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HLW Melter Control Strategy without Visual Feedback, VSL-12R2500-1, Rev. 0

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

Office of River Protection

P.O. Box 450
Richland, Washington 99352

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Final Report

HLW Melter Control Strategy without Visual Feedback

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

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List of Abbreviations

ACM	Aspen Custom Modeler
ADS	Air Displacement Slurry
AOD	Air Operated Diaphragm
ASME	American Society of Mechanical Engineers
BBI	Best Basis Inventory
BNI	Bechtel National, Inc.
DCP-AES	Direct Current Plasma - Atomic Emission Spectroscopy
DF	Decontamination Factors
DM	DuraMelter
DOE	Department of Energy
DWPF	Defense Waste Processing Facility
EPA	Environmental Protection Agency
FTIR	Fourier Transform Infra-Red Spectroscopy
HEME	High-Efficiency Mist Eliminator
HEPA	High-Efficiency Particulate Air
HLW	High Level Waste
LAW	Low Activity Waste
NIST	National Institute of Standards and Technology
NQA	Nuclear Quality Assurance
ORP	Office of River Protection
PBS	Packed-Bed Scrubber
QARD	Quality Assurance Requirements and Description
SBS	Submerged Bed Scrubber
SCR	NO_X Removal System
SOP	Standard Operating Procedure
TCO	Thermal Catalytic Oxidation
TFCOUP	Tank Farm Contractor Operation and Utilization Plan
TOC	Total Organic Carbon
VOC	Volatile Organic Compound
VSL	Vitreous State Laboratory
W.C.	Water Column
WESP	Wet Electrostatic Precipitator
WTP	Waste Treatment Immobilization Plant
WVDP	West Valley Demonstration Project
XRF	X-ray Fluorescence Spectroscopy

SECTION 1.0
INTRODUCTION

Plans for the treatment of high level waste (HLW) at the Hanford Tank Waste Treatment and Immobilization Plant (WTP) are based upon the inventory of the tank wastes, the anticipated performance of the pretreatment processes, and current understanding of the capability of the borosilicate glass waste form [1]. The WTP HLW melter design, unlike earlier DOE melter designs, incorporates an active glass bubbler system. The bubblers create active glass pool convection and thereby improve heat and mass transfer and increase glass melting rates. The WTP HLW melter has a glass surface area of 3.75 m^2 and depth of ~1.1 m. The two melters in the HLW facility together are designed to produce up to 7.5 MT of glass per day at 100% availability. Further increases in HLW waste processing rates can potentially be achieved by increasing the melter operating temperature above 1150°C and by increasing the waste loading in the glass product. Increasing the waste loading also has the added benefit of decreasing the number of canisters for storage.

Development work for the WTP employed a "tiered" approach to vitrification testing involving computer-based glass formulation, glass property-composition models, crucible melts, and continuous melter tests of increasing, more realistic scales. Melter systems ranging from 0.02 to 1.2 m^2 installed at the Vitreous State Laboratory (VSL) have been used for this purpose, which, in combination with the 3.3 m^2 low activity waste (LAW) Pilot Melter operated by Energy*Solutions*, 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), which is the HLW Pilot Melter that has been installed at VSL with an integrated prototypical off-gas treatment system. That system replaced the DM1000 system that was used for HLW throughput testing during Part B1 of the privatization contract [2]. Both melters have similar melt surface areas (1.2 m^2), but the DM1200 is prototypical of the present WTP HLW melter design whereas the DM1000 was not. In particular, the DM1200 provides for testing on a vitrification system that includes the specific train of unit operations that has been selected for both HLW and LAW WTP off-gas treatment [3].

Over the course of testing on the DM1200 system, over one and a half million pounds of feed had been processed, producing almost 620,000 pounds of glass by the end of BNI WTP testing in 2006 [4-19]. These tests were conducted to address several objectives, including determination of glass production rates and melt pool characteristics, as well as evaluation of the prototypical off-gas system. The HLW compositions used for the extensive technology development and design work performed for the WTP baseline were iron limited with respect to waste loading (AZ-101, AZ-102, C-16/AY-102, and C-104/AY-101) [5, 6, 9, 11-15, 17, 18]. More recently however, the DM1200 has been used to process simulated high aluminum [20, 21] and bismuth [22] HLW streams identified by ORP [23]. These tests processed high waste loading compositions, demonstrated processing rates above the WTP baseline requirement and, in the case of the high bismuth waste, investigated potential issues related to foaming in the poured glass canisters. In all DM1200 testing to date, melter operations relied heavily on visual feedback of the interior of the melter, per direction from BNI. Changes to feed rates and bubbling rates were made based on observation of cold-cap behavior. This is in contrast to testing performed on the LAW Pilot Melter that relied mostly on the measured plenum temperature to control feed rate together with other measured parameters (e.g., melt pool temperatures, glass melt density, melter pressure) to identify over feeding. Visual feed back to control operations is not planned for the WTP HLW melter. Accordingly, it is necessary to develop an operational strategy to control HLW melter operations without using visual feedback of the conditions in the melter. An effective strategy would permit processing waste at the maximum rate possible without over feeding the melter since that could result in undesirable operating conditions, unsteady temperatures, and large pressure fluctuations.

The work described in this report is informed by a review of operational data from the LAW Pilot Melter and available data from HLW processing facilities such as the Defense Waste Processing Facility (DWPF) and the West Valley Demonstration Project (WVDP) for methods of controlling melter operations based on measured melter parameters. Also of importance is the proposed method of operation for the WTP HLW melters. Melter tests were conducted on the DM1200 during which operations were controlled using solely measured melter parameters. To the extent possible, the tests mimicked the WTP HLW melter configuration (lid design and monitoring points). Based on experience from other facilities, the major parameter that was used to control feed rate was the plenum temperature. Other measured melter parameters (e.g., melt pool temperatures, glass melt density, melter pressure) were monitored to identify over feeding leading to unstable conditions in the melter. Based on the test results a preliminary strategy for HLW melter operations was developed. However, further testing and development of that strategy will be required prior to implementation in the WTP.

1.1 Operation of LAW Pilot Melter and HLW Processing Facilities

Large quantities of simulated and actual radioactive wastes have been vitrified in joule-heated ceramic melters at various full scale facilities relying exclusively on measured parameters with no direct observations of the cold cap. In the United States, a variety of simulated Hanford LAW feeds were processed through the LAW DM3300 Pilot Melter in Columbia MD [24-35]; low-level mixed wastes from the Savannah River M-Area facility were processed on the DM5000 melter; and HLW from neutralized reprocessing wastes were processed at WVDP [36, 37] and are still being processed at DWPF. In all of these cases, the wastes were successfully processed using control strategies that do not rely on viewing inside the melter. This includes processing with (LAW Pilot, M-Area, and DWPF post September 2010) and without melt pool bubbling (WVDP and DWPF pre-September 2010). Attempts were made at DWPF and WVDP to install and use remote cameras to provide visual information on the cold cap conditions in the melter but without success: after very limited times of exposure to conditions inside or around the melter, the cameras became inoperative. As a result, various non-visual signals have been employed for controlling the melter feed rate and the primary method used at most of these facilities was based on monitoring the plenum temperature. This temperature is a reflection of the amount of cold cap coverage because thermal radiation from the hot glass diminishes as the extent of the insulating cold cap layer increases and vaporization of water in the feed on the surface of the cold cap reduces the plenum gas temperature. The extent of the melt surface that is covered with reacting feed (the cold-cap) is a measure of the extent of processing capacity utilization. Thus, 100% cold-cap corresponds to the maximum sustainable feed rate under the given set of operating conditions. With visual feedback, the extent of coverage is estimated by direct observation and the result is used to increase or decrease the feed rate: less that ~100% coverage indicates under utilization of the processing capacity and the feed rate is therefore increased; conversely, 100% coverage indicates a potential overfeeding condition in which feed is being introduced at a rate that is greater than the rate that it is being consumed by reaction to form glass. In the absence of visual feedback, the plenum temperature has typically been employed as a measure of cold cap coverage on which to base such feed rate adjustments. The feed rates to the M-Area DM5000 and LAW Pilot Melter were adjusted to achieve a plenum temperature within the operating band of 400±50°C; if the plenum temperature drifted above that range, indicating openings in the cold cap, the feed rate was increased, and vice versa. Similarly at the WVDP, the feed rate was adjusted manually to maintain a plenum temperature in the 400-600°C range and targeted between 475 and 525°C [38].

At the LAW Pilot Plant and M-Area facilities, both of which used bubblers, the bubbling rate was fixed during melter operation and the only adjustments made in response to plenum temperature was to the feed rate. At DWPF, the use of plenum temperature to control feed rate is complicated by the use of plenum heaters and therefore melter plenum pressure instability is also used to indicate over-feeding; however, the minimum vapor space temperature is controlled to greater than or equal to 493°C for melter off-gas flammability control [39].

Plenum temperature is also specified as the control variable for regulating feed rate for the HLW melters at the WTP:

> *"With a consistent cold cap, the target plenum temperature is maintained between 400 and 600°C by adjusting the rate of feed addition to the melter and by adjusting bubbler flowrate." [40].*

Clearly, this very general statement of a control strategy will need to be substantially refined to produce a protocol that is sufficiently detailed to be suitable for incorporation into the WTP HLW melter operating procedures. In particular, the ambiguous response in terms of either feed rate or bubbler rate and the wide operating window will need to be refined based on melter testing. Such testing has to be done at the largest possible scale with prototypical bubblers and feed which forms colds caps with the same properties as those expected for WTP HLW. Testing with simulated WTP HLW feeds on the DM1200 has frequently produced uneven cold cap distributions, resulting in large differences in measured plenum temperature in different locations in the plenum space [4]. Thus, the location of the plenum temperature monitoring points is critical in defining a strategy using plenum temperature as the control signal. The lid design for the WTP HLW melter given in Figure 1.1 shows the two plenum temperature monitoring points on one side of the melter surrounded by bubbling outlets [41]. Establishing the relationship between cold cap coverage and temperature measured at these two points is critical for instituting a control strategy for feeding the WTP HLW melter using plenum temperature.

1.2 Test Objectives

The principal objective of this work is to identify and begin development of a control strategy for operating the WTP HLW melter using only monitored parameters without the benefit of visual observations inside the melter. This was addressed through testing on the HLW Pilot Melter (DM1200) at installed VSL. The DM1200 unit, as the largest test melter of its kind in the US, was selected for these tests primarily because of the importance of scale in addressing the test objectives. The DM1200 was used previously with several HLW waste streams [5, 6, 9, 11-15, 17-22] including the four tank wastes proposed for initial processing at Hanford [5, 6, 9, 11-15, 17-19]. This melter system was also used for development of the WTP HLW bubbler configuration and optimization for the WTP HLW melter [15], as well as for Maximum Achievable Control Technology (MACT) testing for both HLW and LAW [19]. Specific objectives of these tests were to:

- Conduct DM1200 melter testing independent of visual observations of conditions in the melter.
- Conduct DM1200 melter testing mimicking the relationship between monitoring points and bubbling outlets and other design features of the HLW WTP melter.
- Collect melter parameter data including processing rate, temperatures at variety of locations within the melter plenum space, melt pool temperature, glass melt density, and melter pressure while controlling the feed to target plenum temperature ranges at predetermined fixed bubbling rates.
- Compare measured melter parameters with independent visual observations subsequent to testing.
- Conduct melter tests with two different HLW feeds expected to create different cold caps.
- Collect melter exhaust samples to compare particulate carryover at different plenum temperature target ranges.
- Analyze all collected data to establish operational control parameters for the WTP HLW melter.

The work used two different HLW simulants, both of which have been processed previously on the DM1200: an iron limited waste, AZ-101 [5, 6, 14, 15], and an aluminum limited waste [20, 21]. These two simulants represent two significantly different waste compositions and corresponding glass formulations, and thus potentially different cold cap formation behaviors. The Test Plan for this work [42] provides an outline of the objectives of the tests; a brief description of the melter system and experimental methods; the melter test matrix; test monitoring, sampling and analysis methods, and the planned schedule.

1.3 Quality Assurance

This work was conducted under a quality assurance program compliant with applicable criteria of 10 CFR 830.120; Office of Civilian Waste Management DOE/RW-0333P, Quality Assurance Requirements and Description (QARD) Revision 20; the American Society of Mechanical Engineers (ASME) NQA-1, 2004; and DOE Order 414.1 C, Quality Assurance. This program is supplemented by a Quality Assurance Project Plan for ORP work that is conducted at VSL [43]. Test and procedure requirements by which the testing activities are planned and controlled also are defined in this plan. The program is be supported by VSL standard operating procedures that were used for this work [44]. Since this work is not waste form quality affecting, the requirements of DOE/RW-0333P are not applicable to this work.

1.4 DM1200

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, 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 additives can be added to the mix tank. Five calibrated load cells directly mounted on the legs of the feed tank are used to measure additions to, and removal from, the feed tank and are 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 are 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 provides additional mixing.

The feed is introduced into the melter using an air displacement slurry (ADS) pump, which is the present 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 an 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 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 desired delay time (dependent on the desired feed rate) 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.

When necessary, a backup system is used 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.

1.4.2 Melter System

The DuraMelter 1200 (DM1200), which is the HLW Pilot Melter, was used for these tests. Cross-sectional diagrams of the melter illustrating the discharge chamber and electrode configuration are provided in Figures 1.2 and 1.3. 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 nominal glass depth of 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. The DuraMelter™ 1200 is fitted with one pair of electrodes placed high on opposite walls of the melter as well as one bottom electrode. The side electrodes are 11" by 34" giving an electrode area for the pair of about 750 sq. in. Depending on the glass level, the plenum space extends about 33" to 36" above the melt surface resulting in a plenum volume ranging from about 43 to 46 ft^3.

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 the optimum bubbler configuration established during previous tests with HLW simulants [15], consisting of two double-outlet, top-entering bubblers, was used, located in positions to mimic conditions in the WTP HLW melter. Figure 1.4 shows a schematic of the prototypical double-outlet bubbler design that was based on the combination of the results from these DM1200 tests and room-temperature tests that were performed in a transparent fluid simulating the properties of the glass melt [45]. These bubblers have outlets 8 inches apart and were placed on the melter floor. The orientation of the bubblers in the melter, as shown in Figure 1.5, results in one of the bubbling outlets being a horizontal distance of 11.3 inches from the location of the feed tube.

The DM1200 film cooler was replaced immediately prior to the present tests. The design of the new film cooler is very similar to that used for all previous testing on the DM1200 but it incorporates several changes that were made in the WTP HLW film cooler design after the installation of the DM1200 melter system. As a result, the new DM1200 film cooler is more prototypical of the present WTP HLW design. The original and new DM1200 film coolers are compared with a scaled version of the WTP HLW film cooler in Figure 1.6; it should be noted, however, that a simple directly scaled version would not maintain key air flow characteristics of the design, hence the differences between the new DM1200 film cooler and the scaled WTP HLW design. As compared to the original DM1200 film cooler, the new unit includes the prototypical louver on the outside edge, a modified hole size and pattern on the leading edge, fewer louvers (7 vs. 9), and a shorter louvered section (10” vs. 13”).

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 1.7, consists of a submerged bed scrubber (SBS); a wet electrostatic precipitator (WESP); a high-efficiency mist eliminator (HEME), a high-efficiency particulate air (HEPA) filter; a thermal catalytic oxidation unit (TCO); a NO_x removal system (SCR); a caustic packed-bed scrubber (PBS); and a second HEME. Note that the PBS and the second HEME are not part of the WTP off-gas train, which effectively ends at the SCR. The HEME is used to limit entrained particle carryover into the balance of the VSL ventilation system. The system can be functionally divided into four subsystems:

Particulate Removal: Components from the 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 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 TCO unit is designed to oxidize any hazardous organics that are present in the off-gas stream. This is followed by a SCR to remove NO_X gases and a 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, the DM1200 off-gas system processing sequence follows the design for the full-scale WTP HLW melter system, except for cooling of the off-gas stream discharged from the SCR unit (which is present in the WTP off-gas train, but absent in the DM1200 system). Per WTP direction, the SBS unit that was used for previous DM1200 testing was modified in early 2004. Installation of the new system was completed in March 2004 and that unit was used for the present tests. The changes were implemented to reflect modifications to the WTP SBS design that have taken place since the original DM1200 unit was installed. These modifications included changes to the diffuser plate design, down-comer jacket and connection to the diffuser plate, bed diameter, bed packing materials, cooling coils, and liquid overflow level.

Initial quenching of the melter exhaust gas stream is effected by the film cooler. Immediately upstream 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 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. These two units were off-line during the present tests due to the low concentrations of these components in the exhaust stream. Finally, the PBS provides acid gas removal. Water sprays are located in the WESP, PBS, and facility HEME 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 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.

1.5 Feed Sample Analysis

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

1.6 Glass Product Analysis

The glass product from the DM1200 tests was discharged from the melter into 55 gallon drums periodically using an air-lift system. The discharged product glass was sampled by removing sufficient glass from the top of the cans for compositional analysis after the cooling period and visual inspection (see Section 4.0). All of these procedures are routinely conducted at VSL and, therefore, standard operating procedures (SOPs) are in place. Sample preparation for chemical analysis typically involves size reduction and sieving. All samples were subjected to XRF to determine the concentration of all elements except boron and lithium. A series of National Institute of Standards and Technology (NIST) reference materials were used for confirmation of the XRF data. Boron and lithium were determined by total acid dissolution of ground glass samples in HF/HNO_3 and subjecting the resulting solutions to DCP-AES analysis.

1.7 Emission Samples

Melter emission fluxes were measured to complete the mass balance for each melter test. Isokinetic melter exhaust samples (exhaust gas flow velocity equal to velocity through the gas sample probe tip) were combined with the Fourier Transform Infra-Red Spectroscopy (FTIR) spectroscopy continuous monitoring data for gaseous species to characterize fluxes from the melter. In the DM1200 system, independent sampling ports for particulate and FTIR sampling are available throughout the off–gas treatment train (see Figure 1.7). Standard EPA isokinetic off-gas sampling trains and methods (EPA Methods 1A, 2, 4, 5, 26, 29), composed of particulate filters and liquid impingers, were used to collect materials that were subjected to chemical and physical analyses using the techniques described in Sections 1.5 and 1.6.

1.8 Test Overview

One week of melter testing was conducted with a high iron waste stream and a second week of testing was conducted with a high aluminum waste stream. Each test was further subdivided into test segments distinguished by plenum temperature target ranges used to determine feed rate. For each of the two waste compositions, tests were conducted at conditions (bubbling rate, glass temperature, feed solids content) that were used in previous tests that were performed while directly observing the cold cap as an indicator for adjusting feed rate. The melter was fed to achieve the same plenum temperatures obtained previously: 525°C for the AZ-101 waste and 450°C for the aluminum waste but without benefit of feedback from visual observations of the cold cap conditions. Plenum temperatures were measured in eight separate locations (see Figure 1.5); however, only two (B3 and D3 shown in Figure 1.5) were used as indicators for adjusting feed rate in order to reflect the number of temperature measurement points and their locations with respect to bubblers and the feed tube in the WTP HLW melter (see Figure 1.1). The target plenum temperature for subsequent test segments with each waste was contingent on the results of the first test: the plenum temperature target was lowered by 50°C in the event of successful processing during the first test. Tests were conducted while mimicking the configuration and conditions of the WTP HLW melter, including the nominal operating temperature of 1150°C. Also fixed throughout the tests was the bubbling rate of 64 lpm for tests with the AZ-101 waste, which was the rate required to produce glass at a rate of 1050 $kg/m^2/day$ in previous tests[1]. Additional testing was conducted at a bubbling rate adjusted to achieve a production rate of 1050 $kg/m^2/day$ to verify the previously achieved plenum temperature. The bubbling rate was fixed at 85 lpm for tests with the high aluminum waste, which was the rate required to produce glass at a rate of 1150 $kg/m^2/day$ in previous tests.

Production rates obtained using the plenum temperature as a control for melter feed rate for the current tests were compared to production rates obtained in previous tests by adjusting feed rate based on visual observations of melter cold cap. A listing of the results from these previous tests

[1] The production rate of 1050 $kg/m^2/day$ was selected based on the previous requirement of 3 MT/day for the WTP HLW melter and a scaling factor to account for differences in the number of bubbling outlets per unit area in the DM1200 and the WTP HLW melter.

together with the achieved production rates and amount of bubbling used is provided in Table 1.1. The data with production rates close to 1050 kg/m^2/day show the trend for ease of melting, starting with the fastest melting iron-limited HLW compositions as follows: spiked C-106/AY-102 [19], AZ-101 [15], high waste loading C-106/AY-102 [18], and AZ-102 [18].

Throughout the tests, extensive melter operating data were collected to provide a basis for determining a strategy for operating the melter using only measured parameters. Visual observations of the cold cap were made independently and separate from the operating staff for comparison after testing to the monitored data. Melter exhaust samples were also taken to provide a connection between cold cap coverage, plenum temperature, and particulate carryover during testing.

SECTION 2.0
WASTE SIMULANT AND GLASS FORMULATIONS

2.1 Aluminum Limited Waste

2.1.1 Waste Simulants

The waste stream compositions previously provided by DOE are given in Table 2.1 on an oxide basis [23]. Of the four waste compositions listed, the work described in the present report was focused exclusively on the aluminum limited waste stream as a result of previous processing experience on the DM1200 [20, 21]. Actual Hanford tank HLW streams are aqueous solutions with suspended solids and dissolved salts including hydroxides, nitrates, nitrites, halides, and carbonates. For the purpose of the previous [20, 21] and present work, the concentrations of the volatile components (i.e., carbonate, nitrite, nitrate, and organic carbon) are assumed to be similar to those found for the AZ-102 HLW [11]. With the waste compositions defined, formulation of the HLW simulant proceeds in a straightforward fashion. In general, oxides and hydroxides are used as the starting materials, with a slurry of iron (III) hydroxide (13% by weight) as one of the major constituents. Volatile inorganic components are added as the sodium salts, whereas organic carbon is added as oxalic acid. Although crucible melts have been prepared using the appropriate radioactive components (i.e., thorium and uranium), substitution of non-radioactive starting materials was required in preparing the simulated waste for melter testing. The exact substitution depended on the measured properties of the radioactive glass prepared in a crucible melt and was determined on a case-by-case basis. Finally, water content was adjusted to target a glass yield of 400 g of glass per liter of feed. The composition of the waste simulant with boehmite as the aluminum source formulated to produce 100 kg of waste oxides are given in Table 2.2.

2.1.2 Glass Formulation

The HWI-Al-19 glass formulation for the ORP high aluminum waste composition [23] was developed and tested on both the DM100 and DM1200 to determine processing rates [20, 21]. These tests demonstrated that the formulation exceeded WTP requirements with respect to glass production rate and processed at a faster rate than the previous formulation (HLW-E-Al-27 [46]) with the same waste, while maintaining the 45 wt% waste loading.

The composition and properties of the HWI-Al-19 formulation are listed in Table 2.3 and the melter feed composition with boehmite as the aluminum source is shown in Table 2.4. Based on the results from small-scale melt rate testing, the formulation emphasized increased boron concentrations to improve melt rates and compensating changes to maintain other glass properties within acceptable ranges. The additional constituents required to form the target test glass from the

HLW high aluminum waste simulant are boron, calcium, lithium, sodium, and silicon. The corresponding chemical additives that are the sources for these elements were selected based on previous testing and the current baseline chemicals for the WTP Project. The measured viscosity and conductivity of HWI-Al-19 at 1150°C are 33 P and 0.27 S/cm, respectively. No crystalline phases were observed in the as-melted sample, and heat treatment for 72 hours at 950°C resulted in 1.3 vol% crystals. Chemical durability was verified on crucible and product melter glasses with leachate concentrations well below regulatory limits [20]. 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. Additional water to achieve the target glass yield of 400 g glass per liter was added to the feed at VSL.

2.2 Iron Limited AZ-101 Waste

The AZ-101 waste data, blending assumptions, and glass formulation used for these tests are the same as those used in previous melter tests [47]. The composition of the AZ-101 HLW simulant was derived and specified in a corresponding BNI Test Specification [48] and been processed extensively on the DM1200 [6, 14, 15].

2.2.1 AZ-101 Waste Simulant

Formulation of the AZ-101 waste simulant makes use of inventory data from the TFCOUP Rev. 3A [49], calculated data from ACM modeling, and analytical data on Cs- and Tc-removal eluates[2] from LAW pretreatment [48].

The composition of the AZ-101 Envelope D solids (Stream FRP02) is based on the inventory data found in Revision 3A of the TFCOUP [49]. As seen in Table 2.5, Revision 3A of the TFCOUP also provides information on minor components that were not included in earlier revisions [50] and the Best Basis Inventory (BBI) database (e.g., cadmium). The use of other data sources (e.g., HLW Feed Staging Plan [51]) 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., 1.30E+04 lb/day for Envelope D solids and 1.28E+03 lb/day for the recycle stream on a dry solid basis). The resulting material is concentrated and pretreated before ultra-filtration to produce the pretreated HLW solids. The separation factors due to HLW pretreatment and ultra-filtration are given in Table 2.5.

[2] It is recognized that technetium removal in pretreatment is no longer part of the WTP flow-sheet but this stream is retained in order to maintain a direct comparison with previous tests. However, for practical purposes, this stream has a negligible impact on the overall melter feed composition.

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, Sr/TRU removal products from pretreatment of Envelope C wastes will be omitted since the current processing schedule indicates that AN-102 (first Envelope C tank) waste will be processed after AZ-101. Analytical data on eluates from Cs- and Tc-removal on an Envelope B sample (AZ-102) [48] 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., 1.71E+01 lb/day for Cs-removal and 3.32E−01 lb/day for Tc-removal). It can be seen in Table 2.5 that incorporation of these streams primarily leads to increase of sodium and nitrate in the HLW simulant.

The calculated composition of the blended HLW solids (HLP09b) is shown in Table 2.5, which lists a total of 53 components. Similar to the approach taken during previous testing, radionuclides, noble metals (including silver), and minor components (< 0.05 wt% oxide basis) are omitted from the simulant formulations. Exceptions include cesium, which is included for analytical purpose, and praseodymium, which is replaced with another rare earth element, neodymium. The resulting HLW simulant formulation is given in Table 2.6.

2.2.2 AZ-101 Glass and Melter Feed Formulations

The glass composition selected as the basis for these tests, HLW98-77, is presented in Table 2.6. On an oxide basis, this glass incorporates 24.65 wt% of Envelope D waste and 25.25 wt% of all wastes. The glass HLW98-77 meets the contract specification by incorporating 21.20 wt% of (Al_2O_3+Fe_2O_3+ZrO_2) from Envelope D waste.

Crucible melts of HLW98-77 have been prepared and tested to determine that it meets the necessary processing requirements. The measured viscosity and conductivity at 1150°C are 50 P and 0.36 S/cm, respectively. Heat treatment of HLW98-77 at 950°C results in <0.5 vol% of spinel crystals. The target glass formulation for these tests, which is also given in Table 2.6, differs slightly from HLW98-77 by the removal of silver and the addition of small amounts of barium from the projected waste composition.

The additional constituents required to form the target test glass from the AZ-101 HLW simulant are boron, lithium, sodium, silicon, and zinc. The corresponding chemical additives that are the sources for these elements were selected based on previous testing and with direction of the WTP Project. Table 2.7 lists the starting materials and amounts required to produce the target AZ-101 simulant and melter feed. Note that all of the TOC is assumed to be oxalate and that more carbonate (0.429 g/100 g oxide) is present in the simulant than that required per the basis documents (0.106 g/100 g oxide). The small excess in carbonate is not expected to impact the tests since much greater amounts are present in the glass forming additives. The theoretical glass yield of the resulting feed is 375 g of glass/kg of feed (about (485-550) g/l of feed, dependent on feed density), when the total solids content of the *simulant* is assumed to be 20 wt%.

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. Additional water to achieve the target glass yield of 400 g glass per liter was added to the feed at VSL. Sugar was added to the AZ-101 feed at 2 grams per liter feed.

SECTION 3.0
DM1200 OPERATIONS

A series of tests with the HLW AZ-101 and high aluminum simulants were conducted between 1/30/12 and 2/11/12, producing over eight and half metric tons of glass. The total duration of waste and water feeding, was 187 hours, during which over 26 metric tons of feed was processed. Summaries of the test conditions and results are provided in Tables 3.1 and 3.2. The tests were conducted to determine the relationship between plenum temperature, cold cap observations and production rate as well as to identify strategies for controlling feed rate by using only remotely monitored parameters. All tests were conducted with bubblers in a previously defined and tested bubbler configuration; this consisted of two double-outlet lance bubblers on the melter floor, 8" apart on the East and West side, with one bubbler outlet a horizontal distance of 11.3" from the feed tube location [4, 15, 18, 20-22]. The AZ-101 and high aluminum feeds employed glass formulations HLW98-77 and HWI-Al-19, respectively, and both have been processed previously on the DM1200 [15, 21]. Both feeds had solids contents corresponding to 400 g glass per liter. The tests are listed below in the order in which they were conducted:

- Test 1: 24 hours processing AZ-101 composition, 525°C target plenum temperature, constant bubbling at 65 lpm.
- Test 2a: 17.5 hours processing AZ-101 composition, 475°C target plenum temperature, constant bubbling at 65 lpm.
- Test 2b: 11.9 hours processing AZ-101 composition, 425°C target plenum temperature, constant bubbling at 65 lpm
- Test 2c: 11 hours processing AZ-101 composition, 375°C target plenum temperature, constant bubbling at 65 lpm.
- Test 2d: 24.6 hours processing AZ-101 composition. Bubbling was adjusted to obtain a production rate of 1050 $kg/m^2/day$.
- Test 2e: 4.8 hours processing AZ-101 composition, 400°C target plenum temperature, constant bubbling at 80 lpm.
- Test 2f: 3 hours processing AZ-101 composition, 375°C target plenum temperature, constant bubbling at 80 lpm.
- Test 2g: 3 hours processing AZ-101 composition, 350°C target plenum temperature, constant bubbling at 80 lpm.

- Test 3: 67.2 hours processing high aluminum composition, 450°C target plenum temperature, constant bubbling at 85 lpm.

- Test 4: 12 hours processing high aluminum composition, 350°C target plenum temperature, constant bubbling at 85 lpm.

The tests employed a prototypical ADS feed system, a single feed tube in the center of the melter lid, a nominal glass temperature of 1150°C for all tests, and a side-to-side electrode firing pattern. In each test, the feed rate was adjusted to achieve the target plenum temperature; visual observations of the cold cap were made and recorded independently for information only but were not used to control the feed rate. A chronology of melter operations during the tests is provided in Table 3.3; a listing of all the cold cap observations is provided in Table 3.4.

The ADS feed system performed well in tests with the AZ-101 feed but could not be used for the high aluminum waste feed. Despite increasing the pump line air pressure to the maximum value, manipulating the pump dwell time, and repeated line flushes, the pump was not able to move any material. It is likely that solids could not be moved through the screen and were caked on the outer portion of the pump since such behavior was seen for several previous feeds: the LAW Sub-Envelope B1 feed [10]; HLW feeds adjusted to higher feed viscosity [18]; and this same high aluminum waste at higher solids content with boehmite as the aluminum source [21]. Therefore the backup AOD feed system was used to process the high aluminum waste feed and performed without incident. Only two significant interruptions occurred during testing: one in the latter five and half hours of Test 2c as a result of issues with the computer control of the feeding system and a second during Test 3 for about four and half hours due to failure of breaker, which required replacement before the resumption of testing. A few hours of feeding the AZ-101 composition was conducted prior to Test 3 in an attempt to collect additional data; however, due to a feed system malfunction, no useful data were collected over that short interval.

3.1 Glass Production Rates

A primary objective of these tests was to measure glass production rates at various plenum temperatures and determine whether using plenum temperature as an indicator for adjusting feed rate would result in under or over feeding, resulting in lower than attainable production rates or positive pressure events from excessive build up of feed, respectively. Glass production rates and target plenum temperatures are illustrated in Figures 3.1.a, 3.1.b, 3.2 to address this question. Also of interest are the test average and steady state values, which are provided in Tables 3.1 and 3.2. Steady state values were determined by eliminating portions of tests which were not indicative of the operating conditions, such as startup as the cold cap is developed and down-time associated with equipment repairs. Over Tests 1, 2a, 2b, and 2c conducted at 65 lpm bubbling with the AZ-101 composition, the glass production rate increased from about 600 kg/m^2/day at a target plenum temperature of 525°C to a rate approaching 800 kg/m^2/day at a target plenum temperature of 375°C. Production rates increased with decreasing plenum temperature; however, production rates were significantly lower than the 1050 kg/m^2/day previously measured with the same melter feed and operating conditions [15]. This discrepancy was addressed in Test 2d by adjusting the bubbling rate to determine the amount of bubbling required to achieve 1050 kg/m^2/day and determine the plenum temperature associated with this production rate. Increasing the bubbling rate by only 8 lpm per lance to a total of 80 lpm was required to achieve the desired production rate, which resulted in a plenum temperature of 400ºC; these values were used as the basis for Tests 2e, 2f, and 2g. Production rates were further increased at the higher bubbling rate to about 1350 kg/m^2/day as the plenum temperature approached 350ºC. However, longer duration testing would be required to determine if this production rate can be sustained at this plenum temperature and whether yet higher production rates could be achieved while further reducing the plenum temperature.

Testing with the high aluminum waste achieved the same production rate of 1150 kg/m^2/day at a 450ºC plenum temperature while bubbling at 85 lpm as that achieved in previous tests with this feed [21]. The feed rate was increased to reduce the plenum temperature to 350ºC, which resulted in a production rate of about 1300 kg/m^2/day. An average plenum temperature of 350ºC was obtained for all thermocouples except for one of the two in the locations corresponding to those used as indicators in the WTP HLW melters, which averaged 429ºC during Test 4. The plenum temperature gradient over this test suggests the cold cap coverage was irregular and that processing at this rate may not be sustainable for an extended duration.

3.2 Monitored Melter Parameters

Measured plenum temperatures, given in Figure 3.3.a and 3.3.b, spanned a wide range during the testing from near 100 to over 900°C. Plenum temperatures were over 600°C from the beginning of each test as the cold cap was being formed, during the two periods in which feeding was suspended for about five hours each as repairs were made to the systems, and after feeding stopped at the end of the tests. Target plenum temperatures ranging from 350 to 525°C were approximated for each of the respective test segments by adjustments to the feed rate. Two of the eight installed thermocouples (B3 and D3 shown in Figure 1.5) were designated for this purpose based on the similarity of their locations to the two thermocouples installed in the WTP HLW melter. The test average plenum temperatures are graphically illustrated in Figures 3.4.a – 3.4.j. The temperature gradient across the plenum space ranged from about 30 to 100°C depending on the targeted temperature; the lower the targeted plenum temperature, the higher the temperature gradient across the plenum space. The highest measured plenum temperature was in Port D3, near the exhaust outlet, throughout the tests. This is particularly significant since this monitoring point was one of the two designated points used as the plenum temperature indicator to adjust feed rate during the tests. Notice that the average of the two thermocouples used to control plenum can be up to 50°C higher than the average of the other six thermocouples at the lower plenum temperature targets. This is primarily a result of the higher temperature at port D3 since the other seven monitored plenum temperature were typically within a relatively narrow range depending on the targeted plenum temperature. Variability in measured plenum temperature results from variability in cold cap coverage, which is more evident at higher feed rates. The higher measured temperatures at port D3 is not attributable to closer proximity to bubbling outlet locations since other monitoring locations are equally close or closer to bubbling outlets (see Figure 1.5). The D3 port is the closest monitoring point to both the exhaust outlet and the airlift. It is suspected that the higher reading is due to air from the airlift, which can flow between the melter wall and the cold cap to produce an opening in the cold cap and increased radiant heat at this location.

A variety of other operational parameter measurements recorded during these tests, including temperatures throughout the melter system, are given in Table 3.5. The target glass temperature of 1150°C was successfully maintained for most of the glass pool during each test, as illustrated in Figures 3.5.a and 3.5.b. Exceptions were near the surface (27" from the floor) where temperatures were lower due to the thermocouples being in or near the cold cap. Another exception was during the loss of power 10 to 15 hours into testing with the high aluminum waste when the glass temperature dropped to about 1050°C as the breaker was replaced. Aside from this excursion, bulk glass temperatures were relatively constant throughout the glass pool. The east and west side electrode temperatures varied mostly over the narrow range of 1100 – 1150°C while feeding with an established cold cap, and typically varied by no more than 20°C from the mean during each test, as shown in Figures 3.6.a and 3.6.b. The bottom electrode, which was not powered in these tests, was 70 – 130°C cooler than the side electrodes while feeding. The difference between these temperatures decreased with increasing bubbling as the melt pool was better mixed. The discharge chamber and riser temperatures were largely maintained above 950°C throughout the tests. (The riser thermocouple is located about 4 inches above the bottom of the riser pipe, which is about 7.5 inches above the melter floor.) Gas temperatures after the film-cooler averaged between 272 and 377°C depending on the plenum temperature during each test segment. The film cooler was cleaned by a water spray every 12 hours during most of the testing, resulting in a short-duration reduction of about 75°C in the film cooler outlet temperature.

Conditions in the glass pool are illustrated for electrical properties in Figures 3.7.a and 3.7.b, level and density in Figure 3.8, and bubbling in Figures 3.9.a and 3.9.b. Power supplied to the electrodes was relatively constant once the cold cap was established for each feed composition and bubbling rate. With the AZ-101 composition, power usage largely varied between 125 and 150 kW while bubbling at 65 lpm and between 175 and 200 kW while bubbling at 82 lpm. This increase in power utilization is associated with a doubling of production rate. Power utilization largely ranged between 200 and 225 kW while processing the high aluminum waste. It is worth noting the relatively uniform power utilization at each bubbling rate and feed type despite the increasing production rate and decreasing plenum temperature. The effect of increasing the extent of the cold cap preventing heat loss from the molten glass appears to offset the additional power required to evaporate more water and incorporate more feed constituents into the glass.

