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Final Report: Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A3 Feed in Support of the LAW Pilot Melter, VSL-01R62N0-1, Rev. 2

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

Office of River Protection

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Compositional Variation Tests on DuraMelter 100 with LAW Sub-Envelope A3 Feed in Support of the LAW Pilot Melter

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SECTION 1.0
INTRODUCTION

The Vitreous State Laboratory at The Catholic University of America (VSL) is developing and testing glass formulations for RPP-WTP waste envelopes to provide data to meet the RPP-WTP contract requirements and to support system design activities [1]. That work is based upon small-scale batch melts ("crucible melts") using waste envelope simulants. Selected formulations have also been tested in small-scale continuously -fed joule-heated melters (DM10 and DM100 systems) [2, 3] and, ultimately, in the LAW Pilot Melter [4-6]. Such melter tests provide information on key process factors such as feed processing behavior, dynamic effects during processing, sulfate incorporation, processing rates, off-gas amounts and compositions, foaming control, etc., that cannot be reliably obtained from crucible melts. This sequential scale-up approach in the vitrification testing program ensures that maximum benefit is obtained from the more costly pilot-scale tests and that the most effective use is made of that resource. The principal objective of the work described in this report was to collect the necessary small-scale melter test data with a LAW Sub-Envelope A3 waste simulant in order to support the next series of tests with the same melter feed on the LAW Pilot Melter. This work was conducted under a corresponding Test Specification [7] and Test Plan [8].

A previous series of tests on the LAW Pilot Melter was directed towards demonstration of the ability to process flow-sheet levels of sulfate following the decision to delete the sulfate removal process from pretreatment [4-6]. Those tests were based on supporting crucible and small-scale melter tests [1-3, 9]. High-sulfate feeds based on a representative tank composition from each waste envelope (A, B, and C) were used for those tests. In particular, the Envelope A tests were based on the composition of tank AN-104, which is designated as "Sub-Envelope A3" [1], and which is also the subject of the present work. While the earlier tests were based on nominal feed compositions, the objective of the present work, and the parallel LAW Pilot Melter tests, was to determine the effects of process variations around the nominal composition and, in particular, to evaluate variations in the ratio of waste to glass formers. The motivation for these tests is that the process should be robust enough to accommodate reasonable variations in the feed make-up without deleterious consequences such as the formation of a salt layer on the molten glass pool, unfavorable processing behavior, or adverse feed rheology or melt and glass product properties.

In addition to the feed variation tests, a series of tests was conducted on the DM100 system in which the amount of reductant was varied in order to assess the impact on sulfur partitioning, glass redox, and processing characteristics. While the present flow-sheet shows that sulfur that is captured in the off-gas system will be recycled to the feed, the RPP-WTP Project is evaluating the possibility of instead purging that stream to waste-water treatment. Thus, while in the "recycle" scenario there is a clear incentive to capture as much sulfur in the glass as possible, in the "purge" scenario, waste loadings can be increased by increasing the partitioning of the sulfur to the off-gas stream. The latter approach has been employed at VSL for a number of other high-sulfur wastes in previous melter tests [10, 11]. Accordingly, a second objective of the DM100 tests was to provide data on a representative Envelope A composition for evaluation of the purge approach. It is anticipated that, if the "purge" approach is pursued, other reductants or reductant combinations will be evaluated in order to optimize the partitioning that is achievable without over-reducing the melt.

The three tests described in this report utilized blended feed (glass formers plus waste simulant) prepared by Optima Chemicals according to VSL specifications sufficient to make about 2.25 metric tons of glass. Sugar was added (at VSL) to the nominal feed at a ratio of 0.5 (1 mole sucrose per 16 mole NO_x) for the variation tests and at ratios of 0.75, 1.0 and 1.25 for the test segments with increased sugar. The DM100-WV melter was used in order to provide a direct comparison with the LAW tests previously conducted on the same melter [2, 3]. Three 100-hour melter tests, one for each of the three feed compositions, were conducted: one with 15% excess simulant, one with 15% excess additives, and one with varying sugar content. Key operating parameters including cold cap coverage, feed rate, and glass pool temperature were held constant to investigate the effects of the glass compositional changes on processing characteristics (including salt formation) and the product glass. The bubbling rate was adjusted to provide the desired glass production rate with a near-complete cold cap (90-100% of melt surface covered with feed). Quantitative measurements of glass production rates, melter operating conditions (temperatures, pressures, power, flows, etc.), and off-gas characteristics (NO_X, SO_2, CO, particulate load and composition, and acid gases) were made for each test.

1.1 Test Objectives

The principal objective of the DM100 tests was to demonstrate the robustness of the vitrification process with respect to feed and glass compositional changes resulting from variations in the simulant-to-additive ratio. The DM100-WV unit was selected for these tests; that melter was used for all of the Part B1 tests on LAW Envelopes A, B, and C sulfate incorporation [2, 3] that were used to support the subsequent tests on the Pilot Melter [4-6]. The same melter was selected for the present tests in order to maintain comparisons between the data sets. In addition, the somewhat smaller glass volume for the same melt surface area as compared to the DM100-BL melter means that more glass turnovers are achieved for a given test duration.

The DM100 tests used excesses of 15% glass formers and 15% waste simulant over the nominal. Previous Pilot Melter tests on Envelope A with 10% variations (but with sulfate removal) showed significant impacts on glass production rates that were ultimately corrected by adjustments in the sugar additions. Consequently, robustness with respect to throughput as well as sulfate tolerance are important motivations for these tests. Subsequent to the successful outcome of these tests, the same melter feeds were tested at a larger scale in subsequent Pilot Melter tests. The RPP-WTP Project has developed the underlying technical basis for the selected 15% variations. The amount of glass produced from an individual batch of pretreated waste is expected to be a function of either the sodium or sulfur content of that waste. The Project's estimate for the uncertainty of these analyses that have been used in the error assessments conducted by Process Engineering is 10%. These models have also assumed an error for volume transfer measurements of 5%. The 15% represents the sum of these errors assuming that both occur simultaneously in the same direction, i.e. combined low sulfate or sodium analysis and high volume transfer error for the high waste concentration case. Supporting crucible melt studies performed at VSL have indicated that no sulfate phase separation is expected for such variations. However, one of the objectives of this test was to confirm that only single-phase glass is being produced prior to exposing the LAW Pilot Melter to the high-sulfate feed. The melter was examined at the end of each feeding period to verify that no sulfate phase was detectable.

The second objective of these tests was to examine the effects of increased sugar additions to the feed on sulfur retention in the glass product and partitioning to the off-gas stream. The cost of the large-scale Pilot Melter tests, the capital investment in that asset, and the potential deleterious effects of the formation of either molten sulfate salts or reduced sulfides necessitates smaller-scale testing before advancing any approach to pilot-scale testing.

Thus, the major objectives of these tests were to:

- Perform tests on the DM100-WV system using Sub-Envelope A3 feed compositions with a 15 weight % surplus of either additives or simulant to ascertain the sensitivity of the vitrification process to variations in simulant-additive ratio.
- Perform tests on the DM100-WV using Sub-Envelope A3 feed compositions with a wide range of sugar ratios to ascertain the sensitivity of the vitrification process to variations in reductant concentration and the extent of sulfur partitioning to the off-gas stream that is possible without deleterious processing effects.
- Determine the effect of compositional changes and feed sugar ratio[1] on sulfur retention in the glass product and the tendency to form a separated salt phase on the molten glass pool.
- Demonstrate sustained processability and product quality over compositional ranges resulting from variations of the simulant-additive ratio for a glass formulated for the Sub-Envelope A3 waste stream.
- Collect melter emissions data to determine the effect of composition and feed sugar concentration on melter emissions.
- Determine the effect of feed sugar concentration on the sulfur retention and the iron redox state of the glass product.

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[1] We have <u>defined</u> the sugar to nitrate ratio in terms of an <u>assumed</u> stoichiometry of one mole of sucrose per eight moles of NOx as equal to a ratio of one. The operationally preferred value of this ratio has been determined empirically from many tests with bubbled melters including M-Area, the LAW Pilot melter, and VSL melter tests. These data indicate that a ratio of close to 0.5 is sufficient to mitigate foaming while avoiding over-reduction of the glass melt (typically, $Fe^{2+}/Fe_{tot} < 0.1$). This sugar to nitrate ratio is comparable to that used at WVDP, which was based on generally similar reasoning.

- Provide supporting data necessary to ensure the success of the larger-scale Pilot Melter tests.

1.2 Quality Assurance

This work was conducted under an NQA-1 based quality assurance program that is in place at VSL. This program is supplemented by a VSL Quality Assurance Project Plan (QAPP) for RPP-WTP work. Per RPP-WTP Project direction, the program was revised during the performance of this work. Accordingly, work performed before 8/1/01 was performed under an NQA-1 (1994) program and corresponding QAPP [12], while work performed after that date was performed under an NQA-1 (1989) and NQA-2a (1990) Part 2.7 based quality assurance program and corresponding QAPP [13]. In addition to the results of the work that was performed, this report also documents any material departures from the Test Plan or QAPP.

1.3 Melter System Description

1.3.1 Feed System

A schematic diagram of the DM100 vitrification system is shown in Figure 1.1. The melter feed is introduced in batches into a feed container that is mounted on a load cell for weight monitoring. The feed is stirred with a variable speed mixer and constantly recirculated except for periodic, momentary interruptions during which the weight is recorded. The way in which the feed is introduced into the melter is designed to mimic the operation of an ADS pump, which is the present RPP-WTP baseline. The recirculation loop extends to the top of the melter where feed is diverted from the recirculation loop into the melter through a Teflon-lined feed line and water-cooled feed tube. Two computer operated pinch valves, one on the feed line and one on the recirculation loop, are activated in a timed sequence to introduce feed into the melter at the desired rate. The feed rate is regulated by adjusting the length of each pulse, the time between each pulse, and the pressure applied to the recirculation loop. A compressed air line is attached to the feed line and can be used to automatically clear the feed line into the melter after each pulse. The mixed feed enters the melter through a water-cooled, vertical feed tube.

1.3.2 Melter System

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

1.3.3 Off-Gas System

For operational simplicity, the DM100-WV is equipped with a dry off-gas treatment system involving gas filtration operations only. Exhaust gases leave the melter plenum through a film cooler device that minimizes the formation of solid deposits. The film-cooler air has constant flow rate and its temperature is thermostatically controlled. Consequently, under steady-state operating conditions, the exhaust gases passing through the transition line (between the melter and the first filtration device) can be sampled at constant temperature and air flow 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 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.

SECTION 2.0
WASTE SIMULANT AND GLASS FORMULATIONS

2.1 Waste Simulants

The Sub-Envelope A3 waste simulant is based on composition data for the Part B2 tanks with the highest sulfate content among the planned Envelope A tanks. Thus, the Sub-Envelope A3 simulant was based on tank AN-104 data derived from the TWRS-OUP [14]. Specifically, the Sub-Envelope A3 simulant composition was formulated using the supernate compositions obtained from "Case 3S6D" of the feed delivery sequence [15]. The sodium concentration in the simulant was increased by 2.6% (relative) to account for sodium additions in pretreatment [1, 3]. The cesium content was increased by a factor of 250 to yield sufficient cesium in the glass product (about 0.14 wt%) for mass balance analytical purposes. The sulfate and sodium contents in the simulant were then increased to represent recycle (assumed to be sodium sulfate) from the off-gas treatment system to the melter feed assuming that 20% of the sulfur in the feed is emitted to the off-gas stream[2] [2-6]. The nominal concentration, expressed in terms of the sodium molarity, was selected on the basis of melter feed rheology tests after mixing with appropriate glass forming additives [16]. The results of those tests led to the selection of 6 molar sodium as the nominal simulant concentration for Sub-Envelope A3. It should be noted that the Tank Farm Contractor Operation and Utilization Plan (TF COUP, "Case 3S6E") [17] replaced the TWRS OUP [14] document in April 2000. However, the compositional change for AN-104 from Case 3S6D to Case 3S6E is very small and, therefore, for consistency, the same simulant that was used in the previous testing with AN-104 [3, 4] was retained for the present tests[3].

The nominal simulant formulation is shown in Table 2.1. The resulting waste simulant is a solution of predominantly sodium nitrite, nitrate, carbonate, and hydroxides of sodium and aluminum. It is a green solution, slightly opacified by small amounts of suspended material, with a density around 1.3 g/ml and a pH value around 13.5.

2.2 Glass Formulation

The feed additives were selected on the basis of glass formulation studies, which included optimization with respect to sulfate incorporation and potential salt phase formation [1–3, 9], and

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[2] The integrated WTP flow sheet models that will ultimately provide the basis for the impacts of these streams were not available at the time this work was performed.

[3] Tests performed during Part B1 on the DM100 and the Pilot Melter with AN-104 simulants [3, 4] were based on Case 3S6D. These data result in 0.35 wt% SO_3 in the glass product (formulation LAWA102) at a Na_2O loading of 14.42 wt% (before including the assumed recycle). In comparison, the Case 3S6E data would give 0.33 wt% SO_3 at the same Na_2O loading. In Case 3S6E, AN-104 still has the highest ratio of sulfur to sodium for the early Envelope A tanks.

rheological testing [16]. Based on these results, glass formulations were selected for previous DM100 and pilot plant tests and, specifically, LAWA102 was selected for the Envelope A, AN-104 waste. The composition of these glasses and the waste and additive fractions are shown in Table 2.2; the additive sources are shown in Table 2.3. Glass formulations to be used in this study were derived by adding an additional 15 weight percent simulant or additives to the nominal formulation, as shown in Table 2.2.

Test batches of the proposed feed of approximately 1 kg were made for both surplus feed compositions in order to verify the processability of the feed (rheological properties), the glass melt, and the glass product. The test results are shown in Table 2.4. The majority of the measured parameters show the expected trends: highest water and pH contents for the excess waste simulant formulations and highest density and glass conversion ratio for the excess additive formulations. The measured rheological properties of the feed samples show little effect of the composition variations. An aliquot of each of the feeds was also melted in a platinum crucible and glass processing properties measured, which are included in Table 2.2. Measured glass conductivities and viscosities are still within the acceptable processing envelope. As expected, the excess additive formulation is more viscous and less conductive than the nominal composition, whereas the opposite trend is observed for the excess simulant formulation.

2.3 Preparation of Melter Feed

Optima Chemicals, which has supplied all of the LAW simulants for the previous DM100 and LAW Pilot Melter studies, prepared the simulant and added most of the glass forming chemicals before shipment to VSL in 55-gallon drums. Boric acid and sugar were added at VSL. One third of the drums shipped contained 15% excess glass former additives and two thirds were nominal in composition. Optima also provided a batch of simulant without glass formers for addition at VSL to prepare the feed for the 15% excess waste simulant test. In order to collect data on the partitioning of iodine, the feed received from Optima was spiked with potassium iodide at VSL to provide a target concentration that is equivalent to 0.1 wt% iodine in the glass.

2.4 Analysis of Feed Samples

2.4.1 General Properties

Feed samples were analyzed from each received feed batch and from each test that was conducted to confirm physical properties and chemical composition. Sample names, sampling dates, and measured properties are provided in Table 2.5. Notice that the values measured for the test samples approximate either the nominal target (Test 3) or the results obtained from the crucible tests conducted prior to melter runs. As expected, both the feed density and glass conversion ratio were highest for the excess glass former feed (Test 1) and lowest for the excess simulant feed (Test 2). Samples from the surplus simulant test have the highest pH due to the caustic nature of the waste simulant. Glass yields were about 8% below target for Test 3, probably due to the addition of water during transfer.

2.4.2 Rheology

Samples of the melter feeds that were used for these tests were also subjected to rheological characterization. The results from rheological characterization of a variety of other melter feeds and waste simulants, as well as the effects of a range of test variables, are described in detail in a separate report [16]. Melter feeds were characterized using a Haake RS75 rheometer, which was equipped with either a Z40DIN or a FL22-SZ40 sensor (shear rotor). A typical set of measurements consists of identifying the flow characteristics of the slurry by measuring the shear stress on the slurry at controlled shear rates and temperatures. In these measurements, the shear rate values are preset and are increased stepwise from 0.01 s^{-1} to 200 s^{-1} (70 s^{-1} for FL22-SZ40) with a sufficient delay (typically 15 to 30 seconds) between steps to ensure that shear stress is allowed to fully relax and therefore measured at equilibrium. It should be noted that this approach is somewhat different than the "flow curve" approach that is often used in which the shear rate is ramped up to some maximum value and then ramped back down to produce a hysteresis curve that is dependent on the arbitrarily selected ramp rate. In contrast, the present measurements are equilibrium values of the shear stress at each measured shear rate. The viscosity of the sample as a function of the shear rate is then calculated as the ratio of the shear stress to the shear rate. The yield stress data for the melter feeds were measured using a controlled-stress mode in which the torque on the rotor was slowly increased while the resulting deformation of the fluid was monitored. The discontinuity in the measured deformation-torque curve was identified as the yield stress. It should be noted that this direct measurement of the "true" yield stress can be quite different from the value that is often reported as the yield stress, which is instead obtained simply by extrapolation of the shear stress-shear rate curve to zero shear rate. All of the measurements in this work were made at 25°C; previous work [16], which examined a range of temperatures, showed a relatively weak effect of temperature.

Rheograms for the melter feeds, which show the feed viscosity versus shear rate, are presented in Figure 2.1; measured values for viscosity at selected shear rates and the yield stress values are compared to previously measured values in Table 2.5. As expected, the highest measured viscosities were for samples from the excess additive tests and the lowest for the samples from the excess simulant test. Yield stress values remained low for all of the samples.

2.4.3 Chemical Composition

The chemical compositions of the feed samples were determined by first making a glass from the feed via crucible melt. The glass was subsequently crushed and either dissolved in an HF/HNO_3 acid mixture with the aid of a microwave oven to produce a solution for DCP analysis or analyzed directly by XRF. Boron and lithium oxide target values were used for normalizing the XRF data since those elements were not determined by XRF. The sum of analyzed oxides for DCP is not normalized and therefore is typically slightly below 100%. Data from both methods are compared to the target composition in Table 2.6. These results generally corroborate the consistency of the feed composition and show good agreement with the target composition for the major elements. Agreement between the two procedures is generally good with higher XRF values for silicon, iron, and sodium. Potassium oxide, which was targeted at about a quarter of a weight percent was consistently two to three times above target. This has been observed in past feed analyses for low-potassium feeds and is probably the result of impurities in the raw materials. Volatile minor elements such as sulfur, cesium, and chlorine are below target due to loss during crucible melting. Further comparison of XRF and DCP glass analyses is provided in Section 4.

SECTION 3.0
MELTER OPERATIONS

Melter tests were conducted on the DM100-WV with the LAW Sub-Envelope A3 simulant between 6/18/01 and 8/17/01, producing over 2000 kg of glass. The tests were divided as follows:

- Test 1: +15% Additives
- Test 2: +15% Simulant
- Test 3: Nominal feed with Increasing Sugar Ratio:
    - Test 3A: Sugar Ratio = 0.5
    - Test 3B: Sugar Ratio = 0.75
    - Test 3C: Sugar Ratio = 1.0
    - Test 3D: Sugar Ratio = 1.25

It should be noted that Test 3 was conducted as a single uninterrupted run with the sugar ratio being increased every 24 hours to produce the four test segments.

Test summaries are provided in Table 3.1 for Tests 1 and 2 with excess additives or simulant and in Table 3.2 for Test 3, which investigated the effect of increasing amounts of reductants (sugar) in the feed. Attempts were made to replicate the melter configuration and operating conditions used for the corresponding tests conducted approximately one year earlier [2, 3].

The production rates summarized in Tables 3.1 and 3.2 are depicted in Figures 3.1 - 3.3; note that the target production rates are different for each test segment as a result of the different glass conversion ratios. The target production rate was approximated for Tests 2 and 3 but the production rate achieved for Test 1 was slightly lower than the target (1350 vs. 1550 kg/m^2/d). Initially, this shortfall was attributed to bridging of the cold cap across the melt surface; however, this had not been observed with the earlier tests with the nominal feed. It was later traced to poor bubbler performance as a result of corrosion and the bubbler was therefore replaced during Test 2. Test 2 was initially started on 7/10/01 and stopped after about 48 hours of processing because of the increasing difficulty in obtaining processing rates that were easily attainable in the previous tests [2, 3]. During subsequent inspection, the faulty bubbler was identified and replaced. Test 2 was then started on 7/13/01 and run for over 98 hours with no difficulty in achieving the target production rate. Another difference between data displayed for Test 1 and the other tests is the reduced number of data points collected during Test 1, which was the result of a computer error that was subsequently corrected.

The results of various operational measurements that were made during these tests are given in Table 3.3. The target glass temperature of 1150°C was successfully maintained during each of the tests, as illustrated in Figures 3.4 - 3.6. Glass temperatures for the majority of the glass pool approximated the target, whereas temperature readings made near the melt surface and in the cold cap fluctuated with the level of glass in the melter. The average plenum temperatures for the tests were 492-585°C, well within the 450 - 650°C range targeted for the steady-state portions of the tests. Since plenum temperature is a function of the extent to which the surface of the melt pool is covered by feed, plenum temperatures decrease over the course of each test as the cold cap develops, as shown in Figures 3.7 - 3.9. Efforts to maintain a constant target feed rate occasionally resulted in over feeding of the melter and lower plenum temperatures than desired, particularly for Test 1. Of the two plenum thermocouples, one was exposed and the other was inside a thermowell. The exposed and thermowell-encased thermocouples provided comparable temperatures, with the exposed thermocouple being more sensitive to temperature changes, as expected. Temperatures for the three electrodes and the bubbler are compared in Figures 3.10 – 3.12. The bubbler temperature was typically very close to the bulk glass temperature. The electrode temperatures were all lower than the bulk glass, with the bottom electrode being about 200°C cooler than the side electrodes. Figures 3.4 – 3.12 display the temperature variations and the electrode power for all of the tests.

Gas temperatures at the film cooler typically averaged between 300 and 400°C, depending on the plenum temperature, the amount of added film cooler air, and the temperature of the added film cooler air. Little or no drop in gas temperature was observed across the (insulated) transition line.

SECTION 4.0
GLASS PRODUCT

Over 2000 kg of glass product was discharged from the melter periodically using an airlift system into 5-gallon pails. The discharged product glass was sampled at the end of each test by removing sufficient glass from the top of the cans for total inorganic analysis. Selected samples were also analyzed with wet chemical techniques for iron redox state and with optical microscopy for secondary phases. Product glass masses, discharge date, and analysis performed are given in Table 4.1. Glass samples were also obtained by dipping a rod into the glass pool at the beginning and end of each test. These "dip samples" underwent visual examinations to detect the presence of sulfate salts on glass surface as well as total inorganic compositional analysis.

4.1 Compositional Analysis

Discharge and dip glass samples were crushed and either dissolved in acid with the aid of a microwave oven to produce a solution for DCP analysis or analyzed directly by XRF. Target concentrations for boron and lithium oxides were used for normalizing the XRF data to 100 wt% since these elements were not determined by XRF. Analyzed glass compositions of discharged samples are provided in Tables 4.2 for DCP analysis and Table 4.3 for XRF analysis. Analysis results for dip samples by XRF and DCP are provided Table 4.4. Compositional trends over the course of the tests are plotted for select oxides in Figures 4.1 and 4.2 (DCP results) and in Figures 4.3-4.5 (XRF results). Results from the different methods of analyses agree well for the vast majority of elements, as was the case for feed sample analysis.

DCP data for discharged glass samples generally show good agreement with the target composition for the majority of elements, including boron and lithium oxides, which could not be analyzed by XRF. Total DCP recoveries were generally above 95 %. DCP analyses for silica were about 5% below the target, and those for Na_2O were 5-20 wt% below the target. Since fewer glass samples were analyzed over the course of the tests by DCP, the compositional trends shown in Figures 4.1 and 4.2 may be less meaningful. Generally, good compositional consistency was observed over the course of the tests except for Na_2O, which was expected to change due to the intended variations in the amount of simulant used. The SO_3 values shown for some of the samples were determined by ion chromatography of the digested glass samples; that method tends to be noisier than the results obtained by direct XRF analysis of the glass samples.

The vast majority of the discharged glass samples were subjected to XRF analysis. The majority of the XRF analysis results compared very favorably to their corresponding target values. Compositional trends for selected oxides shown in Figures 4.3 and 4.4 illustrate the closeness to target and the consistency over the course of the tests. Unlike the majority of the oxides comprising the product glass, Na_2O target concentrations vary significantly with the intended changes in the ratio of waste simulant to glass forming additives. Notice in Figure 4.4 that the Na_2O concentrations stabilize near the Test 1 target of 12.88 wt% during the production of the first 550 kg of glass as a consequence of feeding excess additives. Over the next 850 kg of production while excess simulant feed is used, the Na_2O content increases toward the Test 2 target of 16.18 wt%. Sodium oxide concentrations finally approach the nominal target of 14.46 wt% towards the end of Test 3 in response to the use of nominal feed.

The chromium concentrations in the glass product (Table 4.3) tend to be higher at the beginning of each test as a result of the chromium accumulation from the melter refractory during idling (with the starting value increasing with the idling duration); the values then typically fall as each test proceeds. The concentrations fall to somewhat lower values for Test 3, which may be a result of the redox sensitivity of the solubility of chromium.

The concentrations of chlorine, cesium, and sulfur, all of which are relatively volatile, are plotted over the course of the tests in Figure 4.5. The SO_3 concentrations follow the behavior of sodium during the first 1400 kg of production, approaching the lower target (0.39 wt%) during Test 1 and increasing towards the higher target (0.48 wt%) in Test 2. During the last segment of the testing, the SO_3 concentrations decrease from the nominal target of 0.44 wt% to ~0.15 wt.% as the sugar ratio in the feed is increased from 0.5 to 1.25. As the sulfur decreased in the glass product, sulfur emissions from the melter increased (see Section 5). Chlorine concentrations, although well below target throughout the tests, increased over the course of each test segment and decreased substantially during idling periods between test segments. Cesium consistently remained about 15% below target. No measurable iodine was detected by XRF analysis in any of the glass samples.

