

# **Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubblers, VSL-03R3800-2, Rev. 0**

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



**P.O. Box 450  
Richland, Washington 99352**

# Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubblers, VSL-03R3800-2, Rev. 0

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**VSL-03R3800-2**

**Final Report**

**Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using  
Bubblers**

*prepared by*

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 Final Report, VSL-03R3800-2, Rev. 0

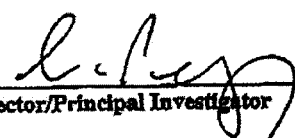
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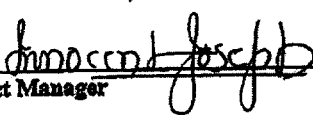
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**Completeness of Testing:**

This report describes the results of work and testing specified by the above-listed Test Specification(s), Test Plan(s), and Text 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.

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### List of Abbreviations

AA	Atomic Absorption Spectroscopy
ADS	Air Displacement Slurry
CFR	Code of Federal Regulation
DCP	Direct Current Plasma Emission Spectroscopy
DF	Decontamination Factor
DM	DuraMelter®
DOE	Department of Energy
DRE	Destruction & Removal Efficiency
EPA	Environmental Protection Agency
FTIR	Fourier Transform Infrared Spectroscopy
GC	Gas Chromatography
HEME	High-Efficiency Mist Eliminator
HEPA	High-Efficiency Particulate Air Filter
HLW	High Level Waste
ISE	Ion Selective Electrode
LAW	Low Activity Waste
PBS	Packed-bed Scrubber
PCB	Polychlorinated Biphenyls
QA	Quality Assurance
QAPjP	Quality Assurance Project Plan for Testing Programs Generating Environmental Regulatory Data
QAPP	Quality Assurance Project Plan
QC	Quality Control
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
TF COUP	Tank Farm Contractor Operation and Utilization Plan
THC	Total Hydrocarbon
TRU	Transuranic
TSS	Total Suspended Solids
VOC	Volatile Organic Compound
VSL	Vitreous State Laboratory
W.C.	Water Column
WESP	Wet Electrostatic Precipitator
WTP	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 AZ-102 feed.

The principal objectives of the DM1200 melter testing were to determine the achievable glass production rates for simulated HLW AZ-102 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 AZ-102 composition provided by the WTP project, from which a suitable simulant was developed for this work. Per the Test Specification, Sr/TRU removal products from pretreatment of Envelope C wastes were omitted from the simulant recipe for these tests. Supporting glass formulation work was performed to develop a compliant glass formulation. Based on these results, melter feed simulant for these tests was prepared by a chemical vendor. The suspended solids content of 20 wt% in the feed material from pretreatment is equivalent to 21.49 wt% total solids, based on the data for actual AZ-102 composite solids. The theoretical glass yield of the resulting melter feed is about 385 g of glass/kg of feed ((520-580) g/l of feed, dependent on feed density).

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. with an 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<sup>2</sup>, as compared to 0.108 m<sup>2</sup> 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<sub>x</sub> 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

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 AZ-102 feed composition. Tests were conducted at three bubbling rates over a nine-day period using feed yielding 545.6 g glass per liter. Over seventeen metric tons of feed were processed to produce about 6.7 metric tons of glass. Cold-cap-limited, steady-state production rates of 380, 650 and 900 kg/m<sup>2</sup>/day were attained for test segments with bubbling rates of 8, 40, and 65 lpm, respectively. Some foaming occurred at the lower bubbling rates but did not prevent the attainment of steady-state conditions.

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 (1.26% of feed) was higher than 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 112,670 and comparable to other HLW tests conducted while using the Project-directed deluge cleaning procedure of the WESP.

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 SBS TSS concentrations were between 1000 and 2400 mg/l, whereas measured TDS values were about 50% 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, nitrite, sulfate, chloride, and ammonium. 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 about 864 gallons. The 1761 gallons of liquid that accumulated in the SBS during the test originated from the condensation of water from the melter feed.

The glass product was close to the intended composition with little variation during testing. No macroscopic secondary phases were evident in the discharged product. No iodine and about 20% of the selenium in the feed were retained in the glass product. A good mass balance was achieved for iodine around the melter and SBS.

The completion of the Test Objectives for this work is summarized in Table 7.1.

#### 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 did not generate data to support HLW waste form 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 for environmental and regulatory data.

#### 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<sup>2</sup>/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. 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<sup>2</sup> vs. two bubblers in 1.2 m<sup>2</sup>), which may lead to lower large-scale glass production rates on a per unit melt surface area basis.

The pressure drop across the SBS increased by about 4.7 in. W.C. over nine days of testing with HLW AZ-102 feed, which is likely associated with the gradual occlusion of the SBS down-comer pipe. At the end of the HLW AZ-102 tests, the SBS was blown down and 368 gallons of liquid was removed from the SBS and overflow tank. After draining the SBS, about 4.72 kg of wet solids (including some legacy ceramic saddle packing) were removed from the bowl. Another 350 grams of solids were removed from the SBS down-comer. The SBS bowl and down-comer were cleaned after the preceding LAW Sub-Envelope B tests and therefore the accumulations resulted from the 4 days of turnover with AZ-101 feed and the nine days of AZ-102 testing reported here.

## 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<sup>2</sup> installed at VSL have been used for this purpose, which, in combination with the 3.3 m<sup>2</sup> 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<sup>2</sup>) 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<sup>2</sup>/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<sup>2</sup>/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 AZ-102 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 AZ-102. 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 AZ-102 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 AZ-102 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 AZ-102 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 and gas chromatography (including H<sub>2</sub>).
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<sub>x</sub>, organics, and iodine under steady-state melter conditions [Note: Iodine removal by silver mordenite system was completed under another Test Plan [9].]
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 will be 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].]

## 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] directs the use of TFCOUP Rev. 3A [15] as the basis for the AZ-102 simulant and stipulates that Sr/TRU (strontium and transuranics) precipitation products not be included. This change in waste composition basis required a revised glass formulation and testing at the crucible scale prior to use in the DM1200. Testing of this formulation on the DM100 melter prior to the DM1200 was deemed unnecessary due to the successful completion of several melter tests with AZ-101 simulants [10] which are very similar in composition to AZ-102.

A nine-day test was conducted on the DM1200 with AZ-102 simulant using bubbling rates determined in previous tests. 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; these rates were 8, 40, and 65 lpm. 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 at 20% undissolved solids in the simulant 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 segment 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 HLW waste form 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<sup>3</sup>. 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 located in diagonally opposite corners were used.

### 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<sub>x</sub> 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:

- Particulate Removal: 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.
- VOC Control/Acid Gas: 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<sub>x</sub> gases and a packed-bed scrubber (PBS) to remove remaining acid gases.
- Stack System: 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.

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.

## SECTION 2.0 WASTE SIMULANT AND GLASS FORMULATIONS

The composition of the AZ-102 HLW simulant used for these tests was derived from the basis specified in the Test Specification [6]. As discussed above, the stipulated waste data and blending assumptions are different than those used in previous tests with AZ-102 simulants such that there was a need to develop and test new glass formulations. This Section summarizes the changes in simulant composition and describes the glass formulation selected for melter testing. The melter feed composition, which is based on both the simulant and glass formulation, is also discussed.

### 2.1 AZ-102 Waste Simulant

Formulation of the AZ-102 waste simulant makes use of inventory data from the TFCOUP [15], calculated data from ACM modeling, and analytical data on Cs- and Tc-removal eluates from LAW pretreatment [20].

The composition of the AZ-102 Envelope D solids (Stream FRP02) is based on the inventory data found in Revision 3A of the TFCOUP [15]. As seen in Table 2.1, in addition to updated information, Revision 3A of the TFCOUP also provides information on minor components that were not included in earlier revisions [14] and the Best Basis Inventory (BBI) database [21] (e.g., cadmium). The use of other data sources (e.g., HLW Feed Staging Plan [22]) to supplement the TFCOUP, as was done in previous tests, is therefore no longer necessary. The ACM model calculates the composition of the recycle stream (PWD01), which is then blended with the Envelope D solids based on the expected daily processing rates (i.e.,  $1.30\text{E}+04$  lb/day for Envelope D solids and  $1.28\text{E}+03$  lb/day for the recycle stream on a dry solid basis). The resulting material is concentrated and pretreated through caustic leaching/water washing and ultra-filtration to produce the pretreated HLW solids (UFP07). The separation factors due to caustic leaching and ultra-filtration are given in Table 2.1.

To complete the simulant formulation, the pretreated HLW solids must be blended with wastes from LAW pretreatment. In contrast to the blending scenario used in Part B1 tests [14], Sr/TRU removal products from pretreatment of Envelope C wastes were omitted from these tests per the Test Specification [6], although the current processing schedule suggests that some blending of Sr/TRU products from AN-102 (first Envelope C tank) may occur during the later stages of AZ-102 processing. Analytical data on eluates from Cs- and Tc-removal on an Envelope B sample (AZ-102) [20] provide the compositional bases for the respective feed streams CNP12 and TEP12. The blending proportions are determined by the projected daily processing rate of sodium in the eluates (i.e.,  $1.71\text{E}+01$  lb/day for Cs-removal and  $3.32\text{E}-01$  lb/day for Tc-removal). It can be seen in Table 2.1 that waste blending primarily leads to increases of sodium and nitrate in the HLW simulant.

The calculated composition of the blended HLW solids (HLP09b), which is shown in Table 2.1, lists a total of 55 components. A few of the components, however, have been left out of the blended solids in the Test Specification [6] because of unknown separation factors and low concentrations (e.g., Se and Y). In addition, similar to the approach taken during previous testing, radionuclides, noble metals (including silver) and minor components (< 0.02 wt% in glass on an oxide basis) are omitted from the simulant formulation. Another modification is the substitution of neodymium for praseodymium, another rare earth element, to reduce the number of components in the simulant. Cesium and iodine are spiked for analytical purposes, at amounts equivalent to 0.05 wt% and 0.10 wt%, respectively, in the glass product. The resulting HLW simulant formulation, which is given in Table 2.2, consists of 25 components, 21 of which are non-volatile (compared with 33 and 29, respectively, for the previous AZ-102 simulant [23, 24]).

## 2.2 Glass and Melter Feed Formulations

With the elimination of Sr/TRU pretreatment products from the HLW simulant, new glass formulations were developed and tested at VSL to support these tests. The glass composition selected to be the basis for these tests, HLW98-80, is presented in Table 2.2. On an oxide basis, this glass incorporates 23.76 wt% of Envelope D waste and 24.25 wt% of all wastes. These can be compared with the respective values of 26.29 wt% and 33.32-wt% for HLW98-66, the AZ-102 reference glass used in Part B1 [23]. The difference is primarily due to the increased limiting component of Fe<sub>2</sub>O<sub>3</sub> in the new HLW simulant and the inclusion of Sr/TRU products in the old simulant. The iron content is increased to such an extent (51.58 wt%) that the reference glass HLW98-80 meets the contract specification by incorporating 12.52 wt% of Fe<sub>2</sub>O<sub>3</sub>, instead of the > 21 wt% of (Al<sub>2</sub>O<sub>3</sub>+Fe<sub>2</sub>O<sub>3</sub>+ZrO<sub>2</sub>) found in previous testing [23].

Crucible melts of HLW98-80 were prepared and tests performed to determine that it meets the necessary processing requirements. The measured viscosity and conductivity at 1150°C are 51 P and 0.36 S/cm, respectively. Heat treatment of HLW98-80 at 950°C for over 70 hours results in < 0.1 vol% of spinel crystals. The target glass formulation for these tests, which is also given in Table 2.2, differs slightly from HLW98-80, with the removal of silver and the addition of small amounts of cesium and iodine. The intrinsic density of HLW98-80 glass is 2.68 g/cc [30].

The additional constituents required to form the target test glass from the AZ-102 HLW simulant are boron, lithium, sodium, silicon, and zinc. The corresponding chemical additives that are the sources for these elements are selected based on previous testing and the RPP-WTP Project baseline glass forming chemicals. Table 2.3 lists the starting materials and amounts required to produce the target AZ-102 simulant and melter feed. Note that all of the TOC is assumed to be oxalate and that only 0.066 (g/100 g oxide) of carbonate is present in the simulant, instead of the required 1.145 (g/100 g oxide). The discrepancy in carbonate does not impact the tests since much greater amounts are present in the glass forming additives. For AZ-102, a suspended solids content of 20 wt% in the feed material from pretreatment is equivalent to 21.49 wt% total solids, based on the data for actual AZ-102 composite solids [25]. The

theoretical glass yield of the resulting melter feed is about 385 g of glass/kg of feed ((520-580) 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 chemical composition and physical properties. Sample names, sampling dates, and measured properties are provided for feed samples in Table 2.4. All samples were taken from the feed line immediately upstream of the entrance point to the melter. The average measured glass yield was almost identical to the target glass yield of 385 g of glass per kg of feed; consequently, the target value was used for calculating glass production rates. The average measured glass yield on mass per volume basis, 545.6 g glass per liter of feed, was well within the 520 – 580 expected range given in the Test Plan [8]. This range was intended as an estimate since the feed density was not known at that time. All measured parameters including glass conversion ratio, water content, density, and pH fall within narrow ranges, confirming the relative consistency of the melter feed.

### 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 [24]. 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 step wise from  $0.01 \text{ s}^{-1}$  to  $200 \text{ s}^{-1}$  ( $70 \text{ s}^{-1}$  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  $25^\circ\text{C}$ ; previous work [24], which examined a range of temperatures, showed a relatively weak effect of temperature.

Rheograms which show the feed viscosity versus shear rate for the feed samples are presented in Figure 2.1; measured values for viscosity at selected shear rates and the yield stress values are shown in Table 2.4. The values are about twice those measured on HLW C-106/AY-102 feed samples [26]; no problems were encountered in pumping, mixing, or processing the AZ-102 feed.

### 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 Table 2.5 and are compared to the target composition.

The compositional analysis results can be discussed by dividing the 22 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, and Si,) are consistently within 10 percent of the target composition for the feed samples with the exception of aluminum which on average is about 20 percent above the target value. Two elements are in the intermediate concentration range (Zn, and Zr); one of which, Zr, was significantly (32%) above the target value. The aluminum deviation in the product glass was about half that observed in the feed samples, whereas the zirconium deviation was relatively consistent (see Section 5.0). The absolute deviation for these two elements was only 0.5 to 1 percent and therefore they are not expected to have any consequential effects on the processing properties of the feed or glass. The large number of minor elements (Ca, Cd, Cs, I, K, La, Mg, Mn, Nd, Ni, P, Pb, S, and Ti) all originate from the simulated waste or were 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, the highly volatile element iodine is under-represented in the glasses. Conversely, common elements, which are typical impurities in bulk chemicals, such as calcium and potassium 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, 26-28], suggesting that titanium is a common contaminant in the source chemicals. Potassium and sulfur, which are not included in glass formulation, were detected at low levels in the feed as impurities.

### SECTION 3.0 DM1200 OPERATIONS

Melter tests were conducted on the DM1200 with the HLW AZ-102 simulant between 11/18/02 and 11/27/02, producing over 6,700 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 and cold-cap burn-off, was 219.4 hours. The test consisted of three 3-day segments of successively higher total bubbling rates of 8, 40, and 65 lpm respectively. The measured glass production rate is depicted in Figure 3.1 as cumulative and one-hour moving averages for each of the three segments. The three steady-state production rates (380, 650, and 900 kg/m<sup>2</sup>/day) were obtained for each three-day 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.

Feeding was conducted throughout the test with the prototypical ADS pump without incident. The prototypical feed tube used with the ADS pump is not cooled and has a 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. After stalactites were removed from the outside of the feed tube, residual feed was sometimes still present inside the tip of the tube which could only be removed by passing a metal rod down the length of the feed tube. Subsequent tests have employed a new feed tube design which lessened the extent of stalactite formation to the point that mechanical intervention has been unnecessary [13, 29].

A variety of operational measurements recorded during these tests, including temperatures throughout the melter system, are given in Table 3.2. The target glass temperature of 1150°C was successfully maintained for most of the glass pool during each test segment, as illustrated in Figure 3.2. 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. Plenum temperatures (Figure 3.3) were typically between 450 - 650°C, with higher temperatures at the beginning of the test during cold cap formation. The lowest plenum temperatures occurred during the first segment as a result of periodic foam layers (note the downward spikes in plenum temperature corresponding to the drops in electrode power) whereas higher plenum temperatures were observed at the beginning of the second segment once the foaming subsided. 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 well below 1150°C throughout testing. The bottom electrode temperature averaged about 35°C colder than the West electrode, which was in turn about 25°C colder than the East electrode, as shown in Figure 3.4 (note that the bottom electrode was not powered in these tests). This small temperature difference between the two sides of the

melter has been observed over the lifetime of the DM1200 [3, 4, 19, 26-28]. Differences between side and bottom electrode temperatures are greater in HLW tests, which do not use the bottom bubbler [4, 26], than in the LAW tests, which do employ them [19, 27, 28]. The discharge chamber and riser temperatures were largely maintained above 950°C throughout the tests. Gas temperatures after the film-cooler were about 200°C lower than the plenum temperature as a result of film cooler and control air dilution. As expected, periods of the test with the highest plenum temperatures also have the highest transition line temperatures (i.e., Test Segment B).

Conditions in the glass pool are illustrated for electrical properties in Figure 3.5, level and density in Figure 3.6, and bubbling in Figure 3.7. Electrode power increased from about 75 to 160 kW over the course of testing as bubbling and production increased, as expected. The variations of about 40 kW during the first test segment were responses to foaming on the glass surface. In contrast, power varied little during each of the last two segments when the foaming had subsided. Glass resistance also varied during the first test segment and became more stable during the latter portions of the test as foaming subsided. The glass level was mostly within a half inch from the average of 27.7 inches from the floor over the course of the test. Small decreases in glass density occurred in response to increases in bubbling. Exceptions occurred at about 27, 41, and 56 hours run time when the density spiked down 0.1 g/cc as a result of foaming. The target total bubbling rates of 8, 40, and 65 lpm were held for each three-day segment, as shown in Figure 3.7. The average values for total bubbling during each segment given in Table 3.2 are slightly below their respective targets 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 two test segments. 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], as well as tests with the current C-106/AY-102 formulations [26]. Significantly more power was used than in the previous LAW tests (3.5-5.1 vs. 1.6-2.0 kW/kg glass) [19, 27] due to the higher feed water content and much lower glass production rates.

## SECTION 4.0 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 packed-bed caustic scrubber (PBS); a high-efficiency mist eliminator (HEME 2); and a second HEPA on the bypass off-gas system. Data on the off-gas system performance collected during the test with HLW AZ-102 feed are presented and discussed in this section.

### 4.1 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 4.1. A plot of the typical sequence of gas temperatures through the DM 1200 off-gas system at various locations is given in Figure 4.1.

#### 4.1.1 Melter Pressure

The time-averaged (hourly average values) computer logged melter pressures measured at the level detector and instrument ports at two-minute interval are shown in Figure 4.2. The average melter pressure was -4.1 in. W.C and melter pressure ranged from -7.1 in. W.C. to 0.5 in. W.C. The test ended at 217.1 hours. The small deviations in the pressure values are a result of the reduction in blower speed at the end of the melter test.

The computer logged melter pressures measured at the instrument port and calculated control air flow rates are plotted in Figure 4.3. The control air system, to control melter pressure, was operational and very effective during this test. The control air flow rate averaged 28.9 scfm during the test. Excursions in melter pressure shown in Figure 4.3 typically occurred during feed introduction into the melter.

The differential pressures across the transition line and film cooler are given in Figure 4.2. The sudden decreases in the film cooler differential pressure are due to cleaning of the film cooler. The transition line sections were not dismantled and inspected in detail during or after this test.

A view from the top of the film cooler, at the end of the test, is shown in Figure 4.4. No visual sign of solids deposition was evident. For reference, the film cooler was replaced on 6/21/02, and the last major dismantling and cleaning was on 3/6/03. During test operations the film cooler is rinsed at 12 hour intervals.

#### 4.1.2 SBS Performance

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 6.0. Results from the analysis of fluids accumulated in the SBS are presented and discussed in Section 4.2.

The SBS inlet and outlet gas temperatures are plotted in Figure 4.5. Periodic downward temperature spikes resulted from the film cooler cleaning that is performed at 12 hour intervals. The inlet gas temperature peaked at 382°C and the outlet gas temperature peaked at 49.4°C. The average inlet gas temperature was 283°C. The average outlet gas temperature was 39.2°C. The inlet, outlet, and differential pressures are shown in Figure 4.6. The inlet gas pressure averaged -7.5 in. W.C., the outlet pressure averaged -50.6 in. W.C., and the pressure drop across the SBS averaged about 45.2 in. W.C. The higher differential pressure readings seen in Figure 4.6, around 50 hours of operation is due to partial clogging of the differential pressure sensor line. The pressure drop across the SBS increased by about 4.7 in. W.C. over nine days of testing with HLW AZ-102 feed, which is likely associated with the gradual occlusion of the SBS down-comer pipe.

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 4.7. There was an average of about 0.6°C difference in water temperatures measured at four depths (48, 60, 72 and 78 inches) within the SBS. The maximum temperature difference was 1.1°C. The liquid in the SBS was heated to a maximum temperature of 53.5°C during the initial period of water feeding, while the average SBS sump temperature during testing was 39.8°C. The average outlet gas temperature was 39.2°C.

SBS jacket, inner coil and heat exchanger water flow rates are plotted in Figure 4.8. Average SBS jacket, inner coil and heat exchanger water flow rates were 4.0, 24.5 and 10.1 gpm respectively. The amounts of heat removed by the SBS cooling jacket and the plate heat exchanger are shown in Figure 4.9. It is noted that the cooling jacket chilled water flow rate readings after 150 hours (Figure 4.8) may be questionable. The trace is suspiciously flat and the resultant approximate threefold calculated jacket heat load increase shown in Figure 4.9 is unexpected. It seems likely that the drop in jacket chilled water flow rate was greater than shown

on Figure 4.8.

The heat load data for the SBS cooling jacket and plate heat exchanger are calculated based on hourly averaged 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 44.2 kW by the plate heat exchanger and 9.38 kW by the cooling jacket. About 82.5% of the heat load to the SBS was removed by the plate heat exchanger and about 17.5 % by the cooling jacket. SBS inner coil and plate exchanger water temperatures are plotted in Figure 4.10. The heat load data for the SBS inner coil was also calculated based on hourly averaged cooling coil water temperature increases (coil water outlet minus its inlet temperature) multiplied by the hourly averaged flow rate of inner cooling coil water. The average SBS inner coil heat load was 45.7 kW. The heat load difference between SBS inner coil and plate heat exchanger is plotted in Figure 4.11 and on average is only about 1.5 kW. Independently calculated SBS inner coil heat load and plate heat exchanger heat load values were thus very close to each other showing that, as expected, the heat removed from the SBS liquid by the cooling coil matches the primary-to-secondary heat transfer in the plate heat exchanger.

At the end of the HLW AZ-102 tests, the SBS was blown down and 368 gallons of liquid was removed from the SBS and overflow tank. 4.72 kg of wet solids (including some legacy ceramic saddle packing) were removed from the bowl after draining the SBS. Photographs of the SBS bowl with the solids, at two magnifications, are given in Figures 4.12 and 4.13. Pieces of the original ceramic saddle packing are clearly visible in Figure 4.13. Another 350 grams of solids were removed from the SBS down-comer. Back scattered electron (BSE) image of a sample taken from SBS down-comer solids is given in Figure 4.14. Energy dispersive x-ray spectroscopy (EDS) was used to determine the composition of the down-comer solids. An EDS spectrum of a particle from SBS down-comer solids is given in Figure 4.15. The major constituents determined by EDS are Fe, Zr, Si, and Al, which are the same as the major components in the melter feed. The particle that was analyzed contained about 52 wt%  $\text{Fe}_2\text{O}_3$ , 23 wt%  $\text{Al}_2\text{O}_3$ , 7 wt%  $\text{ZrO}_2$ , and 4 wt%  $\text{SiO}_2$ . It is important to note that the SBS bowl and down-comer were cleaned after the preceding LAW Sub-Envelope B tests and therefore the accumulations resulted from the 4 days of turnover with AZ-101 feed and the nine days of AZ-102 testing reported here.

#### 4.1.3 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 tests while the WESP current and voltage were recorded manually.

Data on the performance of WESP regarding solids removal from the off-gas stream are presented and discussed in Section 6.0. Results of the analysis of fluids that accumulated in the WESP are presented and discussed in Section 4.2.

The WESP inlet and outlet gas temperatures are plotted in Figure 4.16. The WESP inlet gas temperature averaged 40.3°C and the outlet temperature averaged 41.0°C, indicating a 0.7°C temperature increase across the WESP during this test. The downward spikes in the WESP outlet temperature are a result of the daily deluge of the WESP. WESP differential pressure and gas flow rate out of the WESP are plotted in Figure 4.17. The pressure drop across the WESP averaged 2.3 in. W.C. The average WESP gas flow rate was 214.9 scfm. The changes in the differential pressure and gas flow rate values seen in Figure 4.17 are due to changes in the blower speed made by the melter operators.

The amount of liquid accumulated in the WESP is plotted as a function of run time in Figure 4.18 where it is compared with the amount of fresh water sprayed into the WESP. Inlet spray water was set to  $2.0 \pm 0.2$  gph, as specified by the Test Plan. As evident from Figure 4.18, spray water accounts for the majority of the liquid accumulation in the WESP. The difference between accumulated liquid and fresh water sprayed is the condensed liquid, which is also plotted in Figure 4.18. As planned, the WESP electrodes were deluged daily with water at a nominal rate of 12 gpm for 3.33 minutes (i.e., a total of 40 gallons per deluge).

The WESP voltage and current are plotted as a function of run time in Figure 4.19. The average operating voltage and current were about 29.1 kV and 17.0 mA, respectively. The voltage and current remained steady throughout the test. The WESP current and voltage were very stable when compared with previous tests. The time to restore power to the WESP after a deluge was not requested by the WTP Project or recorded for this test; however, that information was collected for subsequent tests following the request from the Project.

At the end of the test a total of 65.1 gallons of liquid was blown down. After completion of the test, video inspections of the WESP were conducted before and after performing a deluge. The ionizing rods and collector plates were clean both before and after the deluge. Very small amounts of solids were observed at the bottom of WESP before the deluge.

#### **4.1.4 HEME #1**

A HEME (HEME #1) that follows the WESP in the off-gas system removes any water droplets that may be present in water-saturated gas exiting the WESP. The outlet gas temperature and differential pressure are plotted in Figure 4.20. The average HEME #1 gas outlet temperature was 38.9 °C. The downward spikes in outlet temperature are a consequence of the daily WESP deluge. The average pressure drop through HEME #1 was 2.4 in. W.C. At the end of the test, 34.3 gallons of liquid was blown-down from HEME #1.

#### **4.1.5 HEPA Filter**

The 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 HEME # 1 is heated above its dew point before passing through the HEPA filter in order

to prevent moisture condensation in the HEPA filter. The outlet gas temperature and the pressure differential across HEPA #1 are the only two parameters that were monitored by the off-gas data acquisition system and are given in Figure 4.21.

The HEPA # 1 outlet temperature averaged 61.3°C and the differential pressure across HEPA #1 averaged 0.1 in. W.C. These data indicate that no significant particulate loading or moisture blinding of HEPA #1 filter occurred during this test.

#### 4.1.6 First Paxton Blower (Blower-701)

Blower-701 gas outlet and TCO/SCR heater gas inlet temperatures are plotted in Figure 4.22. The blower outlet gas temperature averaged 83.4°C and the TCO/SCR heater gas inlet temperature averaged 83.1°C. Two views of blower B-701 impeller inlet after the test are given in Figures 4.23 and 4.24. A view of the blower outlet after the test is given in Figure 4.25. The very light coating of solids seen in the figures was too thin to allow collection of samples for analysis.

#### 4.1.7 Thermal Catalytic Oxidizer and Selective Catalytic Reduction Unit

The TCO/SCR unit consists of a heater, a Thermal Catalytic Oxidizer (TCO), and a Selective Catalytic Reduction (SCR) unit 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<sub>x</sub> is reduced to nitrogen. TCO inlet, SCR inlet and outlet, and post SCR temperatures during the test are plotted in Figure 4.26. The average TCO inlet gas temperature was 478°C, while the average SCR inlet gas temperature was 383°C. Note, however, that shine from the heater tends to bias the TCO inlet temperature reading high, perhaps by about 30°C. The average SCR outlet gas temperatures were 362°C and 349°C at two locations, one foot apart, at the outlet of the SCR. The average temperature after the SCR was 331°C.

The differential pressures across the TCO, SCR and TCO/SCR are plotted in Figure 4.27. Average differential pressures were 3.0 in. W.C., 6.1 in. W.C. and 9.4 in. W.C. respectively.

Information on NO<sub>x</sub> and CO removal in the TCO/SCR is provided in Table 4.2. Carbon monoxide concentrations were too low in test segment A to allow accurate measurements of its destruction; however, its removal was more than 75% in test segments B and C. During test segments A, B, and C, nitrogen oxide removals were about 87.8%, 92.2%, and 85.7%, respectively. The gas residence time in the TCO during the HLW AZ-102 test averaged 0.2 seconds. The average ammonia injection rates into the SCR during test segments A, B and C were 0.084, 0.080 and 0.125 lbs/hr, respectively. Ammonia slippages (Table 4.3) during the test segments A, B and C were 4.6%, 1.9% and 1.1%, respectively. Average ammonia concentration after the SCR unit, during test segments A, B and C, were 6.6 ppm, 2.6 ppm, and 2.5 ppm respectively.

Inspection of the off-gas system components after TCO/SCR for ammonium nitrate deposition is reported in the DM 1200 LAW Sub-Envelope B1 Test Report [28].

#### **4.1.8 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) 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 4.28. The average PBS differential pressure was 2.7 in. W.C. A spike in the PBS differential pressure at about 93 hours of operation can be seen in Figure 4.28. This is a result of fresh water spray causing a partial air lock in the PBS column. The PBS was immediately blown down and the differential pressure returned to normal. The average PBS inlet temperature for this test was 306.5°C. The PBS sump temperature is plotted in Figure 4.29 and averaged 23.8°C. The pH sensor connected to the LabVIEW data acquisition system was not operational during this test. The pH values were, therefore, measured and recorded manually. The pH during this test was controlled in the range of  $9 \pm 0.5$ .

#### **4.1.9 HEME #2**

A HEME (HEME # 2) that follows the PBS in the off-gas system removes any water droplets that may be present in water-saturated gas exiting the PBS. Inlet and outlet gas temperatures and differential pressure are plotted in Figure 4.30. The average HEME # 2 gas inlet and outlet temperatures were 25.9°C and 27.9°C, respectively. The drop in gas inlet temperature at about 93 hours of operation is probably related to the fresh water spray resulting in a partial air lock of the PBS column, as noted above. The average pressure drop across HEME # 2 was 5.0 in. W.C. At the end of the test, 43.1 gallons of liquid was blown-down from HEME # 2.

#### **4.1.10 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. Caustic solution (25% NaOH) from the same caustic tank that supplies the PBS can also be added to the 500-gallon storage tank that receives acidic effluents from SBS sampling tanks; this storage tank is therefore referred to as the "neutralization tank." The various effluent liquid sampling and storage tanks are visually monitored during periodic rounds and effluent liquid transfers made as needed.

## 4.2 SBS and WESP Process Fluids

### 4.2.1 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 4.4; 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 at the end of each of the three test segments are provided in Table 4.5. The pH values for the SBS liquids are plotted in Figure 4.31. Notice that the solution pH remained between 8.1 and 8.8 during testing. The neutral pH is partly due to the low feed concentrations of nitrates, nitrites, and sulfates, which form acid gases in the melter which decrease the SBS sump pH when scrubbed [4, 19, 27, 28]. In previous HLW tests conducted with AZ-101 simulant and glass pool bubbling [3, 4], as well as recent tests with the C-106/AY-102 simulant [26], SBS sump pH values were also in the neutral region.

Figure 4.32 compares the amount of water fed to the melter to the total volumetric accumulations in the SBS over the course of the test. The water fed to the melter at the beginning of each test segment 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) was also taken into account. There is close agreement between these 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 paired with an increase in the water accumulation rate in the SBS. By the end of the test, about 755 gallons more water was fed than was condensed in the SBS which is only 4 gallons less than the differential observed in the C-106/AY-102 tests [26]. The percent of feed water condensed in the SBS 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 (C1, A1, and B1) [19, 27, 28] and HLW tests [4, 26] that used a sump temperature of 40°C are very similar. The last solution, identified as L12-S-95A in Table 4.4, was taken from the draining of the SBS after the test was over and therefore was not included in calculation of condensed water.

Figures 4.33 - 4.35 compare the feed composition to the SBS dissolved and suspended fractions from a sample taken near the end of the test (L12-S-89A). As might be expected, the dissolved solids consist mainly of species such as halogens, boron, sulfur, and alkali metals. These species are readily volatilized from the glass surface 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, 27, 28], are present only in very small quantities due to the 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 and silicon, with significant amounts of titanium, aluminum, sodium, and zinc. Also note that the minor feed component lead is present in the suspended solids at percentages much greater than in the feed. Iodide was present only in the dissolved fraction.

Particle size characteristics were measured using a Microtrac S-3000 laser light scattering particle size analyzer for a sample taken near the end of the test (L12-S-89A). Results are shown in Figure 4.36 and compared to samples from LAW Sub-Envelope tests [19, 27, 28] as well as to a sample from an HLW C-106/AY-102 test [26] in Table 4.6. Average particle sizes for the AZ-102 sample were larger than for samples from any other tests; the reason for this is not clear. Despite the greater average size of particles in the AZ-102 sample, particle size ranges for samples from all tests were similar, particularly on a number average basis, despite the differences in feed chemistry. This is due in part to the TSS being composed primarily of insoluble glass formers such as silicon, iron, and aluminum that are common to all of the glass compositions.

#### 4.2.2 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 4.7; 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 4.5 and illustrated in Figure 4.37. The WESP solution pH values were higher (7.7 to 9.5 vs. 2 to 7) than the previous HLW tests [3, 4] due to dilution from the added deluge, higher than the previous LAW Sub-Envelope B1 tests [28] (7.7 to 9.5 vs. 2 to 4) due to the lower concentrations of nitrates/nitrites in the feed, and even higher than the recent HLW C-106/AY-102 tests (7.7 to 9.5 vs. 6.5 to 8). 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 and sulfates, and

boron) and ammonium nitrate. The concentrations of all elements are significantly higher in the solutions prior to the deluge, indicating that there are not large amounts of material being washed from the electrodes by the deluge. The results confirm 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.

Anion analysis of the PBS and HEME blow-down solutions taken at the end of the test is given in Table 4.8. The pH of the PBS sump is maintained between 9 and 10 during testing by the addition of 25% sodium hydroxide solution. Conversely, the near neutral pH of HEME solutions is a result of constituents removed from the exhaust stream. Relatively high 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.

#### **4.2.3 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 4.9. The accumulation totals are the product of the average analysis given in Tables 4.4 and 4.7 and the total accumulated liquids given in Tables 4.5 and 4.8. These values are upper estimates of accumulations since the concentration values were taken from 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 4.1.2). The accumulations estimated from blow-down data are also compared to estimates calculated from emissions data as percent of feed. The equivalent of over five kilograms of iodine, four kilograms of sodium, three and half kilograms of boron, two kilograms of iron, silicon, and iodine, as well as hundreds of grams of aluminum calcium, lithium, lead, zinc, and zirconium are estimated to have accumulated in the SBS liquids during testing. However, the SBS liquids could constitute a significant proportion of the elemental mass balance only for sulfur and iodine with between 40 to 100 percent 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, 26, 28] (40 vs. > 50-90%) due presumably to the difference in solution composition or the speciation of iodine in the melter emissions. Estimates of accumulations in WESP solutions are the equivalent of almost half a kilogram of sulfur, over 900 grams nitrate/nitrite, and over 200 grams alkali metals, as well as tens of grams of boron, calcium, magnesium, silicon, and iodine over the course of the test. The WESP liquids constitute a significant proportion of the elemental mass balance only for sulfur. Agreement between the two methods for estimating accumulations was not as good as in the C-106/AY-102 test [26]. Emissions data suggest that two to three times more of most elements should be present in SBS solutions. This is due in part to melter emission data being collected over a three-hour period near the end of the test while the melter is being fed at the highest rate, whereas SBS blow-down solutions used to calculate accumulations are taken at the end of each of the three tests segments. Also, solids on the bottom of the SBS bowl were not included in the estimate but were certainly derived from melter emissions. Both estimation methods indicate little feed accumulation in the WESP with the exception of cesium and sulfate.

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Vitreous State Laboratory*

*DM1200 Tests with AZ-102 HLW Simulants  
Final Report, VSL-03R3800-2, Rev. 0*

Some of the calcium, potassium, 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 comparable to the C-106/AY-102 tests (1.7 vs. 2.6%) however a larger percentage was retained in the SBS in these tests. Finally, as expected, the PBS and HEMEs accounts for only a modest percentage of feed anions.

## SECTION 5.0 GLASS PRODUCT

Over 6,700 kg 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 5.1.

### 5.1 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 5.2. 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. Exceptions are aluminum and zirconium. Aluminum was closer to target in the discharged glass than in the feed samples, whereas zirconium deviated from the target by about the same amount in the glasses and feed samples. Zinc, which was within ten percent of target in the feed samples, was about thirteen percent below target in the product glass. Titanium was again observed in the glass at very low levels, even though it is not included in the feed recipe. Also, several trace elements including calcium, potassium, lead, and sulfur were observed at concentrations higher than target values. Consistent with previous melter tests using lower alkali glasses [4, 19, 28], no measurable feed iodine was retained in the glass product.

Compositional trends from the XRF data are plotted for selected elements in Figures 5.1-5.3. The figures illustrate many of the points apparent in the tabular summaries of the data: good agreement with target for most oxides after the melt pool has experienced three turnovers (~6000 kg of glass produced), excesses of aluminum and zirconium, as well as a small deficit of zinc. The figures also illustrate two of the compositional trends that occurred: elements with oxide concentrations that either did not change as a result of the similarity to the previous AZ-101 composition [7] used to turn the melt pool over from the LAW Sub Envelope B composition [28] (Figures 5.1 and 5.2) and elements that systematically decreased in concentration towards target (Figure 5.3).

## SECTION 6.0 MONITORED OFF-GAS EMISSIONS

### 6.1 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 6.1 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 6.2-6.4 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  $\mu\text{m}$  heated filter. Solids carry-over from the melter averaged 1.26% of feed solids and was the highest carry-over of the tests with the four HLW simulants [10, 11, 13]. The SBS averaged almost 99% removal of the particulates emitted from the melter, which is comparable to performance in the other HLW tests [4, 10, 11, 13] but greater than for the LAW Sub-Envelope C1 and A1 [19, 27] tests and HLW C-106/AY-102 tests [26]. Melter emissions were relatively high in major components such as silicon, sodium, and iron, in contrast to melter emissions from the C-106/AY-102 tests which were composed mostly of volatile species such as selenium and chlorine. Glass formers like silica form coarser particulate that is efficiently captured by the SBS. About 95 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 112,670 and near the low end of those measured for the four HLW compositions.

The composition of the particles in the melter exhaust is different to that observed in previous studies [3, 4, 26-28]: higher in major constituents such as silicon and iron and lower in volatile species such as alkali halides. This is due in part to the low concentration of halides and other volatiles 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 mechanism for emissions, not volatilization from the glass or cold cap. This, coupled with the high overall solids emission rate, suggests that feed may have been directed towards the melter outlet by stalactites or occlusions on the tip of the feed tube (see Section 3.0). 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 the iodine, boron, and sulfur were detected. The presence of these elements in the gas fraction is consistent with observations from previous studies [3, 4, 26-28]. 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 and selenium, 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. As noted in Section 2.1, iodine and cesium are spiked for analytical purposes at amounts higher than anticipated in the WTP AZ-102 feed.

## **6.2 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 second steady-state test segment. Data for the particle size distributions are provided in Table 6.5. About two thirds of the total particulate mass was observed in the coarsest size fraction ( $> 12.2$ - $12.9 \mu\text{m}$ ) with the remainder being spread out over the remaining seven finer size fractions.

## **6.3 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  $0.5 \text{ cm}^{-1}$  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  $150^\circ\text{C}$  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 6.6 displays a summary of the average analyte concentrations measured over the course of the test. Real-time concentrations of NO, NH<sub>3</sub>, CO<sub>2</sub>, and water are presented in Figures 6.5-6.8. Only

NO, CO<sub>2</sub>, 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. Another aspect of the emissions is the high degree of variation during testing, as can be observed in Figures 6.5 and 6.7. Notice that, even over short periods of time, NO emissions can vary by factors of 2 to 3. Moisture percentages for the last test segment at the melter and SBS outlets were comparable to those measured using the stack sampling methods, shown in Table 6.1. The moisture data also indicate that measurable condensation occurs only in the SBS, as intended.

#### **6.4 Iodine Mass Balance**

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 [4, 19, 28]. 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 6.7 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 (100%) or the sum of SBS blow-down solutions and SBS emissions (40 + 61 = 101%). The amount of iodine detected in the WESP emissions is higher than in any previous study due to the lack of acid gases in the exhaust; the presence of these acid gasses neutralizes the impingers solutions that are in place for up to 12 hours during WESP sampling. The data validate the long-held assumption that the WESP removes little or no iodine. In fact, the measured iodine emission rate from the WESP was higher than the emission rate from the SBS as well as the iodine feed rate. Less iodine was detected at the TCO/SCR than at the WESP outlet. The only sink for iodine between the two sampling points is the solution generated in the first HEME, which did contain over half a gram per liter of iodine; however, only 34.3 gallons of liquid accumulated in the unit during the test resulting only 1% of feed iodine accumulation. Solutions from the PBS and HEME 2 also had little impact on the iodine mass balance. This was expected given that the solution pH values were less than 9.5, which is too low to effectively remove iodine. Additional confirmation was provided by a sample taken downstream of HEME 2 which indicated iodine emission rates were similar to those at the PBS inlet (TCO/SCR outlet). The iodine mass balance in these tests is similar to that achieved in the C-106/AY-102 tests [26]. No iodine was detected in the particulate fraction and no more than 3% of the impinger catch was in the acidic impinger solutions, indicating that the iodine is emitted predominantly as a molecular gas (I<sub>2</sub>) as opposed to HI or particles.

## SECTION 7.0 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 AZ-102 feed composition. Tests were conducted at three bubbling rates over a nine-day period using feed yielding 545.6 g glass per liter. Over seventeen metric tons of feed were processed to produce about 6.7 metric tons of glass. Cold-cap-limited, steady-state production rates of 380, 650 and 900 kg/m<sup>2</sup>/day were attained for test segments with bubbling rates of 8, 40, and 65 lpm, respectively. Some foaming occurred at the lower bubbling rates 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<sup>2</sup>/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<sup>2</sup> vs. two bubblers in 1.2 m<sup>2</sup>), which may lead to lower large-scale glass production rates on a per unit melt surface area basis.

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 (1.26% of feed) was higher than 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 112,670 and comparable to other HLW tests conducted while using the Project-directed deluge cleaning procedure of the WESP.

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 SBS TSS concentrations were between 1000 and 2400 mg/l, whereas measured TDS values were about 50% 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, nitrite, sulfate, chloride, and ammonium. 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 about 864 gallons. The 1761 gallons of liquid that accumulated in the SBS during the test originated from the condensation of water from the melter feed.