Glass pool resistance increases from about 0.06 to 0.085 ohms while processing the AZ-101 composition and from 0.085 to 0.11 ohms while processing the high aluminum waste in response to the changes in the glass pool composition. Glass pool density decreased from about 2.5 g/cc at the beginning of tests feeding the high aluminum waste to about 2.1 g/cc at the end testing. The glass pool level varied between 28 and 33 inches while processing the high aluminum feed with frequent decreases in height of about two inches in response to glass discharging. During the power outage between 10 and 15 hours run time, an increase in the glass density and decrease in pool height in response to the drop in glass temperature and loss of cold cap were observed. The glass density and level probe was not functional during tests with the AZ-101 composition.

Bubbling rates from the two double ported bubblers were held constant at the target set points of 64 lpm for Tests 1 – 2c with the AZ-101 composition and 85 lpm for Tests 3 and 4 with the high aluminum feed; actual bubbling rates are slightly higher as a result of an estimated 1.2 lpm flow from the bottom electrodes. During Test 2d, the bubbling was manipulated to achieve a production rate of 1050 kg/m^2/day, which required a total bubbler flow rate of 80 lpm. Throughout the tests the bubbling rate for the two lances was kept the same and hence skewing of the flow between the bubblers to manipulate cold cap conditions was not employed.

The present tests were either of insufficient duration or feed rate to demonstrate over feeding of the melter. Additional data are needed to show the effect of over feeding on remotely monitored parameters such as plenum temperature, plenum pressure, glass density, and glass level, and identify any correlations between these parameters.

3.3 Plenum Temperature Control of Feed Rate and Cold Cap Observations

Feed rates and therefore glass production rates were dictated exclusively by plenum temperatures monitored at two locations in the melter plenum; feed rates were increased if the monitored plenum temperatures were above the target plenum temperature and feed rates were decreased if the monitored plenum temperatures were below the target plenum temperature. Observations of cold cap coverage were made and recorded every 10 to 20 minutes, as listed in Table 3.4. These observations were made from three view ports on the same side of the melter (see Figure 1.5), which permit the viewing of a limited portion of the melt pool surface. Many of the recorded observations are estimations based on the amount of light shining from a portion of the melt surface that cannot be directly observed from the view ports.

The plenum temperatures and cold cap observations are illustrated and compared in Figures 3.10.a – 3.10.k. The results demonstrate that the plenum targets were achieved through most of the testing. Observed cold cap coverage was mostly between about 90 and 100% other than during initial phases of testing as the cold cap was developing and during pauses in feeding. An inverse relationship between observed cold cap coverage and plenum temperature is observed during startup, pauses in feedings, and other periods such as around twenty hours run time during the initial test. However the sensitivity of the visual observations above 90% cold cap coverage is not sufficient to distinguish cold cap changes that are reflected in measured plenum temperature changes. No clear change in cold cap coverage was discerned with a 50°C decrease in plenum temperature between Tests 2b and 2c, a 50°C decrease in plenum temperature between Tests 2e and 2g, and a 50°C decrease in plenum temperature between Tests 3 and 4. Consequently, it would appear that basing feed rate on visual observations has the potential to result in lower production rates than basing feed rate on remotely monitored plenum temperatures. A challenge associated with the use of plenum temperature as an indicator for feed rate is the selection of a plenum temperature range for operation. Results from these tests suggest that each of the two feeds can be processed successfully over a relatively wide range of plenum temperatures. The tests also showed a trend of increasing processing rate as the plenum temperature was lowered. However, since the present tests were of relatively short duration, it is not clear from these tests whether all of these rates would be sustainable in long-term operations; therefore tests with longer processing times at the lower plenum temperature are recommended to demonstrate sustained operation.

Another point of contrast between the plenum temperature control method with constant bubbling and previous tests was the inability to duplicate production rates previously obtained for the AZ-101 composition using different methods of adjusting feed and bubbling rates. Data from the previous tests are shown in Figures 3.11.a – 3.11.c. In the previous tests, bubbling was adjusted to achieve a production rate of 1050 kg/m^2/day. This production rate was obtained over the first 10 hours and maintained for another 130 hours. Based on observations of the cold cap, bubbling was increased to 90 lpm during the first day of operation then reduced to the steady state rate of 65 lpm over the remainder of the test segment. Plenum temperatures dropped to about 400ºC over the initial 10 hours then rose to 500 - 550ºC over the remainder of the test segment. Comparison of the two test series suggests that the use of higher bubbling rates at the beginning of testing, which was reduced later during the test once the cold cap was established, may have resulted in a faster approach to the long-term steady state processing rate in the previous tests. In contrast, the present tests, where the feed rate was adjusted based only plenum temperature without manipulation of bubbling at the beginning of testing, apparently resulted in lower early production rates, as was observed in Tests 1 – 2c. However, it would be expected that, for the same feed and operating conditions, the same long-term production rate would be ultimately obtained regardless of the start-up procedure but the time to reach that condition may vary. The increase in bubbling to 80 lpm in Test 2d to achieve 1050 kg/m^2/day production rate in the present tests was consistent with previous testing. Based on the results from the previous tests, continued processing at this feed rate may have permitted a decrease in the demand for bubbling and an increase in plenum temperature.

SECTION 4.0
DM1200 OFF-GAS SYSTEM PERFORMANCE

Tests on the DM1200 system at VSL have been used extensively to evaluate the performance of a pilot scale off-gas system that is prototypical of that designed for the WTP by BNI engineering [4-22]. In the present tests, the data objectives related primarily to the identification of a control strategy for operating the HLW melters using only monitored parameters without visual observation. Performance of the off-gas system, although important to support the operation of the melter, was not a primary objective for investigation during the present tests. However, data for each of the off-gas system components were collected and evaluated and are provided in this report. Data are collected and electronically logged every two minutes and data and observations are also recorded manually throughout the tests. The average, minimum, and maximum values of the measured off-gas system parameters are given in Table 4.1. Target operational conditions for the system components such as sump temperatures, unit spray rates, and sump pH values that were not specified were adapted from previous tests conducted on the DM1200 [15]. For these tests the silver mordenite / activated carbon system was not used, and the catalytic unit was bypassed.

Plots of the typical sequence of gas temperatures through the DM1200 off-gas system at various locations are given in Figures 4.1 and 4.2 for the first (Tests 1 and 2) and second (Tests 3 and 4) intervals of testing, respectively. As can be seen, the average temperature distribution in the off-gas system is relatively independent of the type of feed. In addition, the SBS cooling system, as discussed below, acts to maintain SBS outlet temperatures at a selected operational value. In summary, plenum gas from the melter is cooled by dilution with film cooler air to about 325°C, drops another 63-69°C by control air dilution and heat loss along the transition line, is quenched to 44°C in the SBS, and reheated to about 72°C to prevent condensation in the HEPA filtration unit. The exhaust is heated by another 15°C to 17°C by the Paxton blowers, as measured at the TCO/SCR inlet. A slight piping heat loss occurs from that point to the PBS inlet.

Tests 1 and 2 were conducted using the AZ-101 feed. A plenum temperature of approximately 525°C was targeted for the first 25 hours, and the target temperature was lowered in the following stages. Problems with feeding occurred between approximately 65 – 70 hours, which had a small influence that is visible in some of the plotted off-gas parameters. Tests 3 and 4 were conducted using a high aluminum feed. Electrical problems between about 10 hours and 14 hours resulted in feed stoppage with effects visible on some of the off-gas plots.

4.1 Melter Pressure

Detailed discussion of the melter conditions during testing is presented in Section 3. This section discusses the vacuum on the melter and differential pressure across the film cooler and transition line to the SBS.

A vacuum on the melter of between two to three and half inches of water was targeted and maintained throughout the majority of the tests. This is achieved by setting blower speeds and using a control air system which constantly monitors the vacuum on the melter and injects sufficient air into the transition line immediately downstream of the film cooler to maintain a relatively constant vacuum on the melter. The melter pressures measured at the instrument port and by the level detector for Tests 1 and 2 (AZ-101 composition) and Tests 3 and 4 (high aluminum composition) are shown in Figures 4.3 and 4.4, respectively. The melter pressure fluctuated between -1 and -4 in W.C. throughout the tests in response to changes in feeding and cold cap conditions. Melter pressure fluctuates constantly between -1 and -4 inches water and does not directly correlate with feed rate or plenum temperature within the parameters used in these tests. Consequently, melter pressure does not appear to be useful as a routine indicator for adjusting feed rate to the melter. Similarly the calculated control air flow rates for the tests shown in Figures 4.5 (Tests 1 and 2) and 4.6 (Tests 3 and 4) do not appear to directly correlate with melter feed rate or plenum temperature within the ranges investigated in these tests. The range of control air flow rates reflect the changes of melter exhaust volume in response to changes in the cold cap and feed rate, including pulsing of the feed (due to the ADS or AOD pump) throughout the tests.

Differential pressure measurements across the film cooler are provided in Figures 4.7 (Tests 1 and 2) and 4.8 (Tests 3 and 4). Reduced differential pressure is evident during periods when the feeding was halted. No rodding of the film cooler was required during these tests. The differential pressure measurements across the transition line are shown in Figures 4.9 and 4.10. During Tests 1 and 2 the transition line differential pressure was generally around 5 in W.C. up to about 70 hours and then increased to about 7 in W.C.; the overall average was 5.3 in W.C. During Tests 3 and 4 the transition line differential pressure was slightly higher, averaging 7.1 in W.C. for the overall duration. The lack of clogging in the film cooler and transition line indicate a lack of solids carryover from the melter resulting from more complete cold cap coverage and/or a greater effectiveness of the new film cooler (see Section 1.4.2) at preventing solids accumulations. Clogging of the previously installed film cooler on the DM1200 increased in frequency at higher bubbling and feed rates [4].

4.2 SBS

The SBS quenches the melter exhaust, condenses much of the water from the melter feed, and removes the majority of the particulate in the exhaust stream. Many parameters of the SBS were recorded during testing, including inlet and outlet gas temperatures, pressures, and flow rates, pressure drops, sump temperature, heat exchanger inlet and outlet water temperatures, and flow rates. The amounts of heat removed by the SBS jacket, and the SBS inner cooling coil were calculated from the measured data using the hourly averaged cooling water temperature increases (outlet temperature minus supply temperature) across the SBS inner cooling coil and cooling jacket multiplied by the same time-averaged water flow rate through each.

The SBS inlet and outlet gas temperatures are plotted in Figures 4.11 and 4.12. The average SBS inlet and outlet gas temperatures were 256°C and 44.4°C during Tests 1 and 2, and 263°C and 44.4°C during Tests 3 and 4. SBS inlet and differential pressures are plotted in Figures 4.13 and 4.14. Differential pressures averaged about 33 in W.C. and inlet pressures generally ranged between -14 and -8 in W.C. during these tests.

The SBS off-gas temperatures in the down-comer measured at various depths (from 3 to 53 inches) and the SBS sump water temperature are given in Figures 4.15 and 4.16. The average SBS sump temperatures were 39.5°C (Tests 1 and 2) and 38.7°C (Tests 3 and 4), which are each about 5 to 6°C lower than the corresponding SBS outlet gas temperature. The measured off-gas temperatures decrease as the depth from the SBS lid increases due to cooling of the gas in the down-comer pipe by the surrounding SBS liquid.

Water temperatures at the SBS inner cooling coil inlet, inner cooling coil, outlet/jacket inlet, and jacket outlet are given in Figures 4.17 and 4.18. The average water temperature differences were 18.7°C (Tests 1 and 2) and 15.2°C (Tests 3 and 4) across the SBS inner cooling coil, and 2.0°C (Tests 1 and 2) and 2.6°C (Tests 3 and 4) across the jacket. The SBS cooling coil and SBS jacket water flow rates are plotted in Figures 4.19 and 4.20 and averaged 16.2 gal/min (Tests 1 and 2) and 27.6 gal/min (Tests 3 and 4). The effects of the feed stoppages are visible on the SBS cooling water temperatures and flow rates, as shown at about 65 – 72 hours for Tests 1 and 2, and 10-15 hours for Tests 3 and 4. When feed is stopped, the heat load to the SBS is reduced because of reduced condensation of the water vapor from the feed. This causes a reduction in the cooling water temperatures (Figures 4.17 and 4.18) and also in the flow rate (Figures 4.19 and 4.20) as the control system adjusts to the change in heat load.

Figures 4.21 and 4.22 show the calculated heat loads and the reduction during feed stoppage is apparent. During Tests 1 and 2, heat removal averaged 63.5 kW by the SBS inner cooling coil and 7.3 kW by the cooling jacket. This corresponds to about 89.7 % of the heat load to the SBS being removed by the inner cooling coil and about 10.3 % by the cooling jacket. During Tests 3 and 4, heat removal averaged 90.7 kW by the SBS inner cooling coil and 15.6 kW by the cooling jacket. This corresponds to about 85.3 % of the heat load to the SBS being removed by the inner cooling coil and about 14.7 % by the cooling jacket.

One of the functions of the SBS is to condense water that originated in the waste feed. In Figures 4.23 and 4.24, the amount of water fed is compared to the total volumetric accumulations in the SBS during testing. The difference between the amounts of water coming from the feed and the amounts blown down from the SBS sump represent the amount of water carried out in the off-gas stream as a result of it being saturated at the SBS sump temperature, as well as a small amount of entrained droplets. This amount is largely determined by the SBS sump water temperature. In Tests 1 and 2, of the 2161 gal of water entering the SBS as part of the exhaust stream, 1204 gal or 56 % was condensed in the SBS. For Tests 3 and 4, of the 2414 gal of water entering the SBS as part of the exhaust stream, 1864 gal or 77 % was condensed in the SBS. Total blow-down volumes for the SBS (and other components) are summarized in Tables 4.2 and 4.3.

4.3 WESP

The primary function of the WESP is to remove fine, often water soluble particles from the exhaust stream that are not efficiently removed by the SBS. The inlet and outlet gas temperatures, differential pressure across the WESP, and the WESP current and voltage were measured and recorded by the computer data acquisition system. The WESP inlet and outlet gas temperatures for the test are plotted in Figures 4.25 and 4.26. A temperature increase of 0.2°C (Tests 1 and 2) and 2.8°C (Tests 3 and 4) is observed in the exhaust temperature as gas passes through the WESP. The periodic downward spikes in the WESP outlet temperature are a result of the daily deluge of the WESP to wash collected deposits off the electrodes and into the WESP sump. The WESP outlet gas flow rates are plotted in Figures 4.27 and 4.28. Measured differential pressure across the WESP averaged 4.3 in W.C. for Tests 1 and 2 and 4.4 in W.C. for Tests 3 and 4. The typical wet gas flow rate exiting the WESP was between 290 and 330 scfm during these tests.

The amount of liquid accumulated in the WESP (not including the deluge volume) is plotted as a function of run time in Figures 4.29 and 4.30, where it is compared with the amount of fresh water sprayed into the WESP during the test. The inlet spray water was targeted at 2.0 ± 0.2 gph; however, the actual spray water flow rate was ≈ 1.7 gph because of the limitations of the spray nozzle. As evident from both figures, spray water accounts for the majority of the liquid accumulation in the WESP. The difference between accumulated liquid and fresh water sprayed is equal to the amount of liquid removed from the off-gas, which is also plotted in Figures 4.29 and 4.30. The WESP electrodes were deluged daily, as planned, with 20 gallons of water introduced over 2 minutes. The total blow-down volume from the WESP is included in Tables 4.2 and 4.3

The WESP voltage and current are plotted as functions of run time in Figures 4.31 and 4.32. During Tests 1 and 2, the voltage averaged 30.6 kV and the current averaged 10.6 mA. During Tests 3 and 4, the voltage averaged 30.1 kV and the current averaged 10.9 mA.

4.4 Secondary Off-Gas System

A HEME filtration unit (HEME 1) follows the WESP in the off-gas system to remove water droplets that may be present in the water-saturated gas exiting the WESP. The outlet gas temperature and differential pressure are plotted in Figures 4.33 and 4.34. The typical pressure drop across HEME 1 during testing was about 2.0 in W.C.

The HEME 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 the HEPA filter are the two parameters monitored by the off-gas data acquisition system; these are shown in Figures 4.35 and 4.36. The typical pressure drop across the HEPA filter was 0.5 in W.C. throughout testing, except during the first 30 hours of Tests 3 and 4 when the value trended upward to about 0.7 in W.C. before dropping back to 0.5 in W.C. The cause of this behavior is not apparent. A vacuum is maintained on the melter by a pair of redundant Paxton blowers (Blowers 701 and 702) immediately downstream of the HEPA filtration unit and a blower (Blower 801) downstream of the packed bed scrubber. The thermal catalytic oxidizer (TCO) and selective catalytic reduction unit (SCR) are located downstream of the HEPA filter and Paxton blowers in the off-gas train is; however, these units were bypassed during the present tests.

A packed bed caustic scrubber (PBS) is used near the end of the off-gas train to remove acid gases from the off-gas stream. The PBS sump solution is derived from process water; caustic solution (25% NaOH) is added to control the solids content and pH of the scrubber liquid. The PBS inlet gas temperature and pressure drop across the PBS are shown in Figures 4.37 and 4.38. The average pressure drops across the PBS were 5.3 in W.C. during Tests 1 and 2 and 5.5 in W.C. during Tests 3 and 4. The average inlet gas temperature at about 87 - 88^{o}C was quenched to about 29 - 30 ^{o}C in the PBS during these tests. The pH for the PBS is plotted in Figures 4.39 and 4.40. In Tests 1 and 2 the pH was generally maintained above 8.3, as shown in Figure 4.39, with little addition of caustic needed. However, in Tests 3 and 4, the pH tended to drift down to about 8.2 during the testing and therefore periodic caustic addition was necessary, as evidenced by the saw-tooth pattern on the plot. The PBS was periodically blown down as required to maintain constant volume. The PBS total blow-down volumes are included in Tables 4.2 and 4.3.

A second HEME (HEME 2) is present near the end of the off-gas train, upstream of the stack blower, to prevent entrained water droplets from entering the stack.

SECTION 5.0
FEED SAMPLE AND GLASS PRODUCT ANALYSIS

5.1 Analysis of Feed Samples

5.1.1 General Properties

Samples from as-received feed were analyzed to adjust feed solids content and verify chemical composition. Feed sampled while testing was also analyzed to confirm physical properties and chemical composition. Sample names, sampling dates, and measured properties are given in Table 5.1. Density, pH, water content, glass conversion ratio, boron and lithium content by DCP, and oxide composition by XRF were measured for all samples. The measured solids content of the as-received feed served as the basis for determining the amount of water required to achieve the target solids content of 400 g glass per liter of feed. Due to the inhomogeneity of feed in the high aluminum waste drums and difficulties in mixing the feed, test samples of diluted feed were also analyzed to verify the amounts of water to be added to the melter feed. The measured glass conversion ratios for feed samples from the AZ-101 feeds were within two to four percent of the target on a weight per weight basis, confirming the amount of water dilution and validating the use of the target conversion ratio for calculating glass production rates. The measured glass conversion ratios for feed samples from the high aluminum feeds were more variable, from about nine percent below to fourteen percent above target solids content. This variability stems from variability in solids content between the as-received feed drums. Attempts were made during testing to process as many drums of feed in the mix tank and feed tank at one time to average out this variation. The average measured solids content was close to target and the overall feed to glass conversion ratio from the tests (total mass of glass discharged/ total mass feed processed) is 0.313 vs. the 0.315 target, validating the use of the target conversion ratio for calculating glass production rates. The measured water content and density are consistent with the solids content measured on a weigh per weight basis. Measured pH values were about 1.5 units higher for the AZ-101 feeds due in part to the boron source: borax was the additive source for boron in AZ-101 feed and boric acid was the additive source for boron in the high aluminum feed.

5.1.2 Chemical Composition

The methods used for analysis of feed sample chemical compositions are described in Section 1.5. The boron and lithium oxide concentrations measured using the DCP procedure and fluorine target values were used for normalizing the XRF data since their concentrations were not determined by XRF. These results, compared to the target composition in Tables 5.2 and 5.3, generally corroborate the consistency of the feed compositions and show good agreement with the target compositions for the major elements. Of the oxides with target concentrations greater than one percent, average melter feed sample concentrations of aluminum, zinc, and zirconium for the AZ-101 feed and calcium for the high aluminum feed deviated by more than 10% from target. All average deviations were less than thirteen percent except for aluminum in the AZ-101 feed, which was less than nineteen percent. The absolute deviations are less than one percent for all oxides. The composition of this feed is further corroborated by comparison to the product glasses (see Section 5.2), which shows all oxides with concentrations greater than 1 wt% in the target composition to be within about 10% of the target, except for phosphorus during some tests. Low concentrations of bismuth, chromium, phosphorus, and titanium in the AZ-101 feed and manganese and neodymium in the high aluminum feed, were measured, even though they are not included in the target composition. Also, common elements such as calcium, magnesium, titanium, and sulfur, when targeted at low concentrations, were typically above these targets. These positive deviations are often observed in melter feeds due to their ubiquity in the raw materials used to make up the simulants and in the glass forming additives. None of these relatively small deviations would significantly affect the glass processing rates.

5.2 Analysis of Glass Samples

Over eight and a half metric tons of glass was produced in the present tests. The glass was discharged from DM1200 into 55 gallon drums using an airlift system. The discharged product glass was sampled at the end of each test by removing sufficient glass from the top of the cans for total inorganic analysis. Product glass masses and discharge date are given in Table 5.4.

All discharge glass samples were crushed and analyzed directly by XRF. Glasses associated with the beginning and end of processing the AZ-101 composition were analyzed using the DCP procedure to measure boron and lithium concentrations. The measured boron and lithium for select glasses and the target values for boron and lithium oxides were used to calculate boron and lithium concentrations and were subsequently used for normalizing the XRF data to 100 wt%. Fluorine analysis by XRF required a polished monolith as opposed to the standardized ground glass preparation used for the other elements. Over half the glass samples discharged while processing the high aluminum feed were directly analyzed for fluorine; fluorine concentrations of other glasses were interpolated in between the measured values. The XRF analyzed compositions of discharged glass samples are provided in Tables 5.5 and 5.6. The melt pool composition at the beginning of each test was very different than the target composition and only slightly over two melt pool turnovers occurred while processing each composition; therefore the composition at the end of processing each feed composition was not expected to match the respective target composition. The XRF analysis of the last glass discharged while processing each composition compared favorably to their corresponding target values and feed sample analyses (see Section 5.1.2), particularly considering the lack of complete melt pool turnover. Oxides with a target concentration greater than one weight percent all showed below 20% deviation from the target values. Compositional trends for selected constituents shown in Figures 5.1.a - 5.1.f show the changes in melt pool composition through the transitions between the three glass formulations and the closeness to targets at the end of tests with each composition. At the onset of testing, the glass pool consists of a high-sodium LAW glass composition [52] with virtually no lithia; however, the silica and alumina concentrations are very similar to those in the AZ-101 composition. Iron, lithium, boron, lanthanum, neodymium, and zirconium increase in concentration at the expense of sodium, alkaline earths, and titanium oxides while processing the AZ-101 composition. The high aluminum composition contains about four times more alumina, twice the boron oxide, and half the silica than the AZ-101 composition. Aluminum, boron, bismuth, and calcium increase in concentration at the expense of silicon, iron, sodium, lanthanum, neodymium, and zirconium while processing the high aluminum composition. Bismuth, chromium, phosphorus, and titanium were present in the melt pool prior to testing but were not included in the AZ-101 target composition. Sulfur and fluorine are below target for glasses discharged while processing the high aluminum composition due to volatilization from the glass pool and cold cap. Measured sulfur concentrations were above target concentrations while processing the AZ-101 composition suggesting trace level contamination of the feed.

SECTION 6.0
MONITORED OFF-GAS EMISSIONS

6.1 Particulate Sampling

The melter exhaust was sampled for metals/particles according to 40-CFR-60 Methods 3, 5, and 29 at steady-state operating conditions during each test segment. The concentrations of off-gas species that are present as particulates and gaseous species that are collected in impinger solutions were derived from laboratory data on solutions extracted from air samples (filters and various solutions) together with measurements of the volume of air sampled. Particulate collection required isokinetic sampling, which entails removing gas from the exhaust at the same velocity that the air is flowing in the duct (40-CFR-60, Methods 1-5). Typically, a sample size of 30 dscf was taken at a rate of between 0.5 and 0.75 dscfm. Total particulate loading was determined by combining gravimetric analysis of the standard particle filter and chemical analysis of probe rinse solutions. An additional impinger containing 2 N NaOH was added to the sampling train to ensure complete scrubbing of all acid gases. The collected materials were analyzed using direct current plasma atomic emission spectroscopy for the majority of the constituents and ion chromatography (IC) for anions. Melter emission fluxes are compared to feed fluxes in Tables 6.1 and 6.2 for the AZ-101 and high aluminum compositions, 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 0.3 μm heated filter. All samples are within the 90 – 110% limits for isokinetic sampling.

Particulate emissions from the DM1200 constituted 0.73 and 0.77 percent of feed solids while processing the AZ-101 composition at bubbling rates of 65 lpm and 80 lpm, respectively. These results are well within the range of 0.55 to 1.25 percent measured while processing the same feed composition over a variety of feed solids contents, bubbler configurations, and bubbling rates [9, 15]. At the same feed solids content and bubbler configuration, solids carryover was 0.62 percent at 65 lpm bubbling and 1.11 percent at 134 lpm bubbling, bracketing the results collected in the present tests at bubbling rates of 65 and 80 lpm. The results suggest that there is no significant difference in carryover between the two bubbling rates used and between tests conducted using different strategies to control feed rate to the melter.

Particulate emissions from the DM1200 constituted 0.33 and 0.12 percent of feed solids while processing the high aluminum waste in Test 3 and 4, respectively. These results are within the range of 0.1 to 0.46 percent measured while processing the same waste and glass composition using the same bubbler configuration over a variety of feed solids contents, glass temperatures, and sodium sources, and bubbling rates [20, 21]. At the same feed solids content and bubbling rate, in previous tests solids carryover was 0.44 percent [21], which is higher than observed in the present tests suggesting there was a more extensive cold cap on the melt pool surface in the present tests.

Also the decrease from 0.33 to 0.12 percent coincides with a decrease in plenum temperature resulting from a higher feed rate and thus a thicker cold cap, which would serve to further limit particulate carryover.

As expected, the feed elements emitted at the lowest melter decontamination factors (DF) were clearly fluorine and sulfur. Other elements exhibiting some volatile behavior were boron, alkali metals, cadmium, and lead in at least one of the feed compositions. The relative volatility of calcium, magnesium, and titanium are difficult to evaluate due to the low target concentrations in the feed and the ubiquity of these constituents as trace level contaminants in additives and chemicals used to make the waste simulants. Boron, sulfur, and fluorine were the only elements detected in the impinger solutions collected downstream of the heated particle filter in the sampling train, which constitutes the "gas" fraction of the melter emissions.

6.2 Gases Monitored by FTIR

Melter emissions were monitored in each test for a variety of gaseous components, most notably CO and nitrogen species, by FTIR. The off-gas system temperature is maintained well above 100°C beyond the sampling port downstream of the DM100 HEPA filter to prevent analyte loss due to condensation prior to monitoring. The data, therefore, represent the relative concentrations of volatile gaseous species in the melter exhaust. The exhaust stream was sampled at the outlets of several prototypical components (melter, SBS, WESP, and PBS) to discern the effect these components have on the volatiles in the exhaust stream. It should be noted, however, that the off-gas system component most responsible for the removal of nitrogen oxide and volatile organics, the TCO-SCR catalyst unit, was bypassed in these tests due to the relatively low concentrations of these components in the exhaust stream. Also, a single FTIR unit was used for all of the measurements and, therefore, locations were sampled sequentially and not simultaneously.

A summary of the range and average concentrations of gaseous species monitored is provided in Tables 6.3 and 6.4. The concentrations of three of the monitored species are plotted in Figures 6.1 -6.6. The analytes listed in Tables 6.3 and 6.4 are those that were thought likely to be observed during the tests based on previous work; no other species were detected in the off-gas stream by FTIR. The concentration of water in the melter exhaust increased with increasing feed rate and was consistent with the amounts determined using the Method 5-type sampling (see Section 6.1), Generally, emissions were relatively low as a result of the low concentrations of nitrogen, organic carbon, ammonia, and halogens in the feed. The most abundant nitrogen species monitored was NO, with NO_2 being 10 to 20 times lower in concentration than NO, which is in keeping with previous melter tests with both HLW and LAW feeds. Low concentrations of N_2O, nitric acid, nitrous acid, and HCN were also observed in the tests. Consistent with the gaseous fluorine concentrations observed using the Method 5-type sampling (see Section 6.1), HF was observed throughout the testing by FTIR, particularly during tests with the high aluminum feed, in which fluorine is targeted at two thirds of a weight percent in the glass product. Carbon monoxide was detected mostly in the 10 to 35 ppm range as a by-byproduct of incomplete combustion of the feed carbon in the presence of nitrates. Higher concentrations of ammonia were monitored while processing the AZ-101 waste due to the incorporation of small amounts of sucrose in the feed. The variability in the NO and CO concentrations are attributable to the dynamic conditions in the cold cap and is in keeping with previous melter tests; the increase in concentration over the course of the tests reflects the increase in feed rate. Measured concentrations for most constituents at different locations in the DM1200 exhaust system were very similar. This confirms the expectation that the SBS, WESP, HEME, and PBS do not remove significant proportions of nitrogen and carbon oxides. Conversely, moisture is greatly reduced in concentration by removal in the SBS.

SECTION 7.0
SUMMARY AND CONCLUSIONS

A series of tests was conducted on the DM1200 Pilot Melter system to evaluate methods of controlling melter feeding using only remotely monitored parameters. The tests were performed with high iron and high aluminum HLW streams. For each of the two waste compositions, tests were conducted with conditions (bubbling configuration, bubbling rate, glass temperature, feed solids content) that were used in previous tests that employed direct observation of the cold cap as an indicator for adjusting feed rate. In the present tests, bubbling rates were fixed at rates determined in previous tests while feed rates were adjusted to achieve a series of target plenum temperatures while monitoring melter parameters to determine cold cap conditions and indications of over feeding. Plenum temperatures were measured at eight separate locations; however, only two were used as indicators for adjusting feed rate in order to reflect the number and locations with respect to bubblers and the feed tube for the WTP HLW melter. Cold cap conditions were monitored and recorded throughout the tests but were not used as input into the control of the melter feed rates. No significant processing problems were encountered during these tests. The DM1200 tests produced eight and half metric tons of glass from over 26 metric tons of feed.

A primary objective of these tests was to measure glass production rates at various plenum temperatures and determine whether using plenum temperature as an indicator for adjusting feed rate would result in under or over feeding, resulting in lower than attainable production rates or positive pressure events from excessive build up of feed, respectively. In tests conducted with the AZ-101 composition at 65 lpm bubbling, the glass production rate increased from about 600 kg/m^2/day at a target plenum temperature of 525°C to a rate approaching 800 kg/m^2/day at a target plenum temperature of 375°C. Production rates increased with decreasing plenum temperature; however, production rates were significantly lower than the 1050 kg/m^2/day previously measured with the same melter feed and operating conditions. The bubbling rate was increased to 80 lpm to achieve a production rate of 1050 kg/m^2/day at a plenum temperature of 400°C. Production rates were further increased at the higher bubbling rate to about 1350 kg/m^2/day as the plenum temperature approached 350°C.

Testing with the high aluminum waste achieved the same production rate of 1150 kg/m^2/day at a 450°C plenum temperature while bubbling at 85 lpm as that achieved in previous tests with this feed. The feed rate was increased to reduce the plenum temperature to 350°C, resulting in a production rate of about 1300 kg/m^2/day. Collectively, the data clearly showed increasing feed rate with decreasing plenum temperature. Observations of the cold cap coverage of the melt surface were mostly around 90 to 100% over the range of plenum temperatures tested suggesting that the sensitivity of the visual observations above 90% cold cap coverage is not sufficient to distinguish cold cap changes that are reflected in measured plenum temperature changes.

The inability to reproduce the production rates achieved for the AZ-101 feed using visual observations of the cold cap as an indicator for adjusting feed rate may be attributable to the manner in which feeding is initiated and bubbling controlled at the beginning of the test. Comparison of the two test series suggests that the use of higher bubbling rates at the beginning of previous testing, which was reduced later during the test once the cold cap was established, may have resulted in a faster approach to the long-term steady state processing rate in the previous tests. In contrast, the present tests, where the feed rate was adjusted based only plenum temperature without manipulation of bubbling at the beginning of testing, apparently resulted in lower early production rates. However, it would be expected that, for the same feed and operating conditions, the same long-term production rate would be ultimately obtained regardless of the start-up procedure but the time to reach that condition may vary. However, the differences between the two feed compositions in this regard further demonstrate the effect of feed composition on cold cap formation and the rate of incorporation into the glass.

During these tests data were collected throughout the melter and off-gas system to identify any measured parameters that could potentially serve as an indicator for adjusting melter feed rate. Plenum temperatures monitored at eight separate locations were relatively uniform except for one, which was also one of the two used as an indicator for adjusting feed rate. The higher temperatures monitored at this location were likely a result of its closer proximity to the airlift, which underscores the importance of selecting appropriate monitoring locations for critical control parameters such as that used for feed rate. Other monitored parameters such as melter pressure, differential pressure across the film cooler and transition line, glass density, and melt pool height showed little variability with feed rate, plenum temperature, or observed cold cap coverage. However, it is possible that changes in these parameters may result if more aggressive over-feeding conditions were employed.

Film cooler clogging was less frequent in the present test with the AZ-101 feed than was the case in previous tests. This difference could be due to the different method of controlling feed rate or to the change in film cooler design. In view of the potential impacts of film cooler clogging on melter down-time, further investigating of this behavior would be useful.

At two different feed rates for each waste composition, melter exhaust was sampled for particulate and gaseous species to determine the effect of the feed rate determined by plenum temperature on emissions. Total particulate carryover into the off-gas stream was 0.73 and 0.77 percent for the AZ-101 composition at bubbling rates of 65 lpm and 80 lpm, respectively, and was well within range previously measured with the same feed processed at the same conditions. Total particulate carryover into the off-gas stream was 0.33 and 0.12 percent for the two tests with the high aluminum composition and was below the amount previously measured with similar feed processed under the same conditions. Melter DFs were determined for most elements in the feed for both feed compositions. The most volatile species were sulfur and fluorine, which is typical. Gaseous emissions of nitrogen oxides and byproducts of incomplete combustion, such as carbon monoxide and ammonia, were very low due to low concentrations of nitrates and organic carbon in the feed.

7.1 Recommendations for Future Work

The results of the testing presented herein demonstrate the potential use of remotely monitored plenum temperature as an indicator for controlling feed rate to the HLW WTP melter. However, the details of such a strategy including target plenum temperatures and the implications for glass productions rates need to be further explored in subsequent testing. In the present tests, higher or lower feed rates were obtained using plenum temperature as a feed control indicator as compared to those obtained by visual observation of the cold cap, depending on feed composition and potentially the manner in which feed was initiated. It is possible that some of these features are a result of the relatively short durations of the test segments used in the present work and therefore longer duration tests will be required as the preferred control strategy is developed. Some of the elements recommended for the next phase of testing are summarized below.

- *Identification of Control Parameters*: The present testing demonstrated the viability of using plenum temperature as a control parameter; however, plenum temperature control ranges have yet to be optimized and established. A method for determining optimal bubbling rates for a given waste and feed composition without using visual observations of the cold cap also needs to be identified.

- *Identification of Over-Feeding Conditions*: The present tests were either of insufficient duration or feed rate to demonstrate over feeding of the melter. Testing needs to be conducted to show the effect of over feeding on remotely monitored parameters such as plenum temperature, plenum pressure, glass density, and glass level, and identify any correlations between these parameters.

- *Melter Startup*: Procedures for initiating melter feeding are different than feeding in steady state conditions. Beginning testing in a less than optimal manner has the potential to result in undesirable conditions including prolonged production at lower production rates. Melter startup procedures in previous tests have relied on visual observations of the cold cap. Development of startup procedures relying exclusively on remotely monitored parameters such as plenum temperature is required.

- *Film Cooler Clogging*: In view of the potential impacts of film cooler clogging on melter down-time, testing is required to determine whether the observed differences in the frequency of film cooler clogging is a result of the change in method of feed rate control or the change in film cooler design.

- *Longer-Duration Testing:* After control parameters have been established, the duration of testing should be extended in order to ensure steady state processing has been established. Longer duration testing is also recommended to address and quantify any chronic issues such as off-gas line plugging and frequency of film cooler cleaning.

- *Other WTP HLW Waste Types:* The present testing was based on two HLW compositions, high iron and aluminum wastes, from the Hanford tanks. Waste and melter feed compositions have a significant effect on cold cap formation and processing rate. While these results are also relevant to waste from several tanks, the diversity of the Hanford tank wastes has the potential to result in a variety of different cold cap conditions and therefore glass production rates. Therefore the control strategy should be developed and demonstrated over the range of wastes and melter feed compositions projected for HLW WTP operations.

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

SECTION 8.0
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Table 1.1. DM1200 Tests Performed with Final HLW Bubbler Configuration and Glass Temperature of 1150ºC.

