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DM1200 Tests with C-104/AY-101 HLW Simulants, VSL-03R3800-3, Rev. 0

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;
Further Dissemination Unlimited

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VSL-03R3800-3

Final Report

DM1200 Tests with C-104/AY-101 HLW Simulants

prepared by

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for

Duratek, Inc.

and

Bechtel National, Inc.

ACCEPTED FOR
WTP PROJECT USE

For W.L. Tamosaitis
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Completeness of Testing:

This report describes the results of work and testing specified by the above-listed Test Specification(s), Test Plan(s), and Test Exception(s). The work and any associated testing followed established quality assurance requirements and was conducted as authorized. The descriptions provided in this test report are an accurate account of both the conduct of the work and the data collected. Results required by the Test Plan are reported. Also reported are any unusual or anomalous occurrences that are different from the starting hypotheses. The test results and this report have been reviewed and verified.

I.L. Pegg: ____________________ **Date:** 11/24/03
VSL Program Director/Principal Investigator

I. Joseph: Innocent Joseph **Date:** 11-24-03
Duratek Sub-Contract Manager

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List of Abbreviations

AA	Atomic Absorption Spectroscopy
ACM	Aspen Custom Modeler
ADS	Air Displacement Slurry
AOD	Air Operated Diaphragm
CFR	Code of Federal Regulation
DCP	Direct Current Plasma Emission Spectroscopy
DF	Decontamination Factor
DM	DuraMelter®
DOE	Department Of Energy
FTIR	Fourier Transform Infrared Spectroscopy
HEME	High-Efficiency Mist Eliminator
HEPA	High-Efficiency Particulate Air Filter
HLW	High Level Waste
i.d.	Inside Diameter
ISE	Ion Selective Electrode
LAW	Low Activity Waste
MS	Microsoft
MT	Metric Ton
ORP	Office of River Protection
PBS	Packed Bed Scrubber
PLC	Programmable Logic Controller
QAPjP	Quality Assurance Project Plan for Testing Programs Generating Environmental Regulatory Data
RPP	River Protection Project
RPP-WTP	River Protection Project-Waste Treatment Plant
SBS	Submerged Bed Scrubber
SCR	Selective Catalytic Reduction
TCO	Thermal Catalytic Oxidizer
TDS	Total Dissolved Solids
TFCOUP	Tank Farm Contractor Operation and Utilization Plan
TRU	Transuranic
TSS	Total Suspended Solids
VOC	Volatile Organic Compound
VSL	Vitreous State Laboratory
W.C.	Water Column
WESP	Wet Electrostatic Precipitator
WTP	Hanford Tank Waste Treatment and Immobilization Plant
XRF	X-Ray Fluorescence

SUMMARY OF TESTING

A) Objectives

This report documents melter and off-gas performance results obtained on the DM1200 HLW Pilot Melter during processing of simulated HLW C-104/AY-101 feed.

The principal objectives of the DM1200 melter testing were to determine the achievable glass production rates for simulated HLW C-104/AY-101 feed; determine the effect of bubbling rate on production rate; characterize melter off-gas emissions; characterize the performance of the prototypical off-gas system components as well as their integrated performance; characterize the feed, glass product, and off-gas effluents; and to perform pre- and post test inspections of system components.

B) Conduct of Testing

Testing was performed using a flow-sheet based C-104/AY-101 composition provided by the WTP project, from which a suitable simulant was developed for this work. Supporting glass formulation work was performed to develop a compliant glass formulation, including suitable substitutes for thorium and uranium, which are present in significant amounts in the C-104/AY-101 composition. Based on these results, melter feed simulant for these tests was prepared by a chemical vendor. The solids content of the feed was fixed based on the WTP baseline value of 20 wt% undissolved solids from pretreatment, which resulted in a melter feed yielding 528 g glass per liter. Screening tests were performed on the DM100-BL melter system as a prerequisite to proceeding to the larger-scale DM1200 tests. DM1200 testing was then performed in three contiguous 3-day segments, each at a progressively higher bubbling rate.

The DM1200 HLW Pilot Melter is a Joule-heated melter with Inconel 690 electrodes. The melter shell is water-cooled and incorporates a jack-bolt thermal expansion system. The footprint of the melter is approximately 8 ft. by 6.5 ft. with a 4 ft. by 2.3 ft. air-lift discharge chamber appended to one end; the melter shell is almost 8 ft. tall. The melt surface area and the melt pool height are approximately 32 percent and 57 percent, respectively, of the corresponding values for the full-scale HLW melter. The discharge riser and trough are full-scale to verify pouring performance. The surface of the glass pool is about 1.2 m^2, as compared to 0.108 m^2 for the DM100-BL, and the volume is about 849 liters, corresponding to about 2 metric tonnes. The feed system consists of a mix tank and a feed tank, both of which are 750-gallon polyethylene tanks with conical bottoms that are fitted with mechanical agitators. The feed tank is also fitted with baffles to improve mixing and calibrated load cells that were electronically monitored to determine the feed rate to the melter. The feed is introduced into the melter using an air-displacement-slurry (ADS) pump, which is the present RPP-WTP baseline. Feed from the ADS pump flows into the melter through a prototypic un-cooled feed nozzle that is located above the center of the glass pool. The melter and entire off-gas treatment system are maintained under negative pressure by two Paxton external induced draft blowers. This negative pressure is necessary to direct the gases from the melter to the prototypical off-gas system. The off-gas treatment system consists of a submerged bed scrubber (SBS); a wet electrostatic precipitator

(WESP); a high-efficiency mist eliminator (HEME), a high-efficiency particulate air (HEPA) filter; a thermal catalytic oxidation unit (TCO); a NO_x removal system (SCR); a packed-bed caustic scrubber (PBS); and a second HEME. The second HEME is used to limit entrained particle carryover into the balance of the VSL ventilation system; the PBS and the second HEME are not part of the WTP off-gas train, which effectively ends at the SCR. A silver mordenite column is also installed to obtain engineering data on iodine capture efficiency on a 10% slip stream of the SCR/TCO exhaust.

C) Results and Performance Against Objectives

Over eighteen and a half metric tons of feed was processed to produce almost 7 metric tonnes of glass in these tests. Cold-cap-limited, steady-state production rates of 400, 660 and 900 kg/m^2/day were maintained for test segments with bubbling rates of 8, 40, and 65 lpm, respectively. Some foaming occurred at the lowest bubbling rate and at feeding interruptions but did not prevent the attainment of steady-state conditions.

The general performance of the DM1200 and off-gas treatment system was good. A new feed tube design was tested and shown to be less prone to feed blockages observed with the previous design, providing more consistent and reliable feed introduction. The DM1200 test was preceded by a 100-hour DM100 test to ensure that the new glass formulation and melter feed were acceptable for processing in the HLW pilot melter. Extensive sets of process engineering data were collected during both tests. The glass product was close to the intended composition at the end of testing.

Isokinetic particulate samples were taken at the outlets of the melter, SBS, and WESP during the last test segment (65 lpm bubbling) to determine the efficiency of off-gas system components. Elemental DF values were determined across the melter, SBS, and WESP. Particle size distributions were determined for the melter emissions. The total solids carryover from the melter (0.72% of feed) was comparable to that observed for tests with other HLW compositions. Calculated DFs across the SBS were high due in part to the higher melter emission rate of major feed components such as silicon and iron. The WESP, which is effective in collecting finer particles, removed much of the additional particulate material exiting the SBS. As a result, the cumulative DF (Melter+SBS+WESP) was about 301,960 which is higher than for other HLW tests which used the same emission sampling protocol, i.e., where the emission sample collection time includes the period when the WESP is powered down during a deluge.

The volumes of processing solutions generated in the SBS, WESP, HEME, and PBS were documented during testing and representative samples were subjected to complete chemical analysis. The SBS solutions were close to neutral pH, due in large part to the presence of only minor amounts of acid gases in the exhaust stream. The major dissolved species were halogens, boron, and alkali metals, while the suspended species closely resembled the feed composition. The measured SBS TSS concentrations were between 700 and 2200 mg/l, whereas measured TDS values were about 2 times higher. The WESP sump fluid was also in the neutral pH region but had negligible suspended solids. The WESP solutions contained significant concentrations of nitrate, sulfate, and alkali halides. The WESP was sprayed continuously during this test and was deluged with 40 gallons of water once daily, resulting in a total blow-down volume of almost 900 gallons. The nearly 2000 gallons of liquid that accumulated in the SBS during the test originated from the condensation of water from the melter feed.

A relatively good mass balance was achieved for iodine around the melter, SBS, and WESP. Essentially all of the feed iodine was emitted from the melter and no iodine was detected in the glass product. Testing of the silver mordenite system for iodine removal was performed by taking samples at the inlet, one third down, two thirds down, and outlet of the column. No iodine was measured at the column outlet resulting in DF values of over 1500. Lower DFs at other points in the column were consistent with the partial exhaustion of the media from this and the previous C-106/AY-102 test.

The completion of the Test Objectives for this work is summarized in Table 8.1.

D) Quality Requirements

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

E) Issues

The presently required glass output of each of the WTP HLW melters of 3 MT/d corresponds to a specific glass production rate of 800 kg/m^2/d. The highest bubbling rate test on the DM1200 melter exceeded this requirement. However, it should be noted that this test used a high solids content feed (20 wt% undissolved solids) from pretreatment; lower concentrations, which the WTP now expects, will lead to progressively lower rates. It should also be noted that the full-scale WTP melter has slightly fewer bubblers per unit melt surface area than does the DM1200 (five bubblers in 3.75 m^2 vs. two bubblers in 1.2 m^2), which may lead to lower large-scale glass production rates on a per unit melt surface area basis.

Occlusion of the SBS down-comer pipe near the diffuser plate with solid deposits was again observed in these tests, despite the removal of the down-comer extension. Significant solids accumulations were also found in the film cooler and the transition line from the film cooler to the SBS. Clearly, these issues need to be understood and resolved in order to establish confidence in the long-term performance of the off-gas system design.

SECTION 1.0
INTRODUCTION

The RPP-WTP Project has undertaken a "tiered" approach to vitrification development testing involving computer-based glass formulation, glass property-composition models, crucible melts, and continuous melter tests of increasing, more realistic scales. Melter systems ranging from 0.02 to 1.2 m^2 installed at VSL have been used for this purpose, which, in combination with the 3.3 m^2 LAW Pilot Melter at Duratek, Inc. span more than two orders of magnitude in melt surface area. In this way, less-costly small-scale tests can be used to define the most appropriate tests to be conducted at the larger scales in order to extract maximum benefit from the large-scale tests. For HLW vitrification development, a key component in this approach is the one-third scale DuraMelter™ 1200 (DM1200) HLW Pilot Melter system that has been installed at VSL with an integrated prototypical off-gas treatment system. That system has replaced the DM1000 system that was used for HLW throughput testing during Part B1 [1]. Both melters have similar melt surface areas (1.2 m^2), but the DM1200 is prototypical of the present RPP-WTP HLW melter design whereas the DM1000 was not. In particular, the DM1200 system provides for testing on a vitrification system with the specific train of unit operations that has been selected for both HLW and LAW RPP-WTP off-gas treatment [2].

Previous testing with HLW simulants on the DM1000 [1] and DM1200 [3, 4] indicated that while processing rates considerably above the project baseline (400 $kg/m^2/d$) were possible with bubbling, the baseline rate was not achieved in tests performed without bubblers. None of the variables investigated, which included feed concentration, feed acidification, frit as the glass former additive, variable additions of reductant (sugar), continuous feeding (as opposed to pulsed) and increased glass temperature resulted in production rates approaching the project baseline. As a result of this testing it was concluded and recommended that the current WTP HLW melter design is not capable of achieving the baseline production rate of 1.5 Mt/d without the use of bubblers [5]. Testing has shown that the use of bubblers could also provide ORP the performance enhancement necessary to achieve the expanded capacity per melter of 3.0 Mt/d (800 $kg/m^2/d$) required under the revised WTP baseline. Based on these results and Project guidance to include bubblers in the reference design, testing was designed to determine the processing rates for each of the Phase 1 HLW feed compositions in the DM1200 melter with bubbling. The testing is detailed in a Test Specification [6] and a corresponding series of Test Plans issued to address DM1200 testing at a variety of bubbling rates and feed concentrations using AZ-101, AZ-102, C-106/AY-102, and C-104/AY-101 simulants [7-9]. The tests were conducted between 07/02 and 03/03 with summary reports for each test series submitted shortly after the completion of each test [10-13]. This final report addresses DM1200 tests over a range of bubbling rates using the HLW C-104/AY-101 simulant and corresponding melter feed. Separate final reports will be issued to cover the other three Phase 1 HLW feed compositions described in the Test Specification and Test Plans [6-9].

1.1 Test Objectives

As listed in the Test Specification for this work [6], the principal objectives of these tests are identified below. DM1200 testing covered in this final report addresses only C-104/AY-101. Any deviations from the Test Specification are noted below. For traceability to the Test Specification, test objectives are sequential and correspond to the objectives in the referenced Test Specification:

The objectives to be achieved under the Test Specification [6] are:

1. Perform analyses, laboratory and small-melter testing, as required, to assess and specify "working glass" compositions, glass forming chemicals, and additives utilizing the estimated C-104/AY-101 feed composition in this specification.
2. Utilizing the DM1200 melter and associated feed handling and off-gas treatment equipment, design and conduct testing in which representative C-104/AY-101 simulant is processed. The duration of tests shall be sufficient to achieve at least four melter glass inventory turnovers (8 MT) for each composition.
3. Determine the effect of bubbling rate on melter production rate and operating stability for C-104/AY-101 melter feed.
4. Determine the effect of feed concentration on melter production rate and operating stability for *AZ-101* melter feed. [Note: This objective was completed under another Test Plan [7].]
5. Fabricate, install and evaluate the performance of the HLW bubbler design and placement recommended by the Duratek design staff.
6. Characterize the melter emissions (particulate, aerosol, and gaseous) under nominal steady-state operating conditions for inorganic and organic compounds including the effect of air displacement slurry (ADS) pump operation on feed entrainment. Measurement of organic compounds will be satisfied through the use of Fourier Transform Infrared (FTIR) spectrometry.
7. Quantify and document the occurrence and associated operating conditions of any melter off-gas volume surging events.
8. Characterize the performance of the primary off-gas treatment equipment (submerged bed scrubber (SBS), wet electrostatic precipitator (WESP) and high-efficiency mist eliminator (HEME)) to remove particulate, aerosol and gas phase emissions under steady-state melter conditions.
9. Characterize the chemical and physical characteristics of the aqueous streams (feed, SBS, WESP, and caustic scrubber).
10. Characterize the performance of the secondary off-gas treatment equipment (selective catalytic reduction (SCR) and thermal catalytic oxidizer (TCO) and small-scale silver mordenite column) to treat NO_x, organics, and iodine under steady-state melter conditions.
11. Obtain the necessary process measurements to provide mass and energy balances throughout the systems, including process monitoring of power, voltage, current, resistance, temperatures, pressures, flow rates, and cooling water and air flows and inlet and outlet temperatures.
12. Document general equipment operations (reliability, availability, maintainability, etc.); especially non-routine equipment failure and replacement activities.

13. Perform pre- and post-test inspections of key equipment and process lines to monitor for solids accumulations and corrosion/erosion of materials, especially ammonium nitrate downstream of the SCR.
14. Operate the melter plenum pressure control using the variable air-injection control method. Assess and document control stability (melter plenum and off-gas system pressure versus time) as a function of instrument controller settings.
15. Operate and evaluate the performance of the air-displacement slurry (ADS) pump under operating conditions that are applicable to expected WTP plant operations. The ADS pump has been installed and was used during these tests; in addition, a separate Test Plan has been issued to address the detailed pump testing outlined in Section 6.0 of the Test Specification [6].
16. Conduct one of the melter tests with the SBS water circulation tubes (located at the bottom distribution plate) plugged to prevent their use. This test configuration has been requested by Process Engineering to assess the need for these tubes when combined with the perforations in the distribution plate. [Note: This objective was completed under an earlier Test Plan [7].]

The completion of the Test Objectives for this work is summarized in Table 8.1.

1.2 Test Overview

Previous melter testing with HLW simulants was conducted with recipes based on TFCOUP Rev. 1 [14]. The current Test Specification [6] stipulates the use of TFCOUP Rev. 3A [15] and that Sr/TRU precipitation products not be included with the C-104/AY-101 simulant. This change in simulated waste composition required a revised glass formulation and testing at both the crucible and DM100 melter scales prior to use in the DM1200. A 100-hour DM100 melter test was completed prior to the DM1200 melter tests in order to provide the required confidence in the new formulation. Testing parameters such as plenum and glass temperatures mimicked those used in the DM1200 tests.

After successful completion of the DM100 test, a nine day test was conducted on the DM1200. The effects of bubbling rate on glass production rates and the viable range of bubbling rates were addressed in an earlier Test Plan [7]. The results from these tests were used to define the “Low,” “Medium,” and “High” bubbling rates used for the present tests. During each test segment, the bubbling rate was fixed and the feed rate adjusted to attain the desired near-complete cold cap. The solids content of the feed was fixed based on the present WTP baseline value for the solids content of the feeds from pretreatment since the effect of feed solids content was addressed in an earlier Test Plan [7]. Each test segment had a nominal duration of three days. Variables that were held constant during each test to the extent possible included melt temperature, plenum temperature, cold cap coverage, the waste simulant composition, glass-forming additives, and the target glass composition. The feed rate was increased to the point that a constant, essentially complete, cold cap was achieved, which was used as an indicator of a maximized feed rate for each test. A variety of processing data were taken throughout the test to document the performance of the feed, melter, and off-gas systems.

1.3 Quality Assurance

This work was conducted under an NQA-1 (1989) and NQA-2a (1990) Part 2.7 based quality assurance program that is in place at the VSL. This program is supplemented by a Quality Assurance Project Plan for RPP-WTP work [16] that is conducted at VSL. Test and procedure requirements by which the testing activities are planned and controlled are also defined in this plan. The program is supported by VSL standard operating procedures that were used for this work [17].

This work did not generate data to support waste form quality qualification activities; nor did it generate data to support environmental regulatory data to support permitting activities. Therefore, this work was not subject to DOE/RW-0333P or the WTP QAPjP [18] for environmental and regulatory data.

1.4 Melter System Description

1.4.1 Feed System

The feed material for these tests was prepared and controlled according to VSL specifications by a chemical supplier, as detailed in Section 2. Each batch of feed slurry was shipped to VSL in lined 55-gallon drums (approximately 16 per shipment), which were staged for unloading into the mix tank. Both the mix tank and the feed tank are 750-gallon polyethylene tanks with conical bottoms that are fitted with mechanical agitators; the feed tank is also fitted with baffles to improve mixing. Any required feed additive is added to the mix tank manually. Five calibrated load cells directly mounted on the legs of the feed tank were used to measure additions to, and removal from the feed tank and were electronically monitored to determine the feed rate to the melter. The requisite amount of feed is pumped to the feed tank from the mix tank; measured amounts of water were combined by weight with the feed at this point to adjust the concentration of the melter feed. The material in the feed tank is constantly recirculated from the feed tank discharge outlet, at the tank bottom, to the tank inlet at the top, which provided additional mixing.

The feed is introduced into the melter using an ADS pump, which is the present RPP-WTP baseline. The feed transfer line extends from the outlet of the ADS pump in the feed tank to the top of the melter. Feed is introduced into the melter through a prototypic un-cooled feed nozzle that is located above the center of the glass pool. Only one feed tube is used to represent the planned number of feed tubes per unit melt surface area in the full-scale RPP-WTP HLW melter. The operation of the ADS pump is controlled from the melter computer control system. The ADS pump works by opening the pump reservoir to the feed tank using a double-acting air cylinder and mechanical link to actuate the poppet. The reservoir is filled with slurry by gravity. After sufficient time is allowed to fill the reservoir (a few seconds), the poppet is toggled to close the reservoir to the tank and open the transfer line. After a two second delay time the reservoir is pressurized with air to transfer the slurry (about 1.6 liter/shot) to the melter. This cycle is repeated at the rate required to provide the desired feed rate.

A backup system is used when necessary to introduce feed into the melter with an air operated diaphragm (AOD) pump system that simulates the pulsed feeding action of an ADS pump. 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 each of the feed lines and can be used to automatically clear the feed line into the melter after each pulse; air at 40 psi is flowed for 3 seconds through the 0.275" i.d. line for this purpose.

1.4.2 Melter System

The DuraMelter™ 1200 (DM1200), which is the HLW Pilot Melter, was used for these tests. The DM1200 is shown schematically in Figures 1.1 and 1.2. The DM1200 is a Joule-heated melter with Inconel 690 electrodes and thus has an upper operating temperature of about 1200°C. The melter shell is water-cooled and incorporates a jack-bolt thermal expansion system. The footprint of the melter is approximately 8 ft. by 6.5 ft. with a 4 ft. by 2.3 ft. air-lift discharge chamber appended to one end; the melter shell is almost 8 ft. tall. The melt surface area and the melt pool height are approximately 32 percent and 57 percent, respectively, of the corresponding values for the full-scale HLW melter. The discharge riser and trough are full-scale to verify pouring performance. Other aspects of the discharge system are also prototypical such as the chamber ventilation scheme. The glass contact refractory is Monofrax® K-3 while the plenum area walls are constructed of Monofrax® H refractory. The surface of the glass pool is 34" by 54" with a glass depth of nominally 25". The resultant melt volume is approximately 45,000 cubic inches (735 liters), which represents a glass tank capacity of more than 1.7 metric tons of glass. However, since the typical operating glass level is closer to 29 inches, the effective glass volume during testing is actually about 849 liters, giving an inventory of about 2.0 metric tons, which is larger than had been previously assumed [19]. The DuraMelter™ 1200 is fitted with one pair of electrodes placed high on opposite walls of the melter as well as one bottom electrode. The side electrodes are 11" by 34" giving an electrode area for the pair of about 750 sq. in. Depending on the glass level, the plenum space extends about 33" to 36" above the melt surface resulting in a plenum volume ranging from about 43 to 46 ft^3. Cross-sectional diagrams of the melter illustrating the discharge chamber and electrode configuration are provided in Figures 1.1 and 1.2.

The single-phase power supply to the melter electrodes (250 kW design power) is derived from the DuraMelter™ 1000 transformers by wiring them in parallel and using a single large silicon controlled rectifier. Current can be passed either from the side electrodes to the bottom electrode or between the two side electrodes only, by rearranging jumpers; only side-to-side operation was used for the present tests. Programmable process controllers are installed and can be used to control temperature or power. The melt temperature is controlled by configuring the process controller to maintain constant power and adjusting the power set-point as needed to maintain the desired operating temperature. Alarms can be set to detect out-of-range temperatures or power in the melter. Backup process controllers are installed to be used in case of failure of the main controllers. The entire system is supported by a back-up generator that is tripped on in the event of a power outage.

The DuraMelter™ 1200 has several other features. The lid refractory is prototypic and also includes a two-piece construction, which simulates the seam needed for the LAW lid that was planned to be fabricated in three pieces. Nozzles are provided for the off-gas film cooler, a standby off-gas port, discharge airlift, along with 11 ports available for top-entering bubblers, start-up heaters and other components as needed. In addition, a bubbler arrangement is installed in the bottom electrode with the objective of developing permanent bubblers for possible use on future melters. For the present tests, two top-entering bubblers were used, located in diagonally opposite corners. Each bubbler was oriented with its discharge nozzle 6 inches above the melter floor and pointed along the diagonal toward the center.

1.4.3 Off-Gas System

The melter and entire off-gas treatment system are maintained under negative pressure by two Paxton external induced draft blowers. This negative pressure is necessary to direct the gases from the melter to the prototypical off-gas system. The off-gas treatment system, shown schematically in Figure 1.3, consists of a submerged bed scrubber (SBS); a wet electrostatic precipitator (WESP); a high-efficiency mist eliminator (HEME), a high-efficiency particulate air (HEPA) filter; a thermal catalytic oxidation unit (TCO); a NO_x removal system (SCR); a packed-bed caustic scrubber (PBS); and a second HEME. The second HEME is used to limit entrained particle carryover into the balance of the VSL ventilation system. Note that the PBS and the second HEME are not part of the WTP off-gas train, which effectively ends at the SCR. A silver mordenite column is also installed to obtain engineering data on iodine capture efficiency on a 10% slip stream of the SCR/TCO exhaust. The silver mordenite system, as well as an additional sulfur-impregnated carbon column for removal of mercury, is being considered for use in the WTP off-gas system. The system can be functionally divided into four subsystems:

<u>Particulate Removal</u>:	Components from the submerged bed scrubber (SBS) to the HEPA serve to remove essentially all of the particulate from the gas stream with an estimated removal efficiency of greater than 99.9999% for particles greater than 0.3 μm in size. In the RPP-WTP facility, this provision serves to segregate the radioactive from the non-radioactive components in the system for maintenance and handling purposes.
<u>VOC Control/Acid Gas</u>:	The thermal catalytic oxidation (TCO) unit is designed to oxidize any hazardous organics that are present in the off-gas stream. This is followed by a SCR to remove NO_x gases and a packed-bed scrubber (PBS) to remove remaining acid gases.
<u>Stack System</u>:	The emergency/bypass exhaust system, which includes a second HEPA, and the primary off-gas system both feed into the building stack system for exhausting to the atmosphere.

Liquid Processing:	Components including the water spray lines, liquid sampling and water storage tanks, as well as the effluent evaporator, function to sample and process the system liquids for recycle or discharge.

With minor exceptions, noted above, the DM1200 off-gas system processing sequence follows the proposed design for the full-scale RPP-WTP HLW melter system. Additional information on the off-gas processing units is found in Reference [2].

Initial quenching of the melter exhaust gas stream is effected by the film cooler. Immediately downstream of the film cooler is the injection point for control air, which is used to regulate melter pressure. The gas entering the balance of the off-gas system is at a temperature of about 250 to 350°C and a flow rate of about 100-250 scfm, of which about 10-80 scfm is water vapor. The off-gas is then rapidly quenched by direct liquid water contact in the Submerged Bed Scrubber (SBS), which also effects removal of most of the larger particulates. The piping between the film cooler and SBS has a high superficial gas velocity to minimize particulate deposition. The gas stream leaving the SBS is at a low temperature (typically between 40-50°C). Further mist and particulate removal is effected in the WESP, HEME, and HEPA. The TCO and SCR follow the particle removal components and serve to destroy organic compounds and nitrogen oxides. Finally, the PBS provides acid gas removal. Water sprays are located in the WESP, PBS, HEME #1 and facility HEME #2 to wash down deposits and dissolved species into their respective collection sumps from which they can be sampled. The system components are fabricated from corrosion resistant materials including AL6XN in the SBS and 316L stainless steel and various plastics in less demanding locations. There are extensive provisions for sampling both the gas and liquid streams throughout the system in order to collect mass balance information and removal efficiency data for each treatment stage.

The off-gas system maintains the melter plenum under slight negative pressure, typically about -5 in. W.C. The plenum pressure is controlled by means of an air injection system that introduces a controlled air flow into the off-gas jumper just after the film cooler. The air is supplied by a blower through a diverter valve. The setting of the diverter valve, and therefore the air flow rate, is controlled by a process controller that responds to the signal from a melter pressure transducer. When the plenum pressure becomes more positive, the air injection flow rate is decreased, which tends to restore the pressure to the set-point. Conversely, the flow rate is increased when the plenum pressure becomes more negative.

A silver mordenite system was added to the DM1200 system to obtain engineering data on iodine capture efficiency. This system treats a slip-stream of about 10% of the off-gas stream exiting the SCR, which is then returned to the PBS[1]. A schematic diagram of the silver mordenite system is shown in Figure 1.4. The slip-stream gas is first cooled in a non-condensing heat exchanger before entering the top of a glass column that is loaded with 1/16” diameter x 0.12” length pellets of C-Chem Ag-900 silver-impregnated zeolite. The active part of the column is a cylinder, 32” long and 6” in diameter containing about 30 lb of the zeolite packing (57.4 lb/ft^3 bulk density). C-Chem claims an external void fraction of 37% for this material. Temperatures at

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[1] Note that after the completion of these tests, the WTP design was revised to place the silver mordenite column *before* the TCO/SCR; the results of DM1200 tests performed with that configuration will be presented in later test reports.

both the inlet and the outlet, the differential pressure across the column, and the flow at the outlet of the column were monitored continuously. The gas exiting at the bottom of the column is further cooled to protect the down-stream blower. Design ranges of flow conditions at specific points along the system are indicated in Figure 1.4. There are four analytical sampling ports provided: one at the inlet, one each located at 1/3 and 2/3 of the column length, and one at the outlet of the column.

SECTION 2.0
WASTE SIMULANT AND GLASS FORMULATIONS

The composition of the C-104/AY-101 HLW simulant used for these tests was derived and specified in the BNI Test Specification [6]. The C-104/AY-101 waste data and blending assumptions stipulated in the Test Specification are different than those used previously and therefore new glass formulations were developed and tested to support this work. This Section summarizes the composition of the simulant provided in the Test Specification and describes the corresponding glass formulations selected for melter testing.

2.1 C-104/AY-101 Waste Simulant

Calculation of the composition of the C-104/AY-101 HLW simulant follows a similar approach as that for C-106/AY-102 [9]: the TFCOUP data [15] are used in conjunction with the Aspen Custom Modeler (ACM) model and separation (ultra-filtration) factors to estimate the HLW composition after pretreatment operations. The predicted amount of the Envelope D solids (stream FRP02) that will be processed daily is 3.04E+04 lb/day on a dry solid basis, while the recycle stream to be processed remains the same as the C-106/AY-102 case (1.31E+03 lb/day). The separation factors for C-104/AY-101 in many cases are greatly different than those for C-106/AY-102 (e.g., all factors are equal to or less than 1), as can be seen in Table 2.1.

Another difference in the C-104/AY-101 simulant formulation is found in the waste blending scenario [6]. Products from both Sr/TRU-removal of Envelope C waste and Tc-removal of Envelope A waste are *not* added and the compositional basis for the Cs-removal eluate is much simpler than that used for C-106/AY-102. Instead of including all components found in an actual eluate sample, only three components (i.e. potassium, sodium, and nitrate) are added, resulting in a blended waste that is essentially identical to the HLW solids (Table 2.1). The selected waste blending scenario has no net effect on glass formulation since nitrate is volatile and sodium is a glass-forming additive, while the slight increase in potassium is negligible (see below).

2.2 C-104/AY-101 Glass and Melter Feed Formulations

A number of glasses have been formulated, prepared at the crucible scale, and tested with the C-104/AY-101 simulant listed in Table 2.2. This simulant consists of 22 components and does not include any noble metals or other minor components (i.e., Rb_2O and components present at < 0.05 wt% oxide); Nd_2O_3 substitutes for Pr_2O_3 in this simulant. Waste loadings of C-104/AY-102 glasses were found to be limited primarily by the liquidus temperatures of Th- and Zr-containing phases. The reference glass selected for these melter tests is HLW98-96, the composition of which is also found in Table 2.2.

The glass HLW98-96 has a total waste loading of 34.75 wt%, all but 0.1 wt% of which is from Envelope D waste. As discussed above, this glass complies with the contract minimum component requirement by loading > 4.0 wt% of ThO_2, instead of the > 12.5 wt% of Fe_2O_3 in the C-106/AY-102 case. Since 21.17 wt% of (Al_2O_3+Fe_2O_3+ZrO_2) in HLW98-96 originated from Envelope D waste, the glass also meets the minimum component requirement in a way similar to the AZ-101 and AZ-102 test glasses. Characterization of HLW98-96 was completed to ensure that it meets the various processing and performance requirements. Heat treating HLW98-96 at 950°C for 70+ hours results in < 0.2 vol% of crystalline phases that include ZrO_2, $ZrSiO_4$, ThO_2, and spinel. The measured viscosity and electrical conductivity of HLW98-96 at 1150°C are 57 P and 0.28 S/cm, respectively. The normalized 7-day leach rates of HLW98-96 are (in g/(m^2-day)) 0.035, 0.042, 0.029 and 0.018, respectively, for B, Li, Na and Si, compared with the corresponding values of 1.27, 0.64, 0.84 and 0.27 for the reference glass [28].

For pilot-scale melter testing, it was necessary to select replacements for thorium and uranium since those constituents could not be included in the melter feeds to the DM1200 vitrification system. The selected surrogates were tested by preparing crucible melts with substitution of the surrogates for the radioactive components and then comparing the various properties of the prepared glass with those of the original glass.

Based on chemical and other considerations (e.g., ZrO_2 is not chosen to replace ThO_2, despite their similarity chemically, because ZrO_2 is already present at a rather high concentration in the target glass), the following substitutions were made and tested:

- HLW98-96A: substitution of CeO_2 and Nd_2O_3 respectively for ThO_2 and UO_2 on a (elemental) molar basis;
- HLW98-96B: substitution of HfO_2 and Nd_2O_3 respectively for ThO_2 and UO_2 on a (elemental) molar basis;
- HLW98-96C: substitution of HfO_2 and Nd_2O_3 respectively for ThO_2 and UO_2 on a weight basis;
- HLW98-96D: renormalization of HLW98-96 after ThO_2 and UO_2 are deleted from the formulation.

After characterization of the prepared glasses was completed, HLW98-96D (i.e., renormalization after removal of ThO_2 and UO_2) was selected for DM1200 testing since the three other variants exhibited significantly greater crystallization on heat treatment than did the original glass. For comparison, the measured viscosity and conductivity of HLW98-96D (at 1150°C) are 65 P and 0.47 S/cm, respectively, while the crystalline phase identified after 70 hours of heat treatment (at 950°C) is <0.1 vol% of a Zr-containing phase. Table 2.3 provides the simulant oxide composition for C-104/AY-101 formulated by omitting the radioactive ThO_2 and UO_2 along with the composition of HLW98-96D. The composition used for DM1200 testing is also given in Table 2.3, which includes added concentrations of I and CsO that were spiked for analytical purposes.

The compositions of the simulant and the melter feed prepared for the production of 1 MT of C-104/AY-101 glass are presented in Table 2.4. The suspended solids in the *simulant* is assumed to be 20 wt%, which is equivalent to 21.5 wt% total solids, based on the data from AZ-102 testing [20]. The theoretical glass yield of the resulting feed is 357 g of glass/kg of feed (about 500 g/l of feed, dependent on feed density). Melter feeds were produced by NOAH Technologies Corporation, the supplier of simulant and feed samples used in previous testing on the DM100 and DM1200 melter systems.

2.3 Analysis of Feed Samples

2.3.1 General Properties

Feed samples were analyzed from each distinct feed tank charging or at least once per day of operation to confirm the chemical composition and physical properties. Sample names, sampling dates, and measured properties are provided for DM100 and DM1200 feed samples in Table 2.5. All samples were taken from the feed line immediately upstream of the entrance point to the melter. The measured glass yields were slightly higher than the target glass yield of 357 g of glass per kg of feed but were within 6% of that value; consequently, the target value was used for calculating glass production rates. The average measured glass yield on mass per volume basis of 528 g glass per liter of feed was slightly higher than the value estimated (500 g/l) before the feed density was known. All measured parameters, including glass conversion ratio, water content, density, and pH, fall within narrow ranges, confirming the relative consistency of the melter feed. One feed sample, BLF-F-85A, had a higher measured water content and lower solids content than all the other samples. This difference was attributed to sampling bias and therefore the results for this sample were not included in the feed averages. The measured values for the DM1200 and DM100 feed samples were very similar, as expected in light of the shared source and recipe.

2.3.2 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 [21]. 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 measured at equilibrium. 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. All of the measurements in this work were made at 25°C; previous work [21], which examined a range of temperatures, showed a relatively weak effect of temperature.

Rheograms which show the feed viscosity versus shear rate for the DM1200 and DM100 feeds are presented in Figure 2.1; measured values for viscosity at selected shear rates and the yield stress values are shown in Table 2.5. The yield stress and viscosity values for the DM1200 and DM100 feed samples are very similar, as expected given their shared origin and composition. The values are bracketed by measurements on feed samples from other HLW simulants: those from AZ-102, which are slightly higher [22], and those from C-106/AY-101, which are slightly lower [23]. Rheological data from actual C106/AY102 waste are not yet available for comparison.

2.3.3 Chemical Composition

Feed samples collected during this test were subjected to chemical analysis using x-ray fluorescence (XRF). The chemical compositions of the feed samples from the test were determined by first making a glass from the feed samples via crucible melt. The glass was subsequently crushed and analyzed directly by XRF. Target values for boron and lithium oxide were used for normalizing the XRF data since they were not determined by XRF. The data are presented in Tables 2.6 – 2.8 and are compared to the target composition.

The compositional analysis results can be discussed by dividing the 21 elements into three categories: major elements with measured oxide concentrations greater than 3%, intermediate elements with measured oxide concentrations between 0.5 and 3%, the remainder being minor elements. The major elements constitute the bulk of the glass and, therefore, largely determine its properties. XRF results for the major elements (Al, Fe, Na, Si, and Zr), except for zirconium, are within 10 percent of the target composition for most of the feed samples. The zirconium surplus measured in DM1200 product glasses (See Section 6.1) was considerably less than for the DM1200 feed samples (13 vs. 24%), suggesting that sub-sampling feed samples for analysis may bias feed analysis. Both elements in the intermediate concentration range (Mn and Zn) were within 10% of the target value when considering all the samples. The large number of minor elements (Ca, Cr, Cs, Cu, F, I, La, Nd, Ni, P, Pb and Ti) are all contributed by the simulated waste or spiked into the feed at low levels. Deviations were not calculated for these oxides due to the high volatility of many of the constituents and the uncertainty associated with deviation calculations on very low concentrations. As expected, highly volatile elements such as halogens are under-represented in the glasses. Conversely, common elements such as calcium and phosphorus, which are typical impurities in bulk chemicals, are over-represented when the constituent is a minor component. The excess in titanium oxide in the feed samples has also been observed in previous studies [19, 23-25], suggesting that titanium is a common contaminant in the source chemicals. Potassium, magnesium, sulfur, and strontium, which are not included in glass formulation, were detected at low levels in the feed as impurities.

SECTION 3.0
DM100 OPERATIONS

The DM100-BL vitrification system has served extensively as a screening tool for subsequent tests on the DM1200 HLW pilot melter [10, 23, 26]. Factors such as new HLW glass formulations, different glass forming additive sources, and feed nitration were successfully tested on the smaller melter prior to use on the DM1200. A similar tiered approach has also been employed with the combination of the DM100-WV and the LAW Pilot Melter for LAW testing. The C-104/AY-101 simulant and glass composition had not been tested previously in a melter and, therefore, a DM100 test was conducted to identify any issues with the feed or glass prior to embarking on the DM1200 tests. This section presents a description of the DM100-BL system, glass product analysis, and screening level process data from the DM100 test.

3.1 Melter System Description

3.1.1 Feed System

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. 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 mechanical timer-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.

3.1.2 Melter System

The DM100-BL unit is a ceramic refractory-lined melter fitted with a total of five electrodes: two pairs of opposing Inconel 690 plate electrodes as well as a bottom electrode. Power can be supplied in either three-phase or single-phase configurations. All of the tests in the present work were performed with the upper and lower electrodes on each side connected together and powered by a single-phase supply; the bottom electrode was not powered. Melt pool agitation is achieved by either a removable lance entering from the top of the melter or a permanent bubbler installed through the bottom electrode. The lance bubbler was used for this test. The glass product is removed from the melter by means of an airlift discharge system. The melter has a melt surface area of 0.108 m^2 and a variable glass inventory of about 120 kg, when only the bottom pair of electrodes is used and between 180 and 200 kg when both pairs of electrodes are used. In these tests both pairs of electrodes were used.

3.1.3 Off-Gas System

For operational simplicity, the DM 100s are equipped with dry off-gas treatment systems 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, 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 equipped with internal coarse filter elements followed by conventional pre-filters and HEPA filters. The temperatures of the cyclonic filters and the HEPAs are held above 100°C to prevent moisture condensation. For each melter, the entire train of gas filtration operations is duplicated and each train is used alternately. An induced draft fan completes the system.

3.2 Melter Testing

The DM100 test was conducted between 1/13/03 and 1/17/03, producing 455 kg of glass. A summary of the test conditions and results is provided in Table 3.1. The total test duration, including the time for water feeding was 100.8 hours. The measured glass production rate is depicted in Figure 3.1 as cumulative and one-hour moving averages. The glass production rate varied about 20% from the average rate of about 1000 kg/m^2/day over the course of the test. No processing problems such as foaming were encountered during the test other than occasional dried feed bridging from the walls across melt pool. This is much more of an issue in smaller melters and, therefore, was not projected to be a problem with the larger DM1200.

A variety of operational measurements were recorded during these tests, the most important of which are glass temperature (Figure 3.2), electrode power (Figure 3.2), plenum temperature (Figure 3.3), and glass bubbling rate (Figure 3.4). The target glass temperature of 1150ºC was successfully maintained for most of the glass pool during the test. Plenum temperatures were higher than the 400 - 500ºC target range for the DM1200 as a result of intentional openings in the cold-cap required for prevention of excessive bridging across the melt pool. Electrode power varied by only about 2 kW from an average of about 24 kW. Bubbling increased at the beginning of the test to about 18 lpm as the cold cap developed. The average bubbler flow rate was the same as in the corresponding C-106/AY-102 test [23] even though the production rate was about 15% lower.

3.3 Glass Product Analysis

Over 450 kg of glass product was discharged from the melter through an airlift system into 5-gallon pails. The discharged product glass was sampled from each pail by removing sufficient glass from the top for total inorganic analysis. Product glass masses, discharge date, and the analyses performed are listed in Table 3.2.

Glass samples were crushed and analyzed directly by XRF. The target values for the boron and lithium oxide concentrations were used for normalizing the XRF data since boron and lithium were not determined by XRF. Analyzed compositions for discharged glass samples are provided in Table 3.3. There was reasonable agreement with the target composition for the majority of oxides and, in particular, for the major oxides, as described for feed samples in Section 2.3.3, even though the melter had not experienced three complete turnovers (540 - 600 kg of glass produced) at the end of the test. Zirconium was closer to target in the discharged glass than in the feed samples, whereas aluminum was farther from the target. Sulfur, magnesium, strontium and potassium were again observed in the glass at very low levels, even though they are not included in the feed recipe. Trace amounts of arsenic and antimony remained in the glass product from the previous C-106/AY-102 tests [23]. No iodine was retained in the glass product, consistent with its known volatility.

Compositional trends from the XRF data are plotted for selected elements in Figures 3.5-3.7. The graphs illustrate three trends: elements with oxide concentrations that either did not change as a result of the similarity to the previous C-106/AY-102 composition [23] (Figure 3.6), systematically decreased in concentration towards target (Figure 3.5 and 3.7), or systematically increased towards target (zirconium shown in Figure 3.6). The oxides of silicon, boron, calcium zinc, and lithium, changed little over the test due to similarities between the two glass compositions. The principal compositional change, from the C106/AY102 composition existing in the melter at the start of testing, was the large increase in zirconium oxide at the expense of Sr/TRU removal products (Mn and Sr) present in the C-106/AY-102 simulant (Figure 3.5 and 3.7).

SECTION 4.0
DM1200 OPERATIONS

Melter tests were conducted on the DM1200 with the HLW C-104/AY-101 simulant between 2/19/03 and 2/28/03, producing almost 7000 kg of glass. A summary of the test conditions and results is provided in Table 4.1. The total test duration, including the time for water feeding and cold-cap burn-off, was 222.4 hours. The test consisted of three 3-day segments of successively higher bubbling rates of 8, 40, and 65 lpm, respectively. The measured glass production rate is depicted in Figure 4.1 as cumulative and one-hour moving averages for each of the three segments. The three steady-state production rates (400, 660, and 900 kg/m^2/day) were obtained for at least half of each three-day segment and almost the entirety of the first segment. Minor foaming occurred on the surface of the glass during the first test segment but diminished as bubbling increased over the course of the test. The exhaust stream was sampled for particles during the last two days of testing after the final steady-state rate was reached.

The ADS pump was used for the entire HLW C-104/AY-101 test. The prototypical feed tube used with the ADS pump is not cooled and has a much greater tendency for stalactite formation on the feed tube tip, which in turn results in feed being directed into the melter in unpredictable and often undesirable directions. As necessary in the case of extreme build ups, stalactites had to be mechanically removed, which was generally accomplished by tapping the external portion of the feed tube with a rubber mallet. During the last day and a half of the test, a new feed tube design was employed which lessened the extent of stalactite formation to the point that mechanical intervention was unnecessary.

A variety of operational measurements recorded during these tests, including temperatures throughout the melter system, are given in Table 4.2. The glass temperatures for most of the glass pool averaged 1132-1144ºC, slightly below the target of 1150ºC, as illustrated in Figure 4.2. Bulk glass temperatures were relatively constant throughout the glass pool except near the surface (27" from the floor), where temperatures were lower due to the thermocouples being in or near the cold cap. Temperatures at most of the locations in the glass pool decreased slightly during the last three-day test segment as bubbling was increased. Plenum temperatures (Figure 4.3) were typically between 500 - 600ºC, with higher temperatures at the beginning of the test during cold cap formation, and downward spikes to as low as 400ºC during first-segment foaming events. Visual observations of the cold cap corroborated the plenum temperature indications that melt pool coverage was nearly complete for the vast majority of the test.

Electrode temperatures averaged below 1155ºC throughout testing. The temperature difference between the East and bottom electrodes was about 150ºC at the beginning of the test and decreased to only about 25ºC at the end of the test, as shown in Figure 4.4 (note that the bottom electrode was not powered in these tests). The East electrode was about 15 to 25ºC hotter than the West throughout the test. This small temperature difference between the two sides of the melter has been observed over the lifetime of the DM1200 [3, 4, 19, 22-25]. Differences between side and bottom electrode temperatures are greater in HLW tests, which do not use the bottom bubbler [4, 22, 23], than in the LAW tests, which employ them [19, 24, 25]. The discharge chamber and riser temperatures were largely maintained above 950ºC throughout the tests. Gas temperatures after film-cooler dilution typically ranged between 300ºC and 370ºC but were higher during periods of higher plenum temperatures, such as the beginning of the test as the cold cap was forming, and lower during the periods of water-cleaning of the film cooler (once every 12 hours).

Conditions in the glass pool are illustrated for electrical properties in Figure 4.5, level and density in Figure 4.6, and bubbling in Figure 4.7. Electrode power increased from about 90 to 160 kW over the course of testing as bubbling and production increased, as expected. The fluctuations of about 25 kW during the first test segment were responses to foaming on the glass surface. (Detection of glass surface foaming is based primarily on visual observations; however, there are often accompanying indications in glass level, density, and resistance.) Abrupt decreases in power at 137 and 185 hours run-time to respond to minor foaming events that resulted from brief interruptions in feeding required to repair an exhaust flow sensor in the final exhaust stack and to replace the feed tube, as discussed above. The glass level fluctuated over the course of the test from 27 to 29 inches from the floor. The glass density largely remained between 2.30 and 2.45 g/cc, except for downward spikes of about 0.02 g/cc which occurred at the beginning of the test, and at 87 hours run time when feeding was paused to reset the control system, as well as the brief feed interruptions at 137 and 185 hours run time. The target total bubbling rates of 8, 40 and 65 lpm were held for each three-day segment, as shown in Figure 4.7. The average values for total bubbling for the last two segments given in Table 4.2 are slightly below the target because the time for transitioning up in bubbling rate is included. Lance bubbler flow rates were skewed slightly to prevent buildup of feed on the West side of the melter for portions of the last test segment. The steadiest portion of the test with respect to cold cap coverage and behavior, feed rate (Figure 4.1), plenum temperature (Figure 4.3), electrode temperature (Figure 4.4), electrode power and glass resistance (Figure 4.5), and glass density, occurred at the end of the test after the new feed tube was installed. As usual, power per unit glass production decreased with increasing production rate and was similar to previous tests with HLW AZ-101 feeds that had comparable water contents [4, 22, 23]; it was, however, much higher than for the previous LAW tests (3.6-5.0 vs. 1.6-2.0 kW/kg glass) [19, 24, 25] due to the higher feed water content and much lower glass production rates.

SECTION 5.0
DM1200 OFF-GAS SYSTEM PERFORMANCE

The off-gas treatment system, shown schematically in Figure 1.3 consists of a submerged bed scrubber (SBS); a wet electrostatic precipitator (WESP); a high-efficiency mist eliminator (HEME 1); a heater; a high-efficiency particulate arrestor (HEPA); a TCO/SCR catalytic unit, which includes a heater, a thermal catalytic oxidation unit (TCO), and a selective catalytic reduction unit (SCR) equipped with an ammonia injection system; a silver mordenite system for iodine capture, a packed-bed caustic scrubber (PBS); a high-efficiency mist eliminator (HEME 2); and a second HEPA on the bypass off-gas system. A silver mordenite system was installed in January 2003, before the HLW C-106/AY-102 test, which treats a slip-stream of about 10% of the off-gas stream exiting the SCR before returning it prior to the PBS. A schematic diagram of the silver mordenite system is shown in Figure 2.4. Data on the off-gas system performance collected during the test with HLW C-104/AY-101 feed are presented and discussed in this section.

5.1 Off-Gas System Test Results

Data for each of the off-gas system components, logged by the LabVIEW data acquisition and control software, were imported into MS Excel files for data manipulation and plotting. Time “0” on the x-axis of each data plot corresponds to the start of water feed into the melter at the beginning of the first test segment; the two remaining test segments were appended in chronological order. Where indicated, data were smoothed by time averaging instantaneous measurements logged at two minute intervals to reduce data scatter and the number of data points for the plots. The average, minimum, and maximum values of the measured off-gas system parameters are given in Table 5.1. A plot of the typical sequence of gas temperatures through the DM 1200 off-gas system at various locations is given in Figure 5.1.

Between about 64.3 - 66.0 and 136.8 - 137.7 hours of operations the feed was turned off due to malfunction of the roof blower and LabVIEW module, respectively. Control air was turned off between 115.1 and 116.0 hours to install a new controller. The failure of the LabVIEW module resulted in some incorrect instrument readings and operational adjustments until the module was fixed. During this time, the melter operations were controlled manually. Abnormal spikes are apparent in many of the data plots between about 136 and 138 hours of operation.

5.1.1 Melter Plenum, Film Cooler, and Transition Line Performance

The time-averaged (hourly average values) computer logged melter pressures measured at the level detector and instrument ports at two-minute intervals are shown in Figure 5.2. The average melter pressure was -3.9 in. W.C and melter pressure ranged from -6.9 to 0.1 in. W.C.

The computer logged melter pressures measured at the instrument port and calculated control air flow rates are plotted in Figure 5.3. The control air flow rate averaged 45.8 scfm during the test. Between 12.3 and 115.1 hours the control air was operated manually. Between 115.1 and 116.0 hours, the control air was turned off and a new controller for the control air was installed. After the new controller was operational, the melter pressure increased slightly. At 185.6 hours of operations, feeding was paused for 13 minutes to change the feed tube to the new design and the melter off-gas was diverted into the emergency off-gas system, which resulted in a brief spike of about 0.1 in. W.C. melter pressure.

The differential pressures across the transition line and film cooler are also given in Figure 5.2. Some sudden decreases in the film cooler differential pressures due to cleaning of the film cooler can be seen; however, the time-averaging used for the figure masks the effect somewhat. The film cooler was rinsed every 12 hours with 5 liters of water. After about 75 hours, the measured apparent transition line differential pressure increased steadily due to clogging of the differential pressure sensor port. At 206.6 hours of operation, the transition line differential pressure fluctuated erratically, so the sensor port was cleaned.

The film cooler and transition line sections were inspected in detail at the end of the test. The general layout of the film cooler and transition line sections is shown in Figure 5.4. The film cooler is shown on the right hand side of the photograph. Transition line section #1 is located on the right, above the film cooler, and has a Y shape. Transition line section #2 is a long and slightly curved portion following transition line section #1. Transition line section #3 is a shorter straight part following section #2. The transition line bellows is a short section located as the last section in Figure 5.4. The transition line SBS inlet, which is not shown in Figure 5.4, has a similar shape to transition line section #1 and connects the transition line bellows to the SBS.

The masses of the solid deposits removed from the film cooler and transition line sections are given in Table. 5.2a. Photographs of the solid deposits at the inlet and outlet of the film cooler are shown in Figures 5.5 through 5.7. Photographs of the solid deposits at the inlet and outlet of transition line section #1 are provided in Figures 5.8 and 5.9. Photographs of the solid deposits at the inlet and outlet of transition line section #2 are given in Figures 5.10 and 5.11. The largest mass of solids (3.11 kg) was collected from transition line section #2. DCP analysis (Table 5.2b) of solids taken from this section (sample Q12-T-144B) shows composition similar to that of AZ-101, AZ102, C-106/AY-102 and C-104/AY-101 melter feeds for many components (e.g., Al_2O_3 about 4%, B_2O_3 about 7%, Fe_2O_3 about 12 %, Na_2O about 7% and SiO_2 about 26%). An exception is SeO_2 which was present only in C-106/AY-102 feed at low amount (~0.4%). However, since SeO_2 is a semi volatile oxide, higher (~5%) SeO_2 presence in transition line #2 deposits is reasonable. Other notable elements were zinc, zirconium, lithium and manganese which also exist in all of the four HLW feeds. Sulfur is present in the sample and existed only in AZ-101 and AZ-102 feeds.

Photographs of the solid deposits at the inlet and outlet of transition line section #3 are presented in Figures 5.12 - 5.14. Photographs of the solid deposits at the inlet and outlet of the transition line bellows are given in Figures 5.15 and 5.16, and a photograph of the solid deposits at the transition line on SBS inlet is given in Figure 5.17. Feed composition, cooling of the off-gas, flow direction changes, and the film cooler washing process all probably contribute to the amount of solids deposition; however, the exact cause of the deposits is under investigation and is not known at this time. The film cooler and all sections of the transition line were cleaned before reassembly. The cleaned sections are shown in Figures 5.18 through 5.22.

As indicated in Table 5.2a, the solid deposits are the accumulations since 6/21/2002 for the film cooler and the transition line sections #1, #2 and #3. The transition line bellows and the transition line on SBS side were cleaned on 10/24/2002 and the deposits on these two sections are accumulations since that time. The film cooler photographs (Figures 5.18 and 5.19) indicate that there is some corrosion of the film cooler leading surfaces and some plugging of the air holes. As noted above, this film cooler, which is constructed of Inconel 690, has been in service since 6/21/02. Corrosion of the film cooler is likely somewhat enhanced during idling since it is exposed to higher temperatures than during normal feeding as a result of the absence of a cold cap. This component is one that is expected to need occasional replacement.

5.1.2 SBS Performance

It should be noted that, per WTP direction, the SBS was operated without the down-comer extension in place for the C-106/AY-102 and C-104/AY-101 tests in order to investigate the effects on operation and solids build up in the down-comer.

SBS inlet and outlet gas temperatures, pressures and flow rates, pressure drop across the SBS, SBS water temperature, heat exchanger inlet and outlet water temperatures, and flow rates were recorded during the test. The amounts of heat removed by the SBS jacket cooling water, and the plate heat exchanger/SBS inner cooling coil were calculated from the measured data.

Data on the performance of the SBS regarding solids removal from the off-gas stream are presented and discussed in Section 7.0. Results from the analysis of fluids accumulated in the SBS are presented and discussed in Section 5.2.

The SBS inlet and outlet gas temperatures are plotted in Figure 5.23. The inlet gas temperature peaked at 354°C and the outlet gas temperatures peaked at 49.0°C. The average inlet gas temperature was 259.6°C. The average outlet gas temperature was 39.8°C. The temperature spikes (decreases) at the inlet are due to off-gas cooling resulting from film cooler cleaning, which occurred at 12 hour intervals. The inlet, outlet, and differential pressures are shown in Figure 5.24. The inlet gas pressure averaged -7.8 in. W.C., the outlet pressure averaged –46.5 in. W.C., and the pressure drop across the SBS averaged about 40.5 in. W.C. This differential pressure is about 5 to 6 inches lower than in previous tests and is consistent with the fact that the down-comer extension, which was in place for previous tests, was removed for this test. The pressure drop across the SBS increased by about 3.3 in. W.C. over nine days of testing with HLW C-104/AY-101 feed.

Water temperatures in the SBS, SBS chilled cooling water supply temperature, water cooling jacket outlet temperature, and water outlet temperature from the plate heat exchanger, are shown in Figure 5.25. There was an average of about 3.9°C difference in water temperatures measured at four depths (48, 60, 72 and 78 inches) within the SBS. The liquid in the SBS was heated to a maximum average temperature of 58.6°C during the initial period of water feeding, while the average SBS sump temperature was 46.0°C. The average outlet gas temperature was 39.8°C. As was observed in the C-106/AY-102 test, all of the installed thermocouples showed SBS sump temperatures that are higher than the SBS outlet gas temperature, which is contrary to thermodynamic principles and different than observations in all previous tests with the down-comer extension in place. The temperature measurements were, therefore, checked and verified. Since the installed thermocouples in the SBS sump are inside the packed column, it was surmised that the apparent higher sump fluid temperature was the result of an increased temperature gradient because it is not thermodynamically possible for the temperature of all of the sump fluid to be higher than that of the outlet gas temperature. In agreement with this, an additional temporary thermocouple inserted into the sump fluid in the outer annulus of the SBS showed lower temperatures that were consistent with the outlet gas temperature. This result is also consistent with the temperatures at the recirculation pump discharge, which are close to the outlet gas temperature and very close to the values observed in previous tests.

SBS jacket, inner coil and heat exchanger water flow rates are plotted in Figure 5.26. Average SBS jacket, inner coil, and heat exchanger water flow rates were 6.7, 24.6 and 8.1 gpm, respectively. The amounts of heat removed by the SBS cooling jacket and the plate heat exchanger are shown in Figure 5.27. The heat load data for the SBS cooling jacket and plate heat exchanger are calculated based on hourly average cooling water temperature increases (outlet temperature minus supply temperature) across the cooling jacket and plate heat exchanger multiplied by the time-averaged flow rate through each. For this test, heat removal averaged 39.7 kW by the plate heat exchanger and 13.1 kW by the cooling jacket. About 75% of the heat load to the SBS was removed by the plate heat exchanger and about 25% by the cooling jacket. The SBS inner coil and plate exchanger water temperatures are plotted in Figure 5.28. The heat load data for the SBS inner coil is also calculated based on hourly averaged cooling coil water temperature increases (coil water outlet minus its inlet temperature) multiplied by the hourly average flow rate of inner cooling coil water. The average SBS inner coil heat load was 41.3 kW. The heat load difference between SBS inner coil and plate heat exchanger is plotted in Figure 5.29 and averages only about 1.6 kW; independently calculated SBS inner coil heat load and plate heat exchanger heat load values were thus in good agreement.