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The glass product was close to the intended composition with little variation during testing. No macroscopic secondary phases were evident in the discharged product. No iodine and about 20% of the selenium in the feed were retained in the glass product. A good mass balance was achieved for iodine around the melter and SBS.

The completion of the Test Objectives for this work is summarized in Table 7.1.

## SECTION 8.0 REFERENCES

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**Table 2.1. Compositional Summary of Different Waste Streams and Blended Solids.**

Feed Constituent	AZ-102 Solids FRP02 (lb/day)	Recycle Stream PWD01 (lb/day)	Separation Factor (fraction remained)	Cs-Eluate CNP12 (lb/day)	Tc-Eluate TEP12 (lb/day)	Blended Solids HLP09b (lb/day)
Ag	7.68E+00	4.17E-21	1.00E+00	--	--	7.68E+00
Al	1.75E+03	1.77E+00	4.20E-01	5.29E-01	2.12E-02	7.36E+02
As	5.19E-01	1.21E-01	1.00E+00	--	--	6.40E-01
B	3.60E+01	3.11E+00	1.00E+00	6.66E-01	6.80E-02	3.98E+01
Ba	6.13E+00	1.64E-04	2.42E-01	--	--	1.48E+00
Be	1.18E-01	0.00E+00	1.00E+00	--	--	1.18E-01
Bi	9.70E-01	2.34E-04	1.00E+00	--	--	9.71E-01
Ca	4.19E+01	8.14E-02	9.88E-01	3.41E-02	2.32E-03	4.15E+01
Cd	2.97E+02	6.19E-04	8.27E-02	--	--	2.46E+01
Ce	8.56E+00	5.88E+00	7.72E-02	--	--	1.11E+00
Cl	4.24E+00	9.42E-02	7.95E-02	--	1.29E-02	3.57E-01
Co	6.82E-01	0.00E+00	1.00E+00	--	--	6.82E-01
Carbonate	5.27E+02	2.24E+00	1.31E-01	--	--	6.91E+01
Cr	2.11E+01	2.15E-01	1.52E-01	6.83E-02	3.32E-03	3.31E+00
Cs	6.82E-01	0.00E+00	1.15E-01	2.73E-01	--	3.52E-01
Cu	2.30E+00	2.37E-44	1.00E+00	2.90E-01	--	2.59E+00
F	8.96E+00	1.27E+00	8.25E-02	--	--	8.44E-01
Fe	2.19E+03	1.41E+00	9.94E-01	1.19E-01	2.22E-02	2.18E+03
Hg	2.01E-01	1.90E-05	1.00E+00	--	--	2.01E-01
K	5.14E+01	6.82E-01	9.29E-02	1.86E+00	4.15E-02	6.74E+00
La	8.09E+01	1.80E-02	9.85E-01	--	--	7.96E+01
Li	9.99E-02	8.15E-01	1.00E+00	--	--	9.15E-01
Mg	1.07E+01	7.28E-06	1.00E+00	--	3.32E-04	1.07E+01
Mn	5.60E+01	8.20E-02	9.99E-01	--	3.32E-04	5.60E+01
Mo	1.22E+00	0.00E+00	1.00E+00	--	--	1.22E+00
Na	7.29E+02	3.59E+02	1.15E-01	1.71E+01	3.32E-01	1.43E+02
Nd	2.96E+01	0.00E+00	1.00E+00	--	--	2.96E+01
Ni	8.84E+01	1.07E-01	9.83E-01	2.56E-01	2.65E-03	8.73E+01
Nitrite	3.13E+02	2.56E-01	7.84E-02	--	--	2.46E+01
Nitrate	7.86E+00	8.21E+02	7.77E-02	4.92E+01	--	1.14E+02
Hydroxide	1.08E+02	3.16E+01	5.97E-01	--	--	8.32E+01
Hydroxide(Bound)	5.74E+03	0.00E+00	7.68E-02	--	--	4.41E+02
Pb	1.63E+01	2.00E-02	1.00E+00	1.19E-01	--	1.64E+01
Pd	9.82E-01	1.95E-09	1.00E+00	--	--	9.82E-01
Phosphate	3.81E+01	5.01E-03	2.20E-01	5.23E-02 <sup>@</sup>	2.03E-03 <sup>@</sup>	8.43E+00
Pr	5.60E+00	0.00E+00	1.00E+00	--	--	5.60E+00
Rb	8.39E-02	0.00E+00	1.00E+00	--	--	8.39E-02
Rh	5.90E-01	0.00E+00	--	--	--	5.90E-01
Ru	2.63E+00	0.00E+00	--	--	--	0.00E+00
Sb	7.17E-02	0.00E+00	--	--	--	0.00E+00
Se	1.68E-01	0.00E+00	--	--	--	0.00E+00
Si	1.11E+02	6.46E+00	9.97E-01	4.61E-01	9.29E-02	1.18E+02
Sulfate	1.36E+02	2.46E+01	7.69E-02	--	--	1.23E+01
Sr	2.39E+00	0.00E+00	9.58E-01	--	--	2.29E+00
Ta	3.94E-02	0.00E+00	--	--	--	0.00E+00
Te	9.30E-01	0.00E+00	--	--	--	0.00E+00
Th	4.25E+00	0.00E+00	--	--	--	0.00E+00
Ti	6.42E-01	1.39E-03	1.00E+00	--	--	6.43E-01
Tl	3.94E-02	0.00E+00	--	--	--	0.00E+00
TOC	3.90E+01	0.00E+00	7.67E-02	--	--	2.99E+00
U	2.33E+02	0.00E+00	--	6.14E-01	0.00E+00	6.14E-01
V	5.02E-01	0.00E+00	--	--	--	0.00E+00
Y	2.06E+00	0.00E+00	--	--	--	0.00E+00
Zn	1.47E+00	4.71E-01	1.00E+00	5.12E-02	3.32E-04	2.00E+00
Zr	3.26E+02	3.13E-01	9.99E-01	--	--	3.26E+02
TOTAL	1.30E+04	1.26E+03 <sup>#</sup>	--	7.16E+01	6.02E-01	4.69E+03

\* Analytes with undetermined separation factors are omitted. <sup>#</sup> 1.28E+03 if H<sup>+</sup> is included. <sup>@</sup>Converted from P. "--" indicates empty data field

**Table 2.2. Compositional Summary (Oxide Basis) of the HLW Simulant, Glass Additives, Target Test Glass, and the Reference Glass (HLW98-80).**

	AZ-102 HLW Simulant	Glass Former (as wt% of glass)	Melter Test Target Glass	HLW98-80
Ag <sub>2</sub> O	--	--	--	0.034%
Al <sub>2</sub> O <sub>3</sub>	23.01%	--	5.58%	5.590%
B <sub>2</sub> O <sub>3</sub>	2.12%	12.00%	12.51%	12.529%
CaO	0.96%	--	0.23%	0.233%
CdO	0.47%	--	0.11%	0.114%
Cs <sub>2</sub> O	0.21%	--	0.05%	--
Fe <sub>2</sub> O <sub>3</sub>	51.58%	--	12.51%	12.530%
I	0.42%	--	0.10%	--
K <sub>2</sub> O	0.13%	--	0.03%	0.032%
La <sub>2</sub> O <sub>3</sub>	1.55%	--	0.37%	0.376%
Li <sub>2</sub> O	0.03%	3.25%	3.26%	3.260%
MgO	0.30%	--	0.07%	0.073%
MnO*	1.47%	--	0.36%	0.357%
Na <sub>2</sub> O	3.18%	11.25%	12.02%	12.033%
Nd <sub>2</sub> O <sub>3</sub>	0.68%	--	0.16%	0.165%
NiO	1.84%	--	0.45%	0.447%
PbO	0.29%	--	0.07%	0.070%
P <sub>2</sub> O <sub>5</sub>	0.10%	--	0.03%	0.024%
SiO <sub>2</sub>	4.17%	47.25%	48.26%	48.308%
SO <sub>3</sub>	0.17%	--	0.04%	0.041%
ZnO	0.04%	2.00%	2.01%	2.012%
ZrO <sub>2</sub>	7.29%	--	1.77%	1.772%
TOTAL	100.00%	75.75%	100.00%	100.000%
<i>Volatiles (g/100 g oxide)</i>				
Carbonate	1.145	--	--	--
Nitrite	0.407	--	--	--
Nitrate	1.883	--	--	--
TOC	0.050	--	--	--

\*MnO<sub>2</sub> in Reference [6] "--" indicates empty data field

**Table 2.3. Composition of Melter Feed to Produce 1 Metric Ton of Target Glass from AZ-102 HLW Simulant (20 wt% suspended solids).**

AZ-102 HLW Simulant		Glass-Forming Additives	
Starting Materials	Target Weight (kg)*	Starting Materials	Target Weight (kg)
Al(OH) <sub>3</sub>	89.85	--	--
H <sub>3</sub> BO <sub>3</sub>	9.24	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> ·10H <sub>2</sub> O	331.99
Ca(OH) <sub>2</sub>	3.14	--	--
CdO	1.14	--	--
CsOH (50% solution)	1.06	--	--
Fe(OH) <sub>3</sub> (13% slurry)	1284.59	--	--
KI	1.22	--	--
KNO <sub>3</sub>	0.71	--	--
La(OH) <sub>3</sub> ·3H <sub>2</sub> O	5.67	--	--
Li <sub>2</sub> CO <sub>3</sub>	0.20	Li <sub>2</sub> CO <sub>3</sub>	82.44
Mg(OH) <sub>2</sub>	1.05	--	--
MnO <sub>2</sub>	4.40	--	--
NaOH	5.87	Na <sub>2</sub> CO <sub>3</sub>	102.06
Nd <sub>2</sub> O <sub>3</sub>	1.67	--	--
Ni(OH) <sub>2</sub>	5.74	--	--
FePO <sub>4</sub> ·xH <sub>2</sub> O (80%)	0.67	--	--
PbO	0.72	--	--
SiO <sub>2</sub>	10.21	SiO <sub>2</sub>	477.27
Na <sub>2</sub> SO <sub>4</sub>	0.74	--	--
ZnO	0.10	ZnO	20.20
Zr(OH) <sub>4</sub> ·xH <sub>2</sub> O (50%)	45.69	--	--
NaNO <sub>2</sub>	1.52	--	--
NaNO <sub>3</sub>	5.70	--	--
H <sub>2</sub> C <sub>2</sub> O <sub>4</sub> ·2H <sub>2</sub> O	0.64	--	--
Water	102.00	--	--
TOTAL	1583.54	TOTAL	1013.96
--	--	FEED TOTAL	2597.50

\*Target weight values have been adjusted based on assay information of starting materials.  
"--" indicates empty data field

**Table 2.4. Properties of AZ-102 Melter Feed Samples.**

Test Segment	Date	Name	Wt% Water	Density (g/ml)	Glass Yield		pH	Yield Stress (Pa)	Viscosity (Poise)		
					kg/kg	g/l			@1/s	@10/s	@100/s
A	11/18/02	J12-F-97A	54.2	1.42	0.362	513.2	10.50	NA	NA	NA	NA
	11/19/02	J12-F-129A	54.6	1.40	0.388	544.6	10.53	8.8	46.74	5.98	0.92
	11/20/02	K12-F-12A	54.5	1.41	0.386	544.8	10.53	NA	NA	NA	NA
B	11/21/02	K12-F-43A	54.0	1.41	0.395	556.8	10.45	NA	NA	NA	NA
	11/21/02	K12-F-45A	54.0	1.41	0.386	544.8	10.69	NA	NA	NA	NA
	11/22/02	K12-F-75A	53.9	1.42	0.381	540.5	10.32	NA	NA	NA	NA
	11/23/02	K12-F-110A	55.0	1.40	0.359	503.2	10.36	NA	NA	NA	NA
C	11/24/02	K12-F-143A	53.9	1.42	0.398	565.7	10.27	9.6	31.71	4.77	0.67
	11/25/02	L12-F-25A	54.0	1.41	0.394	555.0	10.26	NA	NA	NA	NA
	11/26/03	L12-F-62A	52.6	1.45	0.405	587.3	10.32	NA	NA	NA	NA
Average			54.1	1.42	0.386	545.6	10.43	9.2	39.23	5.38	0.80

NA – Not analyzed

**Table 2.5. XRF Analyzed Compositions for Vitrified DM1200 Melter Feed Samples.**  
(wt%)

Element	Target	J12-F-97A	J12-F-129A	K12-F-12A	K12-F-43A	K12-F-75A	K12-F-110A	K12-F-143A	L12-F-25A	L12-F-62A	Average	%Dev
Al <sub>2</sub> O <sub>3</sub>	5.58	7.59	7.72	7.52	6.67	6.64	6.32	6.06	6.01	5.94	6.72	20.39
B <sub>2</sub> O <sub>3</sub> *	12.51	12.51	12.51	12.51	12.51	12.51	12.51	12.51	12.51	12.51	12.51	NC
CaO	0.23	0.41	0.39	0.38	0.37	0.37	0.36	0.36	0.37	0.37	0.37	NC
CdO	0.11	0.13	0.14	0.15	0.14	0.14	0.13	0.13	0.14	0.14	0.14	NC
Cs <sub>2</sub> O	0.05	0.04	0.05	0.06	0.06	0.06	0.05	0.06	0.06	0.06	0.05	NC
Fe <sub>2</sub> O <sub>3</sub>	12.51	12.88	12.75	12.52	12.49	12.21	12.14	11.62	11.77	11.75	12.24	-2.21
I	0.10	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	NC
K <sub>2</sub> O	0.03	0.14	0.15	0.14	0.13	0.12	0.13	0.12	0.13	0.13	0.13	NC
La <sub>2</sub> O <sub>3</sub>	0.37	0.49	0.48	0.46	0.47	0.46	0.46	0.45	0.46	0.43	0.46	NC
Li <sub>2</sub> O*	3.26	3.26	3.26	3.26	3.26	3.26	3.26	3.26	3.26	3.26	3.26	NC
MgO	0.07	0.10	0.13	0.12	0.13	0.11	0.10	0.09	0.08	0.07	0.10	NC
MnO	0.36	0.38	0.38	0.36	0.38	0.36	0.35	0.35	0.35	0.35	0.36	NC
Na <sub>2</sub> O	12.02	11.61	11.65	12.32	11.93	12.61	11.63	11.72	11.16	10.64	11.70	-2.70
Nd <sub>2</sub> O <sub>3</sub>	0.16	0.18	0.18	0.18	0.17	0.17	0.17	0.16	0.16	0.17	0.17	NC
NiO	0.45	0.45	0.44	0.44	0.42	0.41	0.40	0.39	0.40	0.40	0.41	NC
P <sub>2</sub> O <sub>5</sub>	0.03	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.04	0.04	NC
PbO	0.07	0.06	0.07	0.06	0.07	0.06	0.06	0.06	0.06	0.06	0.06	NC
SiO <sub>2</sub>	48.26	45.13	45.06	45.00	46.32	46.17	47.64	48.55	48.83	49.48	46.91	-2.81
SO <sub>3</sub>	0.04	0.03	0.06	0.05	0.06	0.06	0.06	0.06	0.08	0.08	0.06	NC
TiO <sub>2</sub>	<0.01	0.11	0.11	0.10	0.09	0.09	0.09	0.08	0.09	0.09	0.09	NC
ZnO	2.01	1.98	1.94	1.91	1.89	1.84	1.84	1.76	1.79	1.79	1.86	-7.51
ZrO <sub>2</sub>	1.77	2.49	2.50	2.41	2.39	2.32	2.26	2.18	2.26	2.26	2.34	32.27
Sum	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

**Table 3.1. Summary of DM1200 AZ-102 Test Conditions and Results.**

Test Segment		A	B	C
Time	Feed Start	11/18/02 12:00	11/21/02 13:00	11/24/02 13:02
	Feed End	11/21/02 13:00	11/24/02 13:01	11/27/02 13:03
	Interval	73 hr	72 hr	72 hr
Water Feeding for Cold Cap		1.0 hr	NA	NA
Slurry Feeding		72 hr	72 hr	72 hr
Cold Cap Burn-Off		NA	NA	2.4 hr
Bubbling Rate		8 lpm	40 lpm	65 lpm
Feed	Used	3526 kg	5780 kg	8042 kg
	Glass yield <sup>#</sup>	550 g/l	550 g/l	550 g/l
		0.385 kg/kg	0.385 kg/kg	0.385 kg/kg
	Average Rate	49.0 kg/hr	80.3 kg/hr	111.7 kg/hr
Glass Produced	Poured	1277 kg	2249 kg	3222 kg
	Average Rate <sup>\$</sup>	355 kg/m <sup>2</sup> /day	625 kg/m <sup>2</sup> /day	895 kg/m <sup>2</sup> /day
	Average Rate <sup>*</sup>	377 kg/m <sup>2</sup> /day	618 kg/m <sup>2</sup> /day	860 kg/m <sup>2</sup> /day
	Steady State Rate <sup>*</sup>	380 kg/m <sup>2</sup> /day	650 kg/m <sup>2</sup> /day	900 kg/m <sup>2</sup> /day
	Average Power Use	5.1 kW.hr/ kg glass	4.2 kW.hr/ kg glass	3.5 kW.hr/ kg glass

# - 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 3.2. 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	1147	1089	1193	1147	1114	1168	1148	1116	1171
		15.5" from floor E	1141	1077	1207	1143	1108	1164	1143	1113	1170
		18" from floor E	1144	1084	1206	1144	1108	1166	1144	1114	1167
		27" from floor E	958	313	1181	991	807	1131	956	698	1082
		13" from floor W	1151	1129	1187	1147	1121	1169	1151	1118	1169
		15.5" from floor W	1150	1119	1199	1146	1120	1173	1148	1116	1166
		18" from floor W	1147	1120	1207	1146	1120	1177	1146	1114	1166
		27" from floor W	975	459	1166	1014	766	1136	988	697	1097
	Plenum	8" below ceiling	532	403	723	612	529	682	566	484	644
		17" below ceiling	525	385	716	607	512	676	563	486	651
		Exposed	542	396	723	638	517	729	603	476	698
	Discharge	TC 1	978	847	1041	994	906	1042	1009	908	1052
		TC 2	1029	976	1088	1051	1013	1085	1059	1020	1095
		Air Flow	38	11	71	46	37	60	57	42	70
		Riser	1023	879	1121	1076	1029	1128	1106	1072	1140
	Electrode	East	1094	1045	1145	1111	1073	1130	1138	1121	1150
		West	1059	1014	1128	1091	1036	1117	1114	1087	1127
		Bottom	1031	1012	1065	1048	1016	1074	1082	1066	1096
	Film Cooler	Added Air	82	79	91	83	82	85	84	82	85
		Outlet	353	62	474	414	71	466	369	72	463
	Glass	Density (g/cc)	2.37	2.02	2.45	2.33	2.26	2.40	2.30	2.23	2.37
		Level (" from floor)	27.6	25.9	29.2	27.7	27.0	28.3	27.7	26.7	28.4
		Resistance (ohms)	0.113	0.100	0.137	0.105	0.098	0.114	0.105	0.099	0.112
Differential Pressure (inches water)	Transition line	1.84	0.60	5.45	2.23	0.90	4.31	2.36	0.49	7.44	
	Film Cooler	1.04	0.00	2.70	1.27	0.00	2.66	1.40	0.00	4.70	
Electrodes	Current (A)	922.4	708.8	1002.5	1118.3	958.1	1126.7	1195.6	1125.8	1206.4	
	Voltage (V)	104.1	78.0	129.1	117.1	104.9	124.2	125.6	117.7	129.7	
	Power (kW)	96.1	55.3	129.4	130.9	100.5	139.9	150.2	132.5	156.5	
Lance Bubblers	1	Rate (lpm)	2.9	1.3	5.0	16.4	2.6	23.8	30.0	19.4	38.5
		Temp. (°C)	1136	1099	1165	1133	1111	1153	1132	1116	1150
	2	Rate (lpm)	3.6	1.5	5.2	19.5	6.6	24.4	31.5	19.9	39.2
		Temp. (°C)	1140	1045	1192	1138	1116	1161	1139	1119	1154
Total Bubbling (lpm)		7.9	3.0	8.2	37.4	10.6	40.4	63.0	41.8	67.0	

"-" signifies empty data field

**Table 4.1. Measured Off Gas System Parameters.**

Test Segment		A			B			C		
		Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
Melter	Press. at Level Det. Port ("water)	-4.1	-6.9	0.5	-4.0	-6.3	-0.8	-3.8	-5.7	0.3
	Press. at Instrument Port ("water)	-4.2	-7.1	0.4	-4.1	-6.5	-1.0	-3.9	-5.9	0.2
	Control Air Flow Rate (scfm)	30.7	0.0	69.5	29.9	0.0	70.5	25.9	0.0	57.5
SBS	Differential Pressure ("water)	43.9	38.5	48.8	45.2	40.7	48.4	46.6	42.5	49.2
	Inlet Gas Pressure ("water)	-7.1	-13.0	-2.9	-7.6	-11.8	-4.8	-7.7	-12.0	-3.8
	Outlet Gas Pressure ("water)	-48.7	-55.1	-46.2	-50.8	-54.7	-46.0	-52.2	-57.7	-48.1
	Inlet Gas Temp. (°C)	253	96	382	302	157	338	295	159	348
	Outlet Gas Temp. (°C)	38.8	33.9	49.4	39.5	35.7	42.7	39.4	36.7	43.2
	Chilled Water Inlet Temp (°C)	13.7	7.8	17.8	14.4	8.9	18.4	14.9	9.4	19.2
	Chilled Water Outlet Temp (°C)	19.9	16.2	27.1	20.9	18.0	24.3	33.7	20.0	40.6
	Submerged 48" Temp (°C)	39.4	33.7	52.4	40.2	36.3	44.7	40.1	37.1	44.9
	Submerged 60" Temp (°C)	39.3	33.7	52.4	40.1	36.3	44.6	40.0	37.0	44.7
	Submerged 72" Temp (°C)	40.0	33.9	53.5	40.7	36.6	45.3	40.5	37.8	45.1
	Submerged 78" Temp (°C)	39.6	34.2	53.4	40.5	36.5	44.8	40.4	37.7	45.1
	Recirc. pump discharge Temp (°C)	38.3	33.7	45.7	38.9	35.5	41.4	38.8	36.5	41.3
	Heat Exchanger Outlet Temp (°C)	35.4	23.1	40.9	33.4	29.4	40.7	29.4	26.1	34.0
	Chilled Water Flow (gal/min)	5.9	2.4	29.7	3.6	2.4	11.7	2.5	2.3	3.2
	Heat Exchanger Flow (gal/min)	4.4	0.6	27.7	9.2	1.5	20.6	16.7	10.5	35.4
	Recirc. Pump discharge Pressure	37.7	30.4	40.1	37.7	31.1	40.2	37.8	31.2	40.1
	Inner C. Coil W. Inlet Temp (°C)	32.2	18.0	40.4	27.2	22.3	39.7	22.2	17.6	27.5
	Inner C. Coil W. Outlet Temp(°C)	36.1	27.7	40.8	34.5	30.4	41.2	32.3	29.6	35.8
	Inner C. Coil W. Flow (gal/min)	24.6	24.0	25.2	24.5	23.7	25.1	24.3	23.7	24.8
WESP	Differential Pressure ("water)	2.3	1.7	3.5	2.3	1.5	2.9	2.2	1.4	2.9
	Inlet gas Temp. (°C)	39.6	34.6	51.2	40.8	37.5	43.5	40.4	37.8	44.1
	Outlet gas Temp. (°C)	40.3	23.5	47.7	41.1	23.3	43.4	41.5	22.8	44.1
HEME #1, Outlet Gas Temp. (°C)		38.3	32.1	45.2	39.2	33.7	41.1	39.3	33.2	41.8
HEPA 1	Differential Pressure ("water)	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.3
	Outlet Gas Temp. (°C)	61.2	60.4	62.6	61.3	60.2	61.8	61.6	60.5	62.0
PAXTON 1 Outlet Gas Temp. (°C)		82.4	81.7	84.7	83.7	81.6	85.4	84.0	82.2	86.0
TCO-SCR Heater Inlet Gas Temp. (°C)		82.2	81.2	84.2	83.5	81.4	84.9	83.5	81.8	85.7
TCO	Inlet Gas Temp. (°C)	477	469	491	478	462	483	478	466	488
	Differential Pressure ("water)	3.0	2.7	3.5	3.0	2.6	3.3	2.9	2.4	3.3
SCR	Inlet Gas Temp. (°C)	384	370	391	384	375	390	380	369	387
	Outlet Gas Temp. Right (°C)	363	351	369	363	354	370	361	350	368
	Outlet Gas Temp. Left (°C)	348	341	356	349	342	355	349	342	353
	Differential Pressure ("water)	6.2	5.5	7.3	6.2	5.3	6.7	6.0	4.9	6.7
	Post Outlet Gas Temp. (°C)	331	326	339	332	324	337	331	323	335
PBS	Inlet Gas Temp. (°C)	307	300	312	307	298	312	306	296	310
	PBS Sump Temp. (°C)	22.9	20.3	30.0	23.9	20.8	26.5	24.5	22.2	27.4
	Differential Pressure ("water)	2.9	2.1	4.2	2.7	1.9	18.5	2.6	1.5	3.2
HEME #2	Inlet Gas Temp. (°C)	25.1	23.4	31.2	26.0	19.6	28.0	26.7	24.9	28.6
	Outlet Gas Temp. (°C)	27.3	25.2	33.2	27.9	23.4	29.8	28.6	27.1	30.9
Exhaust Stack Absolute Pressure ("water)		-7.9	-8.1	-7.6	-7.8	-8.2	-6.8	-8.1	-8.3	-7.8

"--" signifies blank data field

**Table 4.2. Nitrogen Oxides and Carbon Monoxide Destruction across TCO-SCR Catalytic Unit.**

Test Segment	--	Input (mol/hr)	Output (mol/hr)	NO <sub>x</sub> , CO Reduction (%)	DF
A	N <sub>2</sub> O	0.031	0.017	--	--
	NO	1.681	0.122	--	--
	NO <sub>2</sub>	0.092	0.080	--	--
	Total NO <sub>x</sub>	1.803	0.219	87.8	8.2
	CO	<0.015	<0.016	NC	NC
	CO <sub>2</sub>	45.9	25.3	--	--
B	N <sub>2</sub> O	0.062	0.036	--	--
	NO	1.816	0.096	--	--
	NO <sub>2</sub>	0.088	0.020	--	--
	Total NO <sub>x</sub>	1.966	0.152	92.2	12.9
	CO	0.065	<0.016	>75.9	>4.1
	CO <sub>2</sub>	68.1	44.0	--	--
C	N <sub>2</sub> O	0.067	0.036	--	--
	NO	2.841	0.311	--	--
	NO <sub>2</sub>	0.132	0.089	--	--
	Total NO <sub>x</sub>	3.040	0.436	85.7	7.0
	CO	0.075	<0.016	>79.2	>4.8
	CO <sub>2</sub>	100.2	71.6	--	--

NC – Not calculated

"--" signifies blank data field

**Table 4.3. Ammonia Slippage from TCO-SCR Catalytic Unit.**

Test Segment	--	Input (mol/hr)	Output (mol/hr)	NH <sub>3</sub> slippage (%)
A	NH <sub>3</sub> (in exhaust)	0.028	--	--
	NH <sub>3</sub> injected	2.236	--	--
	Total NH <sub>3</sub>	2.263	0.104	4.6
B	NH <sub>3</sub> (in exhaust)	0.065	--	--
	NH <sub>3</sub> injected	2.118	--	--
	Total NH <sub>3</sub>	2.183	0.041	1.9
C	NH <sub>3</sub> (in exhaust)	0.084	--	--
	NH <sub>3</sub> injected	3.325	--	--
	Total NH <sub>3</sub>	3.409	0.039	1.1

"--" signifies blank data field

**Table 4.4. Listing of Samples from SBS Blow-Downs.**

Test Segment	Date	Name	pH	Blow-down volume (gal)	Cumulative blow-down volume (gal)	
A	11/18/02	J12-S-96A	8.22	40.03	40.03	
	11/19/02	J12-S-111A	8.30	40.33	80.36	
		J12-S-123A	8.49	40.04	120.40	
		J12-S-130A	8.76	40.00	160.40	
	11/20/02	J12-S-143A	8.66	39.60	200.00	
		J12-S-155A	8.55	40.00	240.00	
		K12-S-12A	8.62	40.00	280.00	
	B	11/21/02	K12-S-24A	8.52	40.05	320.05
			K12-S-38A	8.48	40.04	360.09
		11/22/02	K12-S-43A	8.54	40.02	400.11
K12-S-56A			8.48	40.06	440.17	
K12-S-60A			8.44	40.02	480.19	
K12-S-74A			8.44	40.06	520.25	
11/23/02		K12-S-76A	8.50	40.00	560.25	
		K12-S-80A	8.46	40.06	600.31	
		K12-S-89A	8.46	40.05	640.36	
		K12-S-94A	8.63	40.12	680.48	
11/24/02		K12-S-105A	8.61	40.01	720.49	
		K12-S-109A	8.55	39.59	760.08	
		K12-S-112A	8.53	40.44	800.52	
		K12-S-122A	8.47	39.90	840.42	
		K12-S-126A	8.48	40.05	880.47	
		K12-S-138A	8.46	40.10	920.57	
C		11/25/02	K12-S-141A	8.45	39.49	960.06
			K12-S-143A	8.39	40.00	1000.06
	K12-S-147A		8.32	40.50	1040.56	
	L12-S-8A		8.36	40.02	1080.58	
	L12-S-11A		8.39	40.14	1120.72	
	L12-S-13A		8.33	40.03	1160.75	
	11/26/02	L12-S-23A	8.36	40.03	1200.78	
		L12-S-27A	8.76	40.01	1240.79	
		L12-S-29A	8.35	40.02	1280.81	
		L12-S-39A	8.31	39.80	1320.61	
		L12-S-42A	8.38	39.96	1360.57	
		L12-S-44A	8.25	40.00	1400.57	
		L12-S-46A	8.42	39.99	1440.56	
		L12-S-58A	8.29	40.11	1480.67	
		L12-S-61A	8.37	40.05	1520.72	
		L12-S-63A	8.26	40.06	1560.78	
	11/27/02	L12-S-66A	8.27	39.78	1600.56	
		L12-S-74A	8.14	40.03	1640.59	
L12-S-76A		8.23	40.03	1680.62		
L12-S-79A		8.15	40.04	1720.66		
L12-S-89A		8.14	40.00	1760.66		
		L12-S-95A*	8.37	367.89	2128.55	

\* Sample from drained SBS.

**Table 4.5. Analytical Results for Selected SBS and WESP Blow-Down Fluids (mg/l).**

I.D.	K12-S-24A			K12-S-126A			L12-S-89A			L12-W-95A			L12-W-95B		
Glass (kg)	1119.3			3371.2			6748.0			6748.0			6748.0		
pH	8.52			8.48			8.14			7.68			8.35		
--	Sus*	Dis.#	Total	Sus.	Dis.	Total	Sus.	Dis.	Total	Sus.	Dis.	Total	Sus.	Dis.	Total
Total	1000	1420	2420	2168	3320	5488	2328	3376	5704	<1	706	706	<1	320	320
Al	39.67	1.23	40.89	78.78	1.53	80.31	81.75	1.93	83.69	NA	0.89	0.89	NA	0.65	0.65
B	4.96	200.6	205.6	19.17	525.0	544.2	26.47	586.6	613.1	NA	43.42	43.42	NA	14.40	14.40
Ba	0.10	0.02	0.12	0.10	0.02	0.12	0.09	0.02	0.11	NA	0.05	0.05	NA	0.03	0.03
Ca	8.16	9.54	17.71	7.90	3.10	11.00	7.16	2.56	9.72	NA	30.73	30.73	NA	31.66	31.66
Cd	1.31	<0.01	1.31	3.65	<0.01	3.65	4.32	<0.01	4.32	NA	0.35	0.35	NA	0.14	0.14
Cr	0.21	0.19	0.40	3.17	0.37	3.55	4.02	0.26	4.28	NA	0.17	0.17	NA	0.05	0.05
Cs	0.66	1.21	1.87	3.22	2.63	5.85	4.02	3.07	7.09	NA	5.66	5.66	NA	2.40	2.40
Cu	0.09	<0.01	0.09	0.09	0.01	0.09	0.06	<0.01	0.06	NA	0.06	0.06	NA	0.01	0.01
Fe	180.38	0.04	180.4	360.7	0.37	361.1	348.6	0.52	349.2	NA	0.01	0.01	NA	<0.01	<0.01
K	0.60	5.10	5.70	1.28	5.92	7.21	1.21	4.98	6.19	NA	7.30	7.30	NA	5.08	5.08
La	NA	0.04	0.04	NA	0.142	0.14	NA	0.164	0.16	NA	<0.03	<0.03	NA	<0.03	<0.03
Li	1.38	27.74	29.12	4.05	58.93	62.98	4.36	52.45	56.81	NA	8.29	8.29	NA	4.29	4.29
Mg	2.16	4.09	6.26	3.53	2.60	6.12	3.34	2.05	5.39	NA	6.61	6.61	NA	6.50	6.50
Mn	0.73	0.02	0.75	1.59	0.07	1.65	1.62	0.02	1.64	NA	0.07	0.07	NA	0.02	0.02
Na	8.33	287.8	296.1	38.35	638.3	676.6	47.91	574.1	622.0	NA	50.97	50.97	NA	45.26	45.26
Ni	5.87	0.04	5.91	11.65	0.21	11.86	10.62	0.17	10.79	NA	0.05	0.05	NA	0.01	0.01
P	0.36	<0.07	0.36	1.43	0.38	1.80	0.94	0.31	1.24	NA	<0.07	<0.07	NA	<0.07	<0.07
Pb	0.56	0.33	0.89	1.69	0.88	2.57	84.68	0.93	85.60	NA	0.05	0.05	NA	<0.02	<0.02
Sb	0.29	<0.03	0.29	0.35	<0.03	0.35	0.11	<0.03	0.11	NA	<0.03	<0.03	NA	0.17	0.17
Si	175.96	6.94	182.9	392.8	8.21	401.0	443.6	9.19	452.8	NA	4.12	4.12	NA	3.82	3.82
Sr	0.25	0.04	0.28	0.18	0.18	0.35	0.22	0.04	0.25	NA	0.24	0.24	NA	0.19	0.19
Ti	1.39	<0.01	1.39	2.45	0.03	2.49	2.36	0.04	2.40	NA	0.01	0.01	NA	<0.01	<0.01
Zn	31.20	0.14	31.35	61.15	0.17	61.32	63.67	0.19	63.87	NA	0.19	0.19	NA	0.04	0.04
Zr	7.76	0.01	7.77	14.35	0.08	14.43	16.59	0.07	16.65	NA	<0.01	<0.01	NA	<0.01	<0.01
F	NA	40.83	40.83	NA	51.67	51.67	NA	37.53	37.53	NA	3.88	3.88	NA	3.01	3.01
Cl	NA	46.72	46.72	NA	111.1	111.1	NA	122.8	122.8	NA	75.32	75.32	NA	46.29	46.29
I	NA	140.4	140.4	NA	454.4	454.4	NA	410.6	410.6	NA	16.07	16.07	NA	0.00	0.00
NH <sub>4</sub> <sup>+</sup>	NA	10.8	10.80	NA	25.4	25.40	NA	13.8	13.80	NA	96.9	96.9	NA	6.40	6.40
Nitrite	NA	52.80	52.80	NA	52.20	52.20	NA	67.07	67.07	NA	65.78	65.78	NA	3.52	3.52
Nitrate	NA	13.82	13.82	NA	6.36	6.36	NA	10.93	10.93	NA	454.0	454.0	NA	31.95	31.95
Sulfate	NA	152.2	152.2	NA	260.0	260.0	NA	251.7	251.7	NA	204.1	204.1	NA	100.0	100.0

\* Suspended  
# Dissolved  
NA - Not analyzed  
"--" signifies empty data field

**Table 4.6. Comparison of Characteristics of SBS Fluids for Various Feed Types.**

Test	Sample Name	TSS (mg/l)	TDS (mg/l)	pH	Particle Characteristics			
					mv ( $\mu\text{m}$ )	mn ( $\mu\text{m}$ )	ma ( $\mu\text{m}$ )	ps @ 50%
AZ-102	L12-S-89A	2328	3376	8.14	11.32	0.66	3.14	7.40
C-106/AY-102 [26]	O12-S-33A	1944	4604	7.24	5.09	0.52	1.64	0.44
LAW B1 [28]	H12-S-113A	260	1152	6.89	6.30	0.50	1.73	3.44
	I12-S-37A	240	1832	6.37	7.40	0.48	1.51	3.05
LAW C1 [19]	12R-S-61A	216	1932	7.30	11.22	0.54	2.30	5.71
LAW A1 [27]	12V-S-87A	244	6784	NA	6.02	0.50	1.36	2.73

mv: mean size in term of volume statistics

mn: mean size in term of number statistics

ma: mean size in term of surface area statistics

ps@50%: particle size at 50% volume of particles passed.

**Table 4.7. WESP, PBS, and HEME Blow-Down Liquids.**

--	Date	Name	pH	Blow-down volume (gal)	Cumulative blow-down volume (gal)
<b>WESP</b>	11/19/02	J12-W-115A	7.75	49.03	49.00
		J12-W-115B	7.56	41.05	90.08
	11/20/02	J12-W-147A	8.39	45.99	136.07
		J12-W-147B	8.03	44.18	180.25
	11/21/02	K12-W-28A	8.32	44.20	224.45
		K12-W-28B	8.24	39.19	263.64
	11/22/02	K12-W-62A	7.88	53.53	317.17
		K12-W-62B	8.05	39.15	356.32
	11/23/02	K12-W-95A	8.20	56.11	412.43
		K12-W-95B	8.22	40.40	452.83
	11/24/02	K12-W-127A	8.15	49.60	502.43
		K12-W-127B	8.17	39.00	541.43
	11/25/02	L12-W-13A	8.29	49.29	590.72
		L12-W-13B	8.07	40.11	4630.83
	11/26/02	L12-W-46A	8.32	40.85	671.68
		L12-W-46B	7.94	49.15	720.83
	11/27/02	L12-W-95A	7.68	65.08	785.91
		L12-W-95B	8.35	37.68	823.59
<b>PBS</b>	11/18/02	J12-P-96A	9.39	18.81	18.81
	11/19/02	J12-P-111A	9.16	34.98	53.79
		J12-P-126A	9.37	18.15	71.94
	11/20/02	J12-P-139A	9.08	35.58	107.52
		J12-P-155A	8.93	30.78	138.30
	11/21/02	K12-P-24A	8.93	36.29	174.59
		K12-P-40A	9.18	22.32	175.53
	11/22/02	K12-P-56A	9.30	36.69	212.22
		K12-P-62A	9.30	127.21	339.43
		K12-P-79A	9.19	18.03	340.18
	11/23/02	K12-P-89A	9.05	32.02	372.20
		K12-P-105A	9.06	23.39	395.59
	11/24/02	K12-P-122A	8.94	36.57	432.16
		K12-P-137A	9.06	22.56	454.72
	11/25/02	K12-P-146A	8.9	33.44	488.16
		L12-P-13A	9.06	26.12	514.28
		L12-P-29A	9.22	16.78	531.06
	11/26/02	L12-P-42A	9.42	29.69	560.75
L12-P-62A		9.06	17.93	578.68	
11/27/02	L12-P-74A	9.47	31.10	609.78	
<b>HEME 1</b>	11/27/02	L12-H1-95A	7.05	34.27	34.27
<b>HEME 2</b>	11/21/02	K12-H2-43A	7.98	13.56	13.56
		K12-H2-141A	8.06	11.95	25.51
	11/27/02	L12-H2-95A	8.02	43.09	68.60

"--" signifies empty data field

**Table 4.8. Anion Concentration in PBS and HEME Blow-Down Samples (mg/l).**

--	Sample	pH	F	Cl	NH <sub>4</sub> <sup>+</sup>	I	Nitrite	Nitrate	Sulfate
PBS	L12-P-74A	9.47	16.33	46.41	275.5	15.6	73.26	3.67	3.97
HEME 1	L12-H1-95A	7.05	4.95	94.66	17.5	533.0	235.5	2505	194.7
HEME 2	L12-H2-95B	8.02	3.24	51.88	26.26	579.9	272.7	3404	59.62

"--" signifies empty data field

**Table 4.9. Upper Estimates of Accumulations in Off-Gas Liquids.**

Analyte	Feed (kg)	SBS			WESP			HEME 1		PBS		HEME 2	
		Mass (g)	% Feed	% Feed calculated from emissions data	Mass (g)	% Feed	% Feed calculated from emissions data	Mass (g)	% Feed	Mass (g)	% Feed	Mass (g)	% Feed
Al	199.2	552	0.3	1.4	2	< 0.1	< 0.1	NA	NA	NA	NA	NA	NA
B	261.9	3675	1.4	2.3	90	< 0.1	< 0.1						
Ca	11.1	104	0.9	2.2	98	0.9	< 0.1						
Cd	6.6	25	0.4	1.6	1	< 0.1	< 0.1						
Cs	3.2	40	1.3	3.5	13	0.4	0.3						
Fe	590.2	2401	0.4	1.3	0	< 0.1	< 0.1						
K	1.7	51	3.1	3.4	19	1.2	0.1						
Li	102.2	401	0.4	0.7	20	< 0.1	< 0.1						
Mg	2.8	48	1.7	4.2	21	0.7	< 0.1						
Mn	18.8	11	0.1	0.6	0	< 0.1	< 0.1						
Na	601.7	4300	0.7	1.3	151	< 0.1	< 0.1						
Ni	23.9	77	0.3	1.3	0	< 0.1	< 0.1						
P	0.9	9	1.0	3.5	0	< 0.1	< 0.1						
Pb	4.4	240	5.5	1.8	0	< 0.1	< 0.1						
Si	1522.1	2795	0.2	1.0	12	< 0.1	< 0.1						
Zn	109.0	422	0.4	1.4	0	< 0.1	< 0.1						
Zr	88.4	105	0.1	1.2	0	< 0.1	< 0.1						
I	6.7	2711	40.2	0.6	25	0.4	< 0.1	69	1.0	36	0.5	151	2.2
S	1.1	1790	165.4	65.1	476	44	10.4	25	2.3	3	0.3	16	1.4
Nitrite + Nitrate	32.4	547.8	1.7	NC	868	2.7	NC	357	1.1	178	0.6	958	3.0

NA – Not analyzed, NC – Not calculated

**Table 5.1. Glass Discharged, Masses, and Analysis Performed.**

Test Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)		
A	11/18/02	J12-G-97A	--	492.5	492.5		
		J12-G-100A	--				
	11/19/02	J12-G-109A	--				
		J12-G-111A	--				
		J12-G-112A	--				
		J12-G-115A	--				
		J12-G-123A	--				
		J12-G-124A	--				
		J12-G-125A	--				
		J12-G-129A	XRF				
	11/20/02	J12-G-130A	--			521.5	1014.0
		J12-G-138A	--				
		J12-G-140A	--				
		J12-G-143A	--				
		J12-G-146A	--				
		J12-G-147A	--				
		K12-G-6A	--				
		K12-G-10A	--				
	11/21/02	K12-G-11A	--			526.5	1540.5
K12-G-14A		XRF					
K12-G-23A		--					
K12-G-25A		--					
K12-G-26A		--					
K12-G-37A		--					
K12-G-38A		--					
K12-G-39A		--					
K12-G-42A		--					
K12-G-42B		--					
11/22/02	K12-G-43A	--	541.0	2081.5			
	K12-G-45A	XRF					
	K12-G-46A	--					
	K12-G-56A	--					
	K12-G-59A	--					
	K12-G-60A	--					
	K12-G-61A	--					
	K12-G-62A	--					
	K12-G-70A	--					
	K12-G-74A	--					
11/22/02	K12-G-75A	--					
	K12-G-76A	--					
11/22/02	K12-G-76B	XRF					

"--" signifies blank data field.

