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Final Report – Glass Formulation Testing to Increase Sulfate Volatilization from Melter, VSL-04R4970-1, Rev. 0, dated 2/24/05

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

Office of River Protection

P.O. Box 450
Richland, Washington 99352

Approved for Public Release;
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VSL-04R4970-1

Final Report

Glass Formulation Testing to Increase Sulfate Volatilization from Melter

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for

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and

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

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VSL Program Director/Principal Investigator

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List of Abbreviations

AA	Atomic Absorption Spectroscopy
ADS	Air Displacement Slurry
DCP-AES	Direct Current Plasma Atomic Emission Spectroscopy
DF	Decontamination Factor
DM	DuraMelter®
DOE	Department of Energy
EPA	Environmental Protection Agency
FTIR	Fourier Transform Infrared Spectroscopy
GC	Gas Chromatography
HEPA	High-Efficiency Particulate Air Filter
HLW	High Level Waste
IC	Ion Chromatography
LAW	Low Activity Waste
M	Molarity
N	Normality
ORP	Office of River Protection
PEG	Polyethylene Glycol
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
RPP	River Protection Project
VSL	Vitreous State Laboratory
WTP	Waste Treatment and Immobilization Plant
XRF	X-Ray Fluorescence

SECTION 1.0
INTRODUCTION

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

The Office of River Protection is currently examining options to optimize the Low Activity Waste (LAW) facility and the LAW glass waste form. One option under evaluation is to enhance the waste processing rate of the vitrification plant currently under construction. It is likely that the capacity of the LAW vitrification plant can be increased incrementally by implementation of a variety of low-risk, high-probability changes, either separately or in combination. These changes include:

- Operating at the higher processing rates demonstrated at the LAW pilot melter
- Increasing the glass pool surface area within existing external melter envelope
- Increasing plant availability
- Increasing the glass waste loading
- Removing sulfate from the LAW stream
- Operating the melter at slightly higher temperature
- Installing the third LAW melter into the WTP plant
- Other smaller impact changes

The Vitreous State Laboratory at The Catholic University of America (VSL) and Duratek, Inc. are evaluating several of these potential incremental improvements for ORP in support of its evaluation of WTP LAW facility optimization [1]. The tests described in this report focus on development and testing of glass formulations to increase sulfate volatilization from the melter as a means to increase waste loading in the LAW glass products. Implementation of such an approach would require breaking the recycle loop for off-gas treatment streams in the current WTP flow-sheet. Previous testing at VSL and Duratek has shown that organics and certain inorganic components affect partitioning of sulfur to the off-gas [2-9]. Depending on their type, organics can react mainly in the cold-cap or can persist to higher temperatures such that they can significantly affect glass redox. The ideal additives would have a large effect on sulfur partitioning without significantly affecting glass redox. Excessive reduction of the glass melt is undesirable in the presence of sulfur because it can lead to precipitation of corrosive phases such as sulfides that deleteriously impact melter life. Data provided in this report show the effects of various organics on sulfur partitioning, feed processing, glass redox, and LAW feed rheology. The effect of an inorganic glass former additive, vanadium, on sulfur partitioning was also investigated.

The Vitreous State Laboratory is also developing and testing glass formulations for WTP waste envelopes to provide data to meet the WTP contract requirements and to support system design activities [2]. That work is based upon small-scale batch melts ("crucible melts") using waste simulants. Selected formulations have also been tested in small-scale, continuously-fed, joule-heated melters (DM10 and DM100 systems) [3-9] and, ultimately, in the LAW Pilot Melter [10-16]. 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. Consistent with that proven testing approach, the principal objective of the work reported here was to collect the necessary small-scale melter test data while varying the type and amount of feed additives. The present work was performed in accordance with a corresponding Test Plan that was prepared for ORP [17].

In view of the present recycle loop in the flow sheet, the current WTP strategy is to keep as much of the sulfur as possible in the LAW glass. As a result, partitioning of sulfur to the off-gas has not been investigated in detail for WTP LAW feeds. However, information from previous tests [2, 3, 5, 6-9] indicates that enhanced partitioning is a viable approach provided it can be accomplished without over-reducing the glass melt, which is essential to practical deployment. The tests reported here provide information on the effects of organic and inorganic additives on LAW sulfur partitioning and feed processing. Taking advantage of the increased partitioning of sulfur to the off-gas stream would lead to increases in waste loading, provided the current WTP recycle loop can be broken.

The tests described in this report utilized blended feed (glass formers plus waste simulant) prepared by Optima Chemicals according to VSL specifications. Sufficient feed was prepared to produce nearly seventeen hundred kilograms of glass. Reductants in the form of sugar, urea, starch, and polyethylene glycol (PEG) were added to the feed at ratios of between 0.5 to 1.25 (0.5 = 1 mole sucrose per 16 mole NOx or 3 mole carbon per 4 mole NOx). The DM10 was used to screen the four reductants at four stoichiometric ratios to determine which volatilized the most sulfur without overly reducing the iron in the glass. Subsequently, two 50-hour DM100 tests were conducted: one with urea and sugar at a stoichiometric ratio of 1.0 and the other with starch and sugar at a stoichiometric ratio of 0.75, based on the DM10 results. Another 50-hour test was conducted using vanadium as an additive to determine the effect of this inorganic additive on sulfur volatility. The DM100-WV melter was used in order to provide a direct comparison with the LAW tests previously conducted on the same melter [3-9]. Key operating parameters such as glass temperature and production rate were held constant to investigate the effects of the compositional changes on feed and glass processing characteristics as well as sulfur volatility. The bubbling rate was adjusted to achieve a target glass production rate of 2000 kg/m^2/day 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 (NOx, SO_2, CO, particulate load and composition, and acid gases) were made for each test.

1.1 Test Objectives

The principal objectives of the DM100 and DM10 tests were to determine the impact of four different organics and one inorganic feed additive on sulfate volatilization and to determine the sulfur partitioning between the glass and the off-gas system. The tests provided information on melter processing characteristics and off-gas data including sulfur incorporation and partitioning.

A series of DM10 and DM100 melter tests were conducted using a LAW Envelope A feed. The testing was divided into three parts. The first part involved a series of DM10 melter tests with four different organic feed additives: sugar, polyethylene glycol (PEG), starch, and urea. The second part involved two confirmatory 50-hour melter tests on the DM100 using the best combination of reductants and conditions based on the DM10 results. The third part was performed on the DM100 with feeds containing vanadium oxide (V_2O_5) as an inorganic additive to increase sulfur partitioning to the off-gas. Although vanadium oxide is not a reductant, previous testing has shown that vanadium shows promise for partitioning sulfur to the melter exhaust [3, 18, 19], presumably through its known catalytic effect on the SO_2/SO_3 reaction. Crucible-scale tests were conducted prior to the melter tests to confirm that the glasses and feeds would be processable in the melter and that the glasses would meet the waste form (ILAW) performance requirements.

Thus, the major objectives of these tests were to:

- Perform screening tests on the DM10 followed by tests on the DM100-WV system using a LAW -Envelope A feed with four organic additives to assess their impact on sulfur volatilization.
- Perform tests on the DM100-WV system using a LAW -Envelope A feed containing vanadium oxide to assess its impact on sulfur volatilization.
- Determine feed processability and product quality with the above additives.
- Collect melter emissions data to determine the effect of additives on sulfur partitioning and melter emissions.
- Collect and analyze discharged glass to determine sulfur retention in the glass.

- Prepare and characterize feeds and glasses with the additives to confirm that the feeds and the glass melts are suitable for processing in the DM100 melter.

- Prepare and characterize glasses with the additives to confirm that the glasses meet the waste form (ILAW) performance requirements.

1.2 Quality Assurance

This work was conducted under a quality assurance program that is in place at the VSL that is based on NQA-1 (1989) and NQA-2a (1990) Part 2.7. This program is supplemented by a Quality Assurance Project Plan [20] for WTP work that is conducted at VSL. Test and procedure requirements by which the testing activities were planned and controlled are defined in the Test Plan [17]. The program is supported by VSL standard operating procedures that were used for this work [21]. The requirements of DOE/RW-0333P are not applicable to this work.

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

1.3.3 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 airflow rate. The geometry of the transition line conforms to the requirements of the 40-CFR-60 air sampling techniques. Immediately downstream of the transition line are cyclonic filters followed by conventional pre-filters and 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 A1 waste simulant used in previous tests on the DM100 [7] and DM1200 [22] was based on composition data for tank AN-105 (sup), derived from the TF COUP, Rev. 3 [23]. The composition has changed very little from the previous revision of the TF COUP [24] that was originally used to develop the glass formulation for this LAW feed. The organics data in the TF COUP were supplemented by other Hanford tank waste information [25]. Data from a sample characterization report [25] were used as the basis for the relative concentration of organics. These concentrations were then scaled up to match the total organic carbon (TOC) concentration given in TF COUP, Rev. 3 [23]. Subsequently, minor changes to the simulant composition were directed [26] which resulted in a decrease in TOC but little change in glass forming constituents [17, 27]. The sodium concentration in the simulant was increased by 2.56 % to account for sodium additions in pretreatment [2, 28]. No recyle is included in the present simulant because increased volatilization of sulfate from the melter would only be employed if the present recycle loop were broken. The nominal concentration, expressed in terms of the sodium molarity, was determined on the basis of melter feed rheology tests on similar formulations [29]. The results of those tests led to the selection of 8.0 molar sodium as the nominal simulant concentration for the LAW AN-105 waste. The waste simulant used in DM10 melter tests was based on the composition data for tank AN-105 derived from the TF COUP [23] and the waste simulant used in DM100 melter tests was based on the composition data provided in the WTP Test Specification [26]. The small differences in the waste compositions between these two data sources are not expected to have any significant effect on the behavior of the reductants evaluated in this study.

The nominal simulant formulations are given in Tables 2.1 and 2.2. The resulting simulant is a solution of predominantly sodium, aluminum, hydroxide, nitrate, and nitrite. Samples of the simulant were prepared according to Tables 2.1 and 2.2 and tested at VSL. For the melter tests, Optima Chemicals, which has supplied all of the LAW simulants for the previous DM100 and LAW Pilot Melter studies, prepared the simulant and added the glass forming chemicals before shipment to VSL in 55-gallon drums. Reductants in the form of sugar, urea, starch, and polyethylene glycol **(**PEG) were added at VSL.

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 salt formation [2, 3, 4, 18], as well as rheological testing [29]. Based on these results, LAWA44 was developed for the Sub-Envelope A1, AN-105 waste. Table 2.3 shows the LAW Envelope A glass compositions used for the melter tests. The concentration of SO_3 in this glass was increased to 0.5 wt% based on crucible studies and the need to have a high enough sulfur concentration to show the effects of the reductants on sulfur volatilization for the melter tests. The feed used in the DM10 and the DM100 starch and sugar tests was excess feed remaining from a previous DM1200 test [22]. Iodide (as KI), cadmium oxide, and selenium oxide had been spiked into this feed at a level corresponding to 0.1 wt% each in the glass if all was retained. These low level spikes were intended to trace the volatility of these elements and should have no significant effect on glass properties and sulfur volatility. This formulation at a lower concentration of SO_3 of 0.24 wt% (as variations using ± 15% simulant from the nominal) was tested on the DM100 at VSL [7], the DM1200 at VSL [22], and the LAW Pilot Melter in Columbia, MD [16] with no processing problems. A list of the glass forming chemicals used to prepare the melter feeds is given in Table 2.4; these are the same chemical sources as are presently planned for use in the WTP.

The glass and feed compositions for the melter test with V_2O_5 were selected on the basis of glass formulation studies. A V_2O_5 concentration of 2.0 wt% was selected, as shown in Table 2.3, whereby the vanadium replaced the 2.0 wt% TiO_2 present in the LAWA44 composition. Crucible melts covering a range of vanadium concentrations in the LAWA44 base glass were tested for a variety of properties, including sulfur solubility and glass viscosity and electrical conductivity at various temperatures, as shown in Table 2.5. Little change was observed in these properties with changes in vanadium concentration. The viscosities of all three melts are within the desired 30-70 Poise range at 1150°C. Clear, homogeneous glasses resulted upon heat treatment at 850°C for twenty hours for all vanadium concentrations. The LAW 143 formulation was selected for subsequent melter tests. The glass forming chemicals used to prepare the melter feed were the same as those given for the urea and sugar Test in Table 2.4, except for the substitution of V_2O_5 for TiO_2.

2.3 Sugar Additions

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

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

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

As an example, the calculation of the amount of sugar needed for the present Sub-Envelope A1 feed to achieve a sugar ratio of 0.5 proceeds as follows:

- One liter of simulant contains 1.888 moles of nitrite and 1.978 moles of nitrate, giving a total of 3.866 moles of NOx (see Table 2.1)
- Required total amount of organic carbon for a sugar ratio of 0.5 is 3.866 x 0.75 = 2.900 moles
- One liter of simulant contains 0.462 moles of organic carbon (see Table 2.1)
- Therefore, 2.900 - 0.462 = 2.438 moles of organic carbon must be added.

Since the molecular weight of sucrose is 342 g per mole, 2.438 x 342/12 = 69.48 g sugar must be added per liter of simulant, as shown in Table 2.4. Note that for the version of the simulant given in Table 2.2, the total concentration of nitrate and nitrite is slightly higher (3.905 vs. 3.866 M) and the TOC is lower (0.174 vs. 0.462 M) and therefore the amount sugar required to achieve a stoichiometric ratio of 0.5 is greater (78.5 g vs. 69.48 g), as shown in Table 2.4. Similar calculations were conducted with urea and starch using molecular weights of 60 g per mole with one carbon and 162 g per mole with five carbons, respectively.

2.4 Analysis of Feed Samples

2.4.1 General Properties

Feed samples were analyzed from DM100 tests using each simulant batch to confirm physical properties and chemical composition. Samples taken during testing were from an inline sampling port. Sample names, sampling dates, and measured properties are given in Table 2.6 along with corresponding average measured values from previous tests with a similar melter feed [22]. The narrow range in the measured water content, density, glass yield, and pH values show the consistency of the feed received from Optima and the lack of effect of the test reductants on these properties. The measured glass yields were about 8% below the target values due perhaps to high estimates in the purity of the additives as well as water added during the transfer of feed.

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 [29]. Melter feeds were characterized using a Haake RS75 rheometer, which was equipped with either a Z40DIN or a FL22-SZ40 sensor. 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 is measured at equilibrium. This approach is somewhat different from the "flow curve" approach 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 selected ramp 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 yield stress can be quite different from the value that is often reported as the yield stress, which is obtained 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 [29], 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. Also included in that figure are values measured for feed from the previous DM1200 test using the same LAW A simulant [22]. Figure 2.2 shows an alternative presentation of the data as plots of the shear stress versus shear rate; also included are proposed WTP bounds for feed rheology [30]. Measured yield stress and viscosity at selected shear rates are given in Table 2.6. The rheological properties of the feed with the vanadium additive are very similar to the previously used DM1200 feed and are well within the proposed bounds. Conversely, feeds from the starch and sugar test are considerably more viscous to the extent of being outside the defined bounds. No difficulties were encountered processing this feed; however, tests with feeds with higher starch concentrations tended to gel and could not be processed (see Section 3.3).

2.4.3 Chemical Composition

The chemical compositions of the feed samples were determined by first making a glass from the feed sample via crucible melt. The glass was subsequently crushed and analyzed directly by X-Ray Fluorescence Spectroscopy (XRF). The boron oxide target value was used for normalizing the XRF data since its concentration was not determined by XRF. The results, which are compared to the target compositions in Table 2.7, generally corroborate the consistency of the feed composition and show good agreement with the target composition for the major components. Of the oxides with a target composition greater than one percent, only magnesium oxide had a deviation greater than 10% from target. This deviation was also observed in the product glasses but was considerably smaller in magnitude (see Section 5.1). Deficits of magnesium oxide measured in the feed samples being substantially less in the product glass have been observed in several previous studies [7, 8, 22, 31, 32] and are unexplained. Volatile minor elements such as sulfur, selenium, and chlorine are, as expected, below target due to loss during crucible melting. The target sulfur concentrations in the feed, which is important for determining sulfur retention in the glass, are verified from the simulant vendor’s batching sheets. Additional amounts of sulfur added by the VSL are calculated, checked, and weighed out using calibrated balances.

SECTION 3.0
DM10 SCOPING TESTS

Melter tests were conducted on the DM10 with the LAW Sub-Envelope A1 simulant between 11/17/03 and 12/6/03 to screen four reductants for future use on the DM100-WV. These tests produced over 325 kilograms of glass from approximately 0.7 metric tons of feed. The tests, listed in the order in which they were performed, were as follows:

- Test A1: Four 14-hour feeding segments with sugar at stoichiometries of 0.5, 0.75, 1.0, and 1.25.
- Test A4: Three 14-hour feeding segments with sugar at a stoichiometry of 0.5 and urea at stoichiometries of 0.25, 0.5, and 0.75.
- Test A2: Four 14-hour feeding segments with starch at stoichiometries of 0.5, 0.75, 1.0, and 1.25.
- Test A3: Four 14-hour feeding segments with polyethylene glycol (PEG molecular weight: 600) at stoichiometries of 0.5, 0.75, 1.0, and 1.25.

The principal objective of these tests was to determine the types and concentrations of reductants that result in the maximum amount of sulfur volatilization without overly reducing the glass or creating other processing problems. Processing conditions, including the glass pool temperature of 1150°C, mimicked those to be used on the DM100. Test segment durations of 14 hours were selected since, at the target glass production rate, this provided three melt pool turnovers (24 kg) for each reductant concentration.

3.1 DM10 System Description

3.1.1 Feed System

The feed container is mounted on a load cell for weight monitoring and is stirred continuously except for periodic, momentary interruptions during which the weight is recorded. The material in the feed container is constantly recirculated, which provides additional mixing. The recirculation loop extends to the top of the melter where feed is diverted from the recirculation loop through a peristaltic pump into the melter through a Teflon-lined feed line and vertical water-cooled feed tube. A diverter valve permits direction of the feed stream either to the melter or to a sampling vessel.

3.1.2 Melter

The DM10 system used for this work is a ceramic refractory lined melter, which includes two Inconel 690 plate electrodes that are used for joule-heating of the glass pool and a bubbler for agitating the melt. Glass is discharged from the melter using an air-lift system. The melt pool has a surface area of 0.021 m^2 and typically contains about 8 kg of glass. The plenum volume is 19.5 liters at the nominal glass level.

3.1.3 Off-Gas System

For operational simplicity, the DM10 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. The geometry of the transition line (between the melter and the first filtration device) 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^{o}C while the HEPAs are held above 100^{o}C 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. The sampling location for gaseous species monitored by FTIR is immediately downstream of the draft fan.

3.2 DM10 Test Results

Table 3.1 provides a summary of the DM10 tests including run times, types and amount of reductants used, the amount of feed sulfur and iodine retained in the glass product, the measured iron oxidation state, and the concentration of various gaseous constituents in the emissions. Since the DM10 tests served as scoping tests to identify the best candidates for DM100 testing, not all of the glass samples listed in Table 3.1 were analyzed for their redox state. Previous reports [3-9] provide data from tests with baseline concentrations of sugar (stoichiometric carbon ratio of 0.5) and at marginally higher concentrations up to a stoichiometric carbon ratio of 0.75. Previous tests with LAW Sub-Envelope A1 [7] feed at stoichiometric carbon ratios of 0.57 and 0.44 resulted in glass Fe^{2+} contents of 6% and <0.8% of the total iron, respectively. Tests with a LAW Sub-Envelope C2 feed [9] at 0.75 stoichiometric carbon ratio resulted in 22% of the total iron as Fe^{2+} in the glass. A listing of all the glasses discharged and analysis performed is given in Table 3.2. The methods used were XRF for glass compositional analysis (see Section 2.4.3), colorimetric analysis for iron oxidation state (see Section 5.2), and FTIR for stack exhaust analysis (see Section 6.2). Sulfur and iodine compositional trends over the course of the tests are depicted in Figures 3.1 – 3.4.

Results for most of the reductants showed the expected trends: as the stoichiometric ratio increased, sulfur retention in the glass decreased and the amount of divalent iron in the glass increased. Tests with polyethylene glycol were an exception since very little change in sulfur concentration was observed as a result of changes in PEG concentration and the amount of reduced iron actually decreased as the concentration of PEG increased. However, the redox state at the beginning of the PEG test may have been biased high by the prior starch test. In addition, it was difficult to distinguish differences in glass sulfur concentrations between the two highest urea concentrations, although the glass is clearly more reduced as the urea concentration increases.

The effectiveness of the reductants in volatilizing sulfur from the glass was as follows:

Starch > Sugar > Urea + Sugar > > PEG

The effectiveness of the reductants in reducing iron was slightly different:

Sugar > Starch > Urea + Sugar > > PEG

The optimum reductant would volatilize the maximum amount of sulfur without significantly affecting the redox state of the glass melt. Starch is the more effective reductant tested with respect to volatilizing sulfur and producing a smaller shift in glass redox state than sugar, making it attractive for future tests. A stoichiometric ratio of 0.75 with starch resulted in less than ten percent reduced iron while volatilizing about a quarter of the sulfur; this was therefore selected for further testing on the DM100. The other reductants selected for DM100 testing were urea and sugar at a stoichiometric ratio of 1.0 with half the carbon provided by each compound. This combination resulted in less sulfur retention in the glass than starch at a stoichiometric ratio of 0.75 with less than twenty percent reduced iron in the glass product. Sugar alone was not selected for DM100 testing, even though it was effective at volatilizing sulfur, because of the observed tendency to significantly reduce iron at stoichiometric ratios of 0.75 or greater [5, 9].

Other points of interest in the results from the DM10 tests were the effects that the reductants had on iodine retention in the glass and gaseous emissions. At stoichiometric ratios greater than 0.75, 30-40 percent of the feed iodine was retained in the glass for all reductant types except PEG. This is in keeping with tests using LAW simulants conducted at stoichiometric levels of 0.75 or greater [9]; it is also consistent with results from tests with HLW simulants when sufficient sugar was added to create reducing conditions in the cold cap [34]. Although not depicted here, selenium concentrations were monitored during the DM10 tests and showed no obvious trend with reductant type or concentration. Gaseous emissions followed the expected trends for the sugar and urea plus sugar tests: decreasing NOx emissions and increasing byproduct (carbon monoxide, ammonia, and nitriles) emissions with increasing feed carbon content. Increasing the starch concentration appeared to have no effect on NOx emissions and little effect on byproduct generation. Conversely, increasing PEG concentration resulted in systematic reductions of NOx but concentrations of byproducts, and particularly ammonia, were high at all PEG concentrations.

3.3 Final Evaluation of Reductants Selected from DM10 Tests

No processing problems were encountered with any of the reductants during DM10 testing; however, additional tests were performed to ensure that no problems would occur under the different conditions present in the DM100 feed system. Temperatures in the DM100 feed tank range between 30 and 40°C due to the close proximity to the melter whereas feed in the

DM10 feed tank is close to room temperature. Feed stability for each of the proposed reductants was therefore evaluated at temperatures up to 45°C in beakers placed in a constant temperature bath. No problems were encountered with urea and sugar feed at any of the concentrations tested; however, starch at concentrations higher than a stoichiometric ratio of 0.5 formed a thick gel above 35°C resulting in a feed with unacceptable rheological properties. Therefore, the stoichiometric ratio of 0.75 for the DM100 test was achieved using starch at a stoichiometric ratio of 0.5 in combination with sugar at a stoichiometric ratio of 0.25.

SECTION 4.0
DM100 OPERATIONS

Melter tests were conducted on the DM100-WV with the LAW Sub-Envelope A1 simulant between 12/10/03 and 1/30/04. These tests produced almost 1350 kg of glass from approximately 2.7 metric tons of feed. The tests were 50 to 60 hours in duration and were divided as follows:

- Urea and Sugar Test: Stoichiometric ratio of 1; 0.5 urea and 0.5 sugar
- Vanadium Additive Test: 2.0 wt% TiO_2 in the target glass replaced with V_2O_5; stoichiometric ratio of 0.5 with sugar (i.e., current WTP nominal level)
- Starch and Sugar Test: Stoichiometric ratio of 0.75; 0.5 starch and 0.25 sugar

Table 4.1 provides summaries for the three tests. Attempts were made to replicate the melter configuration and operating conditions used for the corresponding tests conducted earlier [7, 27] and the previous LAW Sub-Envelope [5-9, 33, 35, 36] tests. These conditions include a near-complete cold cap, which is between 80-95% melt surface coverage for the DM100, since a 100% cold cap tends to lead to "bridging" in smaller melters. The target production rate of 2000 kg/m^2/day was approximated for most of the testing (see Figures 4.1.a,b,c), although about a day of processing was required in the Urea and Sugar Test to achieve this rate, as depicted in Figure 4.1.a. As typically observed, production rates vary from the target at the onset of feeding while the cold cap becomes established; in addition, instantaneous rates varied by as much as 25% as a result of variable feed pulse sizes. No processing problems were observed, and no secondary sulfate phase was observed before or after any of the tests. No interruptions were experienced due to feed system clogging.

The results of various operational measurements that were made during these tests are given in Table 4.2. Glass temperatures are shown in Figures 4.2.a – 4.2.c, plenum temperatures in Figures 4.3.a – 4.3.c, and electrode temperatures in Figures 4.4.a - 4.4.c. Power supplied to the electrodes is shown in all the figures. Bulk glass temperatures approximated the target glass temperature of 1150°C. Glass temperatures near the top of the melt pool are not reliable indicators of bulk glass temperatures as a result of gradients near the cold cap. Plenum temperatures typically ranged within the 450 to 650°C target but were mostly in the upper part of the range. This is deliberately somewhat higher than for the larger melters (DM1200 and LAW Pilot Melter) in order to reduce cold cap bridging that occurs in the smaller melters. The West electrode temperature averaged between 1125-1148ºC, the East electrode 10-35ºC less, and the bottom electrode was typically about 200-250ºC cooler than the side electrodes. The bottom electrode was not powered during these tests. Power supplied to the electrodes typically varied by only 2 kW from the average value. The average bubbling rates were higher (22 vs. 16 lpm) for the first two tests than the last test or other previous tests due to natural aging and corrosion of the bubbler, which was apparent upon removal of the bubbler after the Vanadium Additive Test, after which the bubbler was replaced.

The gas temperature at the film cooler averaged between 290 and 294ºC, depending on the plenum temperature as well as the amount and temperature of added film cooler air. Little or no drop in gas temperature was observed across the (insulated) transition line, which serves to prevent condensation, as intended.

SECTION 5.0
DM100 GLASS PRODUCTS

Almost 1350 kg of glass was produced in these tests. The glass was discharged from the melter periodically into 5-gallon carbon steel pails using an airlift system. 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. Product glass masses, discharge date, and analysis performed are listed in Table 5.1. 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 a separate sulfate phase on the glass surface as well as total inorganic compositional analysis.

5.1 Compositional Analysis

Glass discharge and dip samples were crushed and analyzed directly by XRF. The target value for boron oxide, which is not determined by XRF, was used for normalizing the XRF data to 100 wt%. The XRF-analyzed compositions of discharged glass samples are provided in Table 5.2 and, for selected samples, are compared with the results of DCP analysis of solutions generated by microwave aided acid dissolution in Table 5.3. Results for dip samples by XRF are provided in Table 5.4. All discharged glass and dip samples were subjected to XRF analysis. The majority of the XRF analysis results compared very favorably to their corresponding target values. The only significant oxide with a relative deviation from target greater than 10% was MgO, which was about 11% below the target value in the Urea and Sugar test. Measured boron concentrations were within three percent of the target validating the use of the target value for normalizing the XRF data. Agreement between the two analytical methods was excellent except for low sodium values obtained from the DCP analysis, which is likely due to a low-bias for sodium; previous experience indicates that the XRF results are more reliable in this regard. Compositional trends for most of the major constituents during the tests shown in Figures 5.1 and 5.2 illustrate the closeness to target and the consistency of composition over the course of the tests. The intended decrease of titanium and increase in vanadium during the second test is readily observed. Note that the glass pool was turned over with frit generated during the DM10 and Urea and Sugar Tests prior to commencing the last test and therefore the concentrations of titanium and vanadium change abruptly between the Vanadium Additive Test and the Starch and Sugar Test. No deviations in the concentrations of other major constituents were apparent as a result of the turnover with frit or the idling period between the tests.

Cadmium, iodine, and selenium were spiked into the feed that was used in the Starch and Sugar Test at concentrations of 0.1 wt% each in the glass product, assuming total retention. The concentrations of these elements over the course of the tests are depicted in Figure 5.3. Predictably, their concentrations were at or below detectable levels until frit containing these elements was introduced into the melter at the end of the Vanadium Additive Test. Steady-state concentrations were obtained by the end of the Starch and Sugar Test of about 0.024, 0.044, and 0.092 wt% for selenium, iodine, and cadmium, respectively. Previous studies have shown that iodine retention in glass is very low except when processing feed with high alkali content [22, 27, 36] and higher than nominal concentrations of reductants [9, 34]. Feed processed in the DM10 (see Section 3.0) and the Starch and Sugar Test satisfied both of these criteria, resulting in nearly half the iodine being retained in the feed. Selenium and cadmium retentions were 10 to 30% below those observed while processing the same feed in the DM1200 due perhaps to the thicker and more extensive cold cap coverage possible on the larger melter.

The concentrations of chlorine and sulfur, which are also relatively volatile, are plotted over the course of the tests in Figure 5.4. Notice that during each test, steady-state concentrations of SO_3 and chlorine are attained. The concentration of sulfur decreases with increasing feed carbon content; the Vanadium Additive Test had the lowest stoichiometric carbon ratio and had the highest glass sulfur concentrations, whereas the Urea and Sugar test had the highest stoichiometric carbon ratio and had the lowest glass sulfur concentrations. The disparity between the concentration of sulfur in the glass during these tests is greater than observed in previous tests with same formulation [7, 27] due to the higher reductant content, change in additives, and the concentration of sulfur in the feed (0.5 vs. 0.19 – 0.26 wt% SO_3). Sulfur in the glass samples was measured mostly by XRF and occasionally by ion chromatography (IC). XRF results show better precision than the IC results and, based on our previous experience, we place greater confidence in the XRF results. SO_3 measurement by IC requires a glass digestion step during which loss of sulfur by volatilization is a possibility. This is probably the reason for the occasional low sulfur result measured by IC as compared to the XRF result for the same sample. The chlorine concentration was largely unaffected by the changes in additive type and carbon concentration. It is also considerably more volatile than sulfur, as seen by concentrations showing wider deviations from the target and the decreases in concentration during the idling periods between tests.