At the end of the HLW C-104/AY-101 tests, the SBS was blown down and 356.8 gallons of liquid was removed from the SBS and overflow tank. About 7.32 kg of wet solids (with small amount of some left-over ceramic packing) was removed from the bowl after draining the SBS. A photograph of the SBS bowl with the solids is provided in Figure 5.30. Pieces of the original ceramics packing are visible in the photo. The SBS bottom was not opened at the end of the previous C-106/AY-102 test. Since the SBS bowl was cleaned at the end of the AZ-102 test, these solids accumulations are from both the C-106/AY-102 and the C104/AY-101 tests. The SBS down-comer was inspected at the end of the test and about 280 grams of solids were removed. Figure 5.31 provides a view looking upward from the bottom of the SBS inlet pipe showing rings of solids deposited about 3.5 in. above the bottom of SBS inlet pipe. About 68% of the cross sectional area of the pipe was occluded by solids. During the previous tests with the down-comer in place, solids build-up was observed inside the down-comer close to the vertical location of the diffuser plate. Results from the present test indicate that removal of the down-comer extension does not alleviate this problem, but the location of the solids accumulation appears to be somewhat higher. An alternative down-comer design is planned to be evaluated during future tests.

5.1.3 WESP Performance

The inlet and outlet gas temperatures and differential pressure across the WESP were measured and recorded by the computerized data acquisition system during the test, while the WESP current and voltage were recorded manually.

Data on the performance of the WESP regarding solids removal from the off-gas stream are presented and discussed in Section 7.0. Results of the analysis of fluids that accumulated in the WESP are presented and discussed in Section 5.2.

The WESP inlet and outlet gas temperatures are plotted in Figure 5.32. The WESP inlet gas temperature averaged 39.8°C and the outlet temperature averaged 40.9°C, indicating a 1.1°C temperature increase across the WESP during this test. The average WESP inlet temperature was the same as the average SBS outlet gas temperature during this test. WESP differential pressure and the gas flow rate out of the WESP are plotted in Figure 5.33. The WESP gas flow rate decreased sharply when the feeding was interrupted for short periods at 64.3 and 136.8 hours of operations, and when the control air was turned off at 115.1 hours for 0.9 hours. The pressure drop across the WESP averaged 2.3 in. W.C and the average WESP gas flow rate was 204.8 scfm.

The amount of liquid accumulated in the WESP is plotted as a function of run time in Figure 5.34, where it is compared with the amount of fresh water sprayed into the WESP. The inlet spray water flow rate was set at 2.0±0.2 gph, as specified in the Test Plan [9]. The measured spray water flow rate was 2.07 gph. As evident from Figure 5.34, spray water accounts for the majority of the liquid accumulation in the WESP. The difference between accumulated liquid and fresh water sprayed is the liquid collected from the gas stream (by condensation or particulate capture), which is also plotted in Figure 5.34. The WESP electrodes were deluged daily with water at a nominal rate of 12 gpm for 3.33 minutes, as planned [9].

The WESP voltage and current are plotted as a function of run time in Figure 5.35. The voltage and current interruptions at regular intervals seen in the figure are due to the time delay in restoring operating voltage and current after deluges used to clean the WESP electrodes. The average operating voltage and current were about 28.7 kV and 17.0 mA, respectively. The current remained steady throughout the test; however, the voltage generally increased sharply after each deluge and then gradually decreased as the WESP controller required less voltage to maintain the operating current at its set-point. This drop in voltage is probably due to the decrease in the effective gap width between the rods and collector plates as a result of accumulation of solids, since a film of such wet solids will have a much higher conductivity than air. The time required to manually stabilize power to operating values after deluge of the WESP ranged from 5 to 90 minutes and averaged 42.4 minutes, as shown in Table 5.3. It is expected that reduced particulate capture will occur while the WESP is being stabilized. Operation during subsequent testing has indicated that turning off the fogging nozzles improves recovery time; details will be included in the relevant test report.

At the end of the test, 21.7 gallons of liquid were initially blown down. After a final deluge, another 76.1 gallons of liquid were blown down. Video inspections of the WESP were conducted at the end of the test before and after the deluge. Minor build-up of particulate and a few dark-brown spots of solids were observed on the ionizing rods and collector plates before the deluge. The deluge was observed to be very effective in cleaning this material from the rods and collector plates.

5.1.4 HEME #1

HEME #1 follows the WESP in the off-gas system and removes any water droplets present in the water-saturated gas exiting the WESP. The spray water flow rate was set to 0.2 gph. The outlet gas temperature and differential pressure are plotted in Figure 5.36. The average HEME #1 gas outlet temperature was 39.1°C and the average pressure drop was 2.5 in. W.C. The daily deluge of the WESP cooled the off-gas, resulting in the minor spikes (decreases) of the HEME #1 outlet temperatures seen in Figure 5.36. At the end of the test, 56.9 gallons of liquid were blown-down from HEME #1.

5.1.5 HEPA Filter

HEME #1 is followed in the off-gas system by a heater, a HEPA filter **(**HEPA #1), and a Paxton blower (Blower #1). The purpose of the heater is to ensure that water-saturated gas exiting the WESP is heated above its dew point before passing through the HEPA filter in order to prevent moisture condensation in the HEPA filter. The outlet temperature and the pressure differential across HEPA #1 are the only two parameters that are monitored by the off-gas data acquisition system, both of which are given in Figure 5.37. The outlet temperature averaged 61.3°C and the differential pressure averaged 0.2 in. W.C, indicating that no significant particulate loading or moisture blinding of the filter occurred during this test.

5.1.6 First Paxton Blower (Blower-701)

Blower-701 gas outlet and TCO/SCR heater gas inlet temperatures are plotted in Figure 5.38. The blower outlet gas temperature averaged 80.4°C and the TCO/SCR heater gas inlet temperature averaged 80.1°C.

5.1.7 TCO/SCR Unit

The TCO/SCR unit consists of a heater, a Thermal Catalytic Oxidizer (TCO), and a Selective Catalytic Reduction system (SCR) with an ammonia injection system. After the off-gas is heated in the TCO/SCR heater, organics are catalytically oxidized in the TCO. The off-gas is then mixed with ammonia before entering the SCR unit, where NO_x is reduced to nitrogen. TCO inlet, SCR inlet and outlet, and post-SCR temperatures during the test are plotted in Figure 5.39. The average TCO inlet gas temperature was 486°C, while the average SCR inlet gas temperature was 386°C. The average SCR outlet gas temperatures were 349°C and 346°C at two locations 1 foot apart at the outlet of the SCR. The average temperature after the SCR was 323°C.

The differential pressures across the TCO, SCR, and TCO/SCR are plotted in Figure 5.40 and averaged 3.0 in. W.C., 6.5 in. W.C., and 9.7 in. W.C., respectively. The initial differential pressure values were not recorded automatically because the ammonia PLC unit was not activated until 12.9 hours of operations. Spikes at about 65 hours are due to feed interruption; spikes at about 116 hours are due to control air interruption; and spikes at about 136 hours are due to the LabVIEW module malfunction, all mentioned earlier.

Percent NO_x and CO destruction efficiencies are provided in Table 5.4. Note that due to their very low concentrations, a number of the measured values were near or below the detection limit of the measuring instrument and, therefore, the DRE values have large uncertainties. During the test segments A, B, and C, percent nitrogen oxide removals were more than 87.6, 88.0, and 75.9, respectively. Gas residence times in the TCO during the test segments A, B, and C were 0.21, 0.20 and 0.20 seconds, respectively. Average ammonia injections into the SCR during test segments A, B, and C were 0.032, 0.042, and 0.064 lbs/hr, respectively. Ammonia slippages during test segments A, B, and C were >5.5%, 2.5%, and ≈0.9%, respectively, as shown in Table 5.5. The average ammonia concentrations after the SCR unit during test segments A, B, and C were 3.1 ppm, 1.8 ppm, and less than 1 ppm, respectively.

5.1.8 Silver Mordenite System

A silver mordenite system was used to determine iodine removal from a slip-stream of about 10% of the off-gas stream exiting the SCR, which was then returned to the PBS. The silver mordenite system consists of a packed-bed of silver mordenite pellets in a column. The column inlet and outlet temperatures during the test are plotted in Figure 5.41. The average column inlet and outlet gas temperatures were 175°C and 126°C, respectively. The inlet gas temperature falls within the range specified in the Test Plan of 130°C to 230°C. The inlet, outlet, and differential pressures are shown in Figure 5.42 and averaged -21.3 in. W.C., -73.4 in. W.C., and 52.2 in. W.C., respectively.

In general, as the silver mordenite pellets react with iodine in the off-gas stream, discoloration takes place and the original gray color of the silver mordenite pellets turns to a light yellow [23]. This process continued during the present tests but the column capacity was not completely exhausted.

5.1.9 Packed Bed Scrubber (PBS)

The TCO/SCR is followed in the off-gas train by a packed bed caustic scrubber (PBS) to remove iodine and acid gases from the off-gas stream. The effluent solution can be pumped out of the PBS sump and process water and caustic solution (25% NaOH) can be added to control the solid content and pH of the scrubber liquid. The inlet gas temperature and the pressure drop across the PBS during the test are shown in Figure 5.43. The average PBS differential pressure was 3.1 in W.C. The average PBS inlet temperature for this test was 299°C. The PBS sump temperature and pH are plotted in Figure 5.44 and averaged 24.1°C and about 8.8 (between 46 and 136 hours only), respectively. When the sump pH falls below about 9, caustic solution is added to raise the pH. Before 46 hours and after 136 hours of operation, pH values were not electronically recorded due to a sensor error; during this time, pH values were measured and recorded manually. The manually-recorded pH's were in the 8.5 – 9.5 range.

5.1.10 HEME #2

HEME #2 follows the PBS in the off-gas system and removes any water droplets that may be present in water-saturated gas exiting the PBS. The spray water flow rate was set to 0.2 gph. Inlet and outlet gas temperatures and differential pressure are plotted in Figure 5.45. The average gas inlet and outlet temperatures were 25.8°C and 27.9°C, respectively, and the average pressure drop was 5.3 in. W.C. At the end of the test, 41.3 gallons of liquid were blown-down from HEME #2.

5.1.11 Effluent Liquid Treatment System

Effluent liquids from the SBS, WESP, PBS and HEME #2 are all piped to a series of sampling tanks that discharge to three 500-gallon storage tanks for neutralization, mixing, and storage. The largest effluent volume is overflow (blow-down) from the SBS, which is pumped to one of two SBS sampling tanks. The various effluent liquid sampling and storage tanks are visually monitored during periodic rounds and effluent liquid transfers made as needed.

5.2 SBS and WESP Process Fluids

5.2.1 SBS Fluids

One-liter samples were collected from the SBS sump each time liquids were blown down and at the end of each test. Selected samples were subjected to total dissolved solids (TDS) and total suspended solids (TSS) determinations by gravimetric analysis of filtered material and the evaporated filtrate. An additional sample was filtered to generate solids and filtrate for complete chemical analysis, which included pH determination, direct current plasma emission spectroscopy (DCP) analysis for metals, atomic absorption (AA) for cesium, ion selective electrode (ISE) for ammonium, and ion chromatography for all other anions; the dried filtered solids underwent microwave-assisted acid dissolution prior to chemical analysis. The only anions determined in the filtered solids were sulfate and iodide due to interference from the acids required to dissolve the filtered solids.

All of the SBS sump samples that were taken throughout the DM1200 tests are listed in Table 5.6; the middle letter in the sample name is "S" for the SBS samples. The table provides pH values for each sample, as well as the blow-down volume from which each SBS sample was taken and the cumulative SBS blow-down volume. The analyzed chemical compositions for samples taken during each of the three test segments are provided in Table 5.7. The pH values for the SBS liquids are plotted in Figure 5.46. Notice that the solution pH varies by only half a pH unit between 7.8 and 8.3 during testing. The near-neutral pH is partly due to the low feed concentrations of nitrates, nitrites, and sulfates, which form acid gases in the melter and decrease the SBS sump pH when scrubbed. In other tests conducted with HLW simulants and glass pool bubbling, SBS sump pH values were also in the neutral region [4, 22, 23].

Figure 5.47 compares the amount of water fed to the total volumetric accumulations in the SBS over the course of the test. Included is the water fed to cool the melter plenum at the start of the test to create a cold cap and thereby minimize subsequent off-gas surges due to pulsed feeding onto bare glass (this is the same feed start-up protocol as that used at West Valley). There is close agreement between water quantities at the beginning of the test, followed by slight divergence as the testing progressed. Also notice that the change in water feed rate as a result of increased bubbling is reflected in an increase in the water accumulation rate in the SBS. By the end of the test, about 750 gallons more water was fed into the melter than was condensed in the SBS. This difference is dependent on the SBS sump temperature set-point of 40°C (lower temperatures would decrease this difference) and the feed rate of water into the SBS. Previous testing with HLW AZ-101 feed [3, 4] showed that a near-room-temperature SBS sump condensed virtually all of the feed water, whereas a sump temperature of 40°C resulted in a portion of feed water being emitted. SBS water condensation plots from LAW tests (Sub-Envelope C1 [19], A1 [24], and B1 [25]) and HLW tests [22, 23] that used a sump temperature of 40°C are very similar.

Figures 5.48 - 5.50 compare the feed composition to the SBS dissolved and suspended fractions from a sample taken during the last test segment (Q12-S-122A). As might be expected, the dissolved solids consist mainly of species such as halogens, boron, and alkali metals. These species are readily volatilized from the glass and cold cap in the melter as soluble salts. Nitrite and ammonia, which constitute greater than half the dissolved SBS solids in the LAW melter tests [19, 24, 25], are present only in very small quantities due to very low feed concentrations of nitrate/nitrite and the lack of sugar additions. The suspended solids more closely resemble the feed and consist primarily of iron, silicon, zirconium, aluminum, and sodium. Iodide was present only in the dissolved fraction. The sulfate present in SBS solutions originated from residual material from previous high-sulfur LAW Sub-Envelope B1 tests and feed contaminants (see Section 2.3.3).

5.2.2 WESP, PBS, and HEME Fluids

One-liter samples were collected from the WESP, PBS, and HEME sumps each time liquids were blown down and at the end of the test. All of the WESP, PBS, and HEME sump samples that were taken throughout the test are listed in Table 5.8; the middle letter in the sample name is “W”, “P”, and “H” for the WESP, PBS, and HEME samples, respectively. The table provides pH values for each sample, as well as the blow-down volume from which each sample was taken and the cumulative blow-down volumes. About 80 gallons were blown down from the WESP daily: the first 40 gallons from the previous day’s accumulation of water from spraying and condensation (sample with suffix “A” in name) and the second from the 40-gallon deluge (sample with suffix “B” in name). The PBS was blown down as required to maintain constant volume. Since no liquids accumulated in the HEME immediately downstream of the WESP (HEME #1) during testing, a sample was taken only at the end of the test.

Results from the analysis of sump samples from the WESP taken before and after the deluge are compared to SBS results in Table 5.7 and illustrated in Figure 5.51. The WESP solution pH values were higher (6.7 to 7.8 vs. 2 to 7) than for the previous HLW tests [6] due to dilution from the added deluge and higher than for the previous LAW Sub-Envelope B1 tests [25] (6.7 to 7.5 vs. 2 to 4) due to the lower concentrations of nitrates/nitrites in the feed. Values were comparable to more recent HLW tests that also employed a daily deluge for cleaning the WESP elements [22, 23]. A near total absence of suspended material was measured in both the pre- and post-deluge blow-down solutions. The principal constituents in the WESP solutions were volatile salts (alkali halides, boron) carried over from the SBS and residual sulfate from previous tests or feed impurities. This confirms the expectation that the majority of the coarser, less-soluble species were removed by the SBS leaving predominantly highly soluble species for accumulation in the WESP. The concentrations of elements are higher in the solutions prior to the deluge, although the relative proportion of elements is very similar.

Anion analysis of the PBS blow-down solution taken at the end of the test is given in Table 5.8. The pH of the PBS sump is maintained between 9 and 10 during testing by the addition of 25% sodium hydroxide solution. Conversely, the pH of HEME solutions is a result of constituents removed from the exhaust stream. Significant concentrations of several anions including iodide, nitrite, and nitrate were measured in HEME solutions; however, the HEME plays only a small role in the mass balance as a result of the small volumes of liquids collected. It is important to note that while relatively high concentrations of iodine and to a lesser extent other anions such as nitrite were measured in these solutions, they certainly are not removed quantitatively in the PBS in the 9 to 10 pH range.

5.2.3 Estimates of Accumulations in SBS, WESP, and PBS and Fluids

Estimates of elemental accumulations in the SBS, WESP, and PBS blow-down solutions are provided in Table 5.10. The accumulation totals are the product of the average analyses given in Tables 5.7 and 5.9 and the total accumulated liquids given in Tables 5.6 and 5.8. The measured feed impurities shown in Table 2.6 are included in the feed totals. The accumulations given are upper estimates since the concentration values were taken near the end of test segments and the concentrations increased from near zero at the beginning of the test when the sumps were filled with water. They do not include the solids in the SBS bowl or down-comer that were removed at the end of the test (see Sub-Section 5.1.2). The accumulations estimated from blow-down data are also compared to estimates calculated from emissions data as percent of feed. The equivalent of five and a half kilograms of sodium, over three and half kilograms of boron, two kilograms of iron and silicon, almost two kilograms of fluoride, one kilogram of sulfate, as well as hundreds of grams of aluminum, lithium, lead, zinc, zirconium, chlorine, iodine, and nitrate/nitrite are estimated to have accumulated in the SBS liquids during testing. However, the SBS liquids constitute a significant proportion of the elemental mass balance only for sulfur and halogens, with 11% (iodine), 21% (fluorine), and 24% (sulfate) of these feed constituents reporting to the SBS fluids. Although a significant percentage of feed iodine accumulated in the SBS, less accumulated than in LAW Sub-Envelope tests [19, 24, 25] (11 vs. > 50-90%) due presumably to the difference in SBS solution composition (though it is not clear which, if any, of the specific compositional differences would have accounted for this) or the speciation of iodine in the melter emissions. A similar percentage of iodine (15%) was retained in comparable C-106/AY-102 tests [23]. Estimates of accumulations in WESP solutions are the equivalent of almost half a kilogram of sulfur, 380 grams of sodium, 170 grams nitrate/nitrite, and about a third of kilogram of halogens, as well as tens of grams of boron, calcium, lithium, and magnesium over the course of the test. The WESP liquids constitute a significant proportion of the elemental mass balance only for the feed contaminant sulfur. Agreement between the two methods for estimating accumulations in the SBS was not as good as in the C-106/AY-102 test [23] and similar for many elements to the AZ-102 test [22]. Emissions data suggest (Table 5.10) that two to five times more of some elements (Al, Cs, Cu, Fe, Ni, Si, Ti, Zn, Zr and F) should be present in SBS solutions. As described above, the SBS accumulations are upper estimates; however, even so, they are less than calculated values based on melter emissions. The melter emission data were collected over a three-hour period near the end of the test while the melter was being fed at the highest rate. (These calculated values do, however, account for elemental amounts measured exiting at the SBS outlet.) One possible factor contributing to the mismatch between these estimates is the approximation that is introduced by extrapolating three-hour emissions data over the entire test duration, since slight non-uniformities in either melter or SBS outlet emissions will be magnified in the extrapolation. Another factor is that the solids in the SBS bowl and down-comer are not included in the SBS solution calculation but were certainly derived from melter emissions.

Both estimation methods indicate little feed accumulation in the WESP. Some of the calcium, chlorine, fluorine, and magnesium in the WESP solutions originated from city water used to constantly spray the WESP and conduct the deluge, which would not be reflected in the exhaust sampling estimates. Total cesium retention in SBS and WESP solutions was almost the same as for the AZ-102 tests (1.6 vs.1.7%). Finally, as expected, the PBS and HEMEs sump fluids account for only a modest percentage of feed anions.

SECTION 6.0
GLASS PRODUCT FROM THE DM1200

Almost seven metric tons of glass product was discharged from the melter through an airlift system into 55-gallon drums. The discharged product glass was sampled from each drum by removing sufficient glass from the top for total inorganic analysis. Product glass masses, discharge date, and the analyses performed are listed in Table 6.1.

6.1 Compositional Analysis

Glass samples were crushed and analyzed directly by XRF. The target value for the boron and lithium oxide concentrations were used for normalizing the XRF data since boron and lithium were not determined by XRF. Analyzed compositions for discharged glass samples are provided in Table 6.2. There was good agreement with the target composition for the majority of oxides and, in particular, for the major oxides, as described for feed samples in Section 2.3. Zirconium was closer to target in the discharged glass than in the feed samples, whereas aluminum and zinc were farther from the target. Sulfur, magnesium, and potassium were again observed in the glass at very low levels, even though they are not included in the feed recipe. Oxides of arsenic, antimony, and magnesium remained in the glass pool from the previous C-106/AY-102 test [23] and decreased systematically over the course of the test. Consistent with previous melter tests using lower alkali glass [4, 19, 22, 23, 25], no measurable feed iodine was retained in the glass product.

Compositional trends from the XRF data are plotted for selected elements in Figures 6.1-6.3. The figures illustrate many of the points apparent in the tabular summaries of the data: good agreement with target for all oxides after the melt pool has experienced three turnovers (~6000 kg of glass produced), the total loss of iodine, and the increase in zirconium at the expense of Sr/TRU products. The figures also illustrate the three compositional trends that occurred: elements with oxide concentrations that either did not change as a result of the similarity to the previous C-106/AY-102 composition [23] (e.g., calcium and zinc in Figure 6.2), systematically decreased in concentration towards target (e.g., Sr/TRU products and magnesium in Figures 6.1 and 6.3), or systematically increased towards target (e.g., zirconium in Figure 6.2). The oxides of silicon, boron, lithium, sodium, zinc, and calcium, which changed little over the test due to similarities with the C-106/AY-102 glass composition, constitute about three quarters of the total. The principal compositional change was the decrease in manganese and strontium oxides resulting from the lack incorporation of Sr/TRU removal products in the C-104/AY-101 simulant (Figures 6.1 and 6.3) and the increase in zirconium concentration (Figure 6.2). All of these trends closely parallel those observed in the DM100 test, described in Section 3.

6.2 Bulk Density Determination

Measurements were made on the last four drums of glass that were poured to permit the calculation of glass bulk density. The method used was the same as that applied previously to drums of AZ-101 glass [27]. The bulk density of glass that was poured into each of four 55-gallon drums was calculated from the measured glass mass and the estimated bulk volume of the glass in the drum, as shown in Table 6.3. A perfect cylinder was assumed for the bulk volume calculations. This assumption neglects the small volume contribution from the two externally protruding strengthening rings located one-third and two-thirds from the base of the drum and the slightly internally protruding drum bottom. The glass volume was calculated as:

$$\text{Glass volume (cm}^3\text{)} = (D/2)^2 \times 3.1416 \times (H - d) \times 16.3872\ \text{cm}^3/\text{inch}^3.$$

where D = Drum diameter in inches
H = Height of drum in inches
d = Depth from top of drum to glass surface in inches

The bulk glass density was then calculated using this volume and the glass mass. The calculated values are also compared to the averages calculated for the C-106/AY-102 and AZ-101 glass in Table 6.3. Notice that the C-104/AY-101 bulk density of 2.631 g/cc is higher than the other two HLW compositions, which are remarkably similar to each other (2.573 and 2.578 g/cc). The intrinsic density of small shards of last glass discharged during the C-104/AY-101 tests (Q12-G-136A) was determined by pycnometry, as described previously [27]. The value obtained was 2.7835 g/cc, as compared to the lower value of 2.6490 g/cc obtained for the AZ-101 glass. Using these data to calculate the void fraction in the same way as was done for the AZ-101 samples [27] results in a void fraction of 5.5%, as compared to the value of 2.7% for the AZ-101 samples.

SECTION 7.0
MONITORED OFF-GAS EMISSIONS

7.1 Particulate and Gaseous Emissions

Seven exhaust samples were taken from the melter and various off-gas system components using 40-CFR-60 Methods 3, 5, and 29 to examine particulate and certain gaseous fluxes. All samples were taken during the steady-state portion of the third test segment. Sampling durations were one to three hours for the melter and SBS exhaust, whereas a 24-36 hour sample was required for the WESP exhaust due to the low particle concentration. The WESP was deluged during the exhaust sample. Teflon filters were used to allow for analysis of all feed components. The majority of the off-gas analyte concentrations were derived from laboratory data on solutions extracted from air samples (filters and various solutions) together with measurements of the volume of air sampled. The volume of air sampled and the rate at which it can be sampled are defined in 40-CFR-60 and SW-846. 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), was used. Typically, a sample size of 30 dscf is taken at a rate of between 0.5 and 0.75 dscfm. Total particulate loading was determined by gravimetric analysis of the standard particle filter and of probe-rinse solutions. Downstream of the particulate filter in the sampling train are iced impingers with acidic (5% concentrated nitric acid plus 10% hydrogen peroxide) and basic (2 N sodium hydroxide) solutions. The analysis of these solutions permits the determination of total gaseous emissions of several elements, notably halides and sulfur. A list of all inorganic isokinetic samples taken is provided in Table 7.1 including sampling location, air sample volume, air flow rates, particulate emission rates, and air moisture. All samples were within 10% of isokinetic.

Elemental emission rates and DFs are provided in Tables 7.2-7.4 for the melter, SBS, and WESP, respectively. Notice the distinction that is made between constituents sampled as particles and as "gas". The "gaseous" constituents are operationally defined as those species that are scrubbed in the impinger solutions after the air stream has passed through a 0.45 μm heated filter. Solids carry-over from the melter and SBS averaged 0.72 and 2.14 percent of feed solids, respectively, and was comparable to tests with HLW AZ-101 and AZ-102 simulants [10, 22]. The SBS performance was better than for the LAW Sub-Envelope tests [19, 24, 25] and HLW C-106/AY-102 [23] tests due to the lower concentrations of constituents that form fine particles such a halides and selenium. Melter emissions from the AZ-102 and C-104/AY-102 tests were relatively high in glass formers such as silica that form coarser particulate that is efficiently captured by the SBS. About 98 percent of the particles exiting the SBS were removed by the WESP. The cumulative DF value, which is calculated from feed fluxes into the melter and emissions from the WESP, was 301,960 and near the high end of those measured for the four HLW compositions.

The composition of the particles in the melter exhaust is higher in major constituents such as silicon and iron than for the C-106/AY-102 tests, as were emissions in the AZ-102 tests, but also contained significant concentrations of alkali fluorides. This is due in part to the low concentration of volatiles other than fluorine in the feed. Another factor is the likely mechanism of release to the melter exhaust stream. The relatively high proportion of silicon in the melter emissions indicates that simple entrainment of feed is the probable principal mechanism for emissions, as compared to volatilization from the glass or cold cap. The lower emission rate in these versus the AZ-102 tests (0.72 vs. 1.26) may in part be due to the new feed tube installed prior to sampling. The new design limited stalactite growth and occlusions on the tip of the feed tube (see Section 4.0) that sprayed feed in various directions, including toward the melter off-gas outlet, which in turn could have increased solids carry-over. SBS emissions, and to a greater extent WESP emissions, are high in iodine, sulfur, and alkali metals and depleted in major feed constituents, such as silicon, aluminum, and iron. Impinger solutions from off-gas sampling were analyzed for all of the elements in the feed but only iodine, boron, and sulfur were detected. The presence of these elements in the gas fraction is consistent with observations from previous studies [3, 4, 22-26]. The average composition of feed, melter emissions, SBS and WESP emissions (excluding oxygen, carbon, nitrate, and nitrite) are displayed in Figures 6.1-6.4, respectively. Notice that the relative percentages of volatiles, such as halides, increase downstream as the major constituents decrease. Iodine constitutes the majority of WESP emissions as the result of no retention in the glass and poor iodine removal in the SBS and WESP.

7.2 Particle Size Distribution

Samples were taken using a University of Washington cascade impactor, which separates particles into particle size ranges enabling the determination of particle size distributions. The melter exhaust stream was sampled in triplicate during the third steady-state test segment. Data for the particle size distributions are provided in Table 7.5. About two thirds of the total particulate mass was observed in the coarsest size fraction (> 13.1-16.0 μm) with the remainder being spread out over the remaining seven finer size fractions.

Three additional samples were taken during the third steady-state test segment using the same methods at the PBS outlet in response to Project request issued subsequent to issuance of the Test Plan [9]. The results shown in Table 7.6 illustrate the difficulty in obtaining sufficient material on each stage to definitively describe the particle size distribution. The exhaust stream at the PBS has already under gone several treatments, including HEPA filtration, and therefore any measured particle emissions are probably derived from misting out of the packed bed scrubber. In contrast to the melter emissions, almost all measured particulate mass was observed in the finest size fraction (< 1-2 μm).

7.3 FTIR Analysis

Off-gas analysis by Fourier Transform Infrared (FTIR) spectroscopy was performed using an On-Line Technologies Inc. Model 2010 Multi-Gas™ Analyzer. Data were recorded at 71 s intervals, corresponding to an average of 128 scans at 0.5 cm^{-1} spectral resolution. The melter off-gas supplied to the FTIR spectrometer was extracted using a heated sampling and transfer loop, which removed a gas sample stream from the off-gas system at 5 liters per minute. The sampling and transfer loop was maintained at 150°C throughout in order to prevent analyte loss due to condensation.

Off-gas emissions were monitored by FTIR spectroscopy during each test segment for a set of selected species over discrete time intervals at specified off-gas system locations. Table 7.7 displays a summary of the average analyte concentrations measured over the course of the test. Real-time concentrations of NO, NH_3, CO_2, and water are presented in Figures 7.5-7.8. Only NO, CO_2, and water had average concentrations greater than 10 ppmv as a result of the lack of carbon and nitrogen compounds in the feed. As expected, concentrations increased as feed rates increased over the course of the test. The low nitrogen monoxide concentrations were reduced to < 100 ppm downstream of the TCO/SCR. Nitrogen oxide emissions could have further been reduced by increasing the amount ammonia supplied to the catalyst unit at the expense of increased ammonia slippage. Another aspect of the emissions is the high degree of variation during testing, as can be observed in Figures 7.5 and 7.7. Notice that, even over short periods of time, NO_x and CO_2 emissions can vary by factors of 2 to 5. Moisture percentages for the last test segment at the melter, SBS, WESP, and the TCO/SCR outlet were comparable to those measured using the stack sampling methods, shown in Table 7.1. The moisture data also indicate that measurable condensation occurs only in the SBS, as intended.

7.4 Iodine Mass Balance and Silver Mordenite Column Performance

Iodine mass balance closure has been an objective of a large number of melter runs. Deficits of iodine occurred in many tests due to the neutralization of basic impinger solutions and inability of off-gas system components to quantitatively remove iodine from the exhaust stream. This test provided a good opportunity to measure iodine emission rates due to the low concentrations of acid gases in the exhaust stream, which tend to neutralize basic impinger solutions. A summary of the iodine mass balance is presented in Table 7.8 in terms of percent feed iodine. Notice that despite the lack of iodine in the glass, reasonable mass closure around the melter was achieved as either melter emissions (80%) or the sum of SBS blow-down solutions and SBS emissions (11 + 88 = 99%). The amount of iodine detected in the WESP emissions is higher than in many previous studies that featured less efficient sampling [4, 24, 25] but less than more recent HLW tests [22, 23]. The recent HLW tests support the long held assumption that the WESP removes little or no iodine and, therefore, the amount of iodine entering and exiting the WESP are equal. However, in the tests described here, more iodine was detected at the entrance of silver mordenite system (taken as a slipstream from the TCO/SCR catalyst unit outlet) and in PBS blow-down solutions than at the WESP outlet. Clearly, however, the majority of the feed iodine is exiting the WESP and a significant proportion of that is exiting the PBS. The two HEME filtration units do not factor into the iodine mass balance as result of the low liquid accumulations during testing. Also, the measured solution pH range for the HEME as well as the PBS solutions of 8 to 10 is too low to effectively remove iodine. The only particulate iodine detected was about 3% of the melter emissions. None of the impinger catch was in the acidic impinger solutions, indicating that the iodine is emitted predominantly as a molecular gas (I_2) as opposed to HI or particles.

The silver mordenite column for the removal of iodine installed downstream of TCO/SCR catalyst units was operated for the second time during these tests. An off-gas slip-stream of about 25 scfm was passed through the column, which was maintained at 150°C. Air was sampled simultaneously at four locations on the column (inlet, one-third down, two-thirds down, and outlet) and scrubbed in impingers containing 2 M sodium hydroxide solution. These solutions were analyzed for iodide, which, with the known solution and air volumes, allowed calculation of the iodine concentrations that are given in Table 7.9. Since the testing of the column is a continuation from the previous C-106/AY-102 tests, the results from the last sampling during those tests is included in the table. No iodine was measured at the column outlet, resulting in DF values of over 1500, based on present detection limits. The gradual color change of the media from grey to yellow apparent in the previous test continued during these tests as the band gradually spread from near the inlet towards the bottom of the column. The lack of iodine removal from the top one-third into the column observed at the end of the C-106/AY-102 was again observed in these tests. The media was further expended during these tests, as shown by the decrease in efficiency two-thirds into the column along with spread of the yellow coloration down the column.

SECTION 8.0
CONCLUSIONS

Melter tests were conducted on the DM1200 to determine the effects of bubbling rate on glass production rate and off-gas system performance while processing a HLW C-104/AY-101 feed composition. Tests were conducted at three bubbling rates over a nine-day period using feed yielding 528 g glass per liter. Over eighteen and a half metric tons of feed was processed to produce almost 7 metric tonnes of glass. Cold-cap-limited, steady-state production rates of 400, 660 and 900 kg/m^2/day were maintained for test segments with bubbling rates of 8, 40, and 65 lpm, respectively. Some foaming occurred at the lowest bubbling rate and at feeding interruptions but did not prevent the attainment of steady-state conditions. The presently required glass output of each of the WTP HLW melters of 3 MT/d corresponds to a specific glass production rate of 800 kg/m^2/d. The highest bubbling rate test on the DM1200 melter exceeded this requirement. However, it should be noted that this test used a high solids content feed (20 wt% undissolved solids) from pretreatment; lower concentrations will lead to progressively lower rates [10]. It should also be noted that the full-scale WTP melter has slightly fewer bubblers per unit melt surface area than does the DM1200 (five bubblers in 3.75 m^2 vs. two bubblers in 1.2 m^2), which may lead to lower large-scale glass production rates on a per unit melt surface area basis.

The general performance of the DM1200 melter and off-gas treatment system was good. A new feed tube design was tested and shown to be less prone to feed blockages observed with the previous design, providing more consistent and reliable feed introduction. The DM1200 test was preceded by a 100-hour DM100 test to ensure that the new glass formulation and melter feed were acceptable for processing in the HLW pilot melter. Extensive sets of process engineering data were collected during both tests. The glass product was close to the intended composition at the end of testing.

Isokinetic particulate samples were taken at the outlets of the melter, SBS, and WESP during the last test segment (65 lpm bubbling) to determine the efficiency of off-gas system components. Elemental DF values were determined across the melter, SBS, and WESP. Particle size distributions were determined for the melter emissions. The total solids carryover from the melter (0.72% of feed) was comparable to that observed for tests with other HLW compositions. Calculated DFs across the SBS were high due in part to the higher melter emission rate of major feed components such as silicon and iron. The WESP, which is effective in collecting finer particles, removed much of the additional particulate material exiting the SBS. The cumulative DF (Melter+SBS+WESP) was about 301,960 which is higher than for other HLW tests which used the same emission sampling protocol, i.e., where the emission sample collection time includes the period when the WESP is powered down during a deluge [22, 23].

The volumes of processing solutions generated in the SBS, WESP, HEME, and PBS were documented during testing and representative samples were subjected to complete chemical analysis. The SBS solutions were close to neutral pH, due in large part to the lack of acid gases in the exhaust stream. The major dissolved species were halogens, boron, and alkali metals, while the suspended species closely resembled the feed composition. The measured SBS TSS concentrations were between 700 and 2200 mg/l, whereas measured TDS values were about 2 times higher. The WESP sump fluid was also in the neutral pH region but had negligible suspended solids. The WESP solutions contained significant concentrations of nitrate, sulfate, and alkali halides. The WESP was sprayed continuously during this test and was deluged with 40 gallons of water once daily, resulting in a total blow-down volume of almost 900 gallons. The nearly 2000 gallons of liquid that accumulated in the SBS during the test originated from the condensation of water from the melter feed.

A relatively good mass balance was achieved for iodine around the melter, SBS, and WESP. Essentially all of the feed iodine was emitted from the melter and no iodine was detected in the glass product. Data from this and previous HLW tests [22, 23] support the assertion that the WESP removes little or no iodine. A silver mordenite system for iodine removal was installed to treat a 10% slip stream of post SCR/TCO emissions. Testing of the column was continued by taking samples at the inlet, one third down, two thirds down, and outlet of the column. No iodine was measured at the column outlet resulting in DF values of over 1500.

Occlusion of the SBS down-comer pipe near the diffuser plate with solid deposits was again observed in these tests, despite the removal of the down-comer extension. Significant solids accumulations were also found in the film cooler and the transition line from the film cooler to the SBS.

The completion of the Test Objectives for this work is summarized in Table 8.1.

SECTION 9.0
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Table 2.1. Compositional Summary of Different Waste Streams and Blended Solids for the C-104/AY-101 HLW Simulant [6].

Waste Component	C-104/AY-101 Solids	Recycle Stream	Separation Factor	Cs-Eluate	Blended Solids
-	FRP02	PWD01	-	CNP12	HLP09b
-	(lb/day)	(lb/day)	(fraction remained)	(lb/day)	(lb/day)
Ag	6.70E+00	5.49E-21	1.0000	—	6.70E+00
Al	3.07E+03	2.17E+00	0.1511	—	4.64E+02
As	0.00E+00	1.32E-01	1.0000	—	1.32E-01
B	5.36E+00	2.88E+00	0.9705	—	8.00E+00
Ba	9.65E+00	2.69E-04	0.0596	—	5.75E-01
Be	7.32E-01	0.00E+00	1.0000	—	7.32E-01
Bi	1.31E+00	2.58E-04	0.9957	—	1.31E+00
Ca	1.10E+02	9.03E-02	0.7681	—	8.42E+01
Cd	1.64E+01	1.57E-04	0.0264	—	4.33E-01
Ce	1.38E+01	5.90E+00	0.0238	—	4.69E-01
Cl	2.52E+01	2.13E+00	0.0237	—	6.48E-01
Co	3.40E-01	0.00E+00	1.0000	—	3.40E-01
Carbonate	0.00E+00	2.41E+00	0.0900	—	2.17E-01
Cr	6.96E+01	2.01E-01	0.1521	—	1.06E+01
Cs	1.05E-01	0.00E+00	0.1226	—	1.28E-02
Cu	5.94E+00	6.86E-33	1.0000	—	5.94E+00
F	9.30E+02	7.49E-01	0.0316	—	2.94E+01
Fe	1.66E+03	1.49E+00	0.9840	—	1.63E+03
Hg	2.07E+00	2.09E-05	0.9992	—	2.07E+00
K	4.25E+01	9.11E-01	0.0298	1.14E+00	2.43E+00
La	3.37E+01	1.98E-02	0.9930	—	3.35E+01
Li	1.07E+01	7.57E-01	1.0000	—	1.14E+01
Mg	0.00E+00	4.89E-06	1.0000	—	4.89E-06
Mn	2.37E+02	9.01E-02	0.9901	—	2.35E+02
Mo	1.05E-01	0.00E+00	1.0000	—	1.05E-01
Na	5.91E+03	3.65E+02	0.0426	2.02E+01	2.88E+02
Nd	1.74E+01	0.00E+00	1.0000	—	1.74E+01
Ni	1.04E+02	1.10E-01	0.8605	—	8.94E+01
Nitrite	1.31E+03	5.06E-01	0.0245	—	3.21E+01
Nitrate	5.42E+02	8.67E+02	0.0240	1.14E+02	1.48E+02
Hydroxide	1.12E+04	3.16E+01	0.2503	—	2.82E+03
Hydroxide(Bound)	0.00E+00	0.00E+00	0.0237	—	0.00E+00
Pb	4.70E+01	2.27E-02	0.5897	—	2.77E+01
Pd	1.05E-01	2.15E-09	1.0000	—	1.05E-01
Phosphate	1.75E+02	1.66E-02	0.0746	—	1.30E+01
Pr	5.13E+00	0.00E+00	1.0000	—	5.13E+00
Rb	5.86E+00	0.00E+00	1.0000	—	5.86E+00
Rh	2.62E-01	0.00E+00	1.0000	—	2.62E-01
Ru	0.00E+00	0.00E+00	1.0000	—	0.00E+00
Sb	2.62E-02	0.00E+00	0.9996	—	2.61E-02
Se	0.00E+00	0.00E+00	1.0000	—	0.00E+00
Si	2.78E+02	6.02E+00	1.0000	—	2.84E+02
Sulfate	1.69E+02	5.45E-01	0.0318	—	5.40E+00
Sr	4.04E+00	0.00E+00	0.9131	—	3.69E+00
Ta	2.62E-02	0.00E+00	1.0000	—	2.62E-02
Te	0.00E+00	0.00E+00	—	—	0.00E+00
Th	1.13E+03	0.00E+00	0.8227	—	9.29E+02
Ti	3.45E+00	1.53E-03	0.9983	—	3.45E+00
Tl	2.62E-02	0.00E+00	1.0000	—	2.62E-02
TOC	5.10E+02	0.00E+00	0.0236	—	1.21E+01
U	9.35E+02	0.00E+00	0.5975	—	5.59E+02
V	9.94E-01	0.00E+00	1.0000	—	9.94E-01
Y	1.91E+00	0.00E+00	0.9930	—	1.90E+00
Zn	5.23E+00	4.36E-01	0.6475	—	3.67E+00
Zr	1.72E+03	3.44E-01	0.9953	—	1.71E+03
TOTAL	**3.04E+04***	**1.31E+03***	—	**1.35E+02**	**9.51E+03***

– Empty Data Field. *Includes negligible components that are omitted (e.g., CN (< 0.6 lb/day) and Pu (1.26 lb/day).

Table 2.2. Compositional Summary (Oxide Basis) of the Calculated C-104/AY-101 HLW Simulant [6], Simulant Used in Crucible Melts, Glass Additives, and the Reference Glass (HLW98-96).

Oxide	Calculated C-104/AY-101 Compositions*	C-104/AY-101 Simulant for Crucible Melt	Glass Former (as wt% of glass)	HLW98-96
Ag_2O	0.08%	0.08%	—	0.03%
Al_2O_3	9.67%	9.71%	—	3.36%
B_2O_3	0.28%	0.28%	10.00%	10.11%
BaO	0.01%	—	—	—
BeO	0.02%	—	—	—
Bi_2O_3	0.02%	—	—	—
CaO	1.30%	1.31%	—	0.45%
CdO	0.01%	—	—	—
Ce_2O_3	0.01%	—	—	—
Cl	0.01%	—	—	—
Cr_2O_3	0.17%	0.17%	—	0.06%
CuO	0.08%	0.08%	—	0.03%
F	0.32%	0.32%	—	0.11%
Fe_2O_3	25.75%	25.85%	—	8.96%
HgO	0.02%	—	—	—
K_2O	0.03%	—	—	—
La_2O_3	0.43%	0.43%	—	0.15%
Li_2O	0.27%	0.27%	3.00%	3.10%
MnO**	4.10%	4.12%	—	1.43%
Na_2O	4.28%	4.30%	9.25%	10.75%
Nd_2O_3	0.22%	0.29%	—	0.10%
NiO	1.26%	1.26%	—	0.44%
PbO	0.33%	0.33%	—	0.11%
P_2O_5	0.11%	0.11%	—	0.04%
Pr_2O_3	0.07%	—	—	—
PuO_2	0.02%	—	—	—
Rb_2O	0.07%	—	—	—
SO_3	0.05%	—	—	—
SiO_2	6.70%	6.70%	41.00%	43.38%
SrO	0.05%	—	—	—
ThO_2	11.66%	11.70%	—	4.06%
TiO_2	0.06%	0.06%	—	0.02%
UO_2	6.99%	7.02%	—	2.43%
V_2O_3	0.02%	—	—	—
Y_2O_3	0.03%	—	—	—
ZnO	0.05%	0.05%	2.00%	2.02%
ZrO_2	25.45%	25.55%	—	8.86%
TOTAL	100.00%	100.00%	65.25%	100.00%

*From Table 5 in Reference [6]. -Empty Data Field. **MnO_2 in Reference [6]

Table 2.3. Compositional Summary (Oxide Basis) of the C-104/AY-101 HLW Simulant, Glass Additives, and the Reference Glass (HLW98-96D).

Oxide	C-104/AY-101 Simulant Compositions	Glass Former (as wt% of glass)	Target Glass in Melter Tests	HLW98-96D
Ag_2O	—	—	—	0.03%
Al_2O_3	11.89%	—	3.58%	3.60%
B_2O_3	0.34%	10.71%	10.81%	10.81%
BaO	—	—	—	—
BeO	—	—	—	—
Bi_2O_3	—	—	—	—
CaO	1.60%	—	0.48%	0.48%
CdO	—	—	—	—
Ce_2O_3	—	—	—	—
Cl	—	—	—	—
Cr_2O_3	0.21%	—	0.06%	0.06%
Cs_2O	0.17%	—	0.05%	—
CuO	0.10%	—	0.03%	0.03%
F	0.39%	—	0.12%	0.12%
Fe_2O_3	31.67%	—	9.54%	9.58%
I	0.33%	—	0.10%	—
La_2O_3	0.53%	—	0.16%	0.16%
Li_2O	0.33%	3.21%	3.31%	3.31%
MnO*	5.04%	—	1.52%	1.53%
Na_2O	5.26%	9.91%	11.49%	11.50%
Nd_2O_3	0.36%	—	0.11%	0.11%
NiO	1.55%	—	0.47%	0.47%
PbO	0.41%	—	0.12%	0.12%
P_2O_5	0.14%	—	0.04%	0.04%
Pr_2O_3	—	—	—	—
Rb_2O	—	—	—	—
SiO_2	8.24%	43.90%	46.39%	46.39%
ThO_2	—	—	—	—
TiO_2	0.07%	—	0.02%	0.02%
UO_2	—	—	—	—
ZnO	0.06%	2.14%	2.16%	2.16%
ZrO_2	31.30%	—	9.43%	9.47%
TOTAL	100.0%	69.87%	100.0%	100.0%

–Empty Data Field. *MnO_2 in Reference [6]

Table 2.4. Composition of Melter Feed to Produce 1 Metric Ton of Target Glass from C-104/AY-101 HLW Simulant (20 wt% Suspended Solids).

C-104/AY-101 HLW Simulant		Glass-Forming Additives	
Starting Materials	**Target Weight (kg)***	**Starting Materials**	**Target Weight (kg)**
$Al(OH)_3$	57.72	–	–
H_3BO_3	1.86	$Na_2B_4O_7·10H_2O$	296.24
$Ca(OH)_2$	6.50	–	–
Cr_2O_3	0.64	–	–
CsOH (50% solution)	1.06	–	–
CuO	0.30	–	–
NaF	2.65	–	–
$Fe(OH)_3$ (13% slurry)	977.65	–	–
NaI	1.19	–	–
$La(OH)_3·3H_2O$	2.41	–	–
Li_2CO_3	2.54	Li_2CO_3	81.48
MnO_2	18.81	–	–
NaOH	13.98	Na_2CO_3	88.76
Nd_2O_3	1.09	–	–
$Ni(OH)_2$	6.01	–	–
$FePO_4·xH_2O$ (80%)	1.08	–	–
PbO	1.24	–	–
SiO_2	25.08	SiO_2	443.45
TiO_2	0.22	–	–
ZnO	0.19	ZnO	21.63
$Zr(OH)_4·xH_2O$ (50%)	243.75	–	–
$NaNO_2$	1.64	–	–
$NaNO_3$	6.77	–	–
$H_2C_2O_4·2H_2O$	2.12	–	–
Water	496.50	–	–
–	–	–	–
TOTAL	1873.00	TOTAL	931.56
–	–	FEED TOTAL	2804.56

*Target weights adjusted for assay information of starting materials.
– Indicates empty data field.

Table 2.5. Properties of C-104/AY-101 Melter Feed Samples.

–	**Date**	**Name**	**wt% Water**	**Density (g/ml)**	**Glass Yield**		**pH**	**Yield Stress (Pa)**	**Apparent Viscosity (Poise)**		
					kg/kg	**g/l**			**@1/s**	**@10/s**	**@100/s**
DM1200	2/19/03	O12-F-75A	56.0	1.41	0.376	529.9	10.88	5.0	30.6	4.75	0.66
	2/20/03	O12-F-114A	56.2	1.40	0.372	520.4	10.81	NA	NA	NA	NA
	2/21/03	O12-F-129A	55.8	1.39	0.379	526.5	10.82	NA	NA	NA	NA
	2/22/03	P12-F-21A	56.1	1.40	0.375	525.6	10.88	NA	NA	NA	NA
	02/23/03	P12-F-50A	55.7	1.40	0.380	532.4	10.84	NA	NA	NA	NA
	2/24/03	P12-F-103A	55.9	1.41	0.380	536.1	10.95	NA	NA	NA	NA
	2/25/03	P12-F-146A	56.3	1.40	0.377	527.1	10.94	3.7	30.1	3.29	0.49
	2/26/03	Q12-F-39A	56.2	1.41	0.376	529.7	10.91	NA	NA	NA	NA
	2/27/03	Q12-F-77A	56.5	1.39	0.375	521.8	10.91	NA	NA	NA	NA
	2/28/03	Q12-F-104A	56.1	1.40	0.380	531.9	10.94	NA	NA	NA	NA
	Average		56.1	1.40	0.377	528.1	10.89	4.4	30.4	4.02	0.58
DM100BL	1/13/02	BLF-F-35A	56.5	1.40	0.378	529.8	10.79	5.2	34.4	4.72	0.66
	1/14/02	BLF-F-52A	56.1	1.40	0.374	523.5	10.77	NA	NA	NA	NA
	1/15/03	BLF-F-68A	56.3	1.41	0.376	530.3	10.80	NA	NA	NA	NA
	1/16/03	BLF-F-85A	60.6	1.41	0.333	469.2	10.88	NA	NA	NA	NA
	1/17/03	BLF-F-97A	56.6	1.40	0.373	522.8	10.89	5.9	32.9	5.11	0.70
	Average*		56.4	1.40	0.375	526.6	10.83	5.6	33.7	4.92	0.68

NA – Not analyzed
* - Averages do not include the outlier BLF-F-85A.
– Indicates empty data field.

Table 2.6. XRF Analyzed Compositions for Vitrified DM100 Melter Feed Samples (wt%).

-	Target	BLF-F-35A	BLF-F-52A	BLF-F-68A	BLF-F-85A	BLF-F-97A
Al_2O_3	3.58	3.90	4.06	3.78	3.88	4.42
B_2O_3*	10.81	10.81	10.81	10.81	10.81	10.81
CaO	0.48	0.67	0.59	0.52	0.51	0.55
Cr_2O_3	0.06	0.07	0.06	0.07	0.06	0.06
Cs_2O	0.05	0.06	0.05	0.05	0.04	0.05
CuO	0.03	0.03	0.03	0.03	0.03	0.03
F	0.12	NA	NA	NA	NA	NA
Fe_2O_3	9.54	8.72	8.92	8.71	8.87	9.09
I	0.10	<0.01	<0.01	<0.01	<0.01	<0.01
La_2O_3	0.15	0.16	0.16	0.17	0.16	0.16
Li_2O*	3.31	3.31	3.31	3.31	3.31	3.31
MnO	1.52	1.45	1.46	1.43	1.44	1.49
Na_2O	11.49	10.96	10.04	10.93	11.77	9.95
Nd_2O_3	0.11	0.10	0.11	0.10	0.11	0.11
NiO	0.47	0.39	0.40	0.40	0.40	0.41
P_2O_5	0.04	0.09	0.08	0.08	0.09	0.09
PbO	0.12	0.10	0.10	0.10	0.10	0.10
SiO_2	46.40	45.89	45.77	46.25	44.56	45.42
TiO_2	0.02	0.14	0.14	0.12	0.12	0.14
ZnO	2.16	1.92	1.95	1.87	1.88	1.91
ZrO_2	9.43	10.91	11.71	11.08	11.68	11.66
K_2O	Impurities	0.11	0.11	0.10	0.10	0.12
MgO		0.10	0.06	0.06	0.04	0.07
SO_3		0.05	0.04	0.04	0.02	0.03
SrO		0.05	0.01	0.01	0.01	0.01
Sum	100.00	100.00	100.00	100.00	100.00	100.00

* Target values
NA – Not analyzed
NC – Not calculated
\- Empty data field

Table 2.7. XRF Analyzed Compositions for Vitrified DM1200 Melter Feed Samples (wt%).

-	Target	O12-F-75A	O12-F-114A	O12-F-129A	P12-F-21A	P12-F-50A	P12-F-103A	P12-F-146A	Q12-F-39A	Q12-F-77A	Q12-F-104A
Al_2O_3	3.58	3.67	3.83	3.69	3.88	3.63	4.52	3.62	3.56	3.55	3.56
B_2O_3*	10.81	10.81	10.81	10.81	10.81	10.81	10.81	10.81	10.81	10.81	10.81
CaO	0.48	0.54	0.54	0.55	0.55	0.55	0.57	0.55	0.56	0.54	0.57
Cr_2O_3	0.06	0.20	0.19	0.20	0.14	0.22	0.07	0.22	0.26	0.24	0.23
Cs_2O	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.04	0.05
CuO	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.04	0.03
F	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	9.54	9.79	9.60	9.72	9.37	9.76	9.04	9.77	9.93	9.67	9.84
I	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
K_2O	0.00	0.08	0.09	0.09	0.09	0.08	0.14	0.08	0.08	0.08	0.08
La_2O_3	0.15	0.17	0.17	0.17	0.18	0.18	0.16	0.19	0.19	0.17	0.18
Li_2O*	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31	3.31
MnO	1.52	1.48	1.48	1.49	1.47	1.52	1.48	1.57	1.59	1.53	1.57
Na_2O	11.49	10.48	10.61	10.45	10.75	10.45	10.14	10.04	9.96	10.87	10.02
Nd_2O_3	0.11	0.11	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.11
NiO	0.47	0.48	0.45	0.47	0.45	0.48	0.42	0.48	0.51	0.49	0.48
P_2O_5	0.04	0.08	0.07	0.08	0.08	0.07	0.08	0.08	0.07	0.08	0.07
PbO	0.12	0.10	0.10	0.10	0.11	0.11	0.10	0.11	0.11	0.11	0.11
SiO_2	46.40	44.76	45.31	45.05	45.33	44.49	45.76	44.36	44.05	44.15	44.28
TiO_2	0.02	0.12	0.12	0.12	0.12	0.12	0.14	0.11	0.12	0.11	0.13
ZnO	2.16	2.02	1.97	2.00	1.93	2.04	1.92	2.03	2.09	2.01	2.07
ZrO_2	9.43	11.57	10.99	11.38	11.09	11.83	11.08	12.42	12.56	11.99	12.42
MgO	Impurities	0.09	0.11	0.08	0.10	0.11	0.04	0.04	0.04	0.07	0.05
SO_3		0.03	0.01	0.03	0.03	0.03	0.04	0.02	0.02	0.03	0.03
SrO		0.03	0.04	0.04	0.03	0.02	0.01	0.01	<0.01	0.01	<0.01
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Target values
NA – Not Analyzed
NC – Not calculated
- Empty data field

Table 2.8. Comparison of XRF Analyses of Vitrified Melter Feed Samples to Target Composition (wt%).

–	**Target**	**DM100** (6 samples)		**DM1200** (10 samples)		**All Feed** (16 samples)	
		Average	%Dev.	Average	%Dev.	Average	%Dev.
Al_2O_3	3.58	3.95	10.30	3.75	4.73	3.82	6.82
B_2O_3*	10.81	10.81	NC	10.81	NC	10.81	NC
CaO	0.48	0.55	NC	0.55	NC	0.55	NC
Cr_2O_3	0.06	0.06	NC	0.20	NC	0.15	NC
Cs_2O	0.05	0.05	NC	0.04	NC	0.05	NC
CuO	0.03	0.03	NC	0.03	NC	0.03	NC
F	0.12	NC	NC	NC	NC	NC	NC
Fe_2O_3	9.54	8.77	-8.07	9.65	1.14	9.32	-2.31
I	0.10	<0.01	NC	<0.01	NC	<0.01	NC
La_2O_3	0.15	0.16	NC	0.18	NC	0.17	NC
Li_2O*	3.31	3.31	NC	3.31	NC	3.31	-0.02
MnO	1.52	1.44	-5.53	1.52	-0.26	1.49	-2.24
Na_2O	11.49	11.60	0.96	10.38	-9.70	10.84	-5.70
Nd_2O_3	0.11	0.10	NC	0.11	NC	0.11	NC
NiO	0.47	0.40	NC	0.47	-0.04	0.44	NC
P_2O_5	0.04	0.09	NC	0.08	NC	0.08	NC
PbO	0.12	0.10	NC	0.11	NC	0.10	NC
SiO_2	46.40	45.03	-2.95	44.75	-3.55	44.86	-3.32
TiO_2	0.02	0.13	NC	0.12	NC	0.12	NC
ZnO	2.16	1.88	-12.87	2.01	-7.07	1.96	-9.25
ZrO_2	9.43	11.30	19.77	11.73	24.40	11.57	22.67
K_2O	Impurities	0.10	NC	0.09	NC	0.10	NC
MgO		0.07	NC	0.07	NC	0.07	NC
SO_3		0.04	NC	0.03	NC	0.03	NC
SrO		0.02	NC	0.02	NC	0.02	NC
Sum	100.00	100.00	NC	100.00	NC	100.00	NC

* Target values
NC – Not calculated
– Empty data field

Table 3.1. Summary of DM100 C-104/AY-101 Test Conditions and Results.