**Table 5.1. Glass Discharged, Masses, and Analysis Performed (continued).**

Test Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)
B	11/22/02	K12-G-76C	--	505.5	2587.0
		K12-G-77A	--		
		K12-G-79A	--		
	11/23/2002	K12-G-80A	--		
		K12-G-88A	--		
		K12-G-88B	--		
		K12-G-89A	--		
		K12-G-91A	--		
		K12-G-91B	--		
		K12-G-93A	XRF		
		K12-G-95A	--		
		K12-G-104A	--		
		K12-G-104B	--		
		K12-G-106A	--		
		K12-G-107A	--		
		K12-G-109A	--		
		K12-G-110A	--		
		K12-G-111A	--		
K12-G-111B	--				
11/24/2002	K12-G-112A	XRF			
	K12-G-121A	--			
	K12-G-122A	--			
	K12-G-122B	--			
	K12-G-124A	--			
	K12-G-126A	--			
	K12-G-127A	--			
	K12-G-135A	--			
	K12-G-137A	--			
	K12-G-138A	--			
	K12-G-139A	XRF			
	K12-G-140A	--			
	K12-G-141A	--			
	K12-G-142A	--			
	K12-G-142B	--			
C	11/24/2002	K12-G-143A	--	515.5	3629.0
		K12-G-145A	--		
		K12-G-146A	--		
		K12-G-147A	--		
		K12-G-147B	--		
		K12-G-148A	XRF		
11/25/2002	K12-G-146A	--	499.0	4128.0	
	K12-G-147A	--			
	K12-G-147B	--			
	K12-G-148A	XRF			

"--" signifies blank data field.

**Table 5.1. Glass Discharged, Masses, and Analysis Performed (continued).**

Test Segment	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)
C	11/25/2002	L12-G-7A	--	496.0	4624.0
		L12-G-8A	--		
		L12-G-11A	--		
		L12-G-12A	--		
		L12-G-12B	--		
		L12-G-13A	--		
		L12-G-21A	--		
		L12-G-21B	--		
		L12-G-23A	--		
		L12-G-24A	XRF		
		L12-G-24B	--		
	11/26/2002	L12-G-27A	--	502.0	5126.0
		L12-G-27B	--		
		L12-G-28A	--		
		L12-G-29A	--		
		L12-G-30A	--		
		L12-G-39A	--		
		L12-G-39B	--		
		L12-G-39C	--		
		L12-G-40A	XRF		
		L12-G-40B	--		
		11/26/2002	L12-G-42A		
	L12-G-43A		--		
	L12-G-43B		--		
	L12-G-44A		--		
	L12-G-45A		--		
	L12-G-46A		--		
	L12-G-46B		--		
	L12-G-56A		--		
	L12-G-58A		XRF		
	L12-G-60A		--		
	11/26/2002		L12-G-60B	--	498.0
		L12-G-61A	--		
L12-G-62A		--			
L12-G-62B		--			
L12-G-63A		--			
L12-G-64A		--			
L12-G-64B		--			
L12-G-66A	--				
L12-G-66B	XRF				

"--" signifies empty data field

**Table 5.1. Glass Discharged, Masses, and Analysis Performed (continued).**

Test #	Date	Name	Analysis	Mass (kg)	Cumulative Mass (kg)
C	11/27/2002	L12-G-74A	--	513.0	6648.5
		L12-G-75A	--		
		L12-G-76A	--		
		L12-G-77A	--		
		L12-G-77B	--		
		L12-G-79A	--		
		L12-G-81A	--		
		L12-G-81B	XRF		
		L12-G-89A	--	99.5	6748.0
		L12-G-89B	XRF		

"--" signifies blank data field.

**Table 5.2. XRF Analyzed Compositions for Glass Discharged (wt%).**

Test Segment		A		B			C			
Glass Prod. (kg)		492.5	1014.0	1540.5	2081.5	2587.0	3113.5	3629	4128.0	4624.0
Oxide	Target	J12-G-129A	K12-G-14A	K12-G-76B	K12-G-93A	K12-G-112A	K12-G-139A	K12-G-148A	L12-G-24A	L12-G-40A
Al <sub>2</sub> O <sub>3</sub>	5.58	6.38	6.24	6.85	6.38	6.66	5.99	6.14	6.23	6.17
B <sub>2</sub> O <sub>3</sub> *	12.51	12.36	12.40	12.43	12.45	12.46	12.47	12.48	12.49	12.49
CaO	0.23	0.83	0.76	0.56	0.54	0.48	0.52	0.46	0.41	0.40
CdO	0.11	0.09	0.11	0.11	0.13	0.11	0.13	0.12	0.12	0.13
Cs <sub>2</sub> O	0.05	0.03	0.04	0.05	0.06	0.04	0.06	0.06	0.06	0.05
Fe <sub>2</sub> O <sub>3</sub>	12.51	11.63	12.13	11.60	12.66	11.82	12.59	12.51	11.45	11.46
I	0.10	0.01	<0.01	<0.01	0.01	0.01	0.01	0.01	<0.01	<0.01
K <sub>2</sub> O	0.03	0.14	0.14	0.16	0.13	0.15	0.14	0.12	0.12	0.12
La <sub>2</sub> O <sub>3</sub>	0.37	0.40	0.45	0.42	0.44	0.44	0.44	0.46	0.44	0.43
Li <sub>2</sub> O*	3.26	3.32	3.31	3.30	3.29	3.28	3.28	3.27	3.27	3.27
MgO	0.07	0.35	0.30	0.23	0.21	0.16	0.21	0.17	0.12	0.15
MnO	0.36	0.24	0.28	0.30	0.33	0.32	0.34	0.35	0.33	0.33
Na <sub>2</sub> O	12.02	11.13	12.04	11.56	11.59	11.96	12.23	11.75	12.40	11.95
Nd <sub>2</sub> O <sub>3</sub>	0.16	0.27	0.24	0.21	0.22	0.20	0.19	0.18	0.17	0.18
NiO	0.45	0.51	0.51	0.43	0.49	0.42	0.49	0.47	0.39	0.39
P <sub>2</sub> O <sub>5</sub>	0.07	0.04	0.18	0.04	0.05	0.04	0.03	0.04	0.06	0.04
PbO	0.03	0.03	0.04	0.05	0.06	0.05	0.06	0.06	0.05	0.06
SiO <sub>2</sub>	48.26	45.63	44.39	46.55	45.44	46.61	45.59	46.38	47.55	48.11
SO <sub>3</sub>	0.04	0.11	0.12	0.09	0.08	0.08	0.08	0.07	0.07	0.07
ZnO	2.01	2.09	2.19	1.87	2.03	1.87	1.95	1.90	1.78	1.76
ZrO <sub>2</sub>	1.77	4.15	3.81	3.03	3.15	2.71	2.81	2.69	2.38	2.33
Cr <sub>2</sub> O <sub>3</sub>	<0.01	0.05	0.15	0.01	0.12	0.01	0.24	0.18	0.01	0.01
TiO <sub>2</sub>	<0.01	0.20	0.18	0.13	0.13	0.11	0.14	0.12	0.09	0.09
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

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

Table 5.2. XRF Analyzed Compositions for Glass Discharged (wt%) (continued).

Test Segment		C					Statistics	
Glass Prod. (kg)		5126.0	5637.5	6135.5	6648.5	6748.0	Average (>6000 kg)	% Dev. from Target
Oxide	Target	L12-G-45A	L12-G-58A	L12-G-66B	L12-G-81B	L12-G-89B		
Al <sub>2</sub> O <sub>3</sub>	5.58	6.87	6.04	6.06	6.27	6.28	6.20	11.11
B <sub>2</sub> O <sub>3</sub> *	12.51	12.50	12.50	12.50	12.50	12.50	12.50	NC
CaO	0.23	0.61	0.39	0.39	0.38	0.37	0.38	NC
CdO	0.11	0.11	0.13	0.12	0.12	0.12	0.12	NC
Cs <sub>2</sub> O	0.05	0.05	0.07	0.05	0.05	0.06	0.05	NC
Fe <sub>2</sub> O <sub>3</sub>	12.51	11.21	11.61	11.58	11.27	11.34	11.40	-8.91
I	0.10	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NC
K <sub>2</sub> O	0.03	0.15	0.12	0.12	0.16	0.15	0.14	NC
La <sub>2</sub> O <sub>3</sub>	0.37	0.41	0.43	0.43	0.41	0.43	0.42	NC
Li <sub>2</sub> O*	3.26	3.27	3.26	3.26	3.26	3.26	3.26	NC
MgO	0.07	0.22	0.12	0.07	0.10	0.09	0.09	NC
MnO	0.36	0.27	0.34	0.34	0.34	0.34	0.34	NC
Na <sub>2</sub> O	12.02	11.87	11.82	11.66	11.43	11.28	11.46	-4.69
Nd <sub>2</sub> O <sub>3</sub>	0.16	0.22	0.17	0.17	0.17	0.16	0.17	NC
NiO	0.45	0.42	0.39	0.40	0.38	0.39	0.39	NC
P <sub>2</sub> O <sub>5</sub>	0.07	0.04	0.05	0.05	0.04	0.04	0.04	NC
PbO	0.03	0.04	0.06	0.06	0.06	0.06	0.06	NC
SiO <sub>2</sub>	48.26	46.48	48.22	48.46	48.94	49.00	48.80	1.11
SO <sub>3</sub>	0.04	0.09	0.07	0.07	0.06	0.06	0.06	NC
ZnO	2.01	1.84	1.78	1.78	1.73	1.73	1.74	-13.27
ZrO <sub>2</sub>	1.77	3.17	2.34	2.31	2.24	2.23	2.26	27.68
Cr <sub>2</sub> O <sub>3</sub>	<0.01	0.01	0.01	0.01	0.01	0.01	0.01	NC
TiO <sub>2</sub>	<0.01	0.15	0.09	0.09	0.09	0.09	0.09	NC
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC

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

NC – Not analyzed

**Table 6.1. 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	1810	27.470	65.6	210.370	13863	22.04	95.4
	Melter R2	1205	26.934	44.8	210.130	9403	22.65	93.7
	Melter R3	1156	27.214	42.5	207.080	8793	23.43	96.1
	SBS R1	50.2	78.109	0.64	222.520	143	7.47	98.5
	SBS R2	60.0	79.460	0.76	223.970	169	6.74	99.5
	SBS R3	43.0	84.083	0.51	224.120	115	6.66	105.3
	WESP R1	29.1	837.606	0.03	215.735	7.50	9.00	99.7

**Table 6.2. 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 <sup>s</sup>	845000	13863	9403	8793	10688	1.26	79.1
	Al	20984	406.31	239.67	226.24	290.74	1.39	72.2
	B	27598	665.13	356.41	386.99	469.51	1.70	58.8
	Ca	1169	37.09	19.96	19.50	25.52	2.18	45.8
	Cd	700	14.71	9.51	9.08	11.10	1.59	63.1
	Cs	335	14.72	11.75	11.29	12.59	3.76	26.6
	Fe	62182	1001.99	690.46	684.10	792.18	1.27	78.5
	I	711	< 0.10	< 0.10	< 0.10	< 0.10	< 0.01	> 7110
	K	177	7.87	5.86	4.83	6.19	3.50	28.6
	Li	10765	97.45	76.24	68.37	80.69	0.75	133.4
	Mg	300	17.86	10.35	9.83	12.68	4.23	23.7
	Mn	1982	18.45	8.82	9.44	12.24	0.62	162.0
	Na	63394	1107.80	725.57	716.47	849.95	1.34	74.6
	Ni	2514	44.80	28.13	25.99	32.97	1.31	76.2
	P	93	4.87	2.13	2.75	3.25	3.49	28.6
	Pb	462	11.65	6.56	6.79	8.33	1.80	55.4
	S	114	72.49	64.74	56.81	64.68	56.74	1.8
	Si	160367	2333.47	1300.42	1249.97	1627.95	1.02	98.5
	Zn	11479	202.30	139.08	129.69	157.02	1.37	73.1
Zr	9315	186.89	75.84	82.23	114.99	1.23	81.0	
Gas	B	27598	162.01	146.29	179.12	162.47	0.59	169.9
	I	711	622.68	697.43	821.04	713.72	100.38	1.0
	S	114	30.49	18.37	21.63	23.50	20.61	4.9

<sup>s</sup> - From gravimetric analysis of filters and rinse dry downs  
"--" signifies empty data field

**Table 6.3. 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 <sup>s</sup>	10688	143	169	115	142.3	1.33	75.1
	Al	290.74	0.25	1.69	1.02	0.99	0.34	294.7
	B	469.51	6.54	4.67	5.16	5.46	1.16	86.0
	Ca	25.52	< 0.10	0.50	0.28	< 0.29	< 1.14	> 88
	Cd	11.10	0.22	0.21	0.21	0.21	1.92	52.0
	Cs	12.59	1.03	0.98	0.87	0.96	7.63	13.1
	Fe	792.18	0.97	4.19	2.44	2.53	0.32	312.7
	I	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	NC	NC
	K	6.19	0.23	0.17	0.15	0.18	2.96	33.8
	Li	80.69	2.64	2.32	2.09	2.35	2.91	34.3
	Mg	12.68	< 0.10	< 0.10	< 0.10	< 0.10	< 0.01	> 126.8
	Mn	12.24	< 0.10	0.11	0.10	0.11	0.86	116.6
	Na	849.95	24.07	24.18	20.68	22.98	2.70	37.0
	Ni	32.97	< 0.10	0.26	0.11	0.19	0.56	178.2
	P	3.25	< 0.10	< 0.10	0.10	< 0.10	< 0.03	32.5
	Pb	8.33	< 0.10	< 0.10	< 0.10	< 0.10	< 1.20	83.3
	S	64.68	14.14	11.12	10.18	11.81	18.26	5.5
	Si	1627.95	1.36	11.02	8.21	6.86	0.42	237.2
	Zn	157.02	0.54	2.22	0.95	1.24	0.79	127.0
Zr	114.99	< 0.10	1.11	0.46	< 0.56	< 0.01	> 206.6	
Gas	B	162.47	4.02	4.38	< 0.10	< 2.83	< 1.74	> 57.3
	I	713.72	462.28	457.82	392.88	437.66	61.32	1.6
	S	23.50	2.01	3.05	1.31	2.12	9.04	11.1

NC – Not calculated

<sup>s</sup> - From gravimetric analysis of filters and rinse dry downs

"--" signifies empty data field

**Table 6.4. 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 <sup>s</sup>	845000	142.3	7.50	19.0	112670
	Al	20984	0.99	< 0.10	> 9.9	> 209840
	B	27598	5.46	0.29	18.8	95170
	Ca	1169	< 0.29	< 0.10	NC	> 11690
	Cd	700	0.21	< 0.10	> 2.1	> 7000
	Cs	335	0.96	0.11	8.7	3046
	Fe	62182	2.53	0.14	18.1	444200
	I	711	< 0.10	< 0.10	NC	> 7110
	K	177	0.18	< 0.10	> 1.8	> 1770
	Li	10765	2.35	0.24	9.8	44850
	Mg	300	< 0.10	< 0.10	NC	> 3000
	Mn	1982	0.11	< 0.10	> 1.1	> 19820
	Na	63394	22.98	2.45	9.4	25880
	Ni	2514	0.19	< 0.10	> 1.9	> 25140
	P	93	< 0.10	< 0.10	NC	> 930
	Pb	462	< 0.10	< 0.10	NC	> 4620
	S	114	11.81	1.56	7.6	73.1
	Si	160367	6.86	0.19	36.1	844000
	Zn	11479	1.24	< 0.10	> 12.4	> 114790
	Zr	9315	< 0.56	< 0.10	NC	> 93150
Gas	B	27598	< 2.83	2.48	NC	> 11130
	I	711	437.66	896.82	0.5	0.8
	S	114	2.12	0.56	3.8	203.6

NC – Not calculated

<sup>s</sup> - From gravimetric analysis of filters and rinse dry downs

"--" signifies empty data field

**Table 6.5. Melter Emissions Particle Size Distribution Results.**

--	Cutpoint (µm)	Net Weight (mg)	Concentration (mg/dscf)	Mass Fraction
Sample 1	> 12.2	12.61	12.1	75.4
	12.2 – 9.2	0.81	0.78	4.84
	9.2 – 3.56	0.73	0.70	4.36
	3.56 – 1.79	0.70	0.67	4.20
	1.79 – 1.03	0.07	0.07	0.40
	1.03 – 0.58	0.41	0.39	2.45
	0.58 – 0.35	0.19	0.18	1.14
	< 0.35	1.20	1.15	7.2
Sample 2	> 12.4	5.98	5.05	64.6
	12.4 – 9.4	0.60	0.51	6.48
	9.4 – 3.63	0.68	0.57	7.34
	3.63 – 1.83	0.60	0.51	6.47
	1.83 – 1.05	0.22	0.19	2.38
	1.05 – 0.59	0.56	0.47	6.05
	0.59 – 0.35	< 0.01	< 0.01	< 0.01
	< 0.35	0.62	0.52	6.70
Sample 3	> 12.9	12.62	10.61	62.5
	12.9 – 9.8	1.59	1.34	7.88
	9.8 – 3.79	1.52	1.28	7.53
	3.79 – 1.91	1.54	1.29	7.63
	1.91 – 1.09	0.70	0.59	3.47
	1.09 – 0.61	0.55	0.46	2.72
	0.61 – 0.36	< 0.01	< 0.01	< 0.01
	< 0.36	1.67	1.40	8.27

"--" signifies empty data field

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

Port	Melter Outlet			SBS Outlet			WESP Outlet			TCO Outlet		
	A	B	C	A	B	C	A	B	C	A	B	C
N <sub>2</sub> O	2.2	4.0	3.9	2.1	3.7	4.7	2.0	4.1	4.5	1.1	2.3	2.3
NO	100	130	210	120	120	210	110	120	190	7.7	6.1	20
NO <sub>2</sub>	2.4	1.3	1.9	3.6	2.1	2.7	6.0	5.8	8.8	5.1	1.3	5.7
NH <sub>3</sub>	5.2	5.9	7.1	5.6	5.4	7.7	1.8	3.3	5.6	6.6	2.6	2.5
H <sub>2</sub> O [%]	12	17	23	6.6	6.4	6.8	5.1	6.5	6.5	4.3	3.8	4.5
CO <sub>2</sub>	3400	5700	7500	3200	4400	6900	3000	4500	6700	1600	2800	4600
HNO <sub>2</sub>	<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 <sub>2</sub>	<1.0	2.5	3.6	1.1	<1.0	<1.0	1.5	1.2	<1.0	2.7	1.1	<1.0
CO	1.8	4.9	4.1	1.1	3.7	4.4	<1.0	4.3	5.0	<1.0	<1.0	<1.0
HCl	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
HF	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

**Table 6.7. Iodine Mass Balance Summary.**

Location:	% Feed Iodine
Product Glass	< 1 %
Melter Emissions	100 %
SBS Blow-Down Solutions	40 %
SBS Emissions	61 %
WESP Blow-Down Solutions	< 1 %
WESP Emissions	> 100 %
HEME 1 Solutions	1 %
TCO/SCR Emissions	37 %
PBS Blow-Down Solutions	< 1 %
HEME 2 Solutions	2 %
Stack Emissions	31 %

**Table 7.1. 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 AZ-102 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 AZ-102 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 3.1 provides glass production rate data and summary data for melter testing. The production rates attained were sufficient to produce only 6.7 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 AZ-102 melter feed.	Yes	Data provided in Table 3.1 and Figure 3.1.
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 <sub>2</sub> ).	Yes/ No	Section 6.0 provides data and detailed description of melter emissions. Monitoring of H <sub>2</sub> was not performed due to failure of the gas chromatograph.
Quantify and document the occurrence and associated operating conditions of any melter off-gas volume surging events.	Yes	Section 4.0 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 4.0 provides operational details of off-gas system components. Section 6.0 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 4.2 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 4.0 provides operational details of off-gas system components. Table 6.6 and Figures 6.5-6.8 provide SCR/TCO inlet 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 3.0 and data for measured off-gas parameters is in Section 4.0.
Document general equipment operations (reliability, availability, maintainability, etc.); especially non-routine equipment failure and replacement activities.	Yes	Data for measured melter parameters is provided in Section 3.0 and data for measured off-gas parameters is in Section 4.0.
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 4.0. Inspection downstream of the SCR was covered in a previous report [28].
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	Section 4.0 provides 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.

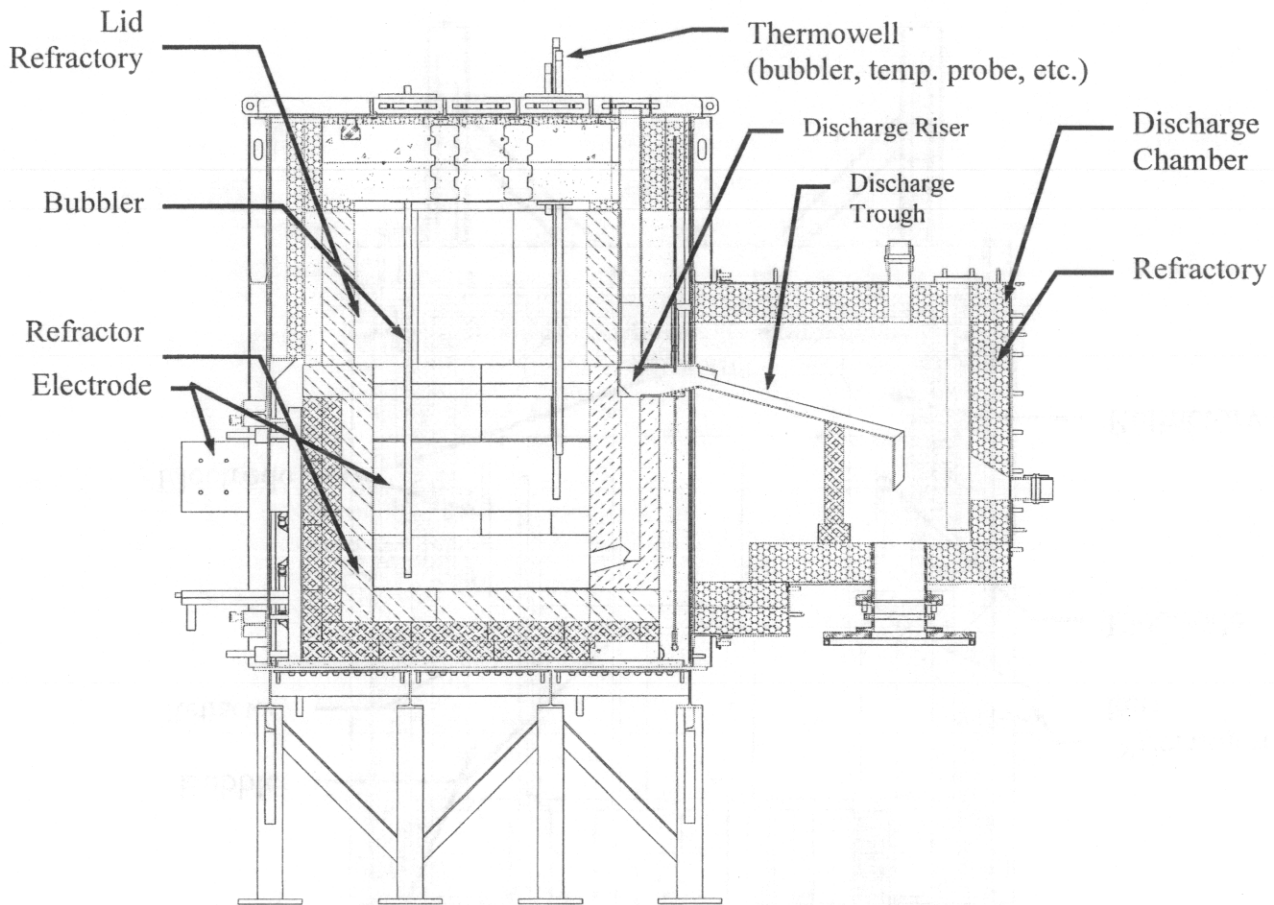


Figure 1.1. Cross-section of the DM1200 melter through the discharge chamber.

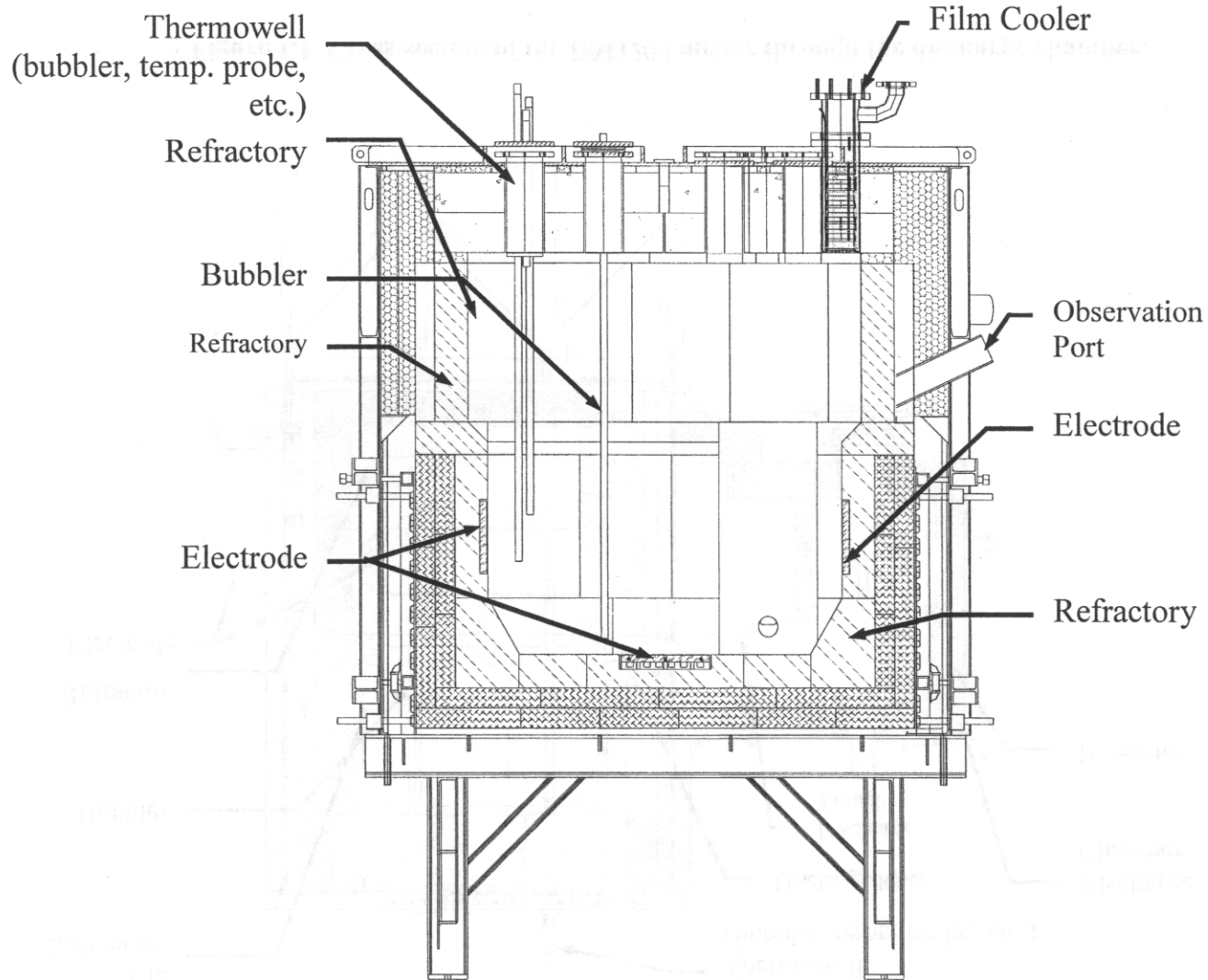


Figure 1.2. Cross-section through the DM1200 melter showing electrodes.

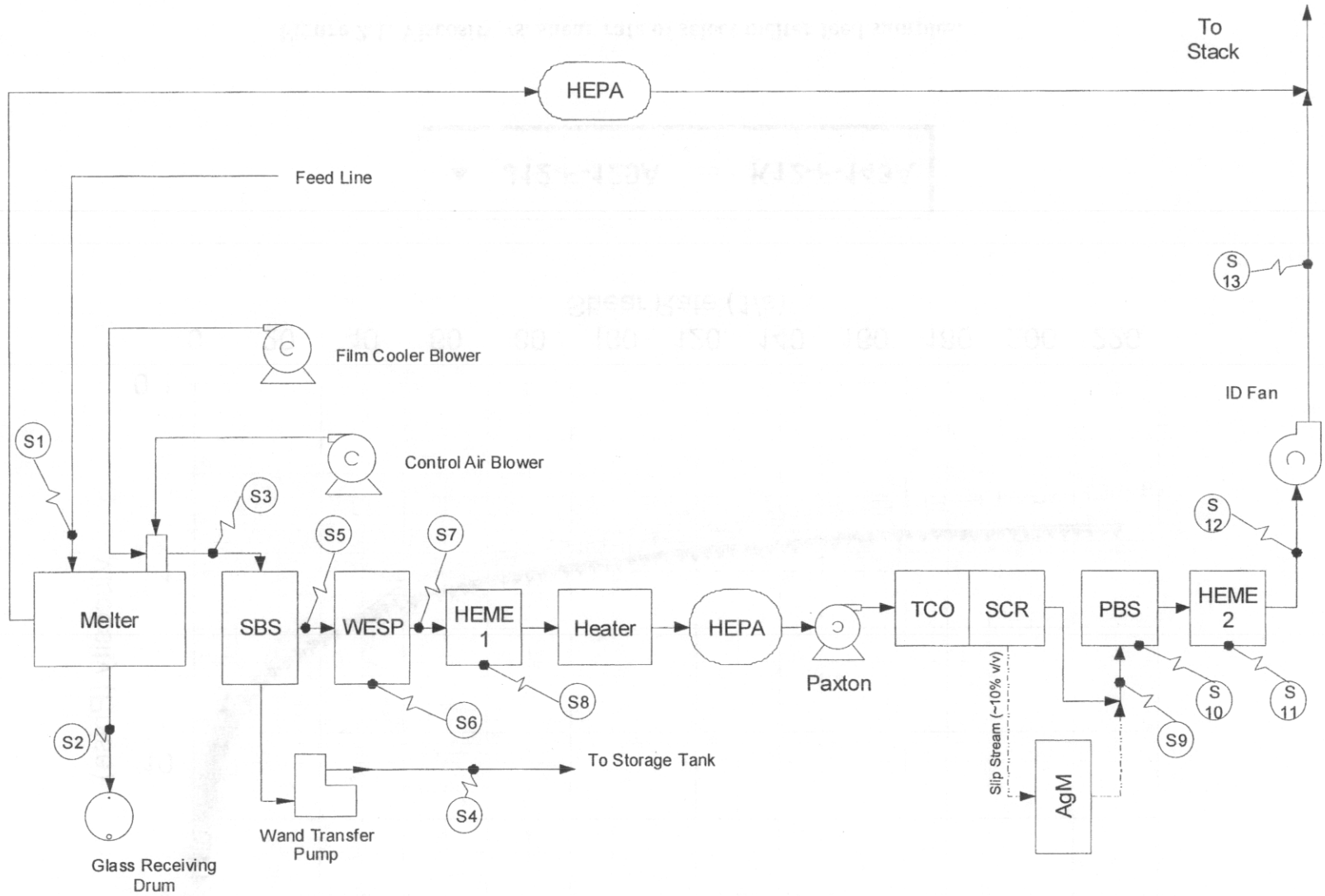


Figure 1.3. Schematic diagram of DM1200 off-gas system. "Sx" indicates sampling point.

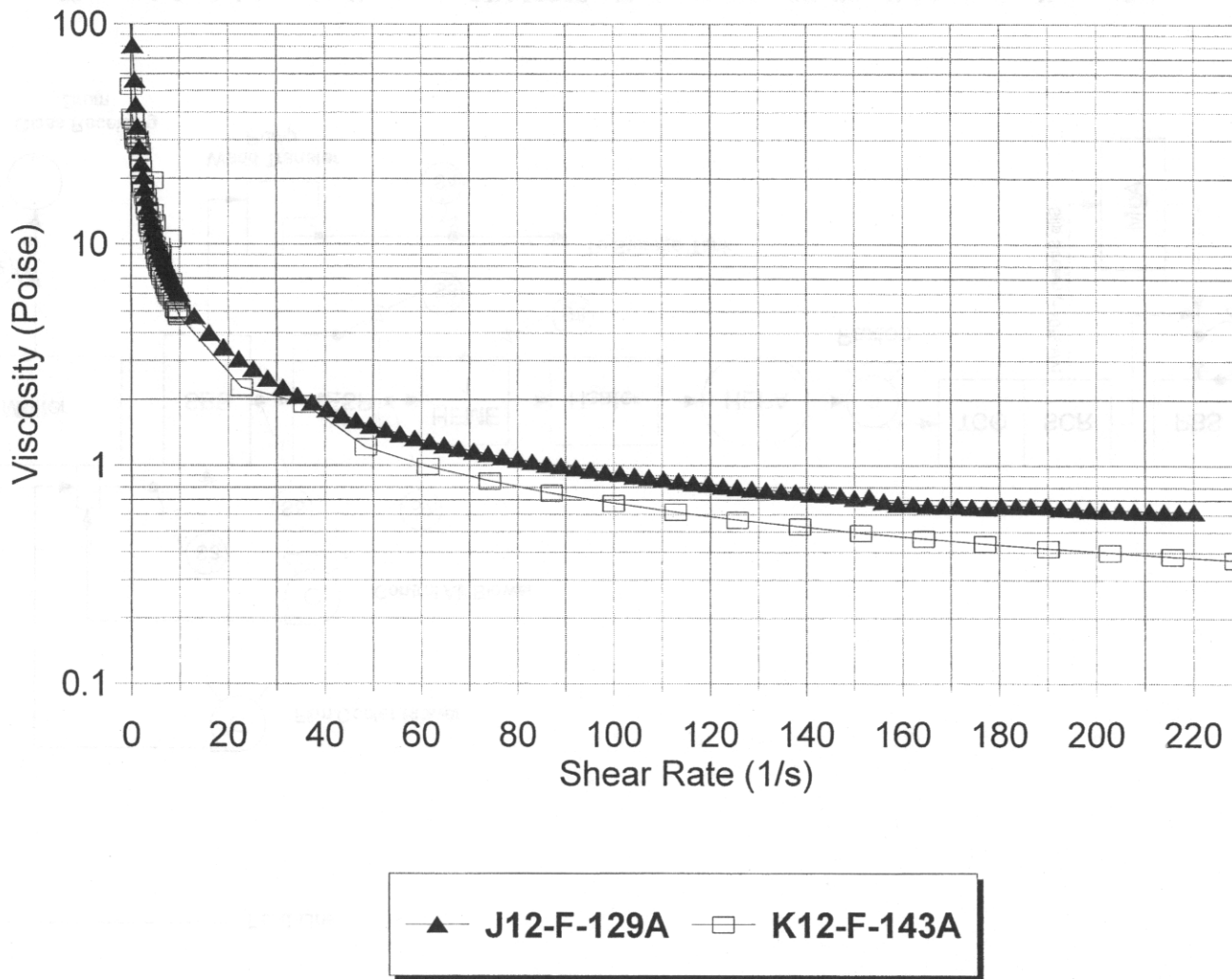


Figure 2.1. Viscosity vs. shear rate of select melter feed samples.

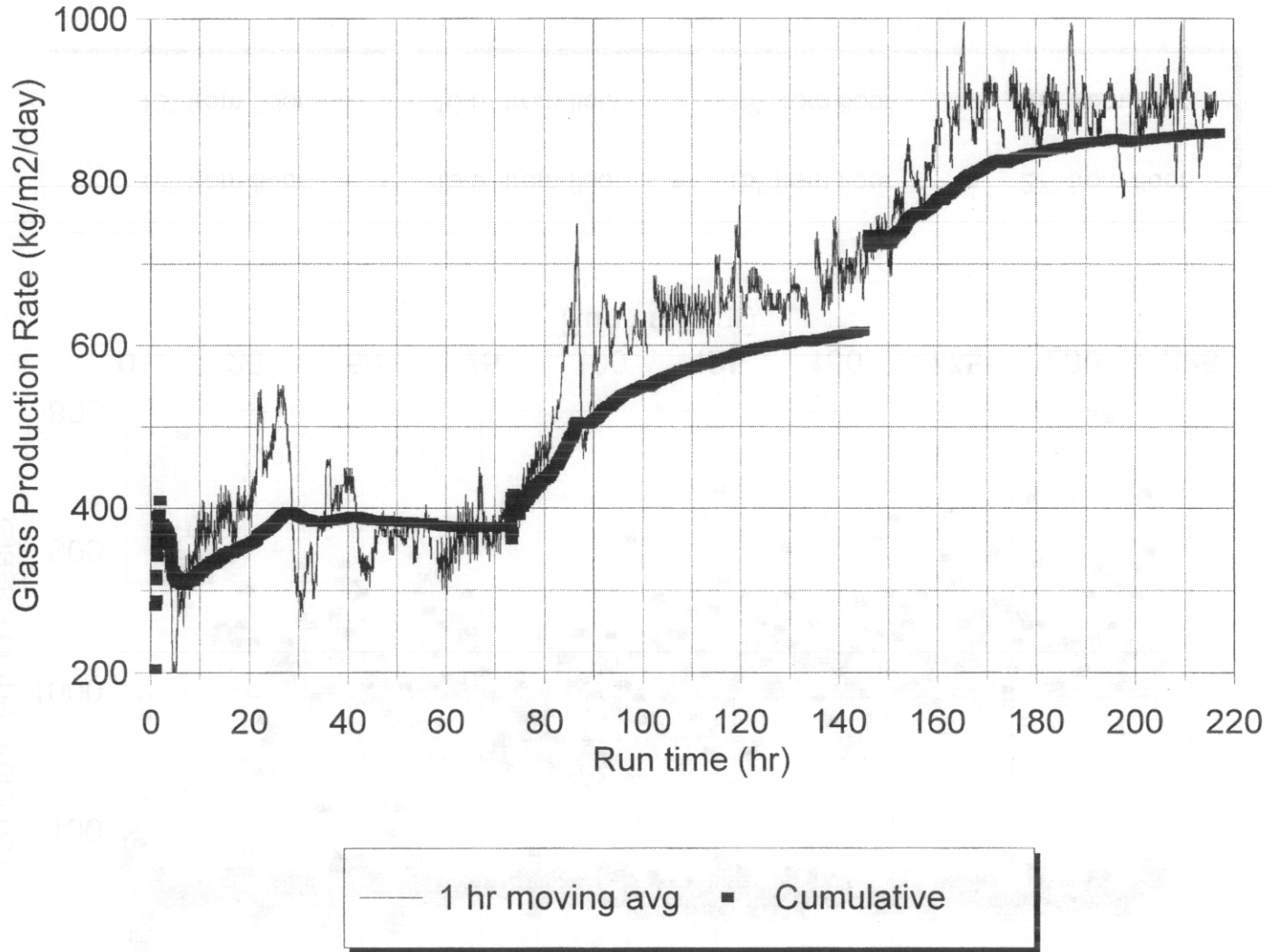


Figure 3.1. Glass production rates for DM1200 tests.

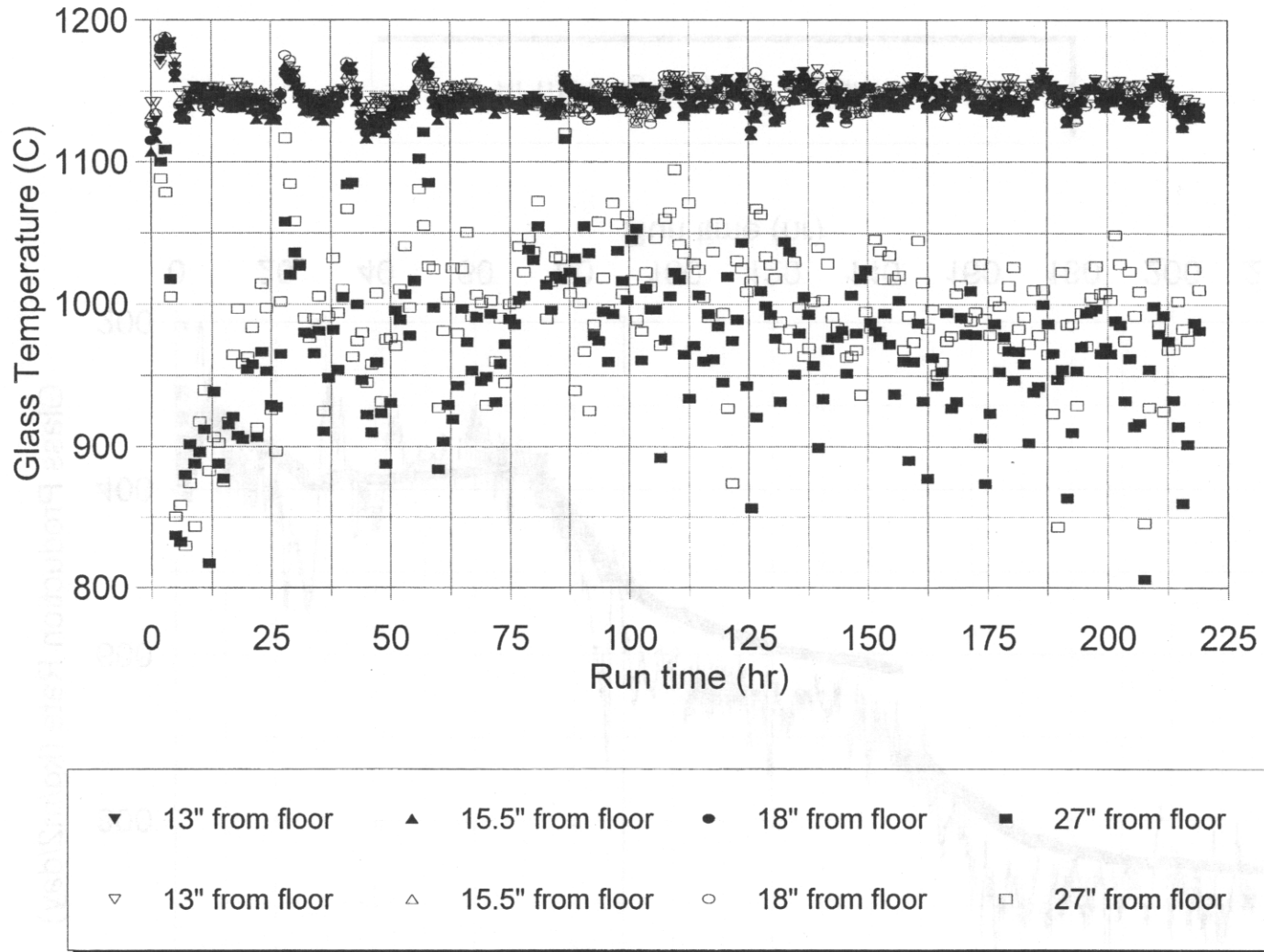


Figure 3.2. Glass temperatures for DM1200 tests (hourly averaged).