Glass dip samples were obtained at the beginning and end of each test, primarily to ascertain whether a secondary sulfate layer had formed on the surface of the glass melt. Table 5.4 provides a listing of all of the dip samples together with their analyzed compositions and whether or not a separate salt phase was evident. All dip samples taken were free of secondary phases. Also note that the measured dip sample compositions are close to the target compositions for most of the major elements and that sulfur and chlorine concentrations in dip samples taken at the end of a test are close to the corresponding concentrations in the discharge samples.

5.2 Iron Redox State

The iron oxidation states for glass samples from all tests were measured using colorimetric methods. The method detection limit of 0.5% divalent iron reported here is dependent on several factors including the level (6.9 wt%) of Fe_2O_3 in the target glass. Sample information including name, test, and the amount of glass produced for all samples analyzed for divalent iron are given in Table 5.5. The glass samples from the end of tests with greater than 0.5 stoichiometric carbon had reduced iron concentrations between 20-25%, whereas glass samples from the Vanadium Additive Test were almost completely oxidized. The latter result is in keeping with previous tests with LAW feeds at stoichiometric ratios of 0.5 [5, 6, 8, 9, 32] as well as the DM10 Starch (Test A2A) and Urea and Sugar (Test A4A) Tests. One of the glass samples from the Vanadium Additive Test was analyzed by both the colorimetric method and Mössbauer spectroscopy and showed 3% and <5% divalent iron, respectively. The amount of reduced iron observed in the Urea and Sugar Test as well as the Starch and Sugar DM100 Test is higher than in the corresponding DM10 tests due in part to more complete cold cap coverage in the larger melter creating more reducing conditions in the underlying glass. The lower concentration of waste organics, which resulted in a higher proportion of the total carbon originating from sugar, also contributed to yielding a more reducing glass in the Urea and Sugar test. Previous tests with LAW simulants and sugar at stoichiometric ratios of 0.75 and 1.0 resulted in divalent iron concentrations of 22-30% and 26-45%, respectively [4, 9]. Tests conducted in the present work with comparable amounts of total carbon but with significant amounts in the form of urea or starch resulted in lower concentrations of divalent iron since these compounds are not as effective at reducing iron in the glass melt as sugar.

SECTION 6.0
MONITORED OFF-GAS EMISSIONS

6.1 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 DM100 test. The concentrations of off-gas species that are present as particulates and gaseous species that are collected in impinger solutions were derived from laboratory data on solutions extracted from air samples (filters and various solutions) together with measurements of the volume of air sampled. Particulate collection required isokinetic sampling, which entails removing gas from the exhaust at the same velocity that the air is flowing in the duct (40-CFR-60, Methods 1-5). Typically, a sample size of 30 dscf was taken at a rate of between 0.5 and 0.75 dscfm. Total particulate loading was determined by combining gravimetric analysis of the standard particle filter and chemical analysis of probe rinse solutions. An additional impinger containing 2 N NaOH was added to the sampling train to ensure complete scrubbing of acid gases, particularly halogens. The collected materials were analyzed using direct current plasma atomic emission spectroscopy (DCP-AES) for the majority of the constituents and ion chromatography (IC) for anions. Melter emission fluxes are compared to feed fluxes in Table 6.1 where the distinction is made between constituents sampled as particles and as "gas". The "gaseous" constituents are operationally defined as those species that are scrubbed in the impinger solutions after the air stream has passed through a 0.3 µm heated filter. All samples were within 10% of isokinetic.

Particulate emissions from the melter were high, at 0.6-2% of feed solids. Particulate melter emissions increase with increasing feed alkali content [3-9, 27, 33, 35-37] and therefore it is not surprising that the LAW Sub-Envelope A formulations, which have the highest sodium and halide content, also have the highest percent of particulate carry-over. The high solids carry-over of nonvolatile elements such as silica in the Starch and Sugar Test suggests that the increase is due to gross entrainment of feed into the exhaust stream, not volatilization. As expected, the feed elements emitted at the lowest melter DF were clearly halogens and sulfur. Iodine was detected in significant quantities as both gaseous and particulate emissions in the Sugar and Starch Test. This is in contrast to previous tests with LAW simulants and sugar at a stoichiometric ratio of 0.5 where iodine was almost exclusively detected in the basic impinger of the sampling train suggesting emissions were mostly in the form of molecular iodine. Chlorine and fluorine emissions were detected exclusively as particulate emissions in all three tests. Fluorine was detected in emissions from the first two tests even though it was not included in the target composition due to its ubiquity as a contaminant in water and raw materials. Sulfur emissions were mostly particulate except in the Starch and Sugar Test. Other elements exhibiting volatile behavior include alkali metals and chromium as well as selenium and cadmium in the Starch and Sugar Test. 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 constitutes the “gas” fraction of the melter emissions.

6.2 Gases Monitored by FTIR

Melter emissions were monitored in each test for a variety of gaseous components, most notably CO and nitrogen species, by Fourier Transform Infra Red Spectroscopy (FTIR). The off-gas system temperature is maintained well above 100°C beyond the sampling port downstream of the HEPA filter to prevent analyte loss due to condensation prior to monitoring. A summary of the average and the range of concentrations monitored during each test is provided in Tables 6.2 and 6.3, respectively. The concentrations of various monitored species are plotted in Figures 6.1 - 6.3. The large variations in the measured concentrations evident in these figures are a result of the pulsed feeding system and the dynamic nature of the cold cap. The analytes listed in the tables are those that were expected to be observed during the test, based on previous work; no other species were detected in the off-gas stream by FTIR. Hydrogen concentrations were also monitored in the tests by gas chromatography and are included in Table 6.2. The most abundant nitrogen species monitored was NO, which is consistent with previous tests [3-9, 27, 33, 35-37] in which nitrates and nitrites were abundant in the feed. The concentrations of NO_2 and N_2O were an order of magnitude lower than NO in the Vanadium Additive Test and decreased with respect to NO by a factor of four as the stoichiometric ratio was increased from 0.5 to 1.0. Measured concentrations of nitrogen oxides decreased with increasing feed carbon content while byproducts of organic matter decomposition such as NH_3 and CO_2 increased, which is also consistent with previous tests. Ammonia concentrations were particularly high in the test with urea, which is expected based on the known production of ammonia on the thermal decomposition of urea. Carbon monoxide and acetonitrile concentrations were the highest in the Starch and Sugar Test, even though more carbon was present in the feed than was used in the Urea and Sugar Test. Hydrogen emissions were highest in the Vanadium Additive Test, suggesting that hydrogen emissions are not solely dependent on feed carbon content; it is not clear what role, if any, vanadium may play in the observed increase in hydrogen concentrations. No gaseous HF or HCl were detected by FTIR, consistent with the results from the Method 5-type sampling discussed in Section 6.1.

The results of a nitrogen mass balance are summarized in Table 6.4. In keeping with previous tests, the percent of feed nitrates and nitrites emitted as nitrogen oxides was inversely related to the amount of carbon in the feed [5, 9]. Also, consistent with previous tests with feed at a sugar ratio of 0.5 [3-9, 27, 33, 35-37], about 50% of the feed nitrogen oxides were reduced to diatomic nitrogen in the Vanadium Additive Test. For the reductants tested in the present work, the quantity rather than the type of carbon appeared to be the dominant factor in determining nitrogen oxide emissions. This observation is in contrast to results from tests using other reductants, such as formic acid [8] and various waste organics (EDTA, glycolic acid, oxalic acid, acetic acid, and citric acid), which indicated that these compounds were considerably less effective at reducing nitrogen oxide emissions than sugar.

6.3 Mass Balance for Volatile Constituents

Table 6.5 provides the percentages of sulfur, chlorine, iodine, and selenium that were retained in the glass product or identified in the various off-gas stream samples for each of the tests. Data for other DM100 tests processing LAW Sub-Envelope A1 simulants are included for comparison. The chlorine mass balance around the melter was excellent for all tests, with totals ranging from 93 – 102 percent. Closure for sulfur was not as good but within 20% for all three tests. Sulfur retention in the glass ranged between 66 and 78%, depending on the concentration of carbon in the feed. Less sulfur was retained in the glass during the current three tests than for any of the previous tests, including those conducted at temperatures as high as 1225°C [31]. At the nominal operating temperatures, a 20 to 30 percent decrease in the sulfur concentrations in the glass can be attributed to the use of vandadium or the reductants used in these tests that are different from the WTP baseline. Emissions of sulfur were mostly in the form of particles for all LAW Sub-Envelope A1 tests except the Starch and Sugar Test, which was the test with the largest excess of sulfur over 100%. The sulfur particulate emissions were similar to those observed in previous tests conducted on the DM100 [27, 33, 36]. About half the chlorine was retained in the glass, with the other half emitted from the melter as particles in the LAW Sub-Envelope A1 tests. The excess chlorine recovery in the high temperature tests suggests the feed used in that test may have had chlorine at above the target concentration. Iodine retention in the glass during the Starch and Sugar Test was higher (40% vs. 20%) than for the comparable test at the nominal stoichiometric carbon ratio. Aside from elements that are not appreciably incorporated in the glass structure such as nitrogen, selenium was the most volatile element studied with less than a quarter of the amount fed being retained in the glass.

SECTION 7.0
SUMMARY AND CONCLUSIONS

Several tests were conducted on the DM10 and DM100 vitrification systems to assess the effectiveness of various reductants in increasing the extent of volatilization of sulfur from glass melts. A previously tested glass formulation for the LAW Sub-Envelope A1 simulant with sulfur content increased to 0.5 wt% SO_3 was used. Four different organic reductants – sugar, urea, starch, and polyethylene glycol, each at several concentrations – were evaluated on the DM10 for their effects on sulfur volatilization and iron redox state in the glass product. Based on these results as well as melter feed rheology testing, combinations of urea and starch with sugar were selected for further testing on the DM100. In addition, the tests also evaluated an inorganic additive for its effects on sulfur volatilization: vanadium was used as an additive in place of titanium in tests performed on the DM100 at the WTP nominal level of organic reductant (sugar at a stoichiometric ratio of 0.5 with respect to nitrates and nitrites). No difficulties were encountered during processing and at no time during or after testing did a separate sulfate phase form on the melt pool surface. Tests were successful at volatilizing between 22 and 34% of the feed sulfur from the glass while maintaining only modest shifts of the redox state of the melt pool. More sulfur was volatilized from the glass than in previous tests conducted at melt temperatures as high as 1225°C.

During the present tests, total particulate emissions from the melter ranged from 0.6 – 2 wt%. Melter DFs were determined for each element in the feed for the three DM100 tests that were performed. Increases in reductant concentrations resulted in increased particulate sulfur emissions but had little effect on other volatile elements such as chlorine. Good mass balance closure around the melter was achieved for sulfur and chlorine. Iodine retention in the glass increased by a factor of two as the stoichiometric carbon ratio increased from 0.5 to 0.75.

For streams for which sulfur is the waste-loading-limiting component, which is the case for many of the Hanford LAW waste streams, partitioning some of the sulfur to somewhere other than the glass will result in a proportionate increase in waste loading, which, in turn, will result in a proportionate reduction in the volume of glass that is produced. These results are therefore potentially significant to the DOE because the volume of glass drives the processing and disposal costs. Therefore, if 20-30% of the sulfur can be volatilized, 20-30% less glass might be produced, *assuming* that the volatilized sulfur is not recycled into the melter feed. This work clearly shows that there are significant differences between reductants in their effect on glass redox and the amount of feed sulfur that is partitioned to the off-gas. This fact is important because it implies that further optimization should be possible simply because there are differences in the behavior of reductants with respect to their effect on glass redox and sulfur retention in the glass.

SECTION 8.0
RECOMMENDATIONS FOR FUTURE WORK

While it is clear that the addition of reductants to the melter feed will increase the extent of sulfur partitioning to the off-gas stream, it is also clear that highly reducing conditions in combination with sulfur in the melt can lead to the formation of metal sulfides and, ultimately metallic phases in the melter, which can have serious deleterious operational consequences. Consequently, the basic issue addressed in the present work is the extent to which reductants, mixtures of reductants, or inorganic additives can be tailored to maximize the partitioning of sulfur to the off-gas stream while minimizing the reducing effect on the glass melt. The results of this work demonstrate that alternative reductants, reductant mixtures, and vanadium as an inorganic additive can indeed be effective in this regard. However, these results obtained on a relatively small number of potential additives also indicate that there is considerable scope for further improvement if this approach were to be pursued for application in the WTP. The present study focused on the magnitude of the effects and the extent of the differences between additives (reductants and inorganics additives) on sulfur partitioning and reduction of the melt under melter test conditions that are relevant to the WTP. However, the present study was not directed at understanding the basic mechanisms involved, and the reasons for the differences in the behavior of the different additives; such a study would be of value in the selection and further optimization of additives to enhance sulfate volatilization for the melter. Future work should address:

- Testing of other reductants over a range of concentrations;
- Testing of other combinations of reductants over a range of concentrations;
- Testing of reductants in combination with vanadium;
- Testing of other potential inorganic additives;
- Testing of reductants, combinations of reductants, and/or inorganic additives at higher temperatures;
- Longer duration tests to evaluate the potential formation of reduced phases;
- Larger scale tests to address scale-up effects;
- Basic tests to address the reactions and processes that are involved in maximizing sulfur partitioning while minimizing melt redox shifts in order to more efficiently down-select potential additives.

The present study clearly demonstrates that this approach for partitioning sulfur to the off-gas is of value in increasing waste loading in LAW glasses, thereby reducing LAW glass volume, and processing and disposal costs. By performing the additional work outlined above, the results of the present study would be confirmed by longer duration testing and at larger melter scales, which would ultimately underpin this promising method of enhancing the waste processing rate at the WTP LAW facility. Results from tests to understand the basic mechanisms involved will help guide selection and further optimization of additives to enhance sulfate volatilization while minimizing undesirable reduction of the glass melt. However, the advantages of this approach are predicated on the present sulfur recycle loop at the WTP being broken.

SECTION 9.0
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Table 2.1. LAW Sub-Envelope A1 Simulant Recipe at 8 Molar Sodium Used in DM10 Tests.

Envelope Constituents	Simulant AN-105 (sup) including Pretreatment		Glass Oxides	LAW A1 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	-	25.849 %	In 285 ml water add following compounds in the order listed below					
Al	28595	1.060	Al_2O_3	16.862	4.359	$Al(NO_3)_3 \cdot 9H_2O$, 60% sol.	1	375.14	0.59	0.14	387.68
						$Al(OH)_3$	7	78.00	0.77	0.65	46.11
Ca	58	0.001	CaO	0.025	0.007	$Ca(NO_3)_2{*}4H_2O$	2	236.16	0.99	0.24	0.34
Cr	166	0.003	Cr_2O_3	0.076	0.020	$Na_2CrO_4{*}4H_2O$	10	234.04	0.99	0.19	0.76
Cs (spike)	1686	0.013	Cs_2O	0.558	0.144	$CsNO_3$	3	194.91	1.00	0.72	2.48
Fe	19	0.000	Fe_2O_3	0.009	0.002	$Fe(NO_3)_3{*}9H_2O$	4	404.01	1.00	0.20	0.14
K	4570	0.117	K_2O	1.718	0.444	KOH	9	56.10	0.85	0.84	7.71
Na	183920	8.000	Na_2O	77.371	20.000	NaOH, 50% sol. d=1.53	8	40.00	0.48	0.77	440.63
Ni	28	0.000	NiO	0.011	0.003	$Ni(NO_3)_3{*}6H_2O$	5	290.81	1.00	1.00	0.14
Si	150	0.005	SiO_2	0.100	0.026	SiO_2	11	60.09	0.99	1.00	0.33
Cl	6933	0.196	Cl	2.164	0.559	NaCl	12	58.45	0.99	0.61	11.55
F	305	0.016	F	0.095	0.025	NaF	13	42.00	0.99	0.45	0.68
PO_4	1121	0.012	P_2O_5	0.261	0.068	$Na_3PO_4{*}12H_2O$	14	380.12	0.99	0.19	4.53
SO_4	2883	0.030	SO_3	0.750	0.194	Na_2SO_4	15	142.06	0.99	0.56	4.31
NO_2	86856	1.888	NO_2	-	-	$NaNO_2$	22	69.00	0.97	0.55	134.31
NO_3	122642	1.978	NO_3	-	-	$NaNO_3$	-	84.99	0.99	0.73	-
CO_3	11938	0.199	CO_3	-	-	Na_2CO_3	23	105.99	1.00	0.58	21.09
NH_3	2335	0.137	NH_3	-	-	NH_4NO_3	21	80.04	1.00	0.21	10.98
OH	93721	5.513	OH	-	-	From KOH + NaOH + $Al(OH)_3$	-	-	-	-	-
Org.Carbon	5543	0.462	-	-	-	-	-	-	-	-	-
EDTA	3640	0.013	-	-	-	$Na_2EDTA{*}2H_2O$ (C10)	6	372.24	0.99	0.32	4.72
HEDTA	4321	0.016	-	-	-	$Na_3HEDTA{*}2H_2O$ 41% sol. (C10)	16	380.24	0.448	0.32	13.34
Acetate	2115	0.036	-	-	-	Sodium Acetate*3H_2O (C2)	17	136.08	0.99	0.18	4.92
Formate	2007	0.045	-	-	-	Sodium Formate (C1)	18	68.01	0.99	0.18	3.06
Oxalate	677	0.008	-	-	-	Sodium Oxalate (C2)	19	134.00	0.99	0.18	1.04
Glycolate	1820	0.024	-	-	-	Glycolic Acid (C2)	20	76.05	0.67	0.32	2.72
-	-	-	-	-	-	Target Glass					1239.60
-	-	-	SUM	100.00	25.849	Total simulant weight					1388.55

NOTE: Potassium iodide was spiked into the feed at VSL at a level corresponding to 0.1 wt% iodine in the glass if it were all retained. Cadmium and selenium were spiked at 1124 mg/l and 899 mg/l, respectively, in the simulant, which corresponds to 0.1 wt% of each oxide in the glass.
"-" Empty data field

Table 2.2. LAW Envelope A (AN-105) Waste Simulant Recipe at 8 Molar Sodium.

Envelope Constituents	Simulant AN-105 including pretreatment		Glass Oxides	AN-105 Wt%	AN-105 Wt% in glass	Source in Simulant	Order for Addition	Formula Weight	Assay	Ratio	Target Weight (g)
-	mg/L	M	Loading	-	26.039%	In 274.40 ml water add following compounds in the order listed below					
Al	30554	1.132	Al_2O_3	17.886	4.657	$Al(NO_3)3.9H_2O$, 60% sol. $Al(OH)_3$	1 8	375.14 78.00	0.61 1.00	0.14 0.66	419.32 35.56
B	79	0.007	B_2O_3	0.078	0.020	H_3BO_3	3	61.83	0.99	0.56	0.45
Cr	149	0.003	Cr_2O_3	0.067	0.018	Na_2CrO_4*$4H_2O$	7	234.04	0.99	0.19	0.68
Cs (spike)	1739	0.013	Cs_2O	0.571	0.149	$CsNO_3$	2	194.91	1.00	0.72	2.56
K	4608	0.118	K_2O	1.720	0.448	KOH	6	56.10	0.91	0.84	7.28
Na	183920	8.000	Na_2O	76.807	20.000	NaOH, 50% sol. d=1.53	5	40.00	0.50	0.77	463.20
Si	157	0.006	SiO_2	0.104	0.027	SiO_2	4	60.09	0.99	1.00	0.34
Cl	6996	0.197	Cl	2.167	0.564	NaCl	9	58.45	0.99	0.61	11.65
F	35	0.002	F	0.011	0.003	NaF	10	42.00	0.99	0.45	0.08
SO_4	2274	0.024	SO_3	0.587	0.153	Na_2SO_4	11	142.06	0.99	0.56	3.40
NO_2	85428	1.857	-	-	-	$NaNO_2$	15	69.00	0.97	0.55	128.79
NO_3	126988	2.048	-	-	-	$NaNO_3$	-	84.99	0.99	0.73	0.00
TOC	2093	0.174	-	-	-	-	-	-	-	-	-
Acetate	2251	0.038	-	-	-	Sodium Acetate.$3H_2O$ (C2)	12	136.08	0.99	0.18	5.24
Formate	2135	0.047	-	-	-	Sodium Formate (C1)	13	68.01	0.99	0.18	3.26
Glycolate	1936	0.025	-	-	-	Glycolic Acid (C2)	14	76.05	0.71	0.32	2.73
-	-	-	-	-	-	Target Glass					1239.60
-	-	-	SUM	100	26.039	Total simulant wt.					1358.94

"-" Empty data field

Table 2.3. Oxide Composition of LAW Sub-Envelope A1 Simulant and Corresponding Glass Compositions (wt%).

Glass Oxides	LAWA44 Glass	DM10 Glass, DM100 (Starch + Sugar Test)	DM100 (Urea + Sugar Test)	DM100 (Vanadium Test)
Al_2O_3	6.18	6.13	6.15	6.15
B_2O_3	8.98	8.91	8.91	8.91
CaO	1.99	1.97	1.99	1.99
CdO	-	0.10	-	-
Cr_2O_3	0.02	0.02	0.02	0.02
Cs_2O	0.14	0.14	0.15	0.15
Fe_2O_3	6.96	6.91	6.93	6.93
K_2O	0.44	0.44	0.45	0.45
MgO	1.99	1.97	1.99	1.99
Na_2O	20.02	20.07	20.24	20.24
NiO	<0.01	<0.01	-	-
SeO_2	-	0.10	-	-
SiO_2	44.44	44.13	44.22	44.22
TiO_2	1.99	1.97	1.99	-
V_2O_5	-	-	-	1.99
ZnO	2.96	2.94	2.95	2.95
ZrO_2	2.98	2.96	2.97	2.97
Cl	0.56	0.56	0.56	0.56
F	0.02	0.02	<0.01	<0.01
I	-	0.10	-	-
P_2O_5	0.07	0.07	<0.01	<0.01
SO_3	0.24	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00

"-" Empty data field

Table 2.4. Glass Forming Additives for 1 Liter of Simulant (8 M Na) and Corresponding Melter Feed Properties.

Additives Source	DM10 Glass, DM100 (Starch + Sugar Test)	DM100 (Urea + Sugar Test)
Additives in Glass (wt%)	74.15	73.96
Kyanite (Al_2SiO_5) 325 Mesh (Kyanite Mining) (g)	42.46	35.84
H_3BO_3 (US Borax – Technical Granular) (g)	200.66	200.17
Wollanstonite NYAD 325 Mesh (NYCO Minerals) (g)	52.14	52.48
Fe_2O_3 (97% Alfa) (g)	81.65	81.90
Olivine (Mg_2SiO_4) 325 Mesh (#180 Unimin) (g)	51.92	52.09
SiO_2 (Sil-co-Sil 75 US Silica)) (g)	466.91	470.39
TiO_2 (Rutile Airfloated Chemaloy)* (g)	25.86	25.95
ZnO (KADOX – 920 Zinc Corp. of America) (g)	36.80	36.88
Zircon $ZrSiO_4$ (Flour) Mesh 325 (AM. Mineral) (g)	55.61	55.63
Addition of Sucrose as Reductant (Stoichiometric Ratio – 0.5) (g)	69.48	78.5
+Na_2SO_4 (based on formulation studies) (g)	4.34	4.34
Simulant Weight for 1 liter (g)	1389	1359
Sum of Additives (g)	1014	1011
Sum of Complete Batch (g)	2403	2370
Final Volume (l) (based on measured density)	1.40	1.35
Target Density (g/ml)	1.67	1.75
Target Glass Yield (g/l of simulant)	1243	1243
Target Weight % Water in Slurry Feed	37.6	35.3
Weight % Additives in Slurry	42.2	42.7
Target Glass Yield (g/kg of Feed)	517	523
Target Glass Yield (g/l of Feed)	860	915
Target Total Solids (g/l of Feed)	1070	1132
Target Additives (g/l of Feed)	703	747

* - V_2O_5 is substituted for rutile in the Vanadium Additive Test.

Table 2.5. Measured Properties of Crucible Glasses.

Glass ID		LAWA144	LAWA143	LAWA145
Target V_2O_5 Concentration (Wt%)		1.0	2.0	4.0
Measured SO_3 Solubility (Wt%)		0.53	0.64	0.61
Viscosity (poise)	900 °C	1446	1648	1275
	950 °C	624	714	570
	1000 °C	301	346	284
	1050 °C	159	184	154
	1100 °C	91	105	90
	1130 °C	67	77	67
	1150 °C	55	64	56
	1200 °C	35	41	36
	1250 °C	23	27	25
Electrical Conductivity (S/cm)	900 °C	0.158	0.160	0.189
	950 °C	0.203	0.212	0.234
	1000 °C	0.256	0.270	0.284
	1050 °C	0.316	0.332	0.339
	1100 °C	0.385	0.396	0.397
	1150 °C	0.463	0.463	0.458
	1200 °C	0.549	0.532	0.522
	1250 °C	0.644	0.601	0.589

Table 2.6. Properties of Feed Samples from DM100 Melter Tests.

Melter	**Test**	**Date**	**Name**	**% Water**	**Density**	**Glass Yield**		**pH**	**Yield Stress (Pa)**	**Viscosity (Poise)**		
					(g/ml)	(kg/kg)	(g/l)			@1/s	@10/s	@100/s
DM100	Vanadium Additive	5/13/04	WVX-F-16A	39.91	1.69	0.486	821	12.17	0.7	2.58	0.50	0.27
	Starch and Sugar	1/30/04	WVV-F-93A	37.48	1.72	0.479	824	12.13	4.4	28.7	4.58	2.34
DM1200	Average [22]			37.60	1.72	0.481	827	12.19	0.8	4.17	0.74	0.38

Table 2.7. XRF Analyzed Composition for Melter Feed Samples (wt%).

-	Vanadium Additive Test			Starch and Sugar Test		
Constituent	Target	WVX-F-16A	%Dev	Target	WVV-F-93A	%Dev
Al_2O_3	6.15	6.24	1.41	6.13	6.23	1.62
B_2O_3*	8.91	8.91	NC	8.91	8.91	NC
CaO	1.99	2.16	8.74	1.97	1.88	-4.72
CdO	§	<0.01	NC	0.10	0.14	NC
Cl	0.56	0.11	NC	0.56	0.03	NC
Cr_2O_3	0.02	0.04	NC	0.02	0.04	NC
Cs_2O	0.15	0.10	NC	0.14	0.07	NC
CuO	§	<0.01	NC	0.02	0.07	NC
Fe_2O_3	6.93	6.37	-8.06	6.91	6.64	-3.85
I	§	<0.01	NC	0.10	0.01	NC
K_2O	0.45	0.46	1.90	0.44	0.48	8.06
MgO	1.99	1.59	-19.97	1.97	1.68	-14.67
Na_2O	20.24	19.73	-2.53	20.07	20.69	3.10
NiO	§	0.01	NC	<0.01	<0.01	NC
P_2O_5	§	0.02	NC	0.07	0.10	NC
SeO_2	§	<0.01	NC	0.10	<0.01	NC
SiO_2	44.22	45.88	3.76	44.13	45.16	2.33
SO_3	0.50	0.27	NC	0.50	0.19	NC
TiO_2	§	0.13	NC	1.97	1.99	1.14
V_2O_5	1.99	2.00	0.53	§	0.01	NC
ZnO	2.95	2.93	-0.76	2.94	2.74	-6.79
ZrO_2	2.97	3.04	2.44	2.96	2.94	-0.56
Sum	100.00	100.00	NC	100.00	100.00	NC

* Target value
§ - Not a target constituent
NC – Not calculated
"-" Empty data field

Table 3.1. Summary of DM10 Test Conditions and Results.

Test #		A1A	A1B	A1C	A1D	A4A	A4B	A4C
Time	Feed Start	11/17/03 14:59	11/18/03 5:19	11/18/03 20:07	11/19/03 10:35	11/20/03 1:50	11/20/03 17:15	11/21/03 7:46
	Feed End	11/18/03 4:59	11/18/03 19:45	11/19/03 10:19	11/20/03 1:30	11/20/03 17:00	11/21/03 7:15	11/21/03 21:46
	Net Slurry Feeding (hr)	14.0	14.4	14.2	14.9	15.2	14.0	14.0
Carbon	Type	Sugar	Sugar	Sugar	Sugar	Urea / Sugar*	Urea / Sugar*	Urea / Sugar*
	Sugar ratio	0.5	0.75	1.0	1.25	0.75	1.0	1.25
	Mol. NO_x : Mol. Total Organic Carbon	1: 0.75	1: 1.13	1: 1.5	1: 1.88	1: 1.13	1: 1.5	1: 1.88
Product	Measured wt% SO_3	0.45	0.38	0.32	0.29	0.39	0.34	0.33
	% Feed Sulfur in Glass Product	90	76	64	58	78	68	66
	% Fe^{+2}	NA	NA	45	55	3	19	29
	Measured wt% I	0.02	0.04	0.04	0.04	0.04	0.04	0.03
	% Feed I in Glass Product	20	45	40	45	45	40	30
Stack Emissions (ppmv)	NO	330	180	120	100	250	65	67
	NO_2	23	4.1	1.1	< 0.1	7.8	1.2	< 0.1
	SO_2	< 0.1	1.8	2.7	3.3	1.7	2.0	2.7
	CO	14	24	110	200	20	25	82
	NH_3	28	73	100	130	76	49	92
	Acetonitrile	< 0.1	7.5	20	25	3.1	3.2	12

* - Sugar was at a stoichiometric ratio of 0.5 for all tests with urea.
NA – Not Analyzed.

Table 3.1. Summary of DM10 Test Conditions and Results (continued).