Glass dip samples were obtained at the beginning and end of each test primarily to determine if a secondary sulfate salt layer had formed on top of the glass melt. Table 4.4 provides a listing of all the dip samples together with their analyzed compositions and whether or not a separated salt phase was evident. No sulfate phase was evident in any of the dip samples from Tests 1 and 2. The melter was idled for about a month prior to starting Test 3. Dip samples taken immediately before starting Test 3 (WVB-D-102A and WVB-D-113A) showed the presence of small amounts of a sulfate phase on the glass pool, which is not uncommon on start-up after protracted idling. The sulfate phase was destroyed by feeding water to the melter, as evidenced by the lack of sulfate salt on the dip sample after that procedure (WVB-D-113B), prior to the start of Test 3.

By the end of Test 3, a sulfur layer was definitely present on the melt surface, as shown by the pervasive visual evidence on repeated dip samples. This occurred despite the low levels of sulfur measured in the discharged glasses as a result of the lower sulfur solubility in reduced glasses (see Section 4.2). XRF analysis results for dip glass samples in which no sulfate phase was observed are in good agreement with the target compositions and comparable discharge samples. Conversely, analysis results of glass dip samples that showed the presence of a salt phase did not agree with target compositions and comparable discharge samples.

4.2 Iron Redox State

The iron oxidation state for glass samples from all three tests was measured using colorometric methods. The method detection limit of 0.8% divalent iron reported here is dependent on several factors including the 5.5 % Fe_2O_3 in the target glass. Sample information including name, test, and the amount of glass produced are given in Table 4.5. The glass samples from Tests 1, 2, and 3A were expected to have below-detectable amounts of reduced iron given the sugar ratio of 0.5 that was used. Subsequently, the percentage of reduced iron increased predictably with increasing sugar ratios during Tests 3B-3D. The last sample measured, WVC-G-40A was discharged about 12 hours after feeding (during Test 3D) had ended. During this period as the cold cap decomposed, the bubbling rate and melt pool temperature were held constant. This was sufficient to oxidize the iron from about 55% divalent iron to only 13% divalent iron. As noted earlier, a sulfate phase was present at the end of Test 3D as a result of the decreasing sulfur solubility as the melt became more reduced. As the iron was re-oxidized, the amount of sulfur dissolved in the glass increased from 0.12 to 0.27% SO_3, presumably due to incorporation of sulfur from the salt layer and any residual cold cap material as a result of the increased sulfate solubility[4]. The trend of sulfur content as a function of divalent iron percentage is illustrated for Test 3 glasses in Figure 4.6. This trend is consistent with measurements made on LAW glasses in crucible melts that are saturated with sulfur under controlled oxygen fugacity conditions.

4.3 Sulfur Mass Balance

Tables 3.1 and 3.2 provide the percentages of feed sulfur that was retained in the glass product or identified in the various off-gas stream samples for each of the tests. It should be noted that the amount of SO_2 determined in the off-gas stream by FTIR should be a sub-set of the "total gaseous sulfur" amount determined in the Method 5 impingers, which should detect all gaseous forms of sulfur, including SO_2. The total recovery of feed sulfur was about 98.5% and 101.0% for Tests 1 and 2, respectively. However, the mass balance closure becomes progressively poorer during Test 3 as the glass became increasingly reduced and less sulfur was retained in the glass product: The total recovery of sulfur was about 106%, 88%, 82%, and 68% for Test 3A, 3B, 3C, and 3D, respectively. Possible sources of the shortfall may be the presence of forms of sulfur that are not being detected by the methods used (although the combination of impingers and FTIR should detect all likely forms of sulfur in the emissions and XRF should likewise detect all forms in the glass) or hold up in the melter as a separate phase. As noted earlier, a sulfate phase was definitely present at the end of Test 3D.

Earlier XRF results on the glass product from Test 3D indicated even lower levels of sulfur than are reported here. However, careful analysis of the XRF spectra revealed that this was an artifact of a slight shift in wavelength of the sulfur line as a result of the gradual shift in sulfur redox; this has been corrected in the present results. This shift in sulfur redox state is an expected consequence of the increased levels of reductants and was also independently confirmed by Raman spectroscopy and synchrotron x-ray absorption spectroscopy. Those results, which will be reported elsewhere, indicated the gradual replacement of sulfate in the glass product by lower valence forms of sulfur (primarily various polysulfides) but with little evidence of sulfides (S^{2-}).

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[4] Assuming a glass inventory of 110 kg and a melt surface area of 0.11 m^2, a sodium sulfate layer of less than 2 mm thickness would be sufficient to account for the observed increase in SO_3 content of the melt as it reoxidized.

4.4 Secondary Phases

Three glass samples, WVA-G-98A, WVB-G-99A, and WVC-40A, were examined using optical microscopy. No crystallization or evidence of secondary phases was detected in any of the samples.

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 during each test segment. 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 0.2 N NaOH was added to the sampling train to ensure complete scrubbing of all acid gases. The collected materials were analyzed using the following: DCP, AA for cesium, and ion chromatography for anions. Complete melter emission fluxes are compared to feed fluxes in Tables 5.1 and 5.2. 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 0.45 μm heated filter.

Particulate emissions from the melter were low, averaging only 0.23% and did not exceed one-third percent of feed solids. The feed element emitted at the highest percentage (or lowest melter decontamination factor (DF)) was clearly iodine, with percentages between 15 and 75% of feed detected in the gas fraction. No iodine was measured in either particulate emissions or glass product leaving a deficit of 25 to 85% with respect to the iodine mass balance. Other elements exhibiting volatile behavior include sulfur, alkali metals, the halides and, to a lesser degree, boron. This trend is in keeping with observations from several previous studies [3, 4, 6]. As expected, alkali metals showed increased volatility with increasing atomic weight (Cs>K>Na>Li). Although, as expected, the halides exhibited high volatility, the relative percentages are difficult to evaluate due to their low concentrations in the feed and their prevalence as contaminants (e.g., even in tap water) and the inability to analyze for chlorine and fluorine in acid digestions of particulate filters. Boron, sulfur, and the halides were the only elements detected in the impinger solutions collected downstream of the heated particle filter in the sampling train, which constitute the "gas" fraction of the melter emissions. Overall, emissions increased with increasing simulant content of the feed (Test 2 > Test 3A > Test 1). Other than gaseous sulfur, no trend was observed in the emissions with increasing sugar content of the feed. Sulfur emissions during Test 3 are plotted along with the iron oxidation state in Figure 5.1. Notice the increase of reduced iron and gaseous sulfur with increasing sugar ratio. Conversely, particulate sulfur emissions show little correlation to redox state, as has been observed previously [2].

5.2 Particulate Size Distributions

Particle size distributions were measured using a University of Washington Mark III Cascade impactor for all the test segments with the exception of the last portion of Test 3. Melter exhaust is iso-kinetically pulled through the impactor, which has collection plates of varying orifice sizes that separate the particulate by size. The data are derived from gravimeteric analysis of the collection plates. The material on each plate can be chemically analyzed if sufficient mass is deposited on that particular stage. Particulate size distribution results are provided in Tables 5.3 and 5.4 with chemical analysis by particle size for Test 1 in Table 5.5. A portion of the particulate material was observed in each size fraction range; however, the majority of the material was less than 1 micron in size. An exception to this is Test 3 where the coarsest fraction accounted for 21 to 42 percent of the particle mass. Observations by scanning electron microscopy of particles sampled in the past from melter exhausts indicated particles to be predominately sub-micron but often in large agglomerates. This would explain the bimodal distribution in the Test 3 samples. The chemical analysis from Test 1 stages support the thesis that small amounts of glass formers are entrained in the off gas as the coarse material and that alkali salts are emitted from the glass as fine particles. Notice the decrease in silicon, aluminum, and iron with decreasing particle size, whereas the alkali metals increase in percentage with decreasing particle size. The average recovery from the stages was about 45%, with the unaccounted portion being anionic species such as oxygen, chloride, and fluoride.

5.3 Gases Monitored by FTIR

Melter emissions were monitored in each test for a variety 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 down-stream of the HEPA filter to prevent analyte loss due to condensation prior to monitoring. A summary of average concentrations monitored during each test is provided in Table 5.6. Concentrations of nitrogen species are plotted in Figures 5.2 - 5.4. The analytes listed in Table 5.6 are those that were thought likely to be observed during the test, based on previous work; however, FTIR is sensitive to many other species, which were not detected. The most abundant gas monitored was nitrogen oxide, which is consistent with numerous previous tests in which nitrates and nitrites were incorporated in the feed. The concentration of nitrogen oxide was ten to sixty times higher than that of nitrogen dioxide and significantly more than that for all other nitrogen oxide species. As expected, nitrogen oxide emissions for the test with excess simulant (Test 2) exceeded any other test since the simulant contains the nitrates and the increase was not compensated with additional sugar.

The most dramatic changes in emissions occurred as additional sugar was added over the course of Test 3. Notice in Figure 5.4 the decreases in NO and NO_2 as the sugar ratio increases. Conversely, byproducts of incomplete combustion, most notably CO and ammonia, increase substantially as more sugar is added. Other key compounds also increase with added sugar including SO_2 and HCN. These trends were expected and observed in several previous studies in which the feed contained high concentrations of nitrates and sugar. In contrast to the Method 5-type sampling discussed earlier, gaseous chlorine and fluorine species were infrequently observed by FTIR. This is due to the impinger method being approximately 10 times more sensitive than the FTIR method and the low concentrations of halogens in the feed. The variations in emissions over the course of each test segment are due in part to the time at which the air is sampled with respect to the feed pulses and changes in instantaneous feed rates.

A nitrogen mass balance is summarized in Table 5.7. The data fit the empirical relationship previously developed for nitrates and sugar; a sugar ratio of 0.5 result in half the nitrogen oxides being presumably reduced to diatomic nitrogen. The 0.5 ratio listed for Test 2 is blind to the addition of the excess nitrate-rich simulant and therefore a much larger percentage of nitrates were emitted as nitrogen oxides.

SECTION 6.0
CONCLUSIONS

A series of tests conducted on a DM100 vitrification system has shown that the nominal LAW Sub-Envelope A3 formulation using an AN-104 waste simulant is robust with respect to substantial variations in the ratio of waste to glass forming additives. The +/- 15% variations investigated in the present tests are expected to conservatively bound the range of variations likely to be encountered in full-scale operations. The test results showed that the system successfully tolerated the resulting variations in feed properties, processing behavior, glass production rate, sulfate formation tendency, and product quality. In particular, no separate sulfate salt phase developed on the melt surface during the feed variation tests. As a result, this formulation was subsequently accepted for larger-scale testing on the LAW Pilot Melter.

Total particulate emissions from the melter averaged about 0.23 wt% and DFs were determined for each element in the feed for each of the three tests that were performed. Of the more volatile species, DFs for iodine and cesium were around 1.8 and 10, respectively, based on feed and emissions data; however, since no iodine was detected in the glass product, the true DF for iodine is probably even lower (<1.1) than the emissions data would suggest.

Sulfur retention in the glass product was high (>90%) for all of the tests with the nominal sugar ratio. As expected, sulfur emissions increased and the retention of sulfur in the glass product decreased systematically as the sugar ratio was increased and the melt became more reduced. In fact, the sulfur solubility decreased to such an extent (0.12 wt% SO_3) that a molten sulfate salt phase formed on the surface of the glass pool by the end of Test 3. After idling the melter at the operating temperature with nominal bubbling for 12 hours, the glass was re-oxidized and the excess sulfate re-dissolved. As a result, the SO_3 content of the subsequently discharged glass had increased to 0.27 wt%. These results have important implications for a potential "purge" strategy in which sulfur is preferentially partitioned to the off-gas stream[5]. As the amount of sugar in the feed is increased, not only is sulfur increasingly partitioned to the off-gas stream, but its solubility in the glass melt is also decreased as the melt is reduced. Thus, perhaps contrary to simple expectations, depending on which of these two effects prevail, it is possible, as was observed in Test 3, for increased sugar in the feed

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[5] The advantage of such an approach is that it would allow increased waste loadings and, consequently, reduced glass volumes. In the present baseline flow-sheet, sulfur (and other constituents) captured in the off-gas treatment system is simply recycled to the feed make-up, so it is advantageous to maximize the retention in the glass product (which is essentially the only purge point). The "purge" strategy would require re-direction of the off-gas treatment streams (e.g., to waste-water treatment) to break the recycle loop.

to *increase* the tendency to form a separate sulfate salt phase. For these reasons we have previously used combinations of reductants, rather than sugar alone, to preferentially partition sulfur to the off-gas stream while minimizing the reduction of the glass melt in order to maintain maximum sulfate solubility [10, 11, 18, 19]. Consequently, additional tests using reductant combinations are recommended if a purge approach for the RPP-WTP is to be pursued.

SECTION 7.0
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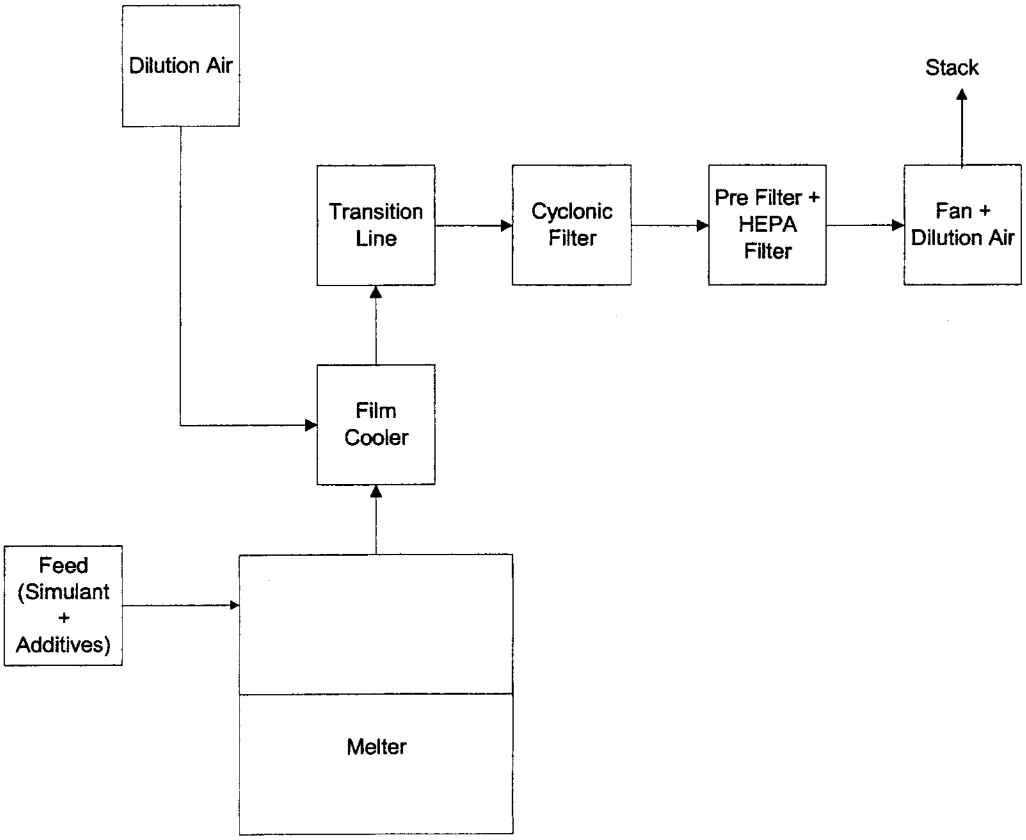

Figure 1.1. Schematic diagram of DuraMelter 100 vitrification system.

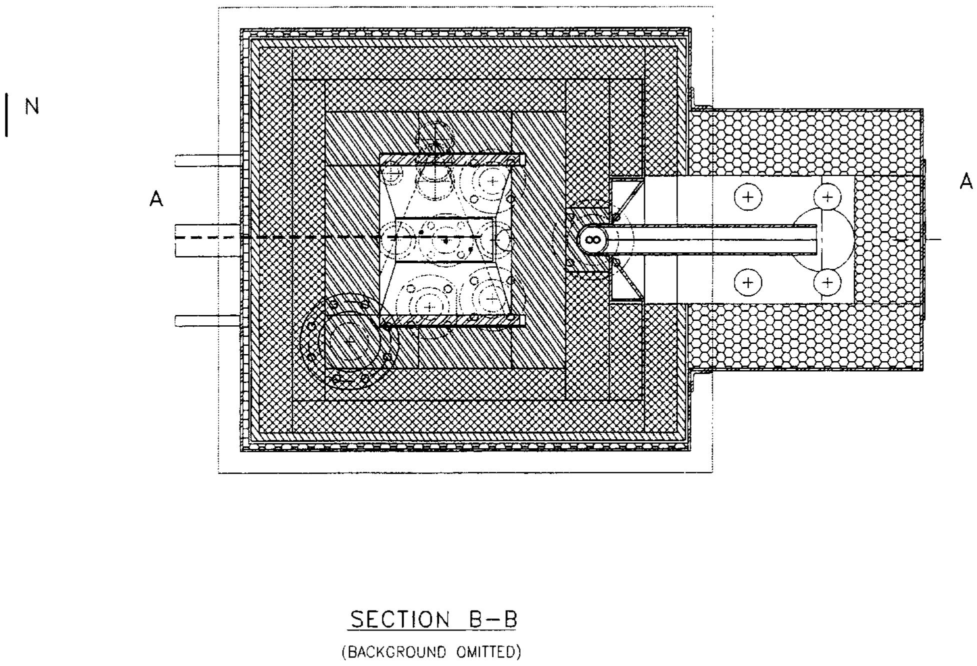

Figure 1.2(a). Cross-section through the DM100-WV melter—Plan View.

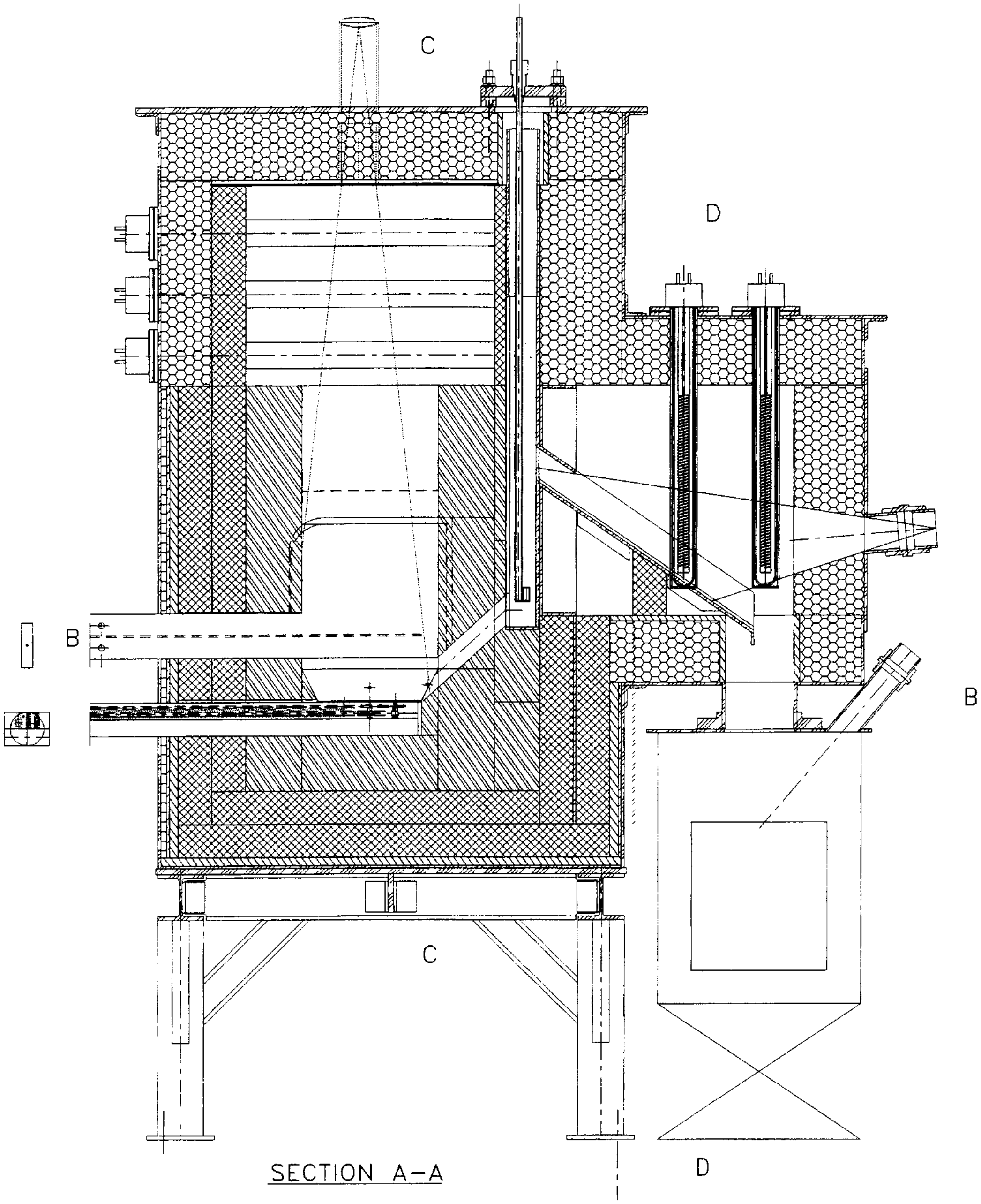

Figure 1.2(b). Cross-section through the DM100-WV melter—Section AA.

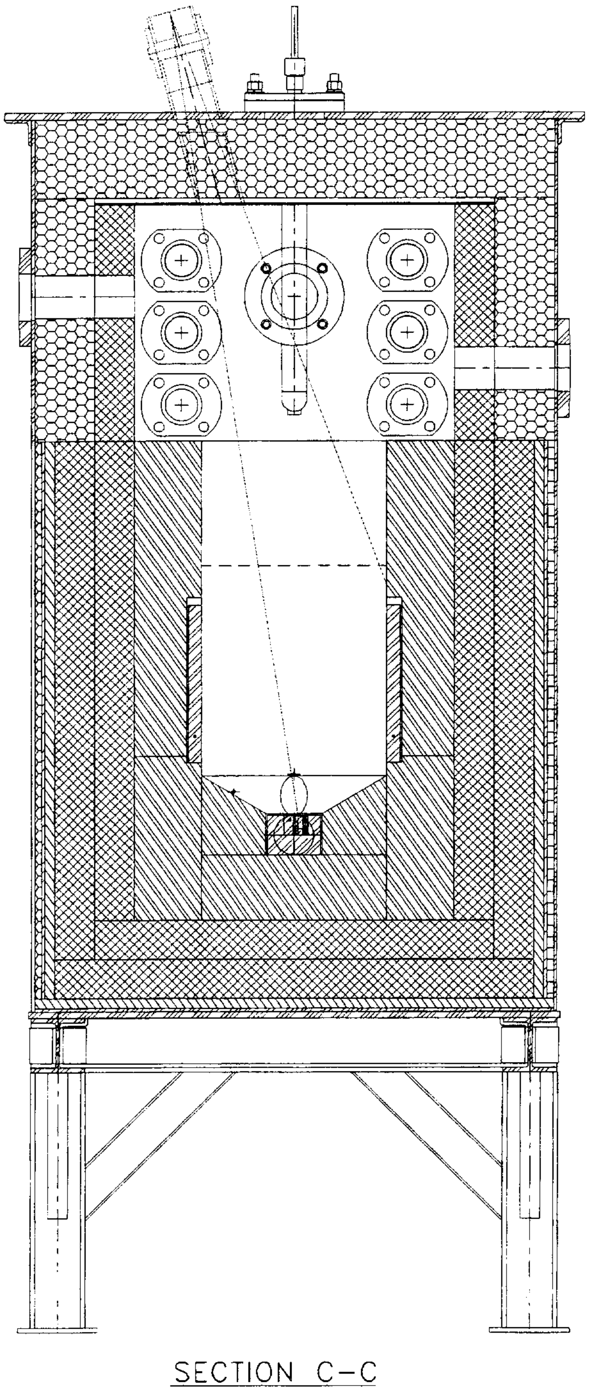

Figure 1.2(c). Cross-section through the DM100-WV melter—Section CC.

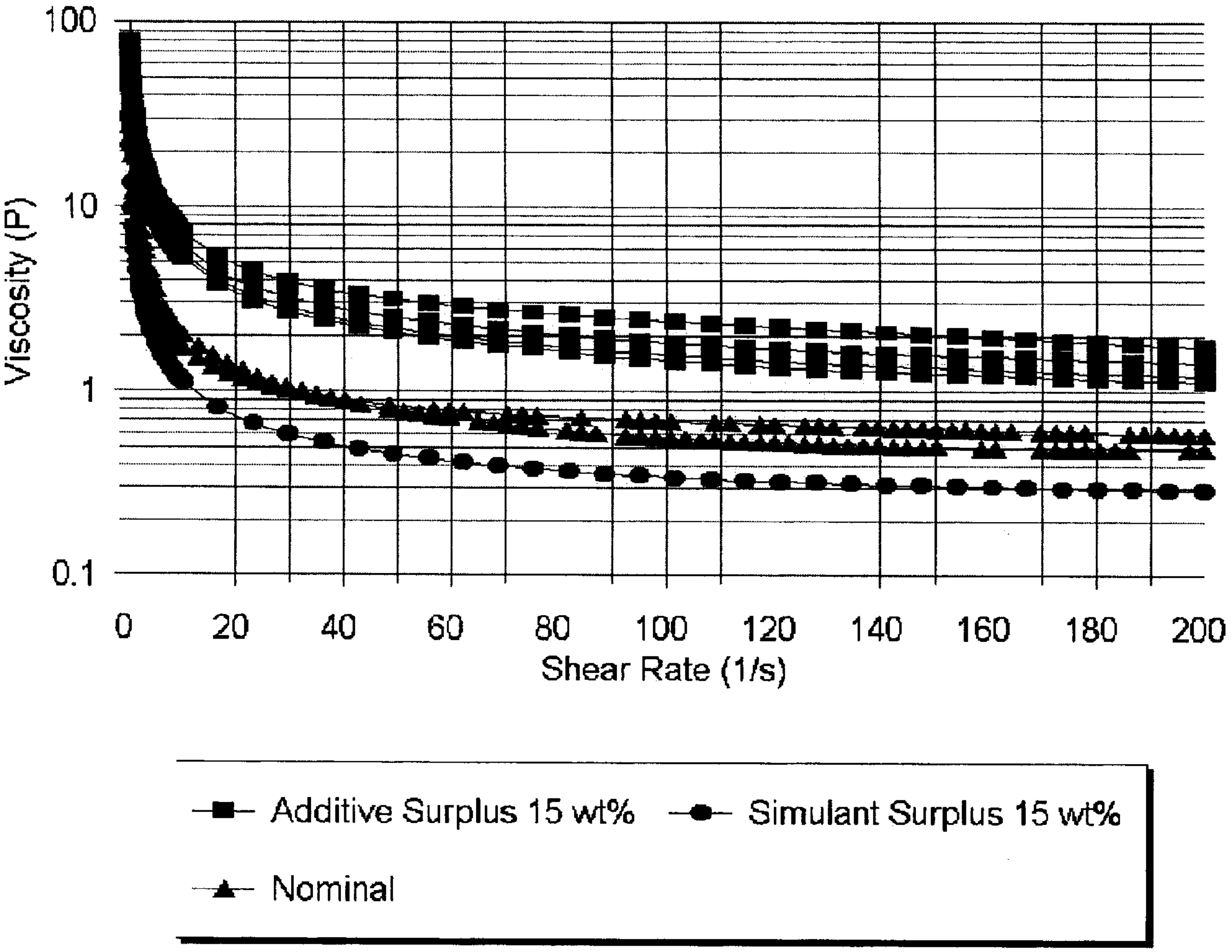

Figure 2.1. Measured viscosity of different melter feed samples collected during these tests.

