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Support for HLW Direct Feed, VSL-14R3090-1

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 HLW Direct Feed

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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.

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TABLE OF CONTENTS

List of Tables

List of Figures

List of Abbreviations

ASME	American Society of Mechanical Engineers
ANL-LRM	Argonne National Laboratory – Low Activity Waste Reference Material
CCC	Canister Center Line Cooling
DCP-AES	Direct Current Plasma Atomic Emission Spectroscopy
DF	Decontamination Factor
DM	DuraMelter
DOE	Department of Energy
DWPF	Defense Waste Processing Facility
EA	Environmental Assessment
EDS	Energy Dispersive X-Ray Spectroscopy
FTIR	Fourier Transform Infrared Spectroscopy
IC	Ion Chromatography
HEPA	High-Efficiency Particulate Air Filter
HLW	High Level Waste
LAW	Low Activity Waste
NIST	National Institute of Standards and Technology
ORP	Office of River Protection
PCT	Product Consistency Test
NQA	Nuclear Quality Assurance
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
SEM	Scanning Electron Microscopy
SOP	Standard Operating Procedure
TCLP	Toxicity Characteristic Leaching Procedure
TOE	Total Operating Efficiency
UTS	Universal Treatment Standard
VGF	Vertical Gradient Furnace
VSL	Vitreous State Laboratory
WTP	Hanford Tank Waste Treatment and Immobilization Plant
XRF	X-Ray Fluorescence Spectroscopy

SECTION 1.0
INTRODUCTION

This report describes work performed to develop and test new glass and feed formulations originating from a potential flow-sheet for the direct vitrification of High Level Waste (HLW) with minimal or no pretreatment. In the HLW direct feed option that is under consideration for early WTP operations, the pretreatment facility would be bypassed in order to support an earlier start-up of the vitrification facility. For HLW, this would mean that the ultrafiltration and caustic leaching operations that would otherwise have been performed in the pretreatment facility would either not be performed or would be replaced by an interim pretreatment function (in-tank leaching and settling, for example). These changes would likely affect glass formulations and waste loadings and have impacts on the downstream vitrification operations. Modification of the pretreatment process may result in: (i) Higher aluminum contents if caustic leaching is not performed; (ii) Higher chromium contents if oxidative leaching is not performed; (iii) A higher fraction of supernate in the HLW feed resulting from the lower efficiency of in-tank washing; and (iv) A higher water content due to the likely lower effectiveness of in-tank settling compared to ultrafiltration. The initial efforts reported here focused on the impacts of increased supernate and water content on wastes from one of the candidate source tanks for the direct feed option.

A series of waste compositions was investigated that span the range of washing efficiencies between the baseline WTP full-wash case and the no-wash case. Crucible melts were formulated and tested to investigate the effects on glass compositions and waste loadings. Based on those results, two intermediate-wash options were selected for subsequent testing on the DM100 melter system. These tests assessed impacts on processability and melt rates as well as the need for redox control resulting from the higher levels of nitrates from the increased supernate fraction. Off-gas data were collected to assess the potential impacts of increased NOx generation on the WTP HLW facility. The DM100 tests were also conducted on representative HLW feeds at solids contents extending below the current WTP baseline, which are likely for the direct feed option. The effects on glass production rate, melter operations, and off-gas carryover were determined. In addition, the ability of increased bubbling to compensate for the increased evaporative load was investigated. These tests form the basis for subsequent larger-scale tests on the DM1200 HLW Pilot Melter, where the effects of enhanced bubbler configurations can also be investigated. This work built on previous work performed at the Vitreous State Laboratory (VSL) for the Department of Energy (DOE) to increase waste loadings in HLW glass formulations and processing rates [1-5].

Projections of the number of HLW canisters to be produced in the Hanford Tank Waste Treatment and Immobilization Plant (WTP) (e.g., [6]) are based upon the inventory of the tank wastes, the anticipated performance of the sludge treatment processes, and current understanding of the capability of the borosilicate glass waste form. The WTP HLW melter design, unlike earlier DOE melter designs, incorporates an active glass bubbler system. The bubblers provide active glass pool mixing and thereby improve heat transfer and glass melting rate. The WTP

HLW melters each have a glass surface area of 3.75 m^2 and depth of ~1.1 m. The two melters in the HLW facility together are designed to produce up to 7.5 MT of glass per day at 100% availability. Further increases in HLW waste processing rates can potentially be achieved by optimization of the feed and glass formulations, increasing the melter operating temperature above 1150°C, and by increasing the waste loading in the glass product. Increasing the waste loading also has the added benefit of decreasing the number of canisters for storage.

The baseline WTP estimates and glass formulation efforts have been conservative in terms of achievable waste loadings. These baseline formulations have been specified to ensure that the glasses are homogenous, contain essentially no crystalline phases, are processable in joule-heated, ceramic-lined melters and meet WTP Contract terms. The overall WTP mission will require the immobilization of tank waste compositions that are dominated by mixtures of aluminum, chromium, bismuth, iron, phosphorous, zirconium, and sulfur compounds as waste-loading-limiting components. In order to improve waste loadings, DOE previously initiated a testing program to develop and characterize HLW glasses for wastes that are limited by Al, Al plus Na, Bi, and Cr [6, 7]. Results of that work demonstrated the feasibility of increases in waste loadings from about 25 wt% to 33-50 wt% (based on oxide loading) in the glass, depending on the waste stream. It is expected that these higher waste loading glasses will reduce the HLW canister production requirement by about 25% or more [5]. Furthermore, it has been shown that a key technological risk area relates to the strong dependence of glass production rate on waste composition [5]. The extent of this variation across the full spectrum of HLW waste types needs to be quantified in order to accurately project waste treatment rates.

Under a separate contract with BNI to support the WTP, VSL has developed and tested glass formulations for WTP HLW waste compositions to provide data to meet the WTP contract requirements and to support system design activities [8-14]. That work was based upon small-scale batch melts ("crucible melts") using waste simulants. Selected formulations were also tested in small-scale, continuously fed, joule-heated melters (DM100 and DM1200) [8, 15-20]. That testing was directed towards waste streams from the then-planned early feed tanks for the WTP (i.e., AZ-101, AZ-102, C-106/AY-102, and C-104/AY-101). These wastes are high in iron (AZ-101, AZ-102 and C-106/AY-102) or thorium (C-104/AY-101) and are significantly different than those used in more recent enhancement tests performed for ORP (i.e., wastes limited by Al, Al/Na, Bi, and Cr). Baseline glass formulations to treat these high-Fe wastes were developed under the BNI contract. During that time, the throughput requirement for the HLW melter was initially 400 kg/(m^2·day), which was subsequently increased to 800 kg/(m^2·day). As a result, the baseline high-Fe HLW glass formulations for WTP perform only slightly better than the 800 kg/(m^2·day) processing rate requirement. Furthermore, the baseline waste loadings for the Fe-limited HLW compositions are only slightly higher than the BNI contract minimum. Since that time, in work performed for ORP on other HLW compositions, VSL has developed small-scale test methods to assess processing rates of melter feeds and included them as an integral part of glass formulation development. This methodology was used successfully to develop glass formulations for high-Al Hanford HLW that showed processing rates in excess of 2000 kg/(m^2·day) and high-Fe Hanford HLW that showed processing rates as high as 1900 kg/(m^2·day) while achieving high waste loadings. The same methodology can be applied to the development of improved glass formulations for other Hanford HLW in order to provide ORP with a significantly more robust operating envelope with reduced risk of throughput shortfalls. These substantial increases in waste processing rates also have the potential to at least partially mitigate melt rate decreases caused by the likely lower solids contents in HLW feeds generated by the direct feed option.

1.1 Test Objectives

The primary objective of this work was to develop and identify HLW glass compositions and glass forming additive blends for vitrification of a direct-feed HLW stream that has undergone various degrees of washing with no other pretreatment, while maintaining high waste loadings, high processing rates, and acceptable glass properties. This was accomplished through a combination of crucible-scale tests, vertical gradient furnace tests, and confirmation tests on the DM100 melter system. The tests were performed according to the Test Plan that was developed for this work [21].

1.2 Quality Assurance

This work was conducted under a quality assurance program that is based on Nuclear Quality Assurance (NQA)-1 2004 and NQA-2a (1990) Part 2.7 that is in place at the VSL. The program is compliant with applicable criteria of 10 CFR 830.120; Office of Civilian Waste Management DOE/RW-0333P, Quality Assurance Requirements and Description (QARD) Revision 20; the American Society of Mechanical Engineers (ASME) NQA-1, 2004; and DOE Order 414.1 C, Quality Assurance. This program is supplemented by a Quality Assurance Project Plan (QAPP) for RPP-WTP work [22] that is conducted at VSL. 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 [23].

1.3 DM100 Melter System

1.3.1 DM100 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. A peristaltic pump is used in order to provide a uniform delivery of feed to the melt surface. Feed is directed from the recirculation loop that extends to the top of the melter and then diverted to the peristaltic pump, which regulates the flow of feed through a Teflon-lined feed line and water-cooled feed tube into the melter.

1.3.2 Melter System

Cross-sectional diagrams of the DM100-BL melter are shown in Figures 1.2.a-c. The DM100-BL unit is a ceramic refractory-lined melter fitted with five electrodes: two pairs of opposing Inconel 690 plate electrodes and a bottom electrode. Power can be supplied in either three-phase or single-phase configurations. All of the tests in the present work were performed with the upper and lower electrodes on each side connected together and powered by a single-phase supply; the bottom electrode was not powered. Melt pool agitation is achieved by either a removable lance entering from the top of the melter or a permanent bubbler installed through the bottom electrode. In these tests, the lance bubbler was used. The glass product is removed from the melter by means of an airlift discharge system. The melter has a melt surface area of 0.108 m^2 and a variable glass inventory of between 110 kg, when only the bottom pair of electrodes is used, and about 170 kg when both pairs of electrodes are used, which was the case in the present tests.

1.3.3 Off-Gas System

For operational simplicity, the DM100-BL 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 HEPAs 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.

1.4 Experimental Procedures and Methods

1.4.1 Feed Conversion by Vertical Gradient Furnace (VGF) Testing

Figure 1.3 shows a schematic diagram of the VGF setup. The temperature gradient inside the VGF is maintained by two separate sets of heating elements, both of which are arranged in cylindrical form and aligned along their axes. The inner heater is set at 1150°C, which is the nominal temperature of the glass pool, and the ambient heater is set at 600°C, which is similar to the melter plenum temperature. A ceramic crucible (4 inches tall) is used to contain the reacting melter feed. The temperature gradient in the furnace is shown in Figure 1.4. For a typical feed conversion test, 10 grams of glass of identical chemical composition to the test feed (expressed on an oxide basis) is preheated in the ceramic crucible positioned in the inner heater before the dried melter feed (to yield 20 grams of glass) is introduced. Feed reactions under the controlled temperature gradient are allowed to continue for the designated test duration (typically, from 5 to

60 minutes) and then stopped by rapid cooling in room temperature air. The top surface of the reacted feed material is then inspected and photographed. The crucibles with their feed contents are then cross-sectioned to reveal the conversion progress of feed blends. The saw cuts of the crucibles are performed dry (without lubricant) to avoid loss of any soluble material.

To characterize the reacted feed material, visual inspection and digital imaging of the top (by photography) and cross section (using an optical scanner) of the reacted sample are performed. The results are assessed by comparison to results obtained previously from a wide range of other feeds that have known processing rates from continuous melter testing.

1.4.2 Feed Samples from Melter Tests

Feed samples were taken directly from as-received drums and the melter feed recirculation line during each test. Feed samples are poured into a platinum/gold crucible and placed into a programmed furnace for drying and fusion to form a glass. The glass produced from this fusion is ground to less than 200 mesh and sealed in 20-ml vials for subsequent analysis by X-ray fluorescence spectroscopy (XRF), or by acid digestion followed by direct-current plasma atomic emission spectroscopy (DCP-AES) on the resulting solution. The feed samples are also characterized for their density, pH, water content, and glass yield.

1.4.3 Glass Product

The glass product is discharged from the melter into 5-gallon steel pails periodically using an air-lift system. The discharged product glass is sampled at the end of each test by removing sufficient glass from the top of the cans for compositional analysis and secondary phase determination. In addition, the Product Consistency Test (PCT, 7 days at 90°C) and Toxicity Characteristic Leaching Procedure (TCLP) were performed on samples of the glass product from the DM100 melter tests. Prior to those tests, the PCT and TCLP were also performed on the crucible melt compositions that were selected for the melter tests to ensure their compliance with the present WTP contract requirements. All of these procedures are routinely conducted at VSL and, therefore, standard operating procedures (SOPs) are in place.

Sample preparation for chemical analysis typically involves size reduction and sieving. All samples are subjected to XRF to determine the concentration of all elements except boron and lithium. A series of National Institute of Standards and Technology (NIST) reference materials are used for confirmation of the XRF data. Boron and lithium are determined by microwave-assisted total acid dissolution of ground glass samples in HF/HNO_3 and subjecting the resulting solutions to DCP-AES analysis.

1.4.3.1 Viscosity

The melt viscosity, η, is measured using a Brookfield viscometer. Measurements are performed in the temperature range of 950-1250°C and the data are interpolated to standard temperatures using the Vogel-Fulcher equation: $\ln \eta = [A/(T-To)]+B$, where A, B, and To are fitting parameters. The equipment is calibrated at room temperature using standard oils of known viscosity and then checked at 950-1250ºC using a NIST standard reference glass (SRM 711). Both precision and accuracy of the viscosity measurements are estimated to be within ±15 relative%.

1.4.3.2 Electrical Conductivity

The electrical conductivity, σ, of each glass is determined by measuring the resistance of the glass melt as a function of frequency using a calibrated platinum/rhodium electrode probe attached to a Hewlett-Packard model 4194A impedance analyzer. Measurements are performed over similar temperature ranges to those employed for the melt viscosity measurements. The results are analyzed to obtain the DC electrical conductivity. The electrical conductivity data are then interpolated to standard temperatures using the Vogel-Fulcher equation: $\ln \sigma = [A/(T-To)] + B$, where A, B and To are fitting parameters. Estimated uncertainties in the electrical conductivity measurements are ± 20 relative%.

1.4.3.3 Product Consistency Test (PCT)

The product consistency test (PCT, ASTM C 1285) is used to evaluate the relative chemical durability of glasses by measuring the concentrations of the chemical species released from 100-200 mesh crushed glass (75-149 µm) to the test solution (de-ionized water in this case). PCT tests on the HLW glasses are performed at 90ºC, in accordance with the current WTP contract requirement. The ratio of the glass surface area to the solution volume for this test is about 2000 m^{-1} (typically, 4 g of 100-200 mesh glass is immersed in 40 ml of deionized water). All tests are conducted in triplicate, in 304L stainless steel vessels, and in parallel with a standard glass included in each test set. The internal standard is the Argonne National Laboratory Low Activity Waste Reference Material (ANL-LRM) glass [24] and/or the DWPF-Environmental Assessment (EA) glass, both of which have undergone round-robin testing. The leachates are sampled at seven days. One milliliter of sampled leachate is mixed with 20 ml of 1M HNO_3 and the resulting solution is analyzed by DCP-AES; another 3 ml of sampled leachate is used for pH measurement.

1.4.3.4 Toxicity Characteristic Leaching Procedure (TCLP)

The TCLP was performed at VSL using SW-846 Method 1311, which employs leaching of crushed glass (< 3/8") in a sodium acetate buffer solution for 18 hours at 22°C with constant end-over-end agitation. A mass of about 100 grams of glass is leached in 2 liters of TCLP extract, according to the extraction method for non-volatiles. The surface area to volume ratio for this test is about 20 m^{-1}, which is about two orders of magnitude lower than that in the PCT. The leachates are analyzed by DCP-AES according to VSL standard operating procedures.

1.4.3.5 Secondary Phases

Secondary phases in the glass samples are determined by optical microscopy and scanning electron microscopy coupled with energy dispersive x-ray spectroscopy (SEM-EDS). Secondary phases due to crystallization and phase separation can be identified using these methods. Quantitative determination of the amount of crystals in glass samples is made by SEM in conjunction with image analysis.

SECTION 2.0
WASTE SIMULANT AND GLASS FORMULATIONS

Per the WTP baseline, tank waste undergoes ultrafiltration in the WTP pretreatment facility to separate the dissolved and un-dissolved fractions. The dissolved fraction, combined with liquids generated from subsequent washing and leaching of the solids, is treated in the WTP LAW vitrification facility whereas the solids are treated in the WTP HLW vitrification facility. The objective of the present tests was to evaluate feed compositions that may arise as a result of bypassing the WTP pretreatment facility. In such "direct-feed" scenarios, some of the functions of the WTP ultrafiltration process would be replaced by interim alternatives such as in-tank settling and washing. Since these processes are likely to be less efficient than the WTP ultrafiltration process, the resulting HLW stream would retain larger amounts of the tank supernate and wash water. To evaluate these effects, tests were performed with blends of solids, supernate, and wash water that might be generated from direct-feed processing of wastes from tank AY-102.

This section summarizes the compositions of the AY-102 un-dissolved solids, dissolved solids, and mixtures of the two representing varying degrees of washing efficiency, and glass formulations for each waste blend.

2.1 HLW and LAW AY-102 Tank Waste Simulants

The composition of the HLW simulant selected for testing is based on the inventory data for tank AY-102 from the Best Basis Inventory (BBI) Hanford Tank Waste Operations Simulator (HTWOS) model run (April 17, 2012). After applying wash factors to the AY-102 solids [25, 26], the calculated oxide mass of the washed solids was 332 MT. This waste has about 50 component oxides, including radioactive oxides such as ThO_2. In order to maintain a manageable number of components and to eliminate the use of radioactivity and noble metals in melter testing, all minor components (i.e., < 0.1 wt%), radioactive oxides, and noble metals are omitted in the definition of the HLW simulant. The resulting HLW composition, which is given in Table 2.1, contains 99.1 wt% of the original oxides. The HLW simulant composition is obtained by normalization of the oxide composition, which is also given in Table 2.1. Although this waste is not leached, the composition of the HLW simulant listed in Table 2.1 remains typical of HLW simulants used in earlier melter tests in that it is high in Fe_2O_3 and Al_2O_3; these two oxides account for > 60 wt% of the waste. The other significant oxides in the HLW simulant include Na_2O, SiO_2, MnO, and P_2O_5. To complete the formulation of the HLW simulant for melter testing, the projected concentrations of volatile components were also included. Table 2.2 provides a recipe to produce the HLW simulant (for 100 kg of waste oxides). The volatiles and their respective concentrations found in tank AY-102 solids are: carbonate (7.489 g/100 g oxide), nitrate (0.018), nitrite (0.172), and organic carbon (0.981).

The composition of the soluble fraction in the AY-102 tank waste is shown in Table 2.3. The concentration of the simulant is 7.134 molar sodium. The supernate is primarily a solution of alkali nitrates and nitrites. On an oxide basis, the waste is greater than 90% sodium and potassium with the balance consisting of aluminum, phosphate, sulfate, and halides. This supernate solution is similar to other LAW waste streams, and particularly the AP-101 simulant previously addressed in LAW formulation work and melter studies [27-31].

2.2 Waste Compositions for Glass Formulation Development and Melter Testing

Four waste compositions were evaluated in the glass formulation development and melter testing work. These represent various blends of the solids and supernate fractions corresponding to various extents of washing of the solids to remove the soluble fraction. The end-members of this series of compositions are the fully washed solids and the pure supernate. Table 2.4 shows the oxide compositions of these end-members together with three intermediate blends selected for testing. Also shown in Table 2.4 are the solids and oxides contents of the selected blends. These blends are based on the assumptions that the blended tank waste can be settled to achieve a slurry with 15 wt% un-dissolved solids and that each in-tank wash cycle results in a three-fold dilution of the soluble fraction followed by settling to achieve a slurry with 15 wt% un-dissolved solids. Thus, the four waste compositions in Table 2.4 selected for testing correspond to:

- Blend 1: AY-102 solids in AY-102 supernate, settled to 15 wt% un-dissolved solids.

- Blend 2: Blend 1 diluted three-fold with water and settled to 15 wt% un-dissolved solids (i.e., one in-tank wash/settle cycle).

- Blend 3: Blend 2 diluted three-fold with water and settled to 15 wt% un-dissolved solids (i.e., two in-tank wash/settle cycles).

- Solids: Fully washed solids (i.e., washed to the same extent as in the WTP baseline) and settled to 15 wt% un-dissolved solids.

All of the waste blends assume settling to 15 wt% un-dissolved solids, which corresponds to 10.5 wt% HLW oxides. The dissolved solids constitute the LAW oxide fraction. The changes in the solids content, waste oxide contribution, and chemical composition in response to the washing process are illustrated in Figures 2.1 and 2.2. The blend representing the unwashed waste consists of the 15 wt% un-dissolved solids with the remaining 85 wt% being the AY-102 supernate solution. Therefore 61 wt% of the oxides in the unwashed waste originates from the supernate, resulting in high alkali concentrations similar to LAW waste streams. The LAW contributions to the solids and oxides, the total solids and oxides, and the alkali content all decrease as the waste is washed. The fully washed waste is composed of only un-dissolved HLW solids with no LAW solids and therefore has a composition generally similar to HLW streams previously addressed in HLW glass formulation and melter studies [1-5, 10-20].

The most abundant dissolved volatile constituents in the waste are nitrate and nitrite, which is typical of LAW waste streams. Sugar is added to LAW waste streams at the WTP to prevent melt pool foaming that results from high concentrations of these constituents. In the present tests, sugar was added to the waste at the ratio of 0.75 moles of carbon per mole of nitrogen oxide present in the waste, which is the same as in the WTP LAW baseline and previous tests with LAW streams [27-31].

A primary formulation objective was to develop and evaluate glass compositions not only with high waste loadings and processing rates, but also acceptable durability and processing properties. Glass formulations were developed using an active design in that characterization data from a set of crucible testing were fed back to design the next set of formulations. Additionally, both WTP HLW and LAW glass property-composition models were used extensively in formulation development [32, 33]. Although the new glass compositions often resided outside the validity range of the models, the model predictions can be useful to provide guidance in selection of glasses to test when used judiciously. A new glass composition predicted by the models to have unacceptable properties might still be chosen for testing if past experience or literature information indicated benefits. Experience from previous work on WTP LAW and HLW was particularly valuable in formulation development for the unwashed and washed wastes. As seen in Table 2.4, Blend 1 and Blend 2 wastes are relatively high in sodium, suggesting that the new formulations will be similar to LAW glasses developed for WTP. Conversely, Blend 3 waste and the washed solids, as expected, are more similar to the HLW tested for WTP, which are generally high in aluminum and iron.

2.3 Glass Formulation for AY-102 Blend 1 Waste

Six glasses were formulated with waste loadings in the range of 37 wt% to 47 wt% for Blend 1 (Table 2.5). Blend 1 is closest in composition to LAW with high sodium and potassium contents. Glass formulations for such low-activity wastes were previously studied for pretreated supernate from tank AP-101. Glass compositions formulated for this type of waste vary from 25 wt% waste loading in the WTP baseline formulation LAWE3, to 29 wt% in the ORP formulations ORPLG9 or ORPLG27 (Table 2.6).

In the AY-102 LAW supernate (Table 2.4), the sum of sodium and potassium is about 91 wt% as oxide with an additional 5.7 wt% Al_2O_3; sulfate at 1.4 wt% SO_3 is the fourth most abundant constituent. Sodium, potassium, and sulfate together establish the waste loading limit in LAW glass formulations. LAW glasses have been successfully formulated in previous work with alkalis at 21 to 24 wt% Na_2O and up to 5.74 wt% K_2O together with up to 0.5 wt% SO_3. For AY-102 Blend 1 waste, sodium and potassium together amount to only 61.6 wt% but they remain the waste loading limiting constituents. Making use of the known domain of vitrification for LAW, Na_2O was set first at 20.5, 22.3, and 24 wt%, with K_2O at 4.1, 4.5 and 4.8 wt%, respectively, which correspond to high waste loadings of 40, 43.5 and 47 wt%. These were tested in the four formulations AY102D1-01 to AY102D1-04. Aluminum oxide (at 15 wt% in the waste) and Fe_2O_3 (14 wt%) are two other glass constituents which would normally be added as glass formers in LAW. At these waste loadings, Al_2O_3 content reaches the range of 6.02 to 7.07 wt%, very similar to the concentration in the WTP LAW reference glasses given in Table 2.6. Iron oxide concentration, which ranges from 5.7 to 6.7 wt%, also approach the concentration in the composition of the WTP reference glass LAWE3. Boron and silicon oxides, tested here in the range of 7.4 wt% to 11.9 wt% B_2O_3 and from 39.4 to 45.6 wt% SiO_2, overlap with the typical ranges tested in LAW for these two additives. CaO, MgO, ZnO, and ZrO_2 are the remaining additives tested in WTP and ORP glasses as well as in this series. These were set respectively at 1.8, 1.8, 3.0 and 4.8 wt% in AY102D1-01 (40% waste loading), and 1.7, 1.7, 2.8 and 4.5 wt% in AY102D1-02 (43.5% waste loading), close to their content in LAW glasses. CaO, MgO, ZnO and ZrO_2 were withheld in formulation AY102D1-03 in order to assess the potential effects of the other components coming from the AY-102 Blend 1 waste (Cr_2O_3, MnO, NiO, PbO, Ce_2O_3, La_2O_3, Nd_2O_3, which sums to 3.4 wt% in the current waste) towards PCT leaching, sulfate saturation, and K-3 refractory corrosion. Finally, AY102D1-04 tests the highest waste loading, with SiO_2, ZnO, and ZrO_2 as additives but without CaO and MgO in order to compensate for the increased alkalis.

For the second and final round of Blend 1 formulations, waste loading was decreased to 39 wt% and 37 wt%, which also decreased the alumina contribution from the waste to 5.87 wt% and 5.56 wt% in AY102D1-05 and AY102D1-06, respectively; Al_2O_3 was therefore included in the additives, along with B_2O_3, CaO, MgO, SiO_2, ZnO, and ZrO_2. In addition, 1.4 wt% TiO_2, used in the baseline LAWE3 glass composition, and which tends to reduce the corrosion of K3 refractory by the glass, was also added in AY102D1-06. This formulation was repeated as AY102D1-06R after the first melt was spilled during stirring and an insufficient amount of the original melt was recovered.

Glass compositions were determined by XRF on powdered glass samples, except for B_2O_3 and Li_2O which were measured by DCP-AES after acid dissolution. Target and analyzed compositions of the AY102-D1 glasses are given in Tables 2.7 and 2.8 for XRF and DCP-AES analyses, respectively. As is evident from the tables, the target and analyzed compositions generally show good agreement.

Testing of all formulations started with optical microscopic evaluation of the as-melted sample. Glass samples were heat treated for 70 hours at 950°C and then evaluated for secondary phases by SEM. The as-melted glass samples resulting from these formulations were all clear and homogeneous as well as after the screening heat treatment at 950°C. AY102D1-05 and AY102D1-06 were further heat treated according to the HLW canister centerline cooling profile and also remained clear of crystals. Table 2.9 summarizes these and other characterization data for the AY102D1 glasses.

The melt viscosities are all acceptable based on predicted values and for the five formulations measured (Table 2.9). All are well within the 10 to 150 P range in the current WTP requirement for HLW glass melt viscosity at 1100°C. Electrical conductivity values between 1100 and 1200°C are within the WTP range of 0.1 to 0.7 S/cm for the glasses AY102D1-01, AY102D1-05, and AY102D1-06. The glass melts of AY102D1-02, AY102D1-03 and AY102D1-04 have electrical conductivity values that exceed the current WTP requirement for HLW.

Sulfate saturation remelts were conducted using both Na_2SO_4 and $(NH_4)_2SO_4$ to verify that sulfur incorporation in melter operating conditions would not create a sulfate layer on the melt surface. The batch saturation tests were performed by remelting finely ground samples of the glasses with an excess of sodium sulfate amounting to 4 wt% SO_3 if all of it were retained in the glass, or ammonium sulfate amounting to 5 wt% SO_3; the latter has the advantage that the sodium content of the melt is not affected. The remelted glass samples are identified with an S4 at the end of the sample name with 4% SO_3 as Na_2SO_4 and S5 with 5% $(NH_4)_2SO_4$. Results of sulfate batch saturation tests are given in Table 2.9. Analyses of glass samples remelted with extra SO_3 were performed after grinding and "acid wash" (in 1% HNO_3) to remove any interstitial sulfate phases to ensure that only the SO_3 that is dissolved in the glass is measured. The sulfate retentions in the glasses varied from about 0.48 wt% SO_3 for the lower waste loading AY102D1-01 to 0.73 wt% SO_3 for the highest waste loading AY102D1-03.

PCT-B and PCT-Na releases were measured on the four glasses AY102D1-01, AY102D1-02, AY102D1-05 and AY102D1-06, as well as AY102D1-05CCC, after canister centerline cooling (CCC); all are well within the WTP HLW contract limits (of 16.70 g/L and 13.35 g/L, respectively, based on the DWPF-EA glass). No lithium leaching is reported since none of these formulations include lithium.

Glasses at the highest waste loadings showed K-3 corrosion above the recommended limit of 0.040" neck corrosion used for LAW glass formulation development work for ORP. However, glasses at 39% and 37% waste loading showed acceptable resistance to K-3 refractory corrosion with a neck corrosion of 0.035 and 0.028 inches for AY102D1-05 and AY102D1-06R, respectively. Formulation AY102D1-05 was recommended as the Blend 1 composition for melter testing since it has a slightly higher in waste loading

Evaluation of the feed processing rate was accomplished through vertical gradient furnace (VGF) tests on melter feed formulation AY102D1-05. The feed was prepared for tests with and without addition of the sugar required to prevent melt pool foaming. The amount of sugar addition was calculated based on the concentrations of nitrites and nitrates, which are highest in Blend 1. Results of the two small-scale melt rate screening tests are shown in Figure 2.3, while the numerical rankings of feed conversion for AY102D1-05 are given in Table 2.10. The results can be summarized as follows:

- When sugar is added in the proportion to be used in melter testing (photos in the right column in Figure 2.3), a rank of 1, the highest rate of feed conversion established among the relative melt rates tested, is found. At 30 minutes, the feed is already converted to glass with a minimum amount of bubbles remaining on the surface, which already has the dark appearance of a glass; at 60 minutes the surface exhibits the shine characteristic of glass.

- Without sugar, the feed-to-glass conversion is slower, yielding a rank of 2. In cross section, the feed is about 30% higher in the crucible due to a foam layer remaining at 30 minutes. After 60 minutes, the height of glass is comparable to that with sugar but traces of a yellowish surface layer characteristic of undissolved salts is still visible, highlighting the beneficial effects of sugar addition.

Finally, results from Toxicity Characteristic Leaching Procedure (TCLP) testing of the recommended formulation AY102D1-05 are given in Table 2.11, all of which are acceptable.

2.4 Glass Formulation for AY-102 Blend 2 Waste

In Blend 2 waste, sodium and potassium together amount to only 41.5 wt% and the alkali content is no longer limiting in potential glasses. Alumina at 21.42 wt% and Fe_2O_3 at 23.9 wt% are the likely constituents that may limit waste loading. Based on former HLW formulations of similar aluminum and iron contents, 12.21 wt% Al_2O_3 and 13.63 wt% Fe_2O_3 were tested first in AY102D2-01, for a waste loading of 57 wt%, adding only B_2O_3 (9 wt%) and SiO_2 (34 wt%), as shown in Table 2.5. This was tested alongside two other formulations using the same additive blend but at increased waste loadings of 65 and 60 wt% in AY102D2-02 and AY102D2-03, respectively. In AY102D2-04, an additional 1 wt% Li_2O and 1% SiO_2 was tested with a decrease in waste loading to 58%. A waste loading of 57% was tested with 0.86 wt% Li_2O and additions of ZnO and ZrO_2 in AY102D2-05. The resulting glasses all showed some metallic surface sheen, which was attributed by SEM evaluation to iron, manganese and chromium. In addition, a sulfate layer was observed on the surface of samples AY102D2-02 and AY102D2-03. Glass samples heat treated for 70 hours at 950°C and then evaluated for secondary phases by SEM revealed crystallization in excess of the 1 vol% limit, and in some cases, 13 vol% nepheline content at 950°C, rising to 20 vol% at 850°C heat treatment and 30 vol% after CCC. The waste loading for the final formulation AY102D2-06 was limited by capping the concentrations of Al_2O_3, Na_2O, and SiO_2 in the glass so that:

$$\frac{x_{SiO_2}}{x_{Al_2O_3} + x_{Na_2O} + x_{Si_2O_3}} \geq 0.62 \,, \tag{2.1}$$

where x_i is the mass fraction of component i. This nepheline discriminator has been found to be very conservative but was effective in screening out the formation of nepheline in this case. Glass AY102D2-06 was found to be free of any crystallization after heat treatment for 70 hours at 950°C and after CCC. A minute amount (less than 0.01 vol.%) of spinel was detected after heat treatment for 70 hours at 850°C.

The melt viscosities of all Blend 2 glass formulations are acceptable based on predicted values and measured values for AY102D2-01 and AY102D2-06 (Table 2.12). All are well within the 10 to 150 P WTP requirement for HLW glass melt viscosity at 1100°C. For both glasses AY102D2-01 and AY102D2-06, the melt electrical conductivity measured between 1100 and 1200°C remain within the range of 0.1 to 0.7 S/cm. Predicted values using the LAW WTP model [33] are close to the measured values.

Sulfate saturation remelts were also conducted using both Na_2SO_4 and $(NH_4)_2SO_4$. Results of sulfate batch saturation tests are given in Table 2.12. The sulfate retentions in the glasses varied from about 0.12 wt% SO_3 for AY102D2-02 to 0.66 wt% SO_3 for AY102D2-04.

The low saturation value of 0.12% in AY102D2-02 is consistent with observation of a sulfate layer in the as melted sample.

PCT releases were measured on three glasses AY102D2-01, AY102D2-05, and AY102D2-06; lithium is present only in the last two compositions. All PCT releases are well within the WTP HLW contract limits (16.70 g/L, 13.35 g/L and 9.57 g/L for B, Na, and Li, respectively). As shown in Figure 2.4, all glasses exhibit a near congruence of boron with sodium or lithium PCT releases, all remaining below 3 g/L; silicon remains at or below 0.5 g/L.

Acceptable resistance to K-3 refractory corrosion were found for the three glasses AY102D2-01, AY102D2-05, and AY102D2-06, with neck corrosions of 0.020, 0.021 and 0.016 inches, respectively.

Formulation AY102D2-06, which remains free of crystallization in all heat treatment conditions tested and meets all other glass testing requirements (see Tables 2.11 and 2.12), was recommended as the Blend 2 composition for melter testing.

Evaluation of the feed processing rate was accomplished through VGF tests on melter feed formulation AY102D2-06, with and without the addition of sugar. Results of the two small-scale melt rate screening tests are shown in Figure 2.5 and Table 2.10. The results can be summarized as follows:

- When sugar is added in the proportion to be used in melter testing, a rank of 5 is assigned to this feed-to-glass conversion. At 30 minutes, foaming extends high on the side of the crucible and some foaming remains, even though the feed is already converted to glass; at 60 minutes the surface starts showing a shine characteristic of glass.

- Without sugar, the feed-to-glass conversion is much slower and foaming is so intense that it created a dome of crusted feed; the cross section revealed that a fraction of the feed has reacted and collapsed below the crusted dome. After 60 minutes, reaction progressed to include the entire feed although foam remains on the side of the crucible and small patches of salt are visible at the surface.

2.5 Glass Formulation for AY-102 Blend 3 Waste

Blend 3 glass formulations were based on HLW glasses tested for the AY-102 washed solids given in Table 2.4 and were developed after a candidate glass (AY102D4-07) for melter testing had been identified for the washed solids. Section 2.6 discusses glass development for the AY-102 washed solids.

A compositional comparison between Blend 3 waste and washed solids (Table 2.4) shows that the major difference is the presence of more Na_2O in Blend 3 waste as a result of the LAW oxide fraction found in the dissolved solids. Since Na_2O is added as a glass former in the glass formulations for washed solids, Blend 3 glasses can be formulated with compositions very similar to those of the washed solids glasses using a higher overall waste loading. Only two glasses were developed for Blend 3 waste and both were based on AY102D4-07, the candidate glass selected for AY-102 washed solids (see Section 2.6).

Table 2.5 lists the waste loadings, glass-forming additives and target compositions of the Blend 3 glasses AY102D3-01 and -02. Results of compositional analyses by XRF and DCP-AES (DCP-AES data for AY102D3-02 only) of the glasses are given in Tables 2.7 and 2.8, respectively. The waste loading of the reference glass AY10D4-07 is 39.00 wt%. With a total waste loading of 45.50 wt%, AY102D3-01 has a composition almost identical to that of AY102D4-07. The higher K_2O content in AY102D3-01 originates mostly from the LAW fraction in Blend 3 waste. The Fe_2O_3 concentration in AY102D3-01 is relatively high at 14.10 wt% and HLW formulation experience suggests that spinel crystallization (i.e., spinel one-percent crystal fraction temperature, [$T_{1\%}$]) will be the primary waste loading-limiting property. Heat treatments of AY102D3-01 at temperatures between 850°C to 1050°C yielded spinel crystal contents ranging from 2.76 vol% to 0.04 vol%. Linear regression of these data resulted in a spinel $T_{1\%}$ of 990.6°C for AY102D3-01, above the desired limit of 950°C. Heat treatment and other characterization data for the AY102D3- glasses are given in Table 2.13, while the spinel $T_{1\%}$ results from regression are found in Table 2.14. Unlike the case with AY102D1- and AY102D2- glasses, sulfate solubility and K-3 corrosion were not characterized because the sulfate and alkali concentrations are considerably lower in the AY103D3- glasses.

To reduce spinel crystallization, the glass AY102D3-02 was formulated with lower waste loading (45.00 wt%) and increased Li_2O. Additional silica was also included to maintain an acceptable melt viscosity. The spinel $T_{1\%}$ measured for AY102D3-02 is 945.4°C. Other properties measured for AY102D3-02, which included melt viscosity, electrical conductivity, and PCT releases, were also acceptable (see Table 2.13). Finally, as shown in Table 2.11, TCLP data for AY102D3-02 show that this glass is compliant with both the Universal Treatment Standard (UTS) limits and the delisting limits. This glass was therefore selected as the target Blend 3 glass for melter testing.

To evaluate the melt rate of formulation of AY102D3-02, crucible scale testing in a VGF was performed on a simulated melter feed. Table 2.10 gives the feed conversion ranking for AY102D3-02 based on visual observation. After 30 minutes of testing, minor foamy residue was seen on the crucible wall and a ranking of 2 to 3 was assigned, suggesting that the melt rate was moderately fast. The top view and cross section images of the reacted samples after 30-minute and 60-minute VGF tests are shown in Figure 2.6. The feed sample showed relatively compact structure and feed conversion appeared fairly complete after 60 minutes.

2.6 Glass Formulation for AY-102 Washed Solids

Previous development and testing of HLW glass formulations at VSL to support pilot scale WTP melter tests covered four different waste streams: AZ-101, AZ-102, C-106/AY-102 and C-104/AY-101 [10]. Two waste blending scenarios, with and without Sr/TRU products from LAW pretreatment, were considered for the C-106/AY-102 waste. The composition of the C-106/AY-102 simulant without Sr/TRU products previously tested is comparable to the present

AY-102 washed solids composition in that the predominant component in both is Fe_2O_3. The major difference between the two simulants is found in Al_2O_3 and MnO; Al_2O_3 (6.10 wt%) is much lower while MnO (12.98 wt%) is considerably higher in the C-106/AY-102 waste. The lower Al_2O_3 was primarily a result of the pretreatment of the C-106/AY-102 HLW solids, which included caustic leaching and water washing, followed by ultra-filtration. Formulation of C-106/AY-102 glasses for both blending scenarios, however, required the addition of Al_2O_3 as a glass former to improve the melt viscosity and glass durability [10]. Directly feeding the AY-102 solids without WTP pretreatment will obviate the need of Al_2O_3 addition. The AY-102 glasses will also be compositionally similar to the C-106/AY-102 glasses but with higher waste loadings. In addition, the lower MnO concentration in the AY-102 solids will also be beneficial to waste loadings since glass formulations for both wastes are limited by spinel $T_{1\%}$.

Seven HLW glasses were tested for the AY-102 washed solids (AY102D4- series). Table 2.5 lists the waste loadings, glass-forming additives and target compositions of these glasses, while Tables 2.7 and 2.8 give the XRF and DCP-AES compositional data for the AY102D4- glasses (only selected glasses were analyzed by DCP-AES). The waste loadings for the first three members in the series (AY102D4-01 through -03) are all above 41 wt%, with over 15 wt% Fe_2O_3 in the glasses. Heat treatments of these glasses from 900°C to 1100°C invariably resulted in relatively heavy crystallization of spinel. For example, more than 4 vol% of spinel was present in AY104D4-03 after heat treatment at 900°C. The spinel crystals were composed mostly of Fe, with minor amounts of Mn, Ni, and Cr (and in a few cases, Al). The spinel $T_{1\%}$ values determined for these three glasses are all higher than 1070°C (Table 2.14) and these glasses were deemed unsuitable for the present melter testing. In attempts to lower the spinel $T_{1\%}$, formulation of subsequent glasses in the series employed reduced waste loadings.

The next three glasses were formulated with waste loadings of 39.00 wt% (AY102D4-04 and -06) and 40.50 wt% (AY102D4-05). In addition, increased amounts of alkalis (Li_2O and Na_2O) were added in these formulations to limit spinel formation. The resulting glasses showed reduced spinel crystallization upon heat treatment. The spinel $T_{1\%}$ values for AY102D4-04 and -06 were, respectively, 933°C and 956°C (Table 2.14), suggesting that they should be considered for further characterization. Melt viscosity and electrical conductivity were therefore measured for AY102D4-06 (Table 2.15). While the measured electrical conductivity (e.g., 0.604 S/cm at 1158°C) was acceptable for melter testing, the viscosity was slightly lower than preferred. Note that the predicted viscosity at 1150°C using the WTP HLW property-composition model was 15.68 P, which can be compared with the measured viscosity of 18.14 P at 1160°C. The predicted viscosity for AY102D4-04 is 22.12 P at 1150°C.

Based on AY102D4-06, another glass with 39.00 wt% waste loading was formulated and tested with the substitution of 3 wt% of SiO_2 for B_2O_3 (2.5 wt%) and Na_2O (0.5 wt%) to increase melt viscosity. Characterization data for the resulting glass, AY104D4-07, are given in Table 2.15. This glass has a $T_{1\%}$ of 936.5°C (Table 2.14), whereas the measured viscosity at 1156°C is 30.49 P. The leaching performance of AY104D4-07 was also found to be satisfactory, with the PCT releases significantly better than those of the DWPF-EA reference glass while the TCLP releases of RCRA metals are all beneath the respective UTS and delisting limits (Table 2.11). The VGF test results for AY102D4-07 are essentially the same as those for AY102D3-02 (Table

2.10 and Figure 2.7), with a visual ranking of 2 to 3, suggesting a moderately fast feed conversion rate; this is not surprising since the two glass formulations are so similar. These characterization data support the selection of AY102D4-07 as the target glass for the washed solids melter test. This glass can be compared with HLW98-86, the glass formulation selected for WTP melter testing of the C-106/AY-102 waste with Sr/TRU pretreatment products (no melter test was performed for the C-106/AY-102 waste without pretreatment products). The total waste loading of HLW98-86 is 27.75 wt% and the Fe_2O_3 loading is 12.56 wt%; the corresponding values for AY102D4-07 are 39.00 wt% and 14.19 wt%.

2.7 Glass and Feed Formulations Used in Melter Tests

Summaries of the glasses developed for melter testing illustrating the waste loadings of the HLW and LAW constituents are provided in Tables 2.16 – 2.19. The waste loading of undissolved solids increases from 15.2 wt% oxide for the unwashed solids to the highest achieved HLW loading of 39 wt% oxide with increased washing, as shown in Figure 2.8. Lower HLW loadings result from the need to dilute the increased amounts of alkali in the supernate. The maximum total waste oxide loadings were achieved with intermediate amounts of washing. The amount of glass required to incorporate each of the waste oxides is illustrated for the waste blending scenarios in Figure 2.9. For all but the unwashed waste, about three kilograms of glass is produced for each kilogram of HLW oxides. For the unwashed waste, over six kilograms of glass is produced for each kilogram of HLW oxides, more than doubling the number of canisters produced.

Sufficient blended feed (glass formers plus waste simulant) was prepared by NOAH Technologies Corporation according to VSL specifications to make over 1.7 metric tons of glass for melter testing. Glass forming additives for each of the four glass compositions are listed in Table 2.20. Upon receipt of the feed at VSL, analysis was performed to verify the oxide composition of the glass that would be produced from each feed and to measure the total solids content. Based on the feed analysis (see Section 4.1), each feed was modified as shown in Table 2.20. Sufficient water was added to each feed to achieve the water content consistent with either 10 or 15 weight percent undissolved solids in the waste depending on the test. The overall solids content of the resultant feed also depends upon the amount and type of glass forming additives used in each formulation. Additions were made to three of the four feeds to achieve target concentrations of sodium, boron, and iron. Sugar was added at the ratio of 0.75 moles of carbon per mole of nitrogen oxide present in the waste.

SECTION 3.0
DM100 MELTER OPERATIONS

Five melter tests were conducted on the DM100-BL vitrification system between 9/17/13 and 10/25/13 with four blends of simulated HLW AY-102 waste solids and supernates processed with glass forming additives optimized for each blend. These tests produced nearly two metric tons of glass from over six and a half metric tons of feed. In each test, the glass temperature was held constant at 1150°C while feeding to determine the effect of the test variables on production rate and processing properties as well as to facilitate comparison with previously conducted tests. Tests were conducted with the same AY-102 simulated HLW waste solids, four different total waste compositions based on blending differing amounts LAW supernate with HLW solids, four different glass compositions corresponding to each of the four waste compositions, and five feed solids contents resulting from two different HLW solids contents. The feed solids content ranged from 0.15 to 0.5 kg glass per kg feed depending on the concentration of HLW solids in the waste, the amount of dissolved solids derived from the LAW supernate, and the amounts and types of glass forming additives that are used. The tests are further distinguished by processing the melter feeds at a bubbling rate of 9 lpm per minute for the first 50 hours for each feed to provide a direct comparison to the results from previous tests with HLW waste compositions followed by optimizing bubbling for 24 to 36 hours to determine the maximum production rate. Summaries of the tests are provided in Tables 3.1-3.5. Attempts were made to replicate the melter configuration and operating conditions used for previous tests with HLW simulants [2-5, 15-20, 34-38]. 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. The bubbling rate was either fixed at 9 lpm or optimized and the feed rate was adjusted to maintain a complete cold cap. This use of fixed bubbling is in contrast to some previous tests where the production rate was fixed between 1000 and 1050 kg/m^2/day and the bubbling rate was adjusted to maintain the complete cold cap [17-20]. This latter approach was also used for testing LAW feeds, where the bubbling rate was adjusted to maintain the complete cold cap at production rates between 2000 and 2500 kg/m^2/day [27-31].

The feed and glass were processed without significant difficulties throughout the majority of the tests. Cold cap conditions while processing feeds containing more HLW than LAW oxides were largely similar to the range of conditions observed in previous tests with HLW feeds [2-5, 15-21, 34-38]. Differences with many of the previous tests was the ponding of liquids often observed on the surface due to the higher water content of the feeds and the rapid movement of this liquid to the glass surface when openings in the cold cap formed. Some shelves along the walls of the melter formed, although not to the rate limiting extent observed while processing some high aluminum formulations [2, 5] or some high iron formulations [36]. On average, manual methods were used following glass discharges to dislodge these deposits without any interruptions in feeding. Most of these deposits were observed after discharging glass, which lowered the glass level in the melter leaving deposits adhering to the walls out of contact with the molten glass. The feed with the highest proportion of LAW oxides processed in a manner similar to LAW feeds [27-31], particularly while the bubbling was optimized. The use of manual methods for dislodging deposits was far less frequent while processing the feed containing the highest proportion of LAW constituents, also in keeping with previous tests with LAW feeds. Short, routine interruptions of up to ten minutes were required during testing to transfer feed to the feed tank and to perform minor maintenance activities. Longer interruptions occurred during fixed bubbling portions of Test 5 to replace valves and unions in the feed recirculation line, Test 2 to replace belts in the exhaust blower, and Test 1 to adjust the inner lid plate. No foamy glass was observed in the glass discharge and no foam was observed on the melt pool surface or cold cap.

Figures 3.1.a – 3.1.e illustrate the glass production rates as moving hourly and cumulative averages during the five tests. The cumulative average rates approximate the steady state processing rates as a result of consistent operation over the course of the majority of the tests. Steady state glass production rates ranged from 500 to 1250 $kg/m^2/day$ for tests with fixed bubbling and 775 to 2500 $kg/m^2/day$ for tests with optimized bubbling. Glass production rates increased with optimized bubbling, consistent with previous tests conducted with HLW wastes [3, 5, 36, 38]. The extent of the increase in production rate ranged from 36% with feed generated from one wash cycle to 100% with feed containing unwashed solids; rate improvements for the other tests with optimized bubbling were between 50 and 70%. All wastes were processed at rates of 1100 $kg/m^2/day$ or greater with optimized bubbling, except for the low solids content feed used in Test 5. Glass production rates decreased with solids washing, feed water content, and HLW solids loading, as illustrated in Figures 3.1.f – 3.1.k. The feed processed in Test 5 with 10 wt% solids had the lowest solids content tested on the DM100 to date and, as expected, processed slowly. Steady state production rates for present tests are compared to previous tests [5, 16, 20] conducted at 9 lpm fixed bubbling or optimized bubbling with HLW wastes and low solids content in Table 3.6. The production rate for the present tests are higher than those measured for high bismuth, aluminum, and aluminum plus sodium HLW streams [5] at comparable solids contents. The production rates achieved at intermediate solids content (420-440 g glass/liter) were slightly below rates previously obtained for another high-Fe HLW composition [16, 20]. Both VGF (see Table 2.10) and melter tests indicate that the feed with unwashed wastes process faster than the other feeds while the VGF method indicates that feed with singly washed solids processes the slowest in contrast to melter tests which indicate that feed with the fully washed solids processed the slowest.

For the direct feed HLW application, the rate of processing the HLW solids is more important than the overall glass production rate. Processing rates of the LAW oxides and HLW oxides are compared to glass production rates for each test segment in Table 3.7 and Figures 3.1.f – 3.1.k. The HLW oxide processing rate ranged from 190 to 297 $kg/m^2/day$ and 302 to 460 $kg/m^2/day$ for nominal and optimized bubbling, respectively. The lowest HLW oxide processing rates are observed for the feed containing 10 wt% solids due to the low glass production rates and for the unwashed waste due to the low HLW waste loading despite the higher glass production rates. Processing rates for the LAW oxides range from zero for the fully washed waste to nearly 600 $kg/m^2/day$ for the unwashed waste.

The results of various operational measurements that were made during these tests are given in Tables 3.8 – 3.12. Glass temperatures are shown in Figures 3.2.a – 3.2.e, plenum temperatures in Figures 3.3.a – 3.3.e, electrode temperatures in Figure 3.4.a – 3.4.e, glass resistance in Figure 3.5.a – 3.5.e., melt pool bubbling in Figure 3.6.a – 3.6.e; electrode power is included in the figures with electrode temperatures and glass resistance. Bulk glass temperatures (measured at 5 and 10 inches from the bottom of the melt pool) were largely within 10°C of the target glass temperatures of 1150°C throughout the vast majority of the tests. Glass temperatures closer to the top of the melt pool (measured at 16 and 27 inches from the bottom) were 10-20°C lower than those deeper in the melt pool and are not reliable indicators of bulk glass temperatures as a result of their sensitivity to variations in the level of glass in the melter and gradients near the melt surface. The temperature of the air lift increases from the discharge chamber temperature of about 980°C to about 1100°C during glass discharge events. Temperatures in the discharge chamber were higher during Test 1 with the unwashed waste due to the more frequent glass discharge events. The upper and lower electrode pairs were typically about 50 to 100ºC colder than the glass pool, respectively. The bottom electrode, which was not powered, was about 325 to 375ºC colder than the powered side electrodes. These electrode temperatures increased modestly with bubbling over the course of some of the tests. Plenum temperatures ranged around 400°C to 500°C over the majority of the tests, indicative of a complete cold and steady processing. A relative 25-50°C increase in plenum temperature was measured in the exposed thermocouple during the latter portions of Tests 1 and 2 in response to the more frequent glass discharging disrupting the cold cap and creating more openings. Higher plenum temperatures were also measured at the beginning of each test during the development of the cold cap. Plenum temperatures measured in the thermowell were on average about 25-50°C lower than those measured by the exposed thermocouple due to more direct exposure to the glass surface. The target bubbling rate of 9 lpm was maintained throughout the first 50 hours of processing each feed; the bubbling rate was reduced during interruptions during Tests 5 and 2 as repairs were made to the system. Bubbling rates ranged mostly between 17 and 19 lpm while being optimized during the latter portion of each test, except for Test 4 in which bubbling was optimized at around 15 lpm. Power supplied to the electrodes averaged from 15.2 to 18.7 kW and 21.2 to 25.6 kW during tests conducted with fixed and optimized bubbling, respectively. The average power usage normalized to glass production decreased with increased glass production rate from 9.7 kWhr/kg at the lowest production rate of 500 kg/m^2/day to 1.9 kWhr/kg at the highest production rate of 2500 kg/m^2/day, due to much of the supplied energy being used to maintain the glass pool at the target melt temperature (i.e., the essentially constant idling power); thus higher production rates result in relatively lower normalized power usage. Normalized power usage decreases are also attributable to decreases in feed water content. Given the constant glass pool temperature of 1150°C, the melt pool resistance changes can be attributed to changes in the composition of the glass pool: From 0.09 ohms at the beginning of testing to about 0.063 ohms after processing the AY102D4-07 glass composition, to 0.073 ohms after processing the AY102D3-03 glass composition, to 0.077 ohms after processing the AY102D2-06 glass composition, and fluctuating between 0.07 and 0.08 while processing the AY102D1-05 glass composition.

The gas temperature at the film cooler averaged between 276 to 293ºC and depended on the plenum temperature, the amount of added film cooler air, the temperature of the added film cooler air, and the moisture content of the gas exiting the melter. Drops of less than twenty degrees in gas temperature were observed across the (insulated) transition line; the high temperature is maintained in order to prevent condensation in the downstream filtration units.

SECTION 4.0
FEED SAMPLE AND GLASS PRODUCT ANALYSIS

4.1 Analysis of Feed Samples

4.1.1 General Properties

Feed samples from as-received drums were analyzed to confirm physical properties and chemical composition. Based on the analysis of the as-received material, boric acid, iron oxide, sodium carbonate, sodium hydroxide, and water were added to the feeds prior to testing to achieve the target compositions and solid contents (see Table 2.20). Samples were also taken during each melter test from either an inline sampling port or directly from the feed tank. Sample names and measured properties are given in Table 4.1. Density, pH, water content, glass conversion ratio, and oxide composition by XRF and DCP were measured on all samples. The analysis shows the intended changes in water content, glass yield, and density as a result of modifications to the as-received feed. In all but Test 1, the analysis of the melter feed shows increases in water content with concomitant decreases in density and glass yield in response to the measured dilution with water. Water was evaporated from feed prior to use in Test 1 to achieve the higher target feed solids content. The measured glass conversion ratios for all feed samples from melter tests were within nine percent of the target on a weight per weight basis, validating the use of the target conversion ratio for calculating glass production rates. The water content, density, glass yield, and pH varied within a narrow range for the feed samples within each as-received feed batch and melter feed. As expected, feed containing a higher proportion of the AY-102 supernate, and thus more sodium and potassium hydroxide, had higher measured pH than feeds that contained mostly HLW solids.

4.1.2 Chemical Composition

The methods used for analysis of feed sample chemical compositions are described in Section 1.4. The boron and lithium oxide concentrations from the DCP-AES analysis were used for normalizing the XRF data since their concentrations were not determined by XRF. The analyzed compositions of the as-received and melter test feeds are compared to the target compositions in Tables 4.2 - 4.5 for each glass composition. The results from the as-received and melter test feed samples generally show agreement with the target composition and corroborate the consistency of the feed for the major elements. Additions were made to the as-received feed to correct for elements targeted at greater than four percent oxide with absolute deficits greater than half a weight percent oxide. Analysis of feed from melter tests shows the additions of boron and iron to feed used in Tests 5 and 4, boron, sodium, and iron to feed used in Test in 3, and sodium to feed used in Test 2 reduced or eliminated deficits in these elements for feeds processed during the melter tests. Occasional deficits of greater than ten percent for lithium, manganese, and zirconium were not consistent and were observed only in either the as-received feed or the feed from melter tests. The low measured magnesium concentration in the feed samples from Test 1 were not found in the final glass product. Deficiencies in potassium in feed from Test 3 are small in terms of absolute concentrations and therefore are not anticipated to affect the results of the tests. Low concentrations (0.01 – 0.39 wt%) of bismuth, titanium, zinc, and zirconium were measured in feed samples, even though they are not included in many of the target compositions. Surpluses of magnesium and sulfur of up to 0.2 wt% were measured in feeds from all but Test 1. These surplus constituents were also present in the last feed processed [38] and presumably originate from trace level contamination of feed additives and chemicals used to produce the waste simulant and are not expected to have an impact on glass or processing properties of the melter feed.

4.2 Analysis of Glass Samples

Over 1900 kg of glass was produced in these tests. The glass was discharged from the DM100 periodically into 5-gallon carbon steel pails using an air lift system. 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 Table 4.6. Glass samples were also taken by inserting a threaded metal rod directly into the glass pool. These "dip" samples serve to document the composition of the glass pool before and after each test. No macroscopic secondary phases were observed in any of the discharged glasses and dip glass samples.

4.2.1 Compositional Analysis of Discharge and Dip Sample Glasses

All discharge glass samples were crushed, sieved, and analyzed directly by XRF. Since boron and lithium are not determined by XRF, boron and lithium concentrations were calculated from the measured concentration in the glass pool prior to testing, measured feed concentrations (see Tables 4.2-4.5), and the nominal glass volume of the melter. The XRF analyzed compositions of discharged and dip glass samples are provided in Tables 4.7 - 4.11. A comparison of analyzed discharge glass compositions with target compositions is provided in Table 4.12. The majority of the XRF analysis results compare favorably to their corresponding target values and feed sample analyses (see Section 4.1.2). The only oxides with a target concentration greater than one weight percent that showed greater than 10% deviation from the target value were manganese at the end of processing the AY102D4-07 glass composition, potassium and lithium at the end of processing the AY102D3-02 glass composition, potassium at the end of processing the AY102D2-06 glass composition, and boron at the end of processing the AY102D1-05 glass composition. All these deviations were less than 16% and were in part attributable to the amount of turnover while processing each composition. Bismuth, tungsten, titanium, zirconium, and zinc were measured in the product glass at low concentrations despite not being included in many of the target compositions as a result of being present in the melt pool prior to these tests and being present in the feed as a contaminant.

Compositional trends for selected constituents shown in Figures 4.1.a-4.1.h illustrate the approach of the majority of the glass constituents to the target compositions over the course of the tests. The composition of the glass in the melter prior to the testing reflects the HLW-HCr-16 glass composition [38], which was modified by feeding a slurry of iron hydroxide and silica with minor amounts of Ce, La, Mg, Mn, Nd, Ni, P, Pb and S. At the onset of the present tests, silicon, iron, and sodium increase in concentration at the expense of aluminum, boron, chromium, and potassium. Also bismuth, tungsten, zinc, and zirconium present in the melt pool at the beginning of testing but not present in the target glass composition decrease in concentration to the trace contamination levels measured in feed samples. Elements originating from the HLW solids such as iron, aluminum, lead, and manganese decrease while elements originating in the supernate, mostly sodium and potassium, increase in concentration reflecting the decreased washing of the wastes over the course of the tests. Chromium and nickel also decrease in concentration over the course of testing with the decreasing proportion of HLW oxides in the feed, except for the increase in concentration over the last test as a result of corrosion of the refractory and Inconel melter components. Increases in chromium concentration in glass are common in high-alkali LAW glasses [27, 28] and was expected based on K-3 corrosion testing on the AY102D1-05 glass formulation (see Section 2.3). Calcium, magnesium, zinc, and zirconium are present at concentrations above the low target values over the first four tests and increase dramatically at the end of testing as a result of their use as additives in the AY102D1-05 glass formulation. Magnesium concentrations were a third of a weight percent higher in the last two discharges and test-end glass pool sample than the preceding discharged glass suggesting that the magnesium additive accumulated in the feed tank and was preferentially fed into the melter as the tank was emptied at the end of the test.

4.2.2 Chemical Durability of Discharge Glasses

Discharge glass from the end of processing each of the four glass compositions was evaluated for chemical durability using the PCT and TCLP methods. The PCT results are compared to those for the benchmark DWPF-EA glass in Table 4.13 and the TCLP results are compared to the WTP delisting limits [39, 40] and Universal Treatment Standard (UTS) limits in Table 4.14. The chemical durability determined for the melter glasses by both of these methods is excellent. All measured PCT concentrations and normalized leach rates on the discharge glass samples are over an order of magnitude lower than the corresponding values for the DWPF-EA glass. All regulated TCLP leachate concentrations are less than 0.3 mg/l and more than an order of magnitude less than WTP delisting limits. All measured concentrations are also well below the UTS limits. The chemical durability of these glasses is largely within the range measured on glasses produced from wastes limited by bismuth, chromium, aluminum, and aluminum plus sodium [5] and chromium and iron [36, 38]. Sodium and boron PCT releases from the AY102D1-05 glass formulation were twice those from the other three glass compositions but are not atypical for high alkali LAW glass formulations [27, 28] and are well below the 2.0 g/m^2 mass loss ILAW requirement [41, 42]. Leach rates were largely similar for melter and crucible glasses although measured PCT leach rates were lower for melter glasses. Higher nickel concentrations measured in TCLP leachates from melter glasses are probably attributable to higher nickel concentrations in the melter glasses as a result of melter component corrosion. These results confirm that glasses can be formulated from a direct-feed HLW stream, which has undergone various degrees of washing with no other pretreatment, while maintaining high waste loadings and high processing rates without compromising the quality of the vitrified product.

4.2.3 SEM Analysis of Melter Glass Samples

Melt pool samples from the end of each of the five tests and prior to the first two tests were subjected to SEM analysis to determine the extent of crystal formation. The results are summarized in Table 4.15. Illustrations of typical crystal morphologies observed in samples from Test 5 and 4 are given in Figure 4.2. The crystalline phases observed by SEM were very similar to those observed in the preceding tests with a high chromium HLW composition [38] and are composed of iron and chromium spinels that also contain small amounts of aluminum, manganese, and nickel. Crystals were often observed in bimodal distributions ranging from sub- to five micron and 10 to 50 microns. Spinels are sub-euhedral, granular, clustered and distributed throughout the glass.