Test #		A2A	A2B	A2C	A2D	A3A	A3B	A3C	A3D
Time	Feed Start	12/1/03 12:45	12/2/03 3:07	12/2/03 17:25	12/3/03 8:00	12/3/03 22:25	12/4/03 13:10	12/5/03 3:30	12/5/03 17:49
	Feed End	12/2/03 2:45	12/2/03 17:07	12/3/03 7:25	12/3/03 22:00	12/4/03 12:25	12/5/03 3:10	12/5/03 17:30	12/6/03 7:02
	Net Slurry Feeding (hr)	14.0	14.0	14.0	14.0	14.0	14.0	14.0	13.2
Carbon	Type	Starch	Starch	Starch	Starch	Polyethylene glycol	Polyethylene glycol	Polyethylene glycol	Polyethylene glycol
	Sugar ratio	0.5	0.75	1.0	1.25	0.5	0.75	1.0	1.25
	Mol. NO_x : Mol. Total Organic Carbon	1: 0.75	1: 1.13	1: 1.5	1: 1.88	1: 0.75	1: 1.13	1: 1.88	1: 1.88
Product	Measured wt% SO_3	0.42	0.38	0.28	0.24	0.36	0.40	0.43	0.40
	% Feed Sulfur in Glass Product	84	76	56	48	72	80	86	80
	% Fe^{+2}	< 1	8	31	37	18	13	2	3
	Measured wt% I	0.01	0.04	0.04	0.03	0.01	0.01	0.01	0.01
	% Feed I in Glass Product	10	40	30	30	10	10	10	10
Stack Emissions (ppmv)	NO	410	470	450	410	230	140	50	NA
	NO_2	42	49	41	30	4.7	1.3	1.4	
	SO_2	1.3	< 0.1	< 0.1	< 0.1	3.7	3.8	9.0	
	CO	140	270	360	320	13	15	6.5	
	NH_3	11	7.7	3.4	< 0.1	440	680	380	
	Acetonitrile	< 0.1	< 0.1	< 0.1	< 0.1	86	140	75	

Table 3.2. Listing of DM10 Glasses Discharged, Masses, and Analysis Performed.

Type Carbon	Test	Sugar Ratio	Date	Sample I.D.	Analysis	Glass (kg)	Cumulative Glass (kg)	SO$_3$ wt%	% Fe^{2+} /Total Fe	I wt%
Sugar	**A1A**	0.50	11/17/03	10G-G-29A	-	3.92	3.92	-	-	-
				10G-G-29B	XRF			0.48	-	0.01
				10G-G-40A	-	4.46	8.38	-	-	-
				10G-G-40B	XRF			0.47	-	0.01
				10G-G-40C	-	4.70	13.08	-	-	-
				10G-G-40D	XRF			0.46	-	0.02
			11/18/03	10G-G-40E	-	4.50	17.58	-	-	-
				10G-G-40F	XRF			0.45	-	0.02
				10G-G-41A	-	4.90	22.48	-	-	-
	A1B	0.75		10G-G-41B	XRF			0.44	-	0.02
				10G-G-45A	-	3.62	26.10	-	-	-
				10G-G-45B	XRF			0.41	-	0.03
				10G-G-45C	-	4.38	30.48	-	-	-
				10G-G-45D	XRF,			0.39	-	0.03
				10G-G-45E	-	4.80	35.28	-	-	-
				10G-G-45F	XRF			0.38	-	0.05
				10G-G-46A	XRF	5.40	40.68	0.38	-	0.04
				10G-G-46B	-	6.10	46.78	-	-	-
	A1C	1.00		10G-G-46C	XRF			0.39	-	0.04
				10G-G-50A	-	5.50	52.28	-	-	-
			11/19/03	10G-G-50B	XRF			0.38	-	0.05
				10G-G-50C	-	3.30	55.58	-	-	-
				10G-G-51A	XRF			0.34	-	0.05
				10G-G-51B	-	3.60	59.18	-	-	-
				10G-G-51C	XRF, Fe^{2+}			0.34	40	0.04
				10G-G-51D	-	3.82	63.00	-	-	-
				10G-G-51E	XRF, Fe^{2+}			0.32	45	0.04
				10G-G-55A	-	4.30	67.30	-	-	-
	A1D	1.25		10G-G-55B	XRF			0.35	-	0.04
				10G-G-55C	-	4.62	71.92	-	-	-
				10G-G-55D	XRF			0.32	-	0.04
				10G-G-57A	-	5.22	77.14	-	-	-
				10G-G-57B	XRF			0.29	-	0.04
				10G-G-57C	-	6.24	83.38	-	-	-
				10G-G-57D	XRF, Fe^{2+}			0.28	47	0.04
				10G-G-60A	-	5.66	89.04	-	-	-
			11/20/03	10G-G-60B	XRF, Fe^{2+}			0.29	55	0.05
				10G-G-60C	-	4.12	93.16	-	-	-
Urea/ Sugar	**A4A**	0.75		10G-G-60D	XRF			0.32	-	0.04
				10G-G-64A	-	4.26	97.42	-	-	-
				10G-G-64B	XRF			0.33	-	0.04

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Table 3.2. Listing of DM10 Glasses Discharged, Masses, and Analysis Performed (continued).

Type Carbon	Test	Sugar Ratio	Date	Sample I.D.	Analysis	Glass (kg)	Cumulative Glass (kg)	SO$_3$ wt%	% Fe^{2+} /Total Fe	I wt%
Urea/Sugar	A4A	0.75	11/20/03	10G-G-64C	-	3.62	101.04	-	-	-
				10G-G-64D	XRF			0.37	-	0.04
				10G-G-64E	-	4.70	105.74	-	-	-
				10G-G-65A	XRF			0.38	-	0.04
				10G-G-65B	-	3.14	108.88	-	-	-
				10G-G-65C	XRF, Fe^{2+}			0.39	3	0.05
	A4B	1.00		10G-G-65D	-	4.92	113.80	-	-	-
				10G-G-69A	XRF			0.38	-	0.04
				10G-G-69B	-	5.24	119.04	-	-	-
				10G-G-69C	XRF			0.37	-	0.04
				10G-G-69D	-	4.00	123.04	-	-	-
			11/21/03	10G-G-69E	XRF			0.37	-	0.04
				10G-G-69F	-	3.26	126.30	-	-	-
				10G-G-70A	XRF			0.34	-	0.04
				10G-G-70B	-	3.68	129.98	-	-	-
				10G-G-70C	XRF, Fe^{2+}			0.34	19	0.04
				10G-G-70D	-	3.24	133.22	-	-	-
	A4C	1.25		10G-G-75A	XRF			0.32	-	0.03
				10G-G-75B	-	3.28	136.50	-	-	-
				10G-G-76A	XRF			0.34	-	0.04
				10G-G-76B	-	4.00	140.50	-	-	-
				10G-G-77A	XRF, Fe^{2+}			0.35	27	0.03
				10G-G-77B	-	4.02	144.52	-	-	-
				10G-G-77C	XRF, Fe^{2+}			0.35	25	0.03
				10G-G-77D	-	3.56	148.08	-	-	-
				10G-G-80A	XRF, Fe^{2+}			0.33	27	0.03
				10G-G-80B	-	3.80	151.88	-	-	-
			11/22/03	10G-G-80C	XRF, Fe^{2+}			0.52	29	0.04
Starch	A2A	0.50	12/1/ 03	10G-G-96A	-	3.26	155.14	-	-	-
				10G-G-96B	XRF			0.43	-	<0.01
				10G-G-96C	-	4.36	159.50	-	-	-
				10G-G-96D	XRF			0.42	-	0.01
				10G-G-96E	-	3.68	163.18	-	-	-
				10G-G-97A	XRF, Fe^{2+}			0.40	< 1	0.01
				10G-G-97B	-	3.62	166.80	-	-	-
				10G-G-97C	XRF			0.42	-	0.01
				10G-G-97D	-	7.10	173.90	-	-	-
				10G-G-97E	XRF, Fe^{2+}			0.40	< 1	0.01
			12/2/ 03	10G-G-100A	-	2.00	175.90	-	-	-
	A2B	0.75		10G-G-100B	XRF			0.42	-	0.01

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Table 3.2. Listing of DM10 Glasses Discharged, Masses, and Analysis Performed (continued).

Type Carbon	Test	Sugar Ratio	Date	Sample I.D.	Glass (kg)	Cumulative Glass (kg)	SO_3 wt%	% Fe^{2+} /Total Fe	I wt%
Starch	A2B	0.75	12/2/03	10G-G-100C	5.06	180.96	-	-	-
				10G-G-100D			0.37	-	0.03
				10G-G-102A	3.24	184.20	-	-	-
				10G-G-102B			0.36	-	0.04
				10G-G-102C	3.96	188.16	-	-	-
				10G-G-103A			0.36	-	0.04
				10G-G-103B	3.47	191.63	-	-	-
				10G-G-103C			0.37	-	0.04
				10G-G-103D	3.74	195.37	-	-	-
				10G-G-103E			0.38	8	0.04
	A2C	1.00		10G-G-106A	3.74	199.11	-	-	-
				10G-G-106B			0.36	-	0.04
				10G-G-106C	4.20	203.31	-	-	-
				10G-G-106D			0.34	-	0.04
				10G-G-106E	4.06	207.37	-	-	-
				10G-G-106F			0.31	30	0.04
			12/3/03	10G-G-108A	4.50	211.87	-	-	-
				10G-G-108B			0.29	-	0.04
				10G-G-108C	3.50	215.37	-	-	-
				10G-G-108D			0.27	-	0.03
				10G-G-108E	4.20	219.57	-	-	-
				10G-G-108F			0.28	31	0.03
	A2D	1.25		10G-G-113A	4.30	223.87	-	-	-
				10G-G-113B			0.27	-	0.03
				10G-G-113C	4.00	227.87	-	-	-
				10G-G-113D			0.27	-	0.03
				10G-G-113E	4.50	232.37	-	-	-
				10G-G-114A			0.25	-	0.03
				10G-G-114B	4.24	236.61	-	-	-
				10G-G-114C			0.25	-	0.03
				10G-G-114D	4.54	241.15	-	-	-
				10G-G-114E			0.24	37	0.03
Polyethylene glycol	A3A	0.50		10G-G-115A	4.70	245.85	-	-	-
			12/4/03	10G-G-119A			0.28	-	0.03
				10G-G-119B	4.30	250.15	-	-	-
				10G-G-119C			0.34	-	0.02
				10G-G-123A	4.20	254.35	-	-	-
				10G-G-123B			0.35	21	0.01
				10G-G-123C	3.80	258.15	-	-	-
				10G-G-124A			0.36	18	0.01
				10G-G-124B	4.08	262.23	-	-	-
	A3B	0.75		10G-G-124C			39	-	<0.01

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Table 3.2. Listing of DM10 Glasses Discharged, Masses, and Analysis Performed (continued).

Type Carbon	Test	Sugar Ratio	Date	Sample I.D.	Glass (kg)	Cumulative Glass (kg)	SO_3 wt%	% Fe^{2+} /Total Fe	I wt%
Polyethylene glycol	**A3B**	0.75	12/4/03	10G-G-124D	4.18	266.41	-	-	-
				10G-G-125A			0.42	-	0.01
				10G-G-125B	4.12	270.53	-	-	-
				10G-G-125C			0.45	-	0.01
				10G-G-125D	4.30	274.83	-	-	-
				10G-G-129A			0.42	-	0.01
				10G-G-129B	4.60	279.43	-	-	-
				10G-G-129C			0.40	13	0.01
			12/5/03	10G-G-129D	3.98	283.41	-	-	-
				10G-G-129E			0.40	8	0.01
	A3C	1.00		10G-G-133A	4.50	287.91	-	-	-
				10G-G-133B			0.41	-	0.01
				10G-G-133C	3.92	291.83	-	-	-
				10G-G-134A			0.41	16	<0.01
				10G-G-134B	3.92	295.75	-	-	-
				10G-G-134C			0.44	-	0.01
				10G-G-134D	3.98	299.73	-	-	-
				10G-G-134E			0.44	-	0.01
				10G-G-134F	4.22	303.95	-	-	-
				10G-G-135A			0.43	2	0.01
	A3D	1.25		10G-G-135B	3.92	307.87	-	-	-
				10G-G-135C			0.42	3	<0.01
				10G-G-135D	3.56	311.43	-	-	-
				10G-G-135E			0.42	-	0.01
				10G-G-140A	3.62	315.05	-	-	-
			12/6/03	10G-G-140B			0.39	-	0.01
				10G-G-140C	3.90	318.95	-	-	-
				10G-G-140D			0.40	-	0.01
				10G-G-140E	4.30	323.25	-	-	-
				10G-G-140F			0.38	3	0.01
				10G-G-143A	3.90	327.15	-	-	-
				10G-G-143B			0.40	-	0.01

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Table 4.1. Summary of DM100 Test Conditions and Results.

-			Urea and Sugar Test	Vanadium Additive Test	Starch and Sugar Test
Time	Feed Start		12/10/03 10:15	12/16/03 18:30	1/28/04 9:45
	Feed End		12/12/03 21:31	12/19/03 5:14	1/30/04 13:30
	Water Feeding (hr)		1.0	1.0	1.0
	Net Slurry Feeding (hr)		58.3	57.7	50.8
	Cold Cap Burn-Off (hr)		1.5	4.6	1.7
Carbon	Type (g/ kg feed)	Waste Organics	4.34	4.34	8.95
		Sugar	33.1	33.1	17.2
		Other	Urea: 74.2	0	Starch: 27.4
	Stoichiometric ratio		1.0*	0.5*	0.75$^{\#}$
	Mol. NO_x : Mol. Total Organic Carbon		1: 1.5	1: 0.75	1: 1.13
Feed Used (kg)			942	980	841
Average Production Rate (kg/m^2/day)			1860	1951	1902
Average Bubbling Rate (lpm)			22.1	22.5	16.4
Product	Measured wt% SO_3		0.33	0.39	0.35
	% Feed Sulfur in Glass Product		66	78	70
	% Fe^{+2}/Total Iron		23	3	24
% Feed Sulfur in Particulate Emissions			15.9	14.4	30.4
% Feed Sulfur in Gaseous Emissions			7.6	0.4	13.6
NO_x	NO: NO_2		43	10	35
	% Feed NO_x emitted as NO_x		22.5	55.8	33.5

* - Sugar is at 0.5 stoichiometry.
$^{\#}$ - Sugar is at 0.25 stoichiometry.
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Table 4.2. Summary of Measured DM100 Parameters.

-			**Urea and Sugar Test**			**Vanadium Additive Test**			**Starch and Sugar Test**		
			AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (C)	Electrode	East	1097	1077	1141	1114	1082	1153	1113	1085	1126
		West	1125	1105	1152	1148	1115	1166	1125	1096	1142
		Bottom	884	870	928	936	892	943	887	877	913
	Glass	19” from bottom	1041	374	1110	1031	386	1133	1095	946	1169
		16” from bottom	1127	878	1172	1143	1026	1184	1146	1102	1180
		10” from bottom	1148	1115	1189	1155	1102	1188	1151	1109	1178
		4” from bottom	1160	1125	1204	1124	1075	1159	1151	1115	1169
	Plenum	Exposed	518	136	720	522	286	684	547	377	653
		Thermowell	542	449	711	526	436	628	535	392	638
	Discharge	Chamber	1023	978	1053	1034	976	1056	1017	970	1038
		Air Lift	1098	1006	1144	1115	1011	1189	1094	980	1160
	Film Cooler Outlet		290	249	333	294	272	320	291	266	307
	Transition Line Outlet		278	234	324	287	264	309	291	235	308
Lance Bubbling (lpm)			22.1	1.7	30.5	22.5	1.5	29.3	16.4	3.5	23.8
Melter Pressure (inches water)			-1.44	-4.24	4.10	-1.79	-4.63	2.88	-1.97	-4.86	1.72
Electrode Voltage (V)			43.55	37.46	49.30	44.50	38.98	50.17	41.42	35.23	47.56
Total Power (kW)			18.76	15.80	24.96	21.08	18.43	25.54	20.13	16.90	23.12

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Table 5.1. Listing of DM100 Glasses Discharged, Masses, and Analysis Performed.

Test	Date	Sample I.D.	Analysis	Mass (kg)	Cumulative Mass Per Test (kg)	Cumulative Mass (kg)
Urea and Sugar Test	12/10/03	WVU-G-54A	-	22.44	22.44	22.44
		WVU-G-55A	XRF			
		WVU-G-55B	-	26.50	48.94	48.94
		WVU-G-57A	-			
		WVU-G-57B	XRF			
		WVU-G-59A	-	22.20	71.14	71.14
		WVU-G-59B	XRF			
	12/11/03	WVU-G-62A	-	18.40	89.54	89.54
		WVU-G-62B	XRF			
		WVU-G-64A	-	21.90	111.44	111.44
		WVU-G-64B	XRF			
		WVU-G-64C	-	14.30	125.74	125.74
		WVU-G-65A	XRF			
		WVU-G-65B	-	25.46	151.20	151.20
		WVU-G-65C	-			
		WVU-G-66A	-			
		WVU-G-66B	XRF			
		WVU-G-66C	-	17.20	168.40	168.40
		WVU-G-66D	-			
		WVU-G-66E	-			
		WVU-G-70A	XRF			
		WVU-G-70B	-	30.02	198.42	198.42
		WVU-G-70C	-			
		WVU-G-71A	-			
		WVU-G-71B	XRF			
		WVU-G-73A	-	21.34	219.76	219.76
		WVU-G-73B	-			
		WVU-G-73C	XRF			
		WVU-G-73D	-	24.62	244.38	244.38
		WVU-G-75A	-			
		WVU-G-75B	XRF			
		WVU-G-75C	-	20.98	265.36	265.36
	12/12/03	WVU-G-75D	-			
		WVU-G-79A	XRF			
		WVU-G-79B	-	17.80	283.16	283.16
		WVU-G-79C	-			
		WVU-G-80A	XRF			
		WVU-G-80B	-	27.20	310.36	310.36
		WVU-G-80C	-			
		WVU-G-81A	XRF			
		WVU-G-81B	-	23.60	333.96	333.96
		WVU-G-83A	-			
		WVU-G-84A	XRF			

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Table 5.1. Listing of DM100 Glasses Discharged, Masses, and Analysis Performed (continued).

Test	Date	Sample I.D.	Analysis	Mass (kg)	Cumulative Mass Per Test (kg)	Cumulative Mass (kg)
Urea and Sugar Test	12/12/03	WVU-G-84B	-	27.00	360.96	360.96
		WVU-G-85A	-			
		WVU-G-85B	XRF			
		WVU-G-85C	-	31.45	392.41	392.41
		WVU-G-88A	-			
		WVU-G-88B	XRF			
		WVU-G-88C	-	27.64	420.05	420.05
		WVU-G-88D	-			
		WVU-G-89A	-			
		WVU-G-89B	XRF			
		WVU-G-89C	XRF, DCP	12.70	432.75	432.75
Vanadium Additive Test	12/16/03	WVU-G-130A	-	24.10	24.10	456.85
		WVU-G-130B	XRF, Fe^{2+}			
	12/17/03	WVU-G-140A	-	25.20	49.30	482.05
		WVU-G-140B	XRF			
		WVU-G-140C	-	24.10	73.40	506.15
		WVU-G-141A	XRF, Fe^{2+}			
		WVU-G-141B	-	21.50	94.90	527.65
		WVU-G-141C	XRF			
		WVU-G-143A	-	18.00	112.90	545.65
		WVU-G-146A	XRF			
		WVU-G-146B	-	25.20	138.10	570.85
		WVU-G-146C	-			
		WVU-G-147A	XRF			
		WVU-G-147B	-	23.30	161.40	594.15
		WVU-G-148A	XRF			
		WVU-G-148B	-	21.24	182.64	615.39
		WVU-G-152A	XRF			
		WVU-G-152B	-	23.48	206.12	638.87
		WVU-G-152C	XRF			
		WVU-G-153A	-	22.56	228.68	661.43
		WVU-G-153B	XRF			
	12/18/03	WVV-G-6A	-	21.60	250.28	683.03
		WVV-G-6B	XRF, Fe^{2+}			
		WVV-G-8A	-	20.10	270.38	703.13
		WVV-G-8B	XRF			
		WVV-G-8C	-	11.00	281.38	714.13
		WVV-G-8D	XRF			
		WVV-G-11A	-	22.90	304.28	737.03
		WVV-G-13A	XRF			
		WVV-G-13B	-	21.00	325.28	758.03
		WVV-G-13C	XRF			
		WVV-G-14A	-	25.90	351.18	783.93
		WVV-G-14B	XRF, Fe^{2+}			

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Table 5.1. Listing of DM100 Glasses Discharged, Masses, and Analysis Performed (continued).

Test	Date	Sample I.D.	Analysis	Mass (kg)	Cumulative Mass Per Test (kg)	Cumulative Mass (kg)
Vanadium Additive Test	12/18/03	WVV-G-15A	-	18.1	369.28	802.0
		WVV-G-15B	XRF			
		WVV-G-18A	-	24.4	393.68	826.4
		WVV-G-18B	XRF			
		WVV-G-18C	-	22.14	415.82	848.6
		WVV-G-19A	-			
		WVV-G-19B	XRF. Fe^{2+}			
		WVV-G-19C	-	24.3	440.12	872.9
		WVV-G-19D	-			
		WVV-G-23A	XRF			
	12/19/03	WVV-G-23B	-	27.9	468.02	900.8
		WVV-G-26A	XRF. DCP			
		WVV-G-27A	-	29.3	497.32	930.1
		WVV-G-29A	XRF.			
Starch and Sugar Test	01/28/04	WVV-G-54A	-	23.10	23.10	953.17
		WVV-G-54B	XRF			
		WVV-G-54C	-	19.60	42.70	972.77
		WVV-G-59A	XRF			
		WVV-G-59B	-	27.80	70.50	1000.57
		WVV-G-60A	XRF			
		WVV-G-60B	-	28.40	98.90	1028.97
		WVV-G-61A	XRF			
	01/29/04	WVV-G-65A	-	23.50	122.40	1052.47
		WVV-G-65B	XRF			
		WVV-G-66A	-	26.10	148.50	1078.57
		WVV-G-66B	XRF			
		WVV-G-67A	-	20.20	168.70	1098.77
		WVV-G-67B	XRF			
		WVV-G-67C	-	25.60	194.30	1124.37
		WVV-G-67D	XRF			
		WVV-G-69A	-	33.30	227.60	1157.67
		WVV-G-69B	XRF			
		WVV-G-74A	-	25.28	252.88	1182.95
		WVV-G-74B	XRF			
		WVV-G-75A	-	27.60	280.48	1210.55
		WVV-G-78A	XRF			
		WVV-G-79A	-	26.40	306.88	1236.95
		WVV-G-81A	XRF			
	01/30/04	WVV-G-81B	-	25.40	332.28	1262.35
		WVV-G-82A	XRF			
		WVV-G-82B	-	20.20	352.48	1282.55
		WVV-G-82C	XRF			
		WVV-G-86A		21.80	374.28	1304.35
		WVV-G-86B	XRF			
		WVV-G-86C		28.28	402.56	1332.63
		WVV-G-87A	XRF			
		WVV-G-87B	XRF. DCP	15.70	418.26	1348.33

"-" Empty data cell

Table 5.2. XRF Analyzed Composition for DM100 Discharged Glass Samples (wt%).

-	**Urea and Sugar Test**																
Glass (kg)	-	22.44	48.94	71.14	89.54	111.44	125.74	151.20	168.40	198.42	219.76	244.38	265.36	283.16	310.36	333.96	360.96
Element	Target	WVU-G-55A	WVU-G-57B	WVU-G-59B	WVU-G-62A	WVU-G-64B	WVU-G-65A	WVU-G-66B	WVU-G-70A	WVU-G-71B	WVU-G-73C	WVU-G-75B	WVU-G-79A	WVU-G-80A	WVU-G-81A	WVU-G-84A	WVU-G-85B
Al_2O_3	6.15	6.93	6.53	6.60	6.51	6.26	6.26	6.08	6.09	6.12	6.41	6.12	6.22	6.08	5.99	5.92	5.99
B_2O_3*	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91
CaO	1.99	1.92	1.94	1.89	1.90	1.91	1.85	1.91	1.90	1.89	1.92	1.91	1.91	1.88	1.95	1.94	1.93
CdO	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cl	0.56	0.15	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.28	0.27	0.27	0.28	0.27	0.30	0.30	0.28
Cr_2O_3	0.02	0.19	0.16	0.14	0.13	0.11	0.10	0.10	0.09	0.09	0.08	0.07	0.07	0.07	0.07	0.06	0.07
Cs_2O	0.15	0.04	0.07	0.09	0.10	0.12	0.12	0.13	0.12	0.13	0.14	0.16	0.16	0.16	0.17	0.16	0.16
Fe_2O_3	6.93	6.53	6.67	6.47	6.43	6.46	6.29	6.58	6.55	6.51	6.47	6.66	6.47	6.44	6.82	6.69	6.69
I	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
K_2O	0.45	0.50	0.51	0.50	0.51	0.52	0.50	0.51	0.51	0.52	0.52	0.52	0.51	0.51	0.50	0.52	0.52
MgO	1.99	1.82	1.86	1.76	1.84	1.85	1.83	1.82	1.83	1.80	1.79	1.80	1.78	1.85	1.89	1.77	1.80
Na_2O	20.24	19.63	19.78	20.15	20.29	19.87	20.54	19.77	19.93	19.71	19.92	19.25	20.38	20.05	19.95	19.90	19.56
NiO	§	0.08	0.06	0.05	0.04	0.04	0.03	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
P_2O_5	§	0.11	0.09	0.08	0.08	0.06	0.07	0.06	0.06	0.06	0.07	0.04	0.05	0.04	0.05	0.04	0.04
SeO_2	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SiO_2	44.22	44.97	44.86	44.94	44.88	45.51	45.36	45.51	45.41	45.71	45.21	45.83	45.10	45.61	44.84	45.30	45.62
SO_3	0.50	0.22	0.25	0.27	0.27	0.30	0.29	0.30	0.31	0.32	0.34	0.33	0.32	0.31	0.32	0.34	0.33
TiO_2	1.99	2.14	2.16	2.11	2.10	2.09	2.04	2.13	2.12	2.12	2.13	2.14	2.10	2.06	2.16	2.15	2.15
V_2O_5	§	0.01	0.01	0.01	0.01	<0.01	<0.01	0.01	<0.01	0.01	0.01	0.01	0.01	0.01	<0.01	0.01	0.01
ZnO	2.95	2.76	2.83	2.76	2.74	2.74	2.66	2.80	2.81	2.80	2.77	2.86	2.73	2.72	2.88	2.85	2.83
ZrO_2	2.97	3.11	3.13	3.05	3.04	3.03	2.90	3.11	3.08	3.02	3.03	3.13	3.00	3.04	3.20	3.15	3.13
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

§ - Not a target constituent
*Target value
"-" Empty data field

Table 5.2. XRF Analyzed Composition for DM100 Discharged Glass Samples (wt%) (continued).

-	**Urea and Sugar Test**						**Vanadium Additive Test**								
Glass (kg)	-	392.41	420.05	432.75	(360-440kg)		-	456.85	482.05	506.15	527.65	545.65	570.85	594.15	615.39
Constituent	Target	WVU-G-88B	WVU-G-89B	WVU-G-89C	Avg.	%Dev.	Target	WVU-G-130B	WVU-G-140B	WVU-G-141A	WVU-G-141C	WVU-G-146A	WVU-G-147A	WVU-G-148A	WVU-G-152A
Al_2O_3	6.15	5.90	5.97	5.91	5.94	-3.38	6.15	6.14	6.17	6.09	6.04	5.98	5.96	5.88	5.74
B_2O_3*	8.91	8.91	8.91	8.91	NC	NC	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91
CaO	1.99	1.94	1.94	1.94	1.94	-2.76	1.99	1.94	1.92	1.91	1.89	1.89	1.87	1.93	1.91
CdO	§	<0.01	<0.01	<0.01	<0.01	NC	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cl	0.56	0.29	0.30	0.28	0.29	NC	0.56	0.18	0.21	0.20	0.21	0.22	0.20	0.22	0.23
Cr_2O_3	0.02	0.06	0.06	0.07	0.07	NC	0.02	0.08	0.08	0.09	0.09	0.10	0.10	0.11	0.11
Cs_2O	0.15	0.17	0.16	0.16	0.16	NC	0.15	0.14	0.15	0.14	0.16	0.17	0.15	0.16	0.16
Fe_2O_3	6.93	6.73	6.80	7.02	6.81	-1.75	6.93	6.86	6.59	6.68	6.76	6.87	7.00	7.27	7.36
I	§	<0.01	<0.01	<0.01	<0.01	NC	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
K_2O	0.45	0.52	0.52	0.52	0.52	NC	0.45	0.51	0.50	0.54	0.54	0.53	0.52	0.50	0.49
MgO	1.99	1.75	1.76	1.76	1.77	-11.21	1.99	1.81	1.82	1.92	1.88	1.94	2.00	1.92	1.83
Na2O	20.24	19.83	19.74	19.29	19.60	-3.14	20.24	19.52	20.14	19.75	19.59	19.38	19.06	18.31	18.64
NiO	§	<0.01	<0.01	<0.01	<0.01	NC	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P2O5	§	0.03	0.04	0.04	0.04	NC	§	0.02	0.03	0.03	0.03	0.02	<0.01	<0.01	0.02
SeO2	§	<0.01	<0.01	<0.01	<0.01	NC	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SiO2	44.22	45.38	45.27	45.31	45.40	2.66	44.22	45.16	45.07	45.22	45.26	45.21	45.27	45.44	45.18
SO3	0.50	0.33	0.33	0.32	0.33	NC	0.50	0.31	0.35	0.35	0.33	0.34	0.33	0.33	0.33
TiO2	1.99	2.14	2.16	2.19	2.16	8.40	§	1.92	1.62	1.37	1.22	1.10	0.92	0.81	0.67
V2O5	§	0.01	<0.01	<0.01	<0.01	NC	1.99	0.32	0.62	0.90	1.08	1.25	1.43	1.64	1.76
ZnO	2.95	2.85	2.86	2.97	2.88	-2.45	2.95	2.91	2.76	2.79	2.83	2.86	2.96	3.10	3.14
ZrO2	2.97	3.16	3.18	3.31	3.20	7.59	2.97	3.25	3.06	3.10	3.17	3.23	3.32	3.47	3.52
Sum	100.00	100.00	100.00	100.00	NC	NC	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

§ - Not a target constituent

*Target value

"-" Empty data field

NC – Not calculated

Table 5.2. XRF Analyzed Composition for DM100 Discharged Glass Samples (wt%) (continued).