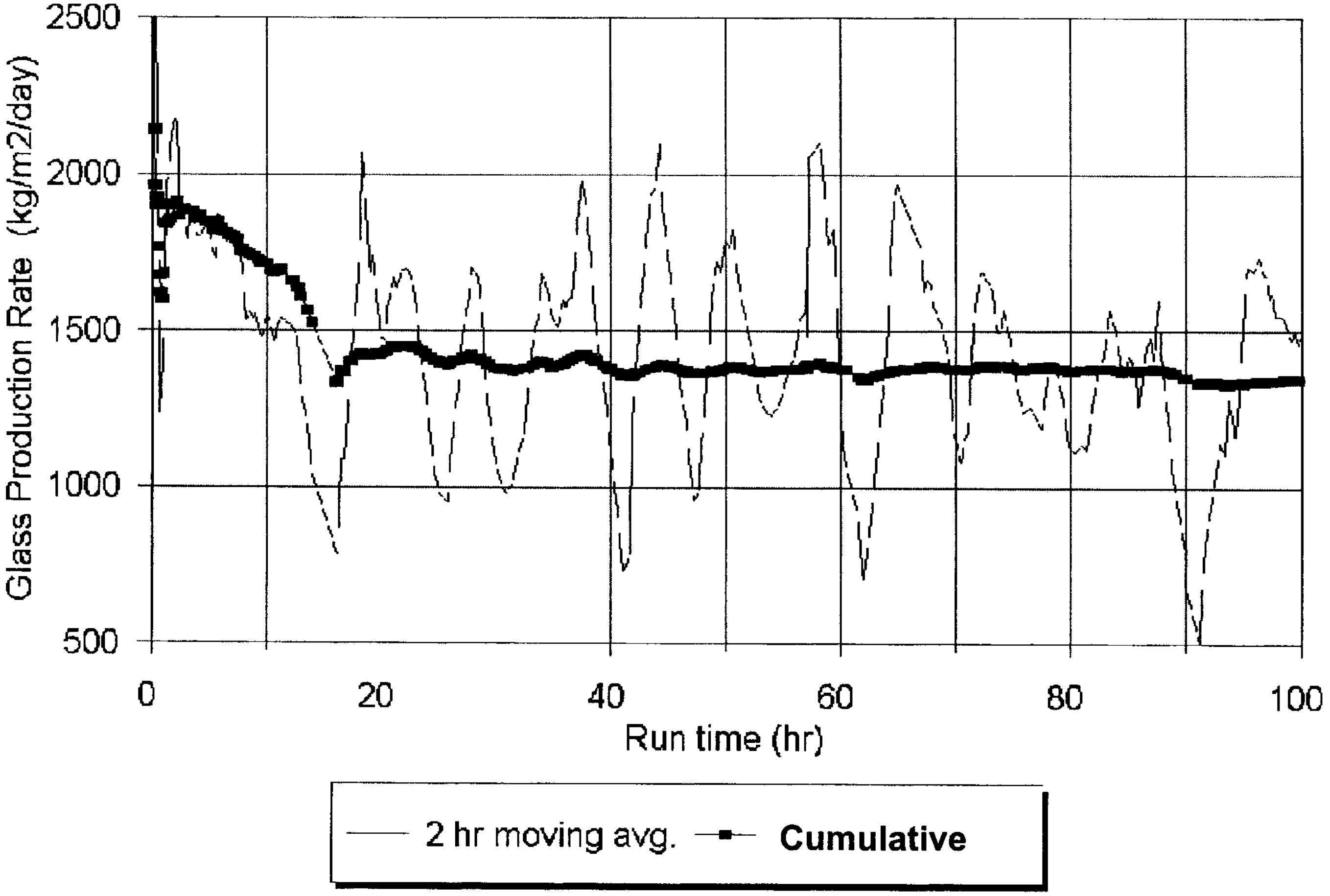

Figure 3.1. Glass production rates for Test 1.

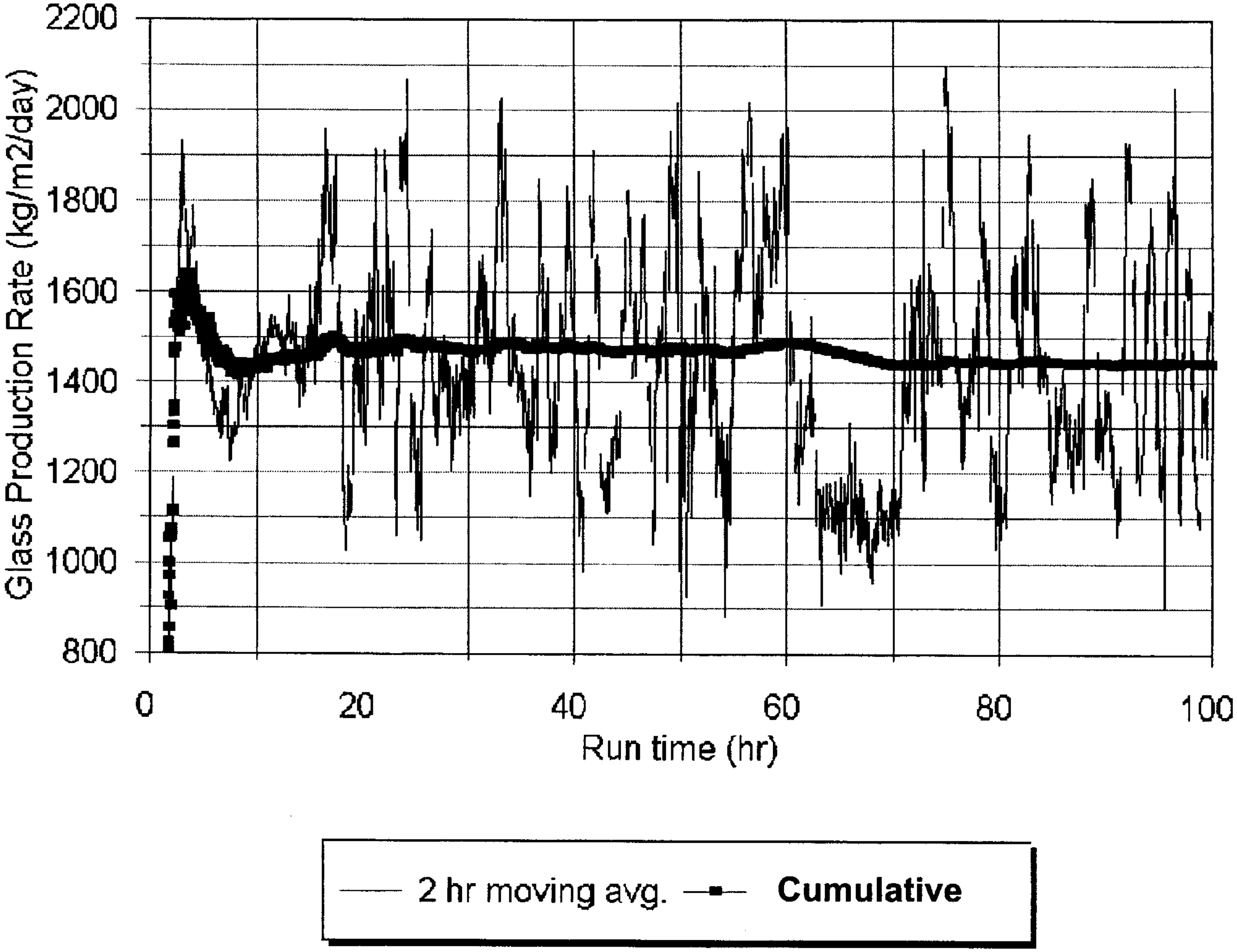

Figure 3.2. Glass production rates for Test 2.

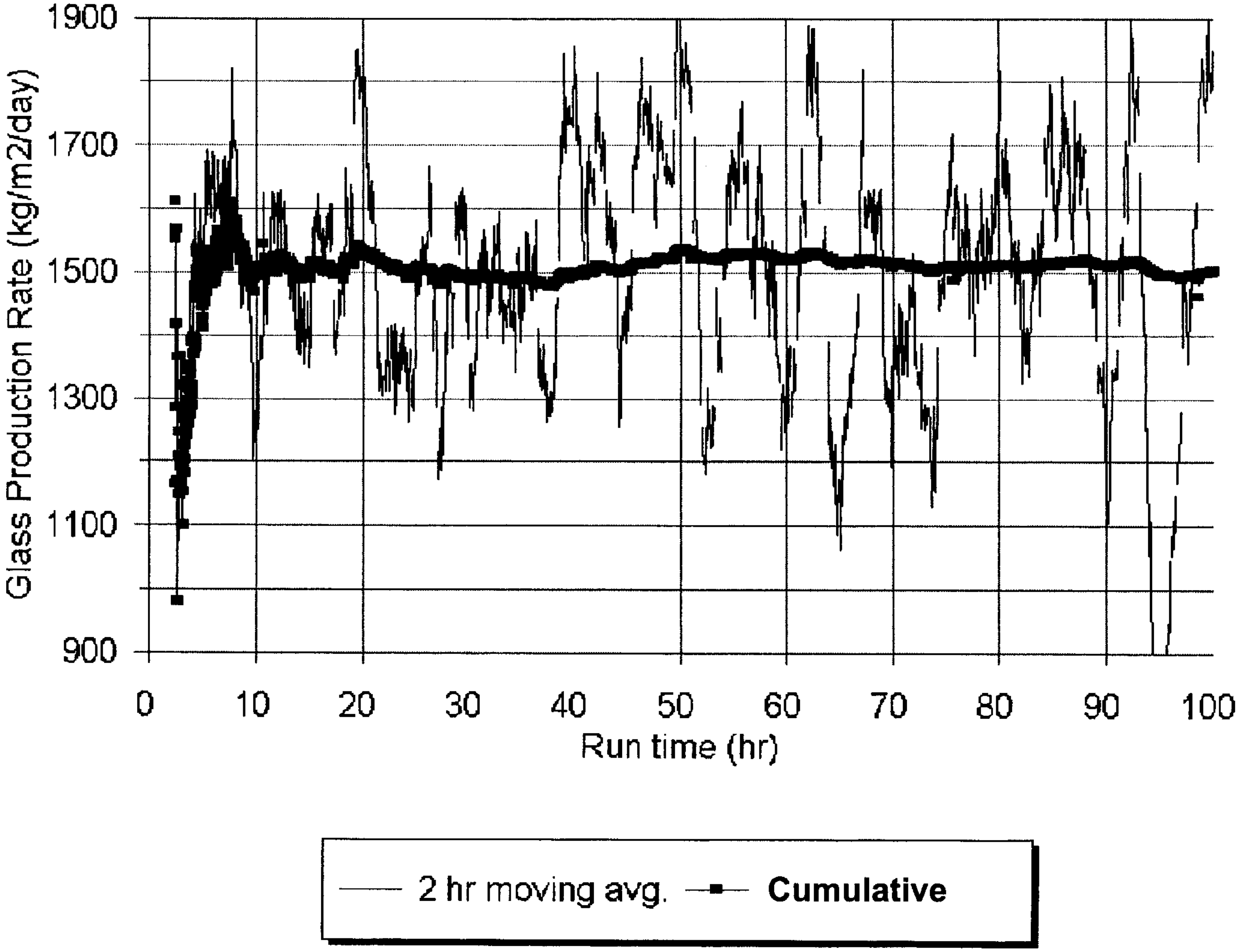

Figure 3.3. Glass production rates for Test 3.

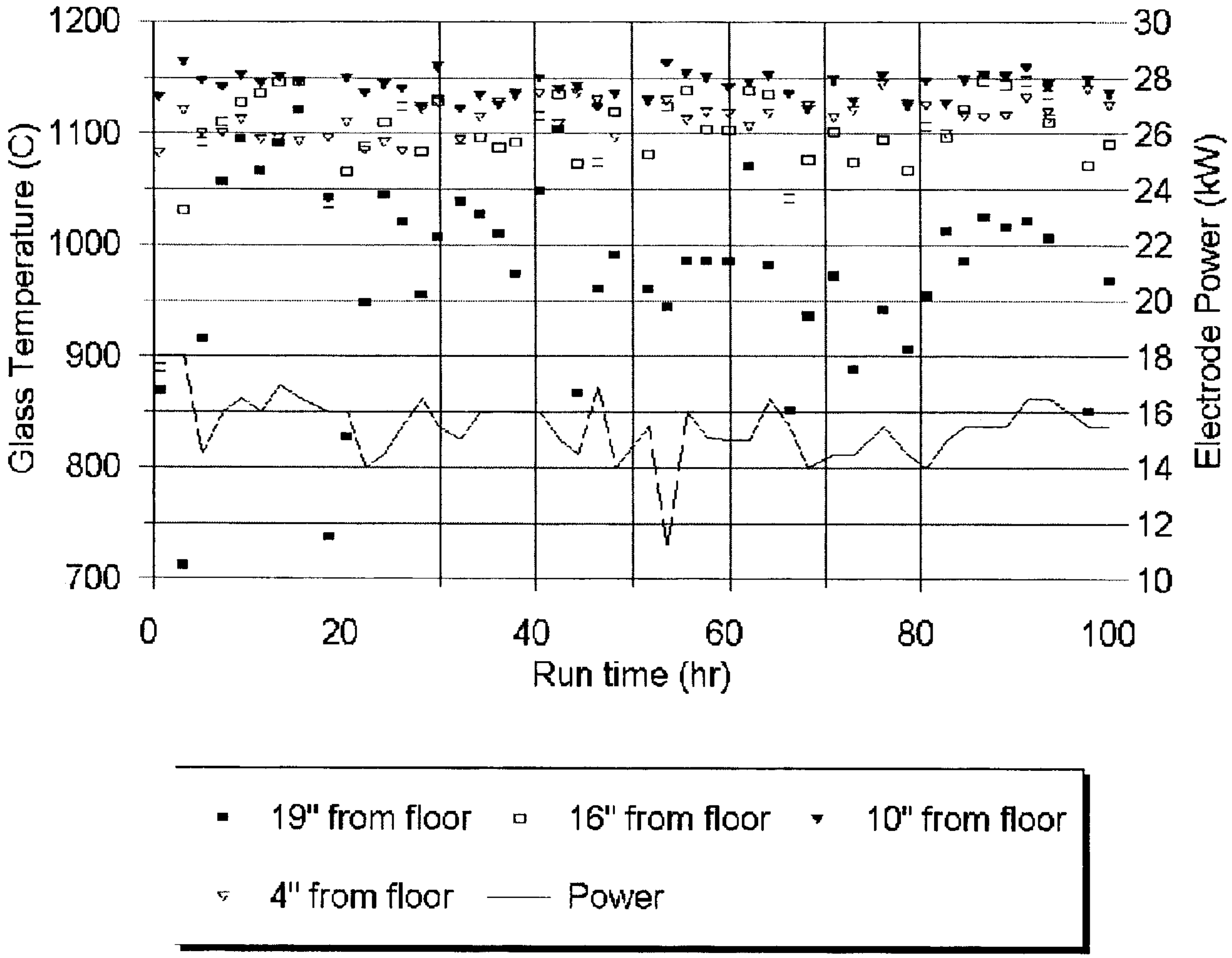

Figure 3.4. Glass temperatures and total electrode power for Test 1.

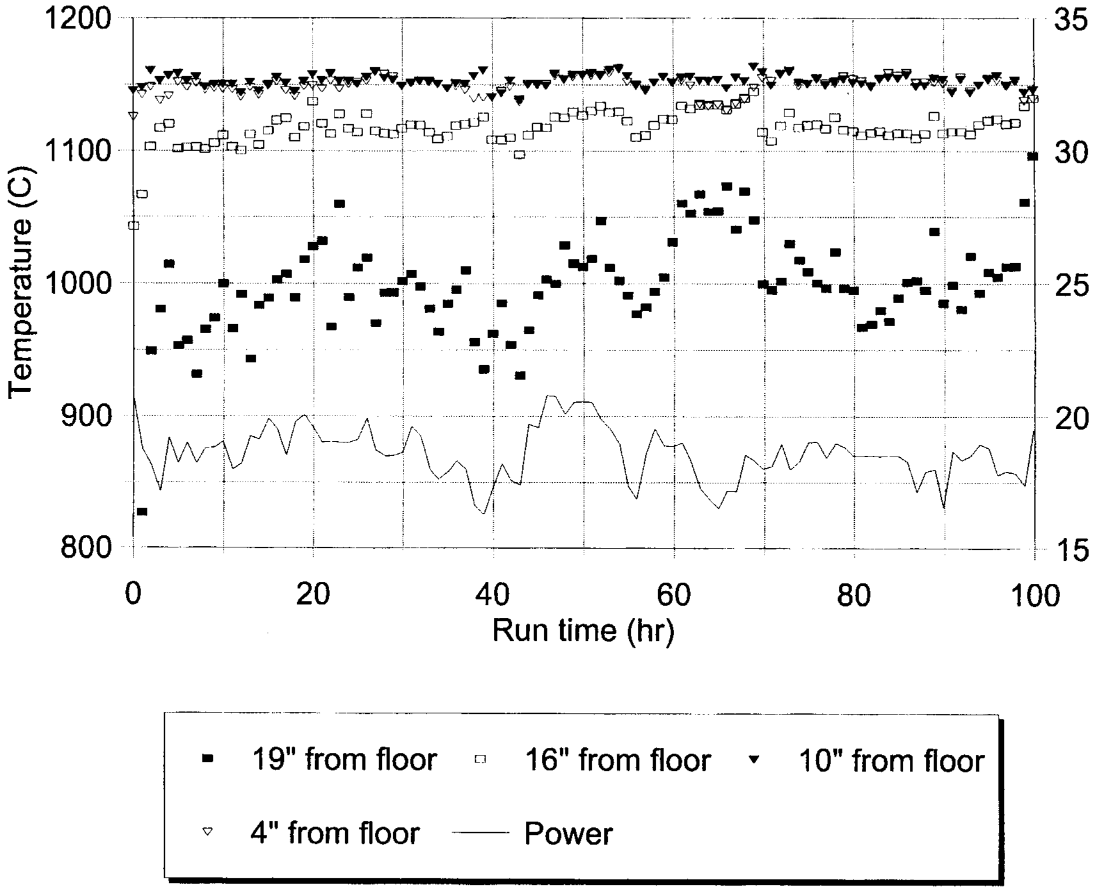

Figure 3.5. Glass temperatures and total electrode power for Test 2.

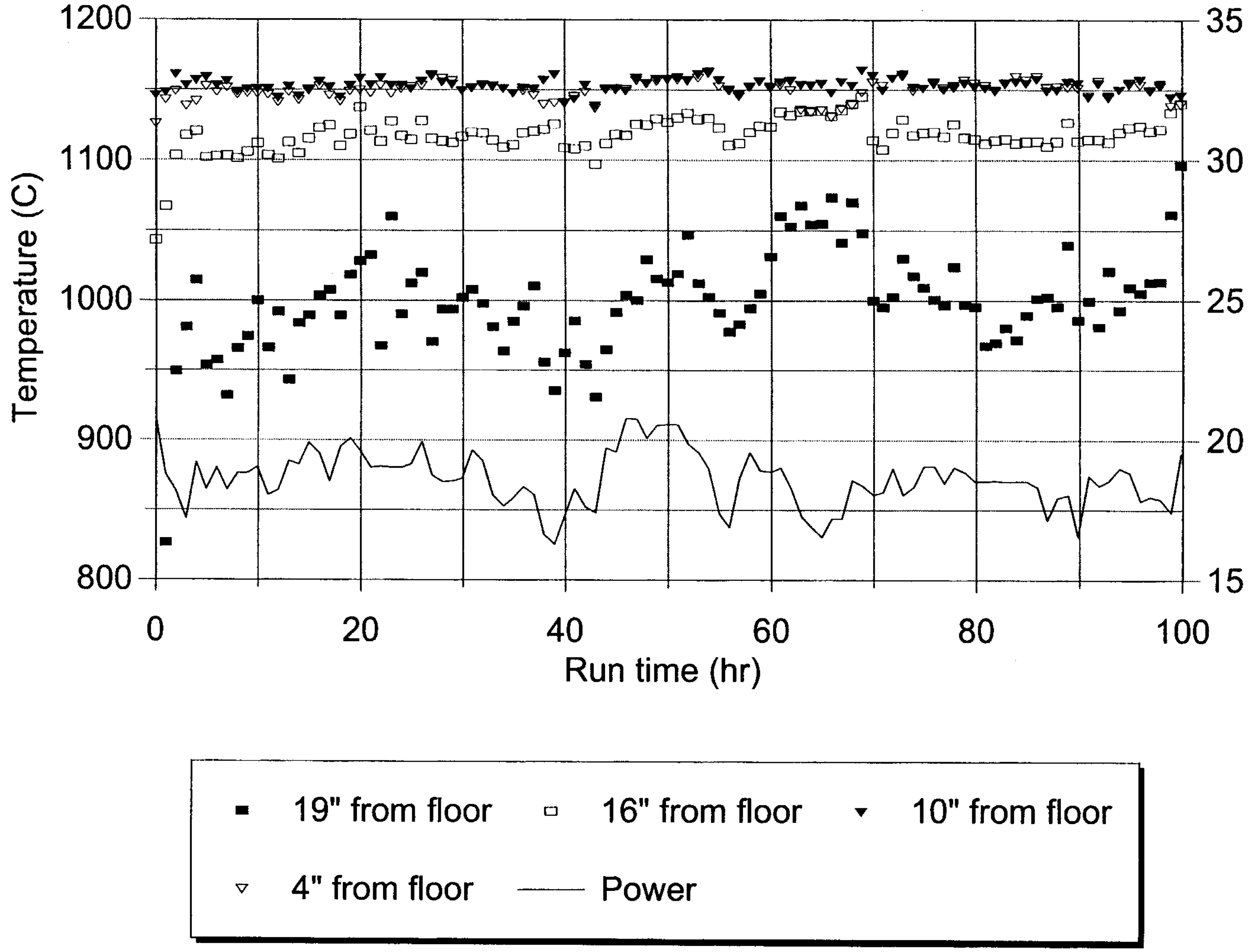

Figure 3.6. Glass temperatures and total electrode power for Test 3.

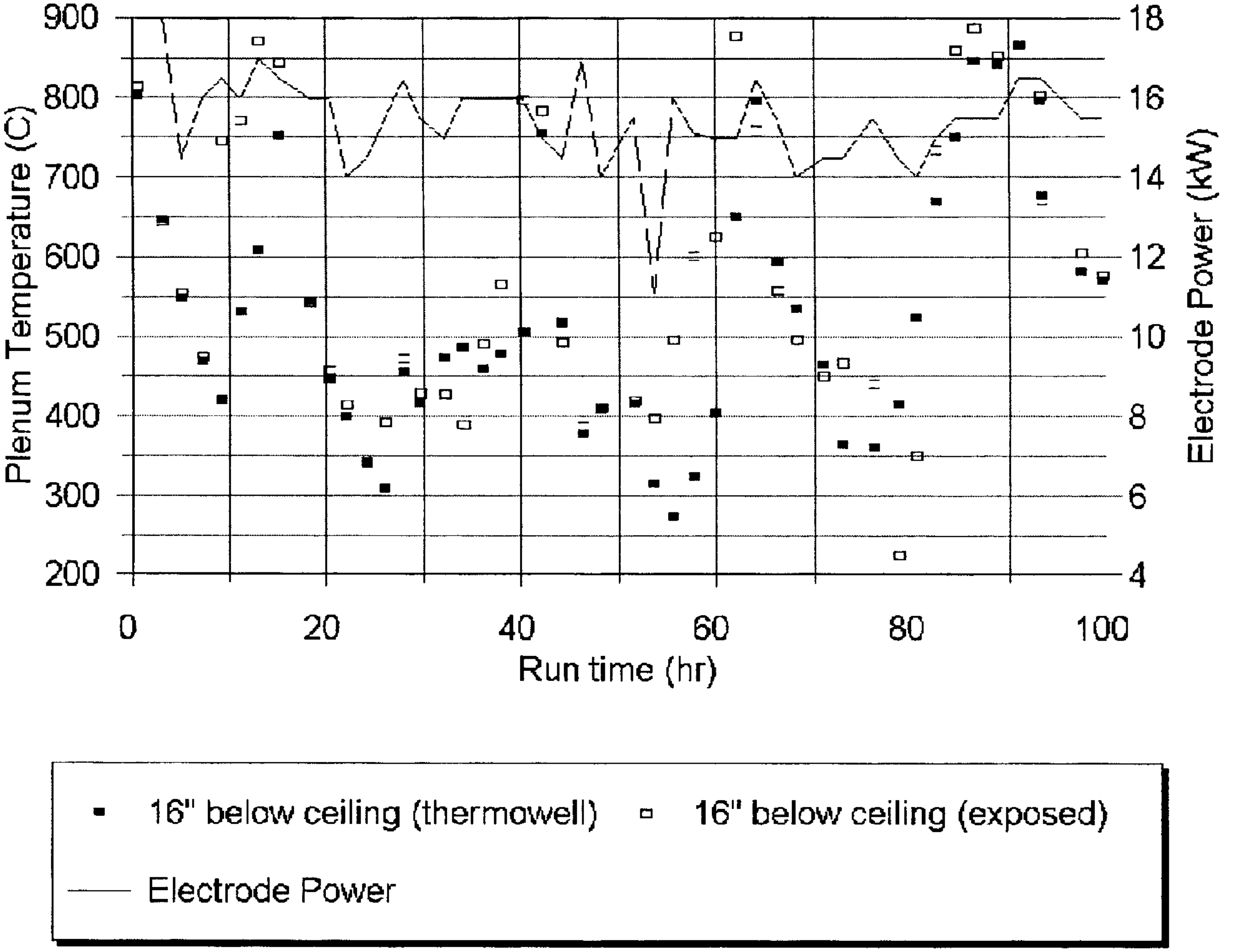

Figure 3.7. Plenum temperatures and electrode power for Test 1.