Crystals were observed in the glass pool samples prior to the test and in diminishing amounts over the first two tests as the AY102D4-07 glass composition was processed. No crystals were observed after processing the AY102D3-02, AY102D2-06, and AY102D1-05 compositions, in agreement with the crucible melts that contained no observable crystalline phases in the glasses melted at 1150°C. The 2.2 volume percent crystals measured in the glass pool prior to the test is actually greater than the 1.67 volume percent measured at the end of the previous tests processing the high chromium HLW composition [38]. The increased crystal content is probably attributable to the iron and manganese added to the melt pool prior to the current tests and the idling time before initiating present tests. As the melter was fed, the melt pool bubbled, and glass discharged, crystals present in the melt pool at the start of testing are progressively washed out of the melter over the course of the first three tests. After 510 kg glass production (2.8 melt pool turnovers), 78% of crystals are removed and after 903 kg glass production (5 melt pool turnovers) no crystals were observed.

SECTION 5.0
MONITORED OFF-GAS EMISSIONS

5.1 Particulate Sampling

The melter exhaust was sampled for metals/particles according to 40-CFR-60 Methods 3, 5, and 29 at steady-state operating conditions and nominal bubbling during each of the five tests. 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 required 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 was taken at a rate of between 0.5 and 0.75 dscfm. Total particulate loading was 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 and, particularly, iodine. The collected materials were analyzed using direct current plasma atomic emission spectroscopy for the majority of the constituents and ion chromatography (IC) for anions. Melter emission fluxes are compared to feed fluxes and emission samples taken while processing the five feed compositions in Table 5.1. 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 five samples were well within the 90 – 110% limits for isokinetic sampling.

Particulate emissions constituted from 0.46 to 1.90 percent of feed solids for feeds processed with bubbling fixed at 9 lpm. The amount of carryover increased with the number of wash cycles and feed water content, as shown in Figures 5.1.a and 5.1.b. Note that carryover increases by factors of about two and a half and three and a half between two wash cycles (68.7% water in feed) and fully washed (71.1% water in feed). This relatively high level of carryover for nonvolatile constituents such as silica suggests that feed solids are physically entrained in the exhaust in the water laden feeds. Also while processing the fully washed waste, iron is emitted at a greater rate than sodium, even though sodium is more volatile. This indicates that the iron hydroxide in the waste is preferentially carried over with the emitted moisture. No tests have been conducted on the DM100 with high iron contents and variable amounts water for comparison to the current tests; however, tests were conducted on the DM1200 with HLW AZ-101 wastes at multiple water contents [43]. These tests showed a similar trend of increasing particulate emissions with increasing feed water content: 0.55, 0.78, and 1.21 percent solids carryover at 55.3, 63.7, and 71.9 percent water content in the feed, respectively. This trend was not observed with bismuth, aluminum, and aluminum plus sodium limited HLW wastes [5], suggesting that the iron hydroxide forms colloids that are entrained in emitted moisture resulting in the elevated carryover. The level of solids carryover for feeds containing unwashed to partially washed HLW solids is 0.46 to 0.53 percent, which is well within the range measured while processing various feeds containing high iron HLW simulants processed on the same melter at a temperature of 1150°C: C-106/AY-102 SIPP (0.61 to 0.81 percent) [16]; the former C-106/AY-102 baseline (0.3 - 0.74 percent) [34]; a C-106/AY-102 high waste loading formulation (0.66 and 0.71) [3], and HLW AZ-101 (0.46 percent) [37] processed under the similar melter conditions. The feed containing unwashed HLW solids has a soda content of twenty percent on a glass basis, similar to many high alkali LAW feeds; carryover while processing this feed was 0.46 percent, which is well within range measured on the DM100 (0.54 – 0.77%) [30, 31], DM1200 (0.4%) [44], and DM3300 (0.42%) [45] melters while processing high alkali LAW feeds.

As expected, the feed elements emitted at the lowest melter decontamination factor (DF) were chlorine and fluorine, which were present only in the three feed formulations containing the AY-102 supernate. Sulfur was also emitted at a low DF, particularly in feeds containing little or no AY-102 supernate. Other elements exhibiting some volatile behavior were boron, chromium, potassium, and lead. The expected increasing volatility of alkali metals with increasing molecular weight was observed: potassium carryover being the highest followed by sodium, then lithium. Boron was the only elements detected in the impinger solutions collected downstream of the heated particle filter in the sampling train, which constitutes the "gas" fraction of the melter emissions.

5.2 Gases Monitored by FTIR

Melter emissions were monitored in each test for a variety of gaseous components, most notably CO and nitrogen species, by Fourier Transform Infra Red Spectroscopy (FTIR). The off-gas system temperature is maintained well above 100°C beyond the sampling port downstream of the DM100 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 melter exhaust. Data were inadvertently not logged electronically during about 20 hours of Test 1 and therefore a gap in the presented data is observed for this test. A summary of the range and average concentrations of gaseous species monitored during the five tests subdivided into fixed bubbling and optimized bubbling test segments is provided in Tables 5.2-5.6. The analytes listed in these tables 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. The concentrations of two of the most abundant monitored species, nitrogen oxides and water, are plotted in Figures 5.2.a - 5.3.e. The amount of moisture in the exhaust was in proportion to the amount of water in the feed and the rate at which feed is introduced into the melter. Generally, emissions from the DM100 of nitrogen oxides and products of incomplete combustion increase with greater proportions of AY-102 supernate in the melter feed. The fully washed HLW solids used in feed processed in Tests 4 and 5 contain low concentrations of nitrogen oxides and organic carbon (see Table 2.2) and therefore monitored concentrations of volatiles were either not detectable or were very low. Conversely, the unwashed waste used in feed processed in Test 1 contains high concentrations of nitrates and nitrites (see Table 2.3) and sugar added in proportion to the feed nitrates and nitrites, which results in high relative concentrations of nitrogen oxides and measurable amounts of products of incomplete combustion such as ammonia and carbon monoxide. Monitored emissions during Tests 2 and 3 while processing feed containing variable amounts of the AY-102 supernate were in between these two extremes. The most abundant nitrogen species monitored was NO, which is in keeping with previous melter tests with both HLW and LAW feeds. The measured concentrations increased from the first segment of each test with fixed bubbling to the second segment with optimized bubbling in response to the increase in feed rate. The scatter in the emissions data over the course of the tests is due in part to changes in the cold cap. Consistent with the Method 5-type results, no appreciable HF, HCl, or gaseous sulfur were monitored during the tests.

SECTION 6.0
SUMMARY AND CONCLUSIONS

In the HLW direct feed option that is under consideration for early WTP operations, the pretreatment facility would be bypassed in order to support an earlier start-up of the vitrification facility. In the present work, this strategy was evaluated by developing new glass and feed formulations originating from the direct vitrification of HLW with minimal or no pretreatment, focusing on the impacts of increased supernate and water content on wastes from one of the candidate source tanks for the direct feed option. A series of waste compositions were investigated that span the range of washing efficiencies between the baseline WTP full-wash case and the no-wash case. Crucible scale testing was conducted to identify HLW glass compositions and glass forming additive blends for a direct-feed HLW stream that has undergone various degrees of washing with no other pretreatment, while maintaining high waste loadings and acceptable glass properties. Based on those results, two intermediate-wash options were selected for testing on the DM100 melter system. These tests assessed impacts on processability and melt rates as well as the need for redox control resulting from the higher levels of nitrates from the increased supernate fraction. Off-gas data were collected to assess the potential impacts of increased NOx generation on the WTP HLW facility. The DM100 tests were also conducted on representative HLW feeds at solids contents extending below the current WTP baseline, which are likely for the direct feed option. The effects on glass production rate, melter operations, and off-gas carryover were determined. In addition, the ability of increased bubbling to compensate for the increased evaporative load was investigated.

Glass formulations were developed for four waste blends from Hanford tank AY-102 with varying amounts of LAW and HLW. As stated above, the compositions of the waste blends given in Table 2.4 were estimated assuming no pretreatment other than washing. Waste Blend 1 assumed no washing, Blend 2 one wash cycle, Blend 3 two wash cycles, and the fourth composition is the fully washed HLW solids. As the number of wash cycles increases, the contribution of LAW to the overall waste composition decreases. Since Blend 1 waste with the highest LAW contribution contains high concentrations of alkali oxides (Na_2O of 51.27 wt% and K_2O of 10.28 wt%), the waste loading was limited by K-3 refractory corrosion. The glass composition selected to treat Blend 1, AY102D1-05, has a waste loading of 39.0 wt% with LAW contribution of 23.8 wt% and HLW contribution of 15.2 wt%. Details of the AY102D1-05 glass composition are given in Table 2.16. Blend 2 waste, with a lower LAW contribution, has lower alkali oxide and higher Al_2O_3 concentrations making nepheline formation due to the combination of Na_2O, Al_2O_3, and SiO_2 that is added as a glass former the waste loading limiting constraint. The glass formulation that was developed for Blend 2, AY102D2-06, given in Table 2.17 has a waste loading of 48.0 wt% with 16.5 wt% from LAW and 31.5 wt% from HLW. The waste loading for Blend 3 waste and the fully washed HLW solids were expected to be limited by spinel crystallization on heat treatment of the glasses. Accordingly, glass formulation efforts were directed at limiting spinel crystallization by adding components such as Na_2O and Li_2O. The glass formulation developed for Blend 3 waste, AY102D3-02, given in Table 2.18 has a waste loading of 45.0 wt% with 6.7 wt% from LAW and 38.3 wt% from HLW. Glass formulation AY102D4-07, developed to treat the fully washed HLW solids, has a waste loading of 39.0 wt%, all from HLW. The above glasses meet all of the processing and product quality requirements for WTP [41, 42] as well as acceptable feed processing rates based on VGF tests. A review of the above four formulations show that the loading of HLW in the glass increases sharply in going from no wash (Blend 1) to one wash cycle (Blend 2), more moderately as the number of washing cycles is increased from one (Blend 2) to two (Blend 3), and very little in going from two wash cycles to fully washed HLW solids. In terms of HLW waste loading in the glass, there is clearly no advantage in conducting more than two wash cycles because the additional sodium that is removed from the waste is put back as glass former additive in order to limit spinel crystallization in the glass formulation for the fully washed HLW solids.

A series of melter tests were conducted on the DM100-BL vitrification system with four blends of simulated HLW AY-102 waste solids and supernates processed with glass forming additives optimized for each blend. The five tests are distinguished by four different total waste compositions based on blending differing amounts LAW supernate with HLW solids, four different glass compositions corresponding to each of the four waste compositions, and five feed solids contents resulting from two different HLW solids contents. The feed solids content ranged from 0.15 to 0.5 kg glass per kg feed depending on the concentration of HLW solids in the waste, the amount of dissolved solids derived from the LAW supernate, and the amounts and types of glass forming additives that are used. Tests on the DM100 were conducted at 1150°C at the nominal bubbling rate of 9 lpm and also with optimized bubbling to achieve maximum production rates; these conditions were selected to allow comparison to results obtained previously with HLW simulants. The feed rate was adjusted to provide the desired complete cold cap. The principal results of these tests can be summarized as follows:

- All feed formulations were readily processed, with HLW waste loadings up to 39 wt% and total waste loadings up to 48 wt% while meeting all WTP processing and product quality requirements and maintaining acceptable glass and feed processing properties.

- Glass production rates ranged from 500 kg/m^2/day for dilute fully washed HLW solids to 1250 kg/m^2/day for unwashed waste at nominal bubbling (fixed at 9 lpm). This increase in glass production rate coincides with an increase in feed solids content from 0.15 to 0.5 kg glass per kg feed (decrease in feed water content from 82 to 39%).

- Glass production rates increased from 36 to 100% (900 vs. 1225 kg/m^2/day to 1250 vs. 2500 kg/m^2/day) with optimized bubbling. While processing feed containing 82% water, glass production rates increased 55% with optimized bubbling.

- HLW oxide processing rates ranged from 190 kg/m^2/day for unwashed waste to 297 kg/m^2/day for waste that had undergone two wash cycles at nominal bubbling (fixed at 9 lpm). HLW oxide processing rates were dependent on the HLW oxide waste loading in the glass as well as the overall glass production rate.

- LAW oxide processing rates ranged from zero for fully washed waste to 297 kg/m^2/day for unwashed waste at nominal bubbling (fixed at 9 lpm). LAW oxide processing rates were dependent on the LAW oxide waste loading in the glass as well as the overall glass production rate.

Melter exhaust was sampled as each feed composition was processed at the nominal bubbling rate to determine the effect of changing feed composition on particulate and gaseous emissions. Particulate emissions constituted from 0.46 to 1.90 percent of feed solids and increased with the number of wash cycles and feed water content. Solids carryover while processing feed containing fully washed HLW solids at 15 and 10 weight percent solids (71 and 82% water) was 1.3 and 1.9%, respectively, in contrast to 0.46 and 0.54% solids carryover while processing feed containing wastes that have undergone fewer wash cycles and less water. High carryover of solids and iron have been previously observed with high iron, diluted HLW streams, confirming the increased carryover of iron and overall particulate with increasing feed water content in high iron HLW feeds [43]. The level of carryover for the other waste streams tested is within the range of solids carryover observed while processing other HLW and high alkali LAW waste streams containing similar amounts of water. Melter DFs were determined for most elements in the feed. The most volatile species were chlorine, fluorine, and sulfur, which is typical. Other elements exhibiting volatile behavior in some of the tests include boron, chromium, potassium, and lead. Gaseous emissions of nitrogen oxides and byproducts of incomplete combustion, such as carbon monoxide and ammonia, ranged from virtually none while processing the fully washed HLW solids to high concentrations of nitrogen oxides (particularly NO) and significant amounts carbon monoxide and ammonia while processing the unwashed waste. This was expected given the lack of nitrates and organic carbon in the fully washed HLW stream and the high concentration of nitrates in the AY-102 supernate. The extent of the nitrogen oxide emissions was partially mitigated by the addition of sugar to the feed (0.75 moles of carbon per mole of nitrogen oxide) using procedures developed for vitrifying LAW wastes.

Glass samples from the crucible and melter tests were subjected to leach testing using the PCT and TCLP methods in order to evaluate product quality. Despite the higher waste loadings and broad compositional range, the glass products significantly out-performed the DWPF-EA benchmark glass on the PCT leaching procedure by at least one or two orders of magnitude and exhibited TCLP leachate concentrations that were well below the WTP delisting limits.

6.1 Implications for HLW Direct Feed at WTP

The results from the glass formulation and melter testing demonstrate the viability of the HLW direct feed approach and illustrate the relative merits for each waste pretreatment strategy. The of amount time required to vitrify the 331,892 kg of HLW oxides in Hanford tank AY-102 [46] using a single HLW melter with a surface area of 3.75 m^2 operated at 70% total operating efficiency (TOE) is depicted in Figure 6.1. Also shown is the number of HLW canisters, each assumed to contain 3020 kg of glass [47], required for HLW oxides in tank AY-102. Processing waste without washing would result in two to three times as many HLW canisters (about 720) for storage than washed waste and would require about 660 days at nominal bubbling conditions to process the HLW contents of tank AY-102. This is primarily attributable to the low HLW waste oxide loading (15.2%) imposed by the high concentration of alkali in the supernate that is not washed from the HLW solids. The addition of a single wash cycle reduces the total canister count by about a factor of two (to about 350) and reduces the number of processing days at nominal conditions to about 450. Adding a second wash cycle prior to vitrification further reduces the required number of canisters to less than 300 and results in the shortest amount of time (about 420 days) required to treat all the HLW solids in the tank. Fully washing the waste results in the fewest number of HLW canisters (about 290) but longer time is required (about 500 days) to vitrify the tank waste due in part to the increased water content of the feed, which decreases the glass production rate. The fully washed waste also has the added disadvantage of higher solids carryover, also attributable to the high water content of the fully washed feed. The use of bubbling optimization reduced the time required to vitrify the HLW solids by 30 to 50%, to about 300 - 340 days, depending on the extent of washing. Finally, the important effect of the solids content that is achievable by settling is illustrated in the results for tests with the diluted fully washed feed, which corresponds to a settled solids content of 10 wt% instead of the 15 wt% value assumed for all other cases. While this change has no effect on the waste loading, and therefore the number of canisters produced, it results in a significant reduction in glass production rate and an increase in the processing time from about 500 days to about 650 days.

The results from this work provide the basis for assessments of the relative merits of progressively more intensive pretreatment in HLW direct feed options. Although a simple in-tank settle/decant washing process was assumed in the present analysis, similar considerations arise in the evaluation of various possible alternative direct feed interim pretreatment facilities and operations. The principal conclusions from the present work are the rapidly diminishing benefits of multiple wash cycles, and, consequently, also of more complex and intensive washing facilities, and the importance of maintaining sufficiently high solids content in the HLW feed to the vitrification facility. Thus, of the pretreatment strategies for direct HLW feed evaluated in this work, the first wash cycle provides the vast majority of the overall benefit of washing in terms of HLW loading and HLW processing time; two wash cycles appears to be optimal in those respects since the second wash cycle provide further, though smaller, gains but that must be weighed against the operational costs of each successive wash cycle. In particular, in the in-tank scenario, settling times to achieve reasonable solids contents can be very long.

It should be noted that the AY-102 supernate evaluated in the present work is relatively low in sulfate and halides and therefore the primary benefit of washing on waste loading is via removal of sodium. Consequently, excessive washing is counter-productive since sodium is a required additive for HLW vitrification. Conversely, for supernates with high levels of sulfur or halides, more extensive washing may be required, particularly in view of the fact that, unlike the WTP LAW melter systems, the WTP HLW melter systems were not designed to tolerate high levels of these species.

6.2 Recommendations for Future Work

The results of the testing presented herein demonstrate the viability of the WTP HLW direct feed strategy, which involves minimal or no pretreatment. It is recommended that testing and assessment of these strategies be continued in order to provide a solid basis for their evaluation and implementation in order to maximize the cost and schedule benefits while minimizing technical risk. Further work that is recommended for optimization of processing of WTP HLW direct feed is outlined below.

- *Other WTP Direct Feed HLW Pretreatment Strategies:* The present testing was based on a simple in-tank settle/decant washing strategy. Other pretreatment strategies should be evaluated to optimize the HLW direct feed approach at the WTP.

- *Other WTP Direct Feed HLW Tank Waste:* The present testing was based on a single HLW tank composition from the Hanford tanks. Subsequent work should extend these results to address the full range of HLW direct feeds expected to be processed at the WTP. In particular, HLW feeds for which the supernate is high in sulfate and/or halides need to be evaluated since the acceptable limits for these components in HLW glass are much lower than those for sodium.

- *Glass Formulation:* The results from the glass formulation work indicate that further improvements may be possible through continued glass formulation optimization using the results of the present work as a basis. In particular, the development of HLW formulations that have improved tolerance to species in the supernate can decrease the burden on the washing process.

- *Salt Formation and Metal Corrosion:* The potential for molten salt formation and increased metal corrosion (bubblers, thermowells, levels detectors, etc.) increases as the levels of halides and sulfates in the HLW feed increase. Consequently, for HLW feeds for which the supernate is high in sulfate and/or halides, these properties will determine the level of washing that is required to reduce these species to acceptable levels. Testing is needed to define these limits.

- *Scale-Up Testing:* As in the previous enhancement work for ORP, testing should be extended to larger-scale melter systems in order to address potential risks associated with scale-up, particularly with respect to processing rates. Testing should be conducted at the DM1200 WTP HLW Pilot Melter scale (1.2 m^2). Optimization of bubbling rate is a critical variable and therefore testing with bubblers in the prototypical orientation at larger scale is required to confirm these findings.

- *Integrated System Testing:* Testing on the DM1200 WTP HLW Pilot Melter system provides data from a one-third scale system with a prototypical feed delivery system and off-gas treatment train. Such testing is necessary to evaluate potential interactive effects on system operation arising from implementation of the direct feed HLW strategy and to provide data on the performance of each unit operation, input for flow-sheet models and regulatory requirements, and information of recycle streams.

- *Throughput:* A key risk area addressed in the present work relates to the strong dependence of glass production rates on waste composition and feed water content and the extent to which shortfalls in processing rate can be mitigated through glass formulation design and optimization of bubbling. The strategy can be extended to evaluate other pretreatment options and corresponding HLW compositions.

SECTION 7.0
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Table 2.1. Composition (oxide wt%) of HLW Simulant.

Oxide	**AY-102 Washed Solids**	**Normalized HLW Simulant Composition**
Al_2O_3	29.32%	29.59%
BaO	0.19%	0.19%
CaO	1.32%	1.33%
Ce_2O_3	0.32%	0.33%
Cr_2O_3	0.65%	0.66%
Fe_2O_3	36.05%	36.38%
K_2O	0.16%	0.16%
La_2O_3	0.22%	0.23%
MgO	0.37%	0.38%
MnO	5.37%	5.42%
Na_2O	15.45%	15.59%
Nd_2O_3	0.39%	0.39%
NiO	0.88%	0.88%
P_2O_5	1.36%	1.37%
PbO	1.37%	1.39%
SO_3	0.26%	0.26%
SiO_2	5.39%	5.44%
TOTAL	99.1%	100.0%

Table 2.2. Composition of HLW Simulant to Produce 100 kg of Waste Oxide (15 wt% total solids).

Starting Materials	Target Weight (kg)*
$Al(OH)_3$	46.679
$BaCO_3$	0.247
$CaCO_3$	2.423
Ce_2O_3	0.329
Cr_2O_3	0.666
$Fe(OH)_3$ (13% Slurry)	374.544
K_2CO_3	0.236
La_2O_3	0.229
MgO	0.389
MnO	5.477
NaOH	9.824
Nd_2O_3	0.397
$Ni(OH)_2$	1.136
Na_3PO_4	3.238
PbO	1.401
Na_2SO_4	0.466
SiO_2	5.495
Na_2CO_3	10.459
$NaNO_2$	0.265
$NaNO_3$	0.024
$H_2C_2O_4\cdot 2H_2O$	5.180
Water	485.905
TOTAL	955.01

*Target weights adjusted for assay information of starting materials

Table 2.3. Simulant Recipe for AY-102 Supernate (35.3 wt% total solids).(1)

Starting Materials	**Target Weight (g)** (2)
Water	770.0
$Al(NO_3)_3 \cdot 9H_2O$ (60% solution)	207.90
H_3BO_3	0.06
Na_2CrO_4*$4H_2O$	0.97
KOH	64.41
NaOH (50% solution)	209.33
SiO_2	0.28
NaCl	3.23
NaF	5.16
$Na_3PO_4 \cdot 12H_2O$	7.15
Na_2SO_4	7.20
$NaNO_2$	81.34
$NaNO_3$	113.79
$NaCO_3$	79.64
$NaOOCCH_3$ (Sodium Acetate)	10.38
NaOOCH (Sodium Formate)	5.19
$Na_2C_2O_4$ (Sodium Oxalate)	2.26
TOTAL	1568.29

(1) Recipe to produce 300.2 g of waste oxides.
(2) Target weights adjusted for assay information of starting materials.

Table 2.4. Compositions of the Supernate and Washed Solids from Tank AY-102 and Various Blends of the Two.

Blending Ratios						
Wt% Oxides from Washed Solids		0%	39.0%	65.7%	85.2%	100%
Wt% Oxides from Supernate		100%	61.0%	34.3%	14.8%	0%
Waste Blend		**Supernate**	**Blend 1**	**Blend 2**	**Blend 3**	**Solids**
Composition Wt%	Al_2O_3	5.74%	15.04%	21.42%	26.06%	29.59%
	B_2O_3	0.01%	0.01%	0.00%	0.00%	0.00%
	BaO	0.00%	0.07%	0.12%	0.16%	0.19%
	Cl	0.65%	0.40%	0.22%	0.10%	0.00%
	CaO	0.00%	0.52%	0.87%	1.13%	1.33%
	Ce_2O_3	0.00%	0.13%	0.22%	0.28%	0.33%
	Cr_2O_3	0.10%	0.32%	0.47%	0.58%	0.66%
	F	0.77%	0.47%	0.27%	0.11%	0.00%
	Fe_2O_3	0.00%	14.18%	23.91%	30.99%	36.38%
	K_2O	16.74%	10.28%	5.84%	2.62%	0.16%
	La_2O_3	0.00%	0.09%	0.15%	0.20%	0.23%
	MgO	0.00%	0.15%	0.25%	0.32%	0.38%
	MnO	0.00%	2.11%	3.56%	4.62%	5.42%
	Na_2O	74.07%	51.27%	35.64%	24.25%	15.59%
	Nd_2O_3	0.00%	0.15%	0.26%	0.33%	0.39%
	NiO	0.00%	0.34%	0.58%	0.75%	0.88%
	P_2O_5	0.45%	0.81%	1.05%	1.23%	1.37%
	PbO	0.00%	0.54%	0.91%	1.18%	1.39%
	SO_3	1.36%	0.93%	0.64%	0.42%	0.26%
	SiO_2	0.09%	2.18%	3.61%	4.65%	5.44%
	TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Volatiles, g/100g oxides	Carbonate	14.967	12.051	10.052	8.597	7.489
	Nitrate	48.046	29.320	16.481	7.131	0.018
	Nitrite	17.640	10.829	6.160	2.759	0.172
	Organic Carbon	0.668	0.790	0.874	0.935	0.981
	Sugar to be added	23.603	13.524	6.614	1.582	0
Solids and Oxide Contents	wt% LAW solids	35.3%	30.0%	10.0%	3.3%	0.0%
	wt% HLW solids	0.0%	15.0%	15.0%	15.0%	15.0%
	wt% Total solids	35.3%	45.0%	25.0%	18.3%	15.0%
	wt% LAW oxides	19.3%	16.4%	5.5%	1.8%	0.0%
	wt% HLW oxides	0.0%	10.5%	10.5%	10.5%	10.5%
	wt% Total oxides	19.3%	26.9%	15.9%	12.3%	10.5%

Table 2.5. Waste Loadings, Glass-Forming Additives, and Target Compositions (wt%) of Glasses for Tank 241-AY-102 Direct Feed Vitrification.

Blend 1 Glasses	**AY102D1-01**	**AY102D1-02**	**AY102D1-03**	**AY102D1-04**	**AY102D1-05**	**AY102D1-06**
Waste Loading	40.00%	43.50%	43.50%	47.00%	39.00%	37.00%
Al_2O_3	0.00%	0.00%	0.00%	0.00%	2.14%	0.63%
B_2O_3	7.80%	7.35%	11.87%	7.95%	9.15%	10.08%
CaO	1.80%	1.70%	0.00%	0.00%	1.83%	1.89%
MgO	1.80%	1.70%	0.00%	0.00%	1.83%	1.89%
Li_2O	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
SiO_2	40.80%	38.42%	44.64%	38.16%	39.04%	40.95%
TiO_2	0.00%	0.00%	0.00%	0.00%	0.00%	1.39%
ZnO	3.00%	2.83%	0.00%	2.65%	3.05%	3.15%
ZrO_2	4.80%	4.52%	0.00%	4.24%	3.97%	3.02%

Glass ID **Composition**	**AY102D1-01**	**AY102D1-02**	**AY102D1-03**	**AY102D1-04**	**AY102D1-05**	**AY102D1-06**
Al_2O_3	6.016%	6.542%	6.542%	7.069%	8.001%	6.195%
B_2O_3	7.804%	7.349%	11.869%	7.955%	9.154%	10.084%
BaO	0.028%	0.030%	0.030%	0.033%	0.027%	0.026%
CaO	2.008%	1.921%	0.226%	0.244%	2.033%	2.082%
Ce_2O_3	0.052%	0.057%	0.057%	0.061%	0.051%	0.048%
Cl	0.160%	0.174%	0.174%	0.188%	0.156%	0.148%
Cr_2O_3	0.128%	0.139%	0.139%	0.150%	0.125%	0.118%
F	0.188%	0.204%	0.204%	0.221%	0.183%	0.174%
Fe_2O_3	5.672%	6.168%	6.168%	6.665%	5.530%	5.247%
K_2O	4.112%	4.472%	4.472%	4.832%	4.009%	3.804%
La_2O_3	0.036%	0.039%	0.039%	0.042%	0.035%	0.033%
Li_2O	—(1)	—	—	—	—	—
MgO	1.860%	1.760%	0.065%	0.071%	1.889%	1.946%
MnO	0.844%	0.918%	0.918%	0.992%	0.823%	0.781%
Na_2O	20.508%	22.302%	22.302%	24.097%	19.995%	18.970%
Nd_2O_3	0.060%	0.065%	0.065%	0.071%	0.059%	0.056%
NiO	0.136%	0.148%	0.148%	0.160%	0.133%	0.126%
P_2O_5	0.324%	0.352%	0.352%	0.381%	0.316%	0.300%
PbO	0.216%	0.235%	0.235%	0.254%	0.211%	0.200%
SO_3	0.372%	0.405%	0.405%	0.437%	0.363%	0.344%
SiO_2	41.672%	39.368%	45.583%	39.185%	39.890%	41.757%
TiO_2	—	—	—	—	—	1.386%
ZnO	3.000%	2.825%	—	2.650%	3.050%	3.150%
ZrO_2	4.800%	4.520%	—	4.240%	3.965%	3.024%
TOTAL	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

(1) — Empty data field (components not present in glass).

Table 2.5. Waste Loadings, Glass-Forming Additives, and Target Compositions (wt%) of Glasses for Tank 241-AY-102 Direct Feed Vitrification (continued).

Blend 2 Glasses	**AY102D2-01**	**AY102D2-02**	**AY102D2-03**	**AY102D2-04**	**AY102D2-05**	**AY102D2-06**
Waste Loading	57.00%	65.00%	60.00%	58.00%	57.00%	48.00%
Al_2O_3	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
B_2O_3	9.03%	7.35%	8.40%	8.40%	7.31%	7.80%
CaO	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
MgO	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Li_2O	0.00%	0.00%	0.00%	1.00%	0.86%	2.08%
SiO_2	33.97%	27.65%	31.60%	32.60%	29.24%	42.12%
TiO_2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
ZnO	0.00%	0.00%	0.00%	0.00%	2.15%	0.00%
ZrO_2	0.00%	0.00%	0.00%	0.00%	3.44%	0.00%
Glass ID / Composition	**AY102D2-01**	**AY102D2-02**	**AY102D2-03**	**AY102D2-04**	**AY102D2-05**	**AY102D2-06**
Al_2O_3	12.212%	13.926%	12.854%	12.426%	12.212%	10.284%
B_2O_3	9.030%	7.350%	8.400%	8.400%	7.310%	7.800%
BaO	0.068%	0.078%	0.072%	0.070%	0.068%	0.058%
CaO	0.496%	0.566%	0.522%	0.505%	0.496%	0.418%
Ce_2O_3	0.125%	0.143%	0.132%	0.128%	0.125%	0.106%
Cl	0.125%	0.143%	0.132%	0.128%	0.125%	0.106%
Cr_2O_3	0.268%	0.306%	0.282%	0.273%	0.268%	0.226%
F	0.154%	0.176%	0.162%	0.157%	0.154%	0.130%
Fe_2O_3	13.630%	15.543%	14.347%	13.869%	13.630%	11.478%
K_2O	3.329%	3.796%	3.504%	3.387%	3.329%	2.803%
La_2O_3	0.086%	0.098%	0.090%	0.087%	0.086%	0.072%
Li_2O	—(1)	—	—	1.000%	0.860%	2.080%
MgO	0.143%	0.163%	0.150%	0.145%	0.143%	0.120%
MnO	2.029%	2.314%	2.136%	2.065%	2.029%	1.709%
Na_2O	20.317%	23.169%	21.386%	20.674%	20.317%	17.109%
Nd_2O_3	0.148%	0.169%	0.156%	0.151%	0.148%	0.125%
NiO	0.331%	0.377%	0.348%	0.336%	0.331%	0.278%
P_2O_5	0.599%	0.683%	0.630%	0.609%	0.599%	0.504%
PbO	0.519%	0.592%	0.546%	0.528%	0.519%	0.437%
SO_3	0.365%	0.416%	0.384%	0.371%	0.365%	0.307%
SiO_2	36.028%	29.997%	33.766%	34.694%	31.298%	43.853%
TiO_2	—	—	—	—	—	—
ZnO	—	—	—	—	2.150%	—
ZrO_2	—	—	—	—	3.440%	—
TOTAL	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

(1) — Empty data field (components not present in glass).

Table 2.5. Waste Loadings, Glass-Forming Additives, and Target Compositions (wt%) of Glasses for Tank 241-AY-102 Direct Feed Vitrification (continued).

Blend 3 Glasses	**AY102D3-01**	**AY102D3-02**	**Washed Solids Glasses**	**AY102D4-01**	**AY102D4-02**
Waste	45.50%	45.00%	**Waste**	41.50%	43.50%
B_2O_3	9.50%	8.50%	B_2O_3	13.50%	13.50%
Li_2O	4.00%	4.50%	Li_2O	2.00%	2.00%
Na_2O	2.50%	2.50%	Na_2O	8.00%	6.50%
SiO_2	38.50%	39.50%	SiO_2	35.00%	34.50%
Glass ID / **Composition**	**AY102D3-01**	**AY102D3-02**	**Glass ID** / **Composition**	**AY102D4-01**	**AY102D4-02**
Al_2O_3	11.860%	11.729%	Al_2O_3	12.281%	12.873%
B_2O_3	9.500%	8.500%	B_2O_3	13.500%	13.500%
BaO	0.073%	0.072%	**BaO**	0.079%	0.083%
CaO	0.514%	0.509%	**CaO**	0.552%	0.579%
Ce_2O_3	0.127%	0.126%	Ce_2O_3	0.137%	0.144%
Cl	0.046%	0.045%	**Cl**	—(1)	—
Cr_2O_3	0.264%	0.261%	Cr_2O_3	0.274%	0.287%
F	0.050%	0.050%	**F**	—	—
Fe_2O_3	14.103%	13.948%	Fe_2O_3	15.099%	15.827%
K_2O	1.192%	1.179%	K_2O	0.066%	0.070%
La_2O_3	0.091%	0.090%	La_2O_3	0.095%	0.100%
Li_2O	4.000%	4.500%	Li_2O	2.000%	2.000%
MgO	0.146%	0.144%	**MgO**	0.158%	0.165%
MnO	2.103%	2.079%	**MnO**	2.250%	2.358%
Na_2O	13.536%	13.415%	Na_2O	14.470%	13.282%
Nd_2O_3	0.150%	0.149%	Nd_2O_3	0.162%	0.170%
NiO	0.341%	0.338%	**NiO**	0.365%	0.383%
P_2O_5	0.560%	0.554%	P_2O_5	0.569%	0.596%
PbO	0.537%	0.531%	**PbO**	0.577%	0.605%
SO_3	0.191%	0.189%	SO_3	0.108%	0.113%
SiO_2	40.616%	41.593%	SiO_2	37.258%	36.867%
TiO_2	—	—	TiO_2	—	—
ZnO	—	—	**ZnO**	—	—
ZrO_2	—	—	ZrO_2	—	—
TOTAL	100.00%	100.00%	**TOTAL**	100.00%	100.00%

(1) — Empty data field (components not present in glass).

Table 2.5. Waste Loadings, Glass-Forming Additives, and Target Compositions (wt%) of Glasses for Tank 241-AY-102 Direct Feed Vitrification (continued).

Washed Solids Glasses	**AY102D4-03**	**AY102D4-04**	**AY102D4-05**	**AY102D4-06**	**AY102D4-07**
Waste	43.50%	39.00%	40.50%	39.00%	39.00%
B_2O_3	11.50%	13.50%	11.00%	12.00%	9.50%
Li_2O	2.00%	3.50%	4.50%	4.50%	4.50%
Na_2O	7.50%	8.00%	7.50%	8.50%	8.00%
SiO_2	35.50%	36.00%	36.50%	36.00%	39.00%
Glass ID **Composition**	**AY102D4-03**	**AY102D4-04**	**AY102D4-05**	**AY102D4-06**	**AY102D4-07**
Al_2O_3	12.873%	11.541%	11.985%	11.54%	11.54%
B_2O_3	11.500%	13.500%	11.000%	12.00%	9.50%
BaO	0.083%	0.074%	0.077%	0.07%	0.07%
CaO	0.579%	0.519%	0.539%	0.52%	0.52%
Ce_2O_3	0.144%	0.129%	0.134%	0.13%	0.13%
Cl	—(1)	—	—	—	—
Cr_2O_3	0.287%	0.257%	0.267%	0.26%	0.26%
F	—	—	—	—	—
Fe_2O_3	15.827%	14.190%	14.735%	14.19%	14.19%
K_2O	0.070%	0.062%	0.065%	0.06%	0.06%
La_2O_3	0.100%	0.090%	0.093%	0.09%	0.09%
Li_2O	2.000%	3.500%	4.500%	4.50%	4.50%
MgO	0.165%	0.148%	0.154%	0.15%	0.15%
MnO	2.358%	2.114%	2.195%	2.11%	2.11%
Na_2O	14.282%	14.081%	13.815%	14.58%	14.08%
Nd_2O_3	0.170%	0.152%	0.158%	0.15%	0.15%
NiO	0.383%	0.343%	0.356%	0.34%	0.34%
P_2O_5	0.596%	0.534%	0.555%	0.53%	0.53%
PbO	0.605%	0.542%	0.563%	0.54%	0.54%
SO_3	0.113%	0.101%	0.105%	0.10%	0.10%
SiO_2	37.867%	38.122%	38.703%	38.12%	41.12%
TiO_2	—	—	—	—	—
ZnO	—	—	—	—	—
ZrO_2	—	—	—	—	—
TOTAL	100.00%	100.00%	100.00%	100.00%	100.00%

(1) — Empty data field (components not present in glass).

Table 2.6. Oxide Composition of Glass (wt%) Previously Used in Melter Tests (wt%) for Pretreated LAW Supernate Originating from Hanford Tank 241-AP-101.

Component	LAWE3 (for AP-101)	ORPLG8 (for AP-101)	ORPLG27 (for AP-101)
Al_2O_3	6.10%	6.75%	6.02%
B_2O_3	10.00%	8.57%	7.91%
CaO	2.02%	2.71%	2.68%
Cr_2O_3	0.08%	0.59%	0.59%
Fe_2O_3	5.50%	0.29%	0.28%
K_2O	4.99%	5.61%	5.74%
MgO	1.48%	0.96%	0.44%
Na_2O[(a)]	18.21%	20.50%	21.00%
NiO	0.01%	0.01%	0.01%
PbO	0.01%	0.01%	0.01%
SiO_2	42.95%	41.15%	42.05%
SnO_2	—(1)	2.86%	3.18%
TiO_2	1.40%	—	—
ZnO	3.50%	3.43%	2.68%
ZrO_2	3.00%	5.71%	6.43%
Cl	0.20%	0.23%	0.23%
F	0.08%	0.09%	0.09%
P_2O_5	0.12%	0.14%	0.14%
SO_3	0.35%	0.40%	0.50%
TOTAL	100.0%	100.0%	100.0%

(1) — Empty data field (components not present in glass).

Table 2.7. Compositions of AY-102 Direct Feed Glasses (wt%) Analyzed by XRF.

Oxide	**AY102D1-01**	**AY102D1-02**	**AY102D1-03**	**AY102D1-04**	**AY102D1-05**	**AY102D1-06**	**AY102D1-06R**
Al_2O_3	6.03%	6.49%	6.38%	6.91%	7.73%	6.11%	6.01%
B_2O_3(1)	**7.80%**	**7.35%**	**11.87%**	**7.95%**	**9.15%**	**10.08%**	**10.08%**
BaO	0.02%	0.04%	0.03%	0.00%	0.03%	0.00%	0.00%
CaO	2.05%	2.01%	0.28%	0.28%	2.19%	2.18%	2.27%
Ce_2O_3(2)	0.06%	0.04%	0.08%	0.08%	0.06%	0.06%	0.06%
Cl	0.12%	0.14%	0.14%	0.15%	0.10%	0.12%	0.12%
Cr_2O_3	0.13%	0.14%	0.15%	0.15%	0.14%	0.13%	0.13%
F(1)	**0.19%**	**0.20%**	**0.20%**	**0.22%**	**0.18%**	**0.17%**	**0.17%**
Fe_2O_3	5.38%	5.77%	6.30%	6.79%	5.56%	4.98%	5.25%
K_2O	4.12%	4.50%	4.49%	4.92%	4.13%	3.76%	3.91%
La_2O_3	0.04%	0.03%	0.03%	0.04%	0.04%	0.03%	0.04%
Li_2O(1)	—(3)	—	—	—	—	—	—
MgO	1.59%	1.51%	0.07%	0.00%	1.58%	1.63%	1.53%
MnO	0.83%	0.94%	0.99%	1.07%	0.86%	0.81%	0.84%
Na_2O	20.89%	22.87%	22.13%	24.02%	20.21%	19.64%	19.05%
Nd_2O_3	0.07%	0.00%	0.08%	0.09%	0.05%	0.06%	0.05%
NiO	0.12%	0.16%	0.17%	0.19%	0.16%	0.15%	0.15%
P_2O_5	0.33%	0.37%	0.40%	0.41%	0.00%	0.32%	0.32%
PbO	0.20%	0.21%	0.23%	0.24%	0.20%	0.17%	0.18%
SO_3	0.57%	0.48%	0.47%	0.49%	0.44%	0.42%	0.40%
SiO_2	41.95%	39.74%	45.48%	38.94%	39.76%	41.89%	41.54%
TiO_2	0.00%	0.00%	0.00%	0.00%	0.00%	1.42%	1.50%
ZnO	2.88%	2.68%	0.03%	2.68%	3.03%	2.98%	3.21%
ZrO_2	4.64%	4.23%	0.00%	4.28%	3.99%	2.84%	3.11%
TOTAL	100.0%	99.9%	100.0%	99.9%	99.6%	99.8%	99.7%

(1) B_2O_3, F, and Li_2O are not analyzed by XRF; target values (boldface) are used.
(2) Analyzed as CeO_2.
(3) — Empty data field (components not present in glass).

Table 2.7. Compositions of AY-102 Direct Feed Glasses (wt%) Analyzed by XRF (continued).

Oxide	AY102D2-01	AY102D2-02	AY102D2-03	AY102D2-04	AY102D2-05	AY102D2-06
Al_2O_3	12.09%	13.61%	12.43%	11.94%	11.88%	9.98%
B_2O_3(1)	**9.03%**	**7.35%**	**8.40%**	**8.40%**	**7.31%**	**7.80%**
BaO	0.07%	0.09%	0.06%	0.07%	0.06%	0.06%
CaO	0.53%	0.63%	0.59%	0.53%	0.54%	0.47%
Ce_2O_3(2)	0.11%	0.20%	0.17%	0.15%	0.13%	0.12%
Cl	0.10%	0.13%	0.10%	0.01%	0.10%	0.09%
Cr_2O_3	0.27%	0.28%	0.30%	0.26%	0.26%	0.23%
F(1)	**0.15%**	**0.18%**	**0.16%**	**0.16%**	**0.15%**	**0.13%**
Fe_2O_3	12.93%	15.39%	14.36%	13.13%	12.80%	11.14%
K_2O	3.34%	3.85%	3.59%	3.61%	3.37%	2.76%
La_2O_3	0.06%	0.08%	0.07%	0.06%	0.04%	0.04%
Li_2O(1)	—(3)	—	—	**1.00%**	**0.86%**	**2.08%**
MgO	0.14%	0.14%	0.14%	0.13%	0.12%	0.11%
MnO	2.01%	2.31%	2.25%	2.01%	1.98%	1.70%
Na_2O	20.30%	23.58%	21.37%	21.55%	21.31%	17.51%
Nd_2O_3	0.15%	0.20%	0.17%	0.11%	0.15%	0.12%
NiO	0.29%	0.34%	0.34%	0.30%	0.28%	0.25%
P_2O_5	0.68%	0.64%	0.65%	0.62%	0.60%	0.00%
PbO	0.45%	0.55%	0.52%	0.47%	0.46%	0.38%
SO_3	0.52%	0.51%	0.61%	0.61%	0.50%	0.40%
SiO_2	36.74%	29.89%	33.71%	34.78%	31.96%	44.03%
TiO_2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
ZnO	0.01%	0.00%	0.01%	0.00%	1.95%	0.00%
ZrO_2	0.01%	0.00%	0.01%	0.00%	3.12%	0.00%
TOTAL	100.0%	100.0%	100.0%	99.9%	99.9%	99.4%

(1) B_2O_3, F, and Li_2O are not analyzed by XRF; target values (boldface) are used.
(2) Analyzed as CeO_2.
(3) — Empty data field (components not present in glass).

Table 2.7. Compositions of AY-102 Direct Feed Glasses (wt%) Analyzed by XRF (continued).

Oxide	AY102D3-01	AY102D3-02	AY102D4-01	AY102D4-02	AY102D4-03
Al_2O_3	11.60%	11.70%	11.92%	12.32%	12.53%
B_2O_3(1)	**9.50%**	**8.50%**	**13.50%**	**13.50%**	**11.50%**
BaO	0.08%	0.08%	0.08%	0.11%	0.11%
CaO	0.57%	0.55%	0.63%	0.66%	0.63%
Ce_2O_3(2)	0.16%	0.21%	0.16%	0.21%	0.18%
Cl	0.04%	0.04%	—(3)	—	—
Cr_2O_3	0.27%	0.25%	0.27%	0.27%	0.28%
F(1)	**0.05%**	**0.05%**	—	—	—
Fe_2O_3	13.77%	13.17%	14.76%	15.24%	15.19%
K_2O	1.23%	1.21%	0.12%	0.10%	0.11%
La_2O_3	0.06%	0.05%	0.07%	0.07%	0.07%
Li_2O(1)	**4.00%**	**4.50%**	**2.00%**	**2.00%**	**2.00%**
MgO	0.12%	0.18%	0.17%	0.15%	0.16%
MnO	2.16%	2.18%	2.36%	2.43%	2.33%
Na_2O	13.79%	13.70%	14.59%	13.63%	14.72%
Nd_2O_3	0.14%	0.14%	0.17%	0.16%	0.16%
NiO	0.42%	0.37%	0.39%	0.39%	0.37%
P_2O_5	0.63%	0.59%	0.60%	0.63%	0.62%
PbO	0.50%	0.45%	0.53%	0.55%	0.52%
SO_3	0.32%	0.32%	0.25%	0.27%	0.26%
SiO_2	40.57%	41.72%	37.41%	37.28%	38.23%
TOTAL	99.9%	100.0%	100.0%	100.0%	100.0%

(1) B_2O_3, F, and Li_2O are not analyzed by XRF; target values (boldface) are used.
(2) Analyzed as CeO_2.
(3) — Empty data field (components not present in glass).

Table 2.7. Compositions of AY-102 Direct Feed Glasses (wt%) Analyzed by XRF (continued).

Oxide	AY102D4-04	AY102D4-05	AY102D4-06	AY102D4-07
Al_2O_3	11.35%	11.64%	11.24%	11.23%
B_2O_3(1)	**13.50%**	**11.00%**	**12.00%**	**9.50%**
BaO	0.08%	0.08%	0.07%	0.05%
CaO	0.60%	0.61%	0.60%	0.58%
Ce_2O_3(2)	0.18%	0.16%	0.16%	0.10%
Cl	—(3)	—	—	—
Cr_2O_3	0.26%	0.27%	0.26%	0.23%
F(1)	—	—	—	—
Fe_2O_3	13.96%	14.33%	13.95%	14.06%
K_2O	0.11%	0.11%	0.07%	0.10%
La_2O_3	0.06%	0.07%	0.07%	0.06%
Li_2O(1)	**3.50%**	**4.50%**	**4.50%**	**4.50%**
MgO	0.12%	0.19%	0.15%	0.14%
MnO	2.18%	2.26%	2.22%	2.23%
Na_2O	13.91%	13.90%	14.63%	14.06%
Nd_2O_3	0.16%	0.16%	0.16%	0.17%
NiO	0.40%	0.48%	0.39%	0.45%
P_2O_5	0.58%	0.57%	0.58%	0.56%
PbO	0.50%	0.53%	0.51%	0.50%
SO_3	0.26%	0.24%	0.24%	0.23%
SiO_2	38.27%	38.86%	38.16%	41.21%
TOTAL	100.0%	100.0%	100.0%	100.0%

(1) B_2O_3, F, and Li_2O are not analyzed by XRF; target values (boldface) are used.
(2) Analyzed as CeO_2.
(3) — Empty data field (components not present in glass).

Table 2.8. Compositions of Selected AY-102 Direct Feed Glasses (wt%) Analyzed by DCP-AES.

Oxide	AY102D1-01	AY102D1-02	AY102D1-03	AY102D1-04	AY102D1-05	AY102D1-06	AY102D1-06R
Al_2O_3	6.04%	6.53%	6.48%	7.04%	8.00%	6.44%	6.17%
B_2O_3	7.80%	7.38%	11.84%	7.74%	8.89%	9.72%	10.00%
BaO	0.03%	0.03%	0.03%	0.04%	0.03%	0.03%	0.03%
CaO	2.03%	1.91%	0.30%	0.32%	2.14%	2.04%	2.14%
Ce_2O_3(1)	**0.05%**	**0.06%**	**0.06%**	**0.06%**	**0.05%**	**0.05%**	**0.05%**
Cl(1)	**0.16%**	**0.17%**	**0.17%**	**0.19%**	**0.16%**	**0.15%**	**0.15%**
Cr_2O_3	0.15%	0.16%	0.17%	0.19%	0.14%	0.13%	0.14%
F(1)	**0.19%**	**0.20%**	**0.20%**	**0.22%**	**0.18%**	**0.17%**	**0.17%**
Fe_2O_3	5.65%	6.17%	6.14%	6.58%	5.18%	5.01%	5.11%
K_2O	4.02%	4.44%	4.43%	4.84%	4.05%	3.61%	3.65%
La_2O_3(1)	**0.04%**	**0.04%**	**0.04%**	**0.04%**	**0.04%**	**0.03%**	**0.03%**
Li_2O	—(2)	—	—	—	—	—	—
MgO	1.80%	1.73%	0.09%	0.09%	1.72%	1.79%	1.71%
MnO	0.98%	1.08%	1.10%	1.21%	0.91%	0.83%	0.82%
Na_2O	18.69%	20.93%	20.36%	22.28%	18.60%	17.12%	18.24%
Nd_2O_3(1)	**0.06%**	**0.07%**	**0.07%**	**0.07%**	**0.06%**	**0.06%**	**0.06%**
NiO	0.12%	0.16%	0.15%	0.18%	0.14%	0.12%	0.13%
P_2O_5	0.33%	0.37%	0.36%	0.39%	0.41%	0.27%	0.21%
PbO	0.24%	0.27%	0.27%	0.29%	0.24%	0.20%	0.22%
SO_3(1)	**0.37%**	**0.41%**	**0.41%**	**0.44%**	**0.36%**	**0.34%**	**0.34%**
SiO_2	42.33%	40.06%	45.04%	40.01%	39.65%	41.54%	42.58%
TiO_2	—	—	—	—	—	1.47%	1.50%
ZnO	2.96%	2.76%	0.00%	2.60%	3.03%	3.01%	3.05%
ZrO_2	4.88%	4.57%	0.00%	4.25%	3.85%	3.05%	2.99%
TOTAL	98.9%	99.5%	97.7%	99.1%	97.8%	97.2%	99.5%

(1) Ce_2O_3, Cl, F, and La_2O_3, La_2O_3, and SO_3 are not analyzed by DCP-AES; target values (boldface) are used.
(2) — Empty data field (components not present in glass). Analyte found below detection limit.
(3) Analyzed with glass remelt as AY102D1-06R.

Table 2.8. Compositions of Selected AY-102 Direct Feed Glasses (wt%) Analyzed by DCP-AES (continued).

Oxide	AY102D2-01	AY102D2-02	AY102D2-03	AY102D2-04	AY102D2-05	AY102D2-06
Al_2O_3	11.82%	13.39%	11.91%	12.02%	11.65%	9.70%
B_2O_3	9.06%	7.35%	8.42%	8.08%	7.27%	7.61%
BaO	0.08%	0.00%	0.08%	0.08%	0.08%	0.06%
CaO	0.62%	0.00%	0.67%	0.61%	0.61%	0.44%
Ce_2O_3(1)	**0.13%**	**0.14%**	**0.13%**	**0.13%**	**0.13%**	**0.11%**
Cl(1)	**0.13%**	**0.14%**	**0.13%**	**0.13%**	**0.13%**	**0.11%**
Cr_2O_3	0.34%	0.00%	0.35%	0.30%	0.30%	0.24%
F(1)	**0.15%**	**0.18%**	**0.16%**	**0.16%**	**0.15%**	**0.13%**
Fe_2O_3	12.94%	14.90%	13.77%	12.75%	12.32%	10.71%
K_2O	3.35%	3.82%	3.47%	3.51%	3.42%	2.73%
La_2O_3(1)	**0.09%**	**0.10%**	**0.09%**	**0.09%**	**0.09%**	**0.07%**
Li_2O	—(2)	—	—	1.17%	1.08%	2.18%
MgO	0.17%	0.19%	0.17%	0.17%	0.16%	0.12%
MnO	2.07%	2.37%	2.17%	2.10%	2.05%	1.72%
Na_2O	18.67%	21.49%	19.93%	19.26%	19.13%	16.20%
Nd_2O_3(1)	**0.15%**	**0.17%**	**0.16%**	**0.15%**	**0.15%**	**0.13%**
NiO	0.30%	0.34%	0.31%	0.30%	0.30%	0.22%
P_2O_5	0.60%	0.69%	0.67%	0.51%	0.51%	0.32%
PbO	0.57%	0.68%	0.62%	0.55%	0.54%	0.44%
SO_3(1)	**0.37%**	**0.42%**	**0.38%**	**0.37%**	**0.37%**	**0.31%**
SiO_2	37.04%	30.85%	34.05%	34.37%	31.01%	44.59%
TiO_2	—	—	—	—	—	—
ZnO	—	—	—	—	2.05%	—
ZrO_2	—	—	—	—	3.33%	—
TOTAL	98.6%	97.2%	97.6%	96.8%	96.8%	98.1%

(1) Ce_2O_3, Cl, F, and La_2O_3, La_2O_3, and SO_3 are not analyzed by DCP-AES; target values (boldface) are used.
(2) — Empty data field (components not present in glass). Analyte found below detection limit.

Table 2.8. Compositions of Selected AY-102 Direct Feed Glasses (wt%) Analyzed by DCP-AES (continued).

Oxide	AY102D3-02	AY102D4-01	AY102D4-02	AY102D4-03	AY102D4-07
Al_2O_3	10.94%	12.11%	11.92%	12.07%	10.74%
B_2O_3	8.33%	14.08%	14.38%	12.28%	9.23%
BaO	0.08%	0.09%	0.09%	0.09%	0.08%
CaO	0.59%	0.76%	0.74%	0.74%	0.60%
Ce_2O_3(1)	**0.13%**	**0.14%**	**0.14%**	**0.14%**	**0.13%**
Cl(1)	**0.05%**	—(2)	—	—	—
Cr_2O_3	0.26%	0.31%	0.33%	0.34%	0.21%
F(1)	**0.05%**	—	—	—	—
Fe_2O_3	13.15%	14.41%	14.96%	15.16%	13.25%
K_2O	1.24%	0.15%	0.13%	0.14%	0.09%
La_2O_3(1)	**0.09%**	**0.10%**	**0.10%**	**0.10%**	**0.09%**
Li_2O	4.37%	2.37%	2.36%	2.38%	4.38%
MgO	0.16%	0.19%	0.19%	0.19%	0.15%
MnO	2.14%	2.28%	2.36%	2.38%	2.15%
Na_2O	12.35%	13.67%	12.70%	13.70%	12.61%
Nd_2O_3(1)	**0.15%**	**0.16%**	**0.17%**	**0.17%**	**0.15%**
NiO	0.32%	0.39%	0.41%	0.42%	0.37%
P_2O_5	0.51%	0.65%	0.65%	0.65%	0.46%
PbO	0.56%	0.63%	0.68%	0.66%	0.56%
SO_3(1)	**0.19%**	**0.11%**	**0.11%**	**0.11%**	**0.10%**
SiO_2	40.60%	36.45%	36.52%	37.43%	40.06%
TiO_2	—	—	—	—	—
ZnO	—	—	—	—	—
ZrO_2	—	—	—	—	—
TOTAL	96.2%	99.1%	99.0%	99.1%	95.4%

(1) Ce_2O_3, Cl, F, and La_2O_3, La_2O_3, and SO_3 are not analyzed by DCP-AES; target values (boldface) are used.
(2) — Empty data field (components not present in glass). Analyte found below detection limit.

Table 2.9. Characterization Data of the AY102-D1 (Blend 1) Series of Glasses.

Property			AY102D1-01	AY102D1-02	AY102D1-03	AY102D1-04	AY102D1-05	AY102D1-06
Crystal Content after Heat Treatment (vol%)		850°C	—(1)	—	—	—	—	Clear glass(3)
		950°C	Clear glass	Clear glass	Clear glass	Clear glass	Clear glass	Clear glass(3)
		Canister Centerline Cooling	—	—	—	—	Clear glass	Clear glass
Viscosity (P)	Predicted at 1150°C		56.80	44.01	48.28	37.86	52.69	44.45
	Experimental	Temperature 1	666.49 (948°C)	399.10 (955°C)	227.23 (953°C)	301.53 (952°C)	558.72 (948°C)	—
		Temperature 2	167.68 (1050°C)	108.49 (1055°C)	74.52 (1055°C)	90.88 (1053°C)	146.54 (1050°C)	—
		Temperature 3	56.68 (1152°C)	38.60 (1156°C)	32.31 (1156°C)	34.52 (1155°C)	51.15 (1151°C)	—
		Temperature 4	23.43 (1252°C)	16.78 (1256°C)	16.45 (1258°C)	15.65 (1256°C)	22.03 (1253°C)	—
	Inter-polated	1050°C	167.86	115.30	78.40	93.95	145.92	—
		1150°C	57.65	40.74	33.69	35.98	51.86	—
		1250°C	24.20	17.51	17.26	16.35	22.49	—
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.510	0.536	0.618	0.712	0.496	0.481
	Experimental	Temperature 1	0.227 (971°C)	0.301 (972°C)	0.378 (965°C)	0.378 (965°C)	0.218 (969°C)	—
		Temperature 2	0.346 (1065°C)	0.454 (1067°C)	0.547 (1061°C)	0.547 (1061°C)	0.333 (1065°C)	—
		Temperature 3	0.517 (1160°C)	0.626 (1162°C)	0.739 (1157°C)	0.739 (1157°C)	0.474 (1158°C)	—
		Temperature 4	0.714 (1255°C)	0.783 (1256°C)	0.973 (1252°C)	0.973 (1252°C)	0.638 (1256°C)	—
	Inter-polated	1050°C	0.328	0.428	0.524	0.524	0.315	—
		1150°C	0.493	0.600	0.728	0.728	0.459	—
		1250°C	0.704	0.775	0.965	0.965	0.628	—
Normalized PCT (7 Day) (g/l)		B	1.719	2.549	—	—	1.844 (1.362)(2)	1.766
		Li	not in glass	not in glass	—	—	not in glass	not in glass
		Na	1.748	2.756	—	—	1.583 (1.294)	1.469
		Si	0.424	0.589	—	—	0.422 (0.377)	0.432
		pH	11.41	11.81	—	—	11.41 (11.30)	11.20
Sulfate Solubility (wt% SO_3 in glass)		Target	0.37%	0.40%	0.40%	0.44%	0.36%	0.34%
		Na_2SO_4 Over-Saturation	0.48%	0.55%	0.73%	0.66%	—	—
		$(NH_4)_2SO_4$ Over-Saturation	0.58%	0.58%	0.66%	0.66%	—	—
K-3 Corrosion		Neck loss (inch)	0.048	0.068	0.132 estimate	0.078 estimate	0.035	0.028
		Half-down loss (inch)	0.005	0.005	—	—	0.001	0.000
		Depth of altered zone (inch)	0.007	0.012	—	—	0.017	0.018

(1) — Empty data field (not analyzed).
(2) PCT Measured after CCC heat treatment in parentheses.
(3) Analyzed with glass AY102D1-06R.

Table 2.10. Ranking Definition for Feed Conversion after 30 Minute VGF Test and Test Results for Selected AY-102 Glass/Feed Formulations.

Ranking	Definition
1	Very Fast, all feed converted
2	Fast with minor residue on side wall
3	Moderate with foamy residue on side wall
4	Slow with thick foam layer
5	Slow with partially collapsed dome
6	Very slow with fully developed dome

Sample	Test Ranking
AY102D1-05F (AY102D1-05 Glass with no sugar)	2
AY102D1-05FS (AY102D1-05 Glass with sugar)	1
AY102D2-06F (AY102D2-06 Glass with no sugar)	6
AY102D2-06FS (AY102D2-06 Glass with sugar)	5
AY102D3-02FD (AY102D3-02 Glass with no sugar)	2-3
AY102D4-07FD (AY102D4-07 Glass with no sugar)	2-3

Table 2.11. TCLP Results (ppm) for Selected AY102D Glasses.

Element	**AY102D1-05**	**AY102D2-06**	**AY102D3-02**	**AY102D4-07**	**Universal Treatment Standard Limit**[1]	**Delisting Limit**
Ba	0.79	0.79	0.79	0.77	21	100
Cr	0.14	0.03	0.02	0.02	0.6	4.95
Ni	0.06	0.04	0.07	0.05	11	22.6
Pb	< 0.1	< 0.1	< 0.1	< 0.1	0.75	5

(1) Not applicable to HLW glass because of the US Environmental Protection Agency Best Demonstrated Available Technology (BDAT). For comparison only.

Table 2.12. Characterization Data for the AY102-D2 (Blend 2) Series of Glasses.