Time	Feed Start	1/13/03, 11:41
	Feed End	1/17/03, 16:30
	Interval	100.8 hr
Water Feeding for Cold Cap		0.7 hr
Slurry Feeding		100.1 hr
Average Bubbling Rate		17.3 lpm
Melt Pool Surface Area		0.108 m^2
Feed	Used	1229 kg
	Glass yield	526.6$^{@}$ g/l
		0.357$^{\#}$ kg/kg
	Average Rate	12.3 kg/hr
Glass Produced	Poured	454.9 kg
	Average Rate$^{\$}$	1010 kg/m^2/day
	Average Rate*	974 kg/m^2/day

@ - Measured values.
# - Target values.
$ - Rates calculated from glass poured.
*- Rates calculated from feed data.

Table 3.2. Glass Discharged, Masses, and Analysis Performed on DM100 Samples.

Date	Sample I.D.	Analysis	Mass (kg)	Cumulative Mass (kg)
01/13/03	BLF-G-32A	-	33.80	33.8
	BLF-G-34A	XRF		
01/14/03	BLF-G-39A	-	26.1	59.9
	BLF-G-41A	XRF		
	BLF-G-44A	-	33.2	93.1
	BLF-G-45A	XRF		
	BLF-G-49A	-	42.3	135.4
	BLF-G-41A	XRF		
01/15/03	BLF-G-53A	-	36.1	171.5
	BLF-G-57A	XRF		
	BLF-G-59A	XRF	21.8	193.3
	BLF-G-61A	-	19.9	213.2
	BLF-G-61B	XRF		
	BLF-G-66A	-	20.7	233.9
	BLF-G-68A	XRF		
	BLF-G-70A	-	24.6	258.5
	BLF-G-71A	XRF		
01/16/03	BLF-G-74A	-	17.7	276.2
	BLF-G-76A	XRF		
	BLF-G-77A	-	18.7	294.4
	BLF-G-77B	XRF		
	BLF-G-77C	-	21.5	316.4
	BLF-G-78A	XRF		
	BLF-G-79A	-	24.5	340.9
	BLF-G-84A	XRF		
	BLF-G-85A	-	15.5	356.4
	BLF-G-87A	XRF		
01/17/03	BLF-G-87B	-	18.7	375.1
	BLF-G-88A	XRF		
	BLF-G-92A	-	23.1	398.2
	BLF-G-94A	XRF		
	BLF-G-95A	-	17.4	415.6
	BLF-G-96A	XRF		
	BLF-G-97A	-	19.5	435.1
	BLF-G-97B	XRF		
	BLF-G-98A	-	19.8	454.9
	BLF-G-102A	XRF		

- Empty data field

Table 3.3. XRF Analyzed Compositions for Glass Discharged from DM100 (wt%).

Glass (kg)		34	60	93	135	172	193	213	234	259	276	295
-	Target	BLF-G-34A	BLF-G-41A	BLF-G-45A	BLF-G-51A	BLF-G-57A	BLF-G-59A	BLF-G-61B	BLF-G-68A	BLF-G-71A	BLF-G-76A	BLF-G-77B
Al_2O_3	3.58	5.44	5.27	5.09	5.03	4.74	4.62	4.40	4.30	4.22	4.32	4.28
B_2O_3*	10.81	9.63	9.79	9.96	10.14	10.26	10.32	10.38	10.42	10.47	10.50	10.53
CaO	0.48	0.46	0.46	0.47	0.48	0.48	0.50	0.50	0.50	0.51	0.51	0.50
Cr_2O_3	0.06	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08
Cs_2O	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06
CuO	0.03	0.04	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.03	0.03
F	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe_2O_3	9.54	11.38	10.65	10.64	10.07	9.90	9.93	9.75	9.64	9.65	9.42	9.23
I	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
La_2O_3	0.15	0.27	0.23	0.24	0.22	0.21	0.21	0.20	0.18	0.19	0.18	0.18
Li_2O*	3.31	3.06	3.09	3.13	3.17	3.19	3.21	3.22	3.23	3.24	3.25	3.25
MnO	1.52	3.26	2.90	2.75	2.49	2.32	2.28	2.16	2.06	2.04	1.95	1.89
Na_2O	11.49	11.21	11.47	10.95	11.17	10.88	10.49	10.63	10.76	10.57	10.67	10.93
Nd_2O_3	0.11	0.15	0.14	0.13	0.13	0.13	0.12	0.12	0.12	0.11	0.12	0.11
NiO	0.47	0.21	0.24	0.28	0.28	0.31	0.33	0.33	0.35	0.35	0.35	0.35
P_2O_5	0.04	0.10	0.09	0.09	0.09	0.10	0.09	0.09	0.09	0.08	0.09	0.08
PbO	0.12	0.11	0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10
SiO_2	46.40	48.77	48.48	48.03	47.90	47.60	47.54	47.54	47.03	46.86	47.03	46.99
TiO_2	0.02	0.20	0.18	0.17	0.16	0.15	0.15	0.14	0.14	0.14	0.14	0.14
ZnO	2.16	1.85	1.78	1.86	1.78	1.83	1.86	1.84	1.88	1.90	1.85	1.82
ZrO_2	9.43	1.52	3.02	4.23	5.23	6.47	6.99	7.42	8.12	8.59	8.61	8.66
As_2O_3	From previous test or impurities	0.15	0.13	0.12	0.09	0.07	0.07	0.06	0.05	0.05	0.04	0.04
K_2O		0.10	0.11	0.11	0.12	0.11	0.11	0.10	0.11	0.11	0.11	0.11
MgO		0.95	0.87	0.74	0.56	0.48	0.45	0.41	0.35	0.30	0.31	0.34
Sb_2O_3		0.25	0.20	0.18	0.14	0.12	0.11	0.10	0.08	0.07	0.07	0.06
SO_3		0.03	0.03	0.03	0.03	0.00	0.00	0.03	0.06	0.03	0.00	0.02
SrO		0.70	0.56	0.51	0.42	0.34	0.32	0.28	0.24	0.22	0.20	0.18
Sum	100.0	100.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Target values calculated based on simple well-stirred tank model
NA – Not analyzed
- Empty data field

Table 3.3. XRF Analyzed Compositions for Glass Discharged from DM100 (wt%), (Continued).

Glass (kg)		316	341	356	375	398	416	435	455	%Dev. (last sample)
-	Target	BLF-G-78A	BLF-G-84A	BLF-G-87A	BLF-G-88A	BLF-G-94A	BLF-G-96A	BLF-G-97B	BLF-G-102A	
Al_2O_3	3.58	4.17	4.21	4.07	4.02	4.05	4.06	3.98	3.98	11.29
B_2O_3	10.81	10.57	10.60	10.61	10.63	10.65	10.67	10.68	10.70	NC
CaO	0.48	0.51	0.51	0.52	0.51	0.51	0.52	0.52	0.52	NC
Cr_2O_3	0.06	0.09	0.08	0.09	0.08	0.08	0.08	0.08	0.08	NC
Cs_2O	0.05	0.06	0.06	0.06	0.05	0.05	0.06	0.06	0.06	NC
CuO	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	NC
F	0.12	NC	NC	NC	NC	NC	NC	NC	NC	NC
Fe_2O_3	9.54	9.25	9.21	9.20	8.92	9.00	8.84	8.91	8.92	-6.55
I	0.10	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
La_2O_3	0.15	0.18	0.18	0.19	0.18	0.18	0.18	0.17	0.17	NC
Li_2O	3.31	3.26	3.26	3.27	3.27	3.28	3.28	3.28	3.29	NC
MnO	1.52	1.87	1.81	1.77	1.72	1.69	1.67	1.65	1.63	7.43
Na_2O	11.49	10.65	10.66	10.48	11.40	11.18	11.35	11.24	10.89	-5.21
Nd_2O_3	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.11	0.11	NC
NiO	0.47	0.36	0.36	0.37	0.36	0.38	0.36	0.38	0.37	NC
P_2O_5	0.04	0.09	0.08	0.09	0.08	0.08	0.09	0.09	0.09	NC
PbO	0.12	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	NC
SiO_2	46.40	46.93	46.73	46.75	46.42	46.30	46.37	46.34	46.59	0.41
TiO_2	0.02	0.14	0.13	0.13	0.12	0.12	0.12	0.12	0.12	NC
ZnO	2.16	1.86	1.84	1.85	1.80	1.82	1.80	1.81	1.82	-15.70
ZrO_2	9.43	9.18	9.46	9.78	9.69	10.00	9.90	10.03	10.17	7.80
As_2O_3	From previous test or impurities	0.03	0.03	0.03	0.02	0.01	0.01	0.01	<0.01	NC
K_2O		0.10	0.11	0.11	0.10	0.10	0.10	0.10	0.10	NC
MgO		0.24	0.20	0.20	0.21	0.14	0.18	0.16	0.14	NC
Sb_2O_3		0.05	0.05	0.04	0.03	0.03	0.03	0.03	0.02	NC
SO_3		<0.01	0.02	0.03	0.02	0.00	0.00	0.03	0.03	NC
SrO		0.16	0.14	0.13	0.12	0.10	0.10	0.09	0.08	NC
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC

* Target values calculated based on simple well-stirred tank model
NA – Not analyzed
NC – Not calculated

Table 4.1. Summary of DM1200 C-104/AY-101 Test Conditions and Results.

Test Segment		A	B	C
Time	Feed Start	02/19/03 18:37	02/22/03 20:14	02/25/03 20:14
	Feed End	02/22/03 20:13	02/25/03 20:14	02/28/03 20:14
	Interval	73.7 hr	72 hr	72 hr
Water Feeding for Cold Cap		1.7 hr	NA	NA
Slurry Feeding		72 hr	72 hr	72 hr
Cold Cap Burn-Off		NA	NA	4.7 hr
Bubbling Rate		8 lpm	40 lpm	65 lpm
Feed	Used	3875 kg	5934 kg	8721 kg
	Glass yield	528[@] g/l	528[@] g/l	528[@] g/l
		0.357[#] kg/kg	0.357[#] kg/kg	0.357[#] kg/g
	Average Rate	53.8 kg/hr	82.4 kg/hr	121.1 kg/hr
Glass Produced	Poured	1487 kg	2245 kg	3251 kg
	Average Rate[$]	413 kg/m^2/day	624 kg/m^2/day	903 kg/m^2/day
	Average Rate[*]	384 kg/m^2/day	588 kg/m^2/day	865 kg/m^2/day
	Steady State Rate[*]	400 kg/m^2/day	660 kg/m^2/day	900 kg/m^2/day
	Average Power Use	5.0 kW.hr/ kg glass	4.3 kW.hr/ kg glass	3.6 kW.hr/ kg glass

@ - Measured values.
# - Target values.
$ - Rates calculated from glass poured.
*- Rates calculated from feed data.
Note: Rates do not take into account the time for water feeding and cold cap burn-off.
NA: Not applicable.

Table 4.2. DM1200 Melter System Measured Parameters.

Test Segment			A			B			C		
-			AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX
TEMPERATURE (°C)	Glass	13" from floor E	1144	1081	1184	1143	1085	1197	1138	1103	1173
		15.5" from floor E	1139	1079	1185	1139	1076	1196	1132	1092	1166
		18" from floor E	1141	1079	1186	1140	1079	1196	1134	1095	1168
		27" from floor E	1079	846	1185	1072	824	1199	1048	852	1162
		13" from floor W	1144	1112	1182	1145	1095	1199	1139	1088	1180
		15.5" from floor W	1143	1107	1183	1143	1090	1200	1136	1088	1181
		18" from floor W	1138	1098	1188	1138	1078	1203	1131	1072	1182
		27" from floor W	1030	782	1174	1013	784	1210	976	685	1152
	Plenum	8" below ceiling	530	402	750	555	459	654	539	469	604
		17" below ceiling	530	419	746	559	477	622	545	477	603
		Exposed	536	400	751	568	456	688	552	459	618
	Discharge	TC 1	994	921	1066	1001	955	1056	1025	947	1097
		TC 2	1058	991	1119	1064	1039	1103	1099	1049	1144
		Riser	1049	942	1139	1100	1052	1156	1131	1092	1169
	Electrode	East	1118	1063	1151	1135	1099	1158	1151	1124	1163
		West	1101	1052	1138	1113	1075	1134	1130	1100	1159
		Bottom	986	966	1009	1019	986	1067	1051	1021	1097
	Film Cooler	Added Air	81	78	83	81	62	85	82	80	83
		Outlet	309	63	484	340	67	409	361	73	417
Glass	Density (g/cc)		2.41	2.22	2.47	2.38	1.84	2.50	2.37	2.20	2.45
	Level (inches from floor)		28.10	27.30	29.77	28.02	26.34	31.34	27.93	26.96	28.79
	Resistance (ohms)		0.110	0.105	0.123	0.112	0.105	0.129	0.111	<0.1	0.121
Differential Pressure (inches water)	Transition line		2.96	1.23	5.19	3.86	1.06	8.14	4.82	2.04	9.03
	Film Cooler		1.07	-0.11	1.89	1.17	0.11	2.17	1.25	0.29	3.02
Electrodes	Current (A)		937	824	1014	1061	847	1095	1182	0	1230
	Voltage (V)		103.1	87.1	112.2	118.6	90.0	124.9	131.5	0	140.7
	Power (kW)		96.6	71.7	113.7	125.8	76.2	136.8	155.4	0	173.1
Lance Bubblers	1	Rate (lpm)	4.05	2.53	5.56	18.45	3.05	24.51	32.75	21.39	38.48
		Temp. (°C)	1155	1103	1182	1125	1074	1187	1081	1050	1111
	2	Rate (lpm)	3.31	1.89	4.92	18.55	2.89	24.53	29.68	17.30	34.94
		Temp. (°C)	1166	1120	1194	1143	1104	1192	1121	1081	1167
Total Bubbling (lpm)			8.36	5.91	8.54	38.01	6.94	40.63	63.43	40.20	65.53

–Empty data field

Table 5.1. DM1200 Measured Off Gas System Parameters.

Test #		A			B			C		
–		Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
Melter	Pressure at Level Det. Port (“water)	-3.9	-6.7	-0.9	-4.0	-6.8	-0.5	-3.7	-5.1	0.1
	Pressure at Instrument Port (“water)	-4.0	-6.9	-1.0	-4.1	-6.9	-0.7	-3.8	-5.2	0.0
	Control Air Flow Rate (scfm)	42.8	20.5	67.9	47.7	22.4	81.8	46.9	0.0	76.0
SBS	Differential Pressure (“water)	39.4	35.4	43.6	40.4	36.3	44.0	41.8	37.7	46.0
	Inlet gas pressure (“water)	-7.0	-10.5	-3.8	-8.0	-10.9	-4.6	-8.5	-11.7	-3.4
	Outlet gas pressure (“water)	-44.7	-48.5	-42.1	-46.6	-49.9	-43.0	-48.3	-54.5	-41.6
	Inlet gas Temp. (°C)	242	97	354	263	143	303	273	150	318
	Outlet gas Temp. (°C)	40.1	31.3	49.0	39.8	29.2	43.8	39.5	36.1	43.5
	Chilled Water Inlet Temp (°C)	14.8	8.2	24.4	14.3	9.1	20.3	14.9	11.2	20.2
	Chilled Water Outlet Temp (°C)	21.3	16.0	46.4	21.1	17.5	29.0	23.1	19.5	37.0
	Submerged 48" Temp (°C)	45.1	35.4	55.3	45.4	34.1	54.5	44.2	37.2	49.6
	Submerged 60" Temp (°C)	44.5	35.3	55.2	44.9	33.2	54.2	43.9	37.2	49.7
	Submerged 72" Temp (°C)	48.1	38.9	58.6	48.9	38.0	58.1	48.2	38.2	53.8
	Submerged 78" Temp (°C)	46.0	37.6	56.4	46.8	35.7	54.5	45.9	38.0	51.6
	Recirc. pump discharge Temp (°C)	39.9	31.2	47.7	39.7	29.4	43.6	39.2	36.5	43.1
	Heat Exchanger Outlet Temp (°C)	37.0	27.4	44.0	34.8	25.3	41.4	31.8	28.1	36.9
	Chilled Water Flow (gal/min)	5.6	2.4	10.7	5.6	2.4	19.7	8.9	2.5	20.6
	Heat Exchanger Flow (gal/min)	4.2	0.5	17.5	7.6	0.6	24.9	12.4	10.6	26.4
	Recirc. pump discharge Pressure	38.5	30.9	40.7	38.6	31.5	40.9	38.7	31.8	40.7
	Inner C. Coil W. Inlet Temp (°C)	34.0	19.8	44.4	29.4	22.2	42.1	24.8	20.6	29.9
	Inner C. Coil W. Outlet Temp(°C)	37.8	29.4	44.3	35.8	26.0	42.8	33.6	30.3	38.0
	Inner C. Coil W. Flow (gal/min)	24.7	24.0	25.2	24.6	23.8	25.1	24.4	23.8	25.0
WESP	Differential Pressure (“water)	2.2	1.7	2.6	2.3	1.4	2.8	2.3	1.6	2.9
	Inlet gas Temp. (°C)	40.0	32.0	49.2	39.7	30.7	43.7	39.6	36.7	43.5
	Outlet gas Temp. (°C)	40.9	17.1	48.1	40.8	16.7	43.8	40.9	17.6	43.9
HEME #1, Outlet Gas Temp. (°C)		39.6	31.0	47.3	38.8	30.2	41.3	38.8	30.7	41.4
HEPA 1	Differential Pressure (“water)	0.2	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.2
	Outlet Gas Temp. (°C)	61.5	60.2	62.5	61.3	55.8	62.1	61.3	60.3	61.8
PAXTON 1 Outlet Gas Temp. (°C)		79.6	78.5	80.7	80.8	68.1	81.7	80.8	79.2	82.9
TCO-SCR Heater Inlet Gas Temp. (°C)		79.2	78.5	80.4	80.6	67.6	81.5	80.6	79.3	82.5
TCO	Inlet Gas Temp. (°C)	485	472	491	486	421	514	486	480	492
	Differential Pressure (“water)	2.9	2.7	3.2	3.1	1.7	3.4	3.1	2.7	3.3
SCR	Inlet Gas Temp. (°C)	386	378	390	387	237	398	385	379	392
	Outlet Gas Temp. Right (°C)	346	331	351	349	186	358	351	344	357
	Outlet Gas Temp. Left (°C)	343	339	347	345	202	356	349	346	352
	Differential Pressure (“water)	6.3	5.8	6.8	6.6	4.5	7.2	6.5	5.6	7.1
	Post Outlet Gas Temp. (°C)	325	318	329	318	173	336	324	302	334
PBS	Inlet Gas Temp. (°C)	301	292	304	295	145	310	301	282	309
	PBS Sump Temp. (°C)	23.7	19.6	32.4	23.7	17.9	27.3	24.8	22.7	28.0
	Differential Pressure (“water)	3.0	2.2	3.7	3.2	1.7	3.9	3.2	2.4	3.9
HEME #2	Inlet Gas Temp. (°C)	25.4	22.1	33.6	25.5	20.1	28.5	26.6	24.1	29.6
	Outlet Gas Temp. (°C)	27.8	24.7	35.8	27.4	22.4	30.7	28.6	26.4	31.3
Exhaust Stack Absolute Pressure (“water)		-8.6	-8.8	-8.1	-8.4	-8.7	0.0	-8.6	-8.8	-7.6

– Indicates empty data field

Table 5.2a. Mass of Solid Deposits Removed from the Film Cooler and Transition Line Sections.

Section Name	Mass (kg)	Pre-cleaning Figures	Post-cleaning Figures	Previous Cleaning Status
Film Cooler	0.062	5.5-5.7	5.18-5-19	Installed new: 6/21/02
Transition line section #1	0.116	5.8-5.9	5.20	Removed + Cleaned: 6/21/02
Transition line section #2	3.11	5.10-5-11	-	
Transition line section #3	0.842	5.12-5.14	5.21	
Transition line bellows	0.236	5.15-5.16	5.22	Removed + Cleaned: 10/24/02
Transition line on SBS side	0.136	5.17	-	Cleaned in place: 10/24/02
Total	4.502	-	-	-

- Indicates empty data field

Table 5.2b. DCP Analyzed Composition (wt%) of a Sample Taken From Transition Line #2 During DM 1200 Off-Gas System Inspections.

Test #	C-104/AY-101
Date/Time	03/05/2003, 18:15
Sample Number	Q12-T-144B
Mass (kg)	3.11
Sample Description	Solids from the transition line section #2.
Wt % water of original sample	Dry
Dried at 110 ^{0}C prior to analysis	No
Al_2O_3	4.14
As_2O_3	0.08
B_2O_3	6.93
BaO	0.01
CaO	0.63
CdO	0.03
Cr_2O_3	0.04
Cs_2O	0.11
CuO	0.03
Fe_2O_3	11.68
K_2O	0.06
Li_2O	1.03
MgO	0.60
MnO	1.11
Na_2O	6.61
NiO	0.37
P_2O_5	0.08
PbO	0.08
SO_3	1.99
Sb_2O_3	0.13
SeO_2	5.06
SiO_2	26.42
SrO	0.38
TiO_2	0.19
ZnO	2.07
ZrO_2	3.48
Sum	73.36

Table 5.3. Time Needed to Restore Power After Deluge of WESP.

DATE	TIME	Time Required to Restore Power (Minutes)
02/20/2003	11:49	85
02/21/2003	11:47	90
02/22/2003	11:50	50
02/23/2003	11:43	79
02/24/2003	11:32	15
02/25/2003	10:41	10
02/26/2003	11:20	5
02/27/2003	11:20	5

Table 5.4. Nitrogen Oxides and Carbon Monoxide Destruction Across TCO-SCR Catalytic Unit.

Test Segment	-	Input (mol/hr)	Output (mol/hr)	NO_x, CO Reduction (%)	DF
A	N_2O	0.018	<0.015	-	-
	NO	1.845	0.144	-	-
	NO_2	0.156	0.091	-	-
	Total NO_x	2.019	<0.250	> 87.6	> 8.1
	CO	<0.014	<0.015	-	-
	CO_2	52.5	19.4	-	-
B	N_2O	0.023	<0.015	-	-
	NO	3.062	0.260	-	-
	NO_2	0.277	0.0.130	-	-
	Total NO_x	3.363	<0.405	> 88.0	> 8.3
	CO	<0.015	<0.015	-	-
	CO_2	74.4	26.0	-	-
C	N_2O	0.030	0.026	-	-
	NO	4.195	0.732	-	-
	NO_2	0.434	0.266	-	-
	Total NO_x	4.659	1.124	75.9	4.1
	CO	0.017	<0.015	-	-
	CO_2	101.3	62.5	-	-

– Indicates empty data field

Table 5.5. Ammonia Slippage from TCO-SCR Catalytic Unit.

Test Segment	–	Input (mol/hr)	Output (mol/hr)	NH_3 slippage (%)
A	NH_3 (in exhaust)	< 0.014	–	–
	NH_3 injected	0.858	–	–
	Total NH_3	< 0.873	0.046	> 5.3
B	NH_3 (in exhaust)	0.048	–	–
	NH_3 injected	1.107	–	–
	Total NH_3	1.155	0.028	2.4
C	NH_3 (in exhaust)	< 0.014	–	–
	NH_3 injected	1.715	–	–
	Total NH_3	< 1.730	< 0.015	~ 0.9

– Indicates empty data field

Table 5.6. Listing of Samples from SBS Blow-Downs.

Test Segment	Date	Name	pH	Blow-Down Volume (Gallons)	Cumulative Volume (Gallons)
A	02/19/03	O12-S-73A	8.28	40.04	40.04
	02/20/03	O12-S-80A	8.26	39.98	80.02
		O12-S-103A	8.27	40.00	120.02
		O12-S-112A	8.21	32.83	152.85
	02/21/03	O12-S-119A	8.17	39.93	192.78
		O12-S-137A	8.10	40.17	232.95
		O12-S-153A	8.10	40.07	273.02
	02/22/03	P12-S-10A	8.23	40.19	313.21
		P12-S-24A	8.21	40.07	353.28
B		P12-S-31A	8.17	40.01	393.29
	02/23/03	P12-S-49A	8.20	40.07	433.36
		P12-S-60A	8.26	40.08	473.44
		P12-S-65A	8.10	40.00	513.44
		P12-S-71A	8.10	40.01	553.45
		P12-S-83A	8.04	39.83	593.28
	02/24/03	P12-S-87A	8.06	40.22	633.50
		P12-S-92A	8.08	40.08	673.58
		P12-S-104A	8.06	50.01	723.59
		P12-S-110A	8.02	40.01	763.60
		P12-S-123A	8.10	40.00	803.60
	02/25/03	P12-S-126A	8.03	39.58	843.18
		P12-S-131A	8.01	39.83	883.01
		P12-S-141A	7.96	40.17	923.18
		P12-S-148A	7.99	40.03	963.21
C		P12-S-154A	8.04	40.04	1003.25
	02/26/03	Q12-S-17A	7.97	40.13	1043.38
		Q12-S-22A	8.01	40.04	1083.42
		Q12-S-25A	8.01	39.99	1123.41
		Q12-S-34A	7.95	40.54	1163.95
		Q12-S-37A	8.02	39.87	1203.82
		Q12-S-39A	7.98	40.03	1243.85
		Q12-S-44A	7.90	40.01	1283.86
		Q12-S-46A	7.91	40.02	1323.88
	02/27/03	Q12-S-56A	7.99	40.08	1363.96
		Q12-S-58A	7.96	40.01	1403.97
		Q12-S-62A	7.94	39.63	1443.60
		Q12-S-65A	7.94	40.15	1483.75
		Q12-S-75A	7.92	39.68	1523.43
		Q12-S-78A	7.98	40.33	1563.76
		Q12-S-80A	7.99	42.38	1606.14
		Q12-S-83A	7.96	39.31	1645.45
		Q12-S-85A	7.97	40.05	1685.50

Table 5.6. Listing of Samples from SBS Blow-Downs (continued).

Test Segment	Date	Name	pH	Blow-Down Volume (Gallons)	Cumulative Volume (Gallons)
C	02/28/03	Q12-S-94A	7.93	40.51	1726.01
		Q12-S-97A	7.91	41.47	1767.48
		Q12-S-99A	7.89	40.73	1808.21
		Q12-S-104A	7.89	40.15	1848.36
		Q12-S-114A	7.91	39.29	1887.65
		Q12-S-118A	7.99	40.00	1927.65
		Q12-S-120A	7.95	40.00	1967.65
		Q12-S-122A	7.95	40.01	2007.66

Table 5.7. Analytical Results for Selected SBS and WESP Blow-Down Fluids (mg/l).

I.D.	P12-S-24A			P12-S-148A			Q12-S-122A			Q12-W-75A			Q12-W-75B		
Glass (kg)	1382			3626			6879			5404			5404		
pH	8.21			7.99			7.95			7.48			7.46		
	Sus*	Dis.#	Total	Sus.*	Dis.#	Total	Sus.*	Dis.#	Total	Sus*	Dis.#	Total	Sus*	Dis.#	Total
Total	736	1428	2164	2212	3816	6028	2172	3812	5984	<1	678	678	<1	506	506
Al	21.45	3.80	25.26	71.61	10.07	81.68	72.37	3.55	75.92	NA	1.23	1.23	NA	1.40	1.40
As	1.62	0.42	2.04	2.63	0.54	3.17	0.84	0.05	0.89	NA	1.65	1.65	NA	1.19	1.19
B	3.86	199.9	203.7	20.31	644.9	665.3	24.15	571.9	596.0	NA	29.10	29.10	NA	14.26	14.26
Ba	0.07	0.02	0.09	0.09	0.02	0.11	0.13	0.02	0.15	NA	0.05	0.05	NA	0.04	0.04
Ca	5.69	13.32	19.01	7.14	2.32	9.46	6.59	2.34	8.93	NA	35.54	35.54	NA	36.76	36.76
Cd	0.07	<0.01	0.07	0.13	<0.01	0.13	0.04	<0.01	0.04	NA	<0.01	<0.01	NA	<0.01	<0.01
Cr	0.41	0.89	1.30	1.16	3.14	4.30	3.78	3.54	7.32	NA	4.62	4.62	NA	2.45	2.45
Cs	0.78	1.84	2.62	3.93	2.71	6.64	3.78	3.46	7.24	NA	3.89	3.89	NA	2.41	2.41
Cu	0.22	<0.01	0.22	0.45	0.01	0.45	0.48	0.02	0.49	NA	0.03	0.03	NA	0.02	0.02
Fe	138.1	0.06	138.1	387.8	0.68	388.5	327.1	0.65	327.8	NA	0.25	0.25	NA	0.36	0.36
K	0.37	3.20	3.57	0.85	2.11	2.96	0.65	2.25	2.90	NA	4.34	4.34	NA	3.81	3.81
La	NA	0.032	0.03	NA	0.124	0.12	NA	0.139	0.14	NA	<0.03	<0.03	NA	<0.03	<0.03
Li	1.34	21.97	23.31	5.40	81.45	86.85	5.47	80.58	86.05	NA	8.03	8.03	NA	6.34	6.34
Mg	1.77	7.26	9.03	3.84	2.99	6.83	3.13	2.90	6.03	NA	8.22	8.22	NA	8.57	8.57
Mn	4.45	0.05	4.50	7.86	0.10	7.96	8.64	0.13	8.77	NA	0.05	0.05	NA	0.04	0.04
Na	7.54	275.9	283.5	50.04	823.2	873.2	70.24	921.0	991.2	NA	130.8	130.8	NA	93.43	93.43
Ni	3.23	0.07	3.29	10.71	0.18	10.90	11.34	0.22	11.56	NA	0.16	0.16	NA	0.12	0.12
P	0.50	<0.07	0.50	2.14	0.19	2.34	1.48	0.58	2.05	NA	<0.07	<0.07	NA	<0.07	<0.07
Pb	0.56	0.31	0.87	3.17	1.00	4.17	69.68	1.10	70.78	NA	0.04	0.04	NA	<0.02	<0.02
Sb	0.87	0.49	1.36	1.25	0.352	1.60	1.00	0.05	1.05	NA	0.28	0.28	NA	<0.03	<0.03
Si	111.5	13.72	125.2	305.0	9.44	314.4	327.3	9.89	337.2	NA	4.43	4.43	NA	3.42	3.42
Sr	1.87	2.561	4.43	1.07	0.09	1.17	0.52	0.52	1.04	NA	0.27	0.27	NA	0.25	0.25
Ti	1.44	<0.01	1.44	3.21	0.05	3.27	3.08	0.07	3.16	NA	0.01	0.01	NA	<0.01	<0.01
Zn	21.82	<0.01	21.82	73.35	0.05	73.40	66.16	0.07	66.23	NA	0.01	0.01	NA	<0.01	<0.01
Zr	21.47	0.01	21.48	62.63	0.63	63.27	89.79	0.98	90.77	NA	0.01	0.01	NA	<0.01	<0.01
F	NA	117.9	117.9	NA	393.6	393.6	NA	176.0	176.0	NA	32.88	32.88	NA	30.52	30.52
Cl	NA	110.4	110.4	NA	142.2	142.2	NA	122.2	122.2	NA	72.10	72.10	NA	66.49	66.49
I	<0.1	75.84	75.84	<0.1	123.1	123.0	<0.1	109.1	109.1	NA	6.09	6.09	NA	3.70	3.70
NH_4^+	NA	3.40	3.40	NA	<1.64	<1.64	NA	<1.64	<1.64	NA	6.40	6.40	NA	4.60	4.60
NO_2^-	NA	50.26	50.26	NA	96.72	96.72	NA	121.1	121.1	NA	39.29	39.29	NA	16.59	16.59
NO_3^-	NA	11.35	11.35	NA	6.91	6.91	NA	8.35	8.35	NA	18.61	18.61	NA	25.09	25.09
SO_4^{2-}	4.08	82.92	87.00	2.46	151.5	154.0	1.69	149.0	150.7	NA	221.0	221.0	NA	145.8	145.8

NA – not analyzed
* Suspended Solids
# Dissolved Solids

Table 5.8. WESP, PBS, and HEME Blow-down Liquids.

Sample Type	Test#	Date	Name	pH	Blow-down Vol. (gal)	Cumulative blow-down Vol. (gal)
WESP	**A**	2/20/03	O12-W-93A	6.67	36.47	36.47
			O12-W-93B	7.64	40.1	76.57
		2/21/03	O12-W-135A	7.68	56.44	133.01
			O12-W-135B	7.82	40.15	173.16
		2/22/03	P12-W-22A	7.62	58.75	231.91
			P12-W-22B	7.86	40.02	271.93
	B	2/23/03	P12-W-62A	7.47	40.00	311.93
			P12-W-62B	7.46	39.02	350.95
		2/24/03	P12-W-102A	7.47	56.89	407.84
			P12-W-102B	7.41	33.76	441.6
		2/25/03	P12-W-141A	7.46	57.86	499.46
			P12-W-141B	7.49	42.04	541.5
	C	2/26/03	Q12-W-34A	7.45	59.39	600.89
			Q12-W-34B	7.44	42.45	643.34
		2/27/03	Q12-W-75A	7.48	56.05	699.39
			Q12-W-75B	7.46	50.63	750.02
		2/28/03	Q12-W-119A	7.47	44.60	794.62
		3/01/03	Q12-W-136A	7.43	21.65	816.27
			Q12-W-136B	7.41	76.10	892.37
PBS	**A**	2/19/03	O12-P-72A	9.73	39.54	39.54
		2/20/03	O12-P-79A	9.37	30.59	70.13
			O12-P-105A	9.47	22.06	92.19
		2/21/03	O12-P-117A	9.41	39.53	131.72
			O12-P-141A	9.27	22.00	153.72
		2/22/03	P12-P-10A	9.48	32.52	186.24
	B		P12-P-30A	9.26	23.38	209.62
		02/23/03	P12-P-48A	9.66	34.66	244.28
			P12-P-65A	9.16	15.83	260.11
		02/24/03	P12-P-85A	9.37	40.03	300.14
			P12-P-106A	9.31	29.43	329.57
		02/25/03	P12-P-130A	9.27	39.40	368.97
			P12-P-149A	9.30	17.67	386.64
	C	2/26/03	Q12-P-22A	9.28	38.94	425.58
			Q12-P-39A	9.31	19.36	444.94
		2/27/03	Q12-P-58A	9.26	33.78	478.72
			Q12-P-84A	9.24	31.38	510.10
		2/28/03	Q12-P-99A	9.29	26.89	536.99
			Q12-P-123A	9.28	25.34	562.33
HEME 1	**C**	3/01/03	Q12-H1-136A	9.05	56.94	56.94
HEME 2	**A**	2/22/03	P12-H2-8A	8.52	18.98	18.98
	B	2/23/03	P12-H2-80A	8.30	12.20	31.18
		2/25/03	P12-H2-151A	8.29	0.59	31.77
	C	2/27/03	Q12-H2-85A	8.01	20.94	52.71
		3/01/03	Q12-H2-136A	7.98	41.34	95.05

Table 5.9. Anion Concentration in PBS and HEME Blow-Down Samples (mg/l).

Sample I.D.	**Source**	**pH**	**F**	**Cl**	**I**	**NH_4^+**	**Nitrite**	**Nitrate**	**Sulfate**
Q12-P-123A	PBS	9.28	65.8	94.0	1020	5.2	314	15.2	2.34
Q12-H1-136A	HEME #1	9.05	21.2	70.2	6.35	42.0	61.9	217	171
Q12-H2-136A	HEME #2	7.98	4.77	56.6	57.5	179	46.7	1028	54.5

Table 5.10. Upper Estimates of Accumulations in Off-Gas Liquids.

Analyte	Feed (kg)	SBS			WESP			PBS		HEME 1	
		Mass (g)	% Feed	% Feed calculated from emissions data	Mass (g)	% Feed	% Feed calculated from emissions data	Mass (g)	% Feed	Mass (g)	% Feed
Al	130	470	0.4	1.0	4	< 0.1	< 0.1	NA	NA	NA	NA
B	230	3700	1.6	< 0.1	73	< 0.1	< 0.1				
Ca	24	95	0.4	0.6	120	0.5	< 0.1				
Cr	2.9	33	1.1	1.5	12	0.3	< 0.1				
Cs	3.3	42	1.3	2.6	11	0.3	< 0.1				
Cu	1.7	3	0.2	0.7	< 1	< 0.1	NC				
Fe	470	2200	0.5	1.3	1	< 0.1	< 0.1				
K	5.2	24	0.5	NA	14	< 0.1	NA				
La	8.9	1	< 0.1	NA	< 1	< 0.1	NA				
Li	110	500	0.5	0.5	24	< 0.1	< 0.1				
Mg[*]	3.8	56	1.5	NA	28	0.7	NA				
Mn	82	54	< 0.1	0.3	< 1	< 0.1	< 0.1				
Na	600	5500	0.92	1.0	380	< 0.1	< 0.1				
Nd	6.6	NA	NA	NA	NA	NA	NA				
Ni	26	65	0.3	0.92	< 1	< 0.1	< 0.1				
P	1.2	12	1.0	1.3	< 1	< 0.1	NC				
Pb	7.8	190	2.5	1.1	< 1	< 0.1	NC				
Si	1500	2000	0.1	0.5	13	< 0.1	< 0.1				
Sr[*]	0.6	17	2.8	NA	< 1	< 0.1	NA				
Ti	0.8	20	2.5	7.4	< 1	< 0.1	NC				
Zn	120	410	0.3	1.0	< 1	< 0.1	< 0.1				
Zr	490	450	0.1	0.5	< 1	< 0.1	< 0.1				
F	8.4	1800	21	77	110	1.3	0.2	140	1.7	5	<0.1
Cl[*]	< 0.1	953	NC	NA	240	NC	NA	200	NC	152	NC
I	7	783	11	< 0.1	17	0.2	62	2200	31	14	0.2
Sulfate	4.2	1000	24	NC	620	15	NC	5	0.1	37	0.9
Nitrite + Nitrate	51	750	1.5	NA	170	0.3	NA	702	1.4	60	0.1

NA – Not analyzed, NC – Not calculated
[*] Impurities detected in feed samples

Table 6.1. Glass Discharged, Masses, and Analysis Performed for DM1200.

Test	Date	Name	Analysis	Mass	Cumulative Mass
#A	02/19/03	O12-G-73A	-	532.0	532.0
	02/20/03	O12-G-76A	-		
		O12-G-78A	-		
		O12-G-80A	-		
		O12-G-83A	-		
		O12-G-92A	-		
		O12-G-101A	-		
		O12-G-103A	-		
		O12-G-106A	-		
		O12-G-109A	XRF		
		O12-G-112A	-	483.0	1015.0
	02/21/03	O12-G-114A	-		
		O12-G-117A	-		
		O12-G-119A	-		
		O12-G-121A	-		
		O12-G-132A	-		
		O12-G-135A	-		
		O12-G-137A	-		
		O12-G-141A	-		
		O12-G-152A	XRF		
		O12-G-155A	-	524.5	1539.5
	02/22/03	P12-G-7A	-		
		P12-G-8A	-		
		P12-G-11A	-		
		P12-G-13A	-		
		P12-G-23A	-		
		P12-G-25A	-		
		P12-G-27A	-		
#B		P12-G-31A	-		
		P12-G-40A	XRF		
	02/23/03	P12-G-45A	-	525.0	2064.5
		P12-G-46A	-		
		P12-G-48A	-		
		P12-G-50A	-		
		P12-G-51A	-		
		P12-G-59A	-		
		P12-G-60A			
		P12-G-61A	-		
		P12-G-65A	-		
		P12-G-66A	XRF		
		P12-G-69A	-		
		P12-G-71A	-		
		P12-G-79A	-		
		P12-G-81A	-		
	02/24/03	P12-G-84A	-		
		P12-G-86A	-		

- Indicates empty data field

Table 6.1. Glass Discharged, Masses, and Analysis Performed for DM1200 (Continued).

Test	DATE	NAME	Analysis	Mass (kg)	Cum. Mass (kg)
#B	02/24/03	P12-G-87A	-	523.0	2587.5
		P12-G-89A	-		
		P12-G-92A	-		
		P12-G-92B	XRF		
		P12-G-101A	-	526.5	3114.0
		P12-G-102A	-		
		P12-G-104A	-		
		P12-G-106A	-		
		P12-G-108A	-		
		P12-G-110A	-		
		P12-G-113A	-		
		P12-G-114A	-		
		P12-G-122A	-		
	02/25/03	P12-G-124A	XRF		
		P12-G-125A	-	512.0	3626.0
		P12-G-127A	-		
		P12-G-130A	-		
		P12-G-131A	-		
		P12-G-140A	-		
		P12-G-141A	-		
		P12-G-144A	-		
		P12-G-147A	-		
		P12-G-148A	XRF		
		P12-G-150A	-	532.0	4158.0
		P12-G-154A	-		
#C		P12-G-155A	-		
		Q12-G-17A	-		
	02/26/03	Q12-G-19A			
		Q12-G-20A	-		
		Q12-G-21A	-		
		Q12-G-22A	-		
		Q12-G-23A	-		
		Q12-G-24A	XRF		
		Q12-G-25A	-	522.0	4680.0
		Q12-G-33A	-		
		Q12-G-34A	-		
		Q12-G-36A	-		
		Q12-G-37A	-		
		Q12-G-38A	-		
		Q12-G-39A	-		
		Q12-G-40A	-		
		Q12-G-41A	-		
		Q12-G-44A	XRF		

- Indicates empty data field

Table 6.1. Glass Discharged, Masses, and Analysis Performed for DM1200 (Continued).

Test	DATE	NAME	Analysis	Mass (kg)	Cum. Mass (kg)
#C	02/26/03	Q12-G-45A	-	519.5	5199.5
		Q12-G-46A	-		
		Q12-G-48A	-		
		Q12-G-48B	-		
	02/27/03	Q12-G-56A	-		
		Q12-G-57A	-		
		Q12-G-58A	-		
		Q12-G-60A	-		
		Q12-G-61A	-		
		Q12-G-62A	XRF		
		Q12-G-63A	-	461.0	5660.5
		Q12-G-65A	-		
		Q12-G-73A	-		
		Q12-G-75A	-		
		Q12-G-75B	-		
		Q12-G-78A	-		
		Q12-G-79A	-		
		Q12-G-79B	-		
		Q12-G-80A	XRF		
		Q12-G-81A	-	363.0	6023.5
		Q12-G-83A	-		
		Q12-G-84A	-		
		Q12-G-85A	-		
		Q12-G-93A	-		
		Q12-G-93B	-		
		Q12-G-94A	XRF		
	02/28/03	Q12-G-95A	-	439.0	6462.5
		Q12-G-97A	-		
		Q12-G-98A	-		
		Q12-G-98B	-		
		Q12-G-99A	-		
		Q12-G-102A	-		
		Q12-G-104A	-		
		Q12-G-113A	XRF		
		Q12-G-114A	-	520.5	6983.0
		Q12-G-115A	-		
		Q12-G-116A	-		
		Q12-G-118A	-		
		Q12-G-119A	-		
		Q12-G-120A	-		
		Q12-G-121A	-		
		Q12-G-122A	-		
		Q12-G-123A	-		
		Q12-G-136A	XRF		

- Indicates empty data field

Table 6.2. XRF Analyzed Compositions for Glass Discharged from DM1200 (wt%).

Test Segment		A		B					C							Statistics	
Glass (kg)		532	1015	1540	2065	2588	3114	3626	4158	4680	5200	5661	6024	6463	6983	>6000 kg	
Element	Target	O12-G-109A	O12-G-152A	P12-G-40A	P12-G-66A	P12-G-92B	P12-G-124A	P12-G-148A	Q12-G-24A	Q12-G-44A	Q12-G-62A	Q12-G-80A	Q12-G-94A	Q12-G-113A	Q12-G-136A	Avg.	%Dev.
Al_2O_3	3.58	5.14	5.01	4.58	4.39	4.24	4.81	4.20	4.62	4.65	4.40	4.47	3.97	4.41	4.03	4.14	15.50
B_2O_3*	10.81	9.73	9.97	10.17	10.32	10.44	10.53	10.59	10.65	10.68	10.71	10.73	10.75	10.76	10.77	10.76	NC
CaO	0.48	0.48	0.48	0.50	0.51	0.53	0.52	0.53	0.52	0.52	0.53	0.52	0.53	0.53	0.53	0.53	NC
Cr_2O_3	0.06	0.19	0.08	0.20	0.21	0.21	0.08	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	NC
Cs_2O	0.05	0.05	0.05	0.06	0.06	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.04	NC
CuO	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	NC
F	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NC	NC
Fe_2O_3	9.54	11.56	10.74	10.83	10.52	10.23	9.56	9.50	9.16	9.10	9.18	8.92	9.15	9.07	8.91	9.05	-5.20
I	0.10	<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
La_2O_3	0.15	0.24	0.23	0.21	0.20	0.19	0.18	0.18	0.18	0.17	0.16	0.17	0.18	0.17	0.17	0.17	NC
Li_2O*	3.31	3.08	3.13	3.17	3.21	3.23	3.25	3.26	3.28	3.28	3.29	3.29	3.30	3.30	3.30	3.30	NC
MnO	1.52	3.19	2.81	2.54	2.34	2.13	1.95	1.86	1.76	1.69	1.65	1.59	1.62	1.59	1.55	1.58	4.20
Na_2O	11.49	11.33	11.05	10.91	11.08	11.06	10.76	10.70	10.83	10.69	10.59	10.87	10.34	10.22	10.51	10.36	-9.87
Nd_2O_3	0.11	0.14	0.13	0.13	0.12	0.11	0.11	0.12	0.10	0.11	0.10	0.11	0.11	0.10	0.11	0.11	NC
NiO	0.47	0.25	0.26	0.33	0.36	0.38	0.35	0.36	0.37	0.38	0.39	0.39	0.41	0.40	0.40	0.41	NC
P_2O_5	0.04	0.10	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.08	0.08	0.08	0.08	NC
PbO	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	NC
SiO_2	46.40	47.45	47.74	46.63	46.15	45.88	46.35	46.42	46.31	46.10	45.86	46.16	46.34	45.97	46.62	46.31	-0.19
TiO_2	0.02	0.19	0.17	0.16	0.15	0.15	0.14	0.13	0.13	0.13	0.13	0.12	0.11	0.13	0.11	0.12	NC
ZnO	2.16	1.94	1.90	1.95	1.93	1.96	1.90	1.93	1.86	1.88	1.91	1.85	1.93	1.92	1.87	1.91	-11.80
ZrO_2	9.43	2.84	4.43	6.13	7.15	8.08	8.48	9.26	9.43	9.88	10.37	10.15	10.63	10.80	10.56	10.66	13.05
As_2O_3	From previous test or impurities	0.15	0.11	0.09	0.08	0.06	0.05	0.03	0.02	0.02	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	NC
K_2O		0.09	0.10	0.09	0.09	0.09	0.12	0.10	0.11	0.12	0.11	0.11	0.11	0.11	0.11	0.11	NC
MgO		0.79	0.66	0.49	0.42	0.38	0.29	0.19	0.17	0.15	0.16	0.11	0.09	0.10	0.05	0.08	NC
Sb_2O_3		0.21	0.17	0.14	0.12	0.08	0.06	0.07	0.03	0.03	0.03	0.02	0.02	0.01	0.02	0.02	NC
SO_3		0.05	0.04	0.05	0.04	0.04	0.03	0.03	0.03	<0.01	0.02	0.03	0.03	0.03	0.02	0.02	NC
SrO		0.63	0.49	0.39	0.32	0.25	0.18	0.15	0.12	0.09	0.07	0.06	0.05	0.04	0.03	0.04	NC
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	NC

* Target values calculated based on simple well-stirred tank model

Table 6.3. Drum Dimensions and Bulk Density for Glass Discharged from DM1200.

Glass Drum Information			**Drum Dimension (inches)**			**Net Glass Volume in Drum (cm^3)**	**Calculated Density (g/cm^3)**
Name	**Date**	**Glass (kg)**	**Height**	**Inner Diameter**	**Depth**		
2/20/2003	O12-G-109A	532.0	34.00	22.50	2.75	203613.751	2.613
2/21/2003	O12-G-152A	483.0	34.00	22.50	6.00	182437.921	2.647
2/22/2003	P12-G-40A	524.5	33.50	22.50	2.50	201984.841	2.597
2/23/2003	P12-G-66A	525.0	33.25	22.50	2.88	197912.566	2.653
2/24/2003	P12-G-92B	523.0	33.38	22.50	2.50	201170.386	2.600
2/25/2003	P12-G-124A	526.5	33.25	22.50	2.88	197912.566	2.660
2/25/2003	P12-G-148A	512.0	33.25	22.50	3.38	194654.746	2.630
2/26/2003	Q12-G-24A	532.0	33.25	22.50	2.38	201170.386	2.645
2/26/2003	Q12-G-44A	522.0	33.00	22.50	2.25	200355.931	2.605
2/27/2003	Q12-G-62A	519.5	33.25	22.50	3.00	197098.111	2.636
2/27/2003	Q12-G-80A	461.0	33.50	22.50	6.75	174293.371	2.645
2/27/2003	Q12-G-94A	363.0	33.63	22.50	12.00	140900.716	2.576
2/28/2003	Q12-G-136A	520.5	33.25	22.50	3.25	195469.201	2.663
Average						190093.798	2.631
Average (C-106/AY-102) [23]						159022.340	2.573
Average (AZ-101) [27]						197958.175	2.578

Table 7.1. Summary of Method 29 Particulate Matter Results.

—	Outlet Location/Run	Total wt. gain (mg)	Meter Volume (dscf)	Concentration (mg/dscf)	Flow Rate (dscfm)	Emission Rate (mg/min)	Moisture (% Vol.)	% Isokinetic
Total PM by Method 29 (Teflon Filter)	Melter R1	778.7	26.588	29.3	208.24	6099	24.95	99.5
	Melter R2	892.3	23.214	38.4	183.83	7066	24.64	98.4
	Melter R3	893.6	22.469	39.8	173.56	6903	26.34	100.9
	SBS R1	58.3	121.279	0.48	232.89	112	7.30	100.1
	SBS R2	78.7	120.513	0.65	230.97	151	7.82	100.3
	SBS R3	87.8	116.226	0.76	219.44	166	7.92	101.9
	WESP R1	20.4	1518.178	0.01	227.78	3.06	6.89	99.0

Note: Rx refers to off-gas sampling run number

Table 7.2. Results from Melter Emissions Sampling.

—		Average Feed Flux (mg/min)	Run 1 (mg/min)	Run 2 (mg/min)	Run 3 (mg/min)	Average (mg/min)	Percent of Feed	DF Across Melter
Particles	Total[$]	924000	6099	7066	6903	6689	0.72	138
	Al	14200	140.09	159.50	142.87	147.49	1.04	96.5
	B	25200	265.50	311.80	313.07	296.79	1.18	84.9
	Ca	2580	13.76	18.38	16.42	16.19	0.63	159
	Cl*	< 1	133.57	108.11	153.94	131.87	NC	NC
	Cr	308	5.59	5.47	5.56	5.54	1.80	55.6
	Cs	354	11.50	9.96	9.82	10.43	2.95	34.0
	Cu	180	0.98	1.47	1.20	1.22	0.68	148
	F*	902	715.41	643.01	711.70	690.04	76.50	1.31
	Fe	50100	612.05	672.27	652.35	645.56	1.29	77.7
	I*	751	16.47	13.43	16.50	15.47	2.06	48.6
	La	961	NA	NA	NA	NA	NA	NA
	Li	11600	58.41	67.94	65.83	64.06	0.55	180
	Mn	8850	24.45	31.94	32.81	29.73	0.34	297
	Na	64100	618.81	681.64	679.18	659.88	1.03	97.1
	Nd	709	NA	NA	NA	NA	NA	NA
	Ni	2780	23.74	28.05	24.96	25.58	0.92	108
	P	131	0.98	1.25	2.75	1.66	1.27	78.9
	Pb	837	7.33	9.99	9.08	8.80	1.05	95.1
	S*	< 1	85.39	84.79	106.31	92.16	NC	NC
	Si	163000	712.49	857.94	783.05	784.49	0.48	207.7
	Ti	90	6.18	7.16	6.71	6.68	7.43	13.5
	Zn	13000	120.70	139.25	134.05	131.33	1.01	99.3
	Zr	52500	157.59	330.54	267.32	251.82	0.48	208
Gas	B	25200	239.02	226.23	209.06	224.77	0.89	112
	Cl	< 1	2.56	4.79	1.82	3.06	NC	NC
	F	902	87.34	91.16	74.27	84.26	9.34	10.7
	I	751	622.26	570.78	567.12	586.72	78.13	1.28
	S	< 1	12.82	10.76	9.08	10.89	NC	NC

NA – Not available

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

* - From water dissolution

- Empty data field

Table 7.3. Results from SBS Emissions Sampling.

—		Average Melter Outlet Flux (mg/min)	Run 1 (mg/min)	Run 2 (mg/min)	Run 3 (mg/min)	Average (mg/min)	Percent of Melter Emissions	DF Across SBS
Particles	Total$	6689	112	151	166	143	2.14	46.8
	Al	147.49	0.36	0.63	0.65	0.55	0.37	270
	B	296.79	1.70	2.36	2.99	2.35	0.79	126
	Ca	16.19	0.23	0.39	0.31	0.31	1.91	52.2
	Cl	131.87	NA	NA	NA	NA	NA	NA
	Cr	5.54	0.91	1.02	1.15	1.03	18.53	5.40
	Cs	10.43	1.08	1.25	1.25	1.19	11.44	8.74
	Cu	1.22	< 0.10	< 0.10	< 0.10	< 0.10	< 8.20	> 12.2
	F	690.04	NA	NA	NA	NA	NA	NA
	Fe	645.56	1.97	3.31	3.11	2.80	0.43	231
	I	15.47	< 0.10	< 0.10	< 0.10	< 0.10	< 0.65	155
	La	NA	NA	NA	NA	NA	NA	NA
	Li	64.06	2.12	2.70	3.28	2.70	4.21	23.7
	Mn	29.73	0.12	0.14	< 0.10	0.13	0.44	229
	Na	659.88	24.57	31.60	35.22	30.46	4.62	21.7
	Nd	NA	NA	NA	NA	NA	NA	NA
	Ni	25.58	< 0.10	0.12	< 0.10	0.12	0.47	213
	P	1.66	< 0.10	< 0.10	< 0.10	< 0.10	< 6.02	16.6
	Pb	8.80	< 0.10	< 0.10	< 0.10	< 0.10	< 1.14	88.0
	S	92.16	13.14	16.74	18.20	16.03	17.39	5.75
	Si	784.49	0.87	1.72	1.73	1.44	0.18	545
	Ti	6.68	< 0.10	< 0.10	< 0.10	< 0.10	< 1.50	66.8
	Zn	131.33	0.67	0.82	0.97	0.82	0.62	160
	Zr	251.82	0.14	0.61	0.16	0.30	0.12	830
GAS	B	224.77	3.27	4.01	4.10	3.79	1.69	59.3
	Cl	3.06	0.15	0.14	0.10	0.13	4.25	23.5
	F	84.26	1.79	2.98	1.84	2.20	2.61	38.2
	I	586.72	661.03	658.50	654.31	657.95	112.14	0.89
	S	10.89	1.51	0.68	0.56	0.92	8.42	11.9

NC – Not calculated
NA – Not available
$ - From gravimetric analysis of filters and rinse dry downs
– Empty data field

Table 7.4. Results from WESP Emissions Sampling.

-		Average Feed Flux (mg/min)	Average SBS Outlet Flux (mg/min)	Run 1 (mg/min)	DF Across WESP	Cumulative DF Across Melter, SBS, WESP
Particles	Total[$]	924000	143	3.06	46.70	301960
	Al	14200	0.55	< 0.10	> 5.50	> 142000
	B	25200	2.35	< 0.10	> 23.50	> 252000
	Ca	2580	0.31	< 0.10	> 3.10	> 25800
	Cl	< 1	NA	NA	NA	NA
	Cr	308	1.03	< 0.10	> 10.30	> 3080
	Cs	354	1.19	< 0.10	> 11.90	> 3540
	Cu	180	< 0.10	< 0.10	NC	> 1800
	F	902	NA	NA	NA	NA
	Fe	50100	2.80	< 0.10	> 28.00	> 501000
	I	751	< 0.10	< 0.10	NC	> 7510
	La	961	NA	NA	NA	NA
	Li	11600	2.70	< 0.10	> 27.00	> 116000
	Mn	8850	0.13	< 0.10	> 1.30	> 88500
	Na	64100	30.46	0.66	46.15	97100
	Nd	1650	NA	NA	NA	NA
	Ni	2780	0.12	< 0.10	> 1.20	> 27800
	P	131	< 0.10	< 0.10	NC	> 1310
	Pb	837	< 0.10	< 0.10	NC	> 8370
	S	< 1	16.03	< 0.10	160	NC
	Si	163000	1.44	< 0.10	> 14.40	> 1630000
	Ti	90	< 0.10	< 0.10	NC	> 900
	Zn	13000	0.82	< 0.10	> 8.20	> 130000
	Zr	52500	0.30	< 0.10	> 3.00	> 52500
GAS	B	25200	3.79	0.22	17.23	115000
	Cl	< 1	0.13	< 0.10	> 1.30	NC
	F	902	2.20	0.32	6.88	2819
	I	751	657.95	194.51	3.38	4
	S	< 1	0.92	< 0.10	> 9.20	NC

NC – Not calculated
NA – Not available
[$] - From gravimetric analysis of filters and rinse dry downs
– Empty data field

Table 7.5. Melter Emissions Particle Size Distribution Results.