Test	Feed	Glass Yield	Duration	Bubbling Rate	Average Plenum Temperature	Glass Production Rate
DM100 and DM1200 Melter Testing with High Waste Loading Glass Formulations for Hanford High-Aluminum HLW Streams VSL-10R1690-1 [21]	Al-Limited Waste [Boehmite] with LAW stream as sodium source, sugar	500 g/l	54 hrs	62 lpm	381°C	1050 $kg/m^2/d$
	Al-Limited Waste [Boehmite] with LAW stream as sodium source, sugar	500 g/l	51 hrs	101 lpm	443°C	1450 $kg/m^2/d$
	Al-Limited Waste [Boehmite] with LAW stream as sodium source, sugar	400 g/l	48 hrs	85 lpm	448°C	1150 $kg/m^2/d$
	Al-Limited Waste [Boehmite] with LAW stream as sodium source, cellulose	500 g/l	50 hrs	81 lpm	442°C	1050 $kg/m^2/d$
Melt Rate Enhancement for High Aluminum HLW Glass Formulations VSL-08R1360-1 [20]	Al-Limited Waste [$Al(OH)_3$]	500 g/l	48 hrs	124 lpm	653°C	1500 $kg/m^2/d$
	Al-Limited Waste [$Al(OH)_3$]	500 g/l	48 hrs	71 lpm	571°C	1050 $kg/m^2/d$
Configuration Test 9A VSL-04R4800-4 [15]	AZ-101	400 g/l	145 hrs	64 lpm	523°C	1050 $kg/m^2/d$
Configuration Test 9B VSL-04R4800-4 [15]	AZ-101	400 g/l	72 hrs	134 lpm	551°C	1400 $kg/m^2/d$
Test 1B VSL-05R5800-1 [18]	AZ-102	340 g/l	114 hrs	65 lpm	659°C	900 $kg/m^2/d$
Test 2B VSL-05R5800-1 [18]	C-106/AY-102, High Waste Loading	340 g/l	105 hrs	90 lpm	538°C	1050 $kg/m^2/d$
MACT HLW 1 VSL-05R5830-1 [19]	C-106/AY-102, spiked	430 g/l	52 hrs	24 lpm	399°C	700 $kg/m^2/d$
MACT HLW 2A VSL-05R5830-1 [19]	C-106/AY-102, spiked	430 g/l	75 hrs	9 lpm	345°C	550 $kg/m^2/d$
MACT HLW 1-cont VSL-05R5830-1 [19]	C-106/AY-102, spiked	430 g/l	19 hrs	28 lpm	401°C	742 $kg/m^2/d$
MACT HLW 2B VSL-05R5830-1 [19]	C-106/AY-102, spiked	430 g/l	54 hrs	43 lpm	522°C	1072 $kg/m^2/d$

Table 2.1. Oxide Composition of Limiting Waste Streams.

Waste Component	Bi Limited Glass	Cr Limited Glass	Al Limited Glass	Al and Na Limited Glass
Al_2O_3	22.45%	25.53%	49.21%	43.30%
B_2O_3	0.58%	0.53%	0.39%	0.74%
CaO	1.61%	2.47%	2.21%	1.47%
Fe_2O_3	13.40%	13.13%	12.11%	5.71%
Li_2O	0.31%	0.36%	0.35%	0.15%
MgO	0.82%	0.16%	0.24%	0.44%
Na_2O	12.97%	20.09%	7.35%	25.79%
SiO_2	12.04%	10.56%	10.05%	6.22%
TiO_2	0.30%	0.01%	0.02%	0.35%
ZnO	0.31%	0.25%	0.17%	0.36%
ZrO_2	0.40%	0.11%	0.81%	0.25%
SO_3	0.91%	1.52%	0.41%	0.44%
Bi_2O_3	12.91%	7.29%	2.35%	2.35%
ThO_2	0.25%	0.04%	0.37%	0.04%
Cr_2O_3	1.00%	3.07%	1.07%	1.44%
K_2O	0.89%	0.37%	0.29%	1.34%
U_3O_8	3.48%	7.59%	7.25%	4.58%
BaO	0.02%	0.03%	0.11%	0.06%
CdO	0.00%	0.01%	0.05%	0.02%
NiO	3.71%	1.06%	0.82%	0.20%
PbO	0.48%	0.48%	0.84%	0.18%
P_2O_5	9.60%	3.34%	2.16%	4.10%
F-	1.58%	2.00%	1.37%	0.46%
Total	100.00%	100.00%	100.00%	100.00%

Table 2.2. Compositions of the Al-Limited Waste (Oxide Basis) and the HLW Waste Simulant to Produce 100 kg of Waste Oxides (20 wt% suspended solids) Using Boehmite as the Aluminum Source.

Al-Limited Waste Composition		Al-Limited HLW Waste Simulant	
Waste Oxide	**Wt%**	**Starting Materials**	**Target Weight (kg)** *
Al_2O_3	49.21	Boehmite, AlO(OH)	64.179
B_2O_3	0.39	H_3BO_3	0.757
CaO	2.21	CaO	2.441
Fe_2O_3	12.11	$Fe(OH)_3$ (13% Slurry)	107.864
Li_2O	0.35	Li_2CO_3	0.961
MgO	0.24	MgO	0.273
Na_2O	7.35	NaOH	4.867
SiO_2	10.05	SiO_2	10.989
TiO_2	0.02	TiO_2	0.022
ZnO	0.17	ZnO	0.186
ZrO_2	0.81	$Zr(OH)_4 \cdot xH_2O$	2.266
SO_3	0.41	Na_2SO_4	0.796
Bi_2O_3	2.35	Bi_2O_3	2.570
ThO_2	0.37	Th Surrogate	Not Used
Cr_2O_3	1.07	Cr_2O_3	1.182
K_2O	0.29	KNO_3	0.684
U_3O_8	7.25	U Surrogate	Not Used
BaO	0.11	$BaCO_3$	0.155
CdO	0.05	CdO	0.055
NiO	0.82	$Ni(OH)_2$	1.142
PbO	0.84	PbO	0.918
P_2O_5	2.16	$FePO_4 \cdot xH_2O$	6.211
F	1.37	NaF	3.295
Carbonate	1.20#	Na_2CO_3	0.697
Nitrite	0.50#	$NaNO_2$	0.769
Nitrate	2.00#	$NaNO_3$	2.186
Organic Carbon	0.05#	$H_2C_2O_4 \cdot 2H_2O$	0.276
—	—	Water	339.820
—	—	—	—
TOTAL	100.0	TOTAL	555.561

* Target weights adjusted for assay information of starting materials
\# Unit for volatile components is g/100 g of waste oxide
— Empty data field

Table 2.3. Composition and Properties of Aluminum Limited Waste and Glass Formulation HWI-Al-19 with 45% Waste Loading (wt%).

-	Al-Limited Waste*	Waste in Glass	Glass Forming Additives	Target Glass HWI-Al-19
Al_2O_3	53.27	23.97	-	23.97
B_2O_3	0.42	0.19	19.00	19.19
BaO	0.12	0.05	-	0.05
Bi_2O_3	2.54	1.14	-	1.14
CaO	2.39	1.08	4.50	5.58
CdO	0.05	0.02	-	0.02
Cr_2O_3	1.16	0.52		0.52
F	1.48	0.67	-	0.67
Fe_2O_3	13.11	5.90	-	5.90
K_2O	0.31	0.14	-	0.14
Li_2O	0.38	0.17	3.40	3.57
MgO	0.26	0.12	-	0.12
Na_2O	7.96	3.58	6.00	9.58
NiO	0.89	0.40	-	0.40
P_2O_5	2.34	1.05	-	1.05
PbO	0.91	0.41	-	0.41
SO_3	0.44	0.20	-	0.20
SiO_2	10.88	4.90	22.10	27.00
TiO_2	0.02	0.01	-	0.01
ZnO	0.18	0.08	-	0.08
ZrO_2	0.88	0.39	-	0.39
Sum	100.0	45.0	55.0	100.0

* Renormalized from Ref. [23] after removal of radioactive components.

Viscosity @1150°C, P			33
Conductivity @1150°C, S/cm			0.27
Crystal Content, As Melted			None
Crystal Content, 72 hr at 950°C			1.3
Crystal Content, CCC			1.9
TCLP			Pass
PCT, g/L	-	DWPF-EA	HWI-Al-19
	B	16.7	0.654
	Li	9.6	0.794
	Na	13.3	0.624

- Empty data field

Table 2.4. Composition of Melter Feed to Produce 100 kg of Target Glass HWI-Al-19 (Target Glass Yield = 500 g/L Feed) from the Al-Limited Waste Simulant Using Boehmite as the Aluminum Source.

Al-Limited Waste Simulant		Glass-Forming Additives	
Starting Materials	**Target Weight (kg)***	**Starting Materials**	**Target Weight (kg)***
Boehmite, AlO(OH)	31.263	—	—
H_3BO_3	0.341	H_3BO_3	34.089
$BaCO_3$	0.070	—	—
Bi_2O_3	1.156	—	—
CaO	1.099	$CaSiO_3$ (Wollastonite)	9.798
CdO	0.025	—	—
Cr_2O_3	0.532	—	—
NaF	1.483	—	—
$Fe(OH)_3$ (13% Slurry)	48.539	—	—
KNO_3	0.308	—	—
Li_2CO_3	0.432	Li_2CO_3	8.625
MgO	0.121	—	—
NaOH	2.190	Na_2CO_3	10.364
$Ni(OH)_2$	0.514	—	—
$FePO_4 \cdot xH_2O$	2.795	—	—
PbO	0.413	—	—
Na_2SO_4	0.358	—	—
SiO_2	4.945	SiO_2	17.276
TiO_2	0.010	—	—
ZnO	0.084	—	—
$Zr(OH)_4 \cdot xH_2O$	1.020	—	—
H_2O	97.687	—	—
Na_2CO_3	0.314	—	—
$NaNO_2$	0.346	—	—
$NaNO_3$	0.984	—	—
$H_2C_2O_4 \cdot 2H_2O$	0.119	—	—
—[2]	—	—	—
Simulant Total	197.148	Additives Total	80.152
—	—	FEED TOTAL	277.300

* Target weights adjusted for assay information of starting materials
— Empty data field

Table 2.5. Compositional Summary of Different Waste Streams and Blended Solids.

Chemical Species	AZ-101 Solids	Recycle Stream	Separation Factor*	Cs-Eluate	Tc-Eluate	Blended Solids
	FRP02	PWD01	-	CNP12	TEP12	HLP09b
	(lb/day)	(lb/day)	(fraction remained)	(lb/day)	(lb/day)	(lb/day)
Ag	4.66E+00	4.17E-21	1.00E+00	-	-	4.66E+00
Al	1.49E+03	1.77E+00	4.20E-01	5.27E-01	2.11E-02	6.26E+02
As	1.43E+00	1.21E-01	1.00E+00	-	-	1.56E+00
B	6.44E+00	3.11E+00	1.00E+00	6.60E-01	6.80E-02	1.03E+01
Ba	1.58E+01	1.64E-04	2.42E-01	1.71E-03	1.33E-04	3.82E+00
Be	2.24E-01	0.00E+00	1.00E+00	-	-	2.24E-01
Bi	1.49E+00	2.34E-04	1.00E+00	-	-	1.49E+00
Ca	4.60E+01	8.14E-02	9.88E-01	3.75E-02	2.29E-03	4.56E+01
Cd	1.54E+02	6.19E-04	8.27E-02	5.12E-03	-	1.27E+01
Ce	1.88E+01	5.88E+00	7.72E-02	-	-	1.90E+00
Cl	1.15E+00	9.42E-02	7.95E-02	-	1.28E-02	1.12E-01
Co	1.00E+00	0.00E+00	1.00E+00	-	-	1.00E+00
Carbonate	4.46E+01	2.24E+00	1.31E-01	-	-	6.12E+00
Cr	7.33E+00	2.15E-01	1.52E-01	6.31E-02	3.18E-03	1.21E+00
Cs	7.06E-01	0.00E+00	1.15E-01	2.80E-01	-	3.61E-01
Cu	5.20E+00	2.37E-44	1.00E+00	2.94E-01	-	5.50E+00
F	1.01E+02	1.27E+00	8.25E-02	-	-	8.42E+00
Fe	1.96E+03	1.41E+00	9.94E-01	1.28E-01	2.22E-02	1.95E+03
Hg	4.55E-02	1.90E-05	1.00E+00	-	-	4.55E-02
K	4.64E+01	6.82E-01	9.29E-02	1.86E+00	4.16E-02	6.28E+00
La	8.02E+01	1.80E-02	9.85E-01	-	-	7.90E+01
Li	1.45E+00	8.15E-01	1.00E+00	-	-	2.26E+00
Mg	1.46E+01	7.28E-06	1.00E+00	-	2.98E-04	1.46E+01
Mn	2.44E+01	8.20E-02	9.99E-01	1.71E-03	2.98E-04	2.45E+01
Mo	1.25E+00	0.00E+00	1.00E+00	-	-	1.25E+00
Na	1.18E+03	3.59E+02	1.15E-01	**1.71E+01**	**3.32E-01**	1.94E+02
Nd	4.88E+01	0.00E+00	1.00E+00	-	-	4.88E+01
Ni	1.11E+02	1.07E-01	9.83E-01	2.61E-01	2.65E-03	1.10E+02
Nitrite	3.04E+02	2.56E-01	7.84E-02	-	-	2.38E+01
Nitrate	2.03E+02	8.21E+02	7.77E-02	4.92E+01	-	1.29E+02
Hydroxide	1.85E+03	3.16E+01	5.97E-01	-	-	1.12E+03
Hydroxide(Bound)	4.15E+03	0.00E+00	7.68E-02	-	-	3.19E+02
Pb	7.00E+00	2.00E-02	1.00E+00	1.14E-01	-	7.14E+00
Pd	0.00E+00	1.95E-09	1.00E+00	-	-	1.95E-09
Phosphate	5.10E+00	5.01E-03	2.20E-01	-	-	1.16E+00
Pr	1.16E+01	0.00E+00	1.00E+00	-	-	1.16E+01
Rb	3.18E-01	0.00E+00	1.00E+00	-	-	3.18E-01
Rh	3.85E+00	0.00E+00	1.00E+00	-	-	3.85E+00
Sb	1.76E-01	0.00E+00	-	-	-	0.00E+00
Se	6.48E-01	0.00E+00	-	-	-	0.00E+00
Si	3.60E+01	6.46E+00	9.97E-01	4.57E-01	9.29E-02	4.29E+01
Sulfate	2.36E+02	2.46E+01	7.86E-02	-	-	2.05E+01
Sr	6.46E+00	0.00E+00	9.58E-01	-	-	6.18E+00
Ta	1.76E-01	0.00E+00	-	-	-	0.00E+00
Te	1.93E+00	0.00E+00	-	-	-	0.00E+00
Th	6.35E+00	0.00E+00	-	-	-	0.00E+00
Ti	7.84E-01	1.39E-03	1.00E+00	-	-	7.85E-01
Tl	1.76E-01	0.00E+00	-	-	-	0.00E+00
TOC	7.02E+01	0.00E+00	7.67E-02	-	-	5.39E+00
U	1.34E+02	0.00E+00	-	6.13E-01	-	6.13E-01
V	7.13E-01	0.00E+00	-	-	-	0.00E+00
Zn	2.09E+00	4.71E-01	1.00E+00	5.29E-02	2.32E-04	2.61E+00
Zr	6.42E+02	3.13E-01	9.99E-01	-	-	6.41E+02
TOTAL	**1.30E+04**	**1.26E+03**#	-	7.16E+01	5.99E-01	5.50E+03

*Analytes with undetermined separation factors are omitted. #1.28E+03 of H^+ is included. - Empty data field.

Table 2.6. Compositional Summary (Oxide Basis) of the AZ-101 HLW Simulant, Glass Additives, Target Test Glass, and the Corresponding Crucible-Melt Glass (HLW98-77).

Constituent	HLW Simulant	Glass Former (as wt% of glass)	Melter Test Target Glass	HLW98-77
Ag_2O	-	-	-	0.02%
Al_2O_3	20.64%	-	5.21%	5.20%
B_2O_3	0.58%	11.75%	11.91%	11.91%
BaO	0.07%	-	0.02%	-
CaO	1.11%	-	0.28%	0.28%
CdO	0.25%	-	0.06%	0.06%
Cs_2O	0.01%	-	0.00%	-
CuO	0.12%	-	0.03%	0.03%
F	0.15%	-	0.04%	0.04%
Fe_2O_3	48.56%	-	12.26%	12.22%
K_2O	0.13%	-	0.03%	0.03%
La_2O_3	1.62%	-	0.41%	0.41%
Li_2O	0.08%	3.50%	3.52%	3.53%
MgO	0.42%	-	0.11%	0.11%
MnO	0.67%	-	0.17%	0.17%
Na_2O	4.56%	10.50%	11.65%	11.66%
Nd_2O_3	1.22%	-	0.31%	0.31%
NiO	2.44%	-	0.62%	0.61%
PbO	0.13%	-	0.03%	0.03%
SiO_2	1.61%	47.00%	47.40%	47.45%
SO_3	0.30%	-	0.08%	0.08%
SrO	0.13%	-	0.03%	0.03%
ZnO	0.06%	2.00%	2.02%	2.02%
ZrO_2	15.12%	-	3.82%	3.81%
TOTAL	100.00%	74.75%	100.00%	100.00%
Volatiles (g/100 g oxide)	-	-	-	-
Carbonate	0.106	-	-	-
Nitrite	0.414	-	-	-
Nitrate	2.237	-	-	-
TOC	0.093	-	-	-

- Empty data field.

Table 2.7. Composition of Melter Feed to Produce 1 Metric Ton of Target Glass from AZ-101 HLW Simulant (22.6 wt% total solids).

AZ-101 HLW Simulant		Glass-Forming Additives	
Starting Materials	**Target Weight (kg)**	**Starting Materials**	**Target Weight (kg)**
$Al(OH)_3$	83.61	-	-
H_3BO_3	2.63	$Na_2B_4O_7 \cdot 10H_2O$	325.08
$Ba(OH)_2 \cdot 8H_2O$	0.37	-	-
$Ca(OH)_2$	3.78	-	-
CdO	0.64	-	-
CsOH (solution)	0.05	-	-
CuO	0.31	-	-
NaF	0.84	-	-
$Fe(OH)_3$ (13% slurry)	1257.25	-	-
KNO_3	0.71	-	-
$La(OH)_3 \cdot 3H_2O$	6.15	-	-
Li_2CO_3	0.51	Li_2CO_3	88.78
$Mg(OH)_2$	1.55	-	-
MnO_2	2.09	-	-
NaOH	9.24	Na_2CO_3	91.03
Nd_2O_3	3.11	-	-
$Ni(OH)_2$	7.89	-	-
PbO	0.33	-	-
SiO_2	4.08	SiO_2	474.75
Na_2SO_4	1.36	-	
$Sr(OH)_2 \cdot 8H_2O$	0.86	-	
ZnO	0.15	ZnO	20.20
$Zr(OH)_4 \cdot xH_2O$	98.27	-	-
$NaNO_2$	1.61	-	-
$NaNO_3$	7.19	-	-
$H_2C_2O_4 \cdot 2H_2O$	1.24	-	-
Water	60.00	-	-
TOTAL	1555.84	TOTAL	999.84
-	-	FEED TOTAL	2555.67

- Empty data field.

Table 3.1. Summary of Test Conditions and Results for Tests 1 and 2.

HLW AZ-101 Waste, HLW98-77 Glass Formulation						
Test		1	2a	2b	2c	2d
Time	Feed Start	1/30/12 11:33	1/31/2012 12:34	2/1/2012 6:03	2/1/2012 18:00	2/2/2012 10:27
	Feed End	1/31/2012 12:26	2/1/2012 6:03	2/1/2012 18:00	2/2/2012 10:27	2/3/2012 11:10
	Interval (hr)	24.9 (19.9)	17.5 (16.2)	12 (7.9)	16.5 (9.9)	24.7
Water Feeding for Cold Cap (hr)		1	0	0	0	0.0
Slurry Feeding (hr)		24 (19.9)	17.5 (16.2)	11.9 (7.8)	11 (9.9)	24.6
Feed Interruptions (hr)		0	0	0.1	5.5	0.2
Target Plenum Temperature (°C)		525	475	425	375	NA
Average Plenum Temperature at 2 Control Locations (°C)		529 (512)	476 (473)	422 (424)	464 (389)	418
Average Plenum Temperature 6 Non-Control Locations (°C)		528 (507)	458 (455)	401 (403)	437 (358)	412
Average Plenum Temperature all 8 locations (°C)		528 (508)	463 (459)	406 (408)	443 (366)	413
Bubbler Set Point (lpm)		64	64	64	64	NA
Average Total Bubbling (lpm)		63 (65)	65 (65)	65 (65)	46 (65)	87
Average Glass Temperature (°C)		1152 (1153)	1151 (1151)	1151 (1151)	1148 (1151)	1149
Feed	Used (kg)	2358 (1796)	1636 (1528)	1299 (843)	1293 (1207)	3994
	Average Rate (kg/hr)	95 (90)	94 (95)	109 (107)	79 (122)	162
Glass Produced	From Feed (kg)	741 (564)	514 (480)	408 (265)	406 (379)	1254
	Average Rate (kg/m2/day)	595 (567)	588 (594)	683 (673)	494 (767)	1015

Note: Values in ( ) represent time periods within tests of steady state processing. Tests without values in () are considered steady state over the entire duration.

Table 3.1. Summary of Test Conditions and Results for Tests 1 and 2 (Continued).

HLW AZ-101 Waste, HLW98-77 Glass Formulation				
Test		2e	2f	2g
Time	Feed Start	2/3/2012 11:10	2/3/2012 16:00	2/3/2012 19:02
	Feed End	2/3/2012 16:00	2/3/2012 19:02	2/3/2012 22:02
	Interval (hr)	4.8	3.0	3.0
Water Feeding for Cold Cap (hr)		0.0	0.0	0.0
Slurry Feeding (hr)		4.8	3.0	3.0
Feed Interruptions (hr)		0.0	0.0	0.0
Target Plenum Temperature (°C)		400	375	350
Average Plenum Temperature at 2 Control Locations(°C)		410	396	387
Average Plenum Temperature 6 Non-Control Locations (°C)		384	374	351
Average Plenum Temperature all 8 locations (°C)		390	380	360
Bubbler Set Point (lpm)		80	80	80
Average Total Bubbling (lpm)		82	82	82
Average Glass Temperature (°C)		1150	1149	1150
Feed	Used (kg)	825	525	648
	Average Rate (kg/hr)	171	173	216
Glass Produced	From Feed (kg)	260	165	203
	Average Rate (kg/m2/day)	1083	1086	1356

Table 3.2. Summary of Test Conditions and Results for Tests 3 and 4.

HLW High Aluminum Waste, HWI-Al-19 Glass Formulation			
Test		3	4
Time	Feed Start	2/7/12 23:47	2/10/12 19:00
	Feed End	2/10/12 19:00	2/11/12 7:00
	Interval (hr)	67.2 (37.2)	12
Water Feeding for Cold Cap (hr)		2	0
Slurry Feeding (hr)		61.2 (37.2)	12
Feed Interruptions (hr)		4.6	0
Target Plenum Temperature (°C)		450	350
Average Plenum Temperature at 2 control locations(°C)		475 (451)	403
Average Plenum Temperature 6 non-control locations (°C)		447 (420)	350
Average Plenum Temperature all 8 locations (°C)		454 (428)	363
Bubbler Set Point (lpm)		85	85
Average Total Bubbling (lpm)		81 (87)	87
Average Glass Temperature (°C)		1146 (1150)	1149
Feed	Used (kg)	11312 (6799)	2509
	Average Rate (kg/hr)	168 (183)	209
Glass Produced	From Feed (kg)	3552 (2135)	788
	Average Rate (kg/m2/day)	1057 (1149)	1313

Note: Values in ( ) represent time periods within tests of steady state processing. Tests without values in () are considered steady state over the entire duration.

Table 3.3. Summary of Operational Events.

Test	Date	Time	Run Time (hours)	Run time note
1&2	1/30/2012	6:25	-	Paused feed tank mixer for mass check. Tank mass is 3855.5 kg
		11:25	-	Transferred feed to mix tank. Tank mass at the start is 0.0 kg, tank mass at the end is 3997.5 kg. Net mass of feed transferred to mix tank is 3997.5 kg.
		11:33	0	Started water feeding at 1 lpm. Average plenum temperature is targeted to be 525 °C.
		11:50	0.28	Water flow rate was raised to 2.0 lpm.
		12:00	0.45	Reduced Bubbling from 10 lpm per lance to 3 lpm per lance to homogenize melt pool temperatures and aid startup
		12:03	0.5	Started SBS booster pump.
		12:11	0.63	Water flow rate was raised to 3 lpm.
		12:26	0.88	Reduced water flow rate from 3.0 to 0.5 lpm.
		12:26	0.88	Commenced feeding iron limited AZ-101 feed.
		12:37	1.07	Secured water feeding.
		13:10	1.62	Increased bubbling to total of 9 lpm in preparation for test
		13:34	2.02	Set bubbling at 64 lpm total
		13:44	2.18	WESP dilution air blower was turned on to 25 SCFM/each, adjusted blower 801 from 17 to 23 Hz
		14:00	2.45	Increased feed rate by reducing T10 setting from 43 to 41 seconds.
		16:15	4.7	Secured SBS booster pump.
		16:24	4.85	Reduced feed rate slightly by increasing T10 setting from 41 to 43 seconds.
		17:19	5.77	Increased feed rate by reducing T10 setting from 43 to 42 seconds.
		17:42	6.15	SBS temperature could not be reduced. Turned on SBS booster pump.
		19:41	8.13	Collected a feed sample.
		20:14	8.68	Since plenum temperatures are still dropping, feed rate was decreased by increasing T10 setting from 50 to 53 seconds.
		21:04	9.52	Reduced feed rate by increasing T10 setting from 65 to 70 seconds
		22:45	11.2	Secured SBS booster pump.

Table 3.3. Summary of Operational Events (Continued).

Test	Date	Time	Run Time (hours)	Run time note
1&2	1/31/2012	0:03	12.5	Performing film cooler rinse.
		1:15	13.7	Increasing feed rate.
		2:01	14.47	Slightly reducing the feed rate by setting T10 setting from 75 to 80 seconds.
		3:01	15.47	Reduced feed rate by increasing T10 setting from 90 to 110 seconds
		4:04	16.52	Increased feed rate by reducing T10 setting from 110 to 105 seconds.
		4:20	16.78	Increased feed rate by reducing T10 setting from 105 to 100 seconds.
		5:01	17.47	Increased feed rate by reducing T10 setting from 100 to 97 seconds.
		5:44	18.18	Increased feed rate by reducing T10 setting from 92 to 85 seconds.
		7:04	19.52	Increased feed rate by reducing T10 setting from 80 to 78 seconds.
		7:25	19.87	Increased feed rate by reducing T10 setting from 78 to 76 seconds.
		7:56	20.38	Decreased feed rate by increasing T10 setting from 76 to 78 seconds.
		8:08	20.58	Decreased feed rate by increasing T10 setting from 78 to 80 seconds.
		8:15	20.70	Decreased feed rate by increasing T10 setting from 80 to 82 seconds.
		8:56	21.38	Decreased feed rate by increasing T10 setting from 82 to 84 seconds.
		9:03	21.50	Decreased feed rate by increasing T10 setting from 84 to 86 seconds.
		9:34	22.02	Decreased feed rate by increasing T10 setting from 86 to 88 seconds.
		9:54	22.35	Decreased feed rate by increasing T10 setting from 88 to 90 seconds.
		10:00	22.45	It is suspected that the level detector is damaged.
		11:20	23.78	Performed WESP deluge.
		12:12	24.65	Terminating the first stage of testing at 24 hours.
		12:26	24.88	Paused feeding to collect feed sample.
		12:34	25.02	Resumed normal feeding. The new average plenum temperature is targeted to be 475°C
1&2	1/31/2012	12:34	25.02	Decreased feed rate by increasing T10 setting from 92 to 80 seconds.
		12:35	25.03	Feed transferred from mix tank to feed tank. Net mass transferred is 1703.0 kg. Dilution water mass is 639.0 kg. Total mass transferred is 2342.0 kg.
		13:26	25.88	EOG tripped, started to investigate.

Table 3.3. Summary of Operational Events (Continued).

Test	Date	Time	Run Time (hours)	Run time note
		14:00	26.45	Performing film cooler rinse. From now on at every 12 hours the film cooler will be rinsed. Missed the film cooler rinse at 24 hours of operations.
		14:21	26.80	Decreased feed rate by increasing T10 from 65 to 68 seconds.
		14:37	27.07	Decreased feed rate by increasing T10 setting from 68 to 70 seconds.
		15:23	27.83	Reduced lance # 2 bubbler flow rate from 16 to 15.3 lpm
		15:36	28.05	Melter switched to EOG due to off gas sampling, transition line port was opened.
		16:34	29.02	Increased feed rate by decreasing T10 setting from 85 to 83 seconds.
		16:36	29.05	Due to off-gas sampling, melter pressure spiked. EOG did not trip.
		16:49	29.27	Decreased feed rate by increasing T10 setting from 83 to 84 seconds.
		17:43	30.17	Lance 2 bubbler flow rate was increased from 15.2 to16 lpm
		18:22	30.82	Transferred feed to mix tank. Tank mass at the start is 2274.5 kg, tank mass at the end is 4138.5 kg. Net mass of feed transferred to mix tank is 1864.0 kg. Reference is VSL-1785-10 page 90.
		21:19	33.77	Increased feed rate by decreasing T10 setting from 80 to 79 seconds.
		22:47	35.23	Increased feed rate by decreasing T10 setting from 78 to 75 seconds.
		23:31	35.97	Increased feed rate by decreasing T10 setting from 70 to 65 seconds.
	2/1/2012	0:01	36.47	Decreased feed rate by increasing T10 setting from 65 to 70 seconds.
		0:15	36.7	Performing film cooler rinse.
		0:45	37.20	Decreased feed rate by increasing T10 setting from 65 to 70 seconds.
1&2	2/1/2012	1:03	37.50	Increased feed rate by decreasing T10 setting from 70 to 65 seconds.
		1:15	37.70	Decreased feed rate by increasing T10 setting from 65 to 70 seconds.
		3:01	39.47	Increased feed rate by decreasing T10 setting from 70 to 65 seconds.
		3:30	39.95	Increased feed rate by decreasing T10 setting from 65 to 63 seconds.
		3:45	40.20	Increased feed rate by decreasing T10 setting from 63 to 60 seconds.
		4:48	41.25	Increased feed rate by decreasing T10 setting from 60 to 58 seconds.
		5:20	41.78	Decreased feed rate by increasing T10 from 58 to 63 seconds
		5:30	41.95	Decreased feed rate by increasing T10 setting from 63 to 68 seconds.

Table 3.3. Summary of Operational Events (Continued).

Test	Date	Time	Run Time (hours)	Run time note
		6:03	42.5	Changed plenum target temperature from 475°C to 425°C.
		6:03	42.50	Increased feed rate by decreasing T10 setting from 68 to 58 seconds.
		6:32	42.98	Increased feed rate by decreasing T10 setting from 58 to 54 seconds.
		9:36	46.05	Decreased feed rate by increasing T10 setting from 56 to 58 seconds.
		11:05	47.53	Decreased feed rate by increasing T10 setting from 58 to 59 seconds.
		12:01	48.47	Paused feeding to collect a feed sample. Resumed feeding in 4 minutes.
		12:06	48.55	Feed transferred from mix tank to feed tank. Net mass transferred is 1699.5 kg. Dilution water mass is 640.0 kg. Total mass transferred is 2339.5 kg.
		12:32	48.98	Increased feed rate by decreasing T10 setting from 59 to 58 seconds.
		12:40	49.12	Performing film cooler rinse.
		15:09	51.60	Decreased feed rate by increasing T10 setting from 58 to 59 seconds.
		15:19	51.77	Decreased feed rate by increasing T10 setting from 59 to 60 seconds.
		18:00	54.45	Average plenum temperature target changed to 375°C.
		18:00	54.45	Increased feed rate by decreasing T10 setting from 61 to 59 seconds.
		18:19	54.77	Increased feed rate by decreasing T10 setting from 59 to 58 seconds.
		19:04	55.52	Increased feed rate by decreasing T10 from 57 to 55 seconds.
		20:00	56.45	Collected a feed sample.
		20:36	57.05	Increased feed rate by decreasing T10 setting from 50 to 48 seconds.
		21:19	57.77	Increased feed rate by decreasing T10 setting from 48 to 46 seconds.
	2/1/2012	22:04	58.52	Increased feed rate by decreasing T10 setting from 44 to 42 seconds.
1&2		22:36	59.05	Performing film cooler rinse.
		22:45	59.20	Increased feed rate by decreasing T10 setting from 42 to 40 seconds.
		23:00	59.45	Increased feed rate by decreasing T10 setting from 40 to 38 seconds.
		23:37	60.07	Increased feed rate by decreasing T10 setting from 38 to 35 seconds.
	2/2/2012	1:04	61.52	Decreased feed rate by increasing T10 setting from 38 to 39 seconds.
		1:14	61.68	Decreased feed rate by increasing T10 setting from 39 to 41 seconds.

Table 3.3. Summary of Operational Events (Continued).

Test	Date	Time	Run Time (hours)	Run time note
		1:21	61.80	Decreased feed rate by increasing T10 setting from 41 to 42 seconds.
		1:37	62.07	Initiated complete WESP blow-down for deluge.
		1:38	62.08	Decreased feed rate by increasing T10 setting from 42 to 45 seconds.
		1:45	62.20	Decreased feed rate by increasing T10 setting from 45 to 50 seconds.
		2:42	63.15	Decreased feed rate by increasing T10 setting from 55 to 60 seconds.
		3:07	63.57	Decreased feed rate by increasing T10 setting from 60 to 65 seconds.
		3:26	63.88	Message that data is being written to local drive has appeared, attempted to reset without any success.
		3:46	64.22	Able to clear and set the computer data recording to the network.
		3:54	64.35	Increased feed rate by decreasing T10 setting from 55 to 45 seconds.
		4:08	64.58	Restarted labVIEW.
1&2	2/2/2012	4:21	64.8	Feed system is not working due to labVIEW error. Tried to preserve cold cap until feeding can be resumed by reducing lance bubbler to 10 lpm each.
		4:27	64.90	Reduced bubbling from 10 lpm per lance to 4 lpm per lance to preserve cold cap.
		4:36	65.05	After 15 minutes of feed interruption, feeding has resumed.
		4:45	65.2	Unable to switch from feed density to ADS feed control screen to make changes to feed rate.
		4:51	65.3	Stopped feeding due to inability to make adjustments to the feed system. labVIEW is displaying error messages, unable to solve the problem via phone. Reduced bubbling from 4 lpm/lance to 2 lpm/lance.
		9:07	69.57	Trouble shooting WESP outlet flow, found absolute pressure gauge is not connected properly. After repair flow reduced from 310 scfm to 290 scfm.
		10:03	70.5	labView issues resolved. Started ADS pump, system was plugged, but now normal feeding has resumed.
		10:15	70.70	Increased bubbling to 16 lpm per lance
		10:27	70.9	Terminating Test 2c. The new target will be the production rate of 1050 kg/m^2/day with bubbling as needed and visual observation controlling melter operations.
		10:31	70.97	Increased bubbling to 32 lpm per lance and reduced the T10 setting from 45 to 35 seconds
		10:45	71.20	Increased bubbling from 32 to 40 lpm/lance
		11:00	71.45	Decreased T10 from 35 to 30 seconds.
		11:14	71.68	Performed WESP deluge.
		11:18	71.75	Decreased bubbling from 40 to 34 lpm/lance
		11:33	72.00	Decreased T10 from 30 to 27 seconds. Increased bubbling back to 40 lpm/lance

Table 3.3. Summary of Operational Events (Continued).

Test	Date	Time	Run Time (hours)	Run time note
		12:46	73.22	Increased bubbling from 40 to 45 lpm per lance
		12:57	73.4	Started SBS booster pump.
		12:59	73.43	Paused feeding to take a feed sample. After 4 minutes resumed feeding.
		13:05	73.53	Feed transferred from mix tank to feed tank. Net mass transferred is 1700.0 kg. Dilution water mass is 639.0 kg. Total mass transferred is 2339.0 kg.
		14:22	74.82	Decreased feed rate by increasing T10 setting from 27 to 32 seconds.
1&2	2/2/2012	15:19	75.77	Melter pressure spike due to large amount of liquid spilling into the west side opening. Increased bubbling on lance 2 from 45 to 50 lpm
		15:34	76.02	Reduced bubbling on lance 2 from 50 to 45 lpm
		15:44	76.18	Performing film cooler rinse twice.
		16:04	76.52	Increased feed rate by decreasing T10 setting from 32 to 31 seconds.
		16:19	76.77	Increased feed rate by decreasing T10 setting from 31 to 29 seconds.
		17:49	78.27	Increased bubbling on lance 2 from 45 to 50 lpm
		18:40	79.12	Transferred feed to mix tank. Tank mass at the start is 708.0 kg. Tank mass at the end is 4094.5 kg. Net mass of feed transferred to mix tank is 3386.5 kg.
		20:04	80.52	Decreased bubbling on lance 1A and 1B from 25 to 22 lpm
		21:19	81.77	Reduced bubbling on lances 1a, 1b, 2a, and 2b from 20 to 19 lpm each
		22:19	82.77	Increased feed rate by decreasing T10 setting from 29 to 26 seconds.
		22:40	83.12	Pulled the screen out of SBS blow down line for cleaning. It was partially occluded.
	2/3/2012	3:00	87.45	Paused feeding to take a feed sample. After 6 minutes resumed feeding.
		3:08	87.58	Feed transferred from mix tank to feed tank. Net mass of feed transferred is 1700.5 kg. Dilution water mass is 639.0 kg. Total mass transferred is 2339.5 kg.
		3:53	88.33	Performing film cooler rinse.
		8:20	92.78	Increased bubbling on lances 1a, 1b, 2a, and 2b from 25 to 30 lpm each
		9:03	93.50	Decreased bubbling from 60 to 50 lpm per lance
		9:12	93.65	Decreased bubbling from 50 to 45 lpm per lance
		9:32	93.98	Decreased bubbling from 45 to 43 lpm per lance
		9:40	94.12	Decreased bubbling from 43 to 40 lpm per lance
		9:53	94.33	Increased bubbling from 40 to 42 lpm per lance
		10:25	94.87	Decreased bubbling from 43 to 40 lpm per lance
		11:10	95.62	Bubbling to stay at 80 lpm total with glass production rate at 1050 kg/m2/day for 1 hour.
		12:07	96.57	Performed WESP deluge.