Test	Vanadium Additive Test																
Glass (kg)	-	615.39	638.87	661.43	683.03	703.13	714.13	737.03	783.93	802.03	826.43	848.57	872.87	900.77	930.07	(816-935kg)	
Constituent	Target	WVU-G-152A	WVU-G-152C	WVU-G-153B	WVV-G-6B	WVV-G-6D	WVV-G-8B	WVV-G-13A	WVV-G-14B	WVV-G-15B	WVV-G-18B	WVV-G-19B	WVV-G-23A	WVV-G-26A	WVV-G-29A	Avg.	%Dev
Al_2O_3	6.15	5.74	5.89	5.84	6.21	6.21	6.04	6.04	5.92	6.03	6.08	6.01	5.99	5.92	6.02	6.00	-2.38
B_2O_3*	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	NC	NC
CaO	1.99	1.91	1.88	1.88	1.90	1.88	1.86	1.86	1.89	1.86	1.89	1.89	1.91	1.88	1.90	1.90	-4.65
CdO	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
Cl	0.56	0.23	0.23	0.25	0.27	0.27	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.28	0.25	0.27	NC
Cr_2O_3	0.02	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.14	0.13	0.14	0.16	0.14	NC
Cs_2O	0.15	0.16	0.16	0.17	0.17	0.17	0.16	0.16	0.15	0.16	0.16	0.15	0.15	0.15	0.17	0.15	NC
Fe_2O_3	6.93	7.36	7.16	7.14	6.82	6.69	6.69	6.75	6.96	6.80	6.71	6.77	6.89	6.70	7.13	6.84	-1.27
I	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
K_2O	0.45	0.49	0.51	0.51	0.51	0.53	0.50	0.52	0.52	0.51	0.49	0.49	0.49	0.48	0.48	0.49	NC
MgO	1.99	1.83	1.93	1.93	1.98	2.09	2.12	2.03	2.01	2.02	2.04	1.97	1.86	1.95	1.74	1.91	-3.96
Na_2O	20.24	18.64	18.60	18.76	19.05	19.00	19.66	19.57	18.96	19.63	19.37	19.43	19.63	19.69	18.97	19.42	-4.06
NiO	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
P_2O_5	§	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.03	NC
SeO_2	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
SiO_2	44.22	45.18	45.51	45.30	45.29	45.54	45.14	45.16	45.42	45.00	45.43	45.36	44.99	45.46	45.08	45.26	2.36
SO_3	0.50	0.33	0.34	0.34	0.38	0.40	0.39	0.38	0.38	0.39	0.39	0.39	0.39	0.40	0.37	0.39	NC
TiO_2	§	0.67	0.58	0.49	0.42	0.35	0.38	0.30	0.23	0.20	0.18	0.16	0.15	0.13	0.12	0.15	NC
V_2O_5	1.99	1.76	1.80	1.90	1.91	1.94	1.92	2.00	2.12	2.08	2.06	2.04	2.07	2.01	2.09	2.05	3.18
ZnO	2.95	3.14	3.01	3.03	2.85	2.79	2.76	2.79	2.90	2.84	2.81	2.85	2.93	2.83	3.14	2.91	-1.33
ZrO_2	2.97	3.52	3.33	3.40	3.17	3.08	3.05	3.12	3.20	3.13	3.05	3.13	3.21	3.04	3.45	3.18	6.99
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	NC	NC

§ - Not a target constituent
*Target value
"-" Empty data cell
NC – Not calculated

Table 5.2. XRF Analyzed Composition for DM100 Discharged Glass Samples (wt%) (continued).

-	Starch and Sugar Test												
Glass (kg)	-	953.17	972.77	1000.57	1028.97	1052.47	1078.57	1098.77	1124.37	1157.67	1182.95	1210.55	1236.95
Constituent	Target	WVV-G-54B	WVV-G-59A	WVV-G-60A	WVV-G-61A	WVV-G-65B	WVV-G-66B	WVV-G-67B	WVV-G-67D	WVV-G-69B	WVV-G-74B	WVV-G-78A	WVV-G-81A
Al_2O_3	6.13	6.13	6.14	6.17	6.24	6.25	6.20	6.08	6.30	6.18	6.03	6.71	5.97
B_2O_3*	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91
CaO	1.97	1.91	1.92	1.88	1.83	1.87	1.85	1.87	1.85	1.84	1.80	1.80	1.86
CdO	0.10	<0.01	0.05	0.06	0.07	0.08	0.08	0.09	0.08	0.09	0.08	0.09	0.08
Cl	0.56	0.14	0.19	0.21	0.25	0.25	0.25	0.28	0.28	0.27	0.26	0.26	0.27
Cr_2O_3	0.02	0.14	0.13	0.12	0.10	0.10	0.10	0.09	0.09	0.08	0.07	0.07	0.07
Cs_2O	0.14	0.13	0.14	0.15	0.14	0.14	0.15	0.16	0.13	0.15	0.14	0.15	0.13
F	0.02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	6.91	6.74	6.80	6.73	6.41	6.77	6.65	6.77	6.53	6.60	6.28	6.47	6.52
I	0.10	0.01	0.02	0.04	0.04	0.04	0.04	0.05	0.04	0.05	0.04	0.05	0.04
K_2O	0.44	0.51	0.53	0.52	0.51	0.53	0.52	0.52	0.55	0.53	0.50	0.58	0.51
MgO	1.97	1.87	1.87	1.90	1.84	1.86	1.84	1.86	1.87	1.87	1.86	1.86	1.93
Na_2O	20.07	20.21	19.44	19.54	20.43	20.07	19.82	20.23	20.09	19.96	20.59	20.21	20.14
NiO	<0.01	0.03	0.03	0.02	0.01	0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P_2O_5	0.07	0.06	0.07	0.08	0.07	0.08	0.07	0.08	0.09	0.09	0.09	0.09	0.10
SeO_2	0.10	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02
SiO_2	44.13	44.94	45.45	45.42	45.40	44.85	45.42	44.79	45.35	45.39	45.82	44.98	45.64
SO_3	0.5	0.36	0.37	0.38	0.37	0.36	0.35	0.36	0.36	0.36	0.35	0.33	0.34
TiO_2	1.97	1.60	1.64	1.68	1.67	1.77	1.74	1.83	1.82	1.84	1.81	1.84	1.89
V_2O_5	§	0.48	0.43	0.37	0.29	0.25	0.27	0.19	0.16	0.13	0.10	0.08	0.08
ZnO	2.94	2.76	2.77	2.76	2.59	2.74	2.69	2.75	2.63	2.68	2.50	2.60	2.63
ZrO_2	2.96	3.06	3.09	3.04	2.83	3.04	3.00	3.04	2.85	2.96	2.73	2.90	2.87
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

§ - Not a target constituent

*Target value

"-" Empty data cell; NA – Not analyzed

Table 5.2. XRF Analyzed Composition for DM100 Discharged Glass Samples (wt%) (continued).

-	Starch and Sugar Test						
Glass (kg)	-	1282.55	1304.35	1332.63	1348.33	(1305-1350kg)	
Element	Target	WVV-G-82C	WVV-G-86B	WVV-G-87A	WVV-G-87B	Avg.	%dev
Al_2O_3	6.13	6.39	6.19	6.14	6.18	6.16	0.49
B_2O_3*	8.91	8.91	8.91	8.91	8.91	NC	NC
CaO	1.97	1.85	1.84	1.87	1.83	1.85	-6.29
CdO	0.10	0.09	0.09	0.09	0.09	0.09	NC
Cl	0.56	0.27	0.27	0.27	0.29	0.28	NC
Cr_2O_3	0.02	0.06	0.06	0.07	0.06	0.07	NC
Cs_2O	0.14	0.15	0.16	0.14	0.15	0.15	NC
F	0.02	NA	NA	NA	NA	NC	NC
Fe_2O_3	6.91	6.82	6.62	6.75	6.70	6.72	-2.70
I	0.10	0.05	0.04	0.04	0.04	0.04	NC
K_2O	0.44	0.53	0.54	0.54	0.54	0.54	NC
MgO	1.97	1.86	1.93	1.91	1.93	1.92	-2.65
Na_2O	20.07	19.62	19.64	19.64	19.86	19.75	-1.60
NiO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
P_2O_5	0.07	0.09	0.10	0.10	0.10	0.10	NC
SeO_2	0.10	0.02	0.02	0.02	0.02	0.02	NC
SiO_2	44.13	45.11	45.68	45.41	45.28	45.35	2.76
SO_3	0.50	0.32	0.36	0.35	0.35	0.35	NC
TiO_2	1.97	1.92	1.90	1.93	1.93	1.93	-1.84
V_2O_5	§	0.06	0.05	0.05	0.04	0.04	NC
ZnO	2.94	2.76	2.65	2.71	2.69	2.70	-8.23
ZrO_2	2.96	3.12	2.95	3.05	3.00	3.03	2.31
Sum	100.00	100.00	100.00	100.00	100.00	NC	NC

§ - Not a target constituent
*Target value
"-" Empty data cell
NA – Not analyzed
NC – Not calculated

Table 5.3. Comparison of XRF and DCP Analysis of Melter Glass Samples (wt%).

-	**Urea and Sugar Test**			**Vanadium Additive Test**		
	Target	WVU-G-89C		Target	WVV-G-26A	
		XRF	DCP		XRF	DCP
Al_2O_3	6.15	5.91	5.87	6.15	5.92	6.09
B_2O_3	8.91	8.91*	8.98	8.91	8.91*	9.13
CaO	1.99	1.94	1.81	1.99	1.88	1.86
Cl	0.56	0.28	NA	0.56	0.28	NA
Cr_2O_3	0.02	0.07	0.06	0.02	0.14	0.13
Cs_2O	0.15	0.16	NA	0.15	0.15	NA
Fe_2O_3	6.93	7.02	6.47	6.93	6.70	6.71
K_2O	0.45	0.52	0.55	0.45	0.48	0.54
MgO	1.99	1.76	1.80	1.99	1.95	1.94
Na_2O	20.24	19.29	18.25	20.24	19.69	18.59
NiO	§	<0.01	0.02	§	<0.01	0.03
P_2O_5	§	0.04	0.04	§	0.02	<0.01
SiO_2	44.22	45.31	44.35	44.22	45.46	45.18
$SO_3^{\#}$	0.5	0.32	0.11	0.50	0.40	0.50
TiO_2	1.99	2.19	2.16	§	0.13	0.16
V_2O_5	§	<0.01	0.01	1.99	2.01	1.86
ZnO	2.95	2.97	2.81	2.95	2.83	2.90
ZrO_2	2.97	3.31	2.83	2.97	3.04	2.88
Sum	100.00	100.00	96.11	100.00	100.00	98.50

* Target values
# SO_3 measured by IC
"-" Empty data cell
§ - Not a target constituent
NA – Not analyzed

Table 5.4. XRF Analyzed Glass Compositions for DM100 Dip Samples (wt%).

-	**Urea and Sugar Test**				**Vanadium Additive Test**			**Starch and Sugar Test**		
Glass (kg)	-	0.00	432.75	432.75	-	432.75	930.07	-	930.07	1348.33
Date	-	12/10/03	12/12/03	12/15/03	-	2/16/04	12/19/03	-	1/27/04	1/30/04
Constituent	Target	WVU-D-42A	WVU-D-89A	WVU-D-97A	Target	WVU-D-121A	WVV-D-35A	Target	WVV-D-45A	WVV-D-93A
Al_2O_3	6.15	6.55	6.00	6.13	6.15	6.12	6.00	6.13	6.44	6.08
B_2O_3*	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91	8.91
CaO	1.99	1.92	1.94	1.88	1.99	1.91	1.87	1.97	1.89	1.85
CdO	§	<0.01	<0.01	<0.01	§	<0.01	<0.01	0.10	<0.01	0.09
Cl	0.56	0.12	0.28	0.18	0.56	0.18	0.25	0.56	0.15	0.27
Cr_2O_3	0.02	0.24	0.07	0.08	0.02	0.09	0.16	0.02	0.14	0.07
Cs_2O	0.15	0.01	0.17	0.17	0.15	0.13	0.16	0.14	0.11	0.16
F	§	NA	NA	NA	§	NA	NA	0.02	NA	NA
Fe_2O_3	6.93	6.61	7.15	6.86	6.93	6.62	7.00	6.91	6.63	6.86
I	§	<0.01	<0.01	<0.01	§	<0.01	<0.01	0.10	0.01	0.05
K_2O	0.45	0.51	0.52	0.50	0.45	0.50	0.48	0.44	0.54	0.52
MgO	1.99	1.87	1.69	1.73	1.99	1.79	1.76	1.97	1.82	1.91
Na_2O	20.24	19.63	18.12	18.78	20.24	20.30	18.67	20.07	19.50	20.27
NiO	§	0.09	<0.01	<0.01	§	0.00	<0.01	<0.01	0.03	<0.01
P_2O_5	§	0.10	0.03	0.03	§	0.03	0.02	0.07	0.06	0.09
SeO_2	§	<0.01	<0.01	<.01	§	<0.01	<0.01	0.10	0.01	0.03
SiO_2	44.22	45.23	45.97	46.09	44.22	45.08	45.69	44.13	45.59	44.60
SO_3	0.50	0.21	0.32	0.31	0.50	0.31	0.37	0.50	0.40	0.34
TiO_2	1.99	2.14	2.20	2.12	§	2.11	0.13	1.97	1.55	1.94
V_2O_5	§	<0.01	0.01	0.01	1.99	0.01	2.04	§	0.53	0.05
ZnO	2.95	2.80	3.19	2.92	2.95	2.85	3.13	2.94	2.71	2.81
ZrO_2	2.97	3.07	3.42	3.29	2.97	3.06	3.35	2.96	2.99	3.13
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sulfate Present?	-	No	No	No	-	No	No	-	No	No

* Target value
§ Not a target constituent
"-" Empty data field
NA – Not Analyzed

Table 5.5. Glass Redox for Selected Glass Samples.

-	Sampling Date	Cumulative Glass (kg)	Sample Name	%Fe^{2+} /Total Fe
Urea and Sugar Test	12/11/03	111.44	WVU-G-64B	18
	12/12/03	333.96	WVU-G-84A	25
		420.05	WVU-G-89B	25
Vanadium Additive Test	12/16/03	456.85	WVU-G-130B	5
		506.15	WVU-G-141A	2
	12/18/03	683.08	WVV-G-6B	1
		848.57	WVV-G-19B	3
Starch and Sugar Test	1/28/04	972.77	WVV-G-59A	28
		1028.97	WVV-G-61A	22
	01/29/04	1052.47	WVV-G-65B	20
		1078.57	WVV-G-66B	29
		1182.95	WVV-G-74B	18
	1/30/04	1262.35	WVV-G-82A	24

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

-		Urea and Sugar Test				Vanadium Additive Test			
Sampling Interval		12/12/03 10:25 – 11:25, 95.2% Isokinetic				12/18/03 17:49 – 18:49, 100.7 % Isokinetic			
Moisture		9.9 %				17.3%			
-		Feed Rate (mg/min)	Emissions Rate (mg/min)	% of Feed	DF	Feed Rate (mg/min)	Emissions Rate (mg/min)	% of Feed	DF
Particulate	Total$^{\$}$	173600	1400	0.81	124	158300	1067	0.67	148
	Al	4736	19.71	0.42	240	4317	9.50	0.22	454
	B	4025	37.57	0.93	107	3669	19.75	0.54	186
	Ca	2071	6.43	0.31	322	1888	2.94	0.16	643
	Cl*	815	342.60	42.04	2.4	743	410.08	55.19	1.8
	Cr	20	0.58	2.93	34.1	18	2.07	11.41	8.8
	Cs	206	45.82	22.25	4.5	188	40.55	21.60	4.6
	F*	0	6.02	NC	NC	0	4.80	NC	NC
	Fe	7054	12.53	0.18	563	6430	5.12	0.08	1255
	K	544	28.85	5.31	18.8	496	24.64	4.97	20.1
	Mg	1747	0.59	0.03	2970	1592	0.26	0.02	6189
	Na	21859	324.23	1.48	67.4	19927	274.84	1.38	72.5
	P	0	0.33	NC	NC	0	0.30	NC	NC
	S*	292	46.82	16.03	6.24	266	37.91	14.25	7.02
	Si	30091	57.69	0.19	522	27431	20.92	0.08	1311
	Ti	1737	8.78	0.51	198	0	< 0.10	NC	NC
	V	0	NA	NA	NA	1479	8.32	0.56	178
	Zn	3450	17.69	0.51	195	3145	8.88	0.28	354
	Zr	3201	2.23	0.07	1436	2918	1.01	0.03	2879
Gas	B	4025	14.87	0.37	271	3669	15.41	0.42	238
	Cl	815	< 0.10	< 0.01	> 8150	743	0.50	0.07	1482
	F	0	< 0.10	NC	NC	0	< 0.10	NC	NC
	S	292	22.03	7.55	13.2	266	0.97	0.36	275

$ - From gravimetric analysis of filters and front-half nitric acid analytical results
NA – Not Analyzed
NC – Not Calculated
* - From water dissolution of filter particulate
"-" Empty data field

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

-		Starch and Sugar Test			
Sampling Interval		01/29/04 16:51 – 17:51, 98.9% Isokinetic			
Moisture		10.2%			
-		Feed Rate (mg/min)	Emissions Rate (mg/min)	% of Feed	DF
Particulate	Total$^{\$}$	182900	3511	1.92	52.1
	Al	4914	48.41	0.99	102
	B	4190	40.68	0.97	103
	Ca	2134	22.74	1.07	93.9
	Cd	136	40.80	30.07	3.3
	Cl*	849	401.07	47.24	2.12
	Cr	21	1.01	4.86	20.6
	Cs	200	47.03	23.50	4.3
	F*	30	71.29	238	NC
	Fe	7322	112.96	1.54	64.8
	I*	152	25.54	16.80	6.0
	K	553	39.79	7.19	13.9
	Mg	1800	1.16	0.06	1549
	Na	22564	598.47	2.65	37.7
	P	46	2.02	4.36	22.9
	S*	304	92.67	30.48	3.28
	Se	108	69.82	64.75	1.5
	Si	31260	179.45	0.57	174
	Ti	1790	42.61	2.38	42.0
	Zn	3579	76.05	2.12	47.1
	Zr	3321	7.01	0.21	473
Gas	B	4190	4.53	0.11	925
	Cl	849	< 0.10	< 0.01	> 8490
	F	30	< 0.10	< 0.01	> 300
	I	152	40.64	26.74	3.74
	S	304	41.13	13.55	7.4
	Se	108	< 1.00	< 1.00	> 108

$ - From gravimetric analysis of filters and front-half nitric acid analytical results
NA – Not Analyzed
NC – Not Calculated
* - From water dissolution of filter particulate
"-" Empty data field

Table 6.2. Average Concentration (ppmv) of Selected Species in Off-Gas Measured by FTIR Spectroscopy during DM100 Tests.

-	Urea and Sugar Test	Vanadium Additive Test	Starch and Sugar Test
	12/10/03 – 12/12/03	**12/16/03 – 12/19/03**	**01/28/04 – 01/30/04**
N_2O	79	110	120
NO	300	1100	560
NO_2	7.0	110	16
NH_3	1700	68	190
H_2O%	4.7	4.9	4.2
CO_2	3300	2100	3000
HNO_2	< 1.0	< 1.0	< 1.0
HNO_3	< 1.0	< 1.0	< 1.0
HCN	< 1.0	< 1.0	< 1.0
SO_2	< 1.0	1.2	< 1.0
Acetonitrile	< 1.0	< 1.0	13
Acrylonitrile	< 1.0	< 1.0	< 1.0
CO	41	32	72
HCl	< 1.0	< 1.0	< 1.0
HF	< 1.0	< 1.0	< 1.0
H_2^*	24	46	17

* Value determined by gas chromatography
"-" Empty data field

Table 6.3. Concentration Ranges (ppmv) of Selected Species in Off-Gas Measured by FTIR Spectroscopy during DM100 Tests.

-	**Urea and Sugar Test**	**Vanadium Additive Test**	**Starch and Sugar Test**
	12/10/03 – 12/12/03	**12/16/03 – 12/19/03**	**01/28/04 – 01/30/04**
N_2O	< 1.0 – 260	< 1.0 – 400	10 – 240
NO	13 – 1100	17 – 3000	56 – 1100
NO_2	< 1.0 – 98	< 1.0 – 560	< 1.0 – 46
NH_3	52 – 4000	2.8 – 340	9.2 – 450
H_2O%	0.8 – 9.0	0.4 – 10	0.7 – 7.5
CO_2	500 – 8500	400 – 6200	800 – 5100
HNO_2	< 1.0	< 1.0 – 2.9	< 1.0
HNO_3	< 1.0	< 1.0	< 1.0
HCN	< 1.0 – 2.1	< 1.0	< 1.0
SO_2	< 1.0 – 7.0	< 1.0 – 7.0	< 1.0
Acetonitrile	< 1.0	< 1.0	< 1.0 – 38
Acrylonitrile	< 1.0	< 1.0	< 1.0
CO	< 1.0 – 110	< 1.0 – 120	< 1.0 – 150
HCl	< 1.0	< 1.0	< 1.0
HF	< 1.0	< 1.0	< 1.0

"-" Empty data cell

Table 6.4. Average NOx Fluxes in Off-Gas Measured by FTIR Spectroscopy.

-	Feed [mol/hr]	Emissions [mol/h]			% Feed NO_x Emitted as Nitrogen Oxides
		N_2O [mol/hr]	NO [mol/hr]	NO_2 [mol/hr]	
Urea and Sugar Test	26.2	1.0	4.8	0.1	22.5
Vanadium Additive Test	27.6	1.3	12.8	1.3	55.8
Starch and Sugar Test	26.6	1.5	7.2	0.2	33.5

"-" Empty data field

Table 6.5. Mass Balance for Sulfur, Iodine, and Selenium During DM100 Tests with LAW Sub-Envelope A1 Simulants (% of Feed).

Test	Stoichiometric Ratio	Element	Glass	Particle Emissions	Gaseous Emissions	Total
Urea and Sugar Test	0.5 Urea + 0.5 Sugar	Chlorine	51	42	< 0.1	93
		Sulfur	66	16	7.55	90
Vanadium Additive Test	0.5 Sugar	Chlorine	47	55	< 0.1	102
		Sulfur	78	14	0.4	92
Starch and Sugar Test	0.5 Starch + 0.25 Sugar	Chlorine	50	47	< 0.1	97
		Sulfur	70	30	13.6	114
		Iodine	40	17	27	84
		Selenium	20	65	< 0.1	85
@ 1175°C (SO_3 = 0.23 wt%) [31]	0.5 Sugar	Chlorine	75	42	< 0.1	117
		Sulfur	91	9.2	0.4	101
@ 1225°C (SO_3 = 0.23 wt%) [31]	0.5 Sugar	Chlorine	66	61	< 0.1	127
		Sulfur	81	19	0.6	100
+15% Simulant (SO_3 = 0.26 wt%) [7]	0.44 Sugar	Chlorine	53	83	1.0	137
		Sulfur	96	12	< 0.1	108
-15% Simulant (SO_3 = 0.22 wt%) [7]	0.57 Sugar	Chlorine	63	30	0.1	93
		Sulfur	86	16	0.1	102
(SO_3 = 0.19 wt%) [27]	0.5 Sugar	Chlorine	56	43	0.1	99
		Sulfur	95	14	< 0.1	109
		Iodine	20	< 0.1	73	93

"-" Empty data field

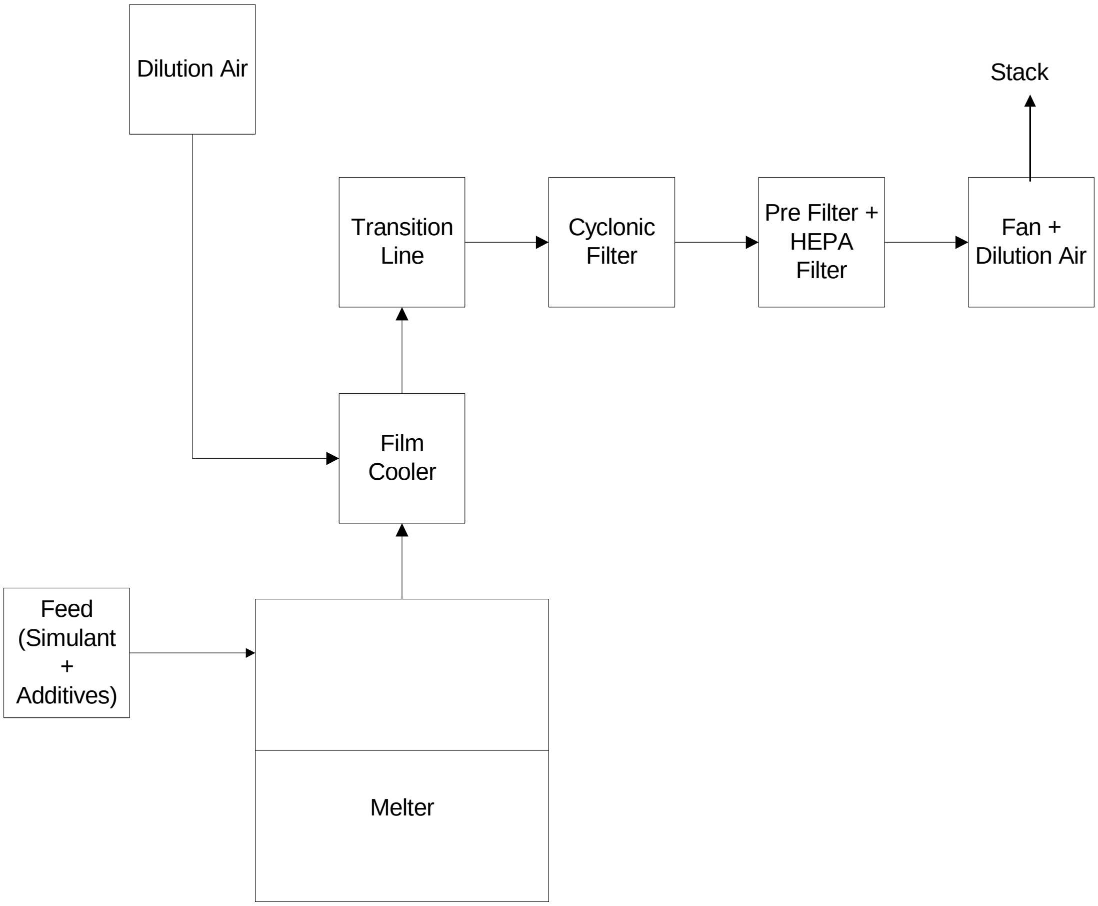

Figure 1.1. Schematic diagram of DuraMelter 100-WV vitrification system.

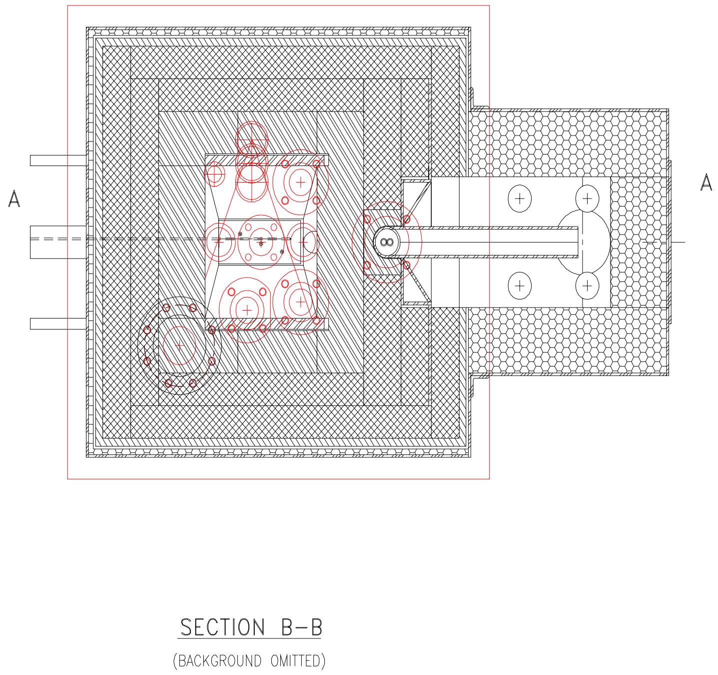

Figure 1.2(a). Cross-section through the DM100-WV melter—Plan View.

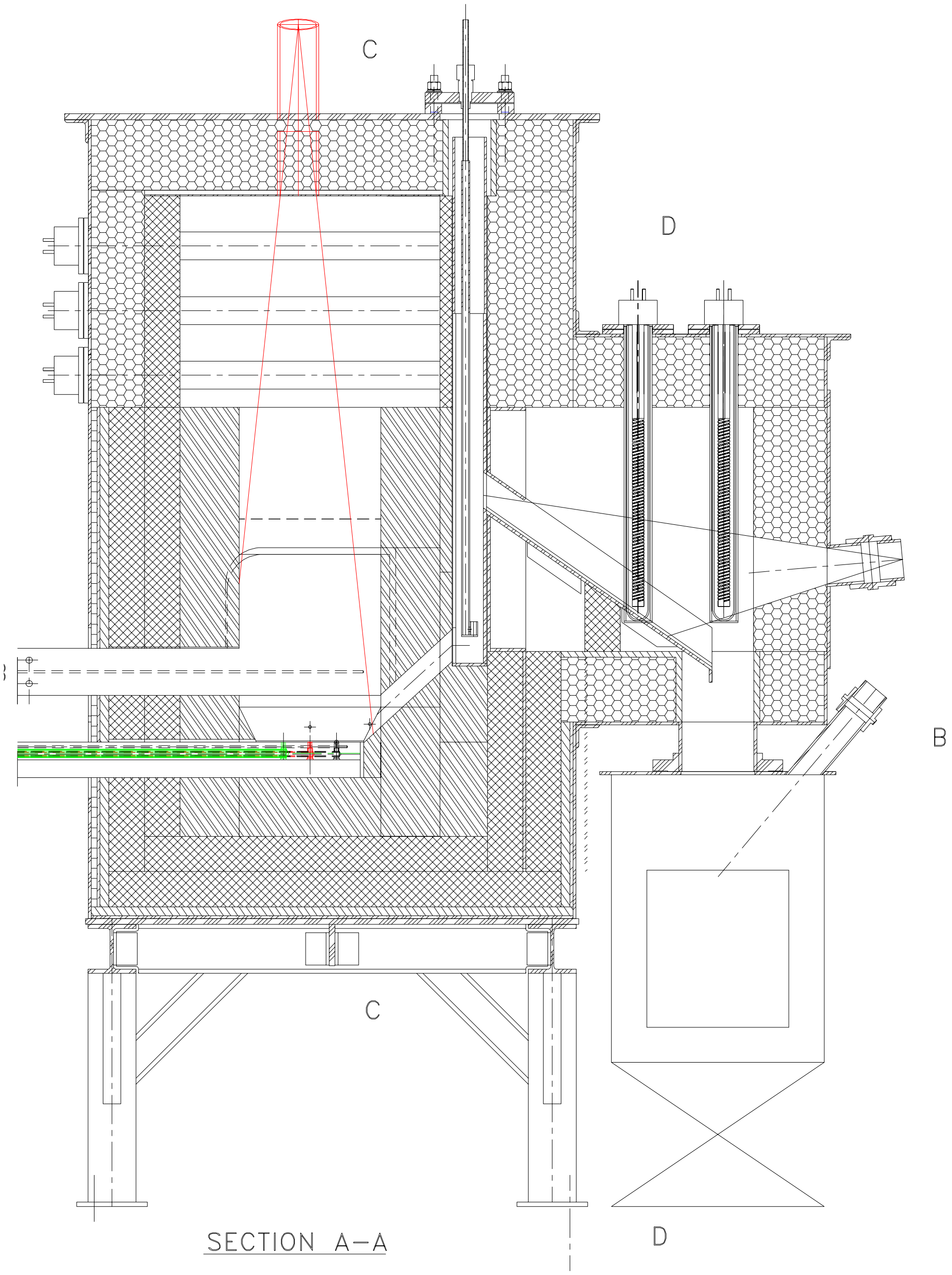

Figure 1.2(b). Cross-section through the DM100-WV melter—Section AA.