–	Cutpoint (µm)	Net Weight (mg)	Concentration (mg/dscf)	Mass Fraction
Sample 1	> 13.2	34.17	15.6	66.7
	13.2 – 9.95	3.43	1.56	6.7
	9.95 – 3.84	5.36	2.44	10.5
	3.84 – 1.93	4.45	2.03	8.7
	1.93 – 1.11	2.20	1.00	4.3
	1.11 – 0.62	< 0.01	< 0.01	< 0.1
	0.62 – 0.37	0.25	0.11	0.5
	< 0.37	1.33	0.61	2.6
Sample 2	> 13.1	42.39	25.2	64.6
	13.1 – 9.89	3.96	2.35	6.0
	9.89 – 3.82	7.30	4.34	11.1
	3.82 – 1.93	2.87	1.71	4.4
	1.93 – 1.11	2.62	1.56	4.0
	1.11 – 0.63	1.75	1.04	2.7
	0.63 – 0.38	0.77	0.46	1.2
	< 0.38	3.99	2.37	6.1
Sample 3	> 16.0	36.11	46.3	69.9
	16.0 – 12.1	3.44	4.41	6.7
	12.1 – 4.67	3.79	4.86	7.3
	4.67 – 2.35	3.49	4.47	6.8
	2.35 – 1.35	1.89	2.42	3.7
	1.35 – 0.75	0.37	0.47	0.7
	0.75 – 0.46	0.66	0.85	1.3
	< 0.46	1.88	2.41	3.6

– Empty data field

Table 7.6. PBS Emissions Particle Size Distribution Results.

–	Cutpoint (µm)	Net Weight (mg)	Concentration (mg/dscf)	Mass Fraction
Sample 1	> 13.7	< 0.01	NC	-
	13.7 – 10.4	< 0.01	NC	-
	10.4 – 4.00	< 0.01	NC	-
	4.00 – 2.02	< 0.01	NC	-
	2.02 – 1.16	< 0.01	NC	-
	1.16 – 0.651	0.02	0.0005	1.1
	0.651 – 0.389	0.03	0.0007	1.6
	< 0.389	1.80	0.041	97.3
Sample 2	> 13.8	0.06	0.0005	14.0
	13.8 – 10.4	0.03	0.0003	7.0
	10.4 – 4.03	0.01	0.0001	2.3
	4.03 – 2.03	0.01	0.0001	2.3
	2.03 – 1.16	0.02	0.0002	4.7
	1.16 – 0.651	0.12	0.001	27.9
	0.651 – 0.385	< 0.01	NC	-
	< 0.385	0.18	0.001	41.9
Sample 3	> 14.0	< 0.01	NC	-
	14.0 – 10.6	0.01	0.00008	1.8
	10.6 – 4.09	< 0.01	NC	-
	4.09 – 2.05	< 0.01	NC	-
	2.05 – 1.18	0.10	0.0008	18.2
	1.18 – 0.660	0.23	0.0019	41.8
	0.660 – 0.390	0.04	0.0003	7.3
	< 0.390	0.17	0.001	30.9

– Empty data field

NC – Not calculated

Table 7.7. Average Concentrations [ppmv] of Selected Species in Off-Gas Measured by FTIR Spectroscopy.

Port	**Melter Outlet**			**SBS Outlet**			**WESP Outlet**			**TCO Outlet**		
Test	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
N_2O	1.3	1.3	1.7	1.3	1.6	2.2	1.3	1.6	2.1	< 1.0	< 1.0	1.7
NO	130	190	240	140	210	310	130	210	290	9.7	17	48
NO_2	4.2	4.4	13	5.6	12	23	11	19	30	6.1	8.5	24
NH_3	< 1.0	2.9	1.2	< 1.0	4.9	< 1.0	< 1.0	3.3	< 1.0	3.1	1.8	< 1.0
H_2O [%]	11	17	24	8.0	7.6	7.4	7.5	7.4	7.2	2.4	2.5	4.4
CO_2	3700	4500	7100	3900	5000	7100	3700	5100	7000	1300	1700	4100
HNO_2	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HNO_3	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
HCN	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
SO_2	1.4	1.7	4.5	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
acetonitrile	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
acrylonitrile	< 1.0	< 1.0	< 1.0	< 1.0	2.6	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0
CO	< 1.0	< 1.0	1.2	1.1	< 1.0	1.4	< 1.0	< 1.0	1.2	< 1.0	< 1.0	< 1.0
HCl	1.2	1.6	2.1	< 1.0	4.1	< 1.0	2.1	4.4	< 1.0	< 1.0	1.1	< 1.0
HF	3.1	2.7	2.2	2.1	2.8	1.8	1.7	2.5	1.2	2.1	1.3	< 1.0

Table 7.8. Iodine Mass Balance Summary.

Location:	Product Glass	Melter Emissions	SBS Blow-Down Solutions	SBS Emissions	WESP Blow-Down Solutions	WESP Emissions	HEME 1	TCO/ SCR* Emissions	HEME 2	PBS Blow-Down Solutions
% Feed Iodine	< 1%	80%	11%	88%	< 1%	26%	< 1%	54%	< 1%	31%

* - Extrapolated from slip stream entering silver mordenite system.

Table 7.9. Iodine Removal from Off-Gas Slipstream by Silver Mordenite Column.

--	C-106/AY-102 [23]		C-104/AY-101			
Sampling Point	01/29/03 08:00 – 16:00		02/25/03 09:55 – 20:10		02/26/03 07:50 – 15:50	
	Conc. (µg/dscf)	**DF**	**Conc. (µg/dscf)**	**DF**	**Conc. (µg/dscf)**	**DF**
Inlet	2040	1	1530	1	2151	1
1/3 into column	1260	1.6	1140	1.3	1721	1.3
2/3 into column	< 1*	> 2040	7.5	204	75.6	28.5
Outlet	< 1*	> 2040	< 1*	> 1530	< 1*	> 2151

* - No iodine was detected. Value provided is an estimate based on current analytical detection limit.
– Empty data field

Table 8.1. Completion of Test Objectives.

Test Objective	Objective Met?	Discussion Section
Perform analyses and laboratory testing, as required, to assess and specify "working glass" compositions, glass forming chemicals, and additives utilizing the estimated C-104/AY-101 feed composition in this specification.	Yes	Section 2.0 provides "working glass" compositions and feed formulations.
Utilizing the DM1200 melter and associated feed handling and off-gas treatment equipment, design and conduct testing in which representative C-104/AY-101 simulant is processed. The duration of tests shall be sufficient to achieve at least four melter glass inventory turnovers (8 MT) for each composition.	Yes/ No	Table 4.1 provides glass production rate data and summary data for melter testing. The production rates attained were sufficient to produce only 7 MT as opposed to 8 MT of glass in the designated testing interval.
Determine the effect of bubbling rate on melter production rate and operating stability for C-104/AY-101 melter feed.	Yes	Data provided in Table 4.1 and Figure 4.1.
Fabricate, install and evaluate the performance of the HLW bubbler design and placement recommended by the Duratek design staff.	Yes	The recommended bubbler design and placement was employed for these tests.
Characterize the melter emissions (particulate, aerosol, and gaseous) under nominal steady-state operating conditions for inorganic and organic compounds including the effect of air displacement slurry (ADS) pump operation on feed entrainment. Measurement of organic compounds will be satisfied through the use of Fourier Transform Infrared (FTIR) spectrometry and gas chromatography (including H_2).	Yes/ No	Section 7.0 provides data and detailed description of melter emissions. Monitoring of H_2 was not performed due to failure of the gas chromatagraph.
Quantify and document the occurrence and associated operating conditions of any melter off-gas volume surging events.	Yes	Section 5.0 provides melter pressure data and control air flow rates during testing.
Characterize the performance of the primary off-gas treatment equipment (submerged bed scrubber (SBS), wet electrostatic precipitator (WESP) and high-efficiency mist eliminator (HEME)) to remove particulate, aerosol and gas phase emissions under steady-state melter conditions.	Yes	Section 5.0 provides operational details of off-gas system components. Section 7.0 provides data and detailed description of SBS and WESP emissions as well as DF values for these components.
Characterize the chemical and physical characteristics of the aqueous streams (feed, SBS, WESP, and caustic scrubber).	Yes	Section 2.3 provides detailed feed analysis. Section 5.2 provides detailed off-gas solution analysis.
Characterize the performance of the secondary off-gas treatment equipment (selective catalytic reduction (SCR) and thermal catalytic oxidizer (TCO)	Yes	Section 5.0 provides operational details of off-gas system components. Table 7.6 and Figures 7.5-7.8 provide SCR/TCO inlet (WESP outlet) and outlet emission data
Obtain the necessary process measurements to provide mass and energy balances throughout the systems, including process monitoring of power, voltage, current, resistance, temperatures, pressures, flow rates, and cooling water and air flows and inlet and outlet temperatures.	Yes	Data for measured melter parameters is provided in Section 4.0 and data for measured off-gas parameters is in Section 5.0.
Document general equipment operations (reliability, availability, maintainability, etc.); especially non-routine equipment failure and replacement activities.	Yes	Data are presented and discussed in Sections 3.0, 4.0, and 5.0.
Perform pre- and post-test inspections of key equipment and process lines to monitor for solids accumulations and corrosion/erosion of materials, especially ammonium nitrate downstream of the SCR.	Yes	Off-gas system inspection information is provided in Section 5.0. Inspection downstream of the SCR was covered in a previous report [26].
Operate the melter plenum pressure control using the variable air-injection control method. Assess and document control stability (melter plenum and off-gas system pressure versus time) as a function of instrument controller settings.	Yes	Sections 3.0, 4.0, and 5.0 discuss melter pressure data and control air flow rates during testing.
Operate and evaluate the performance of the air-displacement slurry (ADS) pump under operating conditions that are applicable to expected WTP plant operations.	Yes	The ADS pump was employed for these tests and performed flawlessly.

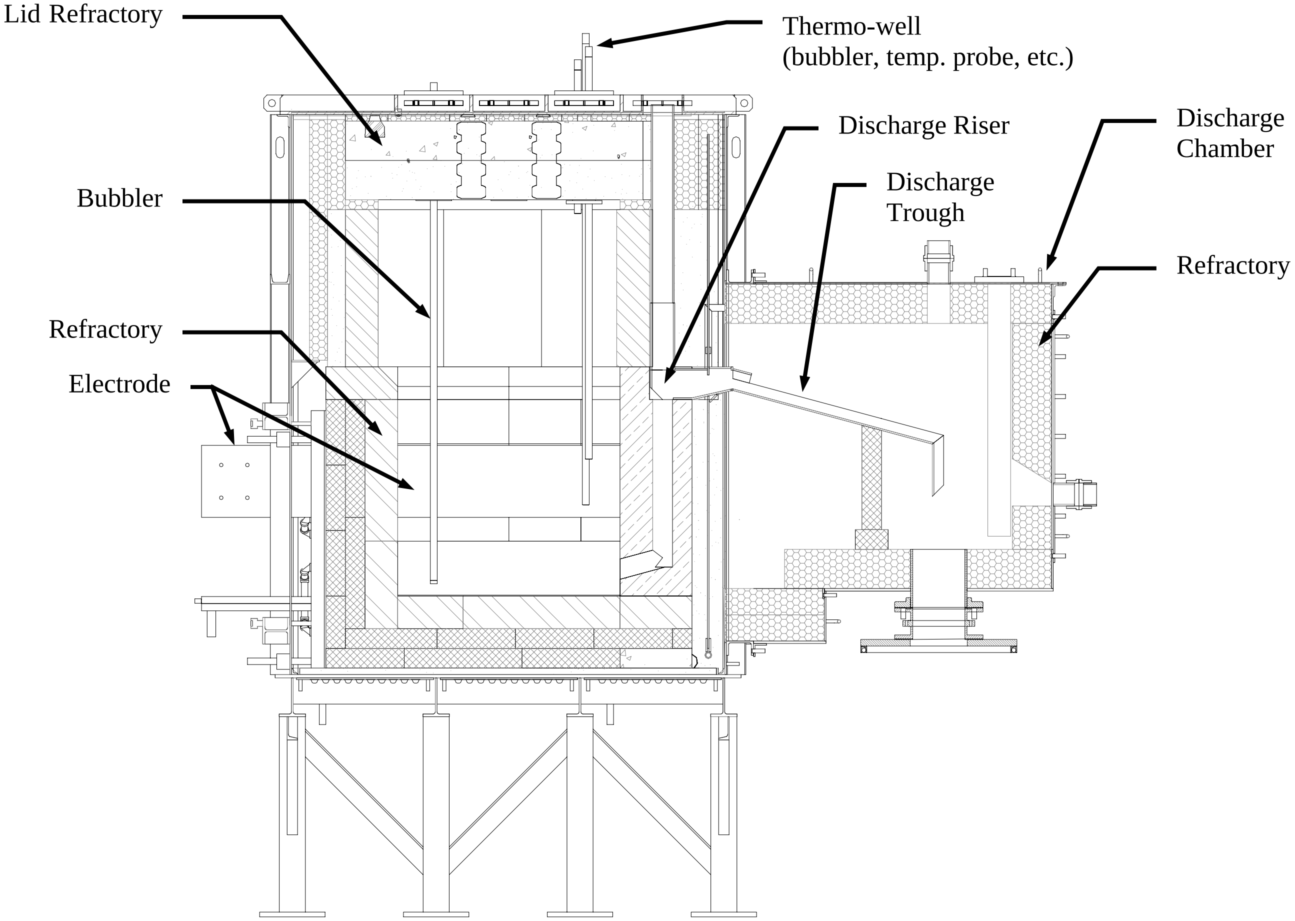

Figure 1.1. Cross-section of the DM1200 melter through the discharge chamber.

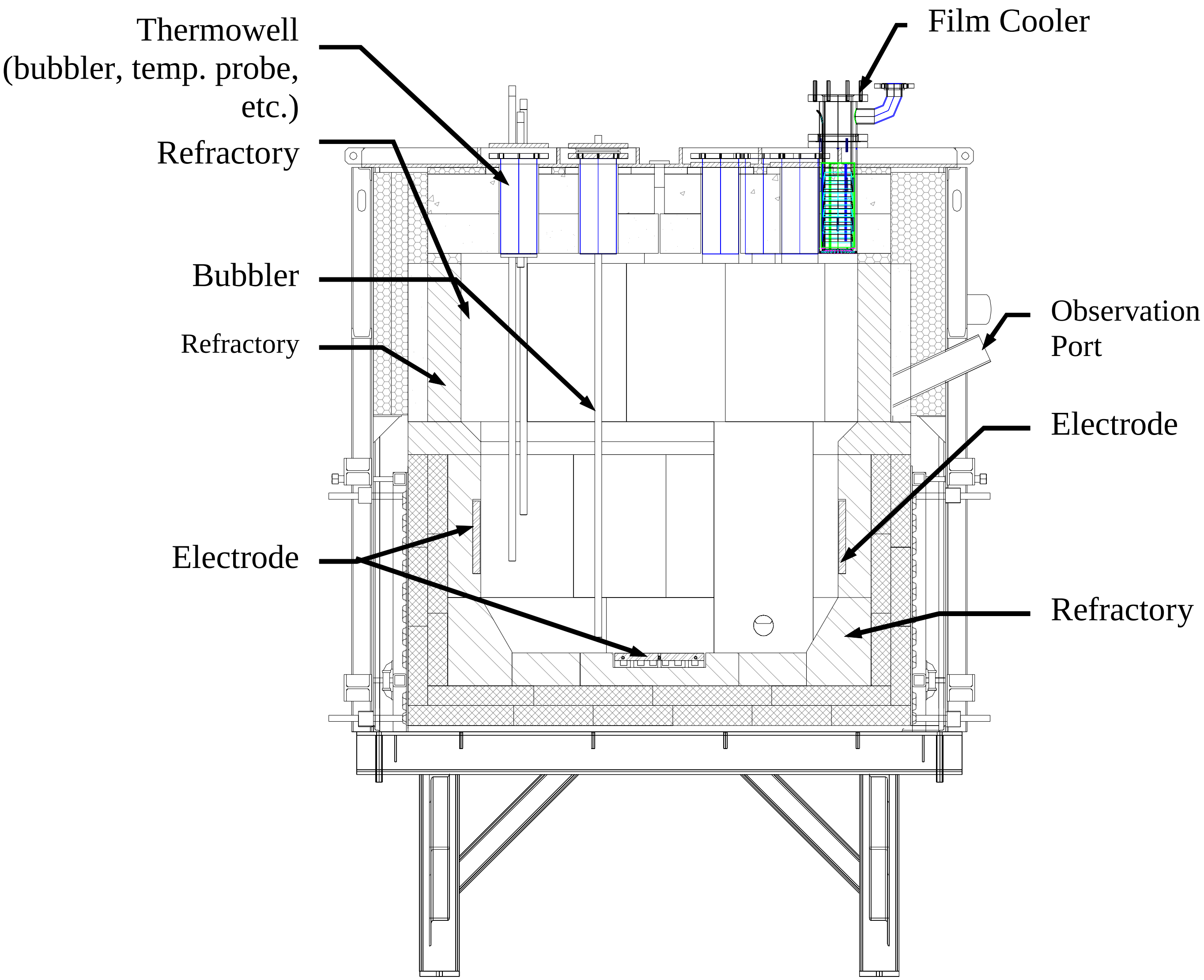

Figure 1.2. Cross-section through the DM1200 melter showing electrodes.

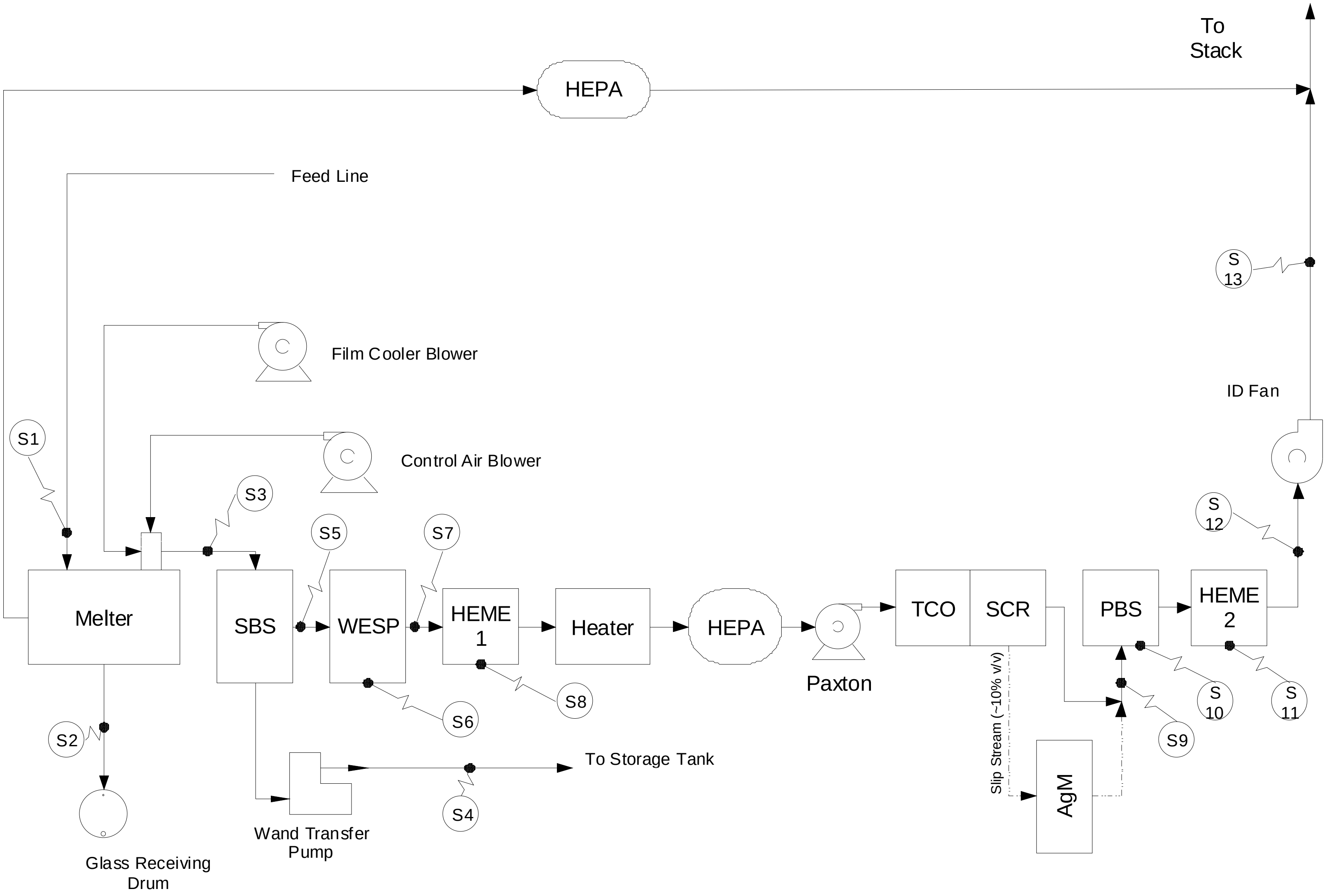

Figure 1.3. Schematic diagram of DM1200 off-gas system. "Sx" indicates sampling point.

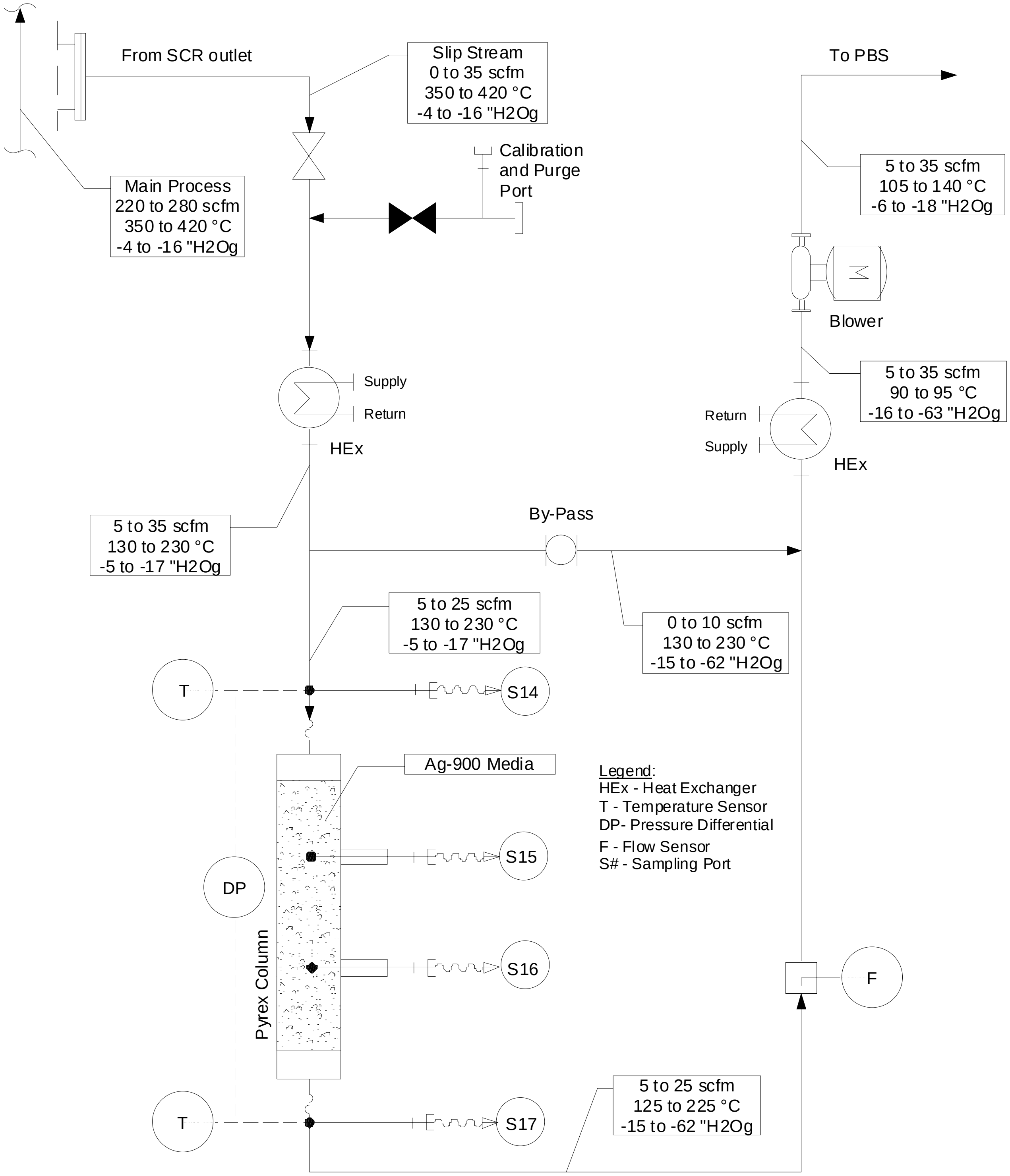

Figure 1.4. Schematic diagram of silver mordenite system. "Sx" indicates sampling point.

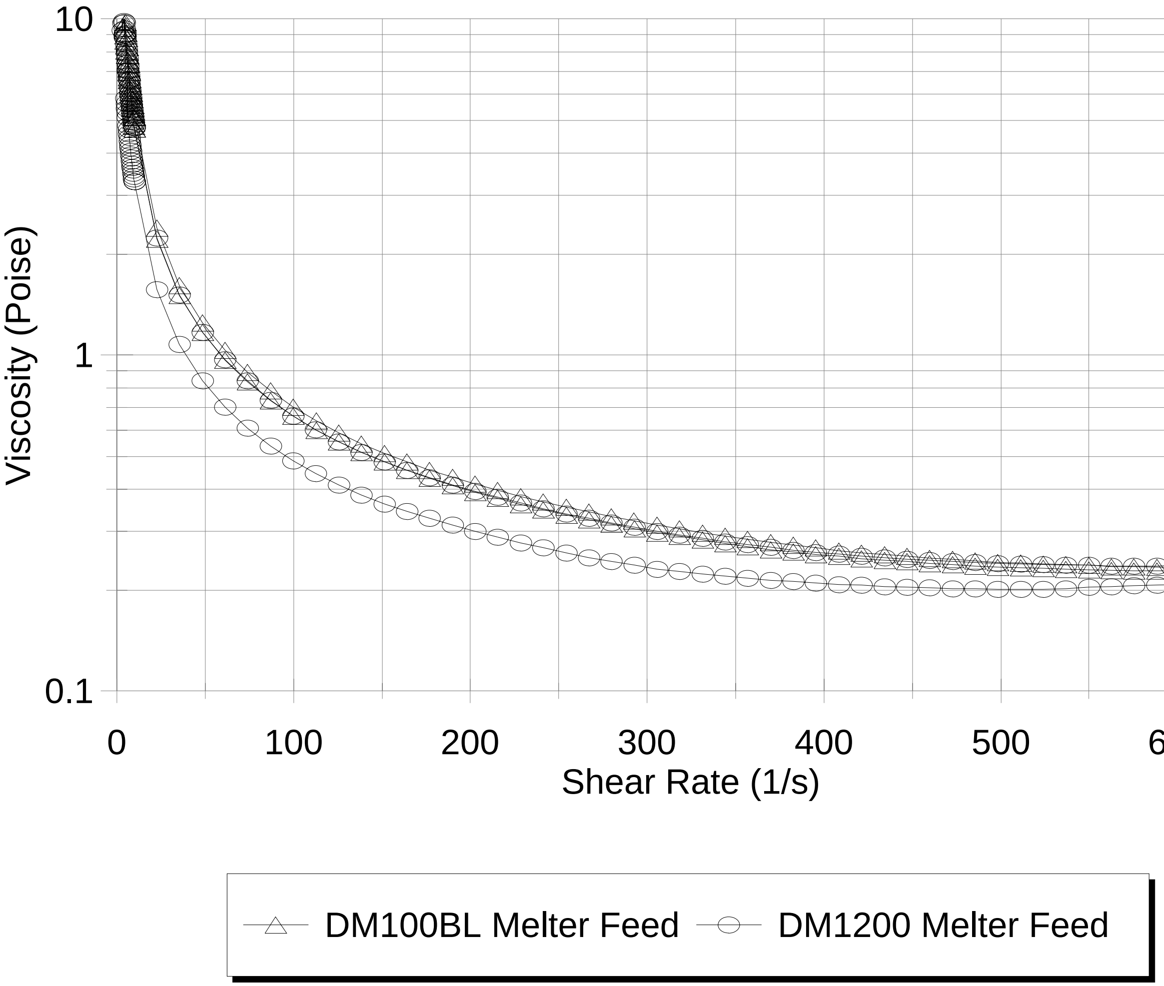

Figure 2.1. Viscosity vs. shear rate for melter feed samples.

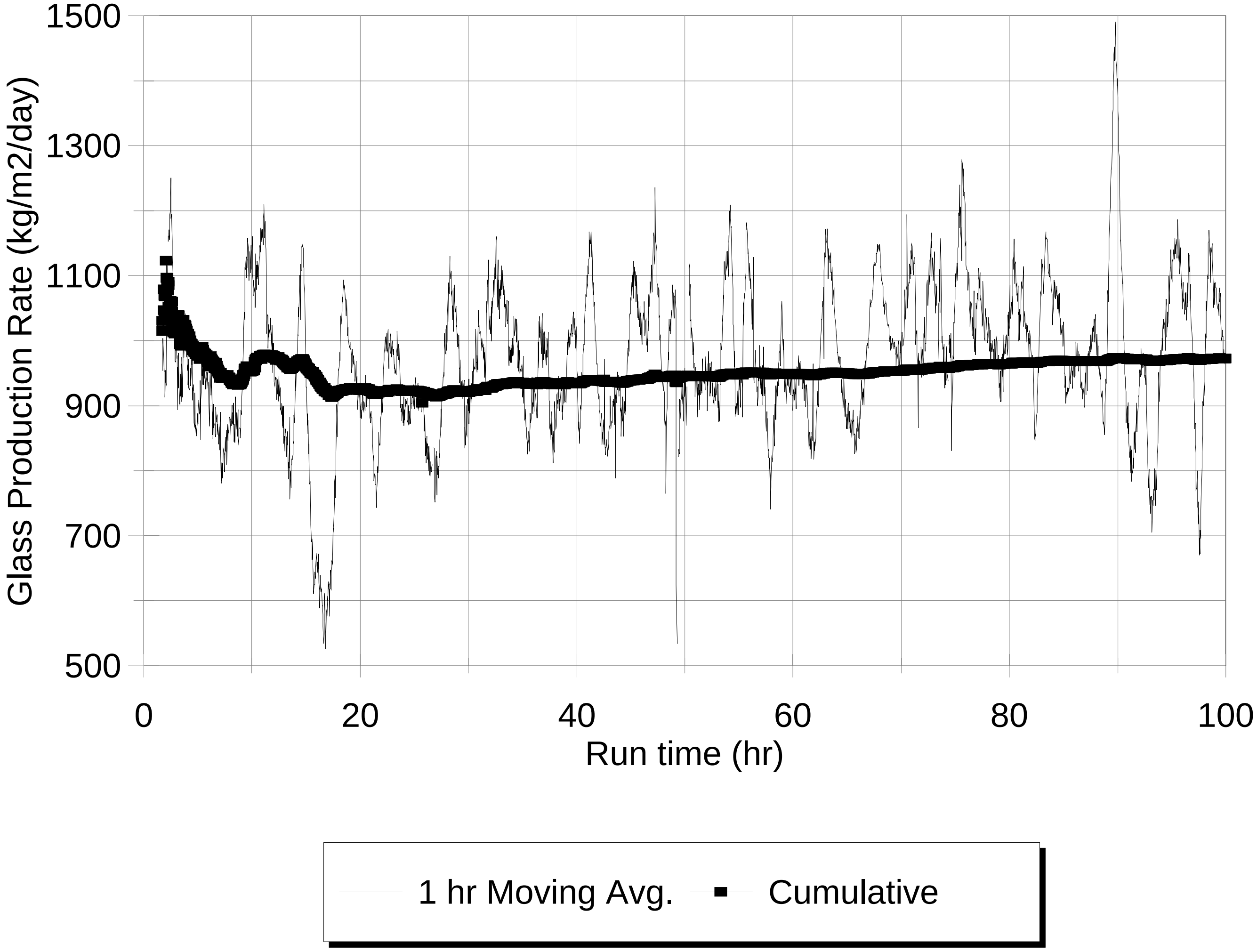

Figure 3.1. Production rates for DM100 test.

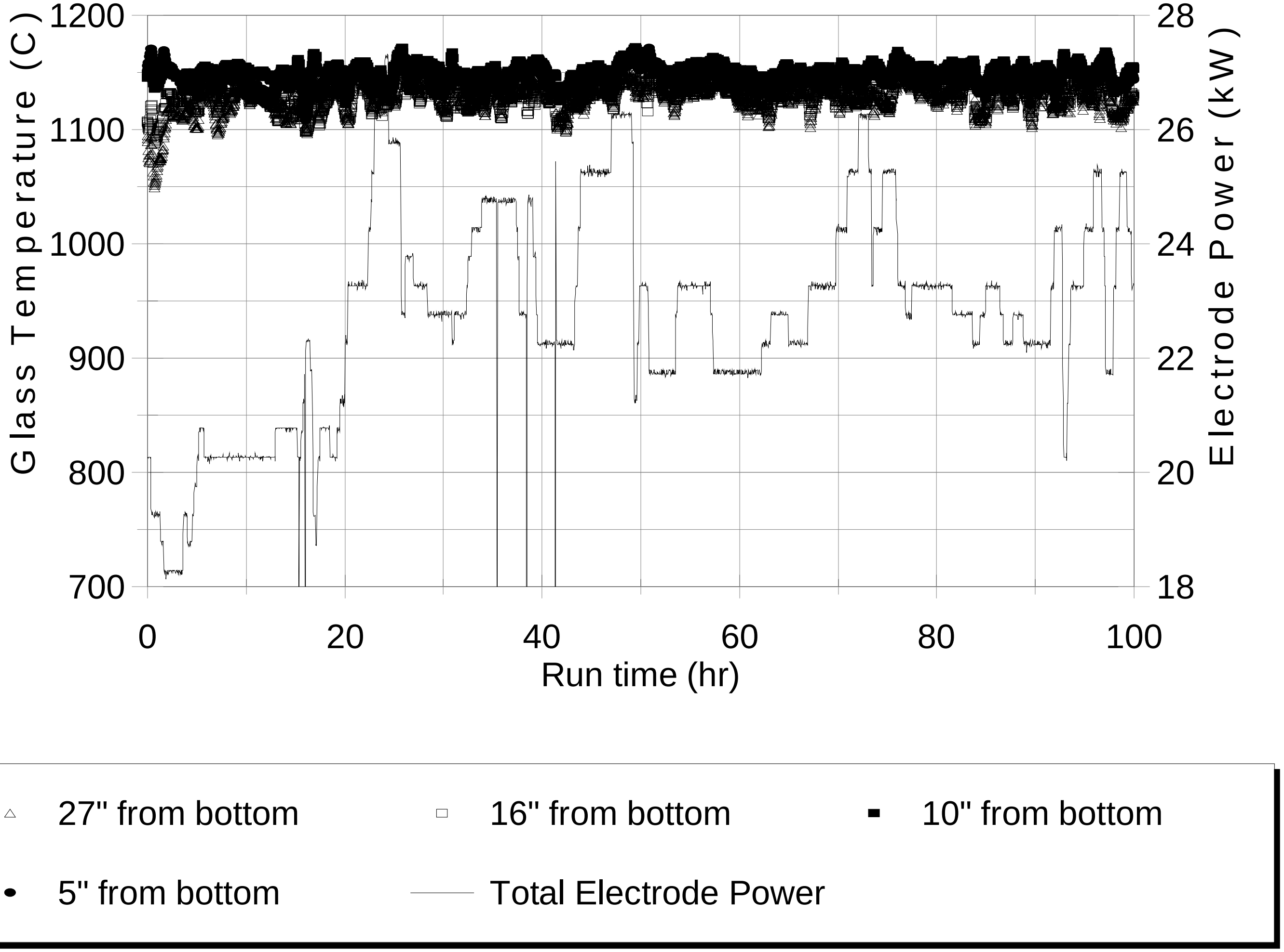

Figure 3.2. Glass temperatures and electrode power for DM100 test.

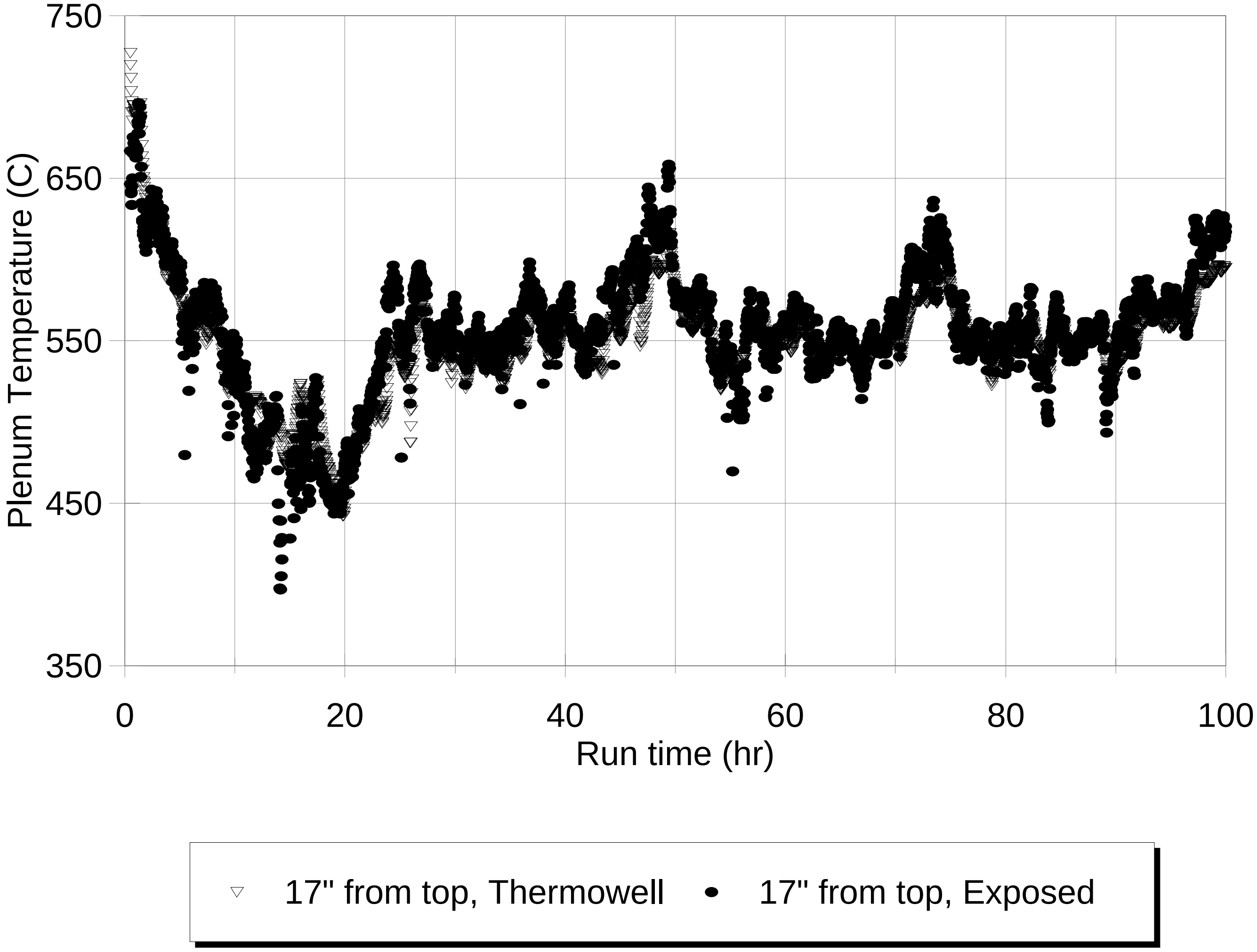

Figure 3.3. Plenum temperatures for DM100 test.

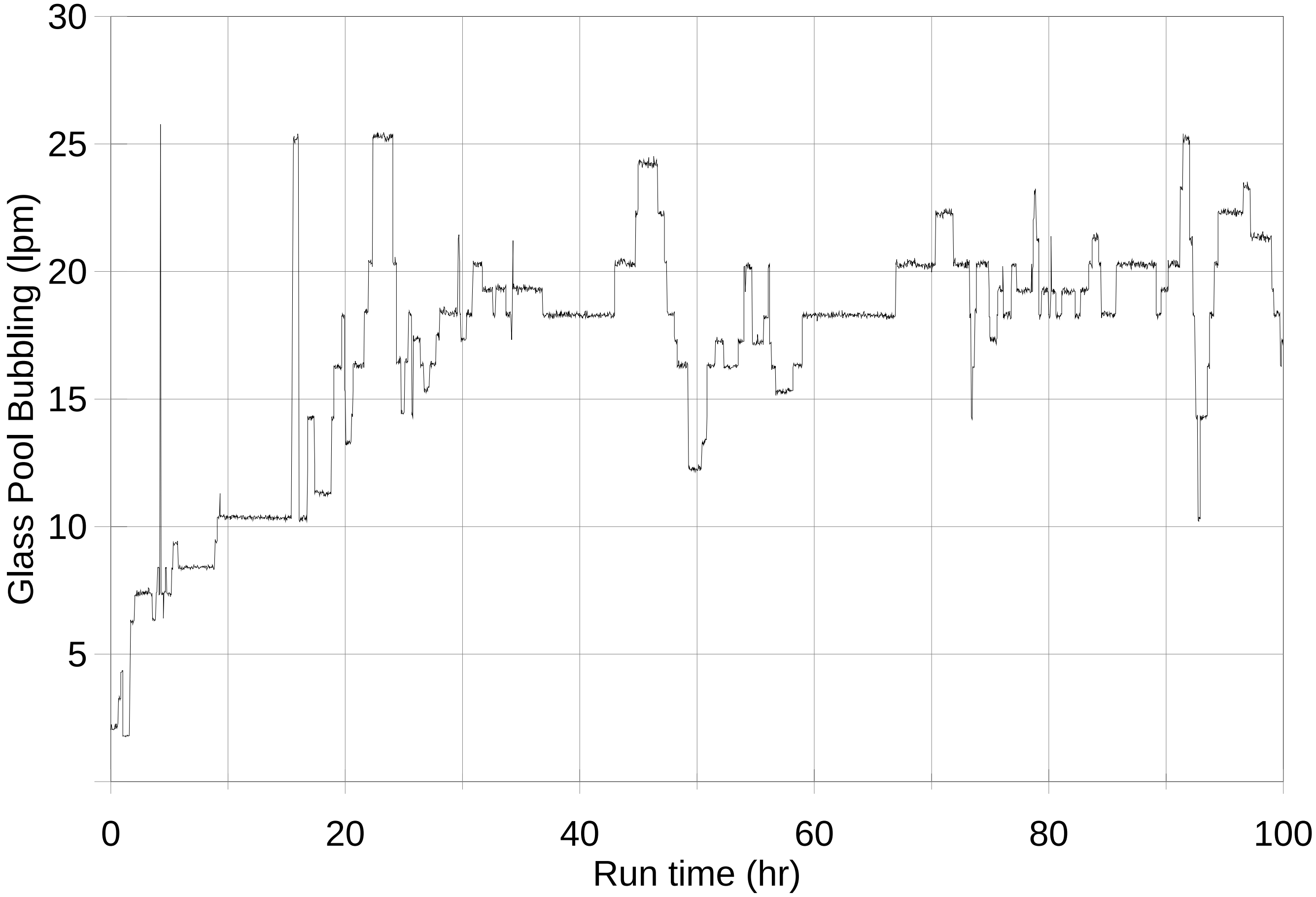

Figure 3.4. Glass pool bubbling for DM100 test.

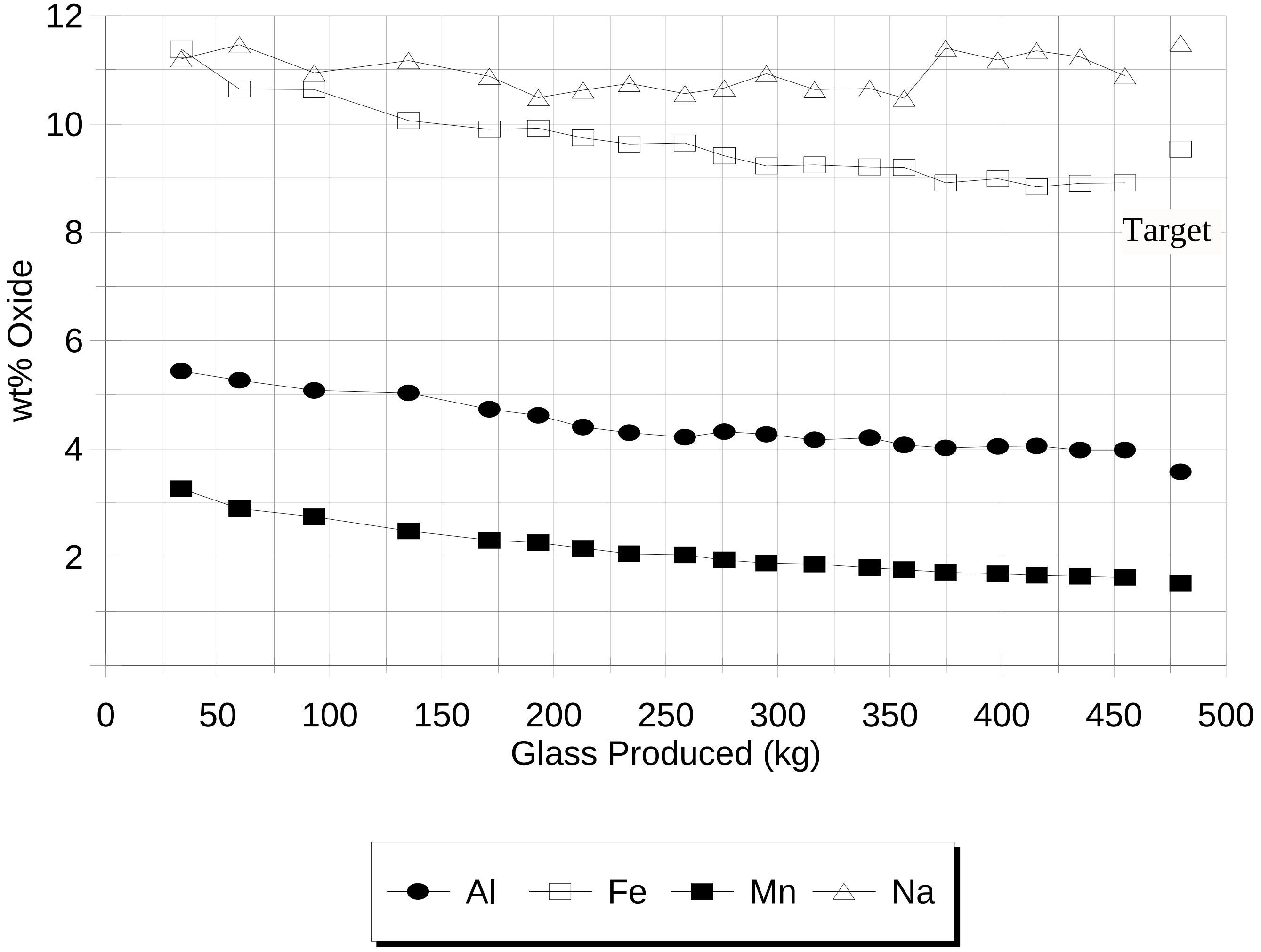

Figure 3.5. XRF analysis of selected oxides in DM100 glasses.

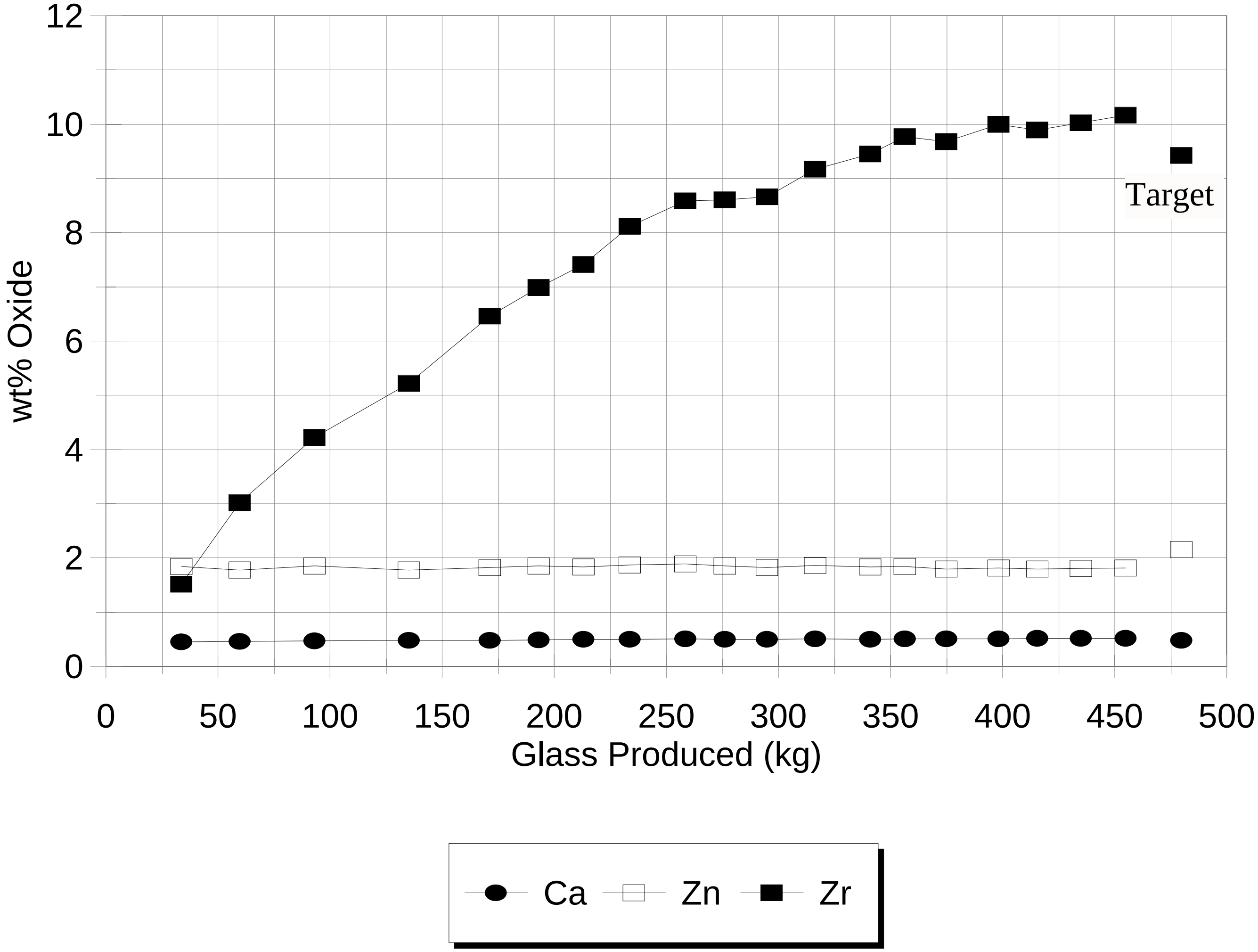

Figure 3.6. XRF analysis of calcium, zinc, and zirconium oxides in DM100 glasses.

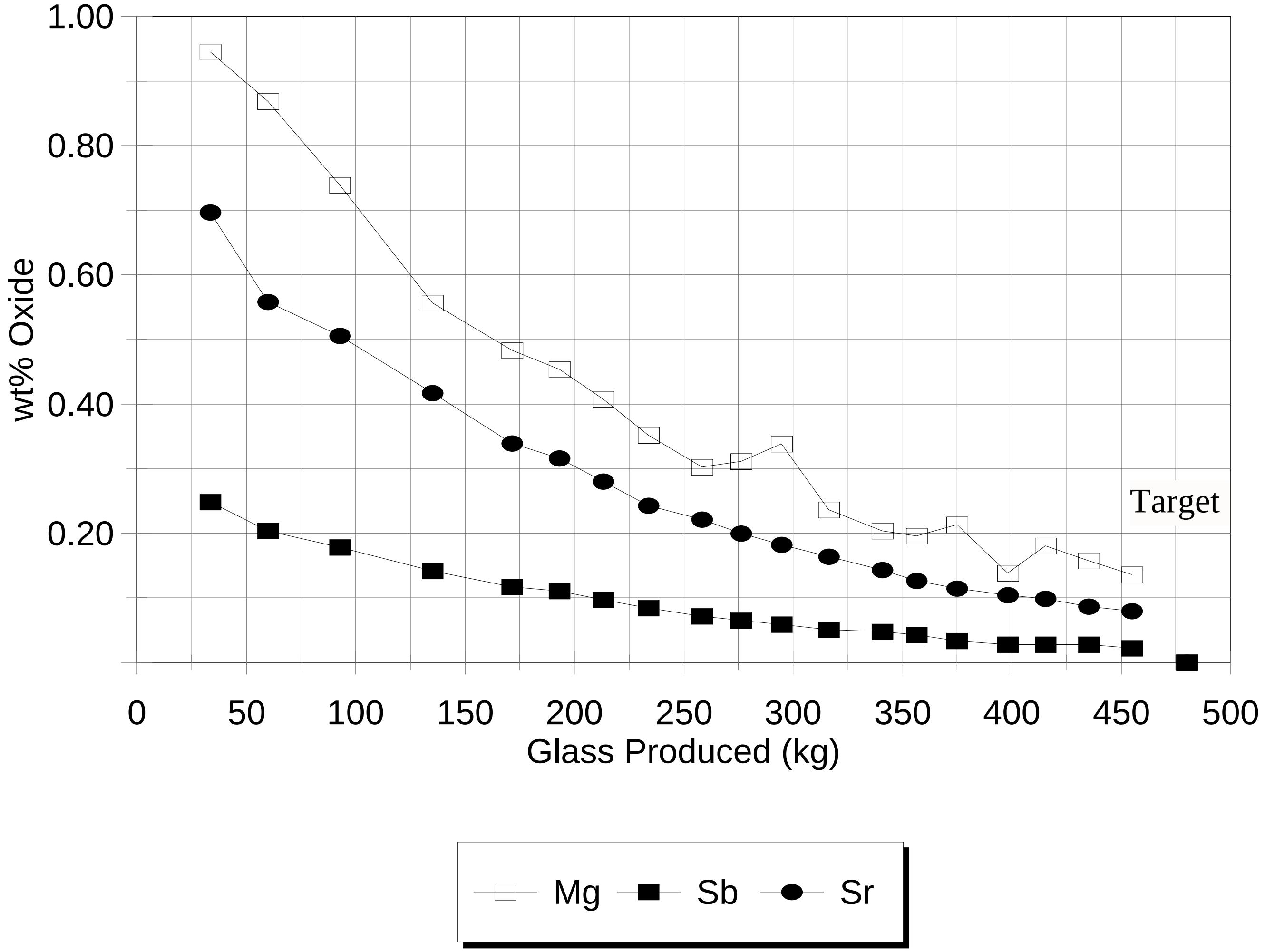

Figure 3.7. XRF analysis of oxides (from preceding test) decreasing in concentration during DM1200 test.

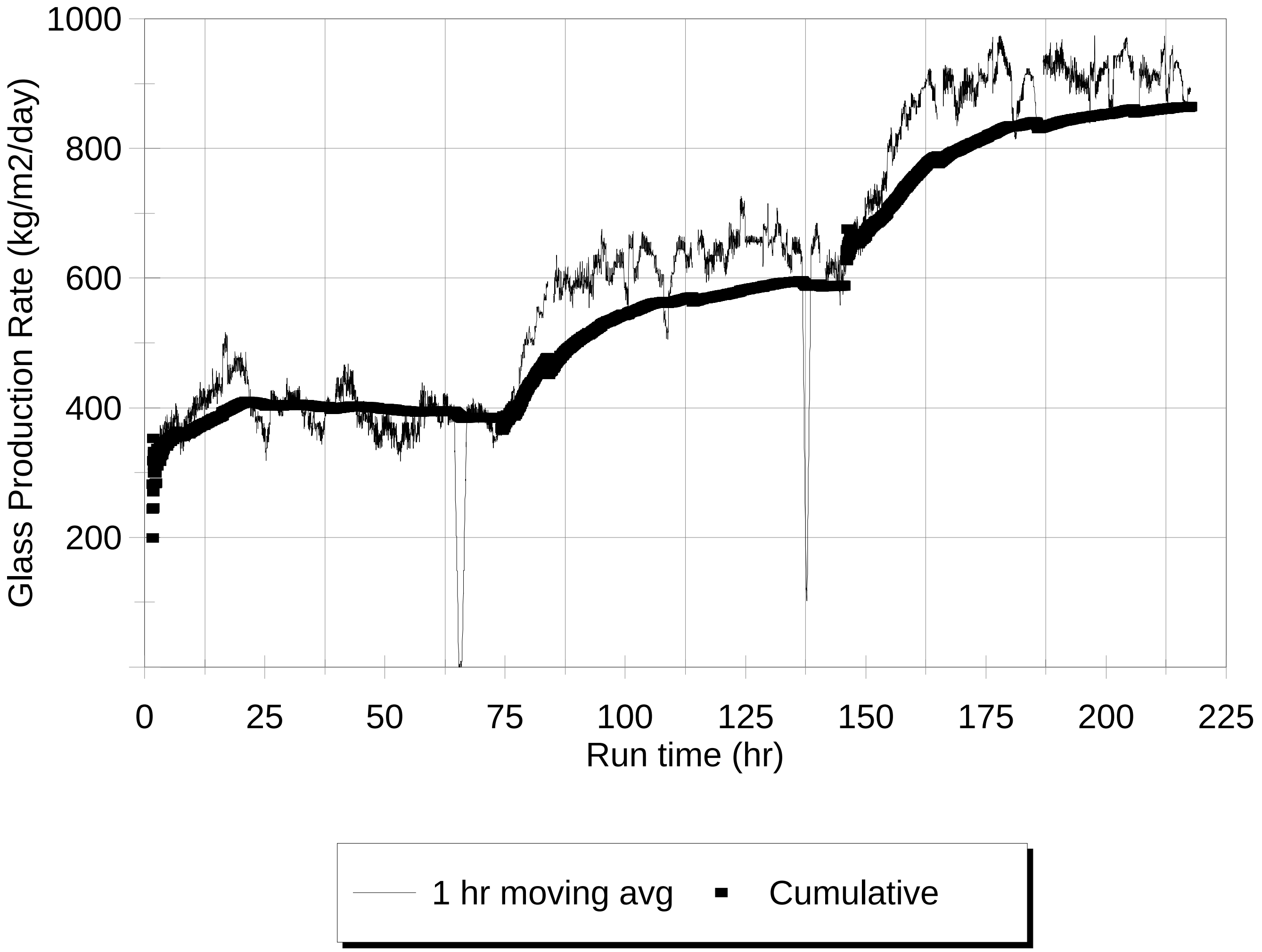

Figure 4.1. Glass production rates for DM1200 tests.