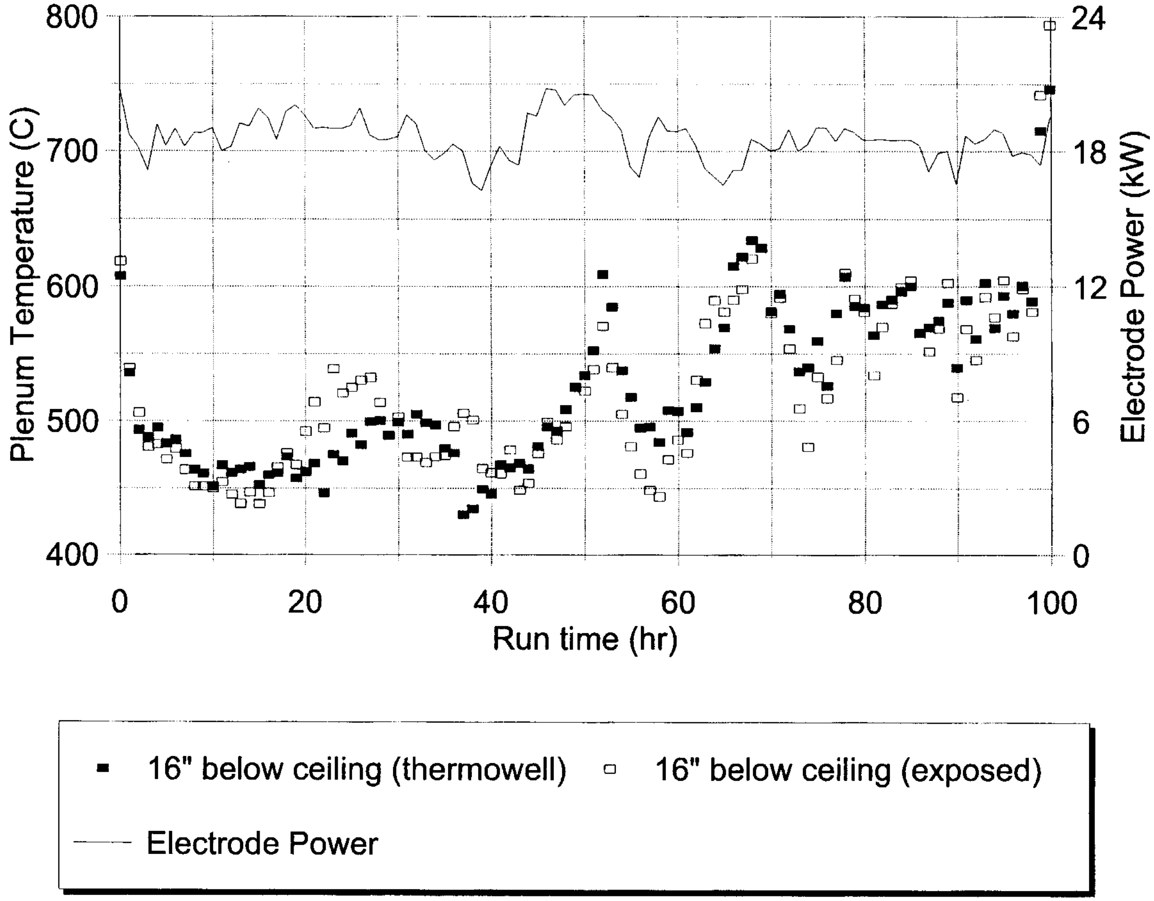

Figure 3.8. Plenum temperatures and electrode power for Test 2.

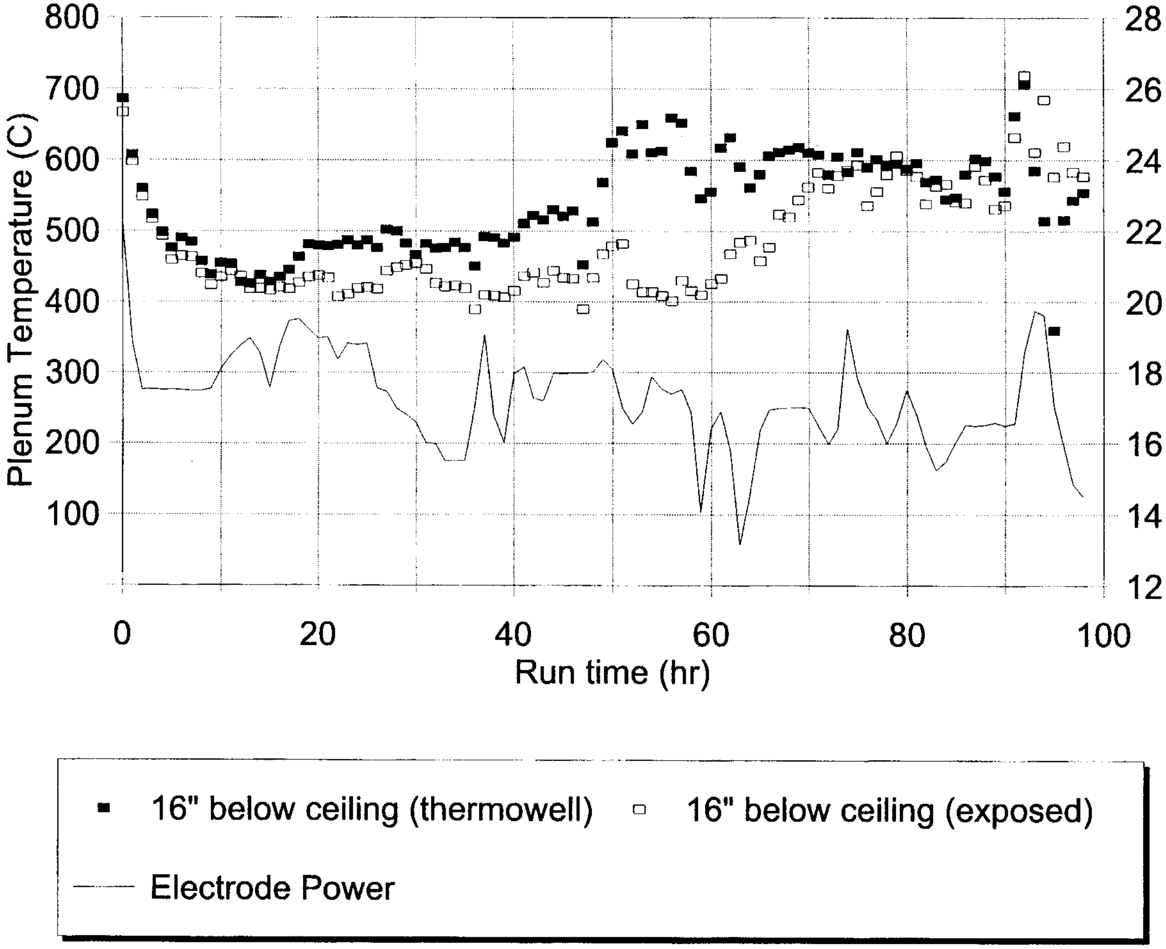

Figure 3.9. Plenum temperatures and electrode power for Test 3.

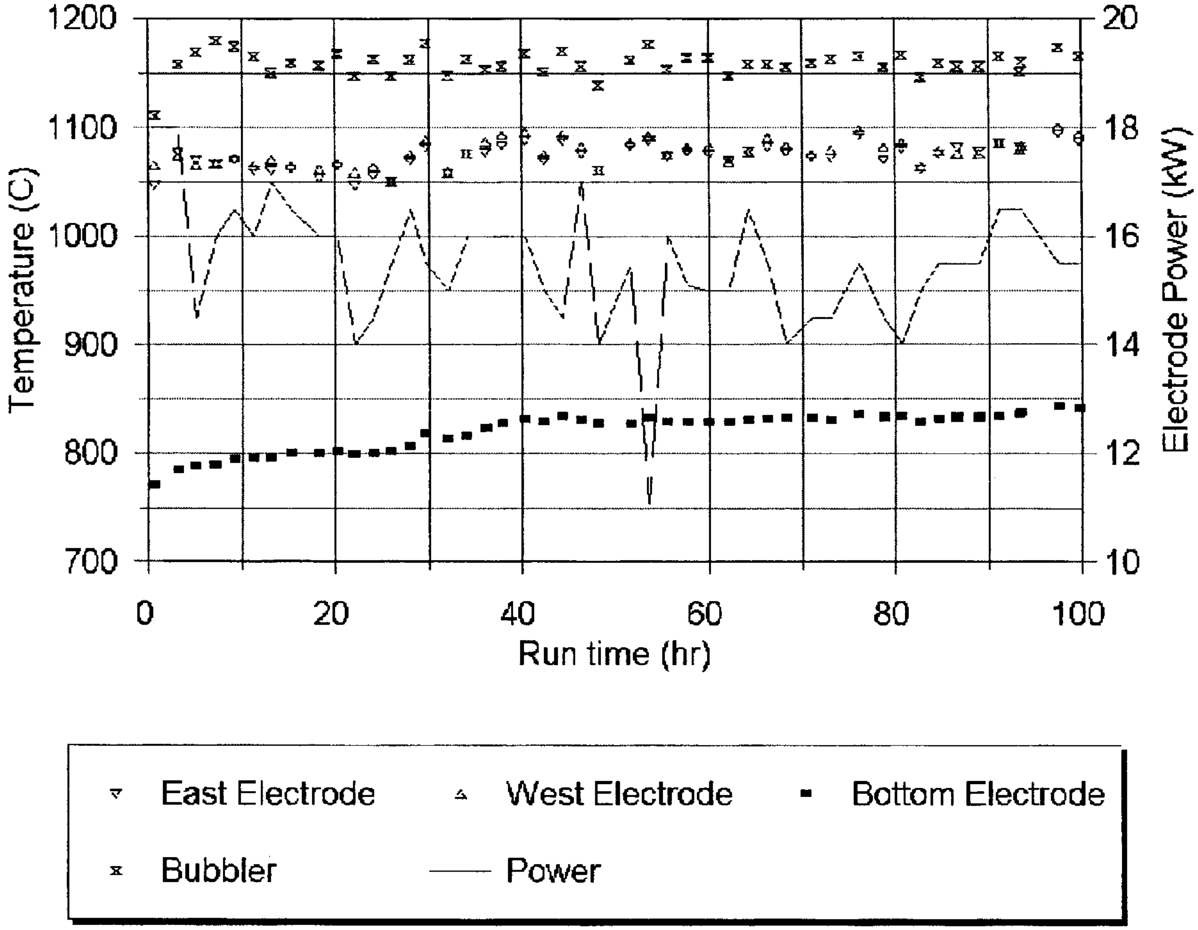

Figure 3.10. Electrode temperature and power plus bubbler temperature for Test 1.

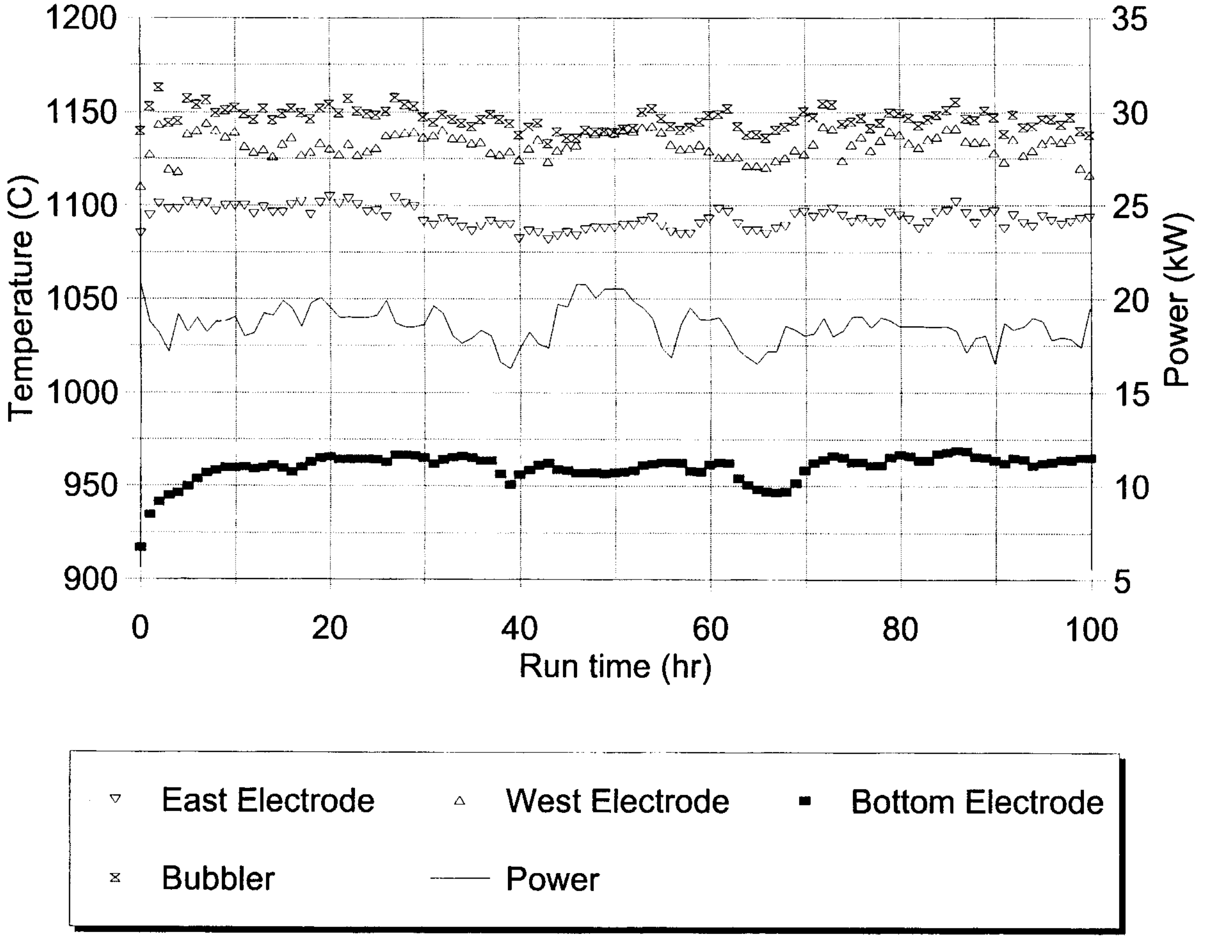

Figure 3.11. Electrode temperatures and power plus bubbler temperature for Test 2.

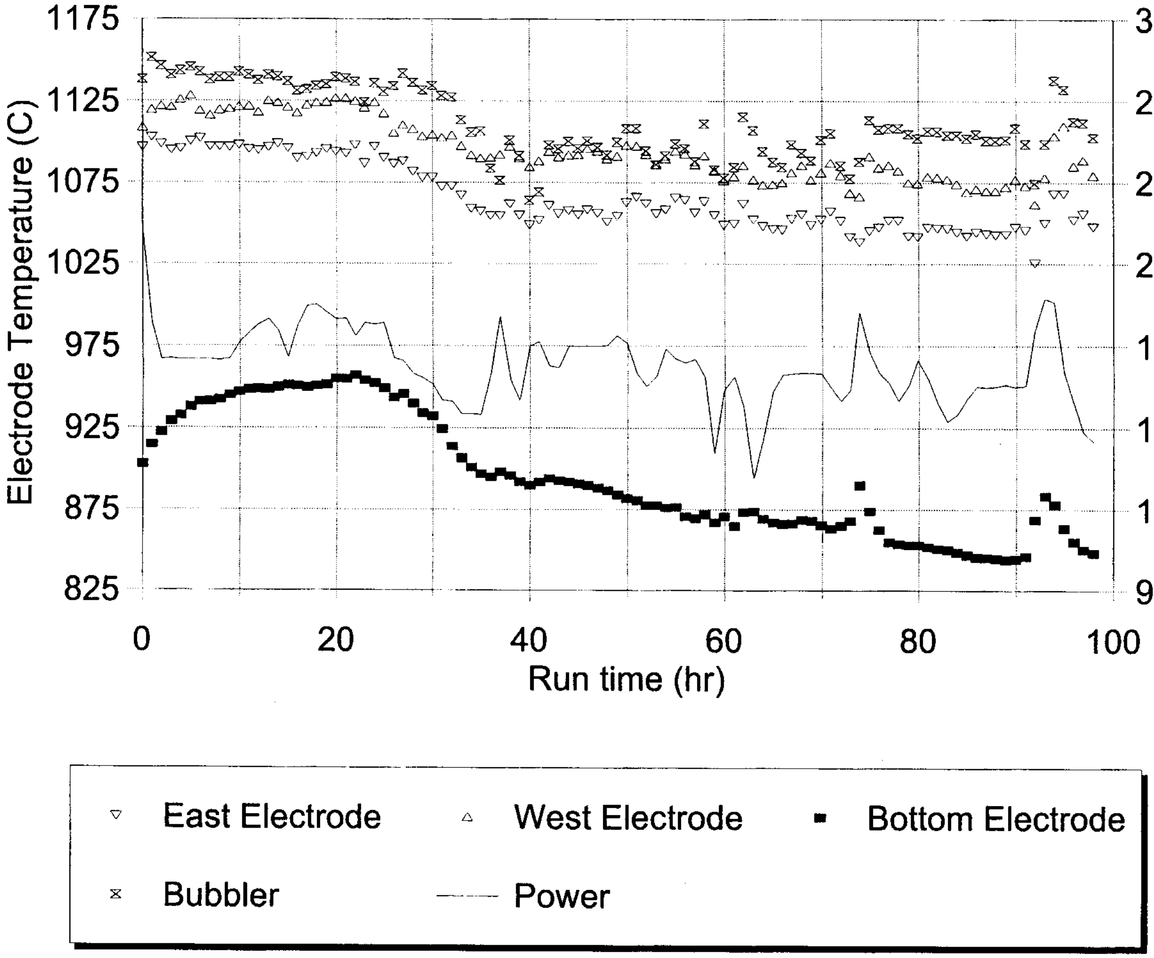

Figure 3.12. Electrode temperature and power plus bubbler temperature for Test 3.

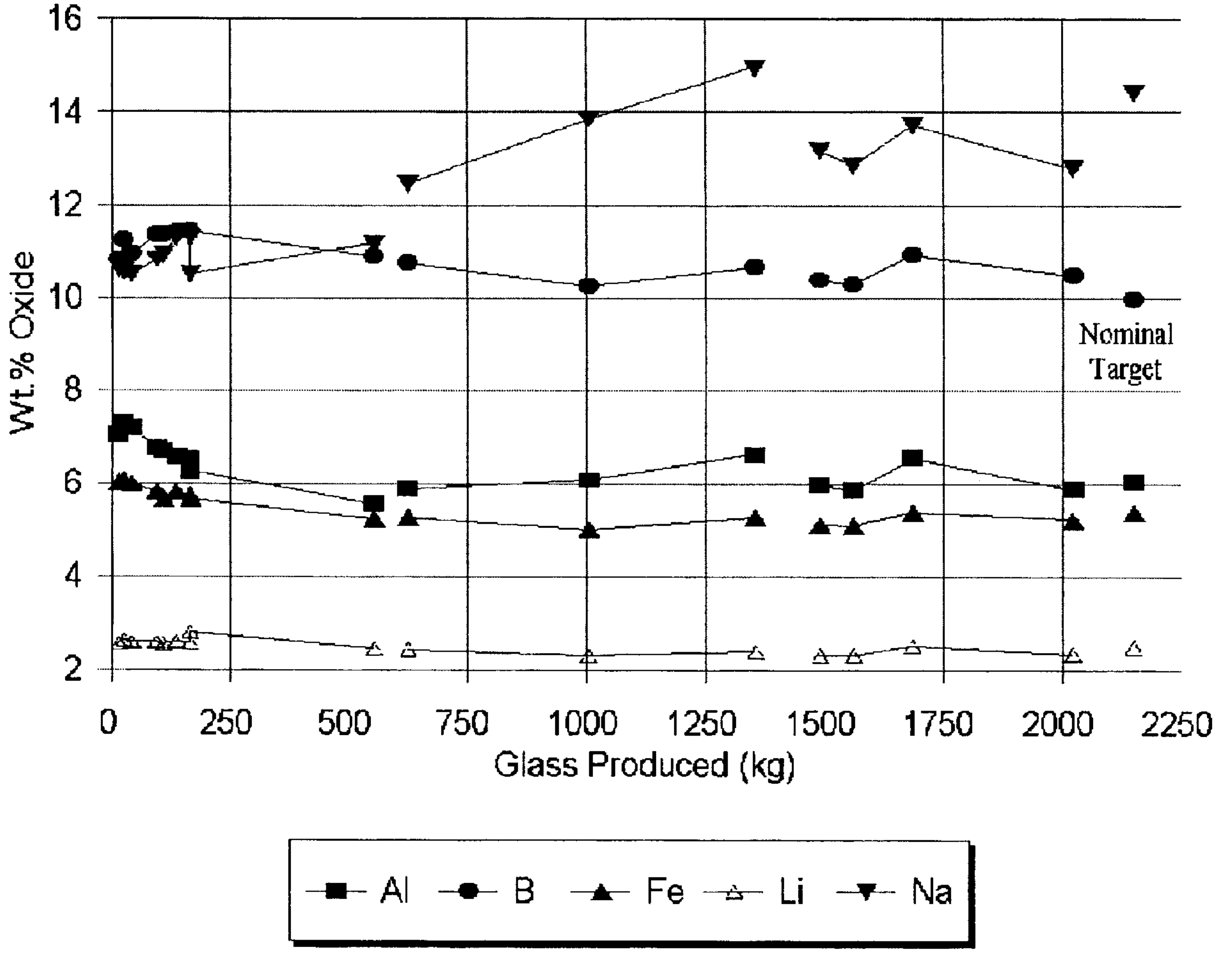

Figure 4.1. DCP Analysis of select major oxides in melter glasses. Tests 1, 2, and 3 (left to right) are separated by breaks in the curves.

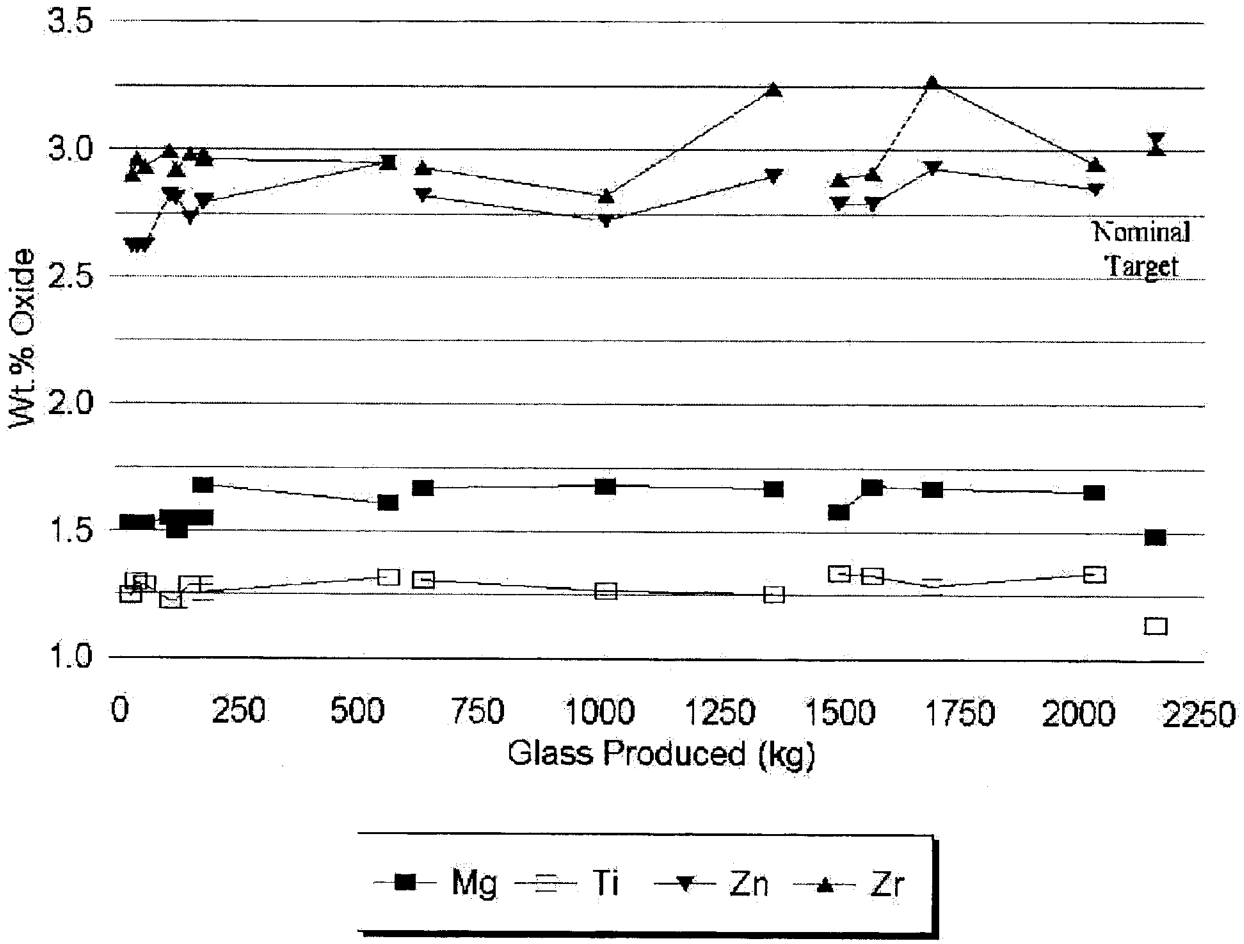

Figure 4.2. DCP analysis of select oxides in melter glasses.
Tests 1, 2, and 3 (left to right) are separated by breaks in the curves.