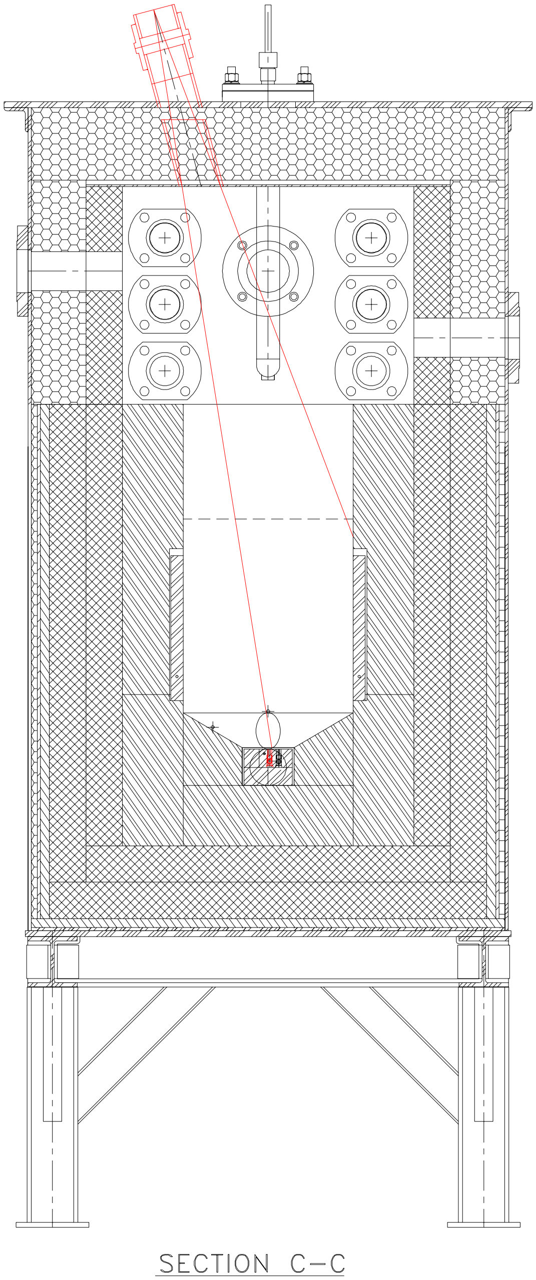

Figure 1.2(c). Cross-section through the DM100-WV melter—Section CC.

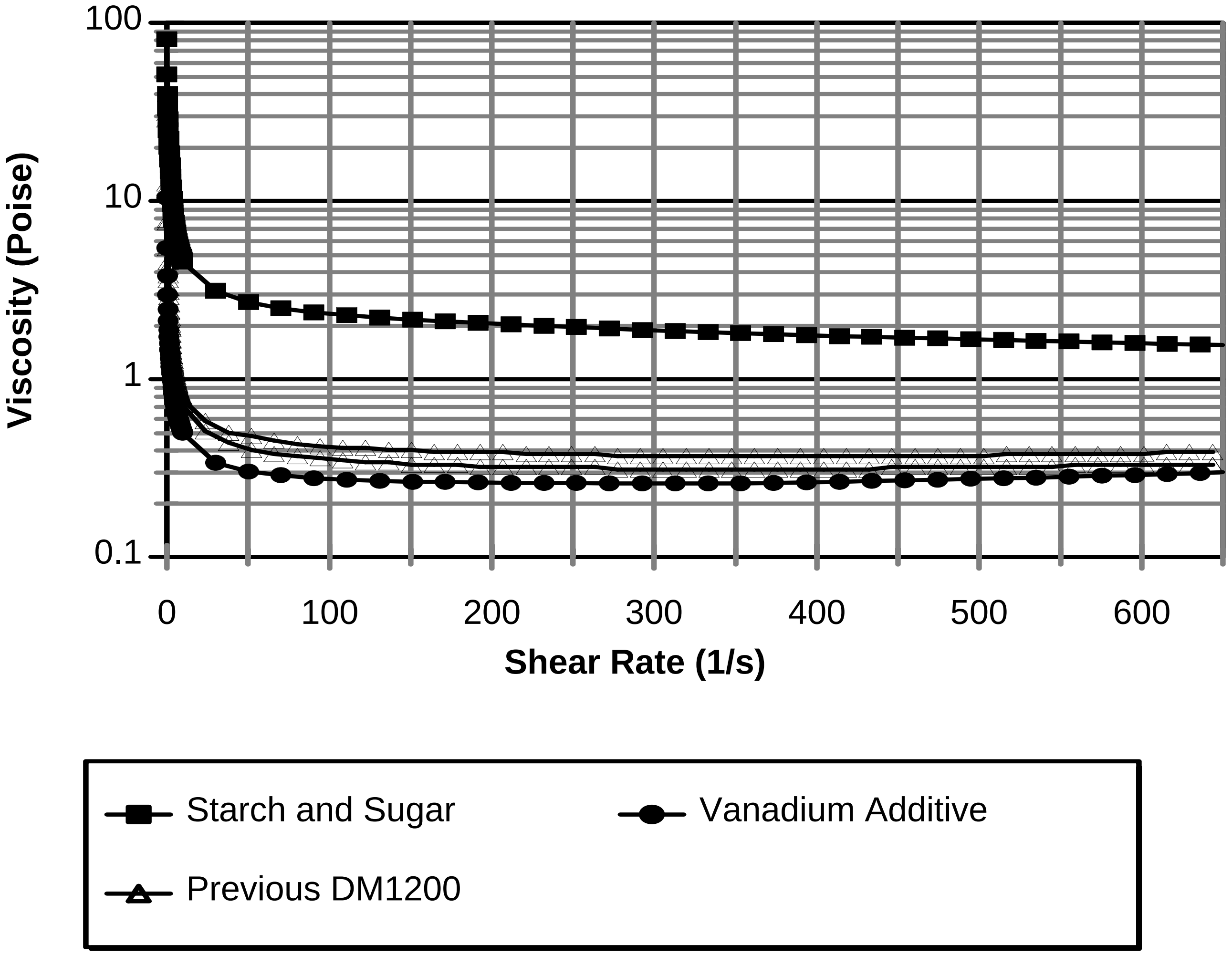

Figure 2.1. Measured viscosity of LAW A melter feed samples.

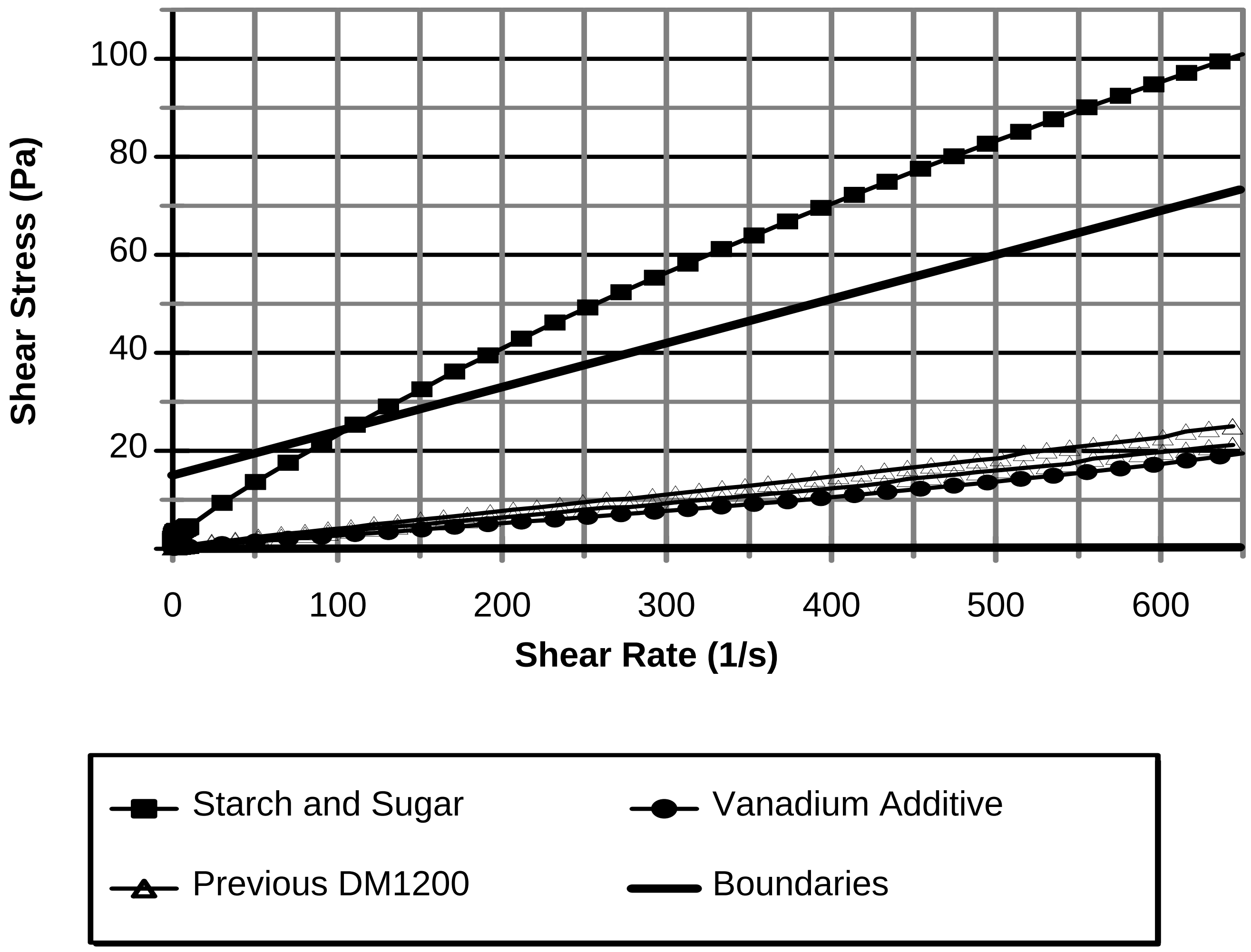

Figure 2.2. Comparison of measured feed rheology with proposed WTP bounds (bounds from WTP-RPT-075, Rev. 0, Feb. 2003).

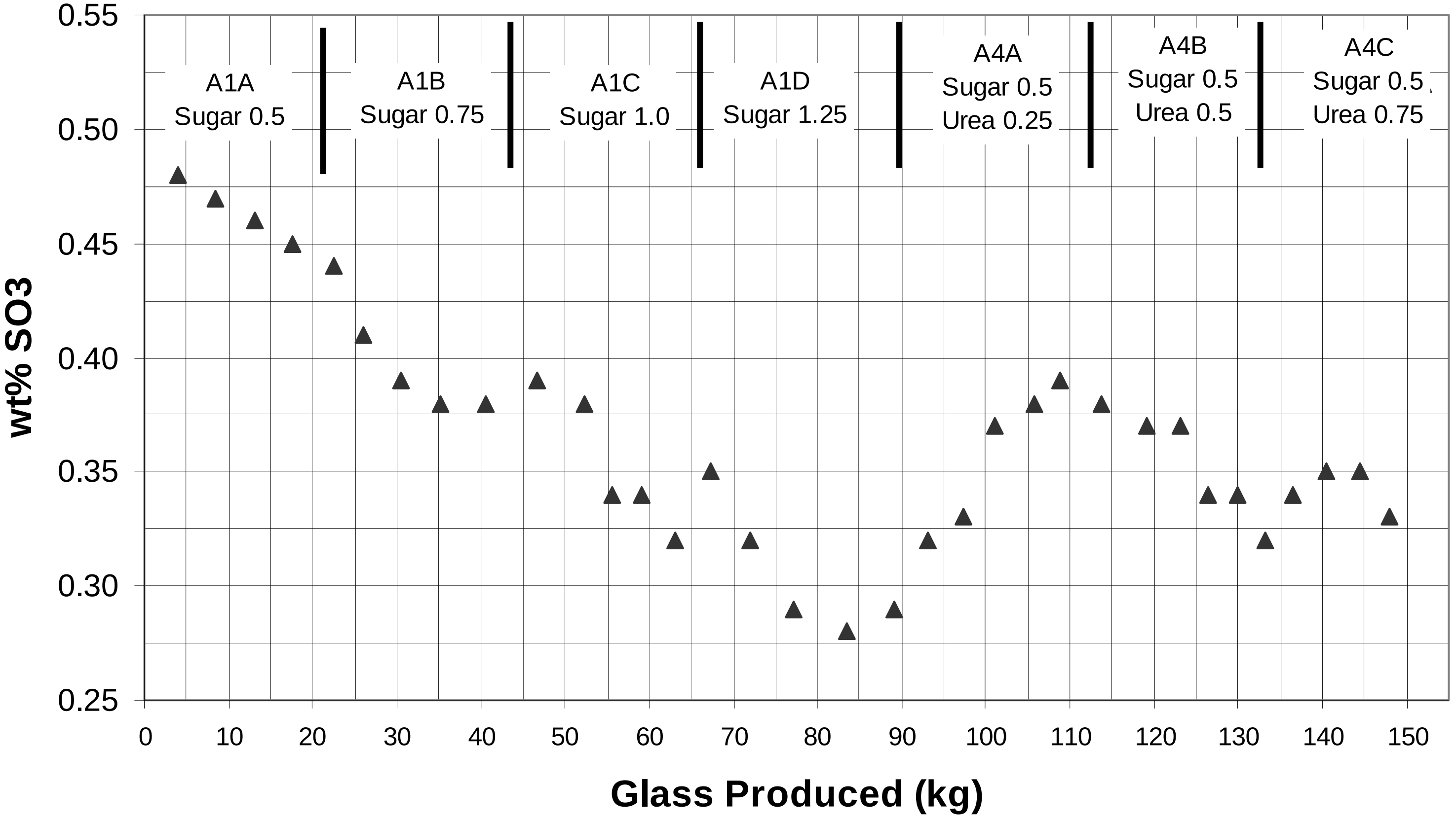

Figure 3.1. XRF analysis of sulfur in DM10 product glasses for tests with sugar and urea.

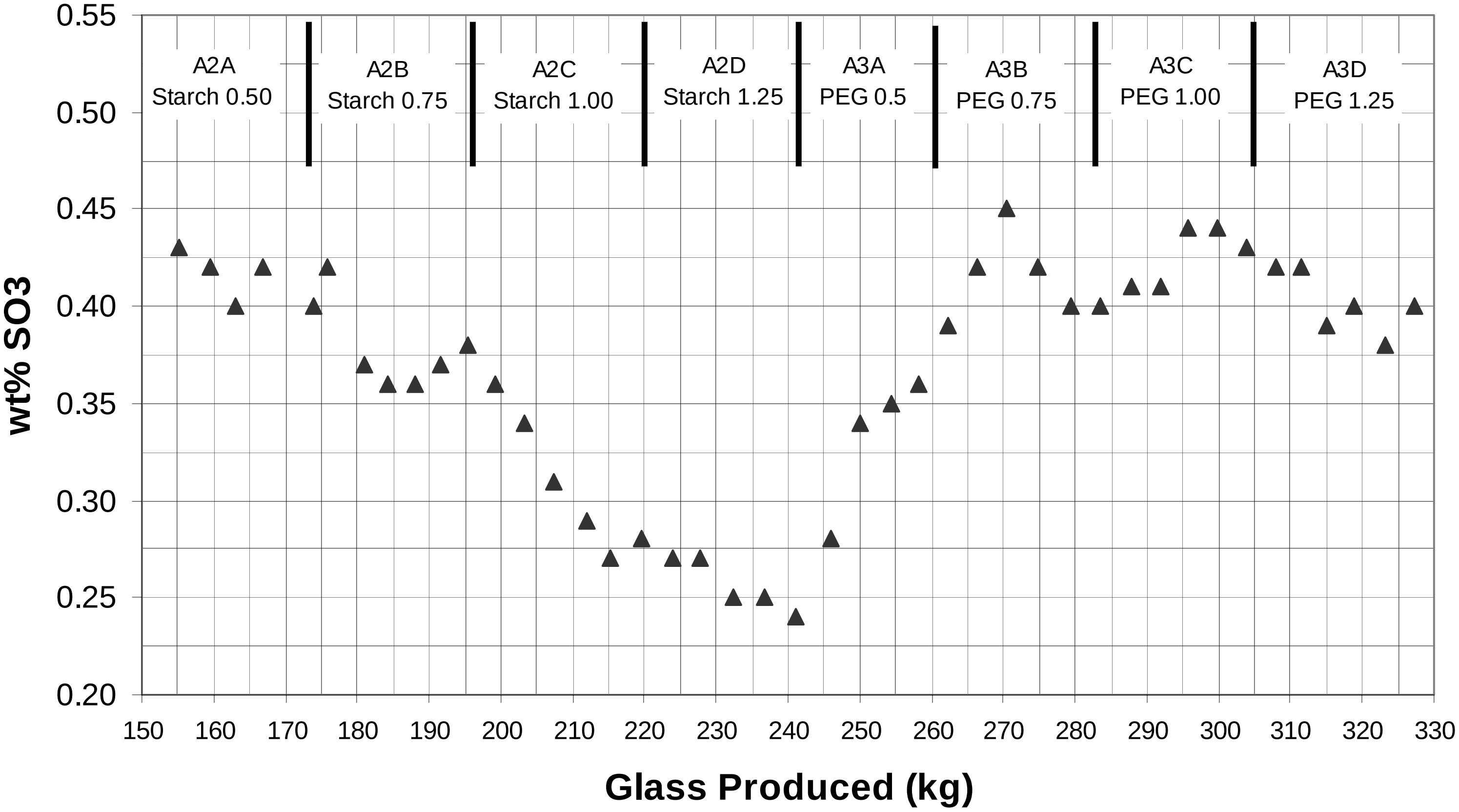

Figure 3.2. XRF analysis of sulfur in DM10 product glasses for tests with starch and PEG.

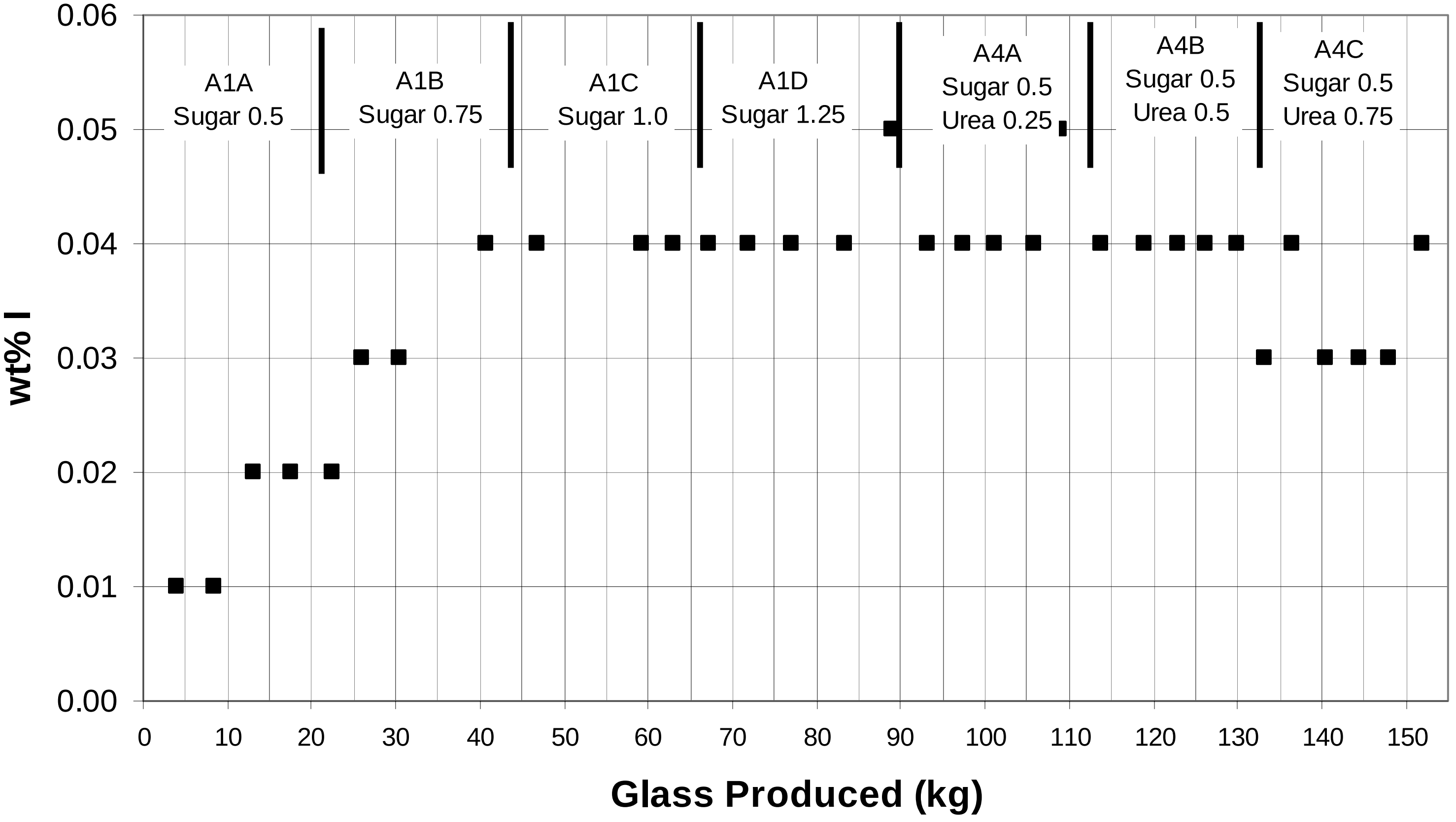

Figure 3.3. XRF analysis of iodine in DM10 product glasses for tests with sugar and urea.

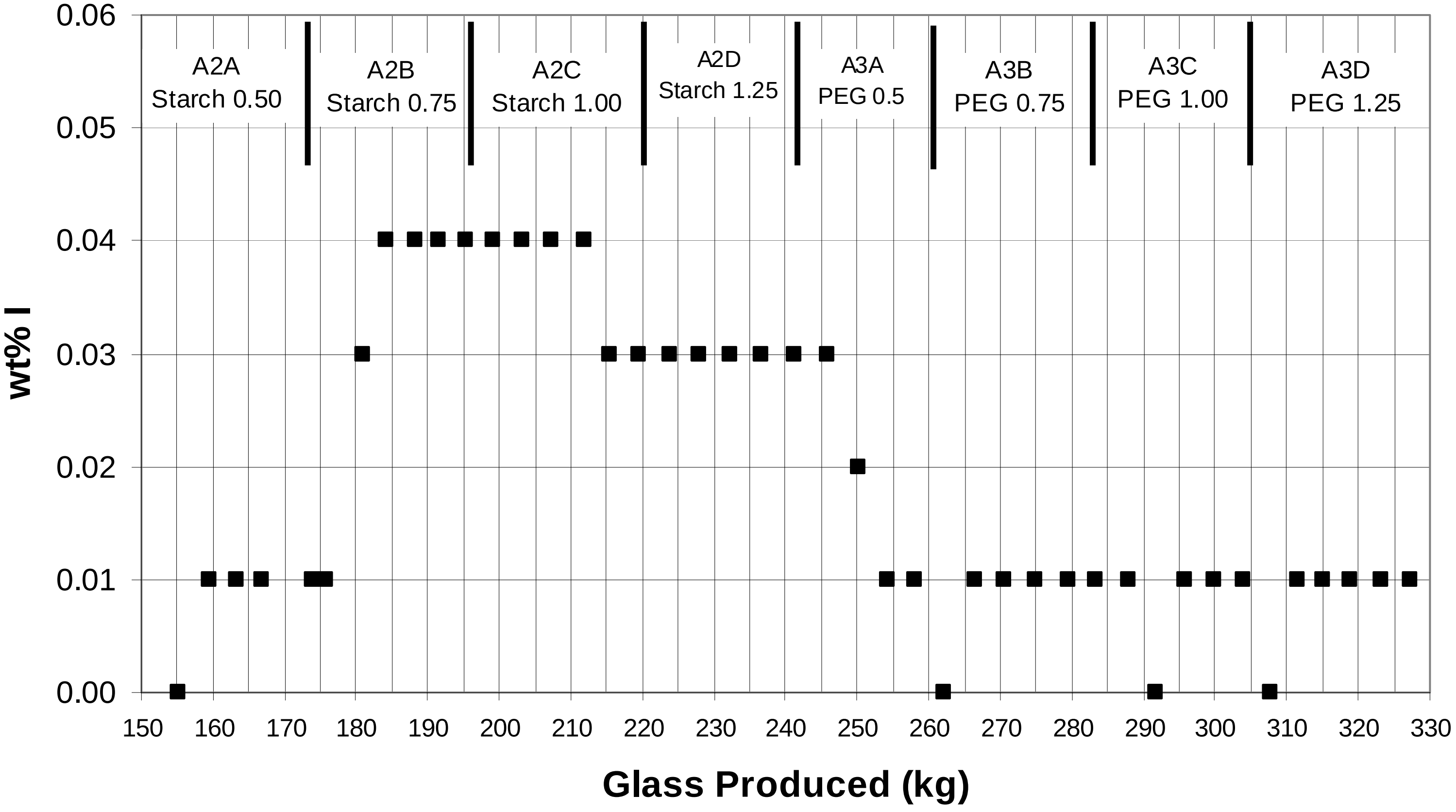

Figure 3.4. XRF analysis of iodine in DM10 product glasses for tests with starch and PEG.

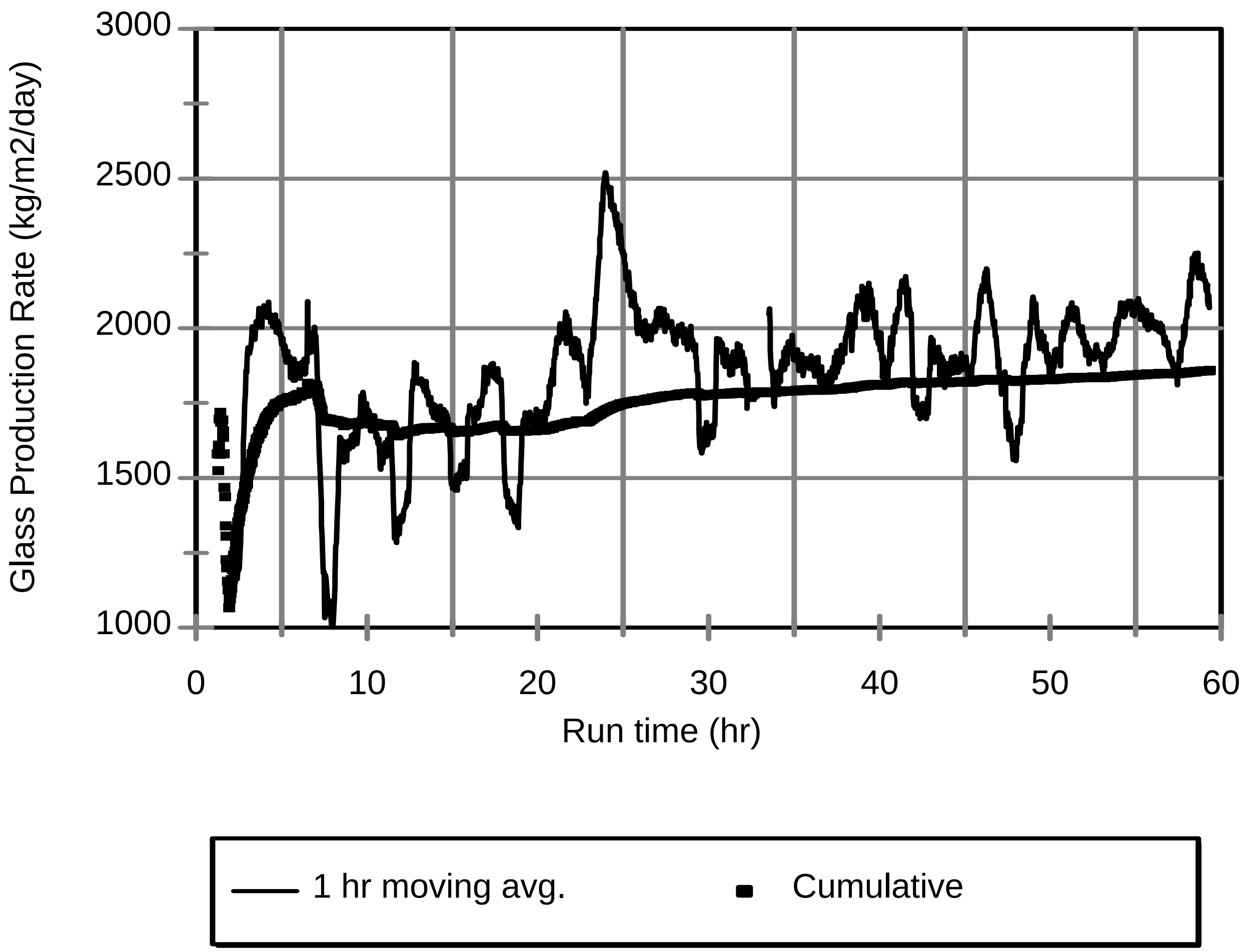

Figure 4.1.a. Glass production rate for the DM100 Urea and Sugar Test.

