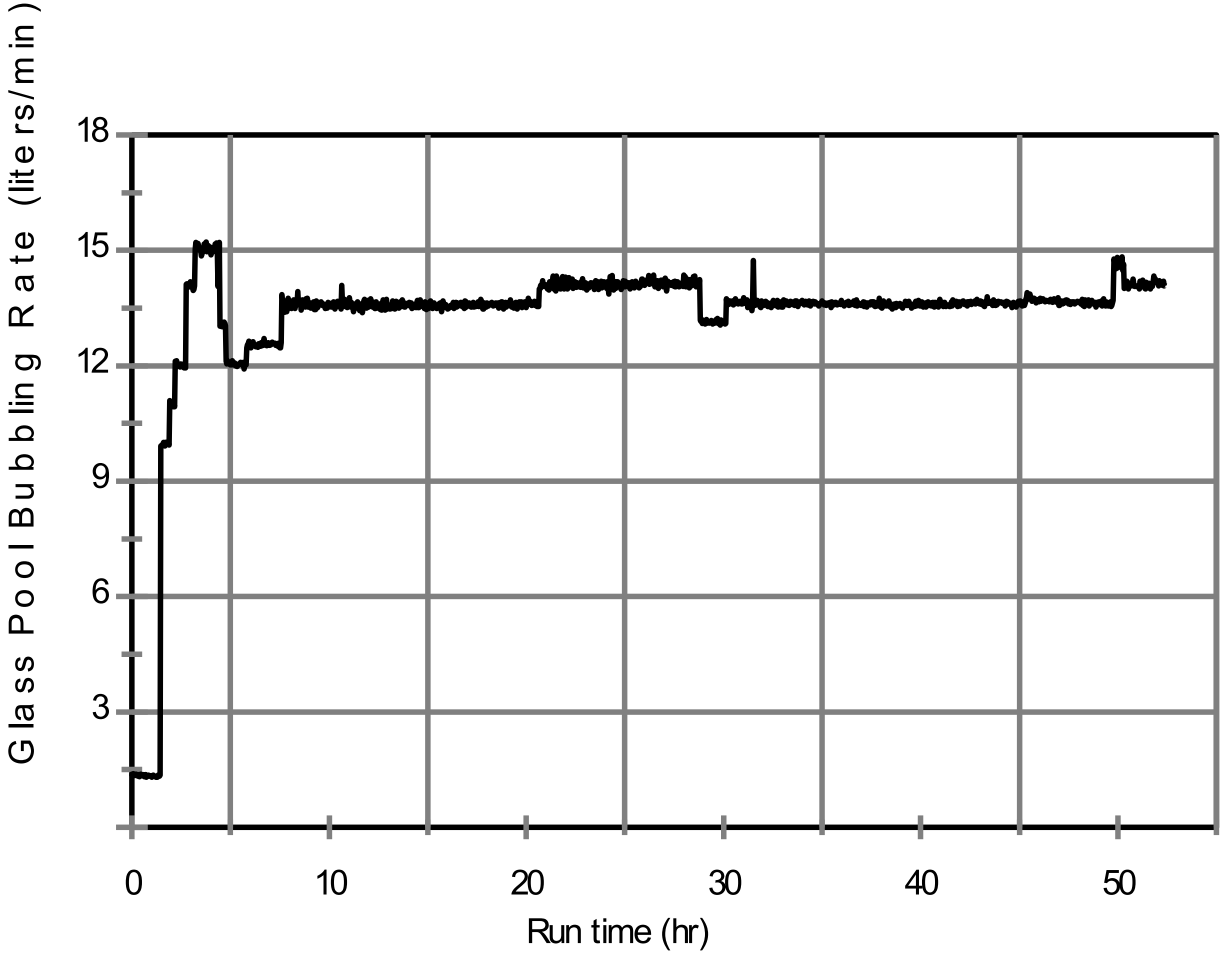

Figure 3.2.a. Glass pool bubbling during DM100 tests with 8 M Na simulant.

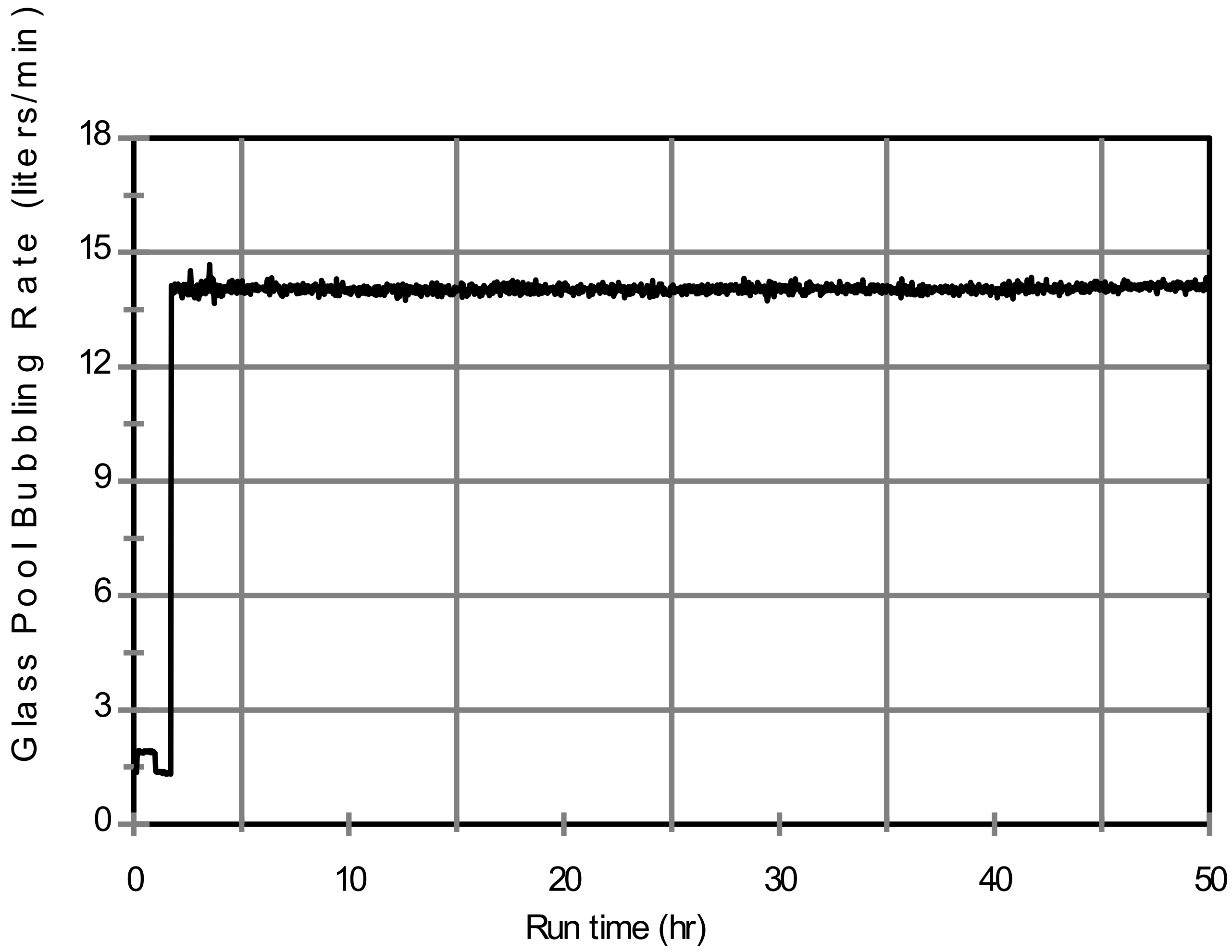

Figure 3.2.b. Glass pool bubbling during DM100 tests with 5.6 M Na simulant.

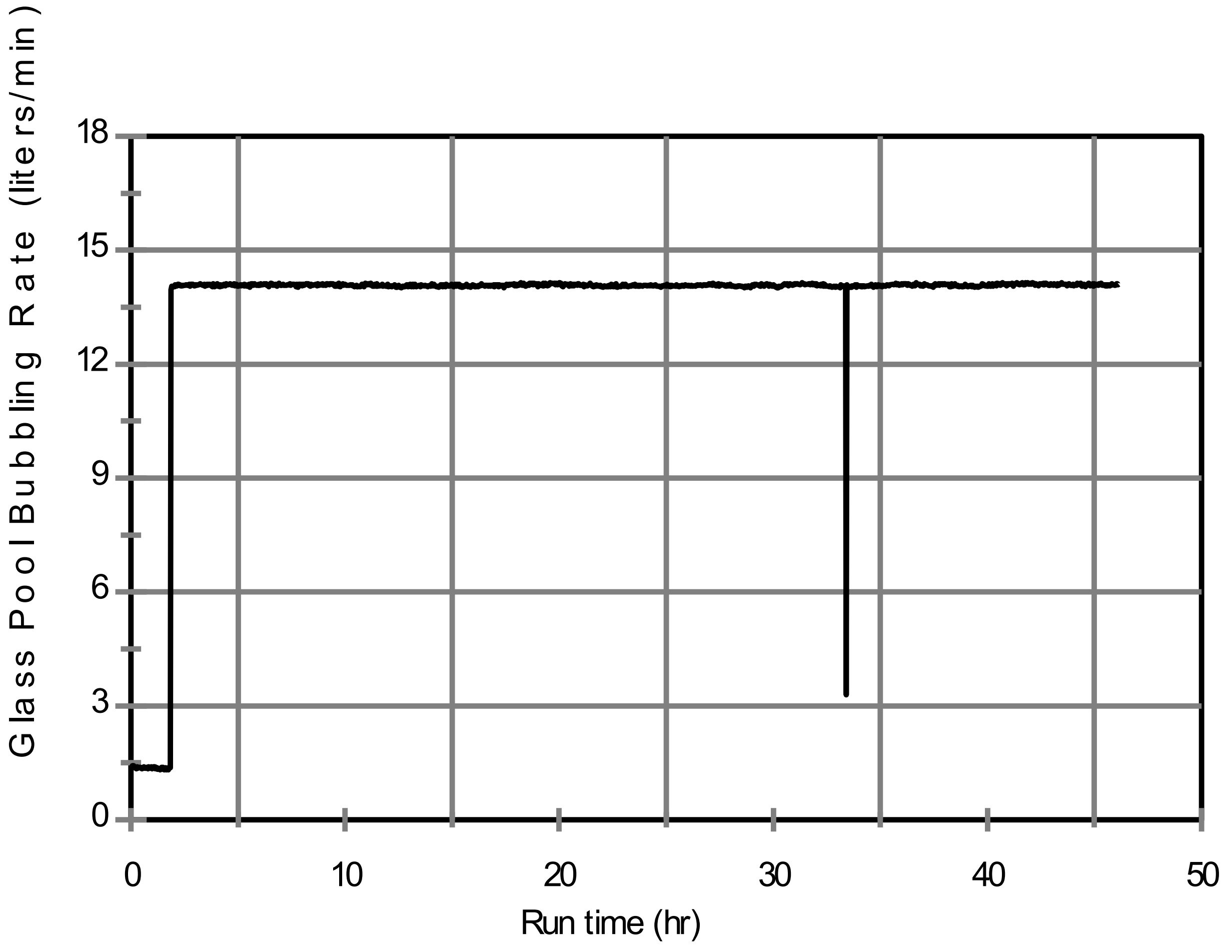

Figure 3.2.c. Glass pool bubbling during DM100 tests with 4 M Na simulant.

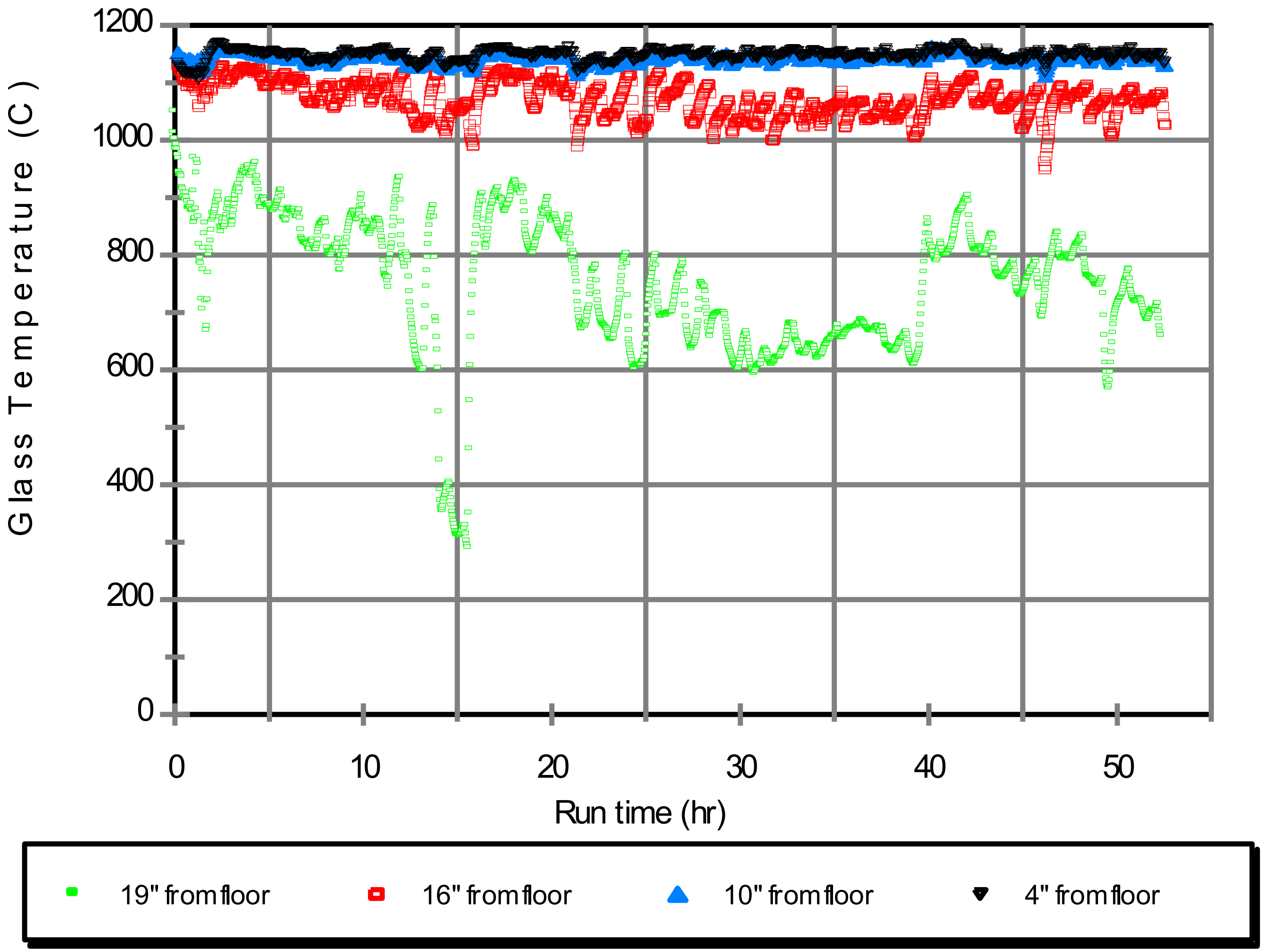

Figure 3.3.a. Glass temperatures during DM100 tests with 8 M Na simulant.

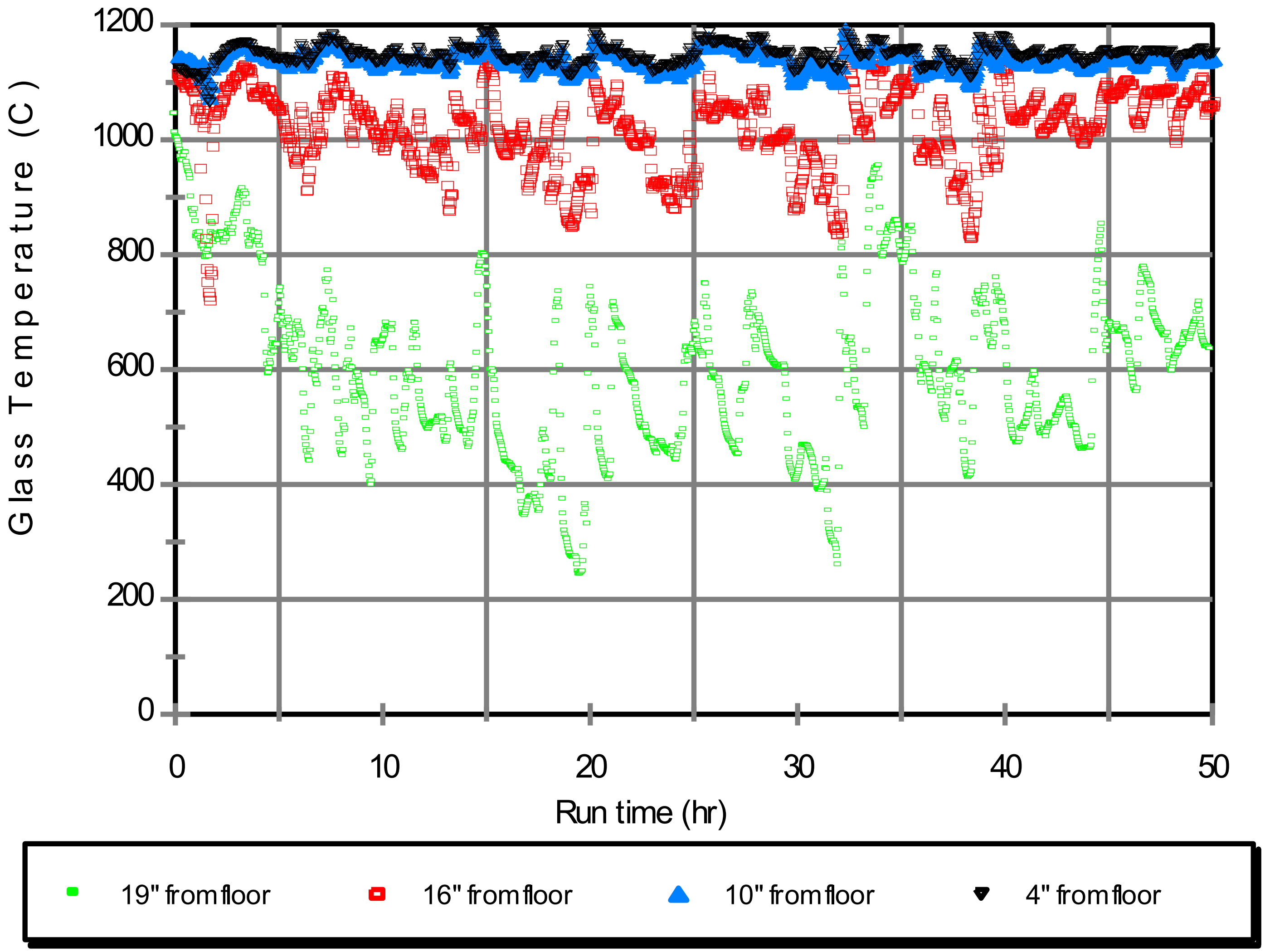

Figure 3.3.b. Glass temperatures during DM100 tests with 5.6 M Na simulant.

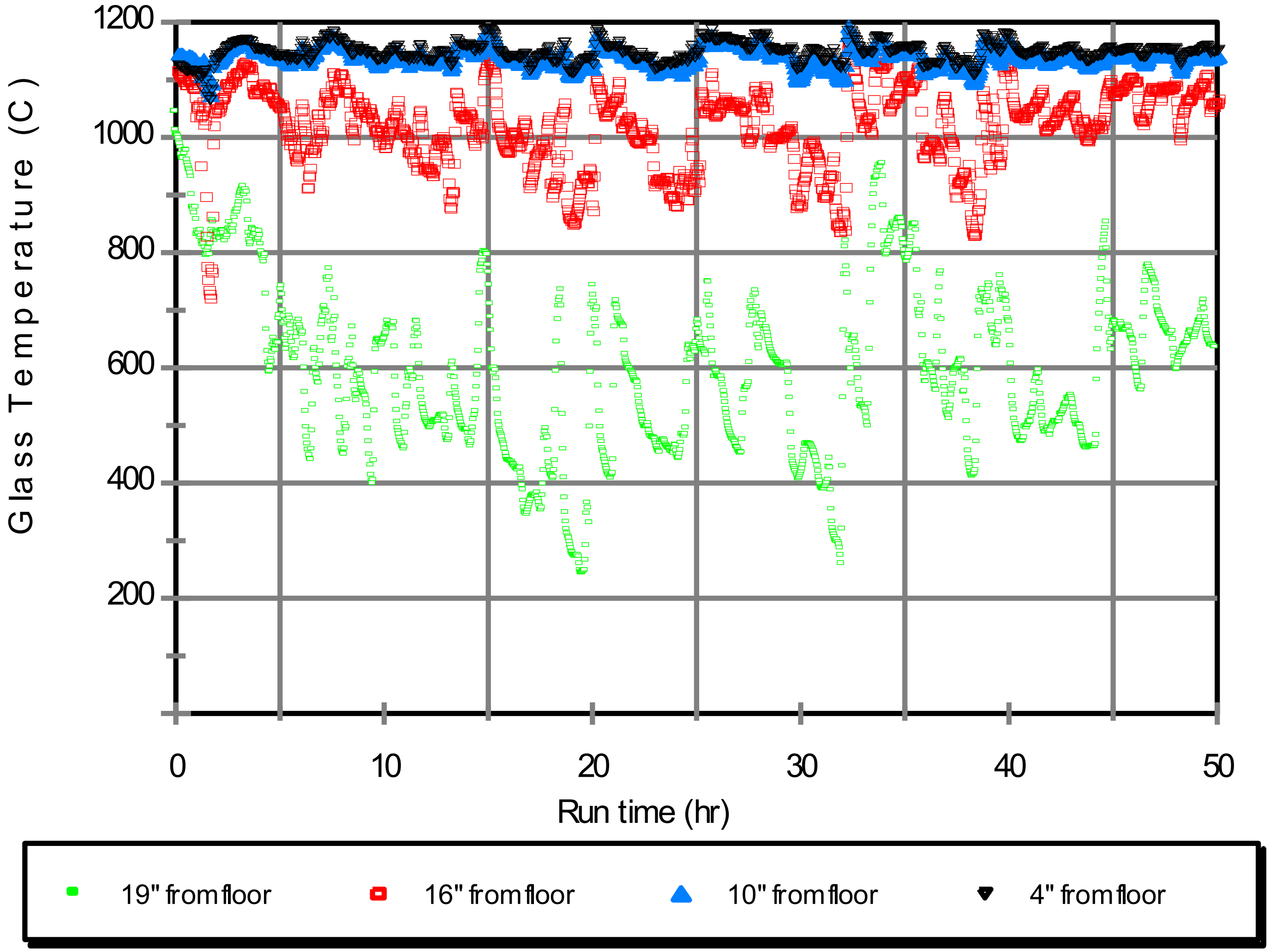

Figure 3.3.c. Glass temperatures during DM100 tests with 4 M Na simulant.

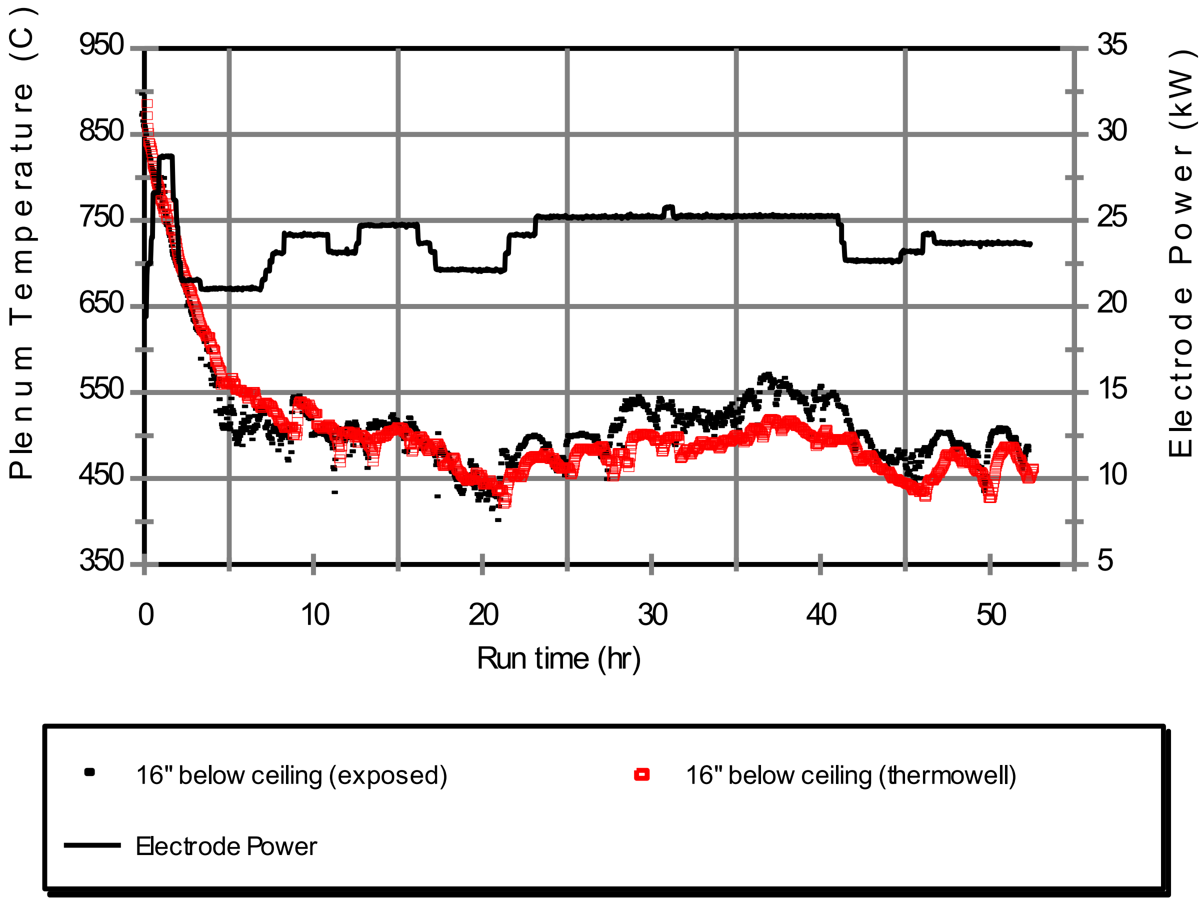

Figure 3.4.a. Plenum temperatures and electrode power during DM100 tests with 8 M Na simulant.

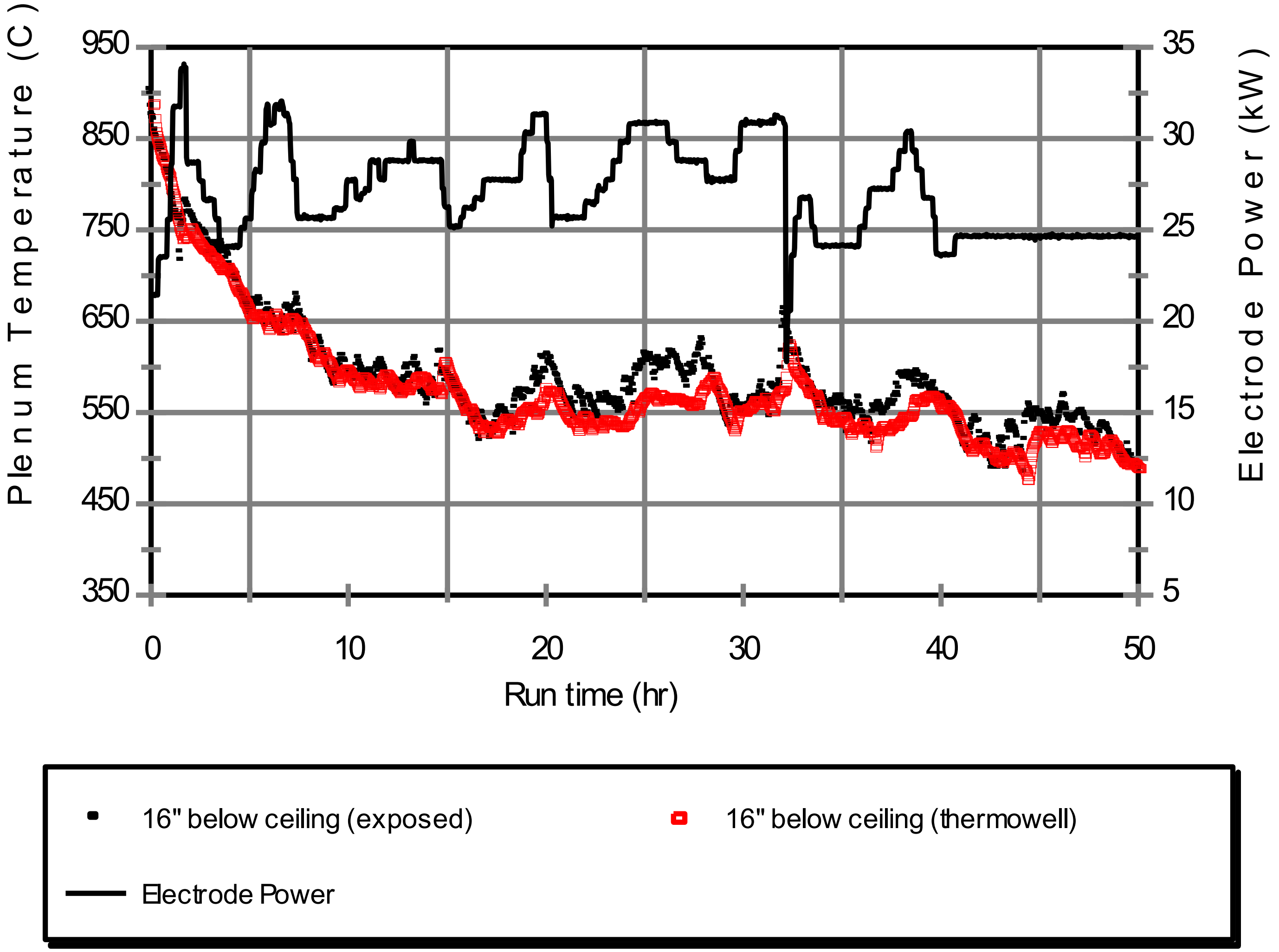

Figure 3.4.b. Plenum temperatures and electrode power during DM100 tests with 5.6 M Na simulant.

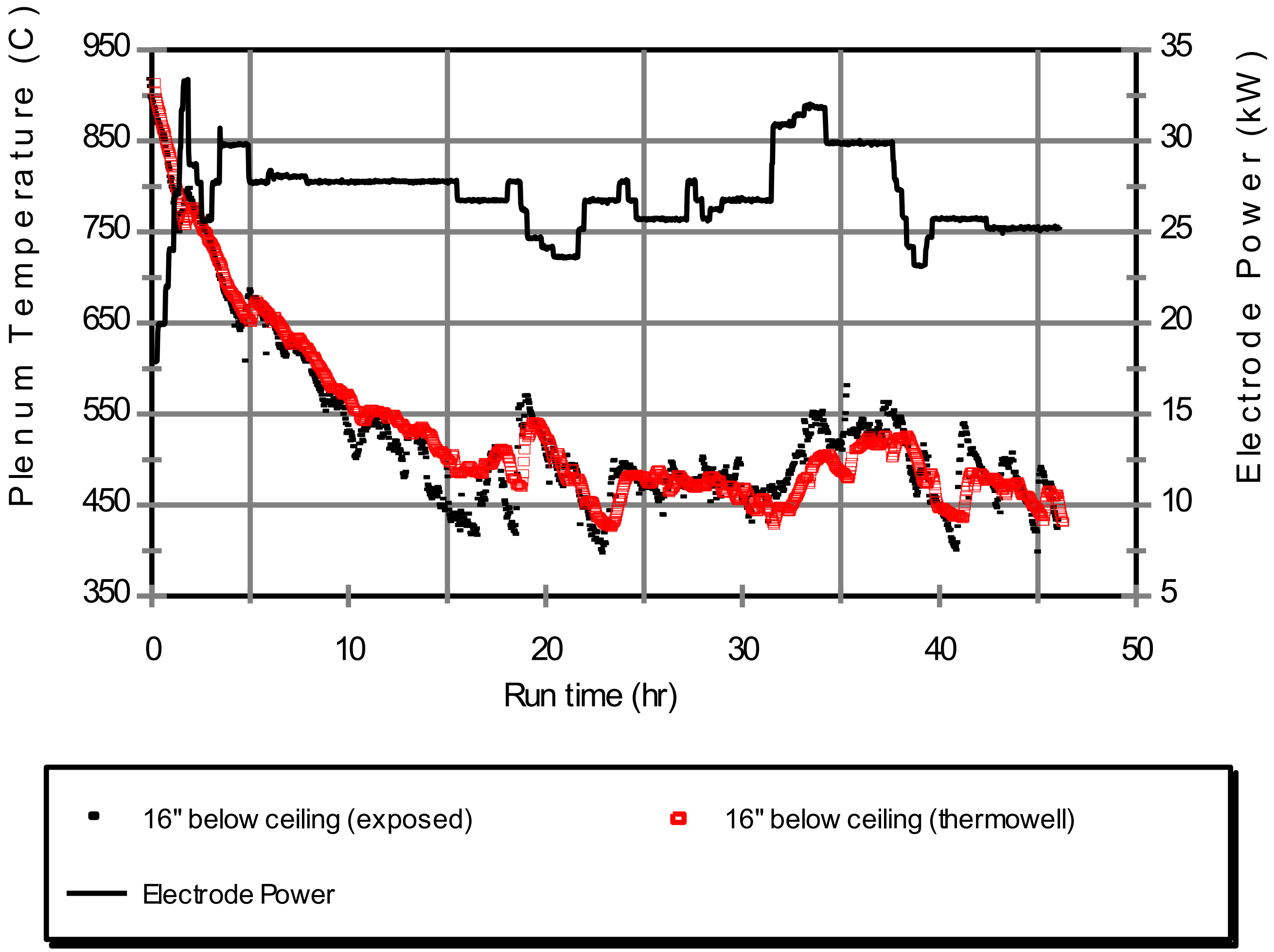

Figure 3.4.c. Plenum temperatures and electrode power during DM100 tests with 4 M Na simulant.