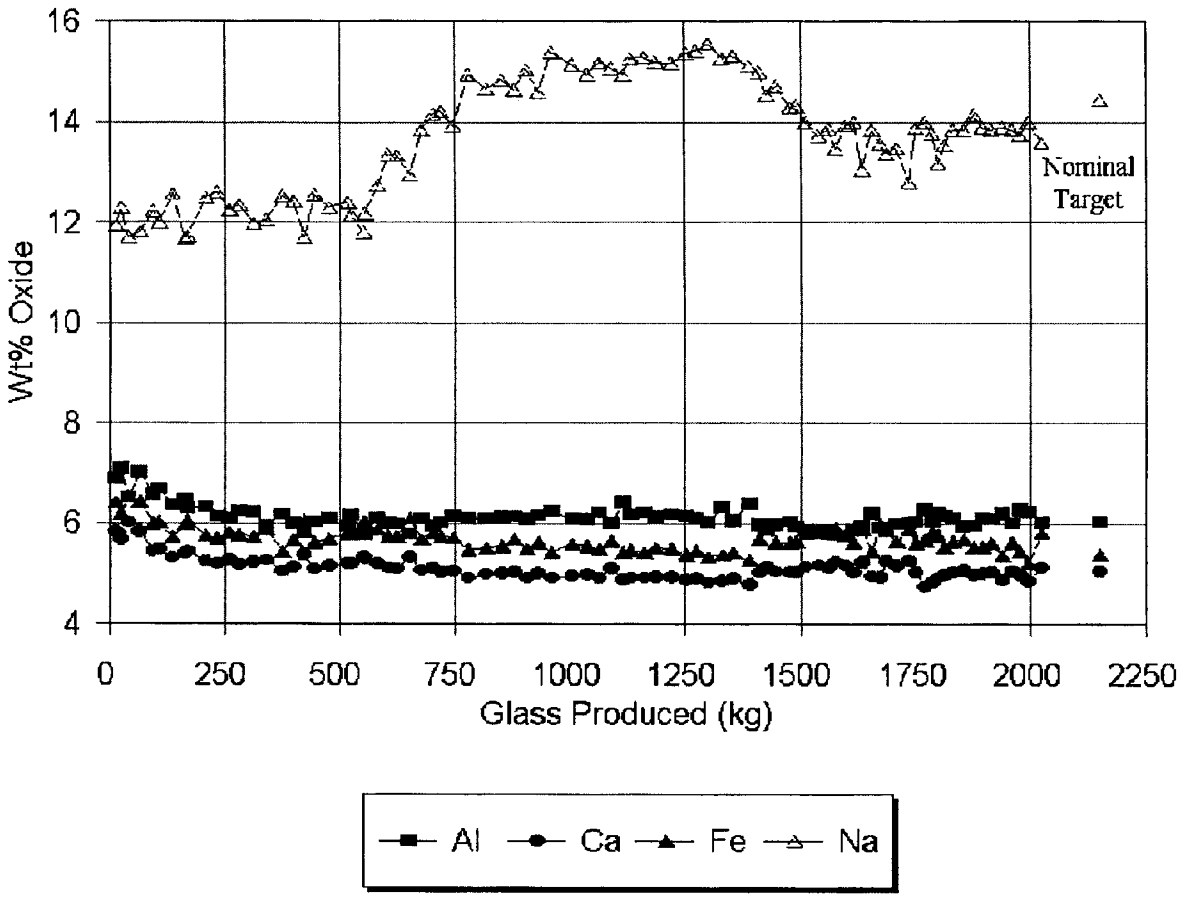

Figure 4.3. XRF analysis of select major oxides in melter glasses. Tests 1, 2, and 3 (left to right) are as in Figure 4.2.

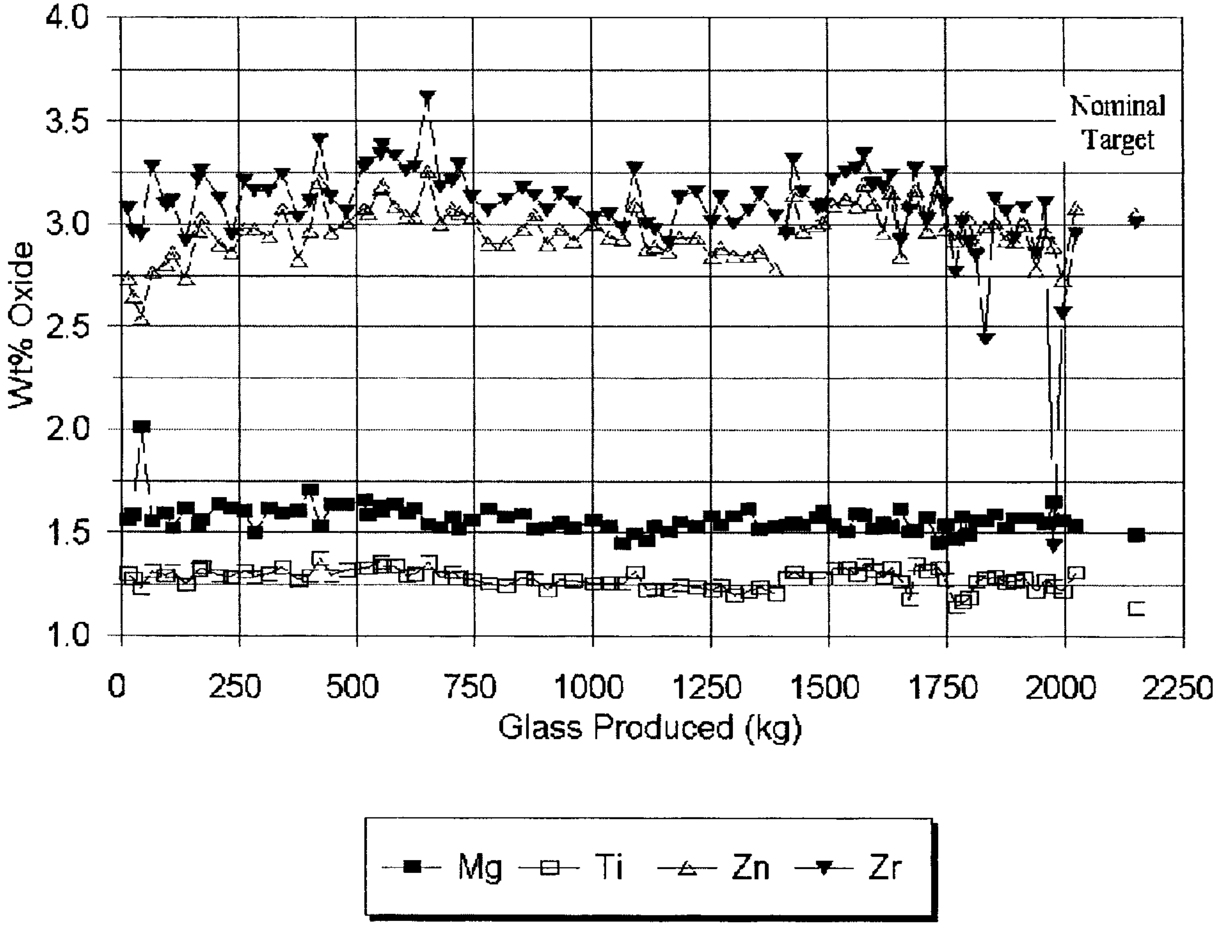

Figure 4.4. XRF analysis of select minor oxides in melter glasses. Tests 1, 2, and 3 (left to right) are as in Figure 4.2.

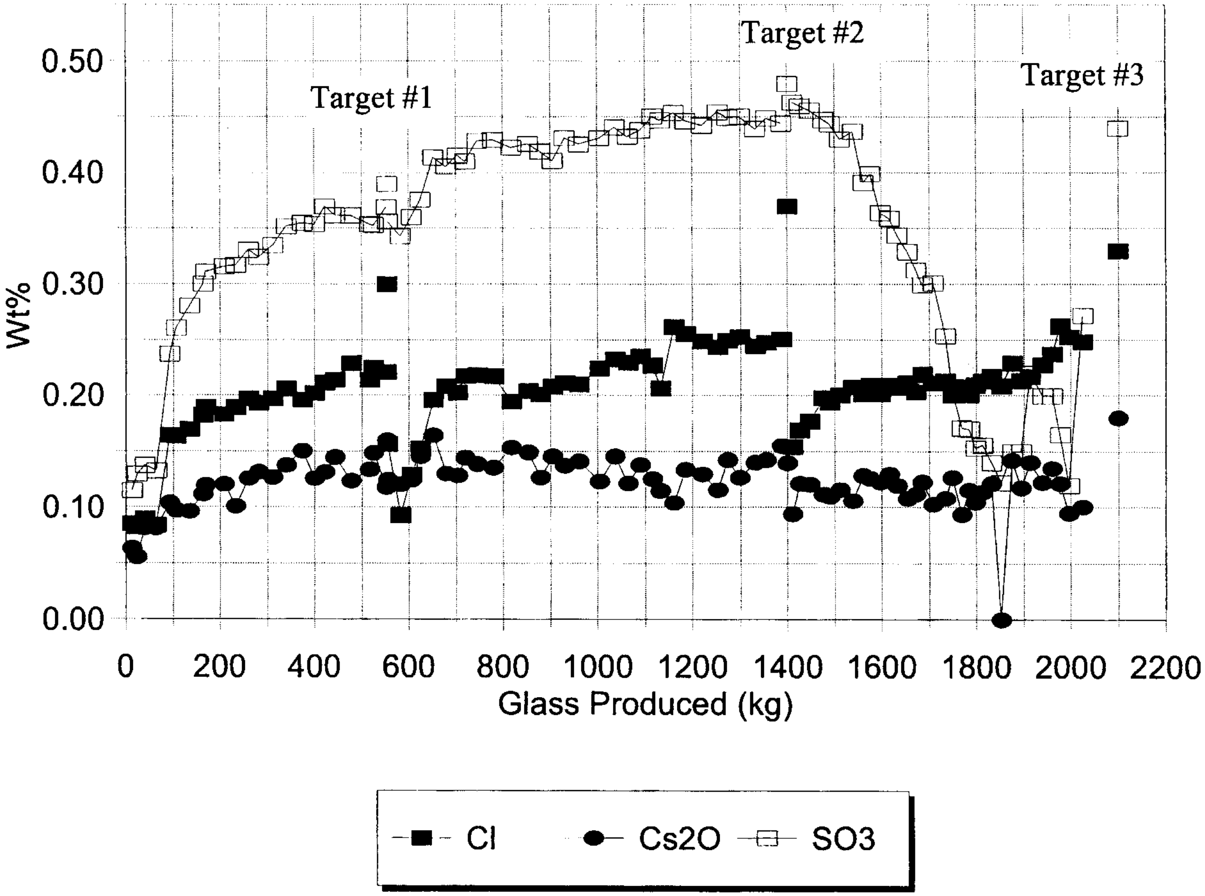

Figure 4.5. XRF analysis of select volatile constituents in melter glasses. Tests 1, 2, and 3 (left to right) are as in Figure 4.2.

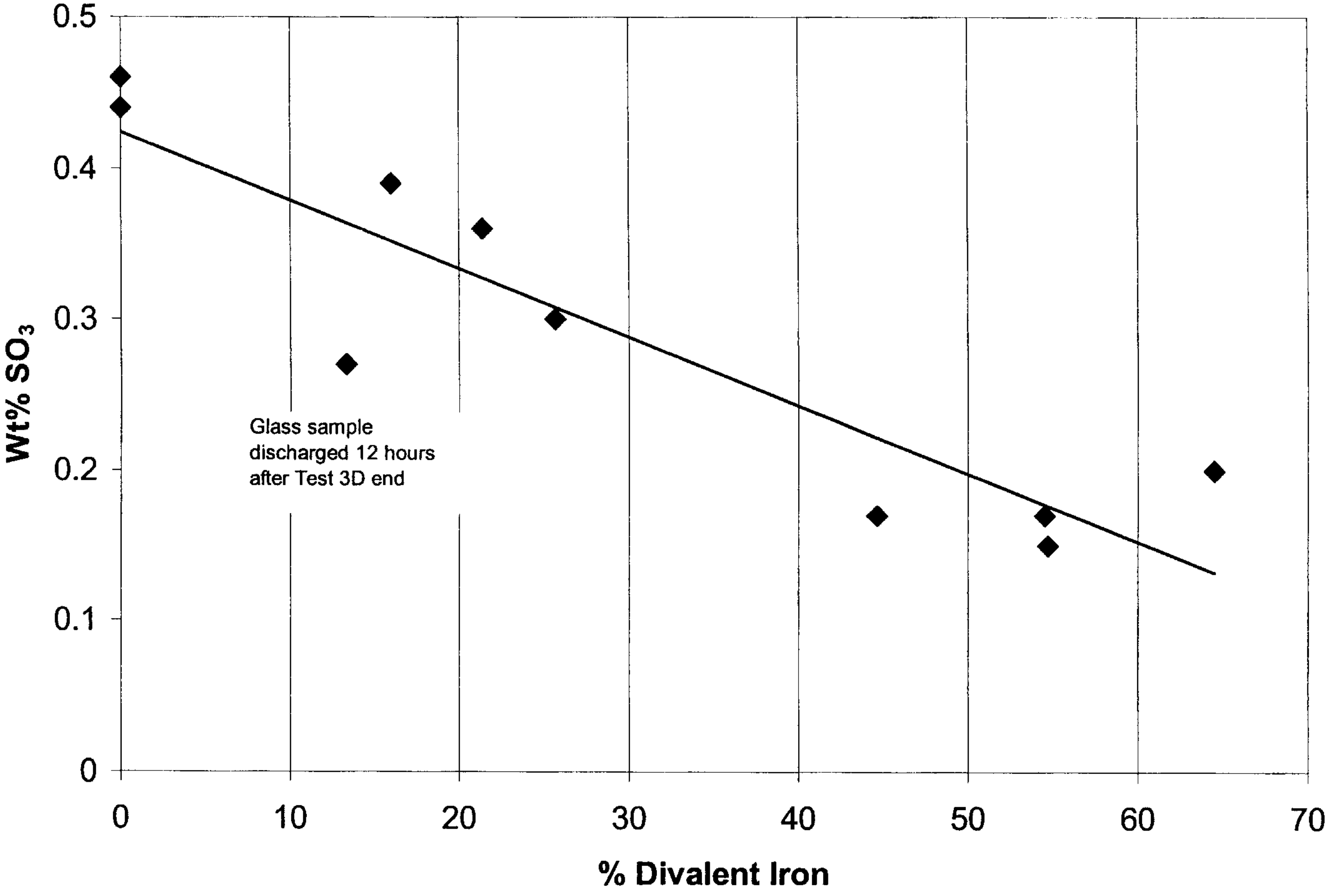

Figure 4.6. Sulfur content of discharged glasses vs. iron oxidation state during Test 3.

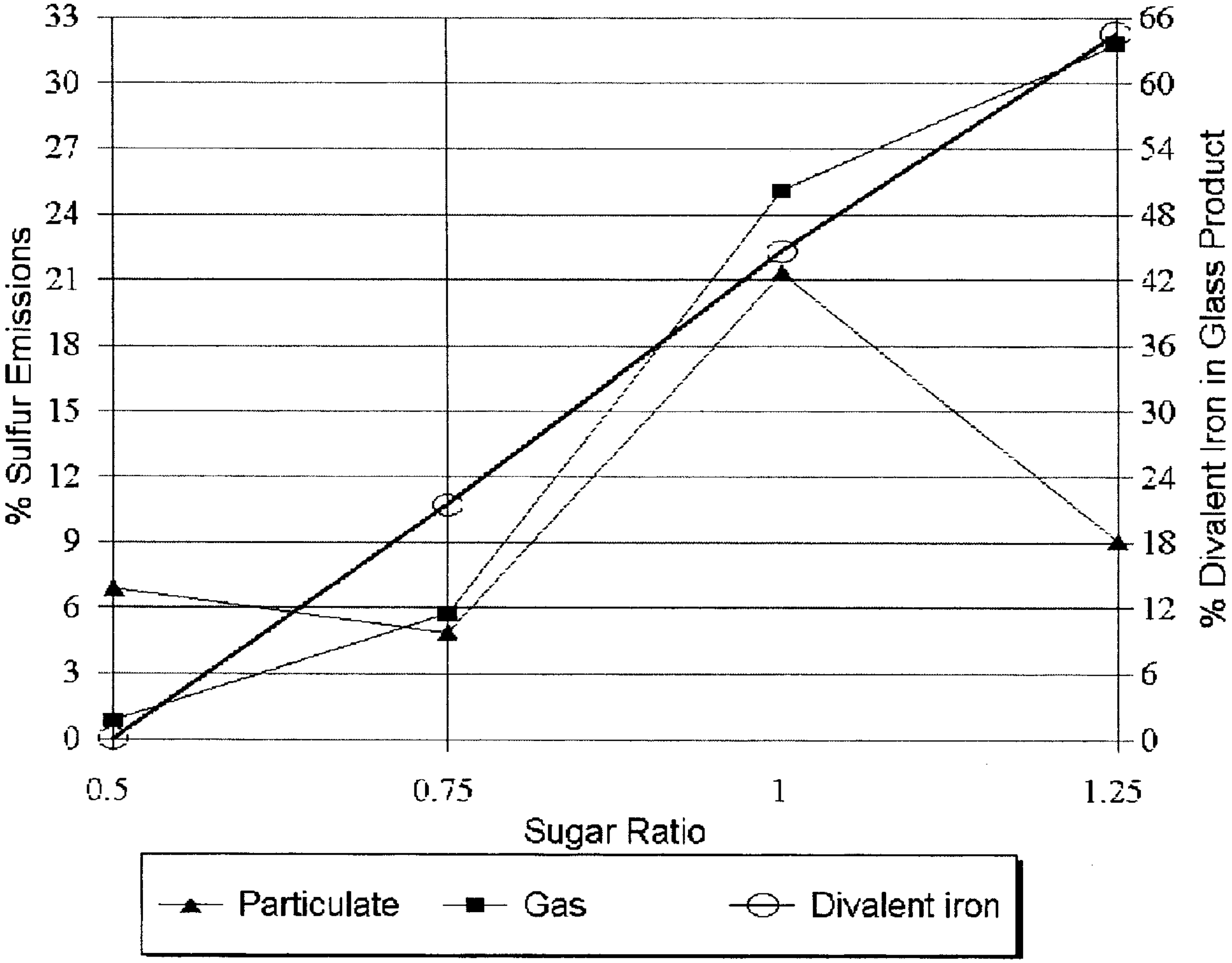

Figure 5.1. Effects of sugar ratio on sulfur emissions and iron oxidation state during Test 3.

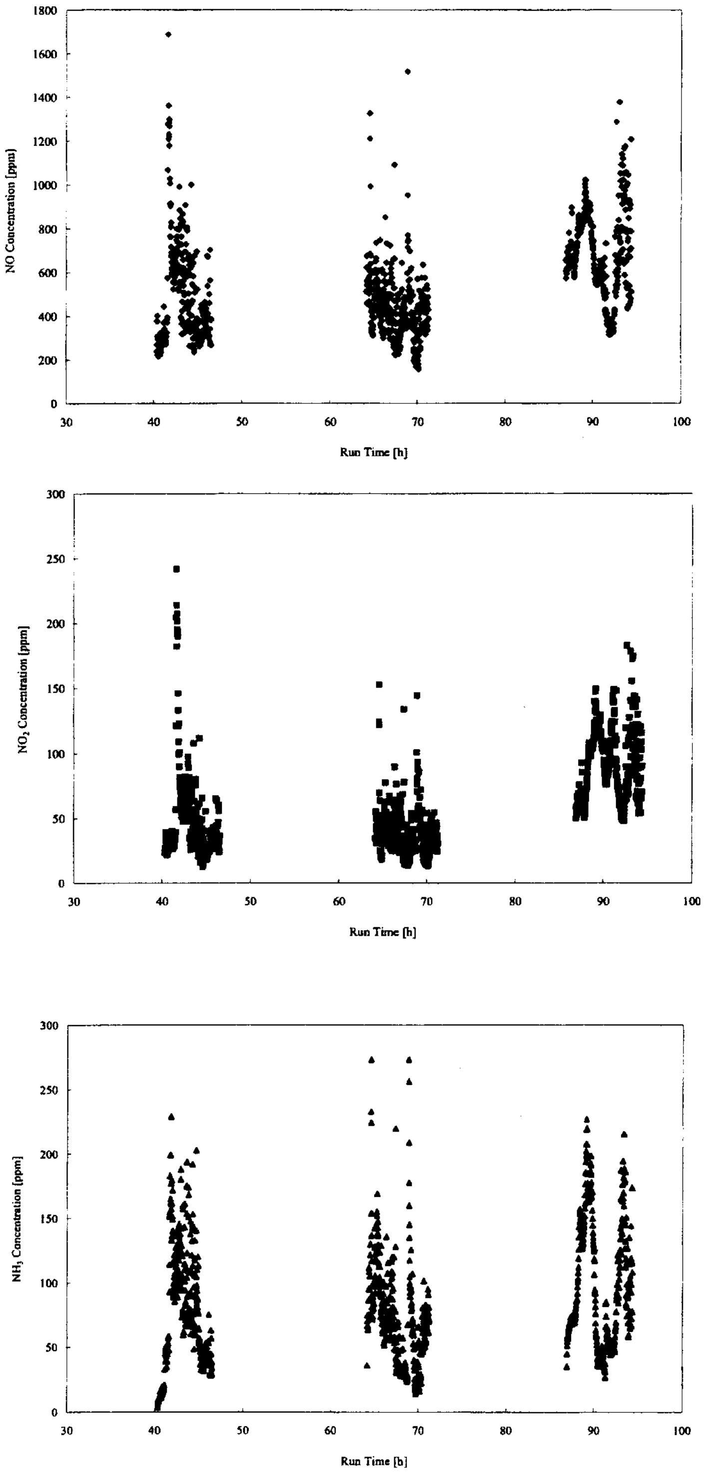

Figure 5.2. Concentration of selected FTIR-monitored species in off-gas during Test 1; average values for these analytes are listed in Table 5.6.

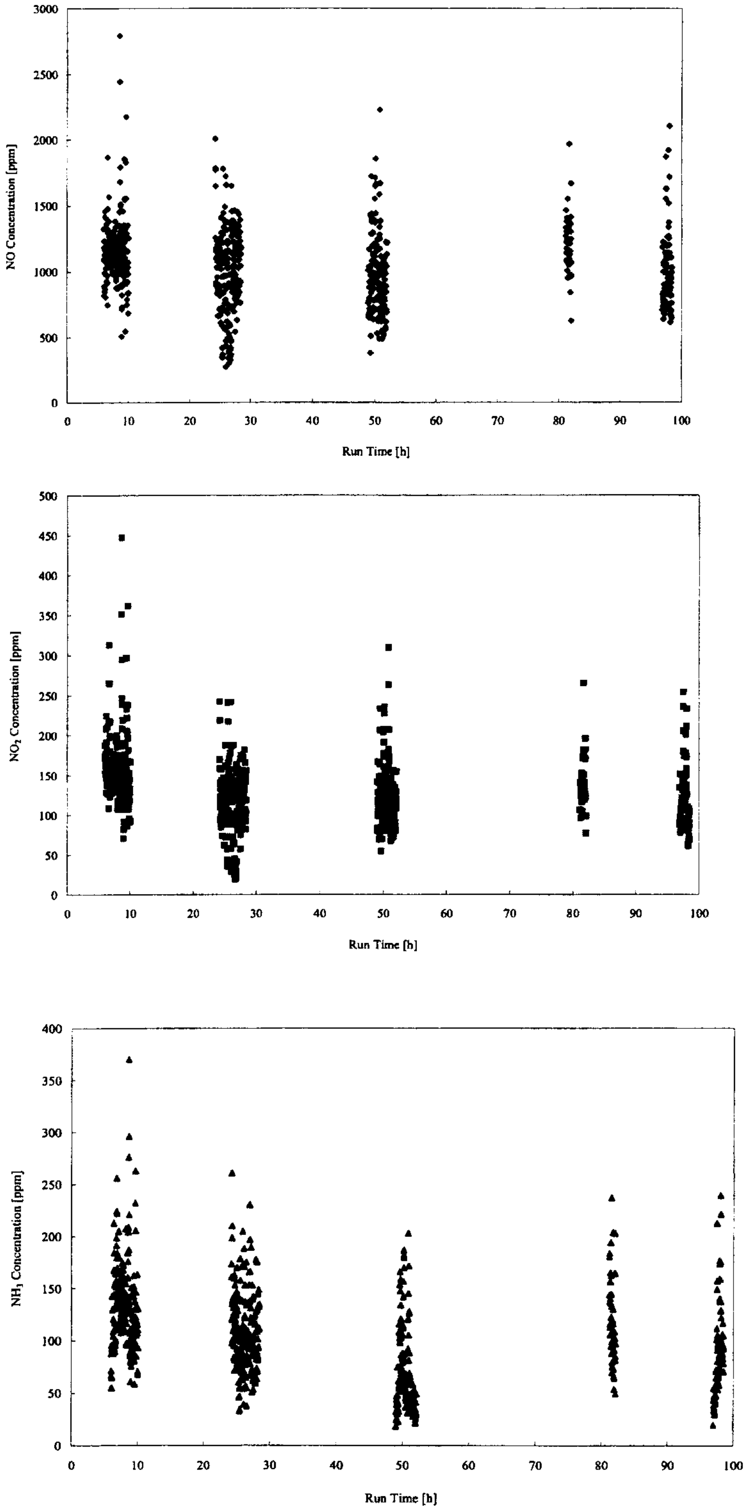

Figure 5.3. Concentration of selected FTIR-monitored species in off-gas during Test 2; average values for these analytes are listed in Table 5.6.