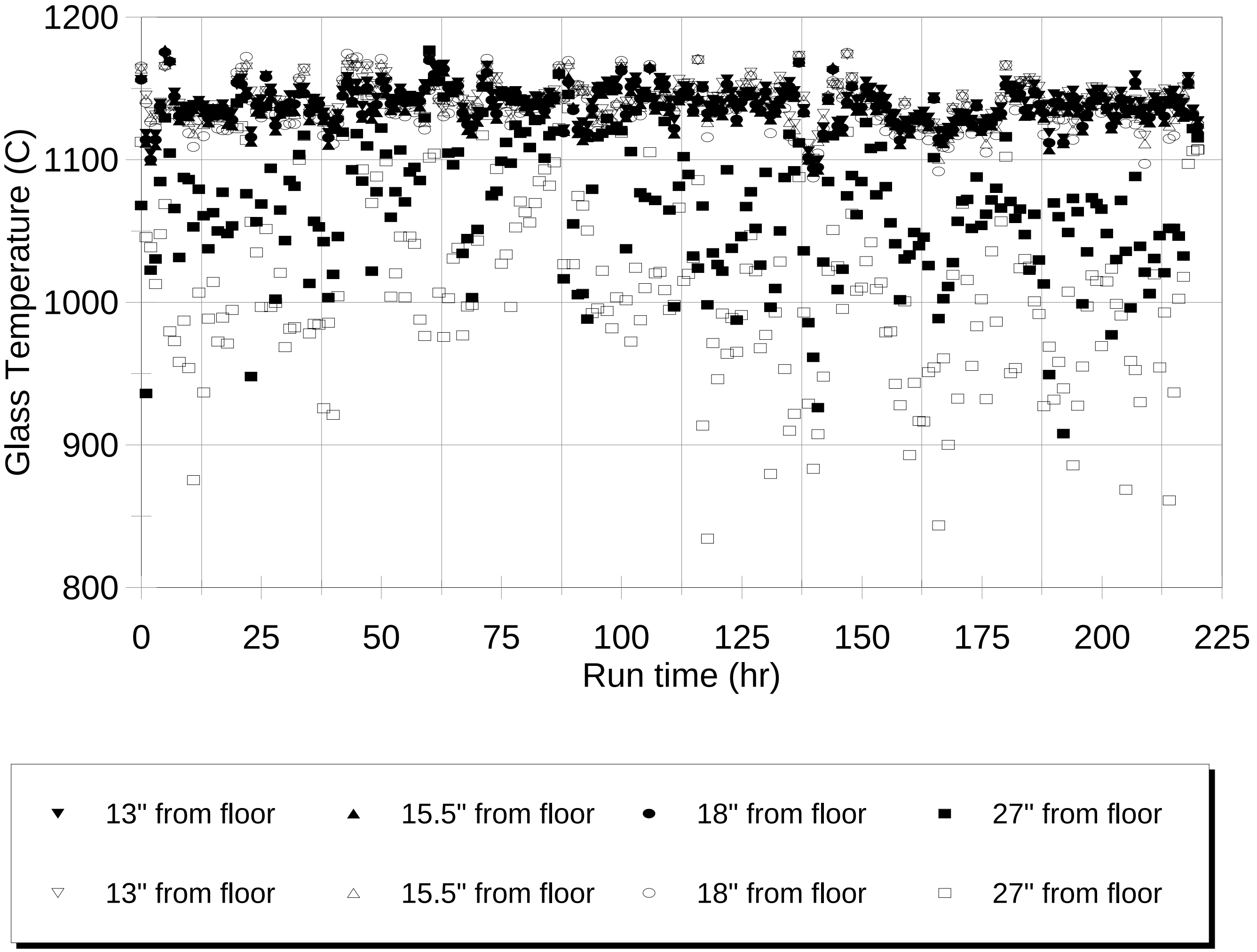

Figure 4.2. Glass temperatures for DM1200 tests (hourly averages).

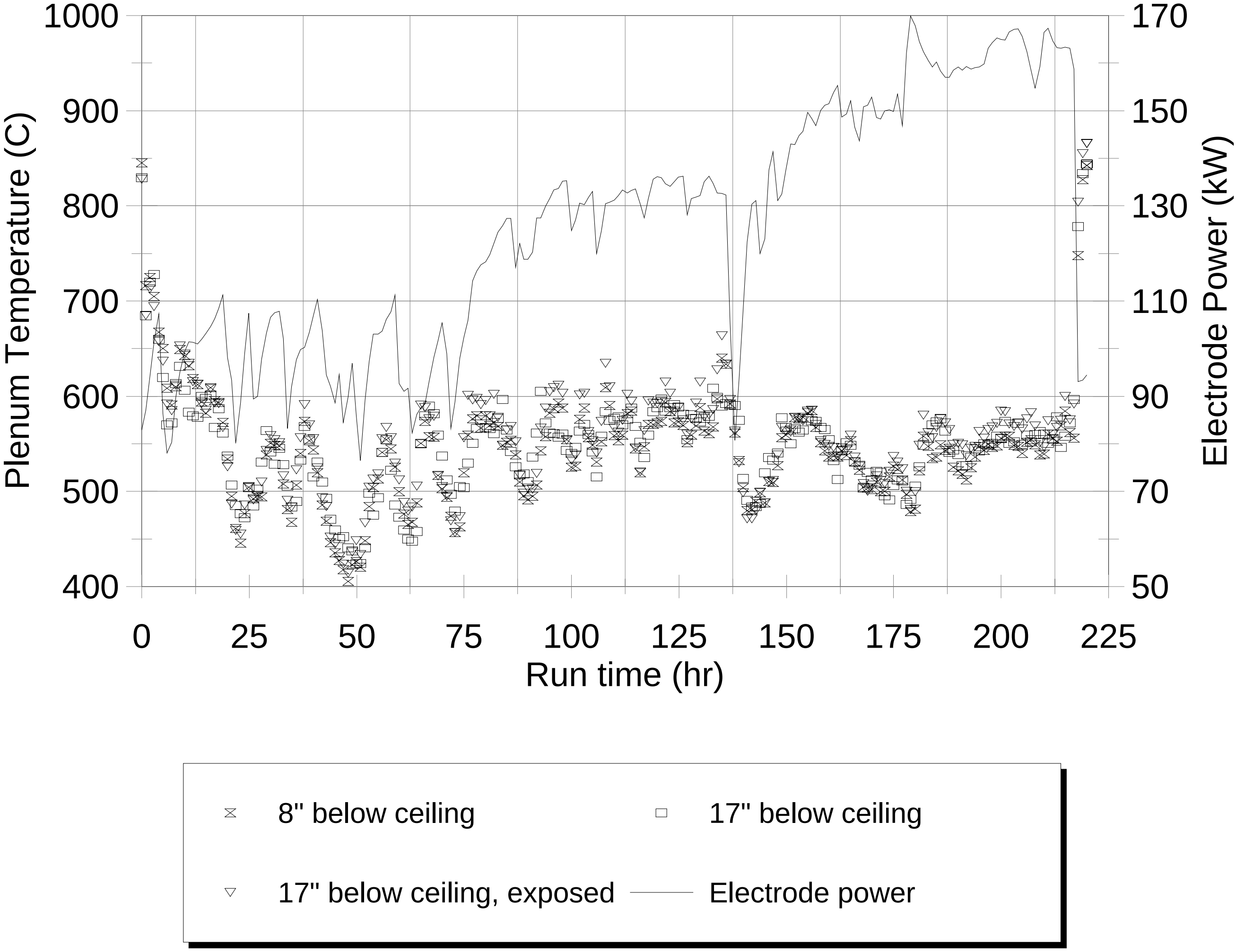

Figure 4.3. Plenum temperatures and electrode power for DM1200 tests (hourly averages).

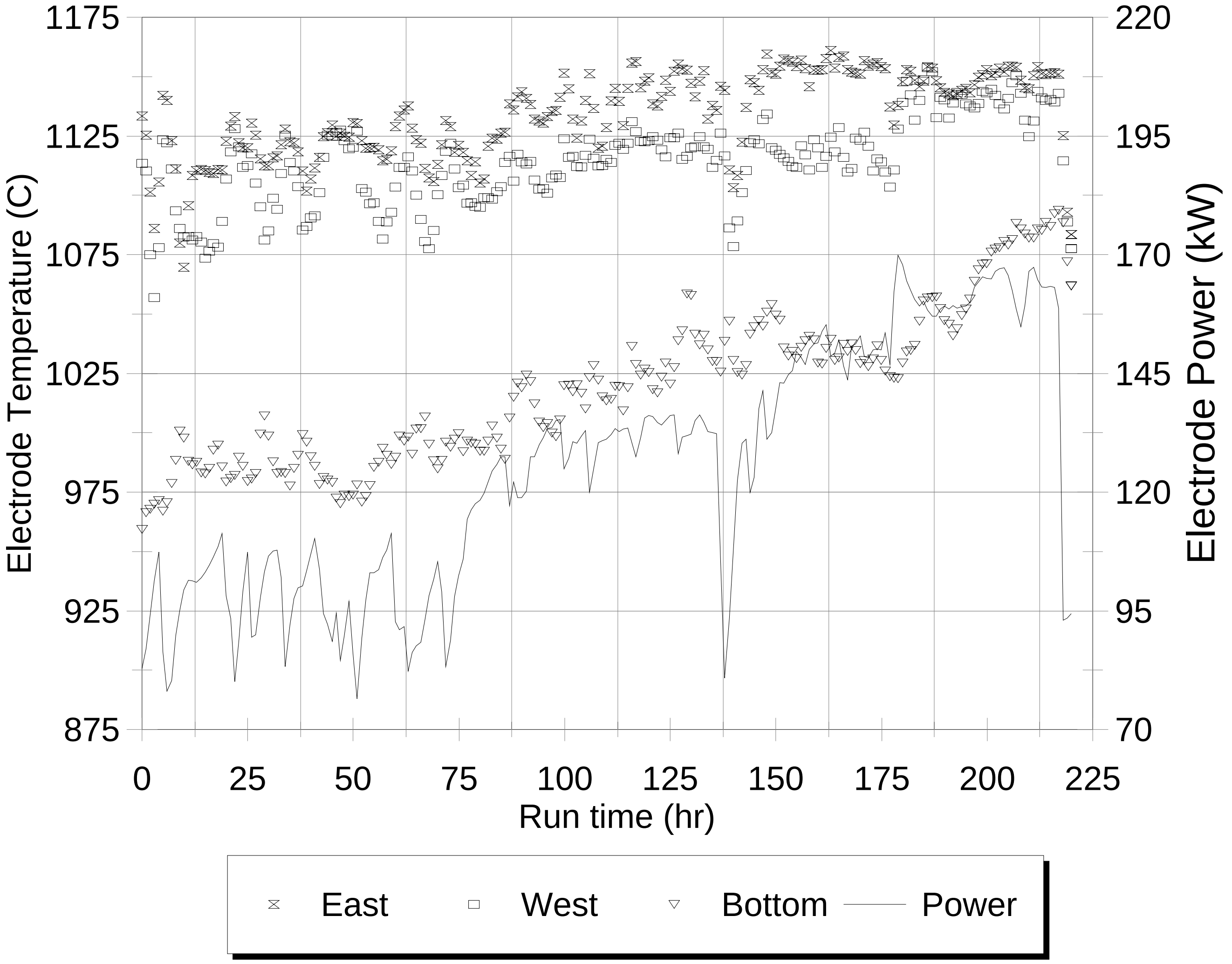

Figure 4.4. Electrode temperatures and power for DM1200 tests (hourly averages).

Figure 4.5. Electrode power and glass resistance for DM1200 tests.

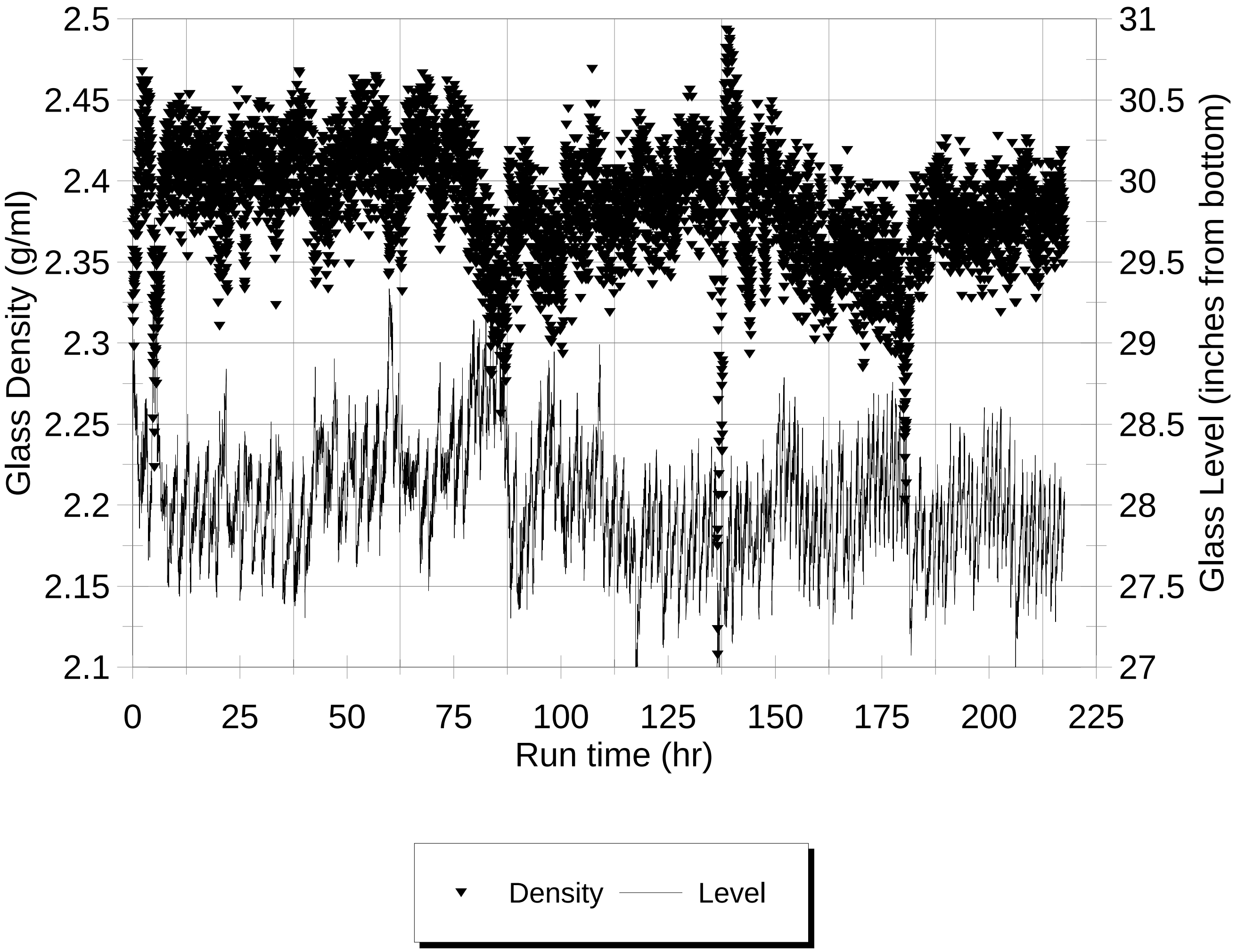

Figure 4.6. Glass density and level for DM1200 tests.

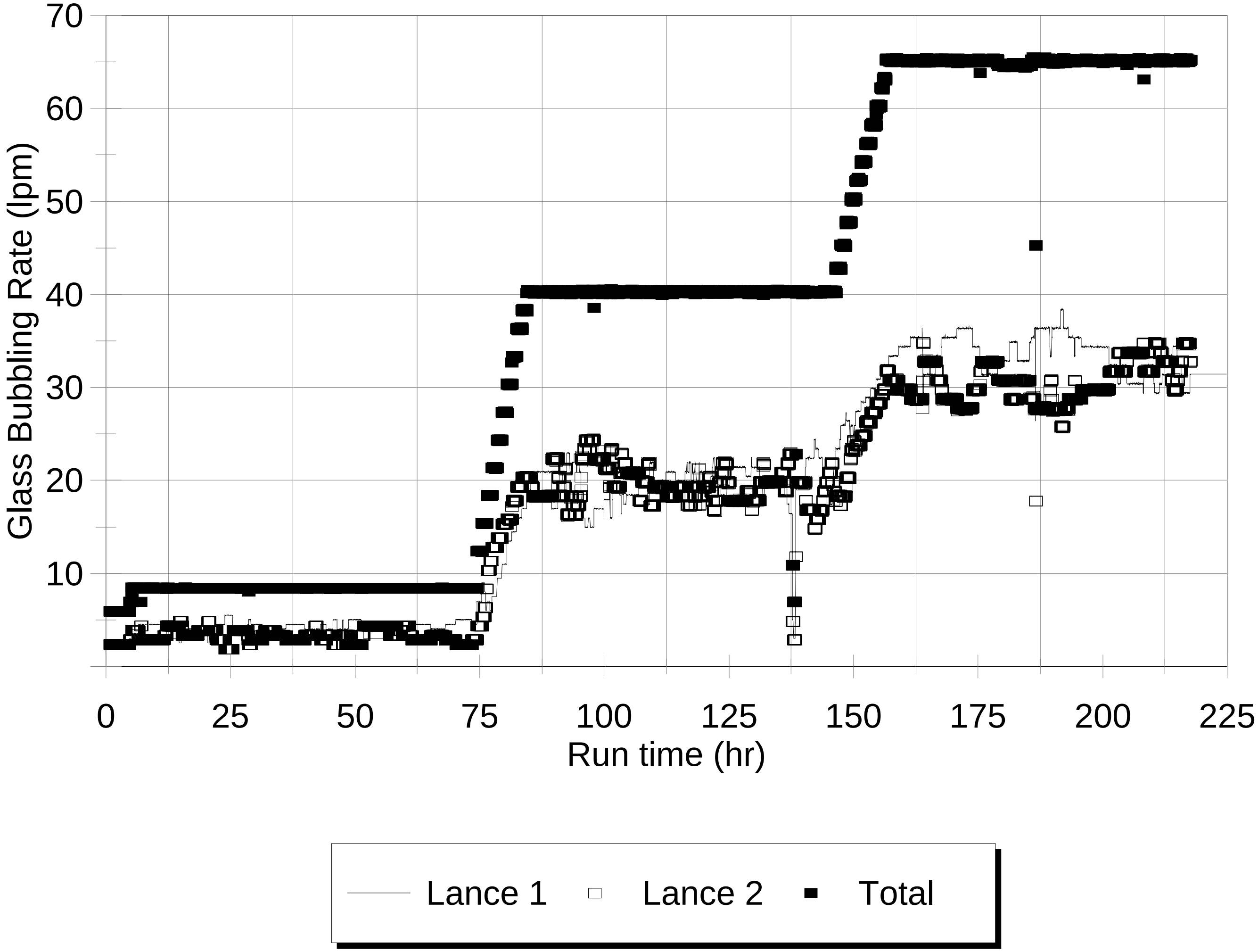

Figure 4.7. Glass pool bubbling for DM1200 tests.

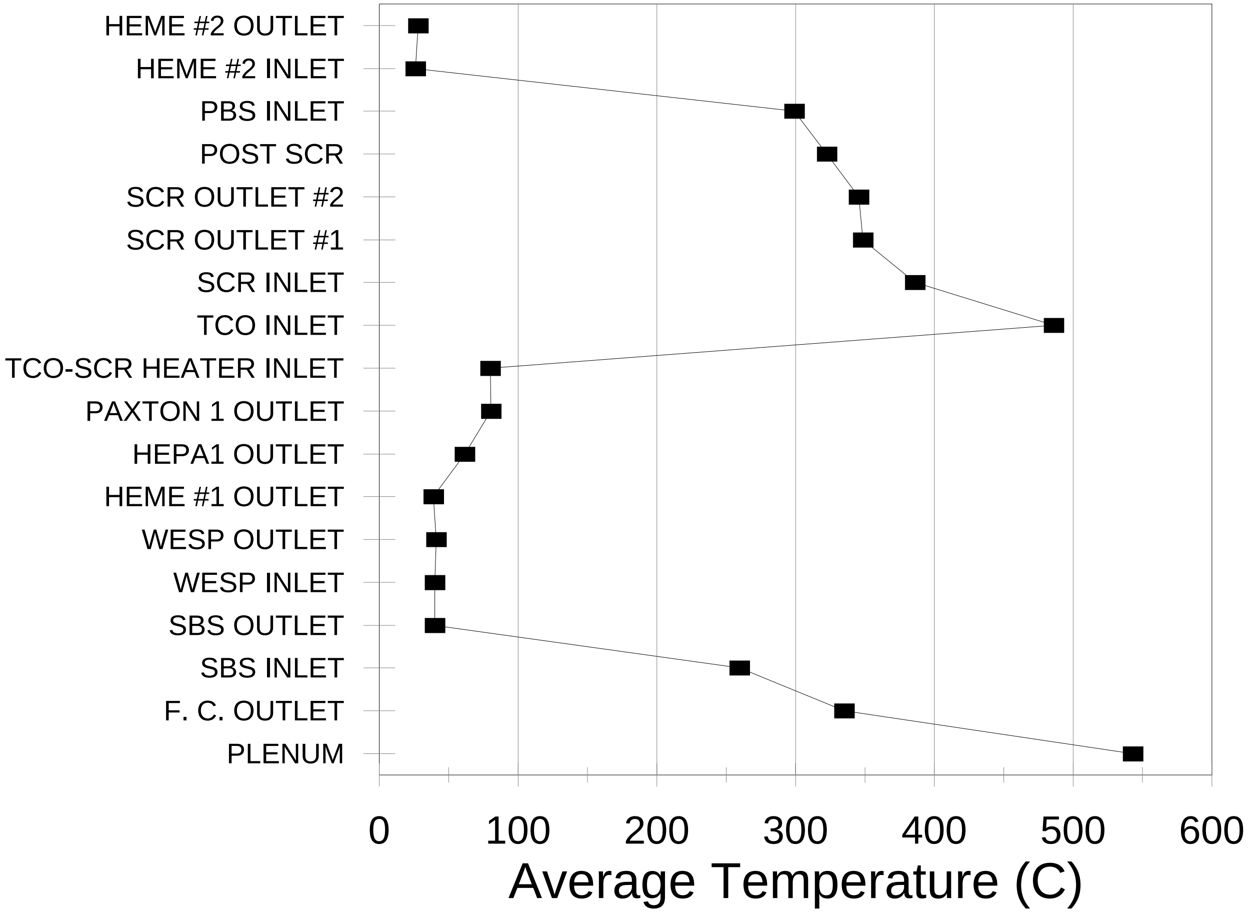

Figure 5.1. Average gas temperatures along the DM1200 off-gas train.

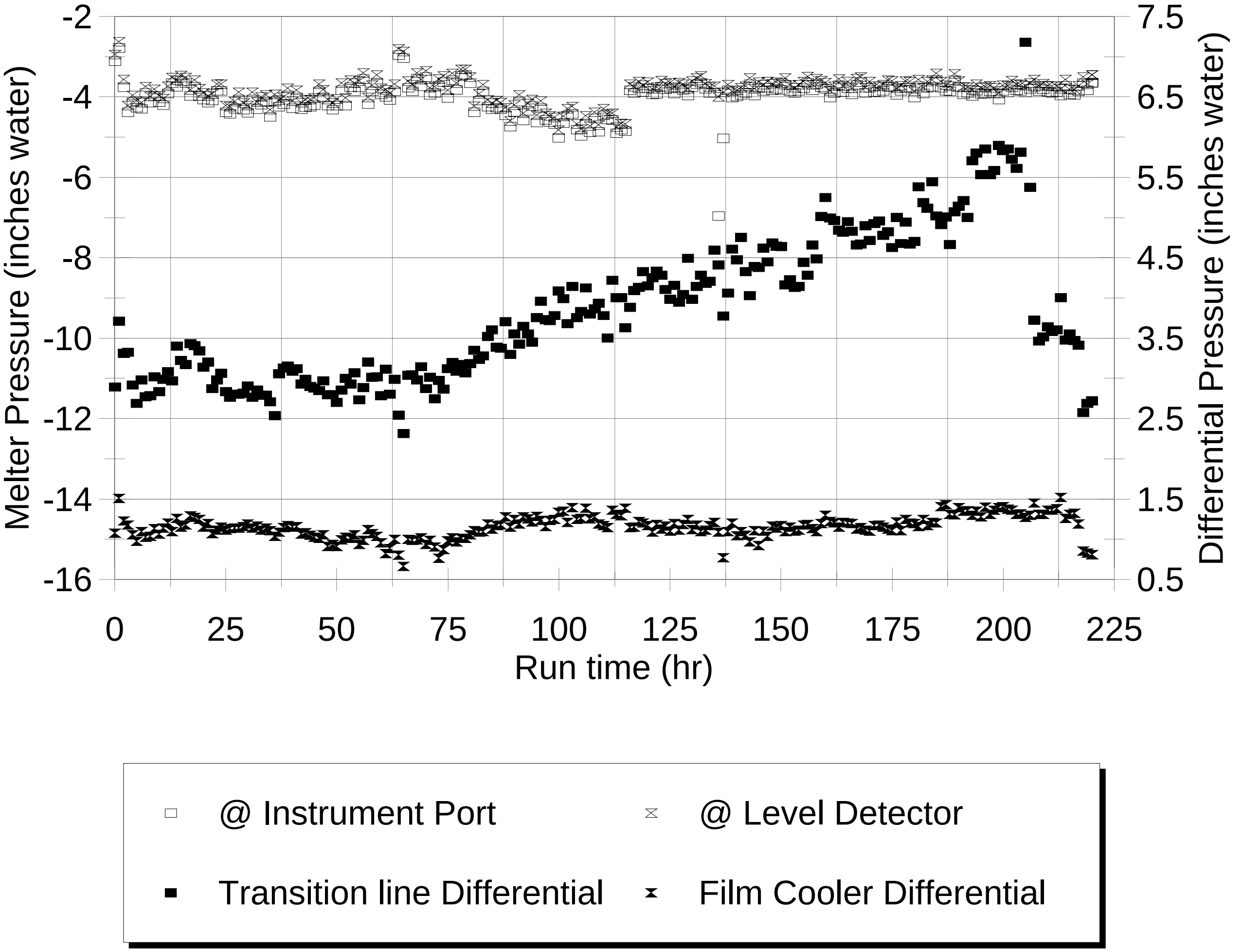

Figure 5.2. Melter Pressure (at level detector and instrument ports) and transition line and film cooler differential pressures (hourly average values).

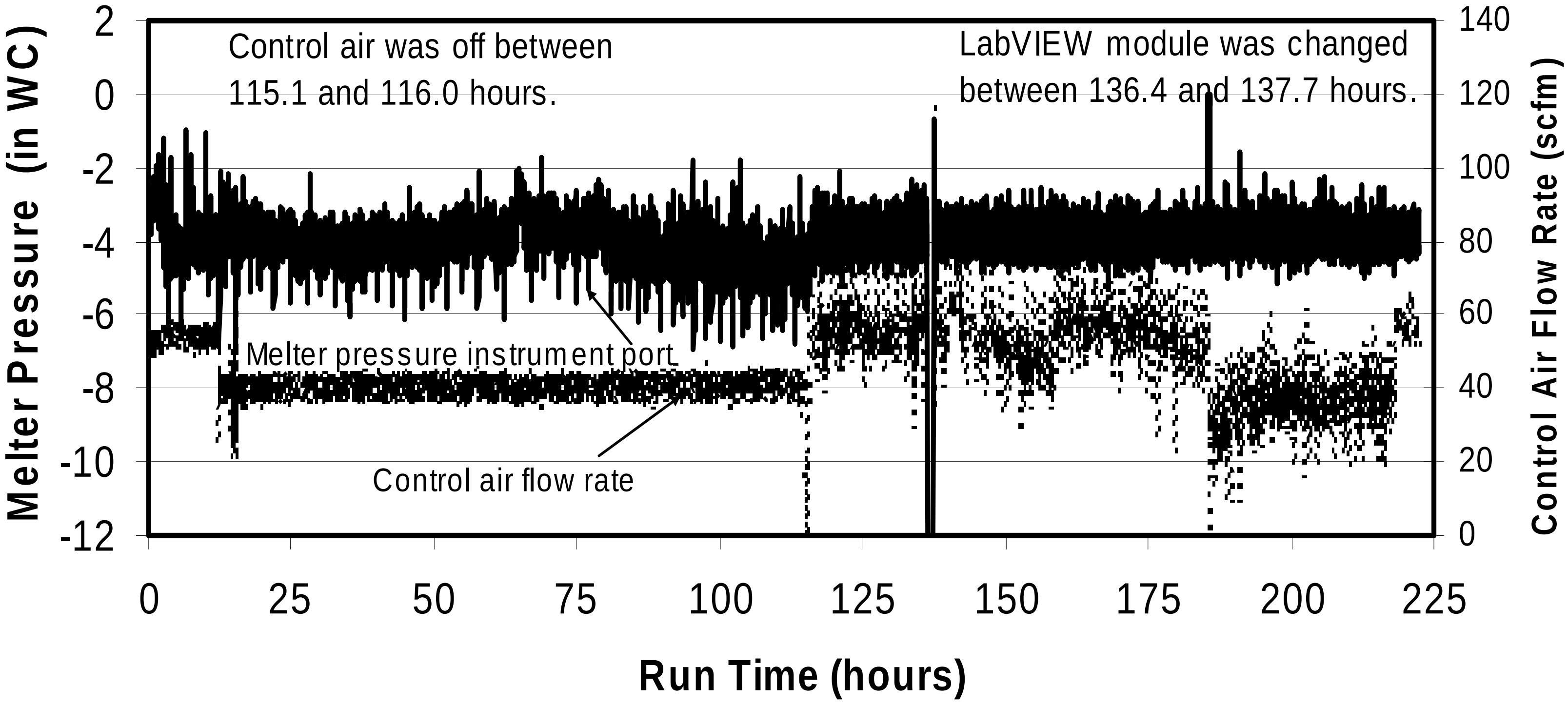

Figure 5.3. Melter pressure at instrument port and control air flow rate.

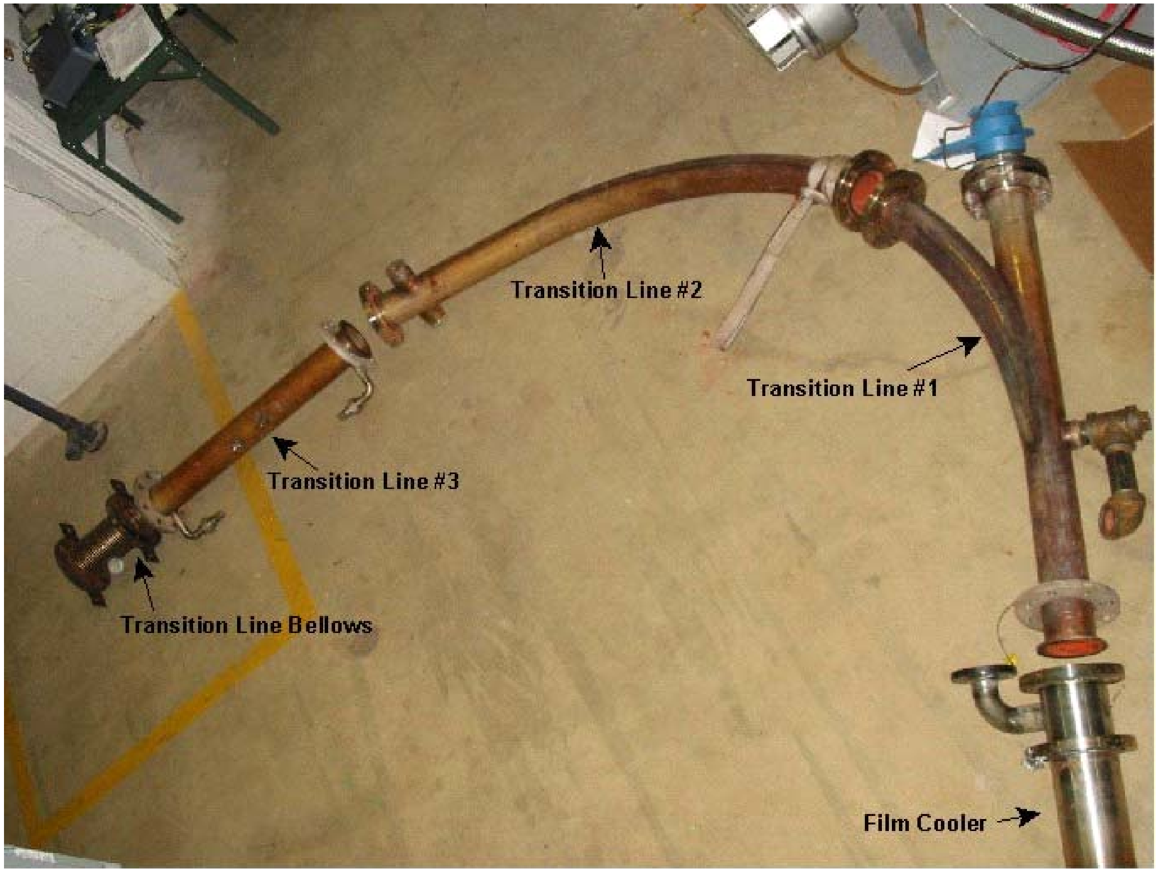

Figure 5.4. Layout of film cooler and transition line sections.

Figure 5.5. Film cooler inlet.

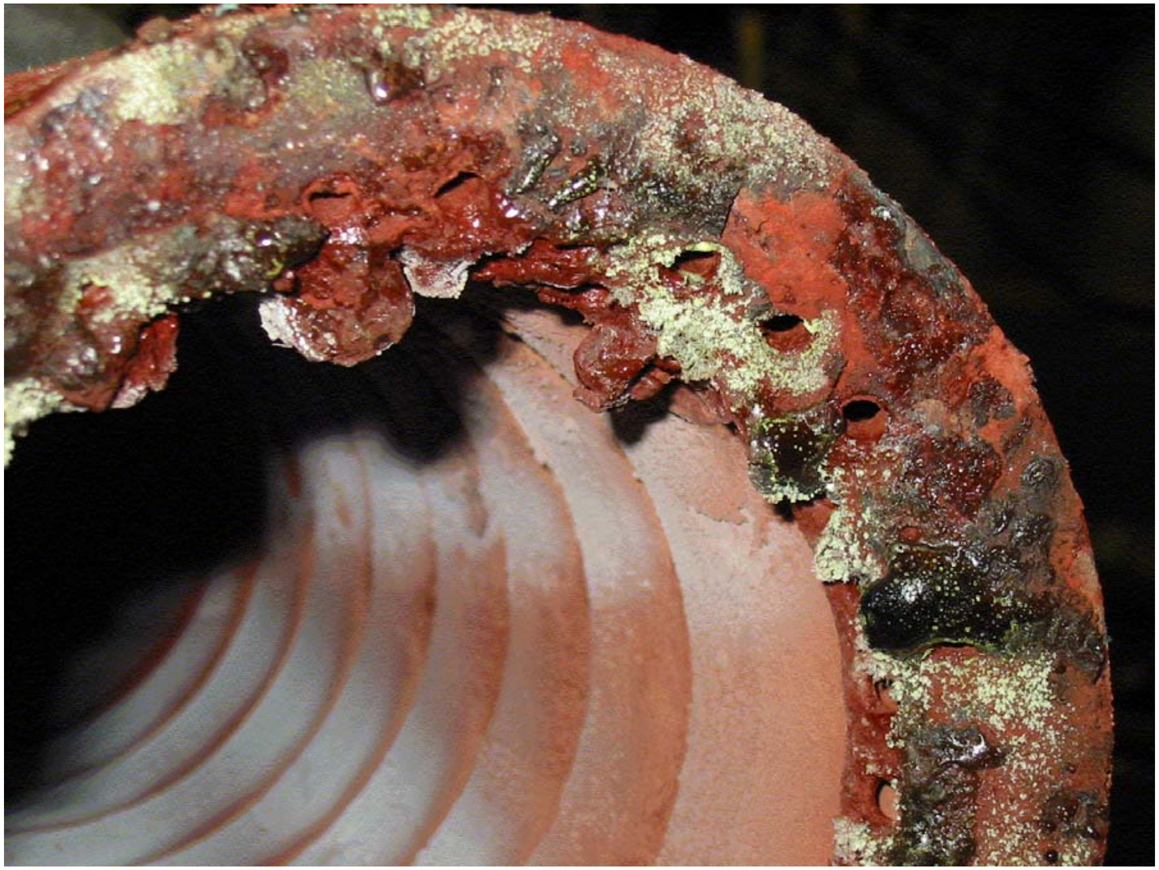

Figure 5.6. Film cooler inlet close-up.

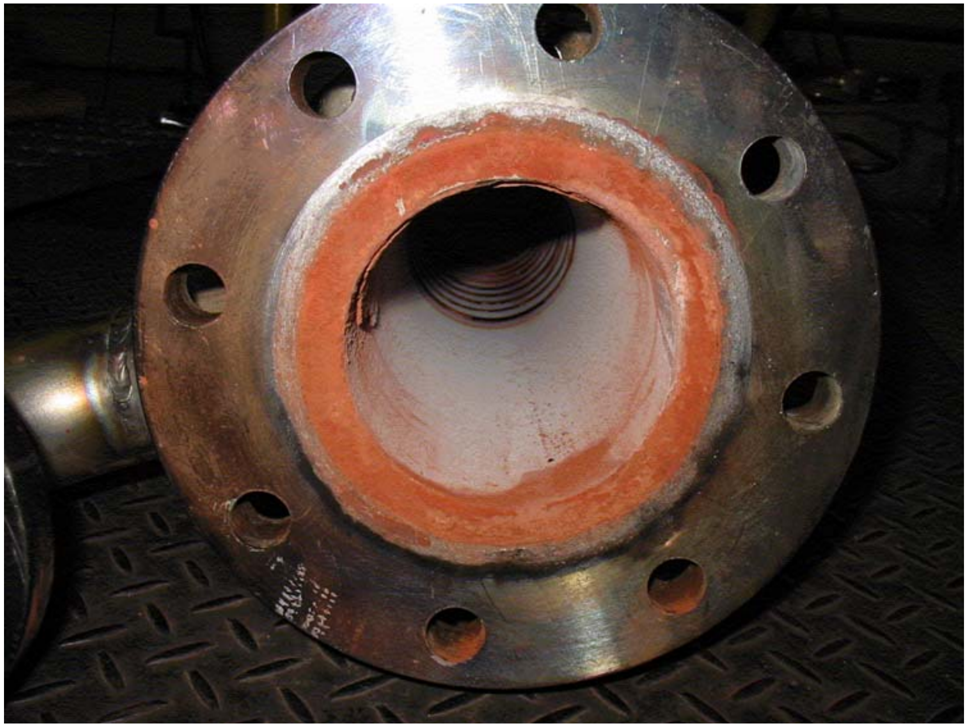

Figure 5.7. Film cooler outlet.

Figure 5.8. Transition line section #1 inlet.

Figure 5.9. Transition line section #1 outlet.

Figure 5.10. Transition line section #2 inlet.

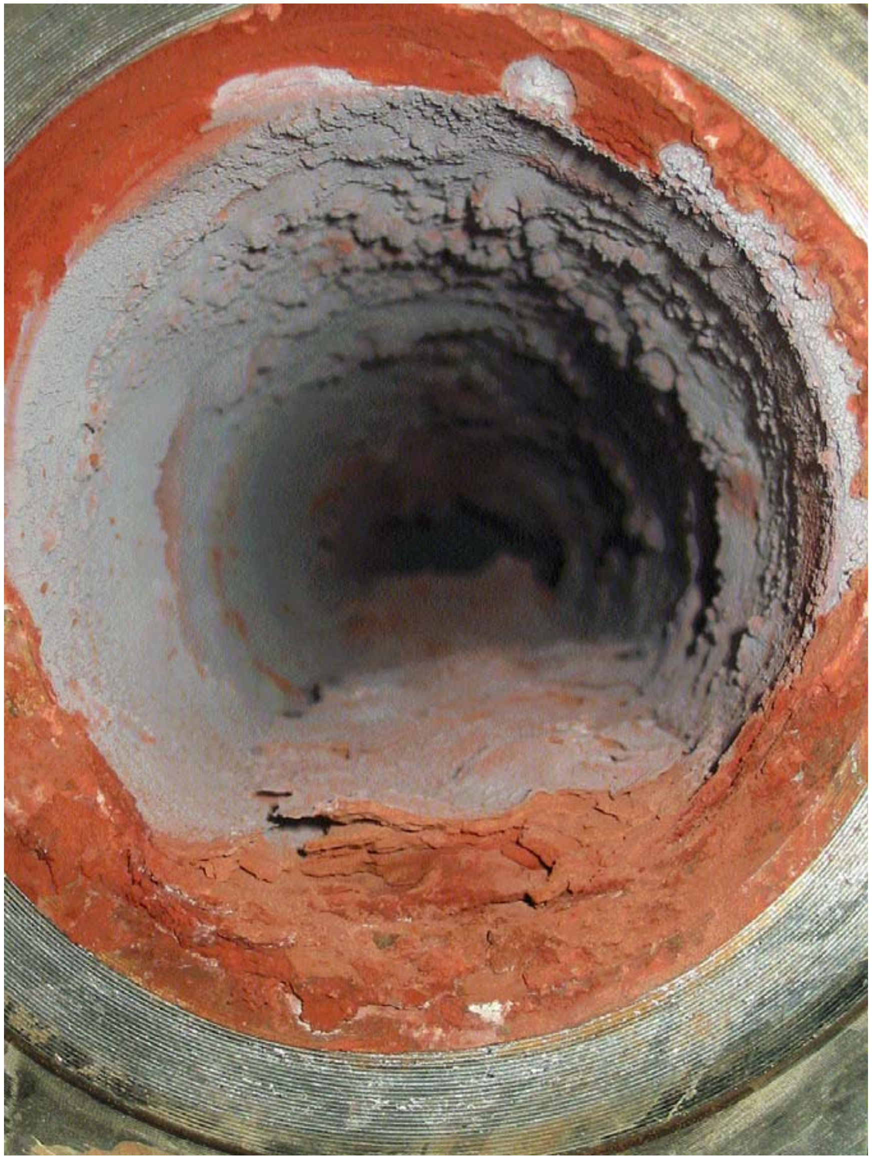

Figure 5.11. Transition line section #2 outlet.

Figure 5.12. Transition line section #3 inlet.

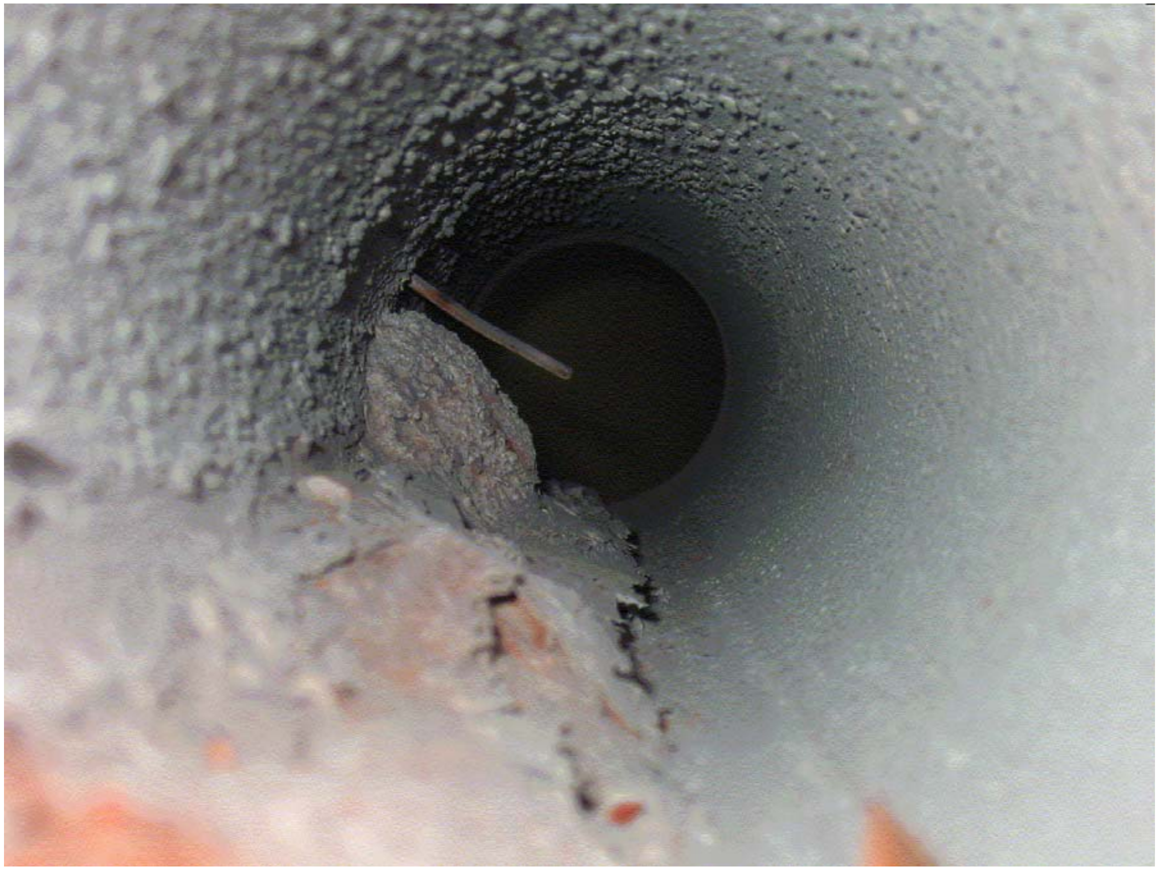

Figure 5.13. Another view of transition line section #3 inlet.

Figure 5.14. Transition line section #3 outlet.

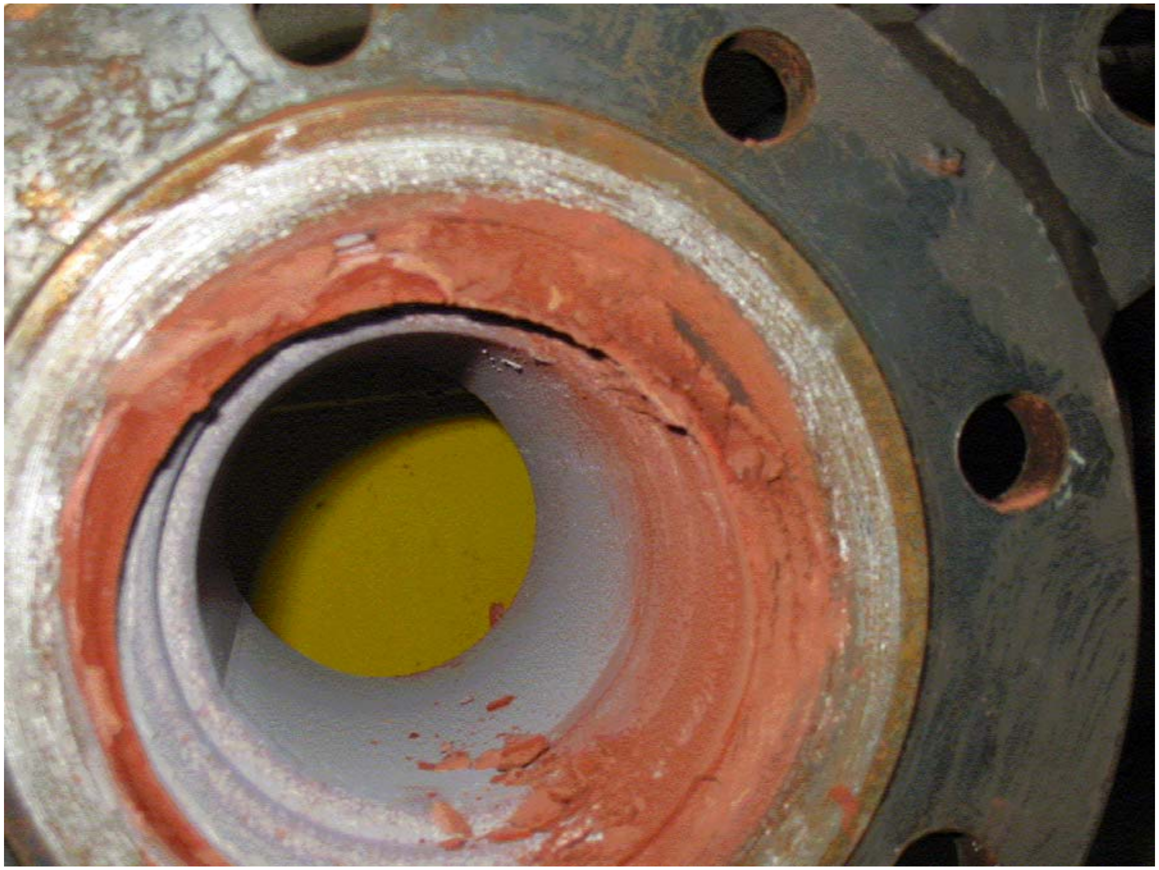

Figure 5.15. Transition line bellows inlet.

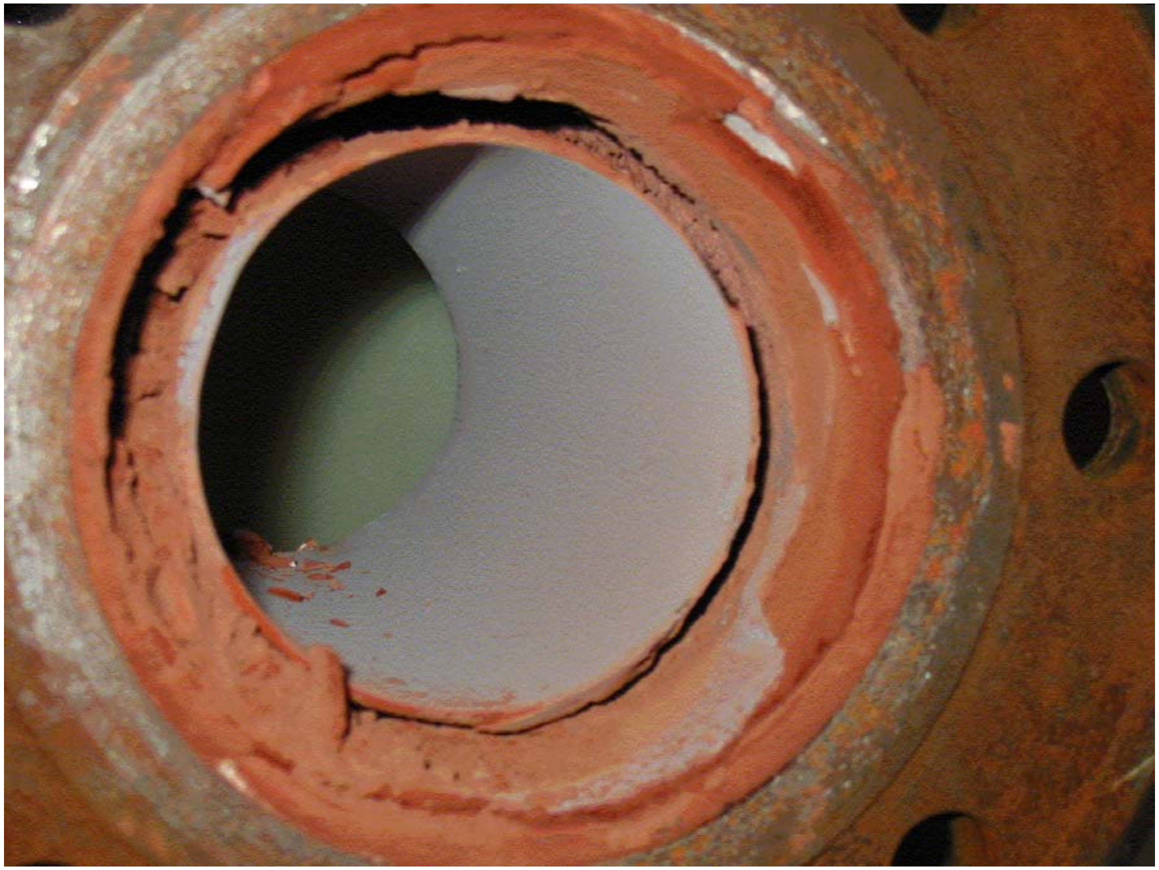

Figure 5.16. Transition line bellows outlet.

Figure 5.17. SBS transition line inlet.

Figure 5.18. Film cooler: close-up of inlet (post cleaning).

Figure 5.19. Film cooler: close-up of louvres (post cleaning).

Figure 5.20. Transition line section #1 inlet-close-up (post cleaning).

Figure 5.21. Interior of transition line section #3 (post cleaning).

Figure 5.22. Transition line bellows inlet (post cleaning).

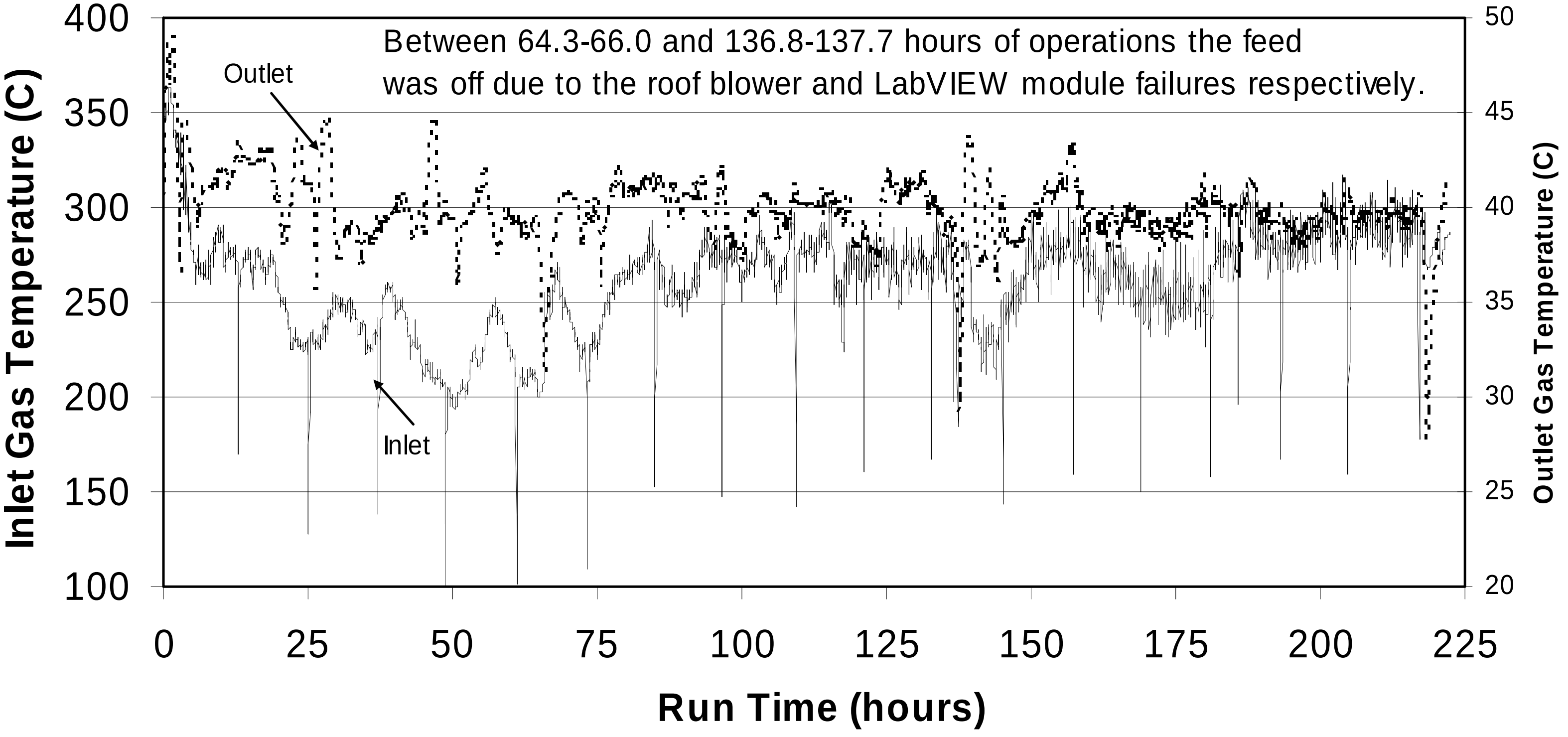

Figure 5.23. SBS inlet and outlet gas temperatures.