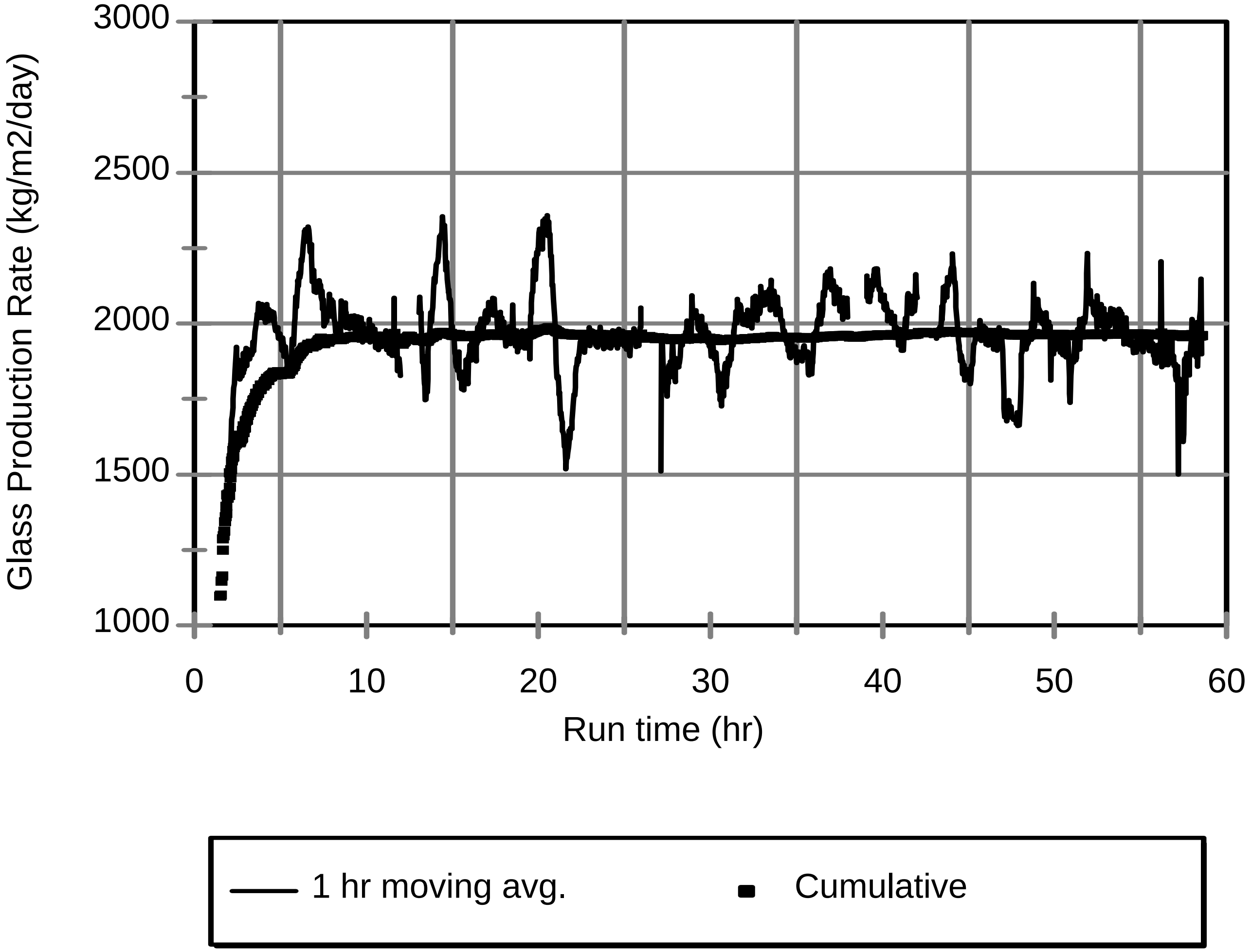

Figure 4.1.b. Glass production rate for the DM100 Vanadium Additive Test.

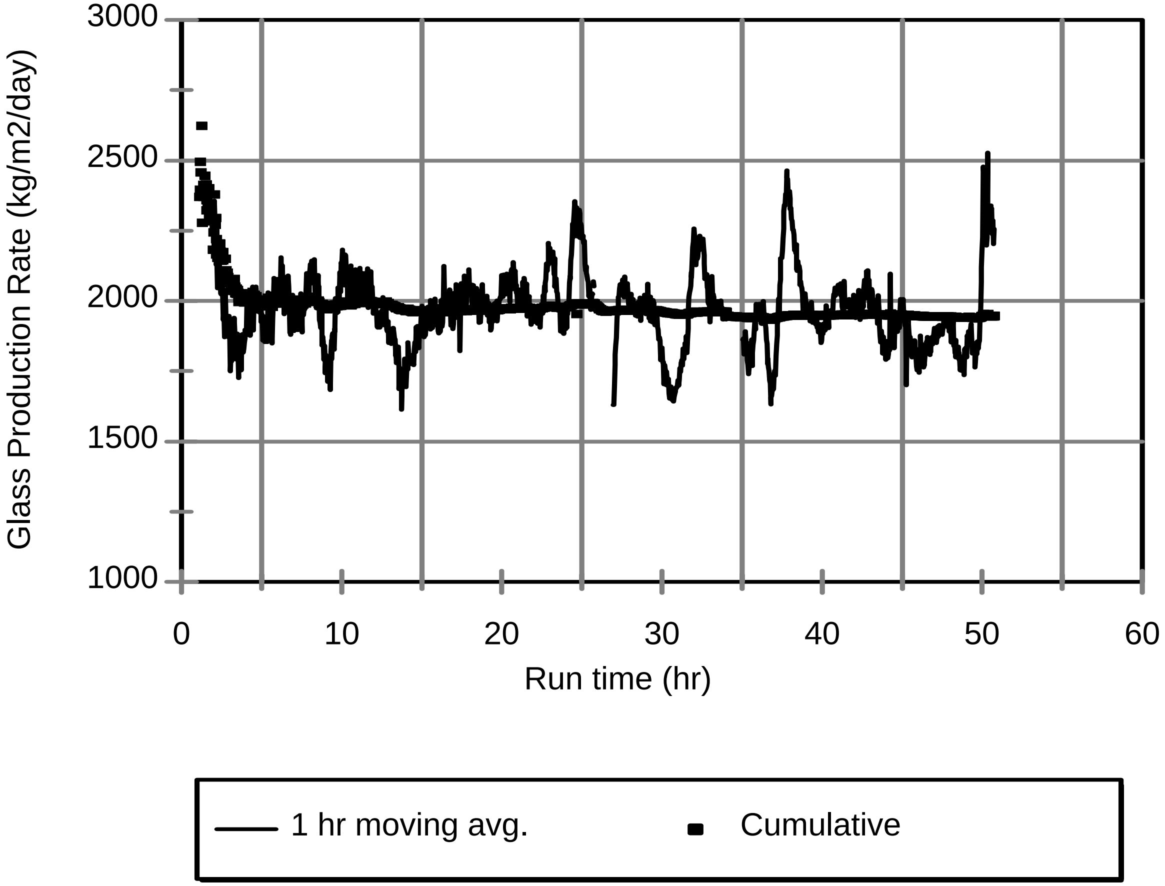

Figure 4.1.c. Glass production rate for the DM100 Starch and Sugar Test.

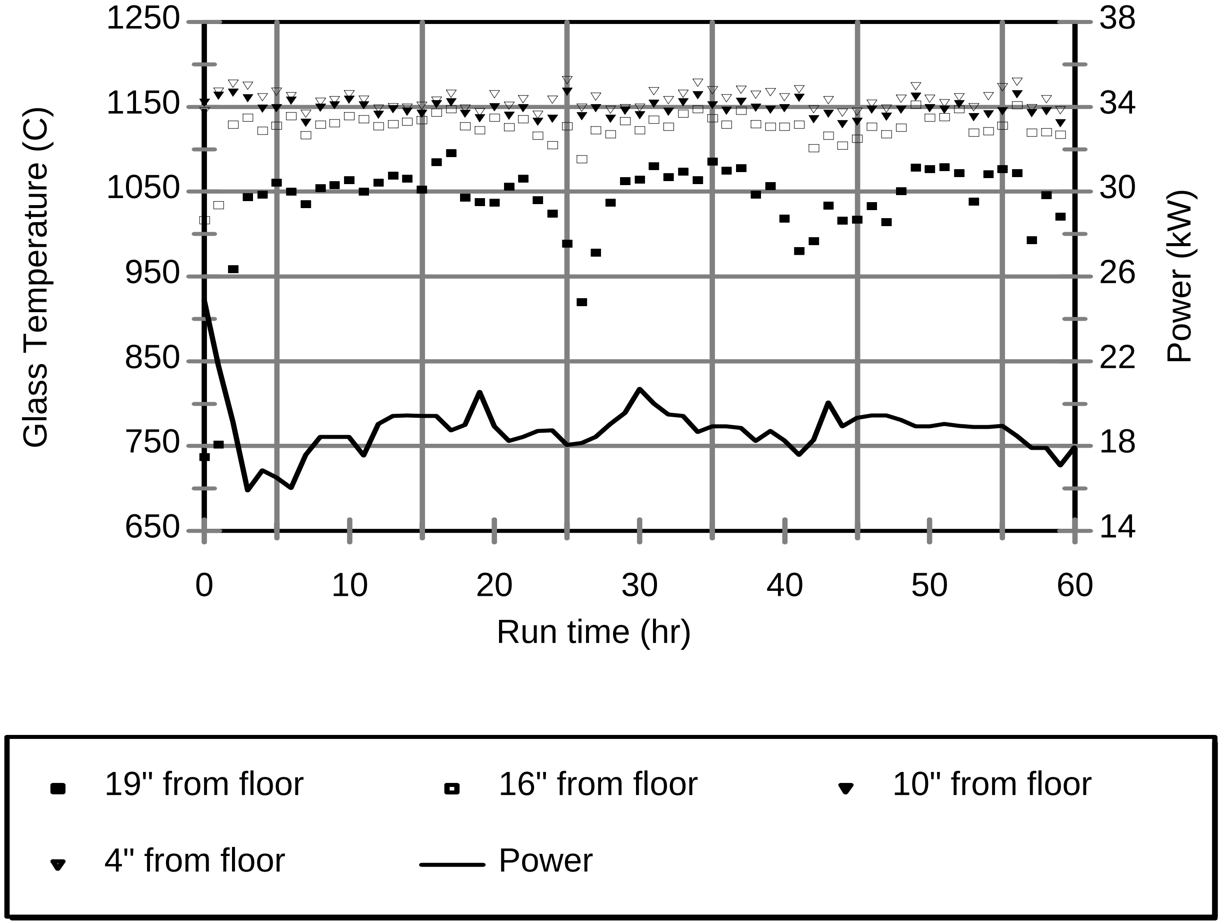

Figure 4.2.a. Glass temperatures and electrode power for the DM100 Urea and Sugar Test.

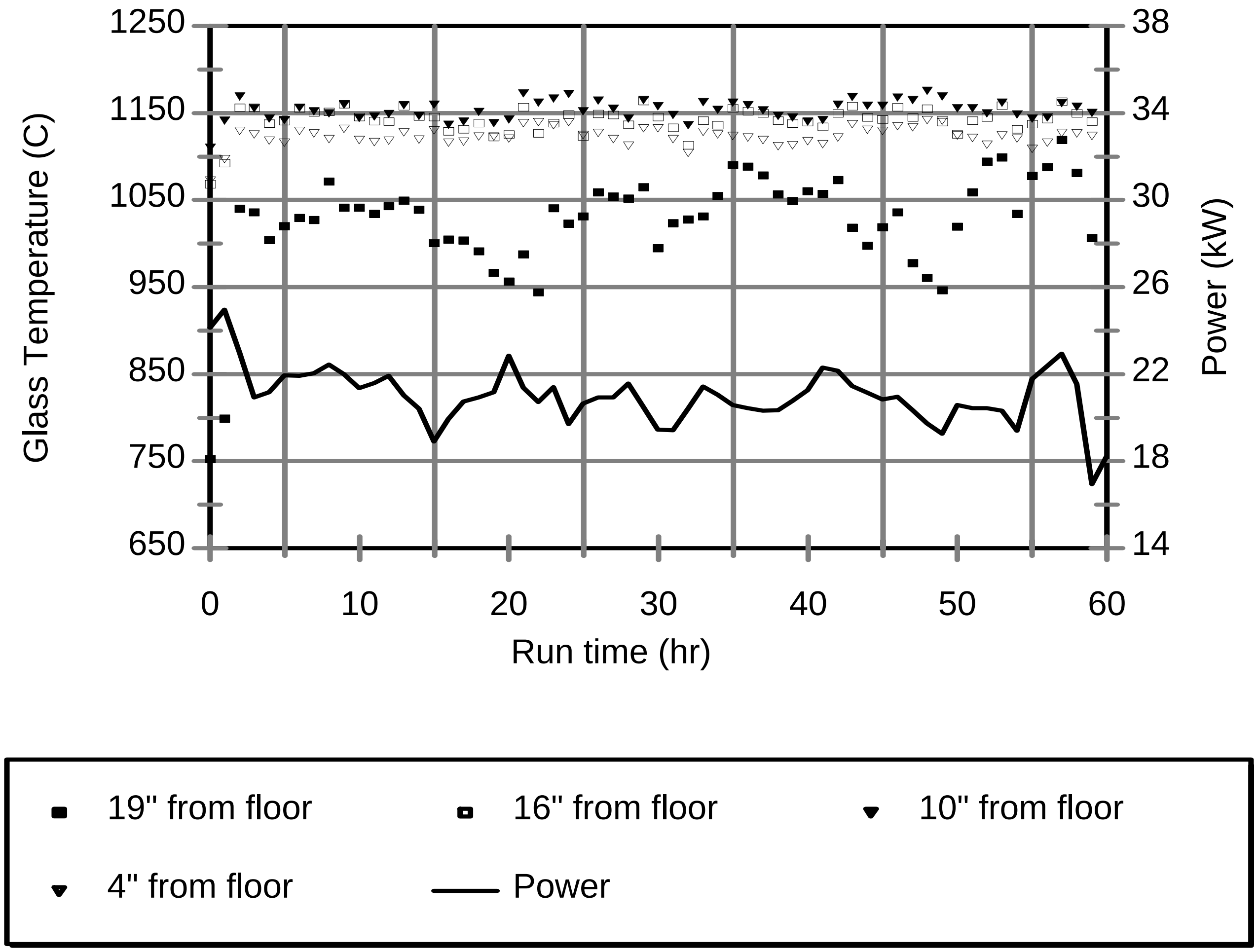

Figure 4.2.b. Glass temperatures and electrode power for the DM100 Vanadium Additive Test.

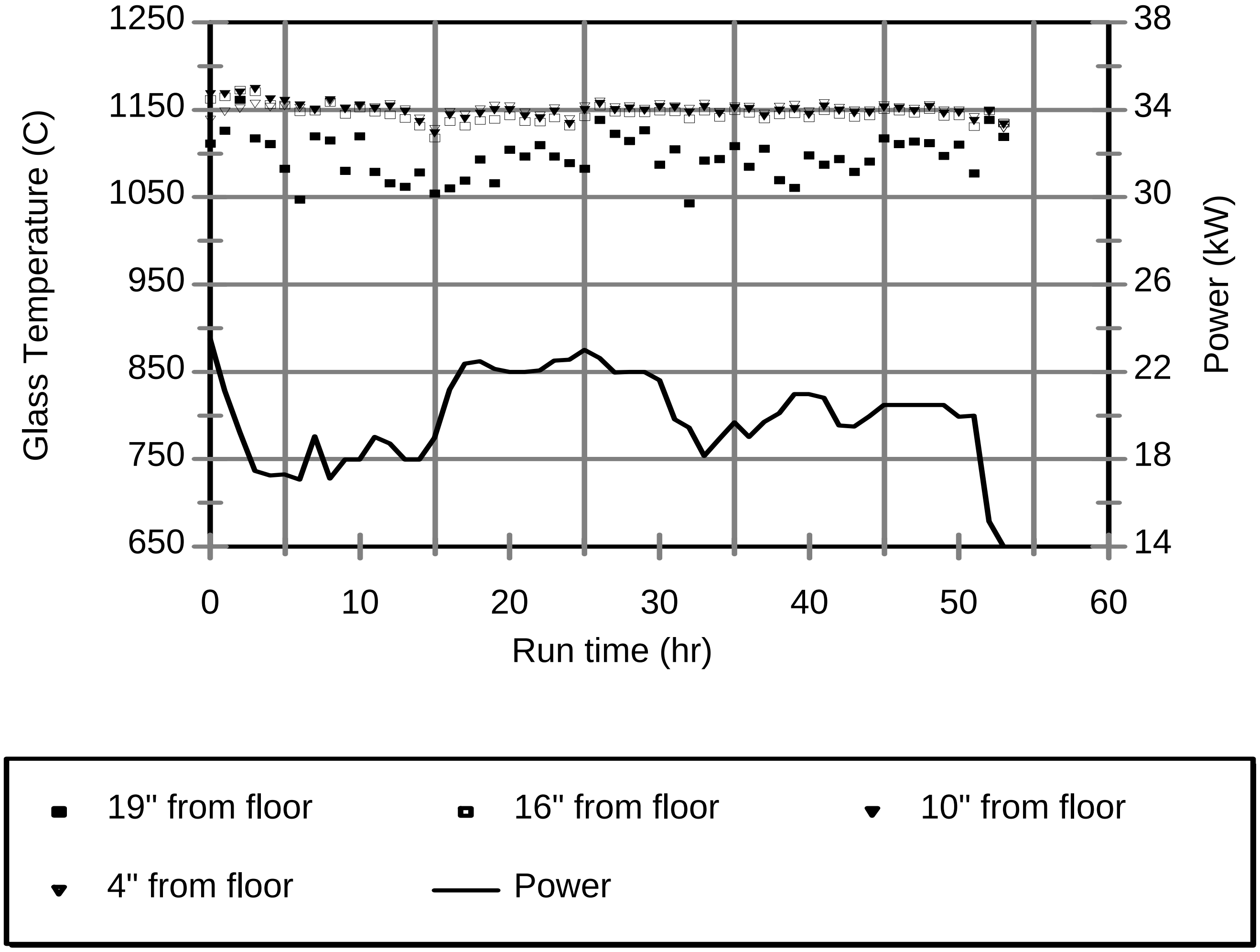

Figure 4.2.c. Glass temperatures and electrode power for the DM100 Starch and Sugar Test.

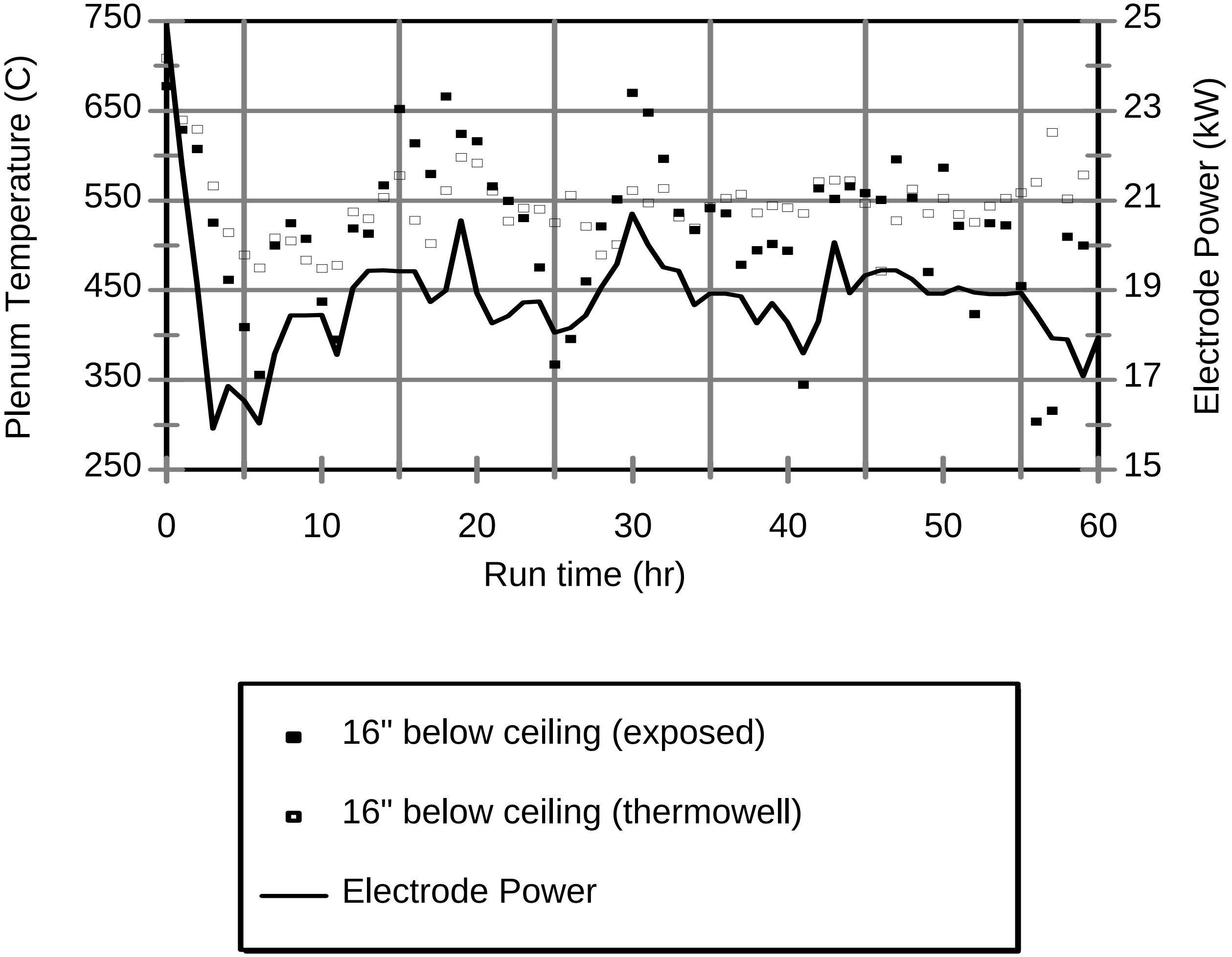

Figure 4.3.a. Plenum temperatures and electrode power for the DM100 Urea and Sugar Test.

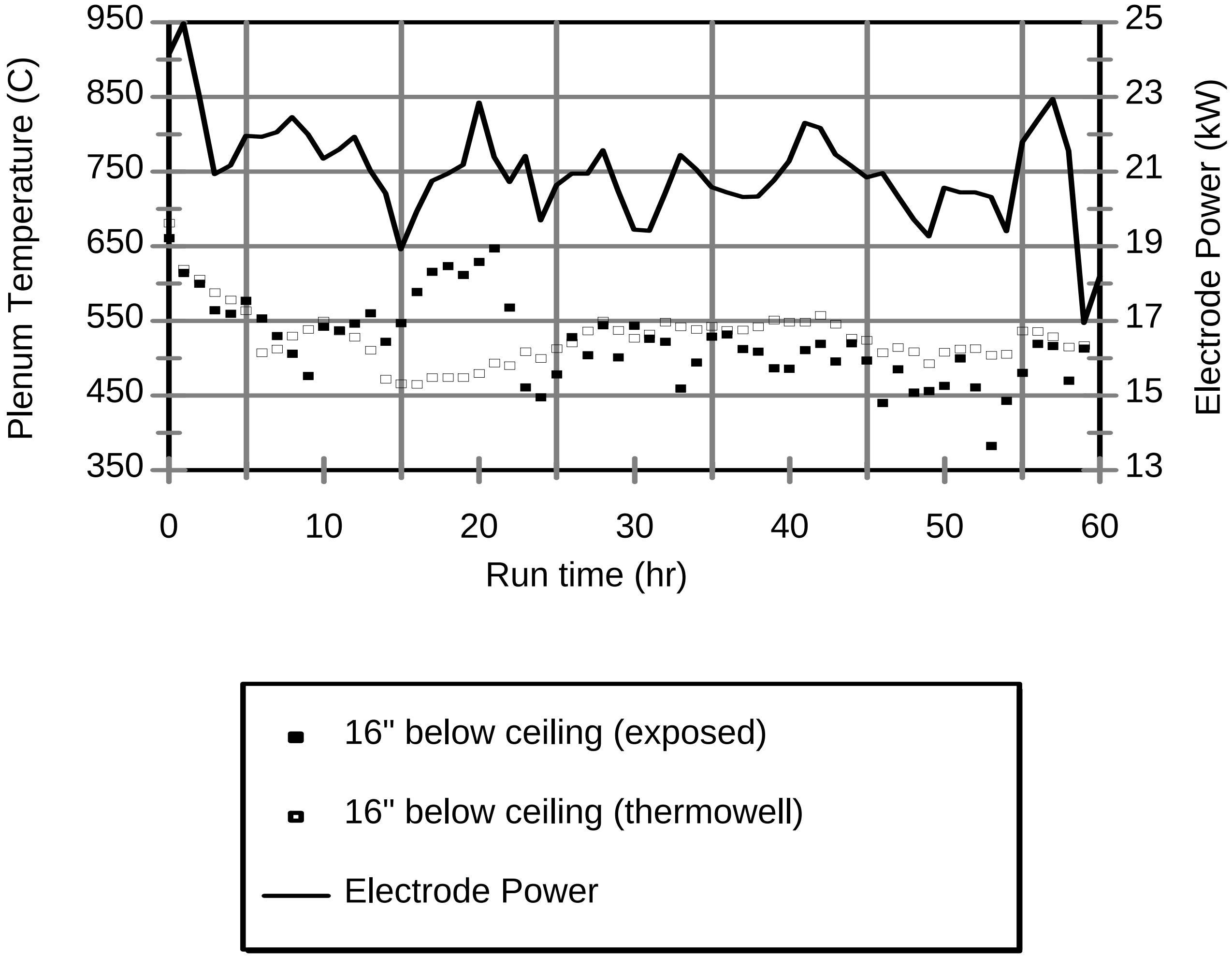

Figure 4.3.b. Plenum temperatures and electrode power for the DM100 Vanadium Additive Test.

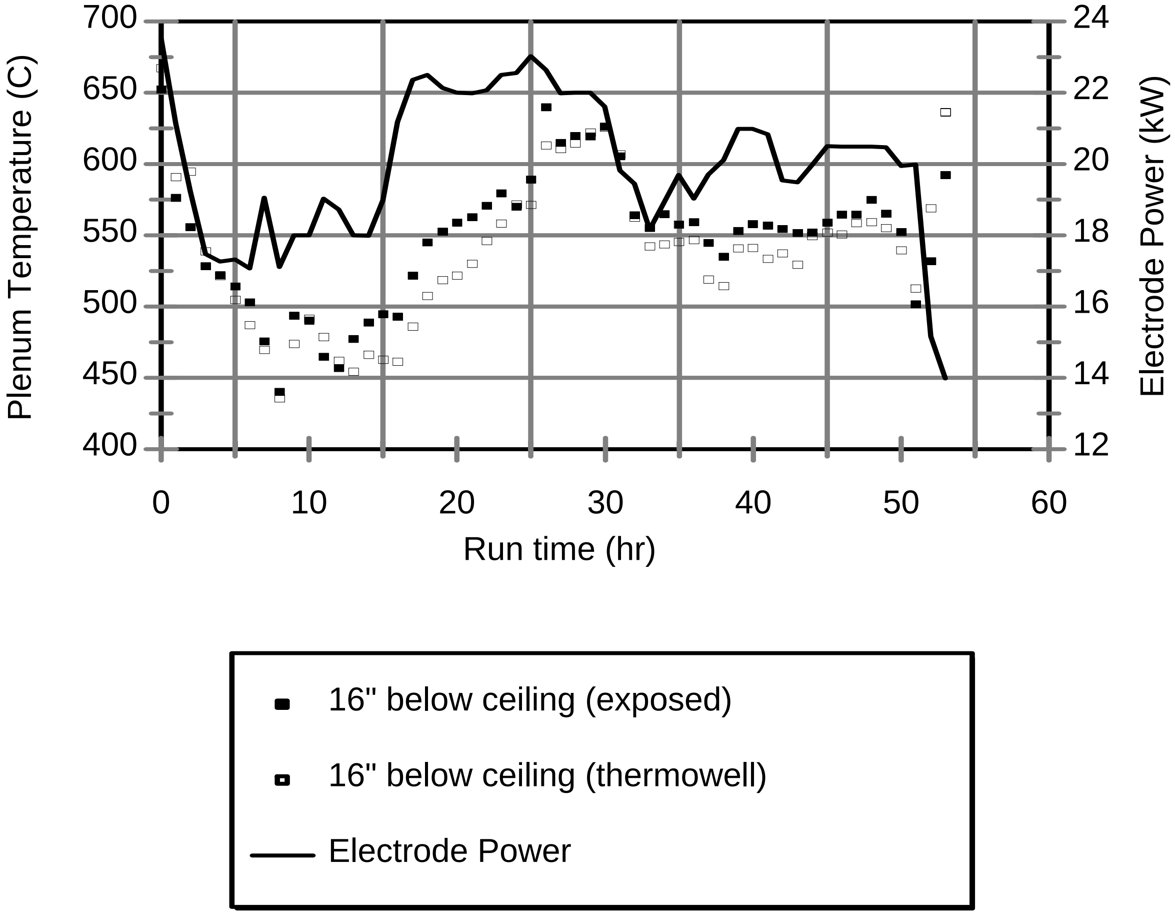

Figure 4.3.c. Plenum temperatures and electrode power for the DM100 Starch and Sugar Test.