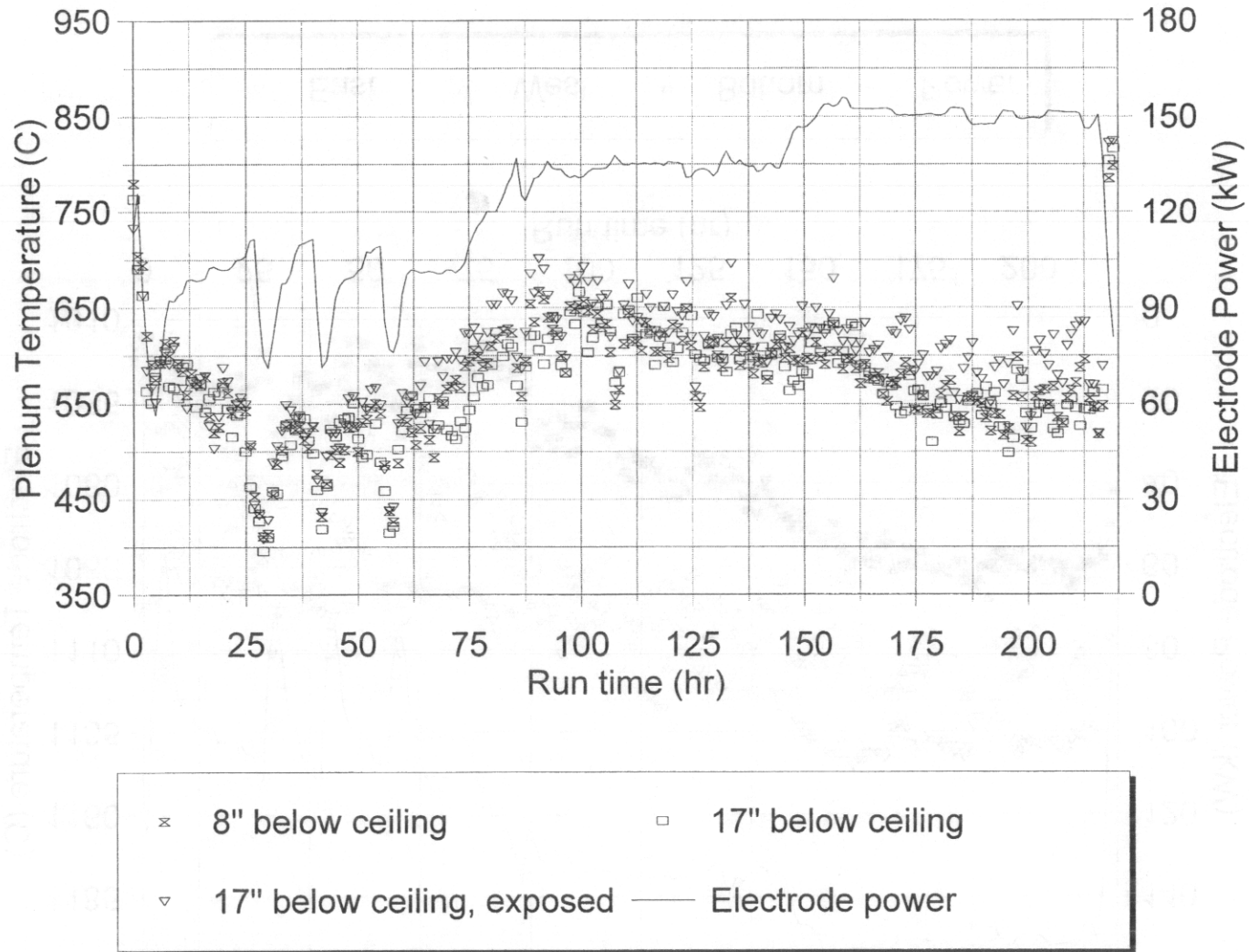


Figure 3.3. Plenum temperatures and electrode power for DM1200 tests (hourly averaged).

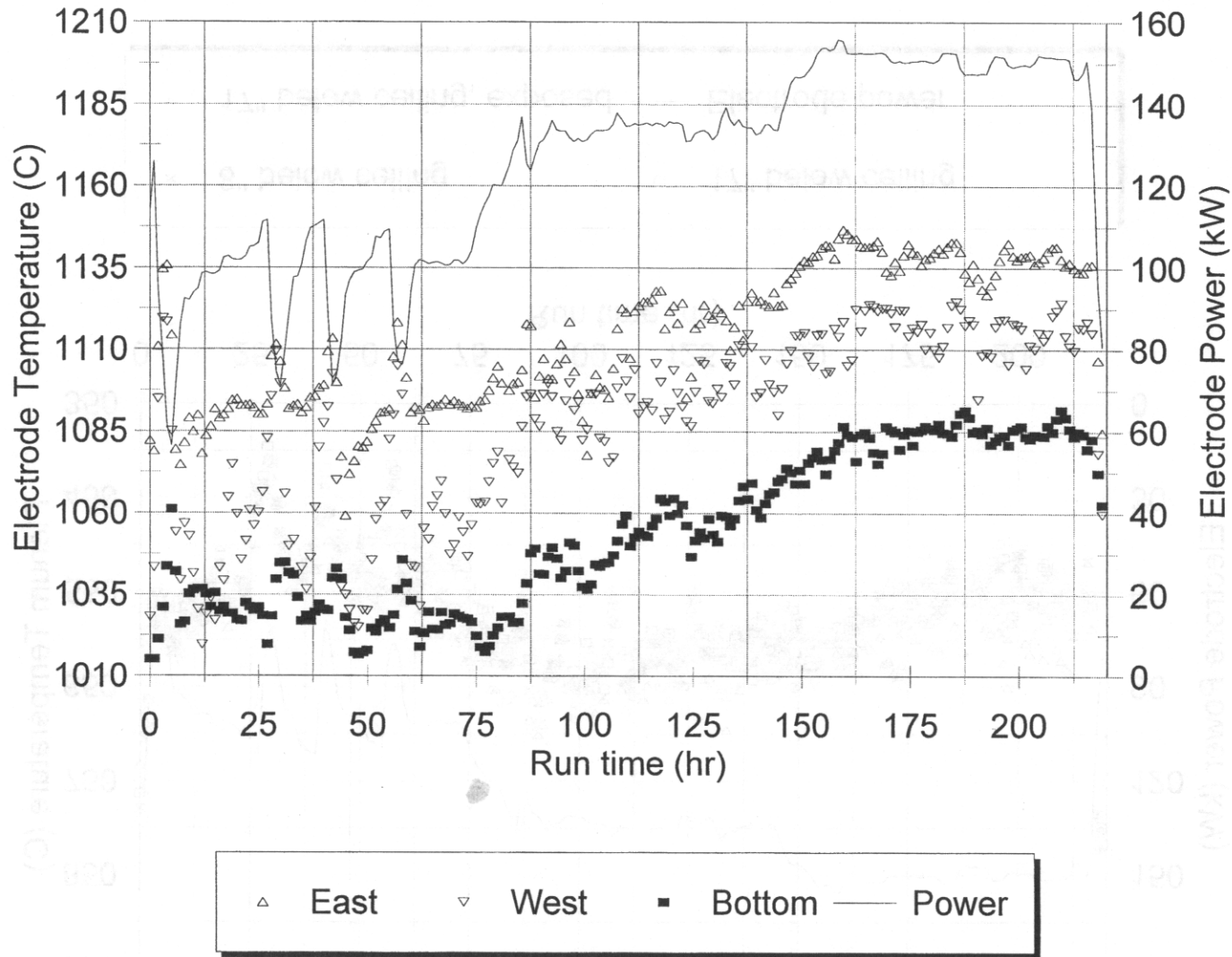


Figure 3.4. Electrode temperatures and power for DM1200 tests (hourly averaged).

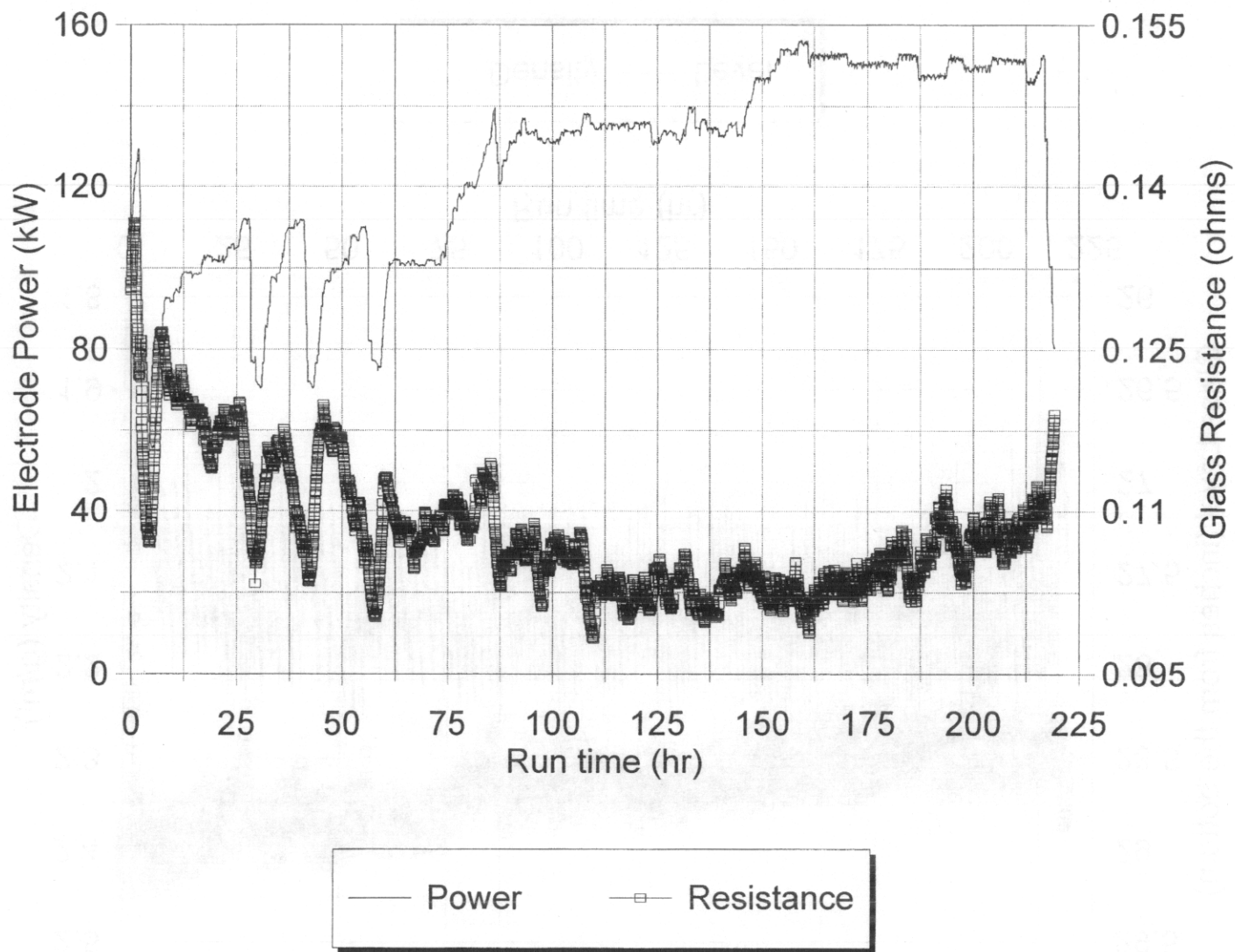


Figure 3.5. Electrode power and glass resistance for DM1200 tests.

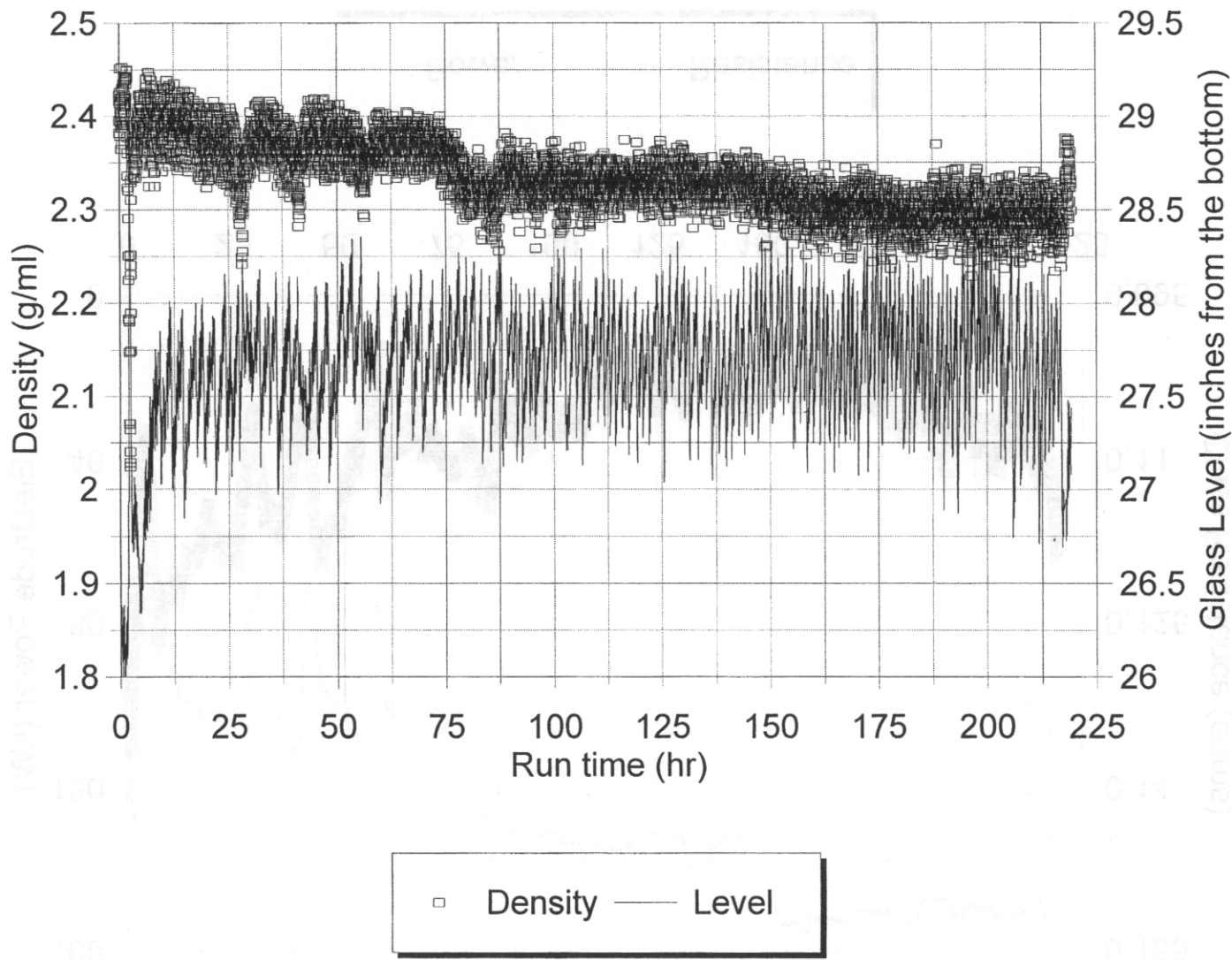


Figure 3.6. Glass density and level for DM1200 tests.

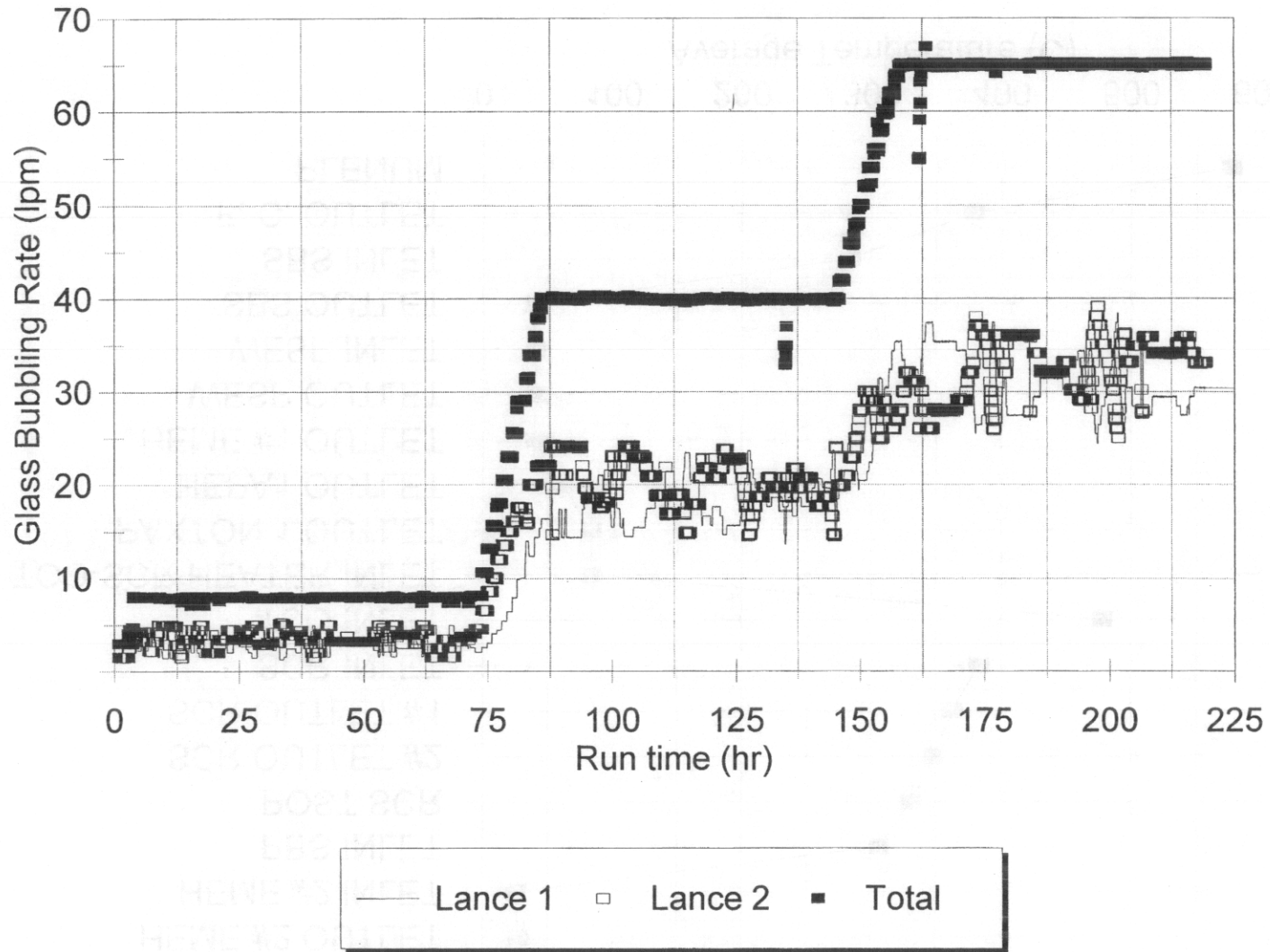


Figure 3.7. Glass pool bubbling for DM1200 tests.

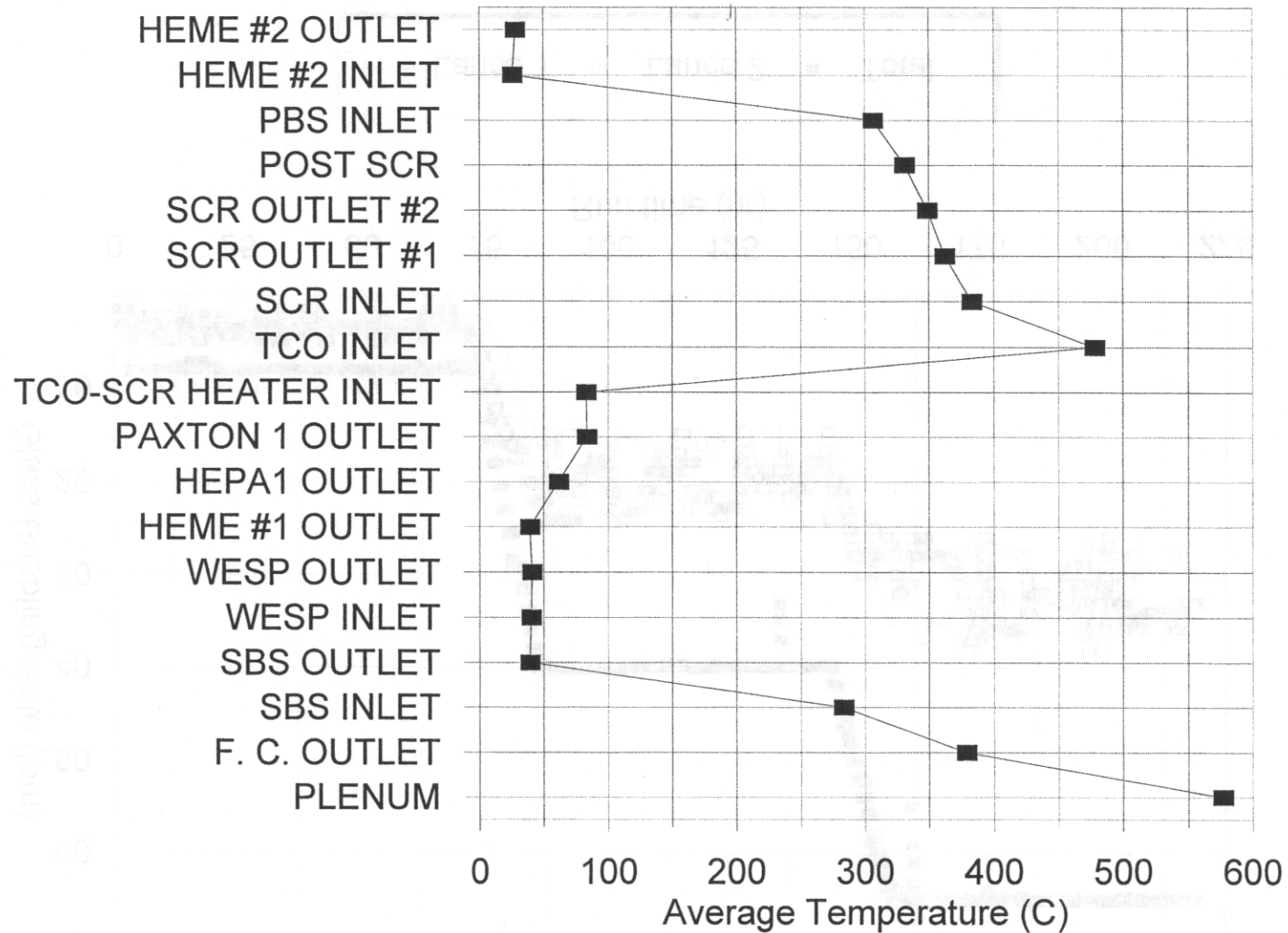


Figure 4.1. Average gas temperatures along the DM1200 off-gas train.

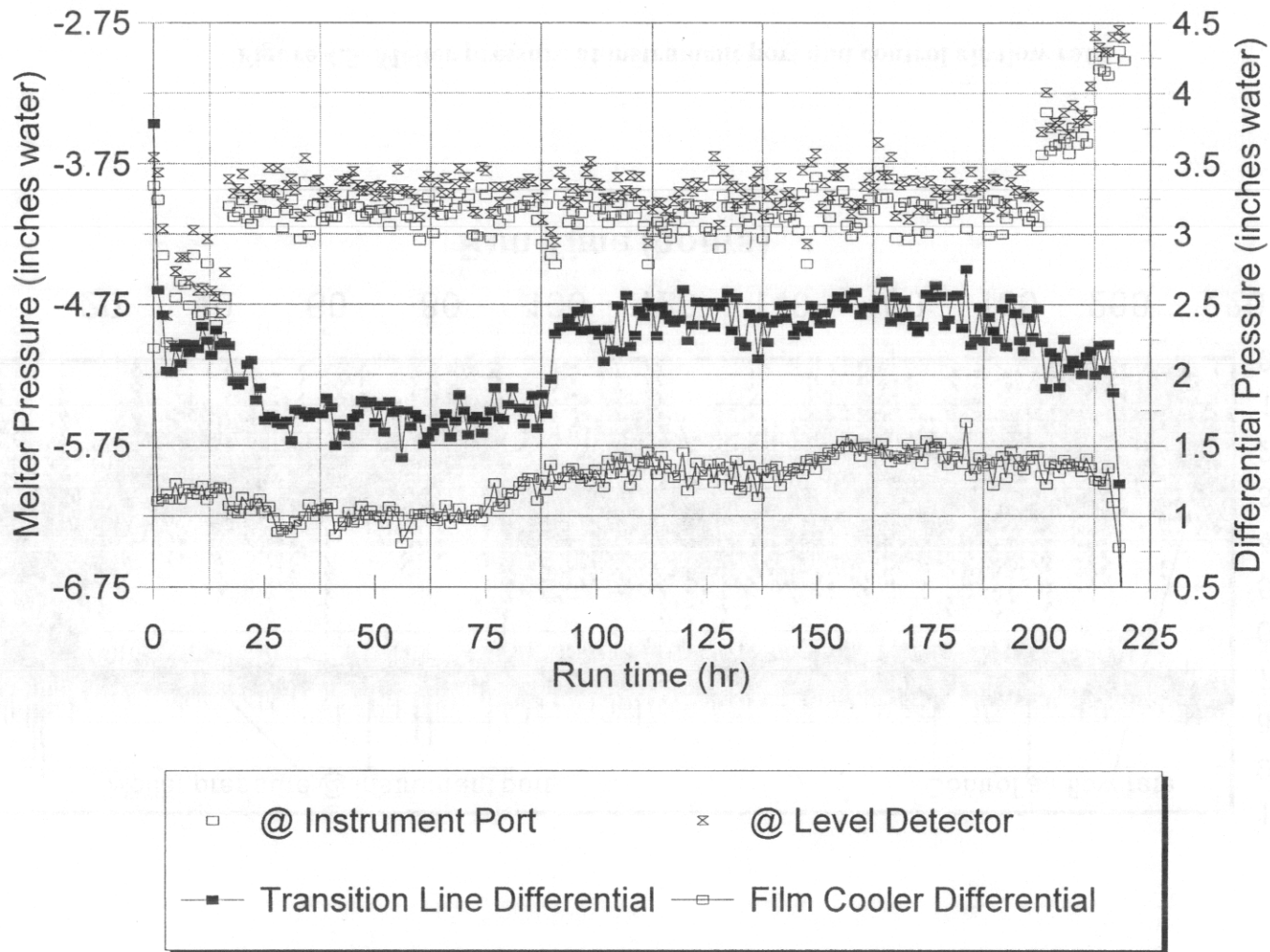


Figure 4.2. Melter pressure (at level detector and instrument ports) and transition line and film cooler differential pressures (hourly average values).

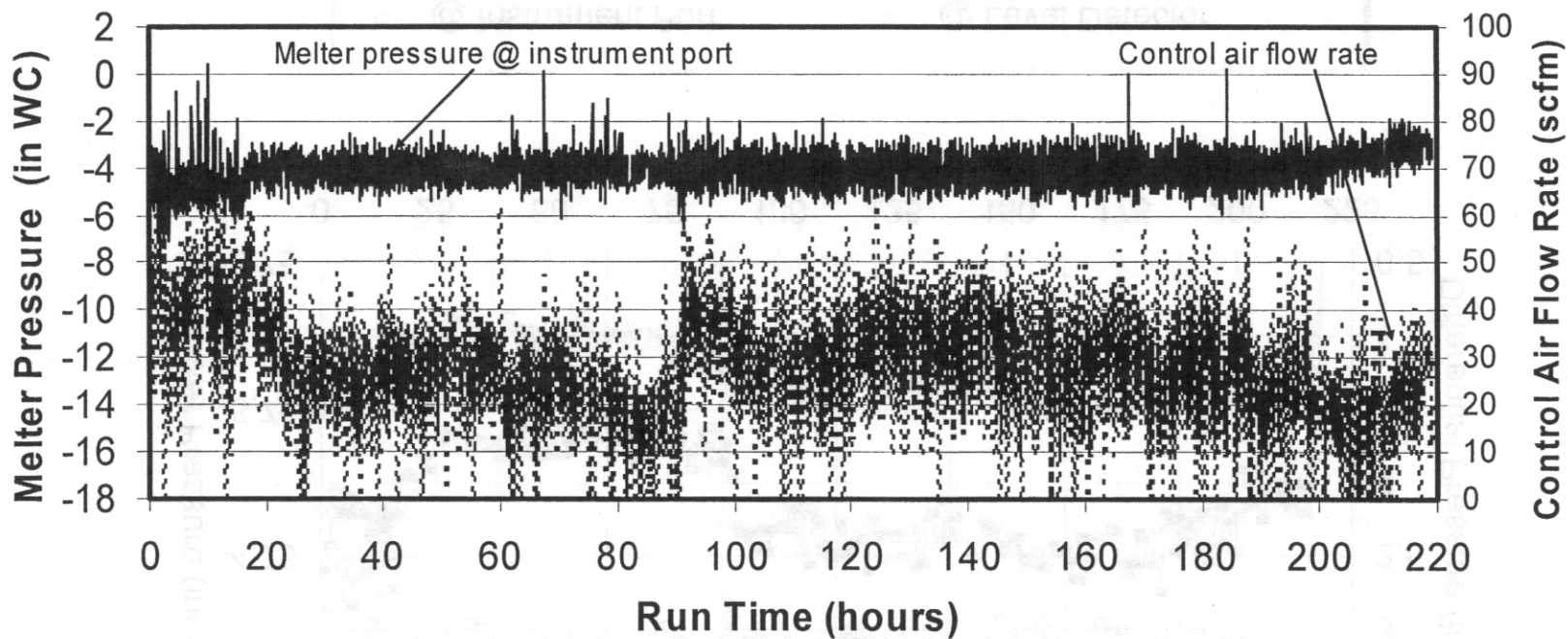


Figure 4.3. Melter pressure at instrument port and control air flow rate.

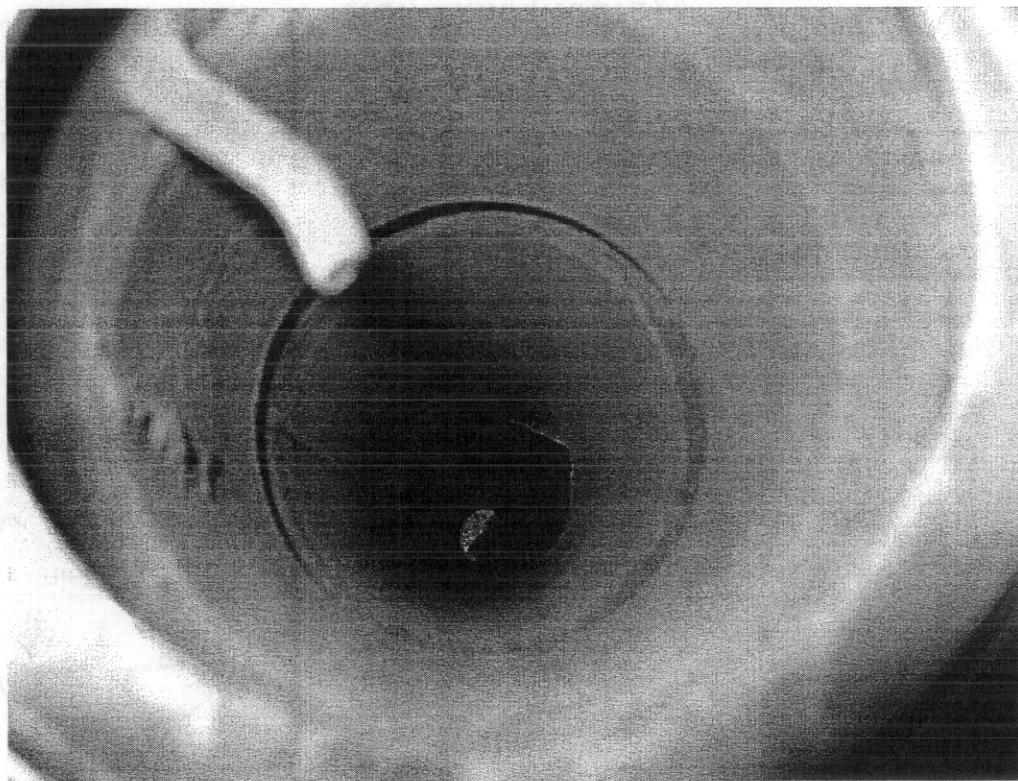


Figure 4.4. View from the top of the film cooler at the end of the test.

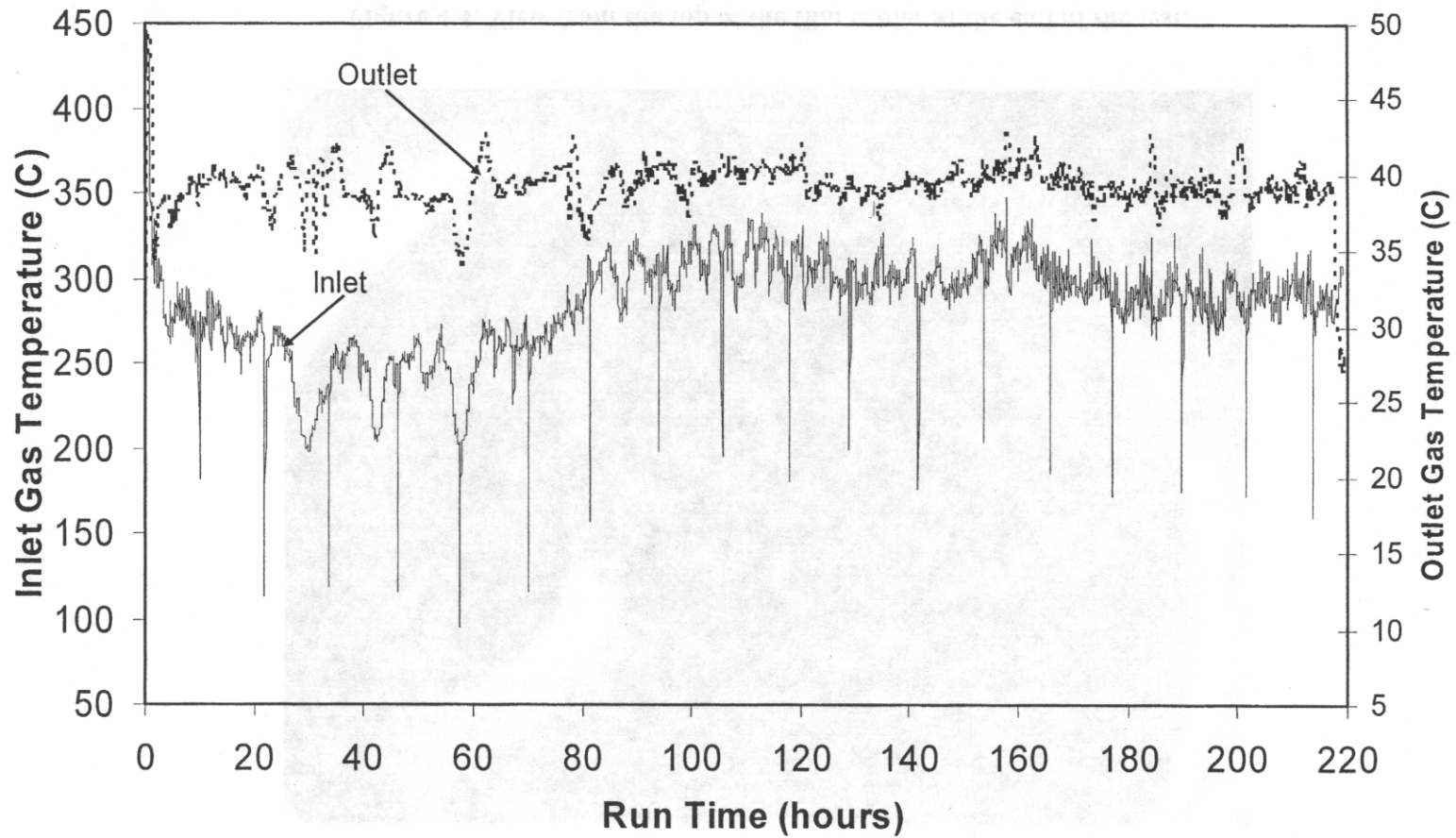


Figure 4.5. SBS inlet and outlet gas temperatures.

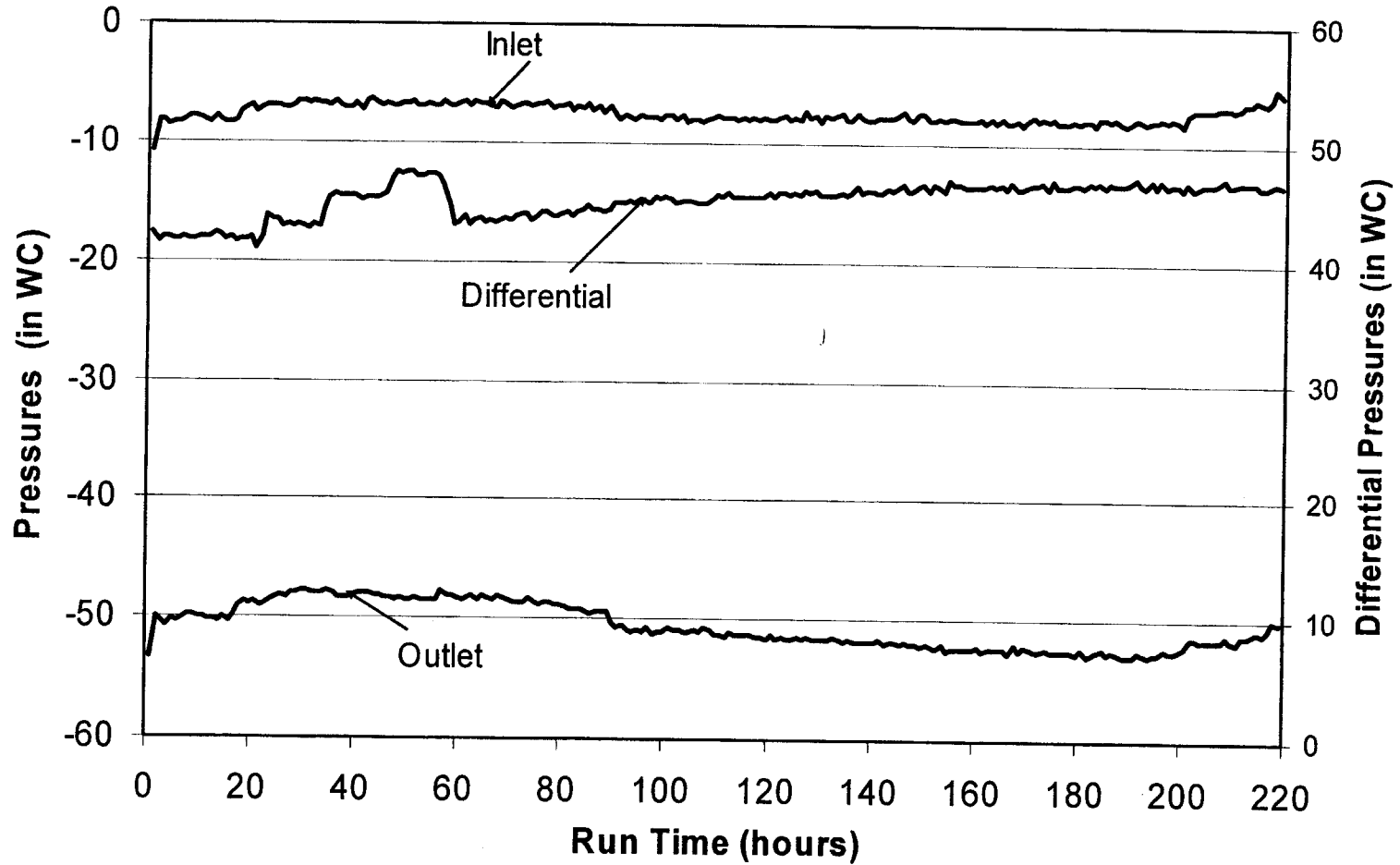


Figure 4.6. SBS inlet, outlet and differential pressure (hourly average values).

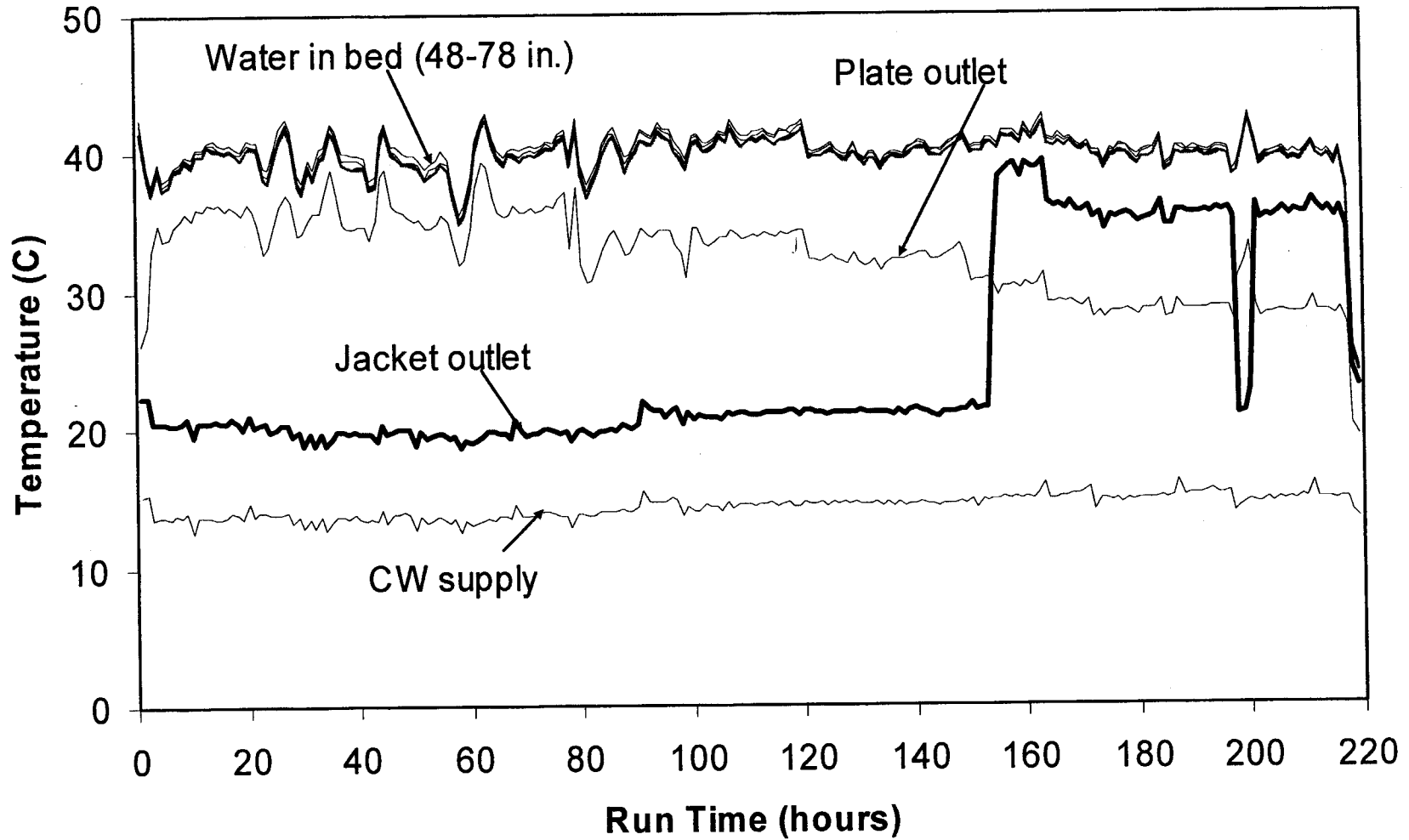


Figure 4.7. SBS cooling water and bed temperatures (hourly average values).