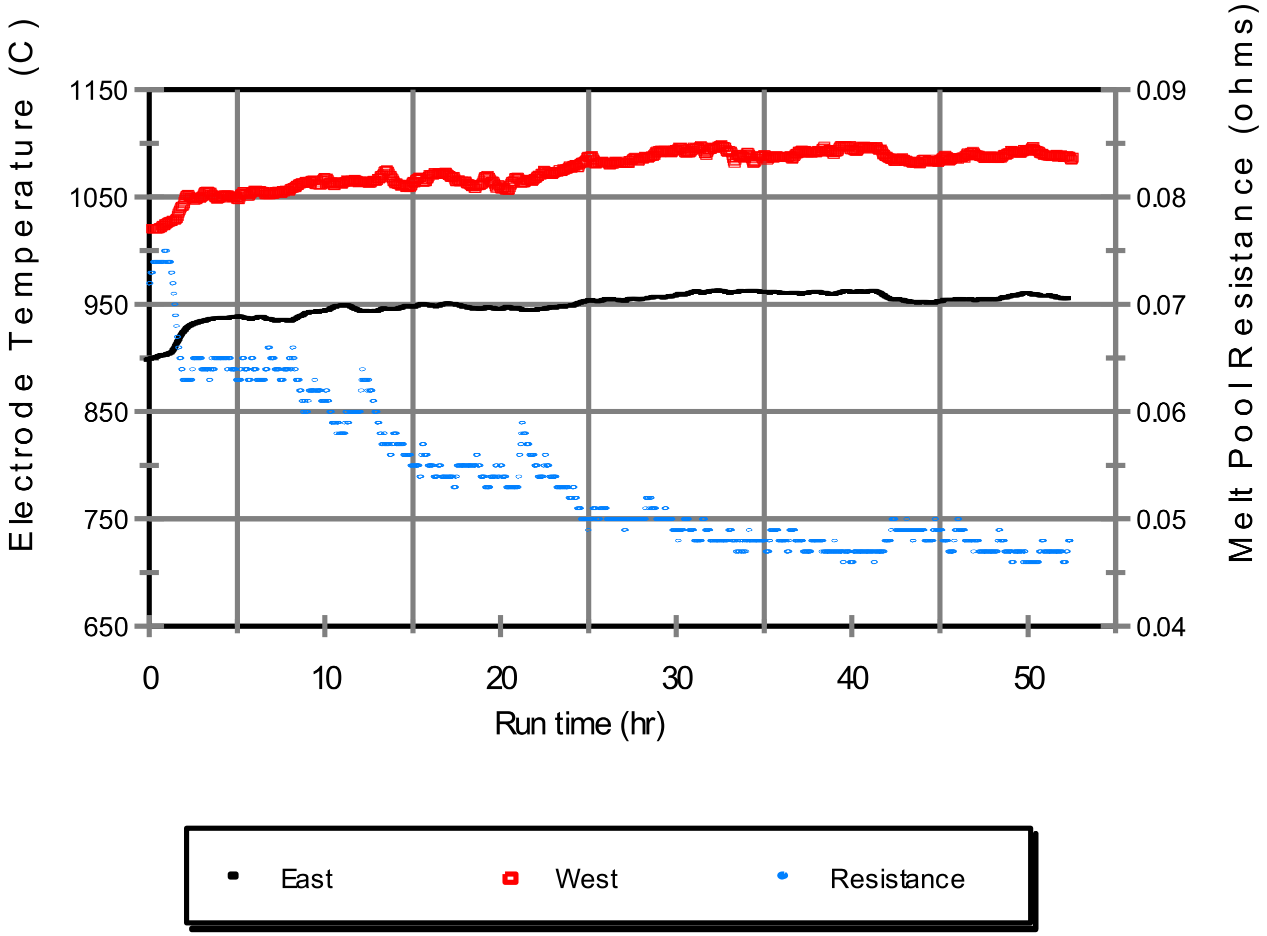

Figure 3.5.a. Electrode temperatures and melt pool resistance during DM100 tests with 8 M Na simulant.

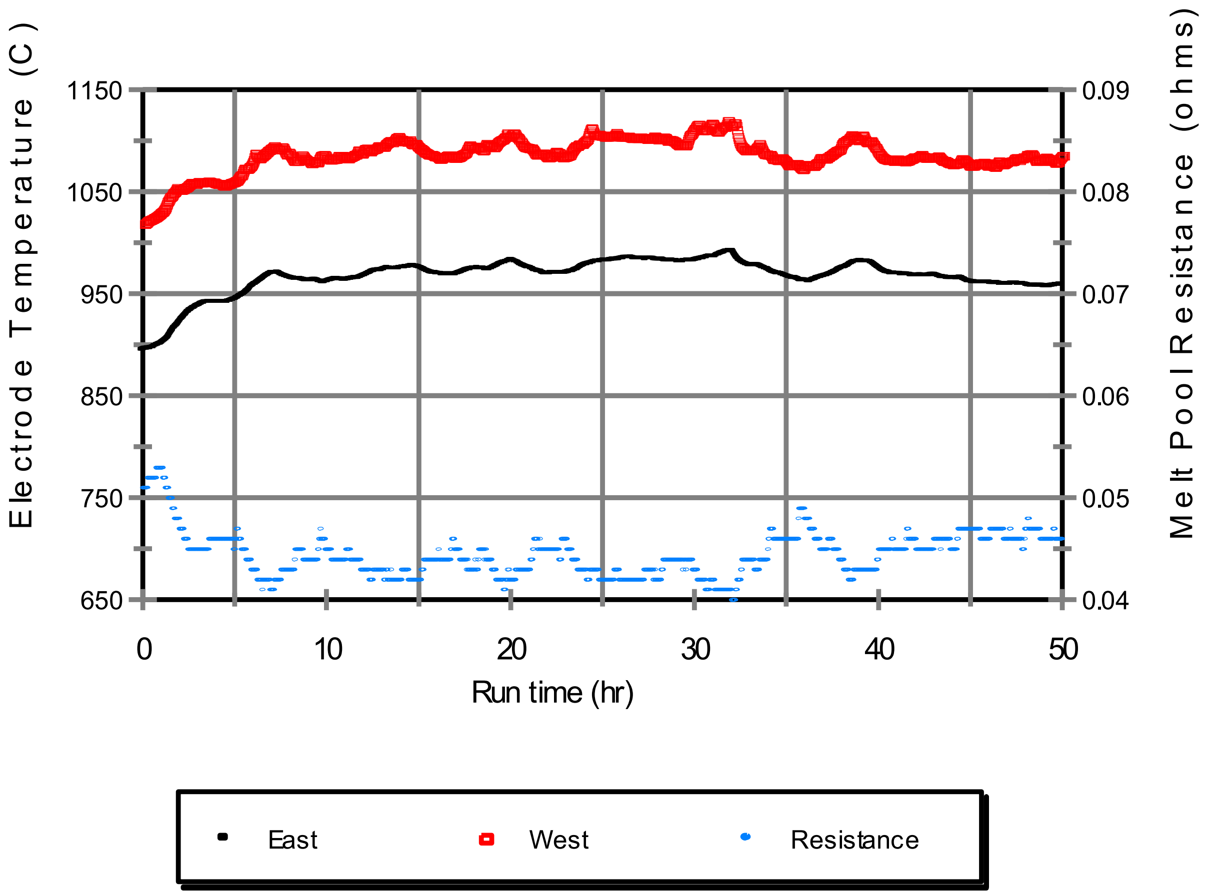

Figure 3.5.b. Electrode temperatures and melt pool resistance during DM100 tests with 5.6 M Na simulant.

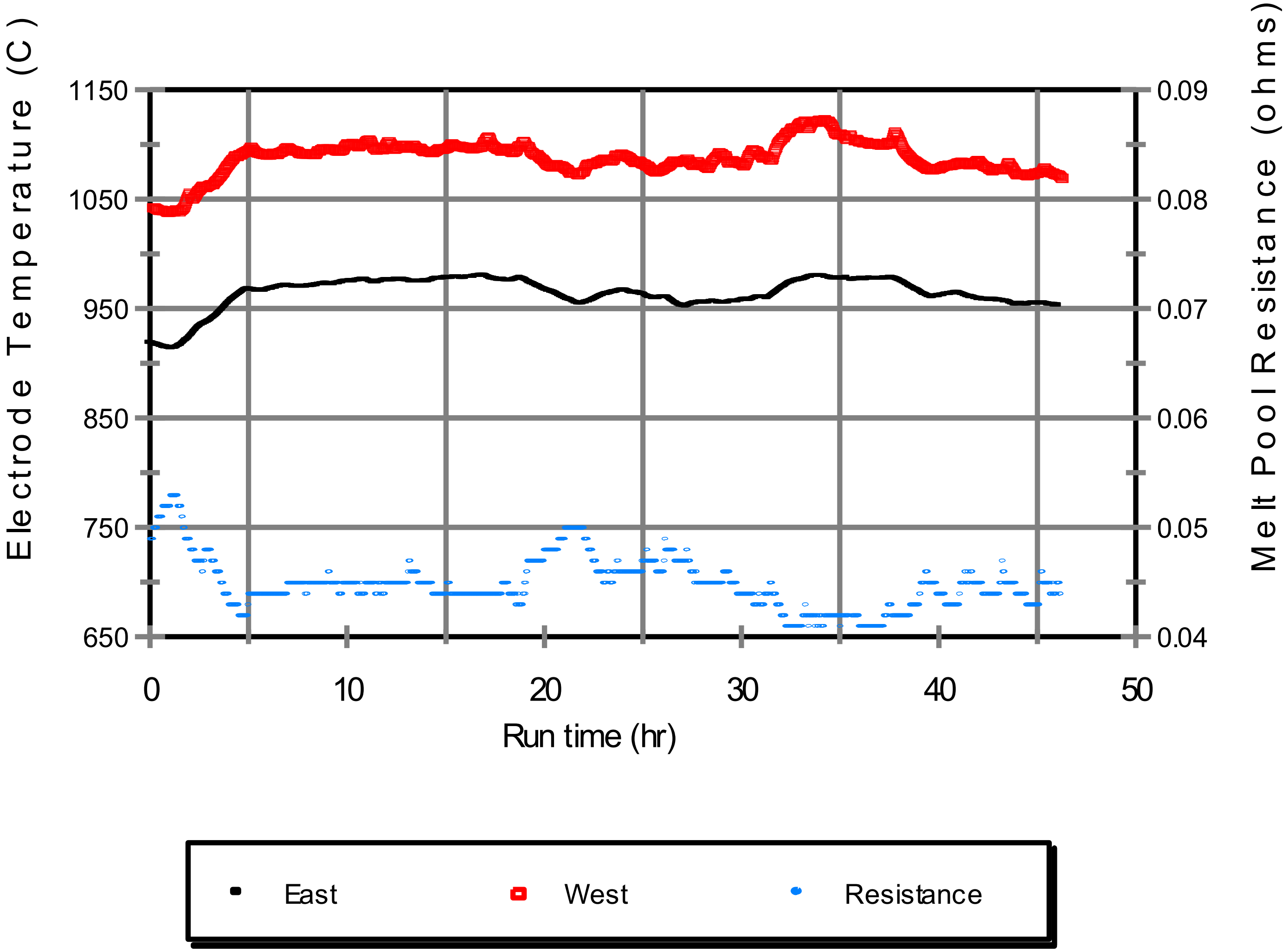

Figure 3.5.c. Electrode temperatures and melt pool resistance during DM100 tests with 4 M Na simulant.

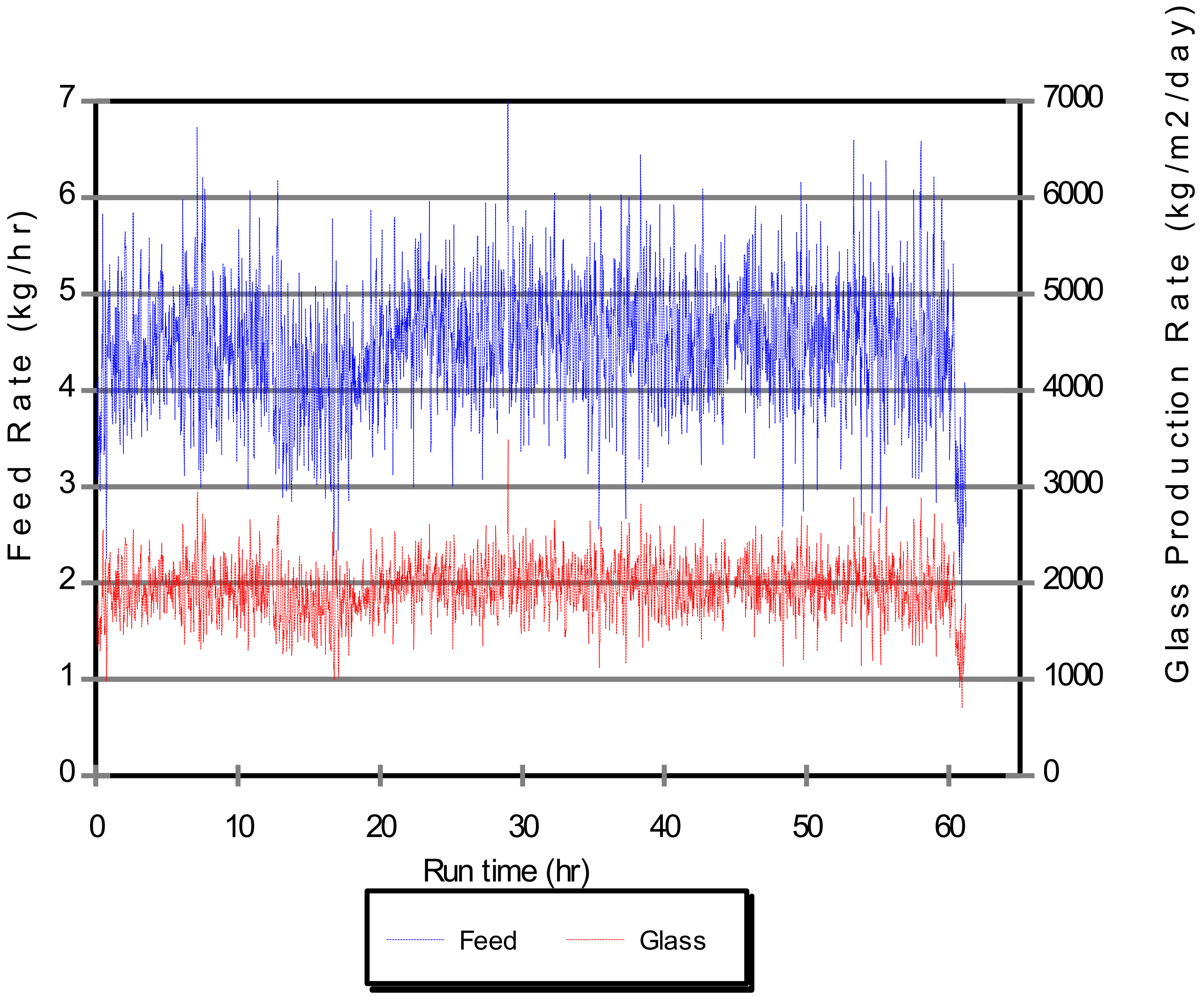

Figure 4.1. Slurry feed and glass production rates during DM10 testing.

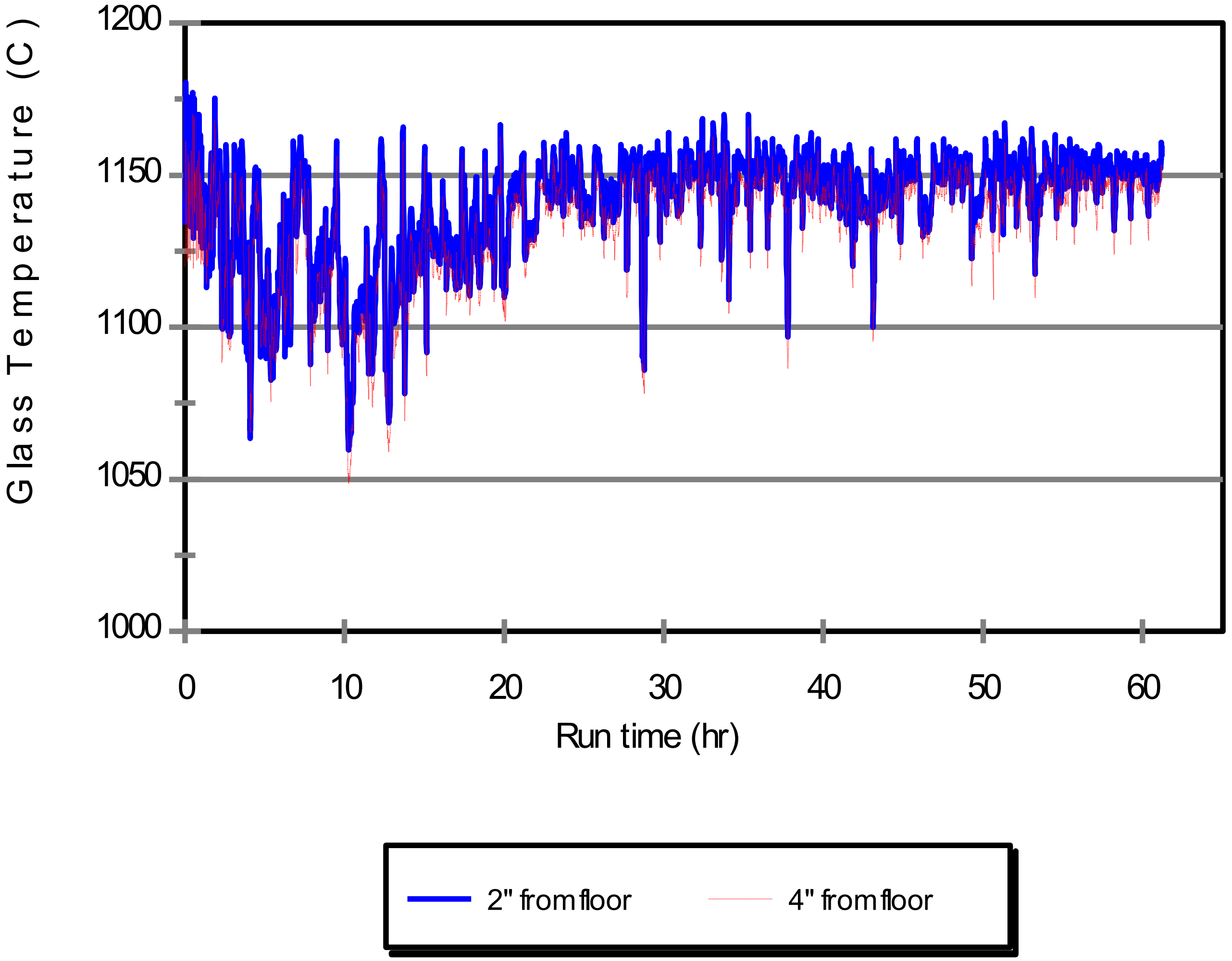

Figure 4.2. Glass pool temperatures during DM10 testing.

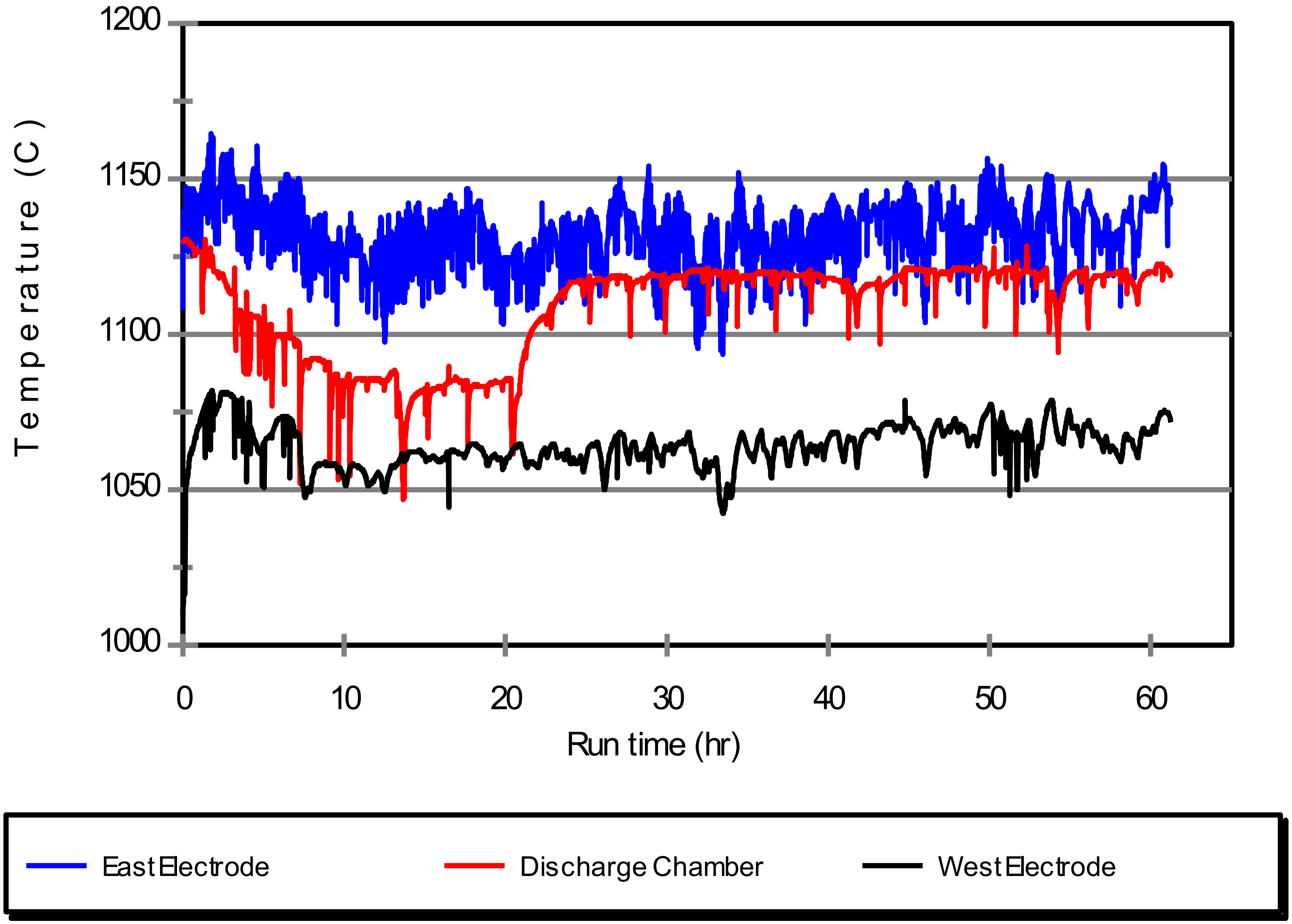

Figure 4.3. Electrode and discharge chamber temperatures during DM10 testing.

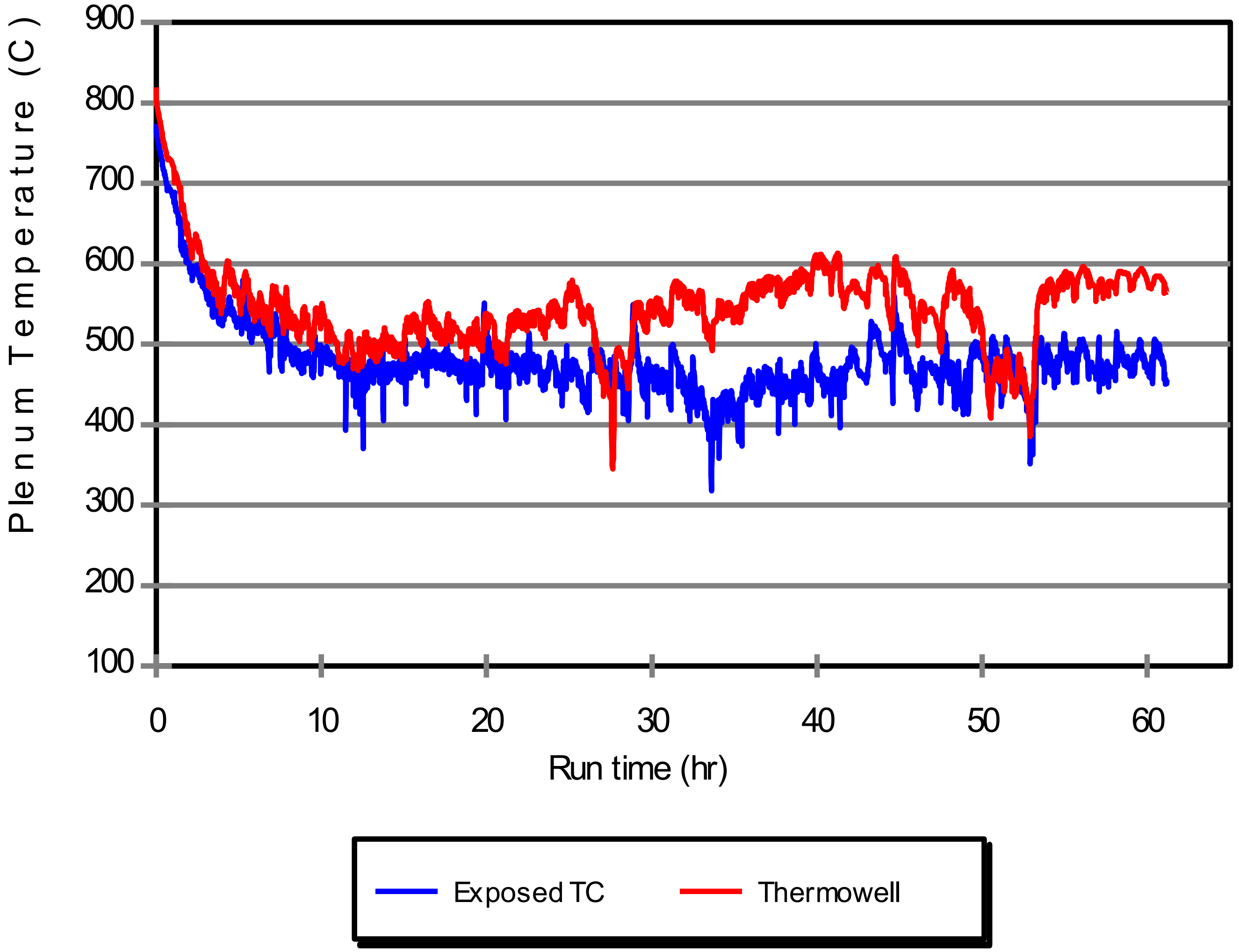

Figure 4.4. Plenum temperatures during DM10 testing.

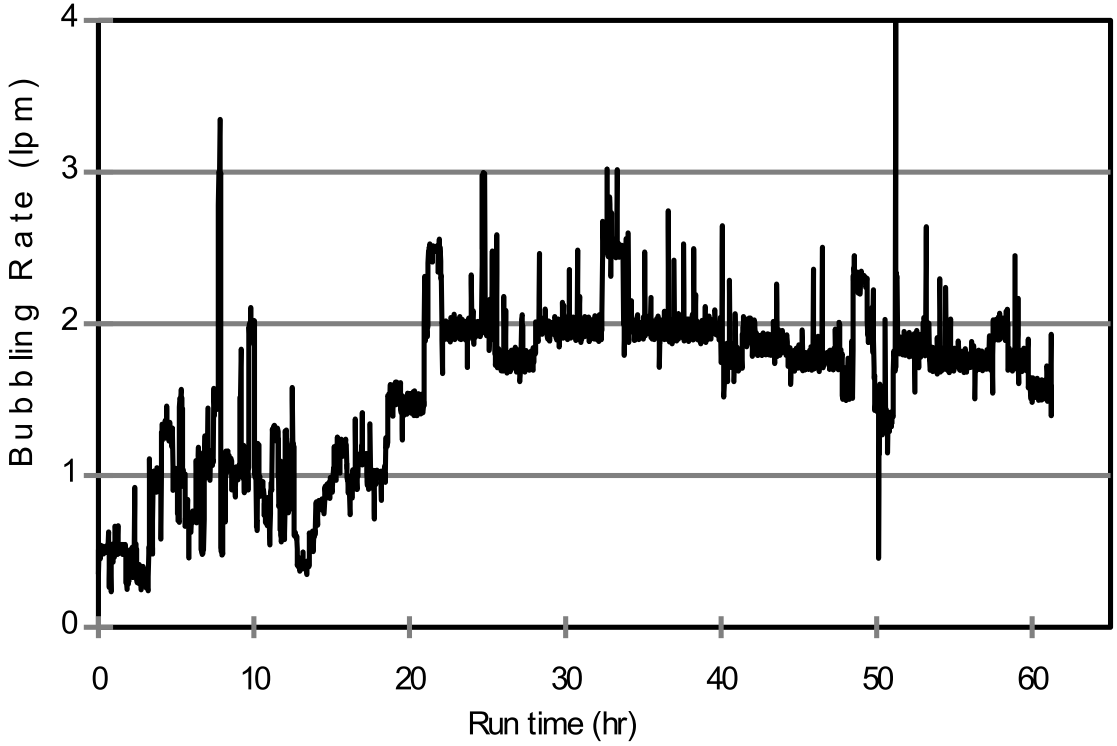

Figure 4.5. Glass pool bubbling rates during DM10 testing.