Property			AY102D2-01	AY102D2-02	AY102D2-03	AY102D2-04	AY102D2-05	AY102D2-06
Crystal Content after Heat Treatment(1) (vol%)		850°C	—(2)	—	—	—	2 (Sp) 20 (Neph)	<0.01(Sp)
		950°C	0.0 (Sp)	0.4 (Sp) 13 (Neph)	1.5 (Sp) 13 (Neph)	0.1 (Sp) 2 (Nos)	0.7 (Sp)	Clear glass
		Canister Centerline Cooling	2 (Neph) 2 (Nos)	—	—	—	1.5 (Sp) 30 (Neph)	Clear glass
Viscosity (P)	Predicted at 1150°C		54.17	33.76	44.75	30.82	34.24	60.80
	Experimental	Temperature 1	551.08 (957°C)	—	—	—	—	435.32 (952°C)
		Temperature 2	164.68 (1059°C)	—	—	—	—	144.34 (1053°C)
		Temperature 3	62.50 (1161°C)	—	—	—	—	59.46 (1154°C)
		Temperature 4	29.27 (1263°C)	—	—	—	—	29.10 (1255°C)
	Inter-polated	1050°C	180.05	—	—	—	—	148.48
		1150°C	69.14	—	—	—	—	61.60
		1250°C	31.91	—	—	—	—	29.99
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.508	0.684	0.528	0.527	0.528	0.381
	Experimental	Temperature 1	0.231 (966°C)	—	—	—	—	0.220 (972°C)
		Temperature 2	0.363 (1060°C)	—	—	—	—	0.342 (1067°C)
		Temperature 3	0.488 (1157°C)	—	—	—	—	0.461 (1162°C)
		Temperature 4	0.644 (1252°C)	—	—	—	—	0.605 (1258°C)
	Inter-polated	1050°C	0.344	—	—	—	—	0.316
		1150°C	0.488	—	—	—	—	0.382
		1250°C	0.635	—	—	—	—	0.520
Normalized PCT (7 Day) (g/l)		B	2.153	—	—	—	1.628	0.617
		Li	not in glass	—	—	—	1.014	0.614
		Na	1.910	—	—	—	1.936	0.854
		Si	0.424	—	—	—	0.438	0.432
		pH	11.26	—	—	—	11.51	11.01
Sulfate Solubility (wt% SO_3 in glass)		Target	0.36%	0.42%	0.38%	0.37%	0.36%	0.31%
		Na_2SO_4 Over-Saturation	0.48%	0.12%	0.50%	0.66%	0.43%	—
		$(NH_4)_2SO_4$ Over-Saturation	0.49%	0.48%	0.46%	0.54%	0.43%	—
K-3 Corrosion		Neck loss (inch)	0.020	—	—	—	0.021	0.016
		Half-down loss (inch)	0.007	—	—	—	0.003	0.001
		Depth of altered zone (inch)	0.014	—	—	—	0.008	0.016

(1) Sp = Spinel, Neph = Nepheline, Nos = Nosean.
(2) — Empty data field (not analyzed).

Table 2.13. Characterization Data for the AY102-D3 (Blend 3) Series of Glasses.

Property			AY102D3-01	AY102D3-02
Crystal Content after Heat Treatment(1) (vol%)(1)		800°C	—(2)	2.91 (Sp)
		850°C	2.76 (Sp)	1.98 (Sp)
		900°C	2.38 (Sp)	1.80 (Sp)
		950°C	1.62 (Sp)	0.51 (Sp)
		1000°C	1.02 (Sp)	0.78 (Sp)
		1050°C	0.04 (Sp)	—
		1100°C	—	—
Viscosity (P)	Predicted at 1150°C		33.92	32.51
	Experimental	Temperature 1	—	257.90 (952°C)
		Temperature 2	—	88.42 (1053°C)
		Temperature 3	—	37.00 (1153°C)
		Temperature 4	—	18.16 (1253°C)
	Interpolated	1050°C	—	90.76
		1150°C	—	38.04
		1250°C	—	18.49
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.433	0.432
	Experimental	Temperature 1	—	0.240 (972°C)
		Temperature 2	—	0.350 (1067°C)
		Temperature 3	—	0.494 (1163°C)
		Temperature 4	—	0.659 (1256°C)
	Interpolated	1050°C	—	0.330
		1150°C	—	0.473
		1250°C	—	0.647
Normalized PCT (7 Day) (g/l)		B	—	0.637
		Li	—	0.791
		Na	—	0.808
		Si	—	0.477
		pH	—	10.90

(1) Sp = Spinel.
(2) — Empty data field (not analyzed).

Table 2.14. Regression Results[(1)], Estimated One-Percent Crystal Fraction Temperature ($T_{1\%}$) and the Major Crystalline Phase Near $T_{1\%}$ for the Direct Feed HLW (Blend 3 and Washed Solids) Glasses.

Glass	Intercept	Slope	$T_{1\%}$ (°C)	Primary Crystalline Phase
AY102D3-01	1062.71	-72.07	990.64	Spinel
AY102D3-02	1021.58	-76.18	945.40	Spinel
AY102D4-01	1173.98	-94.45	1079.53	Spinel
AY102D4-02	1200.00	-83.27	1116.74	Spinel
AY102D4-03	1180.66	-70.85	1109.81	Spinel
AY102D4-04	1076.94	-143.57	933.36	Spinel
AY102D4-05	1131.92	-77.37	1054.55	Spinel
AY102D4-06	1102.94	-147.06	955.88	Spinel
AY102D4-07	1074.61	-138.15	936.46	Spinel

(1) Regression results are rounded to 2 decimal places.

Table 2.15. Characterization Data for the AY102-D4 (Washed Solids) Series of Glasses.

Property			AY102D4-01	AY102D4-02	AY102D4-03	AY102D4-04
Crystal Content after Heat Treatment(1) (vol%)(1)		850°C	—	—	—(2)	2.77 (Sp)
		900°C	2.81 (Sp)	3.60 (Sp)	4.01 (Sp)	1.24 (Sp)
		950°C	2.57 (Sp)	2.88 (Sp)	3.29 (Sp)	0.83 (Sp)
		1000°C	1.51 (Sp)	2.60 (Sp)	2.37 (Sp)	0.60 (Sp)
		1050°C	1.19 (Sp)	1.61 (Sp)	1.59 (Sp)	0.17 (Sp)
		1100°C	1.13 (Sp)	1.32 (Sp)	1.49 (Sp)	—
Viscosity (P)	Predicted at 1150°C		40.73	50.06	54.92	22.12
	Experimental	Temperature 1	331.96 (957°C)	—	—	—
		Temperature 2	101.73 (1057°C)	—	—	—
		Temperature 3	40.11 (1158°C)	—	—	—
		Temperature 4	21.08 (1258°C)	—	—	—
	Interpolated	1050°C	107.60	—	—	—
		1150°C	43.65	—	—	—
		1250°C	21.90	—	—	—
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.323	0.280	0.313	0.409
	Experimental	Temperature 1	0.185 (970°C)	—	—	—
		Temperature 2	0.288 (1065°C)	—	—	—
		Temperature 3	0.395 (1160°C)	—	—	—
		Temperature 4	0.514 (1255°C)	—	—	—
	Interpolated	1050°C	0.270	—	—	—
		1150°C	0.386	—	—	—
		1250°C	0.507	—	—	—
Normalized PCT (7 Day) (g/l)		B	—	—	—	—
		Li	—	—	—	—
		Na	—	—	—	—
		Si	—	—	—	—
		pH	—	—	—	—

(1) Sp = Spinel.
(2) — Empty data field (not analyzed).

Table 2.15. Characterization Data of the AY102-D4 (Washed Solids) Series of Glasses (continued).

Property			AY102D4-05	AY102D4-06	AY102D4-07
Crystal Content after Heat Treatment(1) (vol%)(1)		850°C	—(2)	2.57 (Sp)	1.20 (Sp)
		900°C	2.75 (Sp)	1.41 (Sp)	1.53 (Sp)
		950°C	2.58 (Sp)	0.97 (Sp)	0.62 (Sp)
		1000°C	—	0.54 (Sp)	0.81 (Sp)
		1050°C	1.16 (Sp)	0.56 (Sp)	0.35 (Sp)
		1100°C	0.33 (Sp)	—	—
Viscosity (P)	Predicted at 1150°C		20.67	15.68	25.63
	Experimental	Temperature 1	—	110.18 (956°C)	202.51 (953°C)
		Temperature 2	—	40.39 (1058°C)	71.28 (1055°C)
		Temperature 3	—	18.14 (1160°C)	30.49 (1156°C)
		Temperature 4	—	9.39 (1262°C)	15.27 (1258°C)
	Interpolated	1050°C	—	43.43	74.33
		1150°C	—	19.48	32.08
		1250°C	—	10.08	16.02
Electrical Conductivity (S/cm)	Predicted at 1150°C		0.481	0.520	0.489
	Experimental	Temperature 1	—	—	0.264 (967°C)
		Temperature 2	—	—	0.396 (1062°C)
		Temperature 3	—	—	0.537 (1158°C)
		Temperature 4	—	—	0.717 (1253°C)
	Interpolated	1050°C	—	—	0.374
		1150°C	—	—	0.530
		1250°C	—	—	0.708
Normalized PCT (7 Day) (g/l)		B	—	—	0.736
		Li	—	—	0.745
		Na	—	—	0.797
		Si	—	—	0.374
		pH	—	—	10.61

(1) Sp = Spinel.
(2) — Empty data field (not analyzed).

Table 2.16. Summary of Oxide Contributions (as wt% oxide in glass) from LAW, HLW, and Glass Forming Additives to Blend 1 Target Glass Formulation (AY102D1-05, Waste Loading = 39 wt%)(1).

Oxide	Blended Waste	LAW	HLW	Glass Forming Additive	Target Glass
Al_2O_3	5.87%	1.37%	4.50%	2.14%	8.01%
B_2O_3	0.00%	0.00%	0.00%	9.15%	9.15%
BaO	0.03%	0.00%	0.03%	—(2)	0.03%
CaO	0.20%	0.00%	0.20%	1.83%	2.03%
Ce_2O_3	0.05%	0.00%	0.05%	—	0.05%
Cl	0.15%	0.15%	0.00%	—	0.15%
Cr_2O_3	0.12%	0.02%	0.10%	—	0.12%
F	0.18%	0.18%	0.00%	—	0.18%
Fe_2O_3	5.53%	0.00%	5.53%	—	5.53%
K_2O	4.01%	3.98%	0.02%	—	4.01%
La_2O_3	0.03%	0.00%	0.03%	—	0.03%
MgO	0.06%	0.00%	0.06%	1.83%	1.89%
MnO	0.82%	0.00%	0.82%	—	0.82%
Na_2O	20.00%	17.62%	2.37%	—	20.00%
Nd_2O_3	0.06%	0.00%	0.06%	—	0.06%
NiO	0.13%	0.00%	0.13%	—	0.13%
P_2O_5	0.32%	0.11%	0.21%	—	0.32%
PbO	0.21%	0.00%	0.21%	—	0.21%
SO_3	0.36%	0.32%	0.04%	—	0.36%
SiO_2	0.85%	0.02%	0.83%	39.04%	39.89%
ZnO	—	—	—	3.05%	3.05%
ZrO_2	—	—	—	3.97%	3.97%
TOTAL	39.0%	23.8%	15.2%	61.0%	100.0%

(1) Decimal rounding may cause slight differences in addition results and/or target glass composition when compared to Table 2.5.

(2) — Empty data field (oxides not present in waste or additives not used).

Table 2.17. Summary of Oxide Contributions (as wt% oxide in glass) from LAW, HLW, and Glass Forming Additives to Blend 2 Target Glass Formulation (AY102D2-06, Waste Loading = 48 wt%)$^{(1)}$.

Oxide	Blended Waste	LAW	HLW	Glass Forming Additive	Target Glass
Al_2O_3	10.28%	0.95%	9.33%	—$^{(2)}$	10.28%
B_2O_3	0.00%	0.00%	0.00%	7.80%	7.80%
BaO	0.06%	0.00%	0.06%	—	0.06%
CaO	0.42%	0.00%	0.42%	—	0.42%
Ce_2O_3	0.10%	0.00%	0.10%	—	0.10%
Cl	0.11%	0.11%	0.00%	—	0.11%
Cr_2O_3	0.22%	0.02%	0.21%	—	0.22%
F	0.13%	0.13%	0.00%	—	0.13%
Fe_2O_3	11.47%	0.00%	11.47%	—	11.47%
K_2O	2.81%	2.76%	0.05%	—	2.81%
La_2O_3	0.07%	0.00%	0.07%	—	0.07%
Li_2O	—	—	—	2.08%	2.08%
MgO	0.12%	0.00%	0.12%	—	0.12%
MnO	1.71%	0.00%	1.71%	—	1.71%
Na_2O	17.11%	12.19%	4.92%	—	17.11%
Nd_2O_3	0.12%	0.00%	0.12%	—	0.12%
NiO	0.28%	0.00%	0.28%	—	0.28%
P_2O_5	0.51%	0.07%	0.43%	—	0.51%
PbO	0.44%	0.00%	0.44%	—	0.44%
SO_3	0.31%	0.22%	0.08%	—	0.31%
SiO_2	1.73%	0.01%	1.72%	42.12%	43.85%
ZnO	—	—	—	—	—
ZrO_2	—	—	—	—	—
TOTAL	48.0%	16.5%	31.5%	52.0%	100.0%

(1) Decimal rounding may cause slight differences in addition results and/or target glass composition when compared to Table 2.5.

(2) — Empty data field (oxides not present in waste or additives not used).

Table 2.18. Summary of Oxide Contributions (as wt% oxide in glass) from LAW, HLW, and Glass Forming Additives to Blend 3 Target Glass Formulation (AY102D3-02, Waste Loading = 45 wt%)(1).

Oxide	Blended Waste	LAW	HLW	Glass Forming Additive	Target Glass
Al_2O_3	11.73%	0.38%	11.34%	—(2)	11.73%
B_2O_3	0.00%	0.00%	0.00%	8.50%	8.50%
BaO	0.07%	0.00%	0.07%	—	0.07%
CaO	0.51%	0.00%	0.51%	—	0.51%
Ce_2O_3	0.13%	0.00%	0.13%	—	0.13%
Cl	0.04%	0.04%	0.00%	—	0.04%
Cr_2O_3	0.26%	0.01%	0.25%	—	0.26%
F	0.05%	0.05%	0.00%	—	0.05%
Fe_2O_3	13.95%	0.00%	13.95%	—	13.95%
K_2O	1.18%	1.11%	0.06%	—	1.18%
La_2O_3	0.09%	0.00%	0.09%	—	0.09%
Li_2O	—	—	—	4.50%	4.50%
MgO	0.15%	0.00%	0.15%	—	0.15%
MnO	2.08%	0.00%	2.08%	—	2.08%
Na_2O	10.91%	4.93%	5.98%	2.50%	13.41%
Nd_2O_3	0.15%	0.00%	0.15%	—	0.15%
NiO	0.34%	0.00%	0.34%	—	0.34%
P_2O_5	0.56%	0.03%	0.53%	—	0.56%
PbO	0.53%	0.00%	0.53%	—	0.53%
SO_3	0.19%	0.09%	0.10%	—	0.19%
SiO_2	2.09%	0.01%	2.09%	39.50%	41.59%
ZnO	—	—	—	—	—
ZrO_2	—	—	—	—	—
TOTAL	45.0%	6.7%	38.3%	55.0%	100.0%

(1) Decimal rounding may cause slight differences in addition results and/or target glass composition when compared to Table 2.5.

(2) — Empty data field (oxides not present in waste or additives not used).

Table 2.19. Summary of Oxide Contributions (as wt% oxide in glass) from HLW and Glass Forming Additives to Washed Solids Target Glass Formulation (AY102D4-07, Waste Loading = 39 wt%)(1).

Oxide	HLW	Glass Forming Additive	Target Glass
Al_2O_3	11.54%	—(2)	11.54%
B_2O_3	0.00%	9.50%	9.50%
BaO	0.07%	—	0.07%
CaO	0.52%	—	0.52%
Ce_2O_3	0.13%	—	0.13%
Cl	0.00%	—	0.00%
Cr_2O_3	0.26%	—	0.26%
F	0.00%	—	0.00%
Fe_2O_3	14.19%	—	14.19%
K_2O	0.06%	—	0.06%
La_2O_3	0.09%	—	0.09%
Li_2O	—	4.50%	4.50%
MgO	0.15%	—	0.15%
MnO	2.11%	—	2.11%
Na_2O	6.08%	8.00%	14.08%
Nd_2O_3	0.15%	—	0.15%
NiO	0.34%	—	0.34%
P_2O_5	0.53%	—	0.53%
PbO	0.54%	—	0.54%
SO_3	0.10%	—	0.10%
SiO_2	2.12%	39.00%	41.12%
ZnO	—	—	—
ZrO_2	—	—	—
TOTAL	39.0%	61.0%	100.0%

(1) Decimal rounding may cause slight differences in addition results and/or target glass composition when compared to Table 2.5.

(2) — Empty data field (oxides not present in waste or additives not used).

Table 2.20. Summary of Glass Forming Additives (kg) Required to Produce 100 kg of Target Glasses for Tank 241-AY-102 Direct Feed Vitrification(1).

Waste		**Blend 1**	**Blend 2**	**Blend 3**	**Washed Solids**
Target Glass		**AY102D1-05**	**AY102D2-06**	**AY102D3-02**	**AY102D4-07**
Waste Loading		**39.0 wt%**	**48.0 wt%**	**45 wt%**	**39 wt%**
Melter Test		**1**	**2**	**3**	**4, 5**
Glass Forming Additives (kg) Required to Produce 100 kg of Target Glasses	**Kyanite (Al_2SiO_5)**	3.393	—(2)	—	—
	H_3BO_3	16.259	13.854	15.098	16.874
	$CaCO_3$	3.266	—	—	—
	$LiCO_3$	—	5.144	11.130	11.130
	MgO	1.830	—	—	—
	Na_2CO_3	—	—	4.275	13.681
	SiO_2	35.848	42.120	39.500	39.000
	ZnO	3.050	—	—	—
	Zircon ($ZrSiO_4$)	5.898	—	—	—
	TOTAL	69.544	61.119	70.003	80.684
Modifications to Feed received from NOAH at VSL	**Water**	Evaporated from Feed	Added	Added	Added
	Chemicals Added to Achieve Target Glass	None	Sodium Hydroxide	Sodium Carbonate, Boric Acid, Fe_2O_3	Boric Acid, Fe_2O_3
	Sugar	Added	Added	Added	None

(1) Assay values of all additives assumed to be 100%.
(2) — Empty data field (additives not used).

Table 3.1. Summary of Results from DM100 Test 5 with High Water, Blend 4 Waste and Optimized AY102D4-07 Glass Composition.

Test		**Fixed Bubbling (9 lpm)**	**Optimized Bubbling**
Time	Feed Start	9/17/13 14:00	9/19/13 17:15
	Feed End	9/19/13 17:00	9/20/13 16:50
	Interval	51.0 hr	23.6 hr
Water Feeding for Cold Cap		60 min	0 min
Slurry Feeding		50.0 hr	23.6 hr
Feeding Interruptions		95 min	10 min
Average Bubbling Rate		8.8 lpm	16.9 lpm
Waste	wt% LAW solids	0	0
	wt% HLW solids	10	10
	wt% total solids	10	10
Feed	Used	704 kg	504 kg
	Target Glass Yield	0.158 kg/kg	0.158 kg/kg
	Measured Glass Yield	168 g/l	168 g/l
		0.16 kg/kg	0.16 kg/kg
	Average Feed Rate	14.1 kg/hr	21.4 kg/hr
Glass Produced	Poured	97.6 kg	73.6 kg
	Average Rate based on glass poured	425 kg/m^2/day	694 kg/m^2/day
	Average Rate based on feed consumed	495 kg/m^2/day	750 kg/m^2/day
	Steady State Rate*	500 kg/m^2/day	775 kg/m^2/day
	Average Power Use	9.7 kW hr/kg glass	7.9 kW hr/kg glass

*: Rates estimated from feed data.
Note: Rates do not take into account the time for water feeding and cold cap burn-off.

Table 3.2. Summary of Results from DM100 Test 4 with Blend 4 Waste and Optimized AY102D4-07 Glass Composition.

Test		**Fixed Bubbling (9 lpm)**	**Optimized Bubbling**
Time	Feed Start	9/23/13 15:10	9/25/13 18:10
	Feed End	9/25/13 18:10	9/27/13 6:08
	Interval	51.0 hr	36.0 hr
Water Feeding for Cold Cap		60 min	0 min
Slurry Feeding		50.0 hr	36.0 hr
Feeding Interruptions		11 min	7 min
Average Bubbling Rate		9.0 lpm	14.8 lpm
Waste	wt% LAW solids	0	0
	wt% HLW solids	15	15
	wt% total solids	15	15
Feed	Used	680 kg	784 kg
	Target Glass Yield	0.223 kg/kg	0.223 kg/kg
	Measured Glass Yield	292 g/l	292 g/l
		0.24 kg/kg	0.24 kg/kg
	Average Feed Rate	13.6 kg/hr	21.8 kg/hr
Glass Produced	Poured	151.6 kg	186.8 kg
	Average Rate based on glass poured	660 kg/m^2/day	1154 kg/m^2/day
	Average Rate based on feed consumed	674 kg/m^2/day	1080 kg/m^2/day
	Steady State Rate*	650 kg/m^2/day	1100 kg/m^2/day
	Average Power Use	6.0 kW hr/kg glass	4.7 kW hr/kg glass

*: Rates estimated from feed data.
Note: Rates do not take into account the time for water feeding and cold cap burn-off.

Table 3.3. Summary of Results from DM100 Test 3 with Blend 3 Waste and Optimized AY102D3-02 Glass Composition.

Test		Fixed Bubbling (9 lpm)	Optimized Bubbling
Time	Feed Start	10/1/13 9:15	10/3/13 12:35
	Feed End	10/3/13 12:15	10/4/13 23:00
	Interval	51.0 hr	34.4 hr
Water Feeding for Cold Cap		60 min	0 min
Slurry Feeding		50.0 hr	34.4 hr
Feeding Interruptions		10 min	7 min
Average Bubbling Rate		9.1 lpm	17.7 lpm
Waste	wt% LAW solids	3.3	3.3
	wt% HLW solids	15	15
	wt% total solids	18.3	18.3
Feed	Used	750 kg	811 kg
	Target Glass yield	0.232 kg/kg	0.232 kg/kg
	Measured Glass yield	314 g/l	314 g/l
		0.25 kg/kg	0.25 kg/kg
	Average Feed Rate	15.0 kg/hr	23.6 kg/hr
Glass Produced	Poured	176.4 kg	217.2 kg
	Average Rate based on glass poured	768 kg/m^2/day	1403 kg/m^2/day
	Average Rate based on feed consumed	773 kg/m^2/day	1215 kg/m^2/day
	Steady State Rate[*]	775 kg/m^2/day	1200 kg/m^2/day
	Average Power Use	5.4 kW hr/kg glass	4.1 kW hr/kg glass

*: Rates estimated from feed data.

Note: Rates do not take into account the time for water feeding and cold cap burn-off.

Table 3.4. Summary of Results from DM100 Test 2 with Blend 2 Waste and Optimized AY102D2-06 Glass Composition.

Test		Fixed Bubbling (9 lpm)	Optimized Bubbling
Time	Feed Start	10/7/13 13:15	10/9/13 16:45
	Feed End	10/9/13 16:45	10/10/13 23:00
	Interval	51.5 hr	30.3 hr
Water Feeding for Cold Cap		60 min	0 min
Slurry Feeding		50.0 hr	30.3 hr
Feeding Interruptions		38 min	11 min
Average Bubbling Rate		8.9 lpm	18.4 lpm
Waste	wt% LAW solids	10	10
	wt% HLW solids	15	15
	wt% total solids	25	25
Feed	Used	720 kg	559 kg
	Target Glass yield	0.30 kg/kg	0.30 kg/kg
	Measured Glass yield	425 g/l	425 g/l
		0.32 kg/kg	0.32 kg/kg
	Average Feed Rate	14.3 kg/hr	18.5 kg/hr
Glass Produced	Poured	217.5 kg	158.4 kg
	Average Rate based on glass poured	939 kg/m^2/day	1164 kg/m^2/day
	Average Rate based on feed consumed	951 kg/m^2/day	1232 kg/m^2/day
	Steady State Rate*	900 kg/m^2/day	1225 kg/m^2/day
	Average Power Use	4.1 kW hr/kg glass	4.0 kW hr/kg glass

*: Rates estimated from feed data.

Note: Rates do not take into account the time for water feeding and cold cap burn-off.

Table 3.5. Summary of Results from DM100 Test 1 with Blend 1 Waste and Optimized AY102D1-05 Glass Composition.

Test		Fixed Bubbling (9 lpm)	Optimized Bubbling
Time	Feed Start	10/22/13 9:48	10/24/13 12:45
	Feed End	10/24/13 12:45	10/25/13 17:54
	Interval	51.0 hr	29.2 hr
Water Feeding for Cold Cap		60 min	0 min
Slurry Feeding		50.0 hr	29.2 hr
Feeding Interruptions		77 min	5 min
Average Bubbling Rate		8.9 lpm	17.4 lpm
Waste	wt% LAW solids	30	30
	wt% HLW solids	15	15
	wt% total solids	45	45
Feed	Used	621 kg	655 kg
	Target Glass yield	0.50 kg/kg	0.50 kg/kg
	Measured Glass yield	808 g/l	808 g/l
		0.48 kg/kg	0.48 kg/kg
	Average Feed Rate	12.4 kg/hr	22.5 kg/hr
Glass Produced	Poured	311.4 kg	321.1 kg
	Average Rate based on glass poured	1358 kg/m^2/day	2448 kg/m^2/day
	Average Rate based on feed consumed	1380 kg/m^2/day	2495 kg/m^2/day
	Steady State Rate*	1250 kg/m^2/day	2500 kg/m^2/day
	Average Power Use	2.5 kW hr/kg glass	1.9 kW hr/kg glass

*: Rates estimated from feed data.

Note: Rates do not take into account the time for water feeding and cold cap burn-off.

Table 3.6. Steady-State Production Rates Achieved on the DM100 with HLW Compositions at Nominal Processing Glass Temperature (1150°C) and Low Solids Content.

HLW Waste/Glass	Bubbling Rate (lpm)	Glass Yield (g/L)	Production Rate kg/m^2/day
AY102D4-07	9	168	500
	9	292	650
AY102D3-02	9	314	775
Bismuth Limited [5]	9	250	510
Aluminum Limited [5]	9	250	400
Aluminum and Sodium Limited [5]	9	250	200
AY102D2-06	9	425	900
C-106/AY-102, Nominal Rheology [16]	9	435	1100
C-106/AY-102, Adjusted Rheology [16]	9	435	1150
AY102D2-06	Optimized	425	1225
C-106/AY-102, High Waste Loading [20]	Optimized	420	1350

Table 3.7. Steady-State Production Rates for Waste Components.

	Test	1	2	3	4	5
Waste	Washing	None	1 wash cycle*	2 wash cycles	Complete	Complete
	Wt% HLW Solids	15%	15%	15%	15%	10%
	Wt% HLW Oxides	39	65.7	85.2	100%	100%
	Wt% LAW Oxides	61	34.3	14.2	0	0
Waste Loading	Wt% Total Oxides	39%	48%	45%	39%	39%
	Wt% HLW Oxides	15.2%	31.5%	38.3%	39.0%	39.0%
	Wt% LAW Oxides	23.8%	16.5%	6.7%	0%	0%
Glass Production Rate (kg/m2/day)	9 lpm bubbling	1250	900	775	650	500
	Optimized bubbling	2500	1225	1200	1100	775
Total Waste Oxide Production Rate (kg/m2/day)	9 lpm bubbling	488	432	349	254	195
	Optimized bubbling	975	588	540	429	302
HLW Oxide Production Rate (kg/m2/day)	9 lpm bubbling	190	284	297	254	195
	Optimized bubbling	381	386	460	429	302
LAW Oxide Production Rate (kg/m2/day)	9 lpm bubbling	297	149	52	0	0
	Optimized bubbling	594	202	80	0	0

* A wash cycle is assumed to correspond to a three-fold dilution with water followed by settling to 15 wt% un-dissolved solids.

Table 3.8. Summary of Measured DM100 Parameters from Test 5 with High-Water Blend 4 Waste and Optimized AY102D4-07 Glass Composition.

Test			**Fixed Bubbling 9 lpm**			**Optimized Bubbling**		
			AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (°C)	Electrode	East Upper	1074	1021	1107	1067	1013	1098
		West Upper	1120	1088	1144	1134	1103	1170
		West Lower	1087	1046	1106	1114	1083	1142
		Bottom	711	691	723	734	721	745
	Glass	27” from bottom	1132	1035	1175	1114	935	1157
		16” from bottom	1143	1091	1178	1138	1082	1164
		10” from bottom	1166	1134	1189	1166	1133	1195
		5” from bottom	1143	1085	1172	1155	1114	1183
	Plenum	Exposed	458	283	752	463	384	511
		Thermowell	431	341	729	434	379	493
	Discharge	Chamber	1021	964	1052	1036	1001	1051
		Air Lift	982	919	1104	1016	984	1113
	Film Cooler Outlet		290	273	305	298	286	305
	Transition Line Outlet		274	216	286	282	274	292
Lance Bubbling (lpm)			8.8	1.4	9.2	16.9	4.9	17.9
Melter Pressure (inches water)			-0.88	-2.46	0.20	-0.84	-2.67	0.38
Total Electrode Voltage (V)			38.5	30.2	42.5	42.6	35.4	44.9
Total Electrode Power (kW)			18.6	11.7	22.1	24.8	16.8	26.7
Glass Resistance (ohms)			0.080	0.072	0.090	0.073	0.064	0.084

Table 3.9. Summary of Measured DM100 Parameters from Test 4 with Blend 4 Waste and Optimized AY102D4-07 Glass Composition.

Test			**Fixed Bubbling 9 lpm**			**Optimized Bubbling**		
			AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (°C)	Electrode	East Upper	1077	987	1096	1109	1078	1125
		West Upper	1100	1079	1113	1110	1088	1123
		West Lower	1067	1048	1077	1084	1061	1096
		Bottom	699	679	705	719	704	724
	Glass	27” from bottom	1133	1044	1160	1133	1093	1161
		16” from bottom	1143	1115	1161	1139	1107	1164
		10” from bottom	1157	1136	1171	1154	1131	1177
		5” from bottom	1152	1113	1166	1153	1132	1172
	Plenum	Exposed	474	317	726	471	251	526
		Thermowell	448	364	709	425	315	485
	Discharge	Chamber	1038	1008	1059	1047	1005	1068
		Air Lift	982	927	1126	1006	970	1122
	Film Cooler Outlet		278	273	287	278	271	290
	Transition Line Outlet		269	210	288	274	267	283
Lance Bubbling (lpm)			9.0	2.9	9.3	14.8	9.0	29.3
Melter Pressure (inches water)			-0.91	-2.78	0.09	-0.94	-3.65	1.87
Total Electrode Voltage (V)			35.3	32.8	38.3	40.3	31.6	44.0
Total Electrode Power (kW)			17.8	16.3	19.1	24.4	15.8	26.6
Glass Resistance (ohms)			0.070	0.065	0.079	0.067	0.061	0.076

Table 3.10. Summary of Measured DM100 Parameters from Test 3 with Blend 3 Waste and Optimized AY102D3-02 Glass Composition.

Test			Fixed Bubbling 9 lpm			Optimized Bubbling		
			AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (°C)	Electrode	East Upper	1079	1015	1111	1079	1044	1102
		West Upper	1102	1073	1119	1109	1069	1128
		West Lower	1073	1055	1086	1093	1062	1110
		Bottom	698	681	707	720	706	728
	Glass	27” from bottom	1134	1022	1165	1135	1054	1161
		16” from bottom	1145	1114	1166	1145	1093	1168
		10” from bottom	1155	1133	1173	1153	1113	1176
		5” from bottom	1152	1134	1169	1151	1121	1172
	Plenum	Exposed	478	252	775	474	311	518
		Thermowell	446	323	756	438	347	473
	Discharge	Chamber	1031	991	1056	1040	1019	1059
		Air Lift	990	911	1124	1013	980	1125
	Film Cooler Outlet		276	63	287	278	271	287
	Transition Line Outlet		265	207	349	269	263	280
Lance Bubbling (lpm)			9.1	1.5	9.5	17.7	10.1	23.1
Melter Pressure (inches water)			-0.85	-2.93	0.20	-0.82	-2.79	2.34
Total Electrode Voltage (V)			35.3	31.0	37.2	42.2	34.2	45.4
Total Electrode Power (kW)			18.7	15.0	20.8	25.6	18.0	28.0
Glass Resistance (ohms)			0.067	0.062	0.073	0.070	0.065	0.079

Table 3.11. Summary of Measured DM100 Parameters from Test 2 with Blend 2 Waste and Optimized AY102D2-06 Glass Composition.

Test			Fixed Bubbling 9 lpm			Optimized Bubbling		
			AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (°C)	Electrode	East Upper	1076	944	1107	1093	1052	1117
		West Upper	1092	1056	1113	1096	1064	1118
		West Lower	1072	1041	1081	1084	1067	1099
		Bottom	696	659	707	710	705	714
	Glass	27” from bottom	1130	1052	1166	1134	1016	1165
		16” from bottom	1144	1104	1172	1143	1087	1166
		10” from bottom	1156	1130	1179	1154	1121	1173
		5” from bottom	1153	1116	1171	1150	1120	1169
	Plenum	Exposed	455	118	717	472	213	549
		Thermowell	420	301	703	426	296	494
	Discharge	Chamber	1030	1003	1056	1036	964	1062
		Air Lift	989	918	1135	1008	979	1127
	Film Cooler Outlet		293	150	306	298	280	302
	Transition Line Outlet		278	147	294	282	275	291
Lance Bubbling (lpm)			8.9	1.4	9.3	18.4	13.1	24.3
Melter Pressure (inches water)			-0.83	-2.88	0.39	-0.76	-4.26	0.11
Total Electrode Voltage (V)			35.8	27.0	38.8	41.2	34.2	46.6
Total Electrode Power (kW)			17.3	12.0	20.9	21.2	15.1	23.3
Glass Resistance (ohms)			0.074	0.060	0.085	0.080	0.074	0.099

Table 3.12. Summary of Measured DM100 Parameters from Test 1 with Blend 1 Waste and Optimized AY102D1-05 Glass Composition.

Test			**Fixed Bubbling 9 lpm**			**Optimized Bubbling**		
			AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (°C)	Electrode	East Upper	1115	1018	1143	1125	1082	1140
		West Upper	1113	1072	1131	1112	1070	1136
		West Lower	1096	1072	1114	1114	1087	1129
		Bottom	716	697	726	732	723	741
	Glass	27” from bottom	1141	1035	1169	1131	1064	1165
		16” from bottom	1149	1122	1176	1143	1099	1170
		10” from bottom	1155	1132	1176	1150	1113	1171
		5” from bottom	1151	1131	1170	1150	1119	1170
	Plenum	Exposed	496	191	790	519	278	615
		Thermowell	463	281	767	470	329	529
	Discharge	Chamber	1052	1024	1079	1066	1040	1087
		Air Lift	1018	954	1133	1060	1018	1169
	Film Cooler Outlet		280	253	292	288	280	295
	Transition Line Outlet		265	209	281	278	270	291
Lance Bubbling (lpm)			8.9	2.9	9.1	17.4	15.0	21.1
Melter Pressure (inches water)			-0.80	-2.75	0.08	-0.79	-3.18	0.49
Total Electrode Voltage (V)			32.4	26.4	35.8	39.7	32.8	45.7
Total Electrode Power (kW)			15.2	10.6	18.8	21.5	15.3	24.1
Glass Resistance (ohms)			0.069	0.063	0.080	0.074	0.067	0.090

Table 4.1. Measured Characteristics of Melter Feed Samples.

Base Glass	**Source**	**Date**	**Name**	**% Water**	**pH**	**Density (g/ml)**	**Glass Yield**			
							Measured		**Target (kg/kg)**	**%Dev.**
							(g/l)	**(kg/kg)**		
AY102D4-07F	As Received Feed	9/16/13	MBL-F-128C	51.61	9.93	1.43	565	0.39	NA	NA
	As Received Feed	9/16/13	MBL-F-128D	51.56	9.92	1.45	571	0.39	NA	NA
	Test 5 Melter Feed	9/19/13	NBL-F-18A	81.93	9.97	1.14	168	0.15	0.16	-6.97
	Test 4 Melter Feed	9/26/13	NBL-F-67A	71.06	9.93	1.23	292	0.24	0.22	6.18
AY102D3-02F	As Received Feed	9/16/13	MBL-F-128E	52.31	10.15	1.45	562	0.39	NA	NA
		9/16/13	MBL-F-128F	53.85	10.14	1.45	546	0.38	NA	NA
	Test 3 Melter Feed	10/3/13	NBL-F-109A	68.66	9.89	1.24	315	0.25	0.23	8.55
		10/4/13	NBL-F-126A	68.83	10.04	1.23	312	0.25	0.23	8.59
AY102D2-06F	As Received Feed	9/27/13	NBL-F-79A	42.12	13.06	1.63	757	0.46	NA	NA
		9/27/13	NBL-F-79B	42.35	13.09	1.62	754	0.47	NA	NA
	Test 2 Melter Feed	10/9/13	OBL-F-21A	61.87	12.67	1.33	420	0.32	0.30	4.94
		10/10/13	OBL-F-33A	60.98	12.61	1.35	429	0.32	0.30	5.66
AY102D1-05F	As Received Feed	9/27/13	NBL-F-79C	50.88	11.76	1.47	562	0.38	NA	NA
		9/27/13	NBL-F-79D	52.41	12.05	1.46	567	0.39	NA	NA
	Test 1 Melter Feed	10/22/13	OBL-F-34A	39.12	12.93	1.68	811	0.48	0.50	-3.58
		10/24/13	OBL-F-68A	38.49	12.95	1.68	813	0.48	0.50	-3.26
			OBL-F-77A	38.94	12.70	1.66	796	0.48	0.50	-4.28

Table 4.2. XRF and DCP Analyzed Compositions of Vitrified Melter Feed Samples Corresponding to the AY102D4-07 Glass Composition (Tests 5 and 4) (wt%).

Source	**Target**	**As-Received Feed**				**Melter Feed**			
Constituents	AY102D4-07	MBL-F-128C	MBL-F-128D	Avg.	%Dev	NBL-F-18A	NBL-F-67A	Avg.	%Dev
Al_2O_3	11.54	11.41	11.28	11.34	-1.72	11.22	11.53	11.38	-1.42
B_2O_3#	9.50	8.75	8.73	8.74	-8.00	9.14	9.99	9.57	0.68
BaO	0.07	0.08	0.09	0.09	NC	0.07	0.07	0.07	NC
Bi_2O_3	&	< 0.01	0.01	NC	NC	0.01	0.02	0.02	NC
CaO	0.52	0.64	0.63	0.63	NC	0.61	0.63	0.62	NC
CeO_2	0.13	0.17	0.16	0.17	NC	0.19	0.12	0.16	NC
Cl	0.00	0.02	0.02	0.02	NC	0.02	0.02	0.02	NC
Cr_2O_3	0.26	0.24	0.24	0.24	NC	0.24	0.24	0.24	NC
Fe_2O_3	14.19	13.79	13.66	13.72	-3.29	14.57	14.55	14.56	2.60
K_2O	0.06	0.11	0.10	0.10	NC	0.10	0.12	0.11	NC
La_2O_3	0.09	0.05	0.06	0.06	NC	0.07	0.05	0.06	NC
Li_2O#	4.50	4.54	4.54	4.54	0.89	4.03	3.46	3.75	-16.78
MgO	0.15	0.32	0.33	0.32	NC	0.34	0.32	0.33	NC
MnO	2.11	1.91	1.91	1.91	-9.65	2.25	1.94	2.10	-0.88
Na_2O	14.08	13.55	13.53	13.54	-3.81	12.87	13.83	13.35	-5.20
Nd_2O_3	0.15	0.13	0.14	0.14	NC	0.12	0.16	0.14	NC
NiO	0.34	0.42	0.38	0.40	NC	0.36	0.38	0.37	NC
P_2O_5	0.53	0.54	0.52	0.53	NC	0.48	0.44	0.46	NC
PbO	0.54	0.48	0.47	0.48	NC	0.54	0.43	0.48	NC
SO_3	0.10	0.21	0.21	0.21	NC	0.18	0.22	0.20	NC
SiO_2	41.12	42.53	42.90	42.71	3.87	42.50	41.38	41.94	2.00
TiO_2	&	0.08	0.09	0.09	NC	0.08	0.08	0.08	NC
ZnO	&	0.01	0.01	0.01	NC	0.01	0.01	0.01	NC
ZrO_2	&	0.01	< 0.01	NC	NC	0.01	0.01	0.01	NC
Total	100.00	100.00	100.00	NC	NC	100.00	100.00	100.00	NC

Determined by DCP-AES
& Not a target constituent
$ Estimated from XRF measurements of solid discharged glass samples

Table 4.3. XRF and DCP Analyzed Compositions of Vitrified Melter Feed Samples Corresponding to the AY102D3-02 Glass Composition (Test 3) (wt%).

Source	**Target**	**As-Received Feed**				**Melter Feed**	
Constituents	AY102D3-02	MBL-F-128E	MBL-F-128F	Avg.	%Dev	NBL-F-126A	%Dev
Al_2O_3	11.73	11.29	11.53	11.41	-2.72	11.09	-5.49
B_2O_3#	8.50	7.31	7.46	7.39	-13.12	8.36	-1.65
BaO	0.07	0.06	0.08	0.07	NC	0.06	NC
CaO	0.51	0.59	0.61	0.60	NC	0.57	NC
CeO_2	0.13	0.09	0.15	0.12	NC	0.08	NC
Cl	0.05	0.03	0.03	0.03	NC	0.03	NC
Cr_2O_3	0.26	0.23	0.24	0.24	NC	0.22	NC
F$	0.05	0.03	0.03	0.03	NC	0.03	NC
Fe_2O_3	13.95	12.81	13.49	13.15	-5.69	13.55	-2.86
K_2O	1.18	1.00	1.05	1.03	-12.92	0.95	-19.58
La_2O_3	0.09	0.05	0.06	0.05	NC	0.04	NC
Li_2O#	4.50	4.34	4.06	4.20	-6.67	3.81	-15.33
MgO	0.14	0.36	0.30	0.33	NC	0.35	NC
MnO	2.08	1.98	1.96	1.97	-5.32	1.86	-10.55
Na_2O	13.41	12.56	12.60	12.58	-6.24	13.82	2.99
Nd_2O_3	0.15	0.15	0.16	0.16	NC	0.16	NC
NiO	0.34	0.37	0.38	0.38	NC	0.34	NC
P_2O_5	0.55	0.51	0.46	0.48	NC	0.46	NC
PbO	0.53	0.40	0.44	0.42	NC	0.28	NC
SO_3	0.19	0.27	0.25	0.26	NC	0.25	NC
SiO_2	41.59	45.48	44.57	45.03	8.26	43.61	4.85
TiO_2	&	0.07	0.08	0.08	NC	0.08	NC
ZnO	&	0.01	0.01	0.01	NC	0.01	NC
ZrO_2	&	0.01	0.01	0.01	NC	0.00	NC
Total	100.00	100.00	100.00	100.00	NC	100.00	NC

Determined by DCP-AES
& Not a target constituent
$ Estimated from XRF measurements of solid discharged glass samples

Table 4.4. XRF and DCP Analyzed Compositions of Vitrified Melter Feed Samples Corresponding to the AY102D2-06 Glass Composition (Test 2) (wt%).

Source	**Target**	**As-Received Feed**				**Melter Feed**			
Constituents		NBL-F-79C	NBL-F-79D	Avg.	%Dev	OBL-F-21A	OBL-F-33A	Avg.	%Dev
Al_2O_3	10.28	10.12	10.55	10.33	0.48	10.12	10.18	10.15	-1.34
B_2O_3#	7.80	7.90	7.76	7.83	0.38	7.08	7.36	7.22	-7.44
BaO	0.06	0.07	0.06	0.07	NC	0.07	0.06	0.07	NC
Bi_2O_3	&	< 0.01	< 0.01	NC	NC	0.01	0.01	0.01	NC
CaO	0.42	0.70	0.54	0.62	NC	0.50	0.54	0.52	NC
CeO_2	0.11	0.14	0.15	0.15	NC	0.15	0.12	0.13	NC
Cl	0.11	0.08	0.07	0.08	NC	0.07	0.06	0.06	NC
Cr_2O_3	0.23	0.21	0.21	0.21	NC	0.21	0.19	0.20	NC
F$	0.13	0.07	0.07	0.07	NC	0.07	0.07	0.07	NC
Fe_2O_3	11.48	10.83	11.52	11.17	-2.64	10.95	10.96	10.96	-4.55
K_2O	2.80	2.84	2.77	2.81	0.10	2.56	2.65	2.61	-6.97
La_2O_3	0.07	0.06	0.04	0.05	NC	0.04	0.06	0.05	NC
Li_2O#	2.08	2.02	2.19	2.11	1.20	1.93	1.98	1.96	-6.01
MgO	0.12	0.30	0.26	0.28	NC	0.56	0.24	0.40	NC
MnO	1.71	1.52	1.63	1.57	-7.87	1.60	1.58	1.59	-6.86
Na_2O	17.11	15.13	14.56	14.84	-13.23	17.28	17.38	17.33	1.30
Nd_2O_3	0.12	0.12	0.15	0.13	NC	0.13	0.09	0.11	NC
NiO	0.28	0.31	0.31	0.31	NC	0.28	0.30	0.29	NC
P_2O_5	0.50	0.53	0.51	0.52	NC	0.48	0.49	0.49	NC
PbO	0.44	0.36	0.39	0.38	NC	0.37	0.37	0.37	NC
SO_3	0.31	0.34	0.36	0.35	NC	0.37	0.36	0.36	NC
SiO_2	43.85	45.60	45.68	45.64	4.08	44.97	44.74	44.85	2.28
TiO_2	&	0.07	0.07	0.07	NC	0.06	0.06	0.06	NC
ZnO	&	0.29	0.04	0.17	NC	0.04	0.05	0.05	NC
ZrO_2	&	0.39	0.09	0.24	NC	0.09	0.11	0.10	NC
Total	100.00	100.00	100.00	100.00	NC	100.00	100.00	100.00	NC

Determined by DCP-AES
& Not a target constituent
$ Estimated from XRF measurements of solid discharged glass samples

Table 4.5. XRF and DCP Analyzed Compositions of Vitrified Melter Feed Samples Corresponding to the AY102D1-05 Glass Composition (Test 1) (wt%).

Source	**Target**	**As-Received Feed**				**Melter Feed**				
Constituents	AY102D1-05	NBL-F-79A	NBL-F-79B	Avg.	%Dev	OBL-F-34A	OBL-F-68A	OBL-F-77A	Avg.	%Dev
Al_2O_3	8.00	7.40	7.49	7.44	-6.98	7.56	7.89	7.68	7.71	-3.61
$B_2O_3^{\#}$	9.15	8.94	8.96	8.95	-2.23	8.65	8.30	8.37	8.44	-7.80
BaO	0.03	< 0.01	< 0.01	NC	NC	0.05	0.05	0.05	0.05	NC
Bi_2O_3	&	0.01	< 0.01	NC	NC	< 0.01	< 0.01	0.01	0.01	NC
CaO	2.03	2.18	2.14	2.16	6.35	2.10	2.03	2.09	2.08	2.09
CeO_2	0.05	0.06	0.06	0.06	NC	0.04	0.02	0.03	0.03	NC
Cl	0.16	0.09	0.10	0.10	NC	0.08	0.07	0.05	0.07	NC
Cr_2O_3	0.12	0.12	0.13	0.13	NC	0.14	0.12	0.14	0.13	NC
$F^{\$}$	0.18	0.09	0.09	0.09	NC	0.09	0.09	0.09	0.09	NC
Fe_2O_3	5.53	5.80	5.68	5.74	3.74	5.58	5.63	5.69	5.63	1.66
K_2O	4.01	3.97	3.90	3.94	-1.78	3.78	3.61	3.66	3.68	-8.18
La_2O_3	0.04	0.03	0.00	0.01	NC	0.04	0.05	0.05	0.05	NC
$Li_2O^{\#}$	&	0.04	0.02	0.03	NC	0.04	0.02	0.02	0.03	NC
MgO	1.89	1.29	1.56	1.42	-24.74	1.09	1.37	1.76	1.41	-25.31
MnO	0.82	0.81	0.85	0.83	NC	0.80	0.77	0.84	0.80	NC
Na_2O	20.00	20.06	19.56	19.81	-0.92	20.12	20.95	20.38	20.49	2.45
Nd_2O_3	0.06	0.07	0.06	0.06	NC	0.07	0.06	0.05	0.06	NC
NiO	0.13	0.17	0.15	0.16	NC	0.15	0.15	0.15	0.15	NC
P_2O_5	0.32	0.34	0.31	0.32	NC	0.32	0.32	0.35	0.33	NC
PbO	0.21	0.19	0.19	0.19	NC	0.18	0.18	0.20	0.19	NC
SO_3	0.36	0.38	0.38	0.38	NC	0.40	0.35	0.35	0.37	NC
SiO_2	39.89	41.28	41.83	41.55	4.17	42.30	41.37	41.36	41.68	4.48
TiO_2	&	0.11	0.09	0.10	NC	0.09	0.10	0.09	0.09	NC
ZnO	3.05	3.00	2.97	2.99	-1.99	2.91	2.75	2.86	2.84	-6.90
ZrO_2	3.97	3.58	3.47	3.53	-11.08	3.42	3.76	3.66	3.61	-8.84
Total	100.00	100.00	100.00	100.00	NC	100.00	100.00	100.00	NC	NC

Determined by DCP-AES
& Not a target constituent
$ Estimated from XRF measurements of solid discharged glass samples

Table 4.6. Listing of Discharged Glass Masses.

Test	Date	Sample Name	Mass (kg)	Cumulative (kg)
Test 5 AY102D4-07 Glass Composition	9/18/13	MBL-G-144A	14.88	14.88
		MBL-G-144B		
		MBL-G-145A	23.50	38.38
		MBL-G-145B		
		MBL-G-150A	24.30	62.68
	9/19/13	MBL-G-151A		
		NBL-G-9A	16.30	78.98
		NBL-G-11A		
		NBL-G-11B	18.64	97.62
		NBL-G-15A		
		NBL-G-17A	12.58	110.20
	9/20/13	NBL-G-18A		
		NBL-G-19A	16.00	126.20
		NBL-G-19B		
		NBL-G-22A	19.04	145.24
		NBL-G-22B		
		NBL-G-22C		
		NBL-G-22D	18.04	163.28
		NBL-G-23A		
		NBL-G-23B	7.98	171.26
Test 4 AY102D4-07 Glass Composition	9/23/13	NBL-G-42A	21.50	21.50
	9/24/13	NBL-G-43A	19.32	40.82
		NBL-G-43B		
		NBL-G-47A	19.00	59.82
		NBL-G-47B		
		NBL-G-50A	26.00	85.82
		NBL-G-51A		
	9/25/13	NBL-G-51B	24.72	110.54
		NBL-G-54A		
		NBL-G-56A	24.74	135.28
		NBL-G-56B		
		NBL-G-60A	32.64	167.92
		NBL-G-61A		
	9/26/13	NBL-G-62A	29.14	197.06
		NBL-G-62B		
		NBL-G-66A	19.24	216.30
		NBL-G-66B	23.60	239.90
		NBL-G-67A	30.56	270.46
		NBL-G-73A		
		NBL-G-75A	25.30	295.76
		NBL-G-75B		
	9/27/13	NBL-G-77A	19.80	315.56
		NBL-G-77B		
		NBL-G-78A	22.86	338.42

Table 4.6. List of Discharged Glass Masses (continued).

Test	Date	Sample Name	Mass (kg)	Cumulative (kg)
Test 3 AY102D3-02 Glass Composition	10/1/13	NBL-G-90A	20.68	20.68
		NBL-G-95A		
		NBL-G-98A	14.80	35.48
		NBL-G-98B		
		NBL-G-98C	19.32	54.80
	10/2/13	NBL-G-98D		
		NBL-G-98E	15.88	70.68
		NBL-G-99A		
		NBL-G-99B	20.66	91.34
		NBL-G-99C		
		NBL-G-103A	22.80	114.14
		NBL-G-103B		
		NBL-G-103C		
		NBL-G-103D	16.78	130.92
		NBL-G-105A		
	10/3/13	NBL-G-105B	23.20	154.12
		NBL-G-109A		
		NBL-G-109B	22.24	176.36
		NBL-G-109C		
		NBL-G-113A	20.28	196.64
		NBL-G-114A		
	10/3/13	NBL-G-119A	19.88	244.98
		NBL-G-119B		
		NBL-G-119C	21.10	266.08
	10/4/13	NBL-G-119D		
		NBL-G-120A	23.30	289.38
		NBL-G-120B		
		NBL-G-120C	23.80	313.18
		NBL-G-120D		
		NBL-G-120E		
		NBL-G-123A	16.40	329.58
		NBL-G-123B		
		NBL-G-123C	28.10	357.68
		NBL-G-125A		
		NBL-G-126A	35.90	393.58
	10/5/13	NBL-G-129A		

Table 4.6. List of Discharged Glass Masses (continued).

Test	Date	Sample Name	Mass (kg)	Cumulative (kg)
Test 2 AY102D2-06 Glass Composition	10/7/13	NBL-G-145A	35.52	35.52
		NBL-G-146A		
	10/8/13	NBL-G-147A	21.52	57.04
		NBL-G-147B		
		NBL-G-147C	29.66	86.70
		NBL-G-150A		
		OBL-G-10A	21.46	108.16
		OBL-G-10B		
		OBL-G-11A	31.48	139.64
		OBL-G-11B		
	10/9/13	OBL-G-12A	20.00	159.64
		OBL-G-12B		
		OBL-G-13A	17.58	177.22
		OBL-G-13B	27.68	204.90
		OBL-G-19A		
		OBL-G-20A	25.32	230.22
		OBL-G-21A		
		OBL-G-22A	19.76	249.98
		OBL-G-22B		
	10/10/13	OBL-G-22C	22.68	272.66
		OBL-G-26A		
	10/10/13	OBL-G-26B	31.78	304.44
		OBL-G-27A		
		OBL-G-28A	32.90	337.34
		OBL-G-28B		
		OBL-G-32A	26.28	363.62
		OBL-G-32B		
		OBL-G-32C		
		OBL-G-33A	12.28	375.90
		OBL-G-33B		

Table 4.6. List of Discharged Glass Masses (continued).

Test	Date	Sample Name	Mass (kg)	Cumulative (kg)
Test 1 AY102D1-05 Glass Composition	10/22/13	OBL-G-50A	31.96	31.96
		OBL-G-50B		
		OBL-G-50C	21.74	53.70
		OBL-G-51A		
		OBL-G-51B	23.80	77.50
		OBL-G-51C		
		OBL-G-52A	26.18	103.68
		OBL-G-52B		
	10/23/13	OBL-G-52C	20.44	124.12
		OBL-G-55A		
		OBL-G-55B		
		OBL-G-55C	15.96	140.08
		OBL-G-55D		
		OBL-G-57A	25.86	165.94
		OBL-G-57B		
		OBL-G-57C	17.76	183.70
		OBL-G-57D		
		OBL-G-61A	32.76	216.46
		OBL-G-61B		
	10/24/13	OBL-G-65A	36.58	253.04
		OBL-G-65B		
	10/24/13	OBL-G-65C	22.98	276.02
		OBL-G-67A		
		OBL-G-67B	23.46	299.48
		OBL-G-68A		
		OBL-G-68B	23.80	323.28
		OBL-G-71A		
		OBL-G-71B	20.00	343.28
		OBL-G-71C	16.52	359.80
		OBL-G-72A		
		OBL-G-72B	29.92	389.72
		OBL-G-73A		
		OBL-G-73B	34.78	424.50
		OBL-G-77A		
	10/25/13	OBL-G-78A	31.16	455.66
		OBL-G-78B		
		OBL-G-78C	22.70	478.36
		OBL-G-78D		
		OBL-G-78E	30.74	509.10
		OBL-G-80A		
		OBL-G-80B	21.58	530.68
		OBL-G-80C		
	10/25/13	OBL-G-81A	23.12	553.80
		OBL-G-81B		
		OBL-G-81C	26.60	580.40
		OBL-G-81D		
		OBL-G-81E	25.88	606.28
		OBL-G-84A		
		OBL-G-84B	26.18	632.46
		OBL-G-84C		

Table 4.7. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D4-07 Glass Composition (Tests 5 and 4) (wt%).

Constituents	Glass (kg)	0.00	14.88	38.38	62.68	78.98	97.62
	Target	MBL-G-128A	MBL-G-144B	MBL-G-145B	MBL-G-151A	NBL-G-11A	NBL-G-15A
Al_2O_3	11.54	16.05	14.95	14.32	13.84	13.75	13.44
B_2O_3#	9.50	11.92	11.73	11.47	11.23	11.09	10.94
BaO	0.07	< 0.01	0.00	0.00	0.02	0.03	0.02
Bi_2O_3	&	0.71	0.63	0.55	0.53	0.47	0.41
CaO	0.52	0.83	0.81	0.76	0.78	0.77	0.75
CeO_2	0.13	0.06	0.13	0.13	0.14	0.14	0.15
Cl	&	0.01	0.01	0.01	0.01	0.01	0.01
Cr_2O_3	0.26	1.36	1.01	1.02	0.91	0.85	0.76
Fe_2O_3	14.19	10.39	11.22	11.89	12.43	12.42	12.59
K_2O	0.06	4.38	4.05	3.62	3.04	2.99	2.60
La_2O_3	0.09	0.05	0.05	0.05	0.05	0.04	0.04
Li_2O#	4.50	3.54	3.58	3.63	3.68	3.71	3.75
MgO	0.15	0.23	0.21	0.26	0.23	0.25	0.23
MnO	2.11	1.40	1.39	1.52	1.55	1.54	1.64
Na_2O	14.08	11.22	11.75	11.75	11.81	11.83	12.39
Nd_2O_3	0.15	0.14	0.14	0.13	0.15	0.12	0.12
NiO	0.34	0.37	0.30	0.32	0.30	0.32	0.32
P_2O_5	0.53	0.43	0.44	0.42	0.42	0.43	0.44
PbO	0.54	0.32	0.32	0.33	0.36	0.35	0.36
SO_3	0.10	0.14	0.15	0.16	0.14	0.15	0.13
SiO_2	41.12	36.16	36.86	37.41	38.15	38.50	38.70
TiO_2	&	0.04	0.04	0.04	0.05	0.04	0.05
WO_3	&	0.08	0.06	0.05	0.05	0.04	0.04
ZnO	&	0.08	0.08	0.08	0.08	0.07	0.07
ZrO_2	&	0.10	0.09	0.08	0.07	0.07	0.06
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model

Table 4.7. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D4-07 Glass Composition (Tests 5 and 4) (wt%) (continued).

Constituents	Glass (kg)	110.20	126.20	145.24	163.28	171.26
	Target	NBL-G-18A	NBL-G-19B	NBL-G-22C	NBL-G-23A	NBL-G-23B
Al_2O_3	11.54	13.26	12.98	12.87	12.77	12.83
B_2O_3#	9.50	10.84	10.74	10.62	10.52	10.48
BaO	0.07	0.04	0.04	0.02	0.03	0.05
Bi_2O_3	&	0.38	0.35	0.34	0.29	0.30
CaO	0.52	0.70	0.72	0.73	0.72	0.69
CeO_2	0.13	0.13	0.16	0.10	0.13	0.10
Cl	&	0.01	0.01	0.01	0.02	0.01
Cr_2O_3	0.26	0.70	0.67	0.66	0.64	0.60
Fe_2O_3	14.19	12.86	12.77	13.23	13.26	13.18
K_2O	0.06	2.39	2.23	2.21	1.64	1.60
La_2O_3	0.09	0.06	0.06	0.04	0.06	0.07
Li_2O#	4.50	3.76	3.79	3.81	3.83	3.84
MgO	0.15	0.22	0.33	0.25	0.26	0.29
MnO	2.11	1.64	1.63	1.67	1.63	1.68
Na_2O	14.08	11.91	12.31	12.34	12.80	12.82
Nd_2O_3	0.15	0.14	0.13	0.14	0.14	0.15
NiO	0.34	0.33	0.31	0.33	0.30	0.32
P_2O_5	0.53	0.47	0.47	0.47	0.44	0.48
PbO	0.54	0.38	0.36	0.38	0.37	0.37
SO_3	0.10	0.14	0.12	0.12	0.11	0.11
SiO_2	41.12	39.42	39.62	39.45	39.85	39.83
TiO_2	&	0.06	0.06	0.06	0.05	0.06
WO_3	&	0.04	0.04	0.04	0.02	0.03
ZnO	&	0.06	0.07	0.05	0.05	0.06
ZrO_2	&	0.06	0.05	0.06	0.06	0.07
Total	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent
# - B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model

Table 4.7. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D4-07 Glass Composition (Tests 5 and 4) (wt%) (continued).

Constituents	Glass (kg)	192.76	212.08	231.08	257.08	281.80
	Target	NBL-G-42A	NBL-G-43B	NBL-G-47B	NBL-G-51A	NBL-G-54A
Al_2O_3	11.54	13.05	12.37	12.22	12.16	12.14
B_2O_3#	9.50	10.38	10.29	10.22	10.13	10.06
BaO	0.07	0.04	0.06	0.04	0.05	0.05
Bi_2O_3	&	0.29	0.23	0.22	0.18	0.16
CaO	0.52	0.72	0.70	0.68	0.67	0.67
CeO_2	0.13	0.11	0.15	0.15	0.13	0.09
Cl	&	0.01	0.01	0.01	0.01	0.02
Cr_2O_3	0.26	0.37	0.48	0.49	0.43	0.41
Fe_2O_3	14.19	12.27	13.45	13.70	13.47	13.32
K_2O	0.06	1.57	1.32	1.33	1.16	1.01
La_2O_3	0.09	0.06	0.05	0.05	0.05	0.04
Li_2O#	4.50	3.86	3.88	3.89	3.91	3.93
MgO	0.15	0.28	0.28	0.28	0.33	0.33
MnO	2.11	1.54	1.76	1.86	1.71	1.68
Na_2O	14.08	12.96	12.81	12.70	12.87	13.43
Nd_2O_3	0.15	0.14	0.11	0.11	0.12	0.14
NiO	0.34	0.23	0.32	0.34	0.31	0.31
P_2O_5	0.53	0.48	0.48	0.49	0.52	0.50
PbO	0.54	0.38	0.40	0.40	0.40	0.39
SO_3	0.10	0.14	0.16	0.17	0.16	0.17
SiO_2	41.12	40.93	40.52	40.46	41.09	41.03
TiO_2	&	0.06	0.08	0.07	0.06	0.07
WO_3	&	< 0.01	< 0.01	0.03	< 0.01	< 0.01
ZnO	&	0.06	0.05	0.05	0.04	0.04
ZrO_2	&	0.07	0.04	0.04	0.04	0.03
Total	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model

Table 4.7. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D4-07 Glass Composition (Tests 5 and 4) (wt%) (continued).