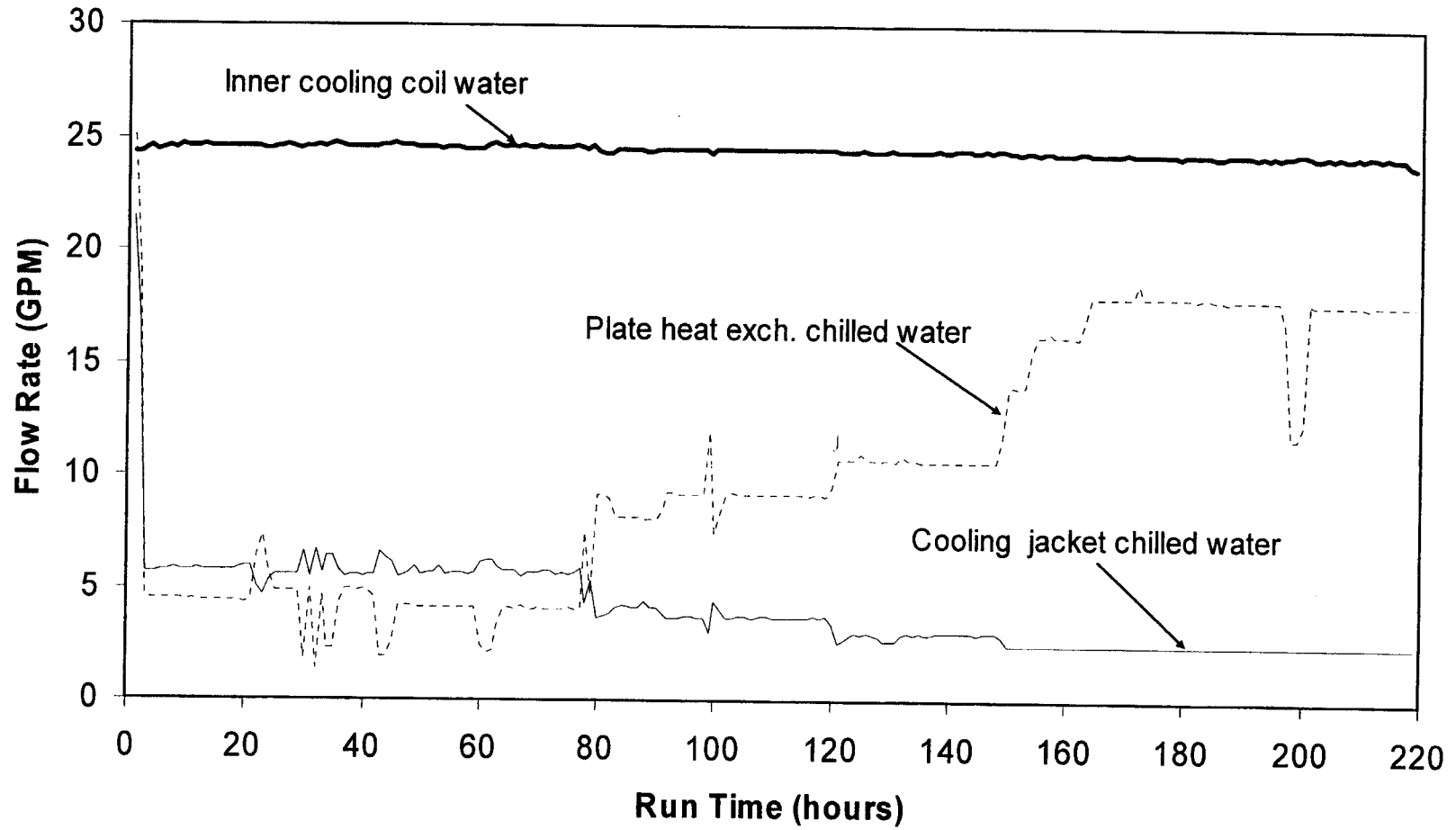


Figure 4.8. SBS jacket, inner coil and heat exchanger water flow rates (hourly average values).

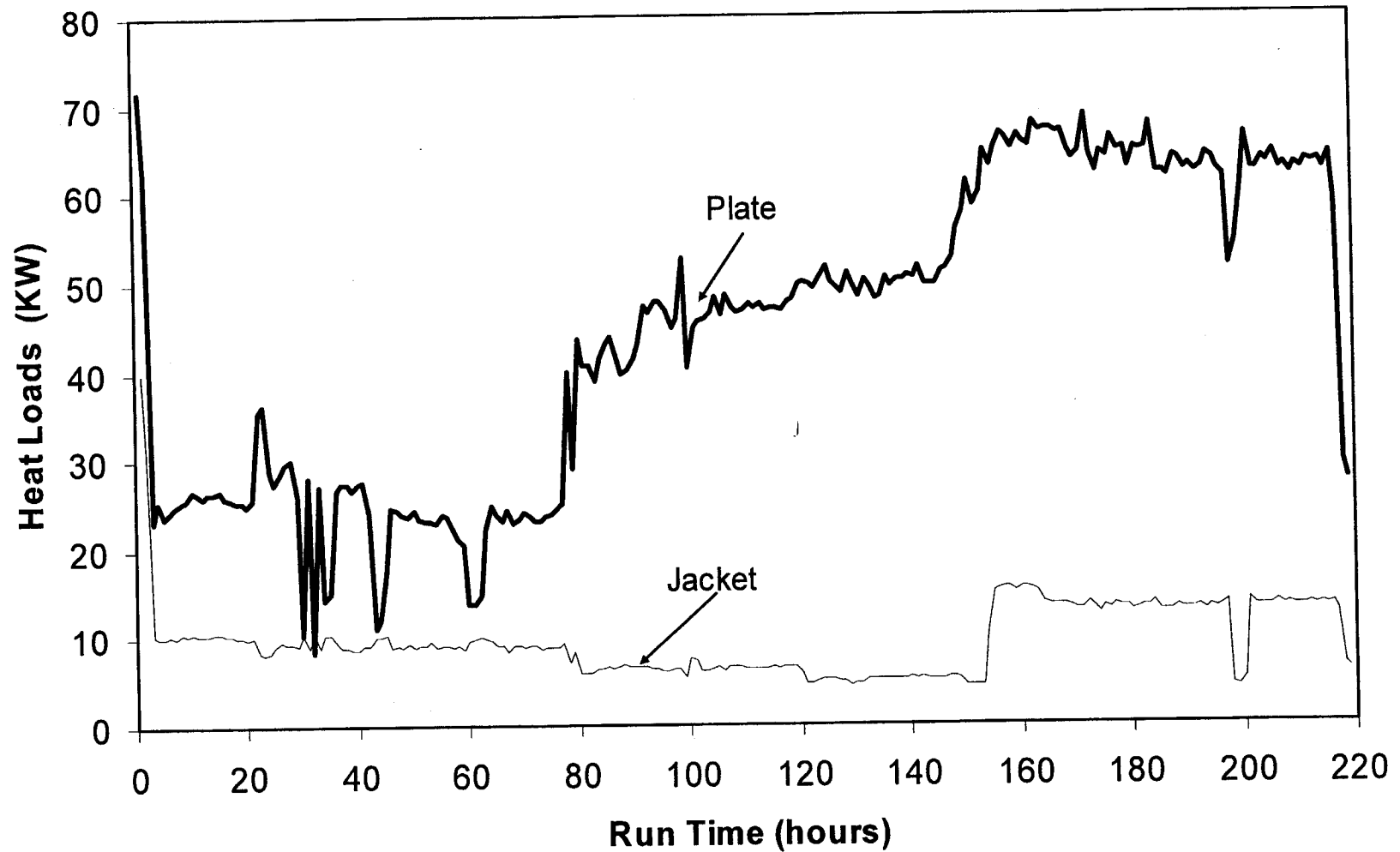


Figure 4.9. Calculated heat loads on the cooling jacket and plate heat exchanger (hourly average values).

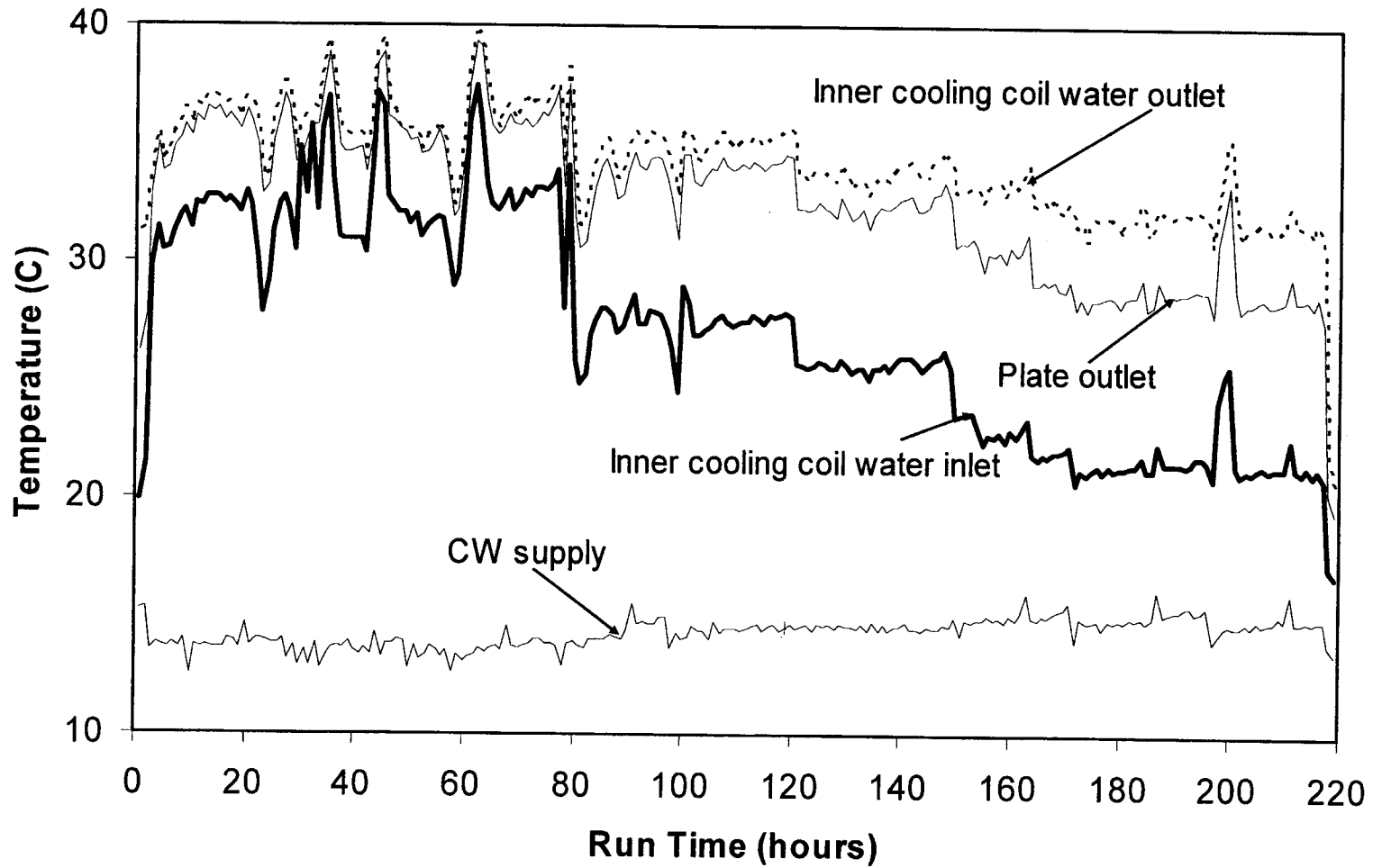


Figure 4.10. SBS inner coil and plate heat exchanger water temperatures (hourly average values).

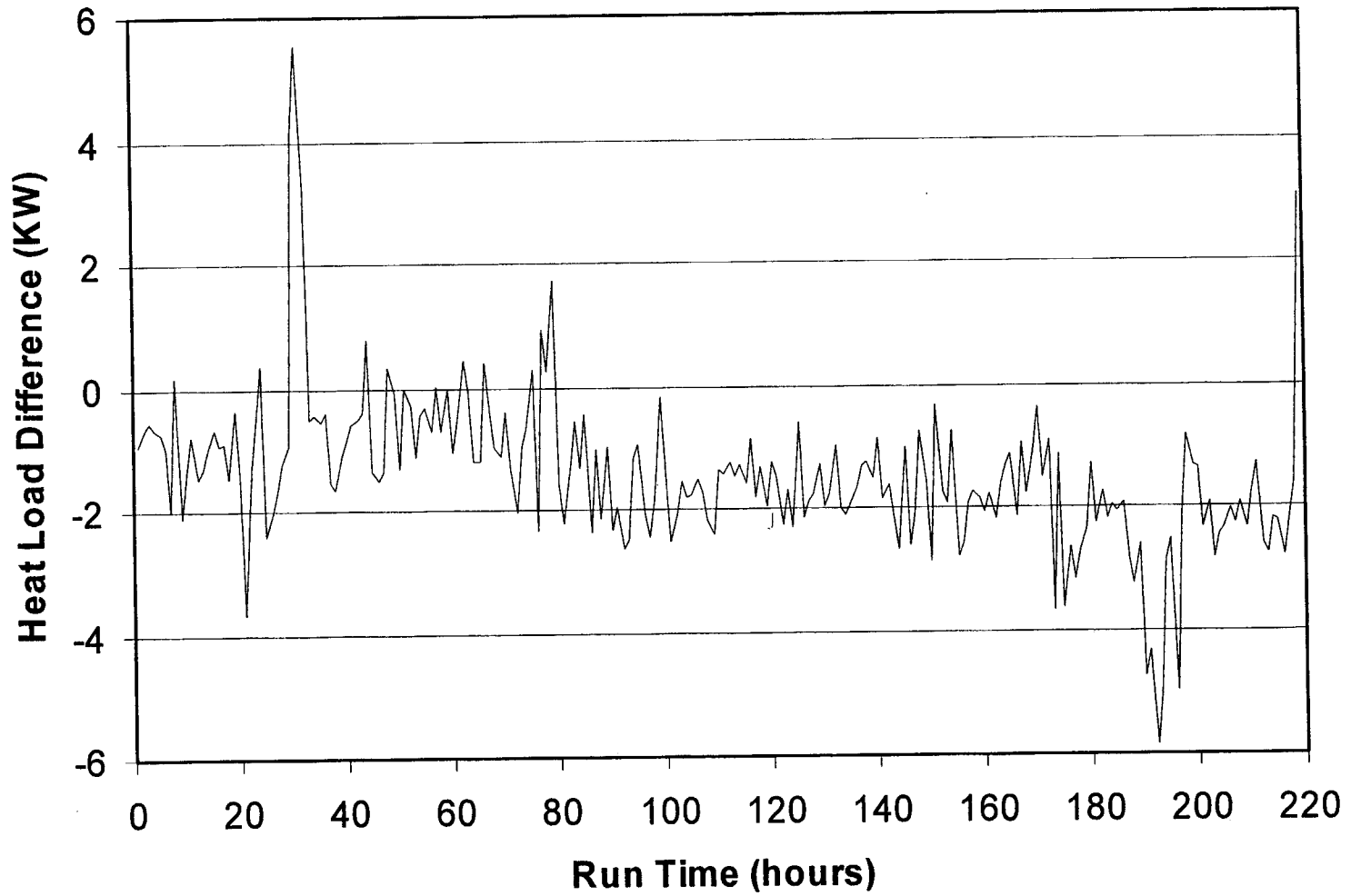


Figure 4.11. Calculated heat load difference of SBS inner coil and plate heat exchanger (hourly average values).

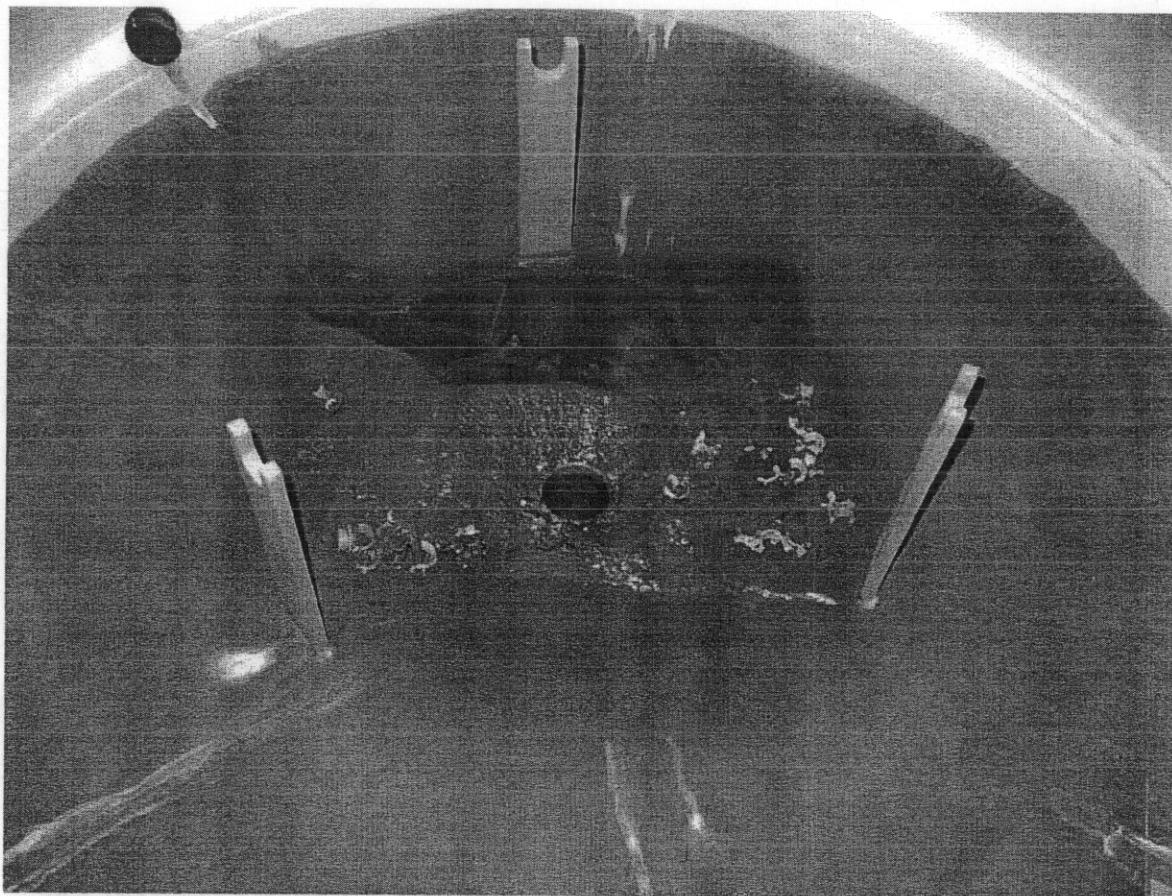
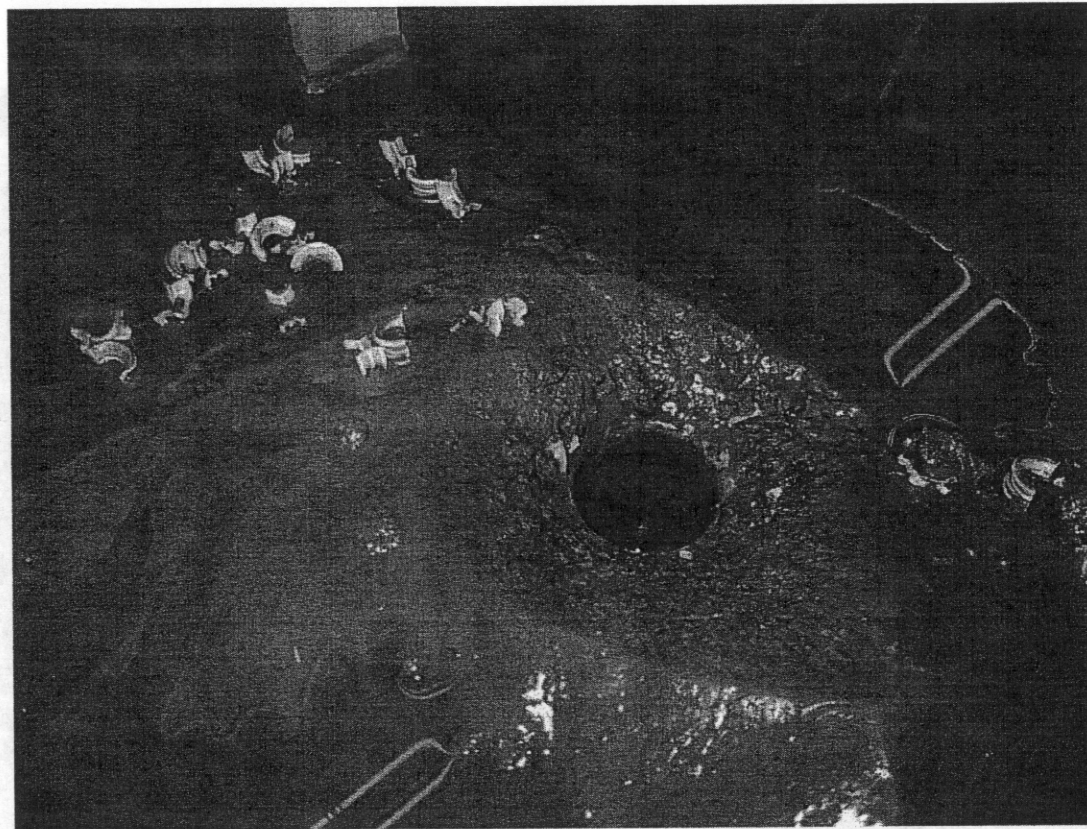


Figure 4.12. SBS bowl before cleaning at the end of the test.



**Figure 4.13. Additional view of SBS bowl before cleaning at the end of the test.**

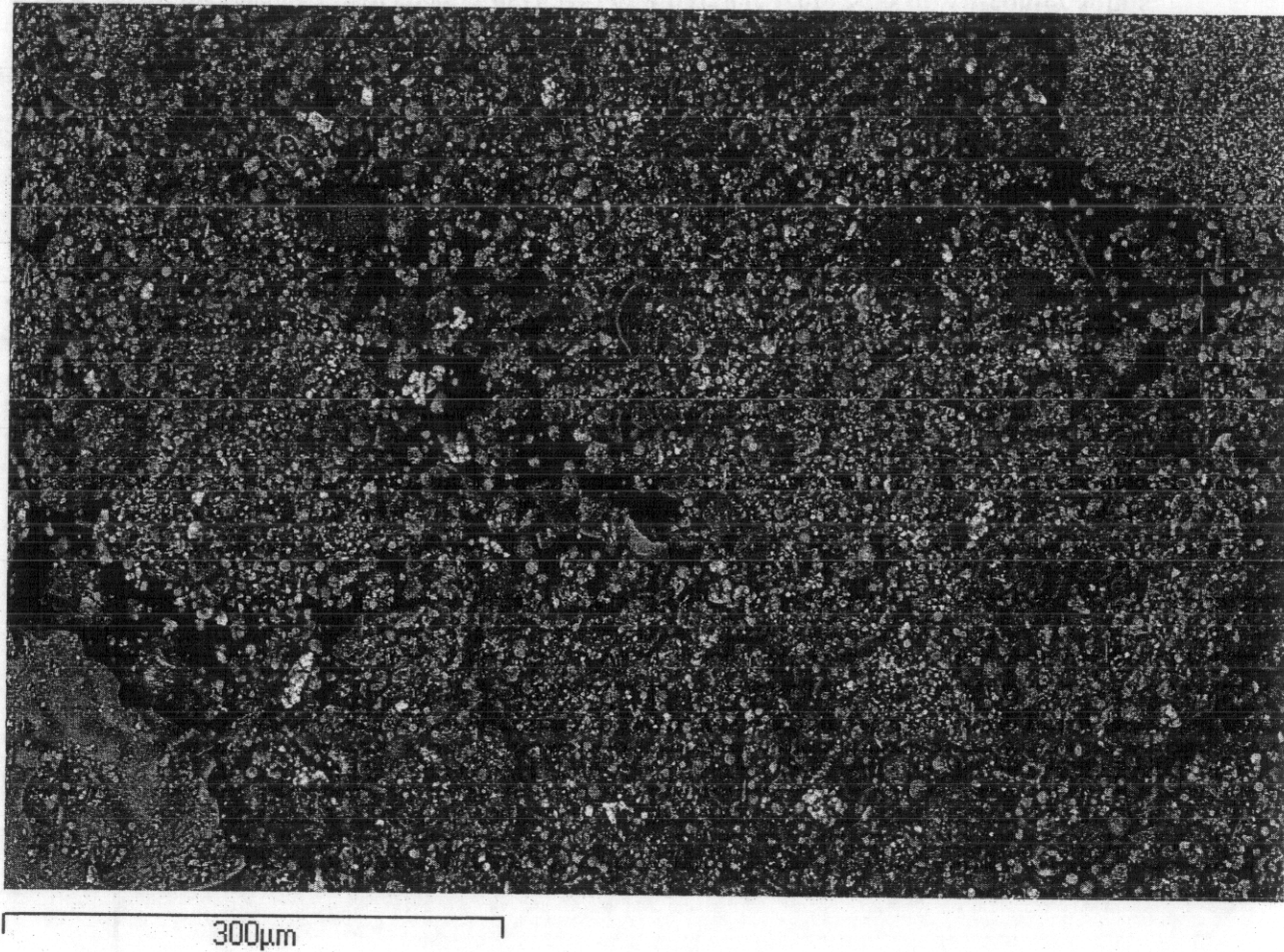


Figure 4.14. Back scattered electron (BSE) image of a sample taken from SBS down-comer solids.

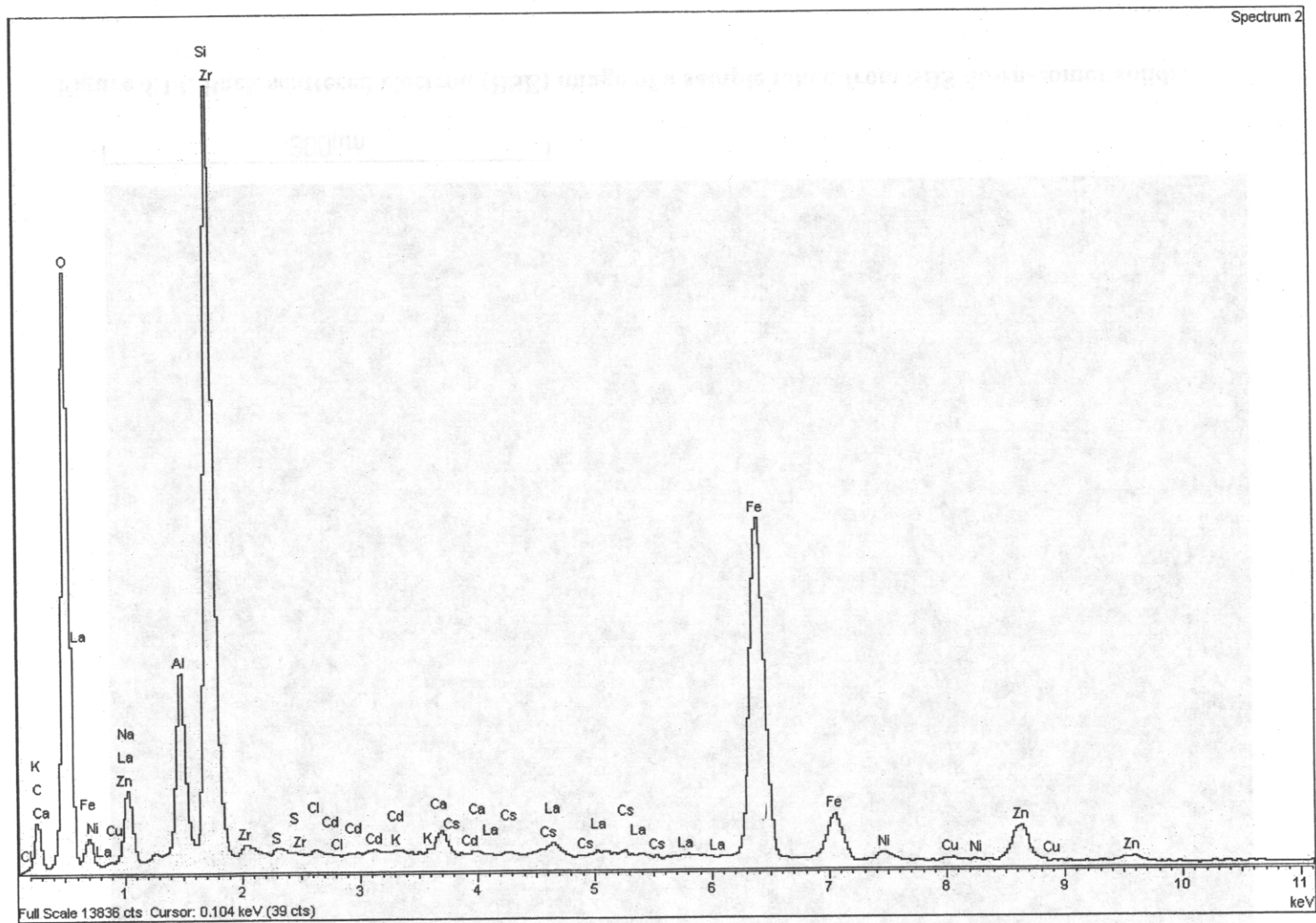


Figure 4.15. Energy dispersive x-ray spectrum (EDS) of a particle from SBS down-comer solids.

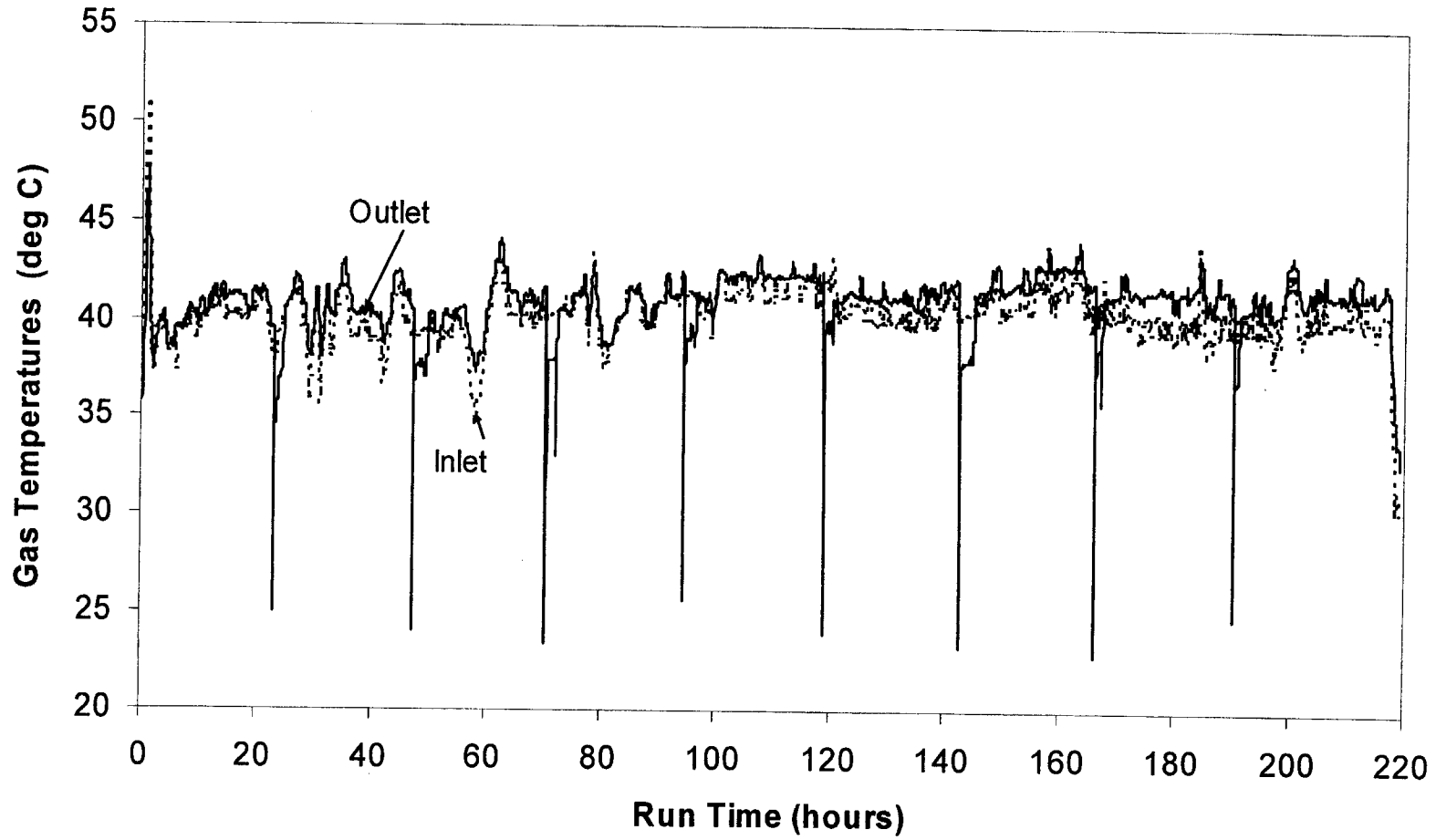


Figure 4.16. WESP inlet and outlet temperatures. (Note: Downward outlet temperatures spikes are the result of WESP deluges.)

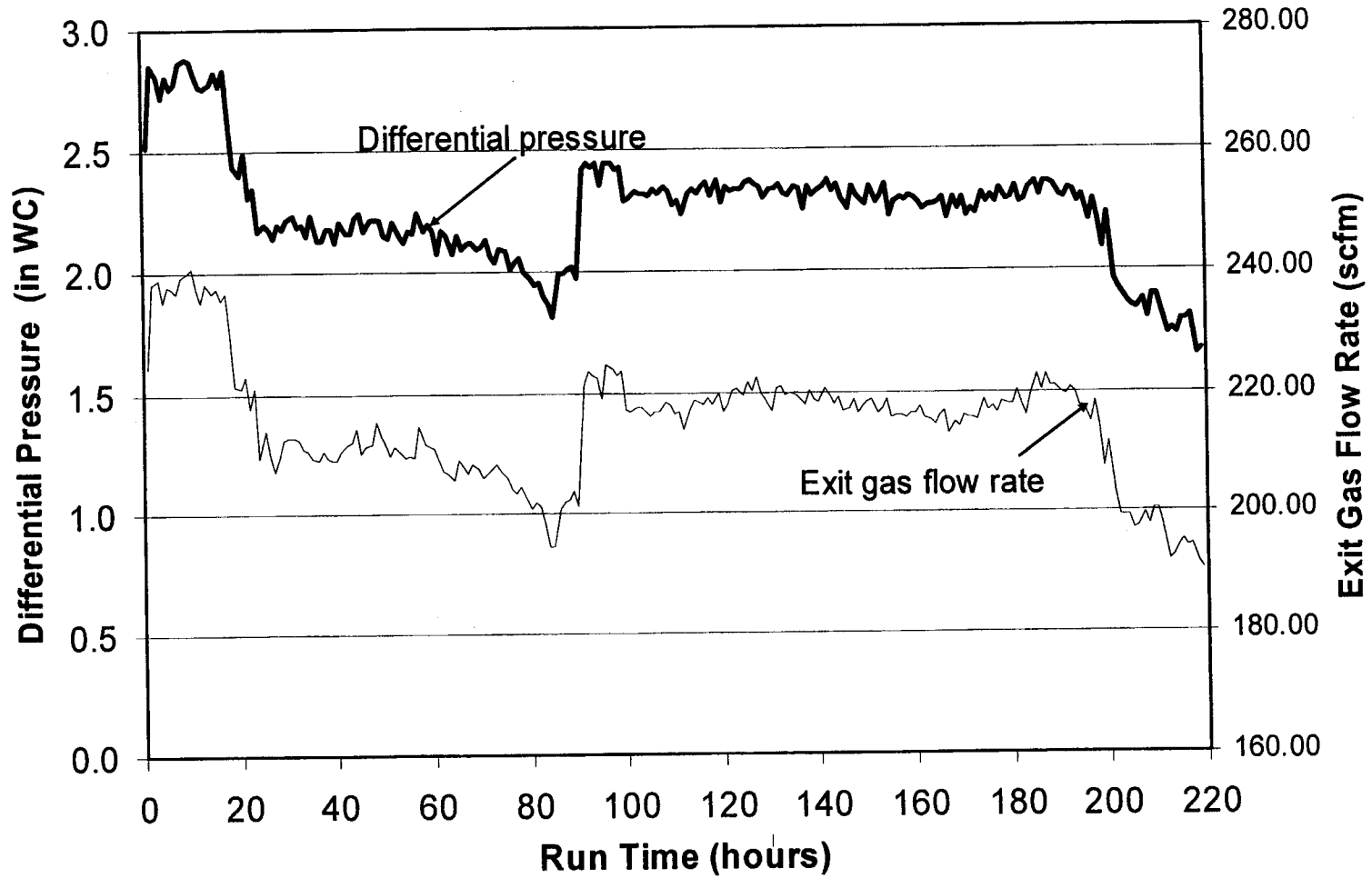


Figure 4.17. WESP differential pressure and outlet gas flow rate (hourly average values).

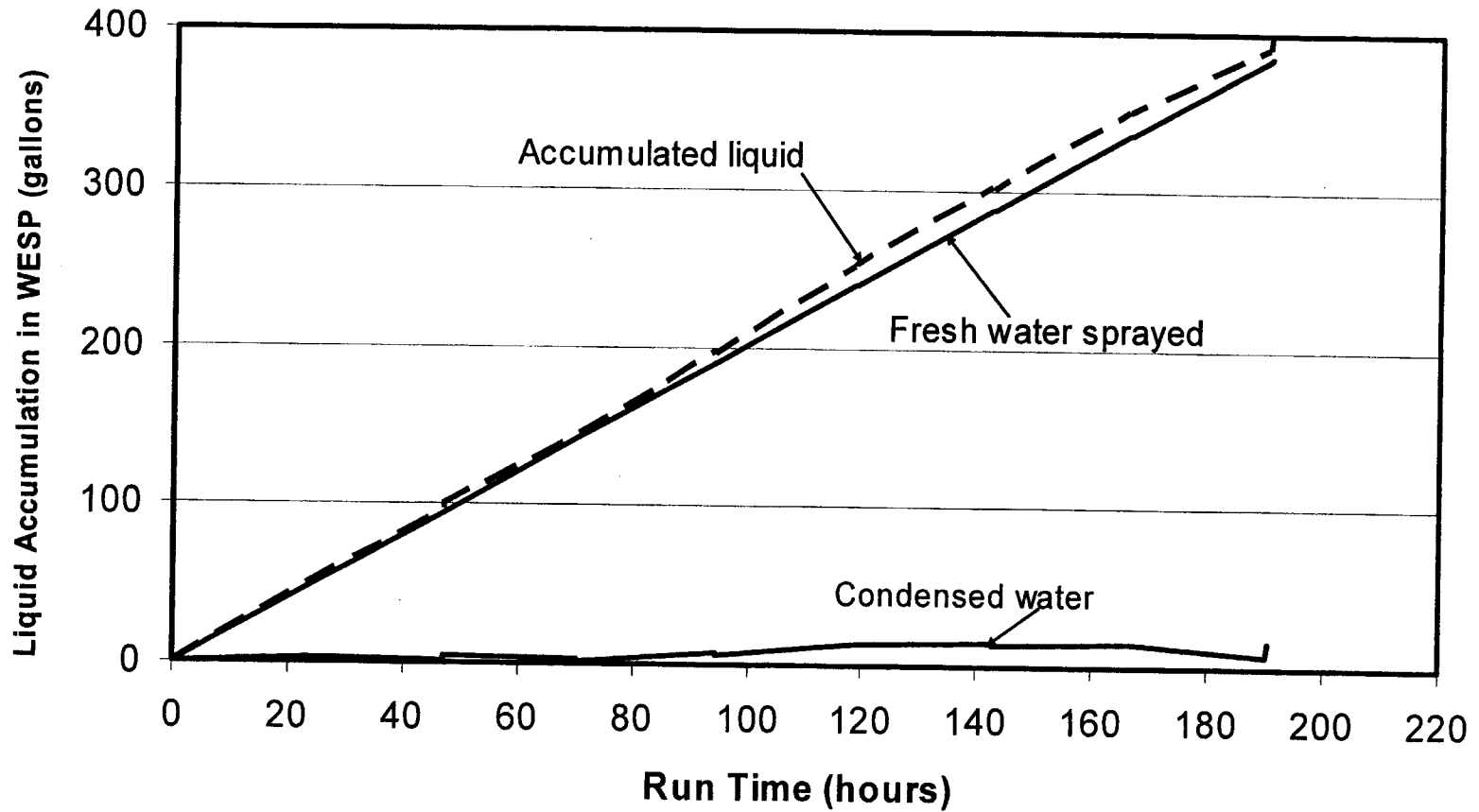


Figure 4.18. Accumulated WESP blow-down volume, accumulated fresh spray water, and condensed water.