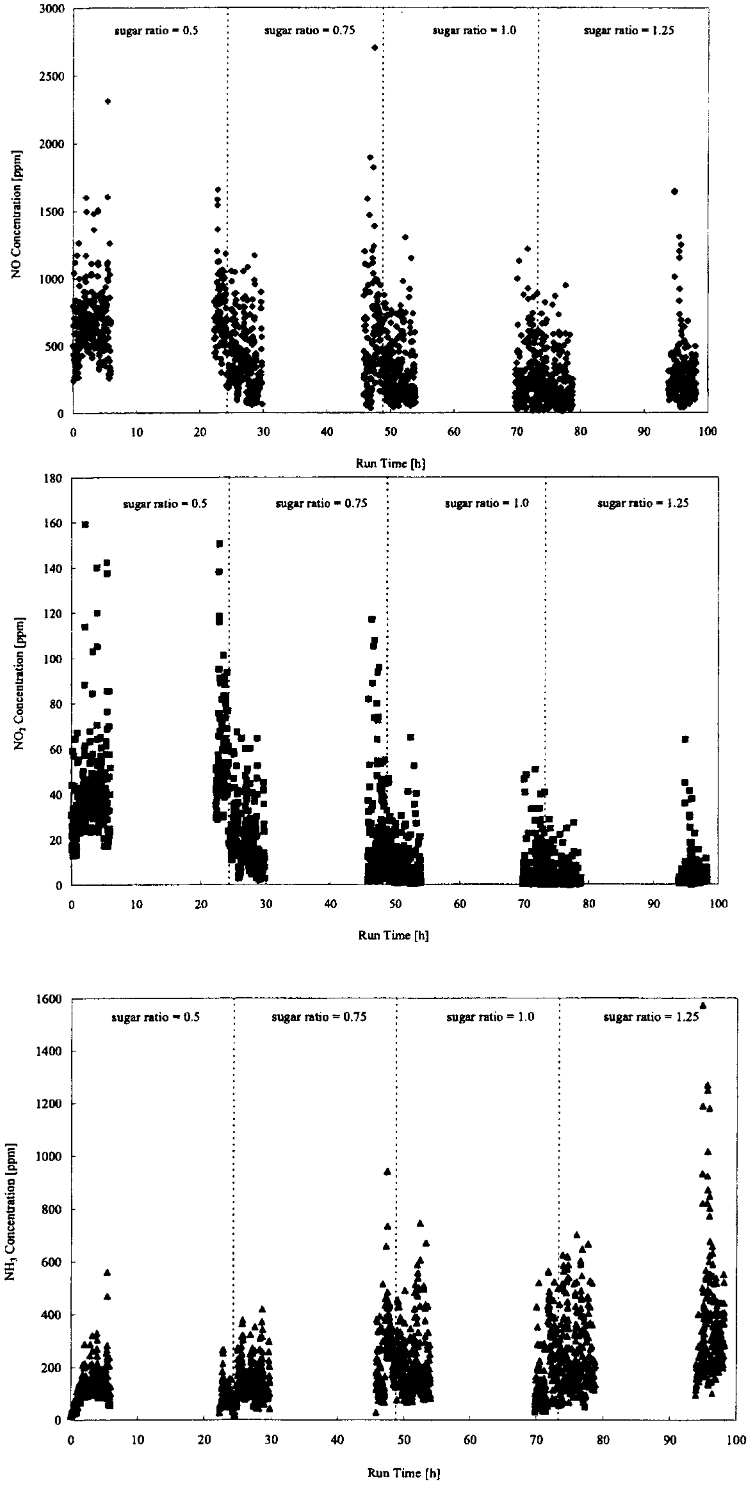

Figure 5.4. Concentration of selected FTIR-monitored species in off-gas during Test 3; average values for these analytes are listed in Table 5.6.

Table 2.1. LAW Sub-Envelope A3 Simulant Recipe at 6 Molar Sodium.

Envelope Constituents	Simulant AN-104 including Pretreatment		GLASS Oxides	LAWA Simulant as Oxides (wt%)	Waste Contribution to Glass	Source in Simulant	Order for Addition	Formula Weight	Assay	Ratio	Target Weight (g)
	mg/l	M	Loading		18.36%	In 741 ml water add following compounds in order listed below:					
Al	17919	0.6642	Al_2O_3	14.40	2.6259	$Al(OH)_3$	2	78.00	0.99	0.65	52.170
B	0	0.0000	B_2O_3	0.00	0.0000	H_3BO_3		61.83	0.99	0.56	0.000
Ca	23	0.0006	CaO	0.01	0.0025	$Ca(NO_3)_2*4H_2O$	4	236.16	0.99	0.24	0.136
Cr	157	0.0030	Cr_2O_3	0.10	0.0177	$Cr(NO_3)_3*9H_2O$	5	400.17	0.99	0.19	1.223
Cs*250	2250	0.0149	Cs_2O	0.89	0.1627	$CsNO_3$	6	194.91	1.00	0.72	2.907
Fe	11	0.0002	Fe_2O_3	0.01	0.0012	$Fe(NO_3)_3*9H_2O$	7	404.01	1.00	0.20	0.076
K	2781	0.0711	K_2O	1.42	0.26	K_2CO_3	21	138.21	0.99	0.84	4.965
Na	138050	6.00	Na_2O	78.55	14.42	NaOH, 50% sol. d=1.53	1	40.00	0.48	0.77	160.921
Si	135	0.0048	SiO_2	0.12	0.0223	SiO_2	14	60.09	0.99	1.00	0.291
Ti	0	0.0000	TiO_2	0.00	0.0000	TiO_2		79.90	0.99	1.00	0.000
Zn	0	0.0000	ZnO	0.00	0.0000	ZnO		81.39	0.99	1.00	0.000
Cl	4293	0.1211	Cl	1.81	0.3330	NaCl	9	58.45	0.99	0.61	7.151
F	329	0.0173	F	0.14	0.0255	NaF	10	42.00	0.99	0.45	0.734
PO_4	2303	0.0242	P_2O_5	0.73	0.1335	$Na_3PO_4*12H_2O$	3	380.12	0.99	0.19	9.310
SO_4	5459	0.0568	SO_3	1.92	0.3529	Na_2SO_4	11	142.06	0.99	0.56	8.155
NO_2	64205	1.3958	NO_2			$NaNO_2$	23	69.00	0.97	0.55	99.287
NO_3	99864	1.6107	NO_3			$NaNO_3$	24	84.99	0.99	0.73	126.317
CO_3	27740	0.4623	CO_3			Na_2CO_3	22	105.99	1.00	0.58	45.225
NH_3	1936	0.1137	NH_3			NH_4NO_3	8	80.04	1.00		9.099
OH	66030	3.8841	OH			$Al(OH)_3$+ NaOH					
Org.Carbon	1710	0.1425									
	EDTA	3.12E-03				$Na_2EDTA. 2H_2O$ (C10)	15	372.24	0.99	0.41	1.175
	HEDTA	4.88E-03				Na_3HEDTA (41% sol.) (C10)	16	380.24	0.99	0.32	4.146
	Acetate	5.82E-03				Sodium Acetate (C2)	17	136.08	0.99	0.18	0.799
	Formate	1.70E-02				Sodium Formate (C1)	18	68.01	0.99	0.18	1.166
	Oxalate	2.39E-03				Sodium Oxalate (C2)	19	134.00	0.99	0.18	0.324
	Gluconate	0.00E+00				Sodium Gluconate (C6)		218.14	0.99	0.06	0.000
	Glycolic	7.44E-03				Glycolic Acid (C2)	20	76.05	0.67	0.32	0.844
	NTA	0.00E+00				Nitrilotriacetic Acid (C6)		191.14	0.98	0.38	0.000
	Citric	0.00E+00				Citric Acid (C5)		192.12	0.99	0.12	0.000
	Imidoacetic	0.00E+00				Iminodiacetic Acid (C2)		133.1	0.98	0.18	0.000
						Target Glass					1289.459
			SUM	100.00	18.36	Total simulant weight					1277.44

Table 2.2. Oxide Composition of LAW Sub-Envelope A3 Simulant and Corresponding Glass Compositions and Properties.

Glass Oxides	AN104 in glass @ 14.4% Na_2O	Additives Mix	Recycled Sulfate	LAWA102 Variations		
				Nominal	+15 wt% Additive	+ 15wt% Simulant
Loading	18.36%	81.64%		18.36%		
Al_2O_3	2.6259	3.44		6.04	5.84	6.26
B_2O_3	0.0000	10.01		9.99	10.22	9.71
BaO	0.0008	0		0.00	0.00	0.00
CaO	0.0025	5.07		5.06	5.18	4.92
Cr_2O_3	0.0177	0		0.02	0.02	0.02
Cs_2O	0.1627	0		0.16	0.14	0.18
Fe_2O_3	0.0012	5.42		5.40	5.53	5.26
K_2O	0.26	0		0.26	0.23	0.29
Li_2O	0.00	2.50		2.50	2.55	2.43
MgO	0.0000	1.50		1.49	1.53	1.46
MnO_2	0.0003	0		0.00	0.00	0.00
Na_2O	14.42	0	0.06	14.44	12.85	16.15
SiO_2	0.0223	46.63		46.51	47.70	45.27
TiO_2	0.0000	1.15		1.14	1.17	1.11
ZnO	0.0000	3.07		3.06	3.13	2.97
ZrO_2	0.0003	3.03		3.02	3.09	2.94
Cl	0.3330	0		0.33	0.30	0.37
F	0.0255	0		0.03	0.02	0.03
P_2O_5	0.1335	0		0.13	0.12	0.15
SO_3	0.3529	0	0.09	0.44	0.39	0.48
Total	18.36	81.64	0.15	100	100	100
Viscosity, Poise						
1200°C				36	38	27
1150°C				55	59	39
1100°C				88	95	61
1050°C				149	164	101
Conductivity, S/cm						
1200°C				0.47	0.34	0.47
1150°C				0.39	0.28	0.39
1100°C				0.33	0.23	0.32
1050°C				0.26	0.18	0.26

Table 2.3. Glass Forming Additives for 1 Liter of Simulant (Nominal) and Corresponding Melter Feed Properties.

Additives Source, (g)	Feed LAWA102
Additives in Glass (wt%)	81.64%
Kyanite (Al_2SiO_5) 325 Mesh (Kyanite Mining)	82.87
H_3BO_3 (US Borax – Technical Granular)	238.88
Wollanstonite NYAD 325 Mesh (NYCO Minerals)	149.65
Fe_2O_3 (97% Alfa)	65.86
Li_2CO_3 (Chemetall Foote Co. Technical grade)	81.51
Olivine (Mg_2SiO_4) 325 Mesh (#180 Unimin)	40.62
SiO_2 (Sil-co-Sil 75 US Silica))	463.80
TiO_2 (Rutile Airfloated Chemaloy)	15.48
ZnO (KADOX – 920 Zinc Corp. of America)	39.96
Zircon $ZrSiO_4$ (Flour) Mesh 325 (AM. Mineral)	58.62
Addition of Sucrose as Reductant (nominal)	60.2
+Na_2SO_4 (from recycled off-gas) g	2.04
Simulant Weight for 1 liter	1277
Sum of Additives (g)	1237
Sum of Complete Batch (g)	2514
Final Volume (l)	1.516
Density (g/ml)	1.67
Expected Glass Produced (g) ; i.e., Glass Yield (g/l of simulant)	1289
Weight % Water in Slurry Feed	36%
Weight % Additives in Slurry	49%
Glass Yield (g/kg of Feed)	511
Glass Yield (g/l of Feed)	851
Total Solids (g/l of Feed)	1066
Additive (g/l of Feed)	816

Table 2.4. Measured Feed Slurry Properties.

		LAWA102	
		+15 wt. % Additive	+15 wt. % Simulant
% Water		35.9	40.5
Density (kg/l)		1.71	1.59
pH		9.25	9.95
Glass yield (kg/kg)		0.528	0.458
Viscosity (poise)	@ 1 s^{-1}	33	32
	@ 10 s^{-1}	5.5	5.2

Table 2.5. Measured Properties of Melter Feed Samples.

Test #, Sampling Date		Sample Name	Wt% Water	Density (g/ml)	Glass Yield (kg/kg)	Glass Yield (g/l)	pH	Yield Stress (Pa)	Viscosity (poise)		
									@ 1/s	@ 10/s	@ 100/s
LAWA102 Nominal (target)			36.0	1.67	0.511	851	NA	NA	NA	NA	NA
LAWA102 (Crucible Test +15% wt. Additives)			35.9	1.71	0.528	903	9.25	0.8	33	5.5	NA
LAWA102 (Crucible Test +15% wt. Simulant)			40.5	1.59	0.458	728	9.95	1.5	32	5.2	NA
1	6/18/01	WVA-F-39A	37.2	1.68	0.513	862	8.89	1.0	37	7.1	2.4
	6/19/01	WVA-F-57A	37.2	1.69	0.507	857	9.04	0.8	24	5.3	1.5
	6/21/01	WVA-F-78A	40.1	1.72	0.484	832	9.04	0.9	26	5.7	1.6
	6/22/01	WVA-F-90A	36.6	1.69	0.515	870	9.09	1.0	28	6.2	1.8
2	7/10/01	WVA-F-124A	40.6	1.61	0.462	744	9.83	NA	NA	NA	NA
	7/12/01	WVA-F-148A	40.3	1.59	0.469	746	9.85	NA	NA	NA	NA
	7/13/01	WVB-F-30A	41.5	1.59	0.448	712	9.86	0.8	7.7	1.1	0.34
	7/15/01	WVB-F-56A	40.4	1.61	0.476	766	10.11	NA	NA	NA	NA
	7/16/01	WVB-F-75A	40.0	1.62	0.453	734	9.89	NA	NA	NA	NA
3*	8/13/01	WVB-F-113A	38.6	1.64	0.473	776	9.41	1.5	27	2.0	0.56
	8/15/01	WVB-F-143A	35.6	1.63	0.480	782	9.30	NA	NA	NA	NA
	8/17/01	WVC-F-31A	38.4	1.66	0.470	780	9.32	0.95	11.4	1.7	0.69

NA: Not Analyzed
* Test # 3 was conducted using the nominal feed
Note: Crucible and melter feed samples were from separately prepared batches

Table 2.6. XRF and DCP Analyzed Compositions of Melter Feed Samples (wt%).

Oxide	Test # 1													Test # 2				
	Target	WVA-F-39A			WVA-F-57A			WVA-F-78A			WVA-F-90A			Target	WVA-F-124A		WVA-F-148A	
		XRF		DCP	XRF		DCP	XRF		DCP	XRF		DCP		XRF	DCP	XRF	DCP
Al_2O_3	5.84	5.95	5.92	5.81	6.01	5.64	5.77	5.71	5.87	5.96	5.86	5.73	5.84	6.26	6.13	6.31	6.19	6.25
B_2O_3	10.22	10.15	10.15	10.96	10.16	10.15	10.99	10.15	10.15	10.92	10.15	10.16	10.68	9.71	9.70	9.93	9.70	9.98
CaO	5.18	5.29	5.07	4.90	5.18	5.48	4.90	5.29	5.14	4.98	5.26	5.34	4.96	4.92	5.03	4.78	4.87	4.79
Cl	0.30	0.15	0.12	NA	0.09	0.11	NA	0.14	0.09	NA	0.09	0.12	NA	0.37	0.02	NA	0.02	NA
Cr_2O_3	0.02	0.04	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.02	0.04	0.04	0.04	0.04
Cs_2O	0.14	0.12	0.12	NA	0.12	0.11	NA	0.13	0.11	NA	0.10	0.13	NA	0.18	0.10	NA	0.08	NA
F	0.02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.03	NA	NA	NA	NA
Fe_2O_3	5.53	5.81	5.50	5.25	5.72	6.28	5.31	5.92	5.65	5.33	5.77	5.99	5.23	5.26	5.62	5.05	5.33	5.07
K_2O	0.23	0.65	0.64	0.62	0.65	0.67	0.61	0.64	0.65	0.62	0.63	0.67	0.62	0.29	0.50	0.48	0.48	0.44
Li_2O	2.55	2.54	2.54	2.51	2.54	2.54	2.52	2.54	2.54	2.54	2.54	2.54	2.57	2.43	2.42	2.38	2.42	2.40
MgO	1.53	1.60	1.66	1.58	1.59	1.57	1.59	1.62	1.66	1.62	1.69	1.57	1.58	1.46	1.46	1.63	1.56	1.60
Na_2O	12.85	11.65	12.39	10.69	12.30	11.74	11.17	11.85	12.59	11.42	11.96	12.07	10.95	16.15	15.07	13.57	15.32	13.60
P_2O_5	0.12	0.15	0.16	0.24	0.16	0.16	0.17	0.16	0.15	0.21	0.15	0.15	0.18	0.15	0.18	0.19	0.19	0.21
SiO_2	47.70	47.90	48.19	43.87	47.67	46.84	44.83	47.69	47.63	45.84	47.99	47.15	43.85	45.27	45.96	42.58	46.63	43.00
SO_3	0.39	0.28	0.24	NA	0.21	0.24	NA	0.26	0.21	NA	0.21	0.25	NA	0.48	0.26	NA	0.25	NA
TiO_2	1.17	1.34	1.28	1.27	1.31	1.41	1.29	1.36	1.30	1.29	1.32	1.35	1.26	1.11	1.28	1.23	1.23	1.20
ZnO	3.13	3.07	2.89	2.94	3.01	3.40	2.95	3.13	3.01	3.05	3.04	3.20	3.06	2.97	2.99	2.80	2.79	2.86
ZrO_2	3.09	3.30	3.08	2.91	3.23	3.62	2.98	3.38	3.20	3.00	3.18	3.54	2.96	2.94	3.22	2.75	2.91	2.79
Sum	100.00	100.00	100.00	93.58	100.00	100.00	95.13	100.00	100.00	96.82	100.00	100.00	93.77	100.00	100.00	93.73	100.00	94.24

NA: not analyzed.

Note: Lithium and boron are not determined by XRF so renormalized target values are listed.

Table 2.6. XRF and DCP Analyzed Compositions of Melter Feed Samples (wt%) (continued).

Oxide	Test # 2						Test # 3					
	WVB-F-30A		WVB-F-56A		WVB-F-75A		Target	WVB-F-113A		WVB-F-143A		WVC-F-31A
	XRF	DCP	XRF	DCP	XRF	DCP		XRF	DCP	XRF	DCP	XRF
Al_2O_3	6.05	6.25	6.08	6.31	6.39	6.05	6.04	6.25	5.87	6.32	5.93	6.00
B_2O_3	9.64	10.11	9.67	10.08	9.67	9.94	9.99	9.64	10.24	9.88	10.11	9.89
CaO	4.92	4.77	5.09	4.81	4.69	4.62	5.06	4.81	4.69	4.84	4.72	5.20
Cl	0.10	NA	0.03	NA	0.04	NA	0.33	0.09	NA	0.13	NA	0.07
Cr_2O_3	0.04	0.04	0.04	0.04	0.04	0.04	0.02	0.03	0.04	0.04	0.03	0.04
Cs_2O	0.12	NA	0.07	NA	0.10	NA	0.16	0.10	NA	0.10	NA	0.09
F	0.00	NA	0.00	NA	0.00	NA	0.03	0.00	NA	0.00	NA	0.00
Fe_2O_3	5.42	5.01	5.62	5.11	4.98	5.06	5.40	5.31	5.10	5.17	5.09	5.77
K_2O	0.51	0.47	0.67	0.59	0.54	0.54	0.26	0.50	0.46	0.49	0.47	0.47
Li_2O	2.41	2.43	2.42	2.47	2.41	2.32	2.50	2.41	2.35	2.47	2.31	2.47
MgO	1.56	1.66	1.47	1.55	1.59	1.53	1.49	1.55	1.65	1.52	1.48	1.42
Na_2O	15.02	13.60	14.74	13.54	15.64	12.95	14.44	14.38	12.10	13.85	12.20	13.71
P_2O_5	0.19	0.23	0.18	0.15	0.19	0.18	0.13	0.18	0.20	0.17	0.21	0.17
SiO_2	46.51	42.03	46.03	42.92	46.73	42.06	46.51	47.66	42.97	48.25	43.99	47.26
SO_3	0.39	NA	0.26	NA	0.28	NA	0.44	0.28	NA	0.13	NA	0.11
TiO_2	1.24	1.20	1.33	1.18	1.20	1.24	1.14	1.21	1.24	1.20	1.29	1.31
ZnO	2.86	2.76	3.07	2.75	2.64	2.77	3.06	2.78	2.80	2.71	2.76	2.86
ZrO_2	3.03	2.77	3.24	2.91	2.87	2.80	3.02	2.82	2.77	2.73	2.78	3.15
Sum	100.00	93.33	100.00	94.42	100.00	92.11	100.00	100.00	92.50	100.00	93.36	100.00

NA: Not Analyzed
Note: Lithium and boron are not determined by XRF so renormalized target values are listed.

Table 3.1. Summary of Results from Composition Variation Tests (Tests 1 and 2).

Test #		**1**	**2**
		+ 15% Additives	+ 15% Simulant
Start Date		6/18/01	7/13/01
Start Time		1900	0940
End Date		6/22/01	7/17/01
End Time		2301	1212
Net Time (hr)		100	98.5
Target Glass SO_3		0.39	0.48
Target Glass Na_2O		12.88	16.18
Glass/feed (g/l)		900	730
Glass Production Rate ($kg/m^2/day$)	Target	1550	1410
	Actual	1350	1440
Sulfate Gall at Test End		NO	NO
Test End SO_3 wt. % Measured in Discharged Glass		0.36	0.45
% Feed SO_3 in Glass		92	94
% of Sulfur Emitted	SO_2*	< 0.1	< 0.1
	Gas$	1.11	< 0.01
	Particles	5.35	7.03

* - Value from FTIR analysis.
$ - "Gas" and "particles" refer to fractions passing and retained on a 0.45 μm filter, respectively..

Table 3.2. Summary of Results from Test 3 (Variable Sugar, 1500 kg/m^2/day Glass Production Rate).

Sugar Ratio			0.5	0.75	1.0	1.25
Time	Feed Start		8/13/01 12:51	8/14/01 13:20	8/15/01 13:46	8/16/01 14:12
	Feed End		8/14/01 13:07	8/15/01 13:35	8/16/01 14:05	8/17/01 15:05
Glass	Target % SO_3		0.44	0.44	0.44	0.44
	Target % Na_2O		14.46	14.46	14.46	14.46
	Measured % Fe^{++}		< 0.8	16 - 21	26 - 45	55-65
	Measured wt% SO_3		0.43	0.33	0.16	0.12
	% SO_3 of target		98	77	36	27
	Sulfate Gall at Test End		ND	ND	ND	YES
Emissions	SO_2	ppm*	< 0.1	3.4	5.8	7.5
		% of Feed Sulfur[&]	< 0.6	8.0	13.7	17.5
	Total gaseous Sulfur	mg/min[#]	1.8	19.5	47.2	80.3
		% of Feed Sulfur	0.85	5.71	25.08	31.77
	Total Particulate Sulfur	mg/min[#]	14.4	16.7	40.2	22.9
		% of Feed Sulfur	6.87	4.86	21.35	9.07

ND- Not determined.
* - Value from FTIR.
# - Value from analysis of impinger solutions, filters and rinses generated from CFR 40 Method 5 stack sampling.
& - Assumes target steady-state processing rate was obtained throughout off gas sampling periods.

Table 3.3. Summary of Measured Melter Parameters.

			Test 1			Test 2			Test 3		
			AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (°C)	Electrodes	East	1074	1047	1098	1093	1064	1106	1066	1022	1106
		West	1078	1050	1102	1132	1078	1149	1095	1051	1135
		Bottom	820	771	844	959	908	970	894	843	958
	Glass Pool	19" from Bottom	974	712	1121	992	696	1128	900	638	1150
		16" from Bottom	1099	890	1148	1115	968	1154	1086	853	1156
		10" from Bottom	1140	1041	1164	1152	1084	1175	1152	1085	1182
		4" from Bottom	1116	1083	1144	1149	1081	1172	1152	1076	1191
	Plenum	Exposed	585	225	889	525	359	772	545	200	791
		Thermowell	535	273	866	521	433	771	492	318	762
	Bubbler		1159	1111	1179	1146	1107	1170	1112	1061	1158
	Discharge	Chamber	NR	NR	NR	921	868	966	924	853	973
		Air Lift	925	797	992	982	926	1116	1020	873	1126
	Film Cooler Outlet		306	301	413	292	270	389	303	295	362
	Transition Line Outlet		305	298	394	308	253	388	315	235	367
Bubbling (scfh)			19	3	20	11	1	20	24	3	35
Absolute Melter Pressure (inches water)			-2.38	-4.10	2.00	-3.10	-5.25	5.05	-2.84	-5.25	0.26
Electrode Voltage (V)			44.6	39.8	53.2	41.9	8.2	52.3	47.2	1.7	63.6
Total Power (kW)			15.5	11.1	18.0	18.7	0.2	24.2	17.5	0.2	27.2

NR - Not Recorded.

Table 4.1. Listing of Glass Discharged, Masses, and Analysis Performed.