Table 3.3. Summary of Operational Events (Continued).

Test	Date	Time	Run Time (hours)	Run time note
1&2	2/3/2012	13:00	97.45	Shifted from production control to average plenum temperature control. The target average plenum temperature is 400°C.
		16:00	100.45	The new target average plenum temperature will be 375 °C for the next 3 hours.
		16:08	100.58	Performing film cooler rinse.
		16:13	100.67	Melter pressure spiked due to off-gas testing.
		17:10	101.62	Off-gas testing completed. Pressure spiked when sampling tool was removed.
		17:12	101.65	Feed transferred from mix tank to feed tank. Net mass of feed transferred is 1723.5 kg. Dilution water mass is 649.0 kg. Total mass transferred is 2372.5 kg.
		18:30	102.95	Due to the shots being erratic, the timing on T6 was changed from 5 to 6 seconds, T7 from 20 to 22 seconds and T10 from 22 to 19 seconds
		19:02	103.45	The target average plenum temperature is now 350°C.
		22:02	106.48	Test ended. Feeding stopped.
		22:30	106.95	Remaining feed in the mix tank transferred to the feed tank. Starting mass is 674.0 kg and ending mass is 157.5 kg residual. The net feed mass transferred to feed tank is 490.25 kg. Dilution water mass is 253.0 kg. Feed tank mass is 3649.0 kg.
	2/4/2012	1:15	109.7	Completing DM1200 ADS feed system shutdown.
		2:20	110.78	Removed level detector and feed tube
		2:37	111.07	Reducing bubbling from 40 to 32 lpm per lance

Table 3.3. Summary of Operational Events (Continued).

Test	Date	Time	Run Time (hours)	Run Time Note
3&4	2/6/2012	20:40	NA	Transferred feed to mix tank. Tank mass at the start is 150.0 kg, tank mass at the end is 3808.5 kg. Net mass of feed transferred to mix tank is 3658.5 kg, HWI AL-19.
		21:02	NA	Took a feed sample.
	2/7/2012	19:44	NA	Feed transferred from mix tank to feed tank. Total net feed mass transferred is 3802.0 kg. Net mass transferred includes 135.0 kg water and 13.0 kg boehmite.
		20:00	NA	Started feeding water at 1.0 lpm
		20:20	NA	Water flow rate was raised to 2.0 lpm.
		20:40	NA	Water flow rate was raised to 3.0 lpm.
		20:56	NA	Turned on SBS booster pump
		21:00	NA	Stopped feeding water and started feeding slurry, HWI-AL-19 with no visual feedback.
		21:02	NA	ADS system may have plugged up. It needs to be investigated.
		21:20	NA	Started feeding water at 1 lpm. ADS system is not working.
		21:30	NA	Switched ADS system to recirculation to see if the system is clogged. It only works when toggle switch is turned on or off.
		21:40	NA	Rebooted computer system. System seems to work in recirculation with longer T7 time. The feed is very thick and hard to move.
		21:49	NA	Increased water flow rate to 2.0 lpm. It will continue at this rate to bring plenum temperature down before starting to feed slurry.
		22:09	NA	Water flow rate was raised to 3.0 lpm.
		22:29	NA	Reduced water flow rate to 0.5 lpm. Started feeding slurry.
		22:33	NA	Feed tube seems to be clogged.
		23:47	0	Feeding water with AOD system at 1.0 lpm. ADS system taken off line. AOD feed tube installed due to inability to feed with ADS. Water feeding commenced at this time.
	2/8/2012	0:02	0.25	Increased water flow rate to 1.5 lpm.
		0:12	0.42	Increased water flow rate to 2.0 lpm.
		0:28	0.68	Increased water flow rate to 2.5 lpm.
		1:03	1.27	Increased bubbling from 4 to 8 lpm per lance, to target 84 lpm
3&4	2/8/2012	1:14	1.45	Resumed feeding water while feeding slurry to help bring plenum to target temperature.
		1:19	1.53	Increased bubbling to 14 lpm per lance (total 28 lpm)
		1:31	1.73	Secured water feeding.
		1:35	1.80	Increased bubbling to 15 lpm per lance; now 60 lpm total
		1:40	1.88	Feed rate significantly low, T4 from 58 to 52 seconds
		1:45	1.97	Increased bubbling to 16 lpm per lance; now 64 lpm total
		1:50	2.05	T4 from 52 to 50 seconds
		1:55	2.13	Increased bubbling to 18 lpm per lance
		1:59	2.20	Increased bubbling to 20 lpm per lance
		2:01	2.23	T4 from 48 to 40 seconds, T2 from 3 to 5 seconds
		2:05	2.30	Bubbling from 20 to 21 lpm per lance and will remain there for the entire 12 hour period
		2:09	2.37	T4 from 40 to 35 seconds

Table 3.3. Summary of Operational Events (Continued).

Test	Date	Time	Run Time (hours)	Run Time Note
		2:20	2.55	T4 from 35 to 30 seconds
		2:30	2.72	T1 from 1 to 1.5 seconds T4 from 30 to 28 seconds
		3:02	3.25	T4 from 40 to 50 seconds
		3:45	3.97	Stopped feeding. Bubbling reduced to 3 lpm per lance, T4 to 28 from 49 seconds.
		4:19	4.53	Resuming feeding after re-routing power to all VI monitors to another power strip. Total downtime 34 minutes.
		4:35	4.80	Bubbling back up to 84 lpm total
		4:51	5.07	T4 to 49 seconds
		6:02	6.25	T4 From 47 to 44 seconds
		6:35	6.80	Found on the feed system that air purge was switched onto the wrong pinch valve. The line up is now correct; Air and water purge are on the "A" line while feed is on "B". As a result, T1 was changed from 1.5 to 1 seconds and T2 from 5.0 to 3.0 seconds
		9:31	9.73	Paused feeding for 3 minutes to collect a feed sample
		10:00	10.22	T4 From 41 to 39 seconds
		10:05	10.30	Electric breaker tripped. Will not be reset due to burning smell. Secured feeding. Reduced bubbling from 42 to 22 lpm per lance (44 total)
		10:10	10.38	Reduced bubbling from 22 to 4 lpm per lance
		11:30	11.72	Broken breaker replaced. Auto control via love controller is not working.
		11:53	12.10	Shifted to auto control again.
		12:05	12.30	Not feeding at this time.
3&4	2/8/2012	13:27	13.67	Adjusted all feed control valves. Feed appears to be bleeding through during the paused status.
		13:55	14.13	Resumed feeding. Started with 2 flush cycles to clear feed tubing.
		13:58	14.18	Increased bubbling from 4 to 22 lpm per lance
		14:02	14.25	Cold cap opened up fast and melter pressure spiked during feed shot to slightly positive. Reduced bubbling from 22 to 10 lpm per lance
		14:15	14.47	Increased bubbling from 10 to 20 lpm per lance
		14:27	14.67	Performed WESP deluge.
		14:35	14.80	Increased bubbling from 20 to 30 lpm per lance
		14:40	14.88	Increased bubbling from 30 to 42.5 lpm per lance
		14:50	15.05	T4 from 39 to 41 seconds
		14:57	15.17	Transferred feed to mix tank. Tank mass at the start is 162.0 kg, tank mass at the end is 3834.0 kg. Net mass of feed transferred to mix tank is 3672.0 kg.
		15:31	15.73	Added water to feed tank using 167 g water to 1 kg of feed. For 1940 kg of feed 333.0 kg water used.
		15:34	15.78	Increased T4 from 41 to 45 seconds
		15:42	15.92	Increased T4 from 45 to 50 seconds
		15:46	15.98	Increased T4 from 50 to 60 seconds
		16:19	16.53	Decreased T4 from 60 to 58 seconds

Table 3.3. Summary of Operational Events (Continued).

Test	Date	Time	Run Time (hours)	Run Time Note
		17:49	18.03	Decreased T4 from 57 to 55 seconds
		18:34	18.78	Decreased T4 from 55 to 53 seconds
		22:20	22.55	Feed transferred from mix tank to feed tank. Net feed mass transferred is 2401.0 kg. Dilution water mass is 415.0 kg. Total mass transferred is 2816.0 kg.
		22:48	23.02	Increased T4 from 55 to 57 seconds
		23:00	23.22	Increased T4 from 57 to 59 seconds
		23:45	23.97	Decreased T4 from 59 to 57 seconds
	2/9/2012	0:42	24.92	Increased T4 from 57 to 58 seconds
		0:55	25.13	Increased T4 from 58 to 59 seconds
		1:47	26.00	Decreased T4 from 59 to 57 seconds
		1:51	26.07	Performed manual water flush across the feed tube.
		2:23	26.60	Increased T4 from 57 to 59 seconds
		3:30	27.72	Changed control set point from -2.75"WC to -3.0"WC.
3&4	2/9/2012	4:44	28.95	Off gas low alarm sounded. Sub-panel is showing 352 scfm while on off-gas labVIEW it is only 335 scfm. This disparity has caused low (flow too high) gas flow alarm. Switched control air set point back to -2.75"WC.
		5:10	29.38	Decreased T4 from 55 to 53 seconds
		5:21	29.57	Decreased T4 from 53 to 50 seconds
		5:30	29.72	Decreased T4 from 50 to 45 seconds
		5:35	29.80	Performed manual water flush across the feed tube.
		6:37	30.83	Decreased T1 from 0.9 to 0.85 seconds. Increased T4 from 47 to 50 seconds
		9:05	33.30	Decreased T4 from 53 to 52 seconds
		10:50	35.05	Decreased T4 from 52 to 50 seconds
		10:55	35.13	Performed WESP deluge.
		13:04	37.28	Paused feeding for 3 minutes to collect feed sample.
		13:10	37.38	Feed transferred from mix tank to feed tank. Net mass of feed transferred is 2400.5 kg. Dilution water mass is 415.0 kg. Total mass transferred is 2815.5 kg.
		15:15	39.47	Melter pressure spiked due to off gas sampling.
		15:49	40.03	Decreased T4 from 51 to 50 seconds
		16:14	40.45	Melter pressure spiked due to off gas sampling.
		16:57	41.17	Decreased cycle time from 50 to 49 seconds
		17:34	41.78	Decreased T4 from 49 to 48 seconds
		17:49	42.03	Changed T1 from 0.85 to 0.90 seconds
		18:42	42.92	Melter pressure spiked due to a collapsed cold cap on the east side of the melter.
		19:05	43.30	Increased cycle time from 49 to 51 seconds
		19:19	43.53	Changed T1 from 0.90 to 0.85 seconds
		22:20	46.55	Transferred feed to mix tank. Tank mass at the start is 1149.0 kg, tank mass at the end is 3924.0 kg. Net feed transferred to mix tank is 2775.0 kg.
		23:01	47.23	Decreased T4 from 51 to 49 seconds
		23:10	47.38	Decreased T4 from 49 to 46 seconds

Table 3.3. Summary of Operational Events (Continued).

Test	Date	Time	Run Time (hours)	Run Time Note
		23:15	47.47	Increased T4 from 46 to 51seconds
		23:25	47.63	Increased T4 from 51 to 53seconds
	2/10/2012	1:05	49.30	Increased T4 from 55 to 57seconds
		1:18	49.52	Increased T4 from 57 to 59 seconds
		4:38	52.85	Paused feeding for 4 minutes to collect feed sample.
		4:45	52.97	Feed transferred from mix tank to feed tank. Net mass of feed transferred is 2401.0 kg. Dilution water mass is 415.0 kg. Total mass transferred is 2816.0 kg.
3&4	2/10/2012	4:53	53.10	Decreased T4 from 49 to 47 seconds
		4:59	53.20	Decreased T4 from 47 to 46 seconds
		5:10	53.38	Decreased T4 from 46 to 44 seconds
		5:46	53.98	Increased T4 from 41 to 44 seconds
		5:54	54.12	Increased T4 from 44 to 46 seconds
		5:59	54.20	Increased T4 from 46 to 50 seconds
		6:35	54.80	Increased T4 from 50 to 51 seconds
		7:00	55.22	Decreased T4 from 51 to 49 seconds
		7:20	55.55	Decreased T4 from 49 to 47 seconds
		8:37	56.83	Decreased T4 from 47 to 46 seconds
		9:35	57.80	Decreased T4 from 46 to 45 seconds
		11:10	59.38	Increased T4 from 45 to 46 seconds
		11:46	59.98	Performed WESP blow down and deluge.
		15:17	63.50	Melter pressure spiked due to off gas sampling.
		16:17	64.50	Melter pressure spiked due to off gas sampling.
		17:19	65.53	Decreased T4 from 43 to 40 seconds
		18:03	66.27	Feed transferred from mix tank to feed tank. Net mass of feed transferred is 1332.5 kg. Dilution water mass is 263.0 kg. Total mass transferred is 1595.5 kg. Reference is VSL-1909-12 page 32.
		18:46	66.98	Increased cycle time from 40 to 41 seconds
		19:00	67.22	As per Test plan, lowering plenum temperature to 350 °C. At this time average plenum temperature is 348 °C. We will continue with current conditions.
		19:12	67.42	Decreased cycle time from 43 to 42 seconds
		19:27	67.67	Decreased cycle time from 42 to 41 seconds
		19:50	68.05	Decreased cycle time from 41 to 40 seconds
		20:09	68.37	Decreased cycle time from 40 to 38 seconds
		20:22	68.58	Decreased cycle time from 38 to 36 seconds
		21:43	69.93	Increased cycle time from 36 to 37 seconds
		21:49	70.03	Performing film cooler rinse 3 times.
		22:06	70.32	Increased cycle time from 37 to 39 seconds
	2/11/2012	0:04	72.28	Increased T4 from 39 to 41 seconds
		0:15	72.47	Increased T4 from 41 to 43 seconds
		2:03	74.27	Decreased T4 from 43 to 41 seconds
		2:33	74.77	Decreased T4 from 41 to 39 seconds
		3:45	75.97	Decreased T4 from 39 to 35 seconds
		4:02	76.25	Decreased T4 from 35 to 32 seconds

Table 3.3. Summary of Operational Events (Continued).

Test	Date	Time	Run Time (hours)	Run Time Note
		4:57	77.17	Melter pressure spiked due to collapsed ridge east side of the melter.
3&4	2/11/2012	5:42	77.92	Decreased T4 from 32 to 30 seconds
		5:55	78.13	Decreased T4 from 30 to 28 seconds
		6:30	78.72	Decreased T4 from 24 to 18 seconds
		7:00	79.22	End of Test. Stopped feeding. Ending feed mass is 141.0 kg.
		8:55	81.13	Feed removal as follows: Starting feed mass is 154.5 kg, ending feed mass is 149.0 kg. Net mass of feed removed is 5.5 kg. Feed sample taken.
		9:15	81.47	Cold cap is gone. Started melter and off gas shut downs.
		13:00	85.22	Melter and off gas shut down are complete.

Table 3.4. Operator Observations of Cold Cap.

Tests	Date	Time	Run Time (Hours)	Cold Cap Observations
1&2	1/30/2012	11:33	0	Start water feeding at 1 liter water/min.
		11:50	0.28	Water flow rate was raised to 2.0 liter/min.
		12:03	0.5	Started SBS booster pump.
		12:11	0.63	Water flow rate was raised to 3 liter/min.
		12:26	0.88	Reduced water flow rate from 3.0 to 0.5 liter/min. Commenced feeding iron limited AZ-101 feed.
		12:37	1.07	~70%, secured water feeding.
		12:49	1.27	~70%.
		13:04	1.52	~75%. Still have boiling feeding on top of glass.
		13:19	1.77	~85%, more bubbling of feed on top of west and east sides of the melter.
		13:34	2.02	~90%, feed on the melter glass surface which is flat and firm.
		13:49	2.27	~90%, flat with boiling feed on top. East and west sides are still visible.
		14:04	2.52	CC observations are same as before.
		14:19	2.77	90-95%, flat and firm with boiling feed on top.
		14:34	3.02	~90-95%.
		14:49	3.27	~95%, still flat and firm. West and east sides are visible.
		15:11	3.63	~95%, feed is boiling between shots than flowing into the melt pool.
		15:19	3.77	~95%, feed is not boiling as much between the shots.
		15:42	4.15	~95%, is mostly flat with large amount of liquids on the melter surface.
		15:49	4.27	CC is same as the last observation.
		16:04	4.52	CC is same as the last observation.
		16:24	4.85	~95-98% and fairly thick (3-4") liquid on surface is mildly boiling. Openings appear to be reducing
		16:34	5.02	~95%. No changes for this observation.
		16:49	5.27	~95%, There are openings on north side and small opening on east side. CC is thick with feed boiling on surface.

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
1&2	1/30/2012	17:04	5.52	~95%, has not changed much. Is ~4" thick with one openings on eastside and two openings on west side.
		17:19	5.77	~95%. There is not much liquid on the surface.
		17:34	6.02	~92% and it is opened up some.
		17:55	6.37	~ 95% one opening on the east side two on the west side, feed boiling on top of 4" cap
		18:04	6.52	~95% and is open on the east side. Now there is one opening on the west side.
		18:19	6.77	~95% and is open on the east side. One opening exits on the west side.
		18:34	7.02	~95% and is open on the east side. Now there is one opening on the west side.
		18:49	7.27	~98%, and there is a small opening on the east side and larger on the west side.
		19:04	7.52	~98%, and there is small opening on eastside. Lots of liquid exist on the CC surface.
		19:19	7.77	~95%, and there is one opening on each of the north and east sides. Feed is boiling on the surface before flowing into the openings.
		19:34	8.02	~95%. There is one large opening on the north side and one small opening on the east side. Feed is boiling on the surface.
		19:49	8.27	~95%, Both east side and west side openings have large ridges around them.
		20:19	8.77	~95%, there are openings on both north and east sides.
		20:34	9.02	~95% and is thick with openings on both north and east sides.
		20:49	9.27	~95% openings exits both on the north and the east sides.
		21:04	9.52	~95% and is fixed to the walls. Feed rate is reduced by increasing T10 setting from 65 to 70 seconds.
		21:19	9.77	~95%. Two openings on the east and the west sides are 4" thick and are detached from melt pool.
		21:34	10.02	~95%. There are two openings on the east and the west sides. They are 4" thick and still detached from melt pool.
1&2	1/30/2012	21:45	10.2	~96%. Two openings on the east and west sides are 4" thick and look like CC level is even with the melt pool.
		22:04	10.52	~95%. There are two openings on the east and west sides and feed is boiling on top of CC.
		22:19	10.77	~95%, observations are same as above.
		22:34	11.02	~95%. There are three opening on the east, north and north-west sides. CC is around the thermo-wells.

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		23:06	11.55	~90%. Openings are on the east and along the west section. Feed is boiling on the surface.
		23:19	11.77	~90%. Three openings exit on east and west sides.
		23:42	12.15	~85-90%. Observation is same as above.
	1/31/2012	0:04	12.52	~85-90%. Three same openings exist however they are larger.
		0:35	13.03	~90-95%, openings are in the north-east and south-west corners. Two large openings are making most of the melt pool.
		0:51	13.3	~90-95%, Small opening is in the north-east corner. South-west corner has large opening that makes up most of the hot cap.
		1:09	13.6	~85-90%. Feed is boiling on the surface. CC level is even with the melt pool.
		1:25	13.87	~85-90% is same as the previous conditions.
		1:42	14.15	~85-90% and floating bubbling. Openings are same as the previous conditions.
		2:03	14.5	~85%. Slight ridge exits around east side opening and feed is flowing into west side opening.
		2:17	14.73	~85% and is same as the last observation
		2:38	15.08	~85-90% and boiling is minimal with no feed overflow to opening.
		3:01	15.47	~85%.
		3:19	15.77	~85% and same as the previous conditions.
		3:47	16.23	~80-85% floating along the east side wall and is firm along the west side.
		4:04	16.52	~80%.
		4:20	16.78	~80%.
		4:34	17.02	~80% and appears unchanged.
1&2	1/31/2012	4:51	17.3	~80% and is floating along the east wall. Some liquid is flowing into the west side opening.
		5:20	17.78	~80% and same as before.
		5:42	18.15	Stalactite is present, will dislodge.
		5:44	18.18	Successfully dislodged stalactite.
		6:08	18.58	~80%. CC appears mostly unchanged.
		6:19	18.77	~80%. CC appears to be slightly wetter otherwise very similar to previous observation.
		6:50	19.28	~75-80%. There are openings on west and east sides and slight ridge build-up around openings.
		7:35	20.03	~75-80%. Openings are visible on east and west sides. Feed is boiling on top of CC and small ridges exist around openings.
		7:55	20.37	~75-80%. Observed conditions are the same as the previous observation.

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		8:15	20.7	~75-80%. Feed is boiling on the surface. Openings are visible on the east and west sides.
		8:56	21.38	~85% and boiling surface is with large openings.
		9:03	21.5	~90% with opening slightly reduced in size. Surface still boiling
		9:23	21.83	~85% liquid boiling, flowing to openings
		9:40	22.12	~85-90% is same as the previous conditions.
		9:50	22.28	~90% no apparent change in conditions
		10:04	22.52	~90% liquid boiling and flowing to openings
		10:18	22.75	~85-90% edges of openings appear
		10:38	23.08	~90% with most of the liquid flowing to the lance #1 area
		10:48	23.25	~85-90% no change in appearance
		11:05	23.53	~85-90% cap is fluid with feed boiling on top and flowing into openings on east and west sides
		11:20	23.78	~85-90% feed boiling on surface and flowing into openings on the east and west sides
		11:35	24.03	~85-90% with distinct "hour glass" shaped openings on lance #1 and #2. Feed boiling on surface and flowing into the melt pool
		11:50	24.28	~85-90% no significant change
		12:05	24.53	~90% large openings on east and west side cap looks flat with boiling feed on top
1&2	1/31/2012	12:18	24.75	~85% openings are slightly larger with feed boiling and flowing into the openings
		12:40	25.12	~85% with definite hour glass openings, feed boiling
		12:48	25.25	~85-90% no observed changes
		13:04	25.52	~ 85% most liquid flowing to lance #1opening, lance #2 area opening up
		13:20	25.78	~90% with openings getting firmer around edges fluid mostly boiling, ~6" stalactite on feed tube
		13:52	26.32	~90% each lance opening now has two individual distinct openings
		14:06	26.55	~90-95% No change from previous observation
		14:20	26.78	~95%
		14:35	27.03	~90% with two distinct openings on the east side lance #1 and "hour glass" opening on west side lance #2. Feed boiling on surface and flowing into openings
		14:41	27.13	~95% openings on north and east side, feed is boiling on surface

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		15:04	27.52	~95% The west side opening is along the west wall it is elongated by 12-14". East side opening is mostly round in shape but has a ridge on the south side of it, north side is flat and allowing feed to flow into glass pool
		15:19	27.77	~95% no change to west side, East side opening ridge has melted down some
		15:34	28.02	~95% feed is not boiling between shots, no visible changes for this observation. There is a stalactite about 12" down from the feed tube
		15:49	28.27	~95% 2 openings E/W west side elongated, feed boiling on top of plenum
		16:04	28.52	~90% 2 openings on east side, one large elongated hole on west side, still about 4" thick, feed boiling on top
		16:19	28.77	~90% one opening elongated on the east side, one opening elongated on the west side
		16:34	29.02	~90% east side opening looks like a figure 8, cap is not as thick. Feed is boiling between shots
1&2	1/31/2012	16:49	29.27	~93% cap is closing up. East side looks like 2 openings now. Larger amount of liquid on surface. Feed flowing into openings
		17:04	29.52	~95% Feed is boiling over into the openings. Stalactite has grown about 6" more since the 15:34 observation
		17:19	29.77	~95% no visible changes at this time.
		17:34	30.02	~90% west side opening has gotten bigger. Stalactite does not have an affect on the shot
		17:49	30.27	~90% glass level dropped but the cap did not. More feed flowing into the openings
		18:04	30.52	~90% cap dropped down now with glass pool, no change in observation
		18:19	30.77	~90% 2 openings on east side, one large elongated hole on west side, feed boiling on top
		18:34	31.02	~90% south side of cap is higher than north side, no change in openings
		18:49	31.27	~90% East side opening elongated running north to south. Opening on west side, feed boiling on surface
		19:04	31.52	~90% East side opening elongated, west side opening round, slight boil of feed on surface
		19:19	31.77	~95% Elongated east side opening starting to close up a bit, west side opening the same
		19:34	32.02	~90% Elongated east side opening, west side a little larger and elongated
		19:45	32.2	~90% looks about the same as before

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		20:04	32.52	~90% one opening on east side feed flowing into it, one larger elongated opening on west side
		20:19	32.77	~90% one opening on east side feed flowing into it, a larger elongated opening on the west side
		20:34	33.02	~90% 2 elongated openings E/W, a lot of feed build up on bubbler
		20:49	33.27	~90% east side opening has ridge and is elongated, west side by bubbler is elongated
		21:04	33.52	~90% little change from last observation
		21:19	33.77	~85% Cap has opened up some, west side has opened up the most, small ridge on east side south of the opening
1&2	1/31/2012	21:34	34.02	~85% East side opening is elongated, west side opening is round with a ridge, feed is boiling on the surface
		21:49	34.27	~85% east side elongated with a ridge, west side elongated with bubbler attached
		22:04	34.52	~90% two openings on the west side, one elongated opening on the east side
		22:19	34.77	~90% two openings on the west side no ridge, one elongated opening on the east side
		22:34	35.02	~90% two openings on E/S feed flowing into melt pool, one larger elongated opening on W/S
		22:46	35.22	~90% E/S both open, boiling feed on cap surface
		23:01	35.47	CC is flat with heavy boiling on the surface
		23:15	35.7	~85% Firm, 2 openings on the east side
		23:31	35.97	~85% 2 openings on the east side
		23:46	36.22	~85% 2 openings, 5% NE 10% east wall
	2/1/2012	0:15	36.7	~85% 2 openings
		0:39	37.1	~85% 2 openings N wall, E wall (larger), removed stalactite from end of feed tube
		0:45	37.2	~85% bubbling on the surface is slightly less, mound south of the liquid pool, openings same as last observation
		1:03	37.5	~90% Heavy liquid surging into both openings
		1:16	37.72	~85% partial ridge developing on east opening
		1:34	38.02	~85% no change from last time
		2:07	38.57	~85% has some buildup of cap around thermowell and similar openings
		2:32	38.98	~85% no real change
		2:48	39.25	~80-85% much less liquid on the surface
		3:04	39.52	~85% unchanged
		3:31	39.97	~80% east opening getting flooded w/feed from the surface

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		3:45	40.2	~80-85% no change
		4:03	40.5	~85% no change
		4:17	40.73	~85% east opening very thick, heavy bubbling
		4:39	41.1	~85% unchanged
		4:53	41.33	~85% unchanged
		5:15	41.7	~85% unchanged
		5:28	41.92	~85% west side by thermowell closing up some.
1&2	2/1/2012	5:43	42.17	~85% unchanged
		6:10	42.62	~80-85% less boiling on the surface, slight ridge on east
		6:55	43.37	~95% cap is flat with feed boiling on the surface
		7:10	43.62	~95% two openings on east and west side from bubblers, feed boiling on surface and flowing into openings
		7:25	43.87	~95% conditions unchanged
		7:40	44.12	~95% dual openings on east and west sides corresponding to the bubblers, feed boiling on surface and flowing into openings
		7:55	44.37	~95% conditions unchanged
		8:10	44.62	~95% conditions unchanged
		8:25	44.87	~95% with openings on east and west sides, feed boiling on the surface and flowing into the openings
		8:51	45.3	~98% appears about 6" thick at the openings, liquid boiling on the surface
		9:06	45.55	~95-98% liquid boiling on the surface, view to lance #2 becoming restricted due to solids on thermowell #2, can still see opening in cap
		9:19	45.77	~95-98% unchanged from last observation
		9:36	46.05	~98% ridges forming around openings, appear to prevent feed from flowing into the opening. Liquid mildly boiling in center of melt pool
		9:50	46.28	~95-98% ridges have formed around the openings preventing feed from flowing into the melt pool, a single opening can be seen on the east side with a slight glow coming from the north east corner. Two openings can be seen on either side of the #2 thermowell
		10:05	46.53	~95-98% conditions unchanged from previous observation
		10:20	46.78	~95% openings on east and west sides correspond to the dual openings on lance #1 and #2. Ridges have formed around the openings preventing most of the feed from flowing into the melt pool. Feed is boiling on the central surface of the CC

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		10:35	47.03	~95% conditions unchanged
1&2	2/1/2012	10:52	47.32	~95% openings on the east side corresponding to lance #1, ridges have decreased allowing feed to flow into the melt pool openings, on west side visible around TW #2, feed boiling on top of the CC
		11:05	47.53	~98% no significant change in conditions
		11:20	47.78	~98% no significant change in conditions
		11:35	48.03	~98% openings on the east and west sides correspond to lances #1 and #2 outlets, feed is flowing into melt pool on east side and boiling on surface
		11:50	48.28	~98% conditions unchanged from previous observation
		12:05	48.53	~98% conditions unchanged from previous observation
		12:19	48.77	~95% openings slightly larger with reduced ridge height, feed boiling
		12:32	48.98	~95% east openings shows 2 distinct bubbling areas, feed flowing into opening during boil
		12:46	49.22	~95% with all liquid flowing to lance #1 opening
		13:05	49.53	~98% conditions unchanged from previous observation
		13:20	49.78	~98% east and west sides have 2 distinct openings corresponding to lance #1 and #2, feed is flowing into openings on east side, feed is boiling on the surface
		13:40	50.12	~98% conditions unchanged from previous observation, the west side openings are becoming difficult to see due to buildup of cold cap and feed on thermowell #2
		13:55	50.37	~98% conditions the same as previous observation
		14:05	50.53	~98% conditions the same as previous observation
		14:20	50.78	~98% two distinct openings on the east side from lance #1, feed flowing freely into east side opening and boiling on the surface. West side has two openings that are difficult to see due to buildup on thermowell #2
1&2	2/1/2012	14:34	51.02	~98% larger elongated opening on the east side, small opening on the west side
		14:49	51.27	~98% east side has a large elongated opening, feed boiling on top, very small opening on the west side
		15:04	51.52	~98% opening on east side is larger than opening on west side, feed is boiling on cap surface

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		15:19	51.77	~98% East side opening is small in size, feed is flowing into opening, no ridge seen. Unable to see west side opening
		15:34	52.02	~98% east side has an opening, cannot see light from west side, feed is boiling on the surface
		15:49	52.27	~98% cap is fixed to the walls, the ridge on the west side is blocking the middle viewport. Able to see light from the west side through the north view port
		16:04	52.52	~99% cap has collapsed after discharge, cannot see glass on the west side opening, small opening on the east side, cannot see feed running into openings, slight feed boil on cap surface
		16:19	52.77	~95% East side has opened up, smaller opening on west side, glass level is below cap
		16:34	53.02	~95% large elongated opening on east side, west side very small opening
		16:49	53.27	~95% 8" opening on east side, there is a cone shaped coming up in the middle of the cold cap about 12" high, west side has no opening
		17:10	53.62	~95% ridge on north side of east opening, small opening on west side that is hard to see through the viewport
		17:19	53.77	~96% the ridges look like domes over the openings which are holding in the heat
		17:34	54.02	~96% no visible change
		17:49	54.27	~98% cannot see the glass pushing through the east opening, west opening surrounded by build up
		18:04	54.52	~95% can see glass moving into the east side opening, ridge around west side opening
1&2	2/1/2012	18:19	54.77	~98% small opening on east side ridge around the opening with feed pooling on top, hard to see west side opening, thermowell is covered with dried feed
		18:34	55.02	~95% east side has opened up allowing more liquid to flow, molted glass is spitting out of the west side onto the cap
		18:49	55.27	~95% east side has opened up and feed is flowing into the melt pool, and west side is a small opening
		19:04	55.52	~90% both east and west have opened up, able to view opening through the middle viewport, west side is elongated running north to south, east side is the same but larger, there is a half dome on the south side of it.
		19:19	55.77	~90% bright inside melter, east side has opened up, west side has opened up, feed is boiling on the surface before flowing into the openings

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		19:34	56.02	~90% east side large elongated opening, no ridge, feed pooling on top of melt pool splashing on top of cap, west has small openings
		19:50	56.28	~90% East side looks the same as before, feed still pooling on top, west side unchanged
		20:04	56.52	~95% east side is elongated with no ridge, feed pooling on top, west side opening is still slightly open
		20:18	56.75	~95% East side opening is about the same, the feed is still pooling on top, can see light on the west side but no opening
		20:34	57.02	~95% East side opening is about the same, the feed is still pooling on top, west side is slightly open
		20:49	57.27	~95% east opening still large a ridge around the opening is causing a large amount of feed to pool, west side is the same
		21:03	57.5	~95% east side opening the same, still a lot of feed boiling on top, west still unchanged
		21:19	57.77	~98% very small opening on west side, east side has a cone shaped opening, not much feed flowing into opening
1&2	2/1/2012	21:34	58.02	~98% 8" opening on the east side with a ridge on it and feed pooling on top, west side closed
		21:49	58.27	~98% 8" opening still on the east side feed boiling and pooling around it, west side still dark
		22:04	58.52	~98% the inside looks the same as before
		22:19	58.77	~98% east side opening still about 8" and cone shaped feed still pooling on top
		22:34	59.02	~98% east side open and the feed is setting on top
		22:43	59.17	~90%
		22:45	59.2	~90% fair amount of feed boiling on the west side surface
		23:15	59.7	~90-95% east and west openings are just partially visible. Heavy boiling on the surface
		23:32	59.98	~90-95% no change, NW remains open with boiling feed on the east side
	2/2/2012	0:05	60.53	~90-95% east side closed up with slight amount of light visible
		0:20	60.78	~95% light visible in east-nothing visible. West appears fully closed
		0:46	61.22	~95% only light visible is from D1 bubbling
		1:07	61.57	CC cannot be distinguished at this point other than the partial opening from D1 bubbling. The opening has a measurable ridge and glass spits occasionally
		1:29	61.93	~95% SE appears to be open, the rest is not visible

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		2:15	62.7	~95% based on illumination available through the south view port
		2:30	62.95	CC is the same-not visible
		2:44	63.18	A small reflection from the C2 indicate there is an opening along the west wall
		3:03	63.5	much greater visibility now available on the North viewport, west opening has a 6" ridge closer to the center, surface of cap can't be determined, partial opening visible through the mid viewport
		3:16	63.72	~90% same as last entry
		3:53	64.33	~90% both openings are now visible
		5:34	66.02	~60-70%
1&2	2/2/2012	10:15	70.7	~75%
		10:20	70.78	~75% with large areas still open
		10:31	70.97	~80%
		10:40	71.12	~ 80-85%
		10:45	71.2	~85% slightly thicker
		11:00	71.45	~85%
		11:10	71.62	~85-90% boiling vigorously and flowing to openings
		11:18	71.75	~85-90% boiling and flowing to openings
		11:33	72	~95%
		11:44	72.18	~95% Flat and boiling to openings
		11:55	72.37	~95% no change since last observation
		12:10	72.62	~95% openings on east and west sides are "hour glass" shaped, feed flowing freely into both openings, feed is boiling on surface.
		12:25	72.87	~95% no change since last observation
		12:46	73.22	~95% slightly thicker
		13:03	73.5	~95% ridge on east side (lance #1) fairly tall ~5-6"
		13:13	73.67	~95% East opening ridge dissolved
		13:24	73.85	~95% and boiling profusely
		13:40	74.12	~95% with openings on east and west sides, feed flowing freely into openings and boiling on surface
		13:55	74.37	~95% no change since last observation
		14:07	74.57	~95% liquid boiling over ridges at the opening on the east side, west opening barely visible
		14:26	74.88	~95% Liquid mildly boiling into openings, view of west (lance #2) bubbling area blocked by solids, but the glow is still visible
		14:49	75.27	~95% glass has dropped below cap hard to see west opening, but able to see light from this side, east side has large ridge around it

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		15:04	75.52	~95% not able to see through middle viewport, cap and melt pool in contact, still large ridge around opening on east side
		15:19	75.77	~95% large amount of liquid has spilled into west side opening, caused a spike in melter pressure
1&2	2/2/2012	15:34	76.02	~90% west side has opened up, east side opening has more of a dome shape around it
		15:48	76.25	~95% not able to see the west side, east side opening is a half dome on the south side and a small ridge on the north side
		16:04	76.52	~95% feed is boiling between shots
		16:19	76.77	~90% both openings have opened up
		16:34	77.02	~90% cap conditions unchanged
		16:49	77.27	~95% west side is closed up due to more feed flowing into its opening, east side ridge has gotten slightly higher
		17:04	77.52	~95% east side elongated, west side closed
		17:19	77.77	~95% west side is small but able to see some light, East side has a cone shaped ridge on the south side and a small ridge on the north side, when feed boils it flows over the small ridge
		17:34	78.02	~95% no visible changes at this time.
		17:49	78.27	~95% west side has a large amount of liquid flowing into melt pool causing glass to spray all over
		18:04	78.52	~95% east side opening has 8" cone ridge around the opening, feed is pooling on top and then flowing into the melt pool, west side pretty much closed up
		18:19	78.77	~90% now 2 8" openings on east and west side
		18:34	79.02	~90% still 3 8" openings on east and west sides, both have cone ridges, feed is pooling on cap and flowing into melt pool
		18:49	79.27	~95% west side has closed up slightly, cap and melt pool has separated during discharge, there is only one opening on the east side
		19:04	79.52	~95% both east and west openings have cone shaped ridges on the south side, both are 12-14" high, large amount of liquid on the surface, boiling slowly between shots
		19:19	79.77	~95% west side no change, east side south cone shape ridge has melted down by half
		19:34	80.02	~95% 2 openings east and west side about 8" around, feed pooling in the middle of the cap
1&2	2/2/2012	19:49	80.27	~95% 2 openings east and west side, east side 8" around, west side more elongated feed still pooling on top of cap