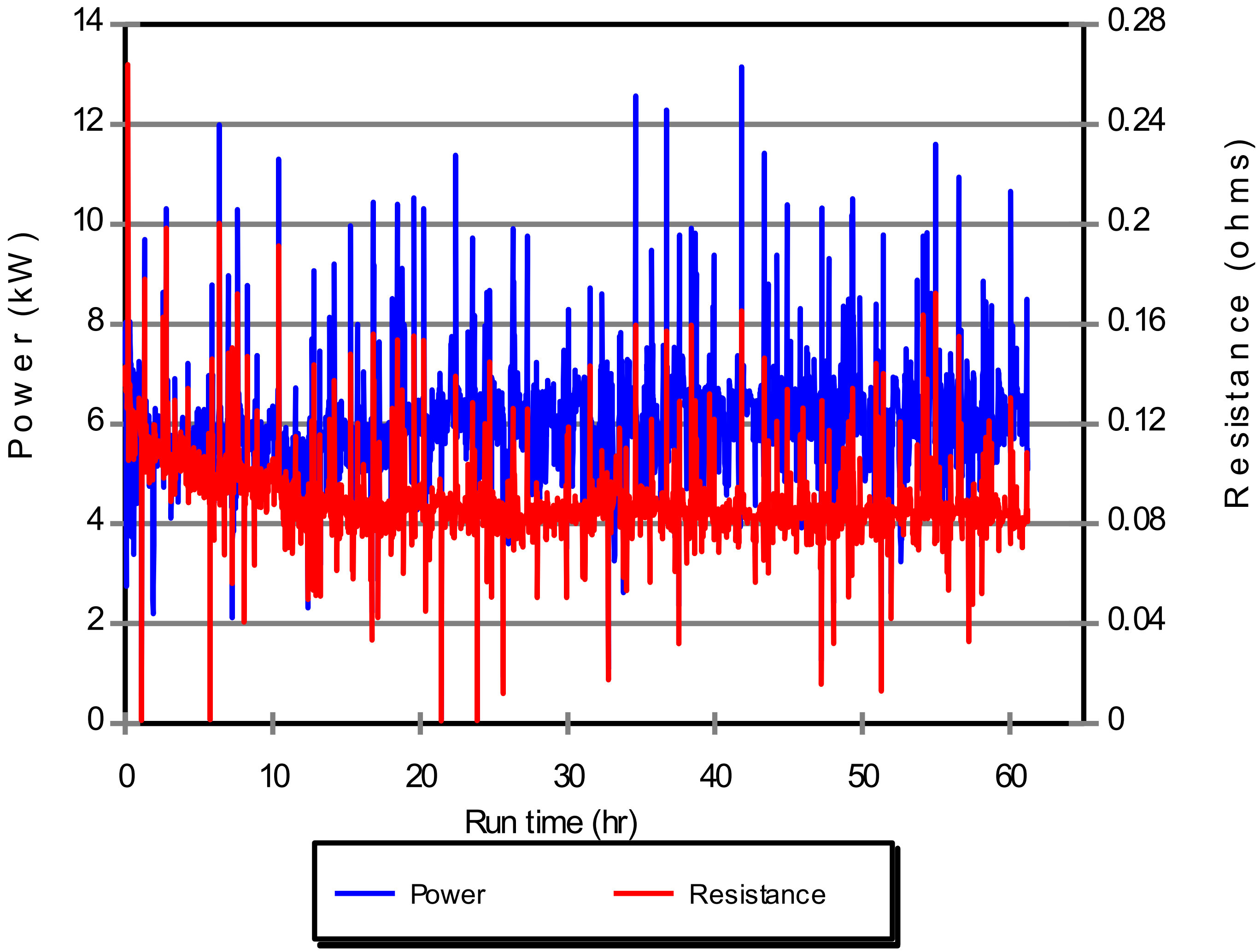

Figure 4.6. Power supplied to electrodes and melt pool resistance during DM10 testing.

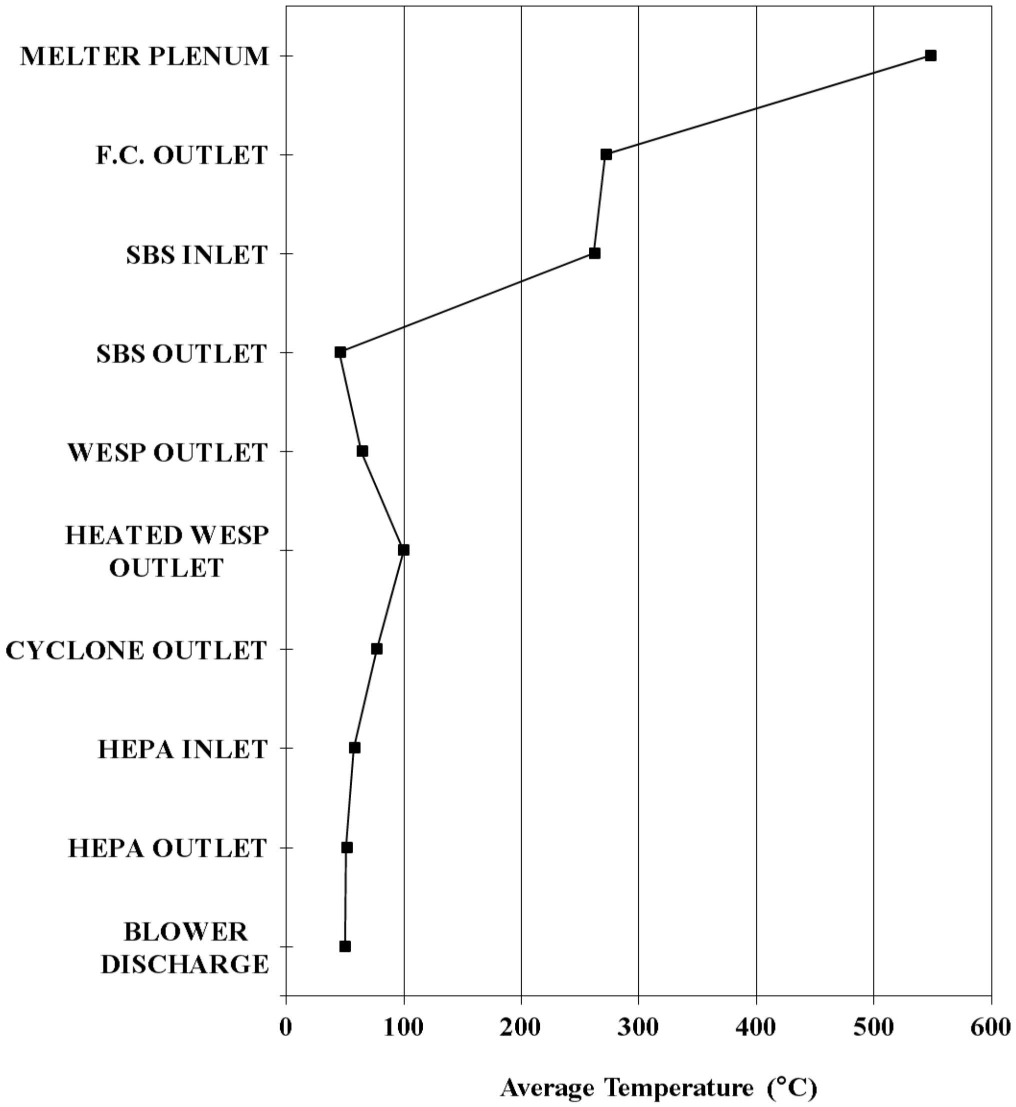

Figure 4.7. Average gas temperature along the DM10 off-gas train.

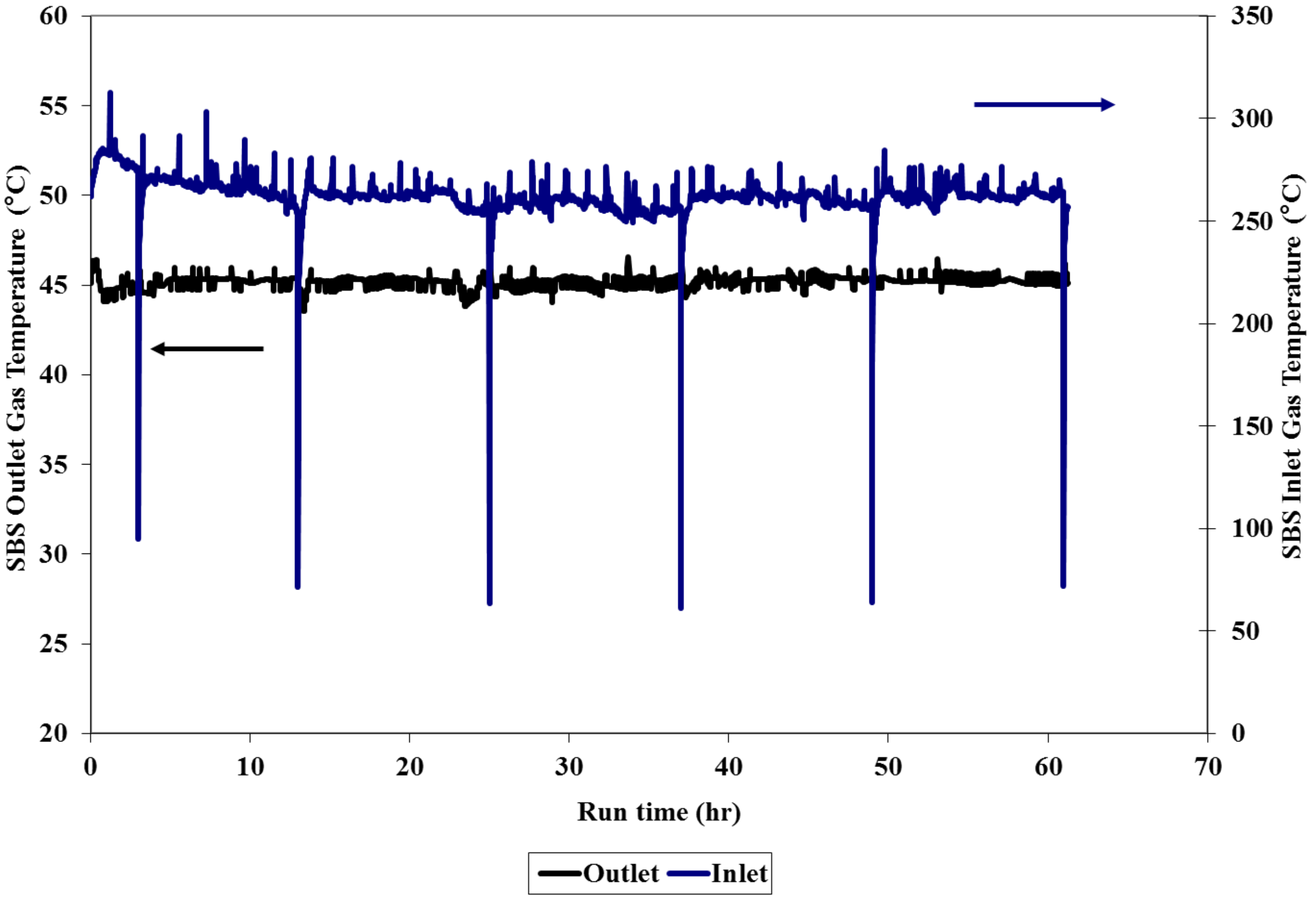

Figure 4.8. SBS inlet and outlet gas temperatures.

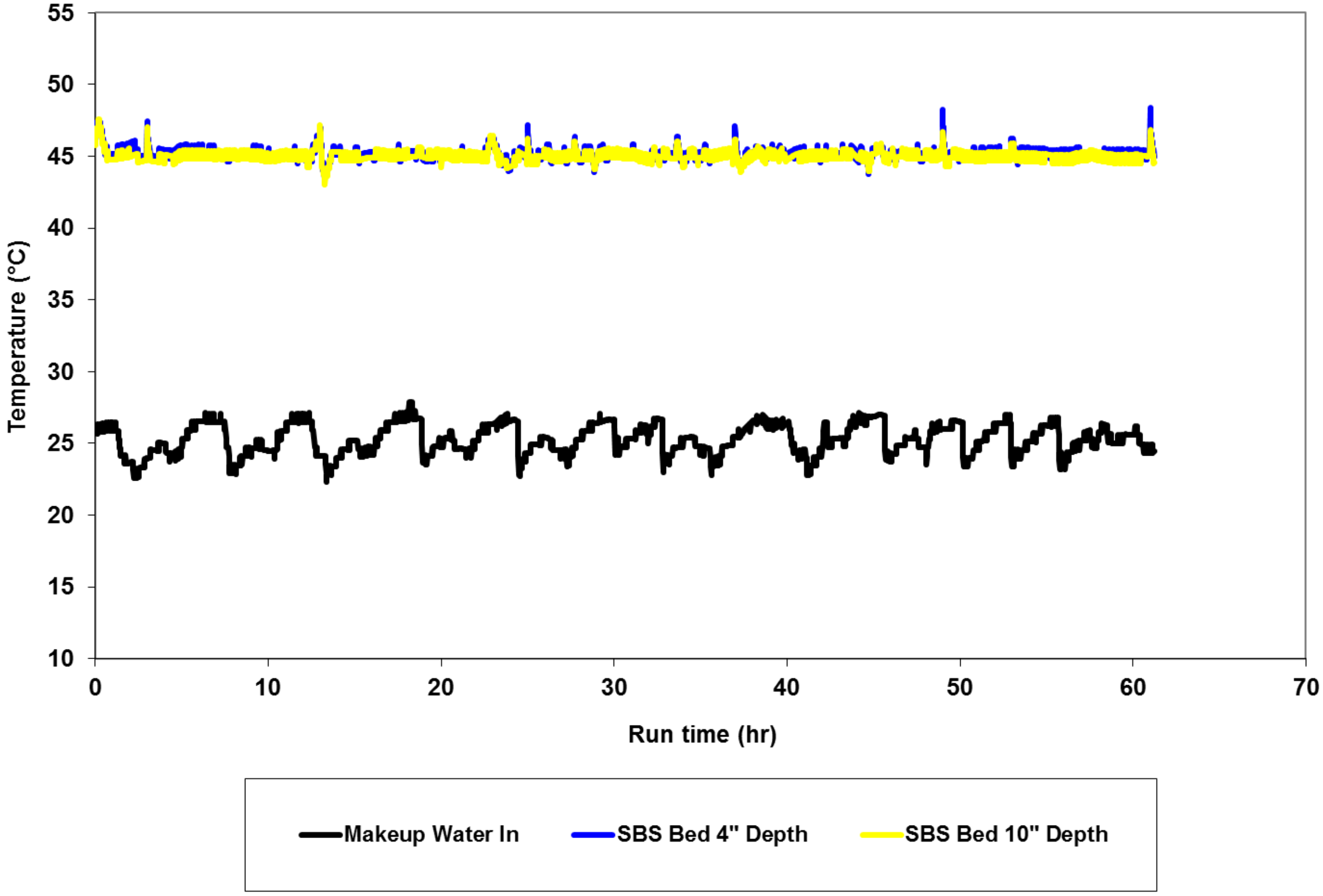

Figure 4.9. SBS liquid sump temperatures.

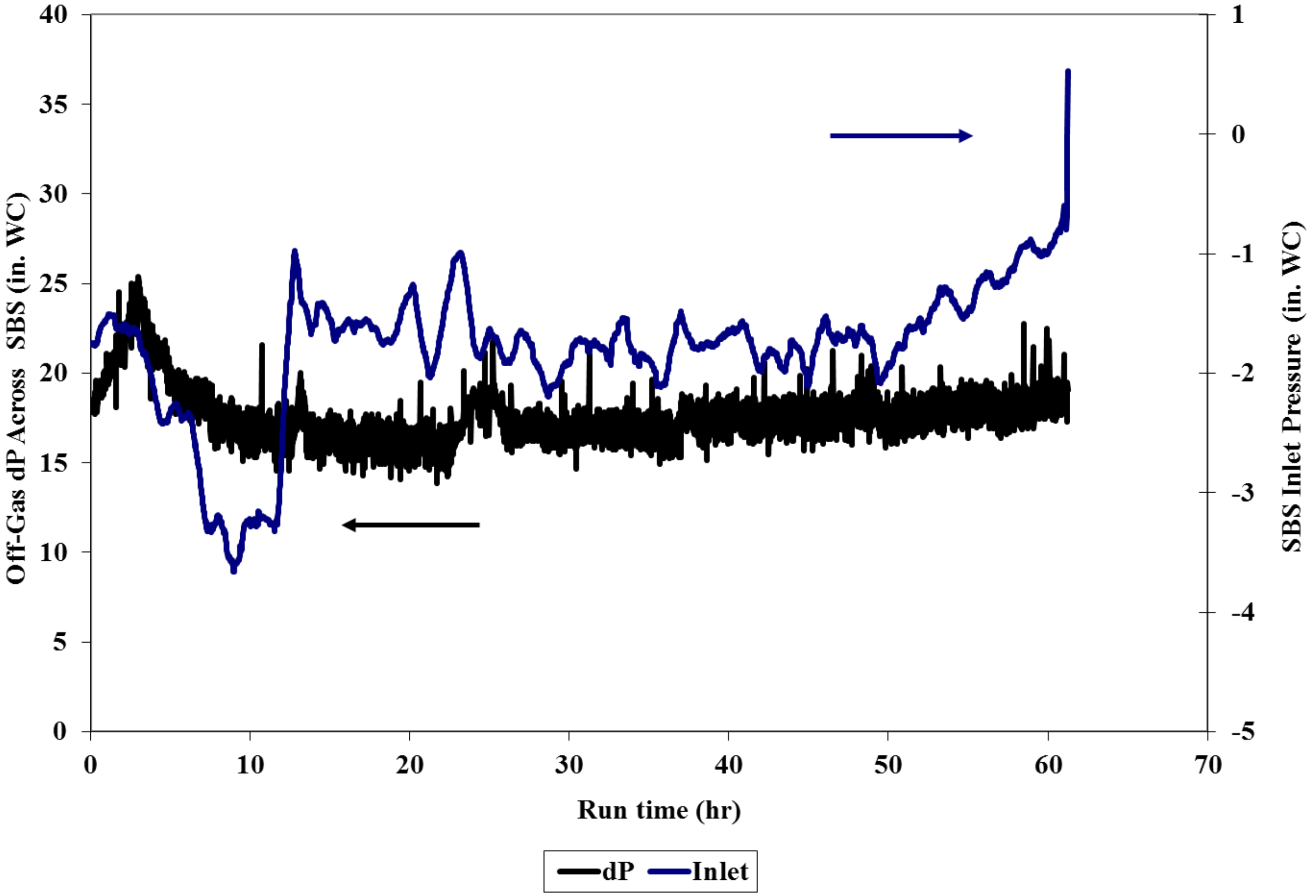

Figure 4.10. SBS inlet pressure and differential pressure across the SBS (1 hour running average used to reduce noise on inlet).

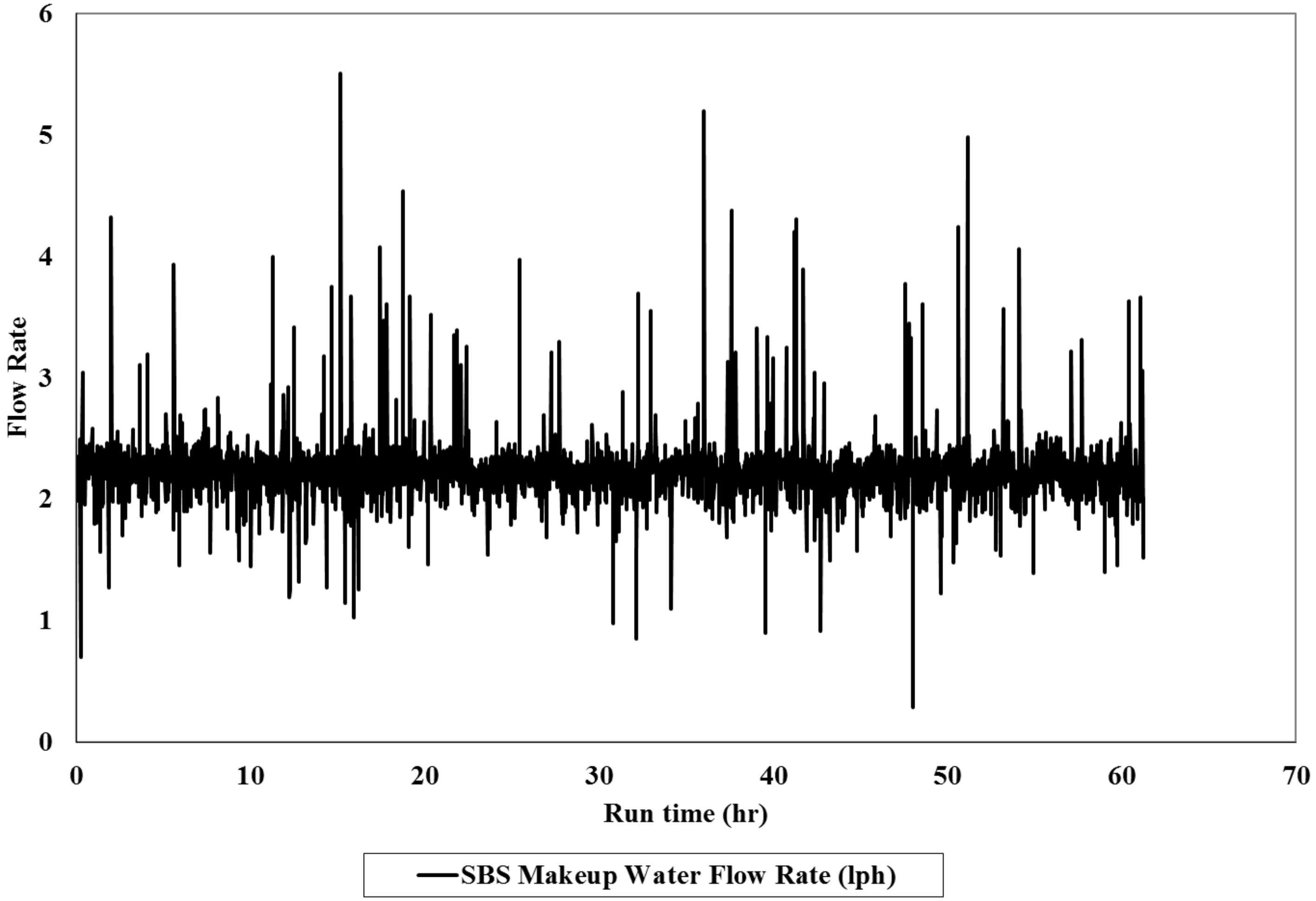

Figure 4.11. Makeup water flow rate into the SBS.

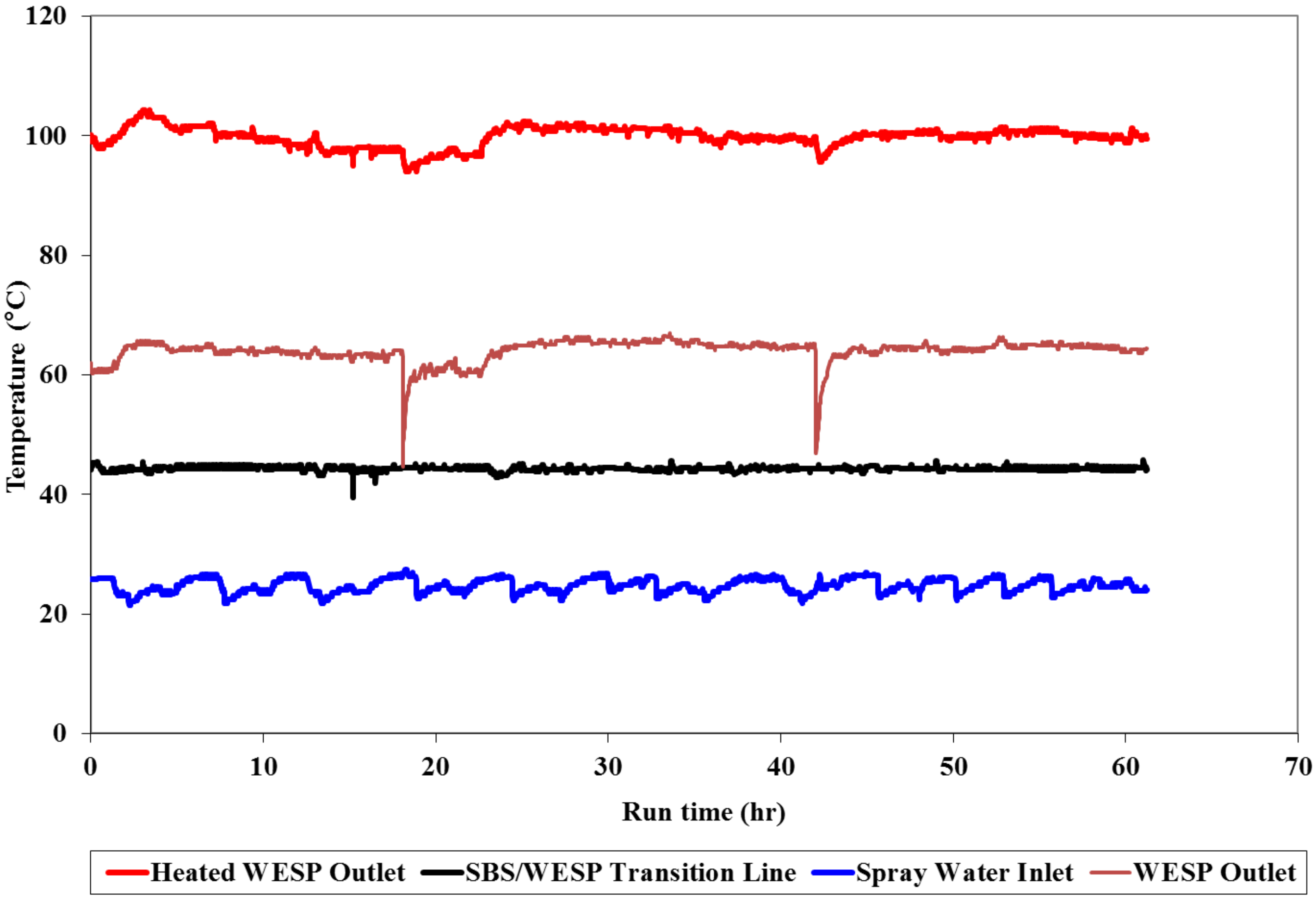

Figure 4.12. Heated WESP outlet temperature (downstream of P-200, and hot dilution air addition), SBS/WESP Transition line temperature, WESP spray water inlet temperature, and WESP outlet temperature.

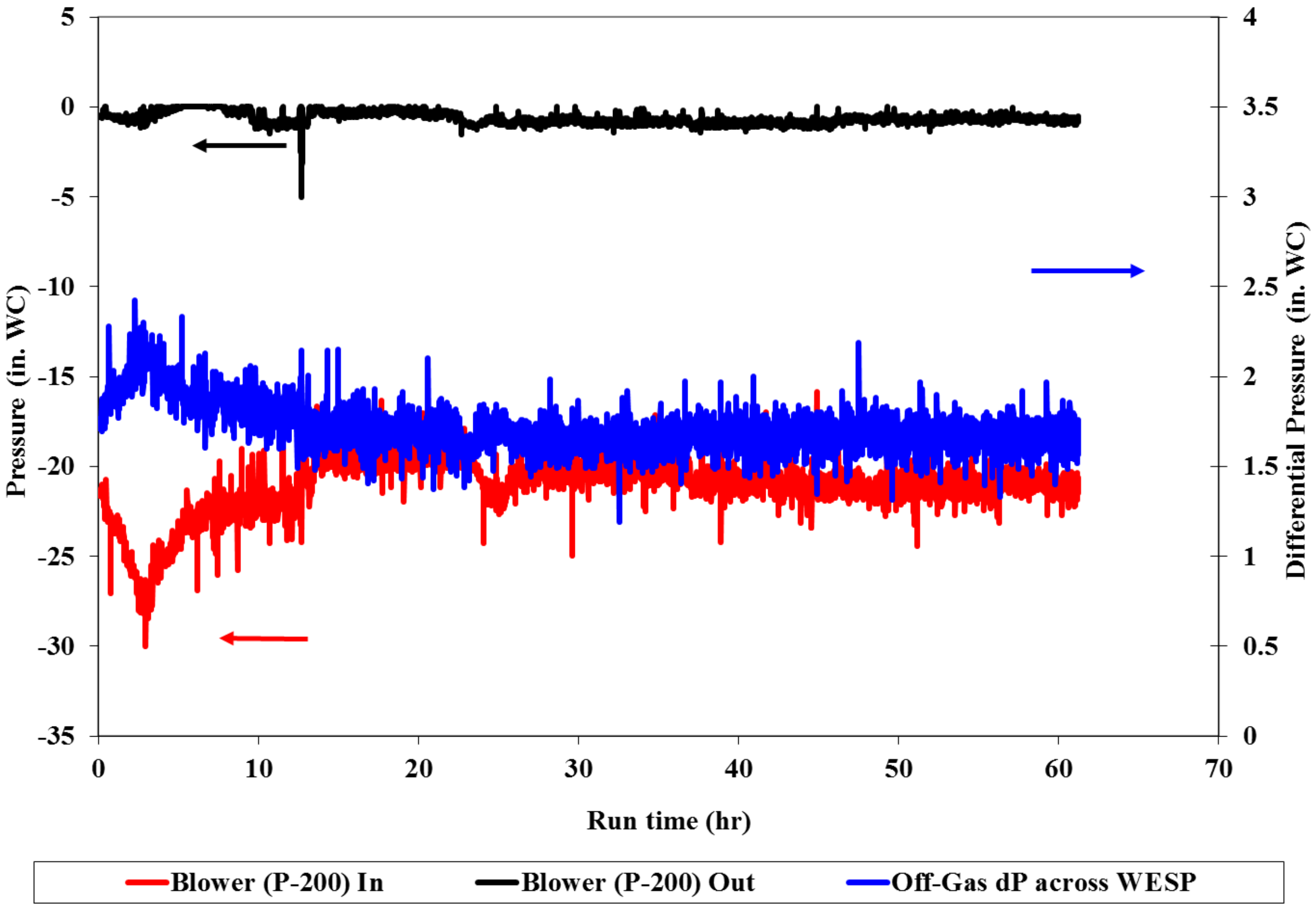

Figure 4.13. Pressure upstream and downstream from P-200 and differential pressure across the WESP.

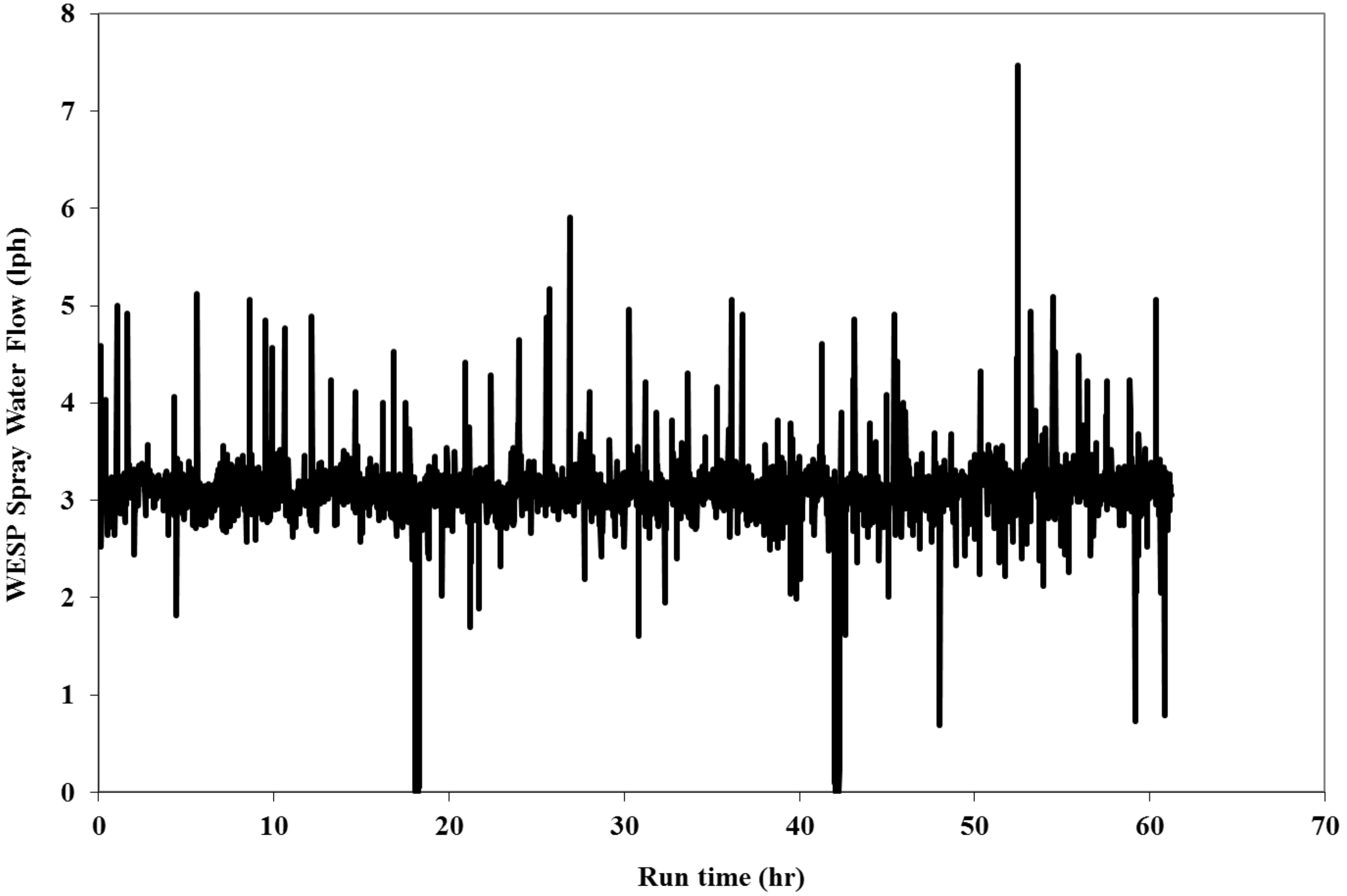

Figure 4.14. WESP spray water flow rate.