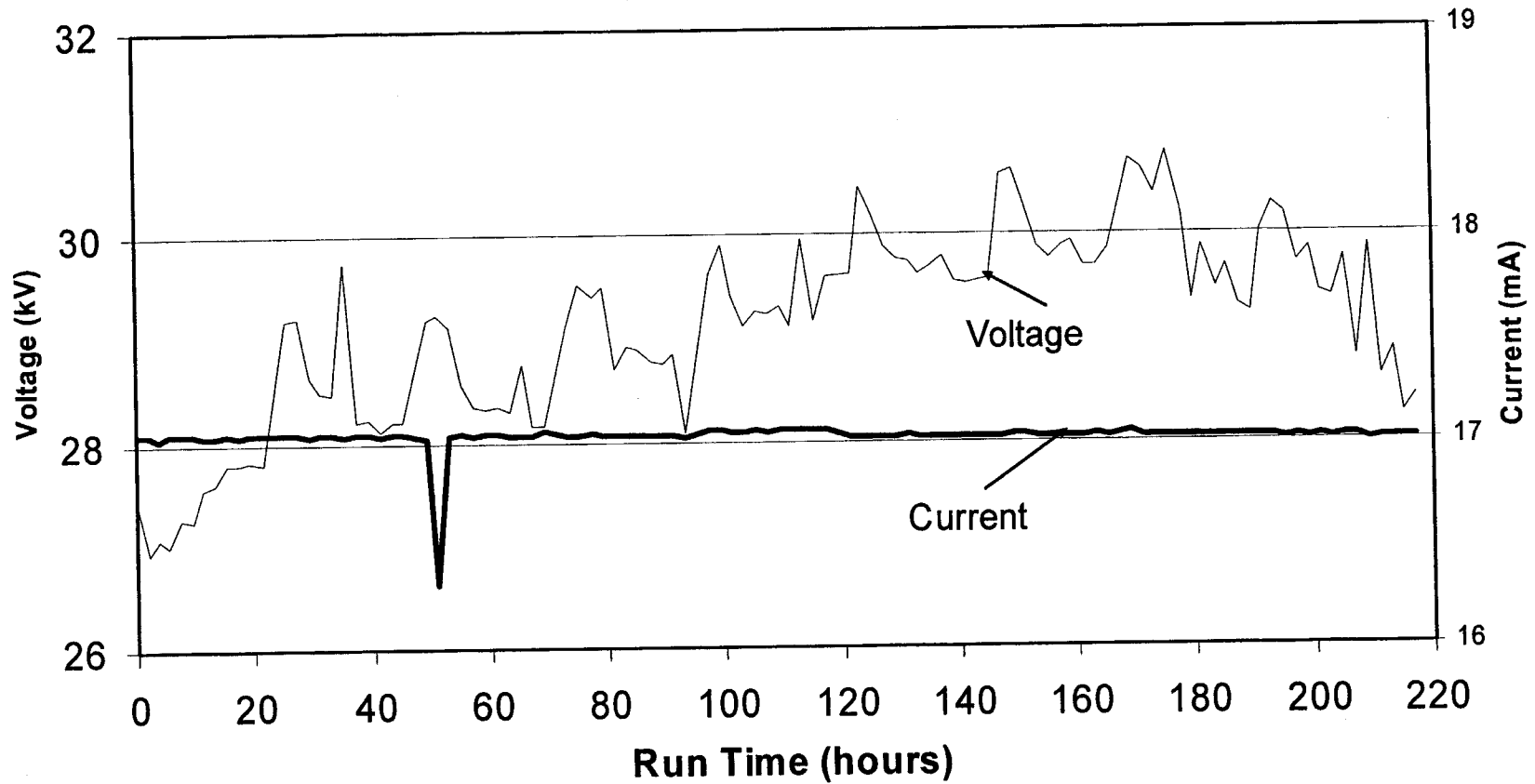


Figure 4.19. Voltage and current across the WESP. (Note; WESP was turned off during the deluges.)

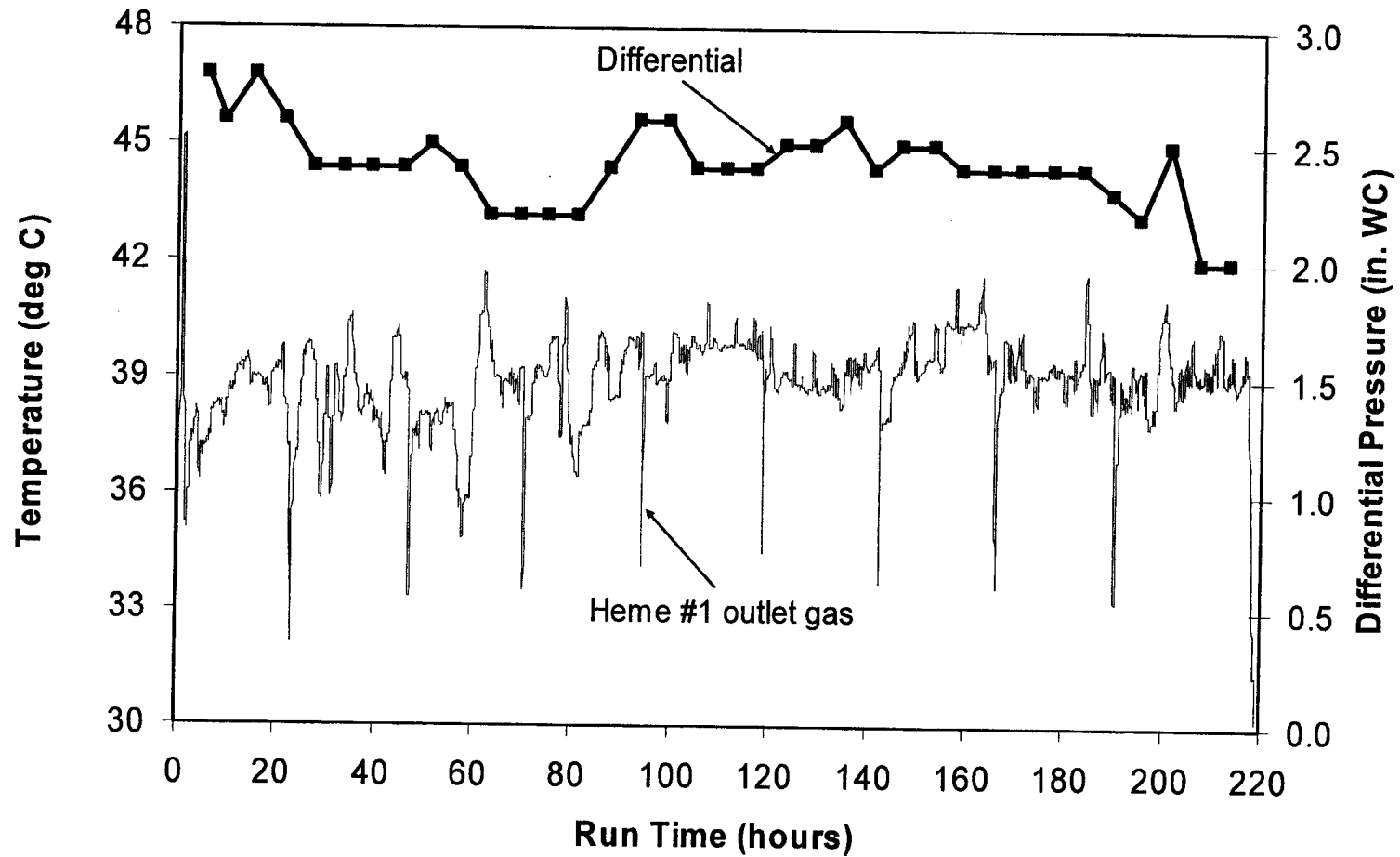


Figure 4.20. Outlet temperature and differential pressure for HEME 1.

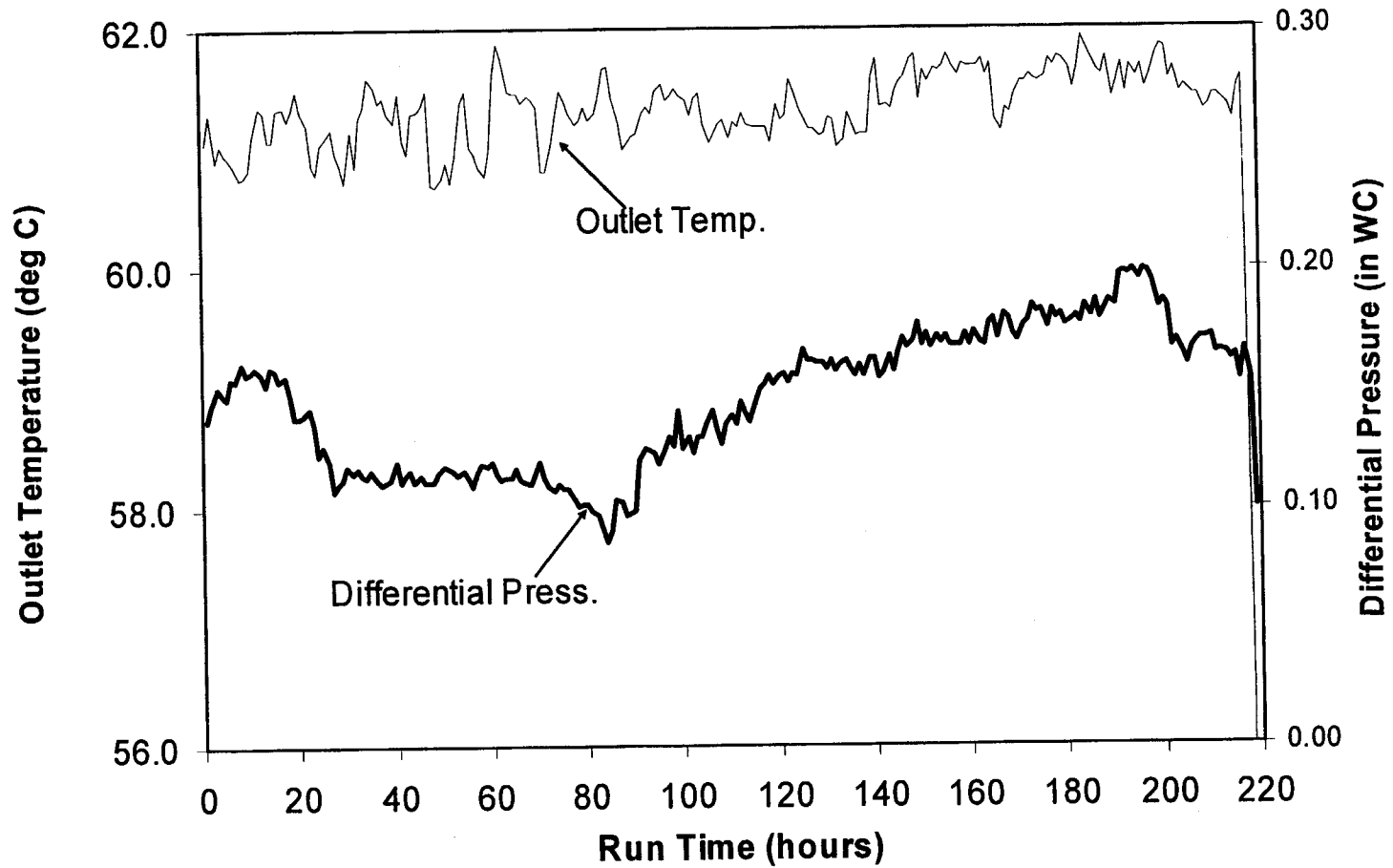


Figure 4.21. Outlet temperature and differential pressure for HEPA 1 (hourly average values).

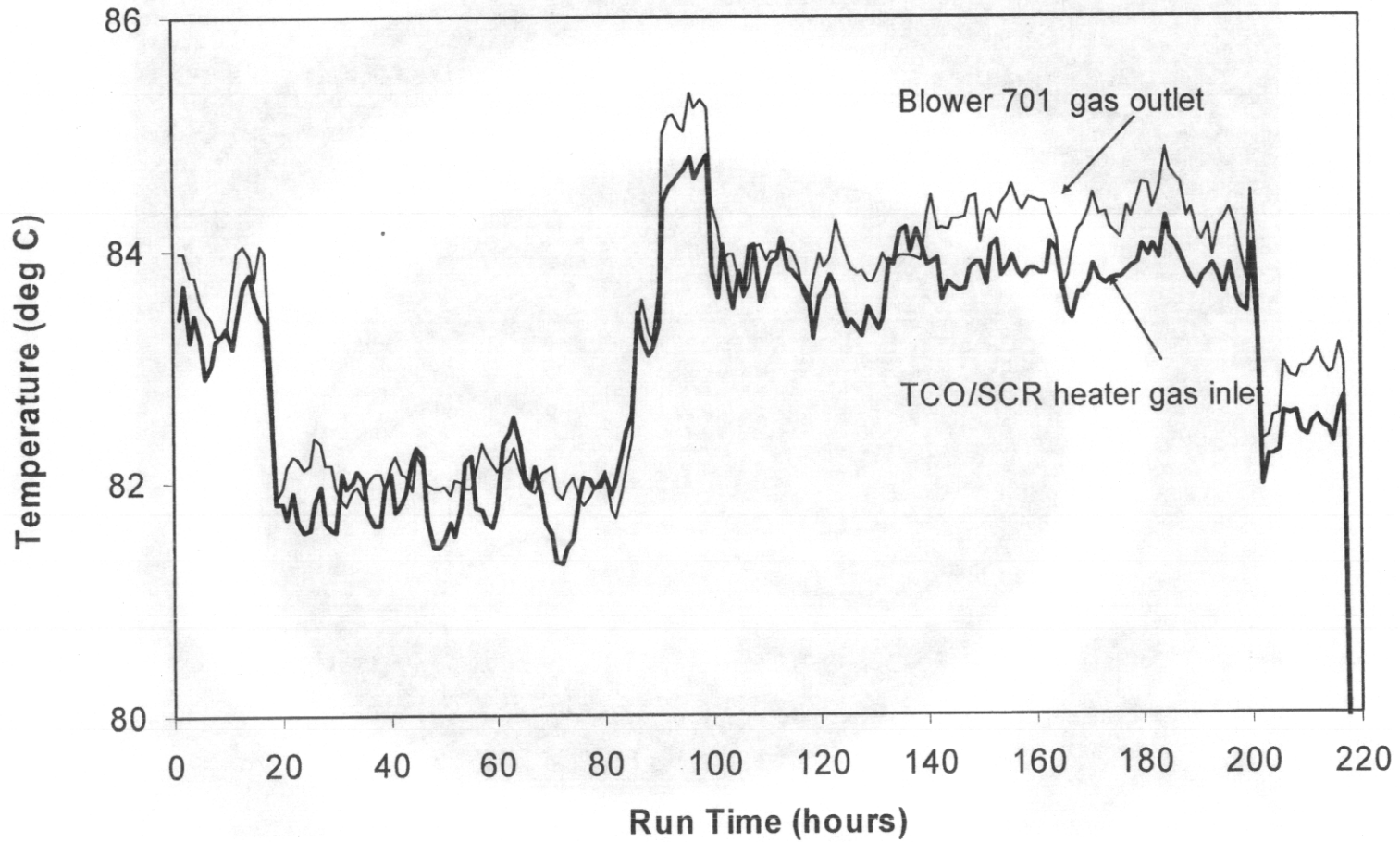


Figure 4.22. PAXTON 1 outlet and TCO/SCR heater inlet temperatures (hourly average values).

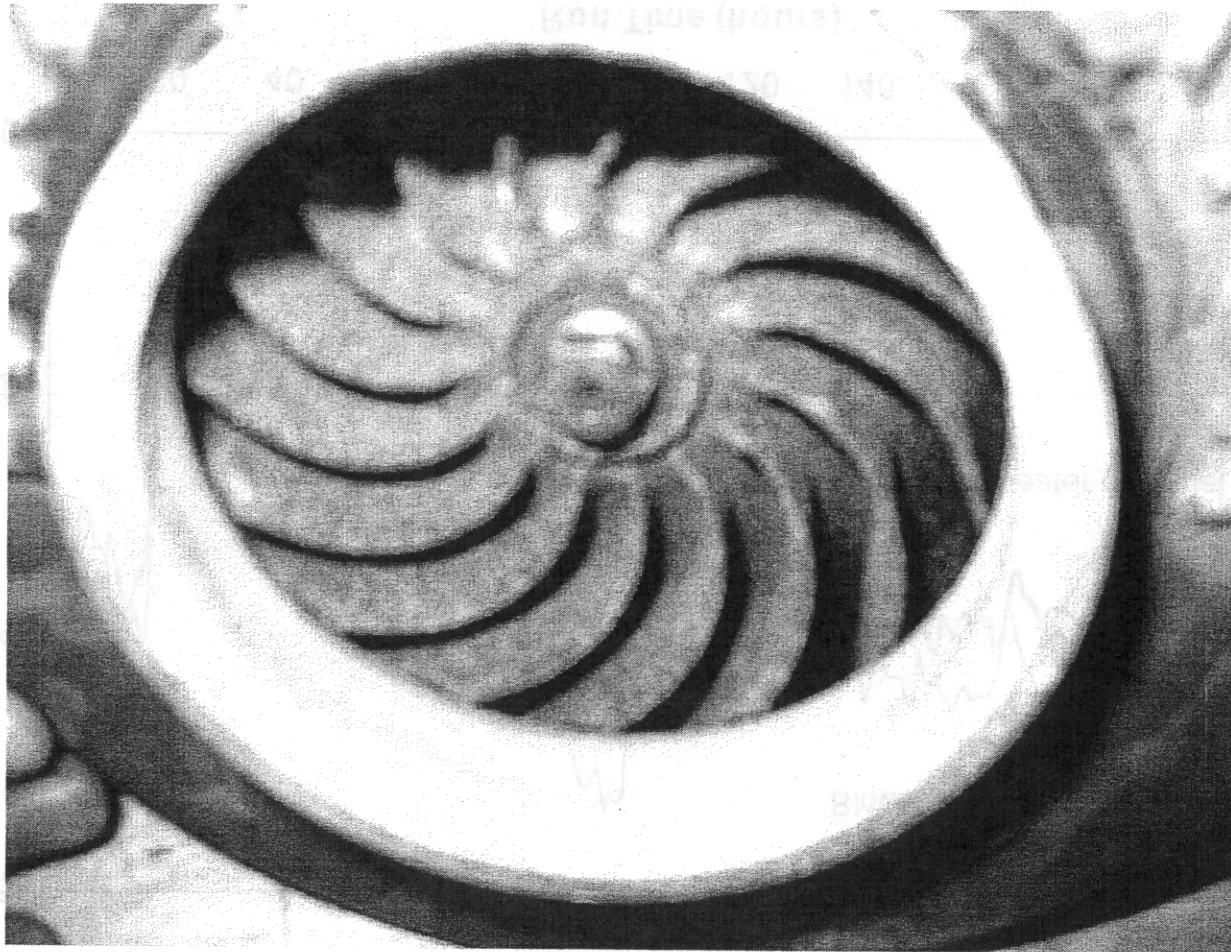
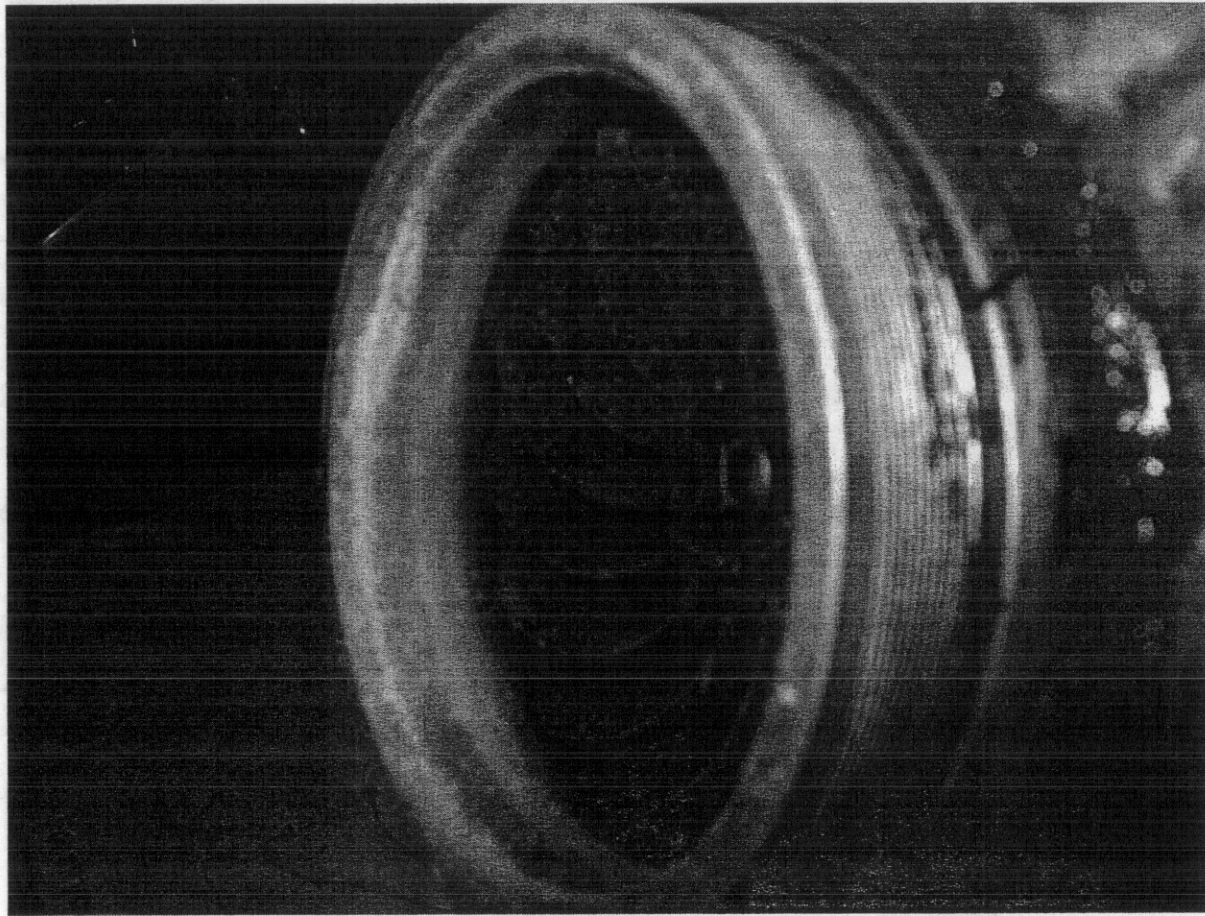


Figure 4.23. View of blower B-701 impeller inlet after the test.



**Figure 4.24. Additional view of blower B-701 impeller inlet after the test.**

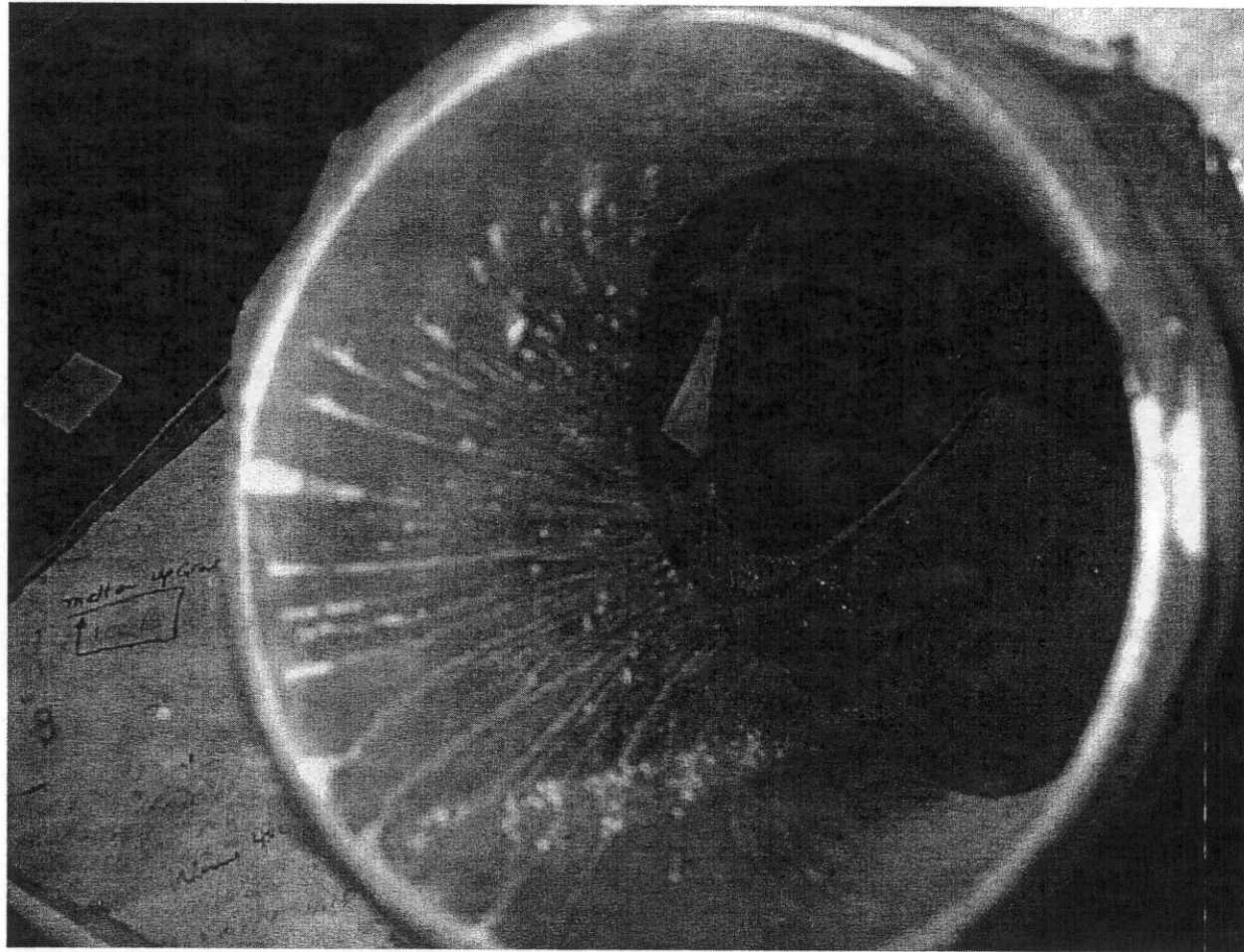


Figure 4.25. View of blower B-701 outlet after the test.

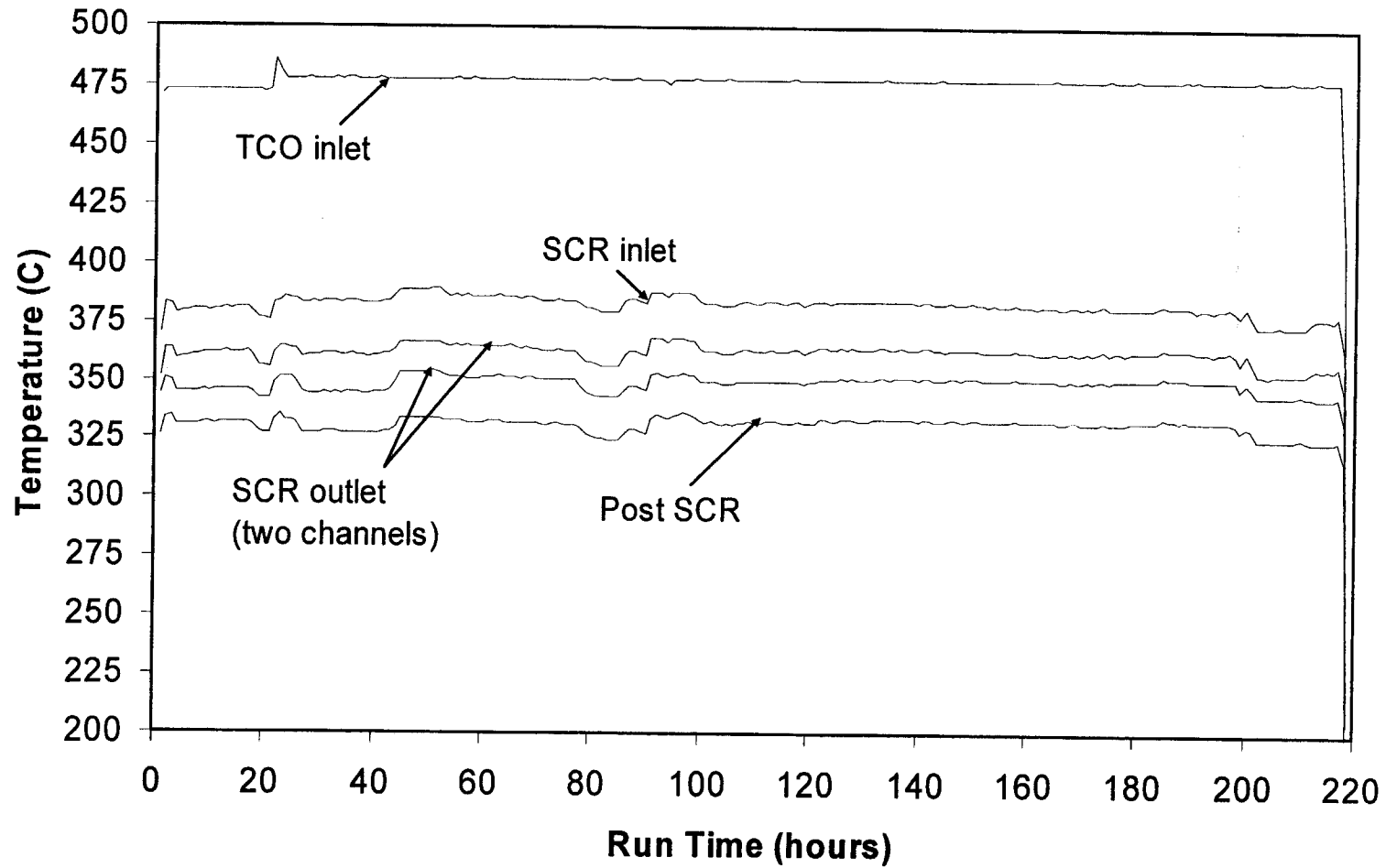


Figure 4.26. TCO/SCR temperatures (hourly average values).

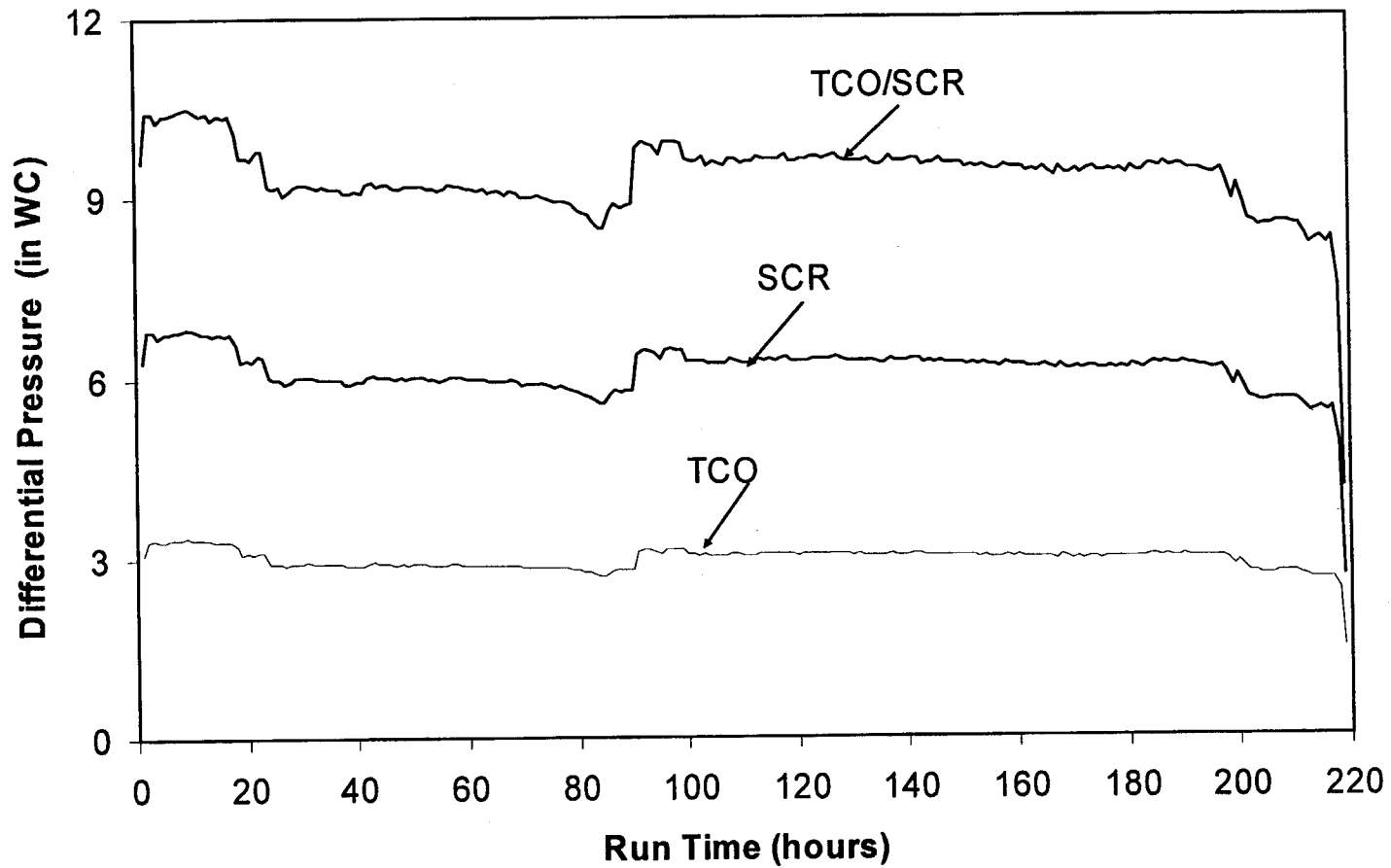


Figure 4.27. TCO/SCR differential pressures (hourly average values).

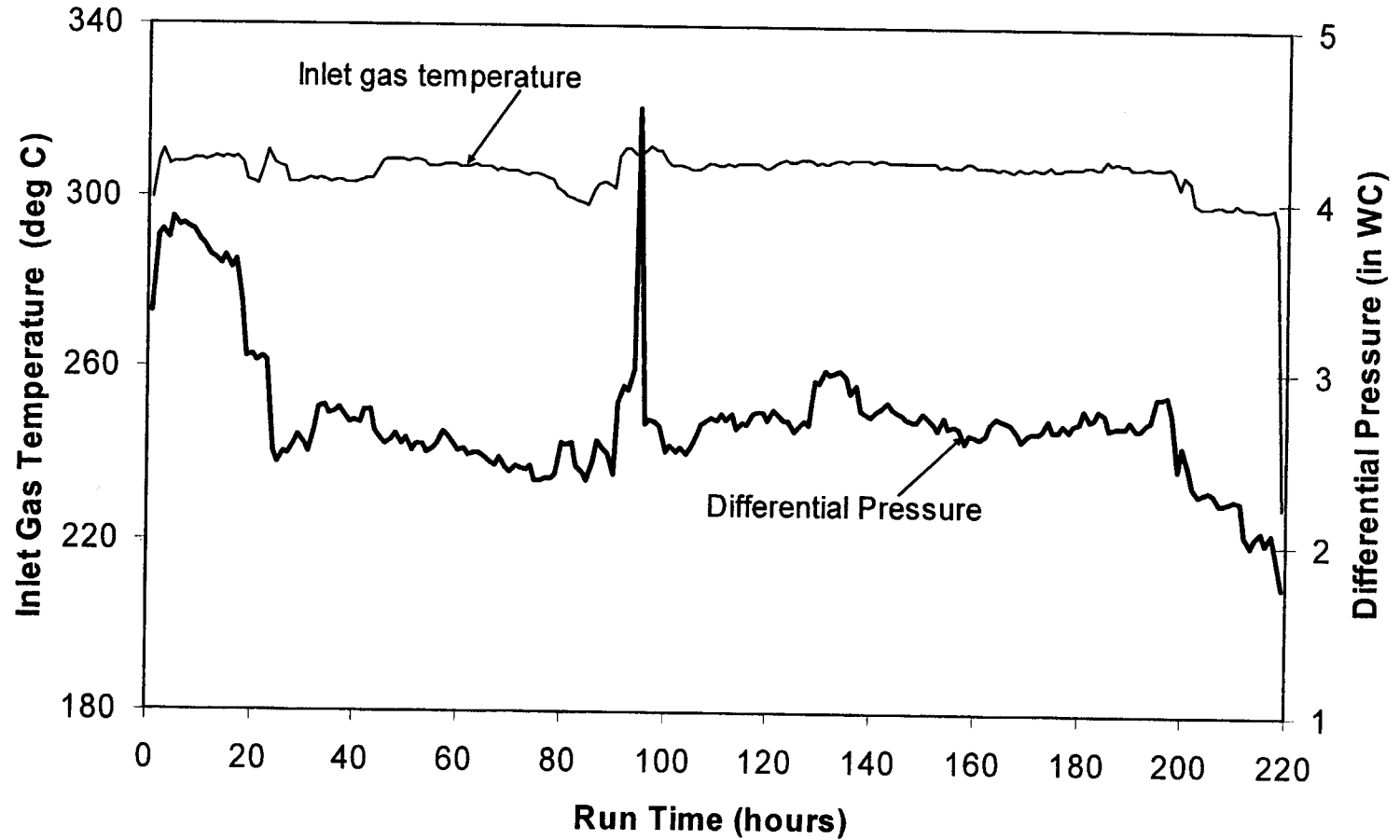


Figure 4.28. Inlet temperature and differential pressure for PBS (hourly average values).

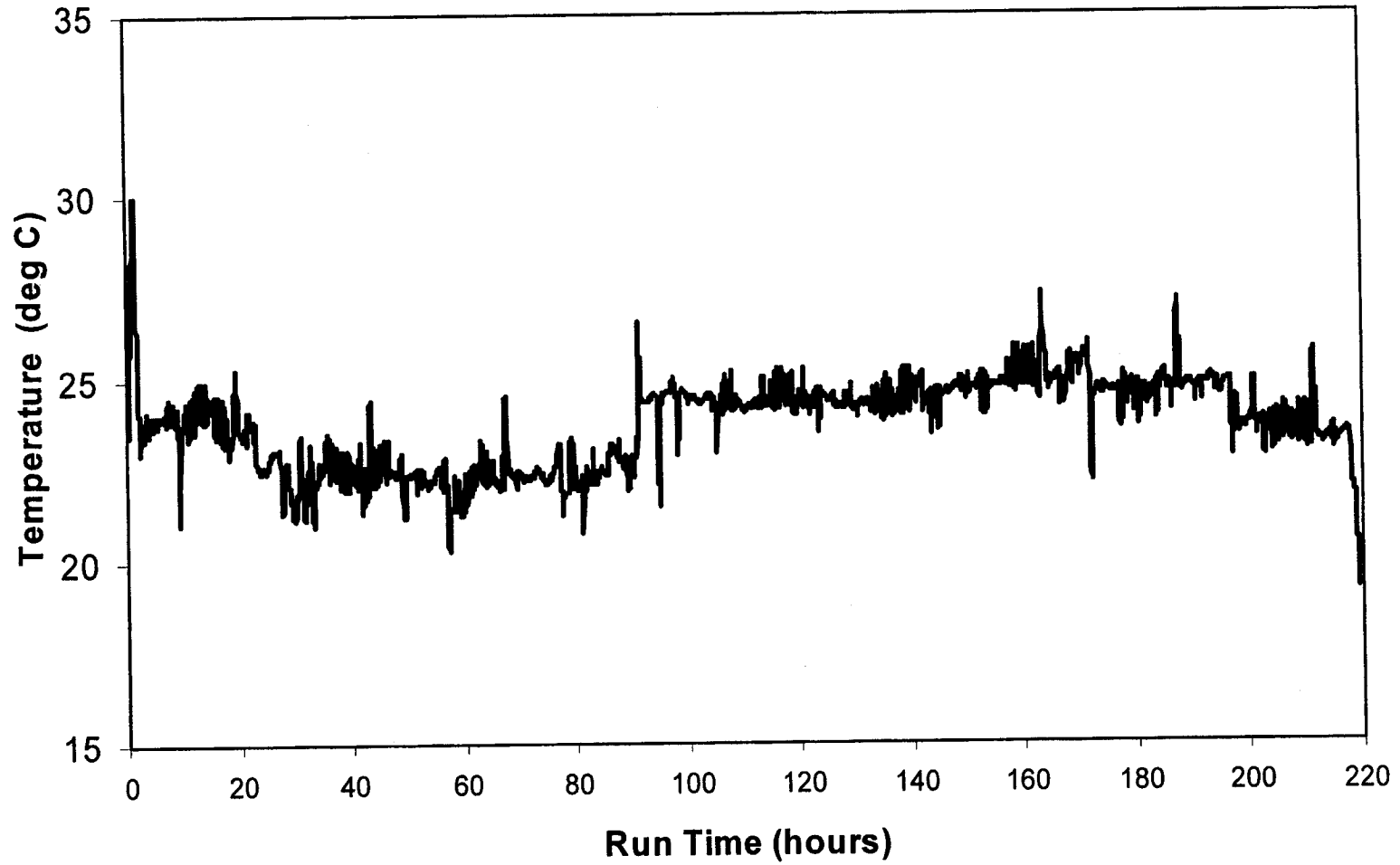


Figure 4.29. PBS sump temperature.

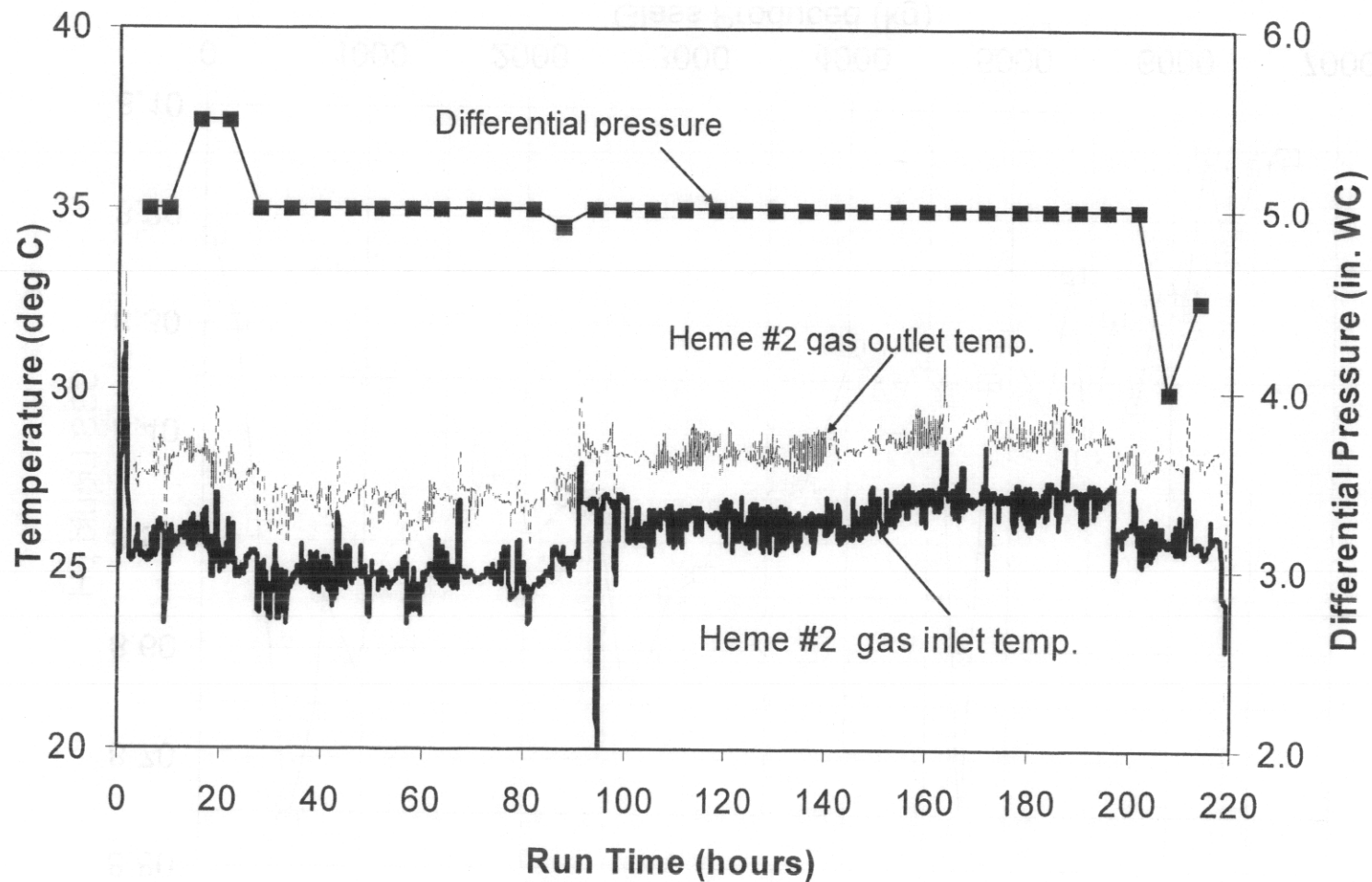


Figure 4.30. Inlet and outlet temperatures and differential pressure for HEME 2.