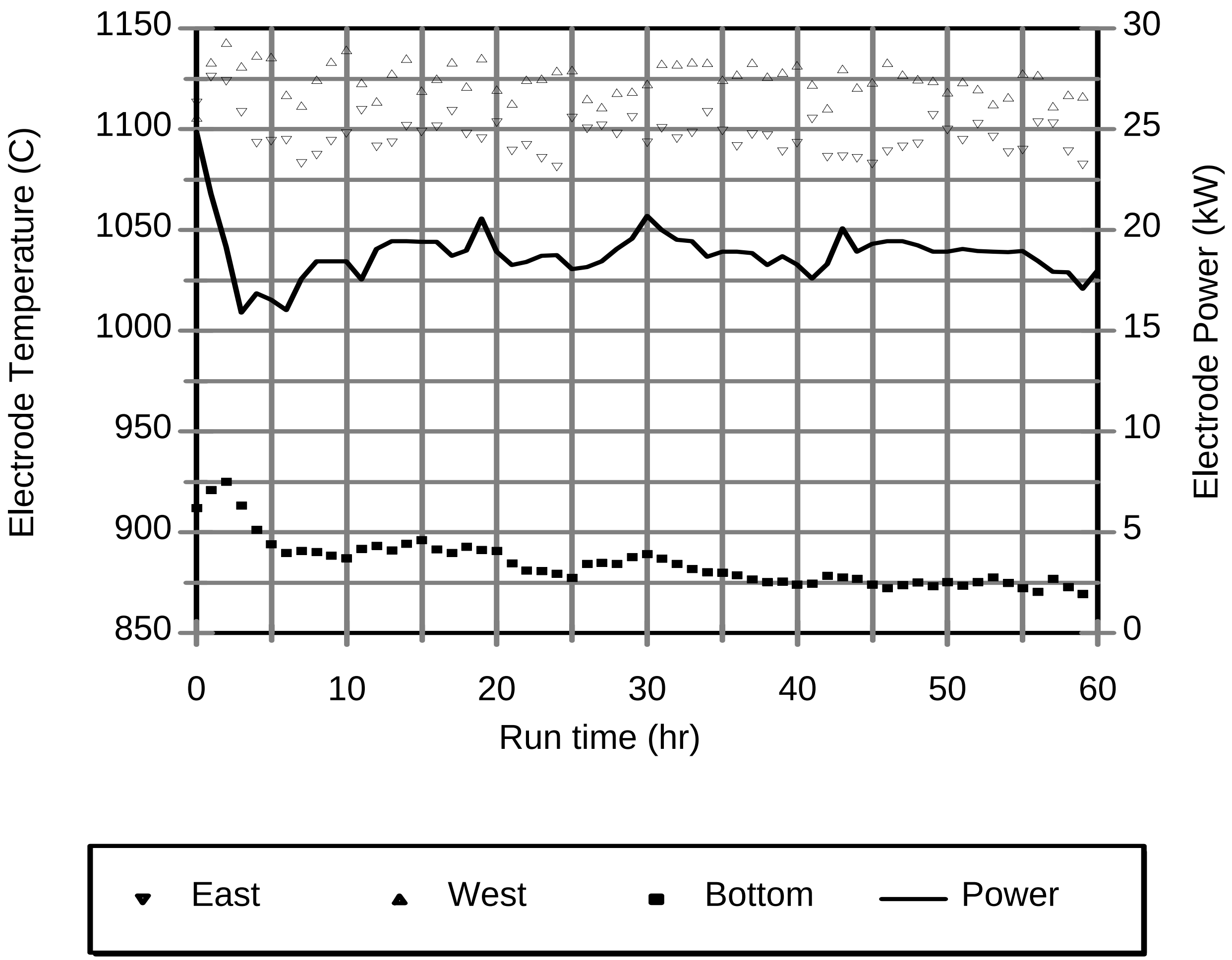

Figure 4.4.a. Electrode temperatures and power for the DM100 Urea and Sugar Test.

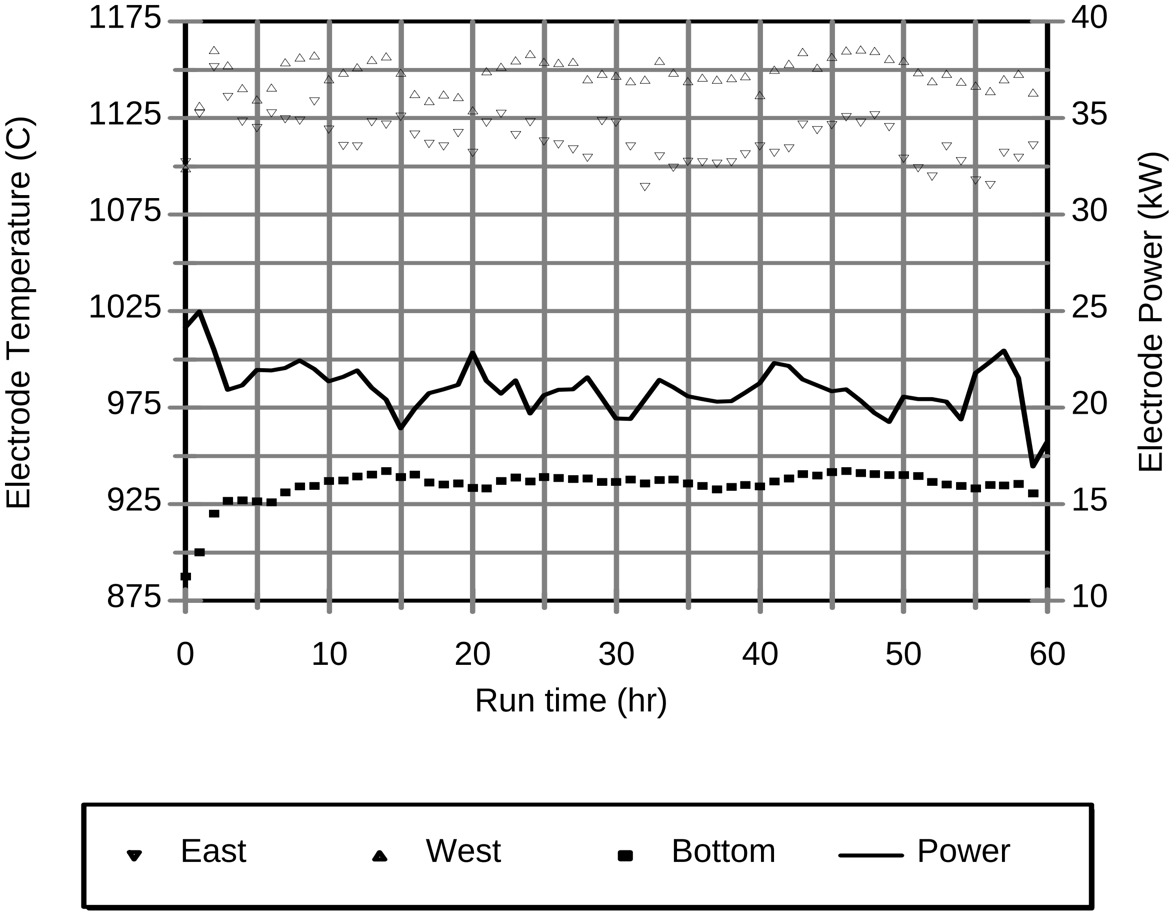

Figure 4.4.b. Electrode temperatures and power for the DM100 Vanadium Additive Test.

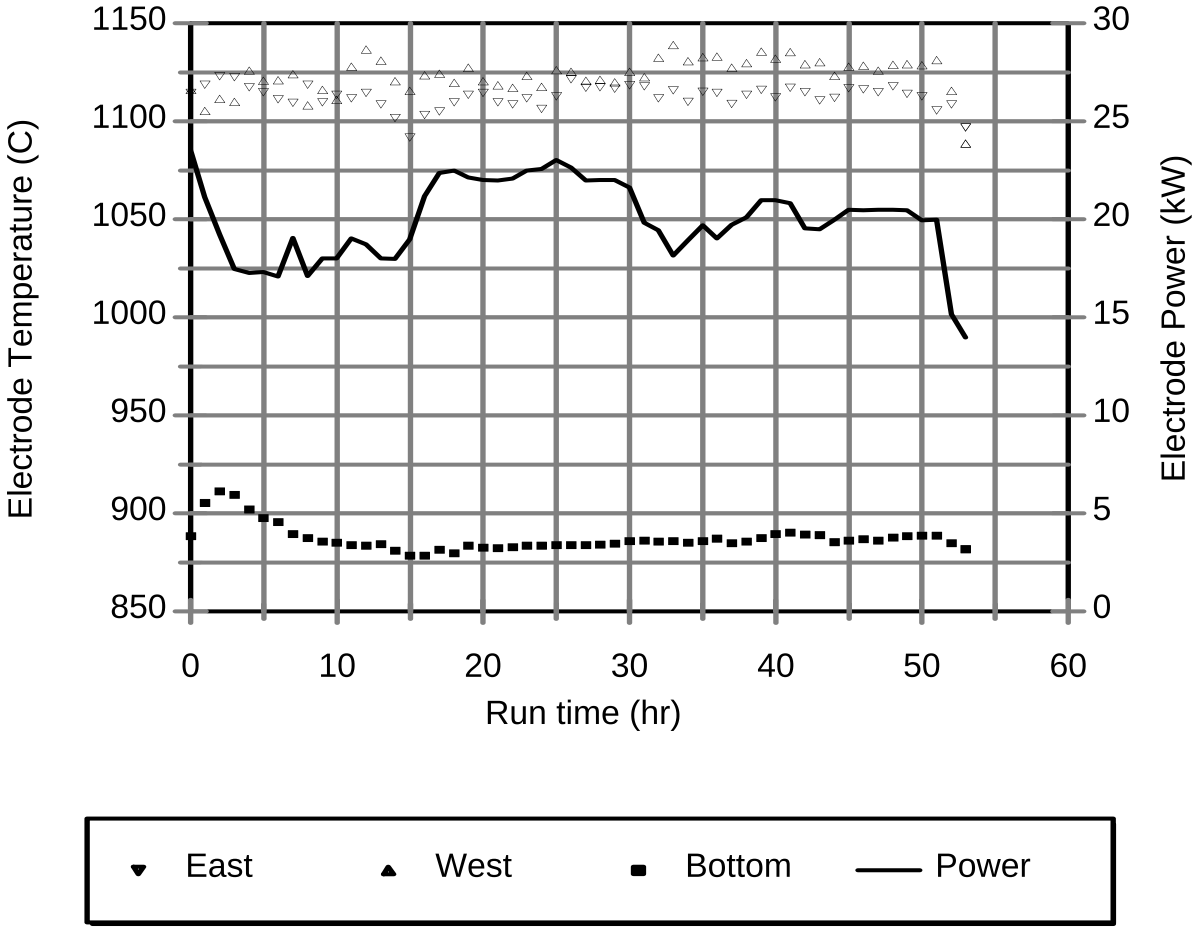

Figure 4.4.c. Electrode temperatures and power for the DM100 Starch and Sugar Test.

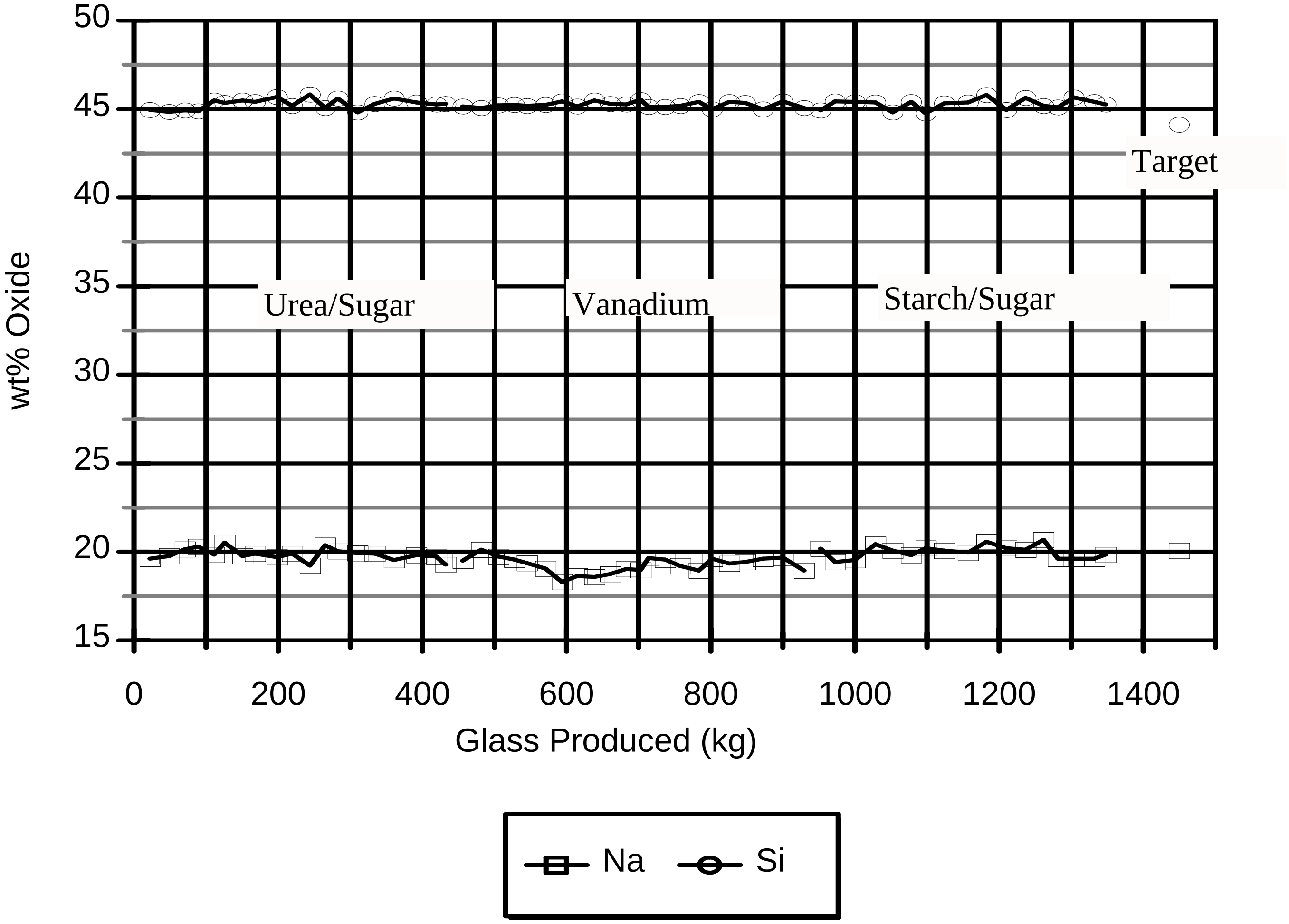

Figure 5.1. XRF analysis of Na_2O and SiO_2 in DM100 product glasses.

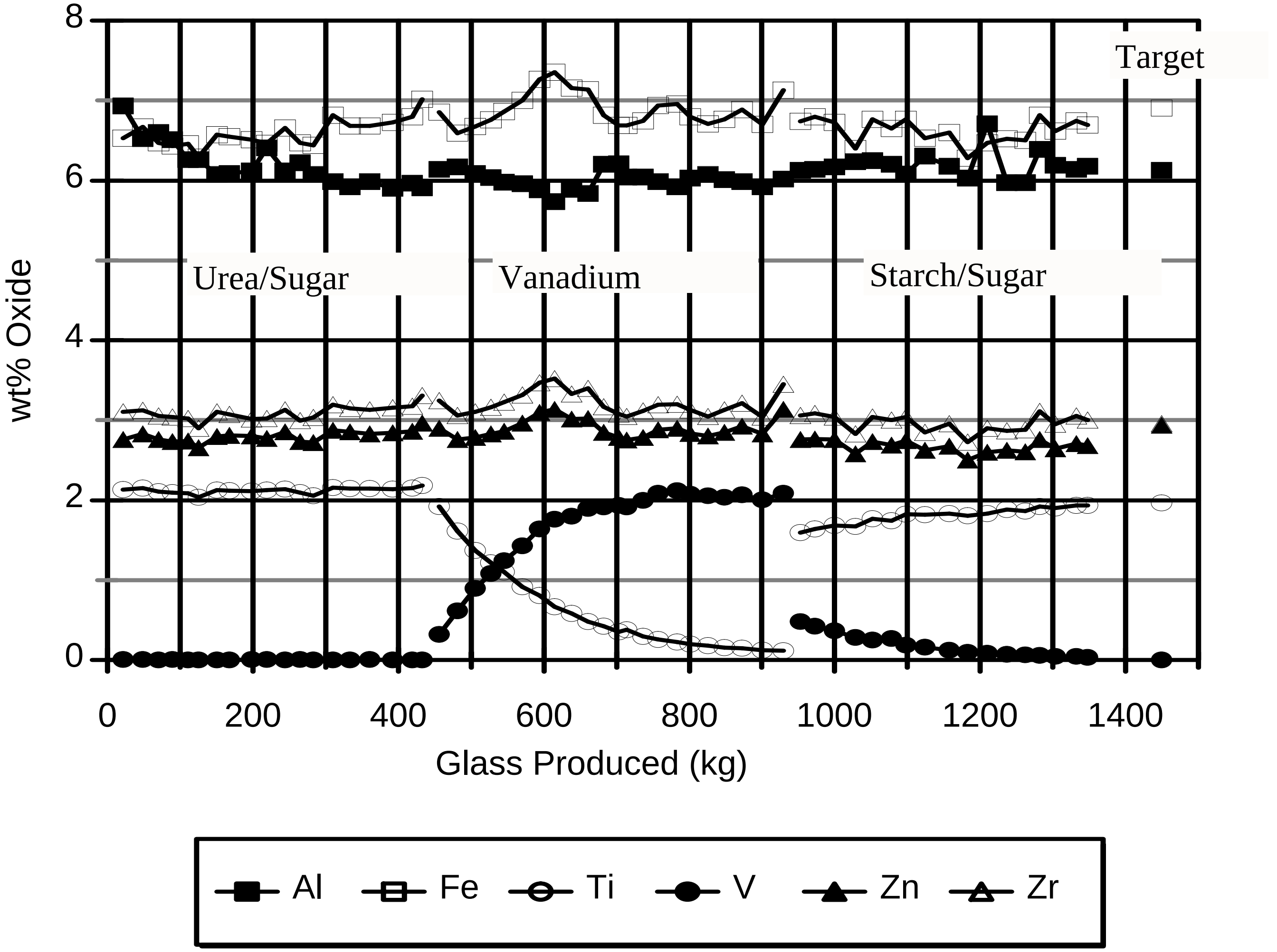

Figure 5.2. XRF analysis of select major oxides in DM100 product glasses.

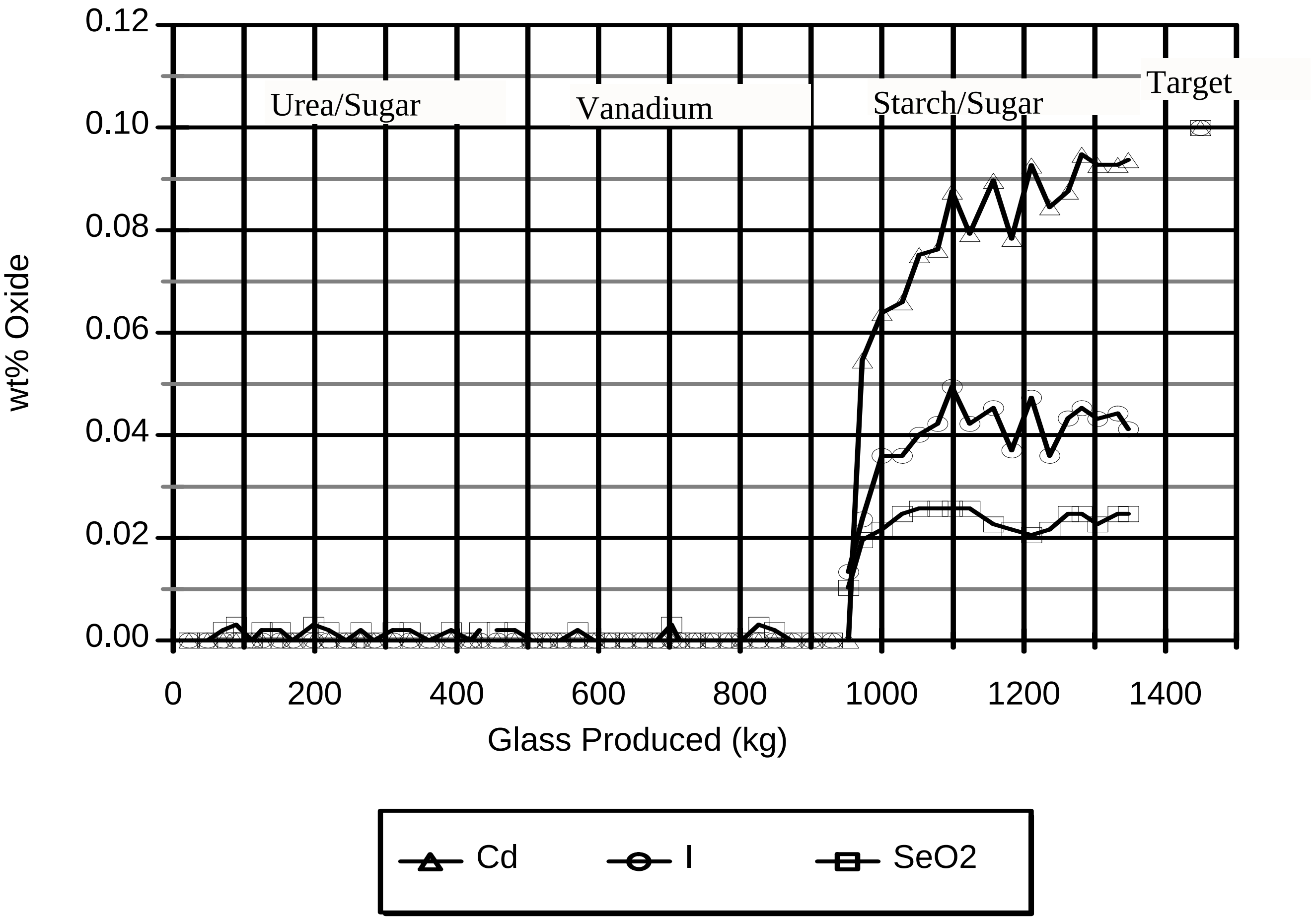

Figure 5.3. XRF analysis of spiked oxides in DM100 product glasses.

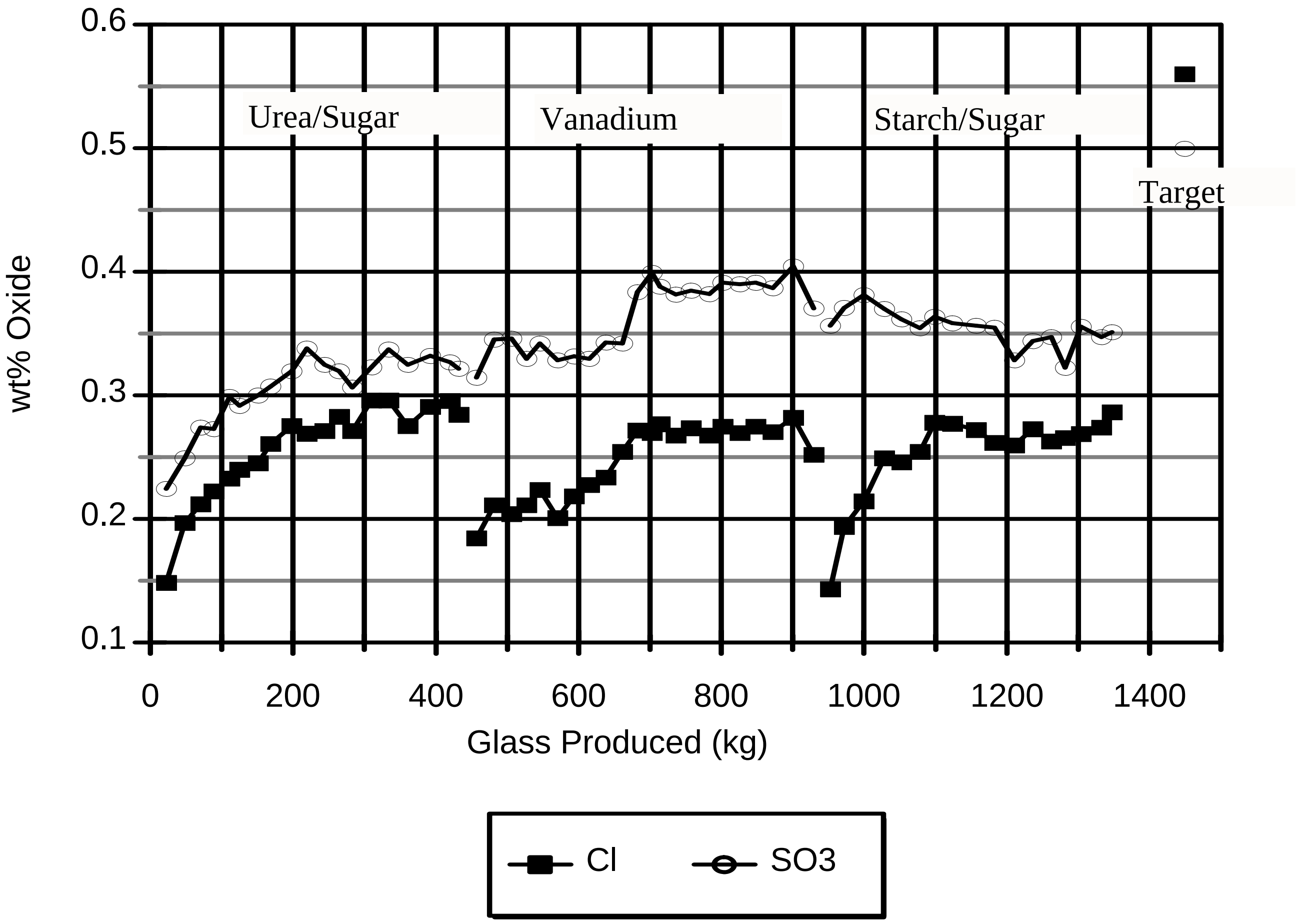

Figure 5.4. XRF analysis of chlorine and sulfur in DM100 product glasses.

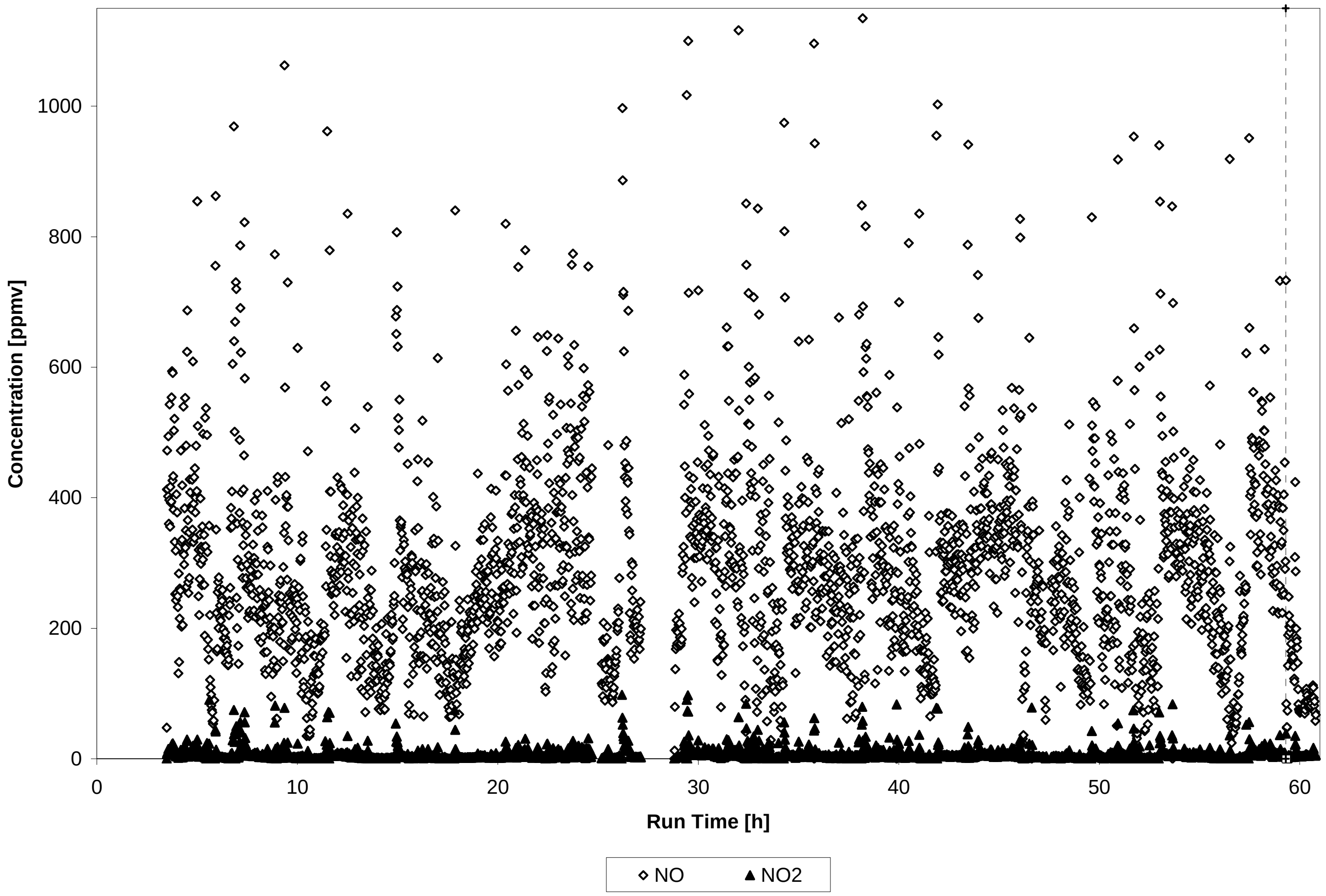

Figure 6.1.a. Nitrogen oxide concentrations in off-gas from FTIR for the DM100 Urea and Sugar Test.