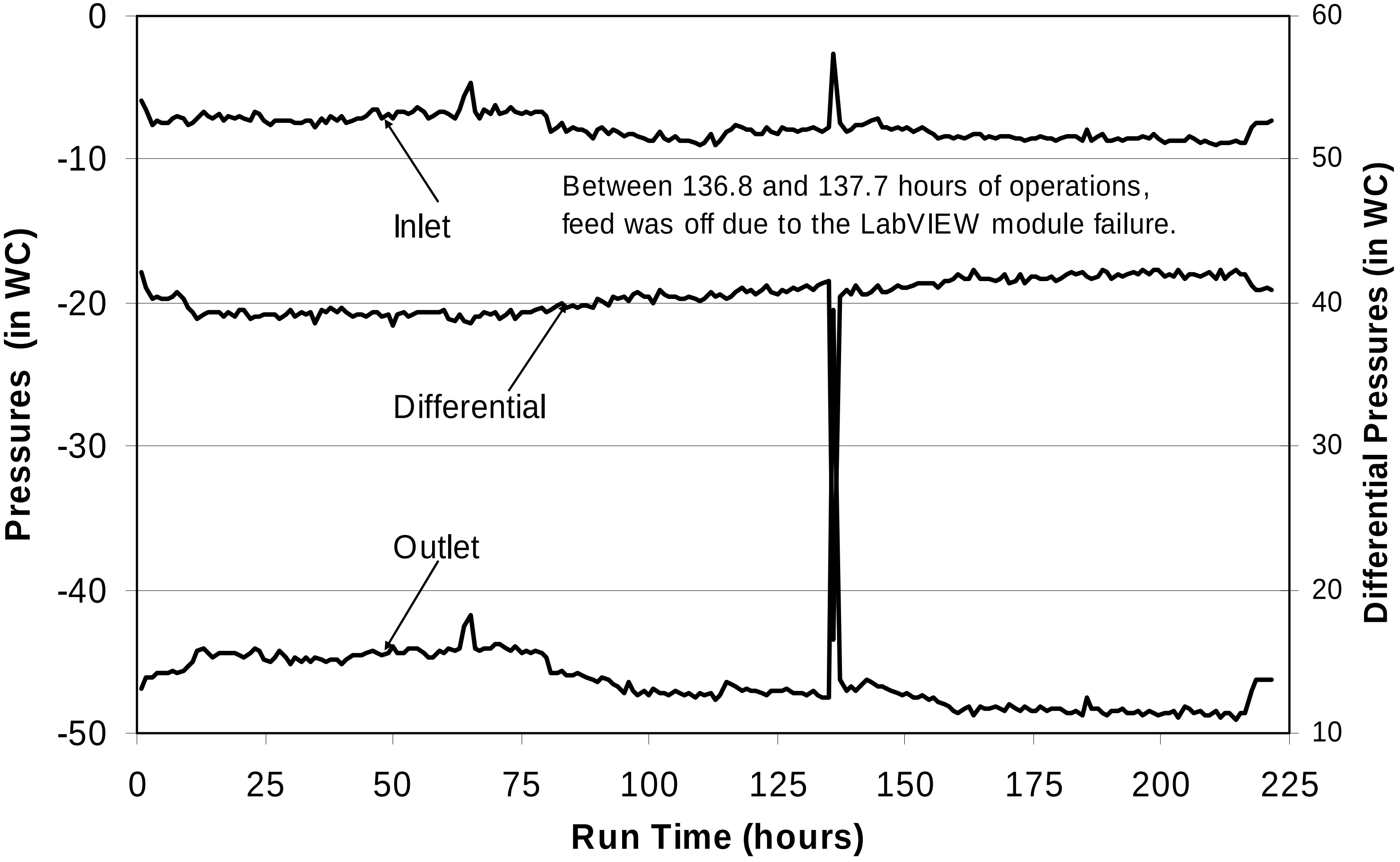

Figure 5.24. SBS inlet, outlet, and differential pressures (hourly average values).

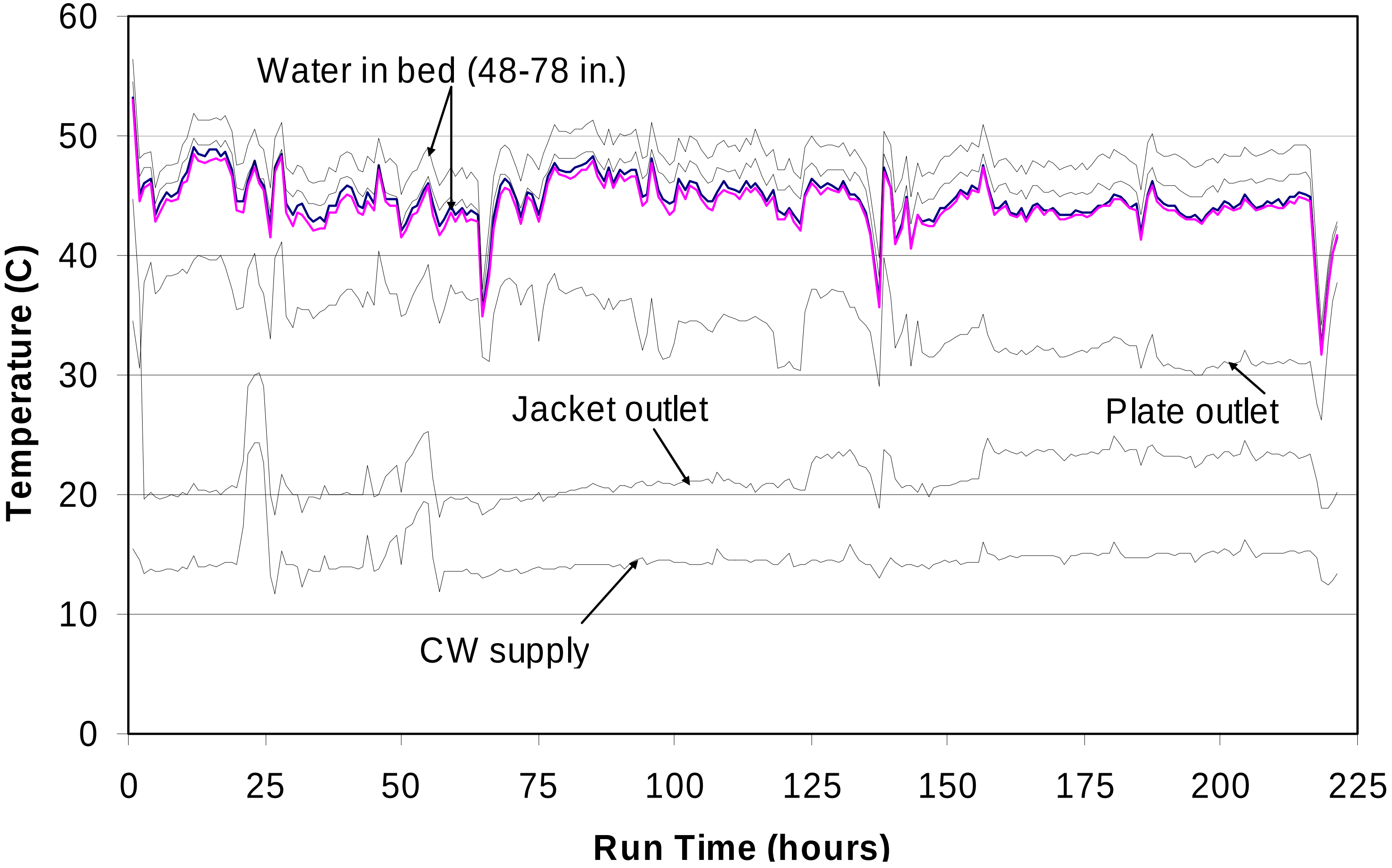

Figure 5.25. SBS cooling water and bed temperatures (hourly average values).

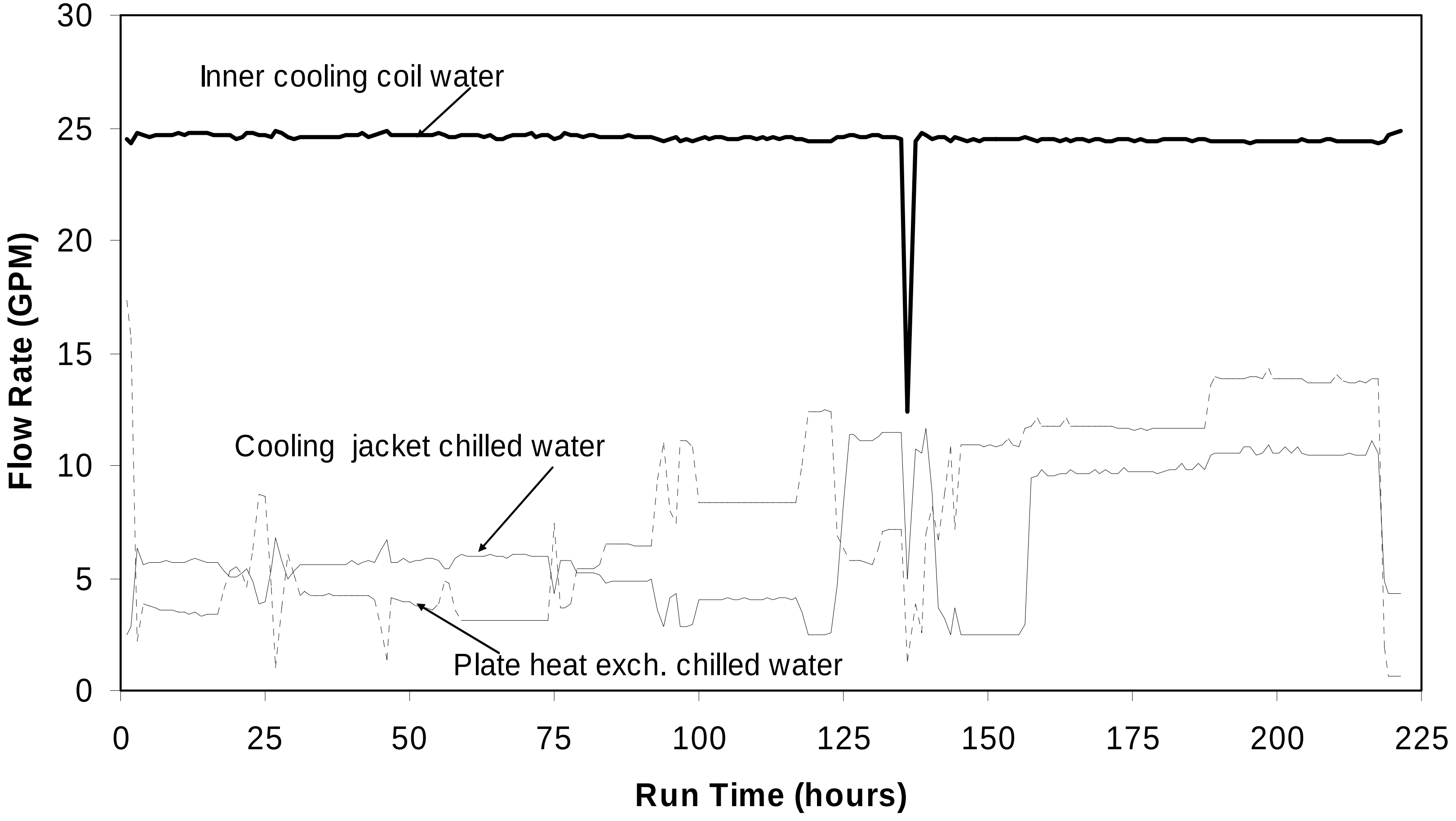

Figure 5.26. SBS jacket, inner coil and heat exchanger water flow rates (hourly average values).

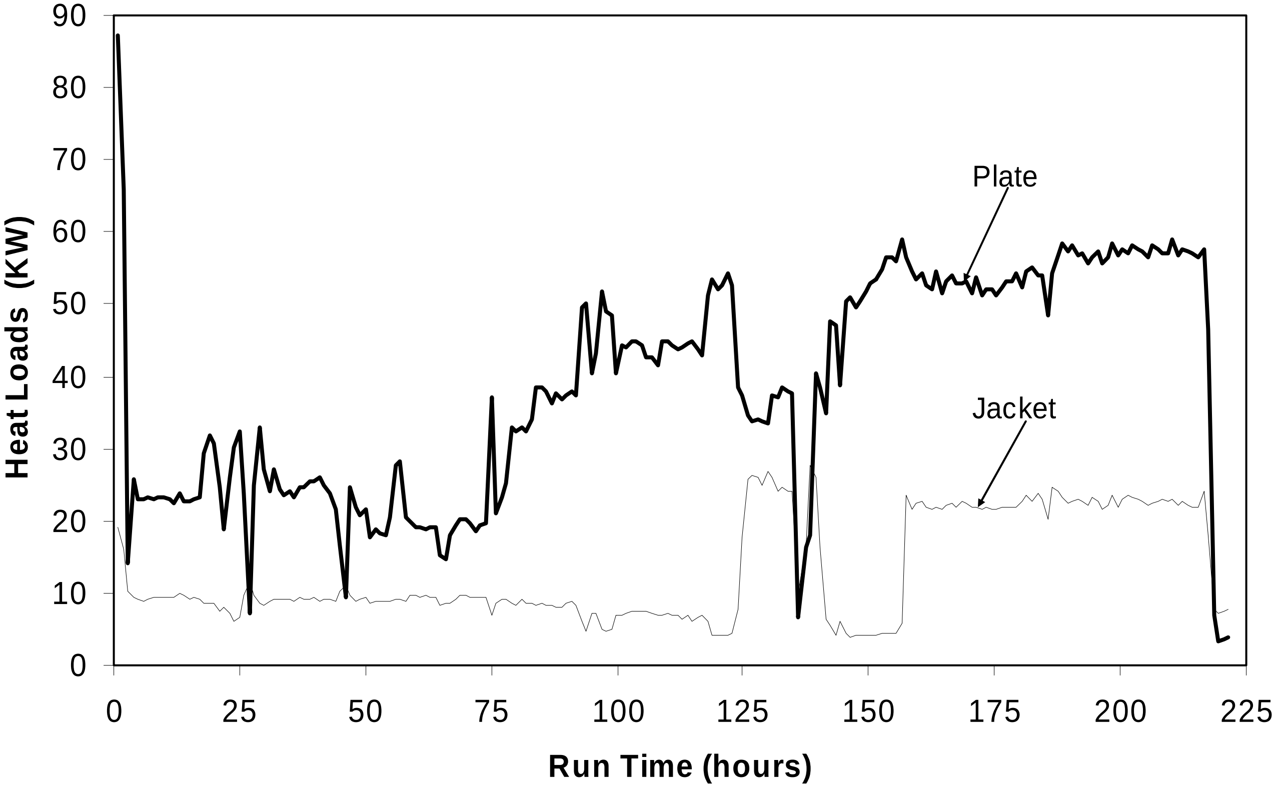

Figure 5.27. Calculated heat loads on the cooling jacket and plate heat exchanger (hourly average values).

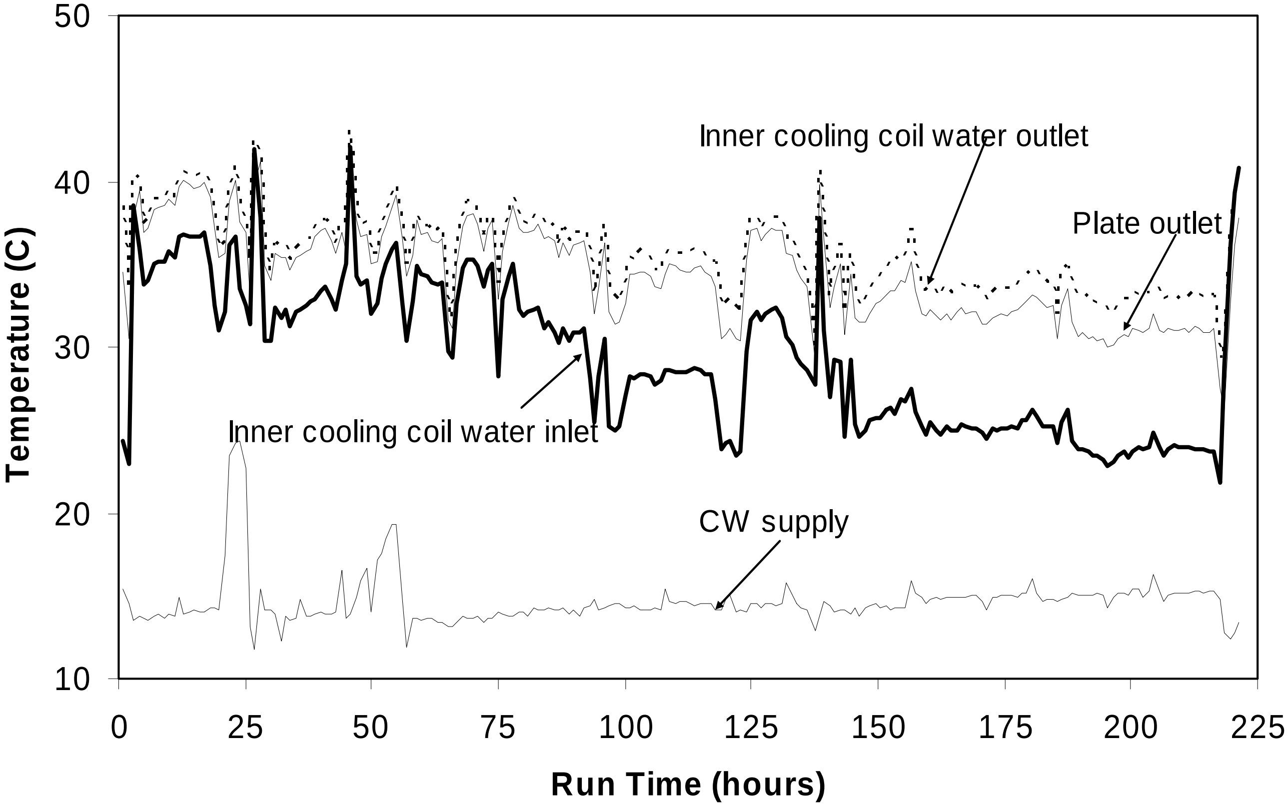

Figure 5.28. SBS inner coil and plate heat exchanger water temperatures (hourly average values).

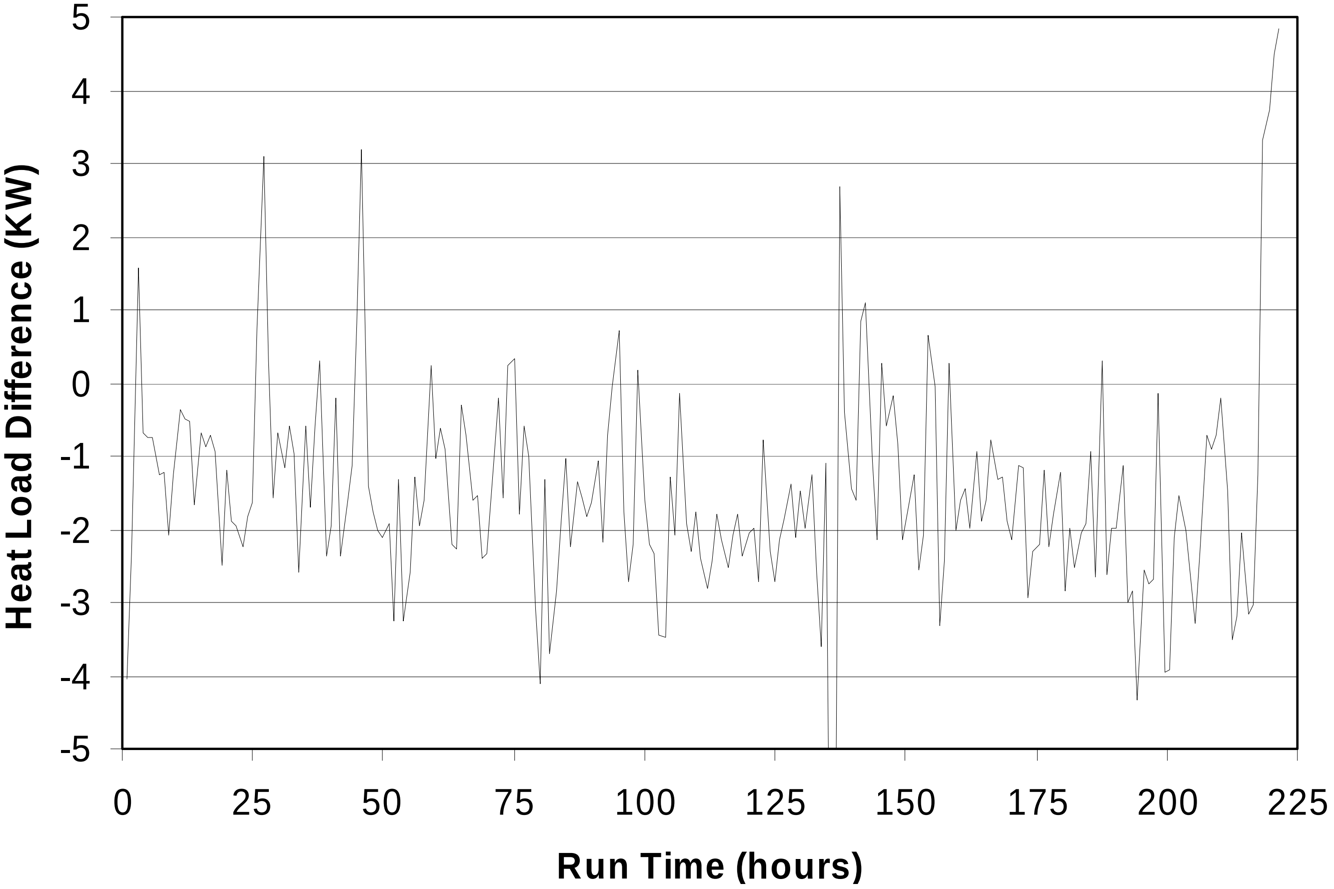

Figure 5.29. Calculated heat load difference between SBS inner coil and plate heat exchanger (hourly average values).

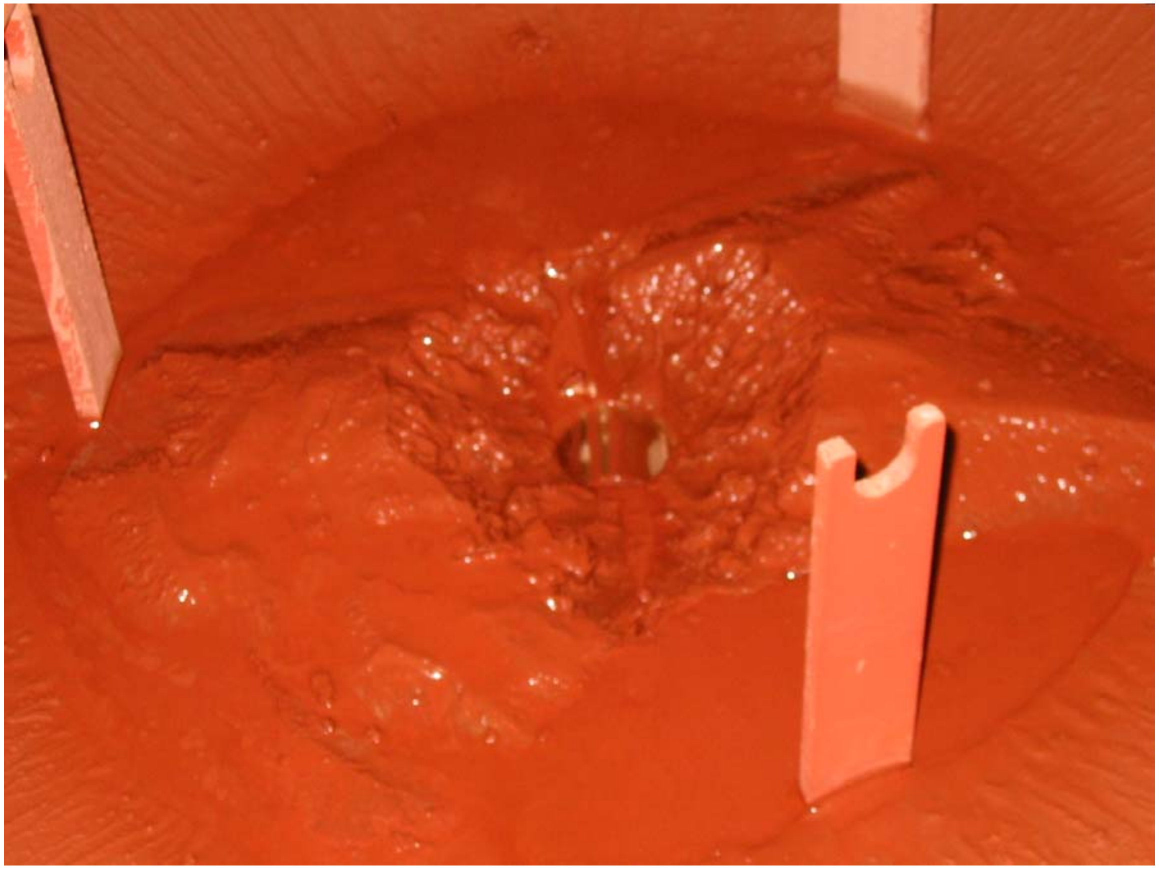

Figure 5.30. SBS bowl before cleaning at the end of the test.

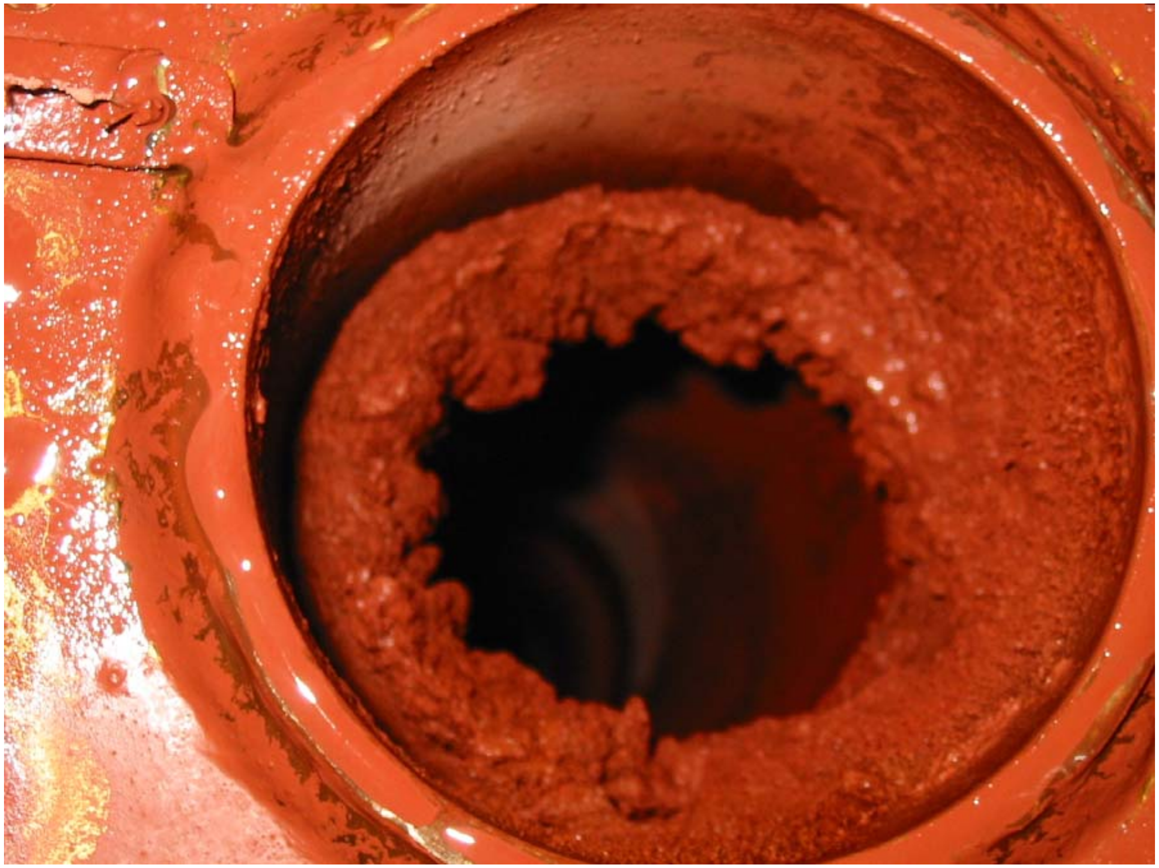

Figure 5.31. View of SBS downcomer showing ring of solids deposited near the bottom at the end of the test.

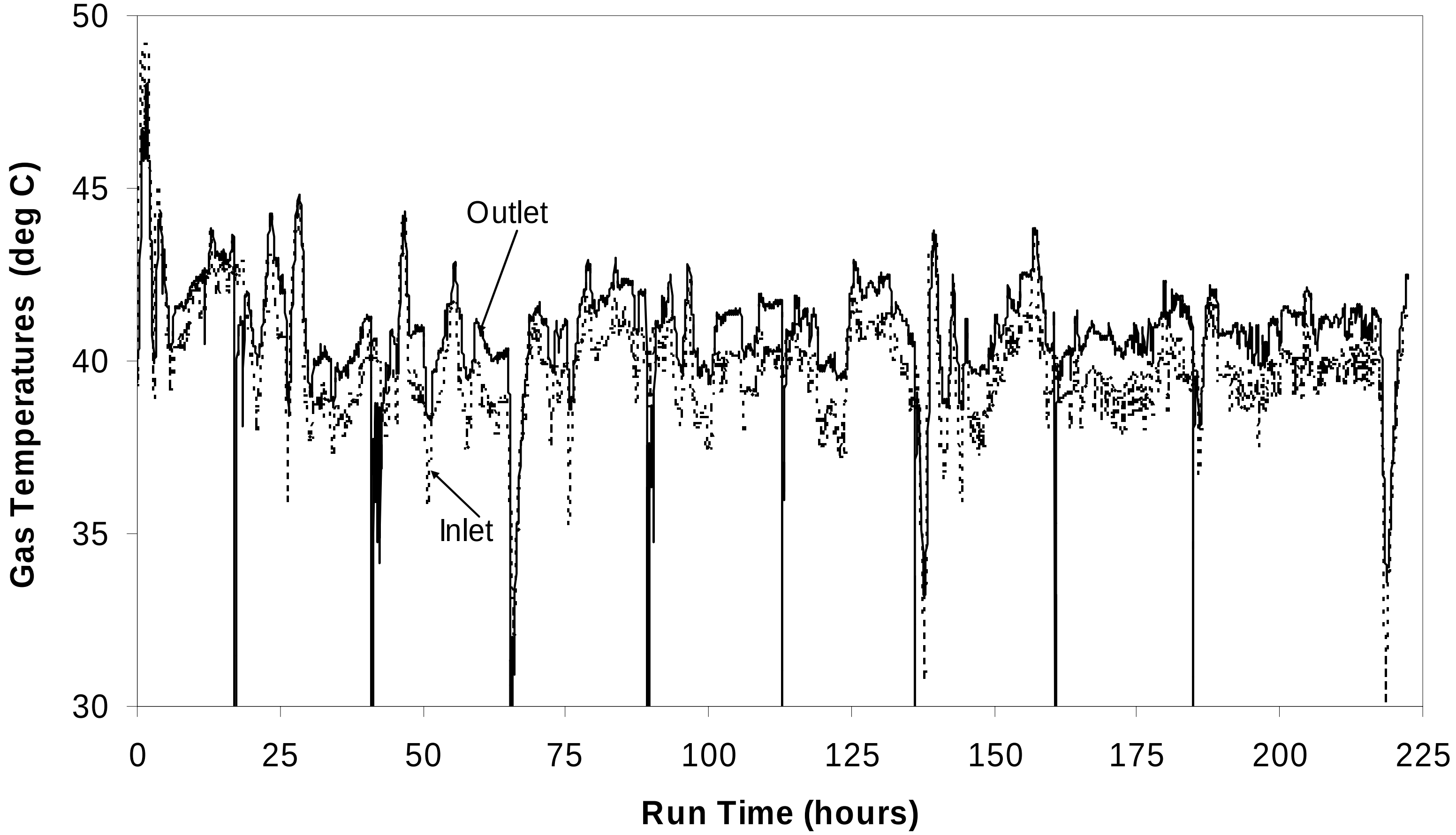

Figure 5.32. WESP inlet and outlet temperatures. (Note: Downward outlet temperature spikes are the result of WESP deluges).

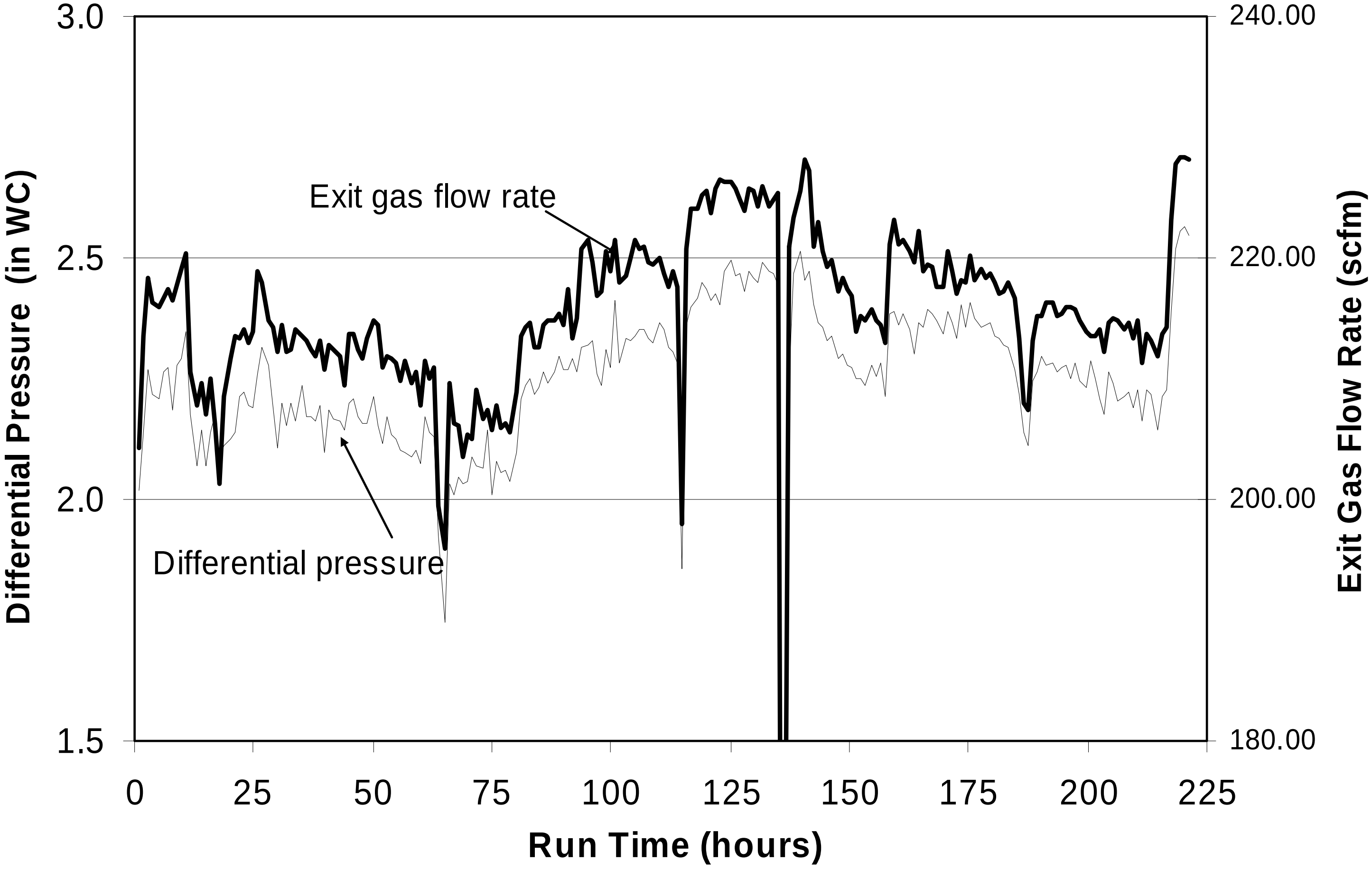

Figure 5.33. WESP differential pressure and outlet gas flow rate (hourly average values).

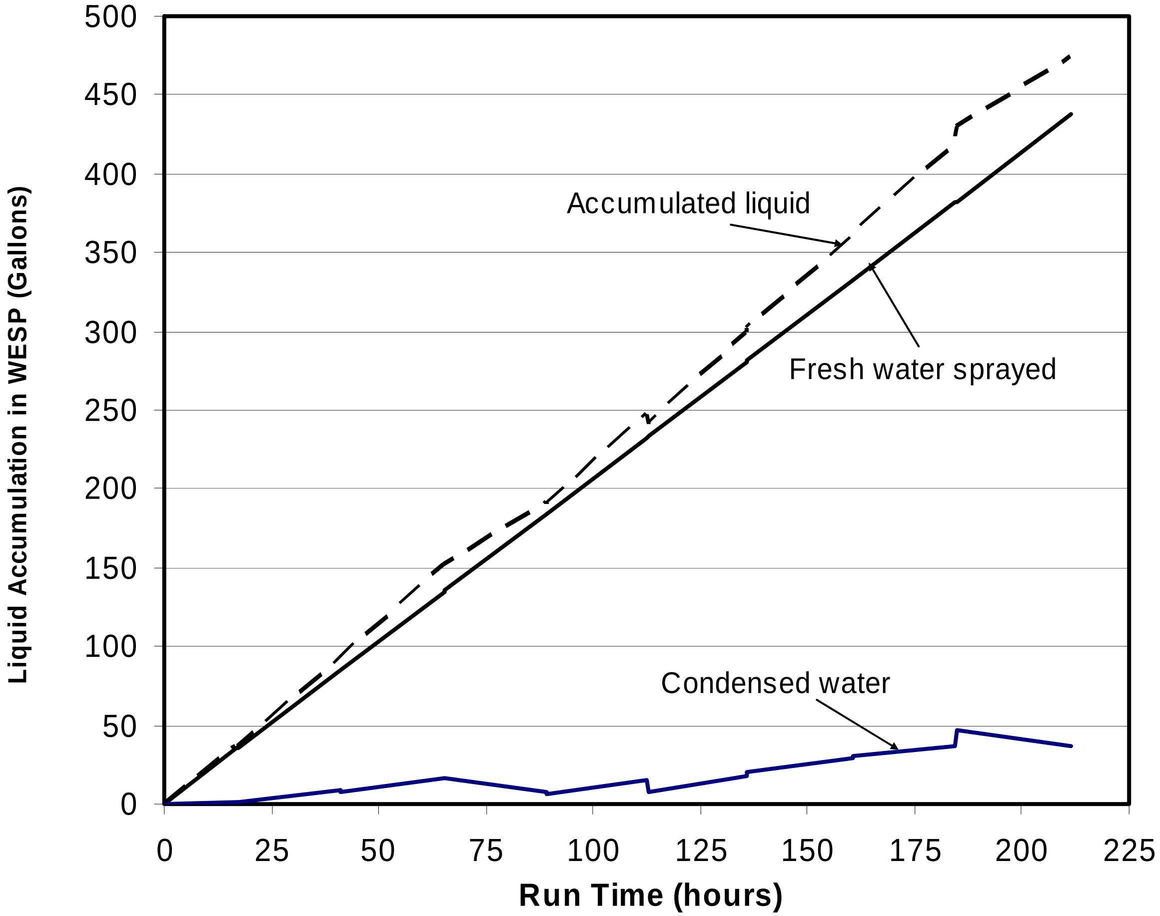

Figure 5.34. Accumulated WESP blow-down volume, accumulated fresh spray water, and condensed/particulate water collected from off-gas stream.

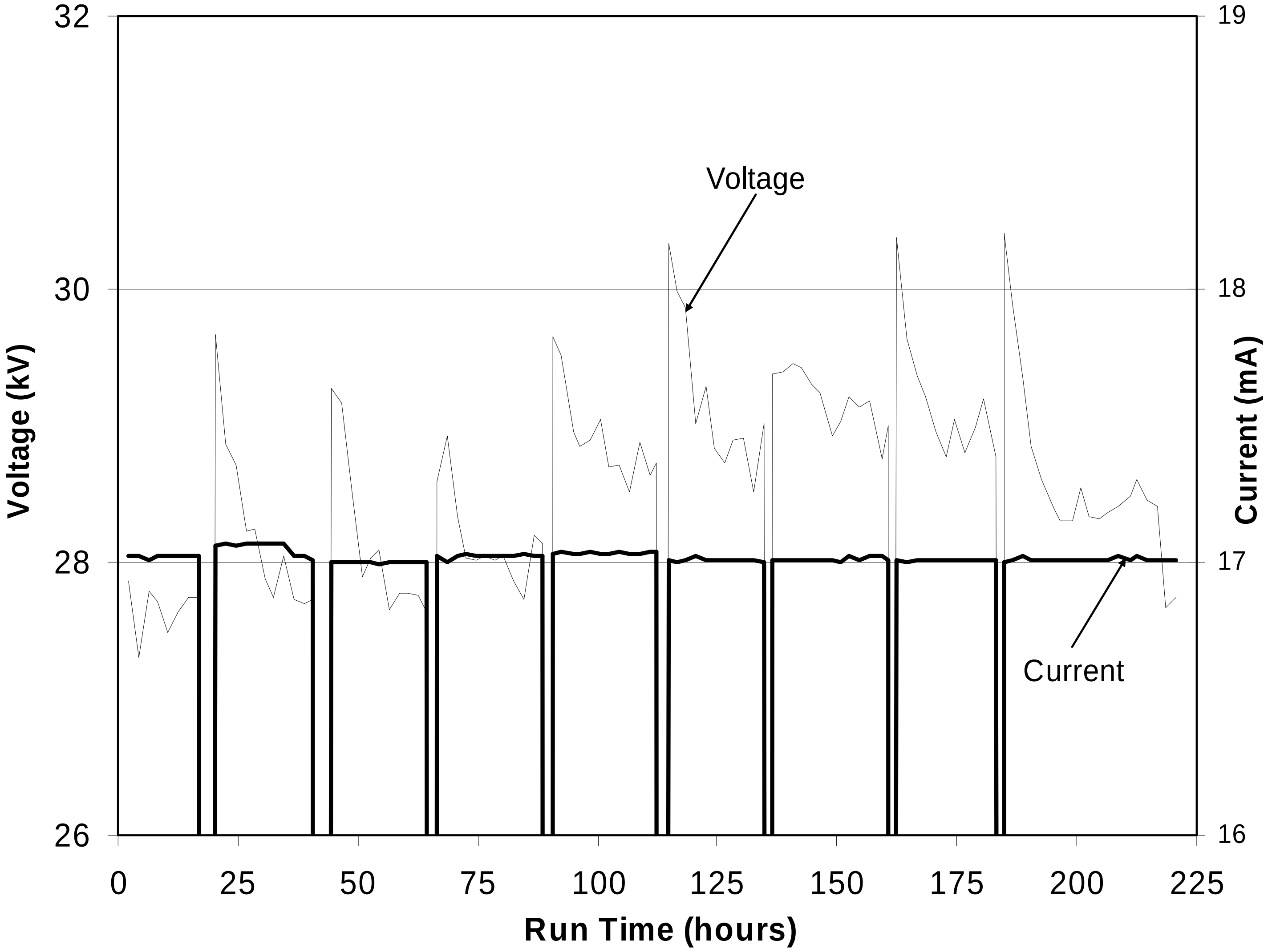

Figure 5.35. Voltage and current across the WESP. (Note: during the deluges, power to WESP was turned off.)

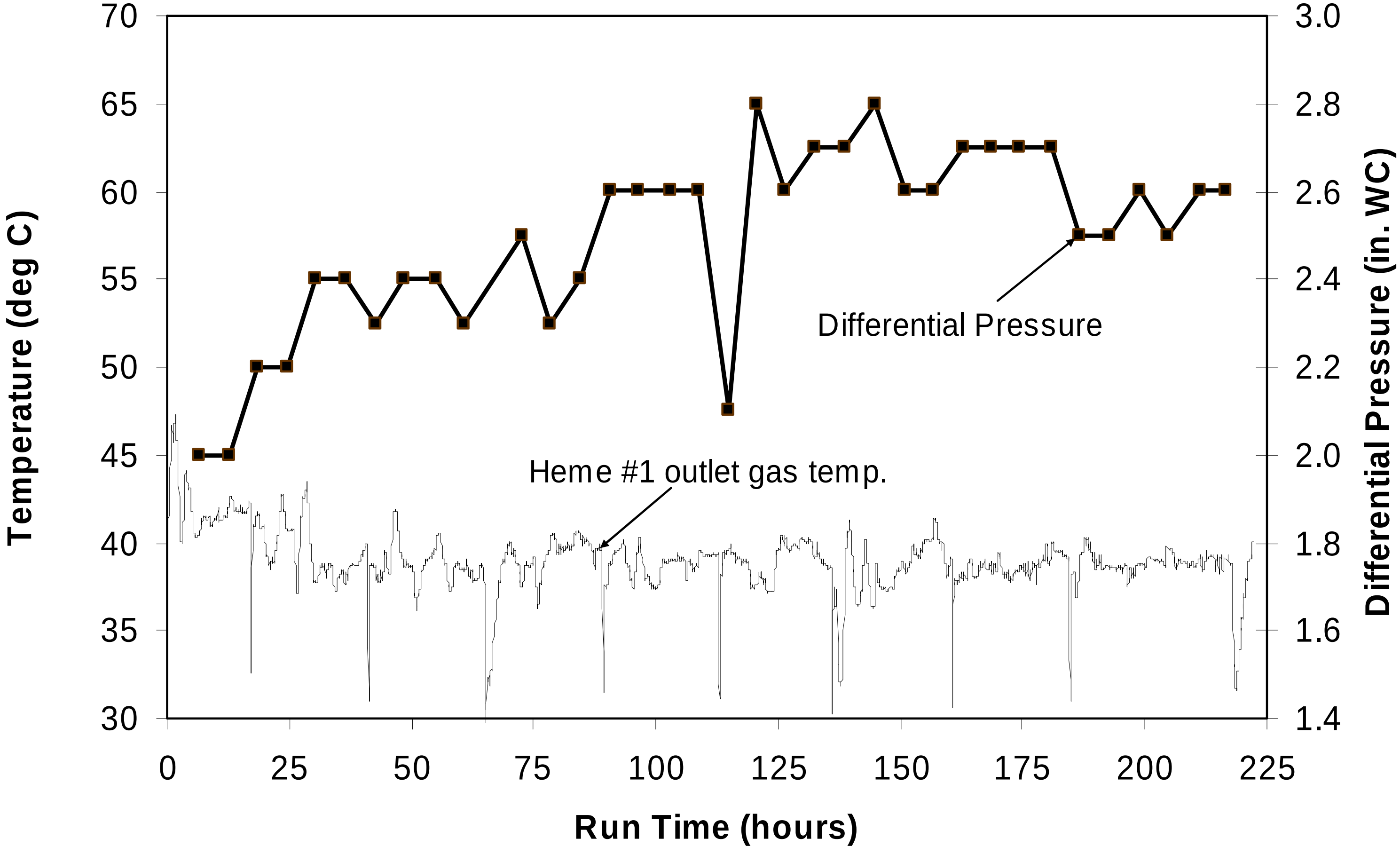

Figure 5.36. Outlet temperature and differential pressure for HEME 1.

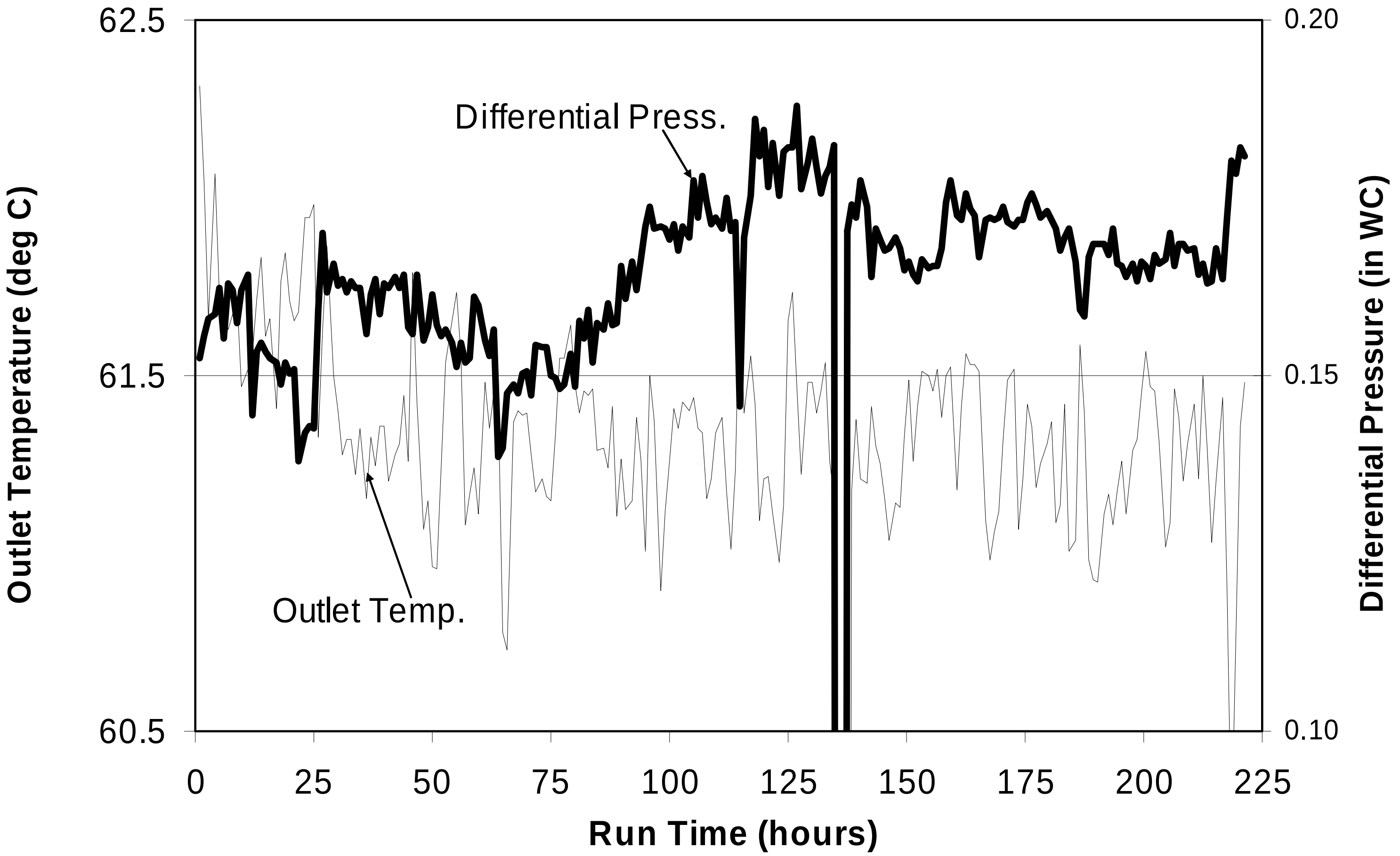

Figure 5.37. Outlet temperature and differential pressure for HEPA #1 (hourly average values).

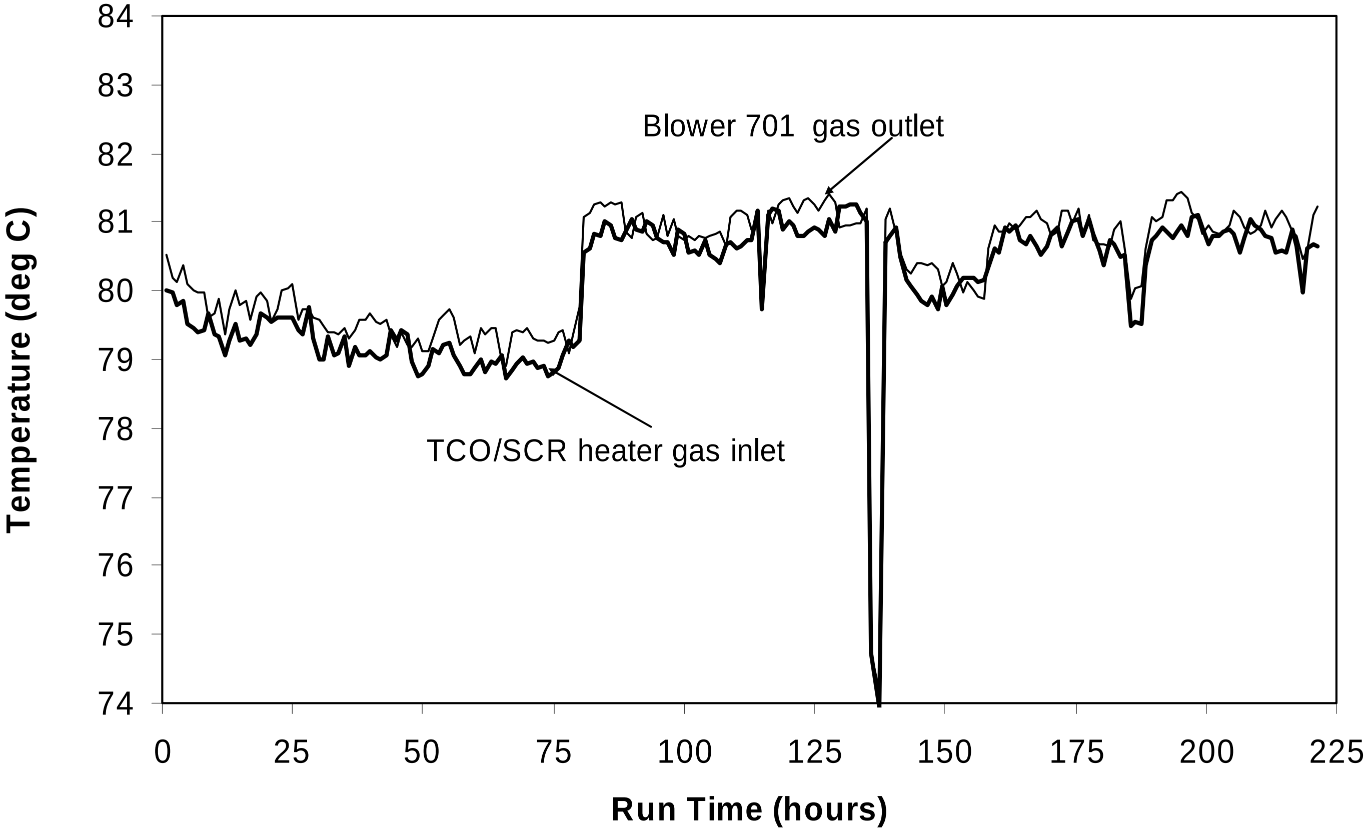

Figure 5.38. Paxton #1 outlet and TCO/SCR heater inlet temperatures (hourly average values).

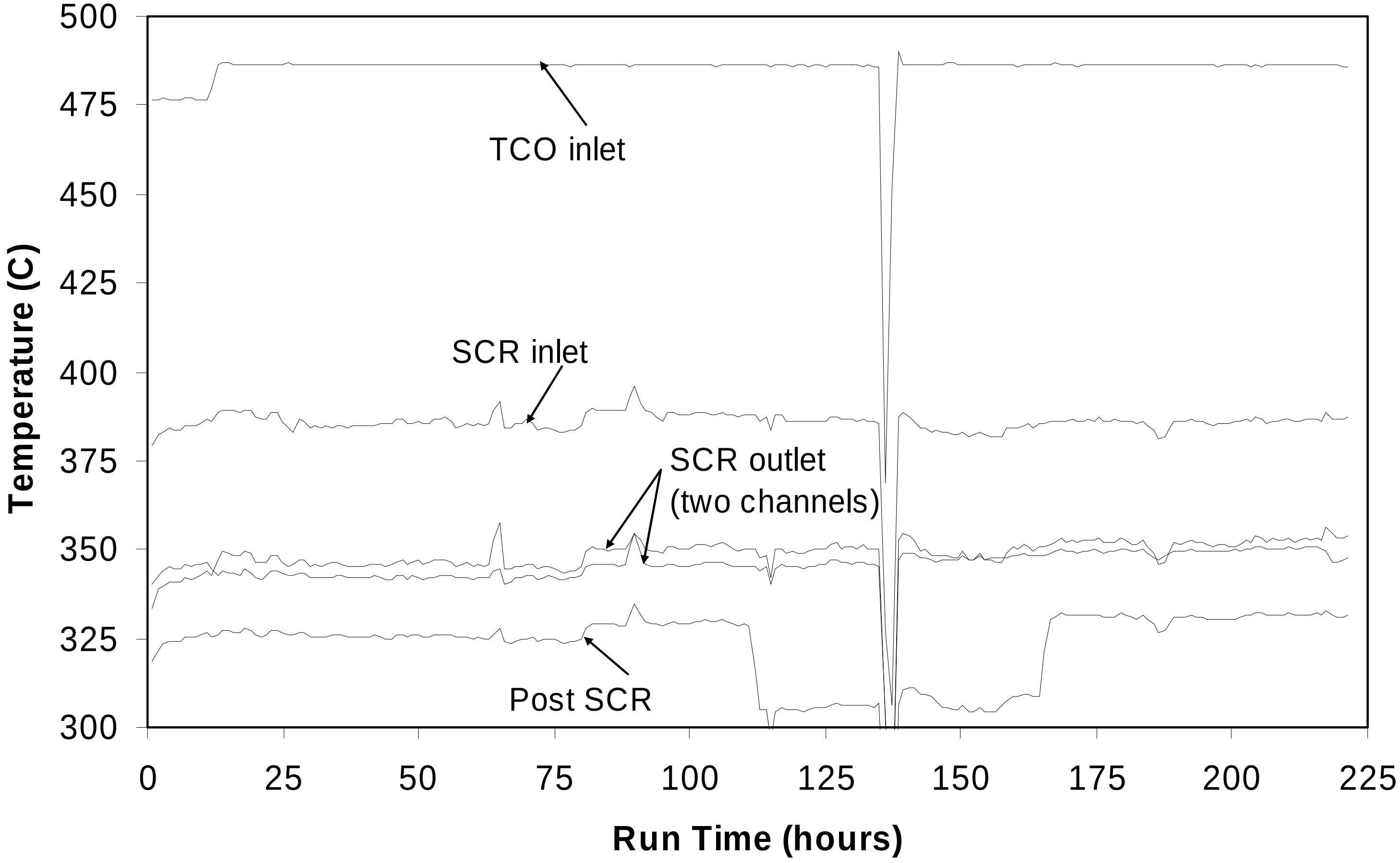

Figure 5.39. TCO/SCR temperatures (hourly average values).