Constituents	Glass (kg)	306.54	339.18	368.32	387.56	411.16
	Target	NBL-G-56B	NBL-G-61A	NBL-G-62B	NBL-G-66A	NBL-G-66B
Al_2O_3	11.54	11.98	11.93	11.92	11.87	11.86
B_2O_3#	9.50	10.00	9.93	9.87	9.84	9.81
BaO	0.07	0.05	0.06	0.06	0.07	0.06
Bi_2O_3	&	0.12	0.10	0.09	0.08	0.08
CaO	0.52	0.67	0.65	0.64	0.65	0.64
CeO_2	0.13	0.12	0.12	0.16	0.17	0.13
Cl	&	0.01	0.02	0.02	0.02	0.02
Cr_2O_3	0.26	0.37	0.32	0.32	0.29	0.26
Fe_2O_3	14.19	13.71	13.70	13.88	13.62	13.71
K_2O	0.06	0.89	0.77	0.61	0.56	0.52
La_2O_3	0.09	0.04	0.07	0.06	0.05	0.04
Li_2O#	4.50	3.94	3.96	3.97	3.97	3.98
MgO	0.15	0.31	0.32	0.29	0.30	0.30
MnO	2.11	1.76	1.83	1.74	1.81	1.79
Na_2O	14.08	13.35	13.11	13.21	13.50	13.37
Nd_2O_3	0.15	0.14	0.14	0.17	0.13	0.16
NiO	0.34	0.32	0.31	0.30	0.26	0.29
P_2O_5	0.53	0.51	0.49	0.50	0.50	0.50
PbO	0.54	0.39	0.40	0.41	0.40	0.41
SO_3	0.10	0.16	0.16	0.16	0.14	0.16
SiO_2	41.12	40.98	41.47	41.51	41.64	41.76
TiO_2	&	0.08	0.08	0.07	0.08	0.07
WO_3	&	0.01	0.02	< 0.01	< 0.01	< 0.01
ZnO	&	0.04	0.03	0.03	0.03	0.03
ZrO_2	&	0.03	0.03	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

\# - B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model

Table 4.7. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D4-07 Glass Composition (Tests 5 and 4) (wt%) (continued).

Constituents	Glass (kg)	441.72	467.02	486.82	509.68
	Target	NBL-G-73A	NBL-G-75B	NBL-G-77B	NBL-G-78A
Al_2O_3	11.54	11.65	11.73	11.74	11.66
B_2O_3#	9.50	9.77	9.75	9.73	9.71
BaO	0.07	0.08	0.08	0.06	0.07
Bi_2O_3	&	0.07	0.06	0.05	0.04
CaO	0.52	0.66	0.62	0.64	0.62
CeO_2	0.13	0.14	0.14	0.17	0.17
Cl	&	0.03	0.01	0.01	0.02
Cr_2O_3	0.26	0.32	0.28	0.29	0.29
Fe_2O_3	14.19	14.19	14.13	13.93	13.76
K_2O	0.06	0.45	0.43	0.40	0.35
La_2O_3	0.09	0.05	0.05	0.06	0.05
Li_2O#	4.50	3.99	3.99	4.00	4.00
MgO	0.15	0.34	0.34	0.34	0.31
MnO	2.11	1.82	1.78	1.78	1.81
Na_2O	14.08	13.12	13.17	13.26	13.49
Nd_2O_3	0.15	0.16	0.11	0.14	0.14
NiO	0.34	0.33	0.29	0.33	0.29
P_2O_5	0.53	0.52	0.49	0.49	0.50
PbO	0.54	0.43	0.44	0.41	0.43
SO_3	0.10	0.19	0.17	0.15	0.16
SiO_2	41.12	41.58	41.78	41.89	42.03
TiO_2	&	0.08	0.09	0.08	0.07
WO_3	&	< 0.01	0.02	< 0.01	< 0.01
ZnO	&	0.03	0.03	0.02	0.02
ZrO_2	&	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent
# - B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model

Table 4.8. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D3-02 Glass Composition (Test 3) (wt%).

Constituents	Glass (kg)	530.36	545.16	564.48	580.36	601.02	623.82
	Target	NBL-G-95A	NBL-G-98B	NBL-G-98D	NBL-G-99A	NBL-G-99C	NBL-G-103C
Al_2O_3	11.73	11.74	11.57	11.45	11.23	11.36	11.33
$B_2O_3^{\#}$	8.50	9.56	9.47	9.35	9.27	9.17	9.08
BaO	0.07	0.05	0.07	0.07	0.05	0.07	0.07
Bi_2O_3	&	0.06	0.05	0.04	0.04	0.03	0.04
CaO	0.51	0.63	0.61	0.60	0.66	0.61	0.60
CeO_2	0.13	0.09	0.11	0.14	0.12	0.13	0.13
Cl	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Cr_2O_3	0.26	0.28	0.30	0.27	0.27	0.26	0.27
$F^{\$}$	0.05	0.03	0.03	0.03	0.03	0.03	0.03
Fe_2O_3	13.95	13.19	13.99	13.95	14.17	13.74	14.03
K_2O	1.18	0.48	0.48	0.56	0.60	0.59	0.68
La_2O_3	0.09	0.04	0.06	0.05	0.04	0.03	0.05
$Li_2O^{\#}$	4.50	3.98	3.97	3.95	3.94	3.93	3.91
MgO	0.14	0.41	0.32	0.35	0.33	0.35	0.35
MnO	2.08	1.73	1.85	1.86	1.76	1.86	1.80
Na_2O	13.41	14.59	13.17	13.41	13.15	13.26	13.45
Nd_2O_3	0.15	0.14	0.12	0.13	0.15	0.13	0.14
NiO	0.34	0.30	0.32	0.33	0.33	0.33	0.32
P_2O_5	0.55	0.53	0.50	0.51	0.55	0.51	0.52
PbO	0.53	0.39	0.43	0.42	0.42	0.41	0.41
SO_3	0.19	0.18	0.21	0.19	0.19	0.20	0.22
SiO_2	41.59	41.48	42.20	42.19	42.54	42.87	42.42
TiO_2	&	0.07	0.08	0.08	0.09	0.07	0.08
ZnO	&	0.03	0.03	0.03	0.03	0.03	0.02
ZrO_2	&	0.03	0.02	0.02	0.02	0.02	0.03
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

\# - B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model

$ Estimated as 50% of target value.

Table 4.8. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D3-02 Glass Composition (Test 3) (wt%) (continued).

Constituents	Glass (kg)	640.60	663.80	686.04	706.32	734.78	754.66
	Target	NBL-G-105A	NBL-G-109A	NBL-G-109C	NBL-G-114A	NBL-G-115B	NBL-G-119B
Al_2O_3	11.73	11.42	11.45	11.33	11.30	11.35	11.15
B_2O_3#	8.50	9.01	8.93	8.87	8.81	8.75	8.71
BaO	0.07	0.07	0.08	0.07	0.08	0.07	0.06
Bi_2O_3	&	0.04	0.02	0.02	0.02	0.03	0.02
CaO	0.51	0.59	0.58	0.59	0.56	0.55	0.58
CeO_2	0.13	0.16	0.14	0.15	0.17	0.12	0.14
Cl	0.05	0.03	0.03	0.02	0.03	0.02	0.03
Cr_2O_3	0.26	0.26	0.26	0.25	0.24	0.25	0.25
F$	0.05	0.03	0.03	0.03	0.03	0.03	0.03
Fe_2O_3	13.95	13.65	13.53	13.72	13.43	13.36	13.76
K_2O	1.18	0.69	0.75	0.77	0.84	0.82	0.87
La_2O_3	0.09	0.06	0.05	0.04	0.05	0.04	0.05
Li_2O#	4.50	3.90	3.89	3.88	3.87	3.86	3.86
MgO	0.14	0.34	0.30	0.30	0.29	0.30	0.28
MnO	2.08	1.76	1.81	1.83	1.85	1.78	1.78
Na_2O	13.41	13.44	13.63	13.69	13.82	13.92	13.59
Nd_2O_3	0.15	0.14	0.15	0.13	0.13	0.12	0.16
NiO	0.34	0.33	0.30	0.31	0.29	0.28	0.30
P_2O_5	0.55	0.53	0.52	0.49	0.49	0.52	0.50
PbO	0.53	0.40	0.38	0.38	0.38	0.36	0.36
SO_3	0.19	0.22	0.23	0.24	0.22	0.23	0.22
SiO_2	41.59	42.82	42.82	42.79	42.99	43.11	43.21
TiO_2	&	0.09	0.08	0.07	0.08	0.08	0.07
ZnO	&	0.02	0.02	0.02	0.02	0.02	0.02
ZrO_2	&	0.02	0.02	0.02	0.02	0.01	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent
# - B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model
$ Estimated as 50% of target value.

Table 4.8. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D3-02 Glass Composition (Test 3) (wt%) (continued).

Constituents	Glass (kg)	775.76	799.06	822.86	839.26	867.36	903.26
	Target	NBL-G-119D	NBL-G-120B	NBL-G-120E	NBL-G-123B	NBL-G-125A	NBL-G-129A
Al_2O_3	11.73	11.20	10.98	11.13	11.16	11.13	11.03
B_2O_3#	8.50	8.67	8.63	8.60	8.58	8.54	8.51
BaO	0.07	0.08	0.07	0.07	0.10	0.06	0.08
Bi_2O_3	&	0.02	0.02	0.02	0.02	0.01	0.01
CaO	0.51	0.61	0.60	0.58	0.58	0.57	0.57
CeO_2	0.13	0.14	0.13	0.15	0.17	0.15	0.15
Cl	0.05	0.03	0.02	0.03	0.02	0.03	0.03
Cr_2O_3	0.26	0.22	0.24	0.23	0.24	0.22	0.27
F$	0.05	0.03	0.03	0.03	0.03	0.03	0.03
Fe_2O_3	13.95	13.73	14.05	13.73	13.42	13.81	14.17
K_2O	1.18	0.88	0.91	0.95	0.91	0.89	0.99
La_2O_3	0.09	0.06	0.05	0.07	0.06	0.06	0.05
Li_2O#	4.50	3.85	3.85	3.84	3.84	3.84	3.83
MgO	0.14	0.31	0.28	0.31	0.29	0.26	0.28
MnO	2.08	1.84	1.86	1.82	1.85	1.84	1.92
Na_2O	13.41	13.41	13.43	13.39	13.70	13.52	13.45
Nd_2O_3	0.15	0.14	0.15	0.16	0.12	0.15	0.16
NiO	0.34	0.34	0.32	0.33	0.31	0.33	0.38
P_2O_5	0.55	0.50	0.53	0.52	0.49	0.51	0.49
PbO	0.53	0.37	0.39	0.36	0.35	0.37	0.39
SO_3	0.19	0.23	0.21	0.23	0.23	0.21	0.22
SiO_2	41.59	43.27	43.15	43.36	43.43	43.38	42.90
TiO_2	&	0.07	0.07	0.08	0.07	0.08	0.07
ZnO	&	0.02	0.02	0.02	0.02	0.02	0.02
ZrO_2	&	0.01	0.01	0.01	0.01	0.01	0.01
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model

$ Estimated as 50% of target value.

Table 4.9. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D2-06 Glass Composition (Test 2) (wt%).

Constituents	Glass (kg)	938.78	960.30	989.96	1011.42	1042.90
	Target	NBL-G-146A	NBL-G-147B	NBL-G-150A	OBL-G-10B	OBL-G-11B
Al_2O_3	10.28	10.91	10.76	10.69	10.61	10.65
$B_2O_3^{\#}$	7.80	8.28	8.16	8.02	7.93	7.81
BaO	0.06	0.06	0.07	0.05	0.06	0.05
Bi_2O_3	&	0.02	0.02	0.01	0.01	0.01
CaO	0.42	0.57	0.55	0.56	0.58	0.55
CeO_2	0.11	0.10	0.08	0.09	0.13	0.10
Cl	0.11	0.03	0.03	0.05	0.05	0.06
Cr_2O_3	0.23	0.27	0.28	0.27	0.26	0.28
$F^{\$}$	0.13	0.07	0.07	0.07	0.07	0.07
Fe_2O_3	11.48	13.30	13.30	12.97	12.67	12.36
K_2O	2.80	1.24	1.42	1.64	1.78	1.89
La_2O_3	0.07	0.04	0.05	0.08	0.06	0.03
$Li_2O^{\#}$	2.08	3.31	3.16	2.97	2.86	2.72
MgO	0.12	0.28	0.26	0.31	0.23	0.26
MnO	1.71	1.80	1.85	1.75	1.76	1.71
Na_2O	17.11	14.04	14.29	14.58	15.17	14.90
Nd_2O_3	0.12	0.11	0.11	0.12	0.11	0.14
NiO	0.28	0.35	0.38	0.36	0.38	0.37
P_2O_5	0.50	0.49	0.52	0.54	0.50	0.54
PbO	0.44	0.39	0.41	0.42	0.40	0.40
SO_3	0.31	0.26	0.27	0.29	0.31	0.29
SiO_2	43.85	43.95	43.83	44.02	43.93	44.65
TiO_2	&	0.07	0.07	0.08	0.07	0.06
ZnO	&	0.03	0.03	0.03	0.04	0.04
ZrO_2	&	0.03	0.04	0.04	0.05	0.06
Total	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent
# - B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model
$ Estimated as 50% of target value.

Table 4.9. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D2-06 Glass Composition (Test 2) (wt%) (continued).

Constituents	Glass (kg)	1062.90	1080.48	1108.16	1133.48	1153.24
	Target	OBL-G-12B	OBL-G-13A	OBL-G-19A	OBL-G-21A	OBL-G-22B
Al_2O_3	10.28	10.58	10.63	10.48	10.42	10.47
B_2O_3#	7.80	7.75	7.70	7.63	7.58	7.54
BaO	0.06	0.05	0.07	0.07	0.05	0.05
Bi_2O_3	&	0.01	0.01	0.01	0.01	0.01
CaO	0.42	0.52	0.53	0.52	0.53	0.53
CeO_2	0.11	0.12	0.13	0.13	0.12	0.13
Cl	0.11	0.06	0.05	0.05	0.06	0.04
Cr_2O_3	0.23	0.28	0.28	0.31	0.28	0.28
F$	0.13	0.07	0.07	0.07	0.07	0.07
Fe_2O_3	11.48	12.30	12.11	12.13	11.85	11.66
K_2O	2.80	2.05	2.05	2.18	2.25	2.23
La_2O_3	0.07	0.04	0.04	0.06	0.05	0.04
Li_2O#	2.08	2.64	2.57	2.49	2.42	2.37
MgO	0.12	0.27	0.25	0.24	0.24	0.26
MnO	1.71	1.69	1.67	1.70	1.66	1.66
Na_2O	17.11	15.67	16.15	16.36	16.31	16.48
Nd_2O_3	0.12	0.12	0.12	0.12	0.12	0.11
NiO	0.28	0.34	0.34	0.37	0.36	0.36
P_2O_5	0.50	0.48	0.50	0.47	0.49	0.49
PbO	0.44	0.42	0.40	0.39	0.39	0.39
SO_3	0.31	0.32	0.31	0.30	0.35	0.32
SiO_2	43.85	44.07	43.84	43.71	44.21	44.31
TiO_2	&	0.08	0.07	0.07	0.07	0.07
ZnO	&	0.04	0.04	0.04	0.05	0.05
ZrO_2	&	0.06	0.07	0.08	0.08	0.08
Total	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model

$ Estimated as 50% of target value.

Table 4.9. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D2-06 Glass Composition (Test 2) (wt%) (continued).

Constituents	Glass (kg)	1175.92	1207.70	1240.60	1266.88	1279.16
	Target	OBL-G-26A	OBL-G-27A	OBL-G-28B	OBL-G-32C	OBL-G-33B
Al_2O_3	10.28	10.28	10.30	10.27	10.18	10.26
B_2O_3#	7.80	7.50	7.46	7.42	7.39	7.38
BaO	0.06	0.07	0.06	0.06	0.06	0.06
Bi_2O_3	&	0.00	0.01	0.01	0.01	0.01
CaO	0.42	0.51	0.54	0.54	0.51	0.52
CeO_2	0.11	0.13	0.12	0.10	0.13	0.11
Cl	0.11	0.05	0.05	0.05	0.05	0.06
Cr_2O_3	0.23	0.30	0.29	0.36	0.28	0.29
F$	0.13	0.07	0.07	0.07	0.07	0.07
Fe_2O_3	11.48	11.93	12.27	11.53	11.84	11.72
K_2O	2.80	2.31	2.39	2.38	2.50	2.48
La_2O_3	0.07	0.07	0.05	0.05	0.05	0.04
Li_2O#	2.08	2.32	2.26	2.21	2.18	2.16
MgO	0.12	0.26	0.23	0.27	0.26	0.26
MnO	1.71	1.68	1.70	1.68	1.71	1.67
Na_2O	17.11	16.22	16.29	16.89	16.30	16.38
Nd_2O_3	0.12	0.11	0.12	0.12	0.11	0.12
NiO	0.28	0.38	0.40	0.40	0.40	0.36
P_2O_5	0.50	0.50	0.48	0.49	0.52	0.49
PbO	0.44	0.41	0.41	0.38	0.39	0.39
SO_3	0.31	0.33	0.32	0.33	0.36	0.36
SiO_2	43.85	44.36	43.98	44.19	44.49	44.58
TiO_2	&	0.07	0.07	0.07	0.08	0.07
ZnO	&	0.05	0.04	0.05	0.05	0.05
ZrO_2	&	0.09	0.09	0.09	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent
# - B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model
$ Estimated as 50% of target value.

Table 4.10. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D1-05 Glass Composition (Test 1) (wt%).

Constituents	Glass (kg)	1311.12	1332.86	1356.66	1382.84	1403.28
	Target	OBL-G-50B	OBL-G-51A	OBL-G-51C	OBL-G-52B	OBL-G-55B
Al_2O_3	8.00	10.05	9.83	9.56	9.47	9.22
B_2O_3#	9.15	7.55	7.65	7.75	7.84	7.91
BaO	0.03	0.05	0.04	0.05	0.05	0.06
Bi_2O_3	&	0.03	0.04	0.03	0.02	0.02
CaO	2.03	0.71	0.89	0.98	1.06	1.28
CeO_2	0.05	0.09	0.08	0.09	0.09	0.10
Cl	0.16	0.03	0.04	0.04	0.06	0.06
Cr_2O_3	0.12	0.43	0.43	0.44	0.41	0.37
F$	0.18	0.09	0.09	0.09	0.09	0.09
Fe_2O_3	5.53	11.25	10.72	10.20	9.80	9.23
K_2O	4.01	2.50	2.59	2.75	2.94	3.07
La_2O_3	0.04	0.04	0.07	0.06	0.03	0.03
Li_2O#	&	1.82	1.61	1.42	1.23	1.10
MgO	1.89	0.38	0.50	0.61	0.64	0.76
MnO	0.82	1.54	1.46	1.37	1.38	1.30
Na_2O	20.00	16.56	17.04	17.52	17.46	17.55
Nd_2O_3	0.06	0.11	0.09	0.08	0.00	0.00
NiO	0.13	0.48	0.45	0.42	0.44	0.40
P_2O_5	0.32	0.48	0.49	0.46	0.43	0.42
PbO	0.21	0.35	0.34	0.31	0.32	0.29
SO_3	0.36	0.35	0.37	0.36	0.36	0.39
SiO_2	39.89	44.15	43.64	43.50	43.35	43.31
TiO_2	&	0.08	0.07	0.08	0.08	0.08
ZnO	3.05	0.38	0.66	0.81	1.10	1.35
ZrO_2	3.97	0.47	0.82	1.03	1.33	1.62
Total	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model

$ Estimated as 50% of target value.

Table 4.10. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D1-05 Glass Composition (Test 1) (wt%) (continued).

Constituents	Glass (kg)	1419.24	1445.10	1462.86	1495.62	1532.20
	Target	OBL-G-55D	OBL-G-57B	OBL-G-57D	OBL-G-61B	OBL-G-65B
Al_2O_3	8.00	9.19	8.67	8.66	8.38	8.21
$B_2O_3^{\#}$	9.15	7.95	8.02	8.06	8.12	8.18
BaO	0.03	0.05	0.04	0.05	0.04	0.03
Bi_2O_3	&	0.03	0.02	0.02	0.01	0.01
CaO	2.03	1.35	1.49	1.51	1.66	1.75
CeO_2	0.05	0.09	0.06	0.10	0.05	0.07
Cl	0.16	0.06	0.08	0.08	0.08	0.08
Cr_2O_3	0.12	0.39	0.35	0.36	0.41	0.37
$F^{\$}$	0.18	0.09	0.09	0.09	0.09	0.09
Fe_2O_3	5.53	9.04	8.50	8.35	7.81	7.41
K_2O	4.01	3.09	3.26	3.28	3.37	3.44
La_2O_3	0.04	0.04	0.04	0.03	0.04	0.05
$Li_2O^{\#}$	&	1.01	0.88	0.80	0.67	0.55
MgO	1.89	0.77	0.90	1.00	1.14	1.23
MnO	0.82	1.27	1.20	1.16	1.07	1.02
Na_2O	20.00	17.69	18.23	18.17	18.49	18.82
Nd_2O_3	0.06	0.10	0.10	0.08	0.00	0.10
NiO	0.13	0.38	0.38	0.37	0.38	0.36
P_2O_5	0.32	0.43	0.39	0.41	0.39	0.34
PbO	0.21	0.29	0.28	0.28	0.26	0.25
SO_3	0.36	0.38	0.36	0.37	0.34	0.36
SiO_2	39.89	43.02	42.75	42.66	42.55	42.43
TiO_2	&	0.08	0.08	0.08	0.07	0.07
ZnO	3.05	1.46	1.74	1.82	2.09	2.18
ZrO_2	3.97	1.75	2.09	2.22	2.49	2.60
Total	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

\# - B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model

$ Estimated as 50% of target value.

Table 4.10. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D1-05 Glass Composition (Test 1) (wt%) (continued).

Constituents	Glass (kg)	1555.18	1578.64	1602.44	1622.44	1638.96
	Target	OBL-G-67A	OBL-G-68A	OBL-G-71A	OBL-G-71B	OBL-G-72A
Al_2O_3	8.00	8.28	8.19	7.99	8.14	8.12
B_2O_3#	9.15	8.21	8.24	8.26	8.28	8.30
BaO	0.03	0.04	0.04	0.03	0.05	0.05
Bi_2O_3	&	0.02	0.01	0.02	0.01	0.02
CaO	2.03	1.75	1.74	1.85	1.82	1.89
CeO_2	0.05	0.08	0.08	0.07	0.09	0.07
Cl	0.16	0.09	0.09	0.09	0.08	0.09
Cr_2O_3	0.12	0.34	0.36	0.36	0.33	0.34
F$	0.18	0.09	0.09	0.09	0.09	0.09
Fe_2O_3	5.53	7.25	6.91	7.01	6.77	6.68
K_2O	4.01	3.46	3.40	3.59	3.41	3.48
La_2O_3	0.04	0.05	0.05	0.03	0.03	0.03
Li_2O#	&	0.49	0.43	0.38	0.35	0.32
MgO	1.89	1.33	1.46	1.47	1.43	1.42
MnO	0.82	1.03	1.00	0.98	0.99	0.93
Na_2O	20.00	18.85	19.69	19.10	19.70	19.53
Nd_2O_3	0.06	0.08	0.00	0.08	0.07	0.06
NiO	0.13	0.38	0.35	0.35	0.34	0.34
P_2O_5	0.32	0.37	0.33	0.36	0.35	0.33
PbO	0.21	0.23	0.21	0.22	0.20	0.21
SO_3	0.36	0.38	0.37	0.37	0.35	0.42
SiO_2	39.89	42.18	42.03	41.89	41.81	41.79
TiO_2	&	0.09	0.08	0.08	0.08	0.09
ZnO	3.05	2.28	2.22	2.37	2.29	2.36
ZrO_2	3.97	2.65	2.64	2.95	2.92	3.03
Total	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model

$ Estimated as 50% of target value.

Table 4.10. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D1-05 Glass Composition (Test 1) (wt%) (continued).

Constituents	Glass (kg)	1668.88	1703.66	1734.82	1757.52	1788.26
	Target	OBL-G-73A	OBL-G-77A	OBL-G-78B	OBL-G-78D	OBL-G-80A
Al_2O_3	8.00	7.85	7.92	7.84	7.94	7.84
$B_2O_3^{\#}$	9.15	8.32	8.34	8.36	8.37	8.38
BaO	0.03	0.03	0.02	0.03	0.06	0.06
Bi_2O_3	&	0.18	0.02	0.01	0.02	0.01
CaO	2.03	1.96	1.92	1.95	1.95	1.92
CeO_2	0.05	0.04	0.06	0.04	0.04	0.06
Cl	0.16	0.09	0.08	0.07	0.08	0.08
Cr_2O_3	0.12	0.33	0.29	0.33	0.32	0.32
$F^{\$}$	0.18	0.09	0.09	0.09	0.09	0.09
Fe_2O_3	5.53	6.87	6.37	6.42	6.23	6.17
K_2O	4.01	3.56	3.56	3.64	3.58	3.63
La_2O_3	0.04	0.04	0.03	0.02	0.04	0.02
$Li_2O^{\#}$	&	0.27	0.23	0.20	0.18	0.16
MgO	1.89	1.43	1.51	1.57	1.56	1.65
MnO	0.82	0.99	0.91	0.94	0.85	0.87
Na_2O	20.00	19.39	19.97	19.66	19.83	19.77
Nd_2O_3	0.06	0.00	0.09	0.07	0.06	0.00
NiO	0.13	0.35	0.33	0.32	0.31	0.29
P_2O_5	0.32	0.32	0.34	0.35	0.35	0.34
PbO	0.21	0.21	0.20	0.20	0.20	0.19
SO_3	0.36	0.37	0.35	0.36	0.38	0.37
SiO_2	39.89	41.34	41.50	41.43	41.52	41.61
TiO_2	&	0.09	0.08	0.08	0.08	0.08
ZnO	3.05	2.53	2.52	2.59	2.58	2.64
ZrO_2	3.97	3.34	3.27	3.40	3.38	3.46
Total	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent
\# - B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model
$ Estimated as 50% of target value.

Table 4.10. XRF Analyzed Composition for Glass Discharged Corresponding to the AY102D1-05 Glass Composition (Test 1) (wt%) (continued).

Constituents	Glass (kg)	1809.84	1832.96	1859.56	1885.44	1911.62
	Target	OBL-G-80C	OBL-G-81B	OBL-G-81D	OBL-G-84A	OBL-G-84C
Al_2O_3	8.00	7.76	7.76	7.85	7.60	7.67
$B_2O_3{}^{\#}$	9.15	8.38	8.39	8.40	8.40	8.41
BaO	0.03	0.06	0.01	0.03	0.04	0.06
Bi_2O_3	&	0.02	0.02	0.01	0.01	0.02
CaO	2.03	1.97	2.02	1.94	2.06	2.02
CeO_2	0.05	0.07	0.06	0.05	0.03	0.04
Cl	0.16	0.08	0.08	0.07	0.09	0.09
Cr_2O_3	0.12	0.30	0.28	0.30	0.26	0.28
$F^{\$}$	0.18	0.09	0.09	0.09	0.09	0.09
Fe_2O_3	5.53	6.22	6.23	6.10	6.17	6.06
K_2O	4.01	3.66	3.70	3.73	3.59	3.68
La_2O_3	0.04	0.04	0.02	0.03	0.04	0.02
$Li_2O^{\#}$	&	0.14	0.13	0.11	0.10	0.09
MgO	1.89	1.62	1.62	1.65	1.97	1.98
MnO	0.82	0.86	0.91	0.88	0.85	0.87
Na_2O	20.00	19.91	19.69	19.68	19.67	19.81
Nd_2O_3	0.06	0.06	0.08	0.08	0.07	0.07
NiO	0.13	0.29	0.30	0.31	0.28	0.27
P_2O_5	0.32	0.33	0.32	0.33	0.33	0.32
PbO	0.21	0.19	0.20	0.19	0.19	0.19
SO_3	0.36	0.37	0.36	0.38	0.37	0.34
SiO_2	39.89	41.32	41.30	41.47	41.33	41.04
TiO_2	&	0.09	0.08	0.09	0.10	0.09
ZnO	3.05	2.65	2.75	2.67	2.78	2.80
ZrO_2	3.97	3.50	3.61	3.53	3.57	3.69
Total	100.00	100.00	100.00	100.00	100.00	100.00

& - Not a target constituent

- B_2O_3 and Li_2O calculated from DCP-AES analysis of glass in the melt pool prior to the tests (MBL-G-128A) and analyzed feed sample composition using a simple well-stirred tank model

$ Estimated as 50% of target value.

Table 4.11. XRF Analyzed Composition for Dip Samples Taken After DM100 Melter Tests (wt%).

	Tests 5 and 4 (AY102D4-07 Glass Composition)					
	Before Test 5	After Test 5 9 lpm bubbling	After Test 5	Before Test 4	After Test 4	Target
Constituents	MBL-D-133A	NBL-D-14A	NBL-D-23A	NBL-D-30A	NBL-D-78A	
Al_2O_3	14.95	13.18	12.42	12.49	11.49	11.54
B_2O_3	10.99*	10.94#	10.52#	10.48#	9.71#	9.50
BaO	< 0.01	0.04	0.06	0.05	0.07	0.07
Bi_2O_3	0.65	0.39	0.27	0.28	0.06	&
CaO	0.85	0.72	0.71	0.71	0.65	0.52
CeO_2	0.13	0.16	0.13	0.11	0.13	0.13
Cl	< 0.01	0.01	0.01	0.01	0.02	0.00
Cr_2O_3	1.27	0.79	0.61	0.73	0.28	0.26
Fe_2O_3	11.94	13.14	13.55	13.82	14.70	14.19
K_2O	4.19	2.67	1.68	1.79	0.35	0.06
La_2O_3	0.06	0.06	0.05	0.05	0.05	0.09
Li_2O	3.67*	3.75#	3.83#	3.84#	4.00#	4.50
MgO	0.23	0.29	0.27	0.29	0.31	0.15
MnO	1.44	1.64	1.74	1.79	1.89	2.11
Na_2O	11.88	12.04	12.40	12.24	13.07	14.08
Nd_2O_3	0.13	0.15	0.15	0.16	0.12	0.15
NiO	0.38	0.38	0.38	0.38	0.38	0.34
P_2O_5	0.39	0.44	0.46	0.48	0.49	0.53
PbO	0.33	0.36	0.39	0.39	0.46	0.54
SO_3	0.15	0.14	0.11	0.14	0.18	0.10
SiO_2	36.07	38.48	40.07	39.57	41.49	41.12
TiO_2	0.04	0.06	0.06	0.06	0.08	&
WO_3	0.07	0.04	0.02	0.03	< 0.01	&
ZnO	0.09	0.07	0.05	0.06	0.02	&
ZrO_2	0.09	0.06	0.04	0.06	0.02	&
Total	100.00	100.00	100.00	100.00	100.00	100.00

& Not a target constituent.
# Value from contemporaneous glass discharge.
* Measured by DCP-AES

Table 4.11. XRF Analyzed Composition for Dip Samples After DM100 Melter Tests (wt%) (continued).

	Test 3 AY102D3-02 Glass Composition		Test 2 AY102D2-06 Glass Composition		Test 1 AY102D1-05 Glass Composition	
Constituents	NBL-D-129A	Target	OBL-D-33A	Target	OBL-D-84A	Target
Al_2O_3	11.28	11.73	10.43	10.28	7.78	8.00
B_2O_3#	8.51	8.50	7.39	7.80	8.40	9.15
BaO	0.07	0.07	0.06	0.06	< 0.01	0.03
Bi_2O_3	0.01	&	0.00	&	0.01	&
CaO	0.55	0.51	0.51	0.42	2.07	2.03
CeO_2	0.18	0.13	0.14	0.11	0.06	0.05
Cl	0.03	0.05	0.05	0.11	0.09	0.16
Cr_2O_3	0.26	0.26	0.26	0.23	0.29	0.12
F$	0.03	0.05	0.07	0.13	0.09	0.18
Fe_2O_3	13.27	13.95	10.87	11.48	5.99	5.53
K_2O	0.91	1.18	2.32	2.80	3.64	4.01
La_2O_3	0.05	0.09	0.05	0.07	< 0.01	0.04
Li_2O#	3.83	4.50	2.18	2.08	0.10	&
MgO	0.29	0.14	0.25	0.12	2.02	1.89
MnO	1.81	2.08	1.57	1.71	0.85	0.82
Na_2O	13.71	13.41	17.36	17.11	19.94	20.00
Nd_2O_3	0.14	0.15	0.12	0.12	0.06	0.06
NiO	0.34	0.34	0.35	0.28	0.26	0.13
P_2O_5	0.53	0.55	0.49	0.50	0.33	0.32
PbO	0.35	0.53	0.36	0.44	0.19	0.21
SO_3	0.22	0.19	0.31	0.31	0.37	0.36
SiO_2	43.54	41.59	44.67	43.85	40.99	39.89
TiO_2	0.07	&	0.07	&	0.09	&
WO_3	< 0.01	&	< 0.01	&	< 0.01	&
ZnO	0.02	&	0.05	&	2.78	3.05
ZrO_2	0.01	&	0.09	&	3.59	3.97
Total	100.00	100.00	100.00	100.00	100.00	100.00

& Not a target constituent.
# Value from contemporaneous glass discharge
$ Estimated as 50% of target value.

Table 4.12. Comparison of XRF and DCP Analysis from Last Glass Discharged to the Analyzed Feed and Target Compositions.

Test	5			4			3			2			1		
Constituent	Target	NBL-G-23B	% Dev.	Target	NBL-G-78A	% Dev.	Target	NBL-G-129A	% Dev.	Target	OBL-G-33B	% Dev.	Target	OBL-G-84C	% Dev.
Al_2O_3	11.54	12.99	12.52	11.54	11.66	1.04	11.73	11.00	-6.23	10.28	10.26	-0.25	8.00	7.69	-3.88
$B_2O_3^{\#}$	9.50	9.43	-0.74	9.50	9.42	-0.84	8.50	8.64	1.65	7.80	7.35	-5.77	9.15	8.20	-10.42
BaO	0.07	0.05	NC	0.07	0.07	NC	0.07	0.08	NC	0.06	0.06	NC	0.03	0.06	NC
Bi_2O_3	&	0.30	NC	&	0.04	NC	&	0.01	NC	&	0.01	NC	&	0.02	NC
CaO	0.52	0.70	NC	0.52	0.62	NC	0.51	0.57	NC	0.42	0.52	NC	2.03	2.03	NC
CeO_2	0.13	0.11	NC	0.13	0.17	NC	0.13	0.15	NC	0.11	0.11	NC	0.05	0.04	NC
Cl	0.00	0.01	NC	0.00	0.02	NC	0.05	0.03	NC	0.11	0.06	NC	0.16	0.09	NC
Cr_2O_3	0.26	0.60	NC	0.26	0.29	NC	0.26	0.26	NC	0.23	0.29	NC	0.12	0.28	NC
$F^{\$}$	&	< 0.01	NC	&	< 0.01	NC	0.05	0.03	NC	0.13	0.07	NC	0.18	0.09	NC
Fe_2O_3	14.19	13.34	-5.96	14.19	13.76	-3.00	13.95	14.14	1.37	11.48	11.72	2.11	5.53	6.07	9.78
K_2O	0.06	1.62	NC	0.06	0.35	NC	1.18	0.99	-15.85	2.80	2.48	-11.37	4.01	3.68	-8.09
La_2O_3	0.09	0.07	NC	0.09	0.05	NC	0.09	0.05	NC	0.07	0.04	NC	0.04	0.02	NC
$Li_2O^{\#}$	4.50	3.82	-15.11	4.50	4.27	-5.11	4.50	3.92	-12.89	2.08	2.19	5.29	&	0.11	NC
MgO	0.15	0.29	NC	0.15	0.31	NC	0.14	0.27	NC	0.12	0.26	NC	1.89	1.98	4.92
MnO	2.11	1.70	-19.54	2.11	1.81	-14.40	2.08	1.92	-7.80	1.71	1.67	-2.01	0.82	0.87	5.58
Na_2O	14.08	12.98	-7.81	14.08	13.49	-4.20	13.41	13.41	-0.01	17.11	16.38	-4.25	20.00	19.85	-0.72
Nd_2O_3	0.15	0.15	NC	0.15	0.14	NC	0.15	0.16	NC	0.12	0.12	NC	0.06	0.07	NC
NiO	0.34	0.33	NC	0.34	0.29	NC	0.34	0.38	NC	0.28	0.36	NC	0.13	0.27	NC
P_2O_5	0.53	0.48	NC	0.53	0.50	NC	0.55	0.49	NC	0.50	0.49	NC	0.32	0.32	NC
PbO	0.54	0.38	NC	0.54	0.43	NC	0.53	0.38	NC	0.44	0.39	NC	0.21	0.19	NC
SO_3	0.10	0.11	NC	0.10	0.16	NC	0.19	0.22	NC	0.31	0.36	NC	0.36	0.34	NC
SiO_2	41.12	40.32	-1.94	41.12	42.04	2.22	41.59	42.79	2.88	43.85	44.59	1.67	39.89	41.13	3.10
TiO_2	&	0.06	NC	&	0.07	NC	&	0.07	NC	&	0.07	NC	&	0.09	NC
WO_3	&	0.03	NC	&	< 0.01	NC	&	< 0.01	NC	&	< 0.01	NC	&	< 0.01	NC
ZnO	&	0.06	NC	&	0.02	NC	&	0.02	NC	&	0.05	NC	3.05	2.81	NC
ZrO_2	&	0.07	NC	&	0.02	NC	&	0.01	NC	&	0.10	NC	3.97	3.70	NC
Total	100.00	100.00	-	100.00	100.00	-	100.00	100.00	-	100.00	100.00	-	100.00	100.00	-

Determined by DCP-AES
& Not a target constituent
$ Estimated as 50% of target value.

Table 4.13. Results from PCT (ASTM C1285, 7-days at 90°C, Stainless Steel Vessel; S/V=2000 m^{-1}).

Formulation		**AY102D4-07**			**AY102D3-02**	
Glass Samples		**NBL-G-23A**	**NBL-G-78A**	**Crucible Glass**	**NBL-G-129A**	**Crucible Glass**
PCT Concentration in mg/L	B	15.32	17.56		13.75	
	Li	10.80	13.10		11.52	
	Na	50.47	59.52		59.47	
	Si	62.79	74.92		74.62	
PCT Normalized Concentrations, g/L	B	0.52	0.60	0.74	0.51	0.64
	Li	0.61	0.66	0.75	0.63	0.79
	Na	0.52	0.59	0.80	0.60	0.81
	Si	0.33	0.38	0.37	0.37	0.48
	pH	10.51	10.61	10.61	10.70	10.90
PCT Normalized Mass Loss (g/m^2)	B	0.26	0.30		0.26	
	Li	0.30	0.33		0.32	
	Na	0.26	0.30		0.30	
	Si	0.17	0.19		0.19	
PCT Normalized Loss Rate, g/d/m^2	B	0.04	0.04		0.04	
	Li	0.04	0.05		0.04	
	Na	0.04	0.04		0.04	
	Si	0.02	0.03		0.05	

Table 4.13. Results from PCT (ASTM C1285, 7-days at 90°C, Stainless Steel Vessel; S/V=2000 m^{-1}) (continued).

		AY102D2-06		**AY102D1-05**		**DWPF-EA**
Glass Samples		**OBL-G-33B**	**Crucible Glass**	**OBL-G-84C**	**Crucible Glass**	
PCT Concentration in mg/L	B	10.17		31.69		
	Li	5.58		BDL		
	Na	80.44		183.92		
	Si	77.68		66.30		
PCT Normalized Concentrations, g/L	B	0.45	0.62	1.25	1.84	17.68
	Li	0.55	0.61	NC	NC	9.98
	Na	0.66	0.85	1.25	1.58	13.69
	Si	0.37	0.43	0.34	0.42	3.72
	pH	10.81	11.01	11.42	11.41	11.85
PCT Normalized Mass Loss (g/m^2)	B	0.22		0.62		
	Li	0.27		NC		
	Na	0.33		0.62		
	Si	0.19		0.17		
PCT Normalized Loss Rate, g/d/m^2	B	0.03		0.09		
	Li	0.04		NC		
	Na	0.05		0.09		
	Si	0.03		0.02		

NC – Not calculated

Table 4.14. TCLP Results for Discharged Glass Samples (mg/L).

Glass Formulation	**Element**	**Ba**	**Cr**	**Ni**	**Pb**
	UTS Limits[#]	21	0.60	11.00	0.75
	Delisting Limits [39, 40]	100	4.95	22.6	5.00
AY102D4-07	NBL-G-23A	0.28	0.03	0.05	< 0.1
	NBL-G-78A	0.26	0.03	0.07	< 0.1
	Crucible Glass	0.77	0.02	0.05	< 0.1
AY102D3-02	NBL-G-129A	0.27	0.03	0.08	< 0.1
	Crucible Glass	0.79	0.02	0.07	< 0.1
AY102D2-06	OBL-G-33B	0.26	0.04	0.12	< 0.1
	Crucible Glass	0.79	0.03	0.04	< 0.1
AY102D1-05	OBL-G-84C	0.27	0.11	0.16	< 0.1
	Crucible Glass	0.79	0.14	0.06	< 0.1

For comparison only; does not apply to WTP glasses
NM – Not Measured

Table 4.15. Results of XRD and SEM Analysis of Melter Glasses.

Target Glass Composition	Sample	SEM	
		Crystal Content	Crystal Morphology
	Dip Sample (MBL-D-133A) prior to testing	2.21 volume percent Cr-Fe-Ni spinels with lesser amounts of Zn, Mn, and Al	Heterogeneously distributed, sub-euhedral, granular, clustered spinels. Crystals mainly of 10-30 micron size.
AY102D4-07	Dip Sample (NBL-D-14A) from end of test segment with fixed bubbling Test 5 (98 kg total glass production)	1.28 volume percent Cr-Fe spinels with lesser amounts of Zn, Mn, Ni and Al	Heterogeneously distributed, sub-euhedral, granular, clustered spinels. Bimodal crystal size distribution: a major 20-50 micron size group and a minor 1-5 micron size fraction.
	Dip Sample (NBL-D-23A) from end of test segment with optimized bubbling Test 5 (171 kg total glass production)	0.94 volume percent Cr-Fe spinels with lesser amounts of Mn and Ni	Heterogeneously distributed, sub-euhedral, granular, clustered spinels. Bimodal crystal size distribution: a major 20-40 micron size group and a minor 1-4 micron size fraction.
	Dip Sample (NBL-D-30A) prior to Test 4	1.26 volume percent Cr-Fe-Mn spinels with lesser amounts of Ni	Heterogeneously distributed, sub-euhedral, granular, clustered spinels. Bimodal crystal size distribution: a major 10-40 micron size group and a minor < 5 micron size fraction.
	Dip Sample (NBL-D-78A) from end of Test 4 (510 kg total glass production)	0.50 volume percent Cr-Fe spinels with lesser amounts of Mn and Ni	Heterogeneously distributed, sub-euhedral, granular, clustered spinels. Bimodal crystal size distribution: a major 1-10 micron size group and a minor 20-50 micron size fraction.
AY102D3-02	Dip Sample (NBL-D-129A) from end of Test 3 (903 kg total glass production)	No crystals observed	No crystals observed
AY102D2-06	Dip Sample (OBL-D-33A) from end of Test 2	No crystals observed	No crystals observed
AY102D1-05	Dip Sample (OBL-D-84A) from end of Test 1	No crystals observed	No crystals observed

Table 5.1. Results from DM100 Off-Gas Emission Samples.

		Test 5 09/18/2013 18:01 – 19:01 16.7 % Moisture, 107.3% Isokinetic				**Test 4** 09/25/2013 13:48 – 14:48 13.2% Moisture, 101.6% Isokinetic			
		Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF	Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total[$]	42465	808	1.90	52.6	65597	861	1.31	76.2
	Al	2267	28.0	1.24	80.9	3086	32.4	1.05	95.4
	B	1095	36.5	3.34	30.0	1490	41.6	2.79	35.8
	Ba	24.6	0.65	2.63	38.0	33.5	0.76	2.26	44.2
	Cl*	0.0	7.15	NC	NC	0.0	6.13	NC	NC
	Ca	138	5.08	3.69	27.1	188	5.83	3.11	32.1
	Ce	40.9	< 0.10	< 0.24	> 409	55.7	< 0.10	< 0.18	> 557
	Cr	65.3	4.84	7.41	13.5	88.9	1.64	1.85	54.2
	F*	0.0	2.95	NC	NC	0.0	1.33	NC	NC
	Fe	3684	107	2.91	34.3	5015	119	2.38	42.1
	K	19.1	21.8	114	0.88	26.0	3.49	13.4	7.5
	La	28.5	< 0.10	< 0.35	> 285	38.8	< 0.10	< 0.26	> 388
	Li	776	14.1	1.82	54.9	1057	12.5	1.18	84.5
	Mg	33.1	2.13	6.44	15.5	45.1	2.66	5.89	17.0
	Mn	608	15.3	2.51	39.8	828	17.7	2.14	46.8
	Na	3879	73.2	1.89	53.0	5281	90.8	1.72	58.2
	Nd	113	< 0.10	< 0.09	> 1129	154	< 0.10	< 0.07	> 1537
	Ni	100	2.20	2.20	45.4	136	2.59	1.90	52.7
	P	86.6	1.17	1.35	74.0	118	1.28	1.08	92.3
	Pb	187	5.23	2.80	35.7	254	5.43	2.14	46.8
	S*	15.0	10.5	69.7	1.43	20.5	5.92	28.9	3.46
	Si	7138	82.1	1.15	86.9	9717	95.4	0.98	102
Gas	B	1095	6.90	0.63	159	1490	5.35	0.36	279
	Cl	0.0	< 0.10	NC	NC	0.0	< 0.10	NC	NC
	F	0.0	< 0.10	NC	NC	0.0	< 0.10	NC	NC
	S	15.0	< 0.10	< 0.67	> 150	20.5	< 0.10	< 0.49	> 205

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

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

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

NC – Not Calculated

Table 5.1. Results from DM100 Off-Gas Emission Samples (continued).

		Test 3 10/02/2013 16:55 – 17:55 13.3 % Moisture, 99.1% Isokinetic			
		Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total[$]	78350	404	0.52	194
	Al	3599	10.3	0.29	350
	B	1530	19.8	1.29	77.4
	Ba	37.4	0.26	0.71	141
	Cl*	26.1	11.1	42.4	2.36
	Ca	211	2.36	1.12	89.5
	Ce	62.4	< 0.10	< 0.16	> 624
	Cr	104	2.07	2.00	50.1
	F*	29.0	3.79	13.1	7.66
	Fe	5657	50.1	0.89	113
	K	568	6.55	1.15	87.6
	La	44.5	< 0.10	< 0.22	> 445
	Li	1212	5.32	0.44	228
	Mg	50.4	1.14	2.27	44.1
	Mn	934	6.22	0.67	150
	Na	5773	53.6	0.93	108
	Nd	173	< 0.10	< 0.06	> 1728
	Ni	154	1.05	0.68	147
	P	140	0.30	0.21	467
	Pb	286	2.12	0.74	135
	S*	43.9	6.57	15.0	6.68
	Si	11277	35.5	0.31	318
Gas	B	1530	5.36	0.35	285
	Cl	26.1	< 0.10	< 0.38	> 261
	F	29.0	< 0.10	< 0.34	> 290
	S	43.9	< 0.10	< 0.23	> 439

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

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

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

Table 5.1. Results from DM100 Off-Gas Emission Samples (continued).

		Test 2 10/09/2013 14:25 – 15:52 8.88 % Moisture, 97.5% Isokinetic				**Test 1** 10/23/2013 17:04 – 18:04 6.52% Moisture, 100.1% Isokinetic			
		Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF	Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF
Particulate	Total[$]	90877	417	0.46	218	127121	582	0.46	219
	Al	3890	9.76	0.25	399	4374	12.7	0.29	344
	B	1731	16.7	0.96	104	2936	28.7	0.98	102
	Ba	37.1	0.19	0.52	193	25.0	0.17	0.68	148
	Cl*	75.8	30.1	39.7	2.52	161	34.8	21.6	4.63
	Ca	214	2.05	0.96	104	1502	8.96	0.60	168
	Ce	32.4	< 0.10	< 0.31	> 324	22.5	< 0.10	< 0.44	> 225
	Cr	111	1.84	2.05	1.85	53.9	88.4	2.53	2.86
	F*	93.0	12.5	13.4	7.44	189	16.4	8.65	11.56
	Fe	5739	27.4	0.48	210	3996	21.9	0.55	183
	K	1664	20.6	1.24	80.7	3439	45.2	1.32	76.0
	La	43.9	< 0.10	< 0.23	> 439	30.8	< 0.10	< 0.32	> 308
	Li	691	4.46	0.65	155	0	0.35	NC	NC
	Mg	51.7	0.63	1.21	82.3	1177	0.79	0.07	1489
	Mn	946	4.19	0.44	226	659	3.33	0.51	198
	Na	9076	72.6	0.80	125	15330	116	0.76	132
	Nd	179	< 0.10	< 0.06	> 1788	122	< 0.10	< 0.08	> 1219
	Ni	156	0.18	0.12	861	108.0	< 0.10	< 0.09	> 1080
	P	157	0.79	0.50	200	143	0.74	0.52	194
	Pb	290	2.71	0.94	107	202	1.74	0.86	116
	S*	88.0	8.32	9.46	10.57	150	7.54	5.02	19.9
	Si	14657	30.2	0.21	485	19269	31.6	0.16	611
	Zn	0	NC	NC	NC	2532	< 0.10	< 0.00	> 25320
	Zr	0	NC	NC	NC	3033	2.61	0.09	1161
Gas	B	1731	1.26	0.07	1376	2936	0.19	0.01	15216
	Cl	75.8	< 0.10	< 0.13	> 758	161	< 0.10	< 0.06	> 1612
	F	93.0	< 0.10	< 0.11	> 930	189	< 0.10	< 0.05	> 1891
	S	88.0	< 0.10	< 0.11	> 880	150	< 0.10	< 0.07	> 1503

[$] - From gravimetric analysis of filters and particulate nitric acid rinses
[#] - Feed rate calculated from target composition and total glass production rate
* - Calculated from analysis of filter particulate by water dissolution and direct analysis of particulate rinse
NC-Not Calculated

Table 5.2. Concentrations (ppmv) of Selected Species in DM100 Exhaust Measured by FTIR Spectroscopy, Test 5.

	Fixed Bubbling (9 lpm)		**Optimized Bubbling**	
	Avg.	Range	Avg.	Range
H_2O [%]	8.2	< 1.0 - 20.1	12.4	2.6 - 23.2
CO	2.9	< 1.0 - 29.2	3.7	1.5 - 14.3
CO_2	1125	< 1.0 - 8130	1560	890 - 5564
HCN	< 1.0	NA	< 1.0	NA
HF	1.8	< 1.0 - 4.4	1.5	< 1.0 - 2.0
HCl	< 1.0	NA	< 1.0	NA
NH_3	1.8	< 1.0 - 8.7	1.8	< 1.0 - 3.5
Nitric Acid	< 1.0	NA	< 1.0	NA
NO	2.1	< 1.0 - 12.8	3.0	1.1 - 10.4
NO_2	< 1.0	NA	< 1.0	NA
Nitrous Acid	< 1.0	NA	< 1.0	NA
N_2O	< 1.0	NA	< 1.0	NA
SO_2	< 1.0	NA	< 1.0	NA

NA: Not applicable.

Table 5.3. Concentrations (ppmv) of Selected Species in DM100 Exhaust Measured by FTIR Spectroscopy, Test 4.

	Fixed Bubbling (9 lpm)		**Optimized Bubbling**	
	Avg.	Range	Avg.	Range
H_2O [%]	7.6	2.9 - 22.3	11.2	3.9 - 29.4
CO	5.6	< 1.0 - 31.0	8.3	1.8 - 35.0
CO_2	1737	372 - 6983	2555	1282 - 9253
HCN	< 1.0	NA	< 1.0	< 1.0 - 1.1
HF	< 1.0	< 1.0 - 1.7	< 1.0	< 1.0 - 1.3
HCl	< 1.0	NA	< 1.0	NA
NH_3	1.4	< 1.0 - 2.7	2.4	1.0 - 4.9
Nitric Acid	< 1.0	NA	< 1.0	NA
NO	2.5	< 1.0 - 11.5	4.3	1.1 - 12.6
NO_2	< 1.0	NA	< 1.0	NA
Nitrous Acid	< 1.0	NA	< 1.0	NA
N_2O	< 1.0	NA	< 1.0	NA
SO_2	< 1.0	NA	< 1.0	NA

Table 5.4. Concentrations (ppmv) of Selected Species in DM100 Exhaust Measured by FTIR Spectroscopy, Test 3.

	Fixed Bubbling (9 lpm)		**Optimized Bubbling**	
	Avg.	Range	Avg.	Range
H_2O [%]	8.3	2.6 - 23.4	12.0	3.3 - 26.1
CO	2.0	< 1.0 - 12.1	3.1	< 1.0 - 12.2
CO_2	1727	432 - 9070	2322	1090 - 10072
HCN	< 1.0	NA	< 1.0	NA
HF	< 1.0	< 1.0 - 1.6	< 1.0	< 1.0 - 1.0
HCl	< 1.0	NA	< 1.0	NA
NH_3	1.2	< 1.0 - 2.3	1.5	< 1.0 - 2.7
Nitric Acid	< 1.0	NA	< 1.0	NA
NO	324.7	9.6 - 1529	483.2	177.8 - 1710
NO_2	14.3	< 1.0 - 82.9	22.5	7.4 - 117.1
Nitrous Acid	< 1.0	< 1.0 - 2.3	< 1.0	< 1.0 - 1.9
N_2O	3.5	< 1.0 - 19.9	4.8	1.1 - 20.0
SO_2	< 1.0	NA	< 1.0	NA

Table 5.5. Concentrations (ppmv) of Selected Species in DM100 Exhaust Measured by FTIR Spectroscopy, Test 2.

	Fixed Bubbling (9 lpm)		**Optimized Bubbling**	
	Avg.	Range	Avg.	Range
H_2O [%]	7.2	1.3 - 20.1	9.0	2.7 - 22.4
CO	7.8	< 1.0 - 42.6	11.1	1.4 - 57.7
CO_2	1673	411.4 - 9710	2098	957.3 - 12506
HCN	< 1.0	< 1.0 - 1.1	< 1.0	NA
HF	< 1.0	< 1.0 - 1.1	< 1.0	NA
HCl	< 1.0	NA	< 1.0	NA
NH_3	42.8	< 1.0 - 207.4	50.7	12.2 - 234.7
Nitric Acid	< 1.0	NA	< 1.0	NA
NO	358.1	< 1.0 - 1913	483.3	170.2 - 2487
NO_2	8.2	< 1.0 - 72.3	14.0	3.8 - 100.3
Nitrous Acid	< 1.0	< 1.0 - 1.2	< 1.0	< 1.0 - 1.4
N_2O	28.1	< 1.0 - 144.9	34.9	8.2 - 196.4
SO_2	< 1.0	NA	< 1.0	NA

Table 5.6. Concentrations (ppmv) of Selected Species in DM100 Exhaust Measured by FTIR Spectroscopy, Test 1.

	Fixed Bubbling (9 lpm)		**Optimized Bubbling**	
	Avg.	Range	Avg.	Range
H_2O [%]	4.2	< 1.0 - 21.9	6.6	1.5 - 19.1
CO	22.4	< 1.0 - 107.7	48.5	< 1.0 - 214.9
CO_2	2712	619.6 - 13906	4535	1422 - 21160
HCN	< 1.0	< 1.0 - 1.4	< 1.0	< 1.0 - 1.1
HF	< 1.0	< 1.0 - 1.5	< 1.0	NA
HCl	< 1.0	NA	< 1.0	NA
NH_3	86.5	5.6 - 650.2	112.2	13.9 - 1032
Nitric Acid	< 1.0	< 1.0 - 1.6	< 1.0	< 1.0 - 1.9
NO	1013.3	101.8 - 3788	1870.7	635.6 - 4705
NO_2	61.2	5.4 - 672.3	139.4	43.9 - 638.5
Nitrous Acid	< 1.0	< 1.0 - 2.0	< 1.0	< 1.0 - 4.7
N_2O	92.3	1.8 - 522.3	139.1	11.2 - 773.2
SO_2	< 1.0	NA	< 1.0	NA

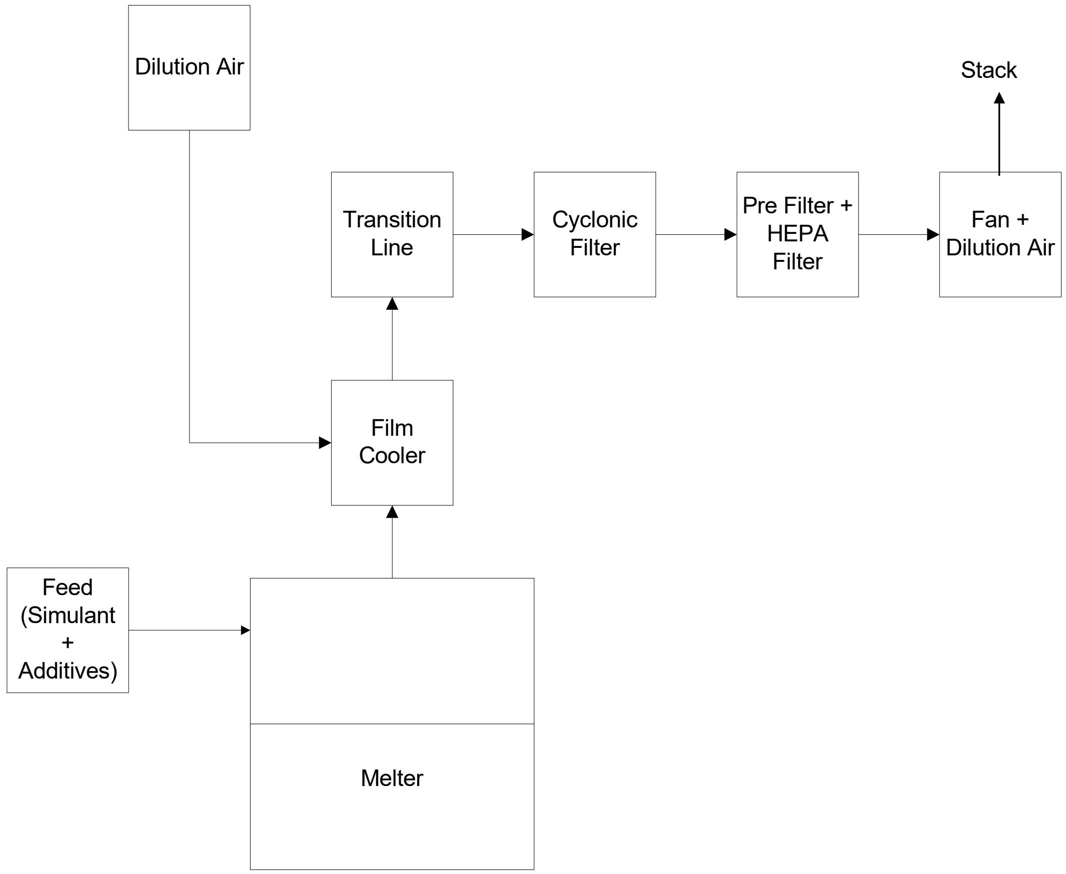


Figure 1.1. Schematic diagram of DuraMelter 100 vitrification system.

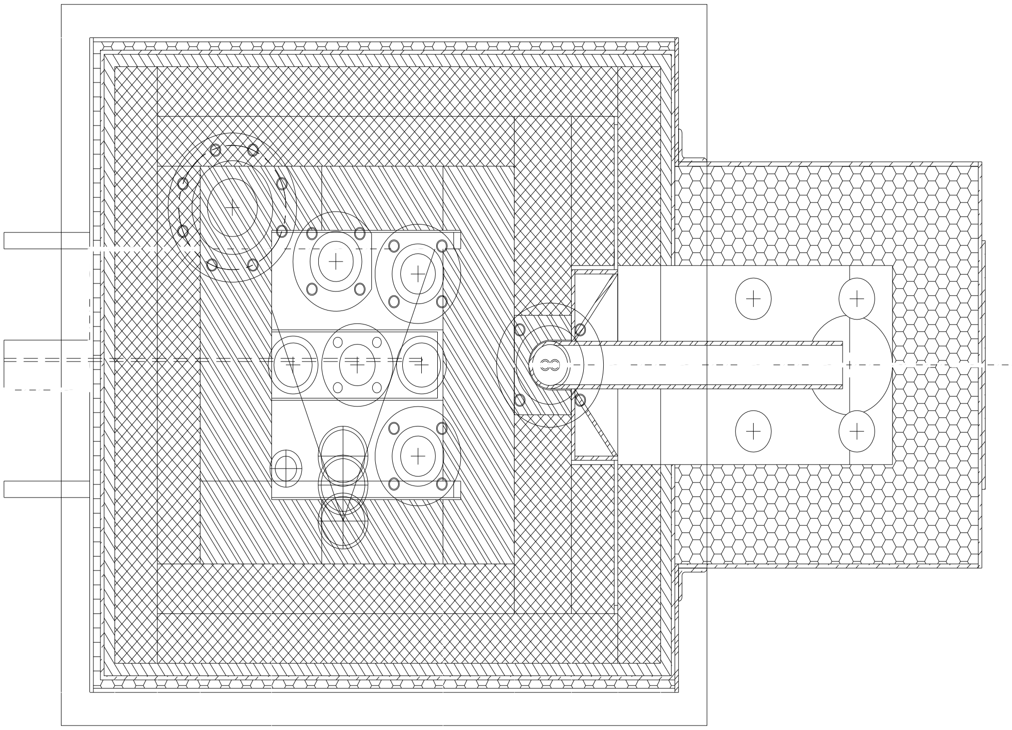


Figure 1.2.a. Schematic diagram showing cross-section through the DM100-BL-melter. Plan view showing locations of lid ports.

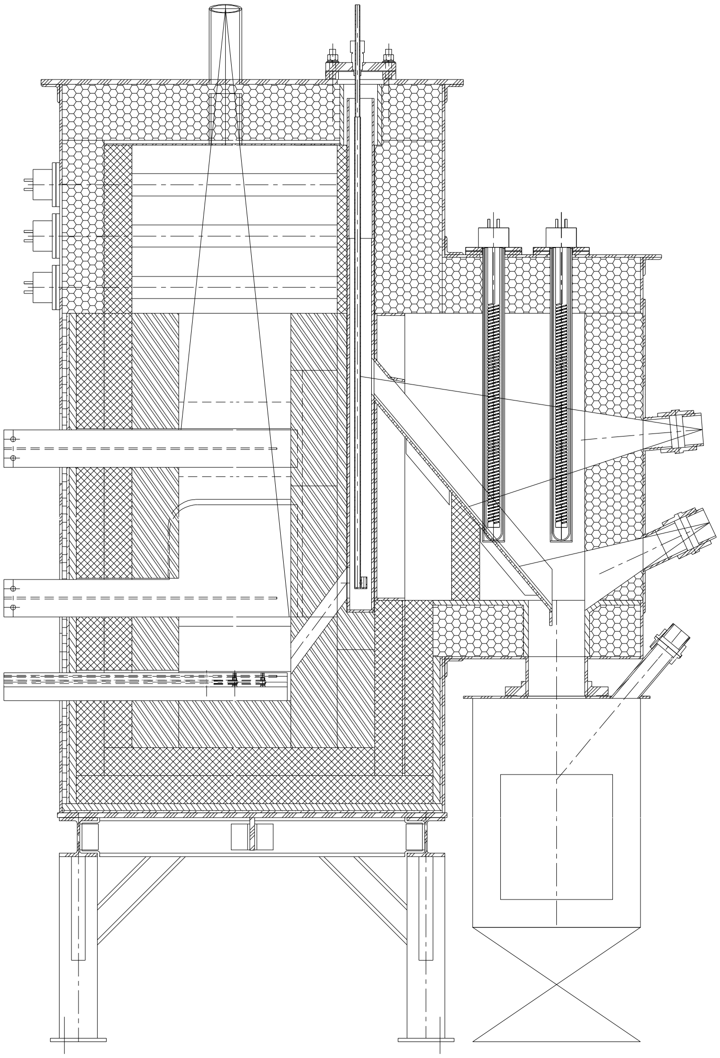


Figure 1.2.b. Schematic diagram showing cross-section through the DM100-BL melter.