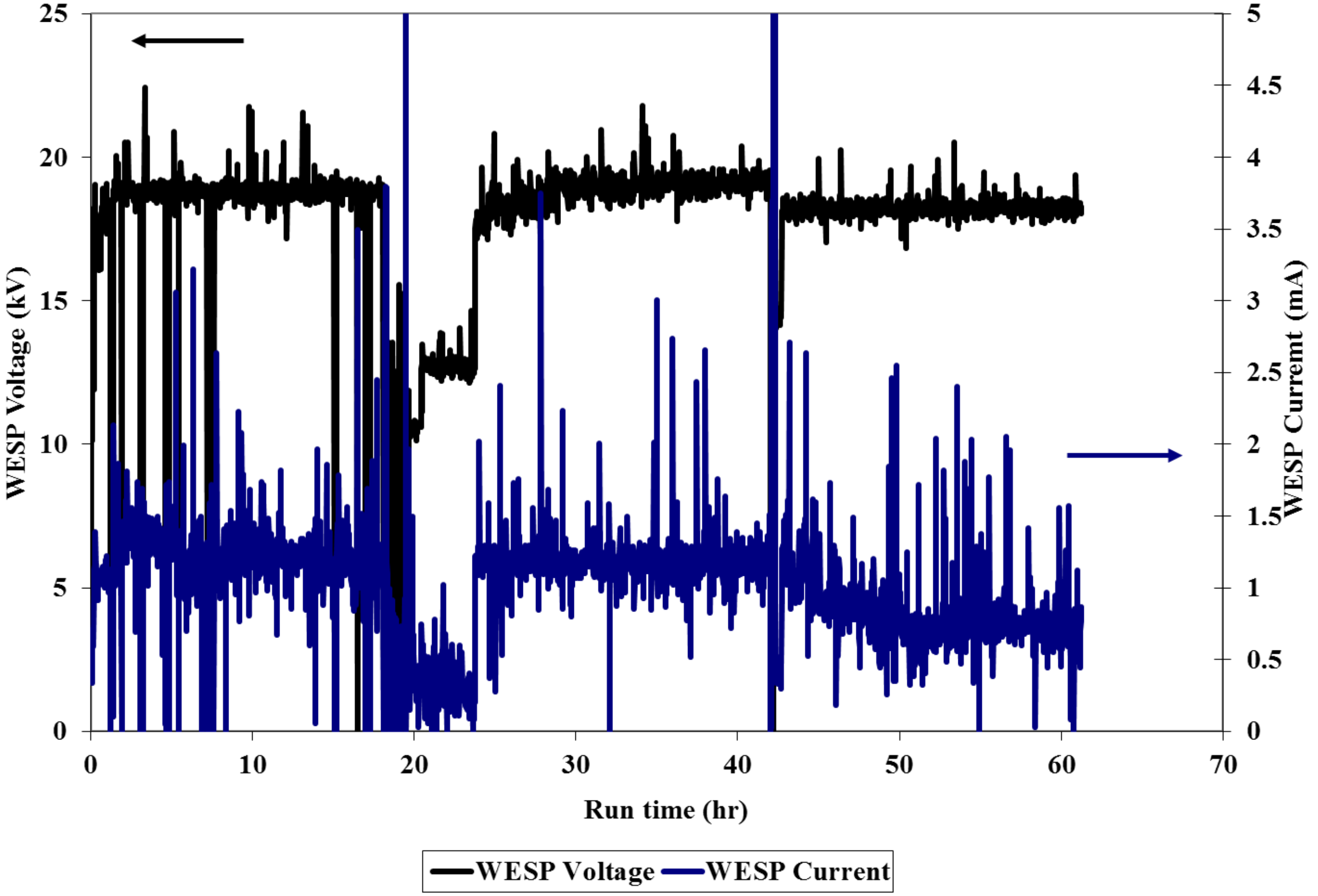

Figure 4.15. WESP voltage and current.

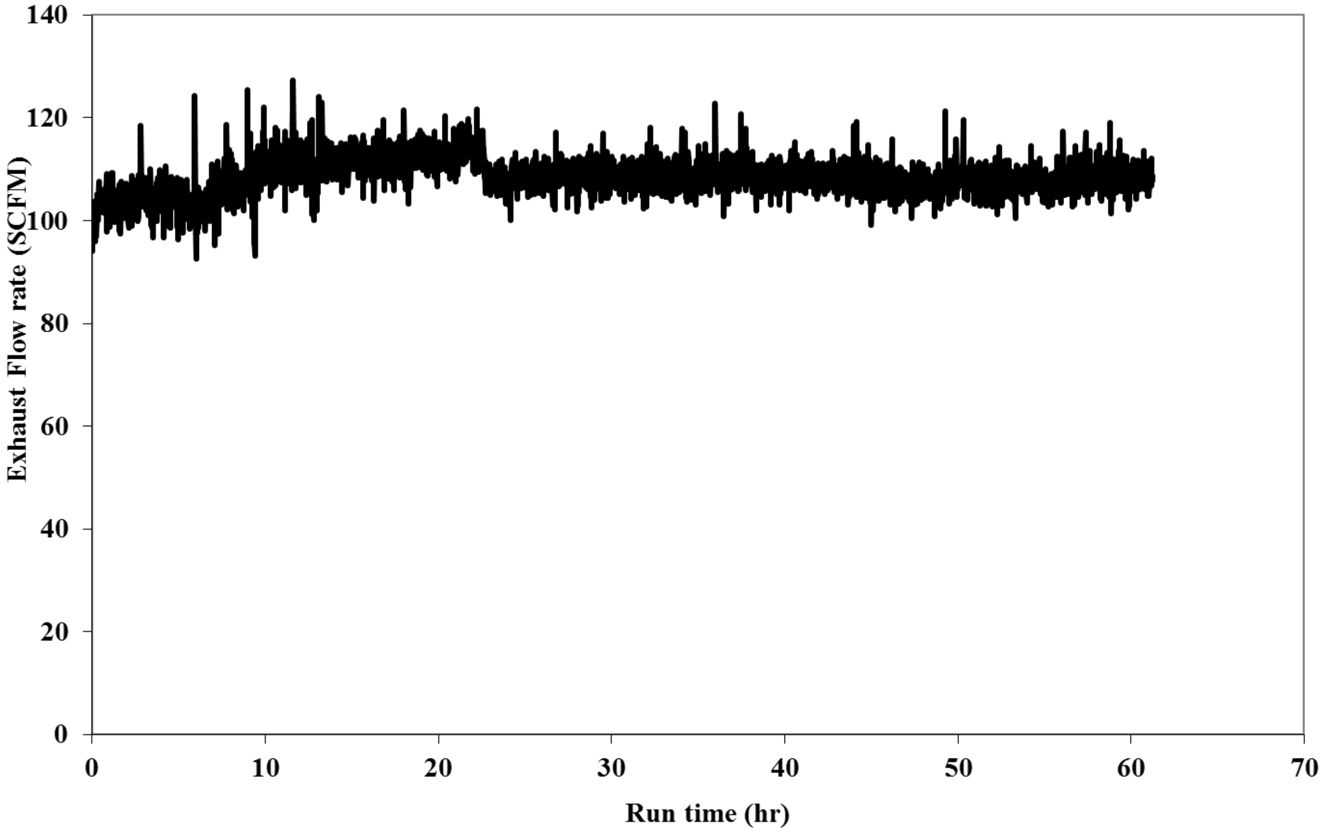

Figure 4.16. Exhaust flow rate to stack (contains additional dilution air that did not pass through the system).

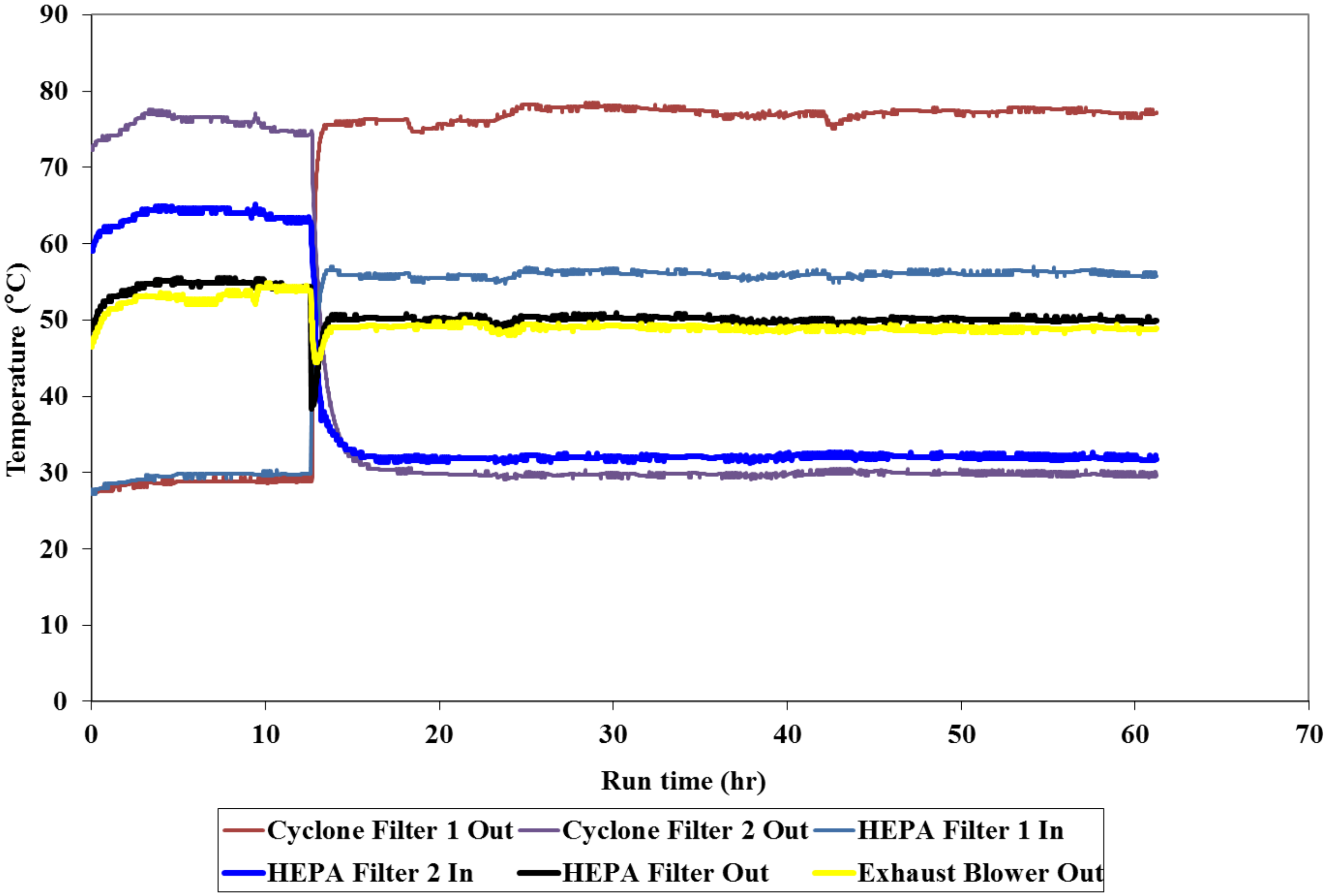

Figure 4.17. Exhaust system temperatures.

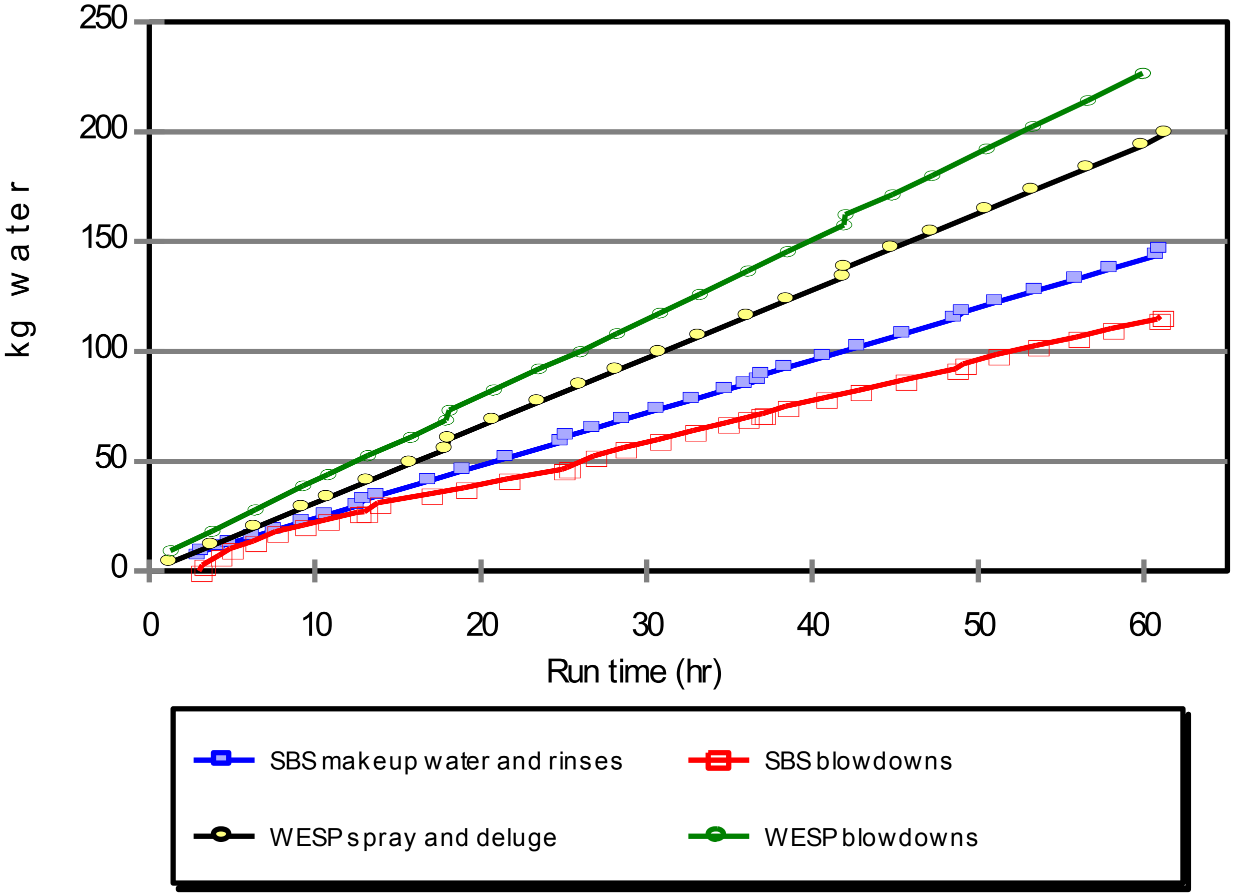

Figure 4.18. Liquid fluxes from SBS and WESP.

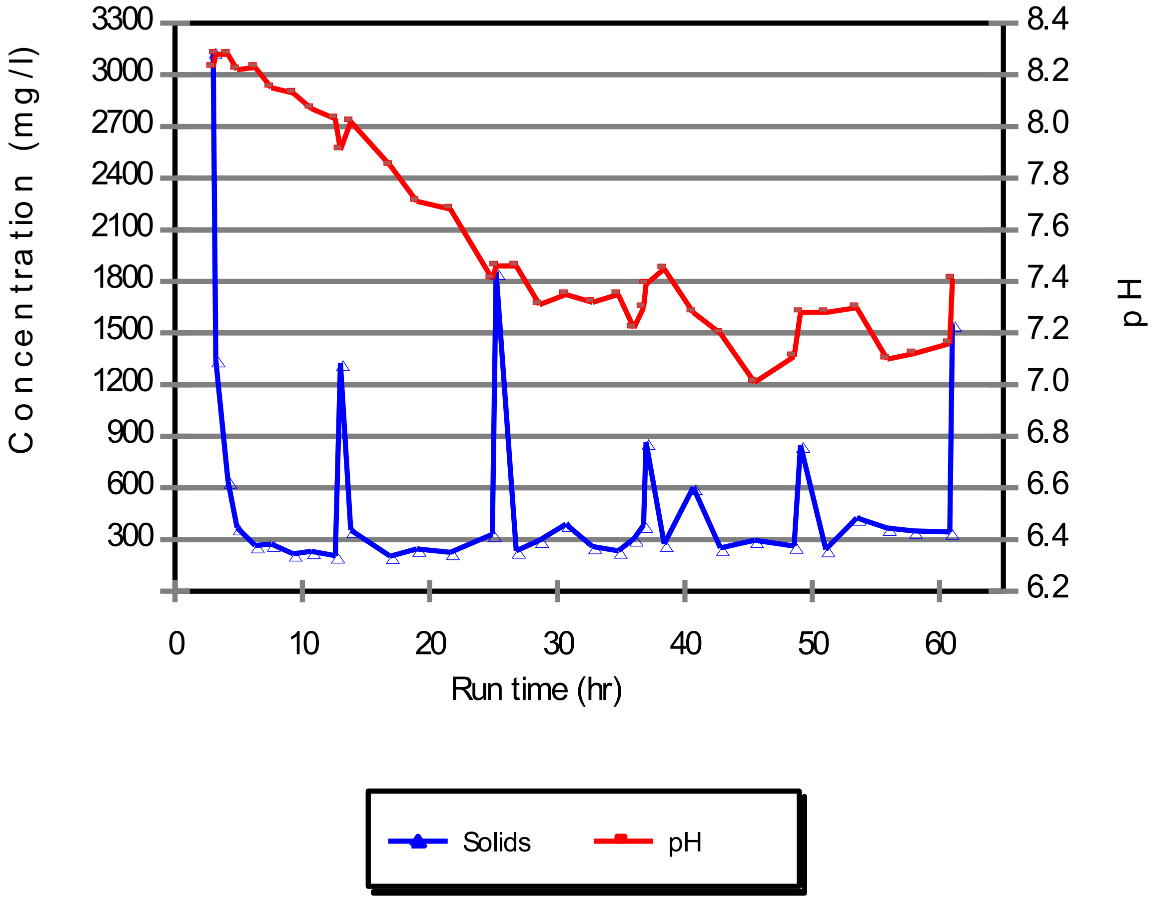

Figure 4.19. pH and solids concentrations in SBS solutions.

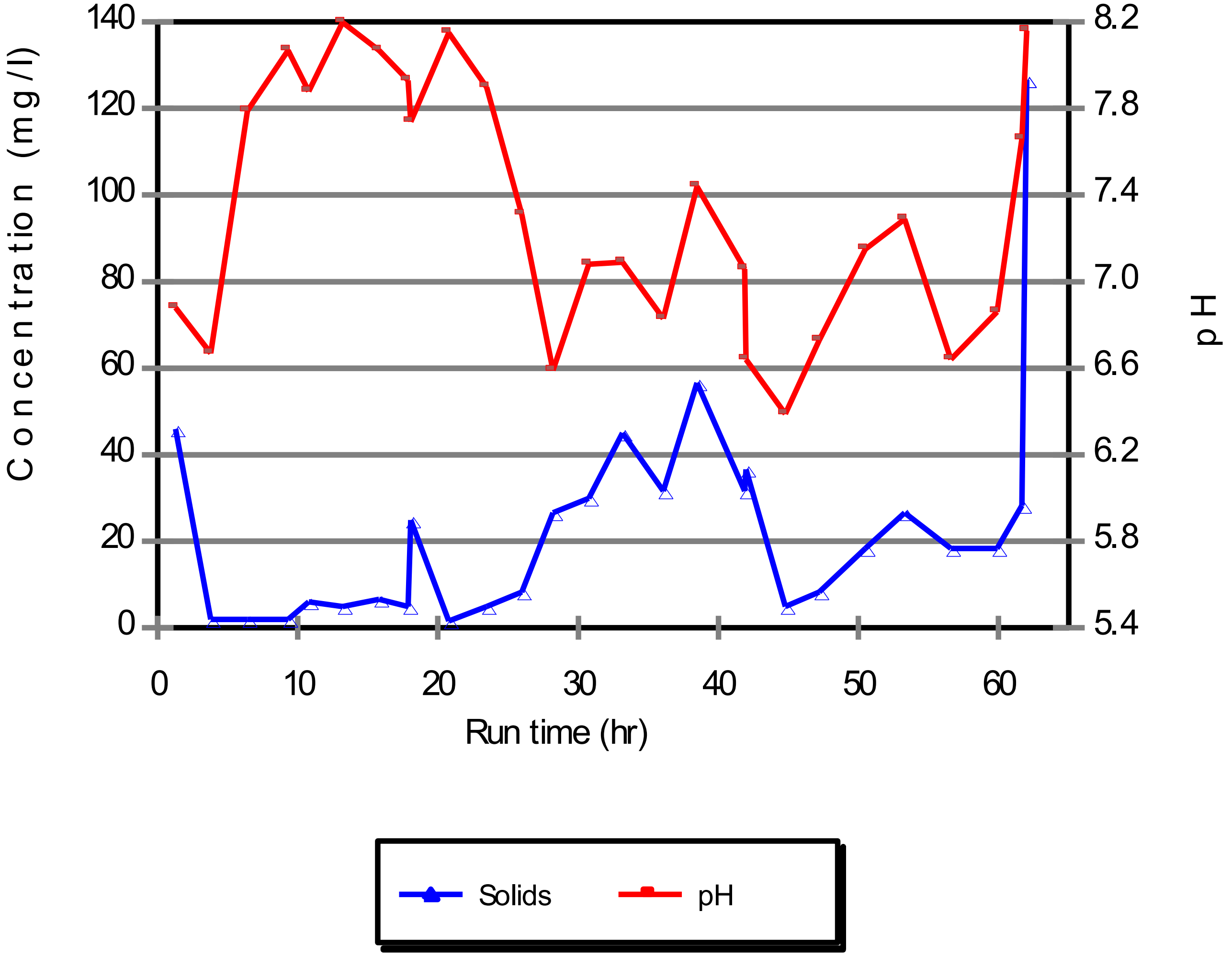

Figure 4.20. pH and solids concentrations in WESP solutions.

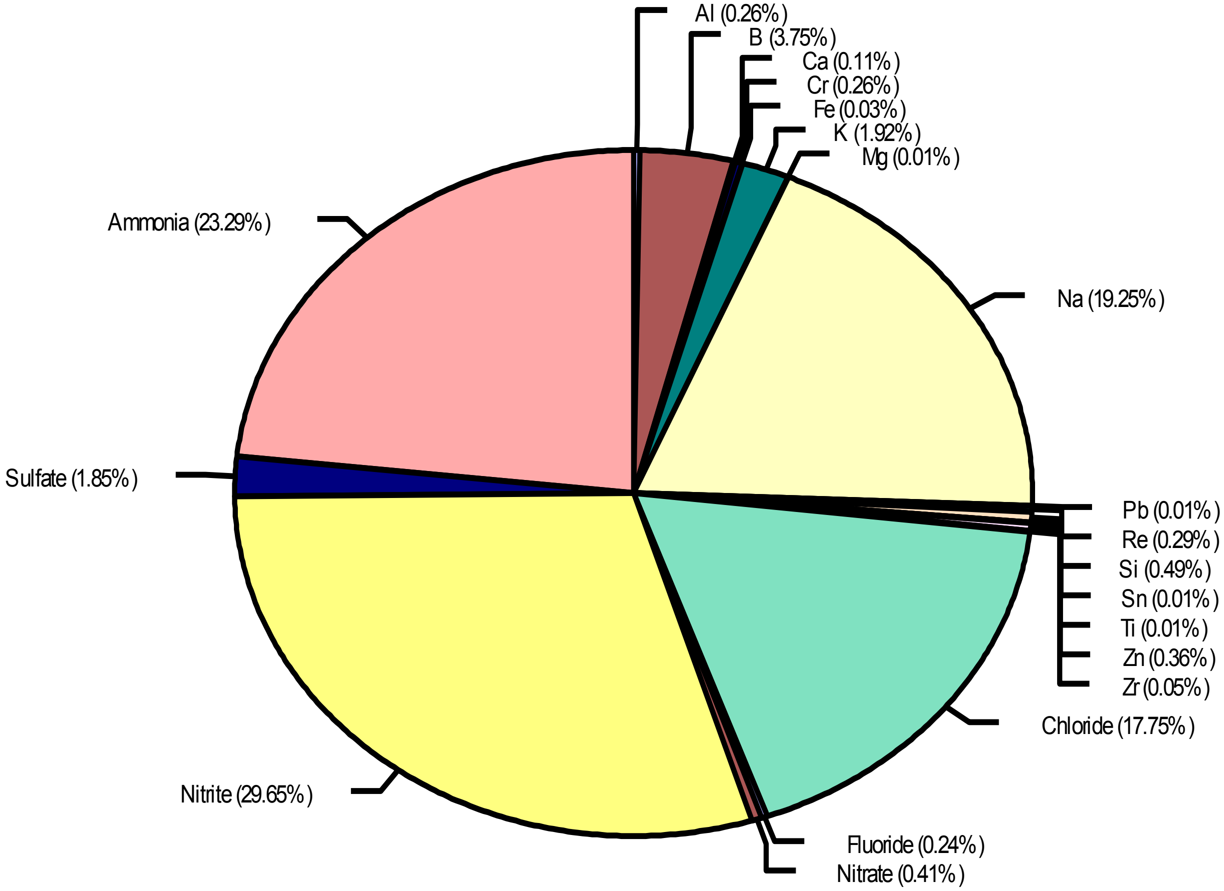

Figure 4.21. Total analyzed composition of SBS sump solution (S-10P-130A).

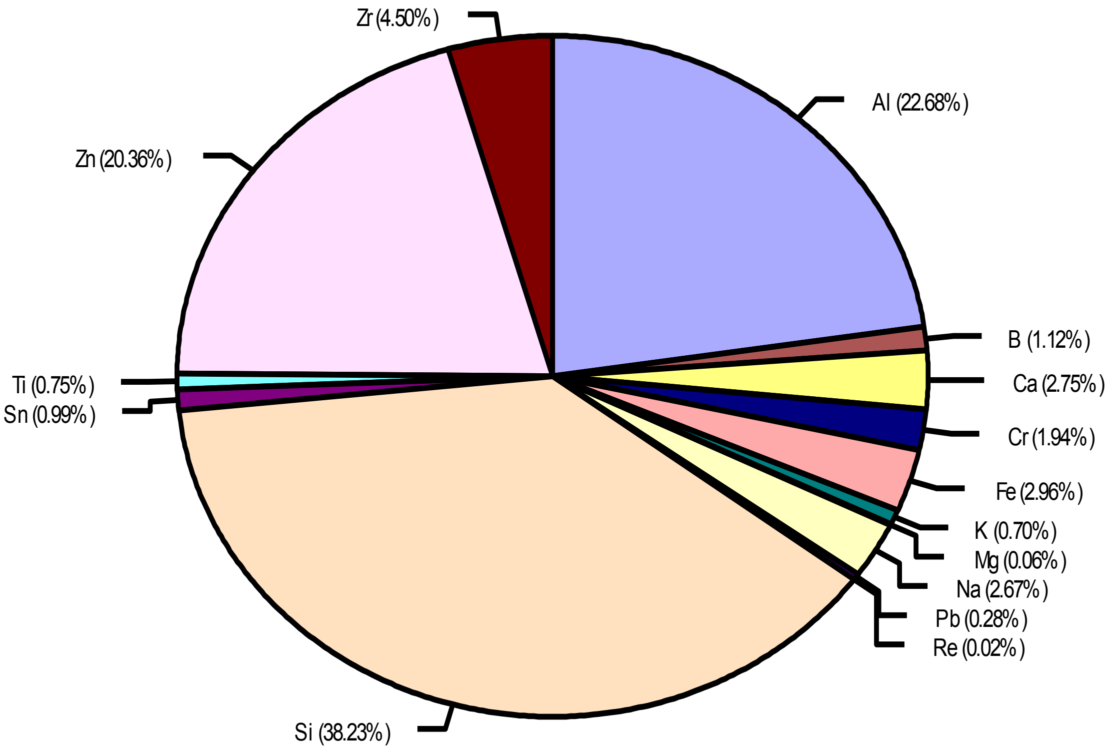

Figure 4.22. Analyzed composition of suspended solids in SBS sump solution (S-10P-130A).

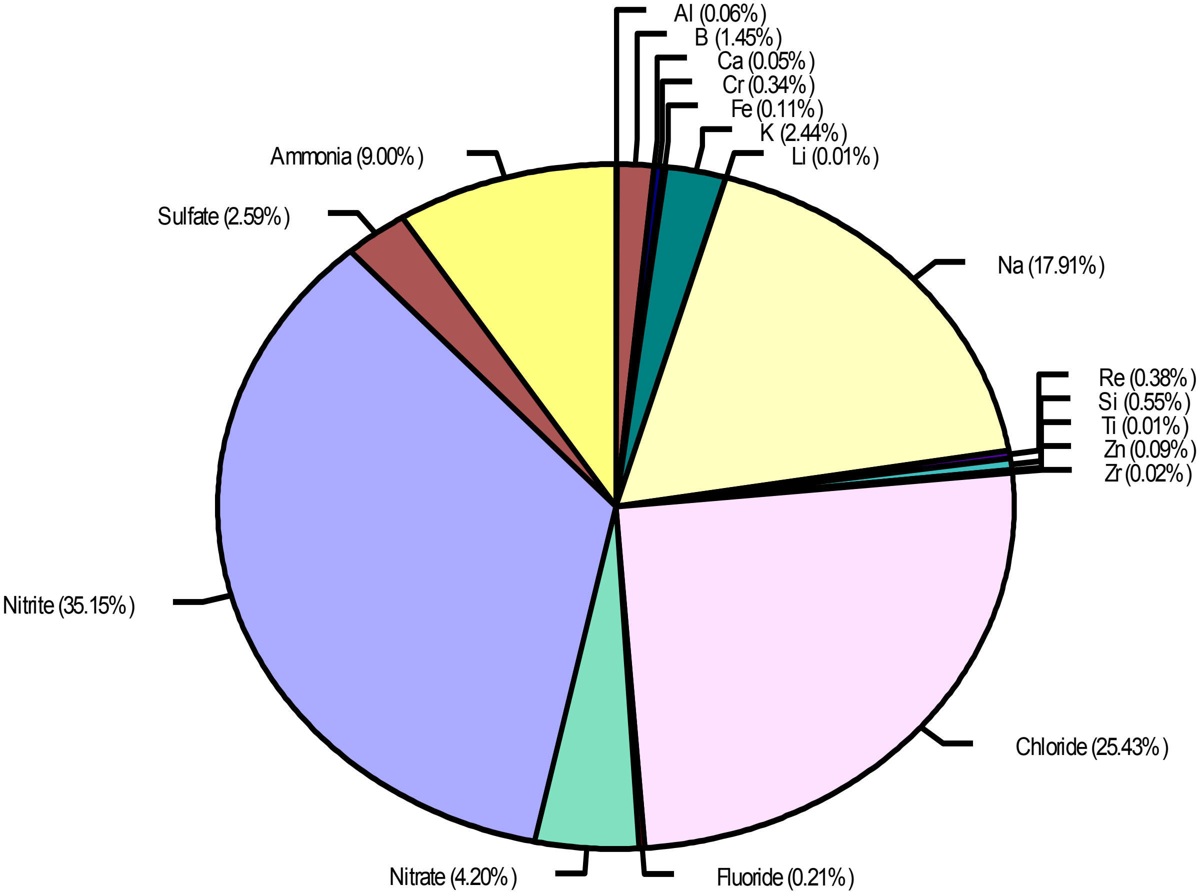

Figure 4.23. Total analyzed composition of WESP sump solution (W-10P-113B).