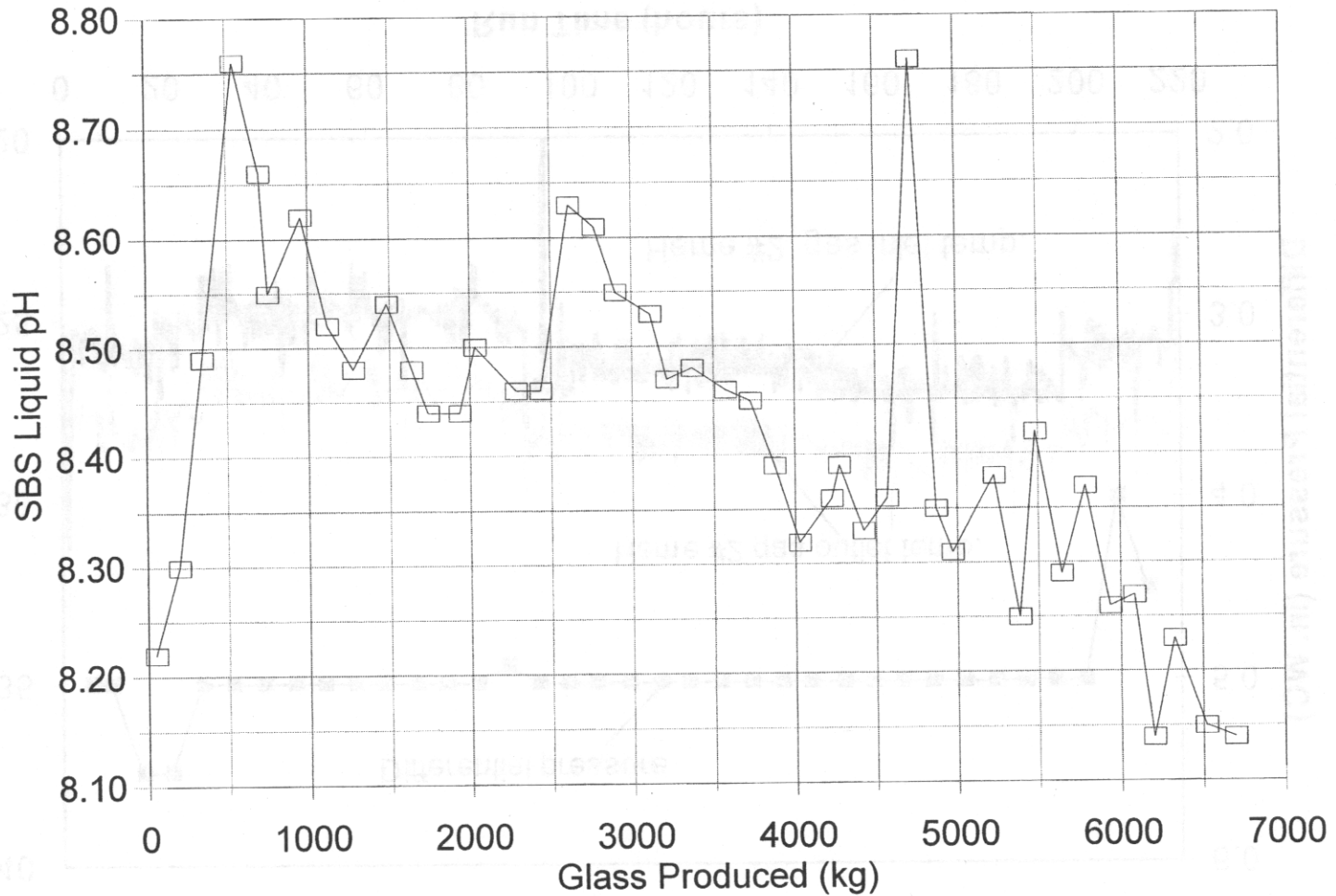


Figure 4.31. pH of SBS blow-down solutions.

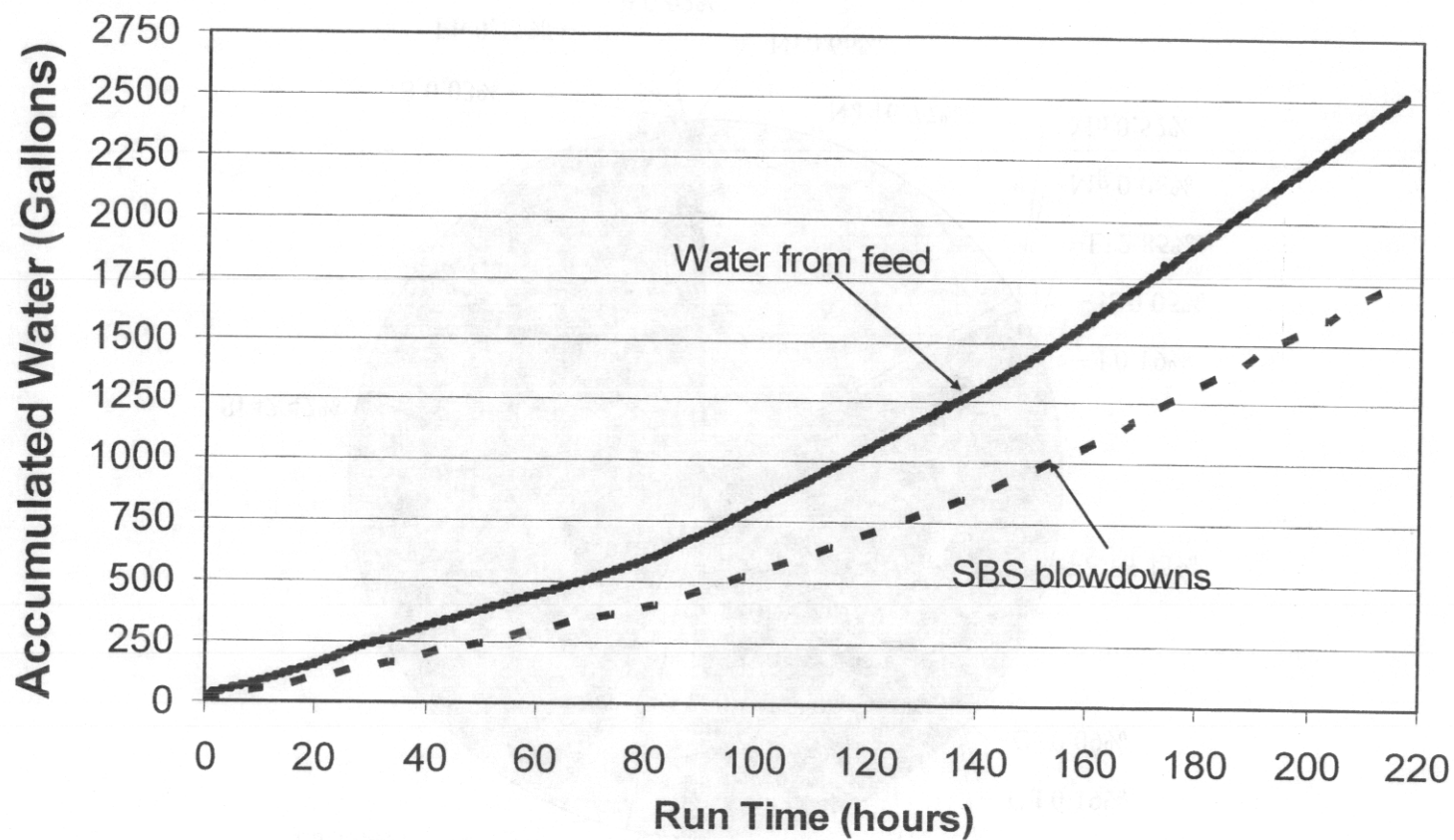


Figure 4.32. Accumulated SBS blow-down volume (gallons) and average accumulated feed water.

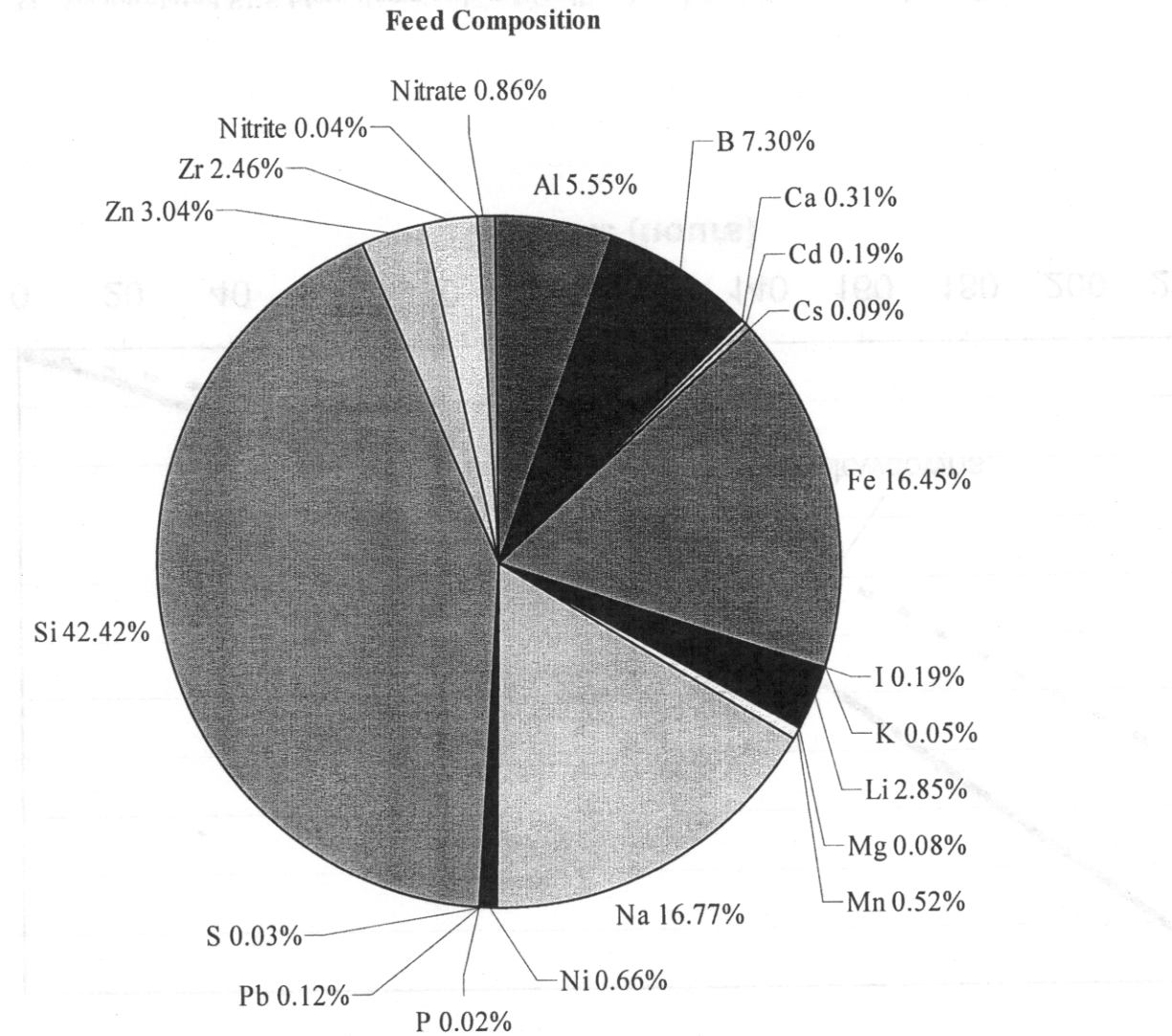


Figure 4.33. Feed composition (excludes oxygen and carbon).

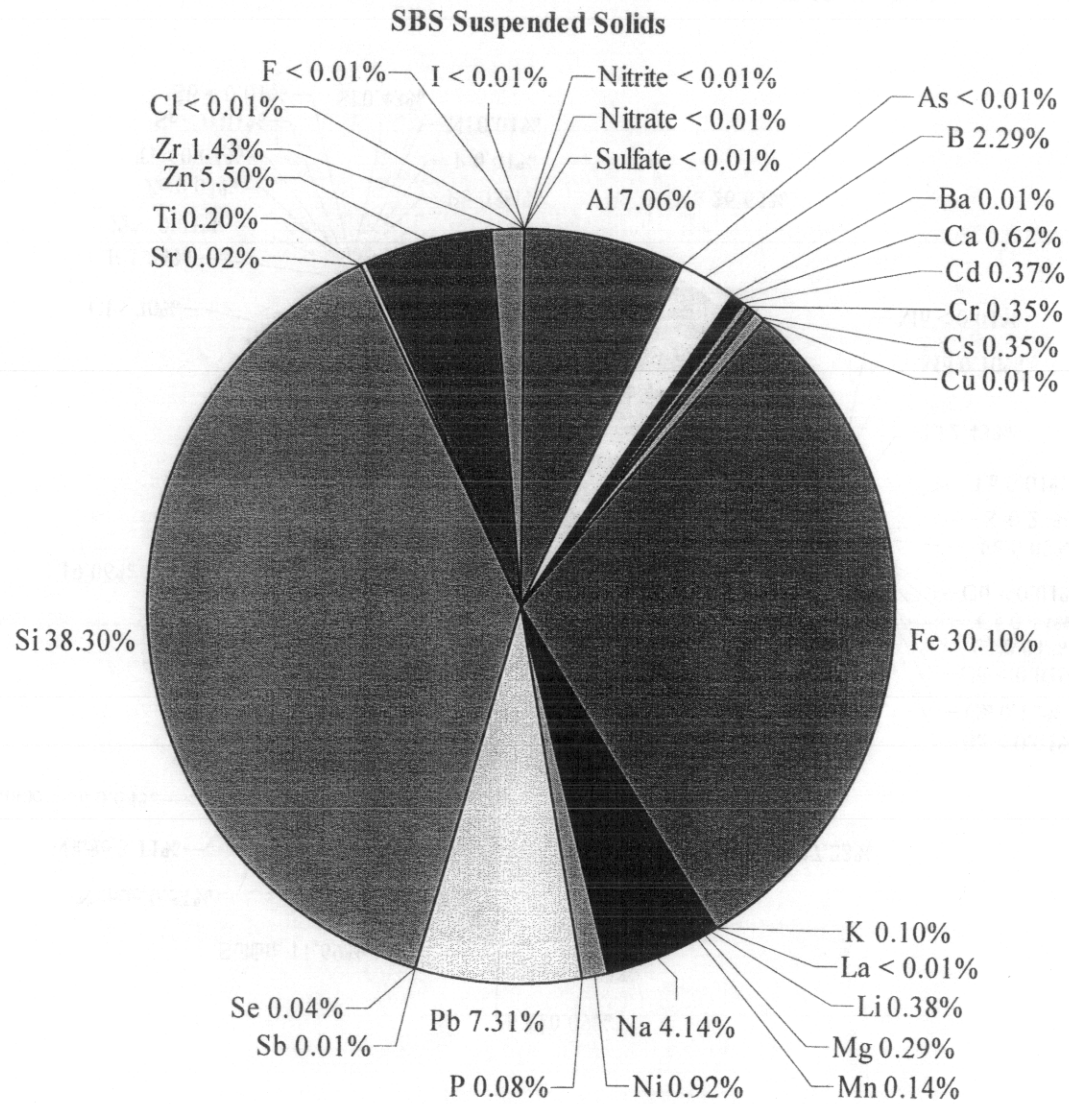


Figure 4.34. Suspended solids composition from SBS sample (L12-S-89A).



The Catholic University of America  
Vitreous State Laboratory

DM1200 Tests with AZ-102 HLW Simulants  
Final Report, VSL-03R3800-2, Rev. 0

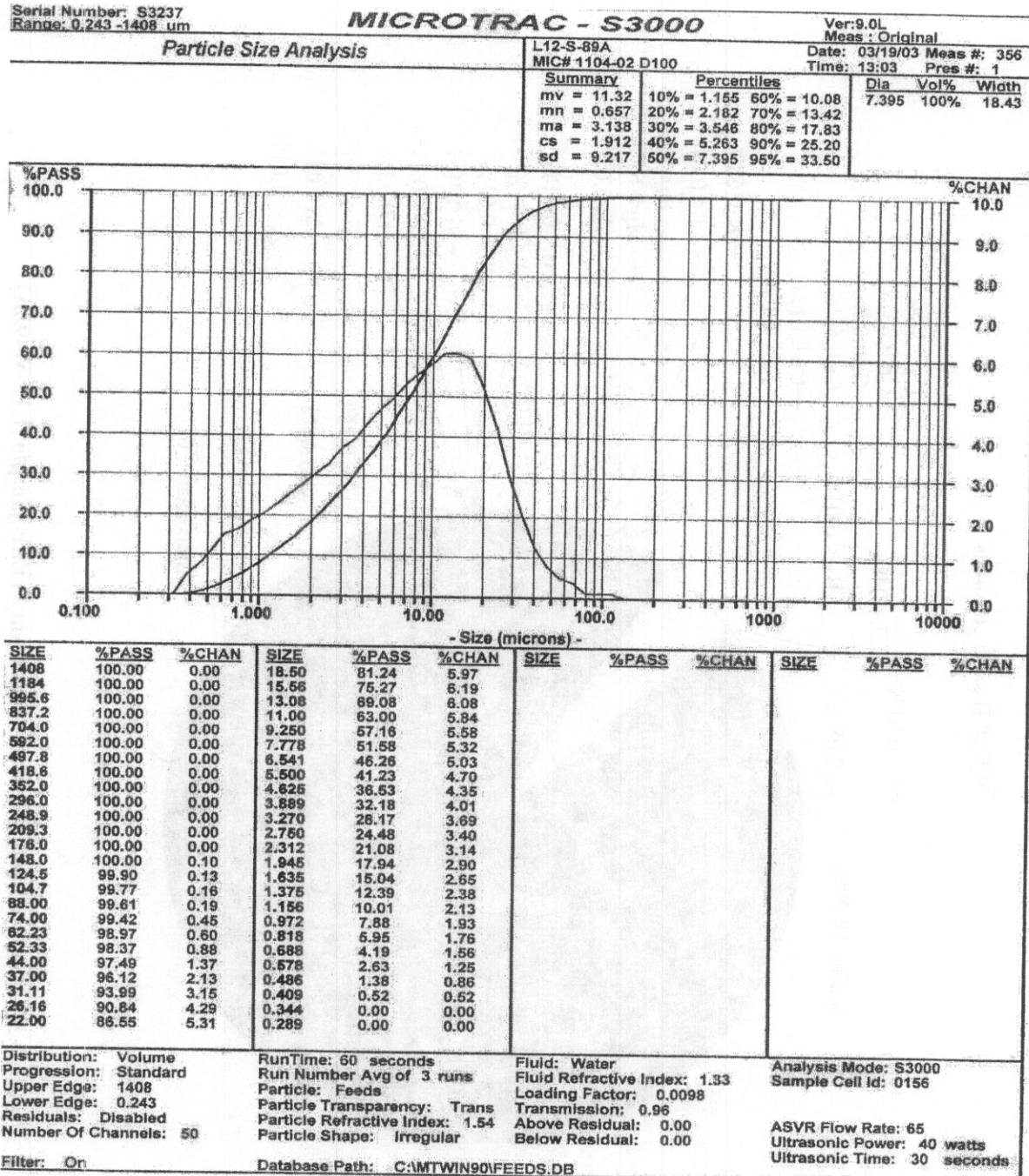


Figure 4.36. Particle Characteristics of Suspended Solids in a SBS Sample (L12-S-89A).



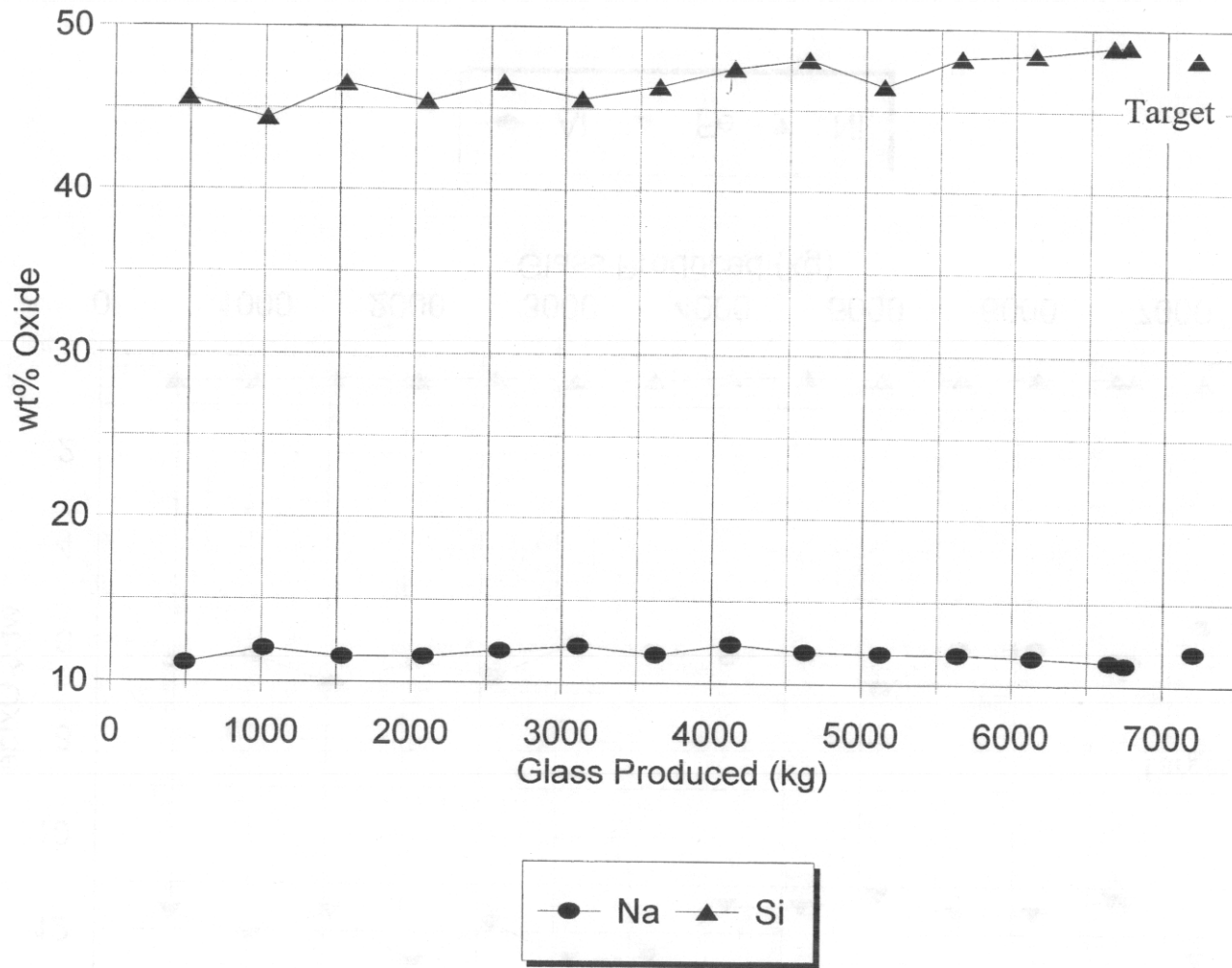


Figure 5.1. XRF analysis of sodium and silicon oxides in glasses from DM1200 testing.

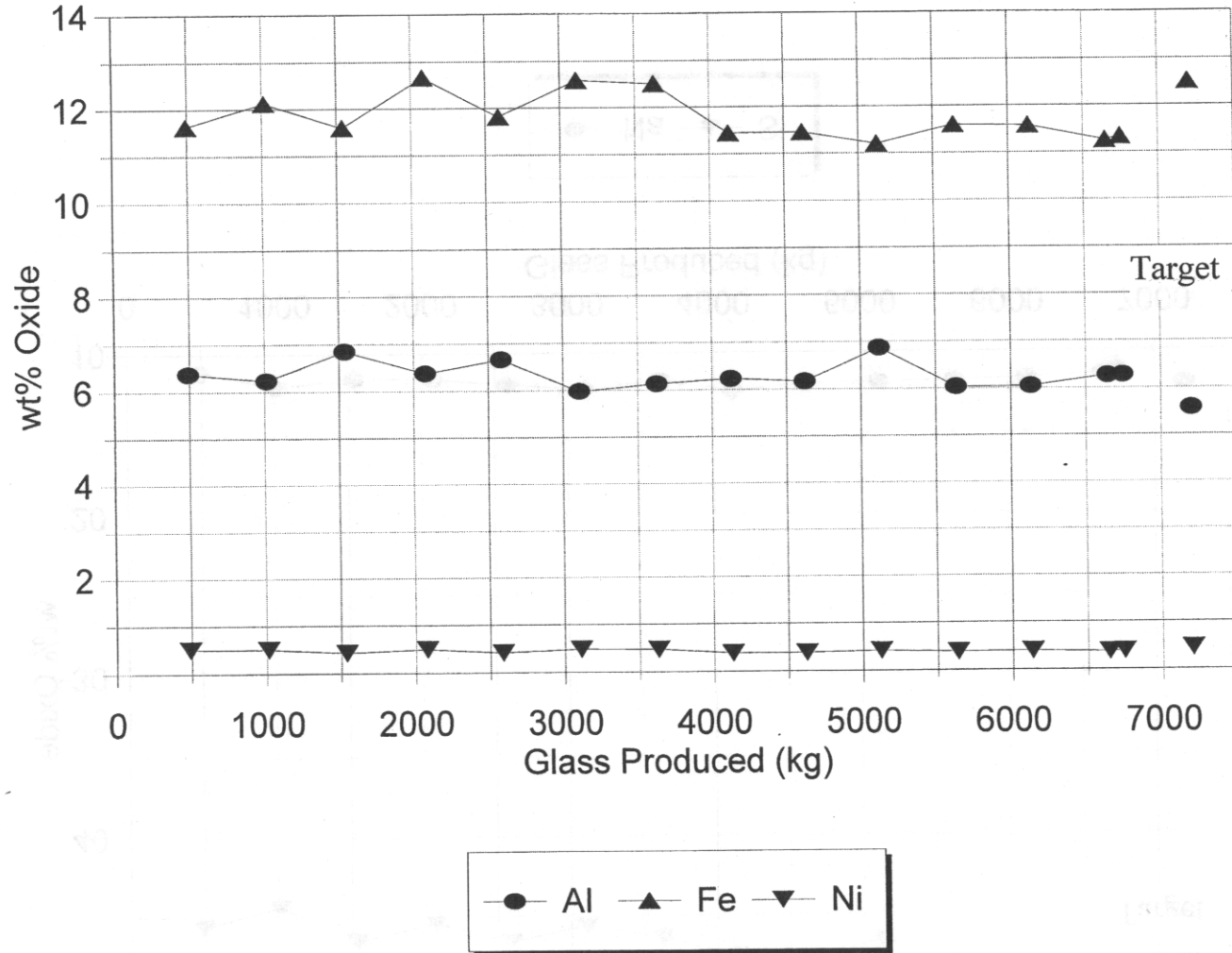


Figure 5.2. XRF analysis of selected oxides in glasses from DM1200 testing.

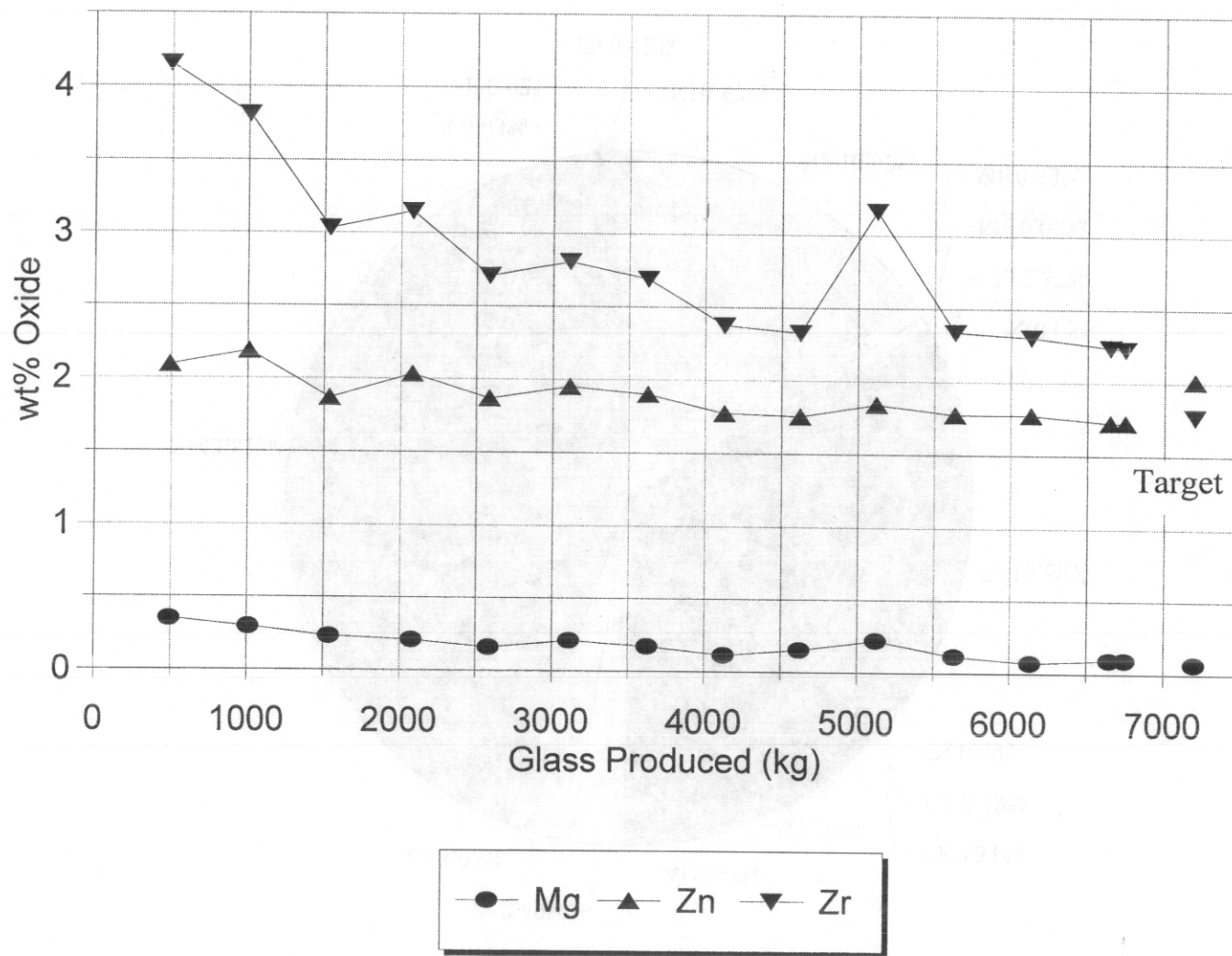


Figure 5.3. XRF analysis of oxides decreasing in concentration in glasses from DM1200 testing.

### Feed Composition

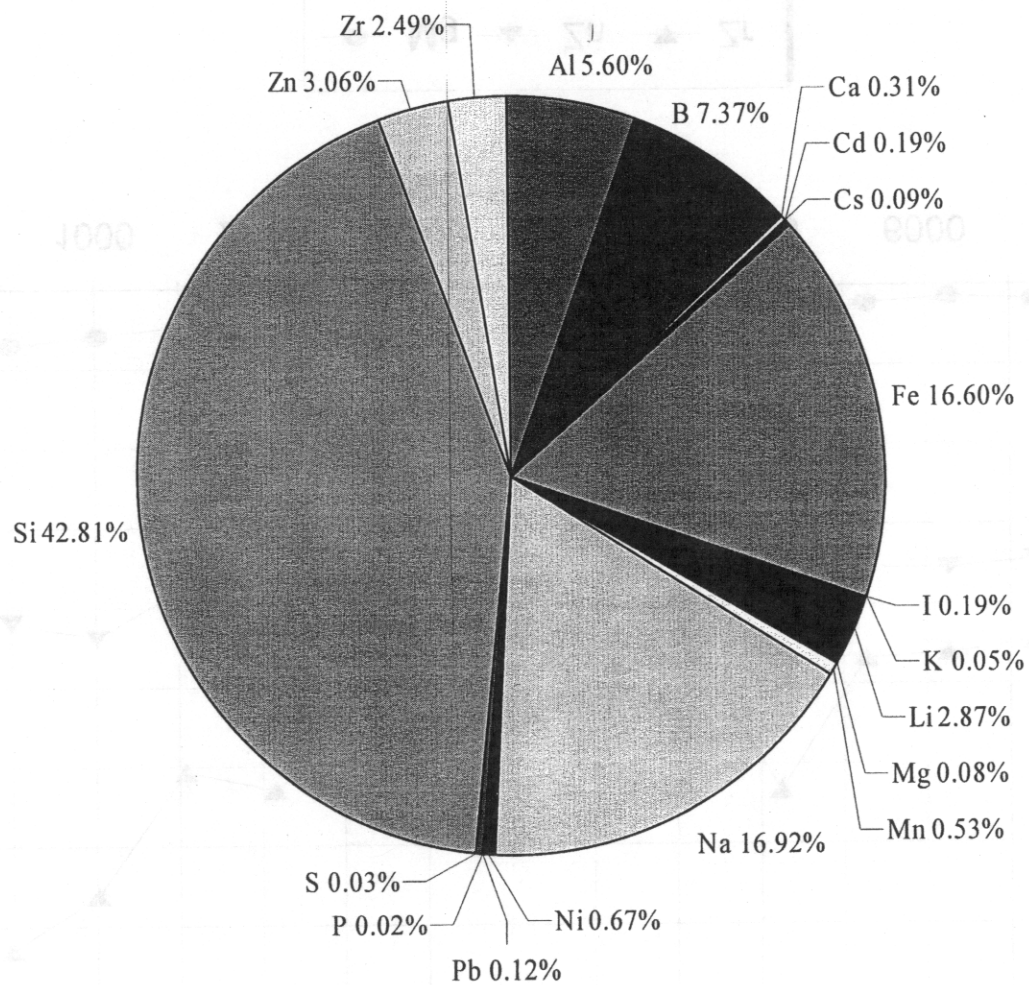


Figure 6.1. Feed composition (excludes oxygen, nitrogen and carbon compounds).

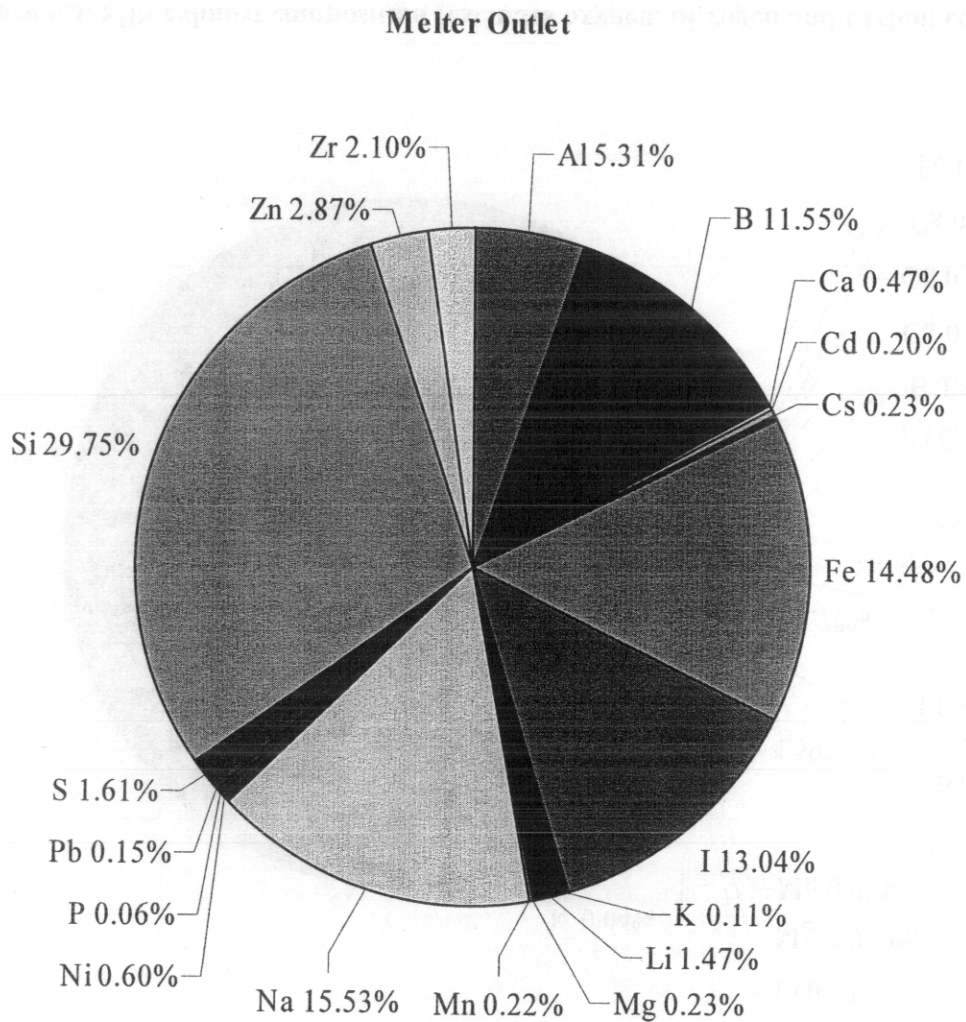


Figure 6.2. Melter exhaust composition (excludes oxygen, nitrogen and carbon compounds).

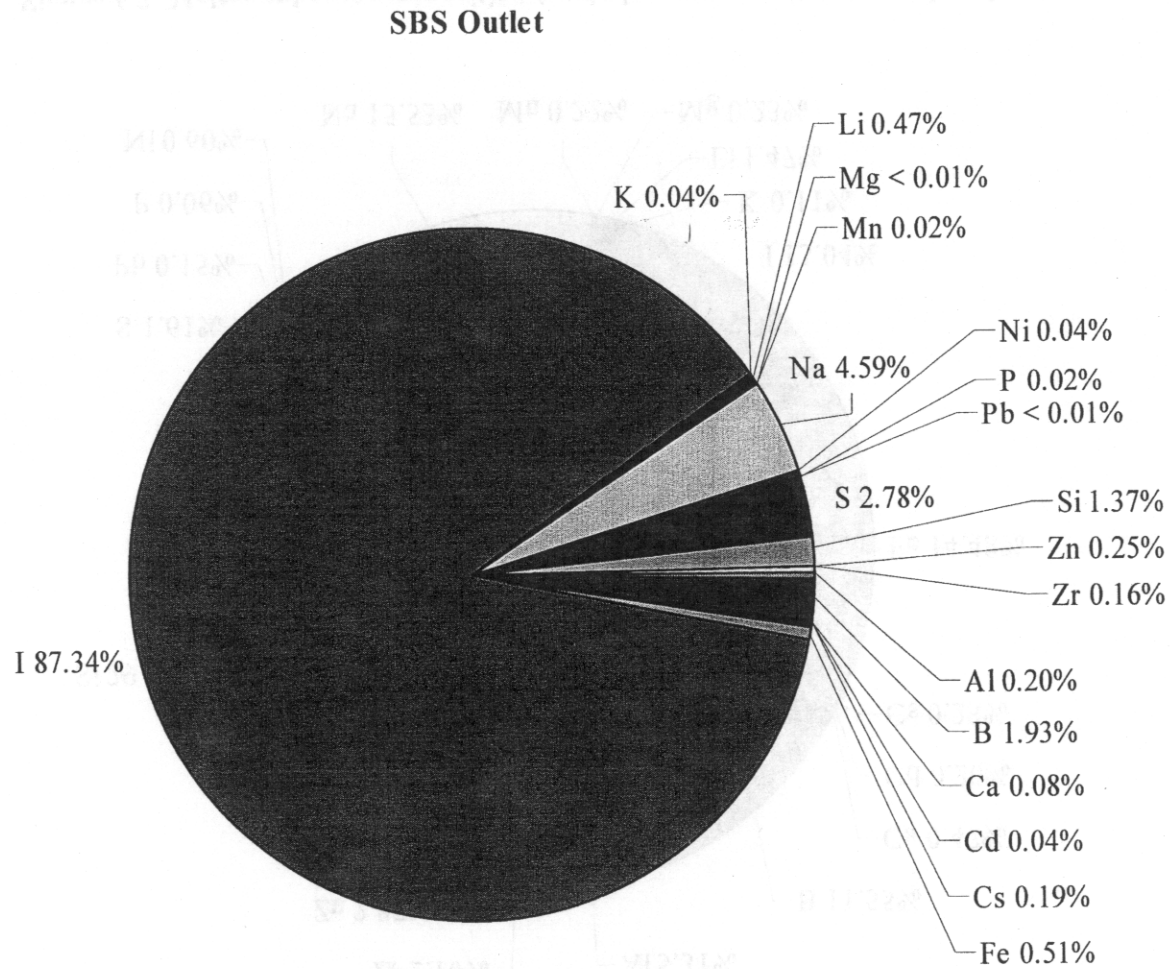


Figure 6.3. SBS exhaust composition (excludes oxygen, nitrogen and carbon compounds).