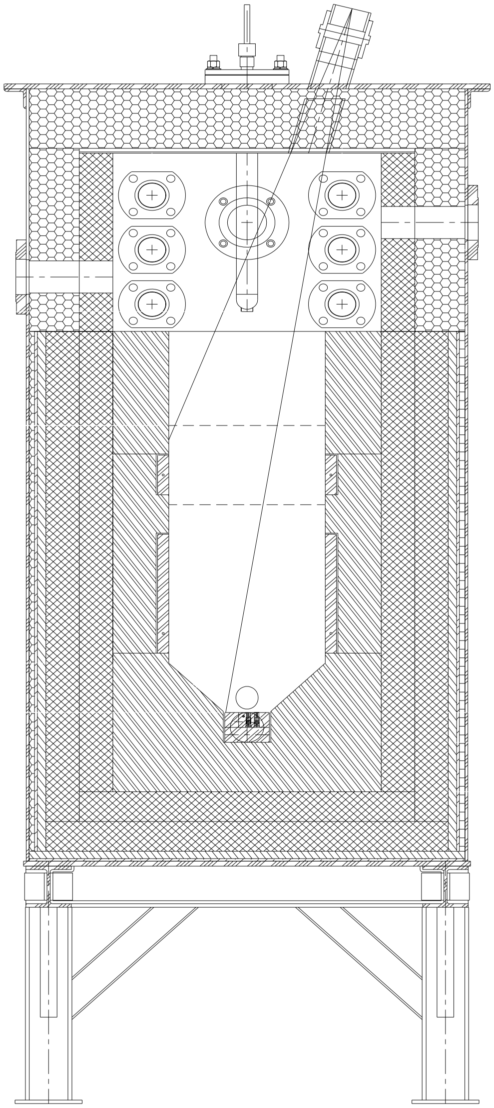


Figure 1.2.c. Schematic diagram showing cross-section through the DM100-BL melter.

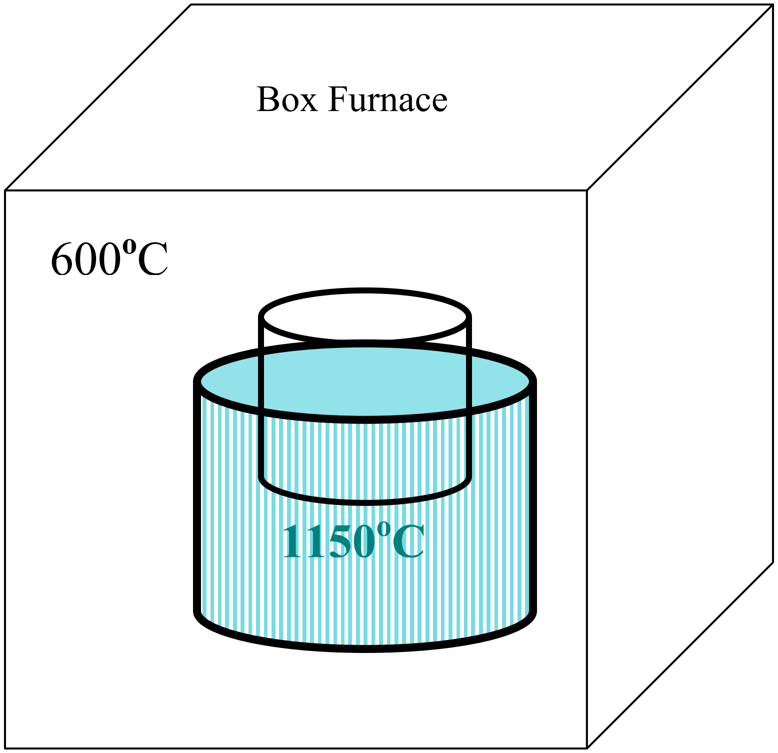


Figure 1.3. Schematic drawing of vertical gradient furnace (VGF) for feed conversion test.

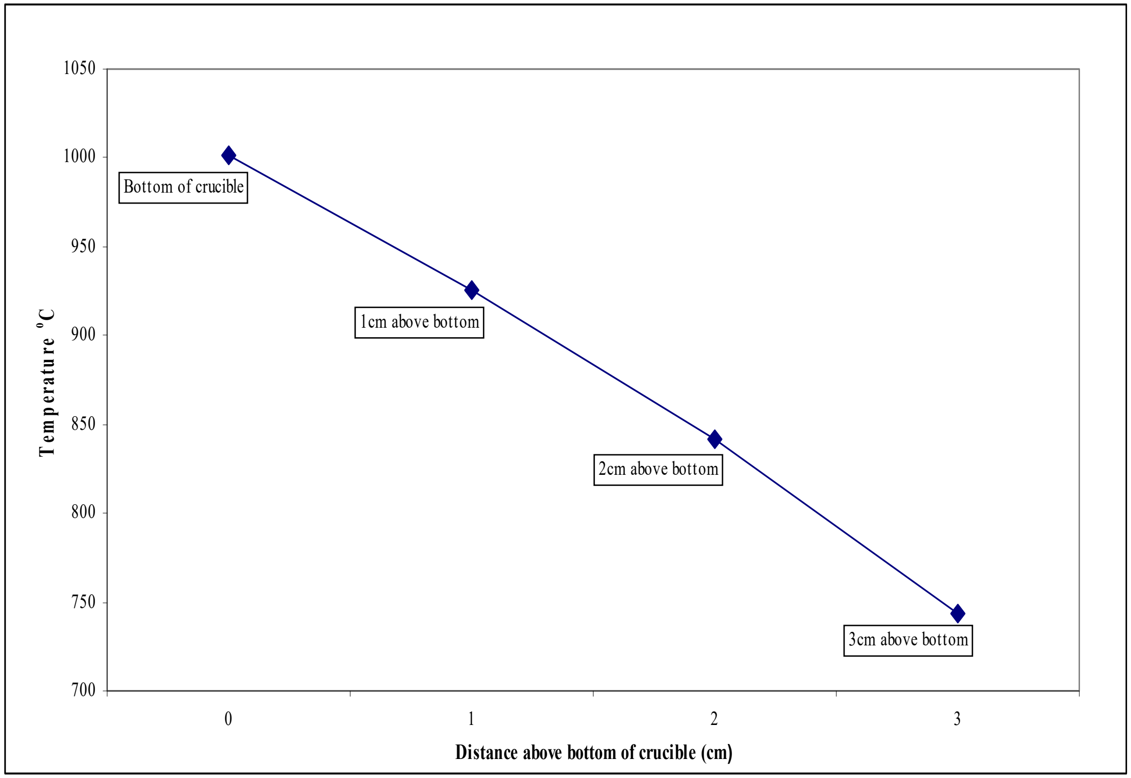


Figure 1.4. Temperature gradient (inside the loaded ceramic crucible) of the Vertical Gradient Furnace (VGF).

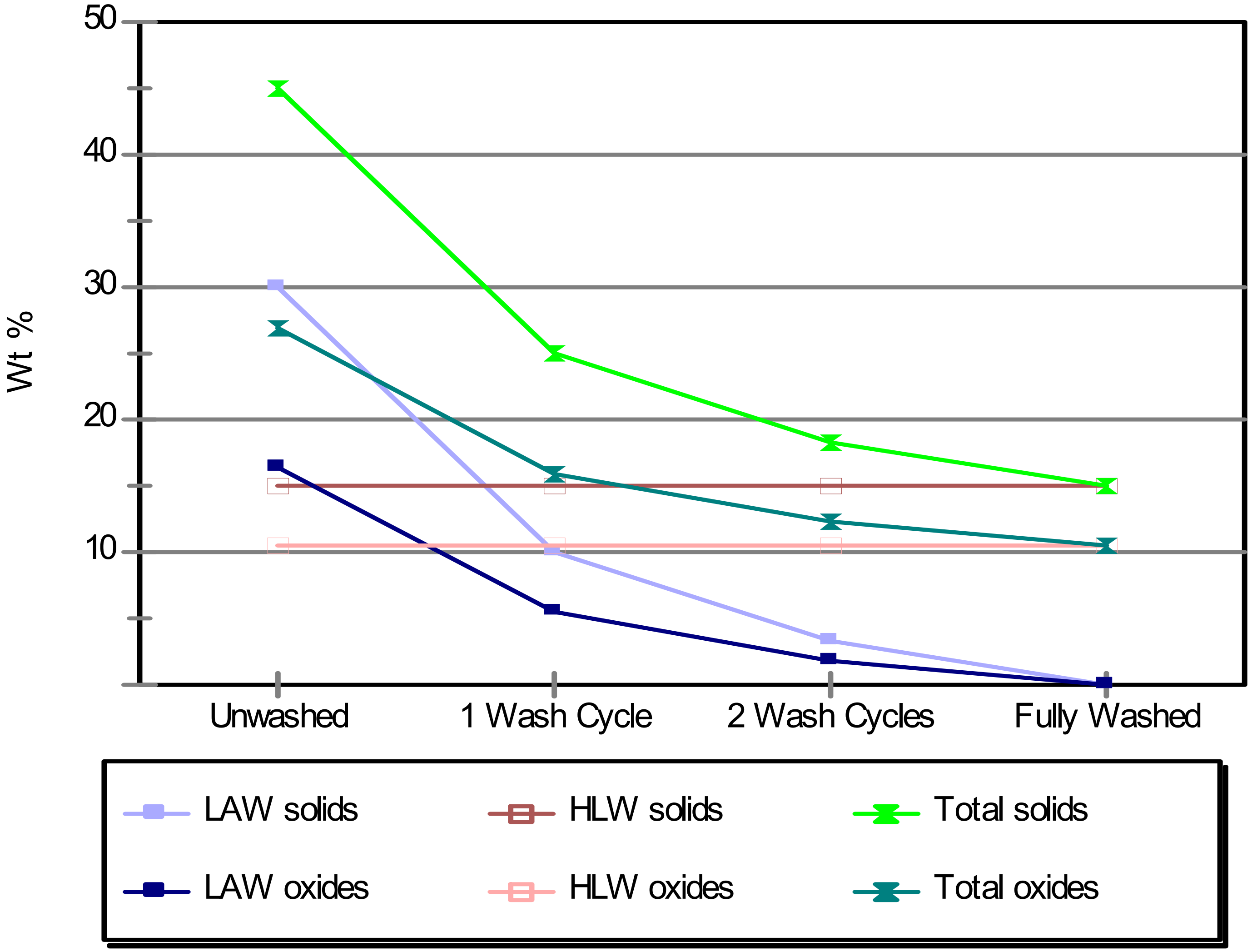


Figure 2.1. Changes in the waste solids and oxide contents in response to waste washing.

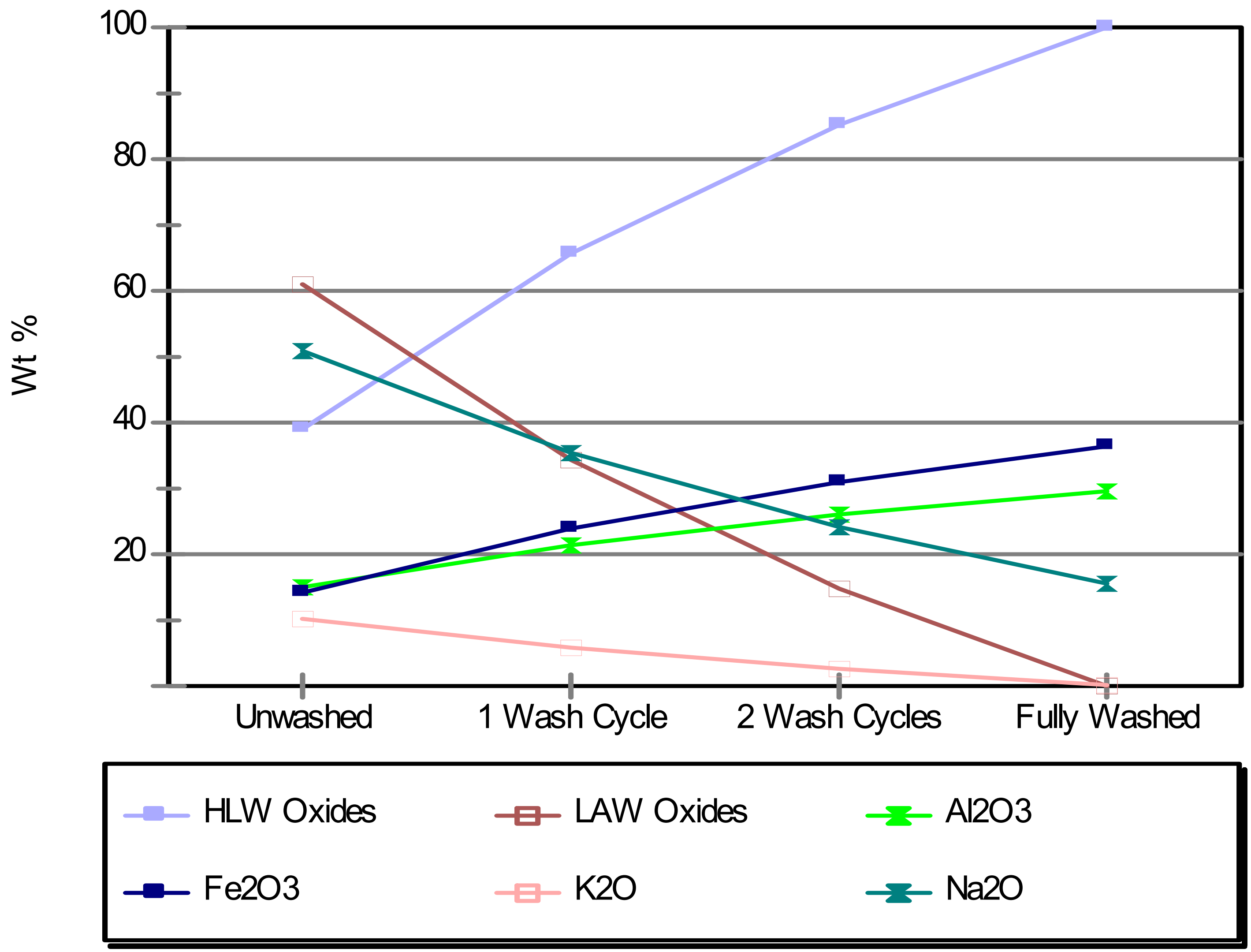


Figure 2.2. Changes in oxide composition in response to waste washing.

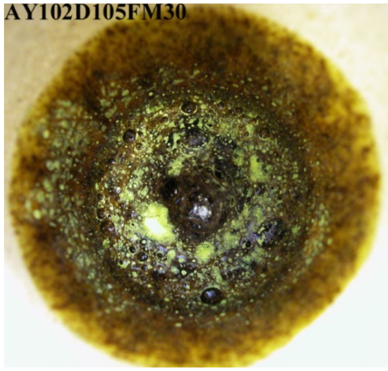
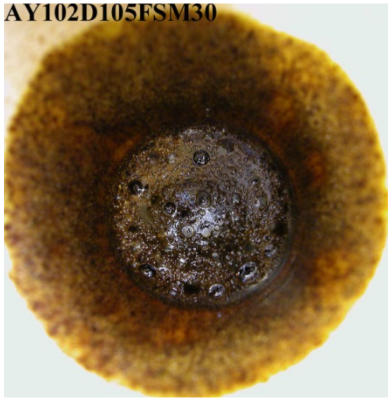
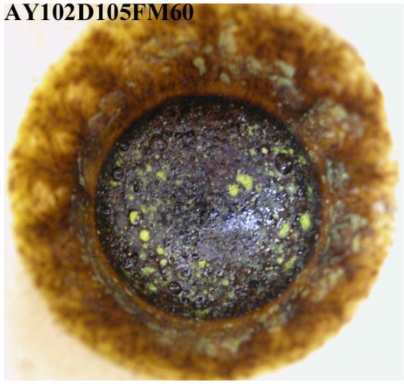
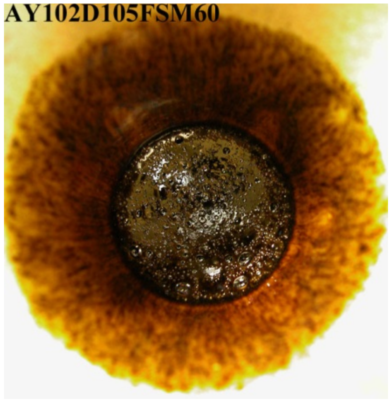
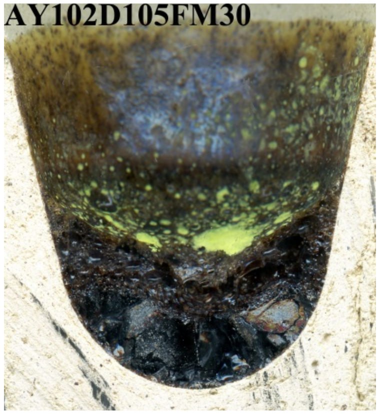
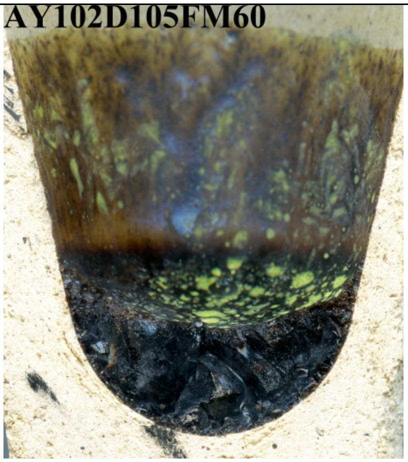
30 minutes		**60 minutes**	
AY102D105F(17g glass yield), No SUGAR	**AY102D105FS(17g glass yield), With SUGAR**	**AY102D105F(17g glass yield), No SUGAR**	**AY102D105FS(17g glass yield), With SUGAR**
 **AY102D105FM30-Top View**	 **AY102D105FSM30-Top View**	 **AY102D105FM60-Top View**	 **AY102D105FSM60-Top View**
 **AY102D105FM30-Crosss Section**	 **AY102D105FSM30-Cross Section**	 **AY102D105FM60-Cross Section**	 **AY102D105FSM60-Cross Section**

Figure 2.3. Images of feed samples of AY102D1-05 after vertical gradient furnace tests.

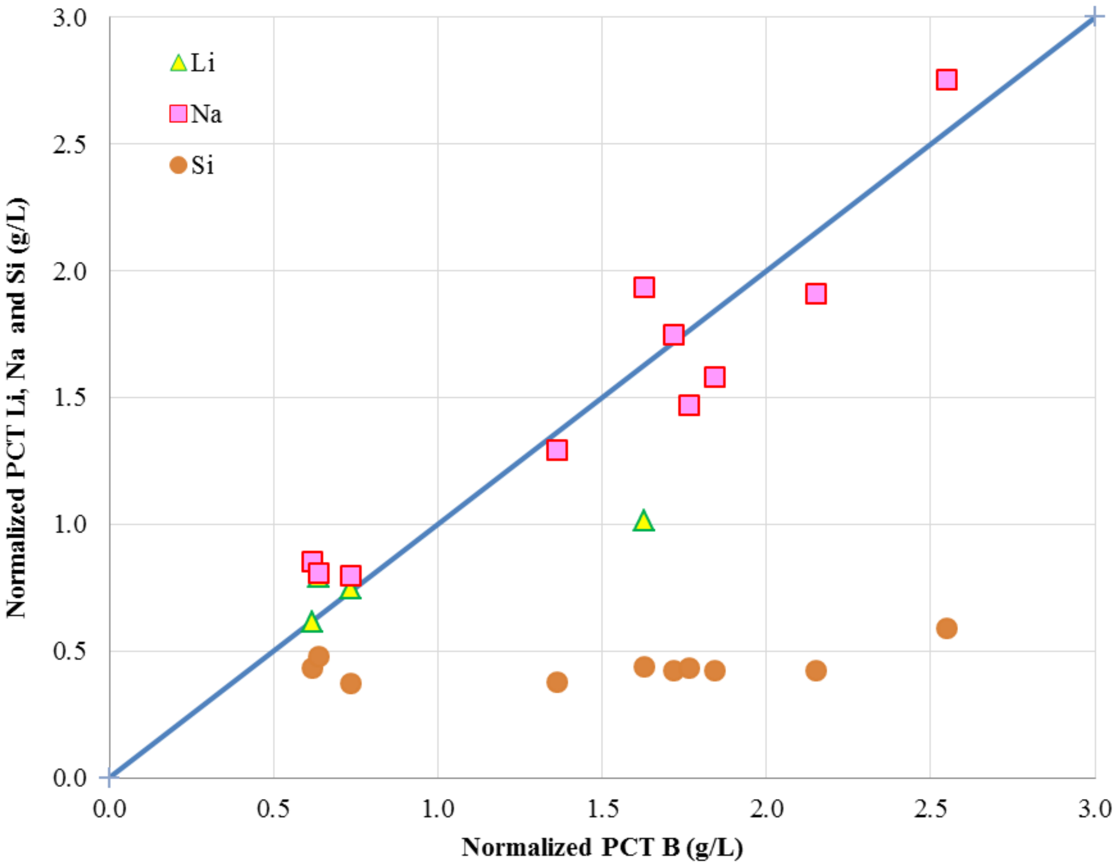


Figure 2.4. Normalized PCT sodium, lithium, and silicon releases (g/m^2) as a function of normalized PCT boron release for ten AY-102 direct feed glasses with PCT data. Na and B leach nearly congruently in all glasses; Li is congruent with B at lower leaching.

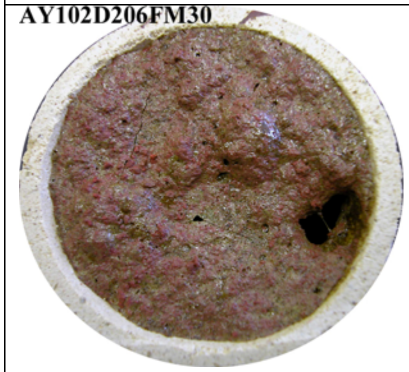
30 minutes		**60 minutes**	
AY102D206F(17g glass yield), No SUGAR	**AY102D206FS(17g glass yield), With SUGAR**	**AY102D206F(17g glass yield), No SUGAR**	**AY102D206FS(17g glass yield), With SUGAR**
 **AY102D206FM30-Top View**	 **AY102D206FSM30-Top View**	 **AY102D206FM60-Top View**	 **AY102D206FSM60-Top View**
 **AY102D206FM30-Cross Section**	 **AY102D206FSM30-Cross Section**	 **AY102D206FM60-Cross Section**	 **AY102D206FSM60-Cross Section**

Figure 2.5. Images of feed samples of AY102D2-06 after vertical gradient furnace tests.

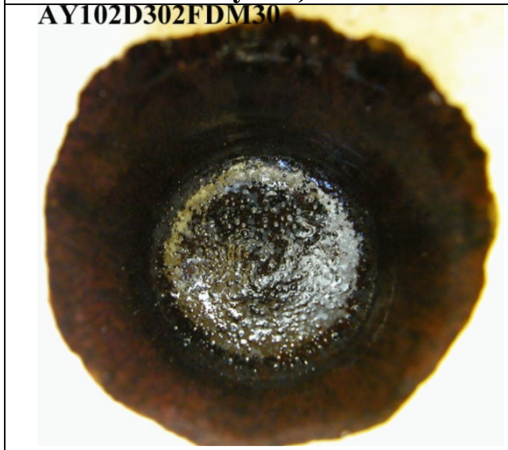
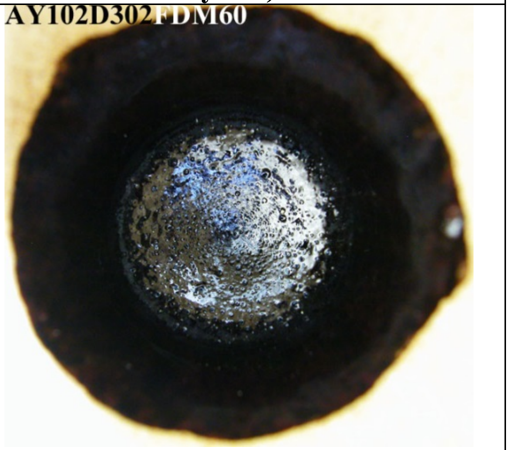
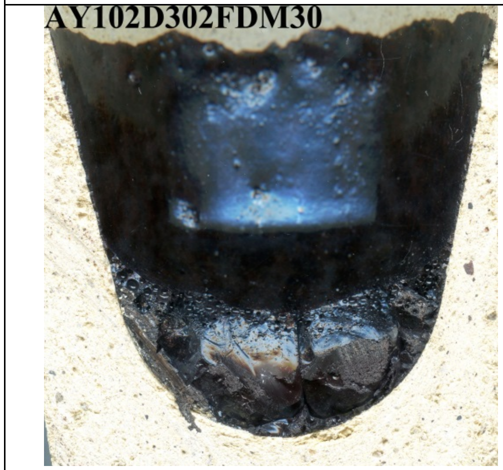
30 minutes	**60 minutes**
AY102D3-02FDM30 (17g glass yield)	**AY102D3-02FDM60 (17g glass yield)**
 **Top View**	 **Top View**
 **Cross Section**	 **Cross Section**

Figure 2.6. Images of feed sample of AY102D3-02 after vertical gradient furnace tests.

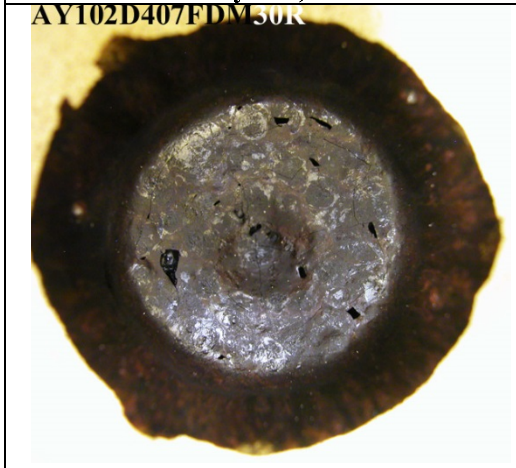
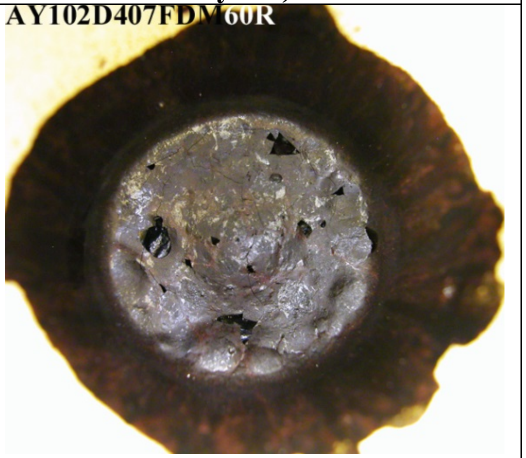
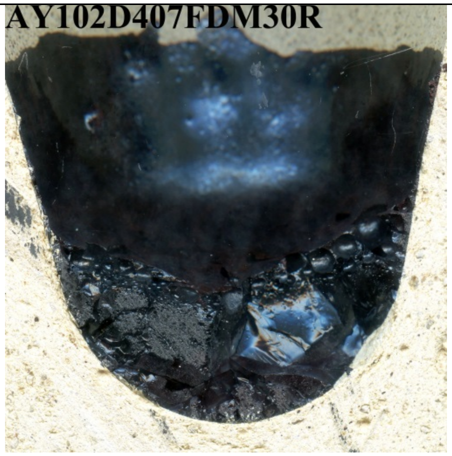
30 minutes	**60 minutes**
AY102D4-07FDM30R (17g glass yield)	**AY102D3-02FDM60R (17g glass yield)**
 **Top View**	 **Top View**
 **Cross Section**	 **Cross Section**

Figure 2.7. Images of feed sample of AY102D4-07 after vertical gradient furnace tests.

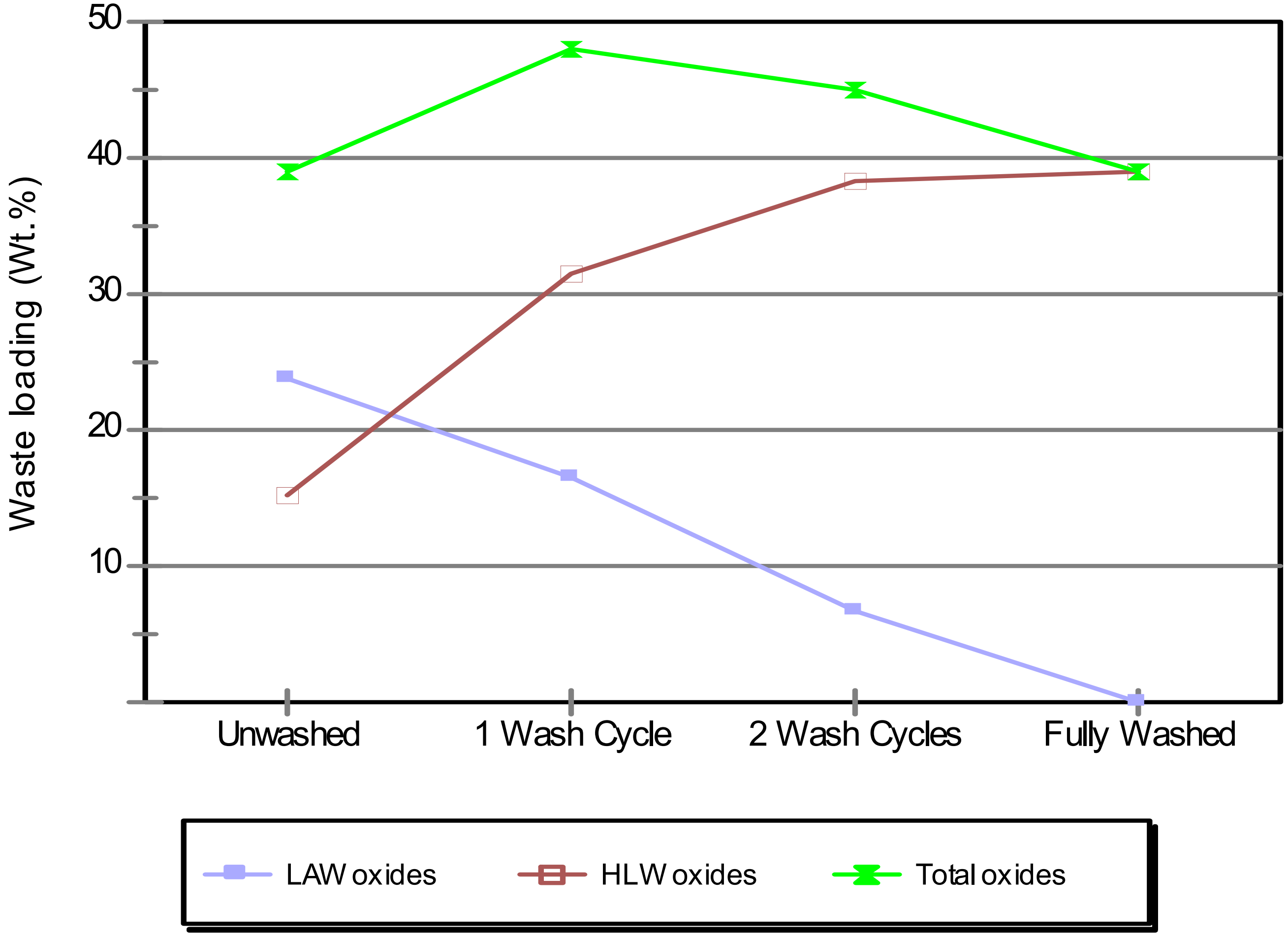


Figure 2.8. Waste loading for glasses formulated with AY-102 un-dissolved and dissolved solids.

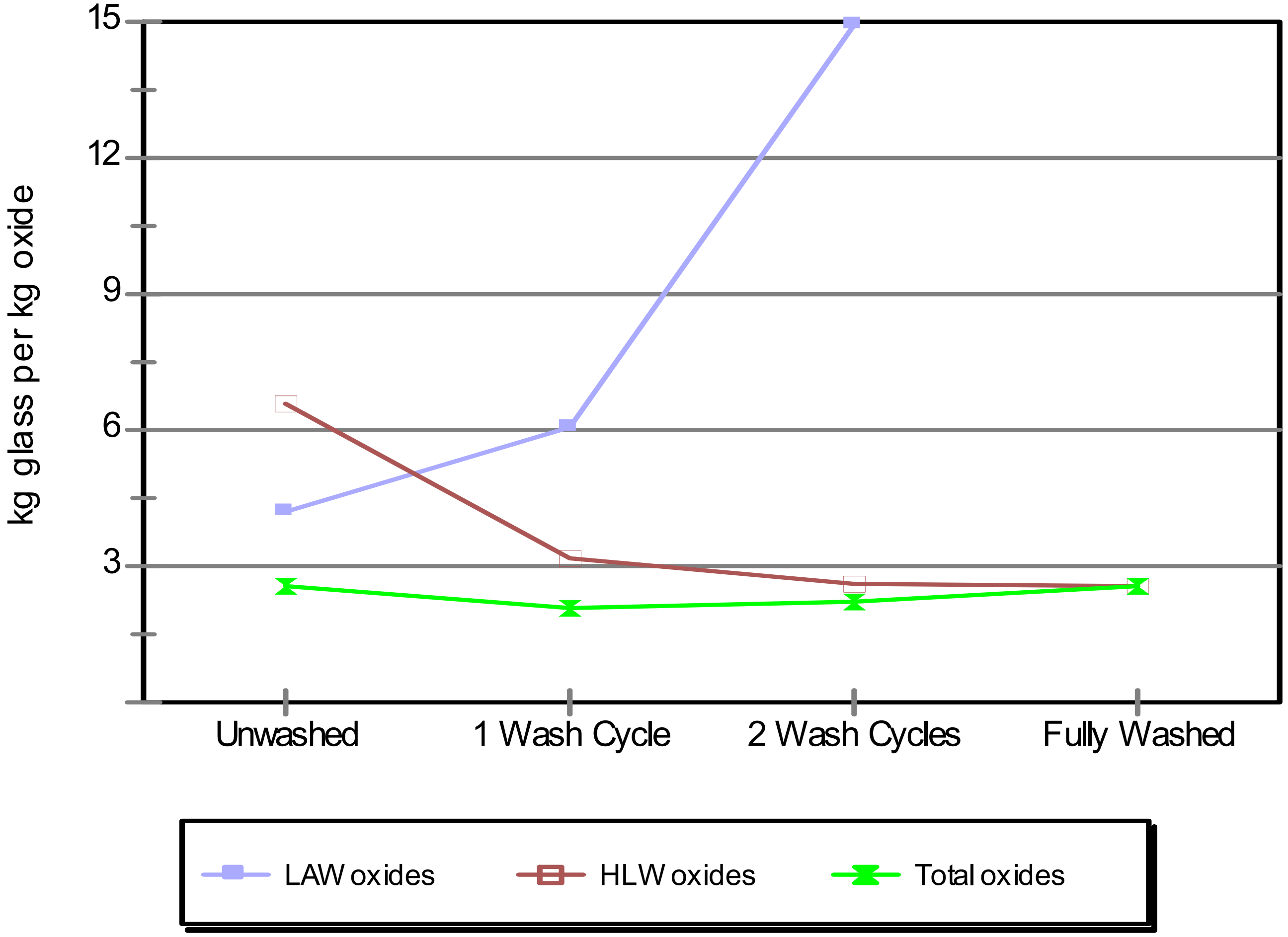


Figure 2.9. Amounts of glass produced for glasses formulated with AY-102 un-dissolved and dissolved solids.

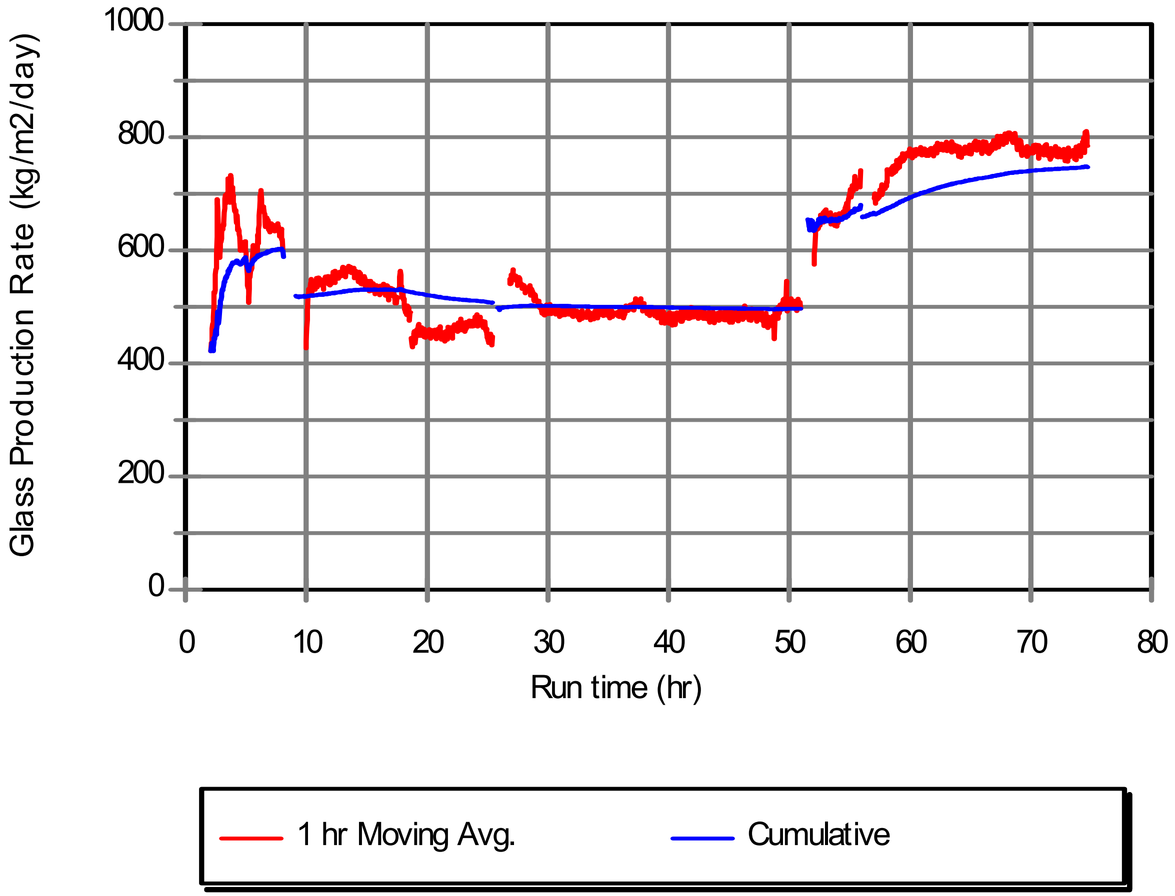


Figure 3.1.a. Glass production rates (hourly moving averages and cumulative) for DM100 Test 5 with high water, Blend 4 waste and optimized AY102D4-07 glass composition at 9 lpm and optimized bubbling.

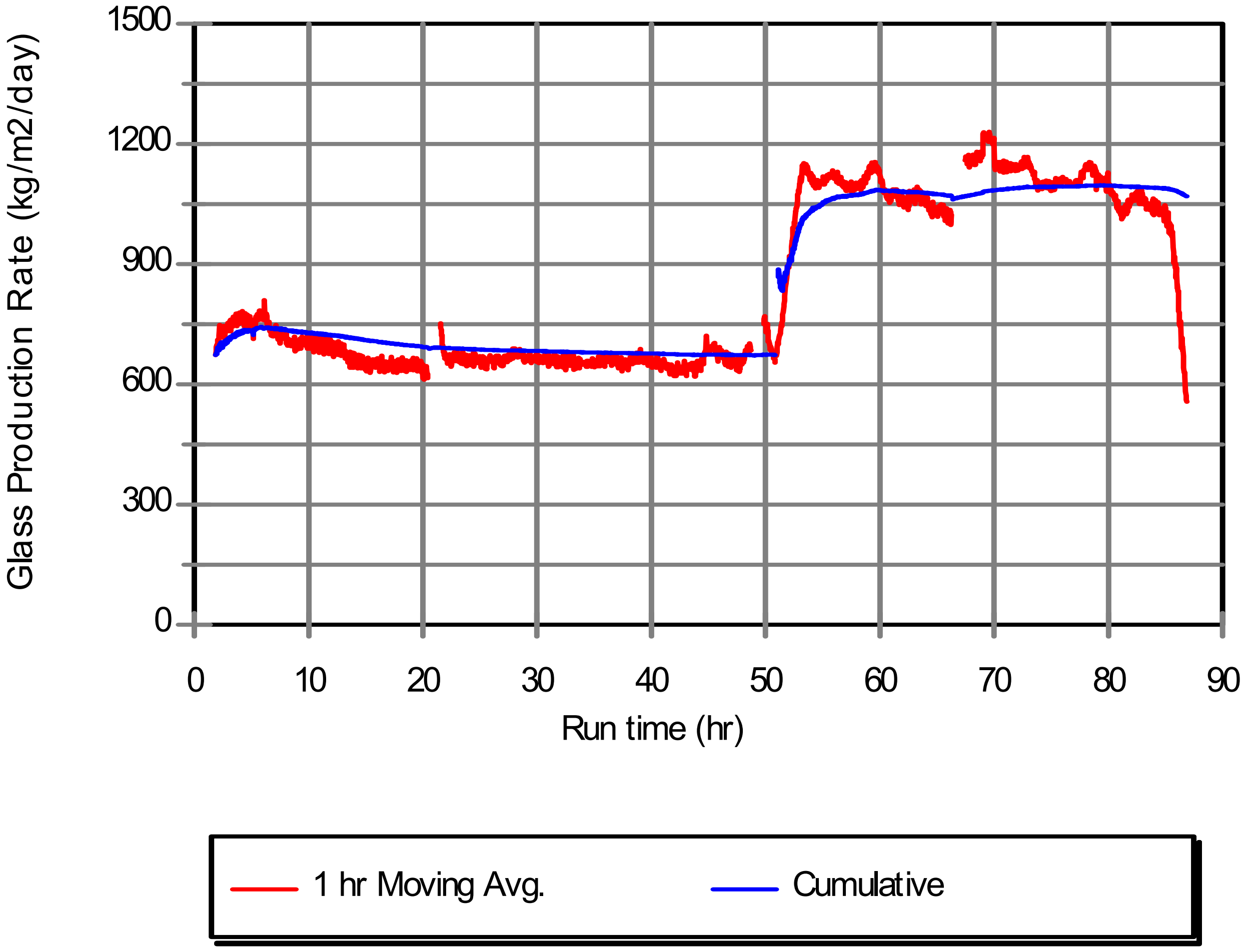


Figure 3.1.b. Glass production rates (hourly moving averages and cumulative) for DM100 Test 4 with Blend 4 waste and optimized AY102D4-07 glass composition at 9 lpm and optimized bubbling.

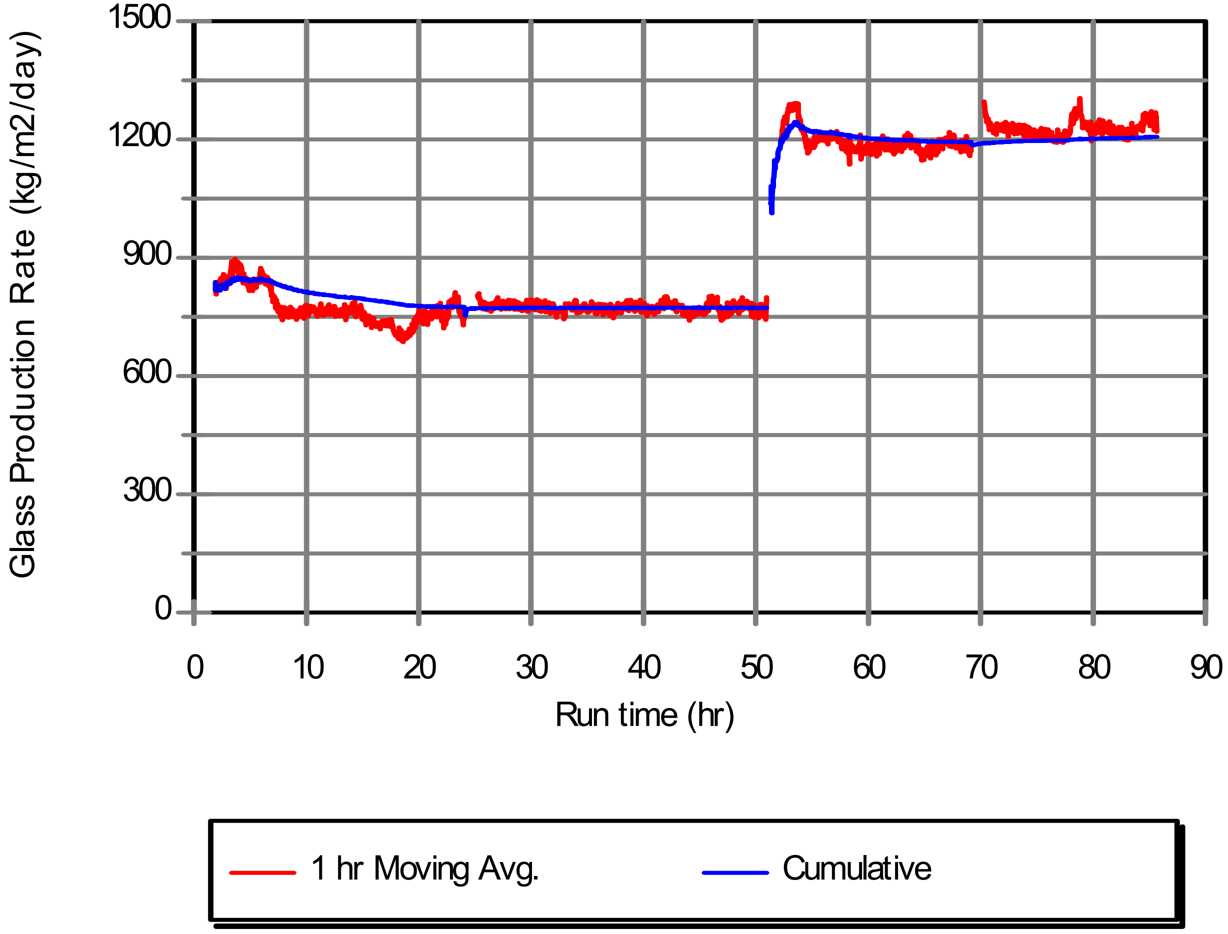


Figure 3.1.c. Glass production rates (hourly moving averages and cumulative) for DM100 Test 3 with Blend 3 waste and optimized AY102D3-02 glass composition at 9 lpm and optimized bubbling.

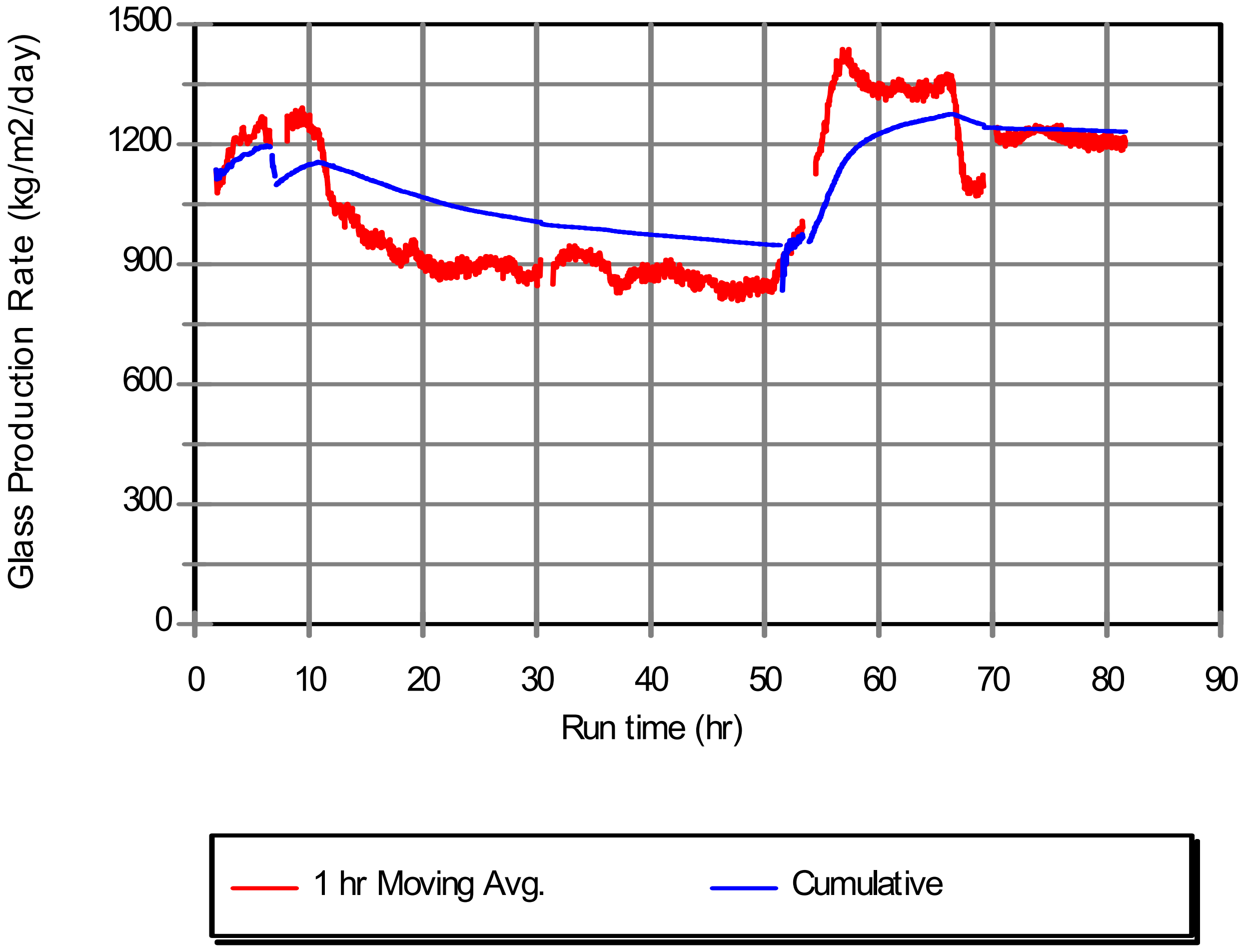


Figure 3.1.d. Glass production rates (hourly moving averages and cumulative) for DM100 Test 2 with Blend 2 waste and optimized AY102D2-06 glass composition at 9 lpm and optimized bubbling.

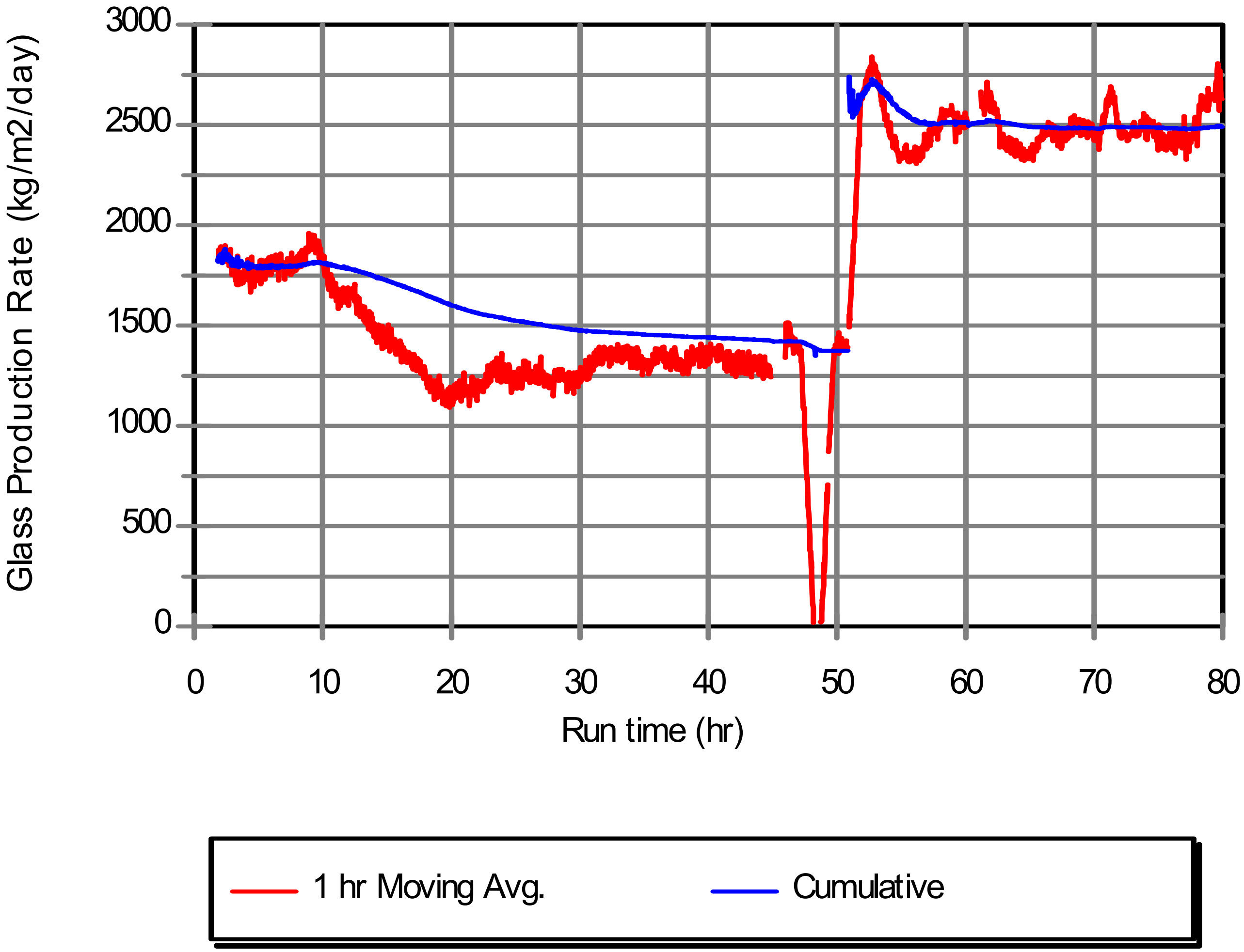


Figure 3.1.e. Glass production rates (hourly moving averages and cumulative) for DM100 Test 1 with Blend 1 waste and optimized AY102D1-05 glass composition at 9 lpm and optimized bubbling.

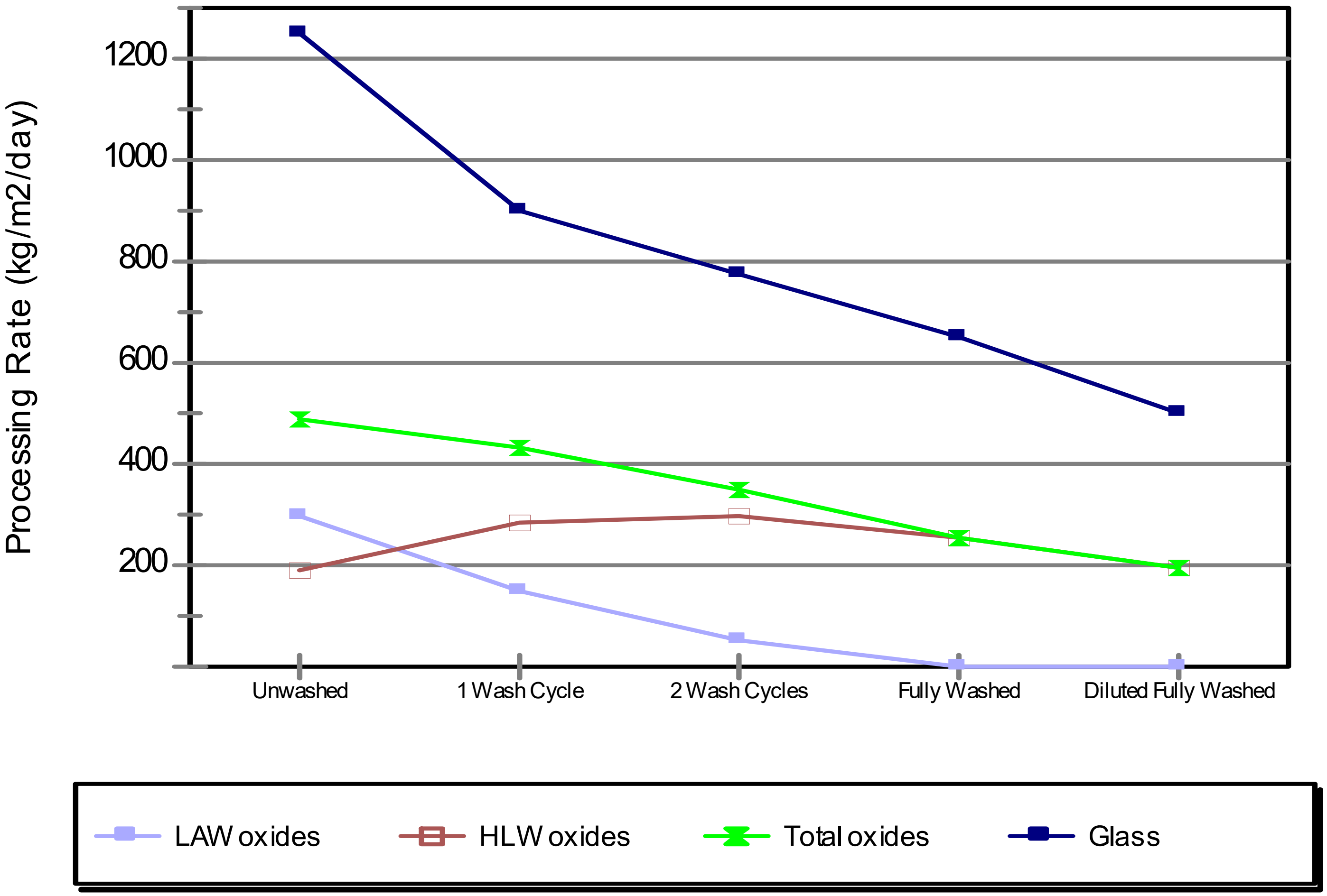


Figure 3.1.f. Glass and AY-102 waste oxide processing rates for DM100 tests conducted with 9 lpm bubbling.

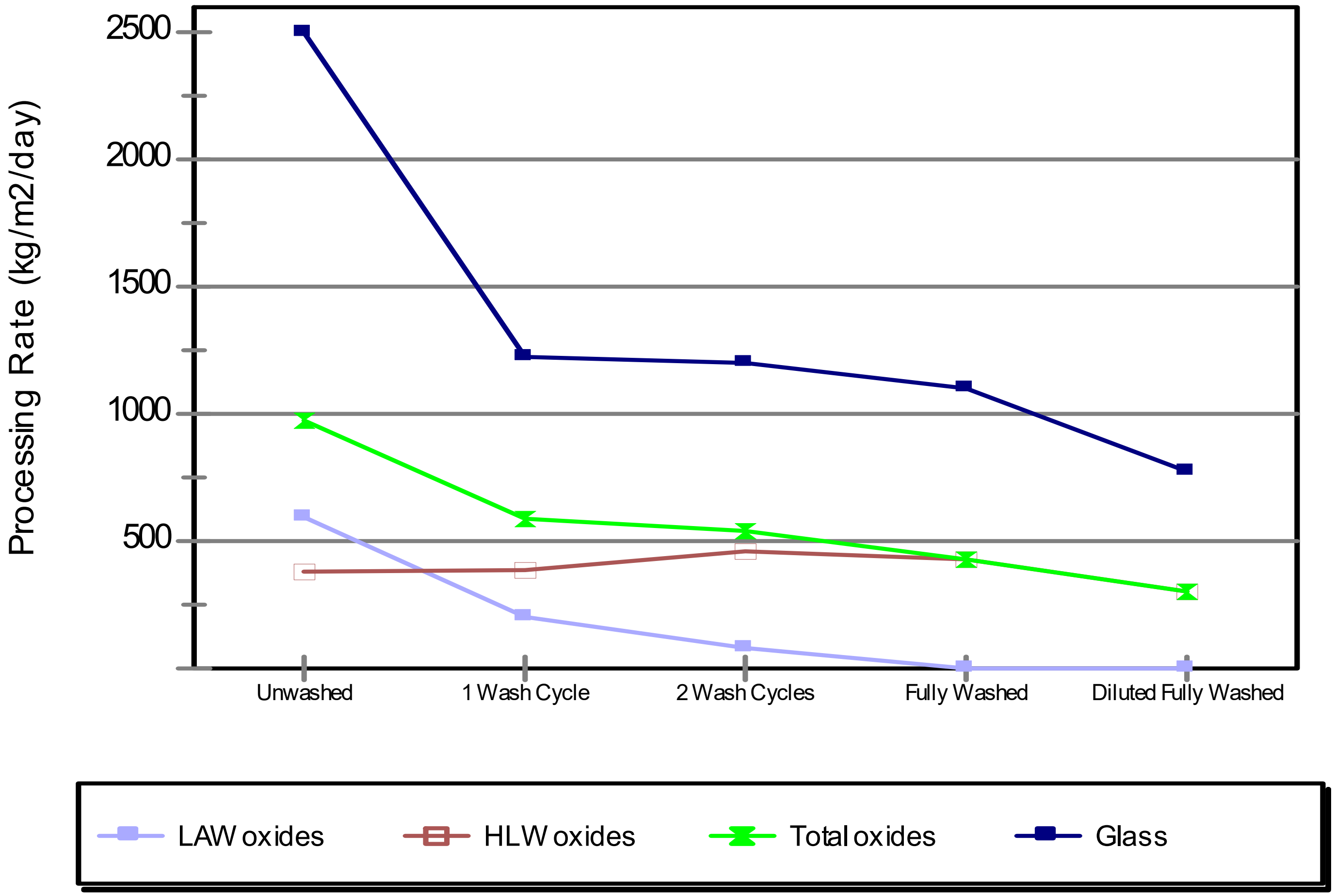


Figure 3.1.g. Glass and AY-102 waste oxide processing rates for DM100 tests conducted with optimized bubbling.