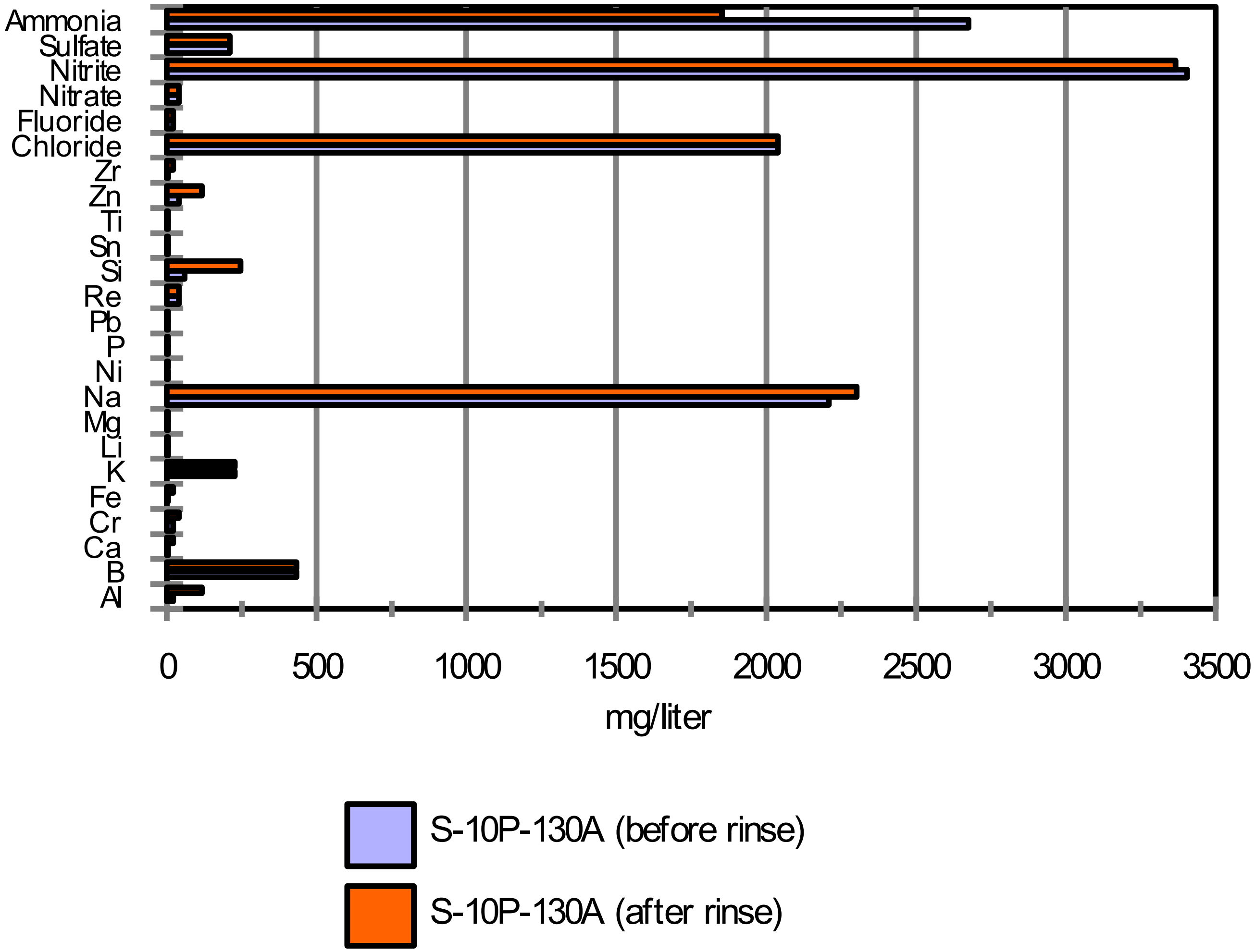

Figure 4.24. Analyzed compositions of SBS sump solutions collected before and after transition line rinse.

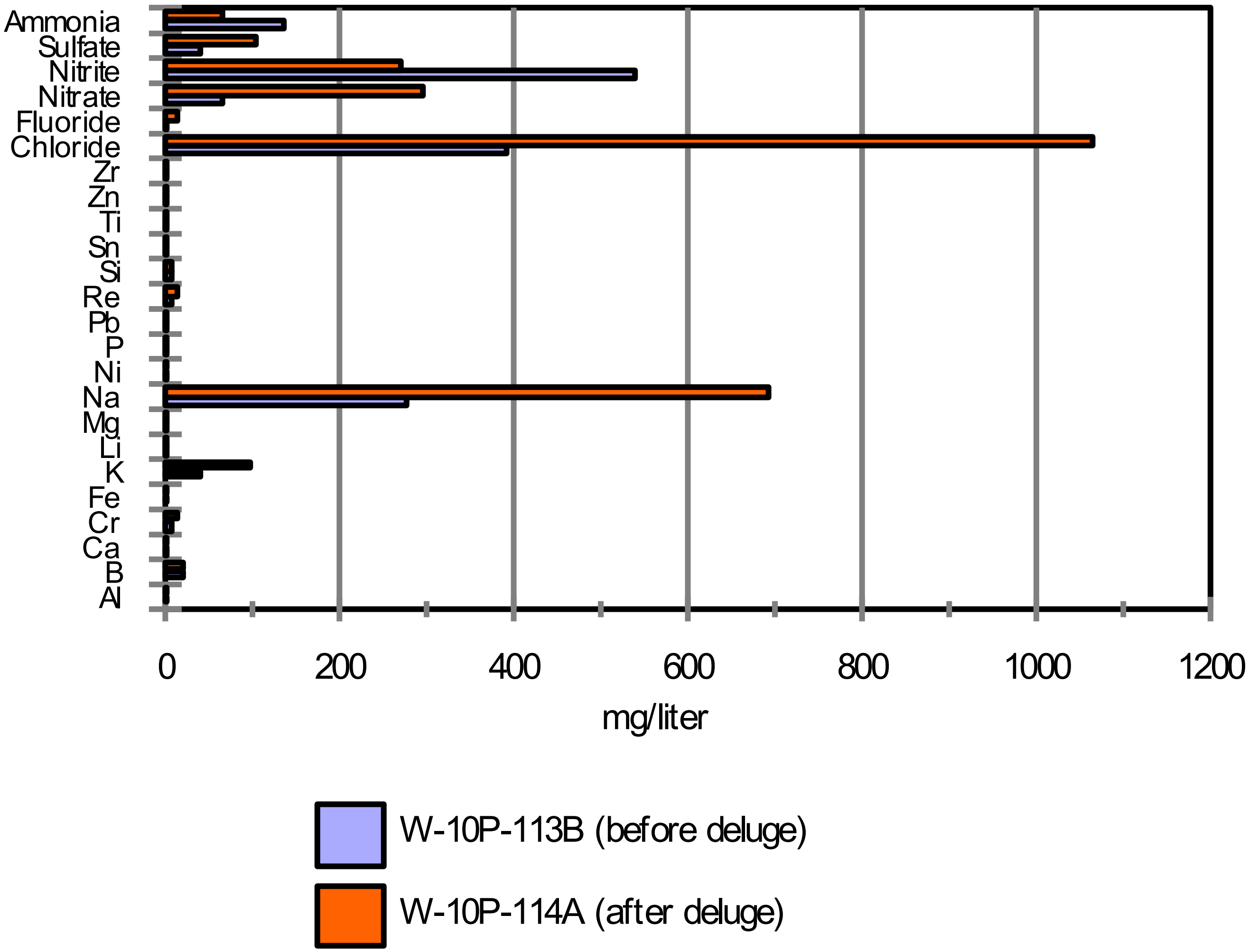

Figure 4.25. Analyzed compositions of WESP sump solutions collected before and after deluge.

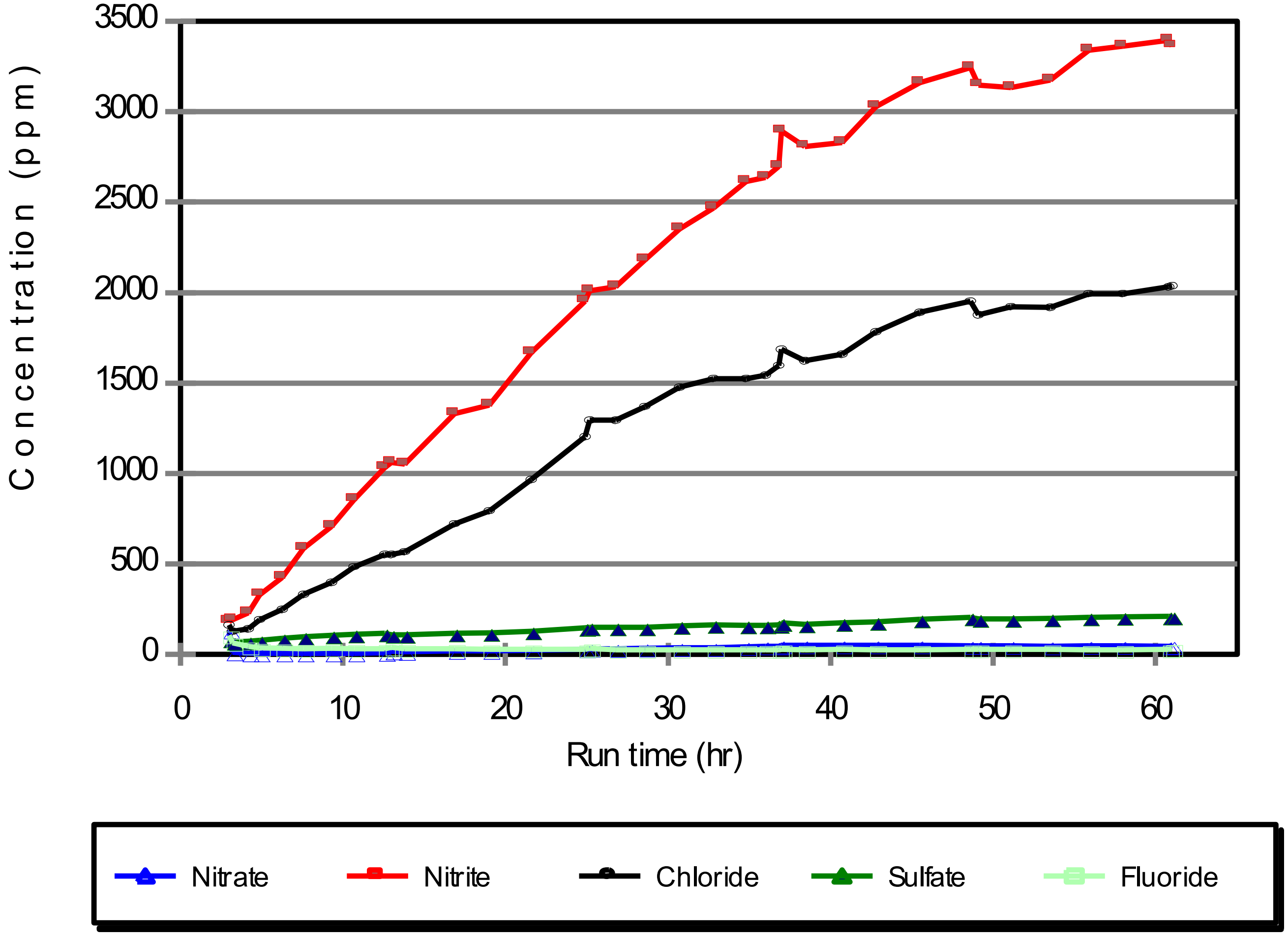

Figure 4.26. Anion concentrations in SBS solutions.

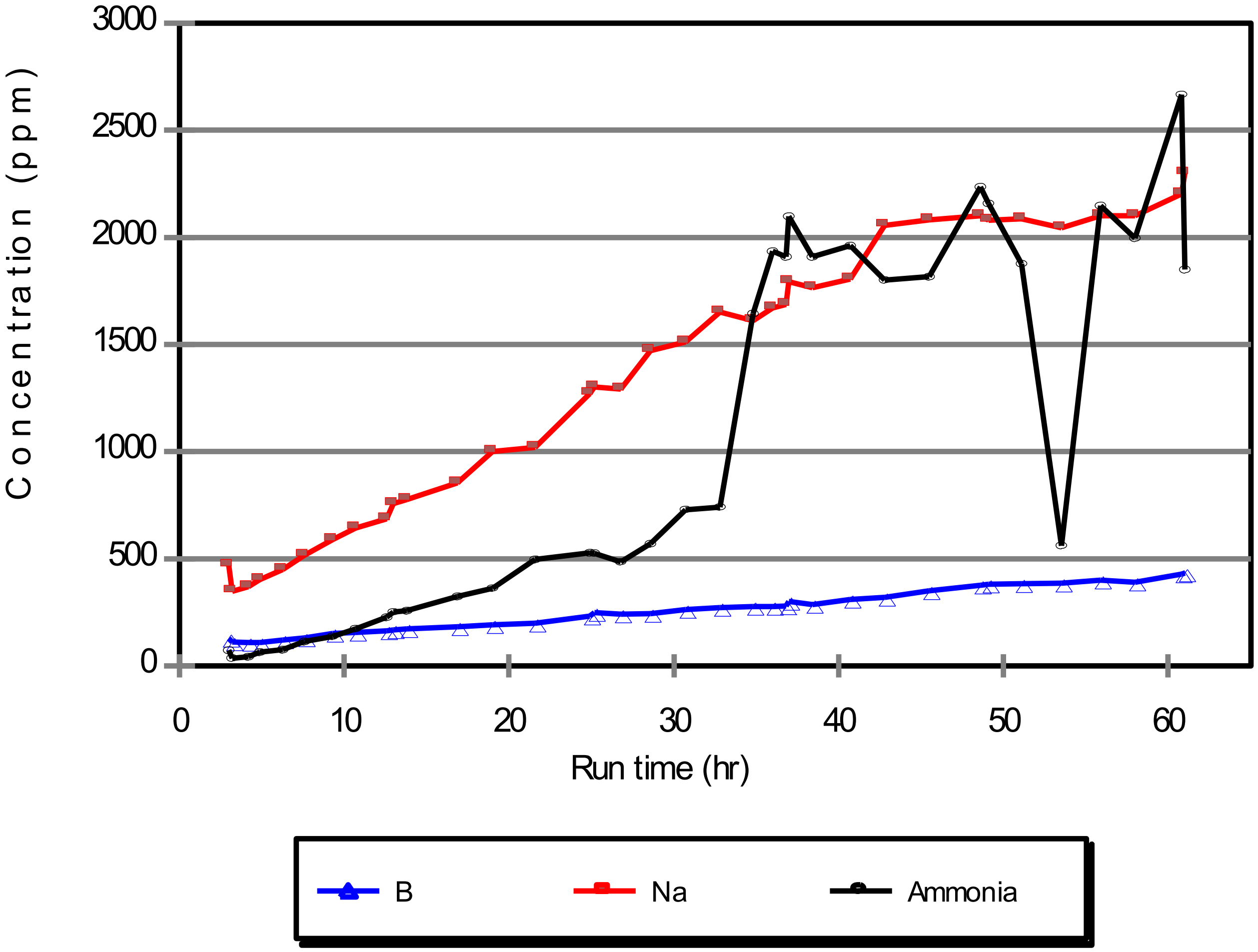

Figure 4.27. Boron, sodium, and ammonia concentrations in SBS solutions.

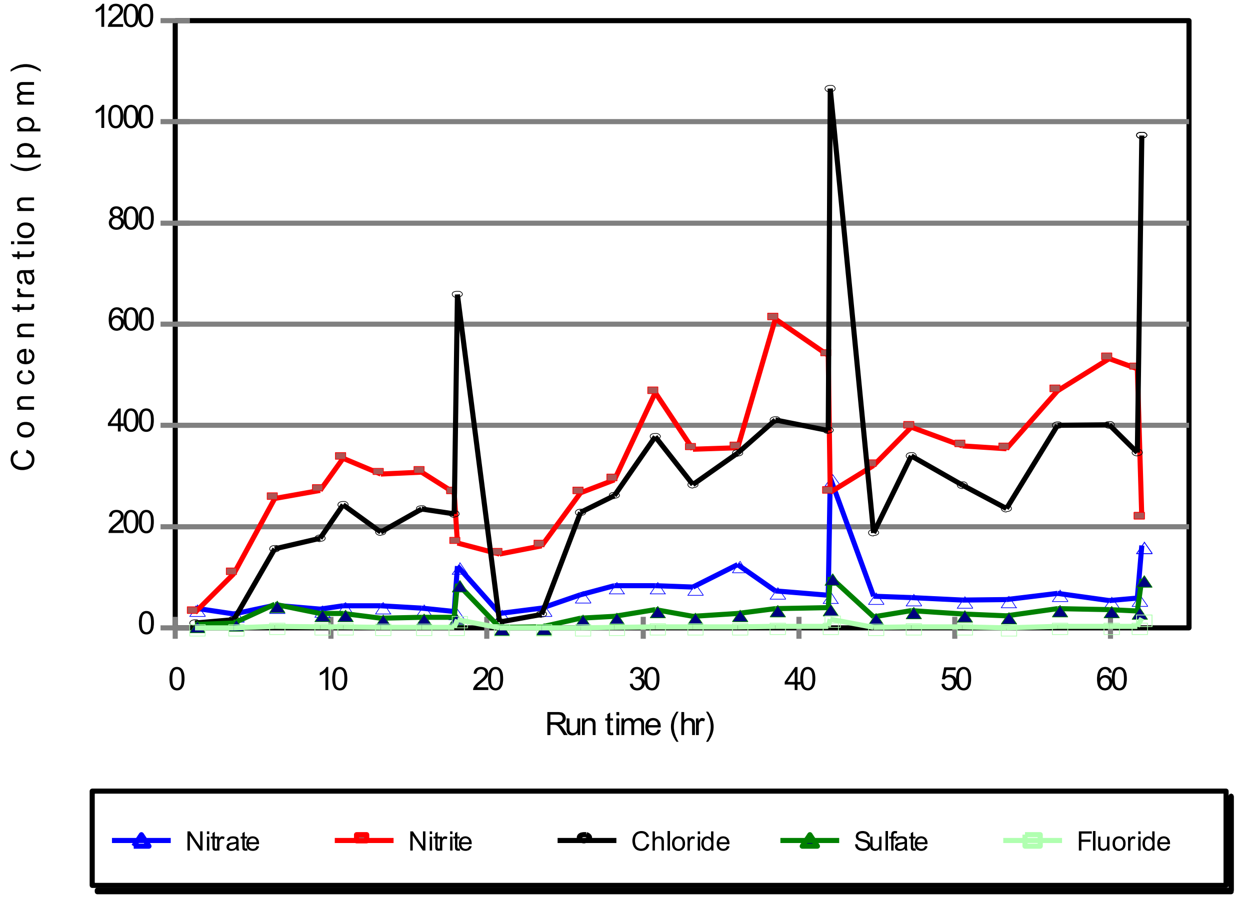

Figure 4.28. Anion concentrations in WESP solutions.

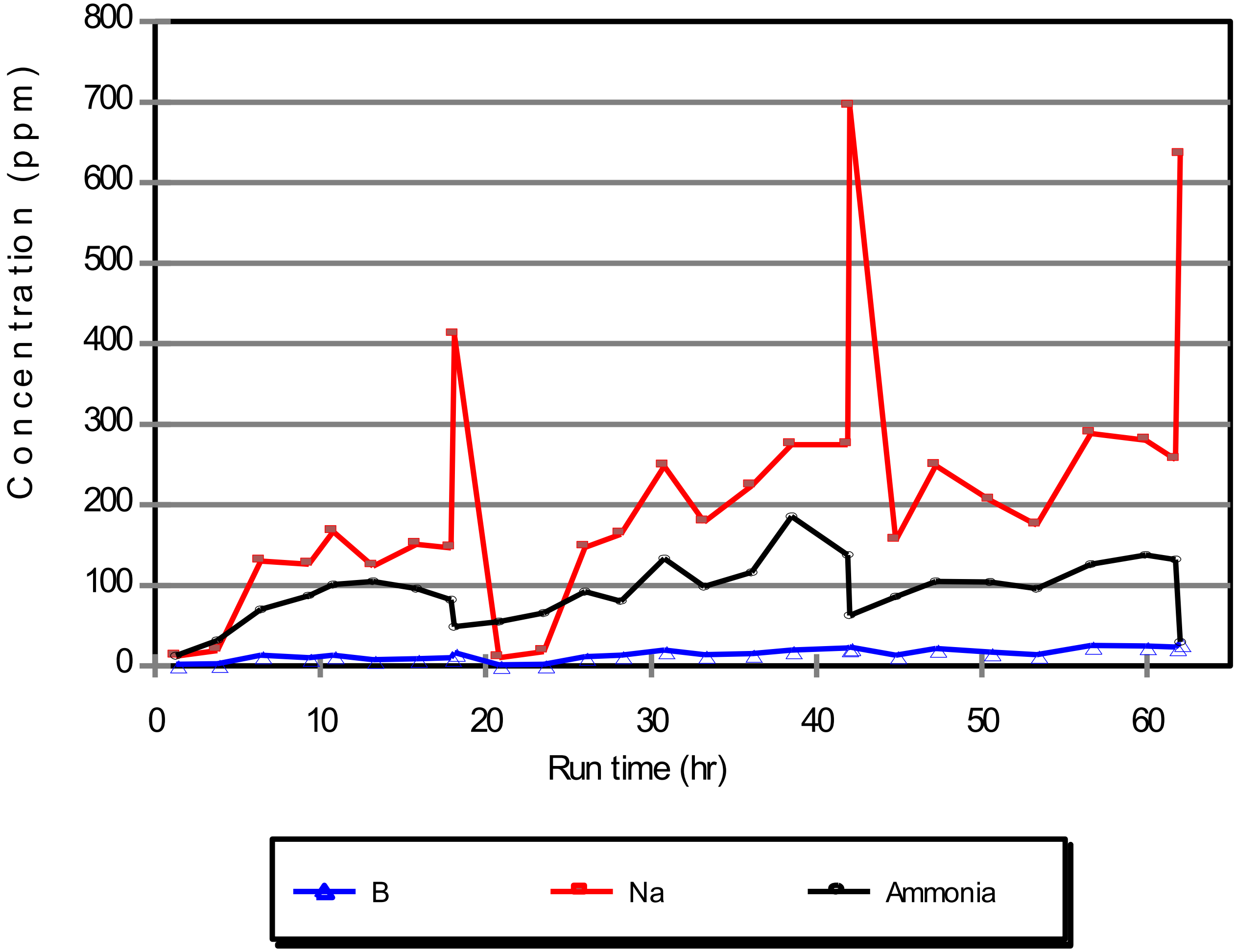

Figure 4.29. Boron, sodium, and ammonia concentrations in WESP solutions.

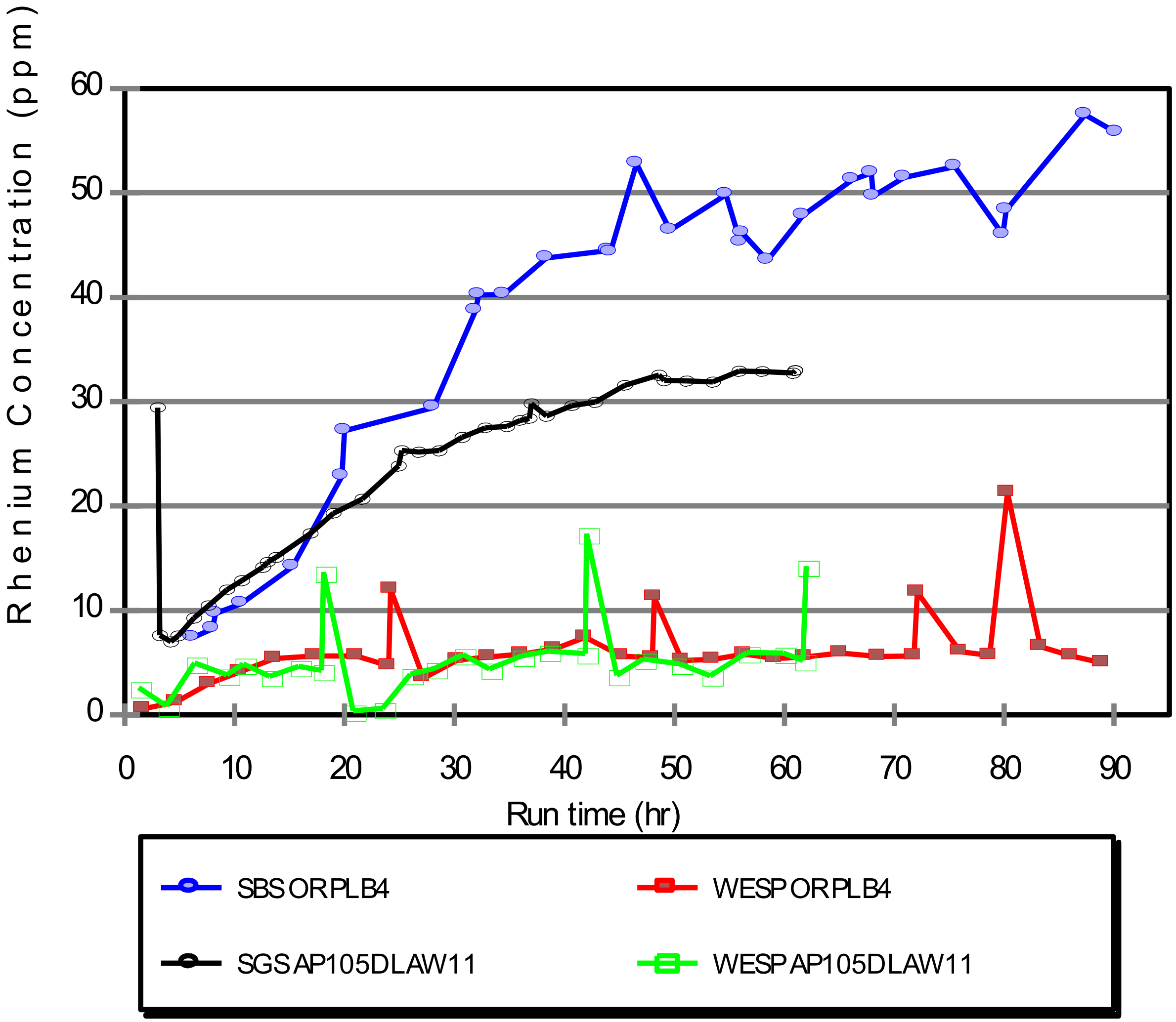

Figure 4.30. Rhenium concentrations in SBS and WESP solutions from tests conducted with a target 0.01 wt% ReO_2 in the product glass.

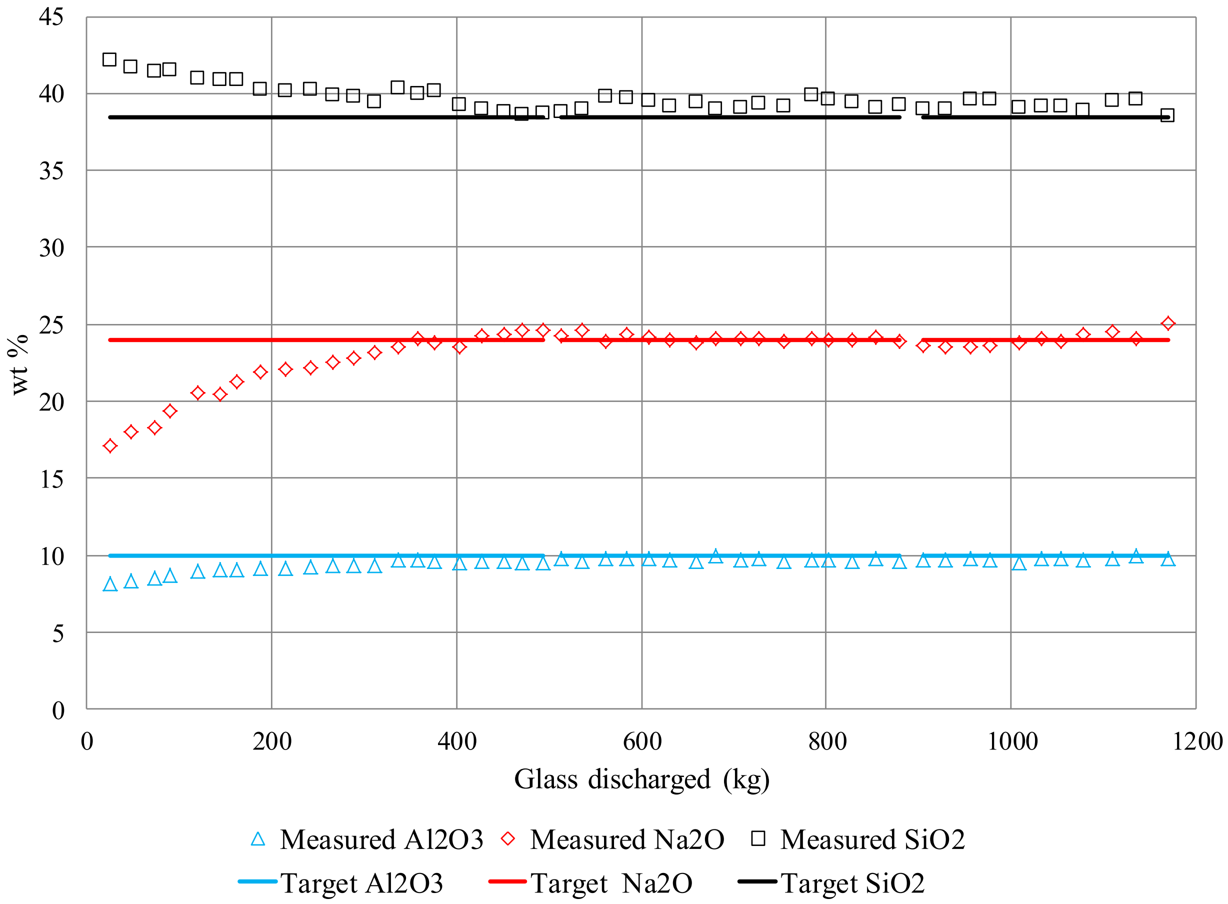

Figure 5.1. XRF analysis of silicon, sodium, and aluminum oxides in DM100 product glasses.

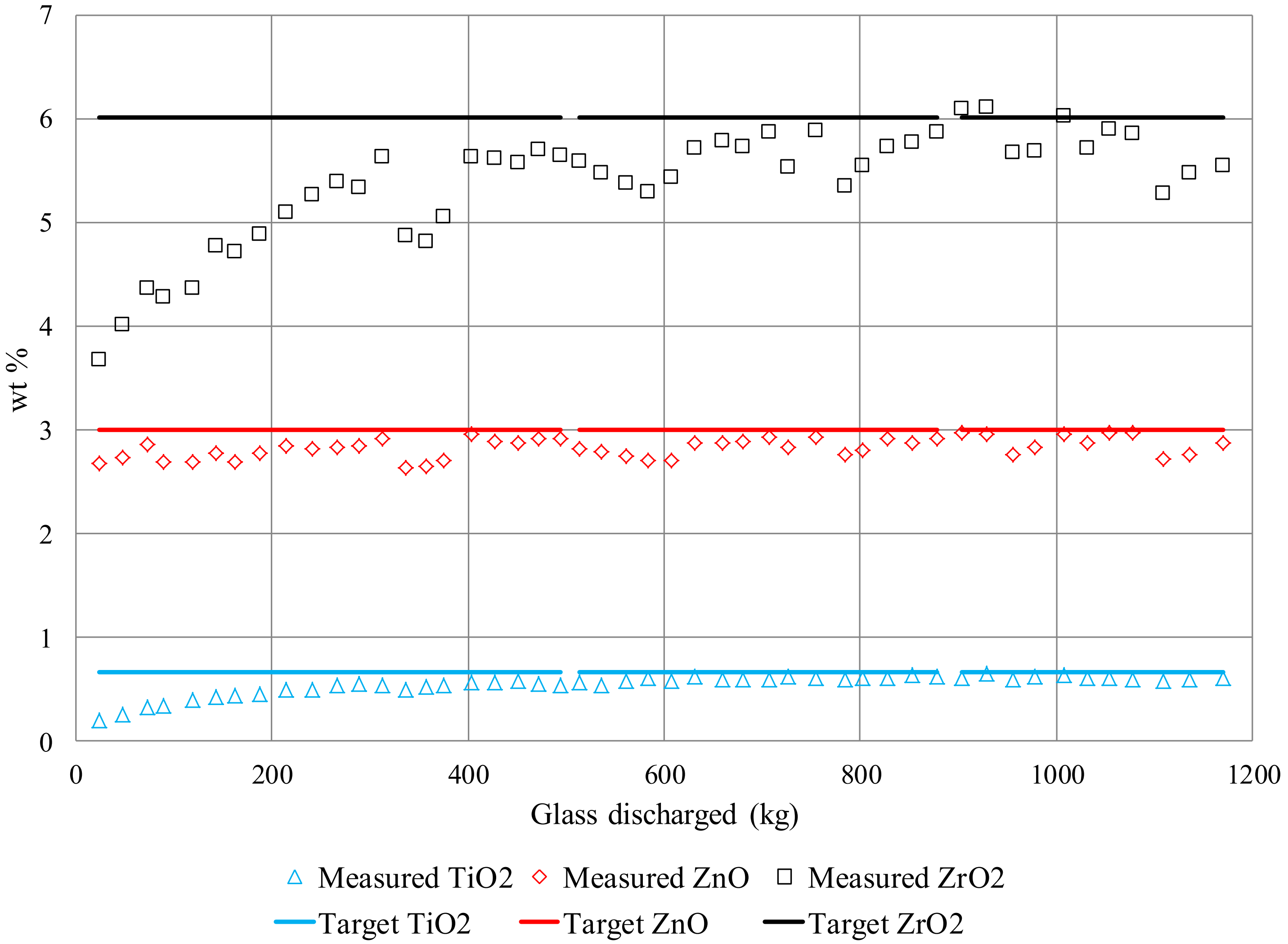

Figure 5.2. XRF analysis of titanium, zinc, and zirconium oxides in DM100 product glasses.