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		20:04	80.52	~90% east side opening about 8" around, west side is elongated about 8"x14", feed still pooling on cap
		20:19	80.77	~90% east side opening still 8", west side is a little larger, feed is still pooling, there are still ridges around openings
		20:34	81.02	~90% east side is closing up, the west side is opening up, feed still pooling on top
		20:49	81.27	~90% east side looks like it is starting to open up, west side looks like it is closing
		21:04	81.52	~90% east side is opening up, west side is closing up, feed still pooling
		21:19	81.77	~90% east side is opening up, west side is the same
		21:34	82.02	~95% all openings are closing up
		21:49	82.27	~95% East side opening 8", west side is about the same but it's hard to tell
		22:04	82.52	~95% East and west side openings are the same
		22:19	82.77	~90% Feed rate has dropped some, cold cap has opened up because of this
		22:34	83.02	~90% able to see both openings now, cone shape mounds are melting
		22:49	83.27	~85-90% east side with ridge around, west opening minimal visibility from mid-viewport. Heavy liquid on the surface and boiling. C2 exposed plenum still coated with buildup, D2 also coated with build up
		23:01	83.47	~90% unchanged from last observation
		23:16	83.72	~90% feed flowing to the opening
		23:30	83.95	~85% heavy boiling on the surface
		23:45	84.2	~90% east opening very thick, west opening much smaller barely visible through viewport
	2/3/2012	0:04	84.52	~90% east side very thick, heavy bubbling on top, west side barely visible through viewport makes up 2% of hot cap
		0:16	84.72	~90% NE corner open, west side closing up 2% of hot cap, heavy bubbling on top of cap
1&2	2/3/2012	0:31	84.97	~90% NE corner open, heavy bubbling on surface, west side barely visible 1% of hot cap open
		0:46	85.22	~95% NE corner closing and very thick west side around T/W only 1% of hot cap open
		1:04	85.52	~90% west closing up some, north east not really visible much
		1:17	85.73	~90% east opening ridge seems to be dissolving, sputtering on the west contributing to more build ups hanging
		1:42	86.15	~90% east opening, west seems mostly shut

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		2:01	86.47	~90% the buildup on C2 is gone, increasing available cap space, heavy liquid on the surface boiling
		2:15	86.7	~90% unchanged from last observation
		2:30	86.95	~90% similar to last observation
		3:10	87.62	~90-95% limited visibility
		3:35	88.03	~90-95% plenty of light visible in south viewport, lots of webbing on west side cannot see much
		4:01	88.47	~95% barely visible in south viewport, North slightly open
		4:17	88.73	~96% no longer see cold cap in SW viewport, NE side small opening, thick cold cap heavy bubbling
		4:33	89	~95% NE opening very thick, heavy bubbling
		4:50	89.28	~95% unchanged from last observation
		5:02	89.48	~95% buildup developing around thermocouple C2
		5:19	89.77	~95% unchanged from last observation
		5:31	89.97	~95% less boiling, liquid accumulation
		5:45	90.2	~95% plenty of light seen through south viewport, not much light along the west wall
		6:05	90.53	~95% no change, a fair amount of buildup on thermowell #2
		6:45	91.2	>95% light visible on east side via south viewport, no light visible on west side
		7:05	91.53	>95% light visible on east side via north and south viewports, no light visible on west side
1&2	2/3/2012	7:20	91.78	>95% light visible on east wall via south viewport, no light visible on west side from any viewport
		7:35	92.03	>95% light visible on east wall via south viewport, some bubble action visible from lance #1 via north port, no light or bubbler action visible on west side
		7:55	92.37	~95% openings visible on east and west side
		8:05	92.53	~95% Visual via north view port: opening near center of cap ~12" and thick. Some light visible on east side. Center viewport: some light visible. South viewport: light visible on east wall
		8:20	92.78	>95% North viewport: no openings and no light. Central viewport: no light or openings visible. South viewport: light visible on east wall
		8:35	93.03	>95% North viewport: some light visible through "cob webs". Central viewport: no light visible or openings. South viewport: light reflection off east wall
		8:50	93.28	~95% North viewport: openings visible on the east side and in center of cap, cap is ~12" thick. Central viewport: no light or openings. South viewport: light visible on east wall

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		9:03	93.5	~95% with openings visible on both sides of melter
		9:12	93.65	~95% unchanged with openings still visible
		9:22	93.82	~95-98% glass "spider webs" beginning to obstruct view through north viewport. Openings on both sides still visible
		9:32	93.98	~95-98% east opening visible and west side light visible through north viewport
		9:40	94.12	~95-98% wall developing at west opening from splatter
		9:53	94.33	~98% opening still visible on east side but no light from west side anymore
		10:07	94.57	~98% east opening visible, no light from west side
		10:16	94.72	~95% east opening shifted slightly towards lance #1 (elongating), beginning to see some molten glass splatter from west area (lance #2)
1&2	2/3/2012	10:25	94.87	~95% unchanged on the east, west opening increasing it is now visible
		10:32	94.98	~90-95%. Ridges formed at openings appear to be preventing feed from flowing to the openings. Cannot determine the liquid state in the center area
		10:50	95.28	~95% no change in observed conditions
		11:10	95.62	~95% openings appear the same as before
		11:35	96.03	~95% openings on east side visible from north viewport. No light or opening visible on the west side, nothing visible from central viewport, light on east wall visible from south viewport
		11:50	96.28	~95% opening on east side visible via north viewport, reflected light visible on east wall via south viewport, nothing visible on west side of melter
		12:05	96.53	~95% conditions unchanged from previous observations
		12:25	96.87	~95% openings visible on east and west sides corresponding to outlets of bubblers. Openings can be seen from the north and central viewports
		12:40	97.12	~95% conditions unchanged from previous observation
		12:55	97.37	~95% conditions unchanged from previous observation
		13:20	97.78	~95% openings on east and west sides with ridges built up around openings feed boiling on top of cold cap in the center of the melter
		13:35	98.03	~95% conditions unchanged from previous observation

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		13:55	98.37	openings on east and west side visible from north viewport. West side is starting to close slightly. Nothing visible in central viewport. South viewport light is visible on east wall
		14:10	98.62	~95% conditions unchanged from previous observation
		14:34	99.02	~95% east side is open web is hanging from top of melter, hard to see through viewport. No light seen on the west side
1&2	2/3/2012	14:49	99.27	~95% east side is open, cannot see west side. Melter has webs hanging from top. Cannot see cap surface
		15:04	99.52	~90% has opened up some able to see more light from the east side
		15:19	99.77	~95% west side has closed up, do not see any light. Able to see large ridge around east side opening
		15:33	100	>95% only able to see a small percentage of the east side
		15:48	100.25	~95% not able to see east side anymore due to a large cone shaped ridge blocking view from the west. It is spitting the molten glass up to make the ridge.
		16:04	100.52	~95% no visible changes for this observation
		16:19	100.77	>95% see light but no openings
		16:34	101.02	~95% same as before, see light only on the south side
		16:50	101.28	~95% same as before
		17:04	101.52	~95% very dim light being emitted from both sides, not able to see anything
		17:19	101.77	>95% still little to no change in observation
		17:34	102.02	~95% It has opened up some during the transfer. Now able to see the east side opening. There is a ridge 6-8" high around it. All exposed thermocouples are covered in glass and feed
		17:49	102.27	~95% dark inside melter, east side is open with ridge around it, unable to see west side.
		18:04	102.52	~95% small amount of glass is bubbling out of east side opening onto the cap. Unable to see anything on west side
		18:20	102.78	~95% cannot see glass in east side opening. After discharge, dark inside melter, webs blocking view, unable to see west side opening
		18:39	103.1	~95% glass is shooting out of opening on east side. Unable to see west side.
		18:49	103.27	~97% east side starting to close up. Dark inside melter, unable to see west side.

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		19:05	103.53	~99% very dark inside melter cannot see any openings
1&2	2/3/2012	19:19	103.77	~99% can only see a small amount of light through south viewport
		19:34	104.02	~99% very little light can be seen
		19:49	104.27	~99% very little light north and west side
		20:04	104.52	~100% no light at all
		20:19	104.77	~100% no light at all
		20:34	105.02	~100% no light at all
		20:49	105.27	~100% no light at all
		21:05	105.53	~100% no light at all
		21:19	105.77	~100% see a very little amount of light emitting from the west side through the north viewport. Middle viewport able to see boiling feed on a fixed cap
		21:33	106	~100% the small hole through the buildup has closed back up, no visible light at this time
		21:49	106.27	~100% no light coming through
		22:02	106.48	Test has ended stopped feeding
	2/4/2012	2:37	111.07	~15-25%
3&4	2/7/2012	20:00	NA	Started feeding water at 1.0 lpm
		20:20	NA	Increased water flow to 2.0 lpm
		20:40	NA	Increased water flow to 3.0 lpm
		21:00	NA	Stopped feeding water and started feeding slurry HWL-AL-19
		21:20	NA	Started feeding water at 1.0 lpm
		21:49	NA	Increased water flow from 1.0 to 2.0 lpm
		22:09	NA	Increased water flow from 2.0 to 3.0 lpm
		22:29	NA	Decrease water to 0.5 lpm and start feeding slurry
		22:33	NA	feed tube seems to be clogged
		23:47	0	Started feeding water at 1.0 lpm
	2/8/2012	0:02	0.25	Increased water flow from 1.0 to 1.5 lpm
		0:12	0.42	Increased water flow from 1.5 to 2.0 lpm
		0:28	0.68	Increased water flow from 2.0 to 2.5 lpm
		1:01	1.23	Stopped feeding water and started feeding slurry HWL-AL-19
		1:27	1.67	~75% boiling on the surface with a light liquid on the surface
		1:31	1.73	secured water feeding
3&4	2/8/2012	1:45	1.97	~60-65% East section still wide open.
		2:09	2.37	~60% while observing the cap notice the feed shot stream appears to be much less than previously observed

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		2:29	2.7	~70% mound slightly building up on the surface
		2:43	2.93	~90%
		2:53	3.1	~90%
		3:11	3.4	~85% minimal boiling
		3:30	3.72	~85% slight ridge on the east opening. Minimal liquid on the surface. Two openings total with west visibly available mid viewport
		3:44	3.95	~85% ridge on east remains, west has small opening
		4:35	4.8	~90% still thin
		4:51	5.07	~80% appears more solid now
		5:09	5.37	West opening partially bridged across. East remains the larger of the two openings
		5:22	5.58	~80-85% some boiling closer to the west opening
		6:02	6.25	~85% same as last
		6:09	6.37	~85% slurry accumulation is now much greater, but at minimal boiling
		6:22	6.58	~85% consistent with last observation
		7:35	7.8	~90% openings visible on east and west side cap is flat with feed boiling on the surface and flowing into the east opening
		7:55	8.13	~90% openings visible from the north view port on the east and west sides. Central viewport opening on west side. Openings consistent with bubbler outlets
		8:10	8.38	~90% conditions unchanged from previous observation
		8:25	8.63	~90% openings on east and west sides. Mounds forming north and south of center with feed boiling in the center and flowing into both the east and west openings
		8:40	8.88	~90% conditions unchanged from previous observation
3&4	2/8/2012	9:04	9.28	~90% liquid boiling around openings but not in center area under feed tube. Cap is floating, not stiff in center appears to be pulsing with bubbling
		9:18	9.52	~90-95% slightly reduced openings otherwise conditions are the same as previous entry.
		9:34	9.78	~90% openings enlarged slightly during feed sample collection.
		9:49	10.03	~90% no change in observed conditions
		12:05	12.3	~85% openings visible on east and west sides
		14:05	14.3	~75-80% still to open to increase bubbling
		14:15	14.47	~80-85% firm in center area feed shot splashing in open areas
		14:40	14.88	~90%

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		15:17	15.5	~90% cap mostly flat surface except around the openings. West side only molten glass can be seen bubbling up. East side opening has large ridge on the south side of it.
		15:34	15.78	~95% cap has closed up on the east side. Through middle view port a small opening on the west side is visible
		15:49	16.03	~95% not able to see east side at this time. West side opening is visible
		16:09	16.37	~95% no ridges seen. Cap has large amount of ridges on surface
		16:19	16.53	~92% cap has opened up some. Feed is boiling between shots not able to view west side anymore
		16:39	16.87	~90% east side is open can see just a little bit of west side through viewport. A lot of wet feed sitting between openings
		16:50	17.05	~90% cap is flat with wet feed on surface east and west sides are open.
		17:04	17.28	~90% east side is open, west side is harder to see as a ridge has built up around the viewport. Cap is flat with wet feed on the surface
		17:19	17.53	~90% no change in observed conditions
		17:34	17.78	~95% east side opening is about 6-7" wide, only see a small opening on the west side
3&4	2/8/2012	17:49	18.03	~90% both openings have gotten larger. Feed is not boiling between shots
		18:04	18.28	~90% both openings have ridges around the south side. Ease opening has a ridge on its west side. Glass is splashing over onto the liquid.
		18:19	18.53	~90% east side is open, build up is starting to hang from thermowell. West side is open but hard to see with build up around viewport
		18:34	18.78	~90% small ridge build up around east side opening, glass is jumping out of opening. West side still open but hard to see.
		18:49	19.03	~95% both openings have slightly closed, more liquid on cap than last observation
		19:09	19.37	~98% east side has closed up. Some light can be seen on the west side. Lots of feed on the cap surface
		19:19	19.53	~98% east side has opened up a little. West side open and throwing glass on the surface. Cap is flat and very wet with feed
		19:34	19.78	~95% large opening on the west side, smaller opening on the east side. Webs hanging from top of melter
		19:49	20.03	~95% no visible changes for this observation

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		20:05	20.3	~90% east and west sides have opened up. Cap is full of bumps and ridges. Pools of wet feed between openings.
		20:19	20.53	~95% west side has still closed up a bit. East side still open. Feed is still boiling on the cap.
		20:34	20.78	~95% only see glass splashing from the west side. East side has a ridge that is holding feedback. Large amount of liquid on surface that boils right before shot.
		20:49	21.03	~95% east side opening has ridge built up around it. West side is open and throwing up feed and glass. Cap has a pool of wet feed on the surface.
		21:04	21.28	~98% Feed is flowing into the west side opening. East side has a small opening with ridge
		21:19	21.53	~98% feed is now flowing into the east opening. Not able to see west side.
3&4	2/8/2012	21:34	21.78	~95% cap has opened up, able to see the cap floating. See some light emitted from west.
		21:50	22.05	~95% east side is open, west side is open and spitting out glass and feed. Webs hanging from top of melter
		22:04	22.28	~98% East side is still open, west side is closing up. A lot of wet feed on the cap surface.
		22:47	23	~95% east opening exists, west opening not visible but splashing from the west opening is visible.
		23:00	23.22	~98% glass splashing over the surface
		23:15	23.47	~95%
		23:40	23.88	~90%
		23:58	24.18	~90% starting to see west opening. Heavy accumulation on the surface but little to no boiling
	2/9/2012	0:16	24.48	~95% view of east opening is somewhat blocked due to web build up on lance bubbler. Small amount of light on west wall.
		0:42	24.92	~95% Farthest to the south is a shelf formed mound on top of the cold cap, visible from the north viewport.
		1:00	25.22	~95% same as last observation
		1:30	25.72	~95% unable to see east opening
		1:47	26	~95-98%
		2:04	26.28	~95% East opening now available again
		2:16	26.48	~95% no change from last observation
		2:35	26.8	~90-95% build up on C2 exposed plenum thermocouple is now touching the cap surface. West opening splashing. Heavy boiling next to east bubbling
		2:51	27.07	~90% no change in observed conditions

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		3:07	27.33	~90% west opening much greater at this cycle. Heavy accumulation at the center of the surface
		3:24	27.62	~90% same accumulation at the center of the cold cap C2 exposed plenum has a large build p
		3:42	27.92	~90% no major change NW corner appears to be a little more open
3&4	2/9/2012	4:13	28.43	~95% only west opening partially available. Earlier build up on C2 (exposed thermocouple) existed as a column but now it is laying across the cold cap.
		4:31	28.73	~95% no change from last observation
		4:50	29.05	~90-95% opening visible on west wall, no view of an east opening. Light is visible via the south viewport. Middle viewport is blocked
		5:15	29.47	~95% no change from last observation
		5:26	29.65	west opening has a ridge. Suspect the east opening under the same condition making it not visible. Through the south viewport light at east bubbler is bright
		5:41	29.9	~95% Heavy boiling on the surface in between shots.
		6:03	30.27	~90-95% no change, west ridge opening still exist
		6:45	30.97	~95-99% large ridge down center of melter only visible light is from the east side via the south viewport
		7:10	31.38	~95% Opening visible on the west side via the north viewport. Light visible on the east wall via the south viewport.
		7:45	31.97	~95% Light visible on east and west sides through "spider webs" via north port. Light on east wall visible from south viewport.
		8:10	32.38	~95% opening visible on west side via north viewport. Feed boiling on surface in center of cap. Light visible on east side via south viewport
		8:34	32.78	~95% no change from last observation
		8:52	33.08	~95% west opening still visible from north viewport. Glow reflecting on east wall visible via the south viewport
		9:05	33.3	~95% unchanged in appearance
		9:19	33.53	~90-95% west opening appears larger. Feed not flowing into openings. Ridges prevent view of center area.
		9:44	33.95	~90-95% west opening now has some feed flowing in. still cannot see center due to ridge
3&4	2/9/2012	9:58	34.18	~95% ridge around west opening beginning to dissolve
		10:20	34.55	~95% no significant change from last observation

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		10:35	34.8	~95% opening visible on west side with ridge around opening. Light visible on east wall via the south viewport.
		10:50	35.05	~95% conditions unchanged from last observation
		11:35	35.8	~95% openings on west side visible via north and center viewport. Light visible on east wall via south viewport.
		12:11	36.4	~95% west opening slightly reduced. Light still visible reflecting on east wall
		12:25	36.63	~95% unchanged
		12:45	36.97	~90% Ridge on west opening preventing feed from flowing
		12:57	37.17	~90-95% unchanged
		13:15	37.47	~90% west ridge higher than previously observed
		13:37	37.83	~95-98% west opening closing up
		13:56	38.15	~95-98%unchanged in appearance
		14:10	38.38	~98% very small amount of light visible in west area, reflected light on east wall
		14:32	38.75	~98% can only see a little light on west side
		14:49	39.03	~98% very small amount of light visible in west area
		15:04	39.28	~98% no visual change at this time
		15:22	39.58	~98% able to see glass spitting out of west side cone shaped mound
		15:34	39.78	~98% no visual change at this time
		15:49	40.03	~95% cone shaped mound has melter back some exposing melt pool. There is a slight glow in the middle viewport. No visible change to the east.
		16:04	40.28	~95% opening on west side is about 8" around cap is about 6-7" thick on the east side
		16:19	40.53	~95% about the same as last time
		16:34	40.78	~95% west side is still about 8" with cone ridge. Looks messy inside (spider webs). East side can only see light.
3&4	2/9/2012	16:49	41.03	~95% cap appears to be getting thicker 7-9" now, still a slight cone shaped ridge
		17:04	41.28	~95% still a 7-9" cone
		17:19	41.53	~95% able to see more light from east side. West side cone shape mound is attached to ED-TR-05 thermocouple, the cone is about 12-14" high
		17:34	41.78	~95% able to see melt pool via middle viewport, it's inside the cone shaped mound. No other changes.
		17:49	42.03	~95% west side cone shape ridge top has collapsed some liquid feed is flowing over it.

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		18:04	42.28	~95% cap closing up inside cone shaped mound seen through middle viewport. Feed is making it around the mound and into the melt pool
		18:19	42.53	~95% still a large cone shaped ridge around the opening. East side only can see light
		18:24	42.62	~95% still a large cone still can see light on the east side
		18:42	42.92	collapse of cold cap on east side, melter is much darker.
		18:49	43.03	~95% east side still darker, west side still a large cone ridge.
		19:04	43.28	<95% much darker on inside after discharge, opening on west side unchanged
		19:19	43.53	~95% more light emitting from east side. Middle viewport block by cap. Cone shaped ridge has become shiny
		19:34	43.78	~95% same as last observation
		19:49	44.03	~95% east side opening still a large ridge. West side still a small amount of light
		20:04	44.28	~95% east side looks darker opening still large, west side still the same
		20:19	44.53	~98% there is a slight glow by the middle viewport, able to see some light from the east side
		20:34	44.78	~98% no visible change for this observation
		20:49	45.03	~98% west cone shaped mound has grown all the way around. No visible changes to the east side
		21:04	45.28	~98% no change
3&4	2/9/2012	21:19	45.53	~98% cone shaped mound has closed up at the top. Able to see feed boiling over into the small opening
		21:34	45.78	>95% small opening in middle viewport next to thermowell #2. West side mound continues to grow. No change east side. Still large build up on lance #1
		21:49	46.03	>95% there are multiple cone shaped mounds, one is right under the feed tube and 1 on the west side
		22:04	46.28	~95% opening in middle viewport closed up, top of cone shaped ridge has broken off. Large amount of liquid flowing into west opening
		22:17	46.5	~95% only opening available is west bubbling. D1 bubbler coated heavily as well as D2 thermowell #2 with splashes significant ridge around west opening
		22:31	46.73	CC coverage is the same; additionally mound and stalactite exist, viewed from the south port.
		22:44	46.95	CC opening at the west bubbler no longer visible
		23:01	47.23	CC in the same condition, stalactite from the feed tube is gone

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		23:15	47.47	~95% no change from last observation
		23:31	47.73	~95% heavy boiling on the surface in between shots. Base of mound seen on the south port is visible on the north port.
		23:47	48	~95% north viewport starting to get covered with webs from splashes
	2/10/2012	0:18	48.52	~95% light on east visible, west not visible due to webbing in front of viewports
		0:46	48.98	~95% light on east wall visible, west not visible.
		1:05	49.3	~95% east side is still open, west side has no visible light. C2 exposed plenum has significant coverage
		1:18	49.52	~95% judged based on the light. The mound seen in the south no longer exists
		1:36	49.82	~95% NW corner appears to have a little more build up. West side is unchanged. South viewport appears unchanged with respect to visible light.
3&4	2/10/2012	1:48	50.02	~95% no major changes to the cap
		2:05	50.3	East side is not opened wide as viewed from north port
		2:31	50.73	~90-95% with east bubbling open, observed accumulation built up on thermowell #2 starting to fall
		2:45	50.97	~90-95% unchanged since previous observation
		3:10	51.38	~90% appears to have opened up some on the east side and light is more visible on the west wall via the middle viewport
		3:30	51.72	~90% no change in observed conditions
		3:46	51.98	~90% no change in observed conditions
		4:00	52.22	~90% visibility becoming limited, ridge developing on the east opening
		4:15	52.47	~90% no change in observed conditions
		4:59	53.2	~85% obstruction/build up on D1 lance bubbler no longer present
		5:21	53.57	~80% east opening is 90% visible, west opening is not available. Surface has accumulation, not boiling. Mid viewport visibility is restricted.
		5:46	53.98	~90% east opening is slightly closing with small ridge developing at the south
		6:11	54.4	~90% west just now starting to become visible. Slurry merging into east opening in between shots
		6:35	54.8	~90-95% little change from last observation
		6:45	54.97	~90% openings on east and west sides, both have small ridges around openings. No mounds visible. Cap looks fairly flat with feed boiling on the surface
		6:55	55.13	~90-95% conditions unchanged from last observation

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		7:10	55.38	~90-95% conditions unchanged from last observation
		7:35	55.8	~95% ridge building around opening on the east side. Light visible on the west side. Feed collecting and boiling in center of cap.
3&4	2/10/2012	7:50	56.05	~95% Ridge on the east side is blocking the view of the opening. Light is visible on east side. Opening on the west side visible with feed flowing freely into the opening. Feed boiling on top of the melt cap
		8:10	56.38	~95% conditions unchanged from last observation
		8:25	56.63	~95% light visible on both east and west sides. Feed boiling on center surface of cap. Feed flowing into opening on west side.
		8:43	56.93	~95% flat and mildly boiling. Feed flowing to openings.
		8:54	57.12	~95% openings closed up slightly during discharge. Cap is still flat with a mild boiling.
		9:01	57.23	~98% discharge seems to have shifted cap conditions with a ridge now formed over the lance #1bubble rise. Lance #1 air now rising through cap more toward center
		9:20	57.55	~95% opening on east side more visible. Feed flowing into northern most opening on east and west side. Feed boiling on surface of cap.
		9:35	57.8	~95% opening on east side visible with two openings corresponding to the discharge of lance #1, opening closer to lance has a canopy over the top of the opening. Feed is flowing into both openings on the east side as well as the west side. Feed is boiling on the surface of the cap.
		9:50	58.05	~95-98% conditions unchanged from last observation
		10:10	58.38	~98% one opening visible on the east and on the west side. Feed boiling on the surface.
		10:25	58.63	~98% openings on the east and west side visible from the north viewport. Feed boiling on the surface.
		10:40	58.88	~98% Opening visible on the east side. Bridge formed between lance #2 and thermowell #2 blocking the view of the opening on the west side.
		10:55	59.13	~98% light visible on east and west sides, bridge on west side still blocking view of opening on the west side.
3&4	2/10/2012	11:10	59.38	~98% light visible on east and west side. Feed boiling on top of the cap.
		11:25	59.63	~98% visible light on east and west side with feed boiling on top
		11:40	59.88	~98% still visible light on both east and west sides no visual change at this time

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		11:55	60.13	~98% visible light on both sides with boiling feed on top of the cap
		12:10	60.38	~98% opening on east side is visible, west side still visible light
		12:25	60.63	~98% no visible change for this observation
		12:40	60.88	~98% visible light on east and west side with feed boiling on top
		13:05	61.3	~98% light visible on east wall. Opening visible on west side. Feed boiling on top of cap.
		13:45	61.97	~98% small opening on west side only, liquid boiling in that area only.
		14:20	62.55	~98% visual light on the east and west side with boiling feed on top of cap.
		14:49	63.03	~98% web hanging from top of melter makes it hard to see the east side, can see some light from the east side. West side is not visible
		15:05	63.3	~98% the east side is open and the west side is closed
		15:19	63.53	~95% view is blocked by buildup on top of the melter, can see some light coming from both the east and west sides
		15:34	63.78	~98% lots of buildup on top of the melter, view is blocked can see a little light on the west side
		15:49	64.03	~98% west side is still open, can see molten glass shooting out on top of the cap. Very little light can be seen on the east side
		16:04	64.28	~98% not able to see much besides glass spitting up from a small opening on the west side. Some light emitting from the east side
		16:19	64.53	~98% West side closing up, east side still seeing some light
		16:34	64.78	~98% west side open and east side still seeing light
		16:49	65.03	~98% same as before
3&4	2/10/2012	17:09	65.37	~95% view is blocked can see some light on the west side
		17:19	65.53	>95% there is a hole on the east side of the west side mound which is allowing feed to flow into the opening.
		18:11	66.4	~95% West side has opened up, cannot see east side. Pools of wet feed on cap.
		18:34	66.78	~95% opening runs from east to west
		18:49	67.03	~95% opening is still running east to west cap so thick that the melt pool cannot be seen.
		19:05	67.3	~95% open on the west side and it is closed on the east side

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		19:20	67.55	~95% open on the west side of the melter the east side is closed
		19:34	67.78	~95% dark inside opening on east to west
		19:55	68.13	~95% open on the west side of the melter and the east side is closed
		20:19	68.53	~98% opening closed up and is now more towards the center of the cap
		20:34	68.78	~98% see light but the opening looks like it closed up
		20:50	69.05	~98% open on the west side of the melter, the east side is closed
		21:04	69.28	~98% slightly open but I can still see light on the east side
		21:19	69.53	~98% about the same as before
		21:35	69.8	~98% now there is an opening west of middle
		21:55	70.13	~98% open on the west side of the melter, the east side is closed
		22:10	70.38	~98% about the same as before
		22:19	70.53	~98% opening in the middle very small see light on the east side
		22:34	70.78	~100% no light at all
		22:41	70.9	>95% light from splashings
		23:10	71.38	~100% unable to see opening
		23:27	71.67	~100% feed still going in
		23:39	71.87	~100% no light visible in the south viewport, north and mid viewport visibility are restricted with buildup
3&4	2/11/2012	0:02	72.25	~99% cap in east has small opening with a small amount of splashing
		0:16	72.48	All ports are now completely restricted, web build up covering the openings
		0:45	72.97	CC is undetermined due to restricted viewports
		0:56	73.15	North viewport regaining some visibility, there is an opening at thermowell one bubbling
		1:19	73.53	~90-95% east side has opening
		1:27	73.67	~100% cap is closed completely
		1:38	73.85	~95% cap has been fluctuating closed and open fairly frequently, east side has an opening
		1:44	73.95	~95%
		1:56	74.15	~95%
		2:03	74.27	~95% east open
		2:20	74.55	~95% cap remains unchanged
		2:33	74.77	~90-95% glass splashing on west, east remains unchanged

Table 3.4. Operator Observations of Cold Cap (Continued).

Test	Date	Time	Run Time (hours)	Cold Cap Observations
		3:15	75.47	~95% small opening on west wall
		3:30	75.72	~95% small opening on west wall
		3:45	75.97	~80-85% west and east bubbling open partially able to see surface now.
		4:02	76.25	~90-95%east opening is a pretty decent size with some splashing
		4:15	76.47	~95% heavy accumulation on the surface
		4:40	76.88	~80% west opening has a ridge around and 2 openings at the east bubbling, slurry pool on the surface
		4:57	77.17	~90% ridge collapsing on the east side flooding the opening
		5:07	77.33	~90-95% visibility through the north viewport is completely whole, ridge on the west opening is folding over. Mid and south viewports are 100% restricted
		5:31	77.73	~95% ridge on the west, bubbling area no longer exists
		5:55	78.13	~95% glass splashes in the west, slurry on the surface not boiling at this time
		6:10	78.38	~95% stagnant on the surface cap pulsing in between shots.
3&4	2/11/2012	6:25	78.63	~98% flat
		6:48	79.02	~95% observed shots are very small compared to previous observed shots
		7:00	79.22	~95-98% Stopped Feeding
		8:44	80.95	~20%
		9:15	81.47	~0%

Table 3.5. DM1200 Melter System Measured Parameters.

TEST			1			2a		
			avg	min	max	avg	min	max
TEMPERATURE (°C)	Glass	13" from floor E	1156	1126	1172	1154	1144	1167
		15.5" from floor E	1153	1122	1170	1151	1142	1163
		18" from floor E	1152	1120	1168	1150	1141	1162
		27" from floor E	1072	748	1133	1076	989	1131
		13" from floor W	1151	1128	1170	1150	1139	1160
		15.5" from floor W	1151	1125	1170	1151	1139	1162
		18" from floor W	1151	1119	1169	1150	1138	1162
		27" from floor W	974	532	1101	1009	813	1092
	Plenum	Exp. Plenum Tc 17" below lid (A1)	544	442	841	459	427	543
		T/W Plenum Tc 8" below lid (A2)	532	454	806	449	430	518
		Exp. Plenum Tc 17" below lid (B2)	528	410	783	472	439	552
		Exp. Plenum Tc 17" below lid (B3)	523	420	790	459	427	536
		Exp. Plenum Tc 17" below lid (C1)	513	419	795	446	411	514
		Exp. Plenum Tc 17" below lid (C2)	526	351	795	467	423	538
		T/W Plenum Tc 17" below lid (D2)	523	448	777	458	425	525
		Exp. Plenum Tc 17" below lid (D3)	536	437	791	492	440	555
	Discharge	TC 1	994	916	1046	1008	964	1046
		TC 2	1035	954	1077	1050	1023	1075
		Air Flow	263	227	284	257	224	278
		Riser	858	581	1015	848	808	952
	Electrode	East	1127	1068	1154	1126	1113	1138
		West	1137	1031	1163	1142	1119	1153
		Bottom	1026	1005	1040	1013	1006	1019
	Film Cooler	Added Air	124	68	219	107	70	123
		Outlet	377	169	579	329	176	376
Glass Resistance (ohms)			0.072	0.060	0.080	0.080	0.070	0.080
Electrodes	Current (A)		1353	1272	1514	1327	1278	1373
	Voltage (V)		98	86	106	103	98	107
	Power (kW)		133	115	159	137	127	145
Lance Bubblers	1	Rate (lpm)	31	3	32	32	32	32
	2	Rate (lpm)	31	3	32	32	31	33
	Total Bubbling (lpm)		63	7	66	65	64	66

Table 3.5. DM1200 Melter System Measured Parameters (Continued).

TEST			2b			2c		
			avg	min	max	avg	min	max
TEMPERATURE (°C)	Glass	13" from floor E	1155	1145	1163	1151	1106	1185
		15.5" from floor E	1152	1142	1160	1146	1100	1176
		18" from floor E	1151	1141	1159	1143	1098	1175
		27" from floor E	997	816	1102	942	777	1114
		13" from floor W	1148	1130	1160	1149	1135	1181
		15.5" from floor W	1149	1137	1162	1150	1135	1181
		18" from floor W	1148	1137	1161	1149	1134	1174
		27" from floor W	909	506	1064	841	605	1046
	Plenum	Exp. Plenum Tc 17" below lid (A1)	411	367	460	439	310	665
		T/W Plenum Tc 8" below lid (A2)	400	360	440	430	317	649
		Exp. Plenum Tc 17" below lid (B2)	409	347	474	448	306	687
		Exp. Plenum Tc 17" below lid (B3)	401	347	458	440	306	682
		Exp. Plenum Tc 17" below lid (C1)	387	336	448	428	298	671
		Exp. Plenum Tc 17" below lid (C2)	405	350	464	440	307	686
		T/W Plenum Tc 17" below lid (D2)	394	355	442	435	324	670
		Exp. Plenum Tc 17" below lid (D3)	443	398	495	488	371	684
	Discharge	TC 1	996	949	1048	976	936	1032
		TC 2	1036	998	1082	1015	979	1063
		Air Flow	246	219	278	236	218	267
		Riser	867	810	963	874	848	956
	Electrode	East	1126	1117	1133	1115	1072	1145
		West	1145	1126	1153	1122	1051	1154
		Bottom	1012	1009	1020	1015	990	1044
	Film Cooler	Added Air	97	74	102	97	66	115
		Outlet	295	204	332	292	82	390
Glass Resistance (ohms)			0.080	0.080	0.080	0.079	0.070	0.080
Electrodes	Current (A)		1317	1281	1357	1250	966	1413
	Voltage (V)		106	103	111	100	71	117
	Power (kW)		139	137	146	127	69	161
Lance Bubblers	1	Rate (lpm)	32	32	32	22	4	32
	2	Rate (lpm)	32	32	32	22	4	32
	Total Bubbling (lpm)		65	65	65	46	9	65

Table 3.5. DM1200 Melter System Measured Parameters (Continued).

TEST			2d			2e		
			avg	min	max	avg	min	max
TEMPERATURE (°C)	Glass	13" from floor E	1154	1124	1170	1156	1146	1161
		15.5" from floor E	1151	1113	1166	1153	1142	1158
		18" from floor E	1149	1107	1166	1151	1141	1157
		27" from floor E	987	559	1142	940	697	1133
		13" from floor W	1145	1107	1163	1146	1133	1155
		15.5" from floor W	1146	1113	1170	1147	1136	1155
		18" from floor W	1146	1114	1163	1146	1134	1155
		27" from floor W	855	569	1119	796	615	939
	Plenum	Exp. Plenum Tc 17" below lid (A1)	427	336	582	401	351	501
		T/W Plenum Tc 8" below lid (A2)	425	362	560	394	366	443
		Exp. Plenum Tc 17" below lid (B2)	418	340	561	378	356	411
		Exp. Plenum Tc 17" below lid (B3)	413	329	551	393	352	434
		Exp. Plenum Tc 17" below lid (C1)	393	325	536	371	339	422
		Exp. Plenum Tc 17" below lid (C2)	409	292	561	376	341	433
		T/W Plenum Tc 17" below lid (D2)	398	336	561	384	363	422
		Exp. Plenum Tc 17" below lid (D3)	422	357	571	426	388	474
	Discharge	TC 1	990	915	1035	1000	979	1035
		TC 2	1026	961	1065	1033	1014	1066
		Air Flow	242	218	272	241	225	265
		Riser	880	839	972	882	851	953
	Electrode	East	1123	1074	1145	1120	1112	1128
		West	1135	1058	1167	1132	1119	1149
		Bottom	1033	989	1047	1041	1034	1051
	Film Cooler	Added Air	103	66	118	102	98	107
		Outlet	317	83	395	311	282	354
Glass Resistance (ohms)			0.084	0.080	0.090	0.084	0.080	0.090
Electrodes	Current (A)		1478	1097	1581	1478	1446	1501
	Voltage (V)		126	93	140	125	122	129
	Power (kW)		186	104	213	185	182	191
Lance Bubblers	1	Rate (lpm)	42	16	60	40	40	40
	2	Rate (lpm)	43	16	60	40	40	41
	Total Bubbling (lpm)		87	33	122	82	81	82

Table 3.5. DM1200 Melter System Measured Parameters (Continued).