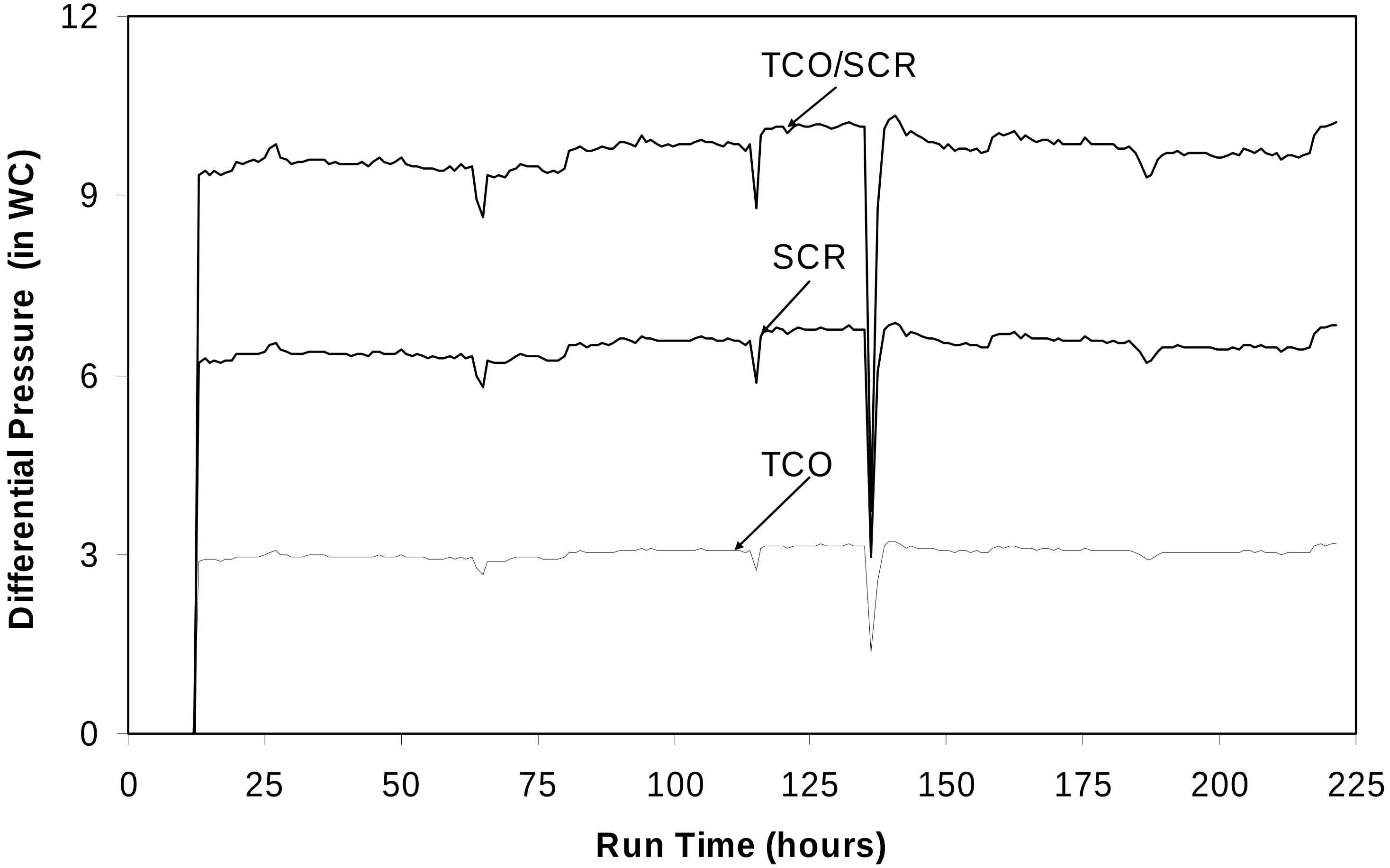

Figure 5.40. TCO/SCR differential pressures (hourly average values).

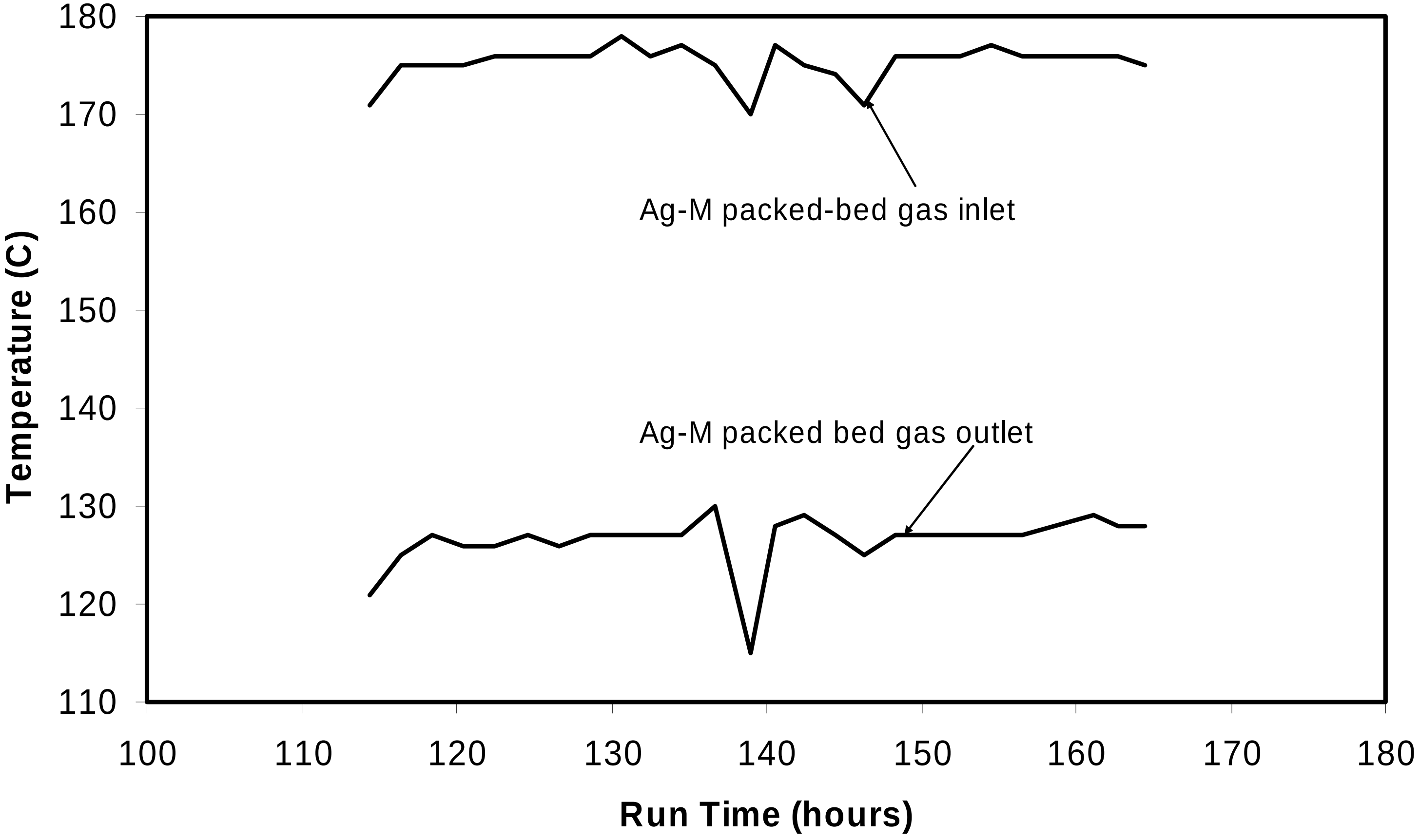

Figure 5.41. Silver mordenite column temperatures.

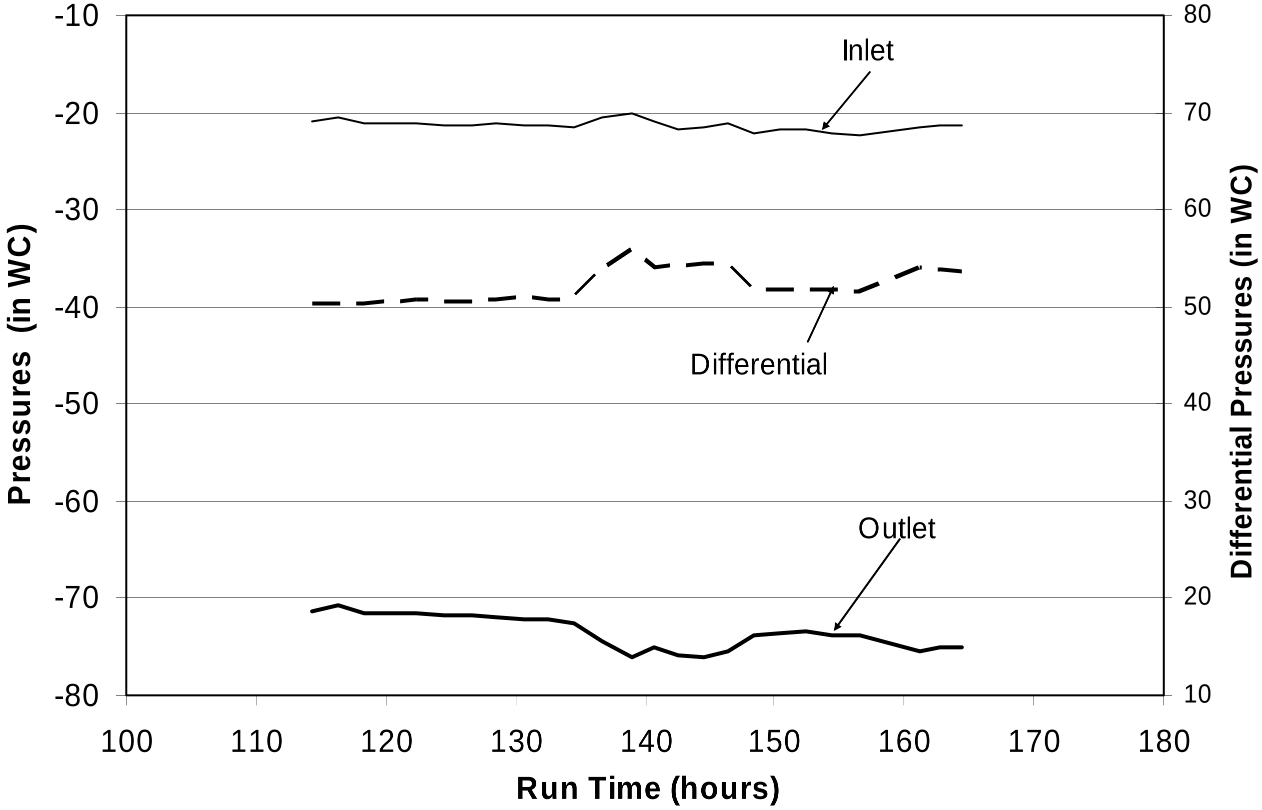

Figure 5.42. Silver mordenite column pressures.

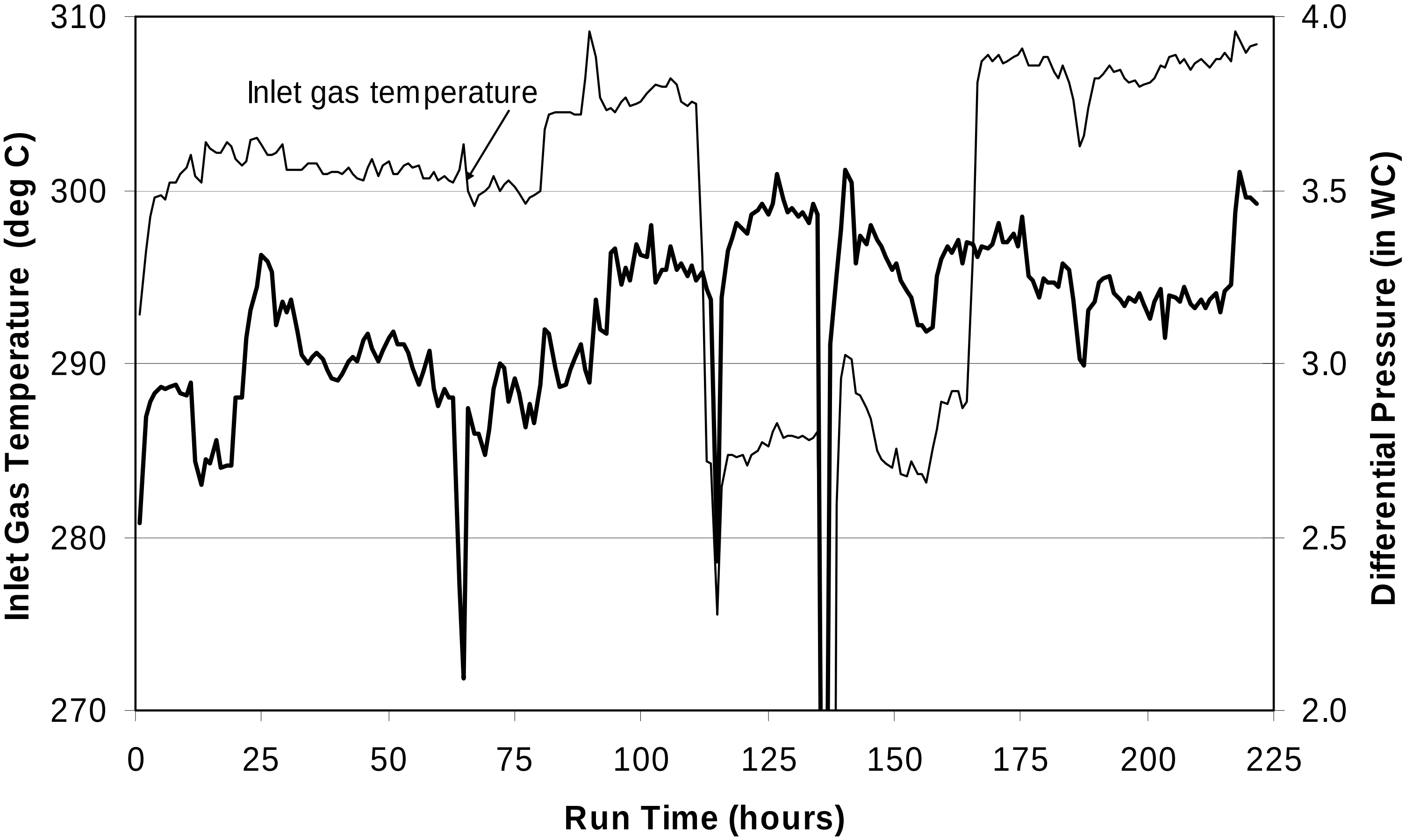

Figure 5.43. Inlet temperature and differential pressure for PBS (hourly average values).

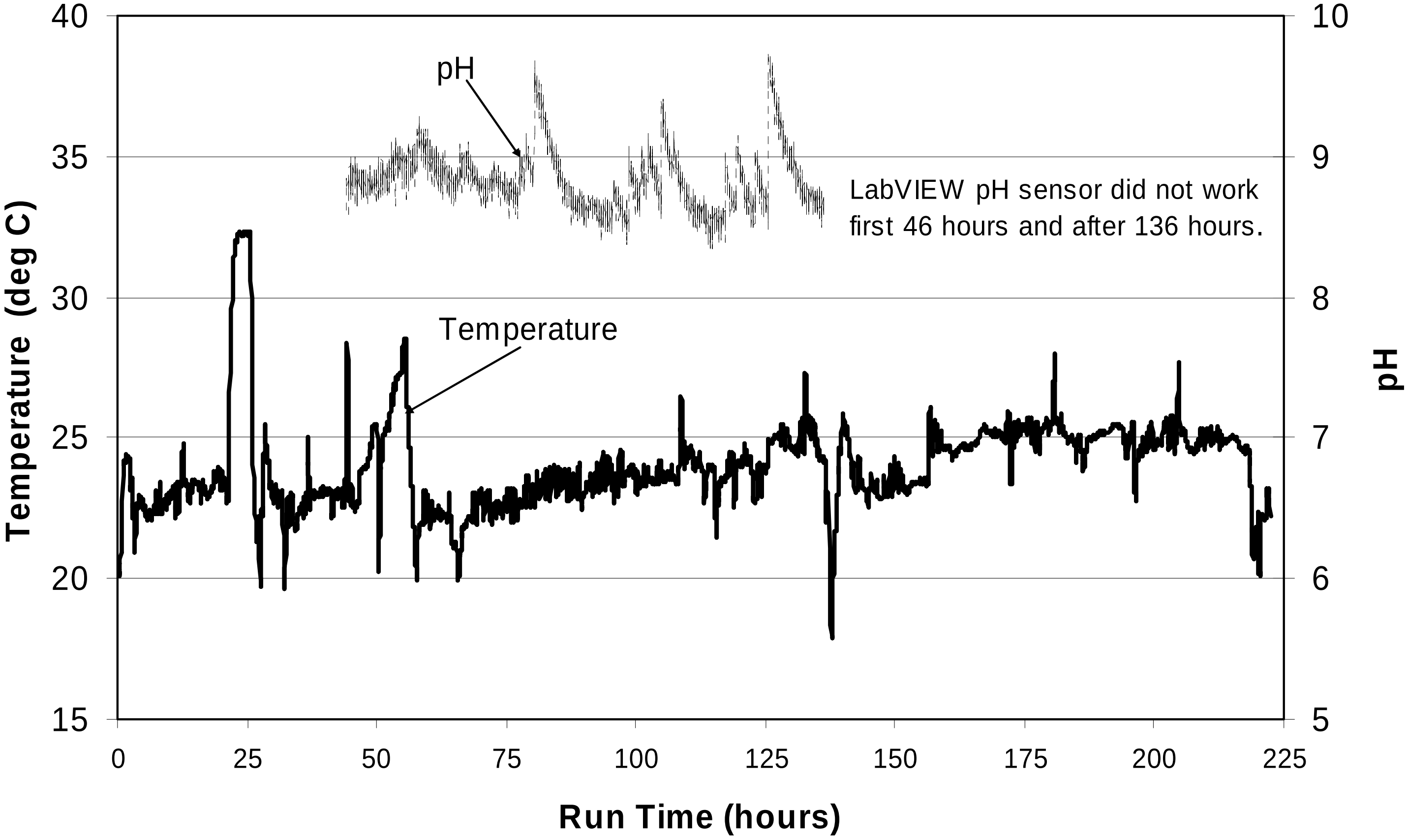

Figure 5.44. Sump temperature and pH for PBS.

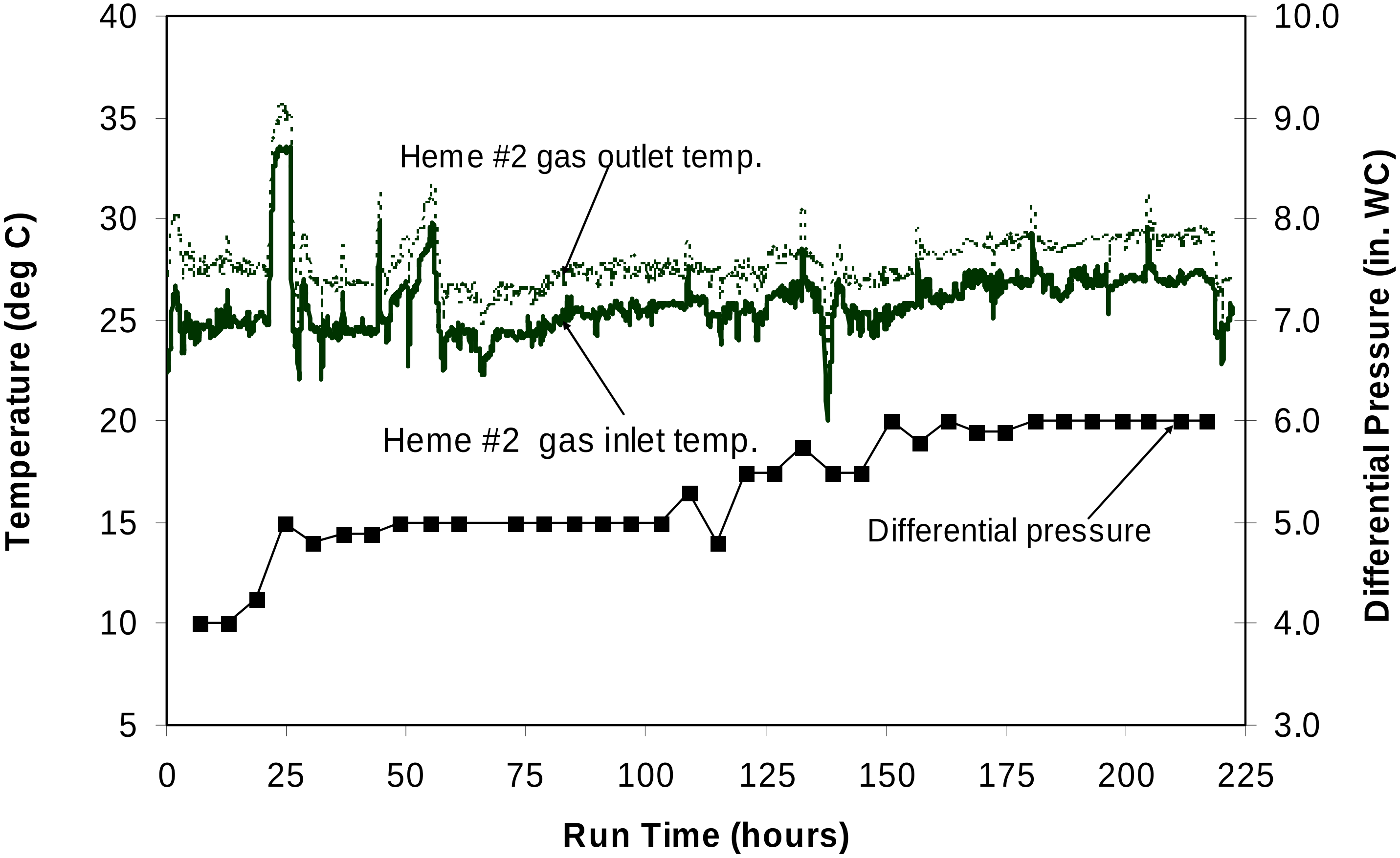

Figure 5.45. Inlet and outlet temperatures and differential pressure for HEME #2.

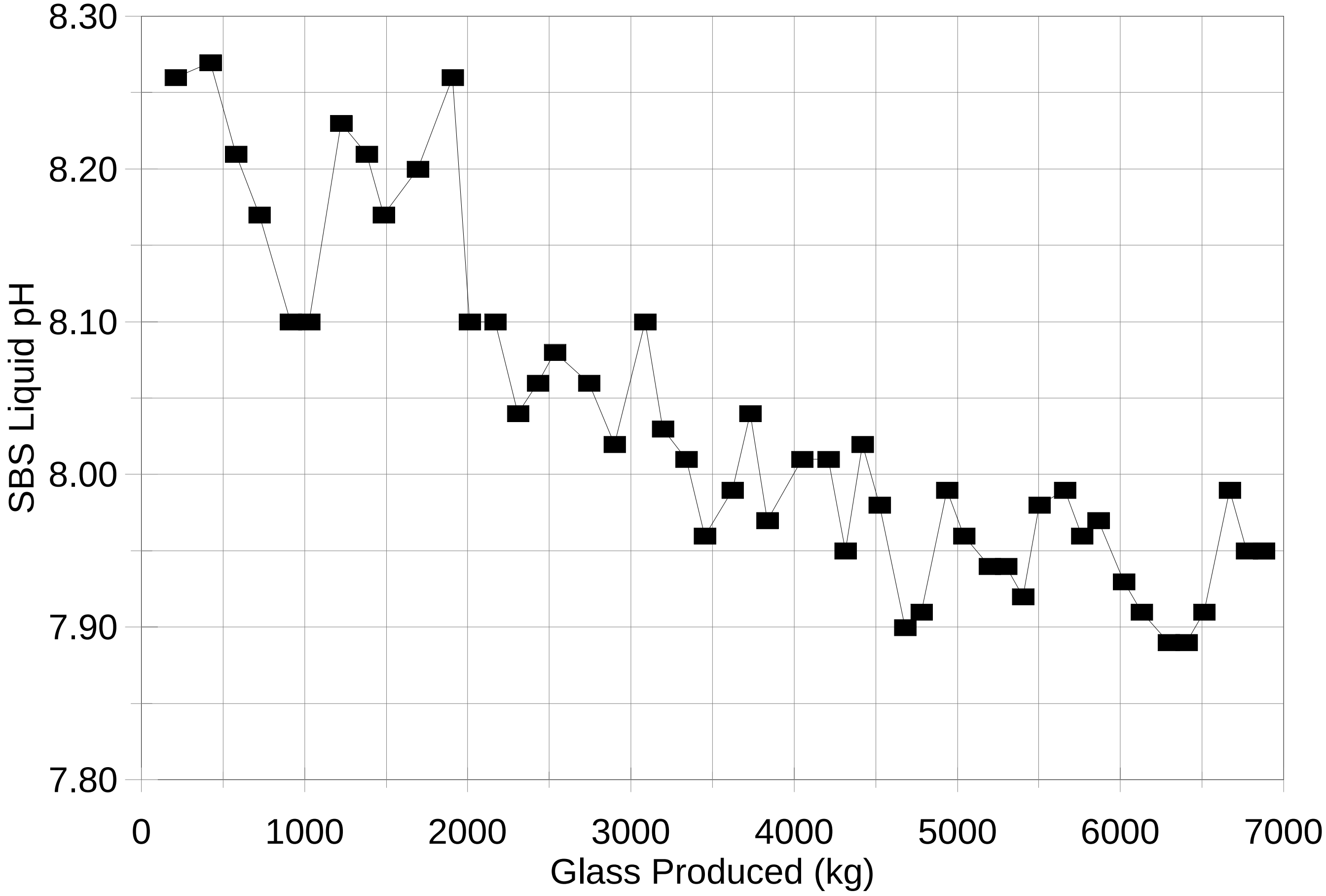

Figure 5.46. pH of SBS blow-down solutions.

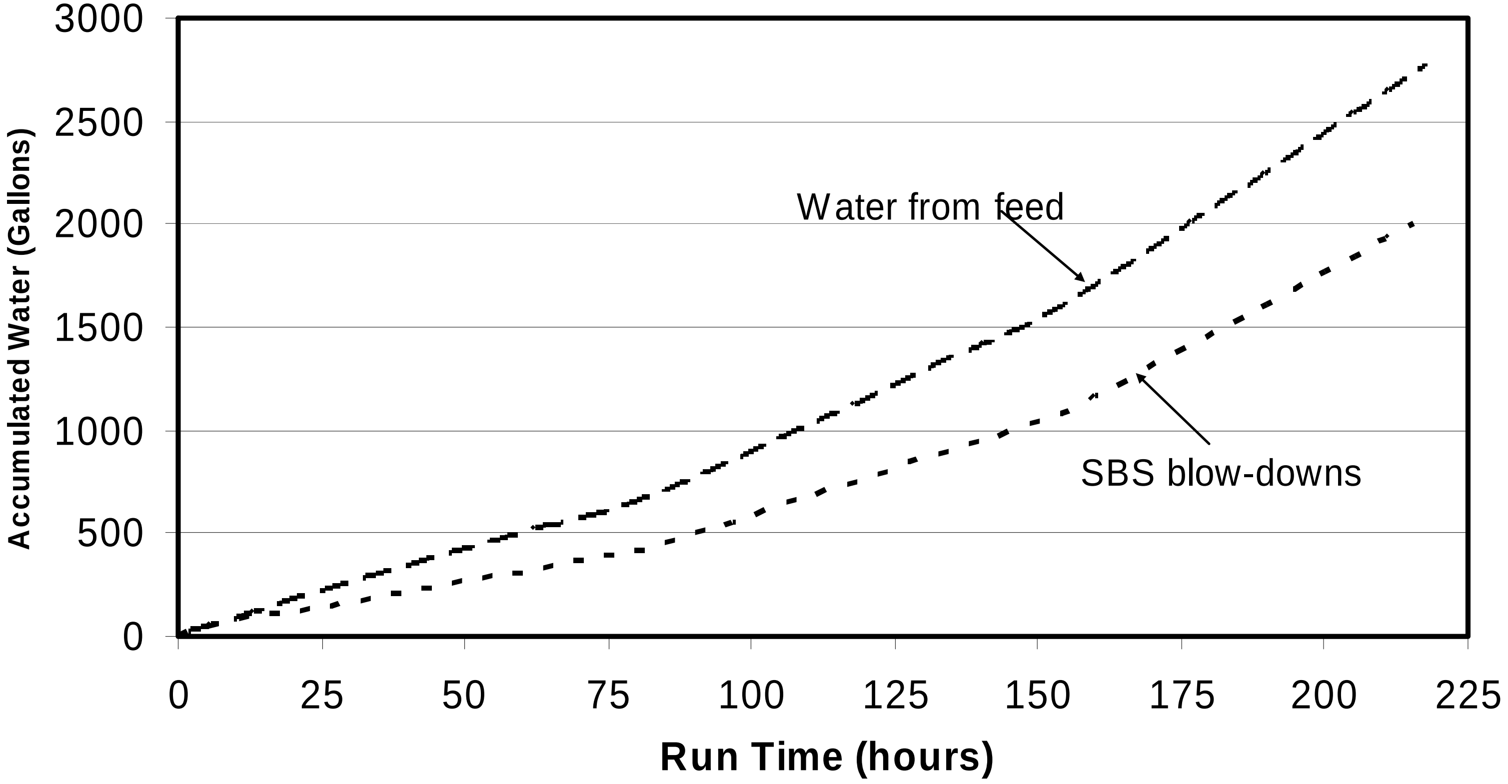

Figure 5.47. Accumulated SBS blow-down volume and average accumulated feed water.

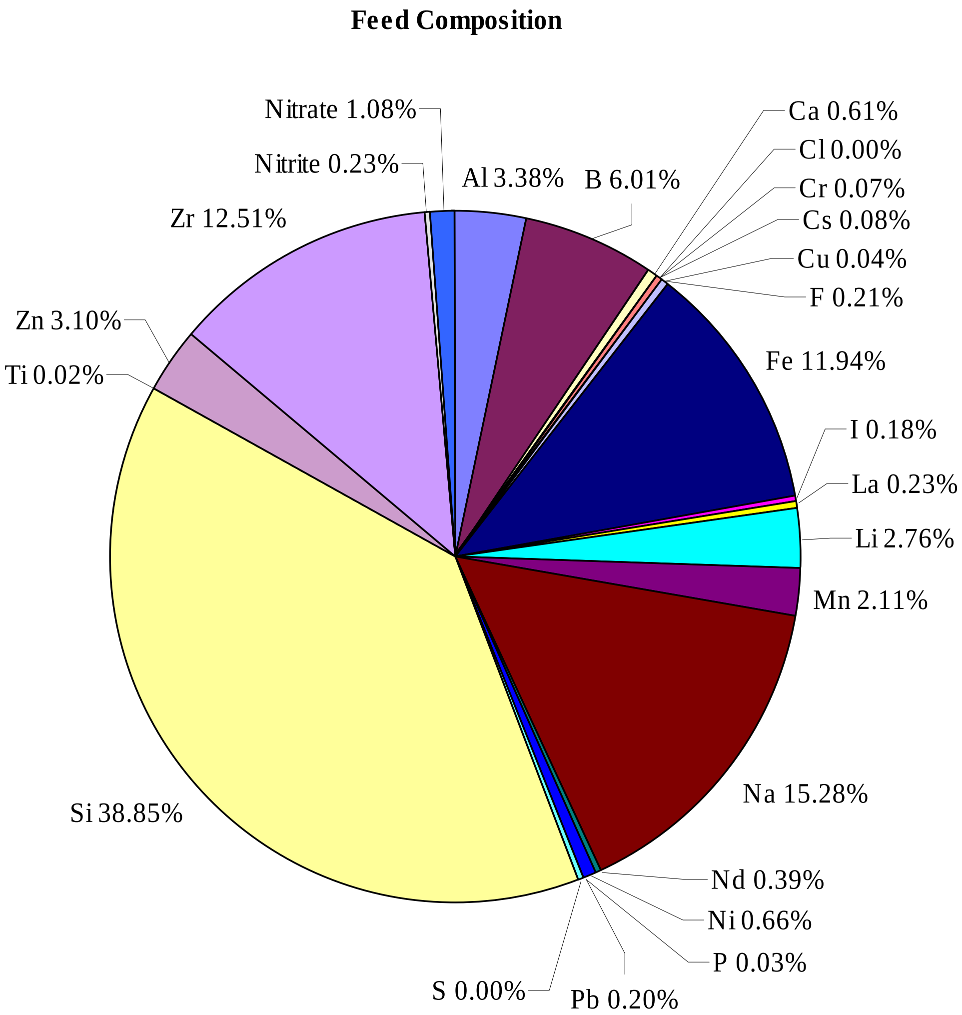

Figure 5.48. Feed composition (excludes oxygen and carbon).

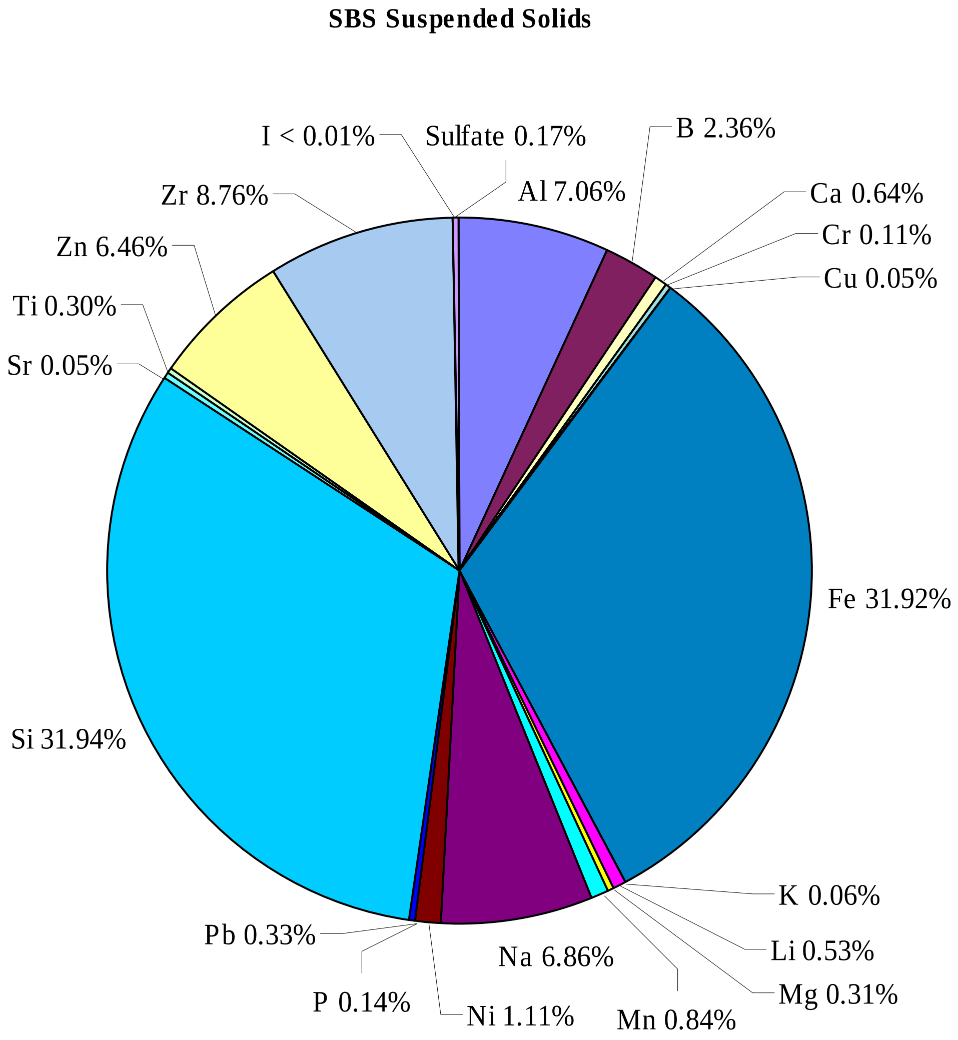

Figure 5.49. Suspended solids composition (excludes oxygen, nitrogen and carbon) from SBS sample (Q12-S-122A).

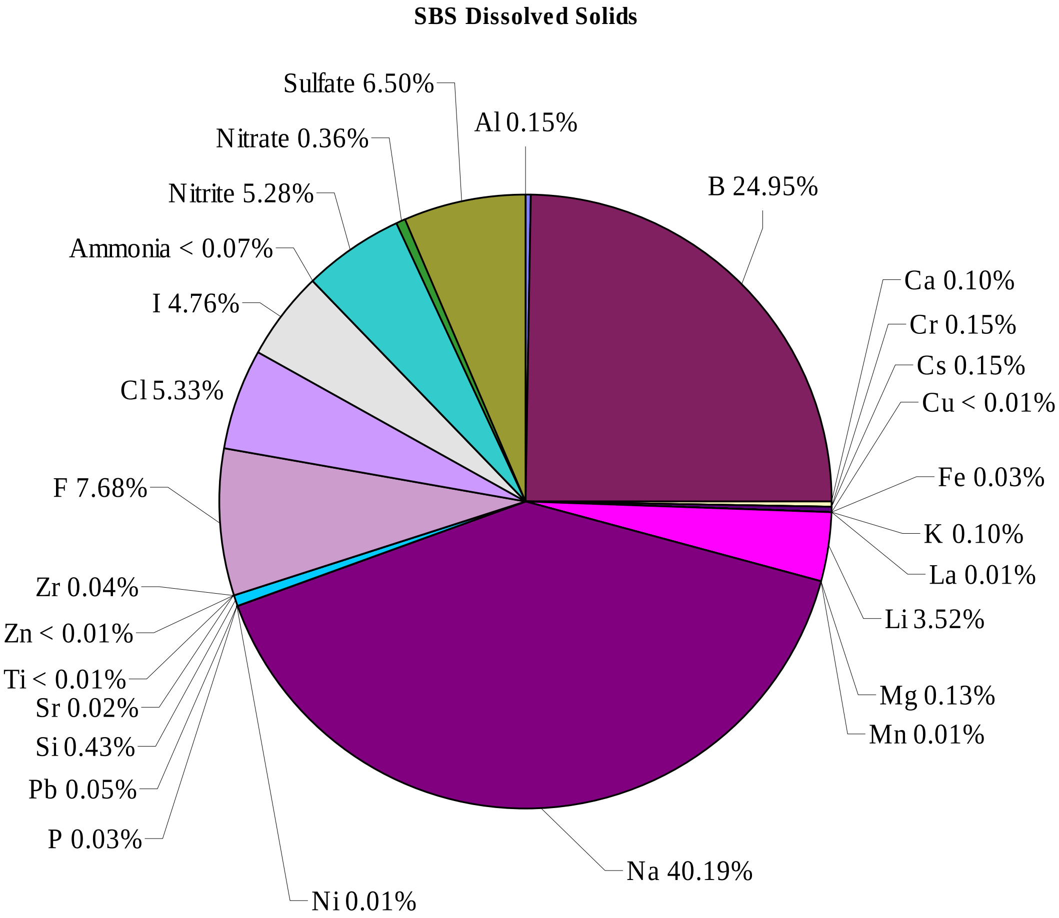

Figure 5.50. Dissolved solids composition from SBS sample (Q12-S-122A).

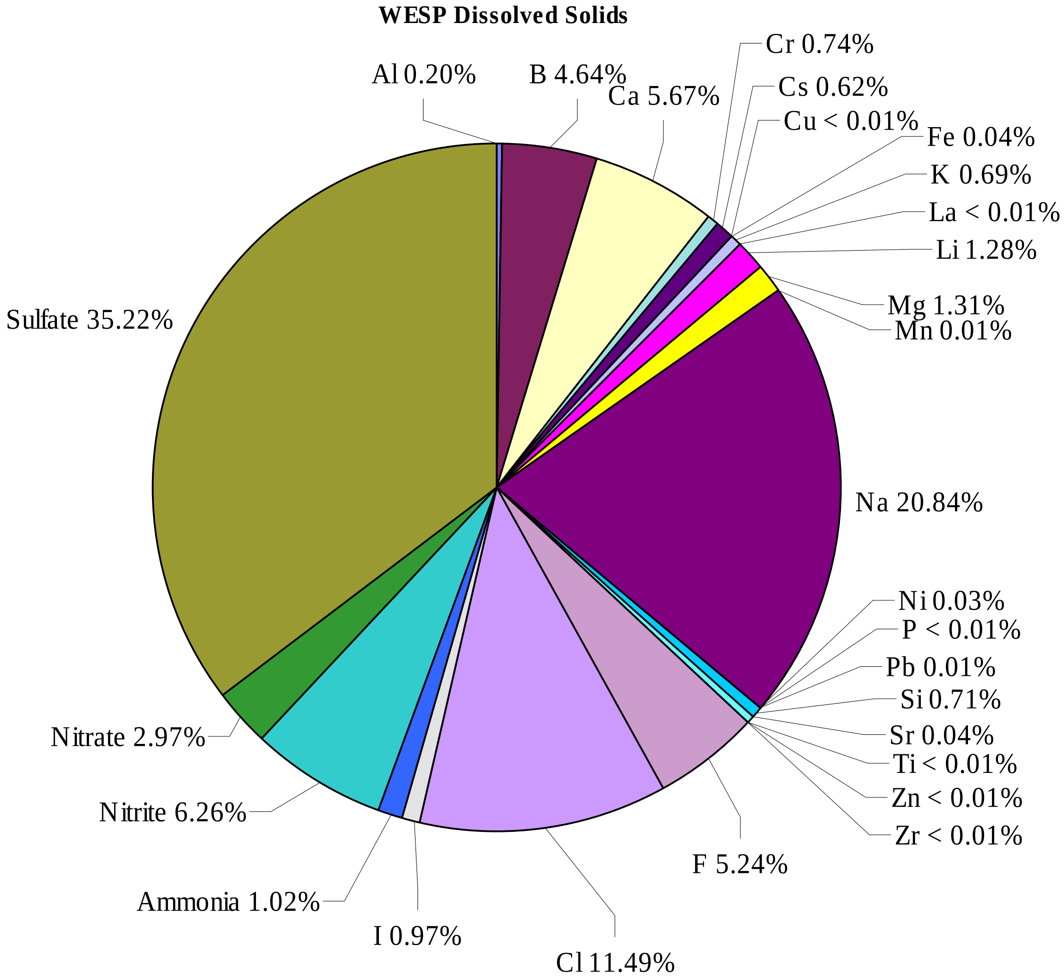

Figure 5.51. Dissolved solids composition from WESP sample (Q12-W-75A).

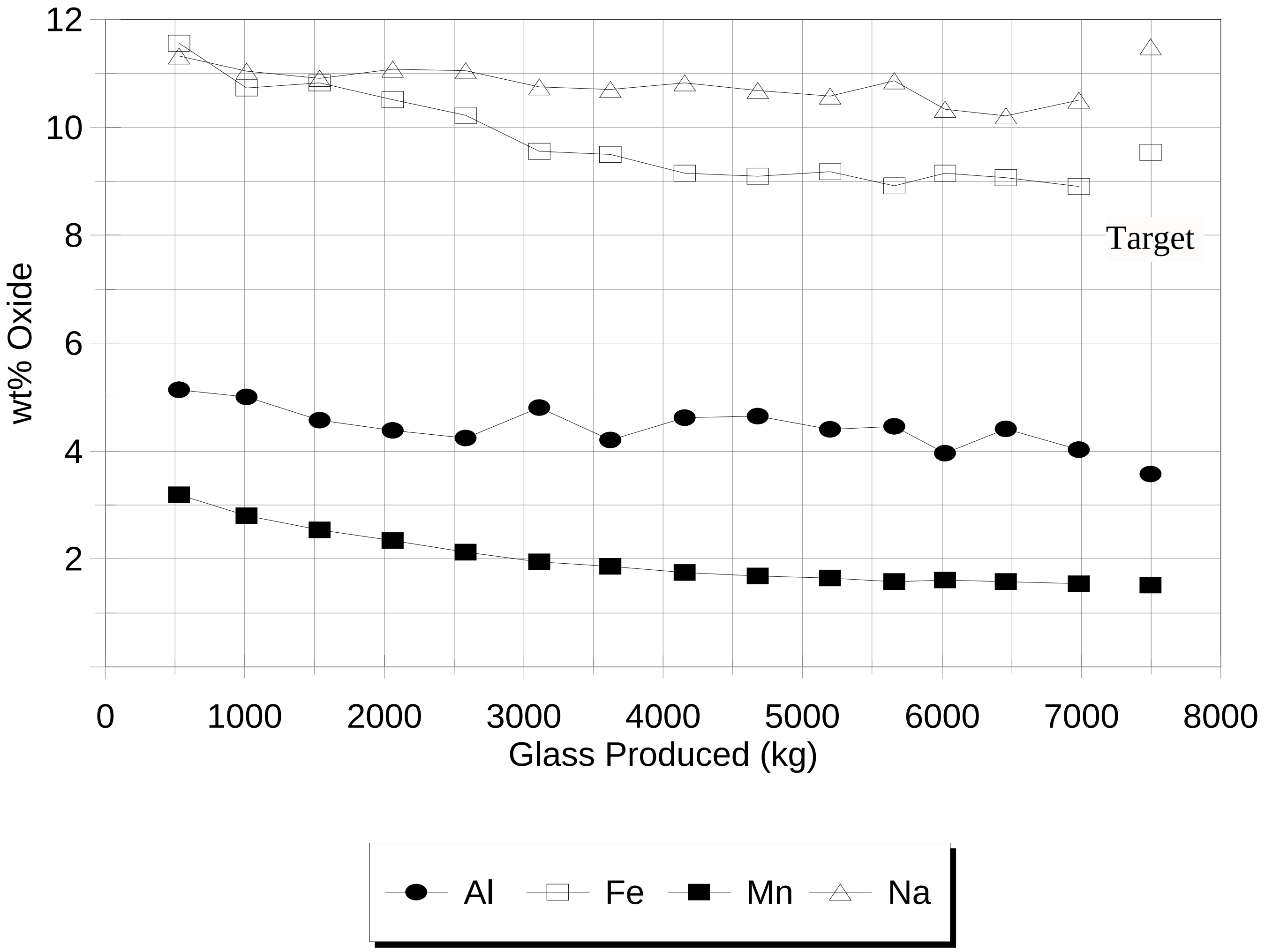

Figure 6.1. XRF analysis of selected DM1200 glasses.

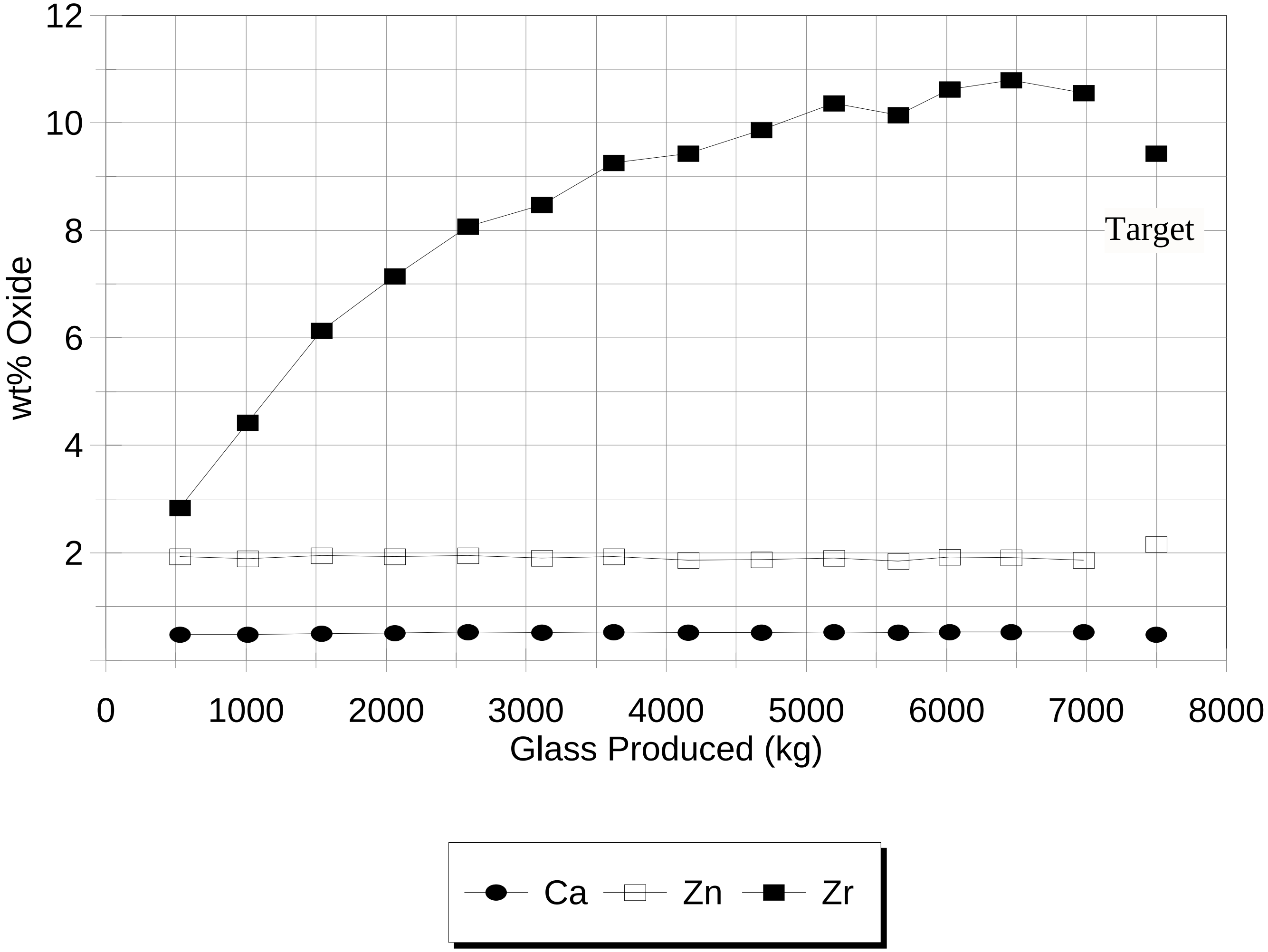

Figure 6.2 XRF analysis of oxides decreasing in concentration during DM1200 test.

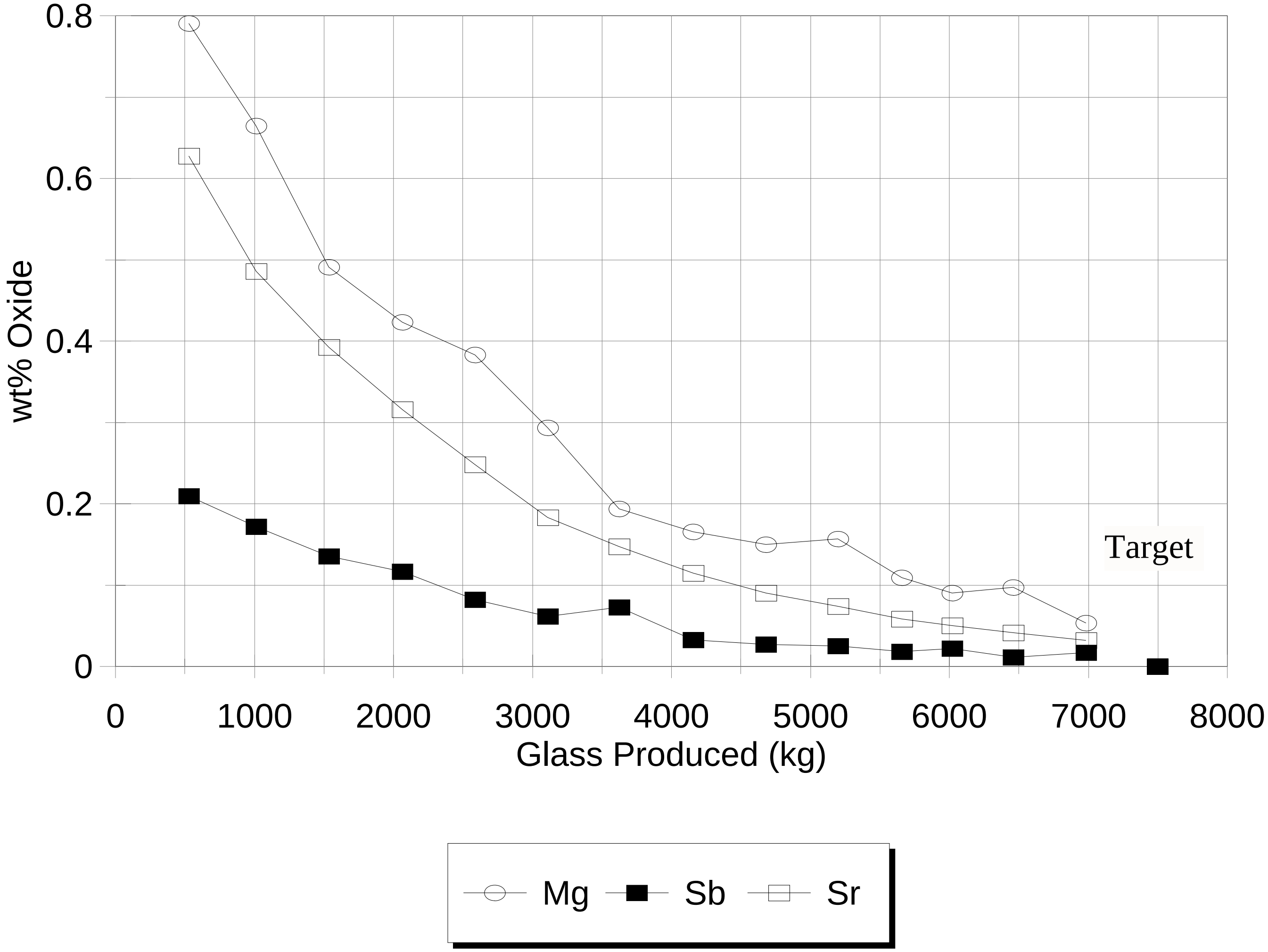

Figure 6.3. XRF analysis of oxides decreasing in concentration during DM1200 test.

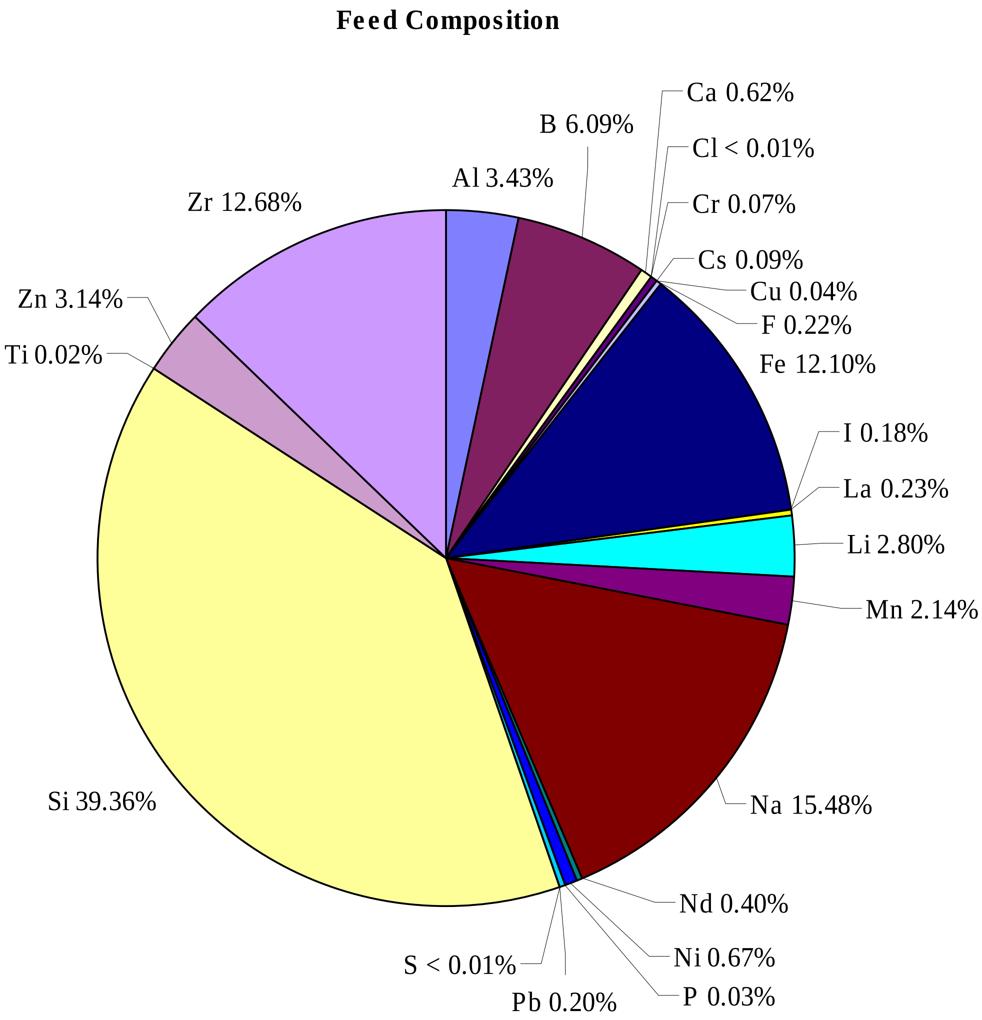

Figure 7.1. Feed composition (excludes oxygen, nitrogen and carbon compounds).