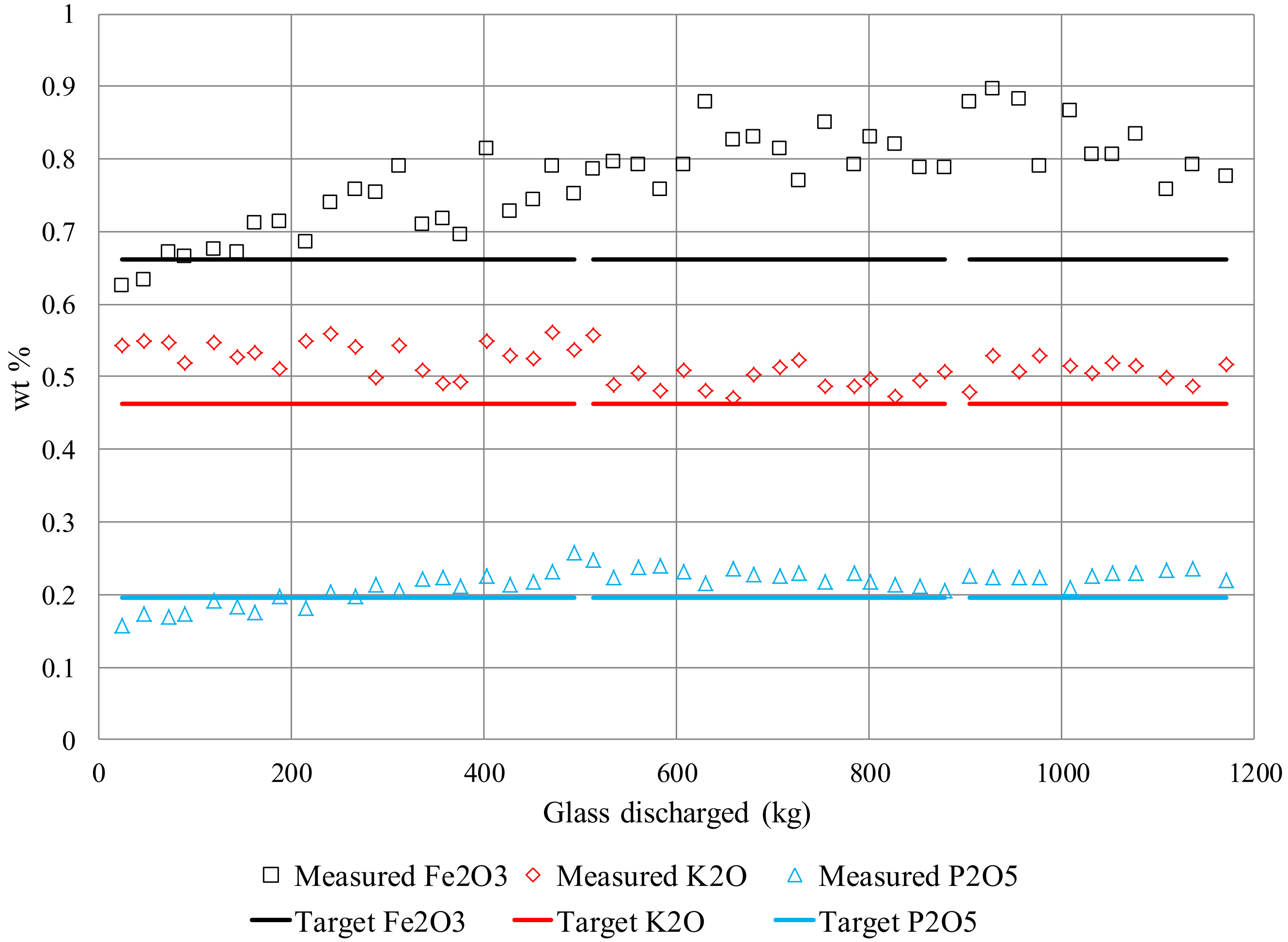

Figure 5.3. XRF analysis of iron, potassium, and phosphorus oxides in DM100 product glasses.

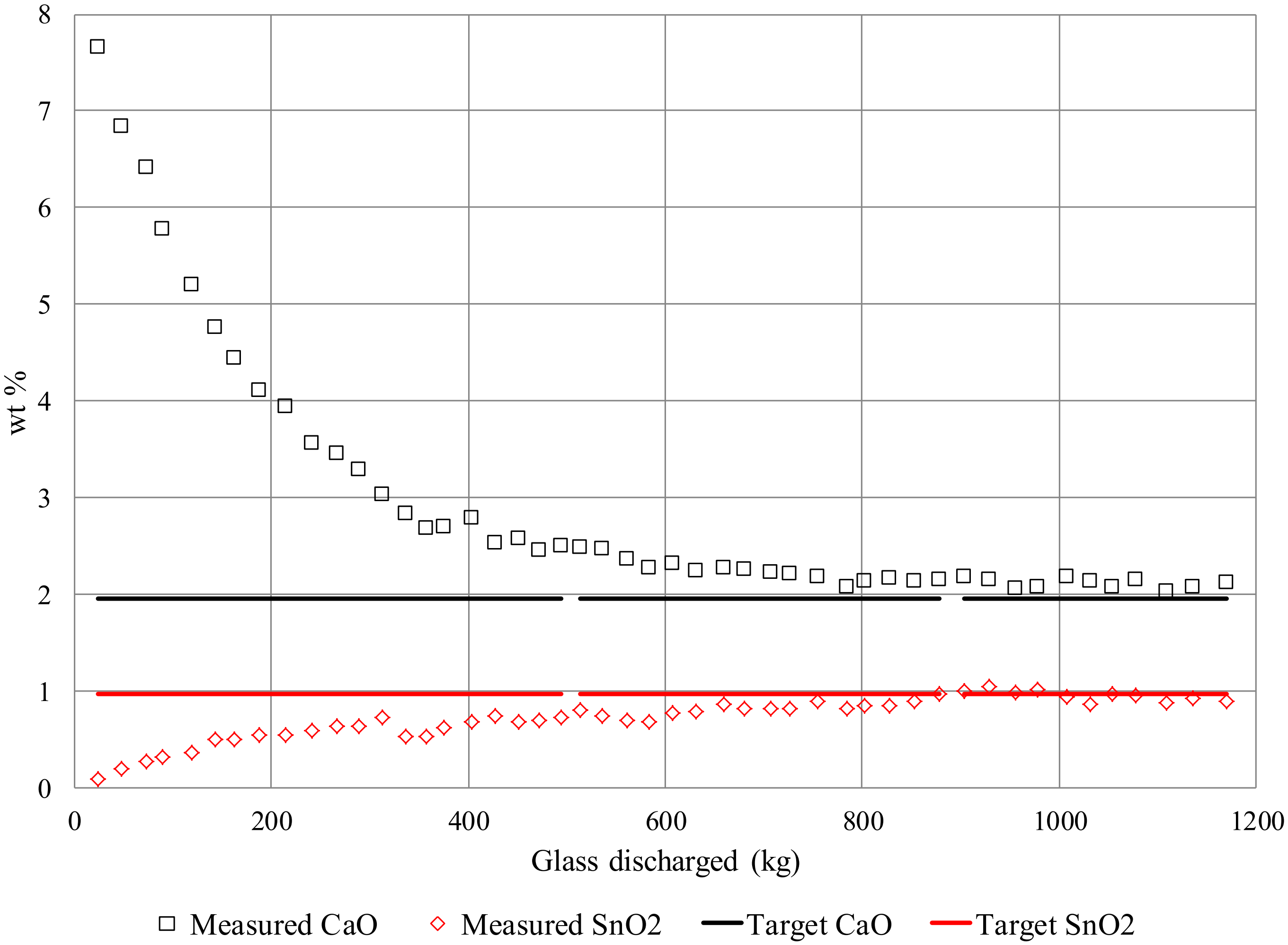

Figure 5.4. XRF analysis of calcium and tin oxides in DM100 product glasses.

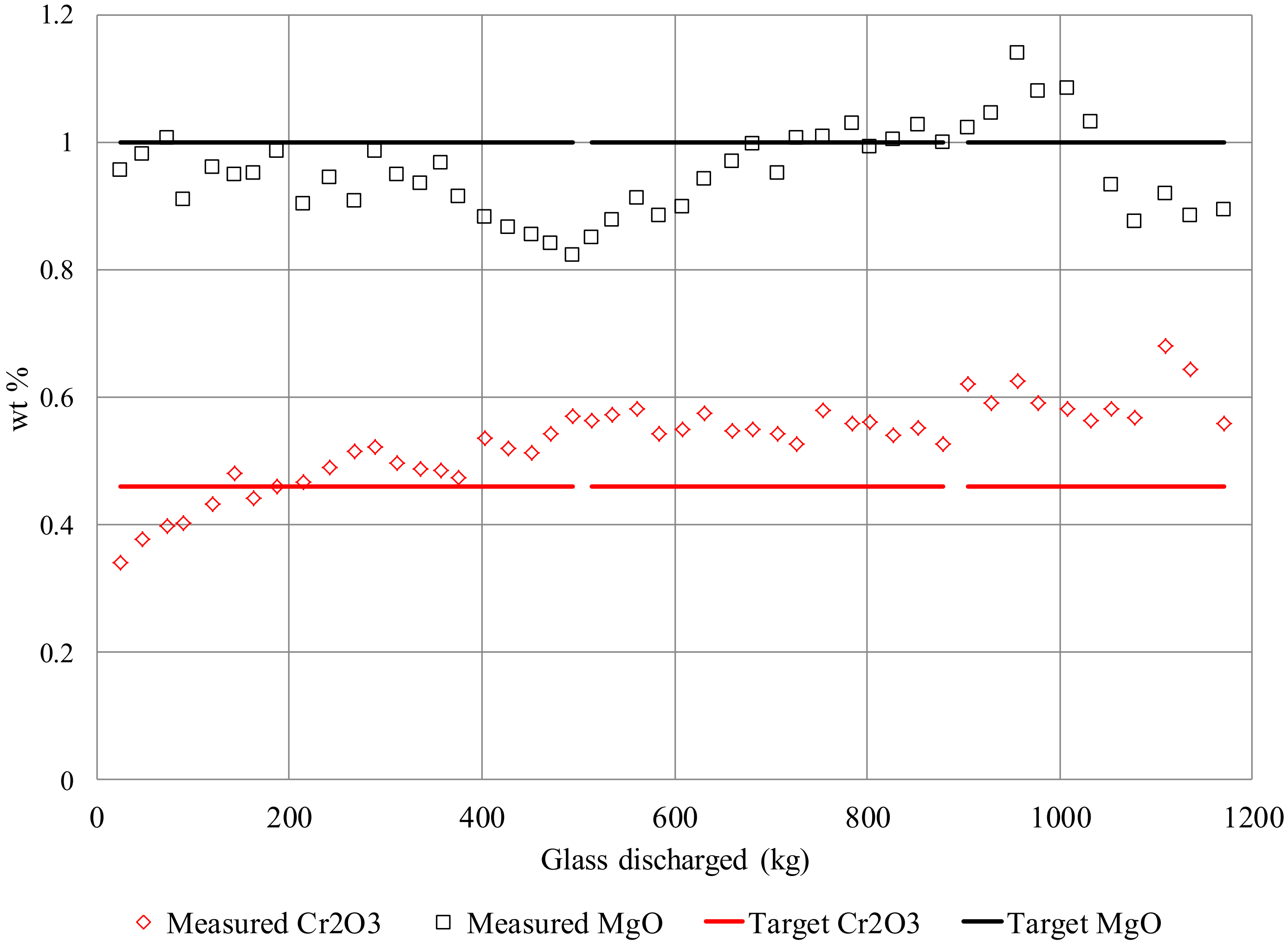

Figure 5.5. XRF analysis of chromium and magnesium oxides in DM100 product glasses.

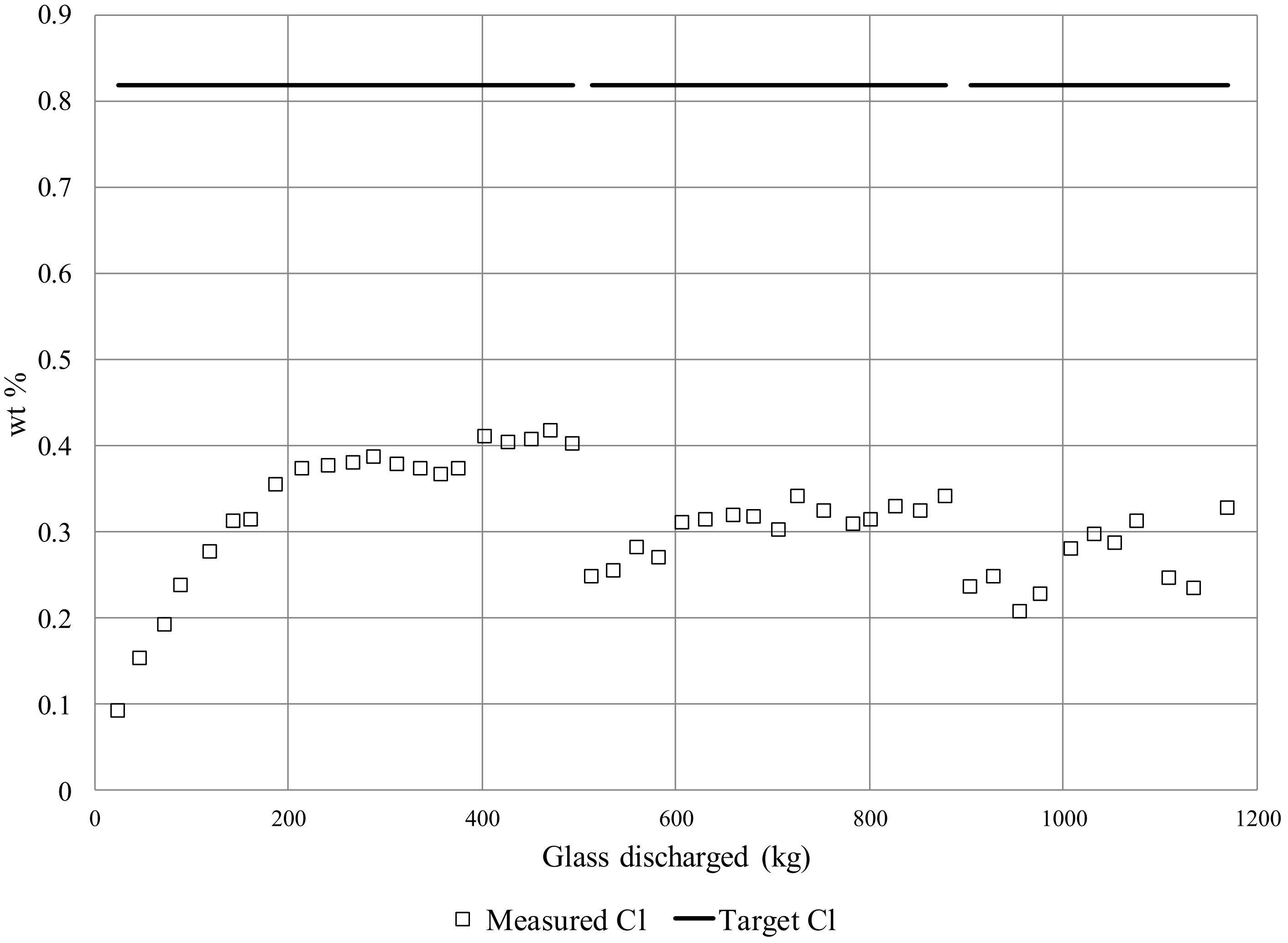

Figure 5.6. XRF analysis of chlorine in DM100 product glasses.

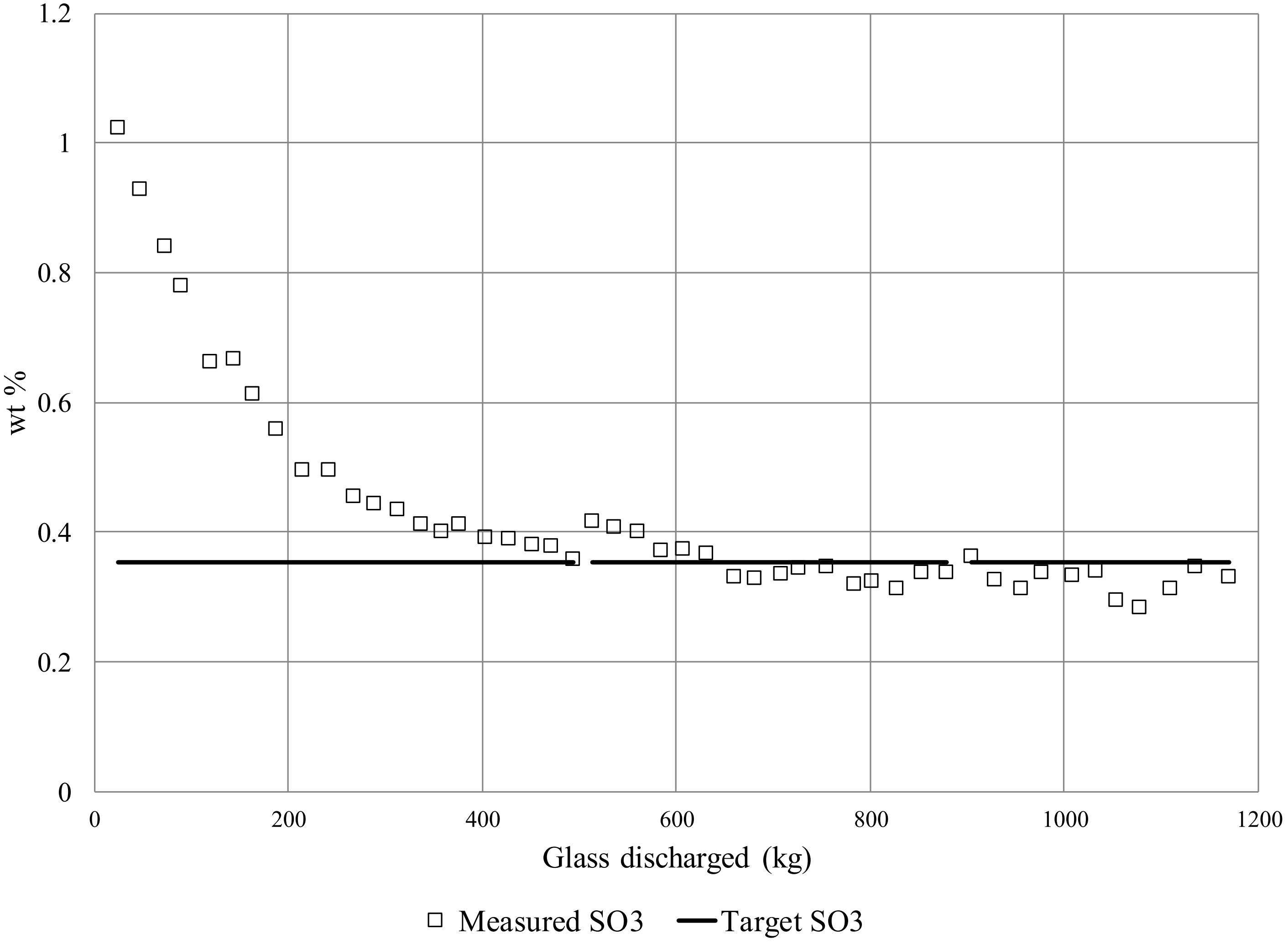

Figure 5.7. XRF analysis of sulfur in DM100 product glasses.

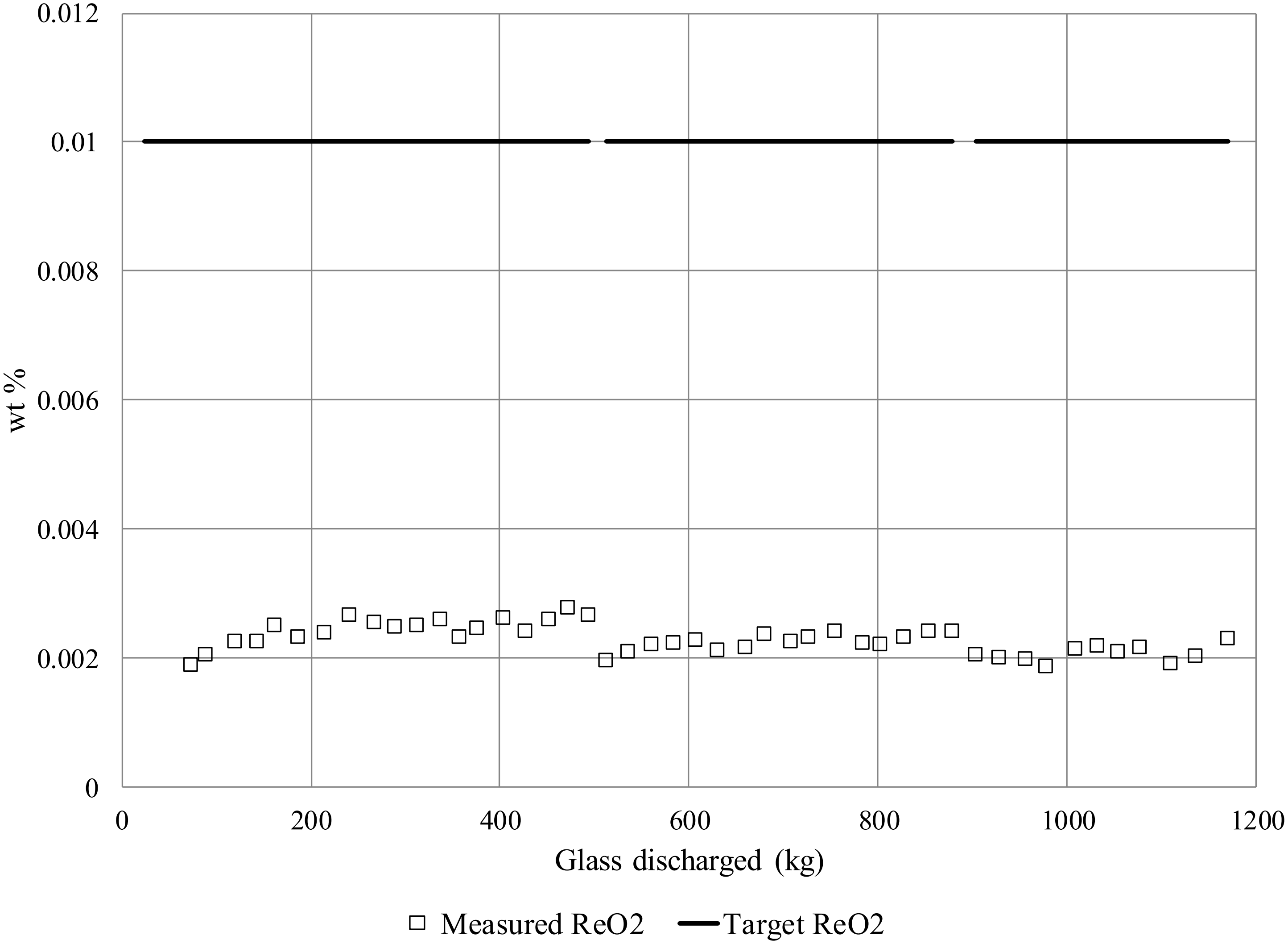

Figure 5.8. XRF analysis of rhenium in DM100 product glasses (values for first two discharge glasses below detectable limits thus not shown).

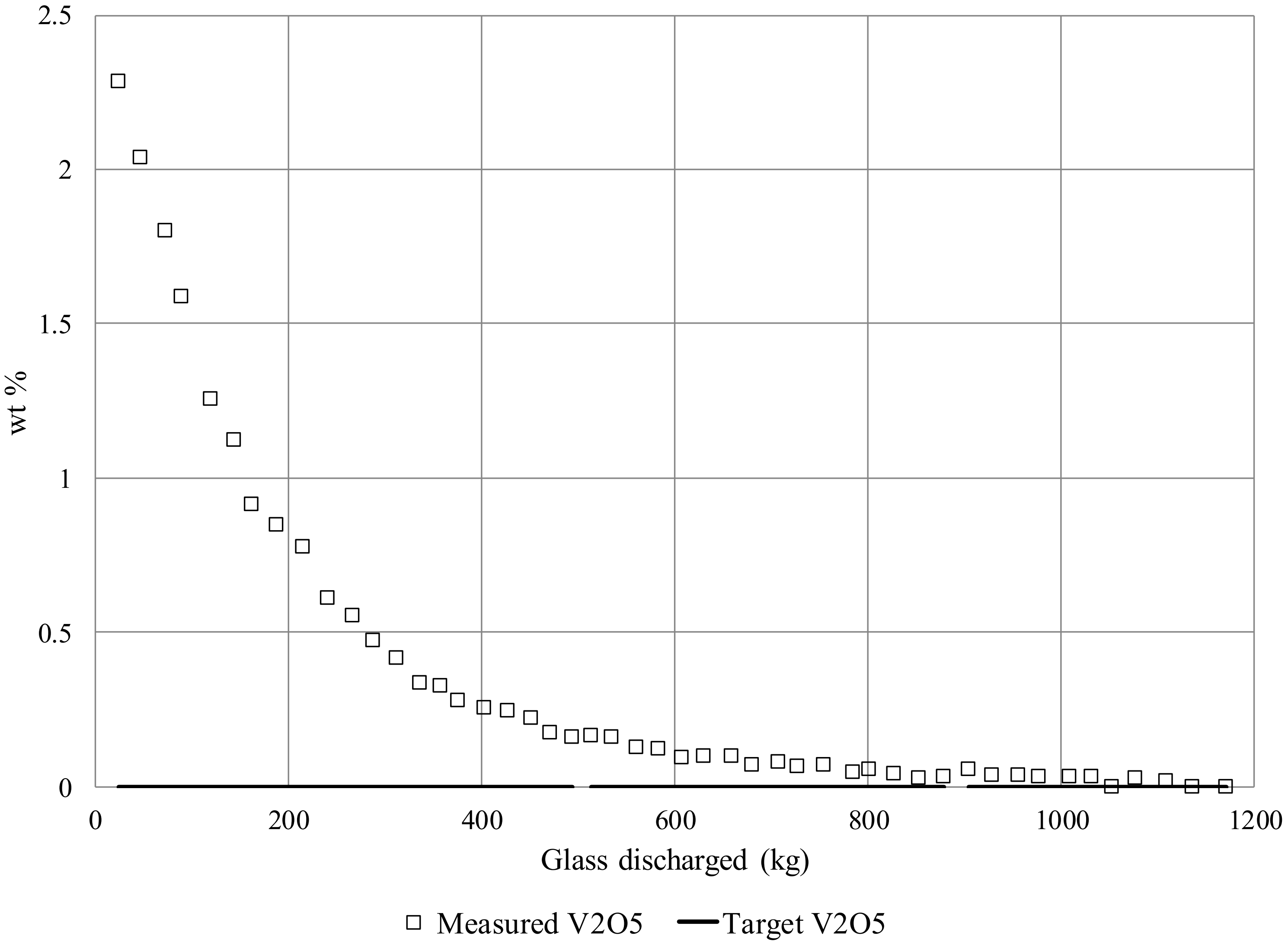

Figure 5.9. XRF analysis of vanadium in DM100 product glasses.

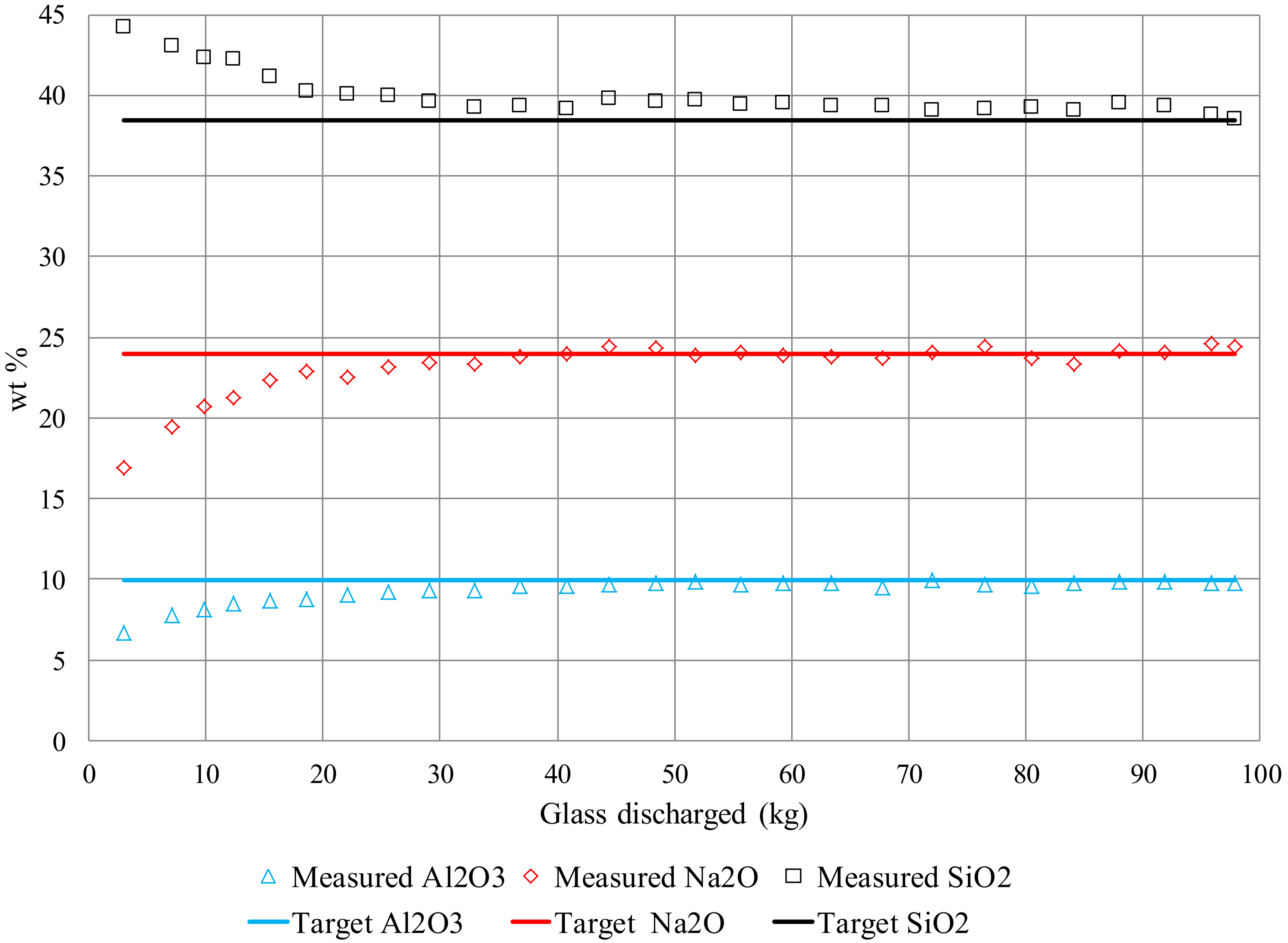

Figure 5.10. XRF analysis of silicon, sodium, and aluminum oxides in DM10 product glasses.