TEST			2f			2g		
			avg	min	max	avg	min	max
TEMPERATURE (°C)	Glass	13" from floor E	1156	1147	1163	1161	1153	1173
		15.5" from floor E	1152	1143	1158	1156	1149	1169
		18" from floor E	1151	1143	1156	1154	1147	1166
		27" from floor E	894	650	1089	870	670	1073
		13" from floor W	1145	1128	1151	1143	1130	1153
		15.5" from floor W	1146	1133	1151	1143	1130	1153
		18" from floor W	1144	1133	1150	1141	1125	1152
		27" from floor W	746	599	967	573	248	1009
	Plenum	Exp. Plenum Tc 17" below lid (A1)	395	367	440	364	342	393
		T/W Plenum Tc 8" below lid (A2)	385	373	401	359	337	400
		Exp. Plenum Tc 17" below lid (B2)	361	329	394	341	318	365
		Exp. Plenum Tc 17" below lid (B3)	373	335	418	353	328	406
		Exp. Plenum Tc 17" below lid (C1)	364	329	401	344	304	401
		Exp. Plenum Tc 17" below lid (C2)	358	317	415	343	309	389
		T/W Plenum Tc 17" below lid (D2)	383	366	393	352	322	391
		Exp. Plenum Tc 17" below lid (D3)	418	396	435	420	396	458
	Discharge	TC 1	1003	979	1038	1003	981	1040
		TC 2	1036	1014	1068	1036	1017	1070
		Air Flow	244	227	267	243	226	266
		Riser	888	852	956	886	857	956
	Electrode	East	1132	1117	1153	1140	1136	1146
		West	1152	1128	1172	1164	1148	1177
		Bottom	1043	1038	1047	1050	1043	1063
	Film Cooler	Added Air	98	65	104	99	96	104
		Outlet	295	104	334	292	268	321
Glass Resistance (ohms)			0.089	0.080	0.090	0.088	0.080	0.090
Electrodes	Current (A)		1503	1477	1527	1545	1509	1564
	Voltage (V)		130	127	133	133	132	136
	Power (kW)		195	190	201	206	201	207
Lance Bubblers	1	Rate (lpm)	40	40	40	40	40	40
	2	Rate (lpm)	40	40	41	40	40	41
	Total Bubbling (lpm)		82	81	82	82	81	82

Table 3.5. DM1200 Melter System Measured Parameters (Continued).

TEST			3			4		
			avg	min	max	avg	min	max
TEMPERATURE (°C)	Glass	13" from floor E	1153	1038	1191	1157	1139	1172
		15.5" from floor E	1149	1035	1184	1153	1131	1169
		18" from floor E	1147	1038	1181	1151	1128	1167
		27" from floor E	1118	889	1170	1073	579	1161
		13" from floor W	1142	1042	1174	1145	1124	1161
		15.5" from floor W	1143	1041	1176	1146	1120	1163
		18" from floor W	1142	1039	1177	1145	1129	1162
		27" from floor W	1053	647	1163	951	693	1154
	Plenum	Exp. Plenum Tc 17" below lid (A1)	462	251	804	358	303	418
		T/W Plenum Tc 8" below lid (A2)	457	338	771	364	317	437
		Exp. Plenum Tc 17" below lid (B2)	441	279	809	343	175	562
		Exp. Plenum Tc 17" below lid (B3)	456	334	812	377	286	524
		Exp. Plenum Tc 17" below lid (C1)	435	316	789	349	195	426
		Exp. Plenum Tc 17" below lid (C2)	438	273	807	328	112	413
		T/W Plenum Tc 17" below lid (D2)	450	360	785	358	312	433
		Exp. Plenum Tc 17" below lid (D3)	494	308	772	429	308	561
	Discharge	TC 1	1010	796	1082	1064	1045	1097
		TC 2	1055	903	1112	1100	1081	1126
		Air Flow	255	187	285	269	249	285
		Riser	1139	352	2795	895	323	984
	Electrode	East	1125	1008	1144	1133	1118	1164
		West	1109	986	1139	1126	1109	1148
		Bottom	1036	927	1059	1054	1042	1065
	Film Cooler	Added Air	113	71	153	103	66	113
		Outlet	336	83	488	272	79	339
Glass	Density (g/cc)		2.30	2.09	2.49	2.22	2.07	2.31
	Level (" from floor)		30.2	28.0	32.9	30.1	27.6	33.0
	Resistance (ohms)		0.094	0.080	0.130	0.106	0.100	0.110
Electrodes	Current (A)		1426	0	1580	1410	1341	1477
	Voltage (V)		133	0	151	149	143	156
	Power (kW)		196	0	223	210	202	223
Lance Bubblers	1	Rate (lpm)	39	4	45	42	42	43
	2	Rate (lpm)	40	5	46	43	43	44
	Total Bubbling (lpm)		81	10	92	87	86	87

Table 4.1. Measured DM1200 Off-Gas System Parameters.

Test		1&2			3&4		
-		Avg.	Min.	Max.	Avg.	Min.	Max.
Melter	Pressure at Level Detector Port ("water)	-2.2	-3.6	-0.4	-2.6	-3.9	1.3
	Pressure at Instrument Port ("water)	-2.7	-3.8	-0.7	-2.9	-4.2	1.4
	Control Air Flow Rate (scfm)	23.2	3.5	48.8	31.5	1.2	67.8
Film Cooler Differential Pressure (“water)		1.6	0.9	4.7	2.1	0.6	5.7
Transition Line Differential Pressure (“water)		5.3	2.5	15.8	7.1	0.0	16.2
SBS	Differential Pressure (“water)	33.0	27.7	36.7	33.5	26.1	49.5
	Inlet gas pressure (“water)	-9.1	-21.1	-5.6	-11.8	-22.8	0.5
	Outlet gas pressure (“water)	-41.5	-53.1	-36.9	-19.7	-51.1	3.6
	Downcomer Annulus Pressure (psia)	NM	NM	NM	NM	NM	NM
	Inlet gas Temp. (°C)	256	196	455	263	181	ND
	Outlet gas Temp. (°C)	44.4	35.4	51.0	44.4	28.6	49.7
	C. Coil W. Inlet Temp (°C)	20.1	15.9	26.9	21.3	15.8	23.3
	C. Coil W. Outlet Temp (°C)	38.8	30.9	45.4	36.5	23.4	42.0
	Jacket W. Outlet Temp (°C)	40.8	32.6	46.5	39.1	25.6	43.6
	Sump Temp. (°C)	39.5	30.9	46.9	38.7	24.0	43.9
	Offgas Downcomer Temp @3” (°C)	202	162	377	206	152	303
	Offgas Downcomer Temp @8” (°C)	216	173	399	221	162	402
	Offgas Downcomer Temp @13” (°C)	219	176	402	224	166	402
	Offgas Downcomer Temp @18” (°C)	213	171	396	218	161	317
	Offgas Downcomer Temp @23” (°C)	211	170	390	215	159	311
	Offgas Downcomer Temp @28” (°C)	208	168	380	212	158	303
	Offgas Downcomer Temp @33” (°C)	205	166	369	207	156	295
	Offgas Downcomer Temp @38” (°C)	204	165	366	203	151	291
	Offgas Downcomer Temp @43” (°C)	198	162	315	187	121	285
	Offgas Downcomer Temp @48” (°C)	183	129	281	142	86	276
	Offgas Downcomer Temp @53” (°C)	122	75.2	215	94	70	238
	C. Coil/Jacket W. Flow Rate (gal/min)	16.2	5.0	29.8	27.6	11.7	29.8
	Recirc. pump discharge Temp (°C)	44.5	35.5	48.3	44.4	29.6	47.6
	Recirc. pump discharge Pressure (psi)	31.1	20.3	33.2	28.4	18.0	33.7
WESP	Differential Pressure (“water)	4.3	1.2	5.7	4.4	2.1	6.1
	Inlet gas Temp. (°C)	44.1	34.6	50.9	42.1	29.4	48.3
	Outlet gas Temp. (°C)	44.3	19.8	49.3	44.9	19.9	48.2
	Wet Gas Flow Rate (scfm)	312	229	349	298	10.7	342
	Voltage (kV)	30.6	0.1	33.0	30.1	0.1	31.4
	Current (mA)	10.6	0.0	16.8	10.9	0.0	16.8
HEME #1	Differential Pressure (“water)	2.0	1.3	2.4	2.0	1.0	2.7
	Outlet gas Temp. (°C)	42.2	31.6	47.7	42.9	30.6	45.9
HEPA 1	Differential Pressure (“water)	0.5	0.4	0.6	0.5	0.4	0.7
	Outlet Gas Temp. (°C)	71.9	40.3	74.8	72.7	41.7	74.6
TCO	Inlet Gas Temp. (°C)	92.0	62.2	95.7	93.8	65.9	97.1
PBS	Inlet Gas Temp. (°C)	86.7	68.4	89.3	88.2	66.0	91.9
	PBS Sump Temp. (°C)	NM	NM	NM	NM	NM	NM
	Differential Pressure (“water)	5.3	2.9	6.5	5.5	2.6	7.7
HEME #2	Inlet Gas Temp. (°C)	28.8	23.2	34.1	30.1	23.9	32.2
	Outlet Gas Temp. (°C)	29.2	23.5	36.8	30.2	24.4	31.9
Exhaust Stack Absolute Pressure (“water)		-8.8	-9.2	-8.5	-8.9	-9.2	-8.7

NM: not measured

Table 4.2. Off-Gas Solution Volumes during Tests 1 & 2.

Type of Sample	Number of Blow-downs	Total Blow-down Volume (gal)
SBS	33	1204
WESP	10	230
HEME 1	NM	NM
PBS	13	521

NM: not measured (failed instrument)

Table 4.3. Off-Gas Solution Volumes during Tests 3 & 4.

Type of Sample	Number of Blow-downs	Total Blow-down Volume (gal)
SBS	42	1864
WESP	8	234
HEME 1	NM	NM
PBS	9	300

NM: not measured (failed instrument)

Table 5.1. Measured Feed Sample Properties.

Test	Source	Date	Name	% Water	pH	Density (g/ml)	Glass Yield (g/l)	Glass Yield Measured (kg/kg)	Glass Yield Target (kg/kg)	Glass Yield %Dev.
HLW AZ-101	As received	1/18/12	NOAH-C2754	51.12	11.14	1.50	767	0.511	NC	NC
	Feed Line to Melter	1/25/12	F-12R-29A	64.78	10.72	1.25	379	0.303	0.314	-3.57
	Feed Line to Melter	1/31/12	F-12R-80A	64.33	10.71	1.19	361	0.304	0.314	-3.31
	Feed Line to Melter	2/1/12	F-12R-113A	64.46	10.68	1.23	374	0.304	0.314	-3.18
	Feed Line to Melter	2/2/12	F-12R-147A	64.38	10.69	1.26	387	0.307	0.314	-2.29
	Feed Line to Melter	2/3/12	F-12S-21A	63.48	10.77	1.30	400	0.307	0.314	-2.10
HWI-Al-19	As received, diluted	1/30/12	F-12R-69A	50.16	8.27	1.84	785	0.427	NC	NC
	As received, diluted	1/31/12	F-12R-69A-1	67.04	8.89	1.24	349	0.281	0.315	-10.73
	As received, diluted	2/1/12	F-12R-127A	65.23	9.17	1.26	379	0.301	0.315	-4.27
	Mixing Tank	2/6/12	F-12S-90A	66.55	9.04	1.26	363	0.288	0.315	-8.63
	Mixing Tank	2/7/12	F-12S-96A	63.78	8.95	1.33	417	0.314	0.315	-0.41
	Feed Line to Melter	2/8/12	F-12S-115A	58.43	8.94	1.37	492	0.359	0.315	14.10
	Feed Line to Melter	2/10/12	F-12T-35A	62.05	9.11	1.31	431	0.329	0.315	4.51

NC – Not calculated

Table 5.2. XRF Analyzed Compositions for the Vitrified Melter Feed Samples; AZ-101 Composition.

Constituent	Target	As-Received Feed	Melter Feed Samples						
		NOAH-C2754	F-12R-29A	F-12R-80A	F-12R-113A	F-12R-147A	F-12S-21A	Average	% Dev.
Al_2O_3	5.21	5.78	6.02	5.97	6.53	6.19	6.23	6.19	18.75
B_2O_3	11.91*	10.78*	10.64*	11.04*	11.49*	11.39*	11.35*	11.18	-6.11
BaO	0.02	<0.01	0.02	<0.01	0.04	0.03	0.03	NC	NC
Bi_2O_3	§	0.01	0.11	0.01	0.05	0.04	0.04	0.05	NC
CaO	0.28	0.37	0.39	0.35	0.43	0.37	0.38	0.38	NC
CdO	0.06	0.08	<0.01	0.05	0.06	0.06	0.06	NC	NC
Cr_2O_3	§	<0.01	0.02	0.01	0.04	0.03	0.04	0.03	NC
CuO	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	NC
F	0.04#	0.04#	0.04#	0.04#	0.04#	0.04#	0.04#	0.04	NC
Fe_2O_3	12.26	12.10	12.32	11.91	11.66	11.82	12.23	11.99	-2.22
K_2O	0.03	<0.01	0.07	0.09	<0.01	0.09	0.07	0.08	NC
La_2O_3	0.41	0.45	0.51	0.58	0.45	0.41	0.43	0.48	NC
Li_2O	3.52*	3.17*	3.11*	3.08*	3.38*	3.43*	3.39*	3.28	-6.88
MgO	0.11	0.27	0.23	0.26	0.25	0.28	0.26	0.26	NC
MnO	0.17	0.18	0.14	0.16	0.11	0.15	0.15	0.14	NC
Na_2O	11.65	11.24	11.10	11.73	12.29	12.06	12.14	11.87	1.85
Nd_2O_3	0.31	0.29	0.30	0.29	0.28	0.28	0.29	0.28	NC
NiO	0.62	0.61	0.65	0.63	0.69	0.71	0.70	0.67	NC
P_2O_5	§	0.02	0.06	0.02	0.05	0.02	0.03	0.04	NC
PbO	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	NC
SiO_2	47.40	49.14	48.70	48.47	46.90	47.10	46.62	47.56	0.33
SO_3	0.08	0.16	0.15	0.18	0.14	0.17	0.13	0.15	NC
SrO	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	NC
TiO_2	§	0.09	0.08	0.07	0.07	0.07	0.08	0.07	NC
ZnO	2.02	1.74	1.75	1.70	1.74	1.84	1.83	1.77	-12.29
ZrO_2	3.82	3.39	3.50	3.30	3.24	3.34	3.38	3.35	-12.23
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC

§ - Not a target constituent
* - DCP-AES result
# - Target value
NA – Not calculated

Table 5.3. XRF Analyzed Compositions for the Vitrified Melter Feed Samples; HWI-Al-19 Composition.

Constituent	Target	As-Received Feed			Melter Feed Samples						
		F-12R-69A	F-12R-69A-1	F-12S-127A	F-12S-90A	F-12S-96A	F-12S-115A	F-12S-151A	F-12T-35A	Average	% Dev.
Al_2O_3	23.97	20.17	19.91	22.61	23.04	23.19	23.51	23.79	23.92	23.49	-2.00
B_2O_3	19.19	18.59*	19.26*	17.68*	19.17*	19.34*	18.54*	17.96*	18.47*	18.70	-2.57
BaO	0.05	0.07	0.05	0.06	0.05	0.07	0.07	0.06	0.07	0.06	NC
Bi_2O_3	1.14	1.19	1.28	1.04	1.10	1.13	1.08	1.06	1.18	1.11	-2.67
CaO	5.58	5.38	5.57	4.96	4.92	4.91	4.91	5.04	5.10	4.98	-10.82
CdO	0.02	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	NC
Cr_2O_3	0.52	0.50	0.54	0.40	0.46	0.44	0.45	0.41	0.46	0.45	NC
F	0.67	0.67#	0.67#	0.67#	0.67#	0.67#	0.67#	0.67#	0.67#	0.67	NC
Fe_2O_3	5.90	6.05	6.44	5.32	5.75	5.48	5.76	5.42	5.87	5.66	-4.13
K_2O	0.14	0.17	0.19	0.10	0.16	0.14	0.18	0.04	0.15	0.14	NC
Li_2O	3.57	3.86*	3.82*	3.46*	3.63*	3.64*	3.50*	3.46*	3.45*	3.54	-0.95
MgO	0.12	0.20	0.19	0.24	0.24	0.18	0.26	0.18	0.24	0.22	NC
MnO	§	0.03	0.03	0.03	0.02	0.03	0.05	0.04	0.03	0.03	NC
Na_2O	9.58	11.36	10.71	10.32	10.63	10.87	10.35	10.14	9.96	10.39	8.47
Nd_2O_3	§	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.02	NC	NC
NiO	0.40	0.42	0.46	0.34	0.38	0.37	0.38	0.36	0.39	0.38	NC
P_2O_5	1.05	1.20	1.15	1.20	1.17	1.21	1.04	1.20	1.09	1.14	8.81
PbO	0.41	0.38	0.42	0.36	0.36	0.36	0.37	0.36	0.39	0.37	NC
SiO_2	27.00	28.94	28.48	30.39	27.40	27.09	27.86	28.94	27.69	27.80	2.95
SO_3	0.20	0.21	0.18	0.22	0.16	0.21	0.23	0.19	0.21	0.20	NC
TiO_2	0.01	0.12	0.11	0.10	0.11	0.11	0.12	0.10	0.10	0.11	NC
ZnO	0.08	0.09	0.10	0.09	0.12	0.09	0.13	0.10	0.09	0.11	NC
ZrO_2	0.39	0.39	0.41	0.38	0.43	0.40	0.49	0.41	0.41	0.43	NC
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC

§ - Not a target constituent
* - DCP-AES result
\# - Target value
NA – Not calculated

Table 5.4. Listing of Glass and Discharged Masses during DM1200 Tests.

Test	Date	Name	Mass (kg)	Cumulative Mass (kg)
1	1/30/2012	G-12R-67A	500.5	500.5
		G-12R-68A		
		G-12R-68B		
		G-12R-69A		
		G-12R-70A		
		G-12R-71A		
	1/31/2012	G-12R-74A		
		G-12R-74B	474.0	974.5
		G-12R-75A		
		G-12R-76A		
		G-12R-80A		
2		G-12R-81A		
		G-12R-91A		
		G-12R-93A		
		G-12R-95A		
		G-12R-97A	482.5	1457.0
	2/1/2012	G-12R-98A		
		G-12R-98B		
		G-12R-108A		
		G-12R-108B		
		G-12R-109A		
		G-12R-111A		
		G-12R-111B		
		G-12R-112A		
		G-12R-114A	505.5	1962.5
		G-12R-123A		
		G-12R-125A		
		G-12R-127A		
		G-12R-127B		
		G-12R-129A		
	2/2/2012	G-12R-129B		
		G-12R-138A		
		G-12R-141A	486.0	2448.5
		G-12R-143A		
		G-12R-145A		
		G-12R-147A		
		G-12R-148A		
		G-12R-149A		

Table 5.4. Listing of Glass and Discharged Masses during DM1200 Tests (Continued).

Test	Date	Name	Mass (kg)	Cumulative Mass (kg)
2	2/2/2012	G-12R-150A	496.5	2945.0
		G-12S-15A		
		G-12S-19A		
	2/3/2012	G-12S-20A		
		G-12S-21A		
		G-12S-30A	496.5	3441.5
		G-12S-31A		
		G-12S-33A		
		G-12S-35A		
		G-12S-36A		
		G-12S-36B		
		G-12S-37A	481.0	3922.5
		G-12S-38A		
		G-12S-39A		
		G-12S-48A		
		G-12S-49A		
2/6/2012		G-12S-87A	384.0	4306.5
		G-12S-90A		
		G-12S-91A		
3	2/8/2012	G-12S-112A	490.5	4797.0
		G-12S-114A		
		G-12S-114B		
		G-12S-114C		
		G-12S-126A		
		G-12S-129A	488.0	5285.0
		G-12S-130A		
		G-12S-131A		
		G-12S-133A		
		G-12S-133B		
	2/9/2012	G-12S-143A	496.5	5781.5
		G-12S-144A		
		G-12S-144B		
		G-12S-146A		
		G-12S-148A		
		G-12S-150A	491.0	6272.5
		G-12S-150B		
		G-12T-17A		
		G-12T-17B		
		G-12T-18A		

Table 5.4. Listing of Glass and Discharged Masses during DM1200 Tests (Continued).

<table>
<tr><th>Test</th><th>Date</th><th>Name</th><th>Mass (kg)</th><th>Cumulative Mass (kg)</th></tr>
<tr><td rowspan="5">3</td><td rowspan="4">2/9/2012</td><td>G-12T-20A</td><td rowspan="5">482.0</td><td rowspan="5">6754.5</td></tr>
<tr><td>G-12T-20B</td></tr>
<tr><td>G-12T-21A</td></tr>
<tr><td>G-12T-22A</td></tr>
<tr><td rowspan="16">2/10/2012</td><td>G-12T-31A</td></tr>
<tr><td rowspan="20">4</td><td>G-12T-33A</td><td rowspan="5">476.0</td><td rowspan="5">7230.5</td></tr>
<tr><td>G-12T-33B</td></tr>
<tr><td>G-12T-35A</td></tr>
<tr><td>G-12T-37A</td></tr>
<tr><td>G-12T-37B</td></tr>
<tr><td>G-12T-39A</td><td rowspan="5">467.5</td><td rowspan="5">7698.0</td></tr>
<tr><td>G-12T-51A</td></tr>
<tr><td>G-12T-51B</td></tr>
<tr><td>G-12T-52A</td></tr>
<tr><td>G-12T-53A</td></tr>
<tr><td>G-12T-54A</td><td rowspan="5">445.0</td><td rowspan="5">8143.0</td></tr>
<tr><td>G-12T-55A</td></tr>
<tr><td>G-12T-64A</td></tr>
<tr><td>G-12T-64B</td></tr>
<tr><td>G-12T-64C</td></tr>
<tr><td rowspan="5">2/11/2012</td><td>G-12T-65A</td><td rowspan="5">470.5</td><td rowspan="5">8613.5</td></tr>
<tr><td>G-12T-67A</td></tr>
<tr><td>G-12T-67B</td></tr>
<tr><td>G-12T-67C</td></tr>
<tr><td>G-12T-69A</td></tr>
</table>

Table 5.5. XRF Analyzed Compositions for Glass Discharged from the DM1200 while Processing the HLW AZ-101 Composition (wt%).

Mass (kg)	500.5	974.5	1457.0	1962.5	2448.5	2945.0	3441.5	3922.5	4306.5		
Sample	G-12R-74A	G-12R-95A	G-12R-112A	G-12R-138A	G-12R-149A	G-12S-21A	G-12S-36B	G-12S-49A	G-12S-91A	Target	% Dev.
Al_2O_3	6.30	6.23	6.26	6.21	6.27	6.19	6.30	6.14	6.15	5.21	18.00
B_2O_3*	9.51$	10.03	10.45	10.78	11.03	11.23	11.38	11.50	11.46$	11.91	-3.75
BaO	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	0.04	<0.01	0.02	NC
Bi_2O_3	0.22	0.18	0.15	0.12	0.11	0.09	0.08	0.06	0.06	§	NC
CaO	1.83	1.52	1.31	1.05	0.94	0.82	0.74	0.66	0.58	0.28	NC
CdO	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.05	0.07	0.06	NC
Cr_2O_3	0.40	0.29	0.24	0.24	0.17	0.15	0.11	0.10	0.09	§	NC
CuO	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	NC
F	0.04&	0.04&	0.04&	0.04&	0.04&	0.04&	0.04&	0.04&	0.01#	0.04	NC
Fe_2O_3	7.97	8.64	9.06	9.88	10.20	10.64	11.38	11.18	11.29	12.26	-7.95
K_2O	0.12	0.14	0.04	0.17	0.14	0.13	0.11	<0.01	0.11	0.03	NC
La_2O_3	0.14	0.19	0.25	0.31	0.28	0.32	0.32	0.39	0.34	0.41	NC
Li_2O*	1.03$	1.57	2.00	2.35	2.61	2.82	2.98	3.10	2.96$	3.52	-15.91
MgO	1.15	0.96	0.78	0.67	0.55	0.50	0.44	0.41	0.40	0.11	NC
MnO	0.25	0.26	0.22	0.21	0.19	0.20	0.20	0.20	0.20	0.17	NC
Na_2O	19.12	17.59	16.63	14.99	15.02	14.25	12.96	13.16	13.19	11.65	13.18
Nd_2O_3	0.10	0.11	0.18	0.18	0.18	0.19	0.23	0.22	0.25	0.31	NC
NiO	0.67	0.64	0.65	0.65	0.66	0.71	0.73	0.67	0.65	0.62	NC
P_2O_5	0.33	0.26	0.20	0.18	0.13	0.11	0.12	0.09	0.08	§	NC
PbO	0.04	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.04	0.03	NC
SiO_2	44.35	45.26	45.66	45.97	45.69	45.86	45.96	46.36	46.55	47.40	-1.80
SO_3	0.11	0.11	0.12	0.14	0.15	0.14	0.14	0.14	0.15	0.08	NC
SrO	0.04	0.04	0.04	0.04	0.03	0.03	0.04	0.03	0.03	0.03	NC
TiO_2	0.98	0.79	0.64	0.51	0.44	0.35	0.28	0.25	0.20	§	NC
ZnO	2.63	2.37	2.19	2.18	2.04	2.05	2.05	1.95	1.90	2.02	-5.87
ZrO_2	2.65	2.70	2.80	3.00	3.00	3.09	3.30	3.21	3.24	3.82	-15.19
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC

* Values calculated from B_2O_3 and Li_2O analysis by DCP-AES on the first discharged glass sample and target values using a simple well stirred tank model.
§ - Not a target constituent
$ - DCP-AES results
& -Target values
\# - F was measured by XRF

Table 5.6. XRF Analyzed Compositions for Glass Discharged from the DM1200 while Processing the HLW HWI-Al-19 Composition (wt%).

Mass (kg)	4797.0	5285.0	5781.5	6272.5	6754.5	7230.5	7698.0	8143.0	8613.5		
Sample	G-12S-126A	G-12S-133B	G-12S-148A	G-12T-18A	G-12T-31A	G-12T-37B	G-12T-53A	G-12T-64C	G-12T-69A	Target	% Dev.
Al_2O_3	10.50	12.55	14.86	16.62	18.00	19.41	20.36	20.95	21.75	23.97	-9.26
B_2O_3*	13.20	14.53	15.59	16.40	17.02	17.49	17.86	18.13	18.36	19.19	-4.33
BaO	0.04	0.05	0.03	0.03	0.05	0.05	0.06	0.06	0.06	0.05	NC
Bi_2O_3	0.27	0.43	0.58	0.68	0.76	0.86	0.90	0.99	1.05	1.14	-7.79
CaO	1.55	2.13	2.93	3.18	3.62	3.94	4.11	4.34	4.46	5.58	-19.98
CdO	0.06	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.02	NC
Cr_2O_3	0.15	0.20	0.28	0.29	0.29	0.32	0.32	0.36	0.37	0.52	NC
CuO	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	§	NC
F	0.06	0.10#	0.14	0.18#	0.20	0.22#	0.24	0.26#	0.31#	0.67	NC
Fe_2O_3	9.44	8.81	8.39	7.66	7.24	6.91	6.58	6.48	6.32	5.90	7.13
K_2O	0.13	0.15	0.12	0.11	0.13	0.14	0.11	0.14	0.15	0.14	NC
La_2O_3	0.28	0.24	0.17	0.16	0.13	0.09	0.12	0.07	0.04	§	NC
Li_2O*	3.10	3.20	3.29	3.35	3.40	3.44	3.47	3.49	3.50	3.57	-1.84
MgO	0.36	0.32	0.31	0.28	0.24	0.23	0.26	0.19	0.23	0.12	NC
MnO	0.15	0.13	0.12	0.09	0.09	0.07	0.07	0.05	0.05	§	NC
Na_2O	12.92	12.31	11.45	11.21	11.05	10.51	10.37	10.49	10.09	9.58	5.30
Nd_2O_3	0.17	0.16	0.11	0.10	0.09	0.06	0.05	0.04	0.04	§	NC
NiO	0.54	0.52	0.49	0.46	0.42	0.39	0.37	0.37	0.36	0.40	NC
P_2O_5	0.30	0.45	0.62	0.71	0.83	0.86	0.93	0.93	1.01	1.05	-4.15
PbO	0.10	0.15	0.21	0.23	0.27	0.29	0.30	0.33	0.34	0.41	NC
SiO_2	42.54	39.81	37.12	35.58	33.86	32.71	31.67	30.71	30.03	27.00	11.19
SO_3	0.16	0.16	0.18	0.16	0.16	0.16	0.20	0.18	0.19	0.20	NC
SrO	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	§	NC
TiO_2	0.17	0.16	0.16	0.13	0.13	0.13	0.14	0.13	0.12	0.01	NC
ZnO	1.35	1.17	0.93	0.77	0.63	0.51	0.43	0.36	0.32	0.08	NC
ZrO_2	2.44	2.16	1.83	1.54	1.32	1.13	1.00	0.88	0.80	0.39	NC
Sum	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	NC

* Values calculated from B_2O_3 and Li_2O analysis by DCP-AES on the last discharged glass sample from previous test and target values using a simple well stirred tank model.
§ - Not a target constituent
\# - F was measured by XRF, values for other samples calculated by interpolation

Table 6.1. Results from Melter Off-Gas Emission Samples Taken While Processing the AZ-101 Composition.

		Test 2a 1/31/2012 15:36 – 16:36 18.6% Moisture, 102% Isokinetic				Test 2g 2/3/2012 16:13 – 17:09 30.2% Moisture, 101% Isokinetic			
		Feed# (mg/min)	Output (mg/min)	% Emitted	DF	Feed# (mg/min)	Output (mg/min)	% Emitted	DF
Particulate & Gas	Total$	563007	4101	0.73	137	1029337	7899	0.77	130
	Al	13643	89.9	0.66	152	24944	178	0.71	140
	B	18296	283.3	1.55	64.6	33451	605	1.81	55.3
	Ba	89	0.79	0.90	112	162	1.27	0.78	128
	Ca	991	17.0	1.71	58.3	1811	24.4	1.35	74.3
	Cd	266	2.50	0.94	106	486	7.73	1.59	62.9
	Cu	119	0.31	0.26	383	217	0.87	0.40	248
	F*	198	51.1	25.82	3.9	362	79.1	21.9	4.6
	Fe	42435	420	0.99	101	77584	987	1.27	78.6
	K	123	16.7	13.57	7.4	225	13.7	6.08	16.5
	Li	8094	44.9	0.56	180	14798	111	0.75	133
	Mg	328	9.53	2.90	34.4	600	22.2	3.70	27.0
	Mn	652	1.51	0.23	431	1192	2.91	0.24	409
	Na	42822	502	1.17	85.3	78291	952	1.22	82.2
	Ni	2373	20.1	0.85	118	4338	35.1	0.81	124
	Pb	138	3.48	2.52	39.6	252.0	6.79	2.70	37.1
	S*	159	52.4	33.03	3.0	290	28.3	9.75	10.3
	Si	109681	447	0.41	245	200529	707	0.35	284
	Zn	8033	77.1	0.96	104	14687	173	1.18	84.7
	Zr	13998	35.4	0.25	396	25593	41.8	0.16	612
Gas	B	18296	53.7	0.29	341	33451	198	0.59	169
	F	198	< 0.10	< 0.05	> 1980	362	9.94	2.74	36.4
	S	159	34.4	21.69	4.6	290	119	40.9	2.4

$ - From gravimetric analysis of filters and particulate nitric acid rinses
# - Feed rate calculated from target composition and total glass production rate
* - Calculated from analysis of water dissolution of filter particulate

Table 6.2. Results from Melter Off-Gas Emission Samples Taken While Processing the High Aluminum Composition.

		Test 3 2/9/12 15:14 – 16:04 33.2% Moisture, 110% Isokinetic				Test 4 2/10/12 14:41 – 16:17 32.0% Moisture, 110% Isokinetic			
		Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF	Feed[#] (mg/min)	Output (mg/min)	% Emitted	DF
Particulate & Gas	Total[$]	1073312	3551	0.33	302	1226509	1418	0.12	865
	Al	121417	390	0.32	311	138747	128	0.09	1081
	B	57024	195	0.34	293	65163	74.6	0.11	873
	Ba	429	1.47	0.34	292	490	0.38	0.08	1286
	Bi	9791	41.1	0.42	238	11189	18.2	0.16	614
	Ca	38190	48.8	0.13	782	43641	21.1	0.05	2064
	Cd	171	4.67	2.72	36.7	196	3.15	1.61	62.3
	Cr	3407	18.5	0.54	184	3893	16.5	0.42	235
	F*	6415	293	4.56	21.9	7331	114	1.56	64.1
	Fe	39502	143	0.36	276	45141	40.6	0.09	1113
	K	1113	12.4	1.11	89.9	1272	8.08	0.64	157
	Li	15879	64.9	0.41	245	18145	31.2	0.17	582
	Mg	693	4.95	0.71	140	792	1.76	0.22	450
	Na	68057	354	0.52	192	77771	166	0.21	469
	Ni	3010	8.55	0.28	352	3439	1.92	0.06	1792
	P	4390	7.24	0.16	607	5016	2.02	0.04	2483
	Pb	3644	24.7	0.68	148	4165	14.1	0.34	296
	S*	767	96.9	12.6	7.9	877	58.8	6.70	14.9
	Si	120852	222	0.18	544	138101	59.5	0.04	2323
	Ti	57	2.62	4.56	21.9	66	0.72	1.09	91.6
	Zn	615	4.85	0.79	127	703	1.27	0.18	553
	Zr	2764	6.15	0.22	449	3159	1.07	0.03	2941
Gas	B	57024	788	1.38	72.4	65163	810	1.24	80.5
	F	6415	1034	16.1	6.2	7331	1170	16.0	6.3
	S	767	212	27.7	3.6	877	225	25.7	3.9

[$] - From gravimetric analysis of filters and particulate nitric acid rinses
[#] - Feed rate calculated from target composition and total glass production rate
* - Calculated from analysis of water dissolution of filter particulate

Table 6.3. Concentrations [ppmv] of Selected Species in Off-Gas Measured by FTIR Spectroscopy while Processing the AZ-101 Composition.

	Melter outlet			SBS outlet			WESP outlet			PBS outlet		
	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.
N_2O	5.1	2.1	7.3	6.1	3.8	12.6	4.3	<1.0	16.6	7.2	5.6	11.0
NO	86.0	32.1	144	97.7	48.7	217	59.8	<1.0	265	123	91.1	169
NO_2	2.7	<1.0	4.4	1.0	<1.0	2.7	2.67	<1.0	11.6	3.2	2.6	4.3
NH_3	34.5	26.2	46.0	29.0	21.0	50.6	19.8	<1.0	37.3	15.9	14.4	16.7
H_2O%	26.1	13.2	46.1	9.8	8.3	13.9	7.6	2.7	20.0	4.1	3.7	4.3
CO_2 %	0.49	0.20	0.73	0.60	0.39	1.13	0.42	0.05	1.61	0.69	0.55	0.83
Nitrous Acid	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Nitric Acid	<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	1.1	<1.0	2.4	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
CO	12.8	5.2	21.4	16.1	8.9	38.9	11.0	<1.0	36.5	18.7	14.4	23.2
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	2.6	1.4	5.5	1.5	1.0	2.5	<1.0	<1.0	1.9	1.6	1.4	1.8

Table 6.4. Concentrations [ppmv] of Selected Species in Off-Gas Measured by FTIR Spectroscopy while Processing the High Aluminum Composition.

	Melter outlet			SBS outlet			WESP outlet			PBS inlet			PBS outlet		
	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.
N_2O	6.3	3.3	9.3	9.1	5.3	20.5	7.5	<1.0	15.4	7.0	4.6	10.2	7.8	5.0	11.8
NO	439	187	664	517	324	1232	396	1.2	747	381	244	550	407	272	629
NO_2	41.0	12.0	73.4	76.1	38.9	271	60.5	2.6	155	56.4	34.4	94.5	64.2	36.0	108
NH_3	5.3	1.8	26.2	1.8	<1.0	3.0	<1.0	<1.0	3.1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
H_2O%	33.0	18.4	73.0	8.7	6.0	11.5	8.2	3.8	13.2	8.0	5.5	10.8	3.9	3.5	4.8
CO_2 %	0.55	0.27	0.90	0.73	0.40	2.12	0.56	0.05	1.16	0.53	0.40	1.13	0.60	0.34	1.14
Nitrous Acid	1.1	<1.0	2.1	1.2	<1.0	5.6	<1.0	<1.0	3.1	1.4	1.0	2.2	<1.0	<1.0	<1.0
Nitric Acid	<1.0	<1.0	<1.0	<1.0	<1.0	7.9	<1.0	<1.0	1.2	<1.0	<1.0	1.03	<1.0	<1.0	<1.0
HCN	1.1	<1.0	2.1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
CO	13.2	5.2	27.5	17.2	3.9	66.4	16.1	<1.0	55.6	14.1	7.2	24.3	14.9	6.5	36.7
HCl	<1.0	<1.0	3.1	<1.0	<1.0	6.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
HF	10.6	3.5	77.4	6.3	4.0	19.9	1.5	<1.0	2.7	5.1	4.4	5.6	1.9	1.5	3.3

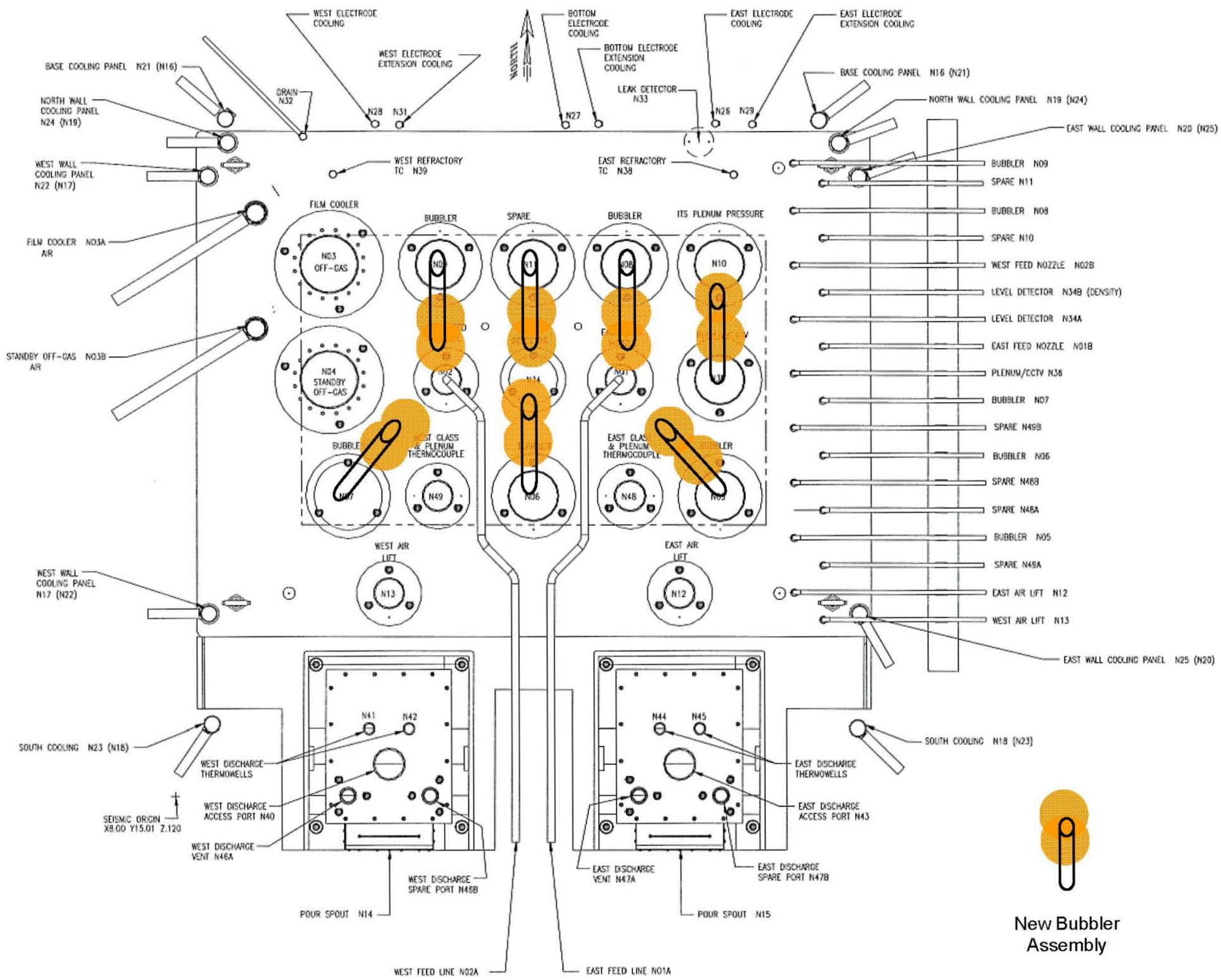

Figure 1.1. Lid diagram for WTP HLW melter.