Test	Dis. Date	Glass Name	Analysis Performed	Measured Mass (kg)	Cumulative Mass (kg)
1	06/19/01	WVA-G-49A	XRF, DCP	13.3	13.3
	06/19/01	WVA-G-51A	XRF, DCP	10.7	24.0
	06/20/01	WVA-G-54A	XRF	16.4	40.4
	06/20/01	WVA-G-54B	XRF, DCP	24.7	65.1
	06/20/01	WVA-G-56A WVA-G-58A	XRF, DCP	28.3	93.4
	06/20/01	WVA-G-58B	XRF, DCP	13.9	107.3
	06/20/01	WVA-G-62A WVA-G-63A	XRF	27.8	135.1
	06/20/01	WVA-G-63B WVA-G-63C	XRF, DCP	28.6	163.7
	06/20/01	WVA-G-68A	XRF	5.3	169.0
	06/20/01	WVA-G-67A WVA-G-68B	XRF	39.4	208.4
	06/20/01	WVA-G-70A WVA-G-70B	XRF	24.3	232.7
	06/21/01	WVA-G-70C WVA-G-75A	XRF	28.1	260.8
	06/21/01	WVA-G-75B WVA-G-77A	XRF	21.2	282.0
	06/21/01	WVA-G-77B WVA-G-78A	XRF	29.9	311.9
	06/21/01	WVA-G-81A WVA-G-83A	XRF	29.5	341.4
	06/21/01	WVA-G-84A WVA-G-84B	XRF	34.0	375.4
	06/22/01	WVA-G-86A WVA-G-89A	XRF	25.1	400.5
	06/22/01	WVA-G-89B WVA-G-89C	XRF	22.1	422.6
	06/22/01	WVA-G-89D WVA-G-90A	XRF	22.1	444.7
	06/22/01	WVA-G-92A WVA-G-92B	XRF	33.3	478.0
	06/23/01	WVA-G-95A WVA-G-96A	XRF	39.2	517.2
	06/23/01	WVA-G-98A	XRF	8.4	525.6
	06/23/01	WVA-G-100A WVA-G-100B	XRF, DCP, Fe	26.8	552.4

Table 4.1. Listing of Glass Discharged, Masses, and Analysis Performed. (continued)

Test	Dis. Date	Glass Name	Analysis Performed	Measured Mass (kg)	Cumulative Mass (kg)
2	07/09/01	WVA-G-109A	XRF	3.8	556.2
	07/09/01	WVA-G-109B WVA-G-116A	XRF	26.8	583.0
	07/10/01	WVA-G-116B WVA-G-120A	XRF	23.0	606.0
	07/10/01	WVA-G-121A WVA-G-121B	XRF, DCP	18.5	624.5
	07/10/01	WVA-G-124A WVA-G-124B WVA-G-125A WVA-G-125B	XRF	28.2	652.7
	07/10/01	WVA-G-130A	XRF	26.6	679.3
	07/11/01	WVA-G-130B WVA-G-130C WVA-G-131A WVA-G-131B	XRF	25.0	704.3
	07/11/01	WVA-G-136A WVA-G-137A WVA-G-137B WVA-G-138A	XRF	15.5	719.8
	07/11/01	WVA-G-138B WVA-G-139A WVA-G-146A	XRF	26.1	745.9
	07/12/01	WVA-G-146B WVA-G-147A WVA-G-148A	XRF	34.0	779.9
	07/13/01	WVB-G-22A WVB-G-23A WVB-G-24A WVB-G-24B	XRF	38.9	818.8
	07/14/01	WVB-G-26A WVB-G-29A WVB-G-32A	XRF	35.1	853.9
	07/14/01	WVB-G-32B WVB-G-33A WVB-G-34A	XRF	25.6	879.5
	07/14/01	WVB-G-36A WVB-G-36B WVB-G-39A	XRF, Fe	25.9	905.4
	07/14/01	WVB-G-39B WVB-G-40A WVB-G-40B	XRF, Fe	26.4	931.8

Table 4.1. Listing of Glass Discharged, Masses, and Analysis Performed. (continued)

Test	Dis. Date	Glass Name	Analysis Performed	Measured Mass (kg)	Cumulative Mass (kg)
2	07/14/01	WVB-G-40C WVB-G-40D WVB-G-42A WVB-G-42B	XRF	29.4	961.2
	07/15/01	WVB-G-44A WVB-G-45A WVB-G-46A WVB-G-50A WVB-G-51A	XRF, DCP, Fe	44.0	1005.2
	07/15/01	WVB-G-52A WVB-G-53A WVB-G-54A WVB-G-54B	XRF	32.0	1037.2
	07/15/01	WVB-G-56A WVB-G-56B WVB-G-56C	XRF, Fe	27.0	1064.2
	07/15/01	WVB-G-59A WVB-G-60A WVB-G-61A	XRF, Fe	26.0	1090.2
	07/15/01	WVB-G-61B WVB-G-62A WVB-G-64A	XRF	25.7	1115.9
	07/16/01	WVB-G-64B WVB-G-69A WVB-G-70A	XRF	17.2	1133.1
	07/16/01	WVB-G-70B WVB-G-71A WVB-G-73A	XRF	28.6	1161.7
	07/16/01	WVB-G-74A WVB-G-74B WVB-G-75A	XRF, Fe	24.4	1186.1
	07/16/01	WVB-G-78A WVB-G-78B WVB-G-79A	XRF, Fe	34.4	1220.5
	07/16/01	WVB-G-79B WVB-G-80A WVB-G-80B WVB-G-82A	XRF	32.8	1253.3
	07/16/01	WVB-G-82B WVB-G-83A WVB-G-83B	XRF, Fe	20.5	1273.8
	07/17/01	WVB-G-84A WVB-G-87A WVB-G-90A	XRF	26.0	1299.8

Table 4.1. Listing of Glass Discharged, Masses, and Analysis Performed. (continued)

Test	Dis. Date	Glass Name	Analysis Performed	Measured Mass (kg)	Cumulative Mass (kg)
2	07/17/01	WVB-G-91A WVB-G-91B WVB-G-91C	XRF	32.3	1332.1
	07/17/01	WVB-G-92A WVB-G-92B WVB-G-93A	XRF, DCP, Fe	23.1	1355.2
	07/18/01	WVB-G-95A WVB-G-95B WVB-G-99A	XRF, Fe	33.9	1389.1
3A	08/13/01	WVB-G-115A WVB-G-115B	XRF, Fe	21.8	1410.9
	08/13/01	WVB-G-115C WVB-G-116A	XRF	16.3	1427.2
	08/13/01	WVB-G-116B WVB-G-116C	XRF, Fe	20.5	1447.7
	08/14/01	WVB-G-120A WVB-G-120B WVB-G-121A	XRF	29.7	1477.4
	08/14/01	WVB-G-122A WVB-G-122B	XRF, DCP, Fe	13.7	1491.1
	08/14/01	WVB-G-124A WVB-G-124B	XRF	21.1	1512.2
	08/14/01	WVB-G-125A WVB-G-128A	XRF	27.6	1539.8
3B	08/14/01	WVB-G-129A WVB-G-131A WVB-G-132A	XRF, DCP, Fe	21.2	1561.0
	08/14/01	WVB-G-132B WVB-G-133A	XRF	15.8	1576.8
	08/15/01	WVB-G-133B WVB-G-136A	XRF	21.4	1598.2
	08/15/01	WVB-G-136B WVB-G-139A	XRF, Fe	18.5	1616.7
	08/15/01	WVB-G-140A WVB-G-142A	XRF	17.2	1633.9
	08/15/01	WVB-G-142B WVB-G-143A		20.9	1654.8
	08/15/01	WVB-G-144A WVB-G-145A	XRF	18.5	1673.3
3C	08/15/01	WVB-G-148A	XRF, DCP, Fe	12.5	1685.8
	08/15/01	WVB-G-148B WVB-G-150A	XRF	24.3	1710.1
	08/15/01	WVB-G-151A WVB-G-151B		25.1	1735.2

Table 4.1. Listing of Glass Discharged, Masses, and Analysis Performed. (continued)

Test	Dis. Date	Glass Name	Analysis Performed	Measured Mass (kg)	Cumulative Mass (kg)
3C	08/15/01	WVB-G-151C WVB-G-151D	XRF	14.9	1750.1
	08/16/01	WVC-G-6A WVC-G-6B	XRF	20.6	1770.7
	08/16/01	WVC-G-11A WVC-G-11B	XRF, Fe	15.1	1785.8
	08/16/01	WVC-G-12A WVC-G-13A	XRF	13.0	1798.8
	08/16/01	WVC-G-14A WVC-G-15A	XRF	15.2	1814.0
	08/16/01	WVC-G-15B WVC-G-15C	XRF	19.5	1833.5
3D	08/16/01	WVC-G-16A WVC-G-18A	XRF	20.9	1854.4
	08/16/01	WVC-G-21A WVC-G-21B WVC-G-21C	XRF, Fe	22.4	1876.8
	08/16/01	WVC-G-22A WVC-G-24A	XRF	19.5	1896.3
	08/17/01	WVC-G-24B WVC-G-25A	XRF	19.0	1915.3
	08/17/01	WVC-G-29A WVC-G-29B	XRF, Fe	25.4	1940.7
	08/17/01	WVC-G-31A WVC-G-31B	XRF	20.7	1961.4
	08/17/01	WVC-G-31C WVC-G-31D	XRF, Fe	15.6	1977.0
	08/17/01	WVC-G-34A WVC-G-34B	XRF	19.1	1996.1
	08/18/01	WVC-G-35A WVC-G-40A	XRF, DCP, Fe	28.6	2024.7

Table 4.2. DCP Analyzed Compositions of Discharged Glasses.

	Test 1							
Sample I.D.	Target	WVA-G-49A	WVA-G-51A	WVA-G-54B	WVA-G-58A	WVA-G-58B	WVA-G-63C	WVA-G-100B
Cum (kg)		13.3	24	40.4	93.4	107.3	163.7	552.4
Al_2O_3	5.84	7.04	7.31	7.19	6.75	6.69	6.28	5.58
B_2O_3	10.22	10.82	11.25	10.95	11.36	11.37	11.45	10.89
CaO	5.18	5.66	5.70	5.62	5.43	5.32	5.17	4.96
Cl	0.30	NA	NA	NA	NA	NA	NA	NA
Cr_2O_3	0.02	0.15	0.16	0.16	0.10	0.10	0.09	0.07
Cs_2O	0.14	NA	NA	NA	NA	NA	NA	NA
F	0.02	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	5.53	6.02	6.06	6.01	5.83	5.69	5.67	5.24
K_2O	0.23	0.30	0.35	0.36	0.46	0.47	0.54	0.63
Li_2O	2.55	2.57	2.63	2.60	2.59	2.55	2.81	2.45
MgO	1.53	1.53	1.53	1.53	1.55	1.50	1.68	1.61
Na_2O	12.85	10.62	10.59	10.52	10.82	10.92	10.51	11.17
P_2O_5	0.12	0.22	0.24	0.20	0.22	0.20	0.16	0.22
SiO_2	47.70	45.03	44.88	44.37	43.52	44.47	44.59	44.54
SO_3^*	0.39	NA	NA	NA	NA	NA	NA	0.31
TiO_2	1.17	1.25	1.30	1.29	1.23	1.23	1.26	1.32
ZnO	3.13	2.62	2.62	2.62	2.82	2.81	2.79	2.95
ZrO_2	3.09	2.90	2.96	2.93	2.99	2.92	2.96	2.95
SUM	100.00	96.73	97.58	96.35	95.67	96.24	95.96	94.89

NA: Not Analyzed.
* = By ion chromatography on dissolved glass.

Table 4.2. DCP Analyzed Compositions of Discharged Glasses (continued).

	Test# 2				Test# 3	3A	3B	3C	3D
Sample I.D.	Target	WVA-G-121B	WVB-G-51A	WVB-G-93A	Target	WVB-G-122B	WVB-G-132A	WVB-G-148A	WVC-G-40A$^{\$}$
Cum (kg)		624.5	1005.2	1355.2		1491.1	1561	1685.8	2024.7
Al_2O_3	6.26	5.89	6.07	6.62	6.04	5.96	5.86	6.54	5.88
B_2O_3	9.71	10.75	10.27	10.67	9.99	10.39	10.29	10.92	10.49
CaO	4.92	4.99	4.84	5.17	5.06	4.88	4.86	5.26	4.95
Cl	0.37	NA	NA	NA	0.33	NA	NA	NA	NA
Cr_2O_3	0.02	0.09	0.12	0.11	0.02	0.13	0.11	0.07	0.06
Cs_2O	0.18	NA	NA	NA	0.16	NA	NA	NA	NA
F	0.03	NA	NA	NA	0.03	NA	NA	NA	NA
Fe_2O_3	5.26	5.27	5.01	5.28	5.40	5.12	5.10	5.39	5.23
K_2O	0.29	0.56	0.48	0.57	0.26	0.50	0.49	0.46	0.47
Li_2O	2.43	2.44	2.32	2.40	2.50	2.32	2.33	2.52	2.35
MgO	1.46	1.67	1.68	1.67	1.49	1.58	1.68	1.67	1.66
Na_2O	16.15	12.46	13.85	14.96	14.44	13.19	12.87	13.73	12.80
P_2O_5	0.15	0.28	0.45	0.25	0.13	0.34	0.29	0.32	0.27
SiO_2	45.27	45.68	44.31	44.63	46.51	44.68	44.92	44.92	44.85
SO_3^*	0.48	0.43	0.43	0.11	0.44	0.43	0.37	0.12	0.37
TiO_2	1.11	1.31	1.27	1.26	1.14	1.34	1.33	1.29	1.34
ZnO	2.97	2.82	2.72	2.90	3.06	2.79	2.79	2.93	2.85
ZrO_2	2.94	2.93	2.82	3.24	3.02	2.89	2.91	3.27	2.95
SUM	100.00	97.57	96.64	99.84	100.00	96.54	96.20	99.41	96.52

NA: Not Analyzed.

* By ion chromatography on dissolved glass.

$ Sample discharged after 12 hours of idling after the end of the run (i.e., re-oxidized).

Table 4.3. XRF Analyzed Composition of Discharged Glasses (wt%).

		Test 1										
Sample I.D.	Target	WVA-G-49A	WVA-G-51A	WVA-G-54A	WVA-G-54B	WVA-G-58A	WVA-G-58B	WVA-G-63A	WVA-G-63C	WVA-G-68A	WVA-G-68B	WVA-G-70B
Cum (kg)		13.3	24	40.4	65.1	93.4	107.3	135.1	163.7	169	208.4	232.7
Al_2O_3	5.84	6.90	7.09	6.51	7.03	6.58	6.69	6.37	6.50	6.30	6.34	6.14
B_2O_3	10.22	10.16	10.15	10.16	10.15	10.15	10.15	10.15	10.15	10.16	10.15	10.15
CaO	5.18	5.83	5.68	6.02	5.83	5.44	5.48	5.32	5.41	5.45	5.24	5.21
Cl	0.30	0.09	0.08	0.09	0.08	0.16	0.16	0.17	0.18	0.19	0.18	0.19
Cr_2O_3	0.02	0.20	0.17	0.22	0.18	0.12	0.12	0.11	0.10	0.12	0.09	0.09
Cs_2O	0.14	0.06	0.06	0.08	0.08	0.10	0.10	0.10	0.11	0.12	0.12	0.10
F	0.02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	5.53	6.44	6.20	6.54	6.44	6.01	6.04	5.73	5.99	6.06	5.77	5.70
K_2O	0.23	0.35	0.38	0.37	0.39	0.51	0.54	0.53	0.60	0.59	0.61	0.61
Li_2O	2.55	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54
MgO	1.53	1.56	1.58	2.01	1.55	1.59	1.52	1.62	1.53	1.56	1.64	1.62
Na_2O	12.85	11.94	12.32	11.71	11.82	12.23	12.01	12.58	11.69	11.73	12.50	12.60
P_2O_5	0.12	0.17	0.16	0.14	0.17	0.17	0.17	0.16	0.16	0.16	0.15	0.16
SiO_2	47.70	46.54	46.56	46.75	46.23	46.96	46.95	47.45	47.23	47.10	47.03	47.48
SO_3	0.39	0.12	0.13	0.14	0.13	0.24	0.26	0.28	0.30	0.31	0.32	0.32
TiO_2	1.17	1.30	1.28	1.23	1.31	1.29	1.31	1.25	1.32	1.33	1.29	1.29
ZnO	3.13	2.73	2.64	2.54	2.76	2.80	2.86	2.73	2.97	3.03	2.90	2.86
ZrO_2	3.09	3.08	2.97	2.95	3.28	3.09	3.11	2.92	3.22	3.26	3.12	2.95
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

NA: Not analyzed.
Note: Lithium and boron are not determined by XRF so renormalized target values are listed.

Table 4.3. XRF Analyzed Composition of Discharged Glasses (wt%) (continued).

		Test 1											
Sample I.D.	Target	WVA-G-75A	WVA-G-77A	WVA-G-78A	WVA-G-83A	WVA-G-84B	WVA-G-89A	WVA-G-89C	WVA-G-90A	WVA-G-92B	WVA-G-96A	WVA-G-98A	WVA-G-100B
Cum (kg)		260.8	282	311.9	341.4	375.4	400.5	422.6	444.7	478	517.2	525.6	552.4
Al_2O_3	5.84	6.10	6.25	6.23	5.96	6.19	6.01	5.83	6.04	6.10	5.95	6.18	5.79
B_2O_3	10.22	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.14	10.15
CaO	5.18	5.28	5.19	5.23	5.27	5.05	5.13	5.38	5.10	5.16	5.21	5.20	5.34
Cl	0.30	0.20	0.19	0.20	0.21	0.20	0.20	0.21	0.21	0.23	0.21	0.22	0.22
Cr_2O_3	0.02	0.09	0.08	0.09	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.08
Cs_2O	0.14	0.13	0.13	0.13	0.14	0.15	0.13	0.13	0.14	0.12	0.13	0.15	0.12
F	0.02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	5.53	5.84	5.79	5.75	5.90	5.44	5.69	6.06	5.64	5.69	5.81	5.81	6.03
K_2O	0.23	0.63	0.66	0.67	0.68	0.65	0.66	0.69	0.66	0.67	0.66	0.68	0.69
Li_2O	2.55	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54
MgO	1.53	1.60	1.50	1.62	1.59	1.60	1.70	1.53	1.64	1.64	1.66	1.58	1.63
Na_2O	12.85	12.26	12.36	11.99	12.06	12.54	12.43	11.70	12.56	12.30	12.42	12.17	11.81
P_2O_5	0.12	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.16
SiO_2	47.70	47.21	47.24	47.51	47.27	47.78	47.41	47.18	47.34	47.41	46.99	47.08	47.22
SO_3	0.39	0.33	0.32	0.34	0.35	0.35	0.35	0.37	0.36	0.36	0.35	0.35	0.37
TiO_2	1.17	1.31	1.29	1.30	1.33	1.27	1.29	1.38	1.29	1.32	1.33	1.33	1.36
ZnO	3.13	2.98	2.98	2.94	3.08	2.82	2.97	3.21	2.96	3.01	3.08	3.06	3.18
ZrO_2	3.09	3.21	3.16	3.16	3.24	3.04	3.11	3.41	3.13	3.06	3.28	3.30	3.34
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

NA: Not analyzed.
Note: Lithium and boron are not determined by XRF so renormalized target values are listed.

Table 4.3. XRF Analyzed Composition of Discharged Glasses (wt%) (continued).

		Test 2													
Sample I.D.	Target	WVA-G-109A	WVA-G-116A	WVA-G-120A	WVA-G-121B	WVA-G-125B	WVA-G-130A	WVA-G-131B	WVA-G-138A	WVA-G-146A	WVA-G-148A	WVB-G-24B	WVB-G-32A	WVB-G-34A	WVB-G-39A
Cum (kg)		556.2	583	606	624.5	652.7	679.3	704.3	719.8	745.9	779.9	818.8	853.9	879.5	905.4
Al_2O_3	6.26	5.87	6.12	6.00	5.99	5.80	6.10	5.95	6.02	6.15	6.10	6.10	6.13	6.14	6.07
B_2O_3	9.71	9.71	9.70	9.70	9.70	9.70	9.70	9.70	9.70	9.70	9.69	9.70	9.42	9.64	9.70
CaO	4.92	5.31	5.21	5.12	5.10	5.33	5.07	5.11	5.04	5.06	4.92	4.99	5.01	5.04	4.93
Cl	0.37	0.16	0.09	0.13	0.15	0.20	0.21	0.20	0.22	0.22	0.22	0.19	0.20	0.20	0.21
Cr_2O_3	0.02	0.09	0.10	0.11	0.10	0.10	0.10	0.10	0.09	0.12	0.12	0.18	0.16	0.16	0.14
Cs_2O	0.18	0.12	0.12	0.12	0.15	0.16	0.13	0.13	0.14	0.14	0.14	0.15	0.15	0.13	0.15
F	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	5.26	6.03	5.89	5.76	5.76	6.11	5.69	5.81	5.75	5.72	5.48	5.52	5.55	5.69	5.49
K_2O	0.29	0.66	0.65	0.62	0.60	0.59	0.56	0.56	0.56	0.56	0.54	0.52	0.52	0.53	0.52
Li_2O	2.43	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.35	2.41	2.42
MgO	1.46	1.60	1.64	1.59	1.61	1.54	1.53	1.57	1.51	1.56	1.61	1.57	1.59	1.52	1.53
Na_2O	16.15	12.19	12.75	13.36	13.33	12.95	13.83	14.15	14.22	13.93	14.93	14.65	14.84	14.65	15.03
P_2O_5	0.15	0.15	0.15	0.16	0.16	0.18	0.18	0.17	0.17	0.18	0.18	0.19	0.18	0.18	0.18
SiO_2	45.27	47.42	47.05	46.95	46.92	46.29	46.60	46.11	46.12	46.39	45.99	46.11	46.04	45.84	46.02
SO_3	0.48	0.36	0.34	0.36	0.38	0.41	0.41	0.42	0.41	0.43	0.43	0.42	0.43	0.42	0.41
TiO_2	1.11	1.34	1.34	1.29	1.30	1.36	1.28	1.31	1.28	1.27	1.25	1.25	1.28	1.27	1.23
ZnO	2.97	3.19	3.09	3.04	3.04	3.25	3.01	3.08	3.06	3.04	2.91	2.91	2.98	3.05	2.91
ZrO_2	2.94	3.38	3.33	3.26	3.28	3.62	3.18	3.21	3.29	3.13	3.07	3.12	3.18	3.14	3.07
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

NA: not analyzed.
Note: Lithium and boron are not determined by XRF so renormalized target values are listed.

Table 4.3. XRF Analyzed Compositions of Discharged Glasses (wt%) (continued).

		Test 2														
Sample I.D.	WVB-G-42B	WVB-G-51A	WVB-G-54B	WVB-G-56C	WVB-G-61A	WVB-G-64A	WVB-G-70A	WVB-G-73A	WVB-G-75A	WVB-G-79A	WVB-G-82A	WVB-G-83B	WVB-G-90A	WVB-G-91C	WVB-G-93A	WVB-G-99A
Cum (kg)	961.2	1005.2	1037.2	1064.2	1090.2	1115.9	1133.1	1161.7	1186.1	1220.5	1253.3	1273.8	1299.8	1332.1	1355.2	1389.1
Al_2O_3	6.26	6.09	6.08	6.22	6.00	6.43	6.19	6.22	6.13	6.18	6.15	6.10	6.02	6.32	6.06	6.40
B_2O_3	9.41	9.70	9.64	9.64	9.42	9.64	9.65	9.64	9.64	9.64	9.64	9.64	9.64	9.63	9.64	9.63
CaO	4.92	4.95	4.98	4.92	5.11	4.89	4.93	4.93	4.94	4.93	4.90	4.91	4.83	4.86	4.91	4.79
Cl	0.21	0.22	0.23	0.23	0.24	0.23	0.21	0.26	0.26	0.25	0.24	0.25	0.25	0.24	0.25	0.25
Cr_2O_3	0.13	0.12	0.12	0.13	0.13	0.12	0.14	0.11	0.11	0.11	0.11	0.12	0.11	0.11	0.11	0.11
Cs_2O	0.18	0.12	0.15	0.12	0.14	0.13	0.12	0.10	0.13	0.13	0.12	0.14	0.13	0.14	0.14	0.16
F	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	5.43	5.59	5.56	5.51	5.66	5.44	5.48	5.44	5.52	5.51	5.38	5.47	5.35	5.40	5.44	5.28
K_2O	0.51	0.52	0.53	0.56	0.57	0.61	0.60	0.63	0.63	0.62	0.60	0.61	0.58	0.60	0.58	0.59
Li_2O	2.35	2.42	2.41	2.41	2.35	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
MgO	1.52	1.56	1.53	1.45	1.49	1.46	1.53	1.51	1.55	1.53	1.58	1.54	1.58	1.61	1.52	1.53
Na_2O	15.38	15.14	14.95	15.18	15.06	14.93	15.26	15.28	15.19	15.15	15.36	15.41	15.55	15.26	15.31	15.10
P_2O_5	0.19	0.17	0.19	0.18	0.18	0.18	0.19	0.19	0.18	0.17	0.20	0.18	0.19	0.18	0.18	0.19
SiO_2	45.81	45.66	45.94	45.85	45.54	45.99	45.76	45.82	45.55	45.58	45.78	45.51	45.86	45.66	45.77	46.09
SO_3	0.43	0.43	0.44	0.43	0.44	0.45	0.45	0.45	0.45	0.44	0.45	0.45	0.45	0.44	0.45	0.44
TiO_2	1.27	1.25	1.26	1.26	1.31	1.23	1.23	1.23	1.25	1.24	1.23	1.25	1.20	1.22	1.24	1.21
ZnO	2.92	3.01	2.94	2.93	3.09	2.88	2.89	2.87	2.94	2.94	2.84	2.89	2.85	2.85	2.87	2.78
ZrO_2	3.11	3.03	3.05	2.98	3.27	3.00	2.98	2.91	3.13	3.16	3.01	3.13	3.00	3.07	3.15	3.04
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

NA: Not Analyzed
Note: Lithium and boron are not determined by XRF so renormalized target values are listed.

Table 4.3. XRF Analyzed Compositions of Discharged Glasses (wt%) (continued).