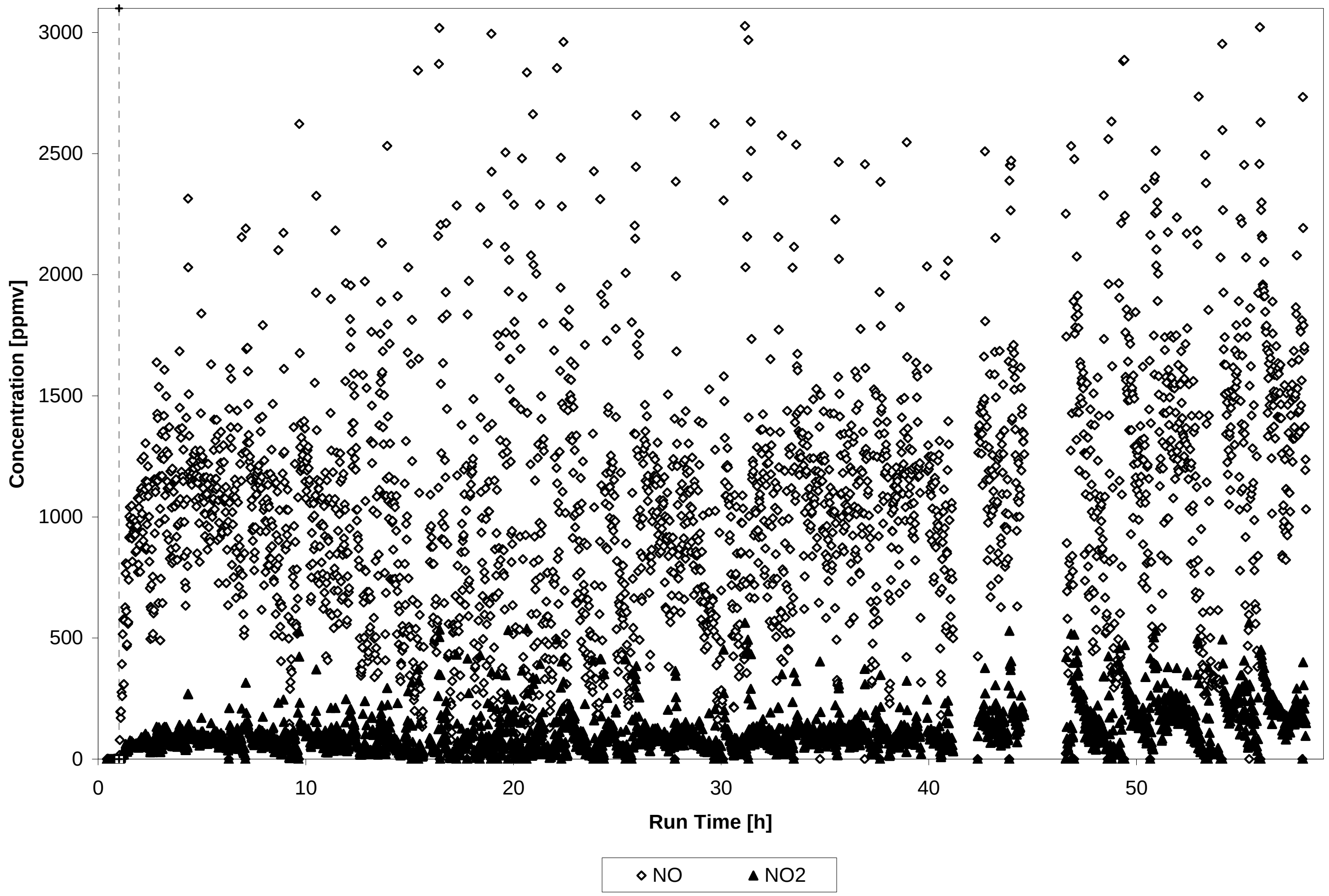

Figure 6.1.b. Nitrogen oxide concentrations in off-gas from FTIR for the DM100 Vanadium Additive Test.

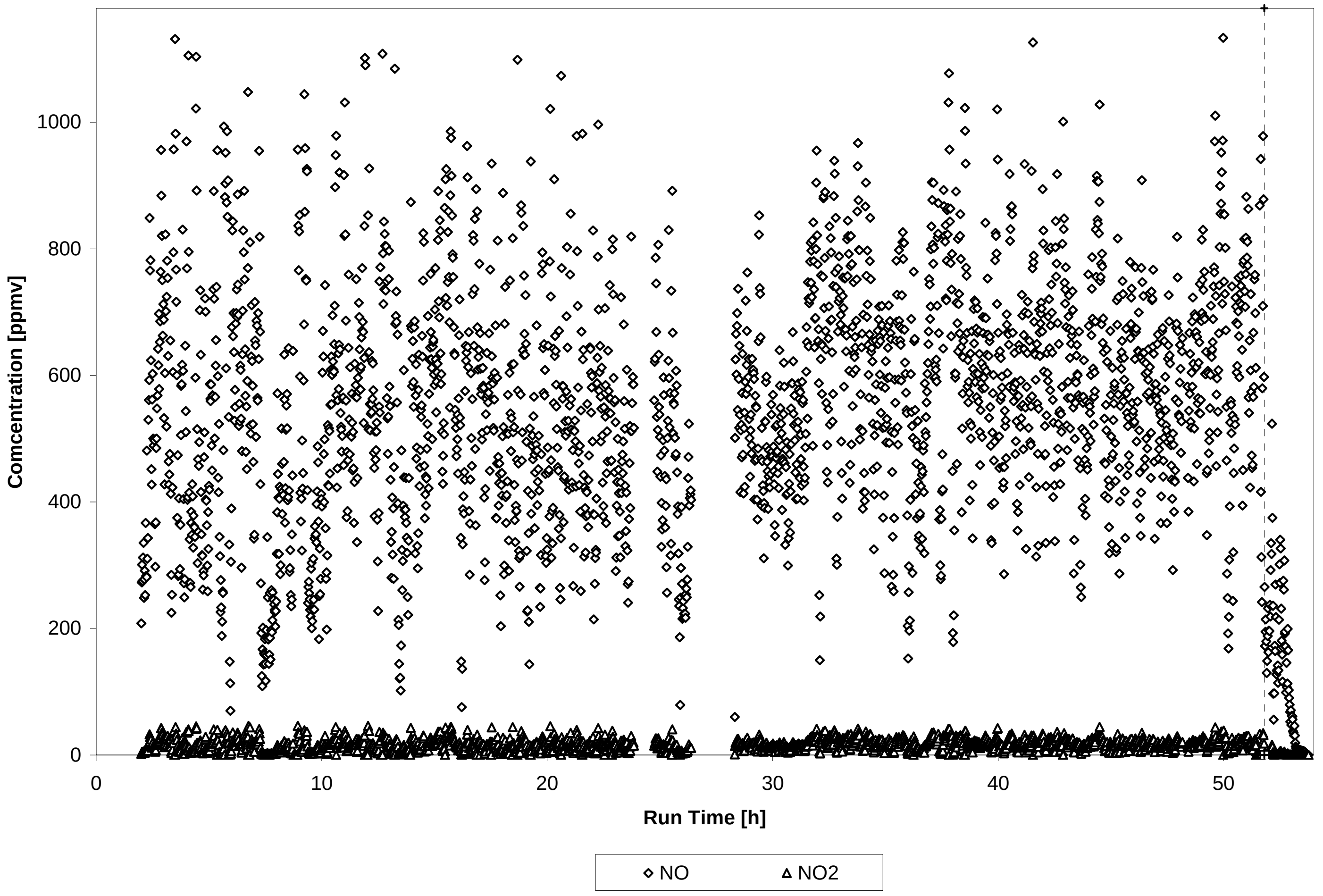

Figure 6.1.c. Nitrogen oxide concentrations in off-gas from FTIR for the DM100 Starch and Sugar Test.

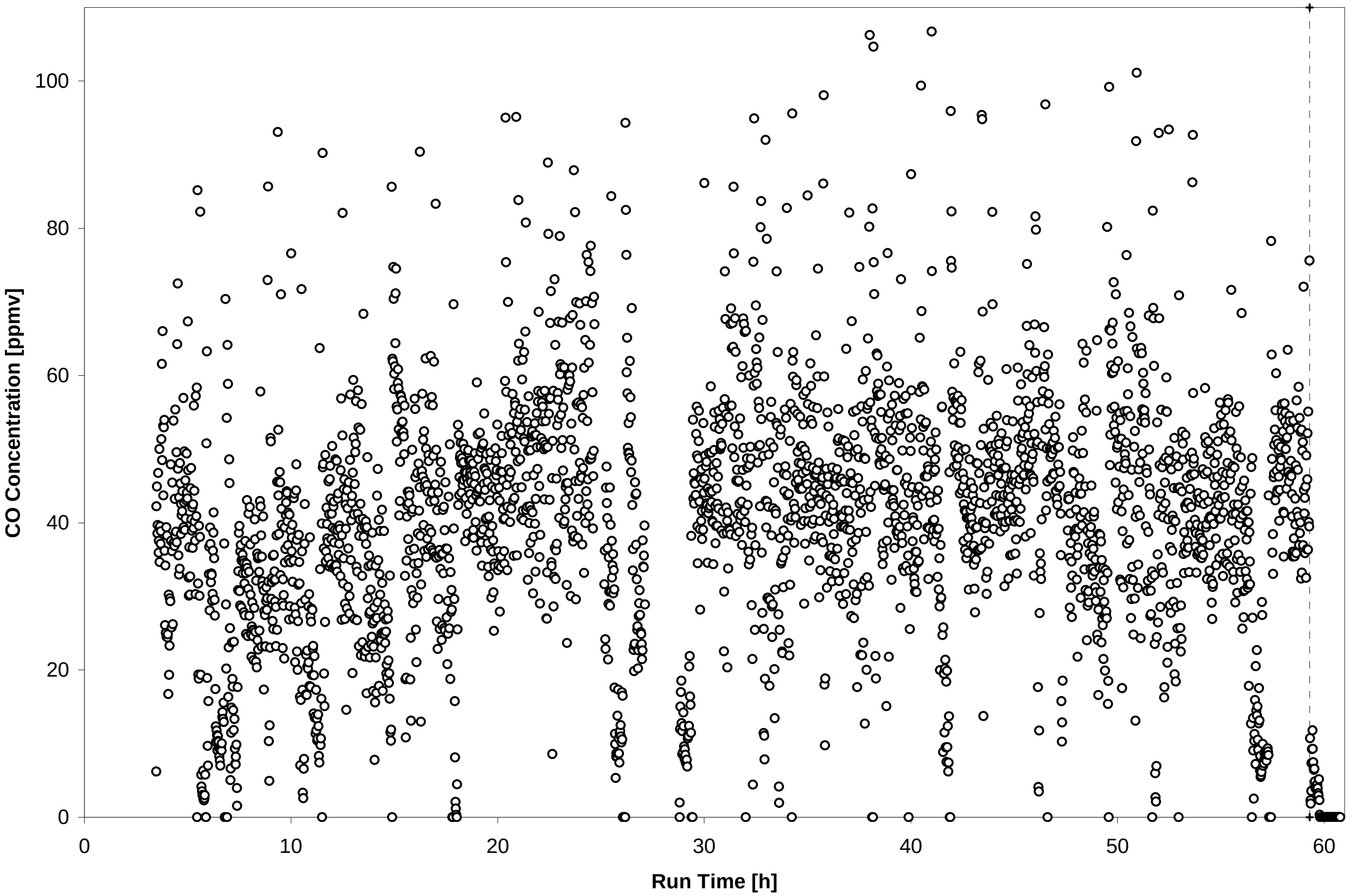

Figure 6.2.a. CO concentrations in off-gas from FTIR for the DM100 Urea and Sugar Test.

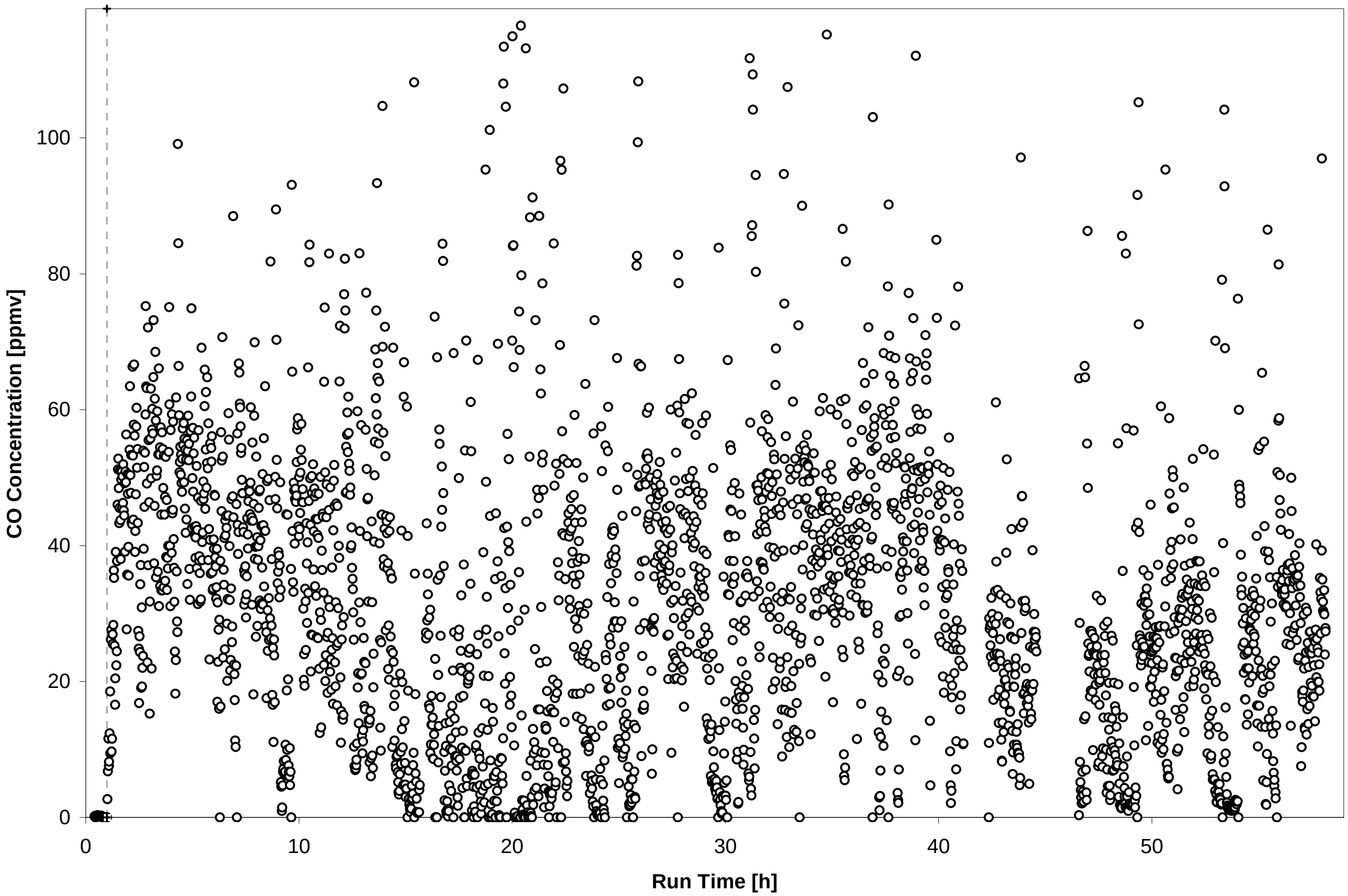

Figure 6.2.b. CO concentrations in off-gas from FTIR for the DM100 Vanadium Additive Test.

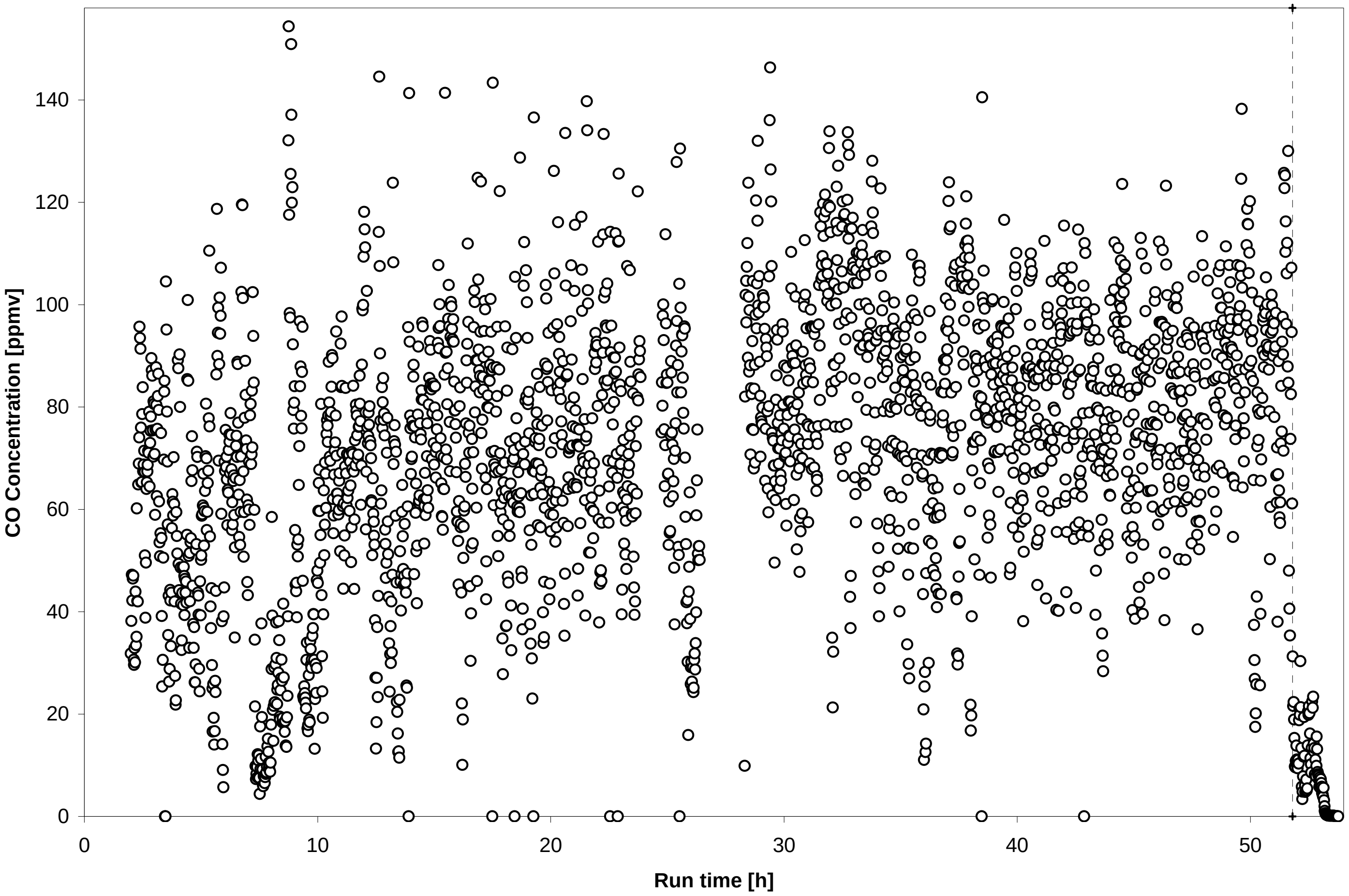

Figure 6.2.c. CO concentrations in off-gas from FTIR for the DM100 Starch and Sugar Test.

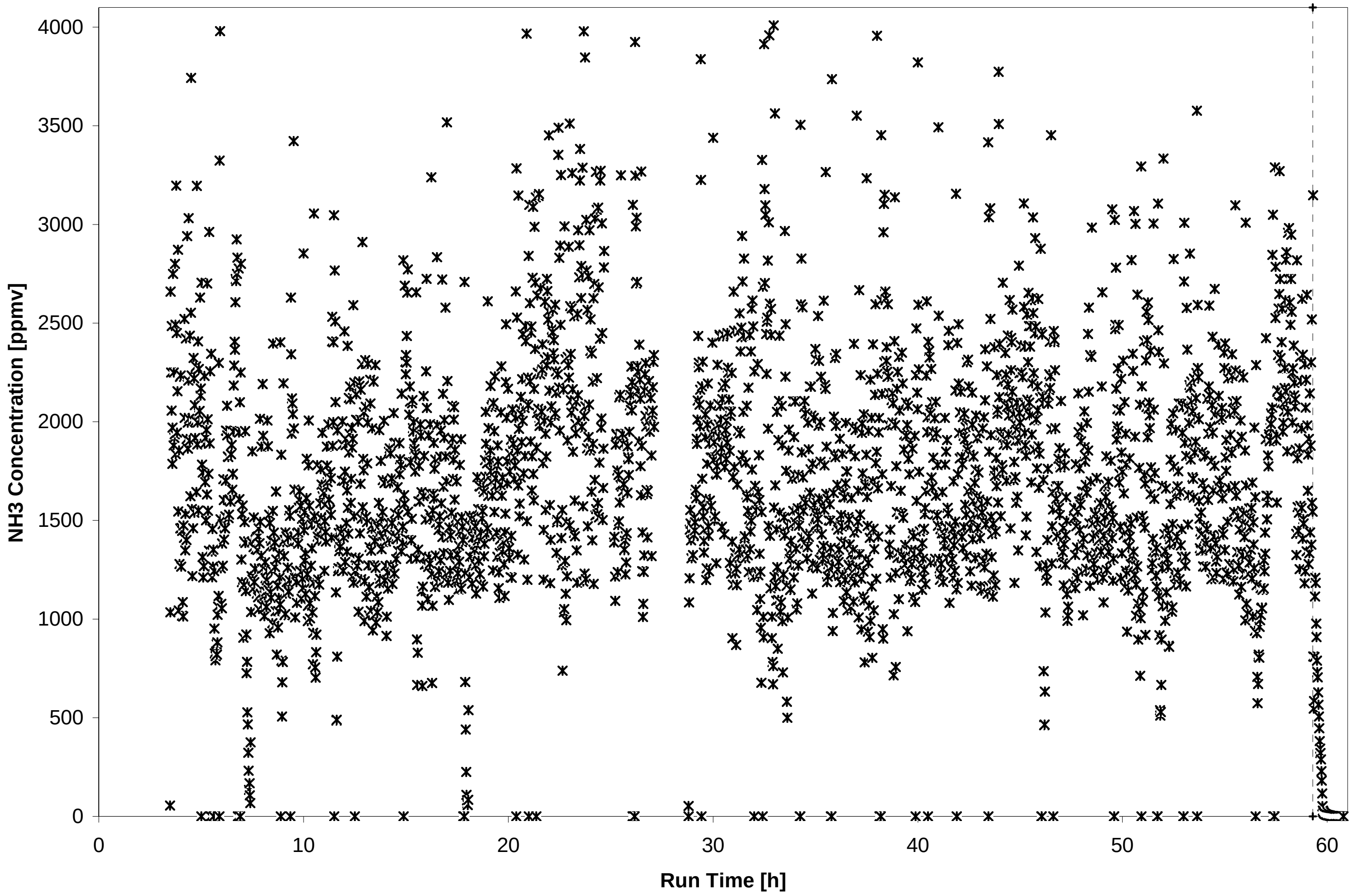

Figure 6.3.a. NH_3 concentrations in off-gas from FTIR for the DM100 Urea and Sugar Test.

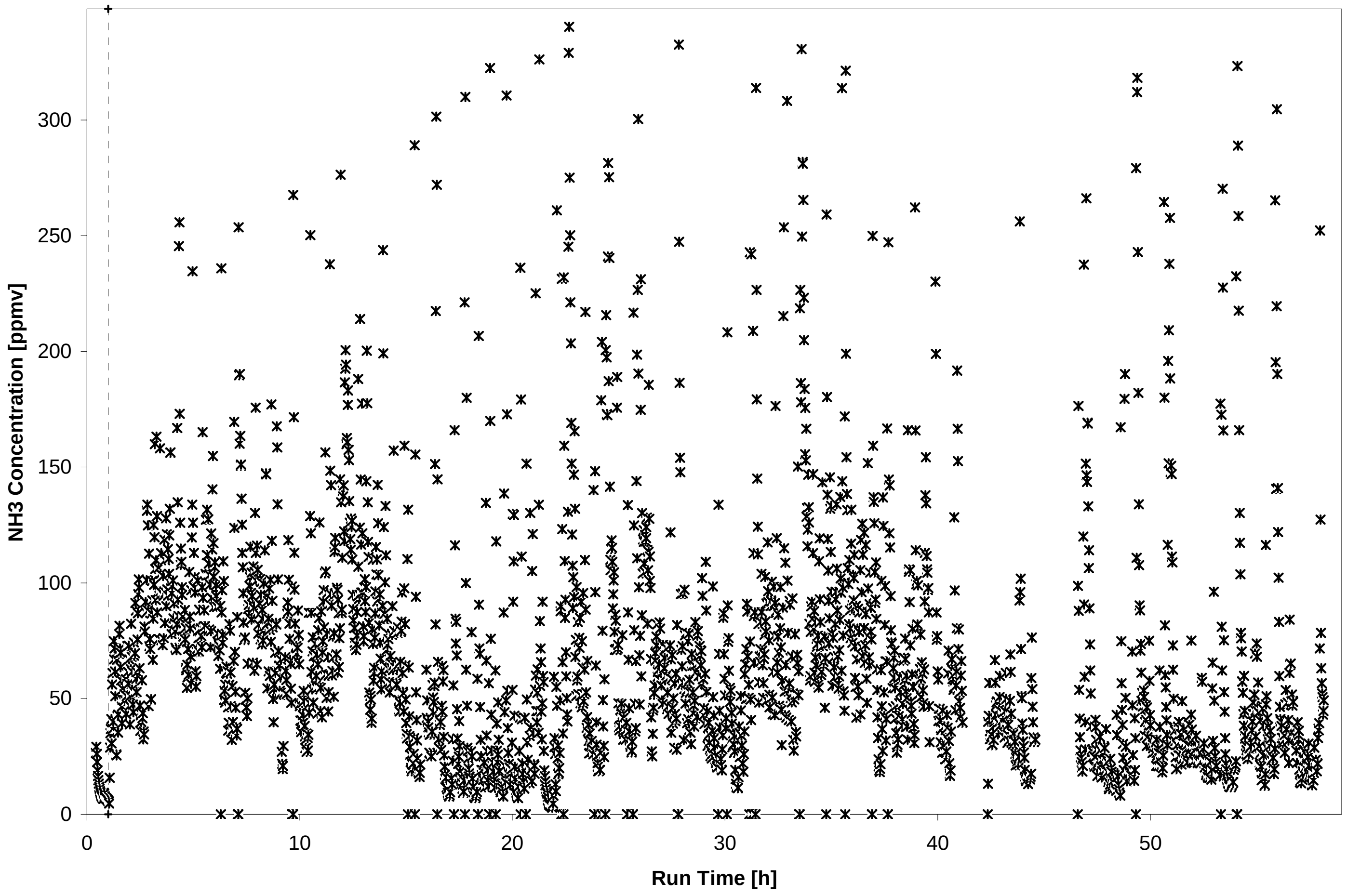

Figure 6.3.b. NH_3 concentrations in off-gas from FTIR for the DM100 Vanadium Additive Test.

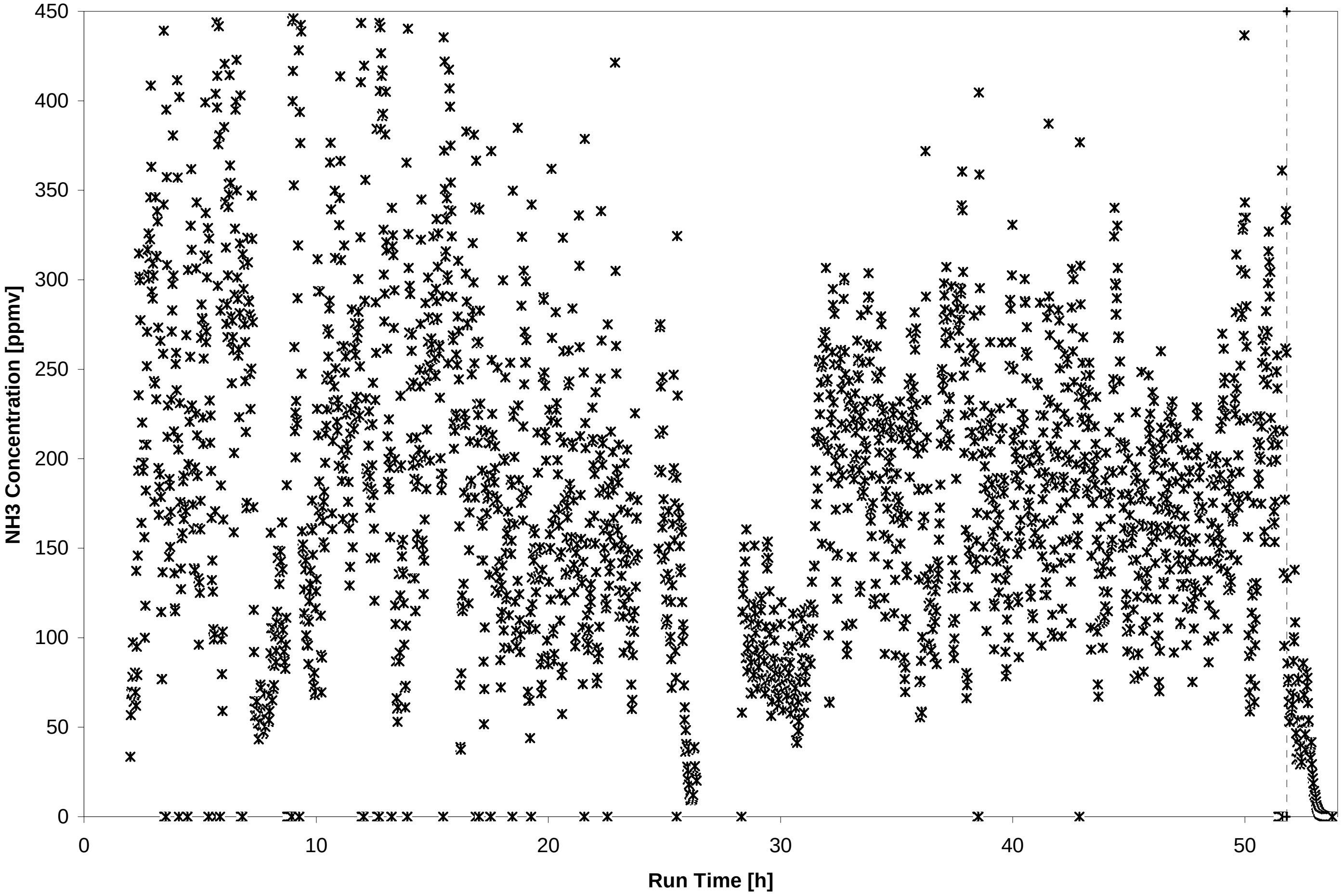

Figure 6.3.c. NH$_3$ concentrations in off-gas from FTIR for the DM100 Starch and Sugar Test.