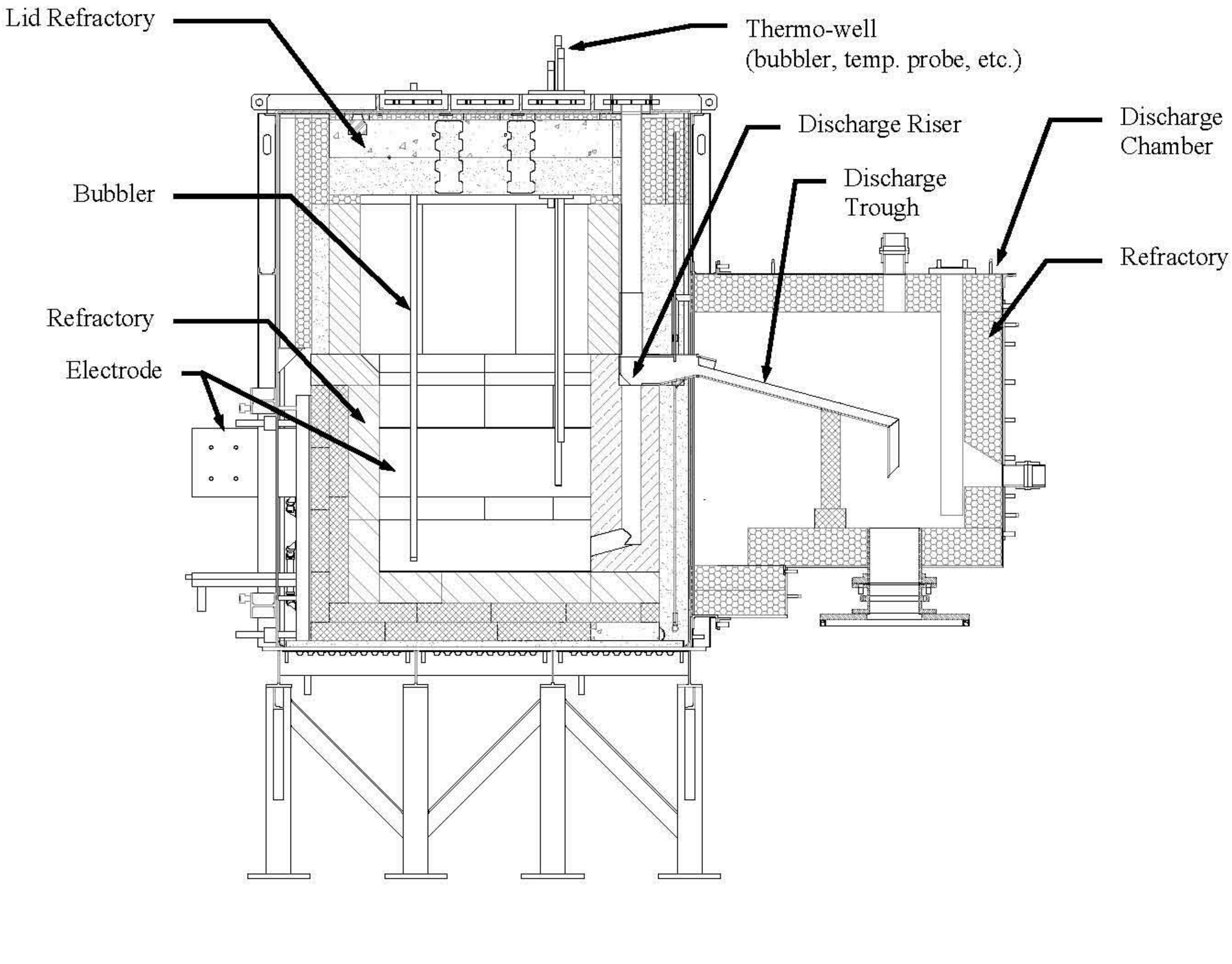

Figure 1.2. Cross-section of the DM1200 melter through the discharge chamber.

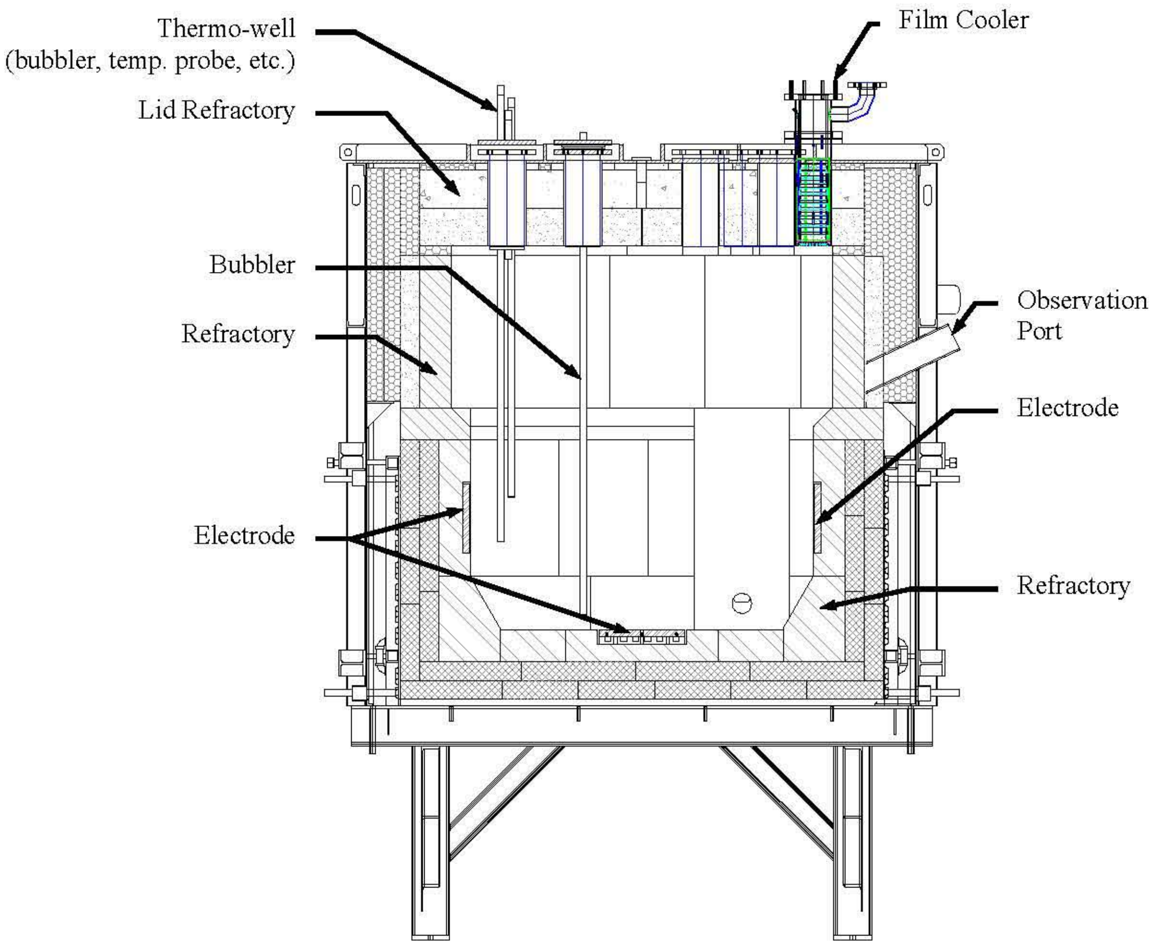

Figure 1.3. Cross-section through the DM1200 melter showing electrodes.

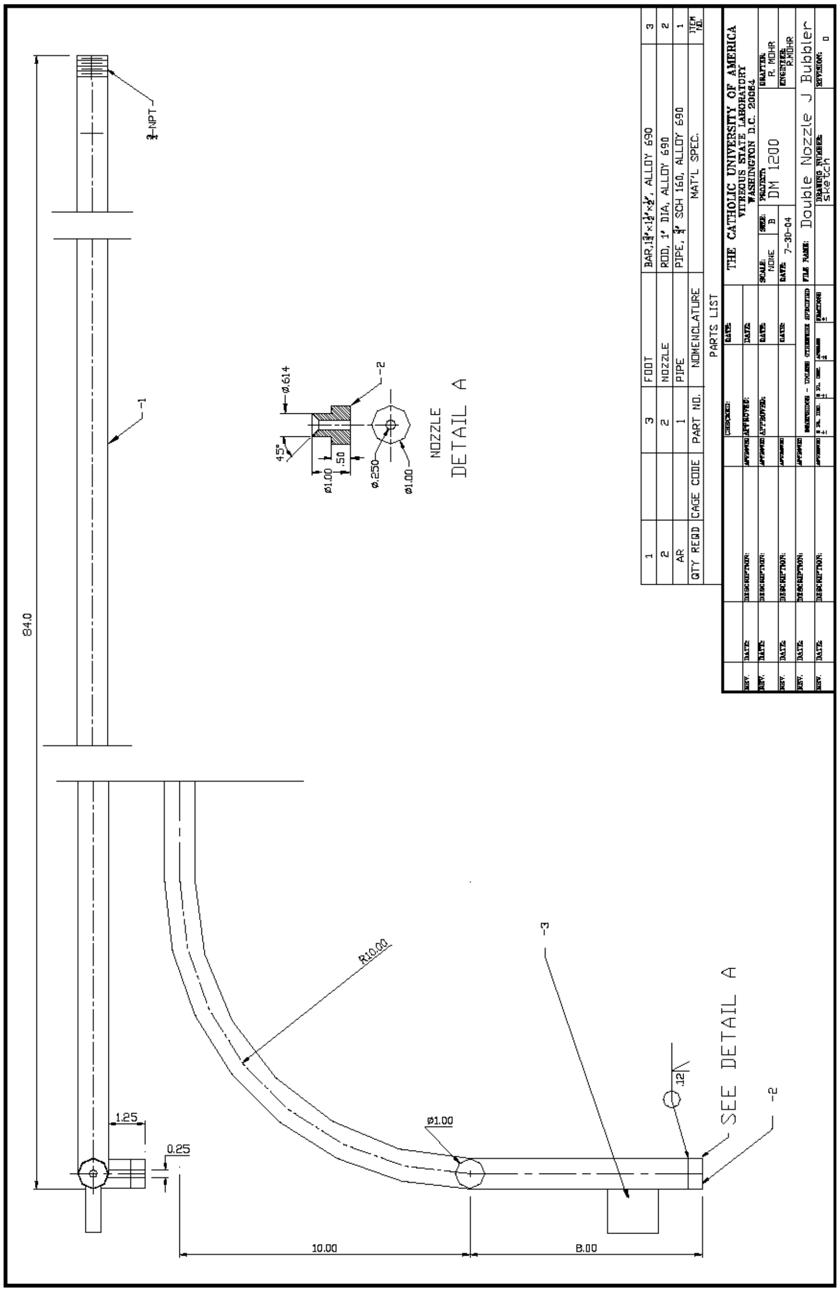

Figure 1.4. Specifications of Double Outlet "J" Bubbler.

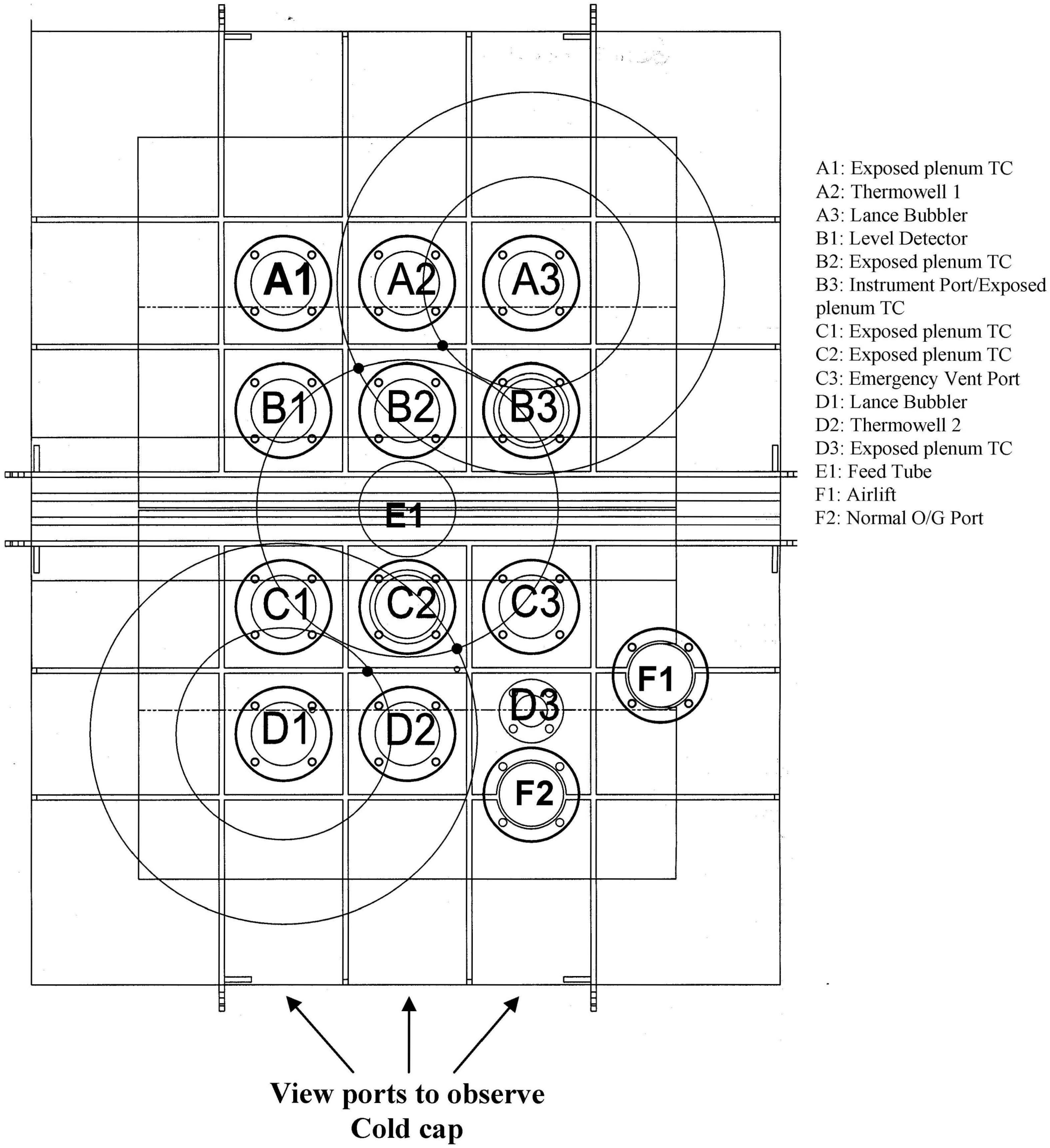

Figure 1.5. Placement of double outlet bubblers in the DM1200 melter. Note: solid circles represent location of bubbler outlet.

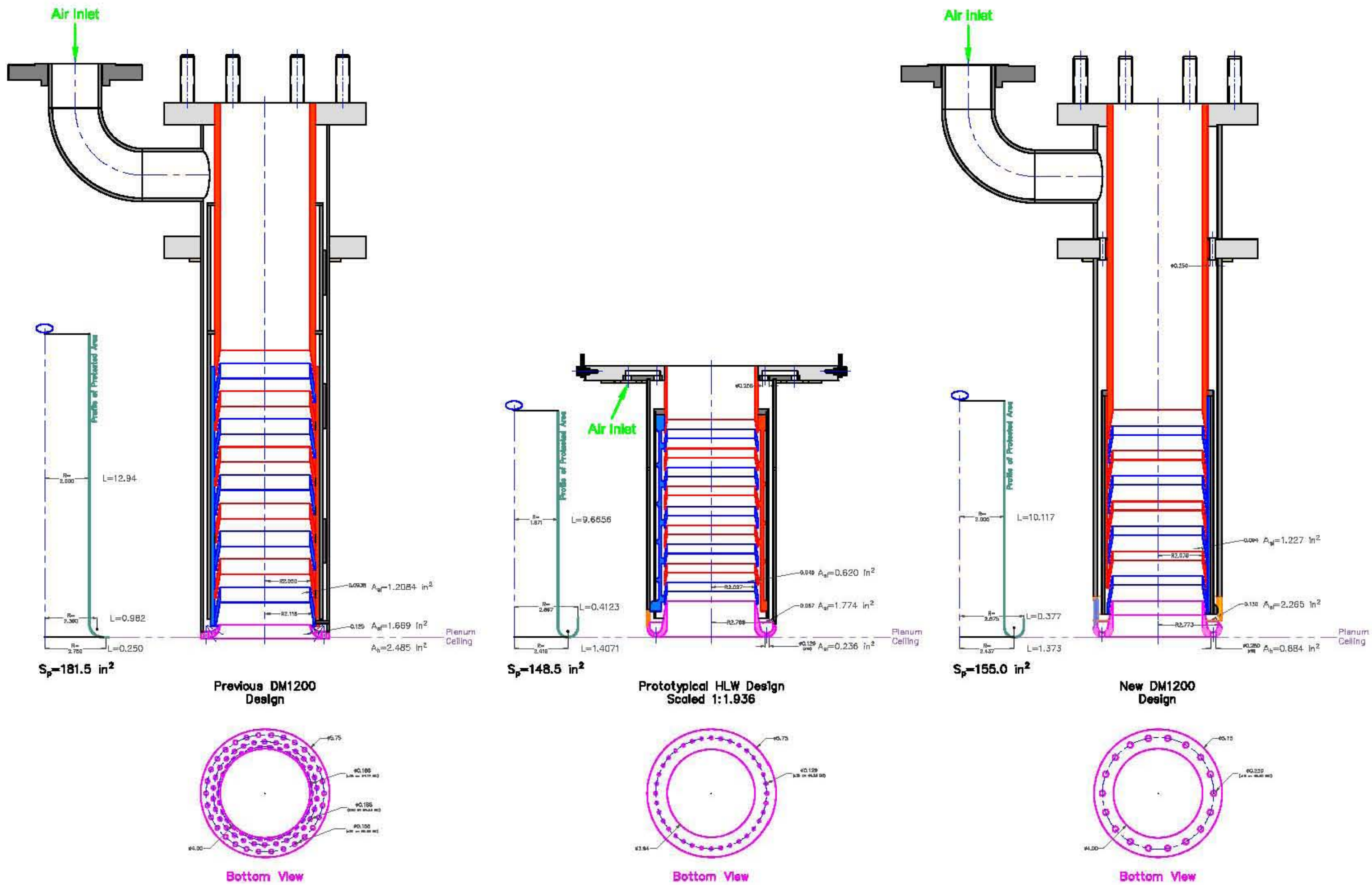

Figure 1.6. Comparison of original (left) and new (right) DM1200 film cooler designs with a scaled-down version of the WTP HLW design.

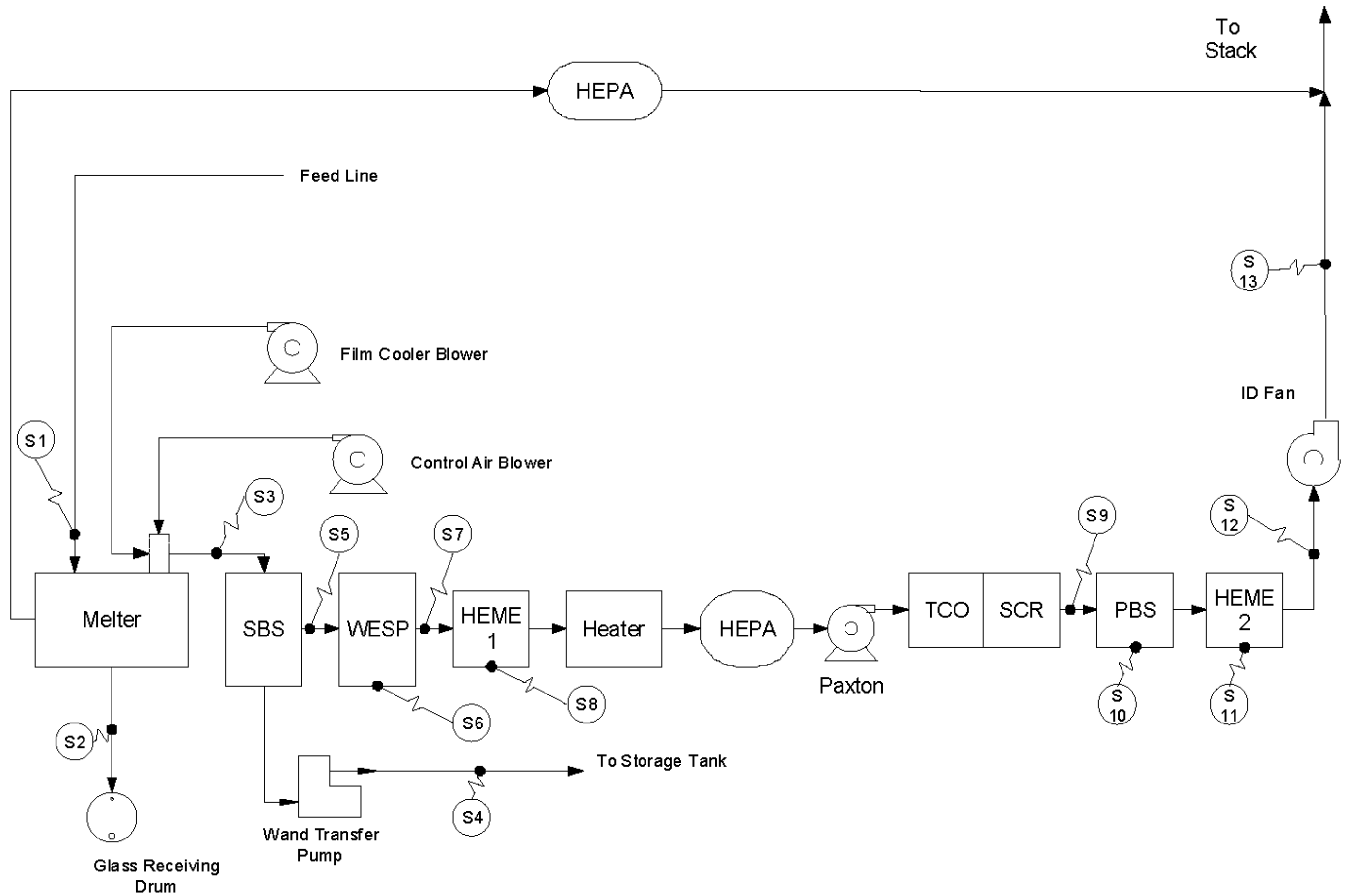

Figure 1.7. Schematic diagram of DM1200 off-gas system. "Sx" indicates sampling point

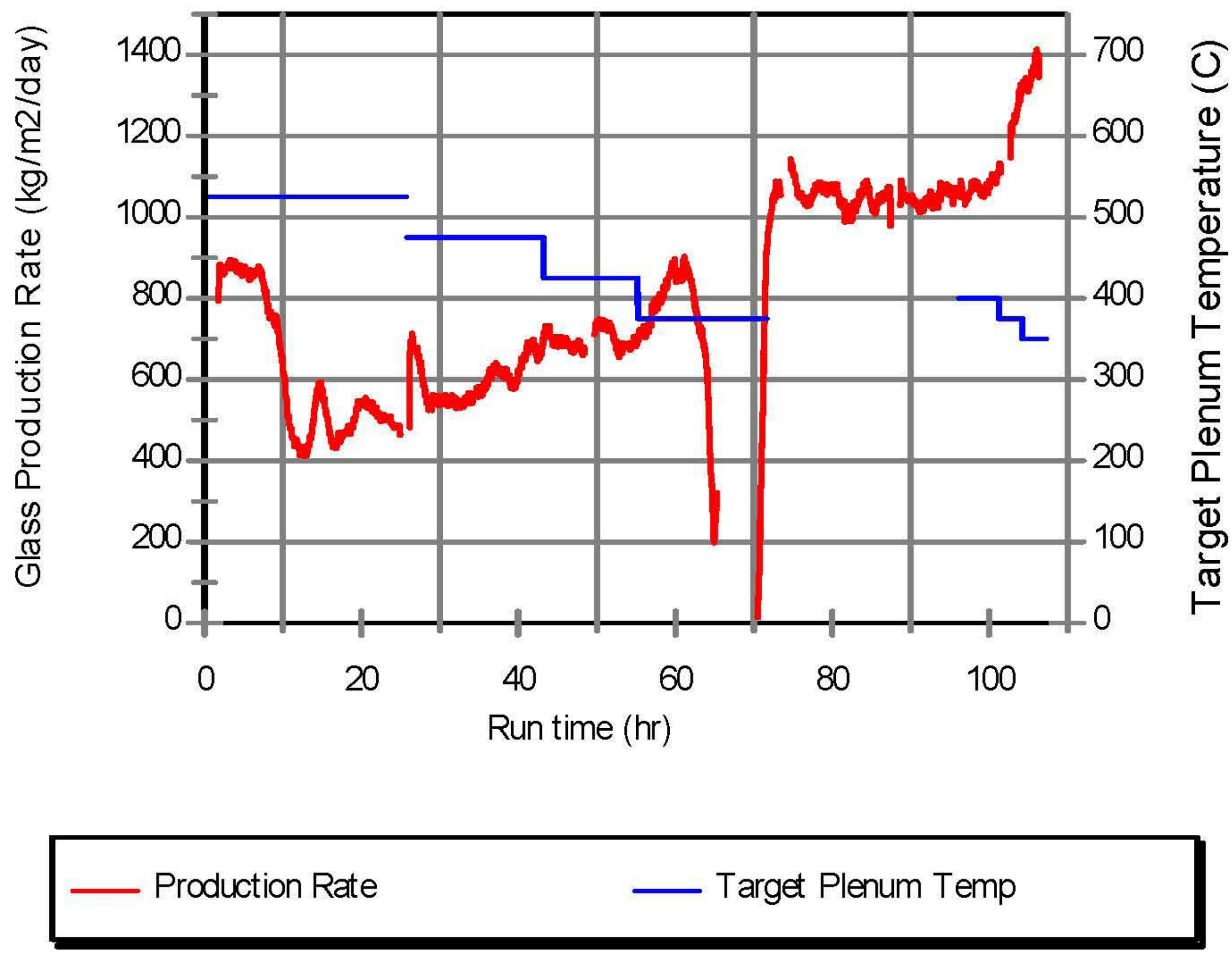

Figure 3.1.a. Production rates (hourly moving average) while processing the AZ-101 composition.

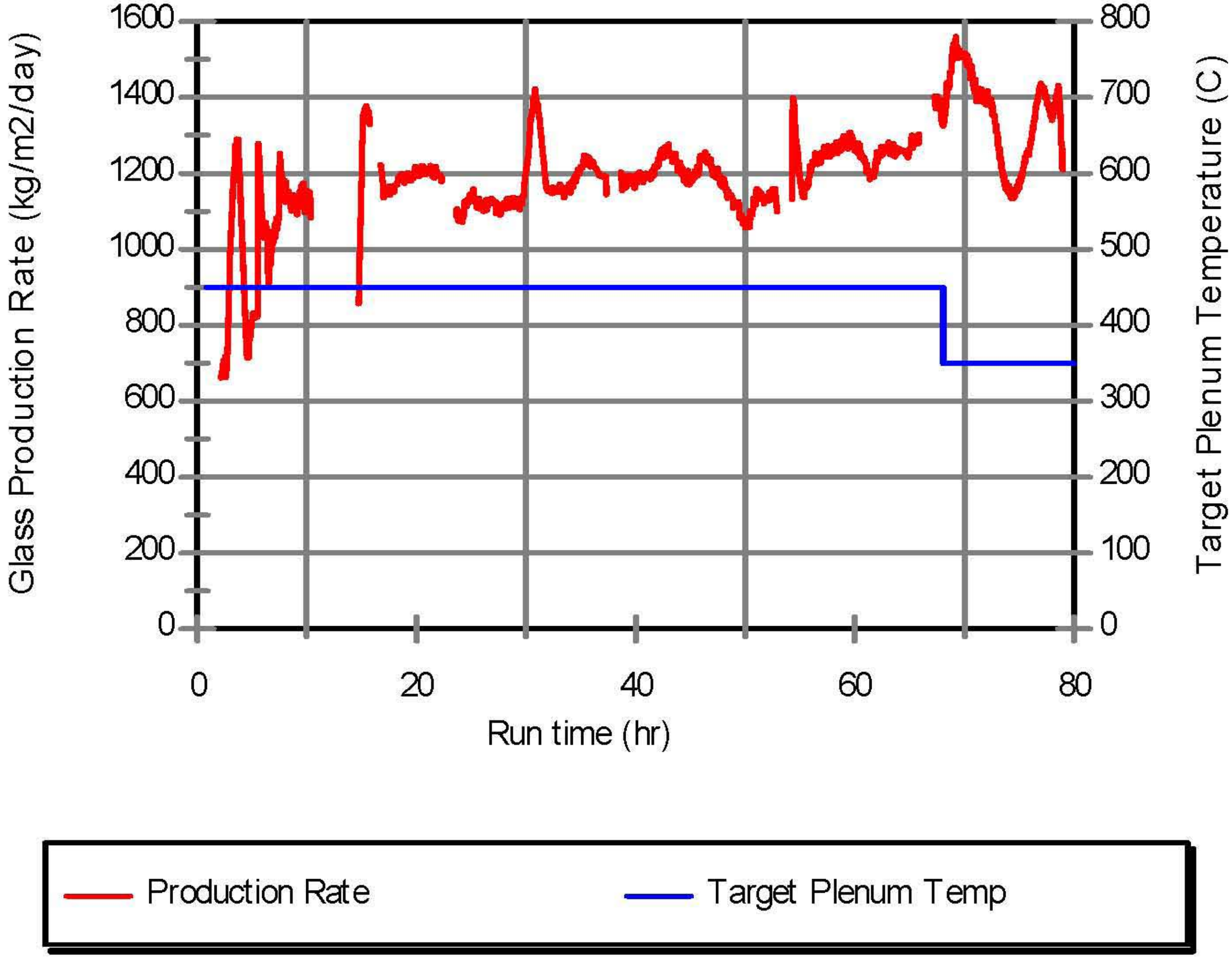

Figure 3.1.b. Production rates (hourly moving average) while processing the high aluminum composition.

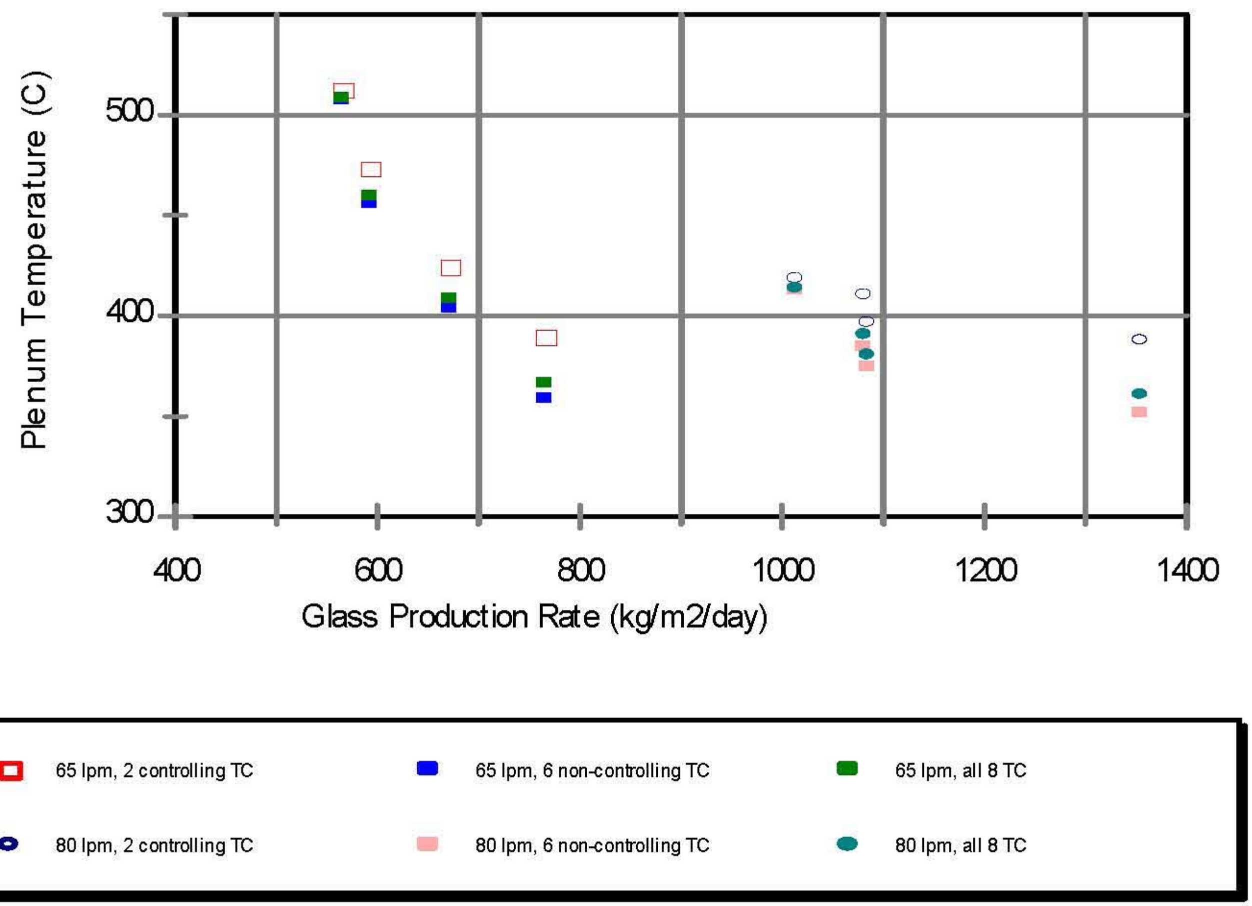

Figure 3.2. Test average steady state production rates and measured plenum temperatures while processing the AZ-101 composition.