Subtask #	3	3A							3B							3C	
Sample I.D.	Target	WVB-G-115B	WVB-G-116A	WVB-G-116C	WVB-G-121A	WVB-G-122B	WVB-G-124B	WVB-G-128A	WVB-G-132A	WVB-G-133A	WVB-G-136A	WVB-G-139A	WVB-G-142A	WVB-G-143A	WVB-G-145A	WVB-G-148A	WVB-G-150A
Cum (kg)		1410.9	1427.2	1447.7	1477.4	1491.1	1512.2	1539.8	1561	1576.8	1598.2	1616.7	1633.9	1654.8	1673.3	1685.8	1710.1
Al_2O_3	6.04	5.98	5.88	5.97	6.05	5.94	5.87	5.85	5.89	5.77	5.74	5.87	5.97	6.21	5.92	5.84	6.05
B_2O_3	9.99	9.90	9.89	9.91	9.90	9.91	9.91	9.91	9.91	9.91	9.91	9.91	9.91	9.91	9.64	9.92	9.90
CaO	5.06	5.03	5.14	5.05	5.04	5.03	5.15	5.18	5.13	5.24	5.18	5.02	5.23	4.95	4.94	5.26	5.04
Cl	0.33	0.15	0.17	0.18	0.20	0.19	0.20	0.21	0.20	0.21	0.20	0.21	0.21	0.21	0.20	0.22	0.20
Cr_2O_3	0.02	0.15	0.15	0.14	0.14	0.13	0.13	0.13	0.11	0.11	0.11	0.10	0.09	0.08	0.08	0.08	0.14
Cs_2O	0.16	0.09	0.12	0.12	0.11	0.11	0.12	0.11	0.13	0.13	0.12	0.13	0.12	0.11	0.11	0.12	0.11
F	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	5.40	5.71	5.91	5.64	5.63	5.66	5.84	5.86	5.83	5.92	5.80	5.61	5.90	5.46	5.99	5.88	5.63
K_2O	0.26	0.56	0.56	0.55	0.55	0.53	0.53	0.52	0.52	0.52	0.50	0.50	0.51	0.51	0.47	0.52	0.55
Li_2O	2.50	2.48	2.47	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48
MgO	1.49	1.54	1.55	1.54	1.57	1.60	1.54	1.51	1.59	1.58	1.52	1.55	1.53	1.62	1.51	1.51	1.57
Na_2O	14.44	15.00	14.53	14.71	14.28	14.32	14.00	13.72	13.87	13.48	13.93	14.00	13.06	13.85	13.57	13.37	14.28
P_2O_5	0.13	0.18	0.17	0.18	0.18	0.17	0.17	0.17	0.18	0.17	0.18	0.17	0.17	0.17	0.17	0.18	0.18
SiO_2	46.51	45.53	45.23	45.67	46.06	46.08	46.01	46.22	46.11	46.20	46.32	46.65	46.74	47.10	47.24	46.53	46.06
SO_3	0.44	0.46	0.46	0.46	0.45	0.44	0.43	0.44	0.39	0.40	0.36	0.36	0.34	0.33	0.31	0.30	0.45
TiO_2	1.14	1.28	1.31	1.28	1.28	1.28	1.33	1.33	1.30	1.35	1.32	1.29	1.33	1.27	1.18	1.35	1.28
ZnO	3.06	2.99	3.14	2.97	3.00	3.01	3.10	3.13	3.09	3.20	3.10	2.96	3.16	2.84	3.11	3.17	3.00
ZrO_2	3.02	2.95	3.31	3.16	3.08	3.09	3.22	3.25	3.27	3.34	3.20	3.18	3.24	2.93	3.07	3.27	3.08
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

NA: not analyzed.

Note: Lithium and boron are not determined by XRF so renormalized target values are listed.

Table 4.3. XRF Analyzed Compositions of Discharged Glasses (wt%) (continued).

	Test 3C						Test 3D								
Sample I.D.	WVB-G-151D	WVC-G-6B	WVC-G-11B	WVC-G-13A	WVC-G-15A	WVC-G-15C	WVC-G-18A	WVC-G-21C	WVC-G-24A	WVC-G-25A	WVC-G-29B	WVC-G-31B	WVC-G-31D	WVC-G-34B	WVC-G-40A
Cum (kg)	1750.1	1770.7	1785.8	1798.8	1814	1833.5	1854.4	1876.8	1896.3	1915.3	1940.7	1961.4	1977	1996.1	2024.7
Al2O3	6.04	6.29	6.06	6.20	6.16	6.11	5.95	5.97	6.10	6.09	6.20	6.01	6.27	6.23	6.04
B2O3	9.91	9.88	9.88	9.89	9.91	9.88	9.88	9.78	9.78	9.78	9.78	9.77	9.90	9.84	9.89
CaO	5.04	4.75	4.84	4.92	4.99	5.04	5.08	4.98	5.01	5.05	4.89	5.06	4.99	4.86	5.14
Cl	0.20	0.21	0.20	0.21	0.21	0.22	0.21	0.23	0.21	0.22	0.23	0.24	0.26	0.25	0.25
Cr2O3	0.07	0.06	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.07
Cs2O	0.13	0.09	0.12	0.10	0.11	0.12	0.00	0.14	0.12	0.14	0.12	0.14	0.12	0.10	0.10
F	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe2O3	5.63	5.68	5.83	5.78	5.54	5.65	5.69	5.55	5.55	5.62	5.36	5.63	5.45	5.23	5.83
K2O	0.51	0.48	0.47	0.50	0.51	0.51	0.50	0.49	0.50	0.51	0.50	0.49	0.50	0.50	0.52
Li2O	2.48	2.47	2.47	2.47	2.48	2.47	2.47	2.47	2.47	2.47	2.47	2.47	2.40	2.48	2.40
MgO	1.54	1.47	1.58	1.49	1.56	1.56	1.59	1.52	1.57	1.57	1.57	1.55	1.65	1.56	1.54
Na2O	13.89	13.99	13.76	13.17	13.53	13.85	13.83	14.14	13.89	13.85	13.89	13.84	13.74	13.99	13.58
P2O5	0.16	0.18	0.17	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.18	0.18	0.18	0.17	0.17
SiO2	46.85	47.44	47.16	47.72	47.55	47.52	46.92	47.10	47.30	46.89	47.71	47.03	48.74	48.10	46.86
SO3	0.20	0.17	0.17	0.15	0.16	0.14	0.12	0.15	0.15	0.22	0.20	0.20	0.17	0.12	0.27
TiO2	1.28	1.14	1.17	1.19	1.27	1.28	1.29	1.26	1.27	1.28	1.22	1.27	1.25	1.22	1.31
ZnO	2.98	2.92	3.03	3.03	2.90	2.99	3.01	2.92	2.91	3.00	2.77	2.96	2.90	2.72	3.08
ZrO2	3.10	2.77	3.02	2.92	2.85	2.44	3.12	3.07	2.94	3.09	2.86	3.11	1.44	2.56	2.96
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

NA: Not Analyzed.

Note: Lithium and boron are not determined by XRF so renormalized target values are listed.

Table 4.4. XRF and DCP Analyzed Compositions of Glass Dip Samples (wt%).

	Test # 1					Test # 2						
Oxides	Target	WVA-D-37A		WVA-D-104A		Target	WVA-D-105A		WVA-D-145A	WVA-D-148A	WVB-D-99A	
Method		XRF	DCP	XRF	DCP		XRF	DCP	XRF	XRF	DCP	
Al_2O_3	5.84	7.40	6.81	5.85	5.42	6.26	5.91	5.31	6.22	6.02	5.97	5.74
B_2O_3	10.22	10.16	9.58	10.15	10.40	9.71	9.71	10.39	9.70	9.70	9.99	9.88
CaO	5.18	6.13	5.38	5.21	4.77	4.92	5.17	4.50	4.94	5.07	4.52	4.39
Cl	0.30	0.00	NA	0.22	NA	0.37	0.05	NA	0.23	0.22	NA	NA
Cr_2O_3	0.02	0.42	0.23	0.15	0.07	0.02	0.10	0.09	0.10	0.13	0.11	0.10
Cs_2O	0.14	0.06	NA	0.13	NA	0.18	0.11	NA	0.14	0.15	NA	NA
F	0.02	NA	NA	NA	NA	0.03	NA	NA	0.00	NA	NA	NA
Fe_2O_3	5.53	6.77	5.72	5.84	5.07	5.26	5.86	5.02	5.57	5.77	4.91	4.85
K_2O	0.23	0.31	0.23	0.65	0.64	0.29	0.64	0.60	0.55	0.56	0.56	0.49
Li_2O	2.55	2.54	2.38	2.54	2.34	2.43	2.42	2.30	2.42	2.42	2.25	2.32
MgO	1.53	1.57	1.55	1.64	1.58	1.46	1.64	1.49	1.45	1.53	1.47	1.55
Na_2O	12.85	11.18	10.13	12.21	10.95	16.15	12.78	10.59	14.80	14.18	13.31	13.36
P_2O_5	0.12	0.16	0.17	0.16	0.21	0.15	0.15	0.21	0.18	0.18	0.20	0.21
SiO_2	47.70	46.23	42.48	47.27	43.87	45.27	47.43	43.05	45.93	45.90	42.07	41.94
SO_3	0.39	0.11	NA	0.37	NA	0.48	0.33	NA	0.42	0.45	NA	NA
TiO_2	1.17	1.29	1.23	1.31	1.30	1.11	1.31	1.27	1.26	1.29	1.24	1.14
ZnO	3.13	2.58	2.36	3.10	2.75	2.97	3.08	2.69	2.97	3.10	2.50	2.51
ZrO_2	3.09	3.10	2.59	3.21	2.75	2.94	3.30	2.73	3.11	3.35	2.71	2.57
Sum	100.00	100.00	90.84	100.00	92.13	100.00	100.00	90.25	100.00	100.00	91.81	91.03
Sulfate Visible		No		No			No		No	No	No	

NA: Not Analyzed.
Note: Lithium and boron are not determined by XRF so renormalized target values are listed.

Table 4.4. XRF and DCP Analyzed Compositions of Glass Dip Samples (wt%) (continued).

Oxides	Test # 3	Prior To Start of Test 3A			At End of Test 3D	
Sample I.D.	Target	WVB-D-102A	WVB-D-113A	WVB-D-113B	WVC-D-40A	WVC-D-41A
Method		XRF	XRF	XRF	XRF	XRF
Al_2O_3	6.04	6.14	6.35	6.23	6.13	5.06
B_2O_3	9.99	9.91	9.90	9.90	9.90	9.53
CaO	5.06	5.07	4.83	5.02	4.88	4.40
Cl	0.33	0.15	0.14	0.14	0.31	0.29
Cr_2O_3	0.02	0.15	0.15	0.16	0.06	0.07
Cs_2O	0.16	0.10	0.14	0.12	0.14	0.19
F	0.03	0.00	0.00	0.00	0.00	0.00
Fe_2O_3	5.40	5.74	5.34	5.71	5.36	4.69
K_2O	0.26	0.59	0.58	0.59	0.51	0.58
Li_2O	2.50	2.48	2.47	2.48	2.47	2.38
MgO	1.49	1.53	1.49	1.49	1.45	1.25
Na_2O	14.44	14.38	15.08	14.86	13.89	16.19
P_2O_5	0.13	0.19	0.18	0.18	0.18	0.16
SiO_2	46.51	45.61	45.45	44.98	46.39	39.45
SO_3	0.44	0.53	0.74	0.51	1.20	9.45
TiO_2	1.14	1.29	1.23	1.29	1.26	1.06
ZnO	3.06	3.04	2.84	3.21	2.85	2.72
ZrO_2	3.02	3.11	3.09	3.14	3.03	2.54
Sum	100.00	100.00	100.00	100.00	100.00	100.00
Sulfate Visible		Yes[*]	Yes[*]	No[$]	Yes	Yes

* After approximately one month of idling prior to start of test.

$ Sulfate layer destroyed by feeding water prior to start of test.

Note: Lithium and boron are not determined by XRF so renormalized target values are listed.

Table 4.5. Measured Iron Redox of Discharged Glasses.

Test	Discharge Date	Glass Name	Cumulative Mass per Test (kg)	% Fe^{++}
1	06/23/01	WVA-G-100B	552.4	< 0.8%
2	07/14/01	WVB-G-39A	353.0	< 0.8%
	07/14/01	WVB-G-40B	379.4	< 0.8%
	07/15/01	WVB-G-51A	452.8	< 0.8%
	07/15/01	WVB-G-56C	481.8	< 0.7%
	07/15/01	WVB-G-61A	537.8	< 0.8%
	07/16/01	WVB-G-75A	633.7	< 0.8%
	07/16/01	WVB-G-79A	668.1	< 0.8%
	07/16/01	WVB-G-83B	721.4	< 0.8%
	07/17/01	WVB-G-93A	802.8	< 0.8%
	07/18/01	WVB-G-99A	836.7	< 0.8%
3A	08/13/01	WVB-G-115B	21.8	< 0.8%
	08/13/01	WVB-G-116C	58.6	< 0.8%
	08/14/01	WVB-G-122B	102.0	< 0.8%
3B	08/14/01	WVB-G-132A	21.2	16.0%
	08/15/01	WVB-G-139A	76.9	21.4%
3C	08/15/01	WVB-G-148A	12.5	25.7%
	08/16/01	WVC-G-11B	112.5	44.6%
3D	08/16/01	WVC-G-21C	43.3	54.7%
	08/17/01	WVC-G-29B	107.2	64.5%
	08/17/01	WVC-G-31D	143.5	54.5%
	08/18/01	WVC-G-40A	191.2	13.3%*

* Glass was discharged 12 hours after feed was stopped, during which time the melt re-oxidized.

Table 5.1. Melter Emissions Sampled During Tests 1 and 2.

		Test #1				Test #2			
		Feed Flux (g/hr)	mg/min	% of Feed	Melter DF	Feed Flux (g/hr)	mg/min	% of Feed	Melter DF
Particles	Total[$]	7621.0	184	0.14	690.3	8968.2	491	0.33	304.4
	Al	229.96	3.2	0.08	1189.6	276.01	5.1	0.11	905.7
	B	235.96	3.5	0.09	1137.6	251.08	10.6	0.25	394.9
	Ba	<0.01	<0.1	NC	NC	<0.01	<0.1	NC	NC
	Ca	275.45	2.4	0.05	1888.9	293.02	2.3	0.05	2131.3
	Cr	1.02	0.3	1.97	50.8	1.14	0.9	4.98	20.1
	Cs	9.81	11.7	7.16	14.0	14.12	27.4	11.64	8.6
	Fe	287.63	3.7	0.08	1295.2	306.41	7.2	0.14	712.9
	I	3.94	<0.1	<0.01	NC	4.02	<0.1	<0.01	NC
	K	14.18	7.8	3.29	30.4	20.02	17.5	5.25	19.0
	Li	88.30	2.4	0.16	609.1	93.86	4.7	0.30	332.3
	Mg	68.50	0.2	0.01	7418.0	73.20	0.2	0.01	7732.9
	Mn	<0.01	0.2	NC	0.0	<0.01	0.1	NC	0.0
	Na	709.54	49.7	0.42	237.9	998.18	136.2	0.82	122.1
	P	3.89	<0.1	<0.01	NC	5.45	0.4	0.43	233.2
	S	11.60	10.3	5.35	18.7	15.99	18.7	7.03	14.2
	Si	1659.11	5.7	0.02	4828.8	1762.74	7.8	0.03	3779.4
	Ti	52.08	0.7	0.08	1253.3	55.33	1.6	0.18	571.3
	Zn	187.31	3.4	0.11	923.7	199.07	5.8	0.18	567.7
	Zr	170.40	0.2	0.01	12513.8	180.97	0.3	0.01	9836.2
Gas	B	235.96	10.8	0.27	364.4	251.08	11.0	0.26	381.2
	Cl	22.28	13.2	3.56	28.1	30.77	<0.1	<0.01	NC
	F	1.49	2.0	8.08	12.4	2.49	0.1	0.12	807.4
	I	3.94	36.1	55.02	1.8	4.02	38.7	57.82	1.7
	S	11.60	2.1	1.11	90.4	15.99	<0.1	<0.01	NC

NC – Not Calculated

[$] - From gravimetric analysis of filters and rinse dry-downs

Table 5.2. Melter Emissions Sampled from Test 3.

		Test #3A				Test #3B				Test #3C				Test #3D			
		Feed Flux (g/hr)	mg/min	% of Feed	Melter DF	Feed Flux (g/hr)	mg/min	% of Feed	Melter DF	Feed Flux (g/hr)	mg/min	% of Feed	Melter DF	Feed Flux (g/hr)	mg/min	% of Feed	Melter DF
Particles	Total[$]	7820.4	334	0.26	390.2	12798.6	314	0.15	679.3	7043.1	404	0.34	290.6	9446.1	229	0.15	687.5
	Al	227.89	5.6	0.15	678.4	372.98	3.9	0.06	1606.4	205.31	3.3	0.10	1044.5	275.29	0.9	0.02	5293.7
	B	220.81	12.2	0.33	302.1	361.40	5.0	0.08	1210.4	198.93	4.4	0.13	746.5	266.74	1.3	0.03	3314.2
	Ba	<0.01	<0.1	NC	NC	<0.01	<0.1	NC	NC	<0.01	<0.1	NC	NC	<0.01	<0.1	NC	NC
	Ca	257.85	3.4	0.08	1274.6	422.02	2.9	0.04	2416.5	232.30	1.8	0.05	2099.7	311.48	0.4	0.01	12042.6
	Cr	0.97	0.6	3.64	27.4	1.59	0.1	0.32	309.3	0.88	0.1	0.46	219.4	1.18	<0.1	0.19	NC
	Cs	10.74	18.8	10.53	9.5	17.58	22.4	7.65	13.1	9.67	18.9	11.75	8.5	12.97	11.1	5.14	19.5
	Fe	269.16	7.9	0.18	569.7	440.52	5.0	0.07	1475.3	242.49	4.1	0.10	975.0	325.14	1.1	0.02	4857.8
	I	3.69	<0.1	<0.01	NC	6.04	<0.1	<0.01	NC	3.33	<0.1	<0.01	NC	4.46	<0.1	<0.01	NC
	K	15.36	7.1	2.77	36.1	25.13	7.3	1.74	57.4	13.84	8.2	3.54	28.3	18.55	5.1	1.66	60.3
	Li	82.63	3.5	0.25	397.5	135.23	2.9	0.13	779.1	74.44	3.0	0.24	418.3	99.81	1.2	0.07	1351.0
	Mg	63.92	0.2	0.02	4565.4	104.62	0.2	0.01	7432.8	57.59	0.1	0.01	8095.9	77.22	<0.1	<0.01	NC
	Mn	<0.01	0.1	NC	0.0	<0.01	<0.1	NC	NC	<0.01	<0.1	NC	NC	<0.01	<0.1	NC	NC
	Na	763.32	80.3	0.63	158.4	1249.32	74.7	0.36	278.7	687.69	82.9	0.72	138.2	922.10	45.2	0.29	340.3
	P	4.04	0.5	0.71	140.9	6.61	0.2	0.17	604.0	3.64	0.2	0.32	312.5	4.88	0.1	0.18	543.3
	S	12.55	14.4	6.87	14.6	20.53	16.7	4.86	20.6	11.30	40.2	21.35	4.7	15.16	22.9	9.07	11.0
	Si	1549.26	13.8	0.05	1876.6	2535.65	10.2	0.02	4145.7	1395.75	5.8	0.02	4023.0	1871.52	1.6	0.01	19663.5
	Ti	48.63	2.0	0.24	415.5	79.59	1.2	0.09	1106.1	43.81	1.0	0.14	730.3	58.74	0.3	0.03	3798.2
	Zn	174.91	6.8	0.23	429.5	286.28	7.3	0.15	651.9	157.58	13.8	0.53	190.2	211.30	8.8	0.25	402.2
	Zr	159.07	0.5	0.02	5494.4	260.35	0.2	<0.01	24329.5	143.31	0.2	0.01	11914.3	192.16	<0.1	<0.01	NC
Gas	B	220.81	10.6	0.29	347.6	361.40	13.3	0.22	451.6	198.93	13.8	0.42	240.1	266.74	10.3	0.23	432.0
	Cl	23.48	6.5	1.65	60.5	38.43	5.5	0.86	116.0	21.15	15.2	4.31	23.2	28.36	9.4	2.00	50.1
	F	2.13	3.2	8.99	11.1	3.49	0.9	1.56	64.3	1.92	2.7	8.50	11.8	2.58	1.1	2.50	40.0
	I	3.69	46.6	75.66	1.3	6.04	17.8	17.67	5.7	3.33	32.8	59.23	1.7	4.46	11.1	14.91	6.7
	S	12.55	1.8	0.85	117.8	20.53	19.5	5.71	17.5	11.30	47.2	25.08	4.0	15.16	80.3	31.77	3.1

NC – Not Calculated

[$] - From gravimetric analysis of filters and rinse dry-downs

Table 5.3. Particle Size Distribution for Melter Emissions from Tests 1 and 2.

	Cutpoint (microns)	Net Wt (mg)	Concentration (mg/dscf)	Mass Fraction (%)
Test 1	> 18.1	0.75	0.114	2.01
	13.7	0.79	0.120	2.12
	5.29	2.72	0.414	7.32
	2.66	3.64	0.554	9.80
	1.53	6.07	0.924	16.3
	0.85	10.84	1.650	29.2
	0.50	5.96	0.907	16.0
	< 0.50	6.37	0.970	17.2
Test 2	> 14.9	0.21	0.070	1.0
	11.2	0.46	0.154	1.0
	4.3	2.29	0.768	7.0
	2.2	4.46	1.496	13.0
	1.3	3.55	1.191	11.0
	0.71	12.92	4.334	38.0
	0.42	4.06	1.362	12.0
	< 0.42	5.65	1.895	17.0

Table 5.4. Particle Size Distribution for Melter Emissions from Test 3.

Test	Cutpoint (microns)	Net Wt (mg)	Concentration (mg/dscf)	Mass Fraction (%)
Test 3A	> 13.7	11.9	5.752	41.9
	10.3	0.89	0.431	3.13
	4.0	0.62	0.300	2.19
	2.01	1.00	0.484	3.52
	1.16	4.34	2.100	15.3
	0.65	2.87	1.388	10.1
	0.39	0.60	0.290	21.1
	< 0.39	0.75	0.363	2.64
Test 3B	> 14.5	3.80	1.442	24.4
	10.9	0.18	0.086	1.16
	4.23	0.29	0.139	1.86
	2.13	0.53	0.254	3.41
	1.22	0.38	0.182	2.44
	0.69	2.02	0.968	13.0
	0.41	4.21	2.017	27.1
	< 0.41	4.14	1.984	26.6
Test 3C	> 13.6	3.6	1.684	24.2
	10.3	0.28	0.132	1.88
	3.98	0.45	0.213	3.0
	2.00	0.38	0.180	2.56
	1.15	1.27	0.601	8.54
	0.65	3.23	1.528	21.7
	0.38	3.32	1.570	22.3
	< 0.38	2.33	1.102	15.7

Table 5.5. Chemical Analysis of Particles by Size Fraction for Test 1.

Particle Size (microns)	>18.1	13.7 – 18.1	5.29 – 13.7	2.66 – 5.29	1.53 – 2.66	0.85 – 1.53	0.50 – 0.85	< 0.50
Total Mass (mg)	0.75	0.79	2.72	3.64	6.07	10.84	5.96	6.37
Mass Fraction (%)	2.02	2.13	7.32	9.80	16.34	29.19	16.05	17.15
Al	2.47	2.59	2.92	1.39	0.21	0.06	0.07	0.04
B	3.27	3.54	4.69	1.83	0.28	0.02	0.09	<0.01
Ba	<0.01	<0.01	0.02	0.01	<0.01	<0.01	<0.01	<0.01
Ca	2.33	3.04	2.33	0.74	0.13	0.12	0.11	0.13
Cr	0.13	0.06	0.06	0.10	0.12	0.13	0.17	0.18
Cs	1.40	1.46	1.08	2.47	3.87	3.78	4.61	4.79
Fe	4.07	4.11	4.98	2.45	0.57	0.23	0.44	0.13
I	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
K	1.00	0.89	1.16	1.91	2.82	2.76	3.22	3.14
Li	0.87	1.01	0.97	0.82	0.87	0.82	0.86	0.83
Mg	0.07	0.13	0.11	0.05	0.01	0.01	0.02	0.02
Mn	0.40	0.13	0.04	0.01	0.01	<0.01	0.01	0.01
Na	10.93	11.58	12.39	17.18	23.15	20.36	27.26	25.64
P	0.60	0.32	0.13	<0.01	<0.01	0.03	0.07	<0.01
S	5.27	4.30	1.51	5.70	10.46	3.74	11.21	11.15
Si	12.20	13.10	8.79	2.75	0.54	0.21	0.33	0.23
Ti	0.47	0.70	0.97	0.48	0.11	0.04	0.03	0.02
Zn	2.07	2.59	2.98	1.14	0.29	0.19	0.24	0.26
Zr	0.67	0.57	0.50	0.18	0.02	<0.01	0.01	0.01
Mass Fraction Sum (%)*	48.20	50.13	45.63	39.22	43.46	32.50	48.74	46.58

NC – Not Calculated.

* Note that this analysis is on an elemental (not oxide) basis.

Table 5.6 Average Concentration [ppm] of Selected Species in Melter Off-Gas Measured by FTIR Spectroscopy.

Test	1	2	3A	3B	3C	3D
Sugar Ratio	0.5	0.5	0.5	0.75	1.0	1.25
H_2O [%]	3.8	5.5	5.3	5.0	5.0	5.1
CO_2 [%]	0.3	0.4	0.3	0.4	0.4	0.5
CO	16.2	43.0	32.1	54.6	188.4	458.3
N_2O	66.6	94.5	82.2	78.4	62.7	59.9
NO_2	59.9	130.9	44.0	21.4	8.0	4.4
NO	535.4	1071.9	691.1	456.1	301.3	247.9
SO_2	< 1.0	< 1.0	< 1.0	3.4	5.8	7.5
HCl	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HF	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HNO_2	< 1.0	1.0	< 1.0	< 1.0	< 1.0	< 1.0
HNO_3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
NH_3	82.9	102.8	116.9	176.4	202.8	290.0
HBr	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HCN	< 1.0	1.4	1.6	2.8	4.6	4.8
Acetonitrile	2.0	2.0	< 1.0	< 1.0	< 1.0	< 1.0
Acrylonitrile	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0

Table 5.7. Average NOx fluxes in Off-Gas Measured by FTIR Spectroscopy.

	Feed NOx [mol/h]	Sugar Ratio	Emissions [mol/h]			% feed NOx emitted as nitrogen oxides
			N_2O	NO	NO_2	
Test 1	13.3	0.5	0.7	5.3	0.6	50
Test 2	16.9	0.5	0.9	10.6	1.3	76
Test 3A	15.8	0.5	0.8	6.8	0.4	51
Test 3B	15.8	0.75	0.8	4.5	0.2	35
Test 3C	15.8	1.0	0.6	3.0	0.1	23
Test 3D	15.8	1.25	0.6	2.4	< 0.1	19