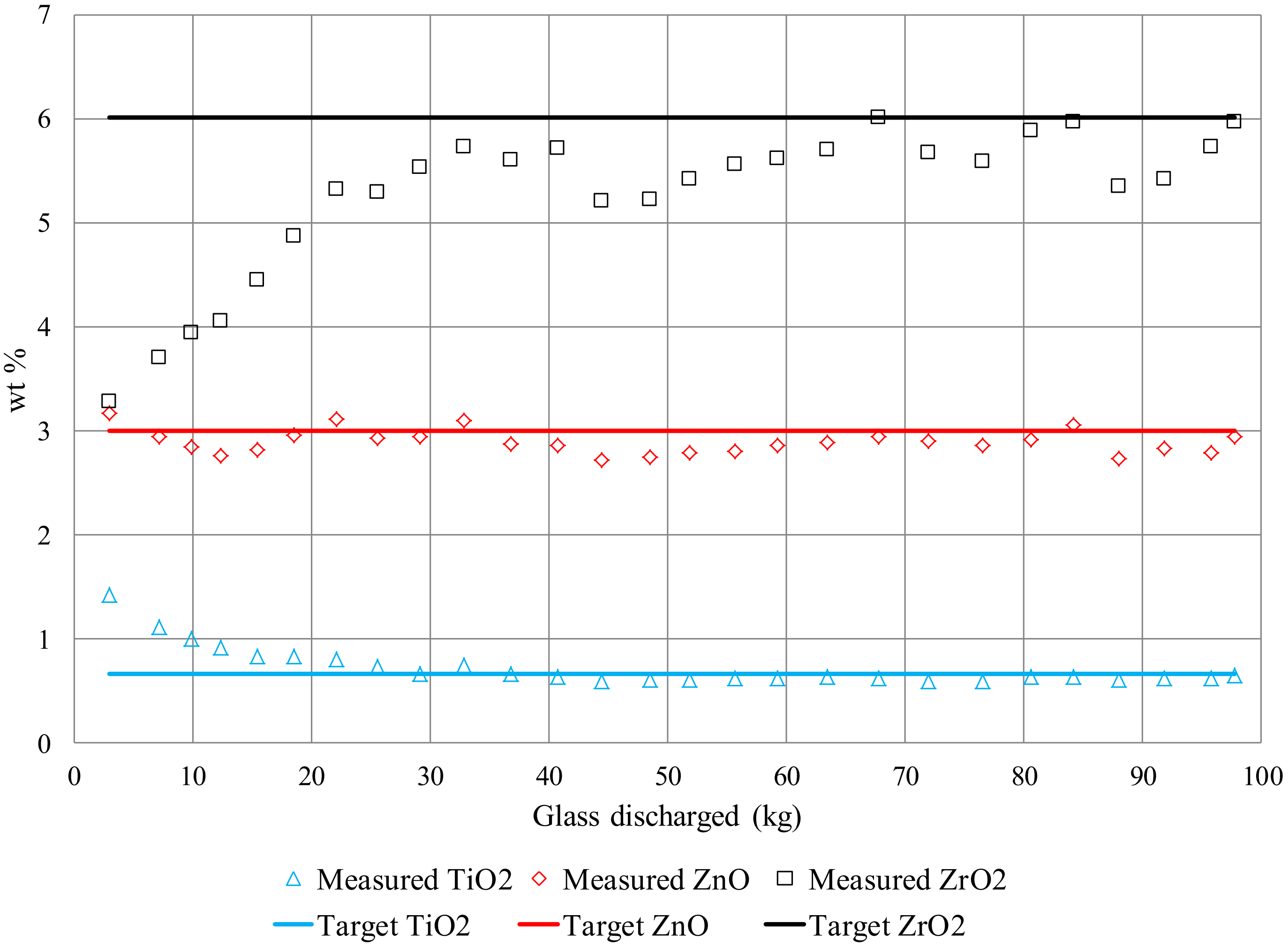

Figure 5.11. XRF analysis of titanium, zinc, and zirconium oxides in DM10 product glasses.

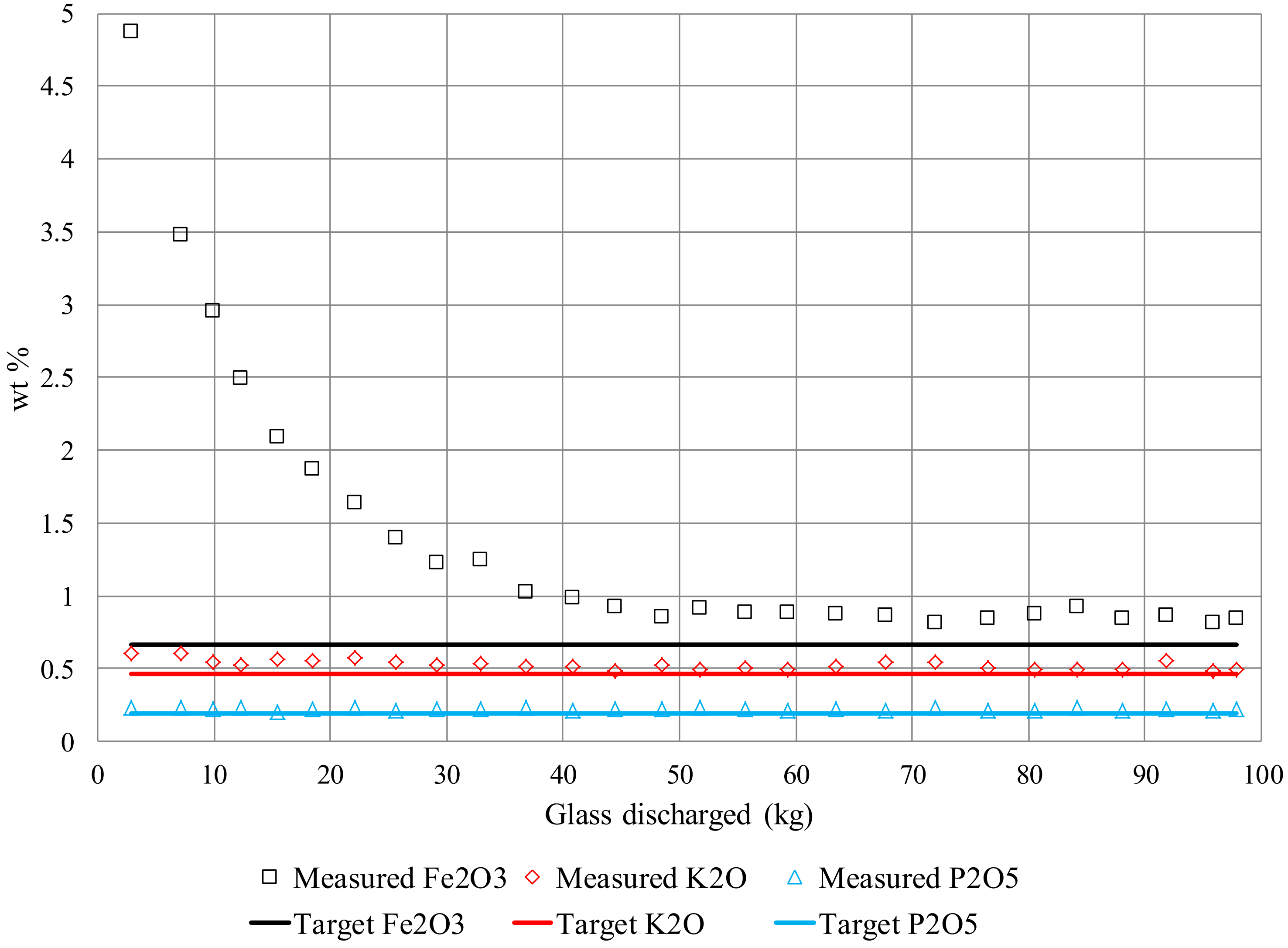

Figure 5.12. XRF analysis of iron, potassium, and phosphorus oxides in DM10 product glasses.

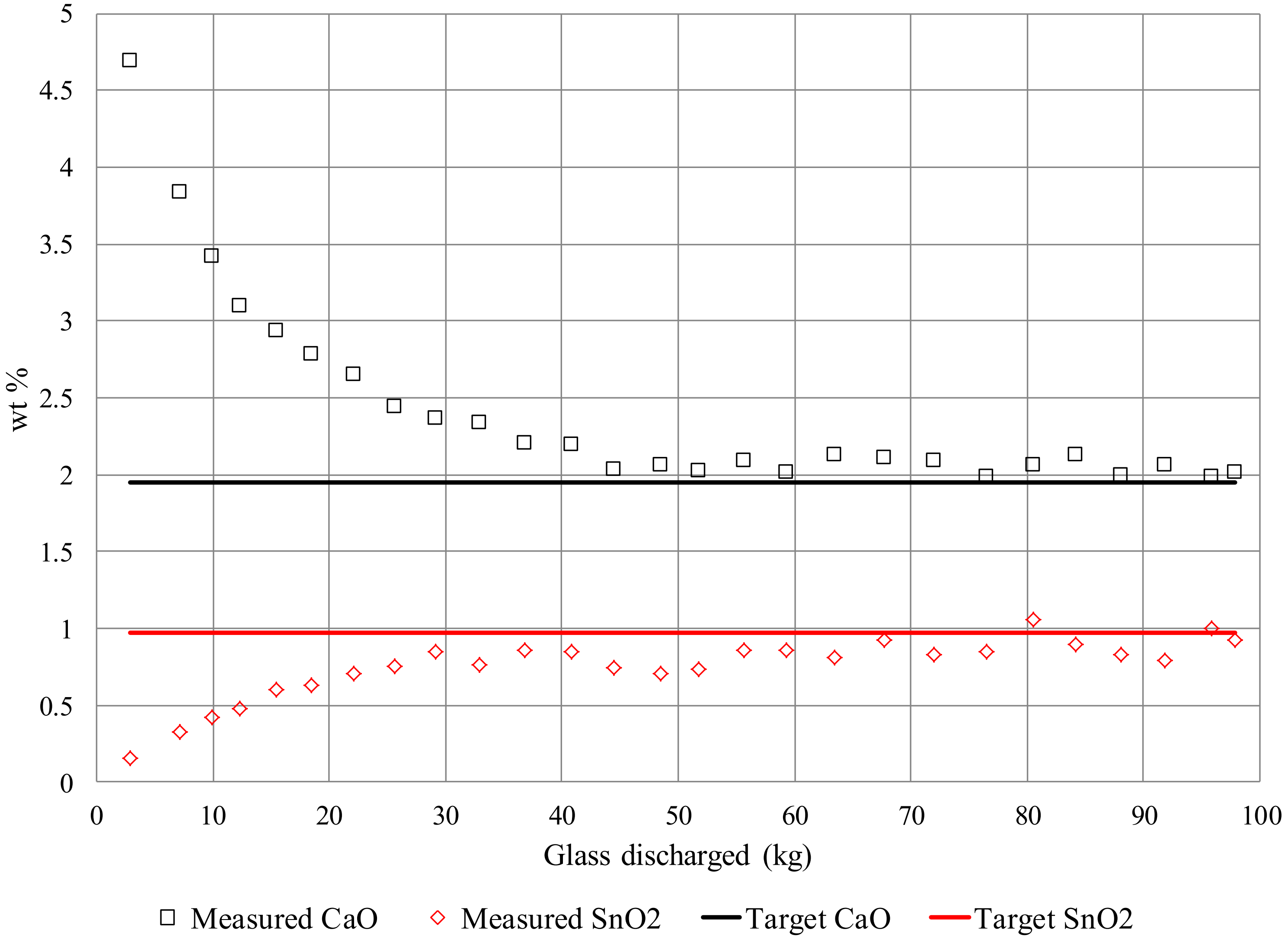

Figure 5.13. XRF analysis of calcium and tin oxides DM10 product glasses.

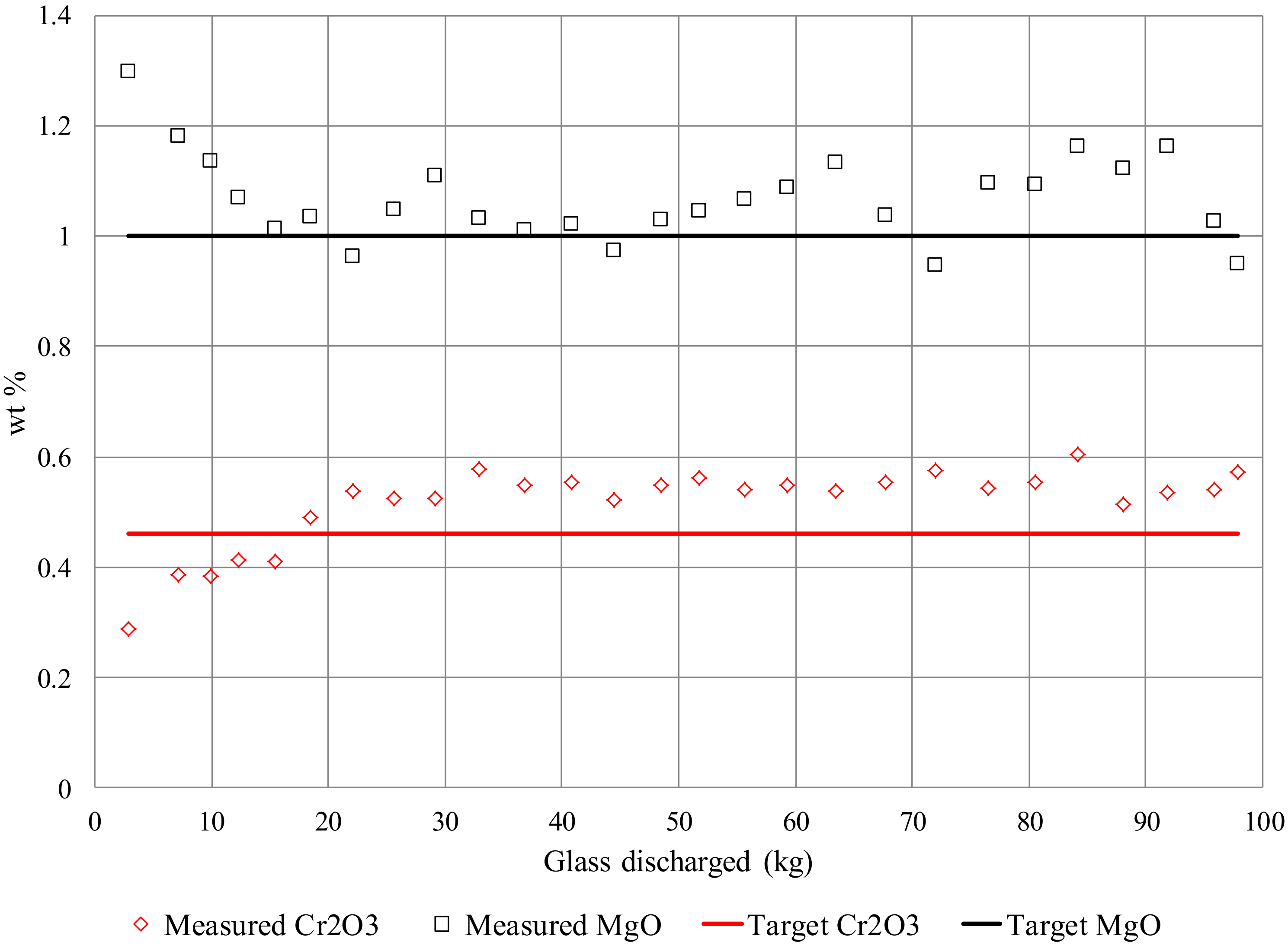

Figure 5.14. XRF analysis of chromium and magnesium oxides DM10 product glasses.

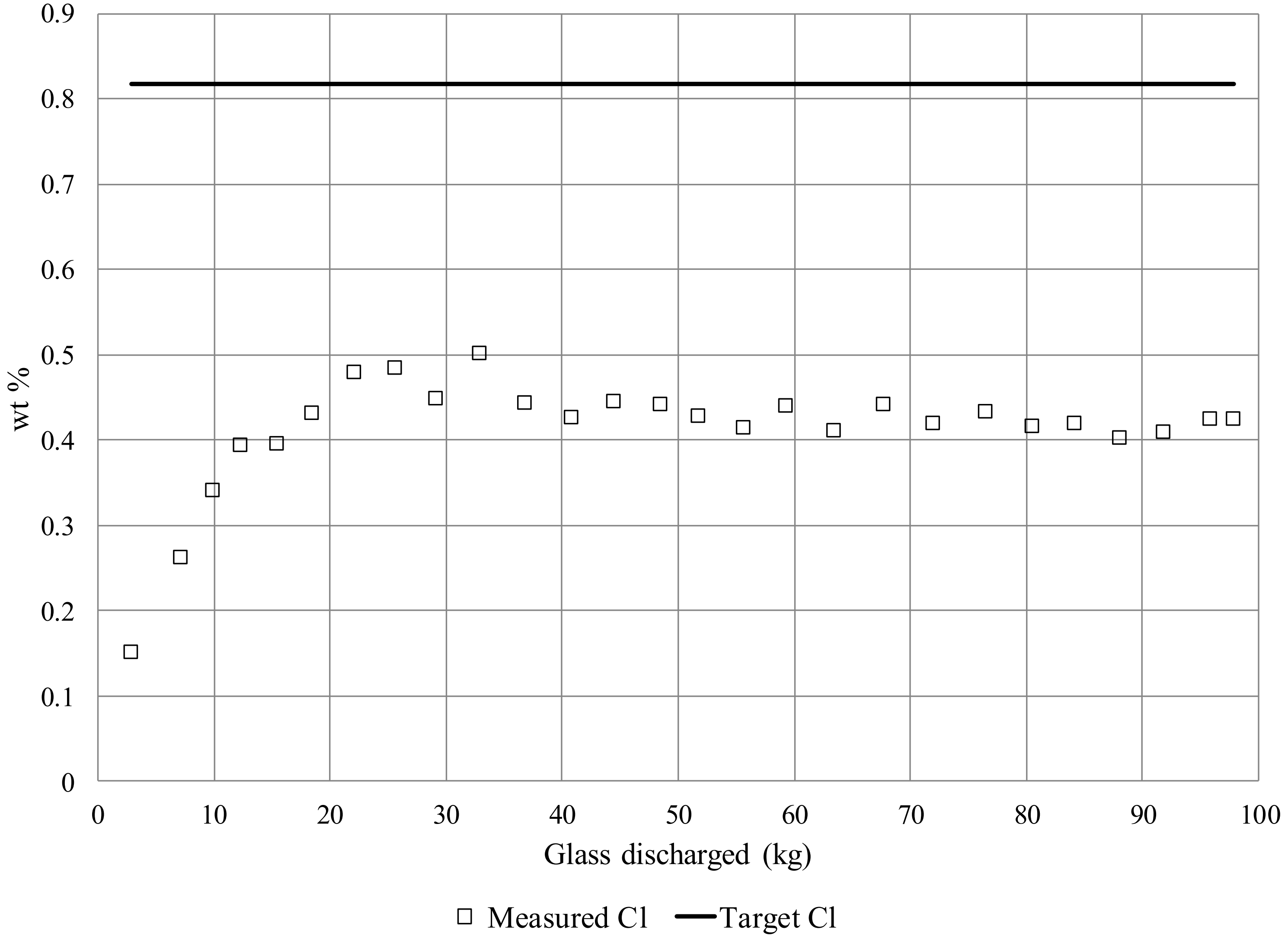

Figure 5.15. XRF analysis of chlorine in DM10 product glasses.

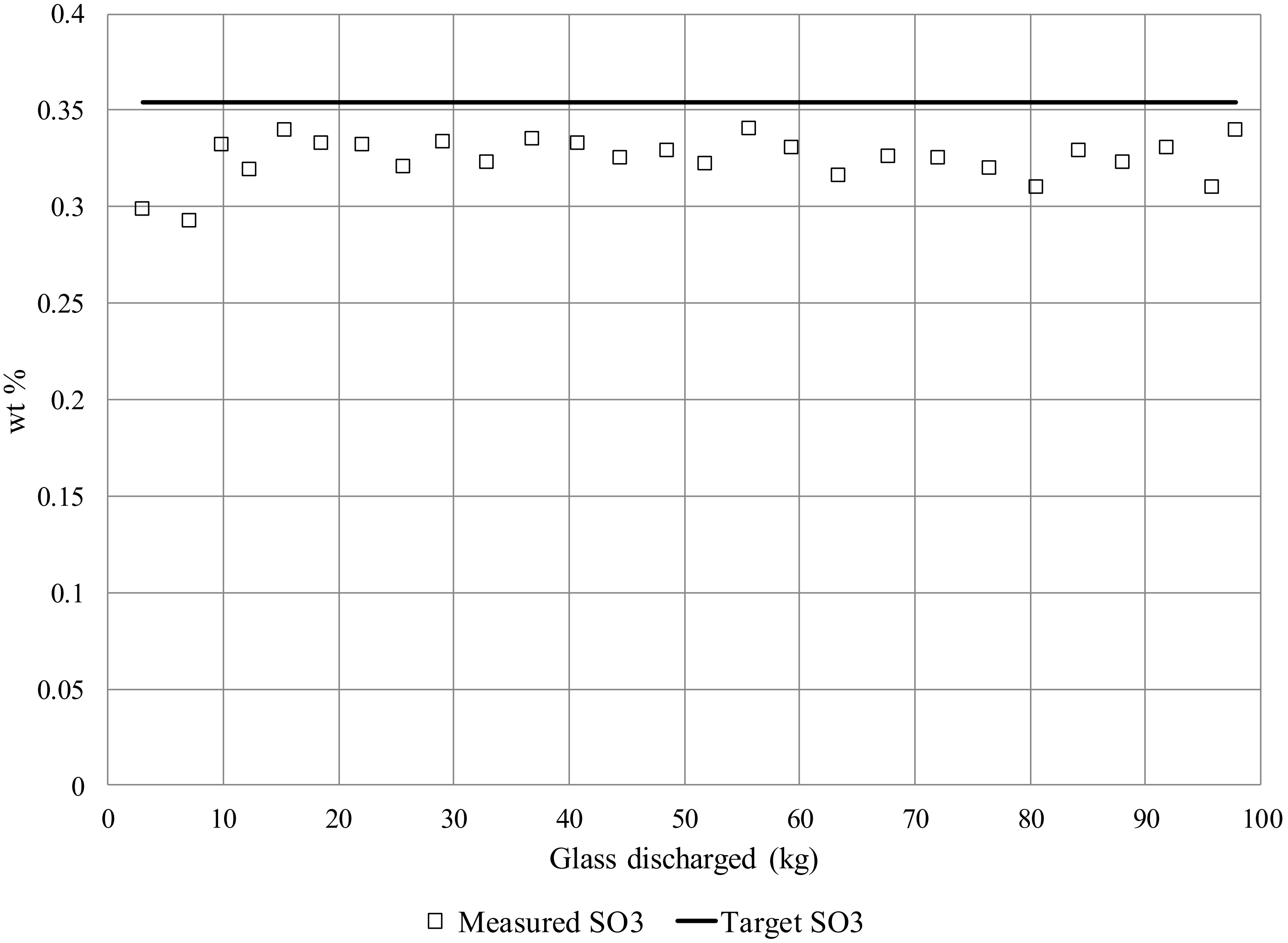

Figure 5.16. XRF analysis of sulfur in DM10 product glasses.

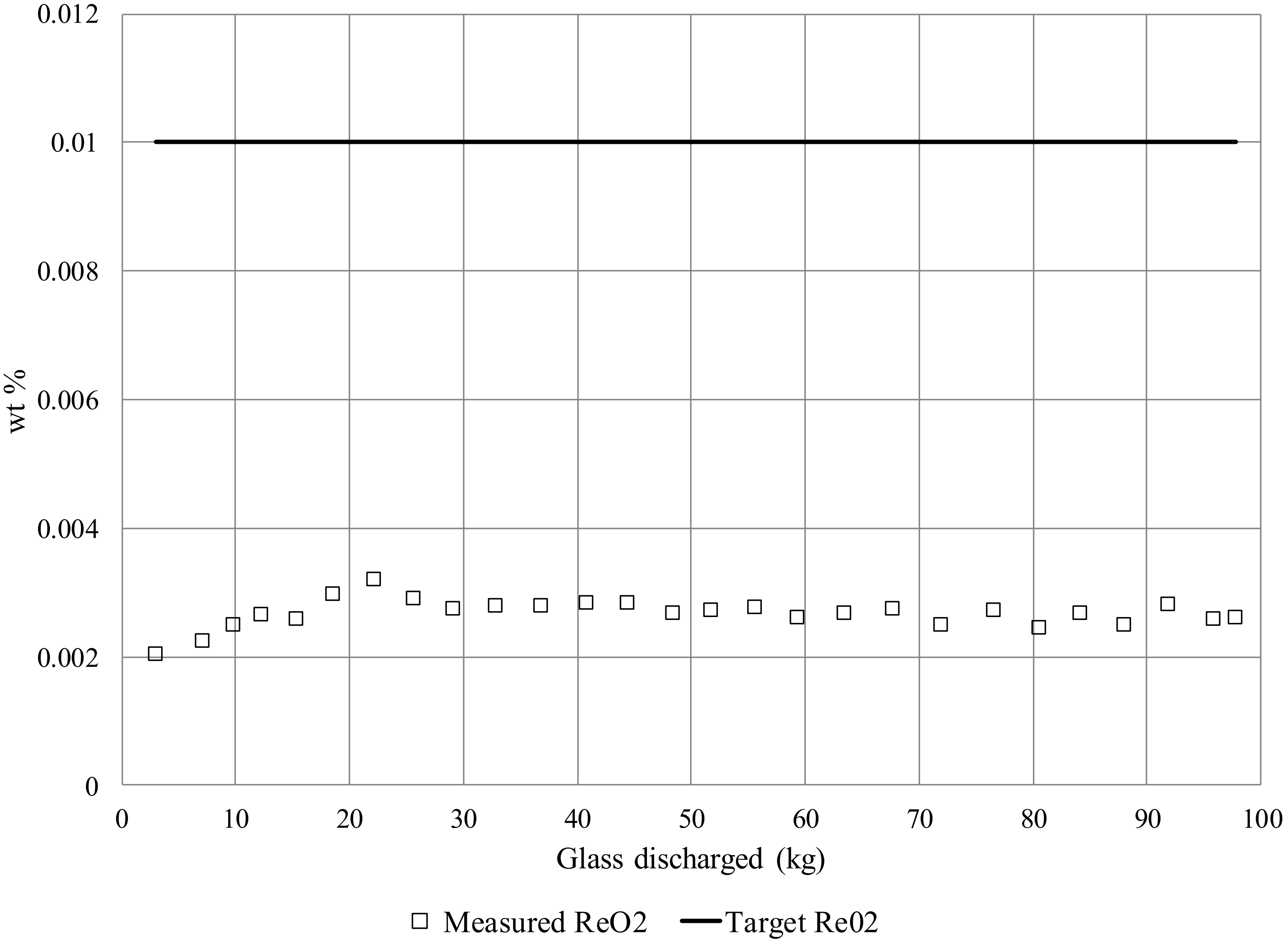

Figure 5.17. XRF analysis of rhenium in DM10 product glasses.

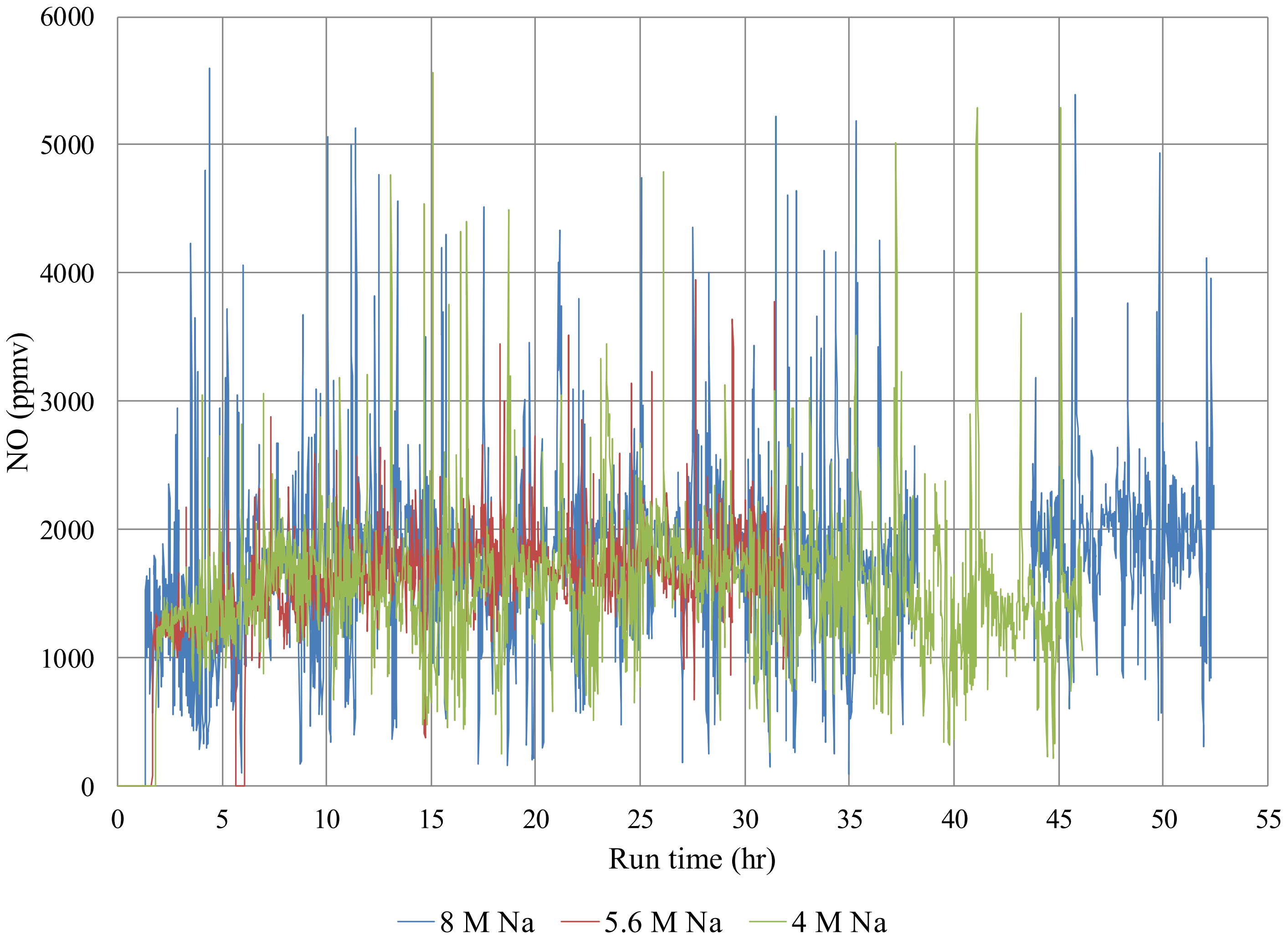

Figure 6.1. Nitrogen monoxide concentrations in off-gas from FTIR during DM100 tests.

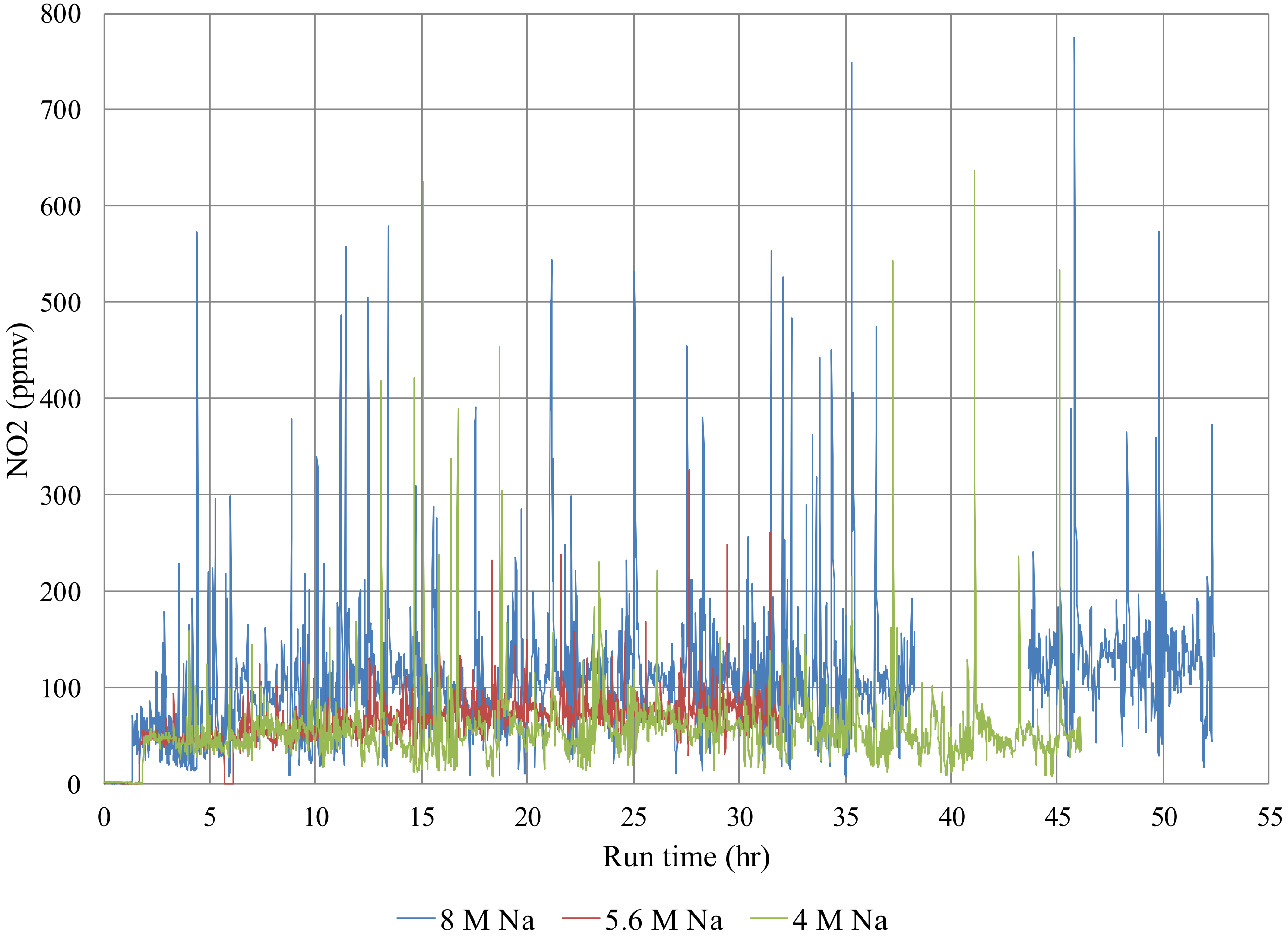

Figure 6.2. Nitrogen dioxide concentrations in off-gas from FTIR during DM100 tests.