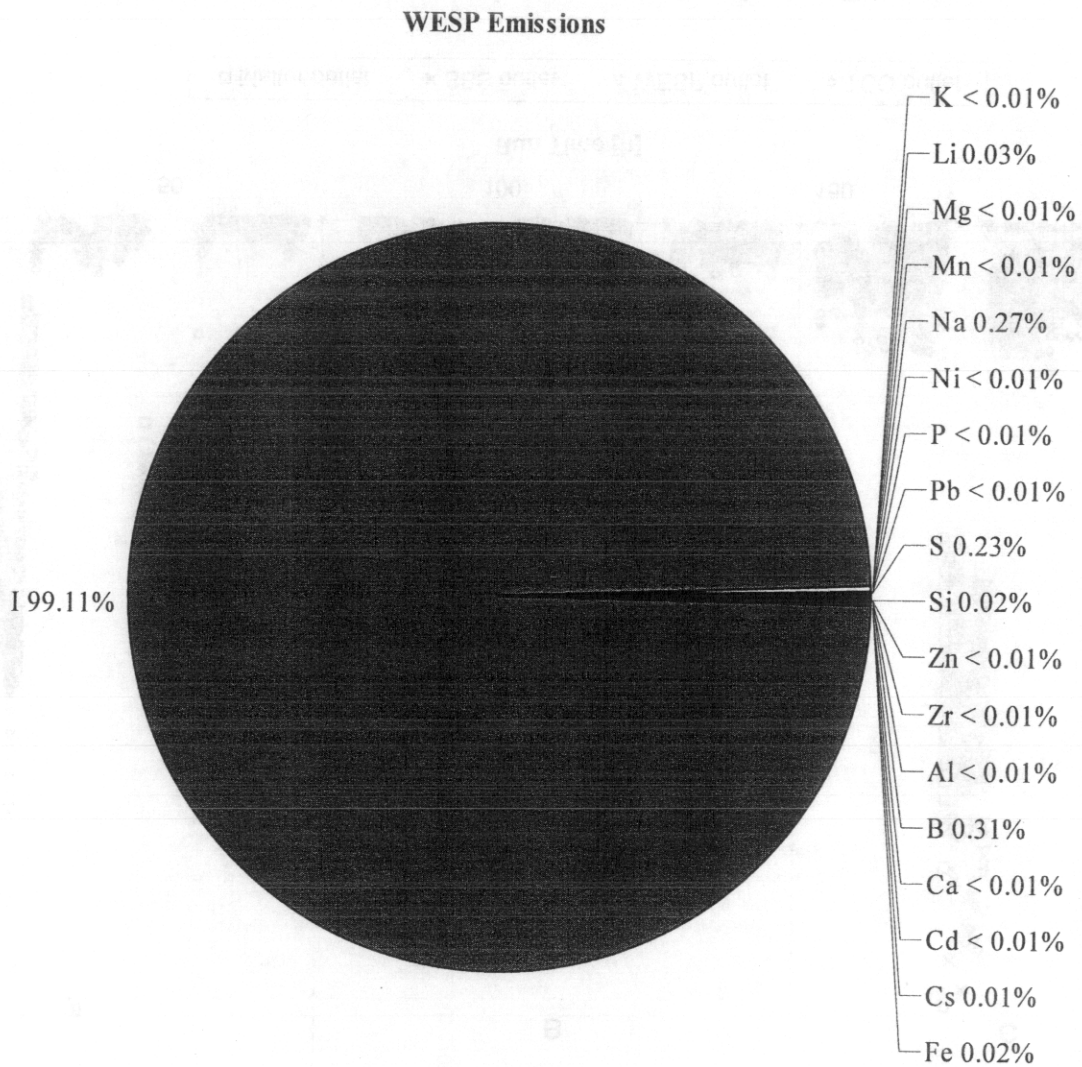


Figure 6.4. WESP exhaust composition (excludes oxygen, nitrogen, and carbon compounds).

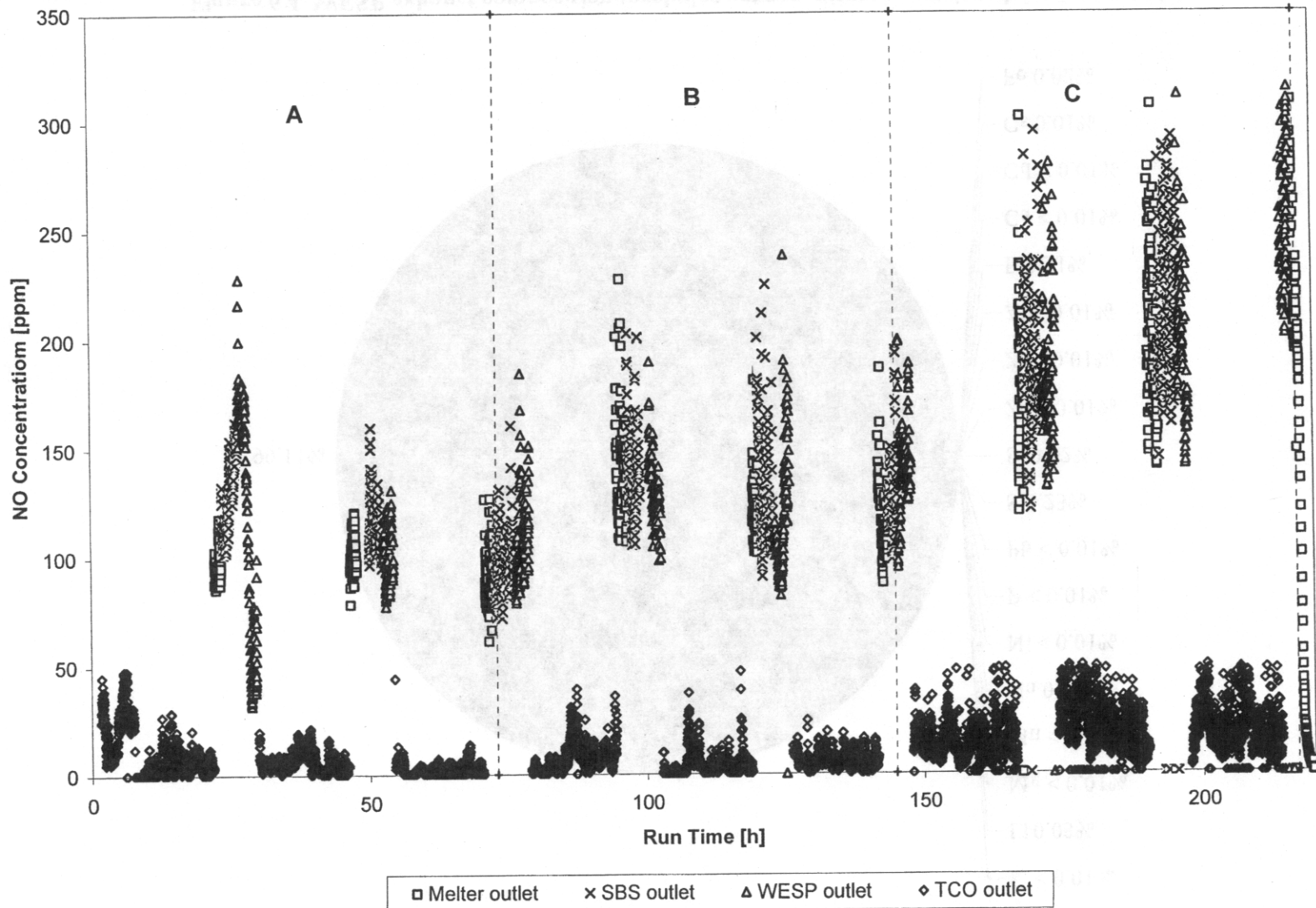


Figure 6.5. Concentration of NO at various points in the off-gas stream.

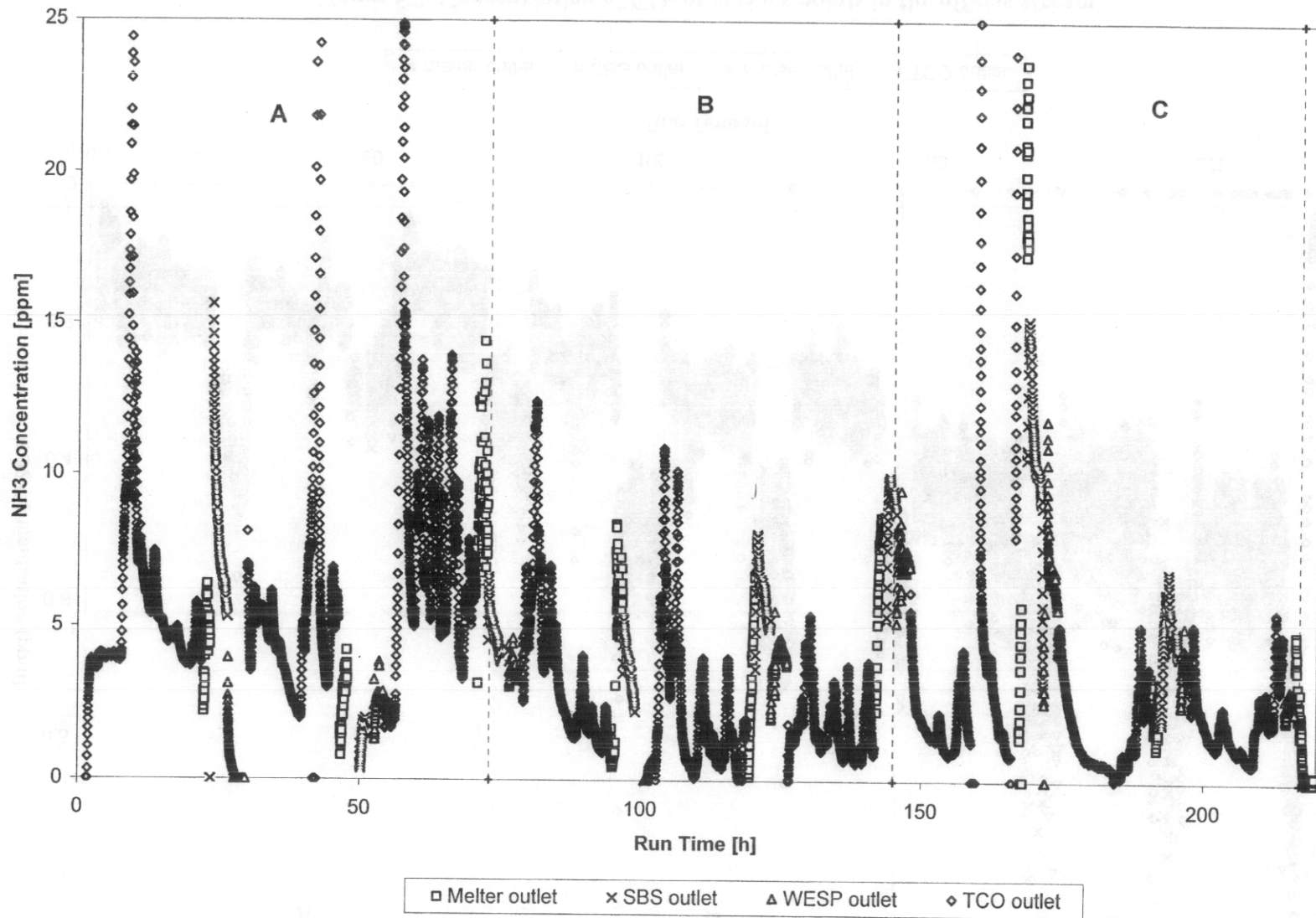


Figure 6.6. Concentration of NH<sub>3</sub> at various points in the off-gas stream.

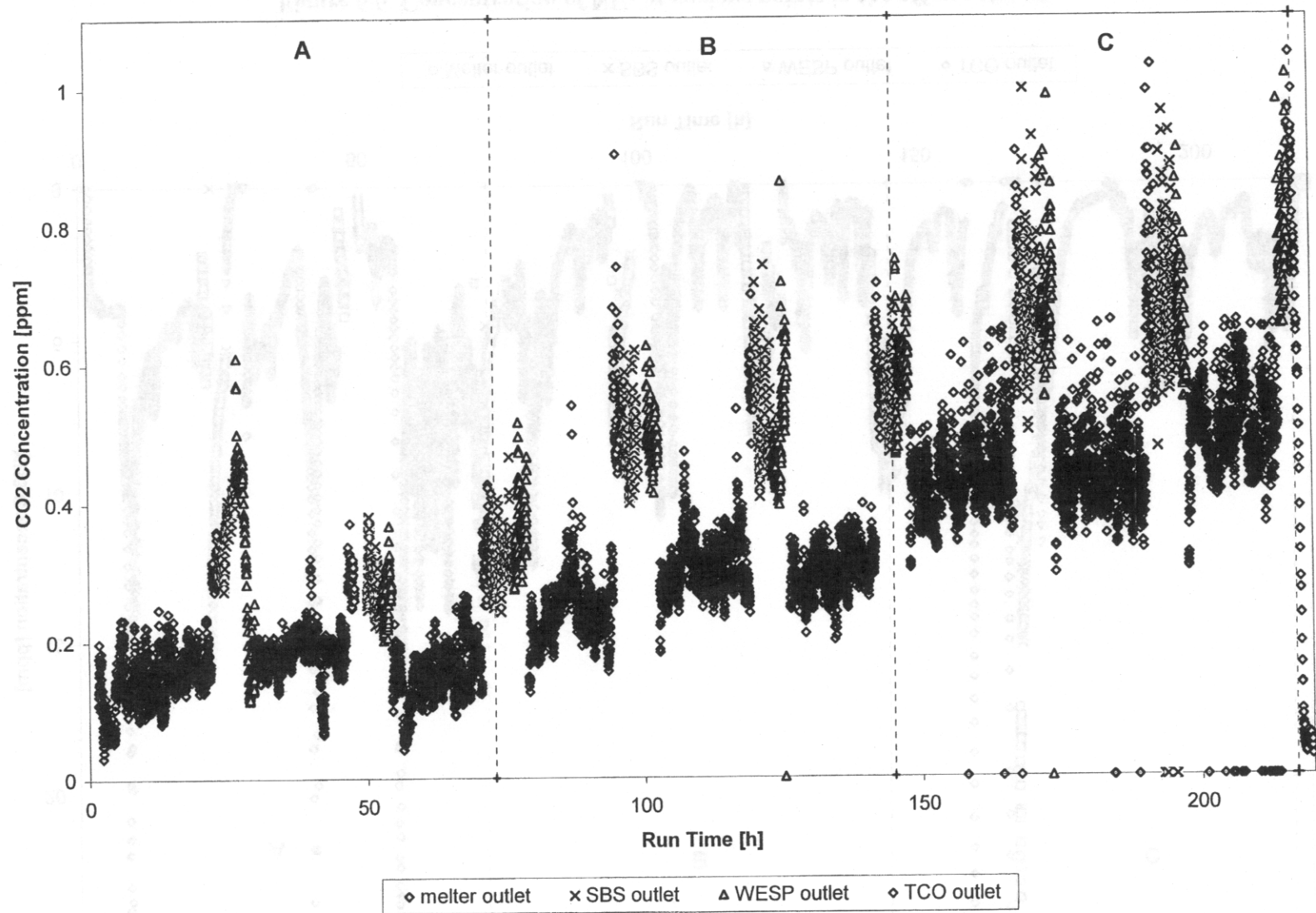


Figure 6.7. Concentration of CO<sub>2</sub> at various points in the off-gas stream.

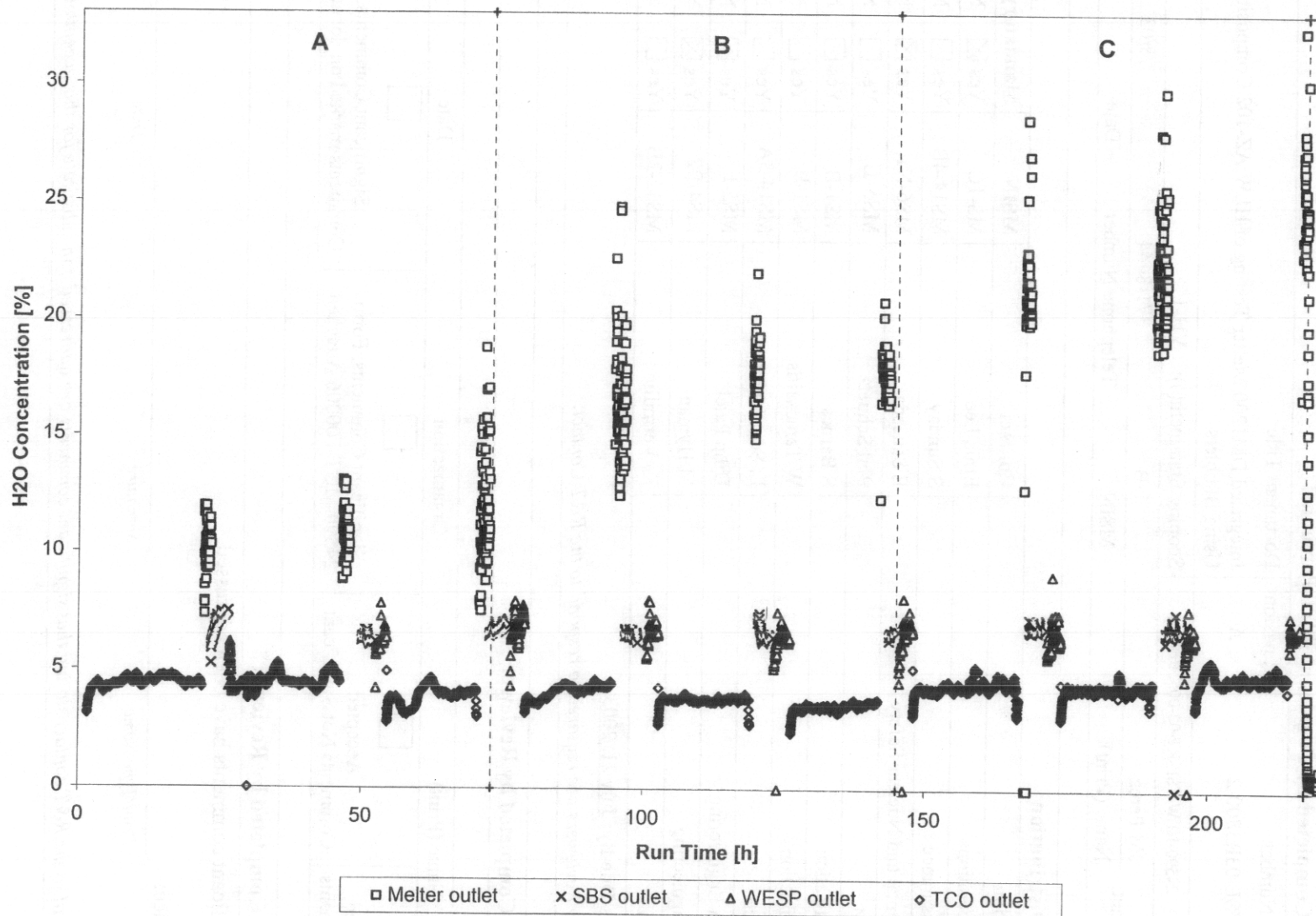


Figure 6.8. Concentration of water at various points in the off-gas stream.



# R&T Subcontractor Document Review Record

<b>1) To Be Completed by Cognizant R&amp;T Personnel</b>			
Document Number VSL-03R3800-2	Revision A	Document Title Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubblers	
Test Spec: 24590-HLW-TSP-RT-02-005, Rev 0		Scoping Statement(s): VH-1	
R&T Contact: JM Perez	1-B	371-8444	7/8/03
Name (Print)	MSIN	Telephone Number	Date

Review Distribution			
Organization	Contact	MSIN	Mandatory?
Process Operations	Ernie Lee	MS-1C	Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>
Quality Assurance	S Sunday	MS14-4B	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
Environmental and Nuclear Safety	E Saucedo	MS6-N1	Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>
HLW APM	Phil Schuetz	MS5-L	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
R&T Vitrification	S Barnes	MS1-B	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
R&T Vitrification	W Tamosaitis	MS1-B	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
Subcontracts	L. Scot Jenkins	MS14-3A	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
HLW Area Engineering	Dilip Patel	MS5-I	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
Process Engineering	M Hyman	MS4-B2	Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>
Operations	K. Vermillion	MS12-2B	Yes <input type="checkbox"/> No <input checked="" type="checkbox"/>
<b>Comments Due By: July 21, 2003</b> <i>Mandatory Reviewers are required to respond to the R&amp;T Contact.</i>			

<b>2) To be Completed by Reviewer</b>			
Reviewer	Name (Print)	Organization	Date
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Accepted, No Comments	Accepted, Comments Not Significant	Significant Comments, Form 24590-MGT-F00006 Attached	Significant Comments, Comments marked on document.

<b>3) To be Completed by Reviewer*</b>		
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.		



# COMMENT RESOLUTION FORM

Return to: JM Perez

Comments Due: July 21, 2003

Document Title: Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubbler		Document No. VSL-03R3800-2		Revision: A	Date: June 20, 2003
Reviewer: Process Operations	Date: 07-21-03	Response by: VSL	Date: 9/24/03	Comments Resolved: <i>Rod Gimpel</i>	Date: 10-9-03

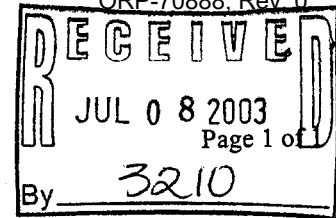
Item No.	Section/ Paragraph	Comment	Response	Significance <sup>a</sup>	Resolution	Incorporated?
1	Figure 2-1	The Viscosity should be labeled "Apparent Viscosity" because this is what it is. (Jake Reynolds)		I		
2.	4.2.1	I was told verbally that iodine was measured in the SBS as iodate. Confirm that iodide was measured rather than iodate. (Jake Reynolds)	The results are iodide as measured by ion chromatography. The method will detect iodate but to date none has been found.	M		
3	4.2.1	The amount of iodine in the SBS liquids is enormous. It should be noted in the text that this was spiked in that this amount of iodine may affect the pH of the SBS, which may affect the retention of other species. (Jake Reynolds)	The data in Table 4.5 for the SBS show iodine amounts ranging from 140 – 454 mg/l, and the pH ranging from 8.1-8.5. Subsequent tests that were conducted without iodine in the feed have produced SBS liquids with indistinguishable pH.	M		
4	1.0/¶ 2	Type the dates "07/02 and 03/03" out as "July 2002 and March 2003". (Rod Gimpel)	No change.	E		
5	1.2	Give an indication how much difference there is in leaving out the Sr-TRU. (Rod Gimpel)	This depends on the blending assumption that is made in plant operations; if more Sr/TRU product is blended with AZ-102 then the difference will be greater.	M		
6	1.4.3	Define what is "sufficient size"? Sufficient size to... (Rod Gimpel)	The phrase has been removed since it is not needed.	I		
7	2.1/last ¶ & Conclusion	Even though the stated excess iodine and cesium is need for analytical purposes it becomes a concern that behavior in the offgas is no longer prototypical. Case in	The data in Table 4.5 for the SBS show iodine amounts ranging from 140 – 454 mg/l, and the pH ranging from 8.1-8.5. Subsequent tests that were conducted	M		

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ORP-70888, Rev. 0



# R&T Subcontractor Document Review Record



### 1) To Be Completed by Cognizant R&T Personnel

Document Number VSL-03R3800-2	Revision A	Document Title Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubblers
Test Spec: 24590-HLW-TSP-RT-02-005, Rev 0		Scoping Statement(s): VH-1
R&T Contact: JM Perez	1-B	371-8444
Name (Print)	MSIN	Telephone Number
		Date 7/8/03

### Review Distribution

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

Comments Due By: July 21, 2003

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

### 2) To be Completed by Reviewer

Reviewer <u>E. SAUCEDA</u>	Organization <u>E&amp;NS</u>	Date <u>7-28-03</u>
Name (Print)	Organization	Date
<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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:** Hyman, Marve  
**Sent:** Monday, September 29, 2003 5:28 PM  
**To:** Perez, Joseph  
**Cc:** Grazzini, Janice; Ongpin, Maria  
**Subject:** FW: Revised report and comment dispositions for DM1200 AZ-102 report, VSL-03R3800-2

I concur with Document VSL-03R3800-2 Rev 0.  
 Marve

*Process  
 Engineering (1)*

-----Original Message-----

**From:** Perez, Joseph  
**Sent:** Monday, September 29, 2003 9:16 AM  
**To:** Gimpel, Rod; Reynolds, Jacob; Lee, Ernest D; Hyman, Marve; Carl, Daniel; Valenti, Thomas  
**Subject:** Revised report and comment dispositions for DM1200 AZ-102 report, VSL-03R3800-2

The subject report has been revised and submitted along with comment dispositions. You will recall that we conducted a telecon with VSL in August to discuss and agree on comment dispositions. The dispositions should, therefore, be in accordance with that meeting. Please review and reply with a concurrence to the comment dispositions or identify if any comments have not been appropriately addressed by COB Friday, October 3rd.

The report and comment forms are at wtps0027/R&T/Vitrification/HLW Mitr Tstg/DM1200/AZ102/Report

Thanks,

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



# COMMENT RESOLUTION FORM

Return to: JM Perez

Comments Due: July 21, 2003

Document Title: Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubbler		Document No. VSL-03R3800-2		Revision: A	Date: June 20, 2003
Reviewer: Tom Valenti, M Hyman	Date: 7/22/03	Response by: VSL 9/24/03	Date:	Comments Resolved: 9/29/03 Per attached e-mail	Date: 10/9/03

Item No.	Section/ Paragraph	Comment	Response	Significance <sup>a</sup>	Resolution	Incorporated?
1	1.2/ 1st ¶	Define the meaning of the 1st use for Sr/TRU.	Added.	M		
2	3.0/ 4th ¶	Temperature data needs to be added to the second sentence.	This did not transmit in the pdf version for some reason. Assume it will be OK in the retransmitted file.	M		
3	4.1.1/ 3rd & 4th ¶s	The last sentence in the third paragraph and the 4th paragraph are contradictory.	The comment has to do with the inspection of the film cooler in place. The report will be revised to clarify that the transition line was not dismantled and inspected in detail at the end of the test.	M		
4	4.2.2/ 2nd ¶	The paragraph discusses why pH is higher than in previous testing. It is evident that ammonium found in the WESP solution is probably the predominant reason for the high pH.	We are not convinced that the value in Table 4.5 (96.9 and 6.4 ppm) support this conclusion. Also, the data in Table 4.7 for the pH of the WESP blow-down solutions show a fairly steady value despite the presumed increase in ammonium in the solutions.	M		
5	Figure 6.5	Other NOx species should also be reported.	Refer to BNI internal response: "Disagree – as shown in Table 6.6, NO was dominant. NO <sub>2</sub> accounted for a few percent. The NO <sub>2</sub> can be expected to exhibit the same range of variability as the NO data."	M		
6	Figures 6.5 thru 6.8	Recommend choosing a different method of	These are the FTIR plots showing scatter.	M		

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**Perez, Joseph**

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**From:** Carl, Daniel  
**Sent:** Tuesday, September 30, 2003 6:32 AM  
**To:** Perez, Joseph; Hyman, Marve  
**Cc:** Eaton, William; Peters, Richard D (WTP); Pullen, Jeff; Rouse, James; 'rmeigs@duratekinc.com'  
**Subject:** RE: Revised report and comment dispositions for DM1200 AZ-102 report, VSL-03R3800-2

Joe, Marve,

*Process Engineering (2)*

Responses are acceptable.

The quality of the responses was particularly good, in that they were thoughtful, and that appropriate investigations into test records, etc. (which are not available to us in a practical sense) had been made while preparing the responses.

Dan

-----Original Message-----

**From:** Perez, Joseph  
**Sent:** Monday, September 29, 2003 9:16 AM  
**To:** Gimpel, Rod; Reynolds, Jacob; Lee, Ernest D; Hyman, Marve; Carl, Daniel; Valenti, Thomas  
**Subject:** Revised report and comment dispositions for DM1200 AZ-102 report, VSL-03R3800-2

The subject report has been revised and submitted along with comment dispositions. You will recall that we conducted a telecon with VSL in August to discuss and agree on comment dispositions. The dispositions should, therefore, be in accordance with that meeting. Please review and reply with a concurrence to the comment dispositions or identify if any comments have not been appropriately addressed by COB Friday, October 3rd.

The report and comment forms are at wtps0027/R&T/Vitrification/HLW Mltr Tstg/DM1200/AZ102/Report

Thanks,

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



# COMMENT RESOLUTION FORM

Return to: JM Perez

Comments Due: July 21, 2003

Document Title: Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubbler		Document No. VSL-03R3800-2		Revision: A	Date: June 20, 2003
Reviewer: D. Carl/Melter Systems	Date: 21JUL03	Response by: VSL	Date: 7/24/03	Comments Resolved: See attached email JP 10/9/03	Date:

Item No.	Section/ Paragraph	Comment	Response	Significance <sup>a</sup>	Resolution	Incorporated?
01	2.2/3	<p>Clarify the reference to 0.066 wt-% carbonate. Table 2.3 shows the required 1.145 wt-%.</p> <p>Also, provide better rationale for accepting low carbonate concentration in the waste simulant. I'd expect similar (or, greater) carbonate contamination in the WTP glass formers. If carbonate does create a 'killer scum,' then prototypic concentrations should be tested unless there is a valid rationale otherwise.</p>	<p>The amount of carbonate shown in Table 2.3 corresponds to 0.066 wt%:</p> $(0.2 \text{ kg} \times 60/73.88) / (1000 \times 0.2425)$ <p>The 0.2425 value is the amount of waste incorporated into the glass.</p> <p>Since large amounts of carbonates are added via the GFC's (about 82 kg of lithium carbonate and 102 kg of sodium carbonate per 1014 kg of GFCs) the effect of slightly lower carbonate in the simulant on the total carbonate content of the feed is likely to be insignificant.</p>	M		
02	2.3.3/2	<p>Perform glass measurements (rheology, crystallinity, etc.) based on achievable glass composition. That is, the reference glass composition should be adjusted based on the persistence of contaminants in glass formers.</p> <p>Further clarification provided to J. Perez 7/22/03 - It seems that we are not able to produce glasses to the recipes because of GF contaminants. I'm suggesting we accept this</p>	<p>Reagent grade chemicals are used for glass formulation work. The results from the glass formulation work are used to support waste form qualification and property-composition models. For the feed, we use industrial chemicals and, consequently, small amounts of impurities can be expected. The contaminants, however, are present only in small concentrations and are not expected to have any significant effect on glass properties. When impurities are present in significant quantities in the raw materials, those raw materials</p>	M		

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**Pérez, Joseph**

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**From:** Beaumier, Cynthia  
**Sent:** Monday, July 21, 2003 1:49 PM  
**To:** Perez, Joseph  
**Cc:** Vermillion, Karen  
**Subject:** Operations Comments on the DM1200 Melter Testing

Joe,

There are no Operations comments on the following document:

**Integrated DM1200 Melter Testing of HLW AZ102 Composition Using Bubblers,  
VSL-03R3800-2, Rev A**



# COMMENT RESOLUTION FORM

Return to: Joe Perez, 371-8444; MS1-B

Comments Due: 7/21/03

Document Title: Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubblers		Document No. VSL-03R3800-2		Revision: A	Date: 6/20/2003
Reviewer: Joe Perez	Date: 7/24/03	Response by: VSL	Date: 9/24/03	Comments Resolved: <i>[Signature]</i>	Date: 10/8/03

Item No.	Section/ Paragraph	Comment	Response	Significance <sup>a</sup>	Resolution	Incorporated?
1	1.4.1/ 1 <sup>st</sup> para.	3 <sup>rd</sup> sentence states a dry-chemical handling system can be used. WTP is not aware that this system is operational. If not operational – delete reference to it.	Sentence revised. System is not currently operational.	M		
2	1.4.1/ 2 <sup>nd</sup> para.	8 <sup>th</sup> sent. states ADS pump is left with feed in the chamber during a “desired delay time”. Reviewers understanding is that the delay time is during the period after discharge and before the next discharge. Otherwise, settling in the chamber can occur. Please clarify.	That is correct. Sentence revised accordingly.	M		
3	1.4.2	“Standard” melter system description needs to be updated to include a description of the bubbler design, location and operation. This will be expected for all future test plans and reports.	This information on bubbler specifics will be included in future test reports.	I		
4	Pg 9/1 <sup>st</sup> full para.	2 <sup>nd</sup> sent. states “Immediately upstream”. Isn’t control air injection is immediately “downstream”?	The blower for control air injects the air immediately downstream of the film cooler. The sentence has been corrected.	E		
5	Pg 9/1 <sup>st</sup> para.	9 <sup>th</sup> sent. does not include the process HEME (your HEME #1) as having a water spray.	There is a small water flow on the HEME 1 of about 0.2 gallons per hour. Section 1.4.3 revised to note both HEME’s have a spray.	E		
6	2.1/pg 10, 3 <sup>rd</sup> para.	2 <sup>nd</sup> sent.: text beginning with “...although the current...” This statement necessarily leads to the conclusion that two AZ102 glass compositions would be required to cover both possible processing periods (w/ and w/o Sr/TRU). The report should	Based on telecon, 8/14/03, no change to the report will be made. Section 2.1 indicates there is some uncertainty and possible changes to plans regarding Sr/TRU addition amounts. Two AZ102 glass composition formulations	M		

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# Research and Technology Completion Form

<b>R&amp;T Scoping Statement(s):</b>	VH-4, VH-5, VHO-3
<b>Test Specification Number/Title:</b>	24590-HLW-TSP-RT-02-005, Rev 0; Integrated DM1200 Testing of HLW Compositions Using Bubblers, Rev.0
<b>Test Plan Number/Title:</b>	VSL-02T8000-3; Integrated DM1200 Melter Testing of HLW AZ-102 Compositions Using Bubblers, Rev. 0
<b>Test Report Number/Title:</b>	VSL-03R3800-2; Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubblers, Rev. 0

List Test Objectives:	State how objectives were met:
<p>2. Utilizing the DM1200 melter and associated feed handling and off-gas treatment equipment, design and conduct testing in which representative AZ-102 simulant is processed. The duration of tests shall be sufficient to achieve at least four melter glass inventory turnovers (8 MT) for each composition.</p>	<p>Melter tests were conducted on the DM1200 with the HLW AZ-102 simulant between 11/18/02 and 11/27/02, producing over 6,700 kg of glass. Although the required 8 MT of glass was not produced, approx. 3.9 turnovers were achieved and the similarity in glass composition to the preceding AZ101 composition (see Fig. 5.1 – 5.3) resulted in no observed composition turnover affects.</p> <p>A summary of the test conditions and results is provided in Tables 3.1, 3.2 and 4.1. The total test duration, including the time for water feeding and cold-cap burn-off, was 218 hours. Some foaming occurred on the surface of the glass but did not prevent the attainment of steady-state conditions. The exhaust stream was sampled for particles during the last test segment (maximum production rate period) after steady state was reached.</p>
<p>3. Determine the effect of bubbling rate on melter production rate and operating stability for AZ-102 melter feed.</p>	<p>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 3.1 as cumulative and one- hour moving averages for each of the three segments. The three steady-state production rates (380, 650, and 900 kg/m<sup>2</sup>/day) were obtained for each three-day segment.</p>
<p>4. Fabricate, install and evaluate the performance of the HLW bubbler design and placement recommended by the Duratek design staff.</p>	<p>Two prototypic bubblers 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.</p>



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<b>Test Report Number/Title:</b>	VSL-03R3800-2; Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubblers, Rev. 0

<b>List Test Objectives:</b>	<b>State how objectives were met:</b>
<p>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 H<sub>2</sub>).</p>	<p>Sections 4 and 6 report the off-gas system performance results. 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 (1.26% of feed) was higher than that observed for tests with other HLW compositions. 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.</p> <p>Hydrogen monitoring via gas chromatography was not completed during this test due to equipment failure.</p>
<p>6. Quantify and document the occurrence and associated operating conditions of any melter off-gas volume surging events.</p>	<p>No off-gas surging volume events were reported.</p>
<p>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.</p>	<p>Sections 4 and 6 present off-gas characterization results. Elemental emission rates and DFs are provided in Tables 6.2-6.4 for the melter, SBS, and WESP, respectively. Solids carry-over from the melter averaged 1.26% of feed solids and was the highest carry-over of the tests with the four HLW simulants. The SBS averaged almost 99% removal of the particulates emitted from the melter, which is comparable to performance in the other HLW tests but greater than for the LAW Sub-Envelope C1 and A1 tests and HLW C-106/AY-102 tests. Melter emissions were relatively high in major components such as silicon, sodium, and iron, in contrast to melter emissions from the C-106/AY-102 tests that were composed mostly of volatile species such as selenium and chlorine.</p> <p>About 95 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 112,670 and near the low end of those measured for the four HLW compositions.</p>



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List Test Objectives:	State how objectives were met:
<p>8. Characterize the chemical and physical characteristics of the aqueous streams (feed, SBS, WESP, and caustic scrubber).</p>	<p>Section 4.2 presents aqueous stream characterization results. The SBS solutions remained between 8.1 and 8.8 throughout the test period, due partly due to the low feed concentrations of nitrates, nitrites, and sulfates, which form acid gases in the melter which decrease the SBS sump.</p> <p>The major dissolved species consist of species such as halogens, boron, sulfur, and alkali metals. The suspended species closely resembled the feed composition. The SBS sump fluid pH ranged from 8.14 to 8.76. The WESP sump fluid pH ranged from 7.6 to 8.4 and had negligible suspended solids.</p>
<p>9. Characterize the performance of the secondary off-gas treatment equipment (selective catalytic reduction (SCR) and thermal catalytic oxidizer (TCO)).</p>	<p>Sections 4.1.7, 6.3 and 6.4 present secondary off-gas performance results.</p> <p>Information on NO<sub>x</sub> and CO removal in the TCO/SCR is provided in Table 4.2. Carbon monoxide concentrations were too low in test segment A to allow accurate measurements of its destruction; however, its removal was more than 75% in test segments B and C. During test segments A, B, and C, nitrogen oxide removals were about 87.8%, 92.2%, and 85.7%, respectively. The gas residence time in the TCO during the HLW AZ-102 test averaged 0.2 seconds at an average inlet gas temperature of 478°C. The average ammonia injection rates into the SCR during test segments A, B and C were 0.084, 0.080 and 0.125 lbs/hr, respectively. Ammonia slippages (Table 4.3) during the test segments A, B and C were 4.6%, 1.9% and 1.1%, respectively.</p> <p>A summary of the iodine mass balance is presented in Table 6.7 in terms of percent feed iodine. Despite the lack of iodine in the glass, reasonable mass closure around the melter was achieved as either melter emissions (100%) or the sum of SBS blow-down solutions and SBS emissions (40 + 61 = 101%). The amount of iodine detected in the WESP emissions is higher than in any previous study due to the lack of acid gases in the exhaust; the presence of these acid gasses neutralizes the impingers solutions that are in place for up to 12 hours during WESP sampling. The data validate the long-held VSL assumption that the WESP removes little or no iodine.</p> <p>The silver mordenite column was installed and operated subsequent to the AZ-102 test documented in this report.</p>



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<b>Test Report Number/Title:</b>	VSL-03R3800-2; Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubblers, Rev. 0

<b>List Test Objectives:</b>	<b>State how objectives were met:</b>
<p>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.</p>	<p>Feed characterization (Section 2), glass characterization (Section 5), condensate liquid characterization (Section 4.2) and off-gas emissions (Section 6) provide adequate data to perform material balance calculations. Process data to support energy balance calculations are provided in Sections 3 (melter) and 4 (off-gas equipment).</p>
<p>11. Document general equipment operations (reliability, availability, maintainability, etc.); especially non-routine equipment failure and replacement activities.</p>	<p>Feeding was conducted throughout the test with the prototypical ADS pump without incident. The prototypical feed tube had a 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.</p> <p>Subsequent tests employed a new smaller-diameter feed tube design, which lessened the extent of stalactite formation to the point that mechanical intervention has been unnecessary. The feed orzzle modification was made in consultation with the melter design engineers.</p> <p>The pressure drop across the SBS increased by about 4.7 in. W.C. over nine days of testing with HLW AZ-102 feed, which is likely associated with the gradual occlusion of the SBS down-comer pipe.</p>
<p>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.</p>	<p>At the end of the HLW AZ-102 test, the SBS was blown down and 368 gallons of liquid was removed from the SBS and overflow tank. About 4.72 kg of wet solids (including some legacy ceramic saddle packing) were removed from the bowl. Another 350 grams of solids were removed from the SBS down-comer. The SBS bowl and down-comer were cleaned after the preceding LAW Sub-Envelope B tests and therefore the accumulations resulted from the 4 days of turnover with AZ-101 feed and the nine days of AZ-102 testing reported here. With the exception of the Paxton blower (see Section 4.1.6), a detailed inspection of the off-gas system lines was deferred until after testing the AY102/C104 composition.</p>



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<b>List Test Objectives:</b>	<b>State how objectives were met:</b>
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 4.3 documents the control air and plenum pressure throughout the test. Stability was acceptable and is described in Section 4.1.1.
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 without incident. Section 3 describes the pump operation. Detailed performance information for the one year of pump operation will be described in a separate report.
<b>List any Test Exceptions:</b>	<b>Did exceptions impact the objective?</b> <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No (Explain)
1) None	
<b>List Success Criteria</b>	<b>Did the test meet the criteria?</b> <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No (Explain)
1) Conduct testing in which representative simulant of AZ-102 is 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.



# Research and Technology Completion Form

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

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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 NO <sub>x</sub> 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.
<b>List QA Requirements:</b>	<b>Did the subcontractor meet the requirements?</b> <input checked="" type="checkbox"/> Yes <input type="checkbox"/> 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.
<b>List R&amp;T Test Conditions:</b>	<b>Were test conditions followed?</b> <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No (Explain)



# Research and Technology Completion Form

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

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<p><u>Melter:</u></p> <ul style="list-style-type: none"> <li>• Bulk glass temperature target - 1150°C (typically allowed to vary <math>\pm 25^\circ\text{C}</math> before power input changes are initiated).</li> <li>• Bubbling rate were determined from the results of AZ-101 tests.</li> <li>• 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).</li> </ul>	<p>Tables 3.2 and 4.1 provide system process measurements.</p> <ul style="list-style-type: none"> <li>• Test condition met, see Figure 3.2.</li> <li>• Test condition met, 3 bubbler rates; 8, 40 and 65 lpm total bubbler flow were achieved. Note that ~1.5 lpm of bubbler air was provided through the floor electrode bubbler, which is not shown in Table 3.2.</li> <li>• Test condition (anticipated) not met but acceptable; average plenum temperatures ranged between 525°C and 638°C (increased with increased bubbler air rate), see Figure 3.3.</li> </ul>
<p><u>SBS:</u></p> <ul style="list-style-type: none"> <li>• Tank temperature - 40°C</li> </ul> <p><u>WESP:</u></p> <ul style="list-style-type: none"> <li>• Operate at maximum current to achieve maximum voltage without sparking. Based on previous experience this would be about 17 milliamps and 31 -33 kilovolts.</li> <li>• Inlet water spray – 2 gph <math>\pm</math> 0.2 gph.</li> </ul>	<ul style="list-style-type: none"> <li>• Test condition met, tank temperature averaged about 40°C, see Figure 4.7.</li> <li>• Test condition met, see Figure 4.19.</li> <li>• Test condition met, see Section 4.1.3.</li> </ul>



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- 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 4.1.3. The information from this test and other DM1200 testing assessing WESP performance will be combined to "determine the preferred protocol for future deluge operations". Testing of the WESP extends through the testing defined under the subject test plan and test specification.
- HEMEs:**  
Operate with ~1 gph continuous water spray or per manufacturer's recommendations (< 50 mg/acfm of entrained liquid water).
- Moisture load in off-gas was sufficient to not require the 1gph water spray.
- 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 met, see Section 4.1.5.
- 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, see Section 4.1.7.
- SCR:**
- Bed temperature – per the catalyst manufacturer's recommendation (350-400°C)
  - Ammonia slip (exit concentration) ≤ 25 ppm, if possible.
  - Test condition met, see section 4.1.7.
  - Test condition met, see section 4.1.7.

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

AZ102 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. This comparison will be made



# 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-02T8000-3; Integrated DM1200 Melter Testing of HLW AZ-102 Compositions Using Bubblers, Rev. 0

Test Report Number/Title: VSL-03R3800-2; Integrated DM1200 Melter Testing of HLW AZ-102 Composition Using Bubblers, Rev. 0

when data is available.

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

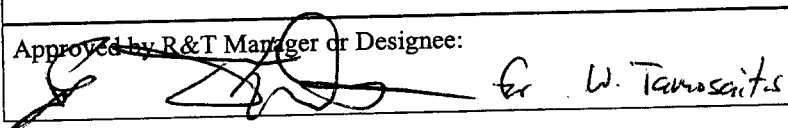
Are all subcontractor signoffs completed?  Yes  No

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

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

- 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. Future testing will be required to demonstrate alternative bubbler designs to increase the throughput performance.
- 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.

Additional comments:

Approved by R&T Manager or Designee:  E. W. Tamascius

Date: 10/19/03