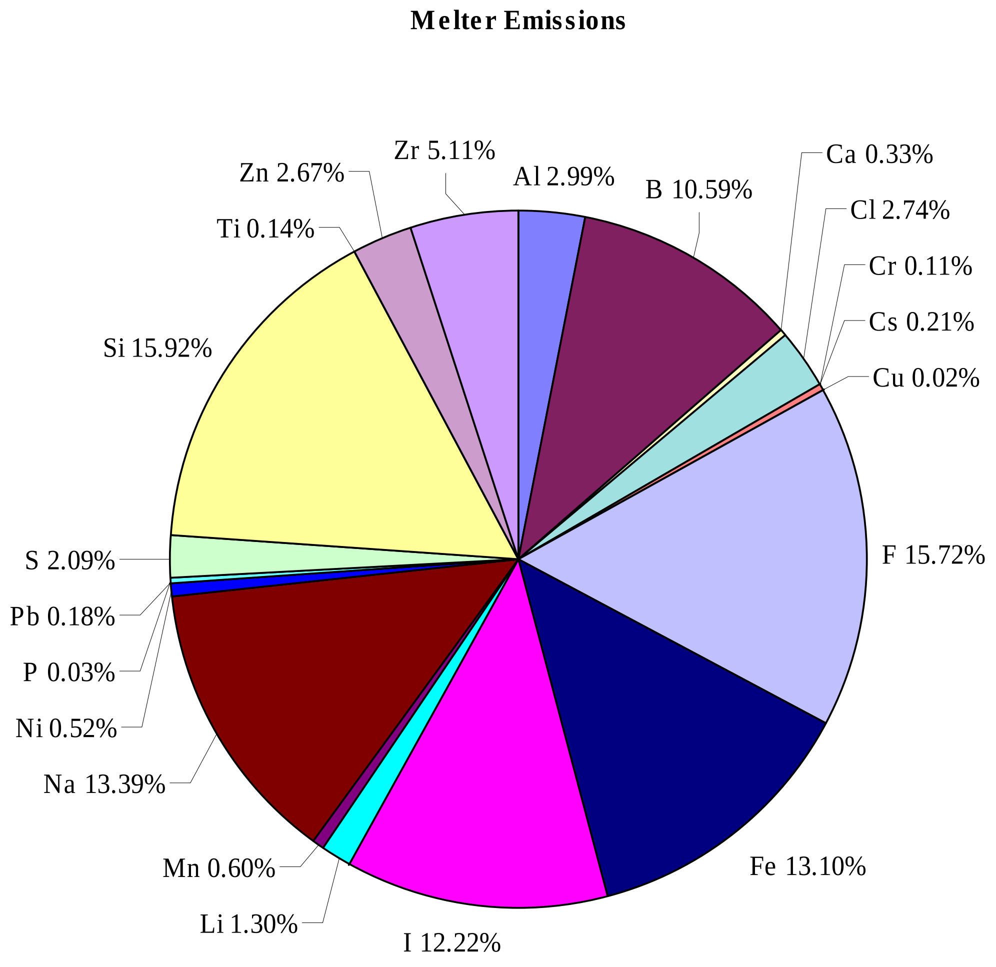

Figure 7.2. Melter exhaust composition (excludes oxygen, nitrogen and carbon compounds) for DM1200 Tests.

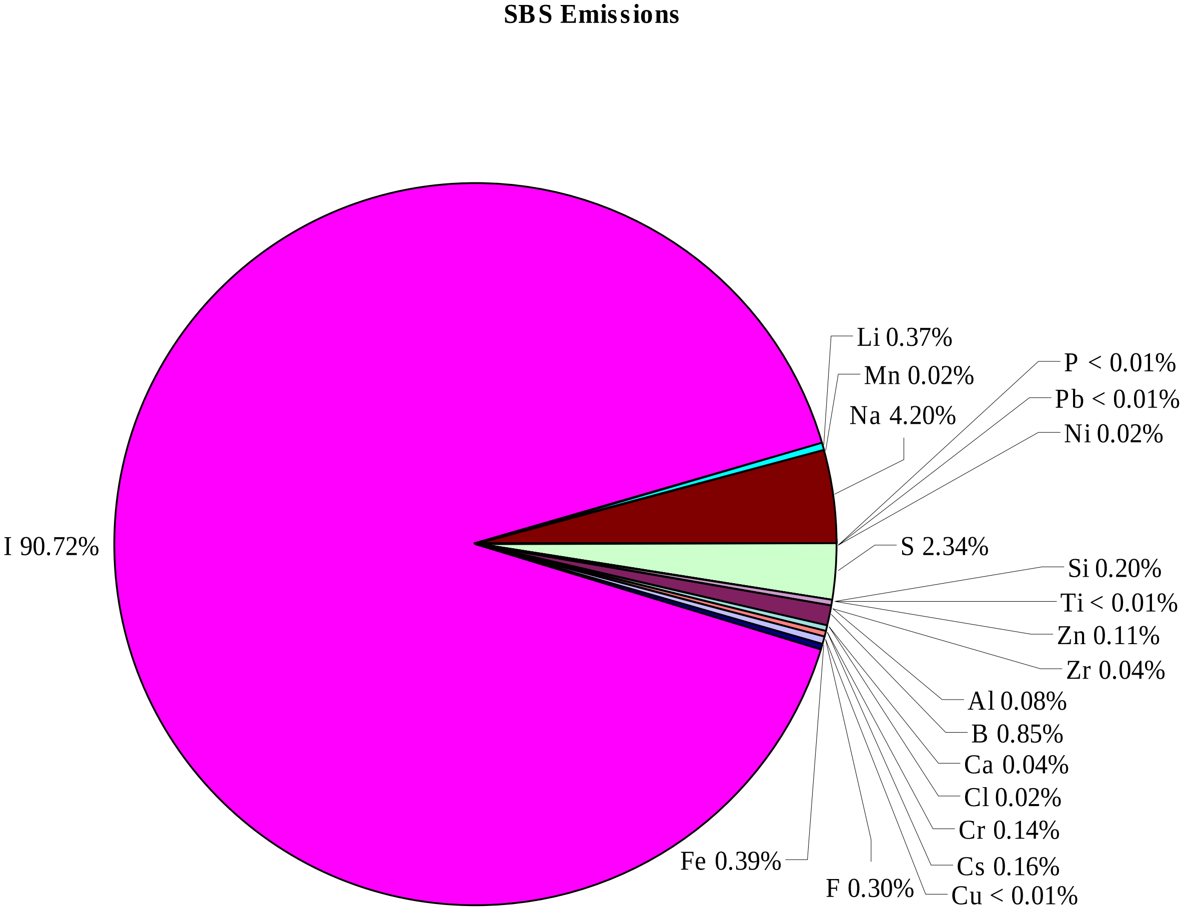

Figure 7.3. SBS exhaust composition (excludes oxygen, nitrogen, and carbon compounds).

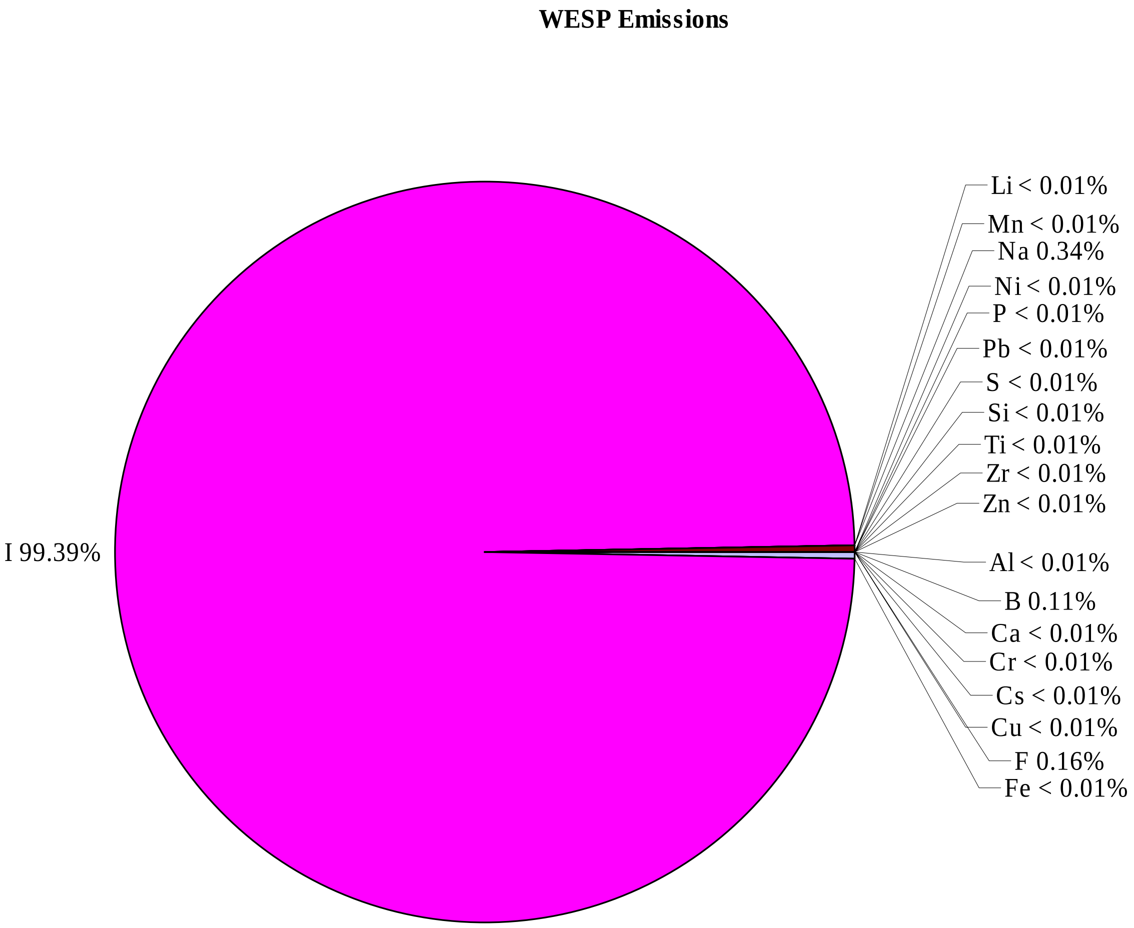

Figure 7.4. WESP exhaust composition (excludes oxygen, nitrogen, and carbon compounds).

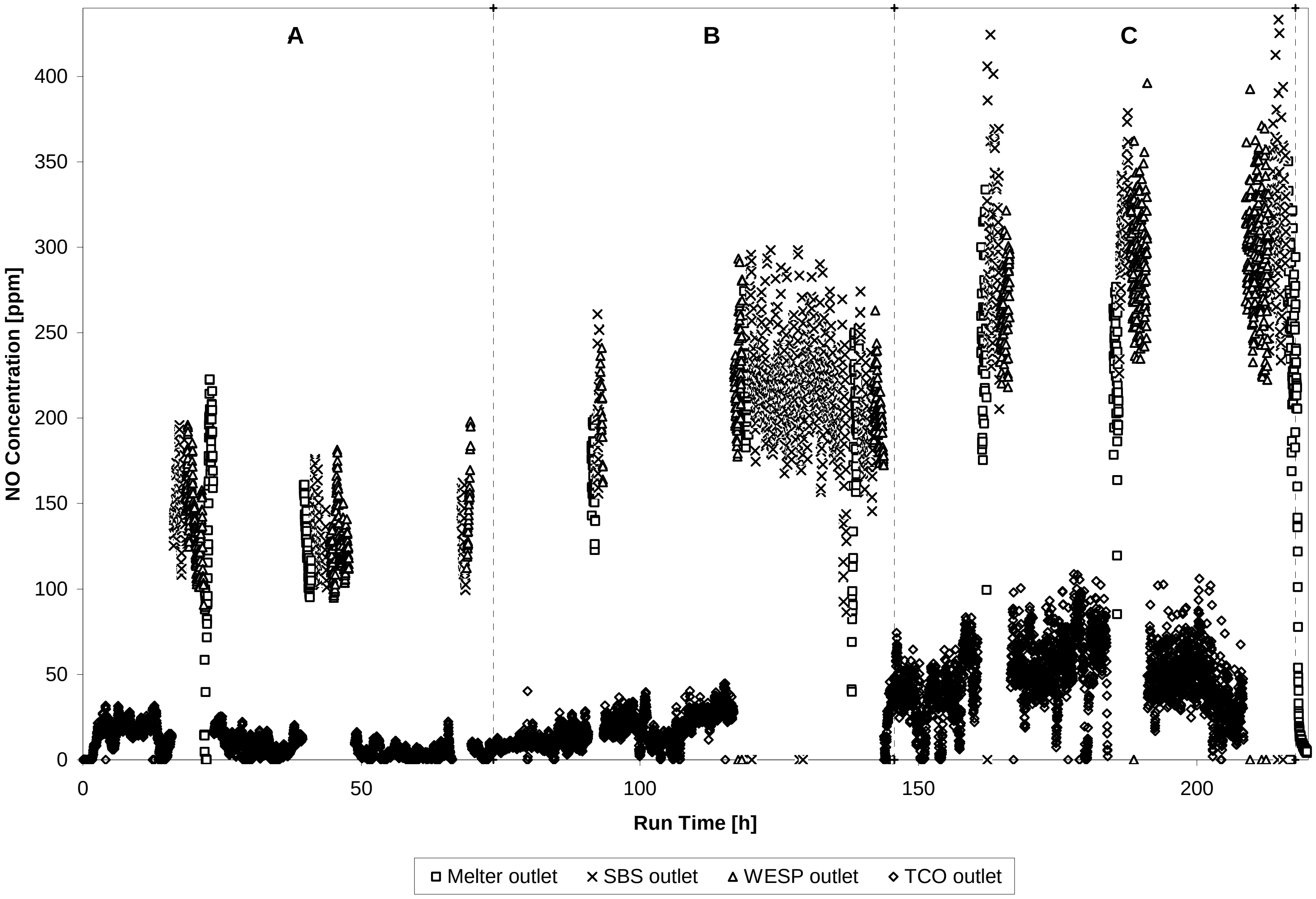

Figure 7.5. Concentration of NO at various points in the off-gas stream. Average values are provided in Table 7.7.

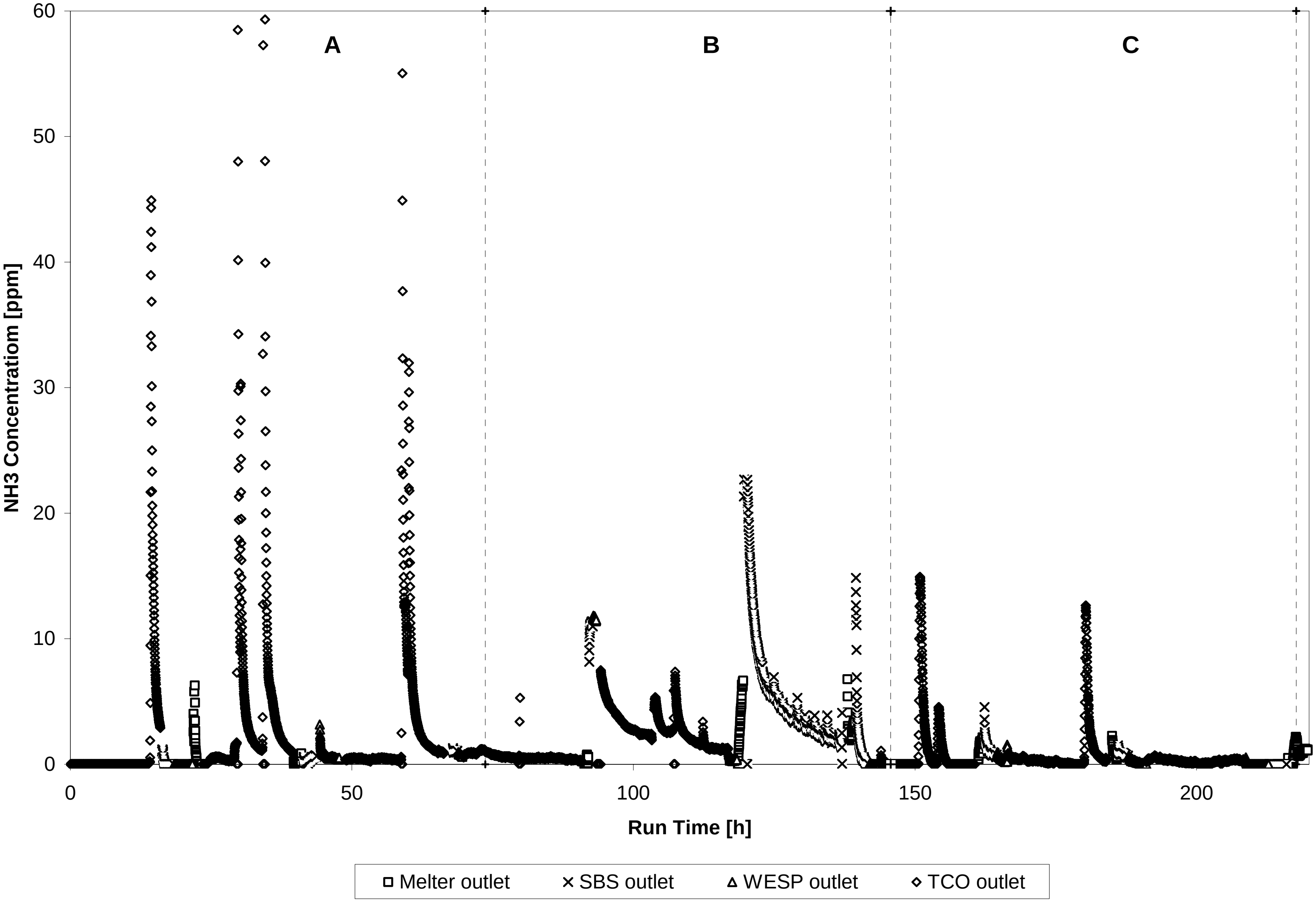

Figure 7.6. Concentration of NH_3 at various points in the off-gas stream. Average values are provided in Table 7.7.

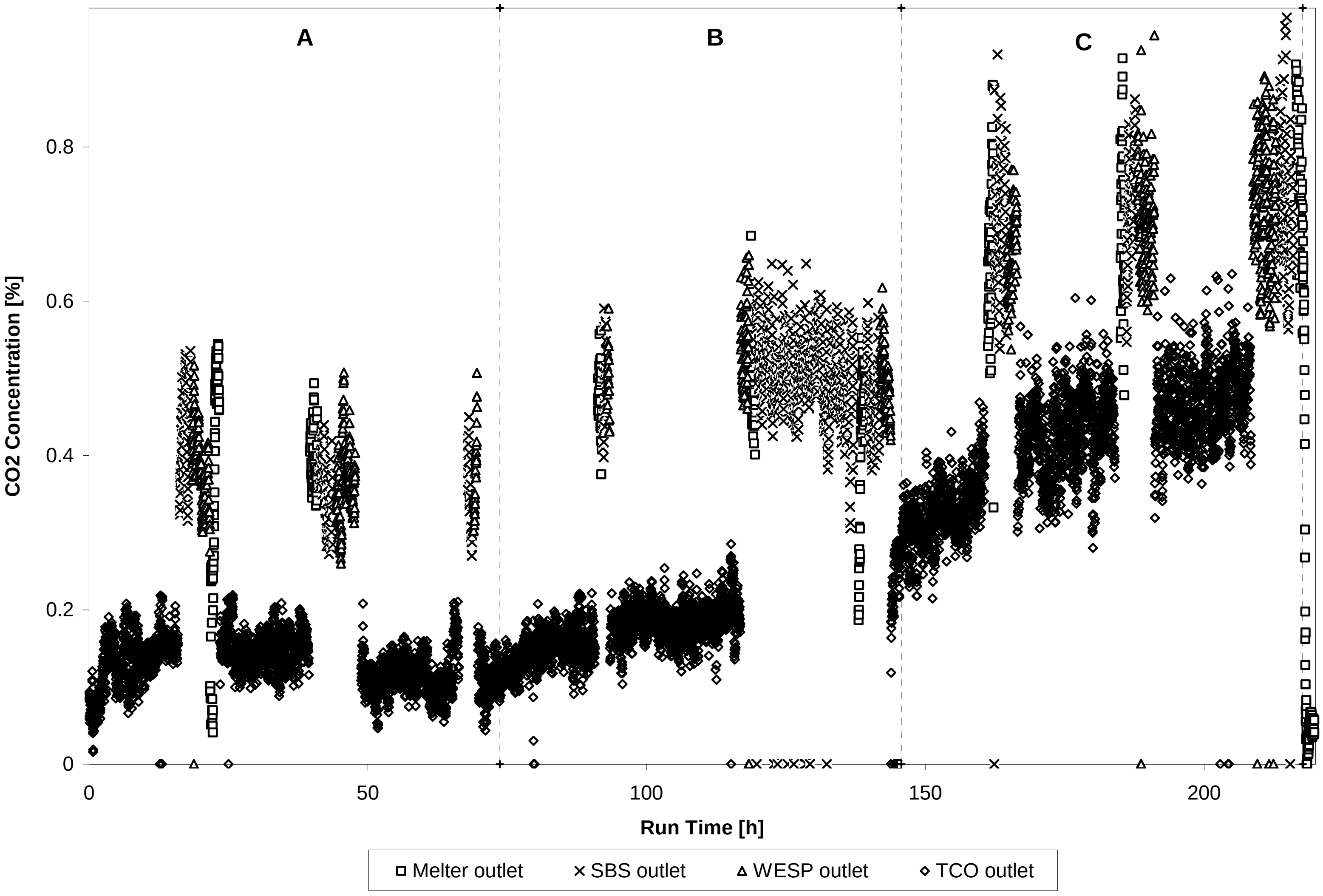

Figure 7.7. Concentration of CO_2 at various points in the off-gas stream. Average values are provided in Table 7.7.

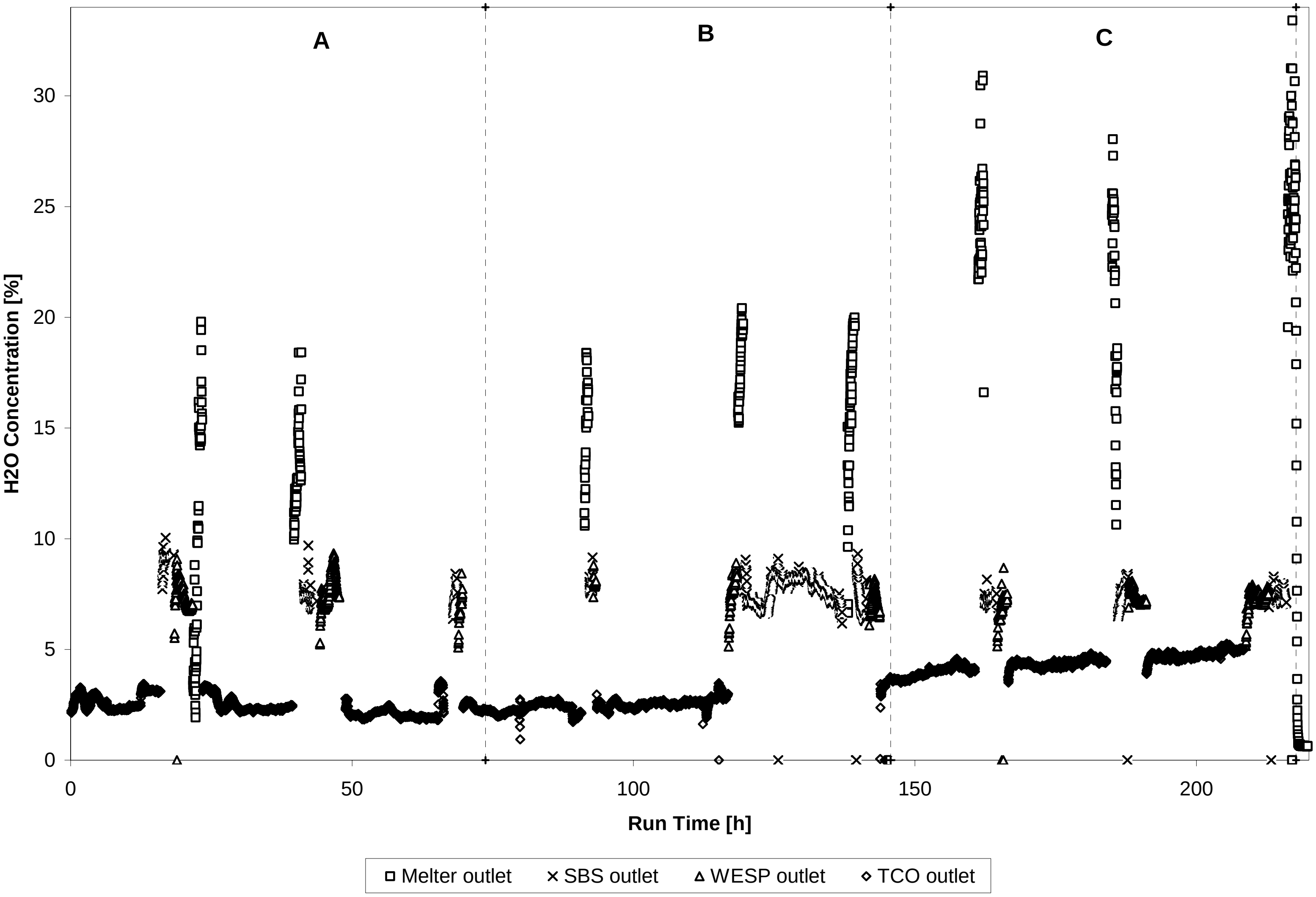

Figure 7.8. Concentration of water at various points in the off-gas stream. Average values are provided in Table 7.7.

R&T Subcontractor Document Review Record

Page 1 of 1

1) To Be Completed by Cognizant R&T Personnel		
Document Number VSL-03R3800-3	Revision A	Document Title DM1200 Tests with C-104/AY-101 HLW Simulants
Test Spec: 24590-HLW-TSP-RT-02-005, Rev 0		Scoping Statement(s): VH-4, VHO-3, VHO-2, VH-5

R&T Contact:

Name (Print)	MSIN	Telephone Number	Date
JM Perez	1-B	371-8444	7/31/03

Review Distribution

Organization	**Contact**	**MSIN**	**Mandatory?**
Process Operations	Ernie Lee	MS-1C	Yes ☒ No ☐
Quality Assurance	S Sunday	MS14-4B	Yes ☐ No ☒
Environmental and Nuclear Safety	E Sauceda	MS6-N1	Yes ☒ No ☐
HLW APM	Phil Schuetz	MS5-L	Yes ☐ No ☒
R&T Vitrification	S Barnes	MS1-B	Yes ☐ No ☒
R&T Vitrification	W Tamosaitis	MS1-B	Yes ☐ No ☒
Subcontracts	L. Scot Jenkins	MS14-3A	Yes ☐ No ☒
HLW Area Engineering	Dilip Patel	MS5-I	Yes ☐ No ☒
Process Engineering	M Hyman	MS4-B2	Yes ☒ No ☐
Operations	K. Vermillion	MS12-2B	Yes ☐ No ☒

Comments Due By: August 14, 2003

Mandatory Reviewers are required to respond to the R&T Contact.

2) To be Completed by Reviewer

Reviewer

Name (Print)	Organization	Date

☐ Accepted, No Comments	☐ Accepted, Comments Not Significant	☐ Significant Comments, Form 24590-MGT-F00006 Attached	☐ Significant Comments, Comments marked on document.

3) To be Completed by Reviewer*

My significant comments have been addressed.

Acceptance:

Print/Type Name	*Signature*	*Date*

* *An E-mail to the R&T contact stating that significant comments are addressed can substitute for this acceptance.*

Perez, Joseph

From: Knauss, Craig — Process Operations
Sent: Wednesday, October 01, 2003 8:06 AM
To: Perez, Joseph
Cc: Gimpel, Rod; Reynolds, Jacob; Lee, Ernest D; Saunders, Scott
Subject: RE: Response to Comments on DM1200 C-104/AY-102 Report

ProcOps Cmnts
/SL03R3800-2_dc-..

Joe,

Attached are my acceptances to your responses for subject review and comment. Jake and Rod will be submitting their acceptance/rejection separately. I will furnish an initialed hard copy ASAP.

Craig

-----Original Message-----
From: Perez, Joseph
Sent: Tuesday, September 30, 2003 5:47 PM
To: Gimpel, Rod; Lee, Ernest D; Knauss, Craig; Reynolds, Jacob
Subject: FW: Response to Comments on DM1200 C-104/AY-102 Report

Please review the submitted responses and reply with whether they are accepted or if additional re-work is necessary.

Jake, I talked to Eugene and we are going to reject their "apparent" viscosity comment and tell them to change the heading.

I need replies by Friday please.

Thanks

Joe Perez
R&T/WTP
Ph.: 509.371.8444
Fax: 509.371.8346

-----Original Message-----
From: ianp@vsl.cua.edu [mailto:ianp@vsl.cua.edu]
Sent: Tuesday, September 30, 2003 5:16 PM
To: Perez, Joseph
Cc: ijoseph@duratekinc.com
Subject: Response to Comments on DM1200 C-104/AY-102 Report

Joe:

Please find comment responses attached.

Regards,

Ian.

Perez, Joseph

From: Reynolds, Jacob - Process Operations
Sent: Monday, November 10, 2003 7:11 AM
To: Perez, Joseph
Subject: RE: Revised Comment Responses on DM1200 C-104 Report

I have reviewed and concur with teh comment response.

Jacob Reynolds
Process Operations

-----Original Message-----
From: Perez, Joseph
Sent: Sunday, November 09, 2003 3:32 PM
To: Reynolds, Jacob; Lee, Ernest D; Valenti, Thomas
Cc: Innocent Joseph (E-mail); Ian Pegg (E-mail); Dick Callow (E-mail)
Subject: FW: Revised Comment Responses on DM1200 C-104 Report

Jake and Tom please review the revised comments in which you disagreed with the first reply.

Ian, I assume all or the bulk of the response text in #12 and #13 of the Process Engineering responses would be added to the report?

The R&T responses are acceptable with the condition the air injection control parameters defined in comment #11 are placed in the report.

Jake and Tom please reply with your response to all the addressees since I will be out of town on travel 11/10 - 11/15

Please replay as soon as possible - a day or two please

Thanks

Joe Perez
R&T/WTP
Ph.: 509.371.8444
Fax: 509.371.8346

-----Original Message-----
From: ianp@vsl.cua.edu [mailto:ianp@vsl.cua.edu]
Sent: Friday, November 07, 2003 9:29 AM
To: Perez, Joseph
Cc: ijoseph@duratekinc.com; dcallow@duratekinc.com
Subject: Revised Comment Responses on DM1200 C-104 Report

Joe:

The revised responses are attached. Let us know if you need the track-changes version of the document.

Regards,

Ian.

R&T Subcontractor Document Review Record

RECEIVED
JUL 31 2003
By 3365

CRD-70890, Rev 0

Page 1 of 1

1) To Be Completed by Cognizant R&T Personnel		
Document Number VSL-03R3800-3	Revision A	Document Title DM1200 Tests with C-104/AY-101 HLW Simulants
Test Spec: 24590-HLW-TSP-RT-02-005, Rev 0		Scoping Statement(s): VH-4, VHO-3, VHO-2, VH-5

R&T Contact: JM Perez (Name (Print)) 1-B (MSIN) 371-8444 (Telephone Number) 7/31/03 (Date)

Review Distribution

Organization	**Contact**	**MSIN**	**Mandatory?**
Process Operations	Ernie Lee	MS-1C	Yes ☒ No ☐
Quality Assurance	S Sunday	MS14-4B	Yes ☐ No ☒
Environmental and Nuclear Safety	E Sauceda	MS6-N1	Yes ☒ No ☐
HLW APM	Phil Schuetz	MS5-L	Yes ☐ No ☒
R&T Vitrification	S Barnes	MS1-B	Yes ☐ No ☒
R&T Vitrification	W Tamosaitis	MS1-B	Yes ☐ No ☒
Subcontracts	L. Scot Jenkins	MS14-3A	Yes ☐ No ☒
HLW Area Engineering	Dilip Patel	MS5-I	Yes ☐ No ☒
Process Engineering	M Hyman	MS4-B2	Yes ☒ No ☐
Operations	K. Vermillion	MS12-2B	Yes ☐ No ☒

Comments Due By: August 14, 2003

Mandatory Reviewers are required to respond to the R&T Contact.

2) To be Completed by Reviewer

Reviewer E. Sauceda (Name (Print)) E+NS (Organization) 8/19/03 (Date)

☒ Accepted, No Comments	☐ Accepted, Comments Not Significant	☐ Significant Comments, Form 24590-MGT-F00006 Attached	☐ Significant Comments, Comments marked on document.

3) To be Completed by Reviewer*

My significant comments have been addressed.

Acceptance: ______ *Print/Type Name* ______ *Signature* ______ *Date*

* *An E-mail to the R&T contact stating that significant comments are addressed can substitute for this acceptance.*

Perez, Joseph

From:	Valenti, Thomas
Sent:	Monday, November 10, 2003 6:52 AM
To:	Perez, Joseph; Reynolds, Jacob; Lee, Ernest D
Cc:	Innocent Joseph (E-mail); Ian Pegg (E-mail); Dick Callow (E-mail)
Subject:	RE: Revised Comment Responses on DM1200 C-104 Report

I have reviewed and concur with the comment responses.

Thomas J Valenti Process Engineering
371-3838
MPF B204

-----Original Message-----
From: Perez, Joseph
Sent: Sunday, November 09, 2003 3:32 PM
To: Reynolds, Jacob; Lee, Ernest D; Valenti, Thomas
Cc: Innocent Joseph (E-mail); Ian Pegg (E-mail); Dick Callow (E-mail)
Subject: FW: Revised Comment Responses on DM1200 C-104 Report

<< File: R&T cmnts report VSL03R3800-2_respond2.doc >> << File: ProcOps Cmnts VSL03R3800-2_respond2.doc >> << File: ProcEng TValenti Cmnts VSL03R3800-2_dc-a-tjv_respond2.doc >> Jake and Tom please review the revised comments in which you disagreed with the first reply.

Ian, I assume all or the bulk of the response text in #12 and #13 of the Process Engineering responses would be added to the report?

The R&T responses are acceptable with the condition the air injection control parameters defined in comment #11 are placed in the report.

Jake and Tom please reply with your response to all the addressees since I will be out of town on travel 11/10 - 11/15

Please replay as soon as possible - a day or two please

Thanks

Joe Perez
R&T/WTP
Ph.: 509.371.8444
Fax: 509.371.8346

-----Original Message-----
From: ianp@vsl.cua.edu [mailto:ianp@vsl.cua.edu]
Sent: Friday, November 07, 2003 9:29 AM
To: Perez, Joseph
Cc: ijoseph@duratekinc.com; dcallow@duratekinc.com
Subject: Revised Comment Responses on DM1200 C-104 Report

Joe:

The revised responses are attached. Let us know if you need the track-changes version of the document.

Regards,

Ian.

Perez, Joseph

From: Carl, Daniel (Process Engineering)
Sent: Wednesday, October 01, 2003 6:21 AM
To: Perez, Joseph
Subject: FW: Response to Comments on DM1200 C-104/AY-102 Report

DCarl cmnts report VSL03R3800-...

Joe,

Comment #3 was intended to garner information useful for remote operations. The response seems to agree that there was a decrease in bulk density with bubbling, without addressing my question about using instruments to detect that the reduced density was not related to onset of foaming. The other responses are acceptable.

Dan

-----Original Message-----
From: Perez, Joseph
Sent: Tuesday, September 30, 2003 5:31 PM
To: Carl, Daniel
Subject: FW: Response to Comments on DM1200 C-104/AY-102 Report

Dan, please review responses and reply if acceptable or which ones need re-work.

It is not clear that where you said "comment on.." that VSL committed to revise the text. If you feel the responses deserve to be incorporate in the report or recorded in the comment form (which accompanies the final report into the PDC electronic file) please speak up.

I'ld like feedback by Friday if possible.

Thanks

Joe Perez
R&T/WTP
Ph.: 509.371.8444
Fax: 509.371.8346

Research and Technology Completion Form

R&T Scoping Statement(s):	VH-4, VH-5, VHO-3
Test Specification Number/Title:	24590-HLW-TSP-RT-02-005, Rev 0; Integrated DM1200 Testing of HLW Compositions Using Bubblers, Rev.0
Test Plan Number/Title:	VSL-02T8000-4; Integrated DM1200 Melter Testing of HLW C-106/AY-102 and C-104/AY-101 Compositions Using Bubblers, Rev. 0
Test Report Number/Title:	VSL-03R3800-3; DM1200 Tests with C-104/AY-101 HLW Simulants, Rev. 0

Prepared by: J. M. Perez **Date:** 11/25/03

List Test Objectives:	**State how objectives were met:**
1. Perform analyses, laboratory and small- melter testing, as required, to assess and specify working glass compositions, glass forming chemicals, and additives utilizing the estimated C-104/AY-101 feed composition in this specification.	Glass testing and selection of the glass for DM1200 teseting is detailed in, "Glass Formulation to Support Melter Runs with HLW Simulants," VSL-03R3760-2. Section 2 presents the simulant and glass laboratory testing performed to develop the test compositions. Waste loadings of C-104/AY-102 glasses were found to be limited primarily by the liquidus temperatures of Th- and Zr- containing phases. The reference glass selected for these melter tests is HLW98-96, the composition of which is also found in Table 2.2. The glass HLW98-96 has a total waste loading of 34.75 wt%, all but 0.1 wt% of which is from Env. D waste. The glass complies with the contract minimum component requirement by loading > 4.0 wt% of ThO_2, instead of the > 12.5 wt% of Fe_2O_3 in the C-106/AY-102 case. Since 21.17 wt% of (Al_2O_3+Fe_2O_3+ZrO_2) in HLW98-96 originated from Envelope D waste, the glass also meets the minimum component requirement similar to the AZ-101 and AZ-102 test glasses. Heat treating HLW98-96 at 950°C for 70+ hours results in < 0.2 vol% of crystalline phases that include ZrO_2, $ZrSiO_4$, ThO_2, and spinel. The measured viscosity and electrical conductivity of HLW98-96 at 1150 °C are 57 P and 0.28 S/cm, respectively. The normalized 7-day leach rates of HLW98-96 are (in g/(m 2 -day)) 0.035, 0.042, 0.029 and 0.018, respectively, for B, Li, Na and Si, compared with the corresponding values of 1.27, 0.64, 0.84 and 0.27 for the reference glass (DWPF-EA). For pilot-scale melter testing, it was necessary to select replacements for thorium and uranium. Testing of rare earth and hafnium surrogates ruled out their use because they resulted in much greater crystallization. Therefore, simple renormalization of the waste composition without U and Th was determined to be the best alternative (see section 2.2). DM100 testing preceeded DM1200 testing to verify processing characteristics. These results are discussed in Section 3.

Research and Technology Completion Form

R&T Scoping Statement(s):	VH-4, VH-5, VHO-3
Test Specification Number/Title:	24590-HLW-TSP-RT-02-005, Rev 0; Integrated DM1200 Testing of HLW Compositions Using Bubblers, Rev.0
Test Plan Number/Title:	VSL-02T8000-4; Integrated DM1200 Melter Testing of HLW C-106/AY-102 and C-104/AY-101 Compositions Using Bubblers, Rev. 0
Test Report Number/Title:	VSL-03R3800-3; DM1200 Tests with C-104/AY-101 HLW Simulants, Rev. 0

List Test Objectives:	**State how objectives were met:**
2. Utilizing the DM1200 melter and associated feed handling and off-gas treatment equipment, design and conduct testing in which representative C-104/AY-101 simulant is processed. The duration of tests shall be sufficient to achieve at least four melter glass inventory turnovers (~8 MT) for each composition.	Melter tests were conducted on the DM1200 with the HLW C-104/AY-101 simulant between 2/19/03 and 2/28/03, producing almost 7000 kg of glass. Table 4.1 provides glass production rate data and summary data for melter testing. The production rates attained were sufficient to produce only 7 MT as opposed to ~8 MT. This resulted in 3.5 to 4 tank turnovers. A comparison of the feed and glass compositions indicate that the composition had essentially reached the C-104/AY101 target compositions after five to six days of operation. This is judged to be acceptable.
3. Determine the effect of bubbling rate on melter production rate and operating stability for C-104/AY-101 melter feed.	The test consisted of three 3-day segments of successively higher bubbling rates of 8, 40, and 65 lpm, respectively. The measured glass production rate is depicted in Figure 4.1 as cumulative and one- hour moving averages for each of the three segments. The three steady-state production rates (400, 660, and 900 kg/m^2/day) were obtained for at least half of each three-day segment and almost the entirety of the first segment. Minor foaming occurred on the surface of the glass during the first test segment but diminished as bubbling increased over the course of the test. (R&T – this is believed due to reduction of MnO_2 to MnO as the cold cap material melts)
4. Fabricate, install and evaluate the performance of the HLW bubbler design and placement recommended by the Duratek design staff.	Two prototypic bubblers were installed and evaluated. They were placed in the DM1200 in opposing corners. The depth of the bubblers was also prototypic, placed near the bottom of the side electrodes (19 in. below the glass surface of the DM1200 floor versus 35 in. in the WTP HLW melter), sufficiently away from the walls to prevent wall affects. Assessment of bubbler air versus throughput was determined. Periodic measurements of bubbler dimensions and inspection are conducted to determine if the two month service life will be met.

Research and Technology Completion Form

R&T Scoping Statement(s):	VH-4, VH-5, VHO-3
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Test Plan Number/Title:	VSL-02T8000-4; Integrated DM1200 Melter Testing of HLW C-106/AY-102 and C-104/AY-101 Compositions Using Bubblers, Rev. 0
Test Report Number/Title:	VSL-03R3800-3; DM1200 Tests with C-104/AY-101 HLW Simulants, Rev. 0

List Test Objectives:	**State how objectives were met:**
5. Characterize the melter emissions (particulate, aerosol, and gaseous) under nominal steady-state operating conditions for inorganic and organic compounds including the effect of air displacement slurry (ADS) pump operation on feed entrainment. Measurement of organic compounds will be satisfied through the use of Fourier Transform Infrared (FTIR) spectrometry and gas chromatography (including H2).	Isokinetic particulate samples were taken at the outlets of the melter, SBS, and WESP during the last test segment (65 lpm bubbling) to determine the efficiency of off-gas system components. Elemental DF values were determined across the melter, SBS, and WESP. Particle size distributions were determined for the melter emissions. The total solids carryover from the melter (0.72% of feed) was comparable to that observed for tests with other HLW compositions. Calculated DFs across the SBS were high due in part to the higher melter emission rate of major feed components such as silicon and iron. The WESP removed much of the additional particulate material exiting the SBS. As a result, the cumulative DF (Melter+SBS+WESP) was about 302,000. This is higher than for other HLW tests conducted while using the water deluge cleaning procedure of the WESP during emission sampling. The ADS pump was used throughout the off-gas sampling period to assure its "contribution" to feed entrainment into the off-gas system was included. Separate testing without the ADS pump was not planned for this test. Section 7.0 provides data and detailed descriptions of melter emissions. Monitoring of H_2 was not performed due to failure of the gas chromatograph. Hydrogen measurements of Env. D flowsheets were obtained for AZ101 and C106/AY102. This is judged sufficient and retesting is not justified.
6. Quantify and document the occurrence and associated operating conditions of any melter off- gas volume surging events.	No off-as surging volume events were reported. Section 5.1 provides melter pressure data and control air-flow rates during testing.
7. Characterize the performance of the primary off- gas treatment equipment (submerged bed scrubber (SBS), wet electrostatic precipitator (WESP) and high-efficiency mist eliminator (HEME)) to remove particulate, aerosol and gas phase emissions under steady-state melter conditions.	Sections 5 and 7 present off-gas characterization results. See Objective 5 for additional details. CO levels were measured at the WESP to be <4 ppm. Hydrogen levels were measured to be 31 ppm at the highest feed rate tested (see Table 7.6).

Research and Technology Completion Form

R&T Scoping Statement(s):	VH-4, VH-5, VHO-3
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Test Report Number/Title:	VSL-03R3800-3; DM1200 Tests with C-104/AY-101 HLW Simulants, Rev. 0

List Test Objectives:	State how objectives were met:
8. Characterize the chemical and physical characteristics of the aqueous streams (feed, SBS, WESP, and caustic scrubber).	Section 5.2 presents aqueous stream characterization results. The SBS solutions were close to neutral pH (7.8 to 8.3 pH units), due in large part to the lack of acid gases in the exhaust stream. The major dissolved species were halogens, boron, and alkali metals, while the suspended species closely resembled the feed composition. The WESP sump fluid was also in the neutral pH region but had negligible suspended solids. The WESP solutions contained principally alkali halides and boron.
9. Characterize the performance of the secondary off- gas treatment equipment (selective catalytic reduction (SCR) and thermal catalytic oxidizer (TCO) and small-scale silver mordenite column) to treat NOx, organics, and iodine under steady-state melter conditions.	Sections 5.1.7, 5.1.8 and 7.3 and 7.4 present secondary off-gas performance results. Sections 5.1.7 and 7.3 present TCO/SCR process and performance results. The silver mordenite column for the removal of iodine installed downstream of TCO/SCR catalyst units was operated for the second time during these tests (see Section 7.4). Off-gas was sampled simultaneously at four locations on the column (inlet, one-third down, two-thirds down, and outlet). Iodine concentrations are given in Table 7.8. No iodine was measured at the column outlet resulting in DF values of over 1000, based on present detection limits.
10. Obtain the necessary process measurements to provide mass and energy balances throughout the systems, including process monitoring of power, voltage, current, resistance, temperatures, pressures, flow rates, and cooling water and air flows and inlet and outlet temperatures.	Feed characterization (section 2), glass characterization (section 6), condensate liquid characterization (section 5.2) and off-gas emissions (section 7) provide adequate data to perform material balance calculations. Process data to support energy balance calculations are provided in sections 4 (melter) and 5 (off-gas equipment).

Research and Technology Completion Form

R&T Scoping Statement(s):	VH-4, VH-5, VHO-3
Test Specification Number/Title:	24590-HLW-TSP-RT-02-005, Rev 0; Integrated DM1200 Testing of HLW Compositions Using Bubblers, Rev.0
Test Plan Number/Title:	VSL-02T8000-4; Integrated DM1200 Melter Testing of HLW C-106/AY-102 and C-104/AY-101 Compositions Using Bubblers, Rev. 0
Test Report Number/Title:	VSL-03R3800-3; DM1200 Tests with C-104/AY-101 HLW Simulants, Rev. 0

List Test Objectives:	**State how objectives were met:**
11. Document general equipment operations (reliability, availability, maintainability, etc.); especially non-routine equipment failure and replacement activities.	The ADS pump was used for the entire test. The prototypical feed tube used with the ADS pump is not cooled and has a tendency for feed "stalactite" formation on the feed tube tip, which in turn results in feed being directed into the melter in unpredictable and often undesirable directions. As necessary in the case of extreme build ups, deposits had to be mechanically removed, which was generally accomplished by tapping the external portion of the feed tube with a rubber mallet. During the last day and a half of the test, a new feed tube design (feed tube diameter reduced from was employed which lessened the extent of stalactite formation to the point that mechanical intervention was unnecessary. All other systems operated without difficulty.

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R&T Scoping Statement(s):	VH-4, VH-5, VHO-3
Test Specification Number/Title:	24590-HLW-TSP-RT-02-005, Rev 0; Integrated DM1200 Testing of HLW Compositions Using Bubblers, Rev.0
Test Plan Number/Title:	VSL-02T8000-4; Integrated DM1200 Melter Testing of HLW C-106/AY-102 and C-104/AY-101 Compositions Using Bubblers, Rev. 0
Test Report Number/Title:	VSL-03R3800-3; DM1200 Tests with C-104/AY-101 HLW Simulants, Rev. 0

List Test Objectives:	**State how objectives were met:**
12. Perform pre- and post-test inspections of key equipment and process lines to monitor for solids accumulations and corrosion/erosion of materials, especially ammonium nitrate downstream of the SCR.	For this test, post-test inspections of the melter off-gas line and SBS off-gas line downcomer (section 5.1.2) and WESP internals (section 5.1.3) were performed. The masses of the solid deposits removed from the film cooler and transition line sections are given in Table. 5.2a. Photographs of the solid deposits are shown in Figure 5.5 through Figure 5.11. The largest mass of solids (3.11 kg) was collected from transition line section #2. DCP analysis shows the deposits to be compositionally similar to that of AZ-101, AZ102, C-106/AY-102 and C-104/AY-101 melter feeds for many components (e.g., Al2O3 about 4%, B2O3 about 7%, Fe2O3 about 12 %, Na2O about 7% and SiO2 about 26%). An exception is SeO2 which was present only in C-106/AY-102 feed at low amount (~0.4%). However, since SeO2 is a semi volatile oxide, higher (~5%) SeO2 presence in transition line #2 deposits is reasonable. Other notable elements were zinc, zirconium, lithium and manganese which also exist in all of the four HLW feeds. Sulfur is present in the sample and existed only in AZ-101 and AZ-102 feeds. The SBS down-comer was inspected at the end of the test and about 280 grams of solids were removed. About 68% of the cross-sectional area of the pipe was occluded by solids. Results from the present test indicate that removal of the downcomer extension does not alleviate this problem, but the location of the solids accumulation appears to be somewhat higher. At the end of the test, 21.7 gallons of liquid were initially blown down. After a final deluge, another 76.1 gallons of liquid were blown down. Video inspections of the WESP were conducted at the end of the test before and after the deluge. Minor build-up of particulate and a few dark-brown spots of solids were observed on the ionizing rods and collector plates before the deluge. The deluge was observed to be very effective in cleaning this material from the rods and collector plates.

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Test Plan Number/Title:	VSL-02T8000-4; Integrated DM1200 Melter Testing of HLW C-106/AY-102 and C-104/AY-101 Compositions Using Bubblers, Rev. 0
Test Report Number/Title:	VSL-03R3800-3; DM1200 Tests with C-104/AY-101 HLW Simulants, Rev. 0

List Test Objectives:	**State how objectives were met:**
13. Operate the melter plenum pressure control using the variable air-injection control method. Assess and document control stability (melter plenum and off-gas system pressure versus time) as a function of instrument controller settings.	The melter plenum pressure control using the variable air-injection control method was used for the entire test period. Figure 5.3 documents the control air and plenum pressure throughout the test. Stability was acceptable and is described in section 5.1.1.
14. Operate and evaluate the performance of the air-displacement slurry (ADS) pump under operating conditions that are applicable to expected WTP plant operations.	The ADS pump was used during the test in a prototypic operational mode. Detailed performance information for the one year of pump operation will be described in a separate report.
List any Test Exceptions:	**Did exceptions impact the objective?** ☐ Yes ☒ No (Explain)
1) None	
List Success Criteria	**Did the test meet the criteria?** ☒ Yes ☐ No (Explain)
1) Conduct testing in which representative simulant of C104/AY101 with Sr/TRU precipitation products and C104/AY101 are processed for periods sufficient to obtain meaningful process data while achieving at least four melter glass inventory turnovers (8 to 9 Mt).	Yes, see Objective #2 summary statements.
2) Submit data defining the effect of bubbler rate on melter production rate and operating stability for each Phase 1 HLW melter feed.	Yes, see Objective #3 summary statements.
3) Obtain, report and assess melter emissions (particulate, aerosol, and gaseous) data under nominal steady state operating conditions for each test.	Yes, see Objective #5 summary statements.
4) Obtain, report and assess the ability of the primary off-gas treatment equipment (SBS, WESP and HEME) to remove particulate, aerosol and gas phase emissions under steady state melter conditions.	Yes, see Objective #7 summary statements.
5) Measure and document the chemical and physical characteristics of the aqueous streams (feed, SBS, WESP and caustic scrubber).	Yes, see Objective #8 summary statements.

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R&T Scoping Statement(s): VH-4, VH-5, VHO-3

Test Specification Number/Title: 24590-HLW-TSP-RT-02-005, Rev 0; Integrated DM1200 Testing of HLW Compositions Using Bubblers, Rev.0

Test Plan Number/Title: VSL-02T8000-4; Integrated DM1200 Melter Testing of HLW C-106/AY-102 and C-104/AY-101 Compositions Using Bubblers, Rev. 0

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6) Measure and document the performance of the secondary off-gas treatment equipment (SCR, TCO and small-scale silver mordenite column) to treat NOx and capture iodine emissions under steady state melter conditions.	Yes, see Objective #9 summary statements.
7) Document process measurements that provide mass, energy and momentum balances throughout the systems, including process monitoring of power, voltage, current, resistance, temperatures, pressures, flow rates, and cooling water and air flows and inlet and outlet temperatures.	Yes, see Objective #10 summary statements.
8) Assess and document general equipment operations (reliability, availability, maintainability, etc.), especially non-routine equipment failure and replacement activities.	Yes, see Objective #11 summary statements.
9) Document pre- and post-test inspections of key equipment and process lines to monitor for solids accumulations and corrosion/erosion of materials.	Yes, see Objective #12 summary statements.
10) Document the performance of the melter plenum pressure control using the variable air-injection control method. Document control stability (melter plenum and off-gas system pressure versus time) as a function of instrument controller settings.	Yes, see Objective #13 summary statements.
11) Document the performance of the air-displacement slurry pump under operating conditions that are applicable to expected WTP plant operations.	Yes, see Objective #14 summary statements.
List QA Requirements:	**Did the subcontractor meet the requirements?** ☒ Yes ☐ No (Explain)
1) Work to be performed under a NQA-1 approved quality assurance plan.	This work was conducted under an NQA-1 (1989) and NQA-2a (1990) Part 2.7 based quality assurance program. There are no limitations on the use of these data.

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R&T Scoping Statement(s): VH-4, VH-5, VHO-3

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List R&T Test Conditions:	**Were test conditions followed?** ☒ Yes ☐ No (Explain)
Melter:	Tables 4.2 and 5.1 provide system process measurements.
• Bulk glass temperature target - 1150°C (typically allowed to vary ± 25°C before power input changes are initiated).	• Test condition met, see Figure 4.2.
• Bubbling rate were determined from the results of AZ-101 tests.	• Test condition met, 3 bubbler rates; 8, 40 and 65 lpm total bubbler flow were achieved.
• Plenum temperature - 400°C – 450°C (this is a dependent variable whose actual value is the result of cold cap coverage, air in-leakage and other conditions).	• Test condition met, average plenum temperatures ranged between 530°C and 568°C, see Figure 4.3.
Film cooler: No special constraints; typically 70 scfm of air at about 100°C.	• Test condition met, film cooler temperature averaged 81°C and rates averaged 43 scfm to 47 scfm.
SBS: • Tank temperature - 50°C	• Test condition met, tank temperature ranged from 45°C to 50°C, see Figure 5.25.
WESP: • Operate at maximum current to achieve maximum voltage without sparking. Based on previous experience this would be about 17 milliamps and 31 -33 kilovolts.	• Test condition met, kilovolts ranged from 27kV to 31kV see Figure 5.35.
• Inlet water spray – 2 gph ± 0.2 gph.	• Test condition met, see section 5.1.3
• As a part of normal operation the WESP electrodes will be deluged with water from the internal overhead nozzle once a day at the nominal rate of 20 gpm for 2 minutes. This will be done initially at the normal operating voltage and current. In case an internal discharge develops, the voltage across the electrodes will be adjusted to the point at which a discharge disappears. The time delay before reinstating the initial voltage and current settings will be also investigated and determined. This information will be used to determine the preferred protocol for future deluge operations.	• Test condition met, see section 5.1.3
HEMEs: Operate with ~1 gph continuous water spray or per manufacturer's recommendations (< 50 mg/acfm of entrained liquid water).	• Test condition met, moisture load in off-gas was sufficient to not require the 1gph water spray, see section 5.1.4.

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HEPA Pre-heater: • Operate to achieve a temperature rise between 10-20°C. Do not exceed a 20°C temperature rise unless condensation in the HEPA housing or downstream of the HEPA or increased pressure drop across the HEPA indicate higher temperatures are required to maintain stable operation.	• Test condition not met but acceptable, a temperature rise of about 22°C across the HEPA preheater was attained based on an average post HEPA filter temperature of 61.4°C and a post HEME average temperature of 39°C, see section 5.1.5. This exceeds the 20°C maximum temperature rise by 2°C. This is judged acceptable by R&T.
TCO: • Bed temperature per the catalyst manufacturer's recommendation and previous test results (approximately 400°C). Based on previous tests, the gas residence time is about 0.16 sec.	• Test condition met,TCO inlet temperature was 486°C based on previous testing to maximize TCO performance, see section 5.1.7.
SCR: • Bed temperature – per the catalyst manufacturer's recommendation (350-400°C)	• Test condition met, see section 5.1.7.
• Ammonia slip (exit concentration) ≤ 25 ppm, if possible.	• Test condition met, see section 5.1.7.
Silver Mordenite System: • Inlet gas temperature – 130 to 230°C • Inlet gas flow rate – 5 to 35 scfm	• Test conditions met, see section 5.1.8.

Was testing performed with simulants? If yes, discuss how results compare to radioactive tests. ☒ Yes ☐ No

C104/AY101 simulant melter feed was used and is described in Section 2. The composition was based on estimated characterization data and expected pretreatment unit operations. The target waste and melter compositions were therefore consistent with radioactive waste within the tolerances of vendor and analytical variability. Actual waste data does not yet exist for key physical properties; pH, rheology, particle size, etc. Actual waste samples from a combined C104 and AY101 will not be available until after 2006. Therefore direct comparison can not be performed. Comparisons to other Envelope D waste tank samples will be performed as an alternative.

Are all discrepancies resolved? If no, explain. ☒ Yes ☐ No

Are all subcontractor signoffs completed? ☒ Yes ☐ No

This work is acceptable to complete the indicated: ☐ Test Specification(s) ☐ Scoping Statement(s)
If Other, please explain what the report completes. ☒ Test Plan(s) ☐ Other

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Does the Testing or Report suggest any follow-on work? If yes, describe the suggested activity and, if appropriate, attach a Request for Technology Development (RTD). ☒ Yes ☐ No

1. Throughput rates were demonstrated to exceed the equivalence of 3.0 MT/d assuming a linear scaling of results based on glass surface area and a solids concentration of 20 wt.% undissolved solids (UDS) prior to glass former addition. However, it is projected that the solids concentration will range between 14 and 17 wt.% UDS. Also, R&T has concluded the DM1200 overestimates the expected plant performance by 30% based on the ratio of bubblers per square meter. Based on these and other Env. D results, subsequent testing was initiated and performed which demonstrated alternative bubbler designs to meet the throughput performance requirements.
2. Solids accumulation at the bottom of the SBS off-gas downcomer line continues to occur and is not believed to be due to the attachment to the bottom of the pipe. Further assessment and testing is required to determine SBS performance in this area. Potential modification of the SBS to make this area prototypical of the WTP design may be required to resolve this issue. Engineering submitted an RTD to continue assessment of this area. Modifications to the SBS were approved and authorized. Further testing will occur in CY2004 to determine whether the modifications were successful.

Additional comments:

Approved by R&T Manager or Designee:
for W. L. Tamosaitis

Date:
12/4/03