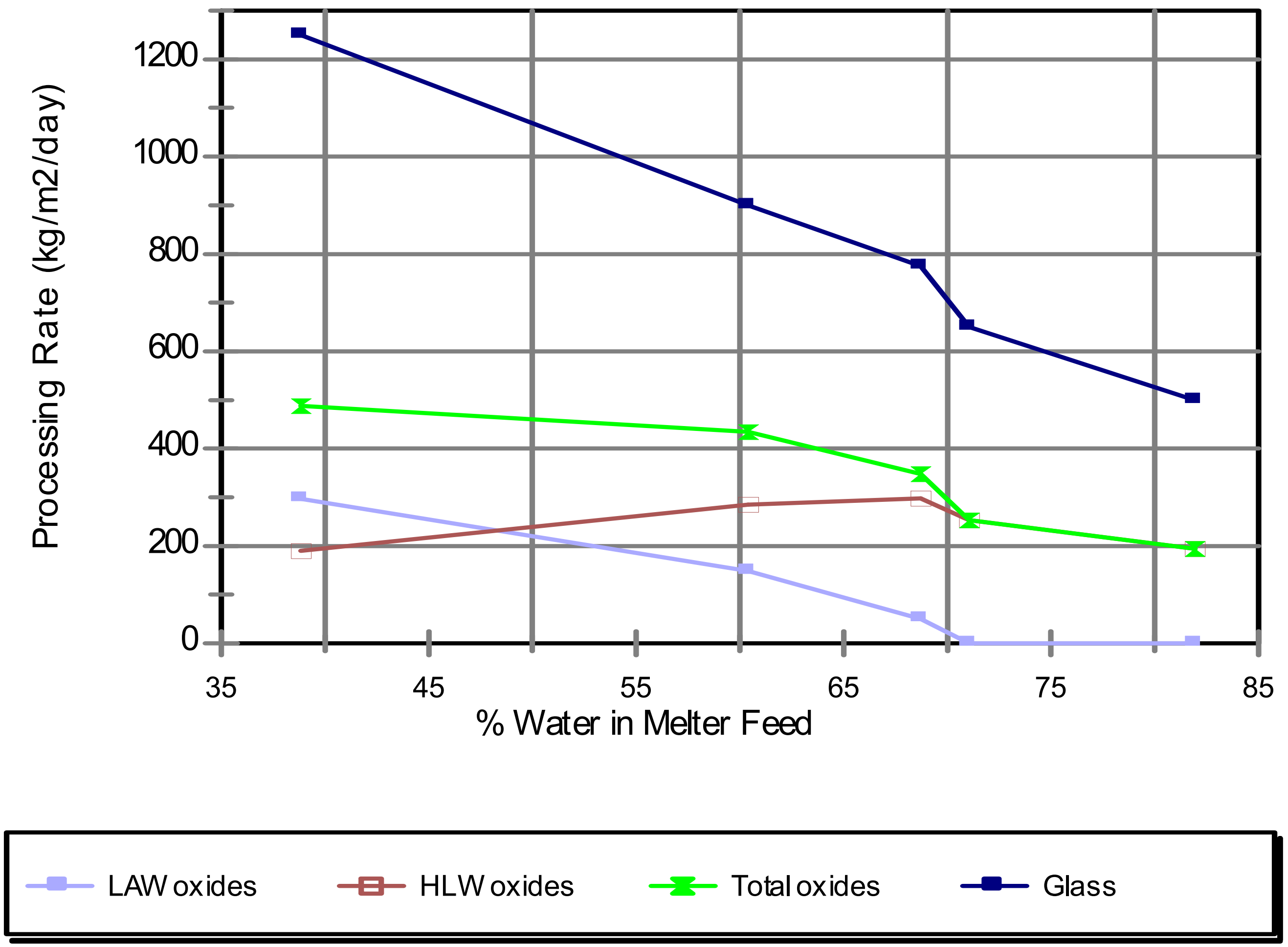


Figure 3.1.h. Glass and AY-102 waste oxide processing rates versus melter feed water content for DM100 tests conducted with 9 lpm bubbling.

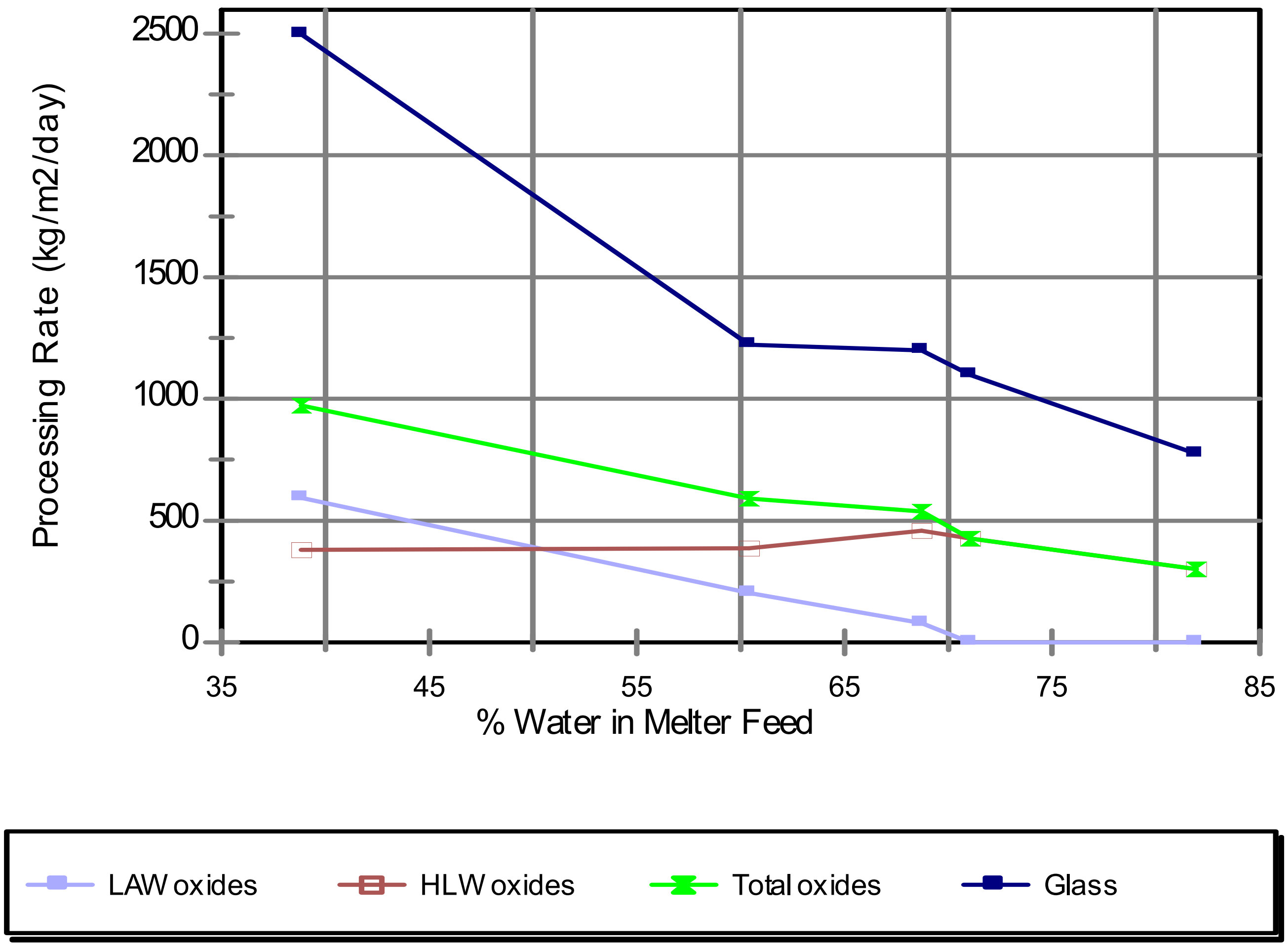


Figure 3.1.i. Glass and AY-102 waste oxide processing rates versus melter feed water content for DM100 tests conducted with optimized bubbling.

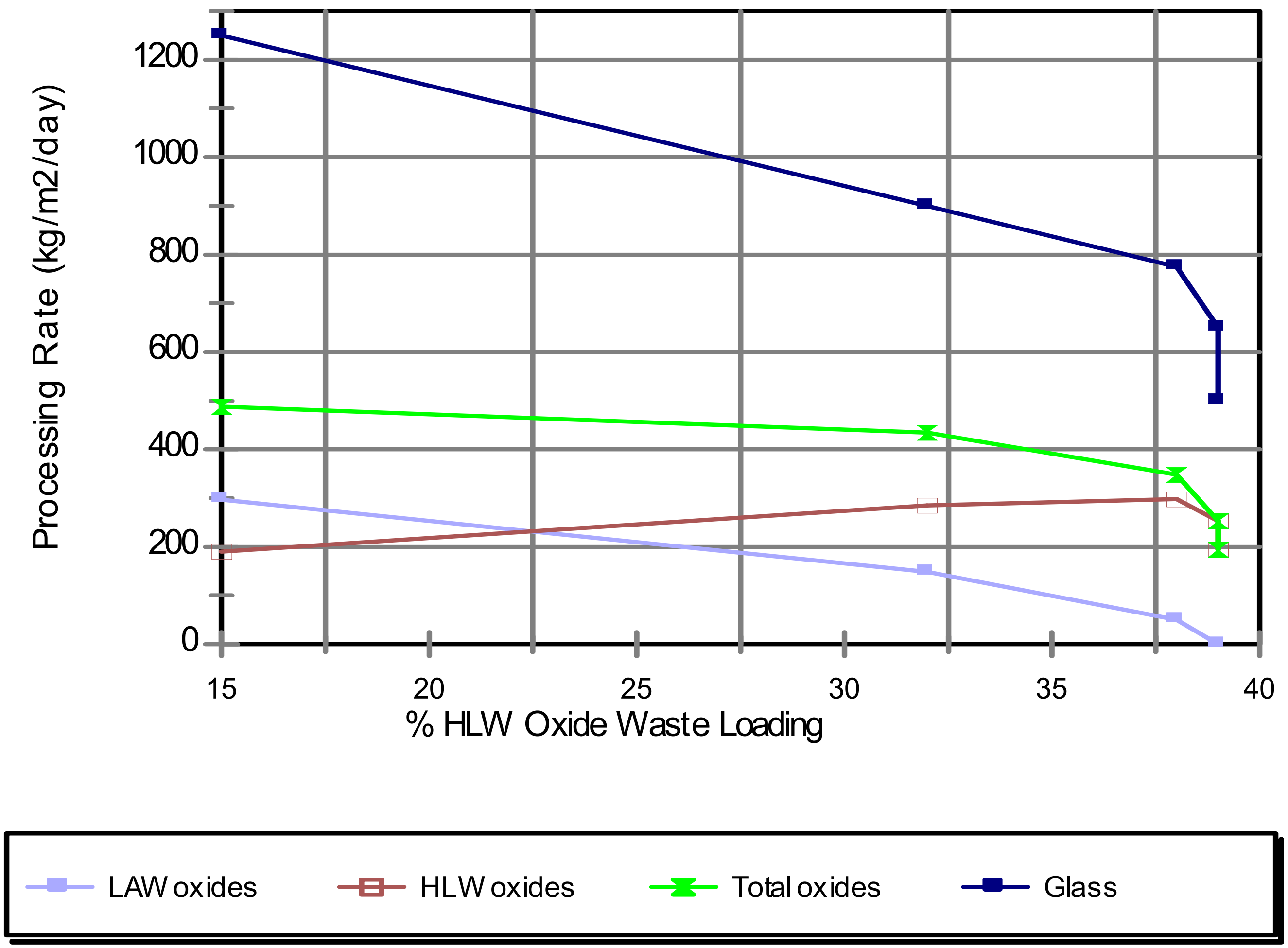


Figure 3.1.j. Glass and AY-102 waste oxide processing rates versus HLW oxide waste loading for DM100 tests conducted with 9 lpm bubbling.

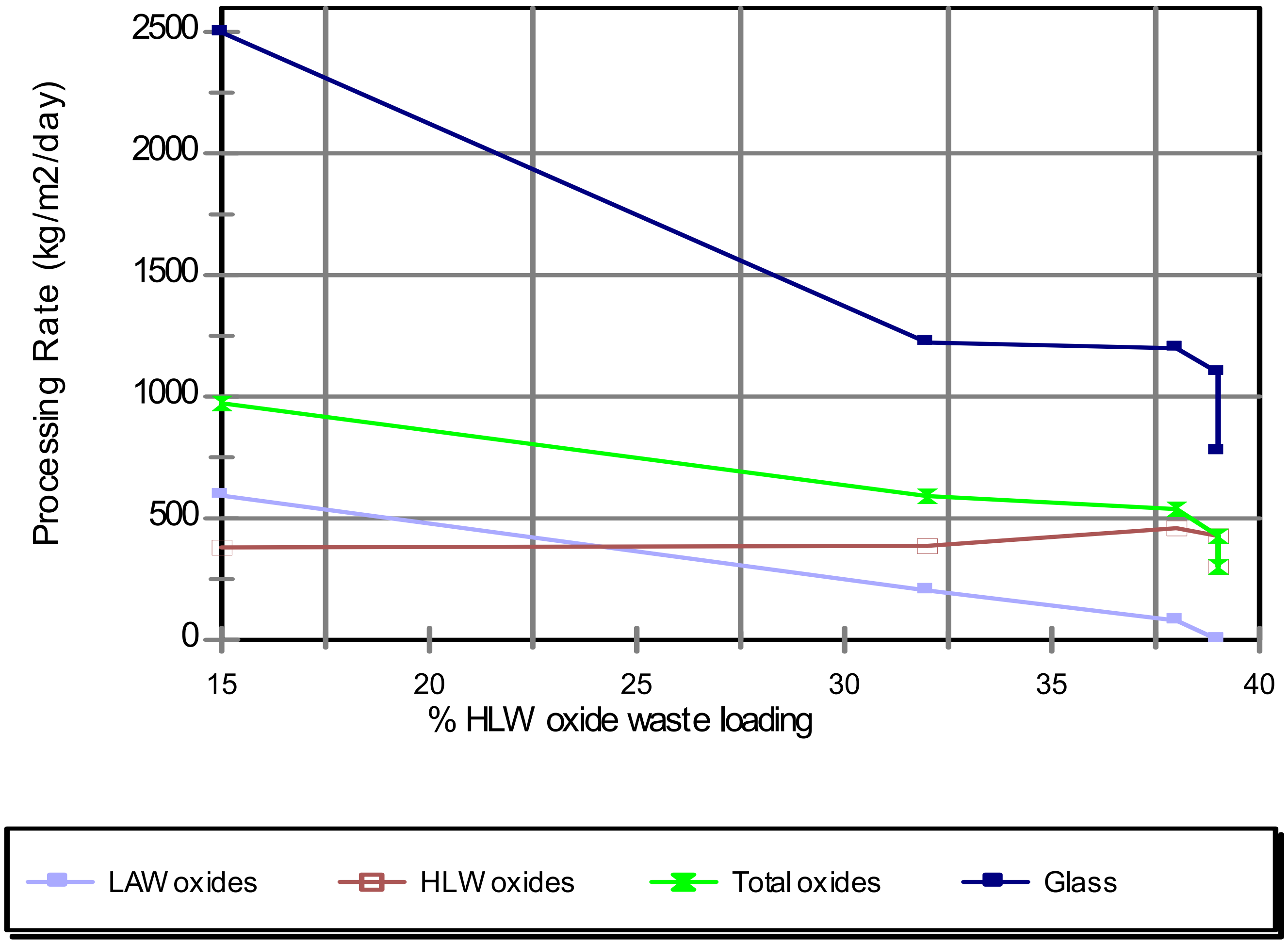


Figure 3.1.k. Glass and AY-102 waste oxide processing rates versus HLW oxide waste loading for DM100 tests conducted with optimized bubbling.

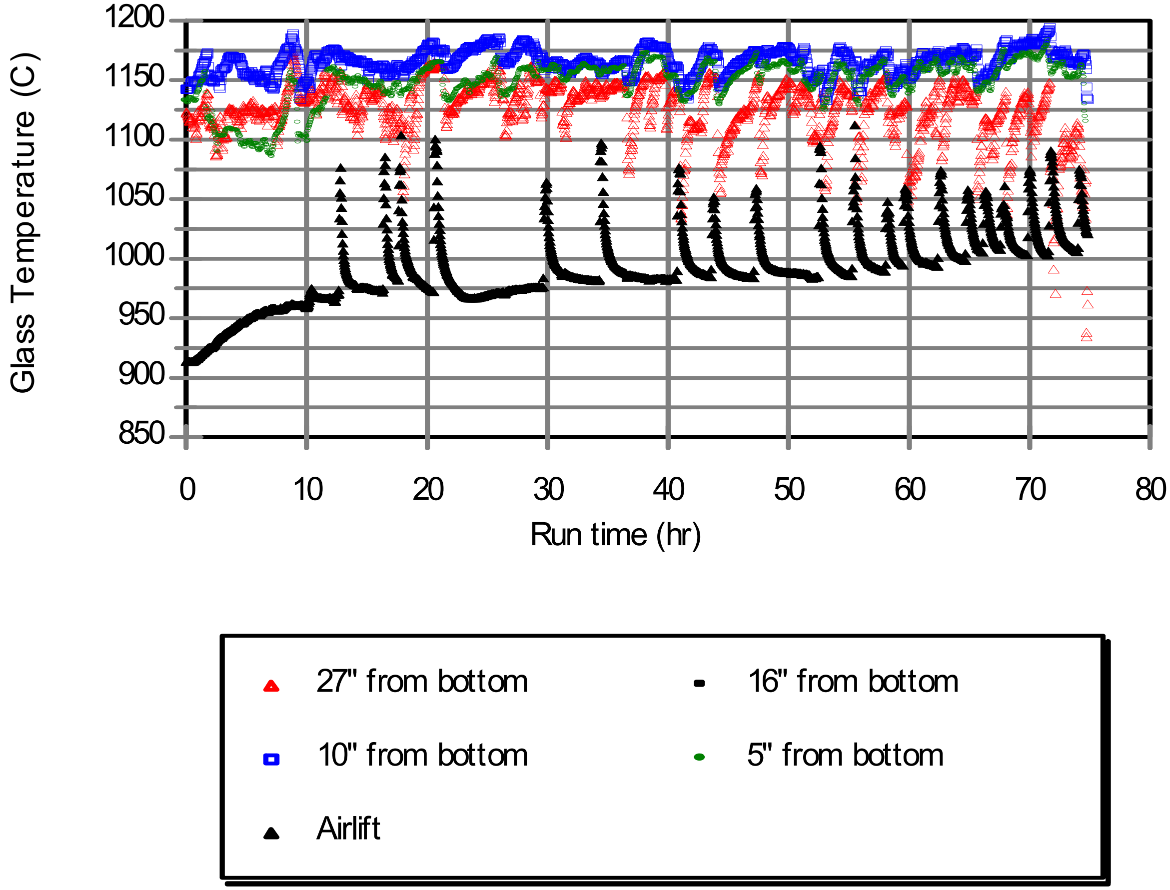


Figure 3.2.a. Glass temperatures during DM100 Test 5 with high water, Blend 4 waste and optimized AY102D4-07 glass composition at 9 lpm and optimized bubbling.

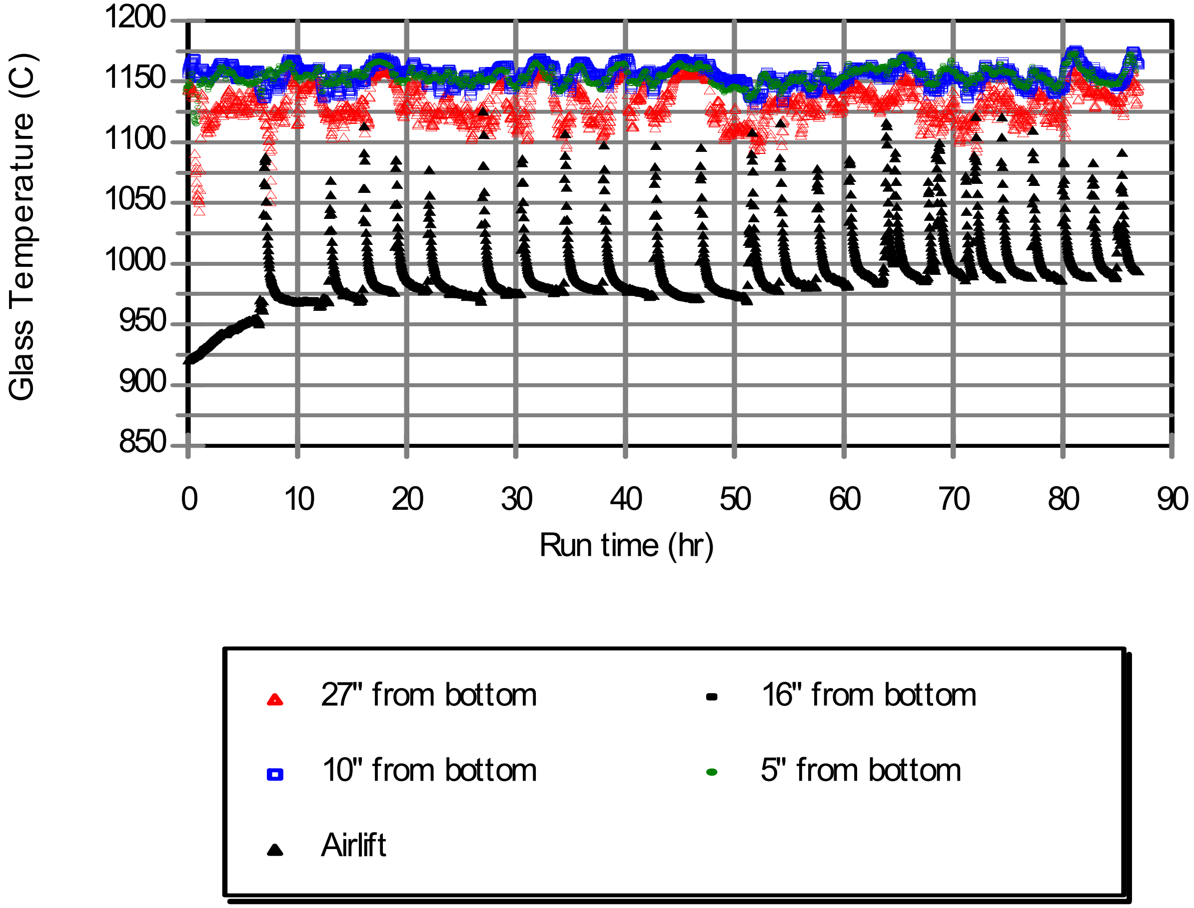


Figure 3.2.b. Glass temperatures during DM100 Test 4 with Blend 4 waste and optimized AY102D4-07 glass composition at 9 lpm and optimized bubbling.

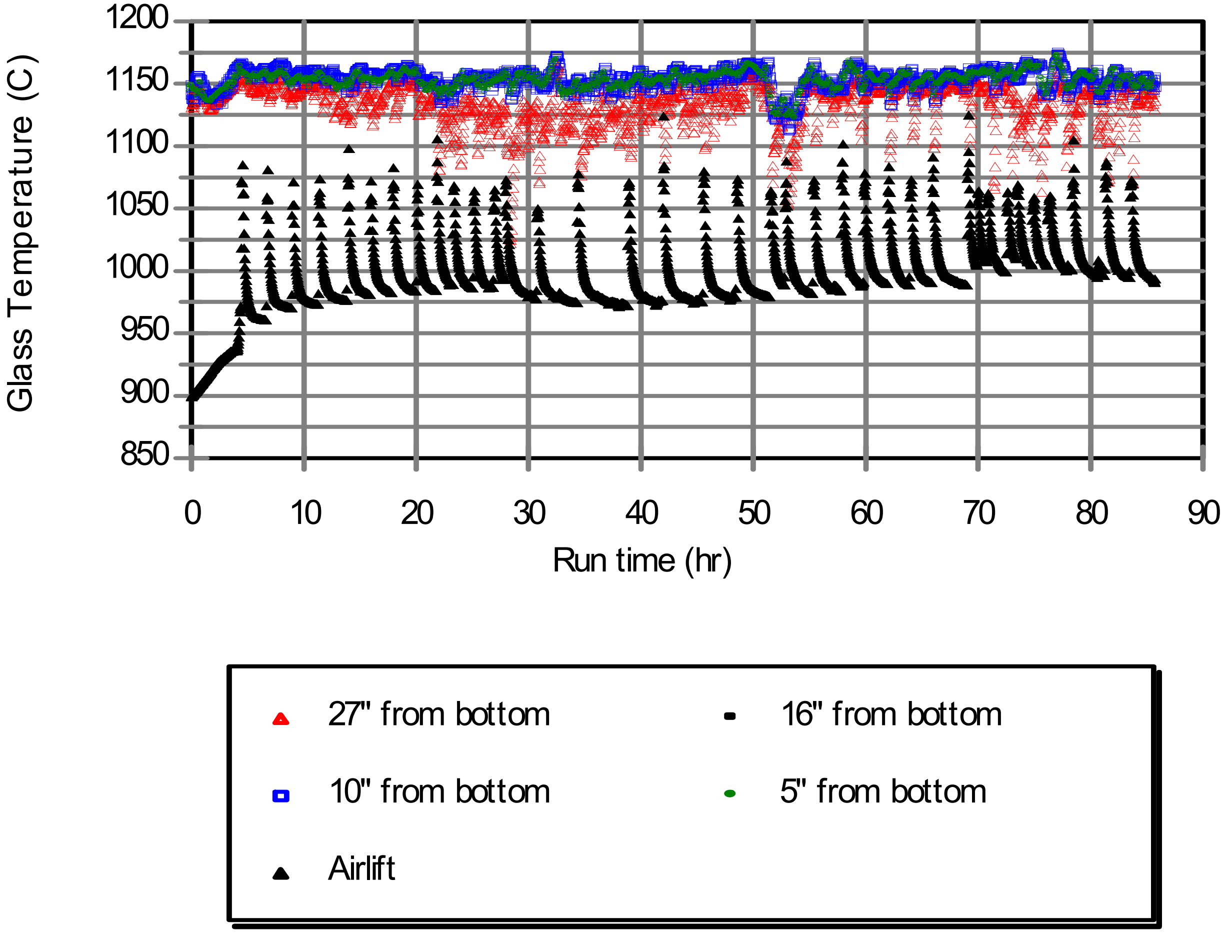


Figure 3.2.c. Glass temperatures during DM100 Test 3 with Blend 3 waste and optimized AY102D3-02 glass composition at 9 lpm and optimized bubbling.

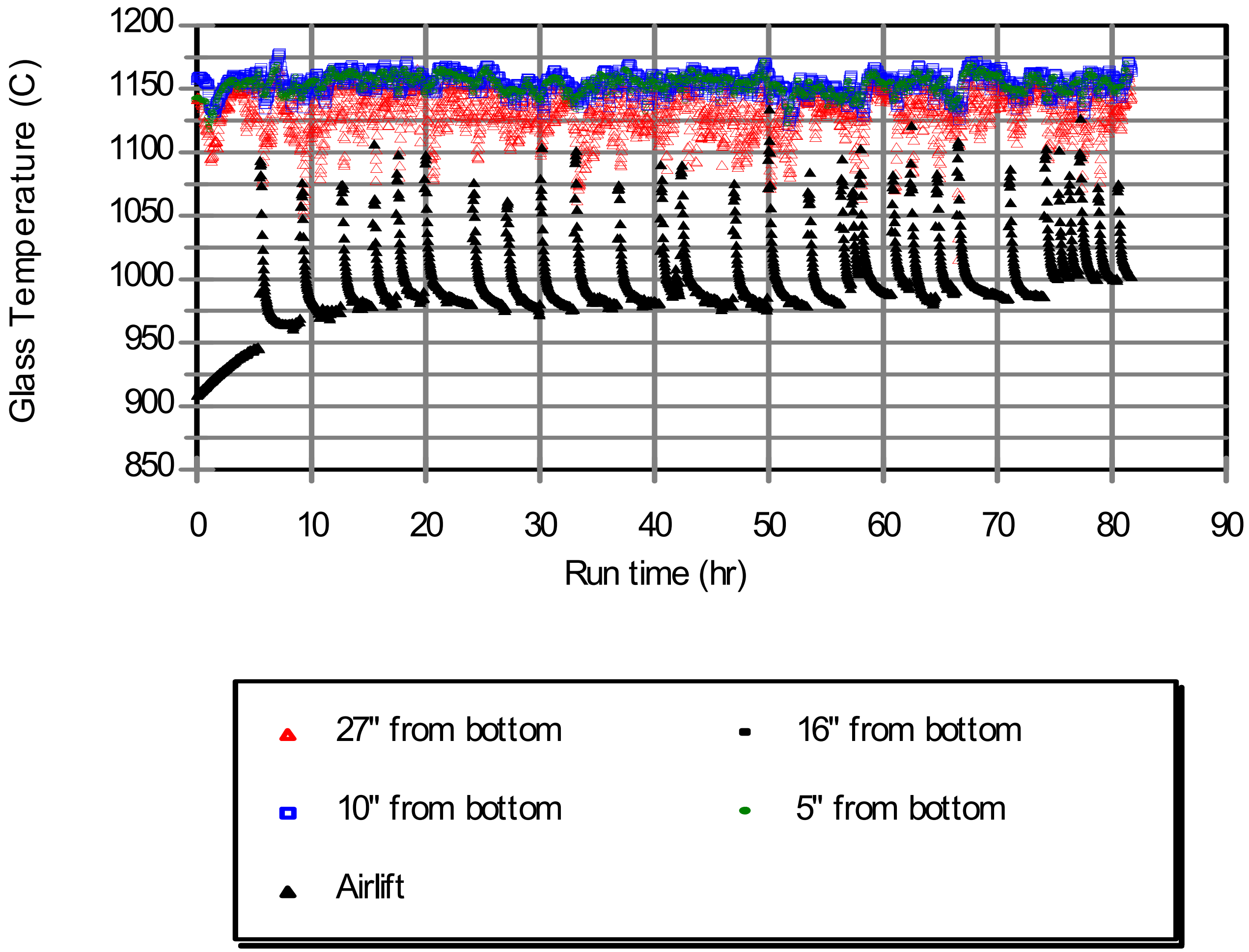


Figure 3.2.d. Glass temperatures during DM100 Test 2 with Blend 2 waste and optimized AY102D2-06 glass composition at 9 lpm and optimized bubbling.

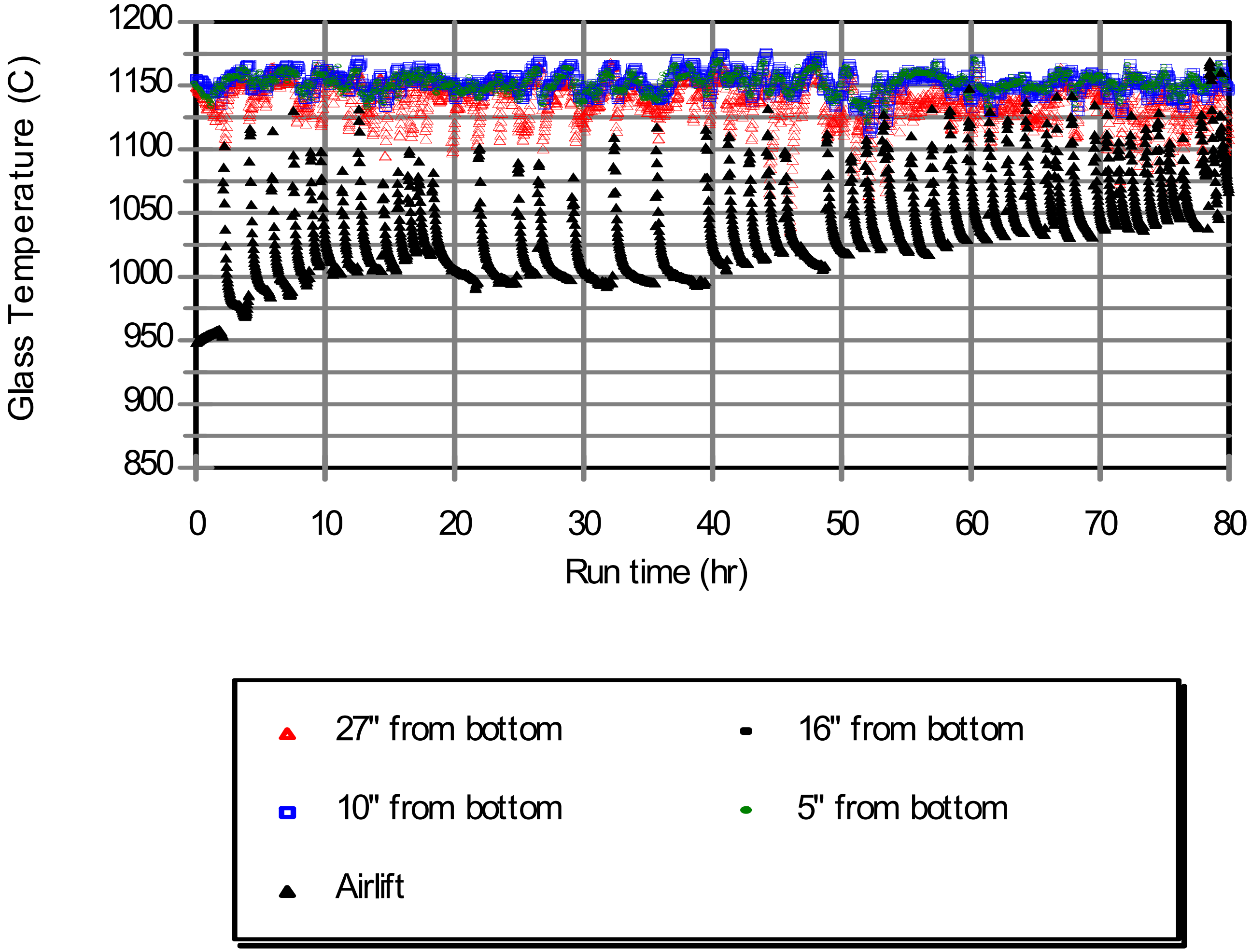


Figure 3.2.e. Glass temperatures during DM100 Test 1 with Blend 1 waste and optimized AY102D1-05 glass composition at 9 lpm and optimized bubbling.

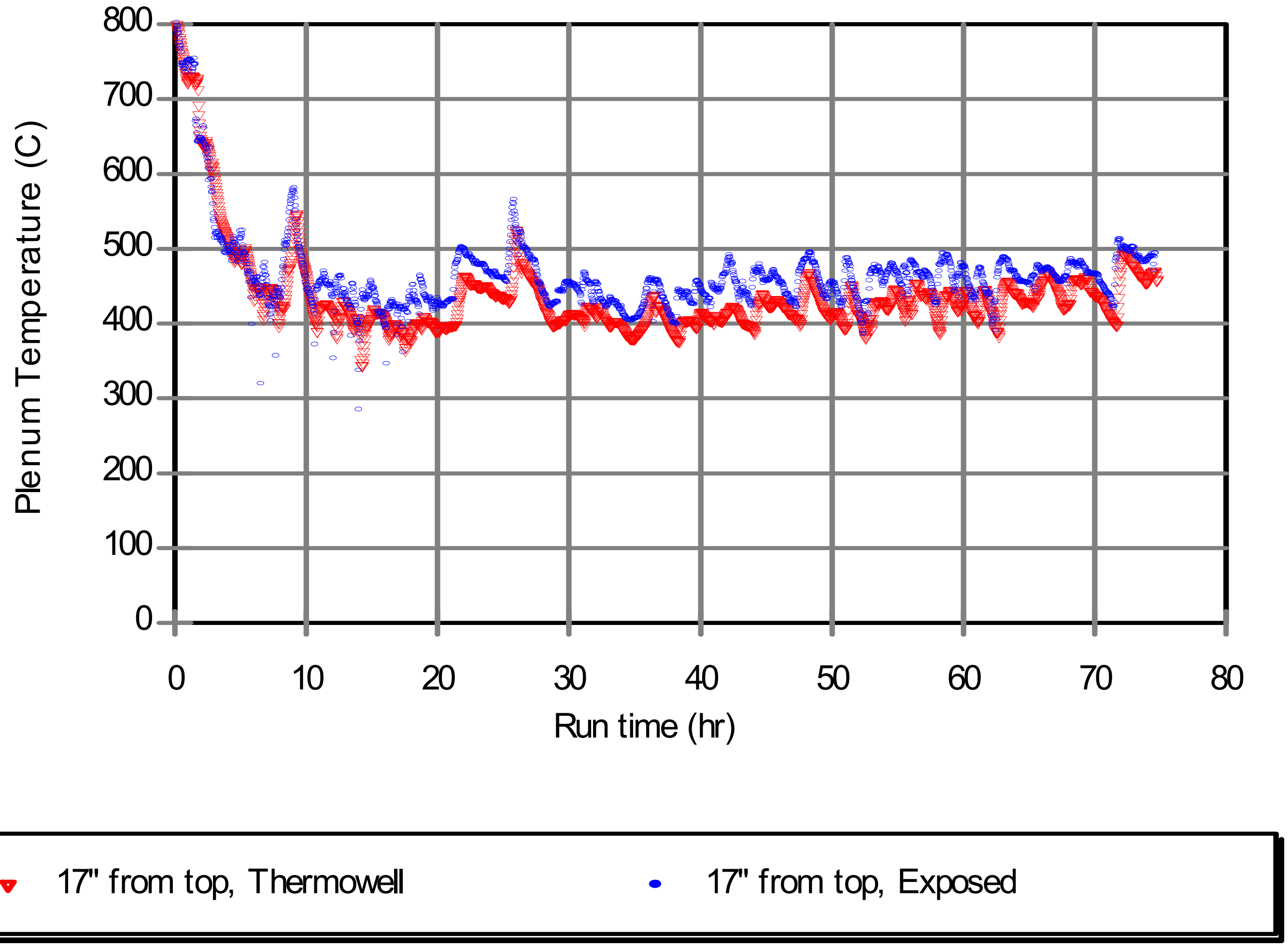


Figure 3.3.a. Plenum temperatures during DM100 Test 5 with high water, Blend 4 waste and optimized AY102D4-07 glass composition at 9 lpm and optimized bubbling.

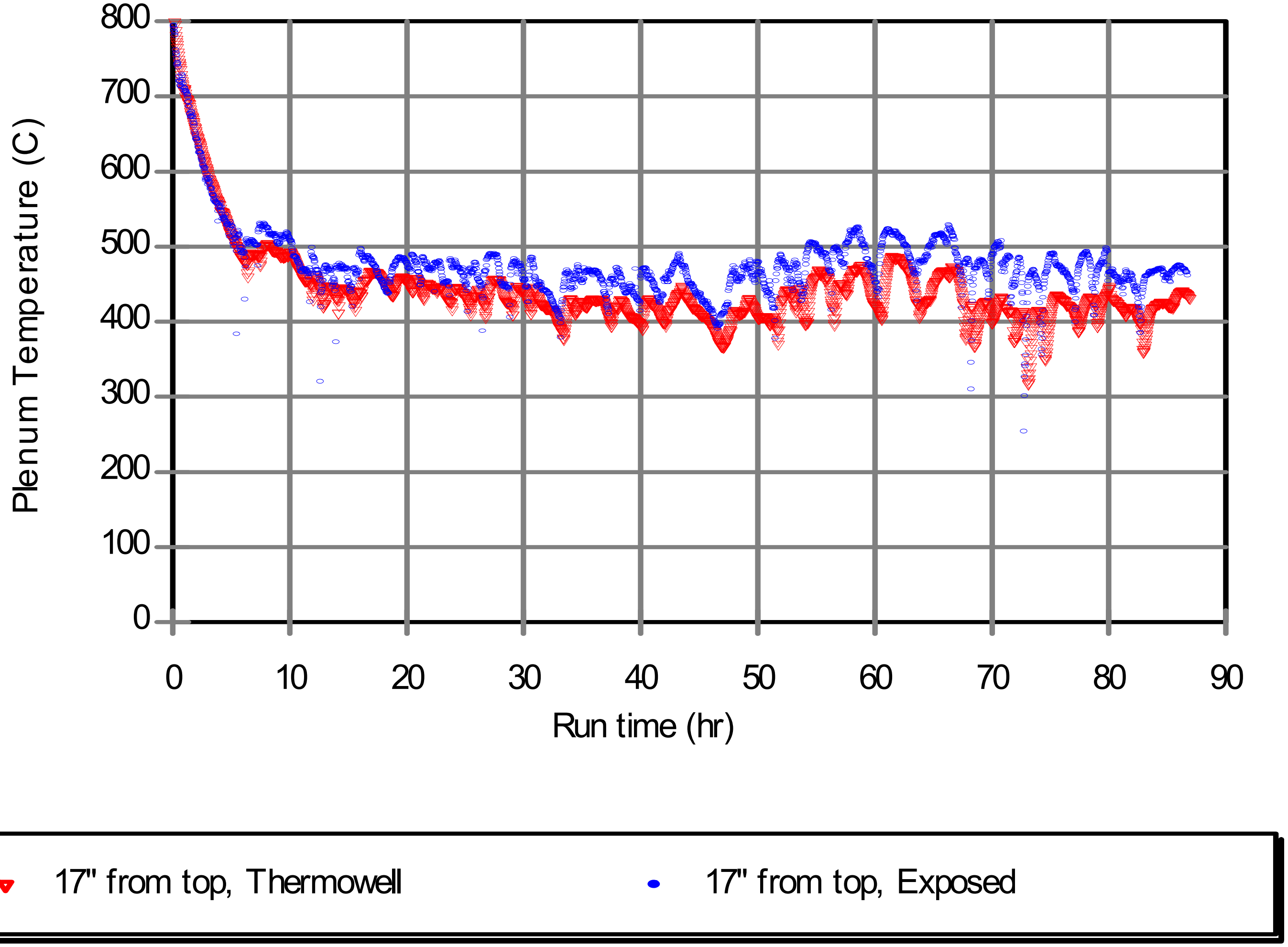


Figure 3.3.b. Plenum temperatures during DM100 Test 4 with Blend 4 waste and optimized AY102D4-07 glass composition at 9 lpm and optimized bubbling.

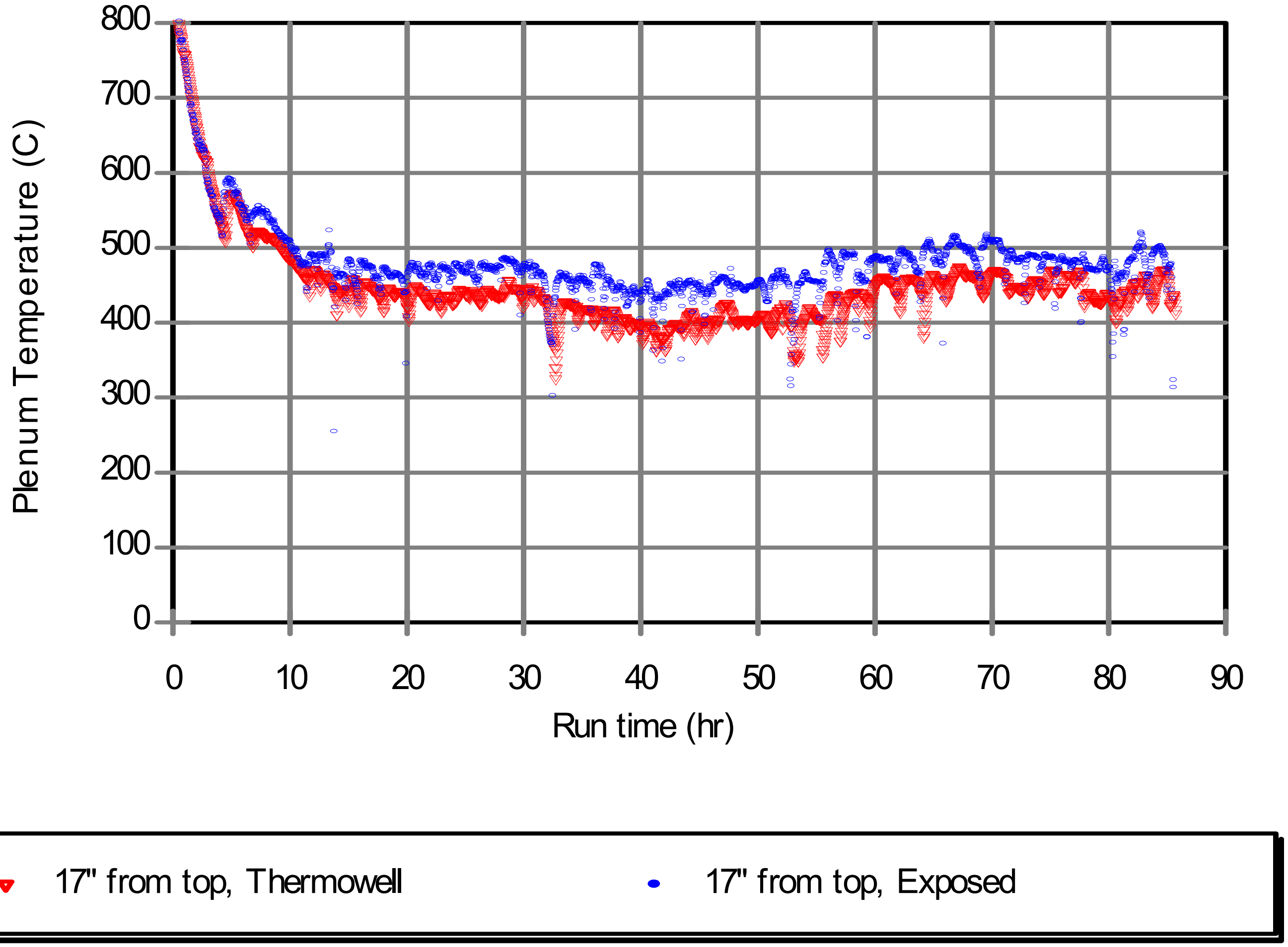


Figure 3.3.c. Plenum temperatures during DM100 Test 3 with Blend 3 waste and optimized AY102D3-02 glass composition at 9 lpm and optimized bubbling.

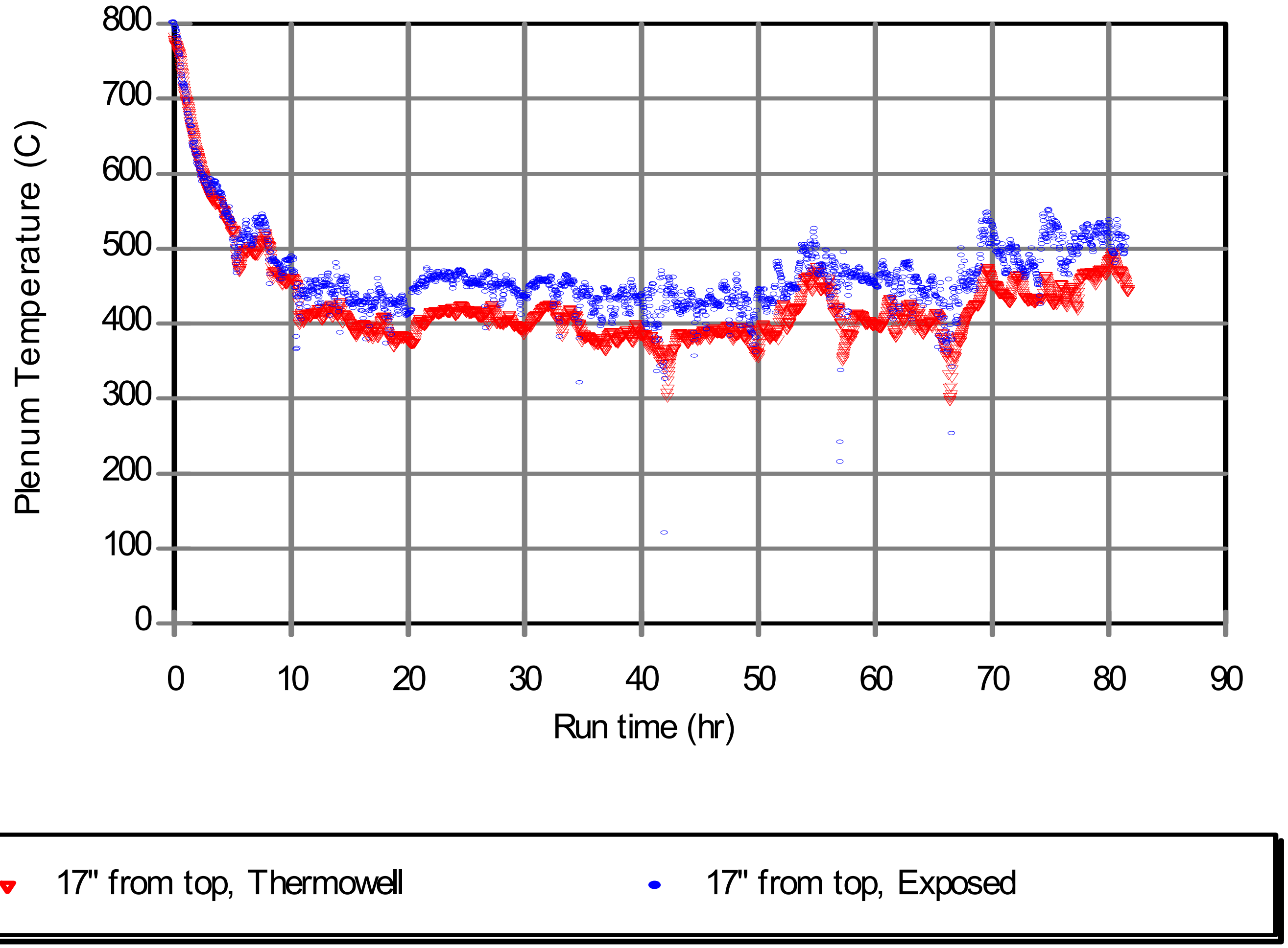


Figure 3.3.d. Plenum temperatures during DM100 Test 2 with Blend 2 waste and optimized AY102D2-06 glass composition at 9 lpm and optimized bubbling.

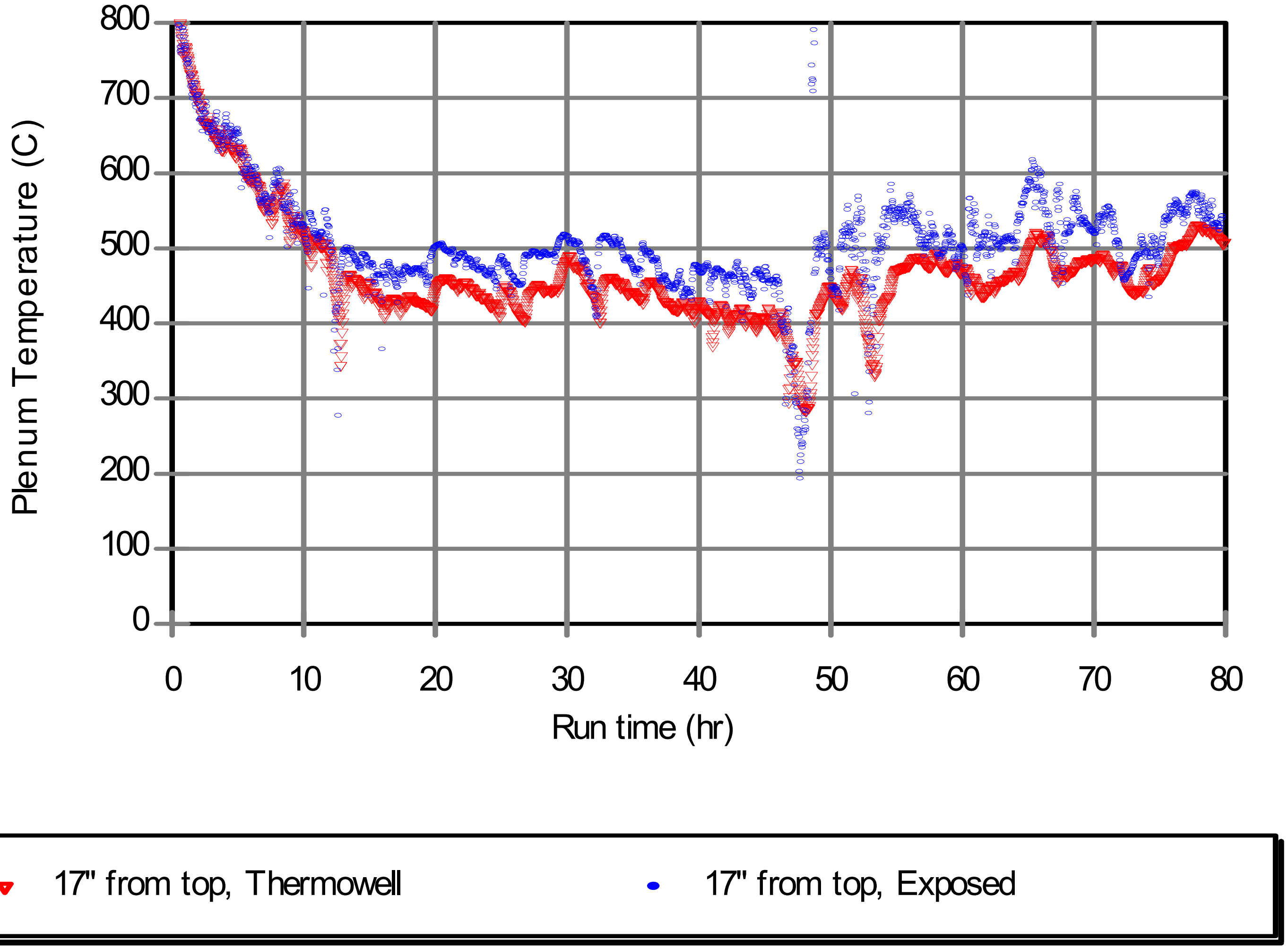


Figure 3.3.e. Plenum temperatures during DM100 Test 1 with Blend 1 waste and optimized AY102D1-05 glass composition at 9 lpm and optimized bubbling.

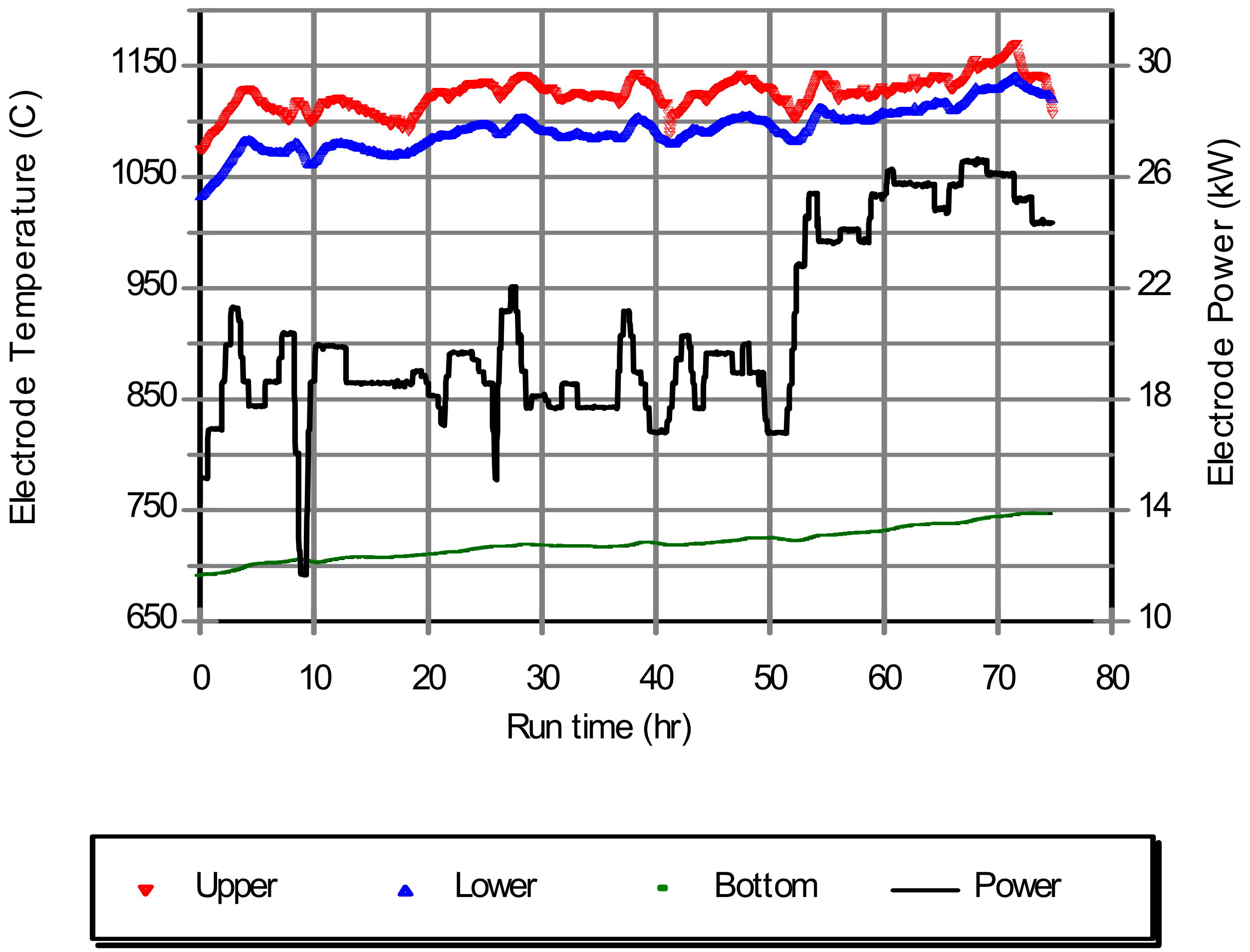


Figure 3.4.a. Electrode temperatures and power during DM100 Test 5 with high water, Blend 4 waste and optimized AY102D4-07 glass composition at 9 lpm and optimized bubbling.

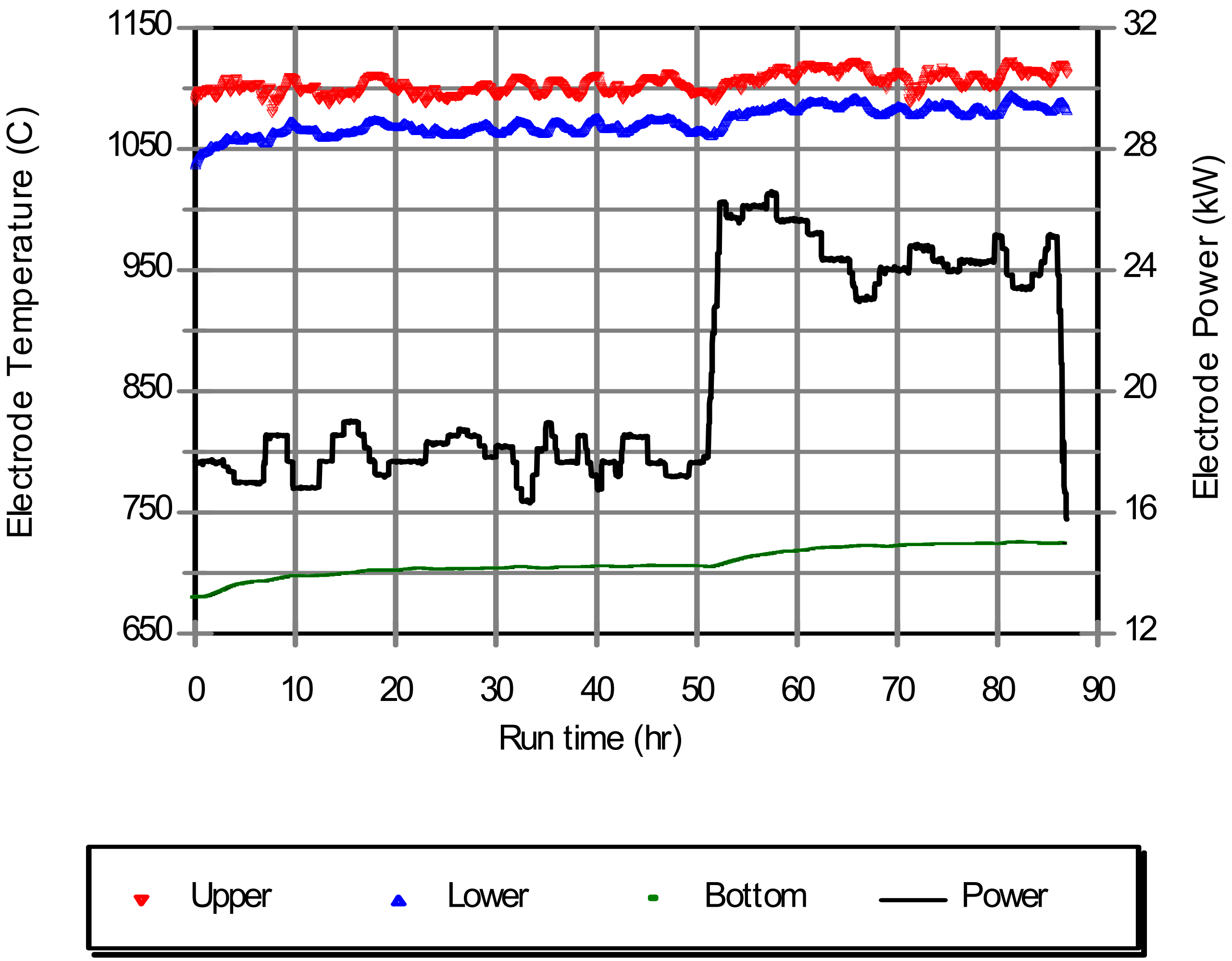


Figure 3.4.b. Electrode temperatures and power during DM100 Test 4 with Blend 4 waste and optimized AY102D4-07 glass composition at 9 lpm and optimized bubbling.