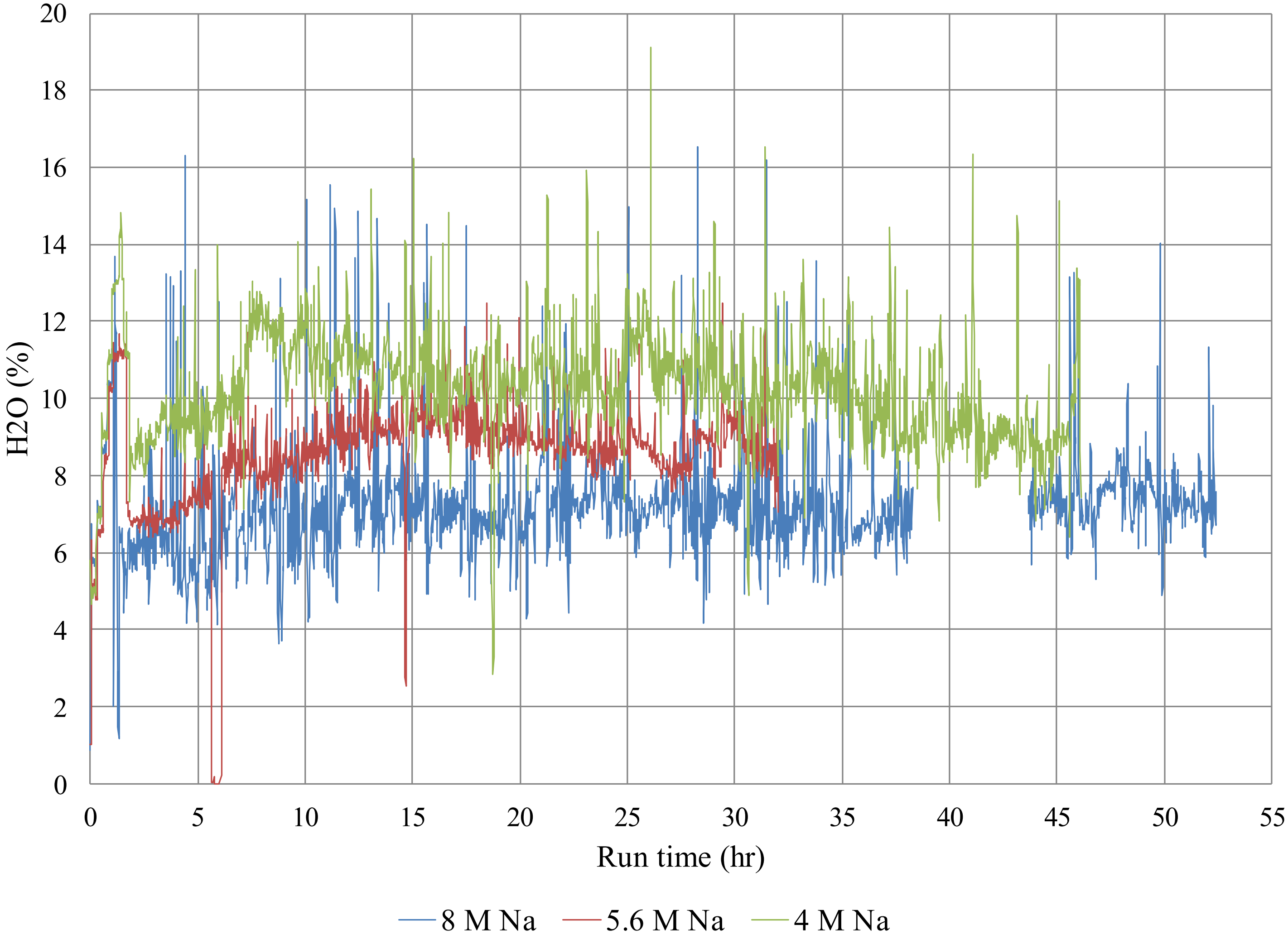

Figure 6.3. Water concentration in off-gas from FTIR during DM100 tests.

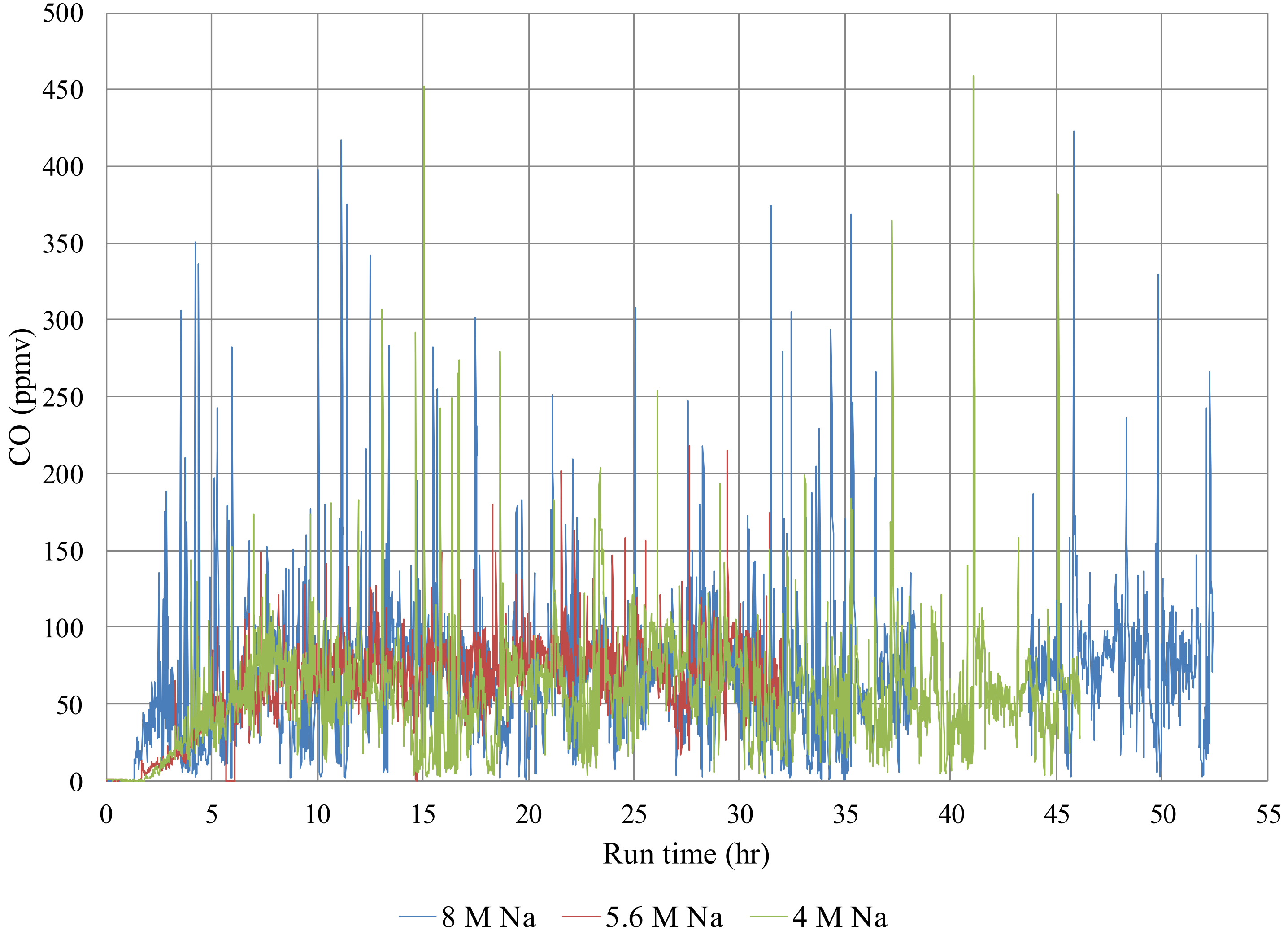

Figure 6.4. Carbon monoxide concentration in off-gas from FTIR during DM100 tests.

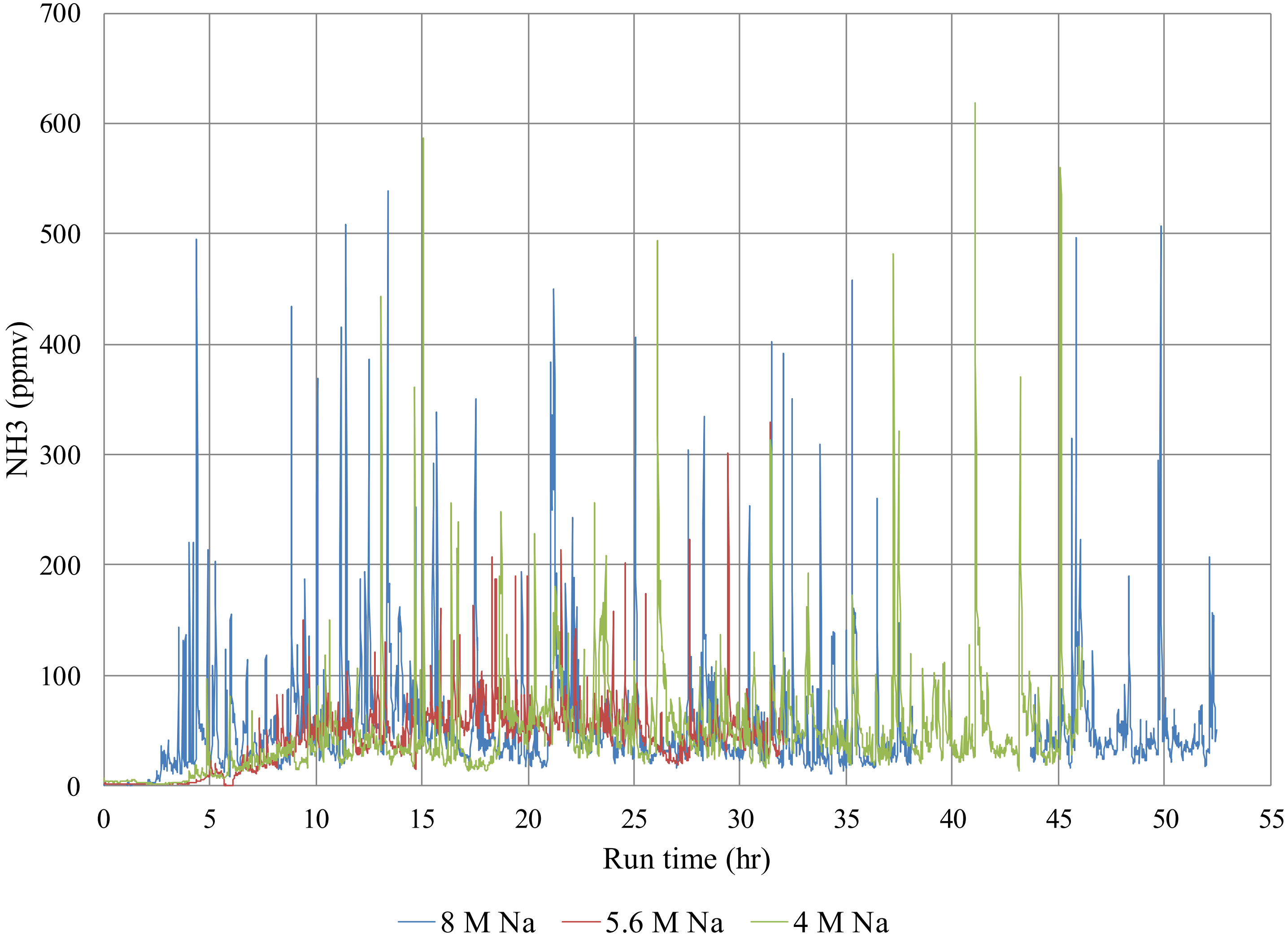

Figure 6.5. Ammonia concentration in off-gas from FTIR during DM100 tests.

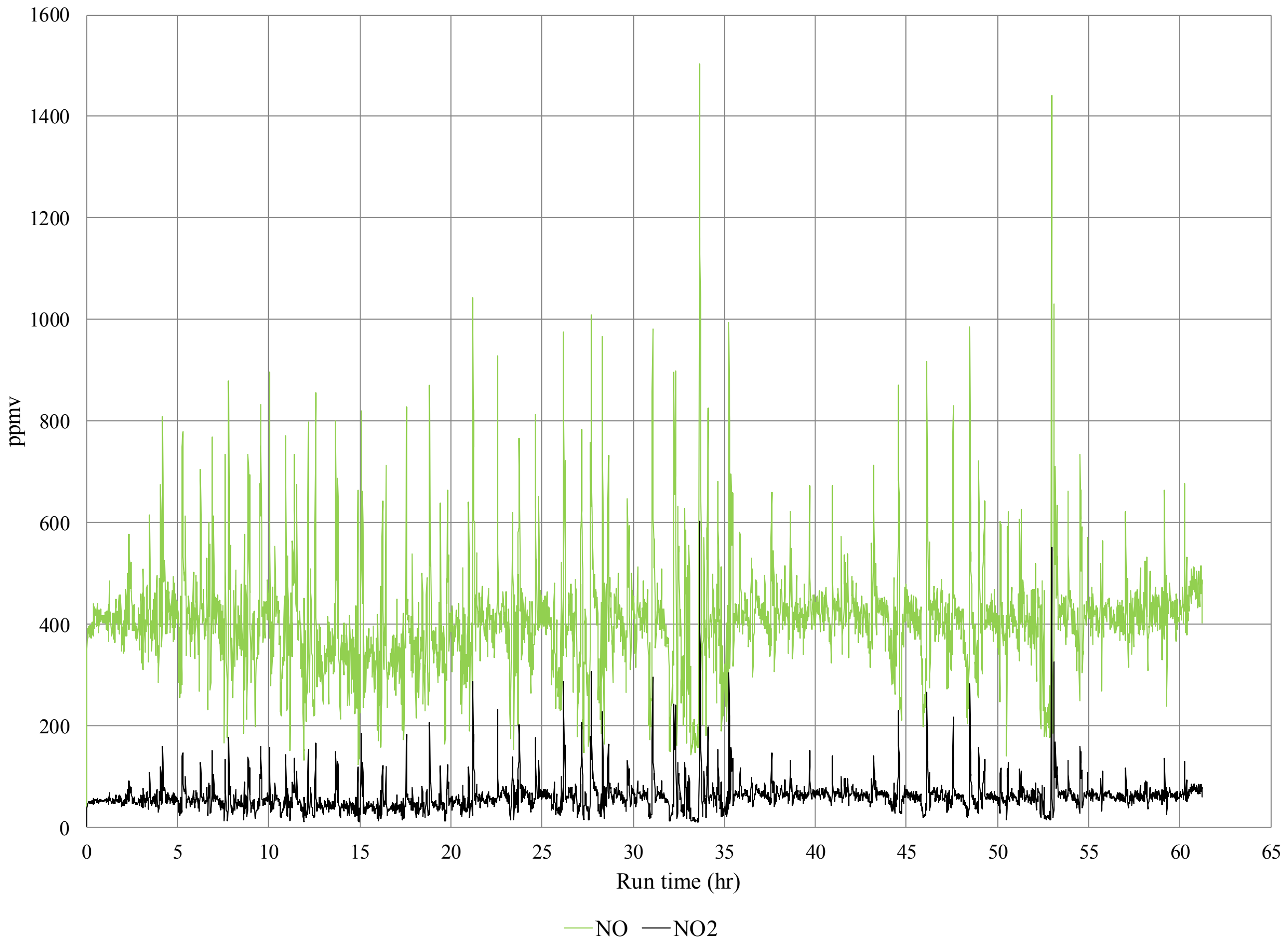

Figure 6.6. Nitrogen oxide concentrations in DM10 off-gas system exhaust measured by FTIR.

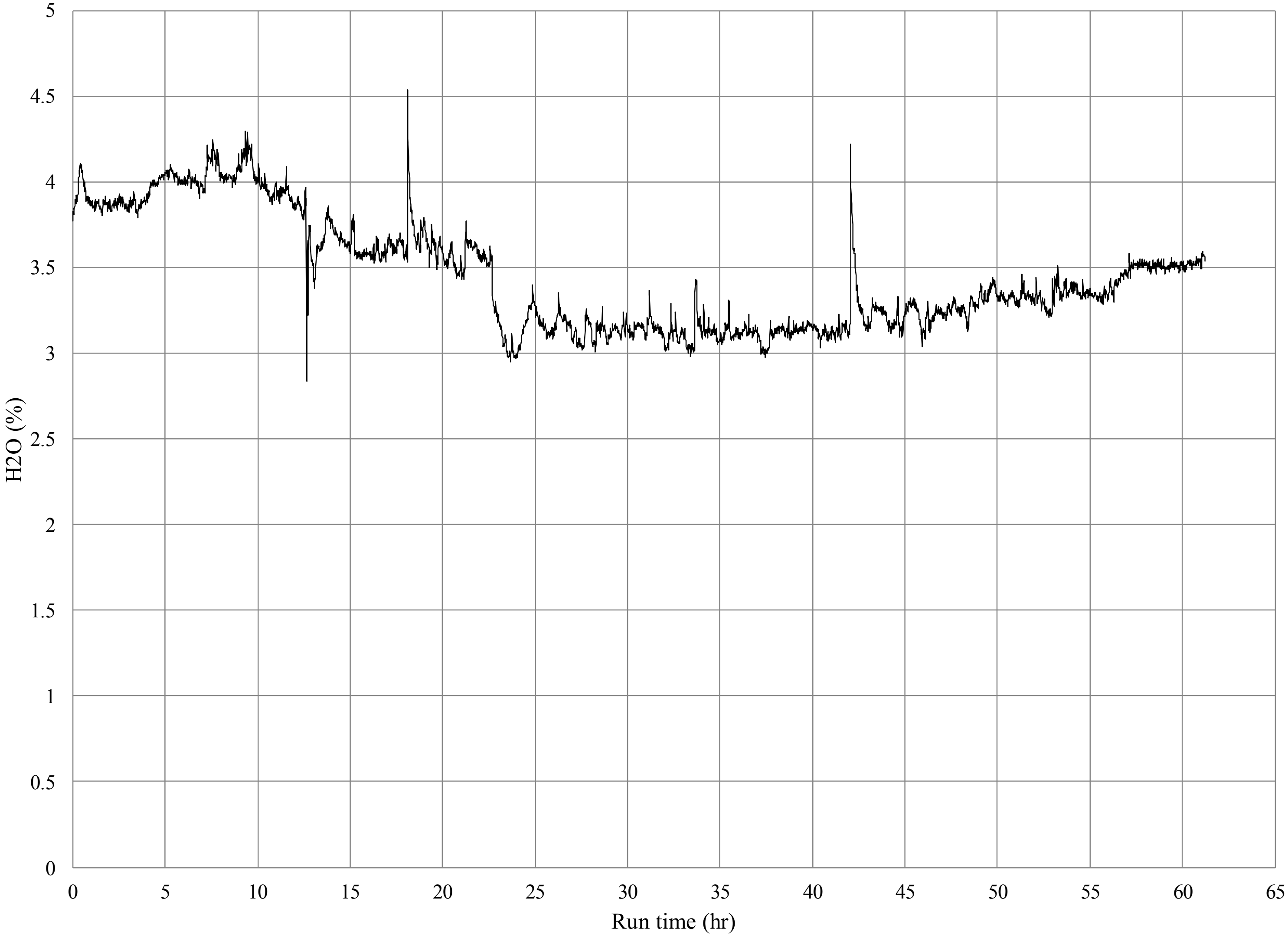

Figure 6.7. Moisture in DM10 off-gas system exhaust measured by FTIR.

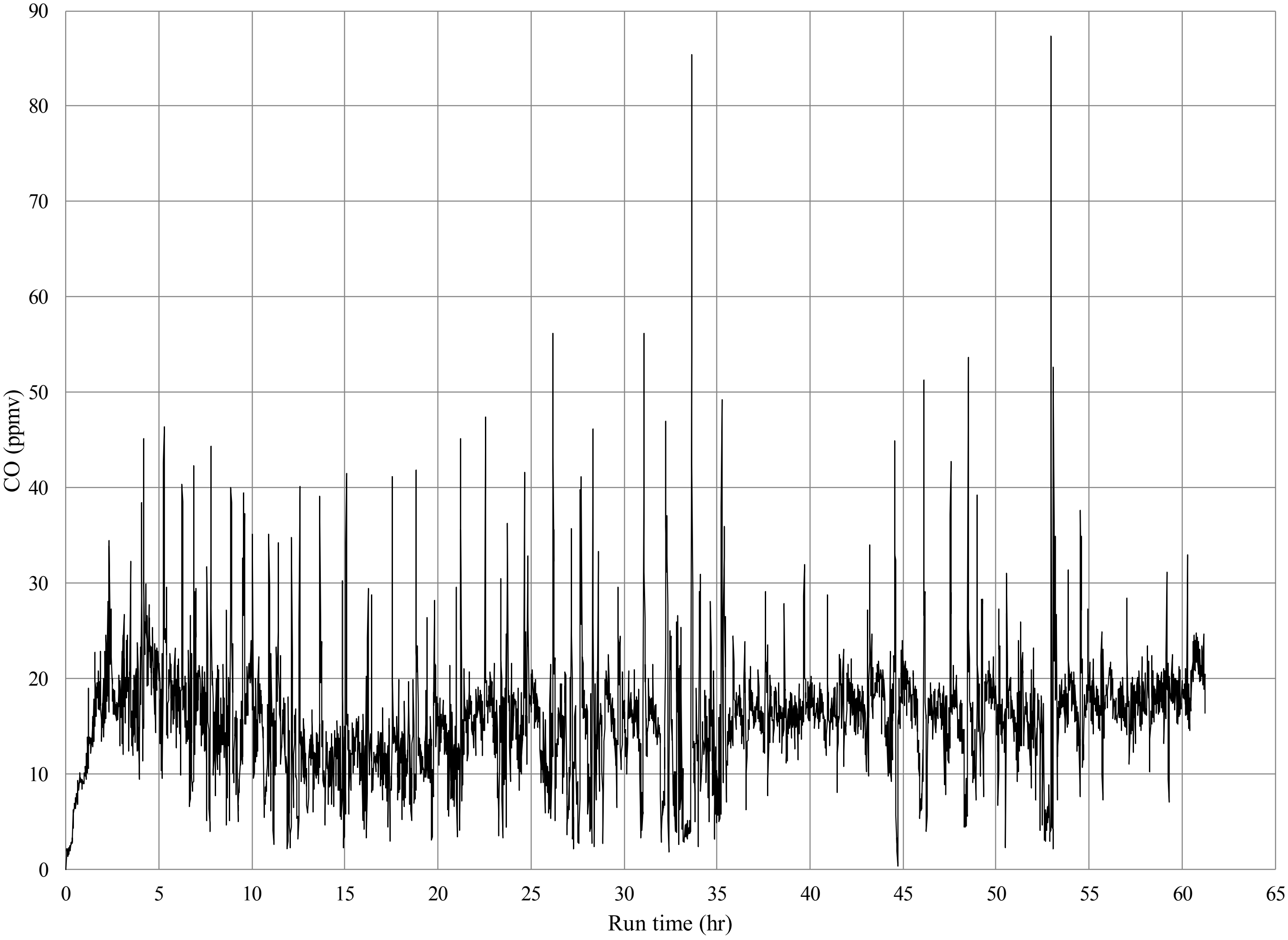

Figure 6.8. Carbon monoxide concentrations in DM10 off-gas system exhaust measured by FTIR.

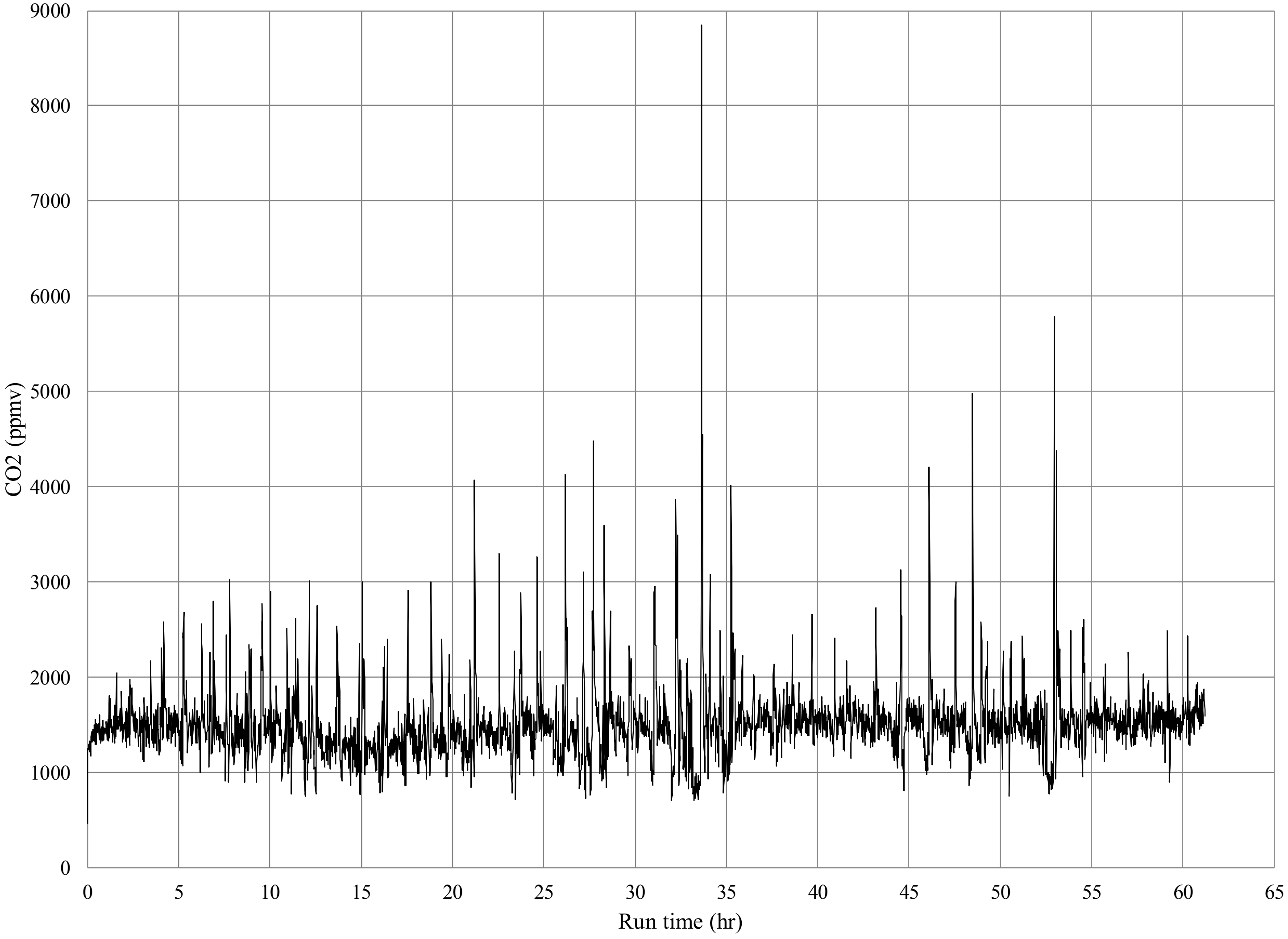

Figure 6.9. Carbon dioxide concentrations in DM10 off-gas system exhaust measured by FTIR.

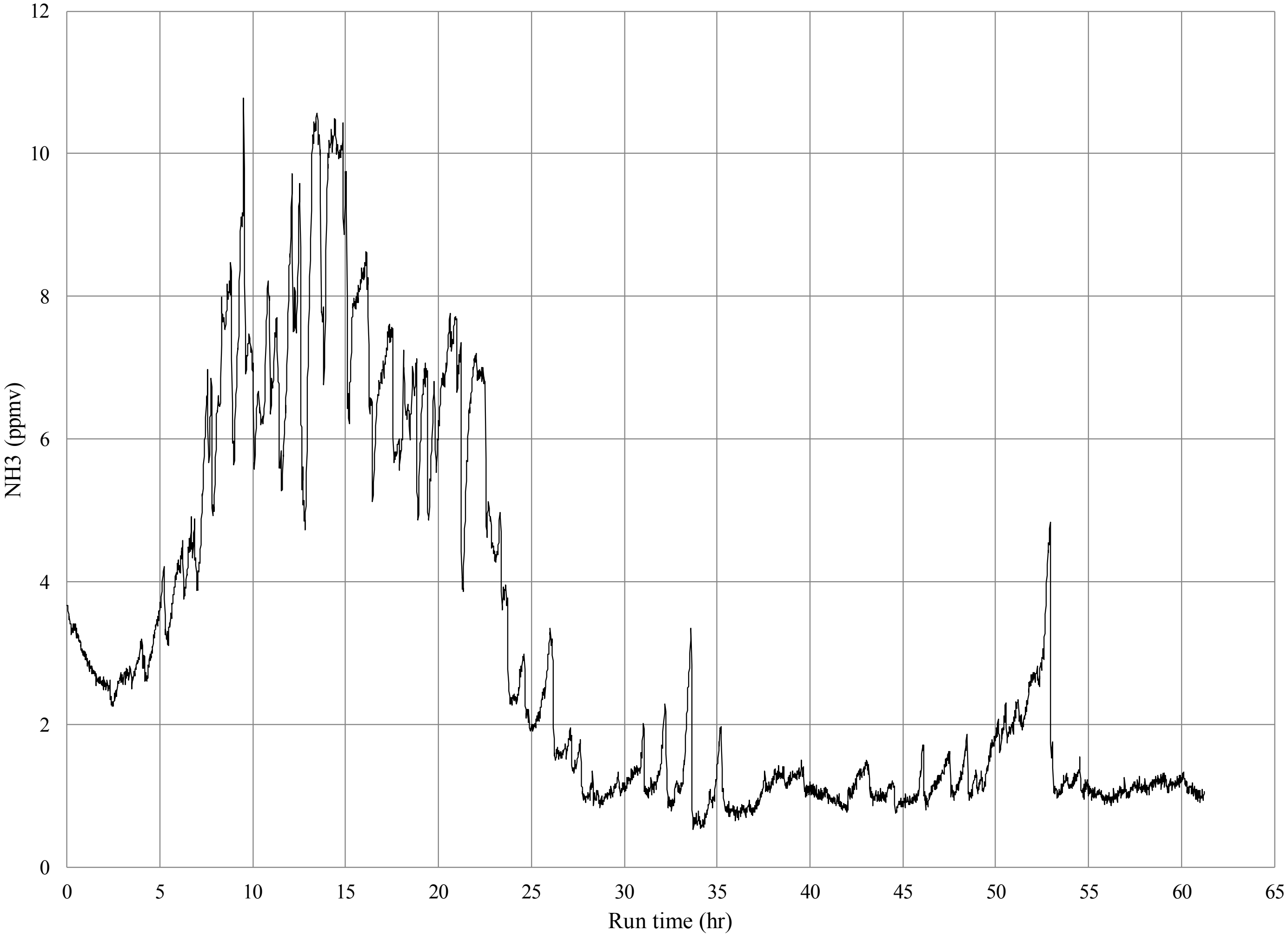

Figure 6.10. Ammonia concentrations in DM10 off-gas system exhaust measured by FTIR.