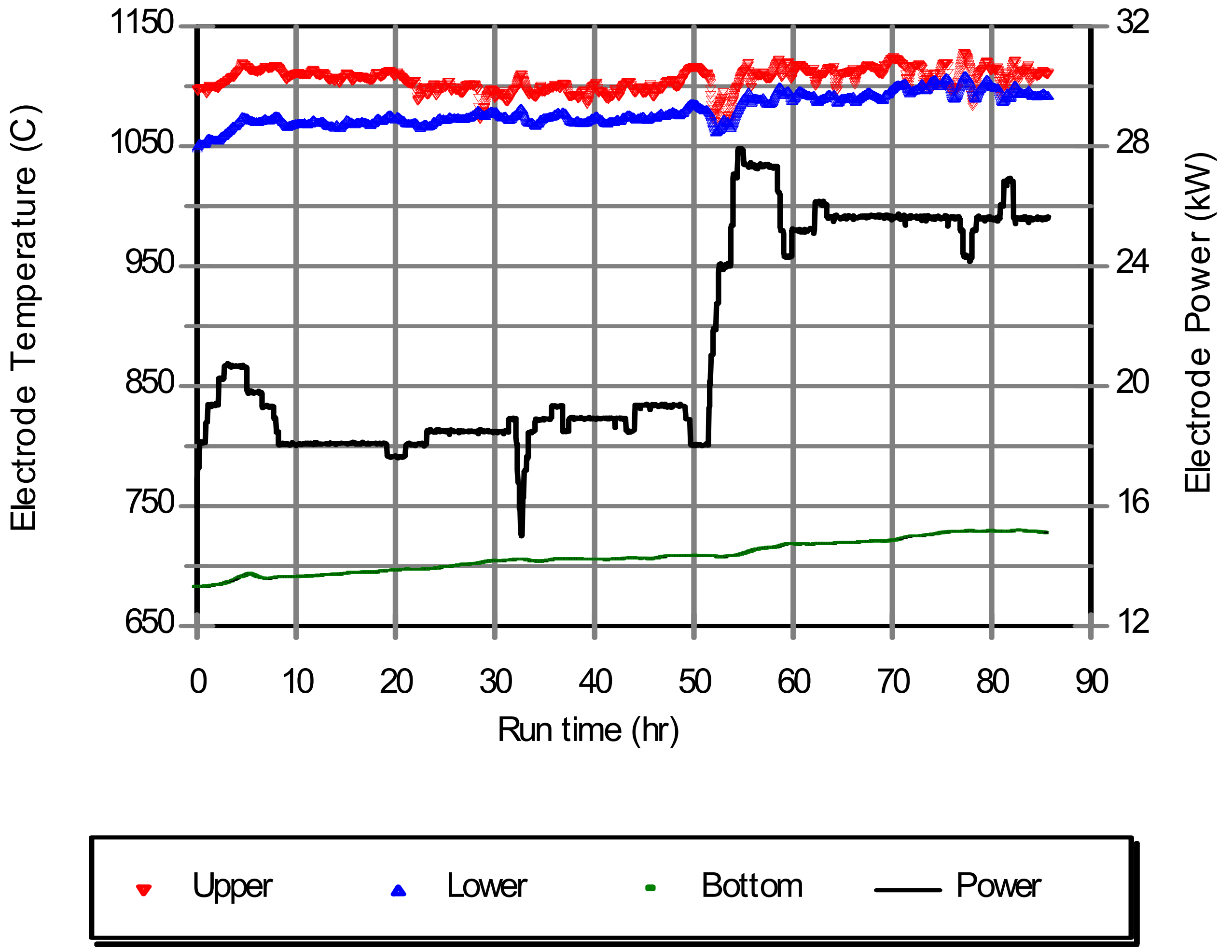


Figure 3.4.c. Electrode temperatures and power during DM100 Test 3 with Blend 3 waste and optimized AY102D3-02 glass composition at 9 lpm and optimized bubbling.

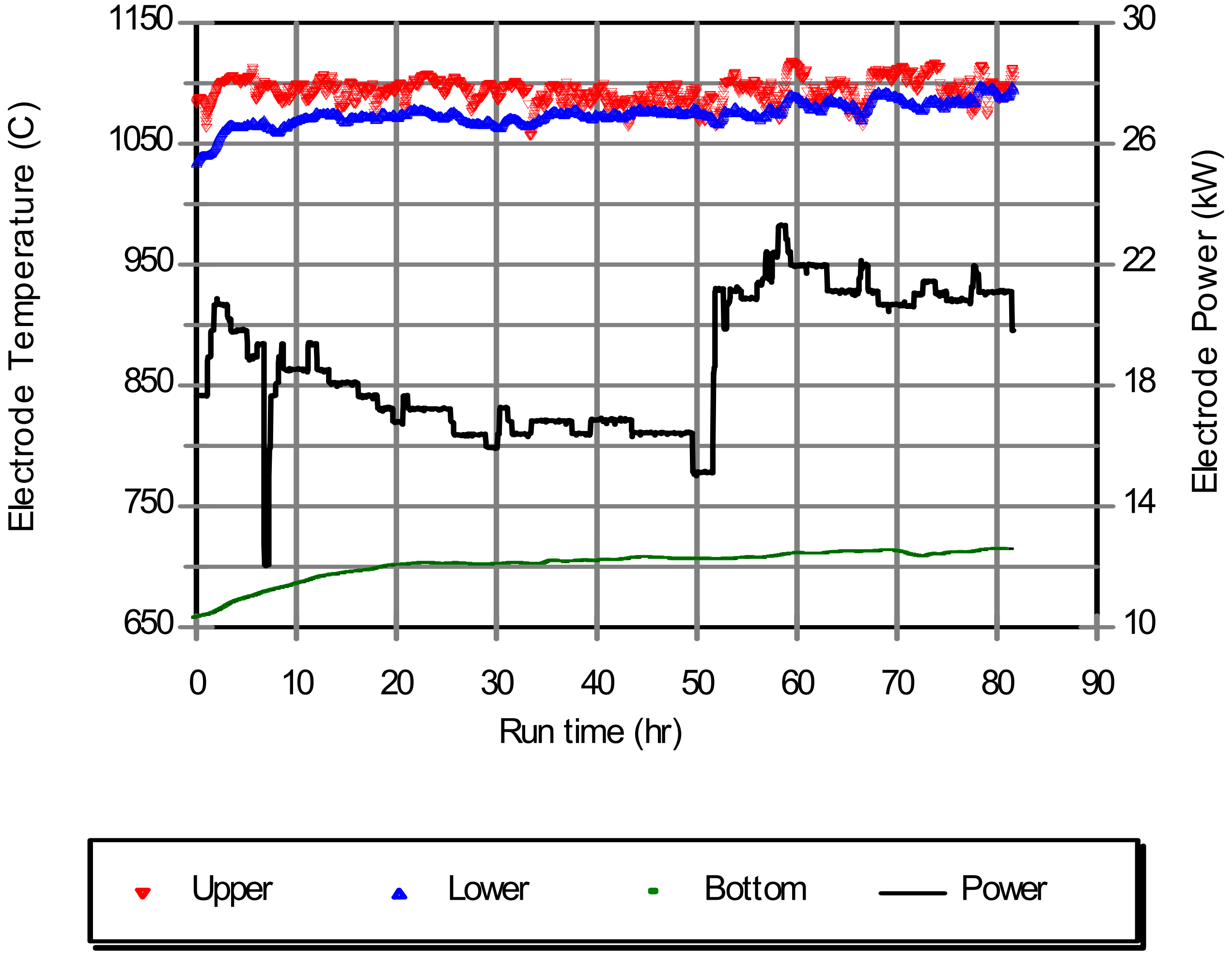


Figure 3.4.d. Electrode temperatures and power during DM100 Test 2 with Blend 2 waste and optimized AY102D2-06 glass composition at 9 lpm and optimized bubbling.

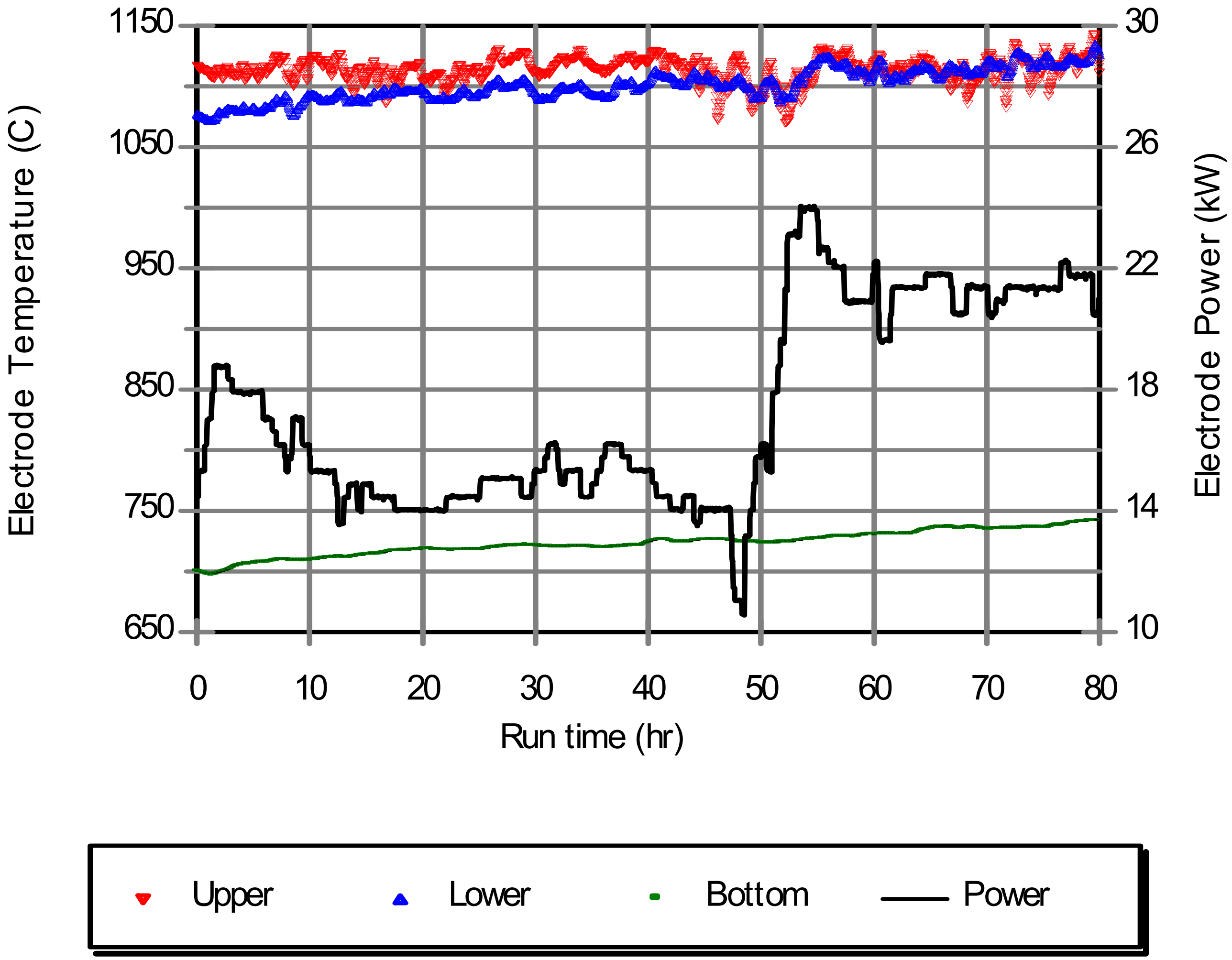


Figure 3.4.e. Electrode temperatures and power during DM100 Test 1 with Blend 1 waste and optimized AY102D1-05 glass composition at 9 lpm and optimized bubbling.

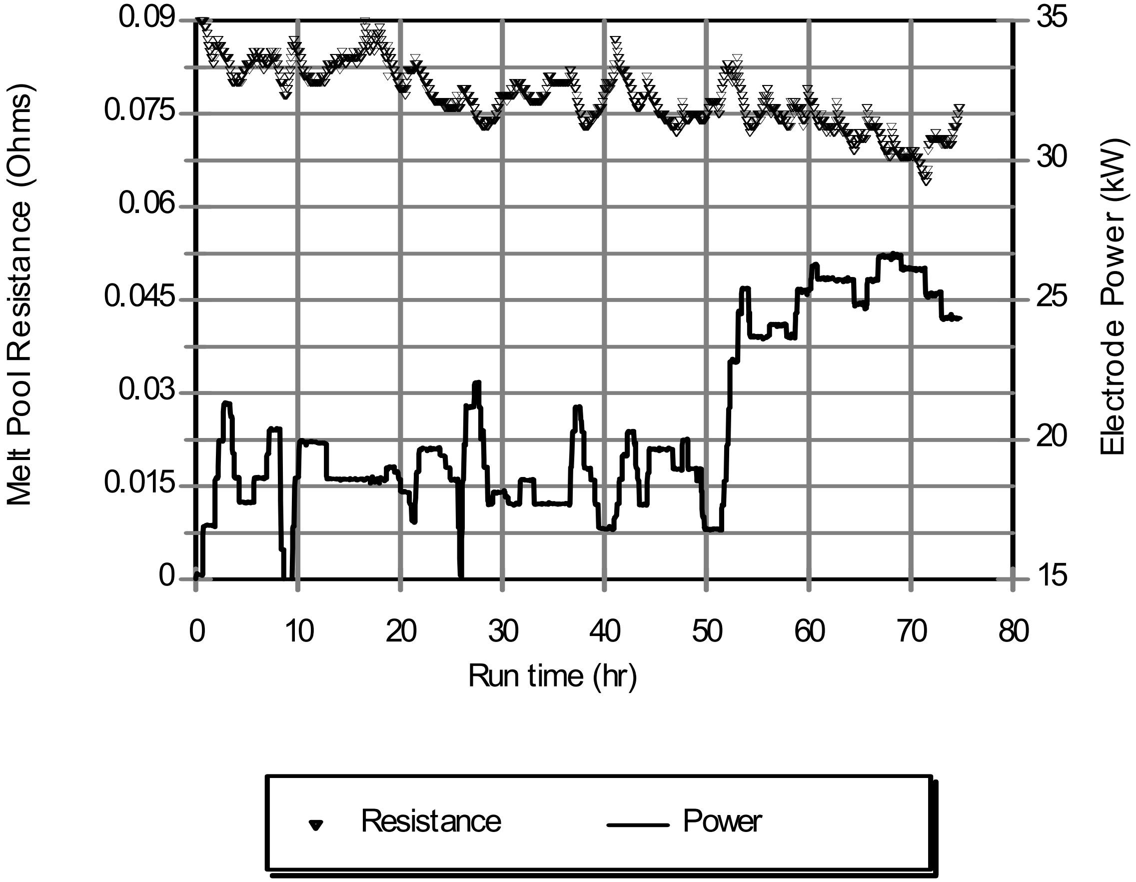


Figure 3.5.a. Melt pool resistance and total electrode power during DM100 Test 5 with high water, Blend 4 waste and optimized AY102D4-07 glass composition at 9 lpm and optimized bubbling.

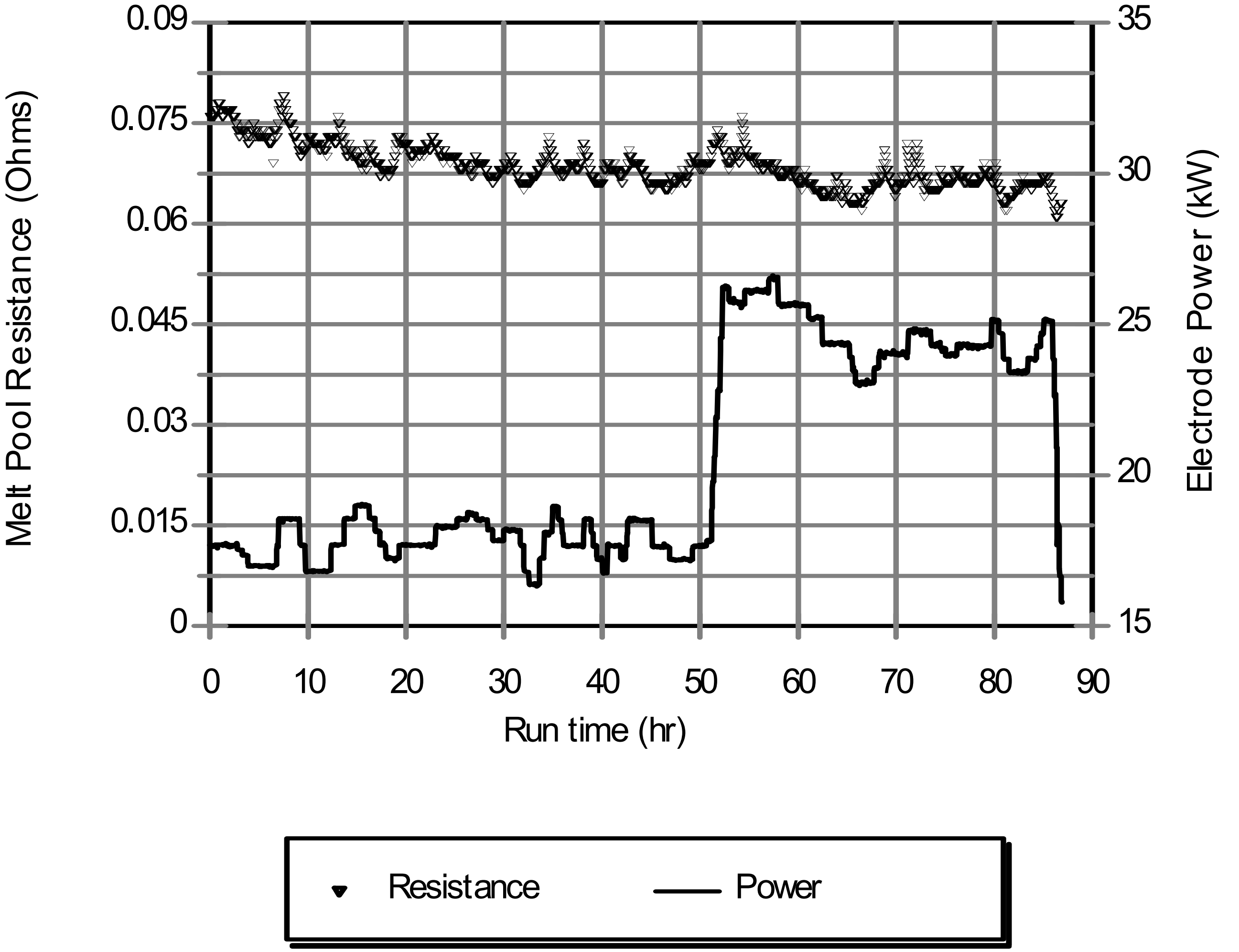


Figure 3.5.b. Melt pool resistance and total electrode power during DM100 Test 4 with Blend 4 waste and optimized AY102D4-07 glass composition at 9 lpm and optimized bubbling.

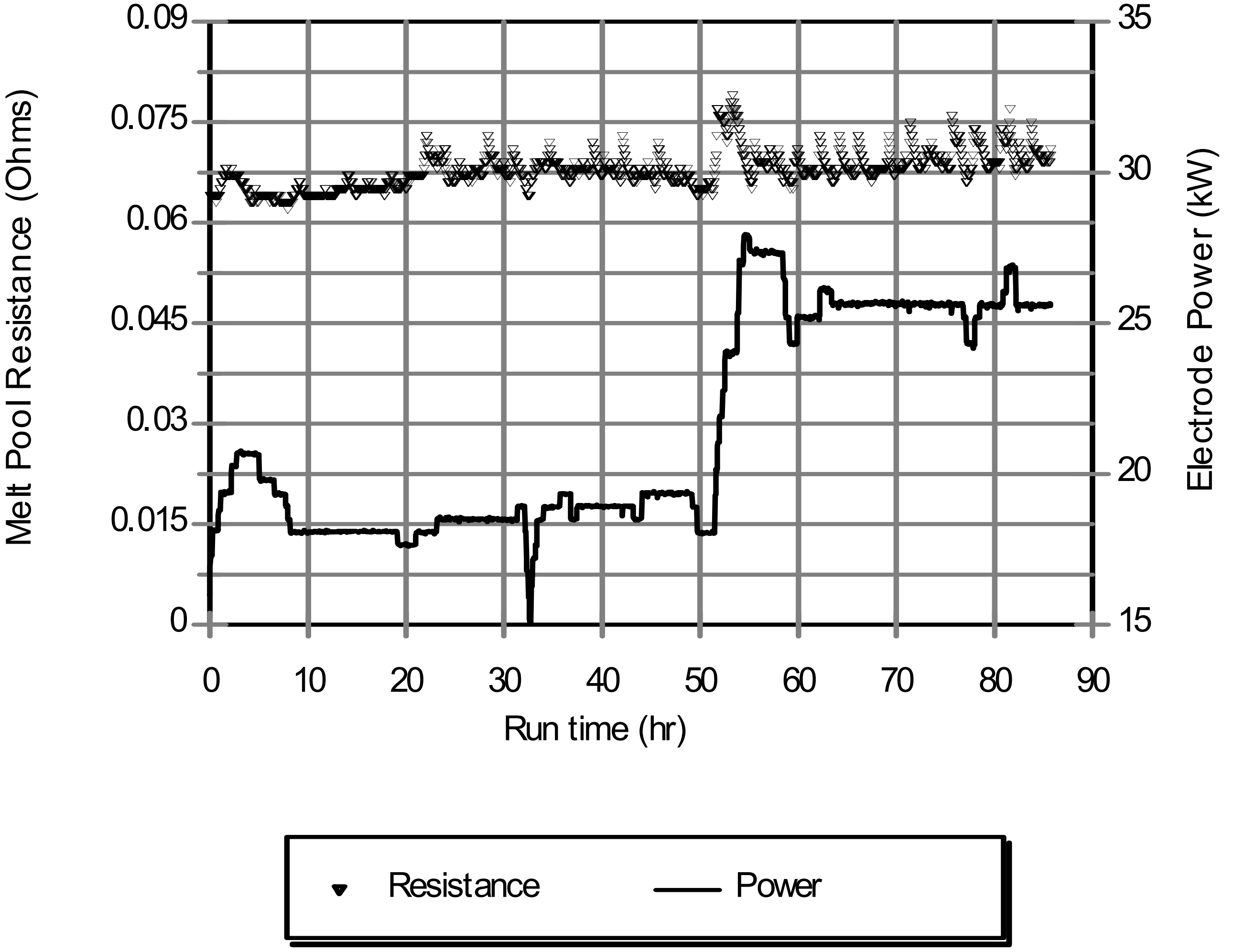


Figure 3.5.c. Melt pool resistance and total electrode power during DM100 Test 3 with Blend 3 waste and optimized AY102D3-02 glass composition at 9 lpm and optimized bubbling.

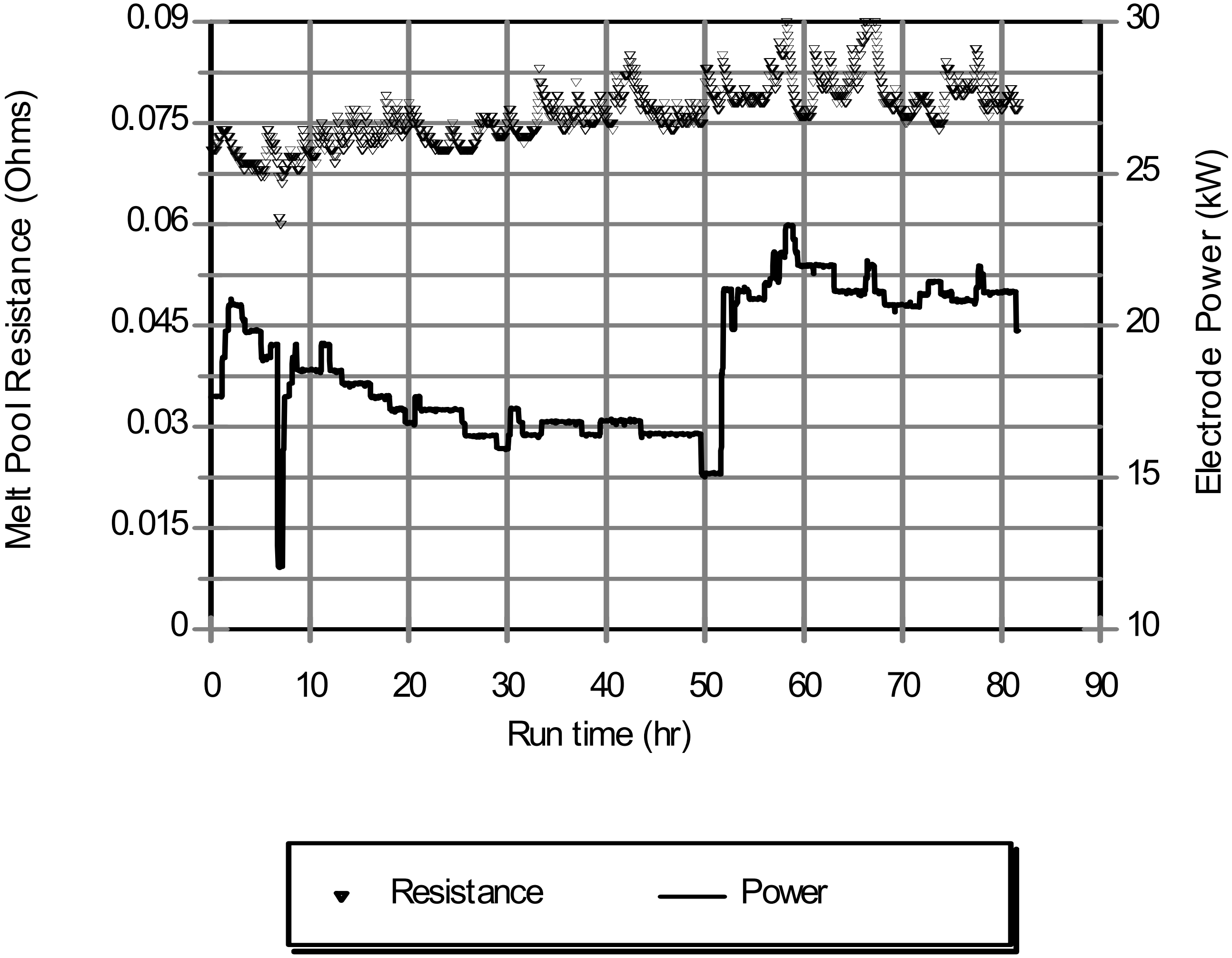


Figure 3.5.d. Melt pool resistance and total electrode power during DM100 Test 2 with Blend 2 waste and optimized AY102D2-06 glass composition at 9 lpm and optimized bubbling.

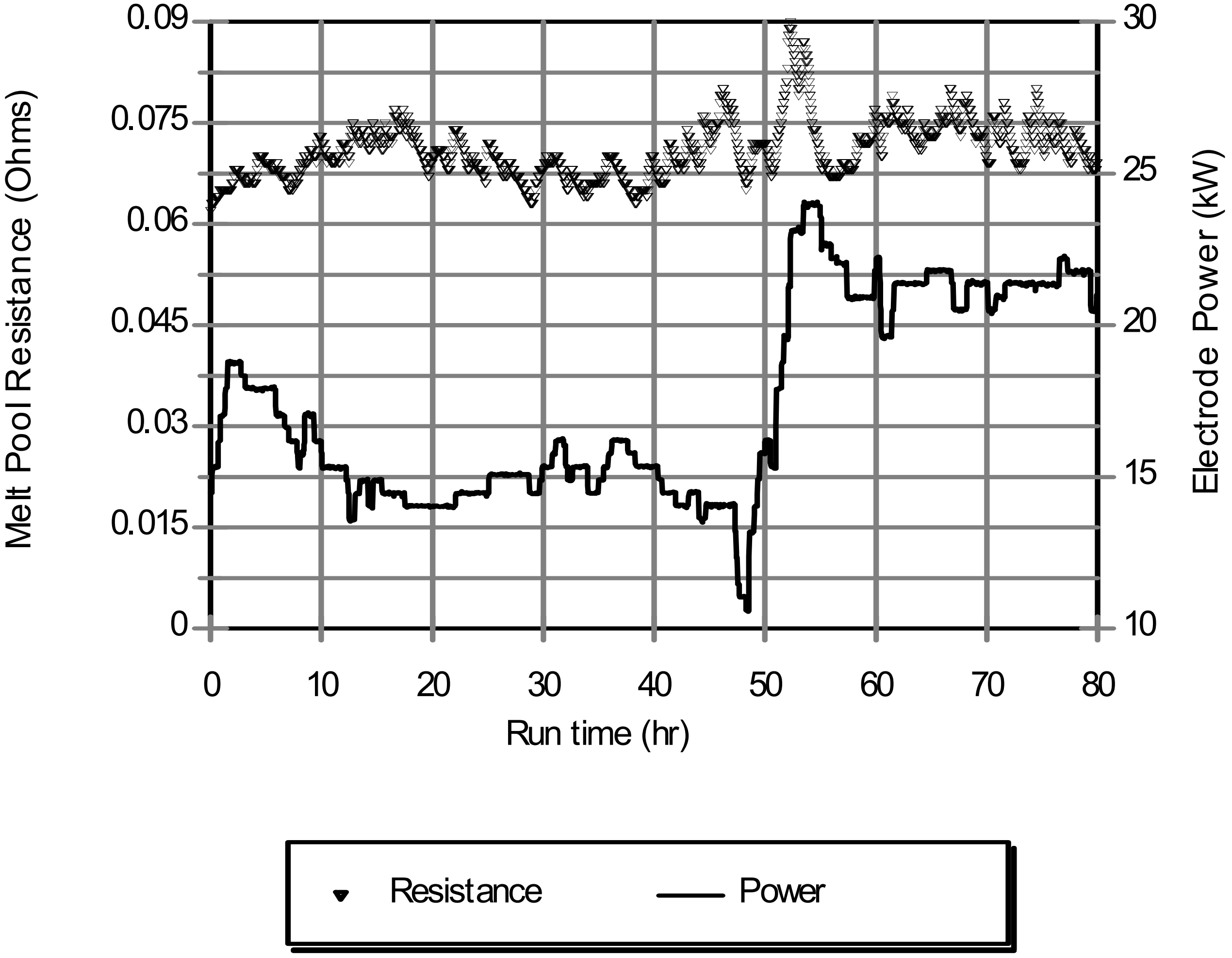


Figure 3.5.e. Melt pool resistance and total electrode power during DM100 Test 1 with Blend 1 waste and optimized AY102D1-05 glass composition at 9 lpm and optimized bubbling.

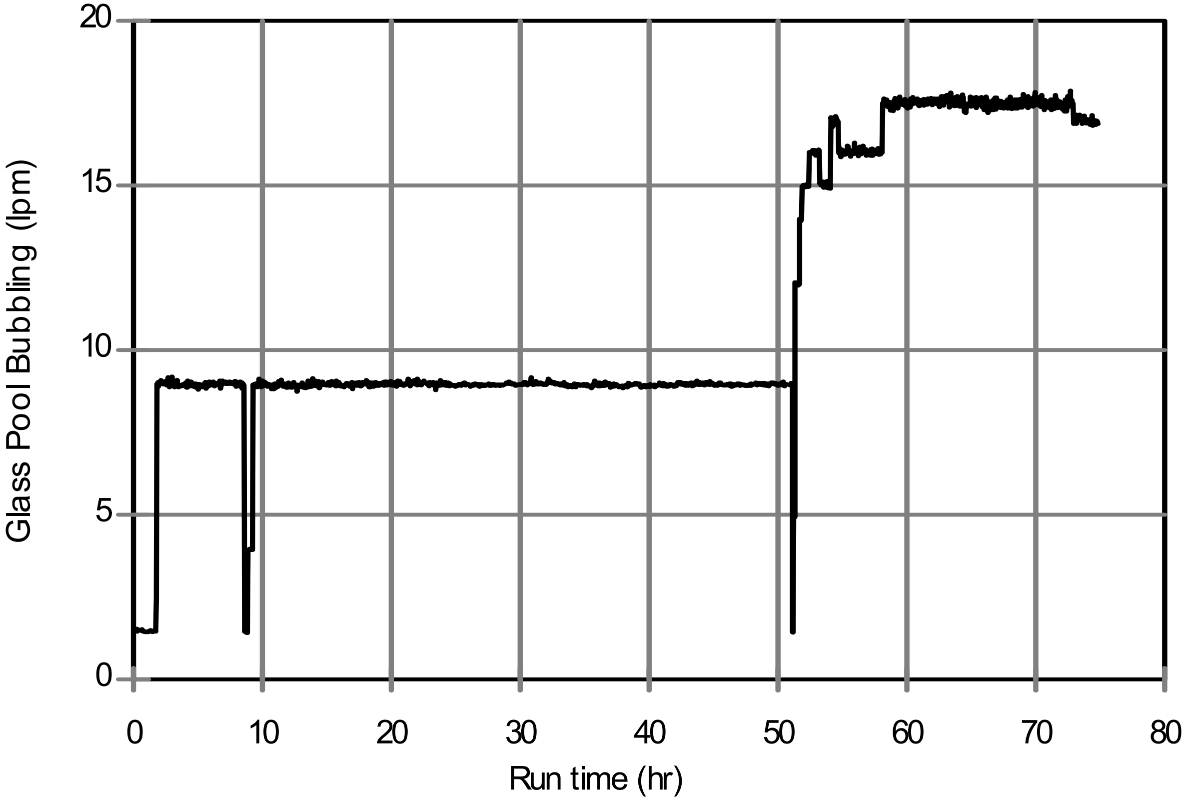


Figure 3.6.a. Melt pool bubbling during DM100 Test 5 with High Water, Blend 4 waste and optimized AY102D4-07 glass composition at 9 lpm and optimized bubbling.

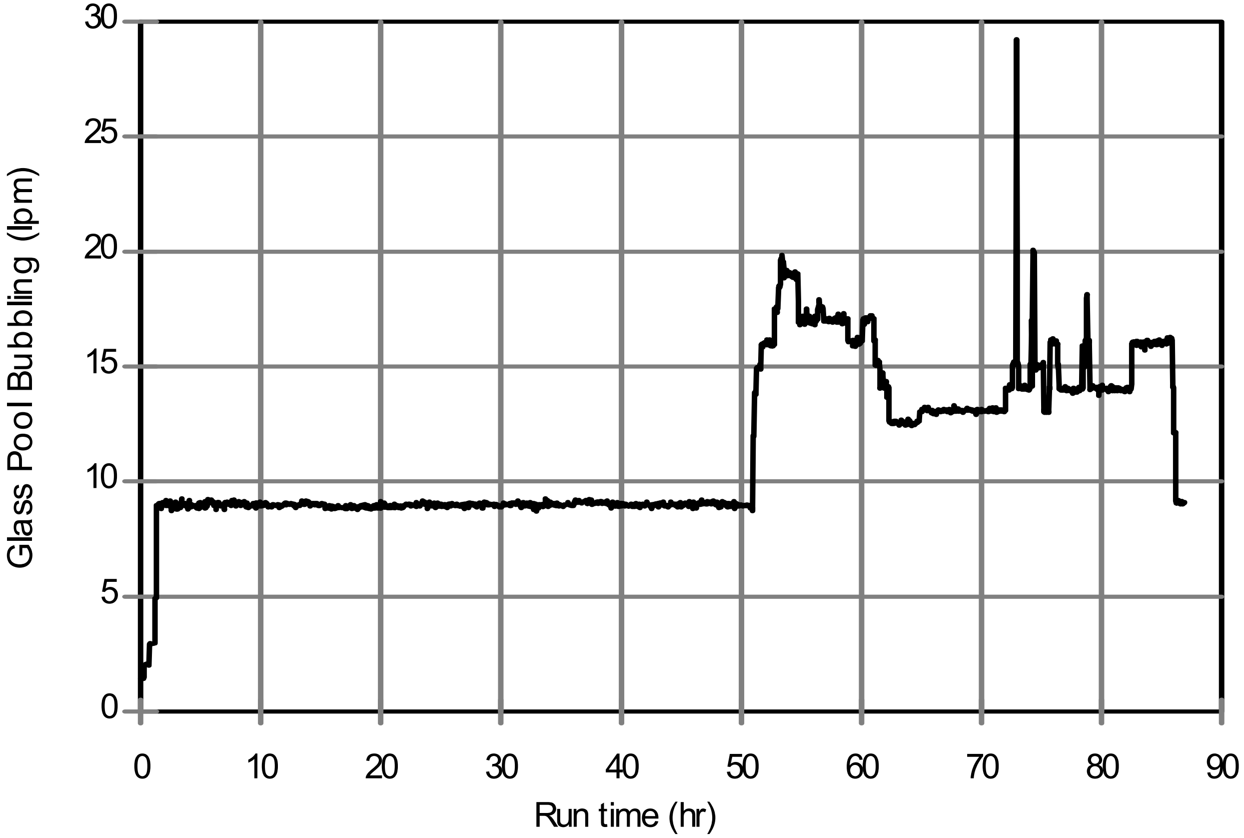


Figure 3.6.b. Melt pool bubbling during DM100 Test 4 with Blend 4 waste and optimized AY102D4-07 glass composition at 9 lpm and optimized bubbling.

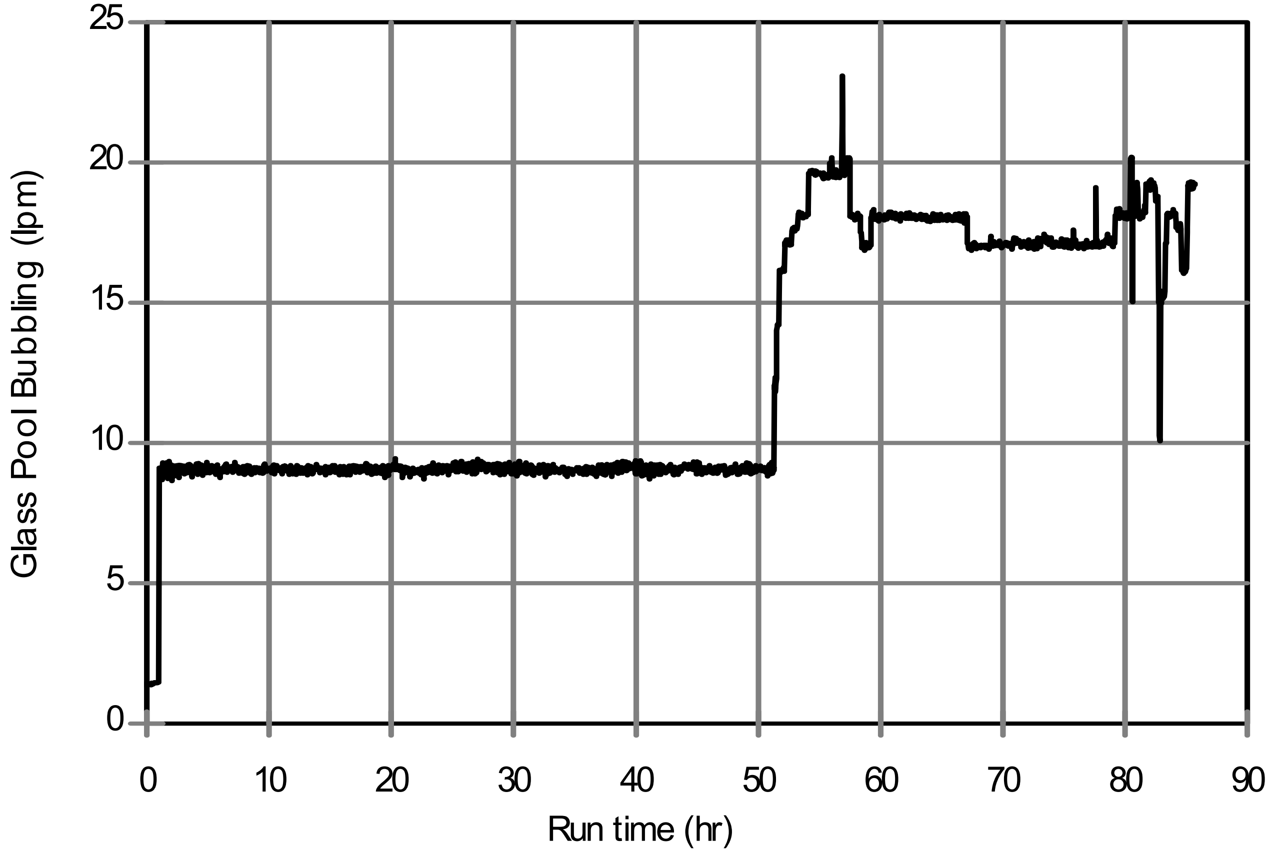


Figure 3.6.c. Melt pool bubbling during DM100 Test 3 with Blend 3 waste and optimized AY102D3-02 glass composition at 9 lpm and optimized bubbling.

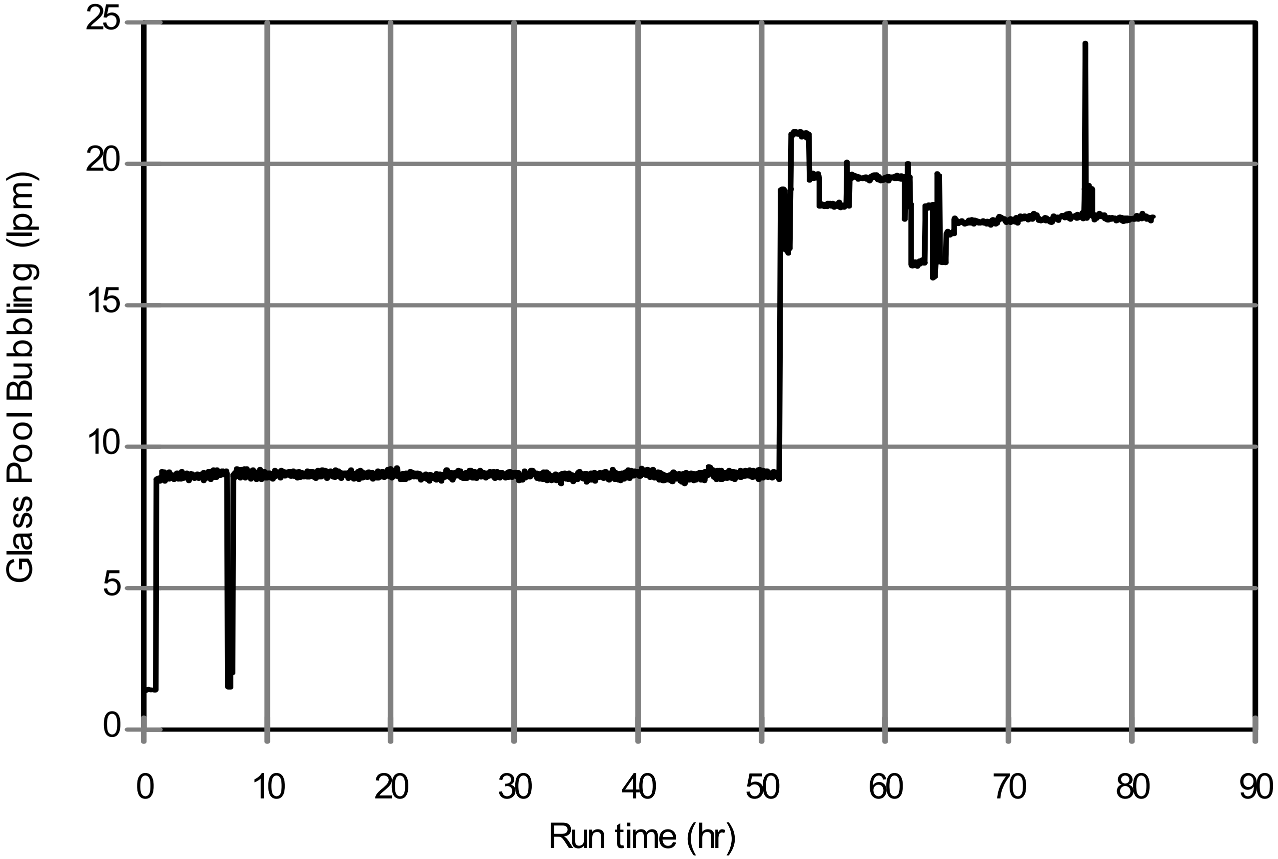


Figure 3.6.d. Melt pool bubbling during DM100 Test 2 with Blend 2 waste and optimized AY102D2-06 glass composition at 9 lpm and optimized bubbling.

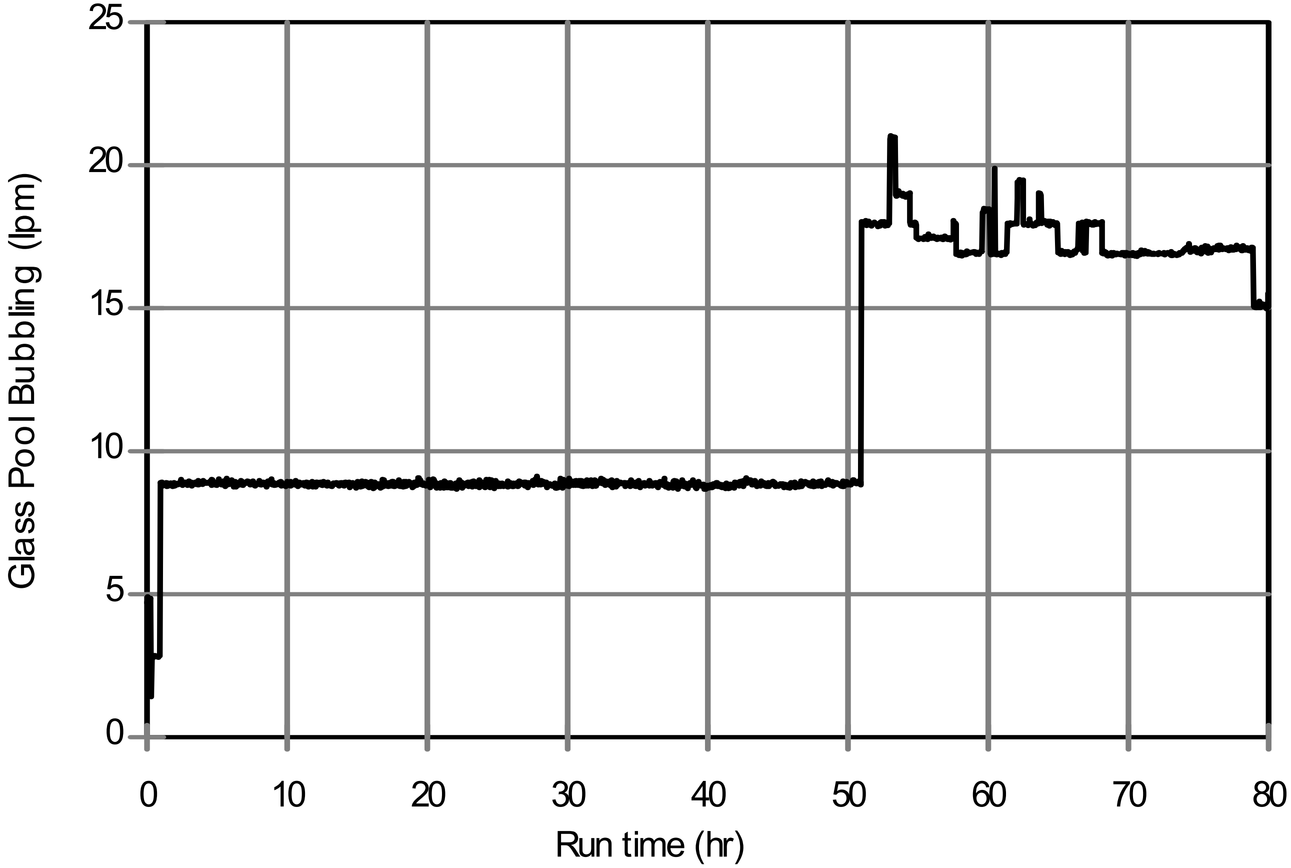


Figure 3.6.e. Melt pool bubbling during DM100 Test 1 with Blend 1 waste and optimized AY102D1-05 glass composition at 9 lpm and optimized bubbling.

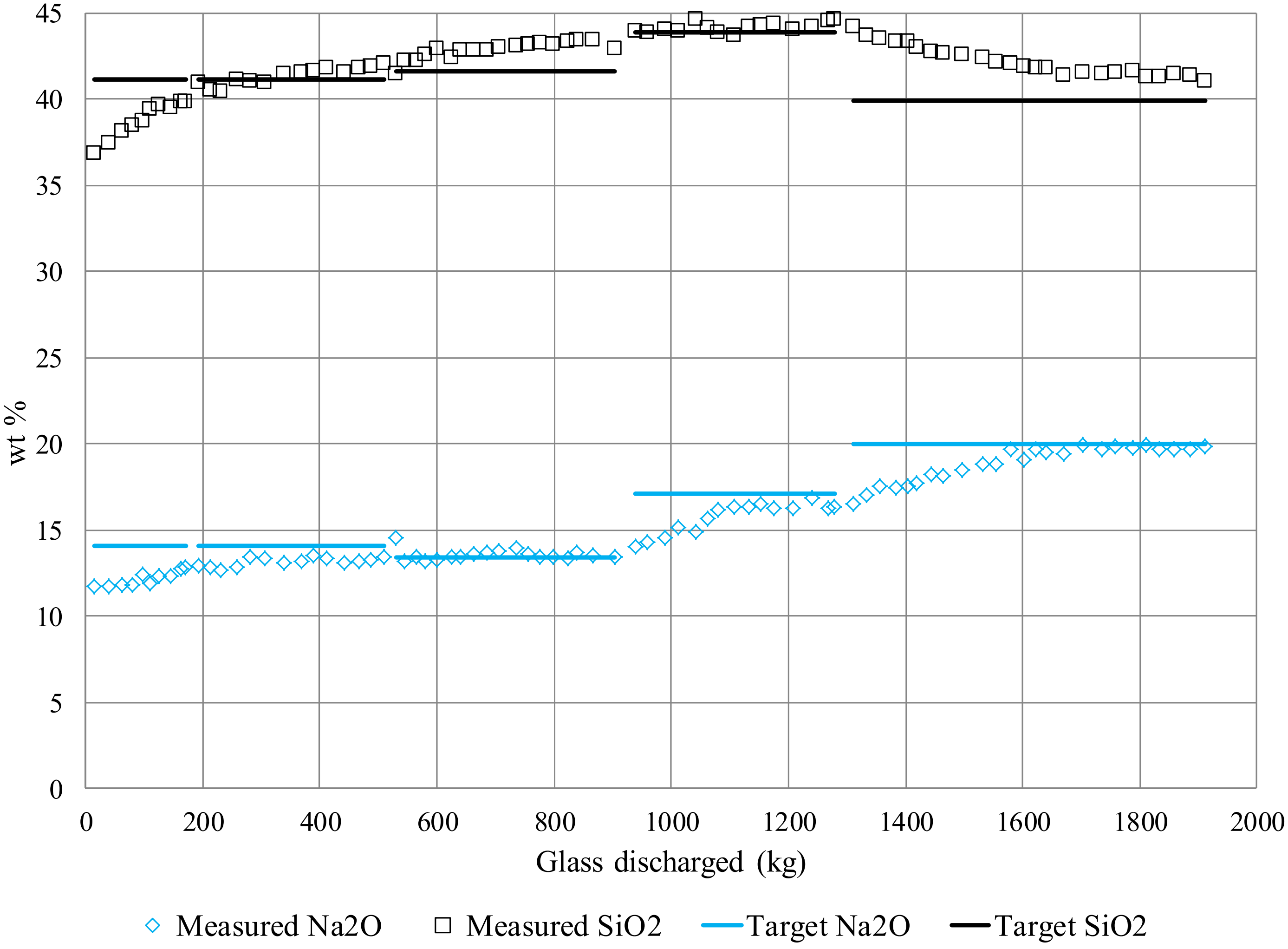


Figure 4.1.a. DM100 product and target glass compositions determined by XRF.

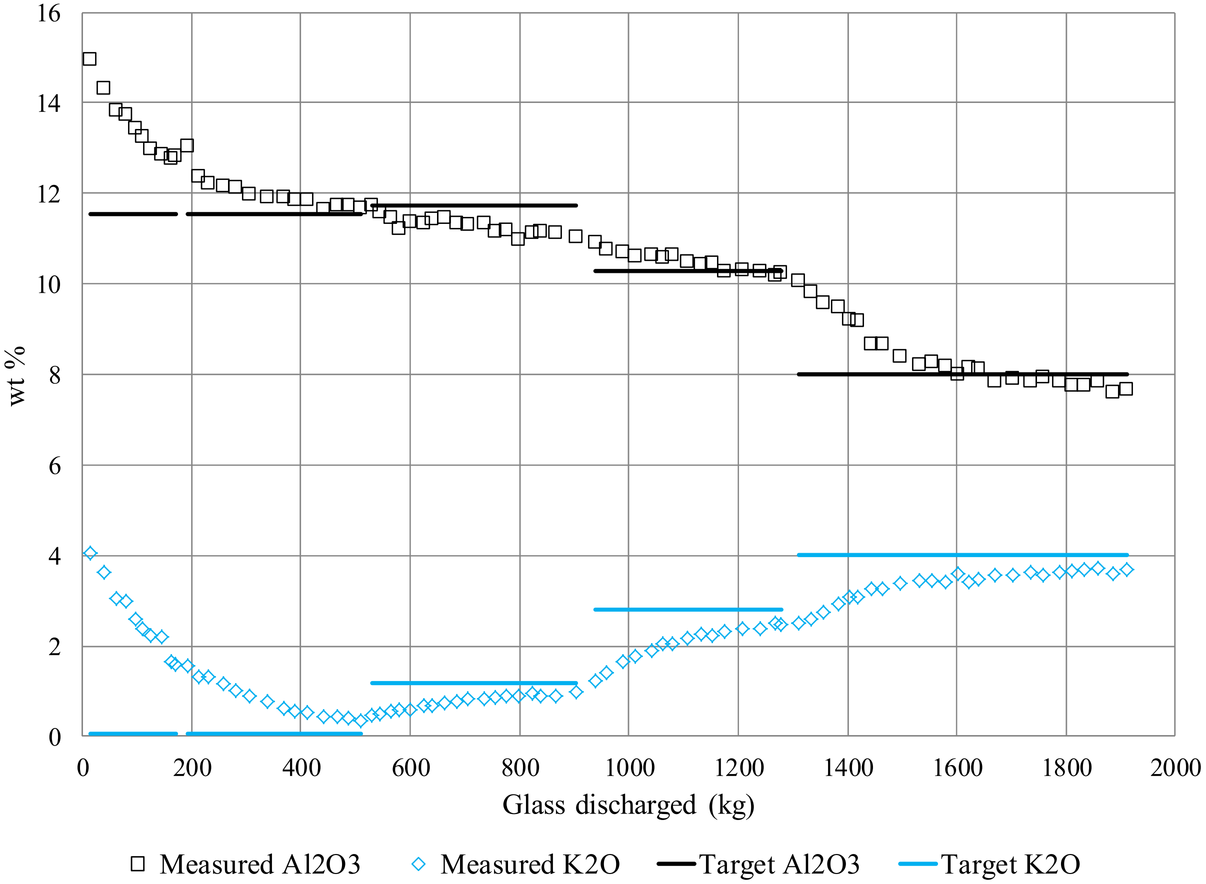


Figure 4.1.b. DM100 product and target glass compositions determined by XRF.

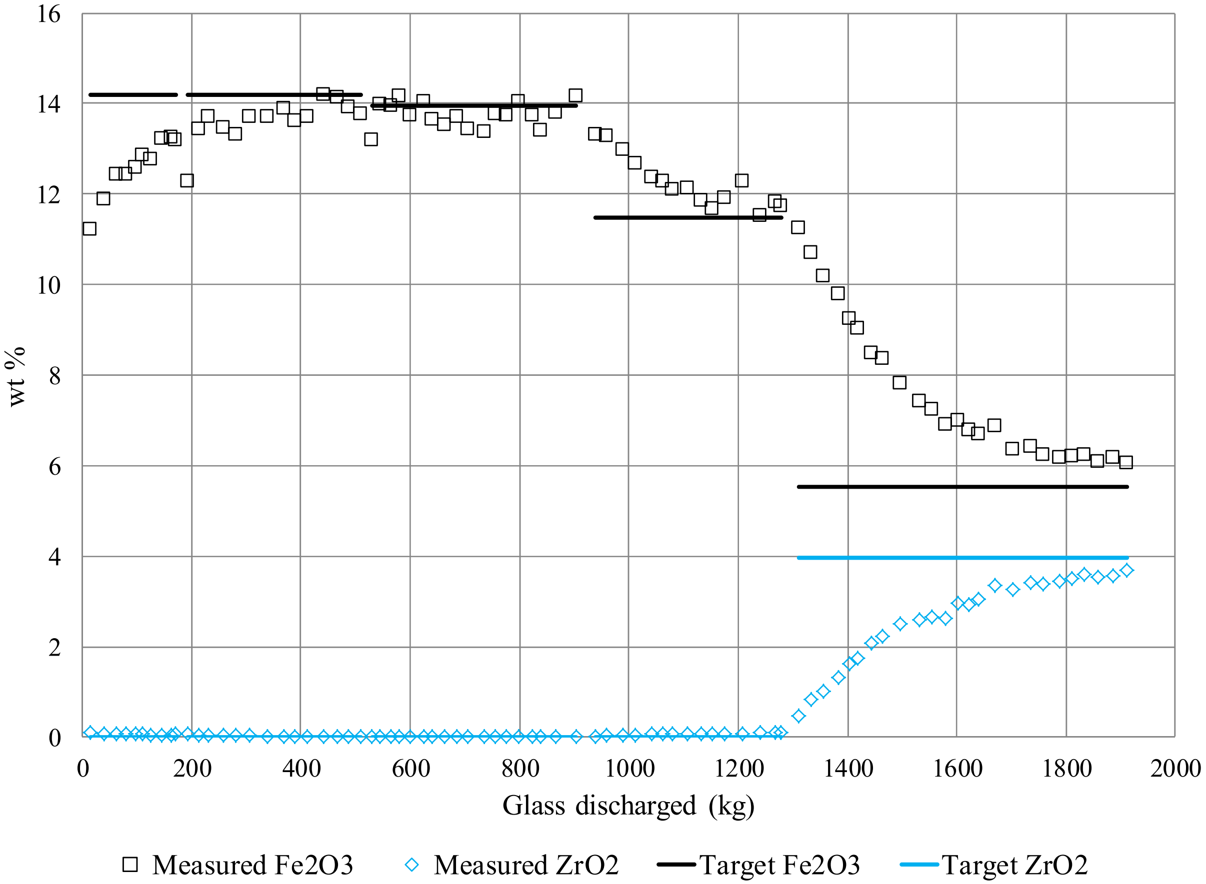


Figure 4.1.c. DM100 product and target glass compositions determined by XRF.

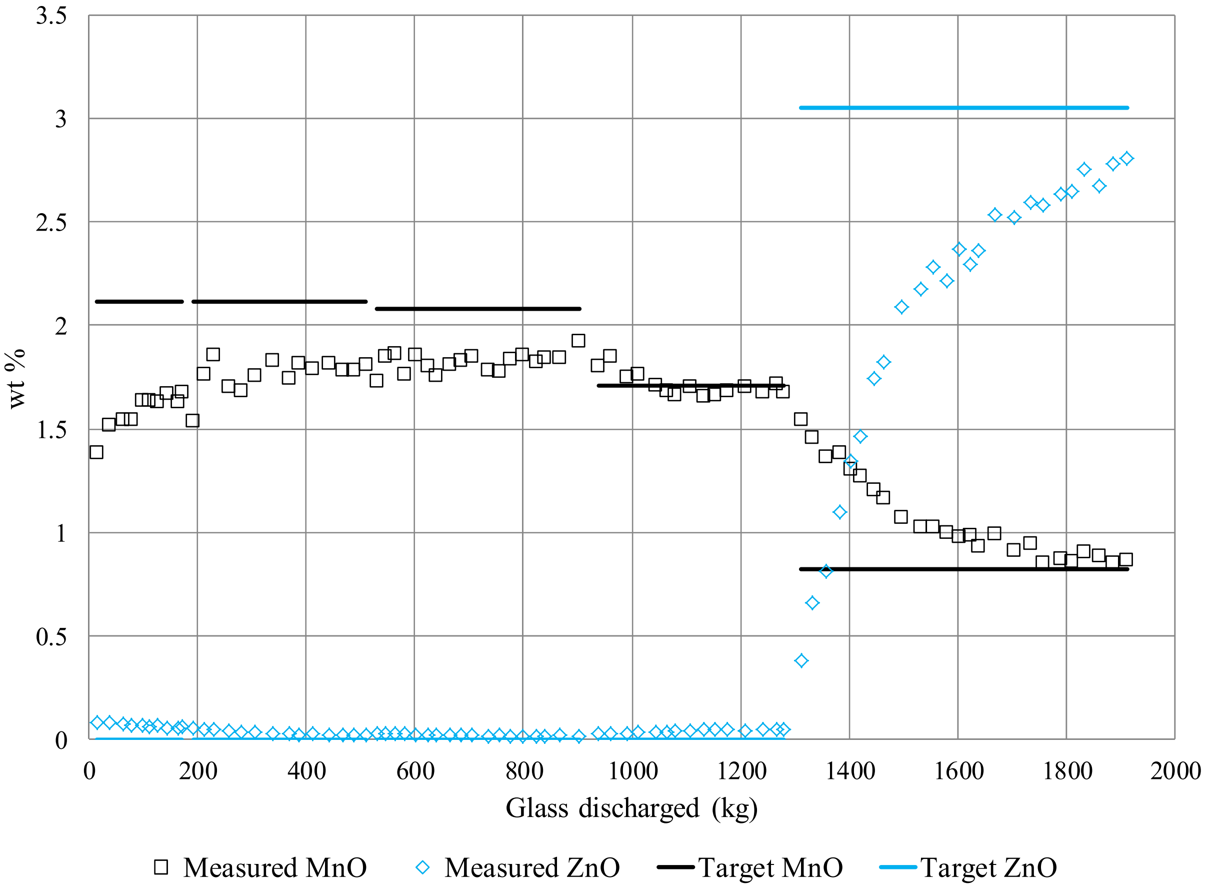


Figure 4.1.d. DM100 product and target glass compositions determined by XRF.

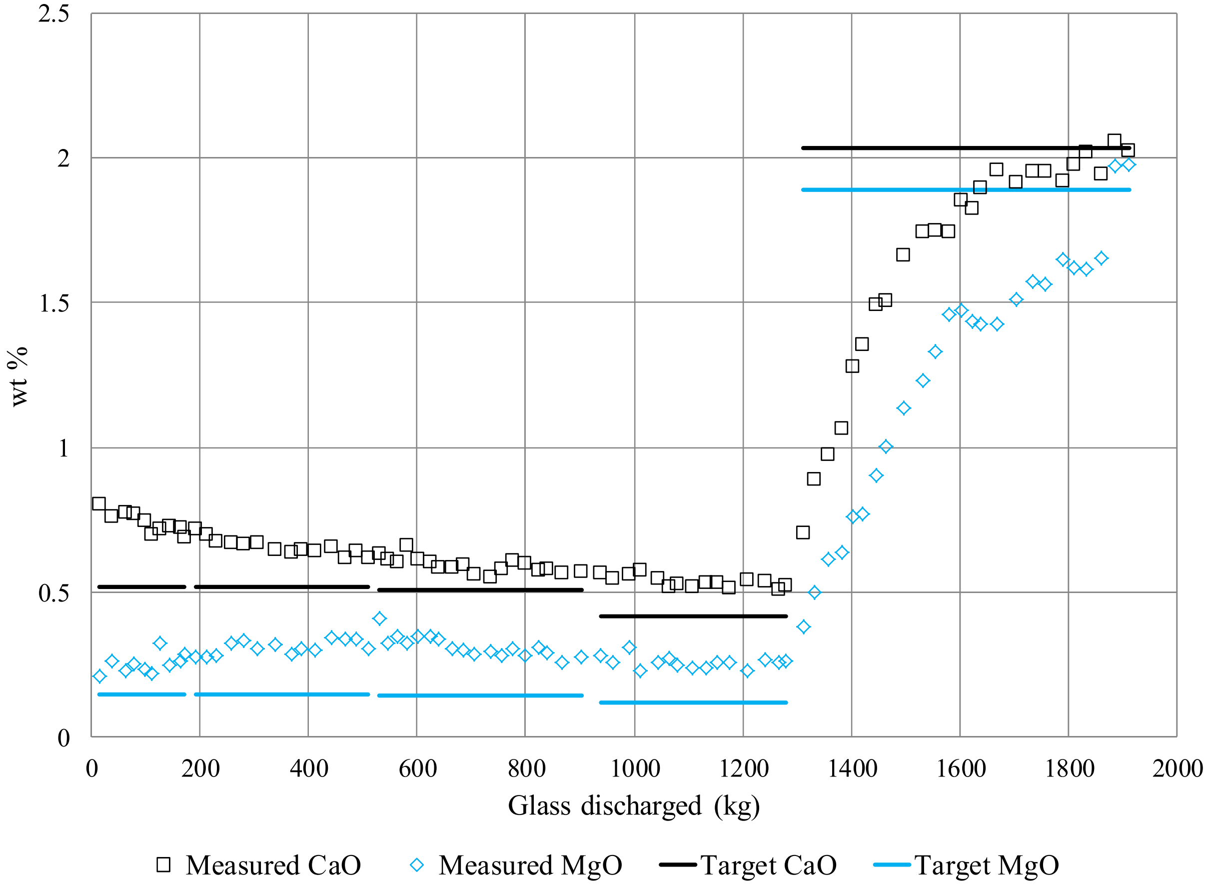


Figure 4.1.e. DM100 product and target glass compositions determined by XRF.

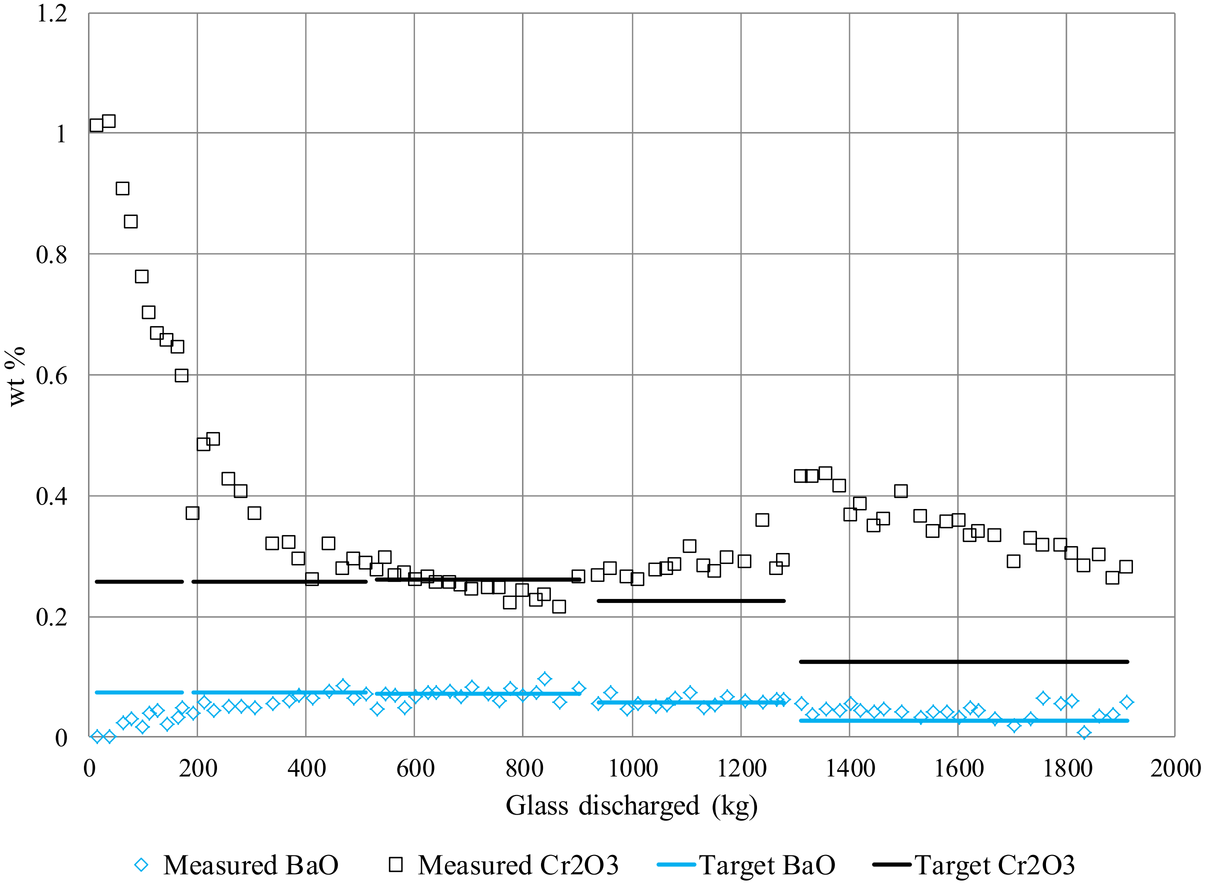


Figure 4.1.f. DM100 product and target glass compositions determined by XRF.

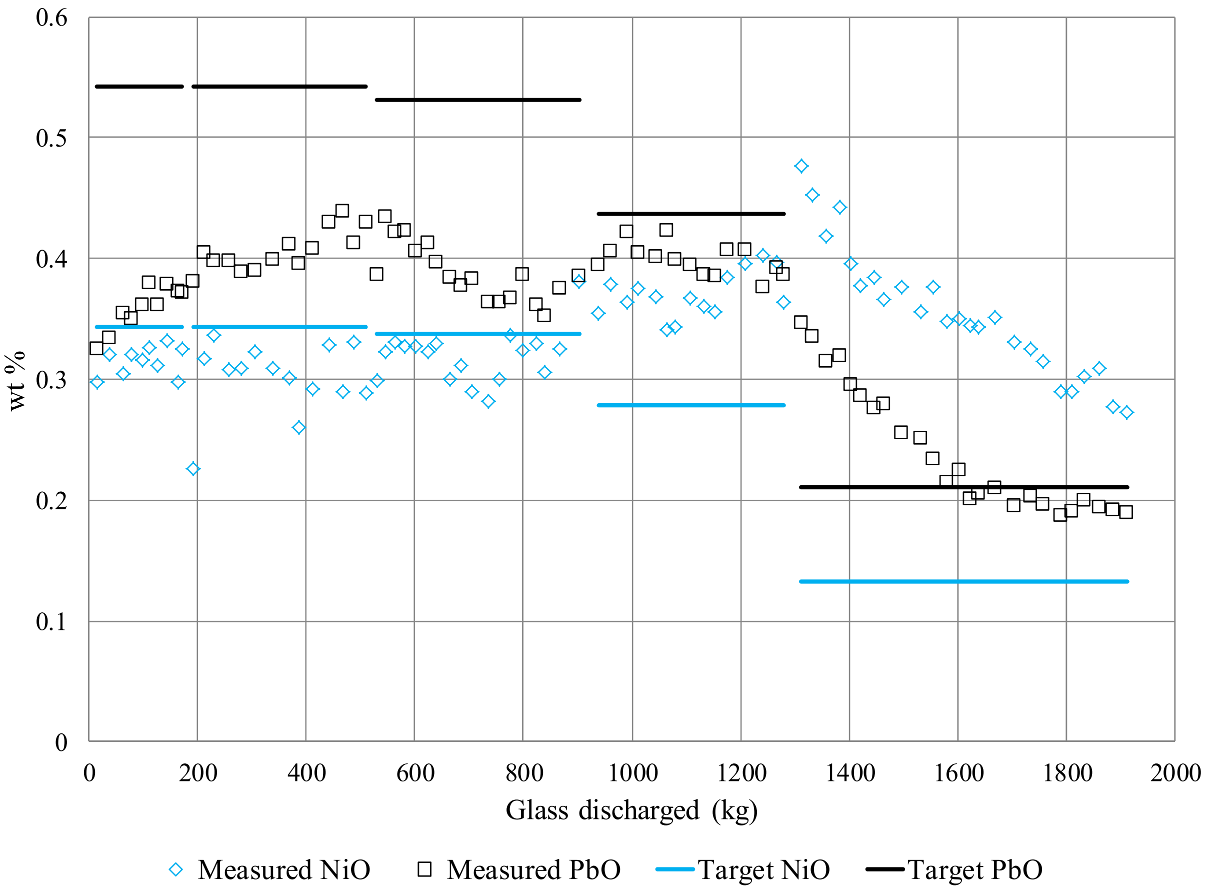


Figure 4.1.g. DM100 product and target glass compositions determined by XRF.

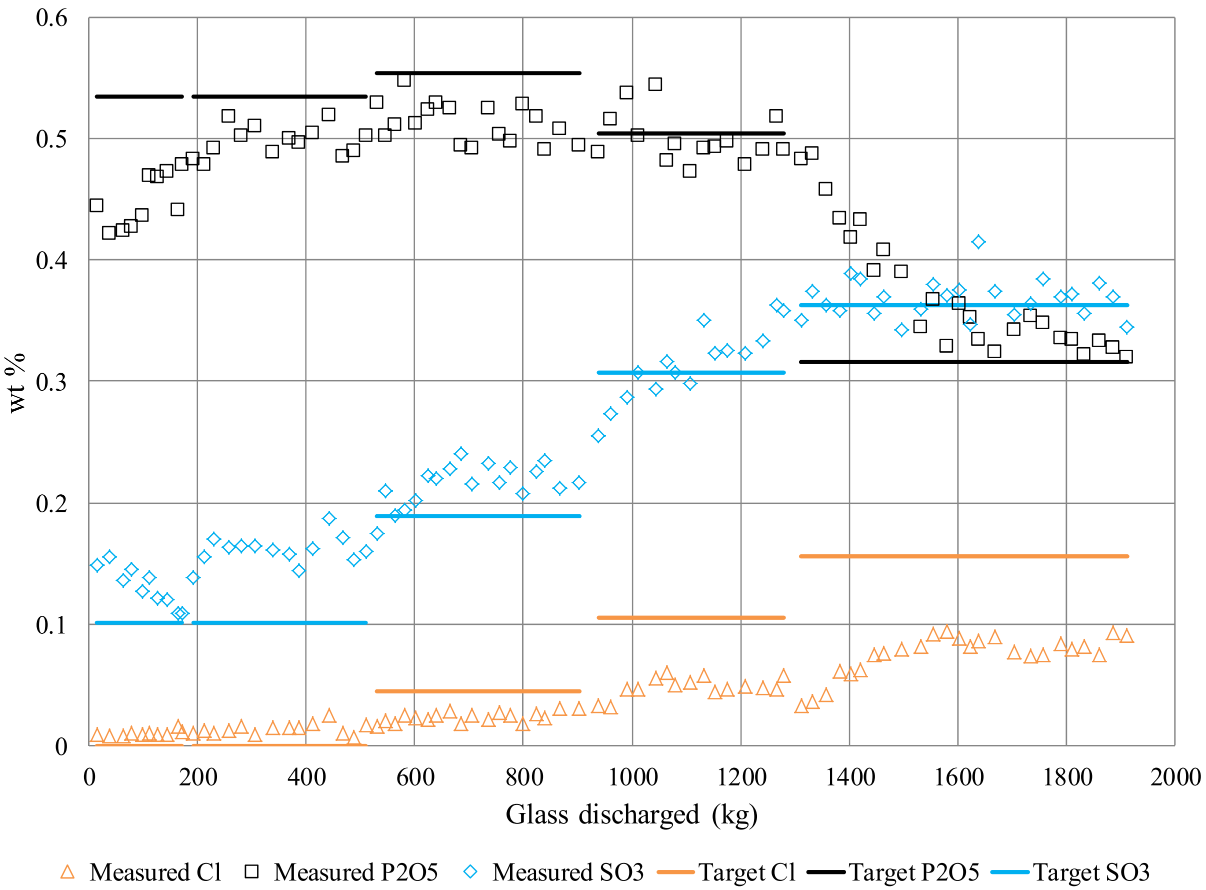


Figure 4.1.h. DM100 product and target glass compositions determined by XRF.

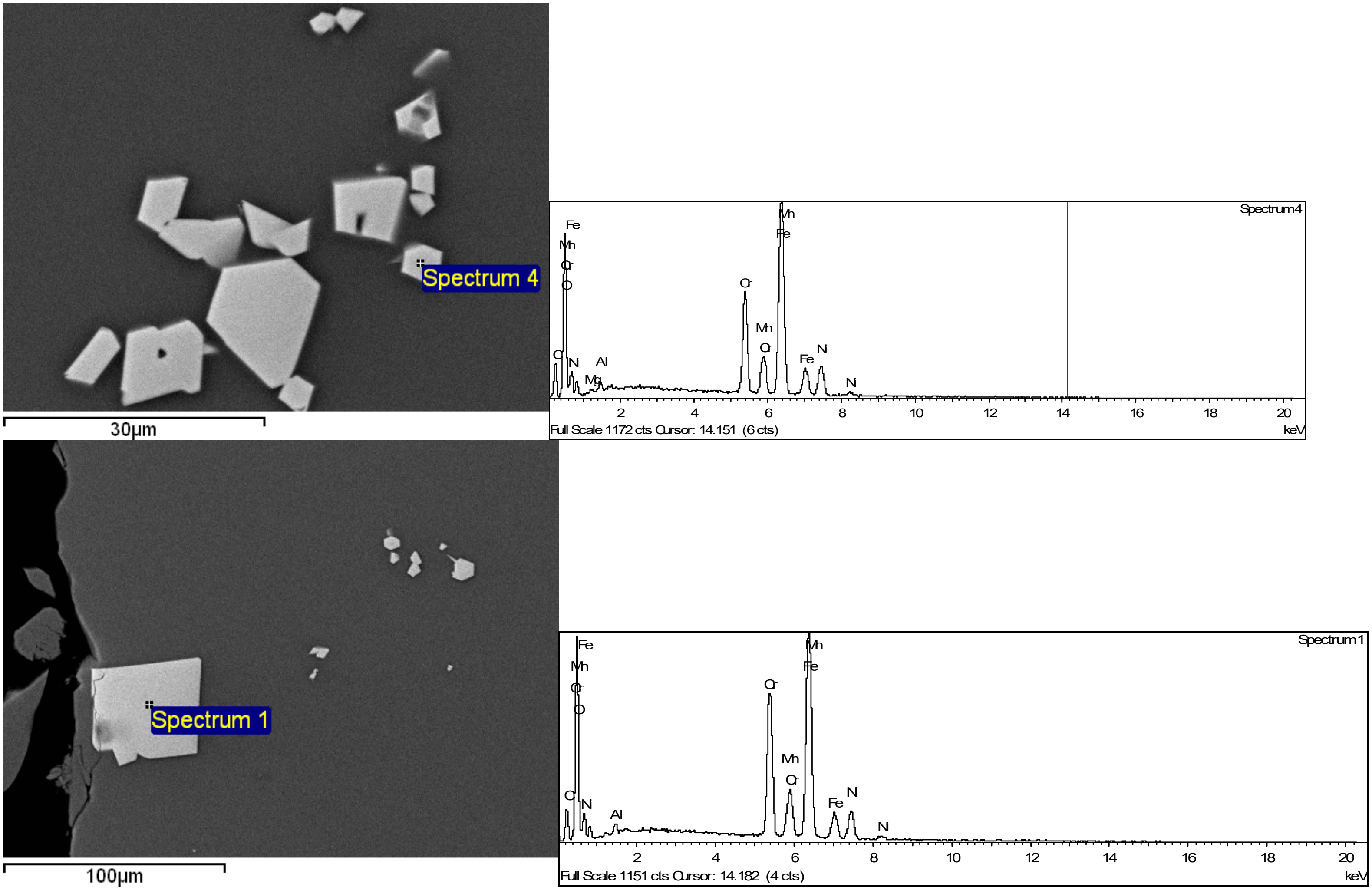


Figure 4.2. SEM micrograph of discharged glass pool sample NBL-D-78A. Spinels are sub-euhedral, and slightly clustered crystals heterogeneously distributed. The crystals are bimodally distributed; a 1-10 micron size major fraction with higher Cr-Mn contents and a lesser amount of 20-50 micron size. The spinels are mainly composed of Fe-Cr with considerable Mn-Ni, small quantity of Al, and possible Mg.

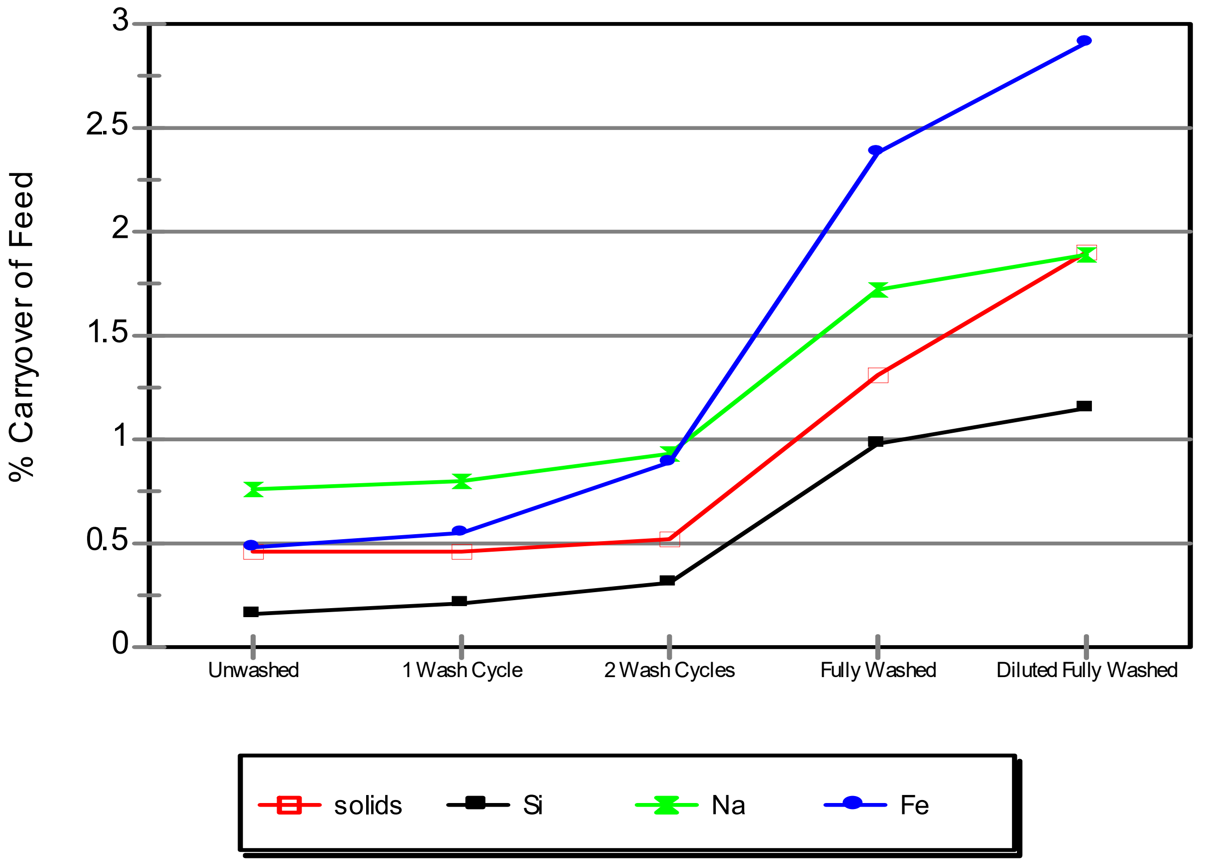


Figure 5.1.a Percent carryover of feed constituents into the melter exhaust during DM100 tests with bubbling fixed at 9 lpm.

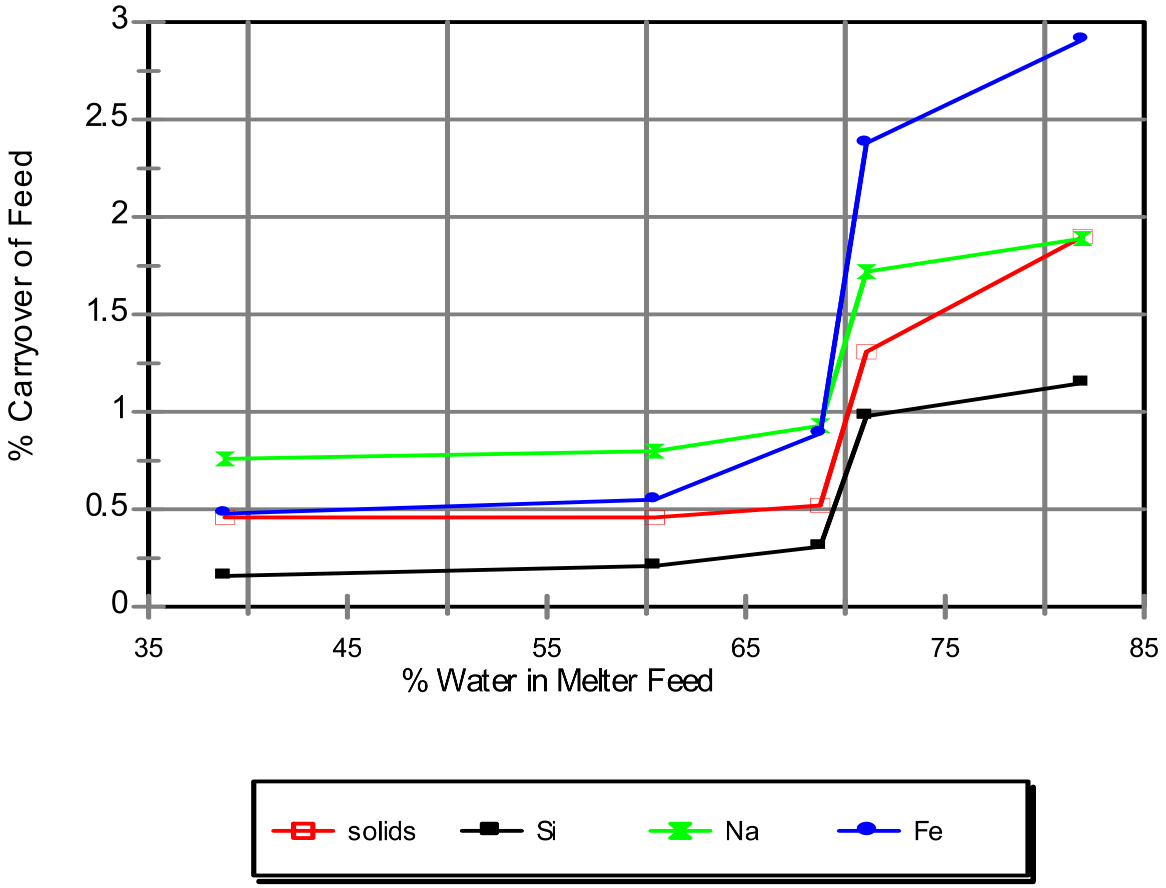


Figure 5.1.b Percent carryover of feed constituents into the melter exhaust versus feed water content during DM100 tests with bubbling fixed at 9 lpm.

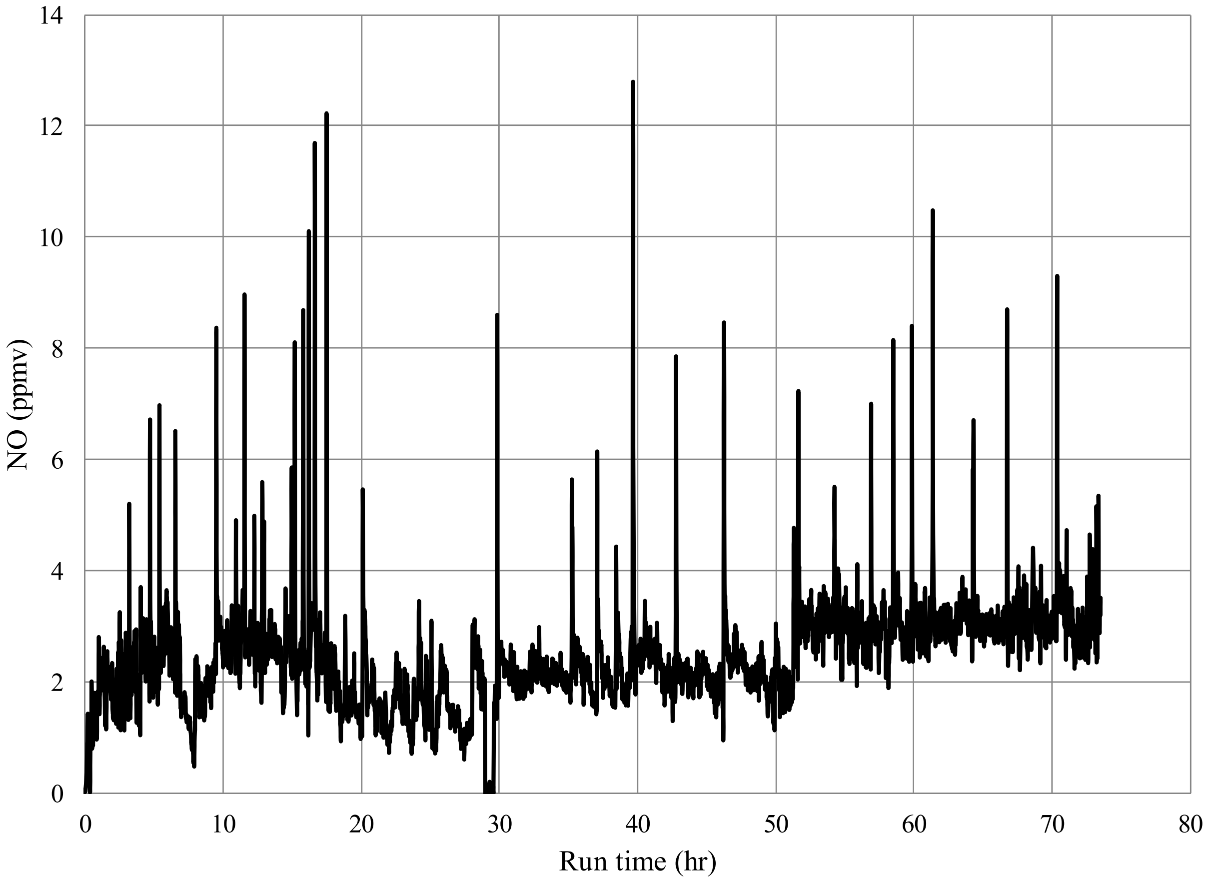


Figure 5.2.a. FTIR monitored NO emissions during tests with fixed and optimized bubbling, Test 5. Note: NO_2 not detected during test.

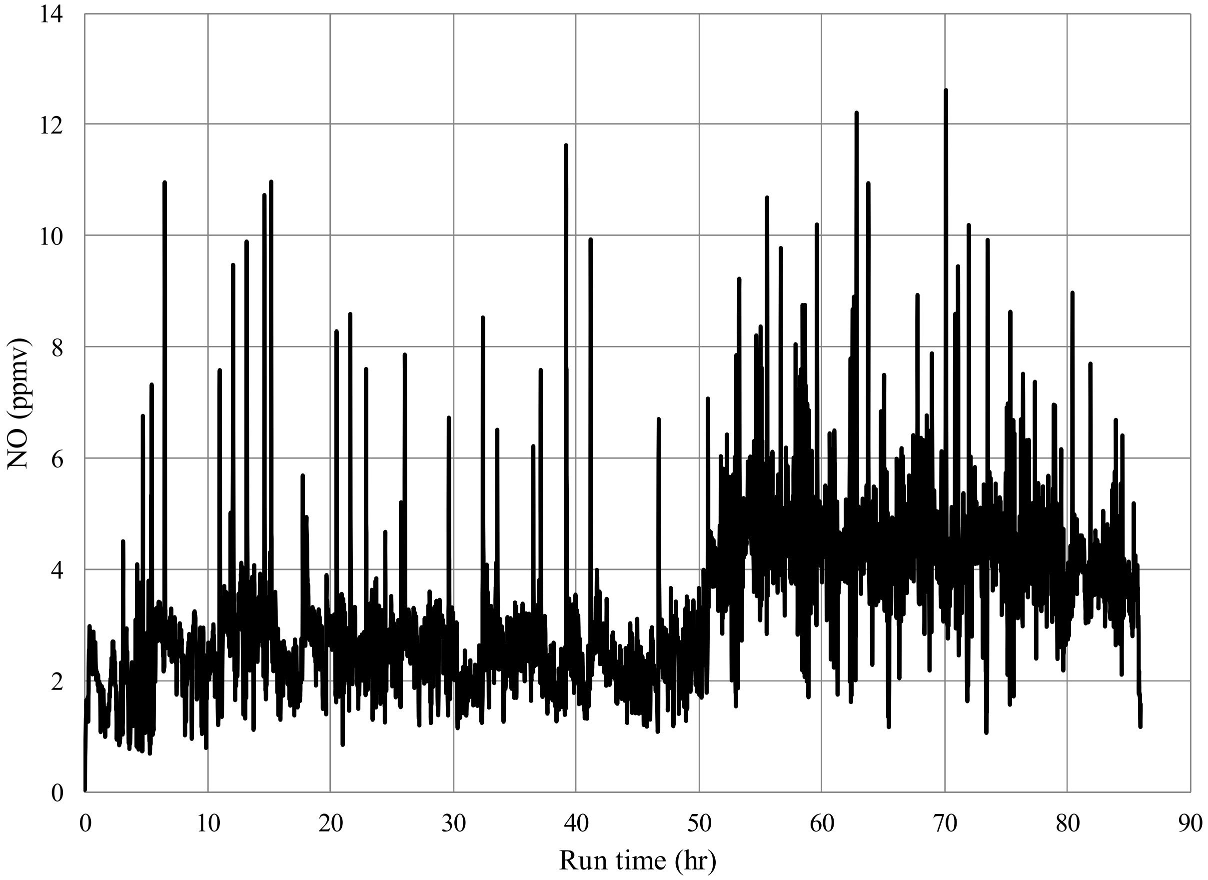


Figure 5.2.b. FTIR monitored NO emissions during tests with fixed and optimized bubbling, Test 4. Note: NO_2 not detected during test.

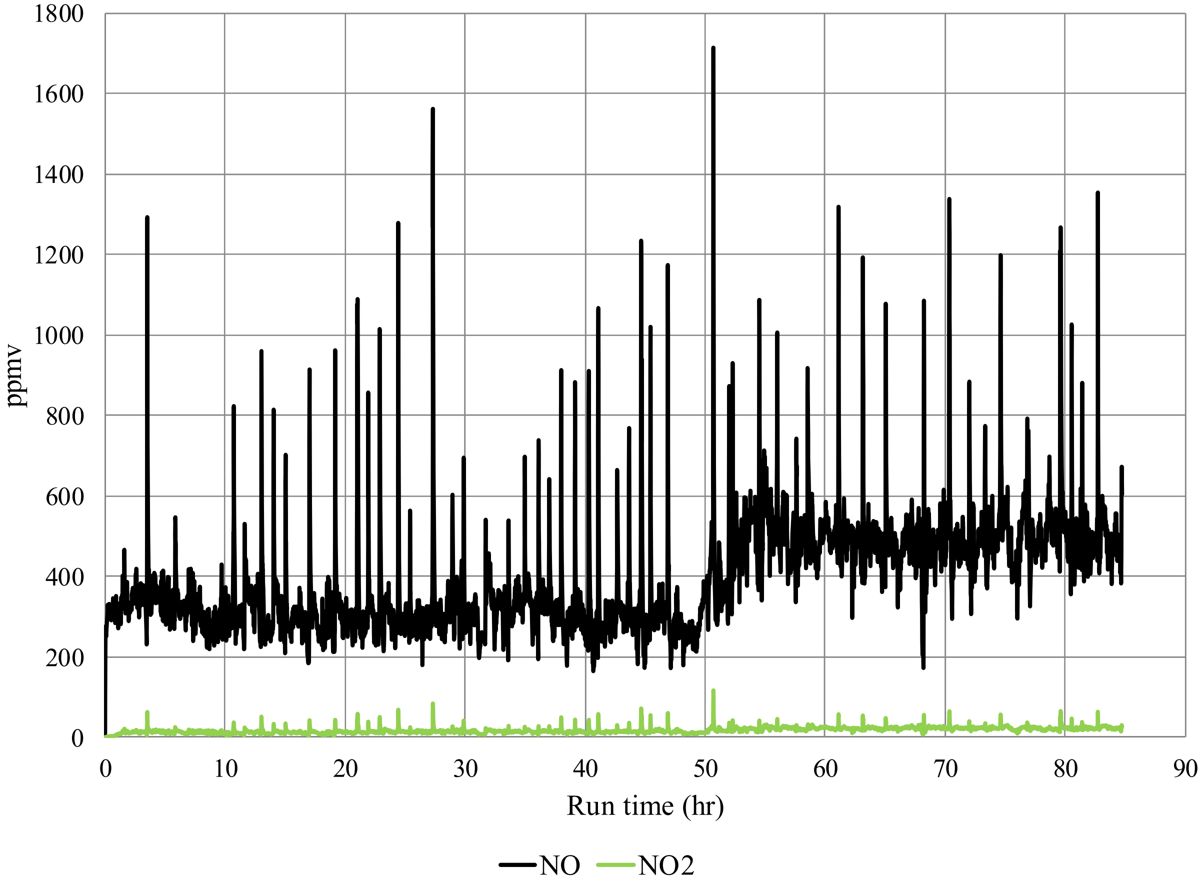


Figure 5.2.c. FTIR monitored NO and NO_2 emissions during tests with fixed and optimized bubbling, Test 3.

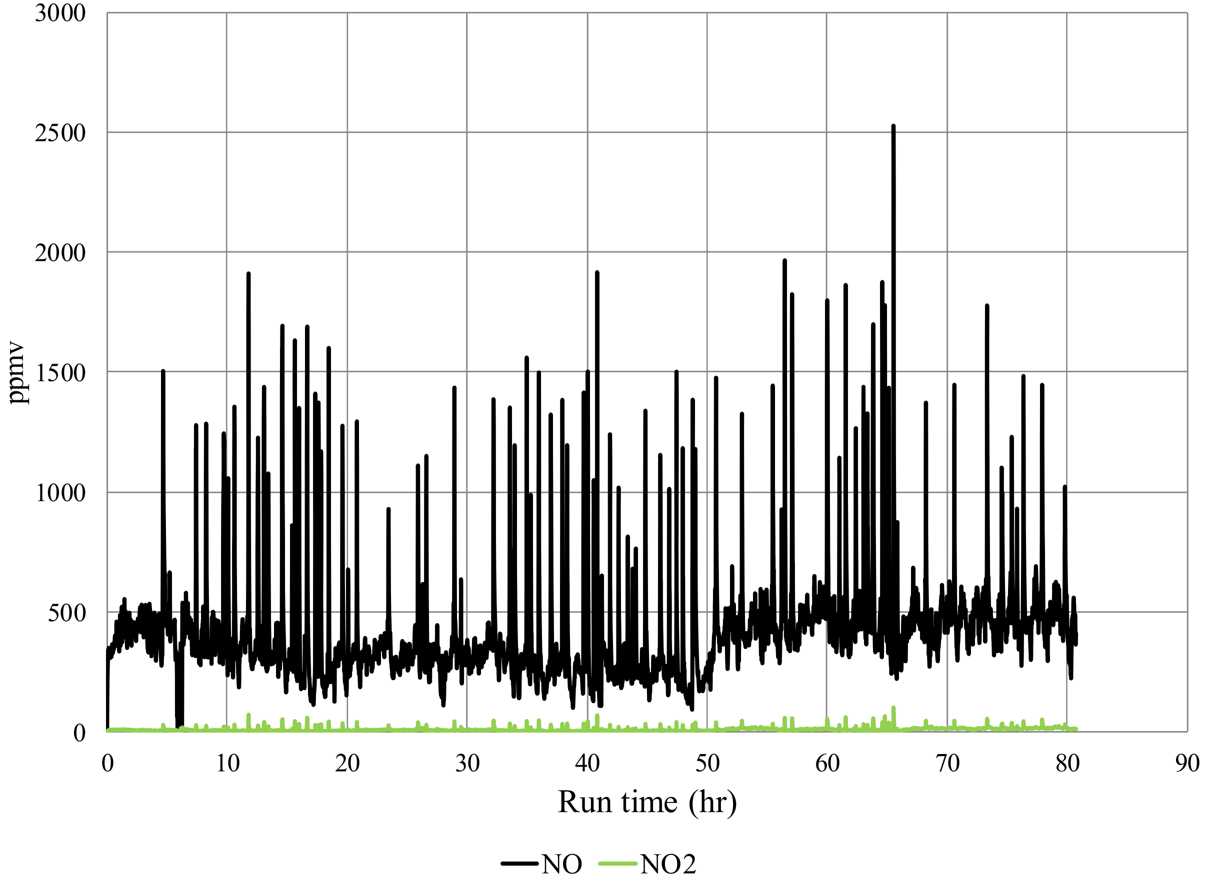


Figure 5.2.d. FTIR monitored NO and NO_2 emissions during tests with fixed and optimized bubbling, Test 2.

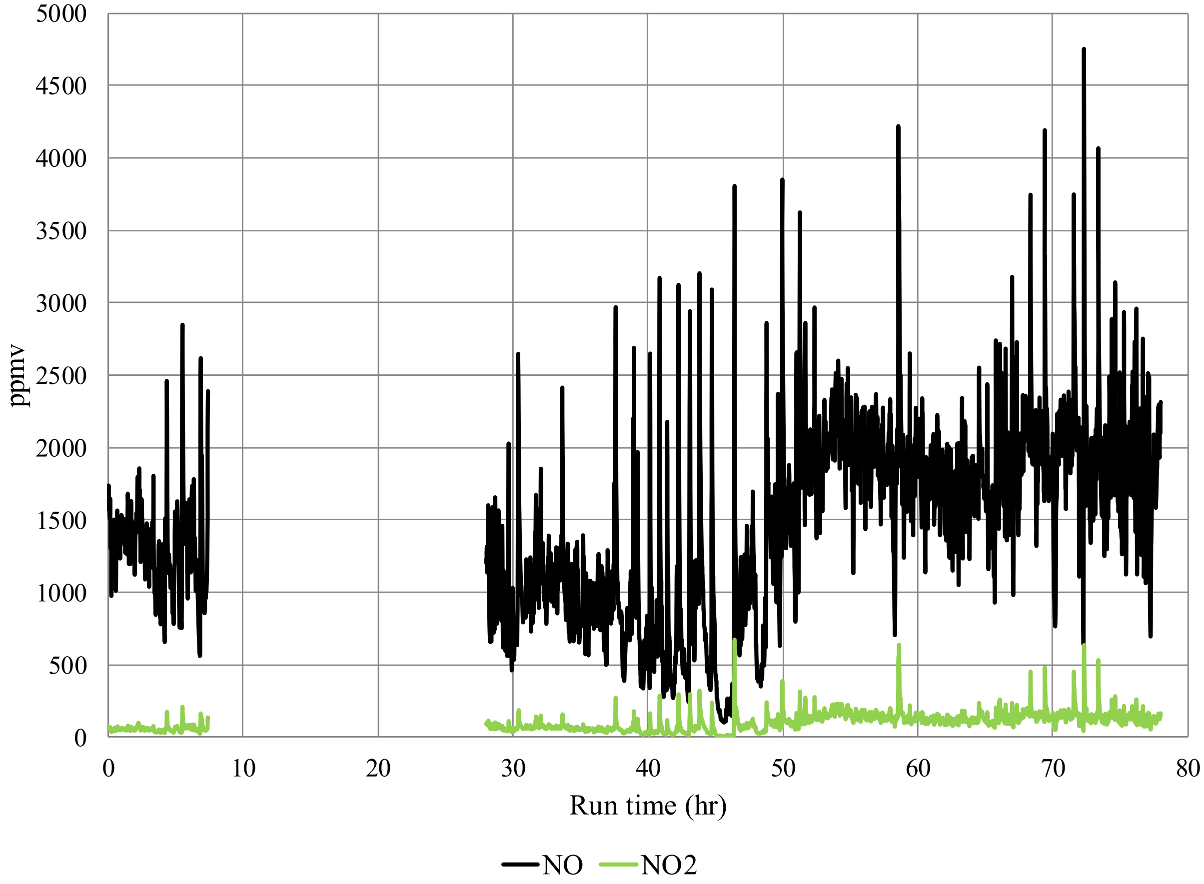


Figure 5.2.e. FTIR monitored NO and NO_2 emissions during tests with fixed and optimized bubbling, Test 1.

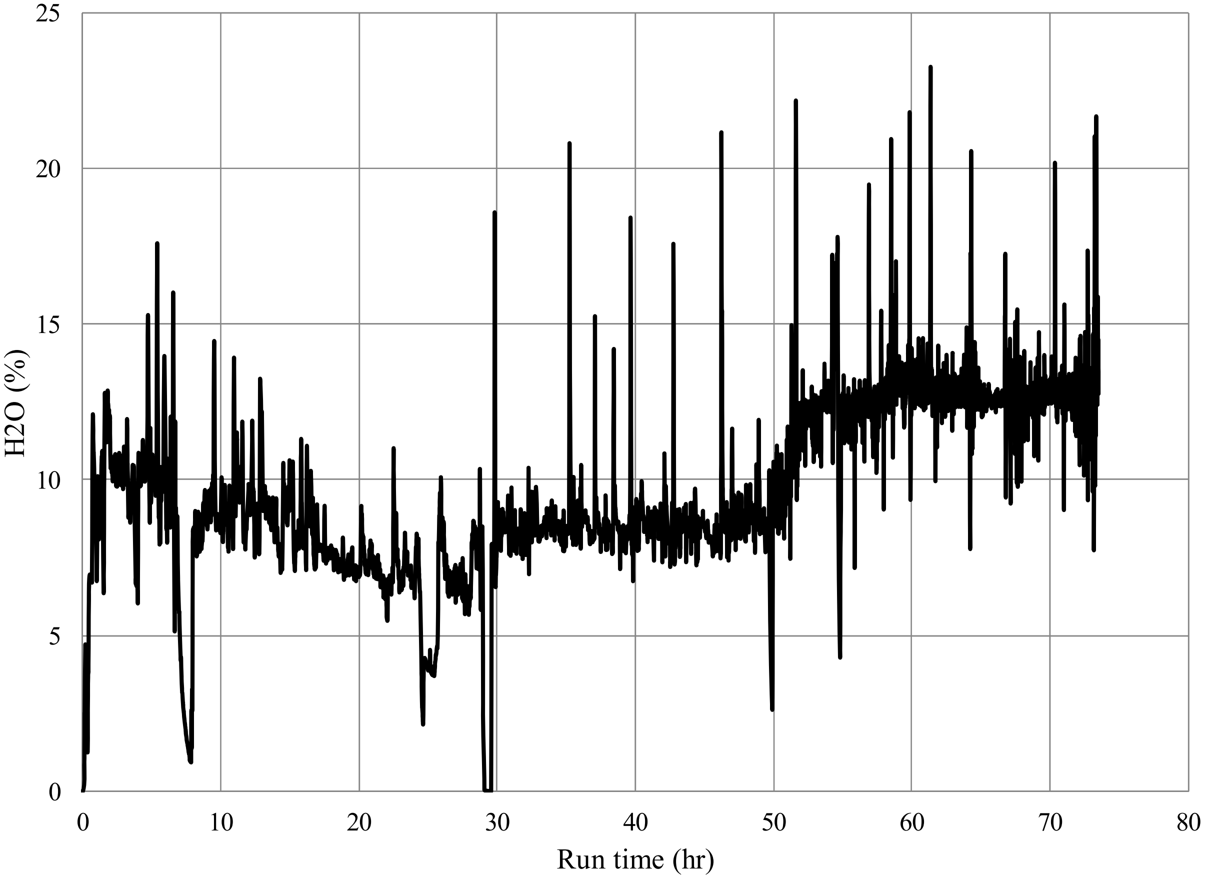


Figure 5.3.a. FTIR monitored water content of exhaust during tests with fixed and optimized bubbling, Test 5.

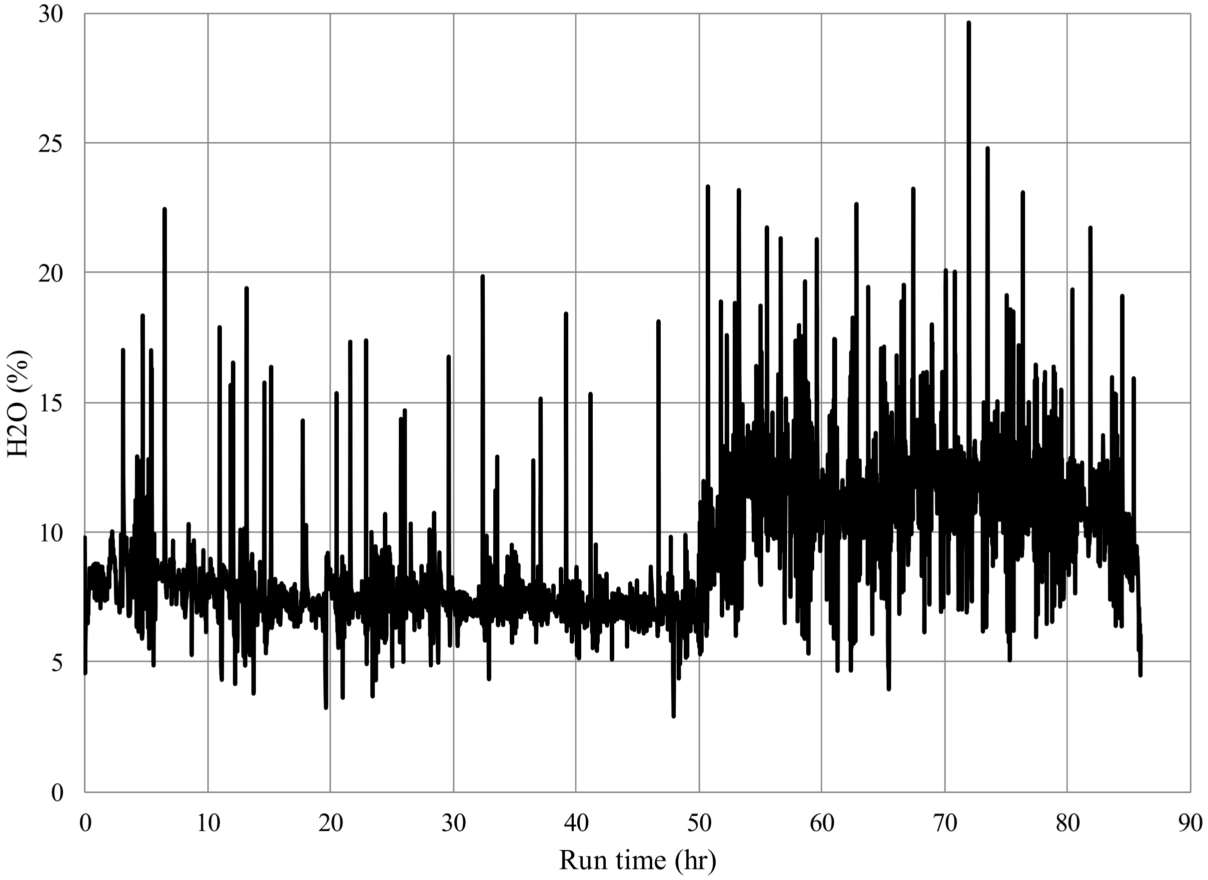


Figure 5.3.b. FTIR monitored water content of exhaust during tests with fixed and optimized bubbling, Test 4.

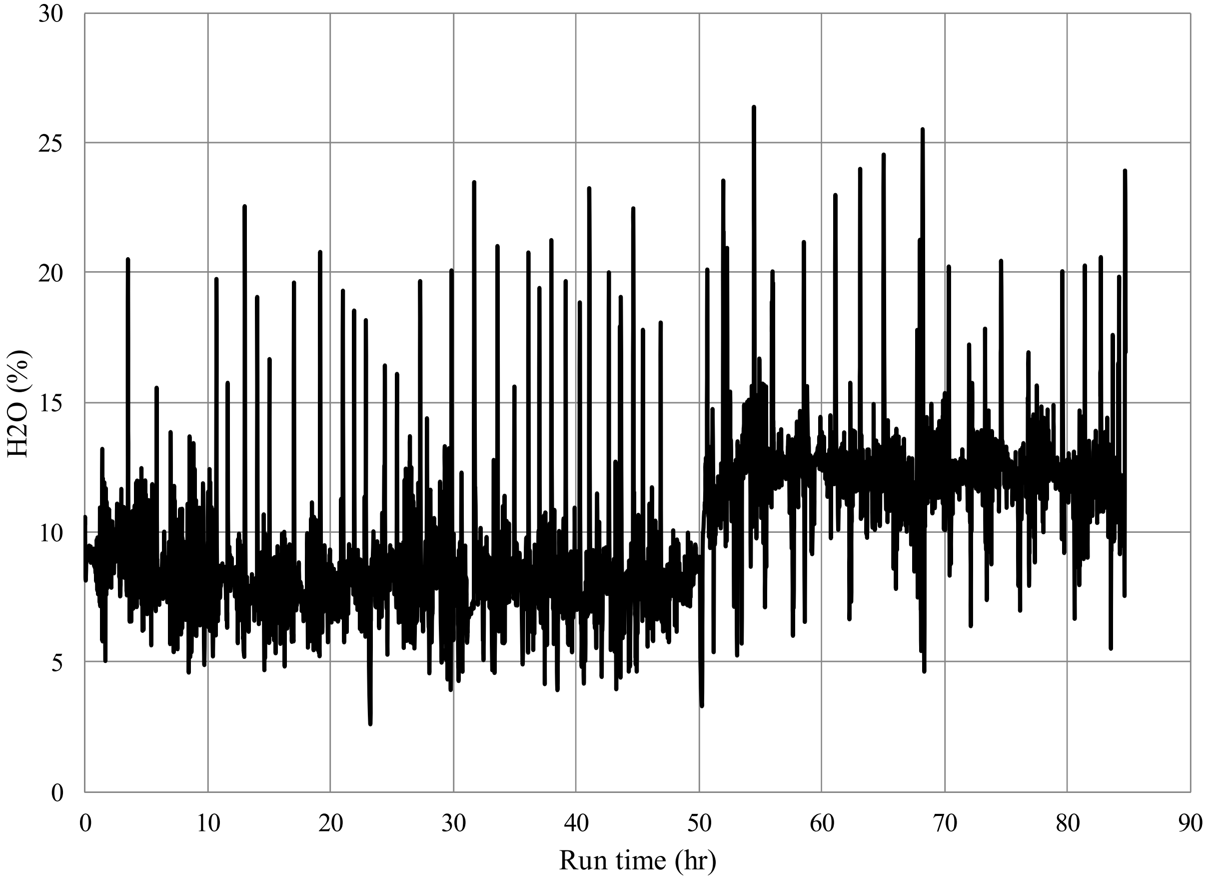


Figure 5.3.c. FTIR monitored water content of exhaust during tests with fixed and optimized bubbling, Test 3.

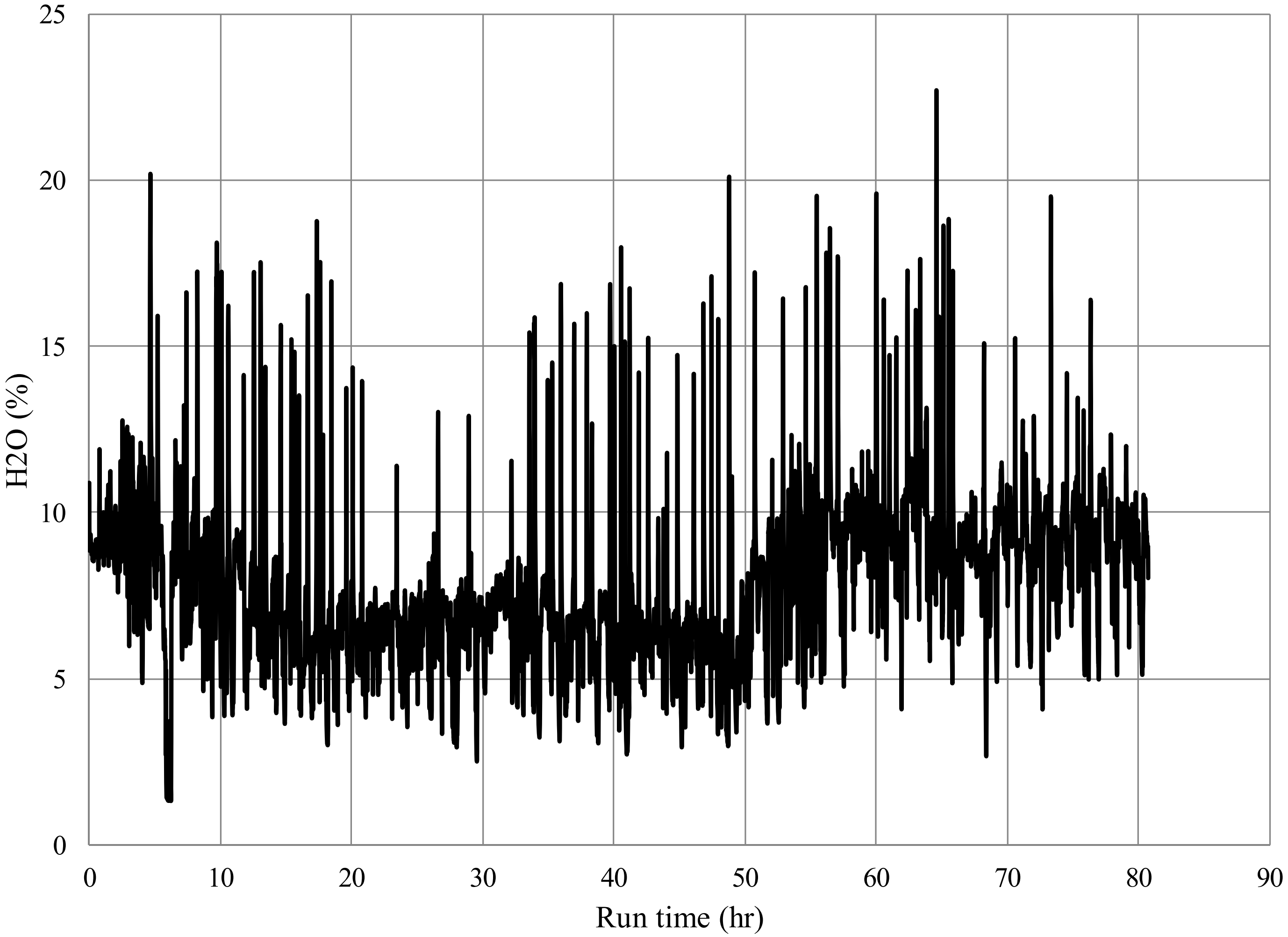


Figure 5.3.d. FTIR monitored water content of exhaust during tests with fixed and optimized bubbling, Test 2.

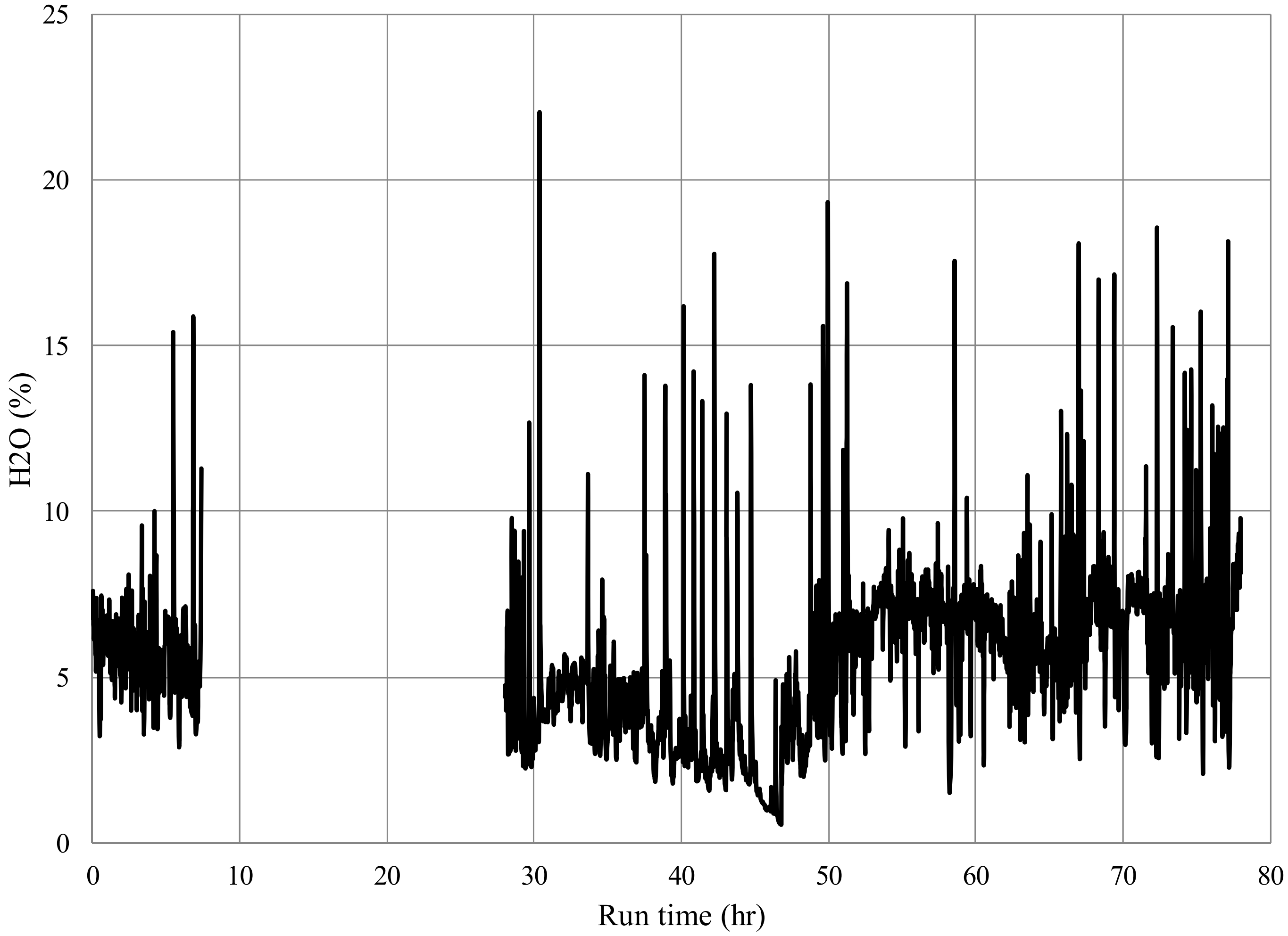


Figure 5.3.e FTIR monitored water content of exhaust during tests with fixed and optimized bubbling, Test 1.

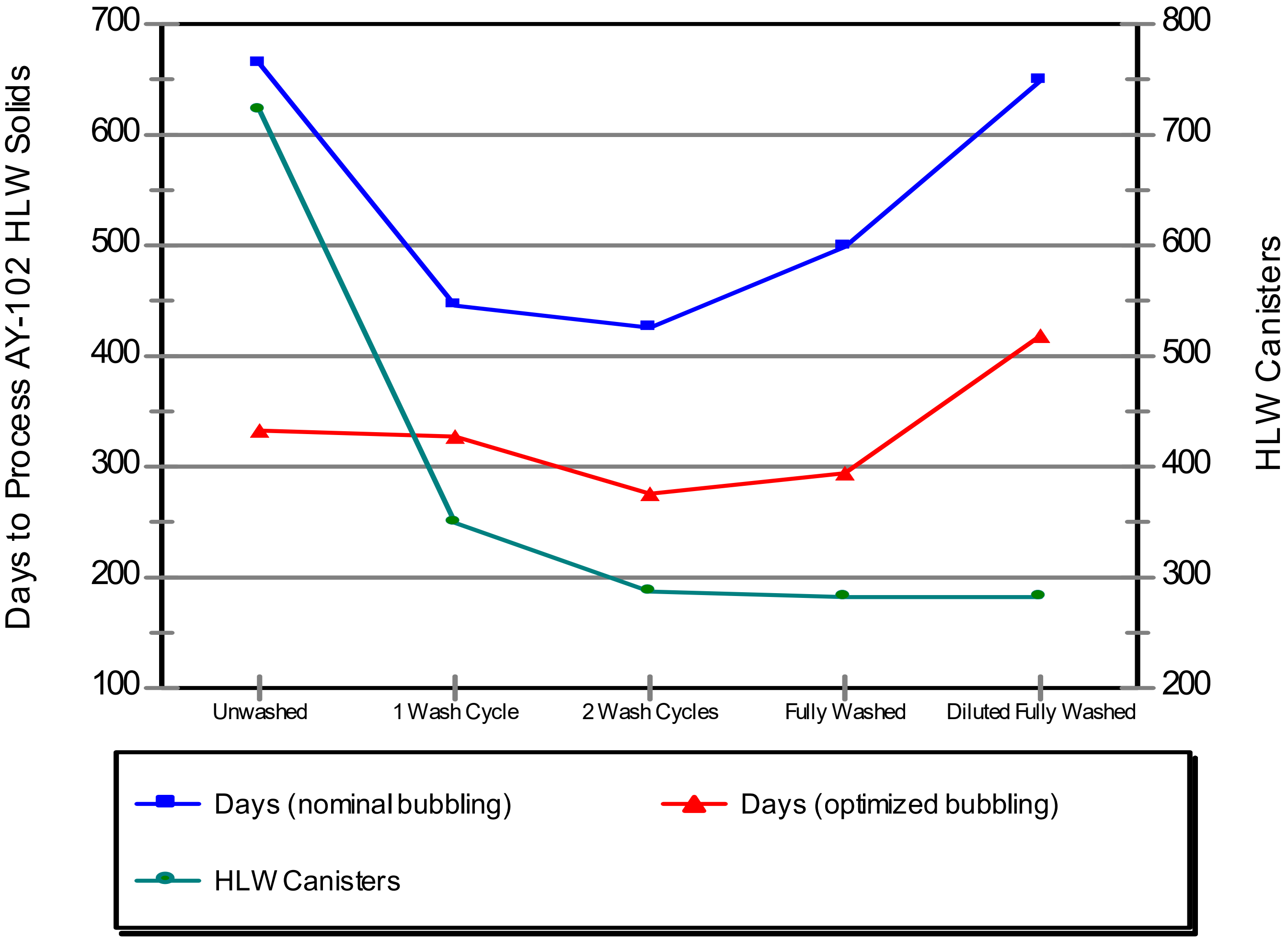


Figure 6.1. Time (at 70% TOE) and HLW canisters required to process 331,892 kg HLW oxides in AY-102 tank.