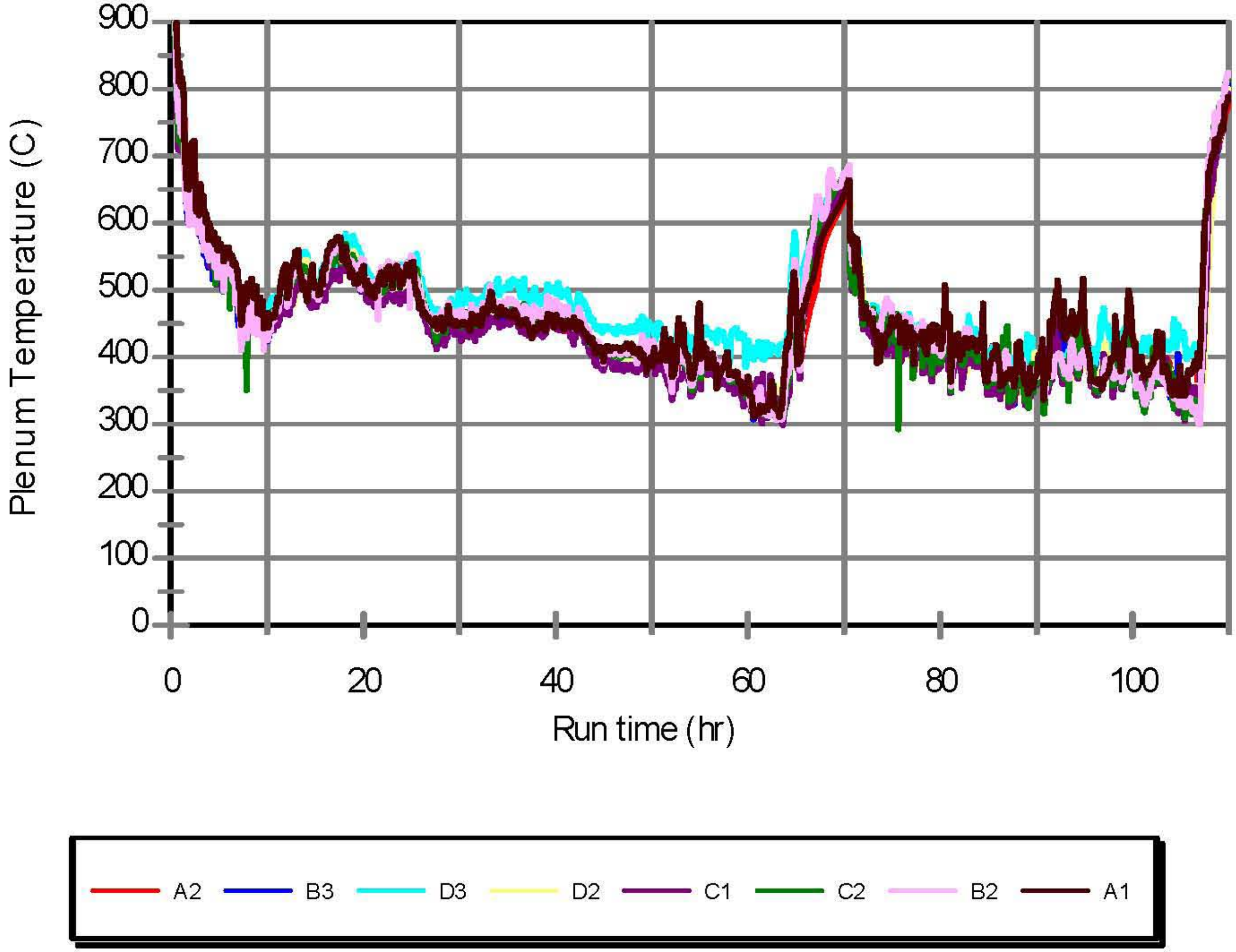

Figure 3.3.a. Plenum temperatures while processing the AZ-101 composition.

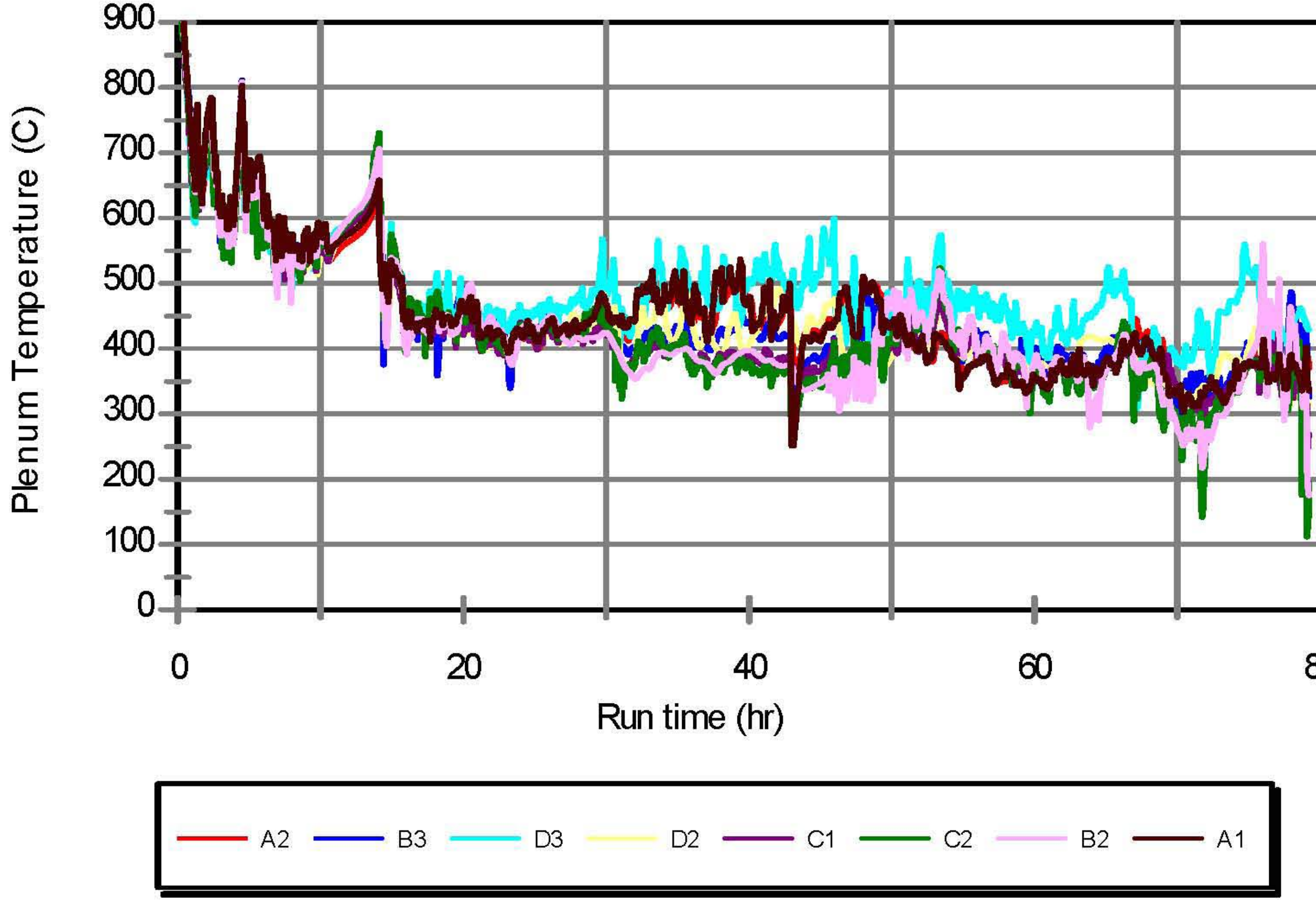

Figure 3.3.b. Plenum temperatures while processing the high aluminum composition.

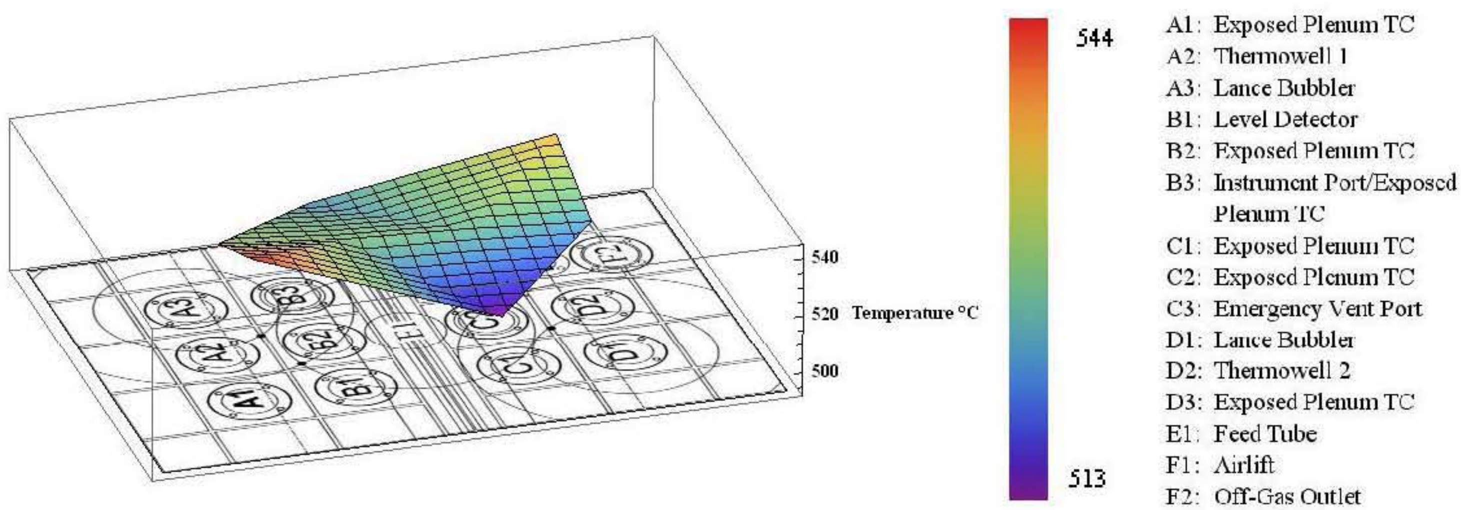

Figure 3.4.a. Average plenum temperatures at monitoring locations; Test 1.

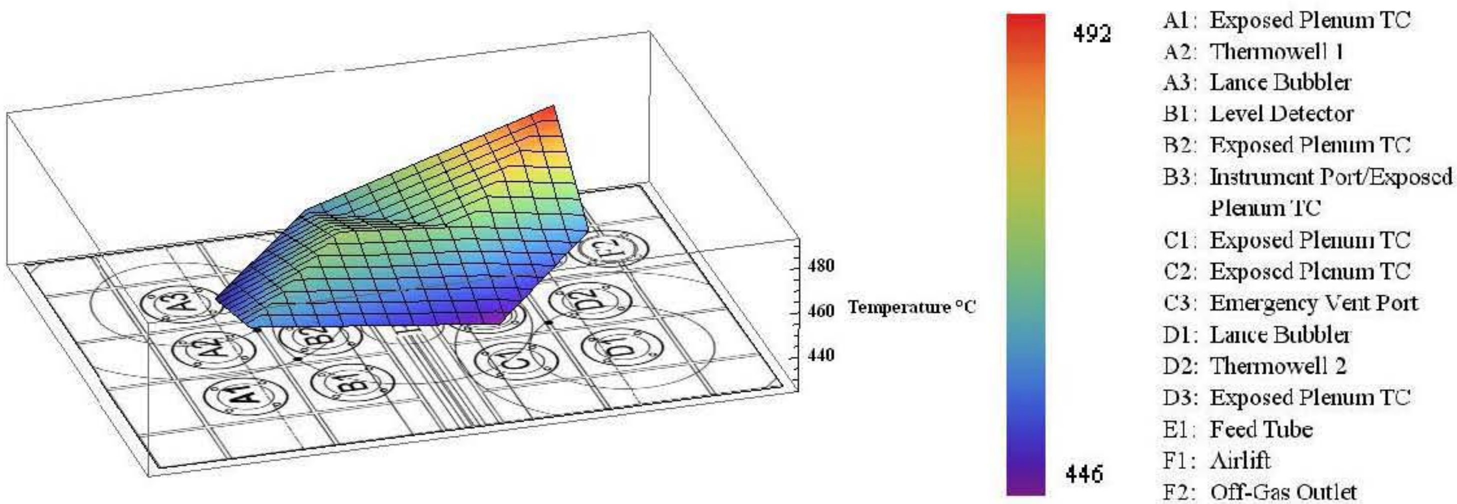

Figure 3.4.b. Average plenum temperatures at monitoring locations; Test 2a.

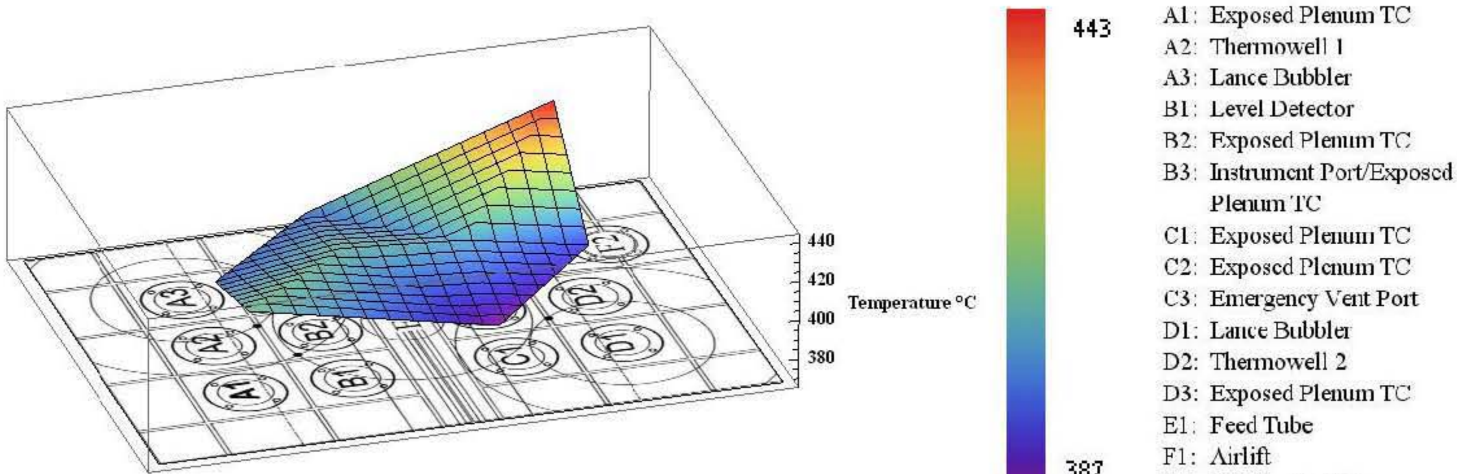

Figure 3.4.c. Average plenum temperatures at monitoring locations; Test 2b.

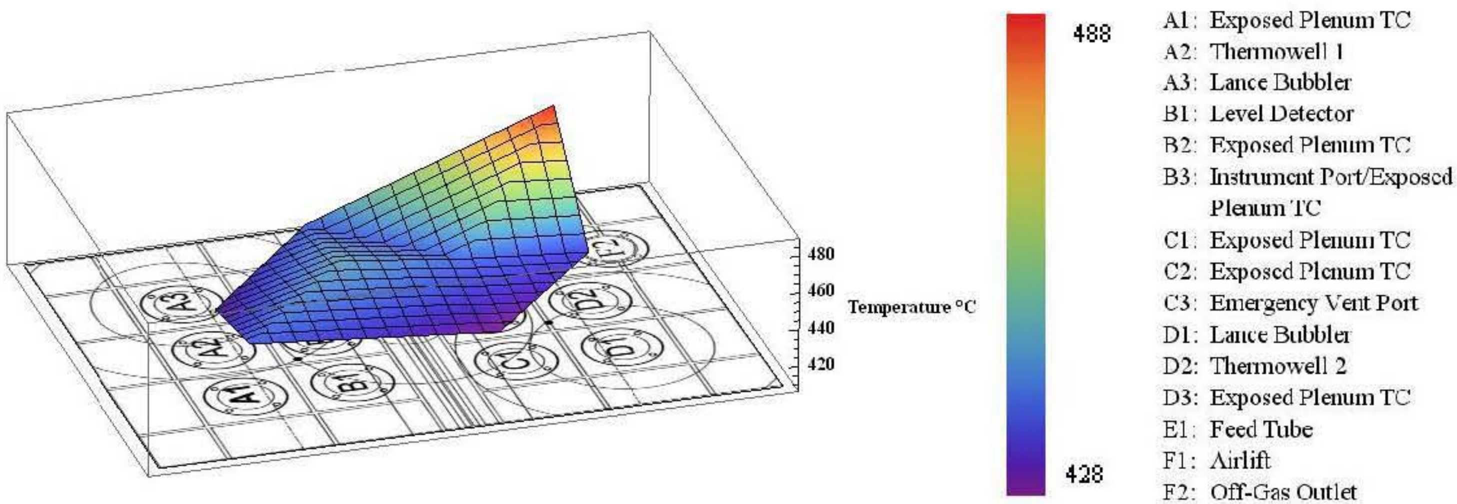

Figure 3.4.d. Average plenum temperatures at monitoring locations; Test 2c.

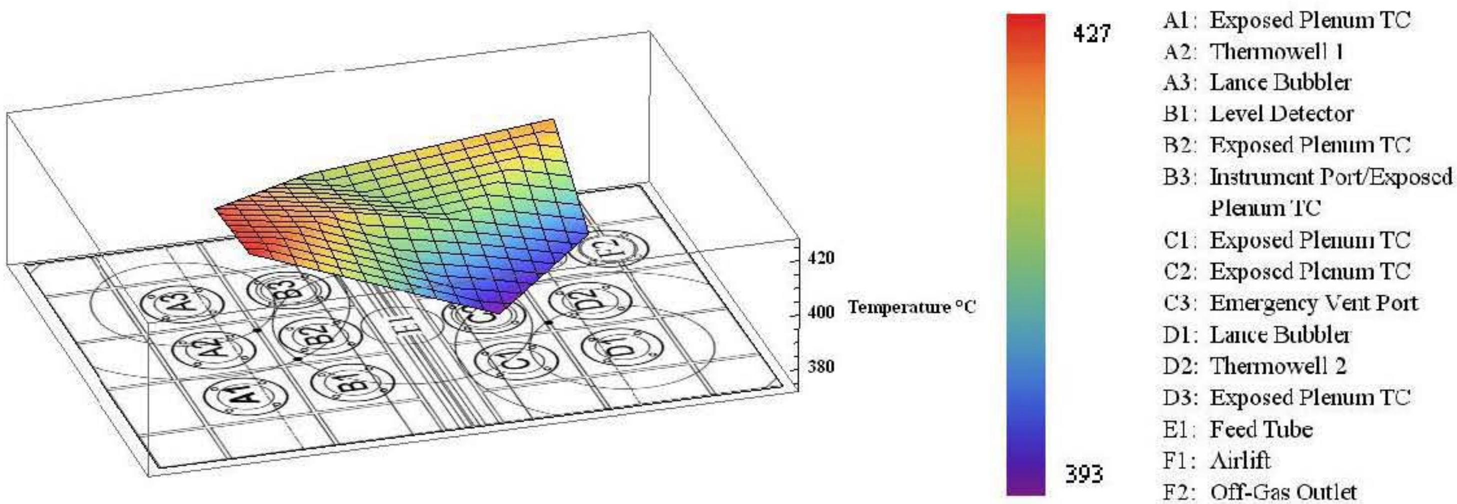

Figure 3.4.e. Average plenum temperatures at monitoring locations; Test 2d.

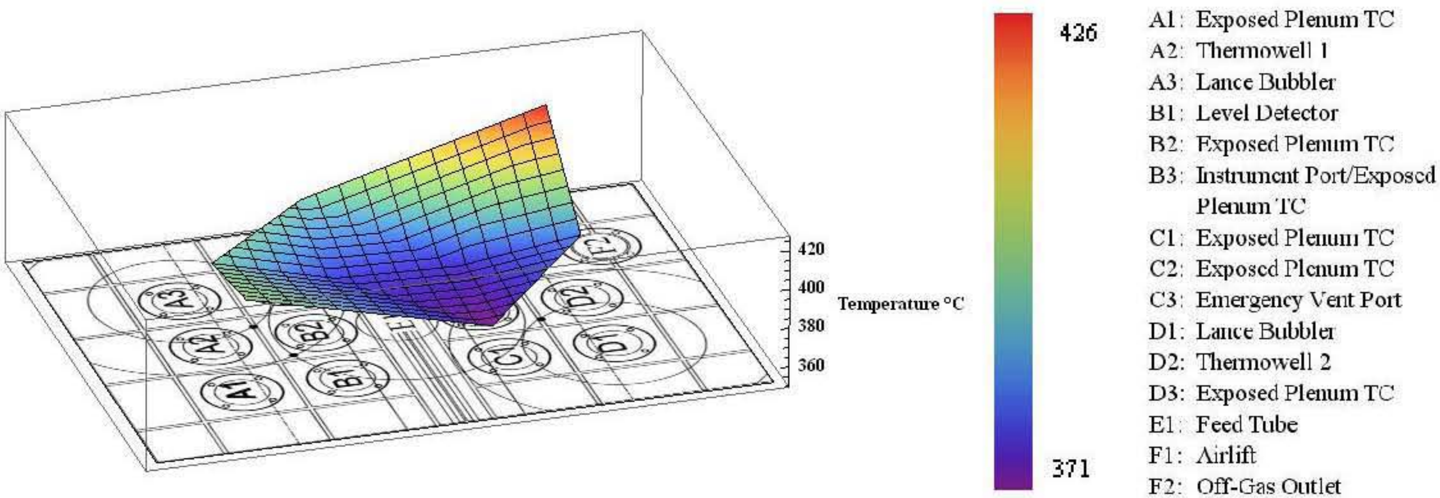

Figure 3.4.f. Average plenum temperatures at monitoring locations; Test 2e.

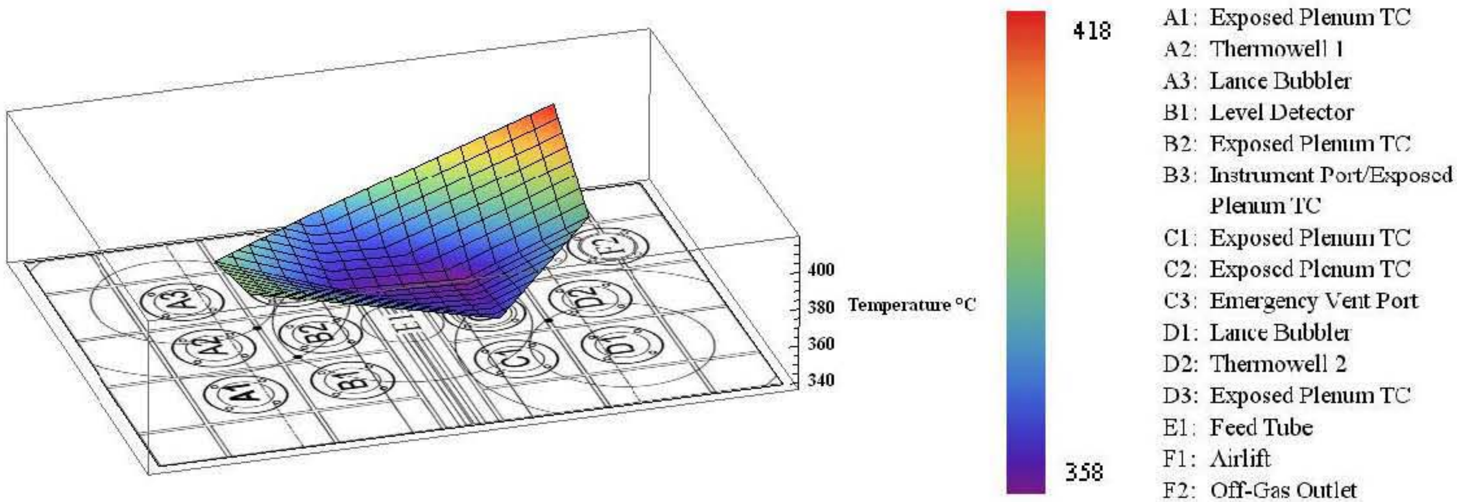

Figure 3.4.g. Average plenum temperatures at monitoring locations; Test 2f.

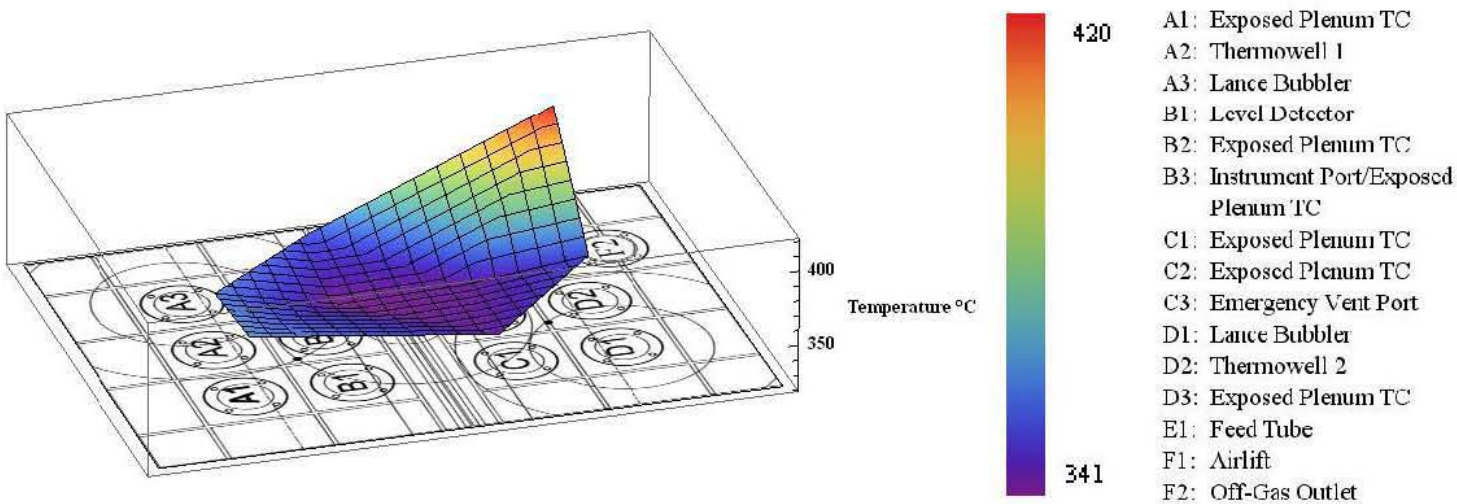

Figure 3.4.h. Average plenum temperatures at monitoring locations; Test 2g.

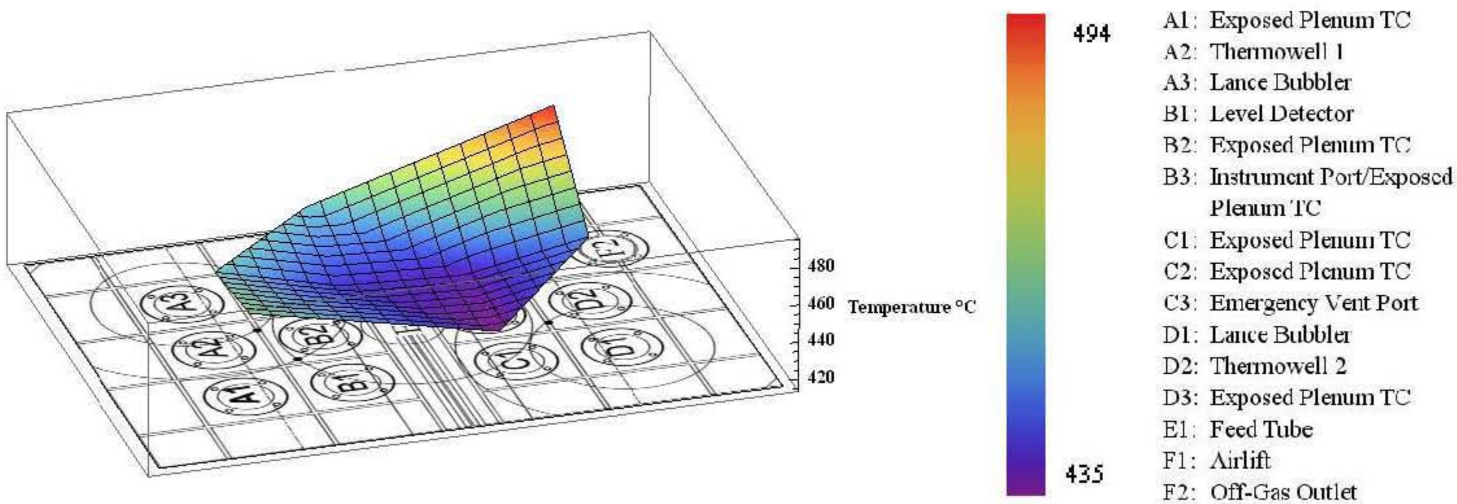

Figure 3.4.i. Average plenum temperatures at monitoring locations; Test 3.

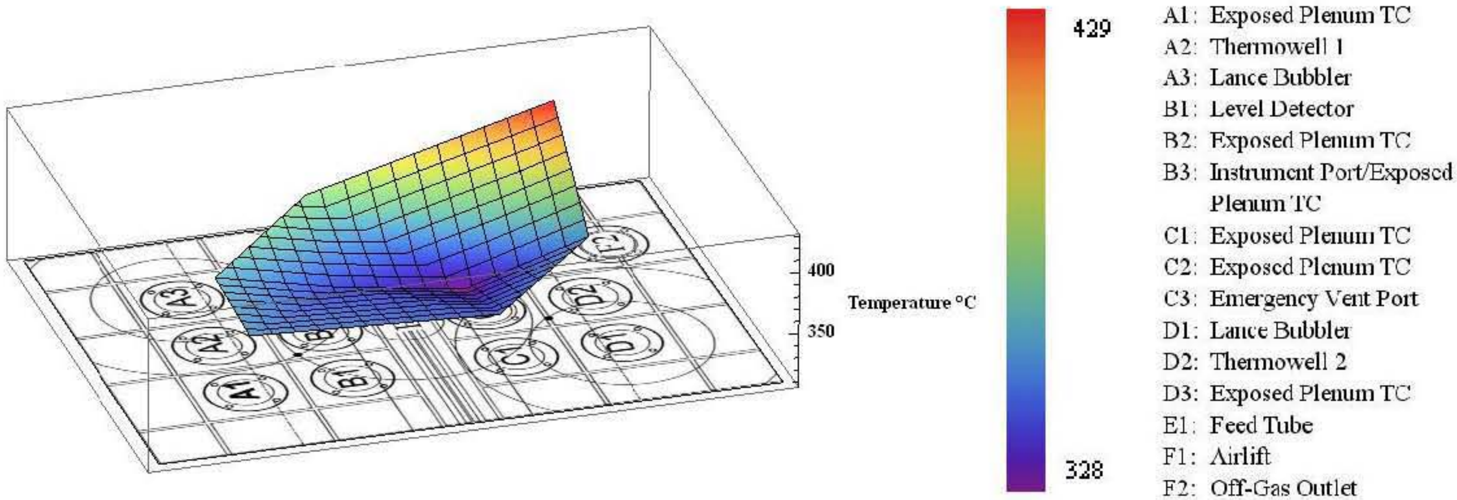

Figure 3.4.j. Average plenum temperatures at monitoring locations; Test 4.

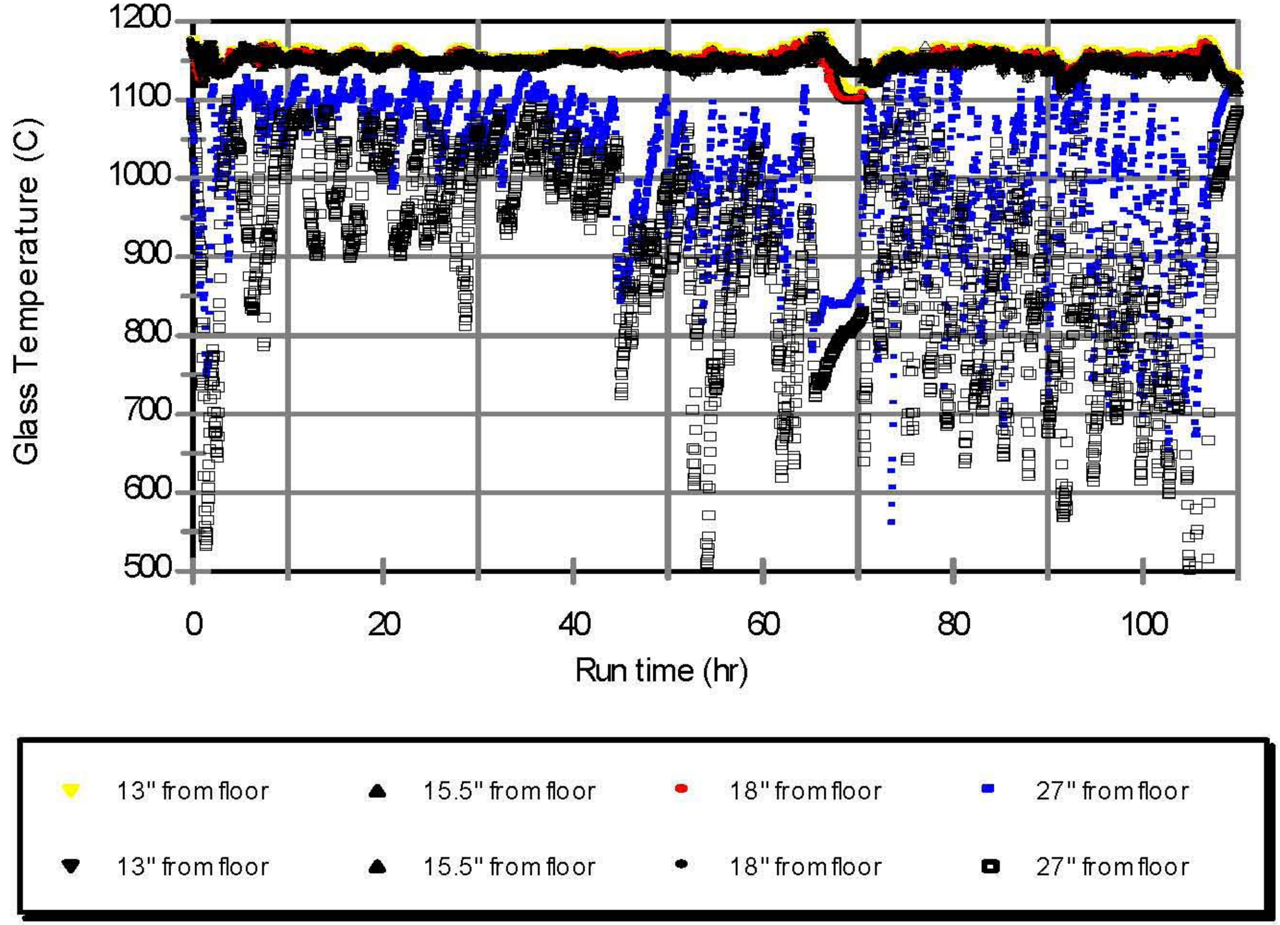

Figure 3.5.a. Glass temperatures while processing the AZ-101 composition.

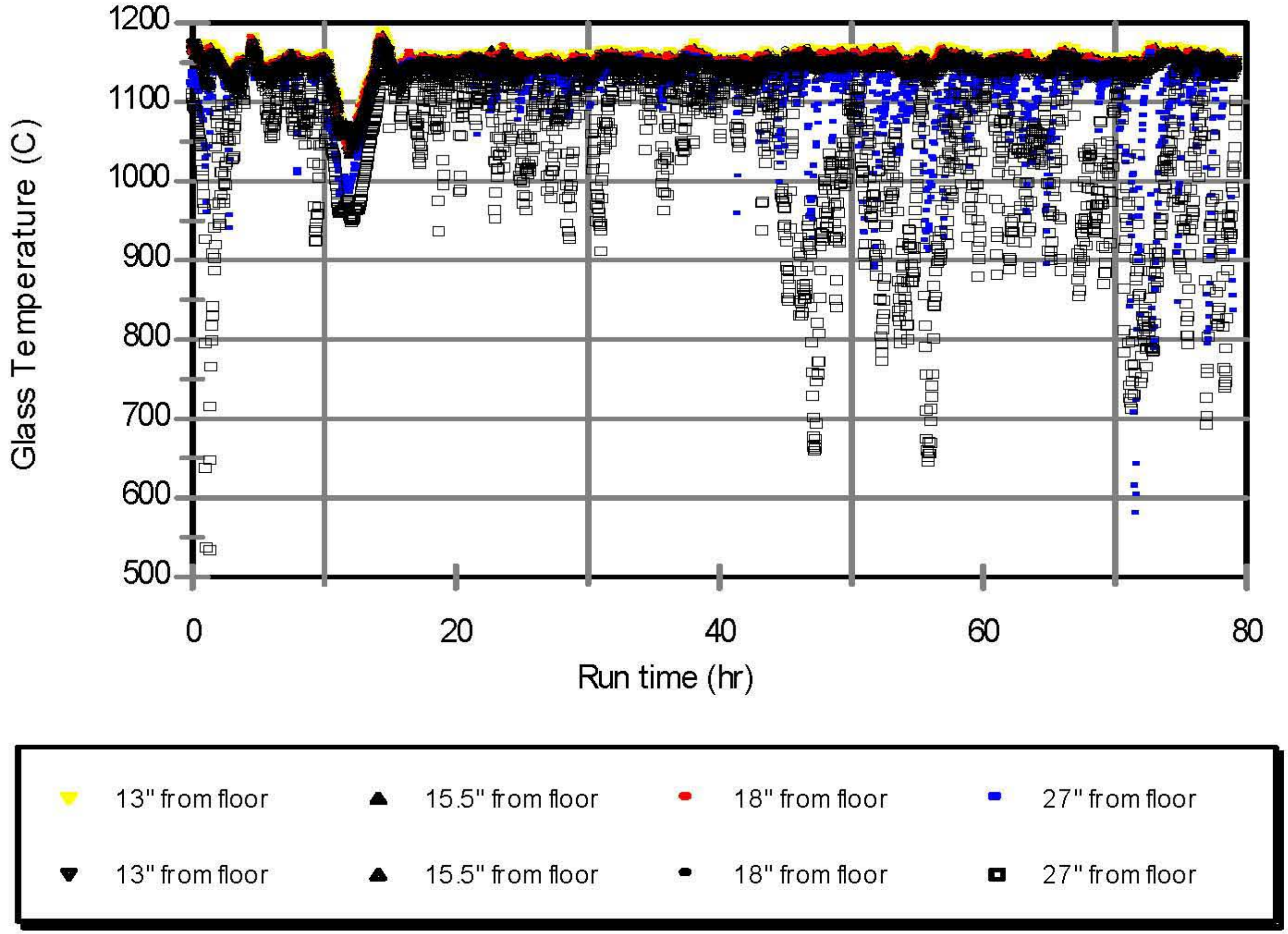

Figure 3.5.b. Glass temperatures while processing the high aluminum composition.

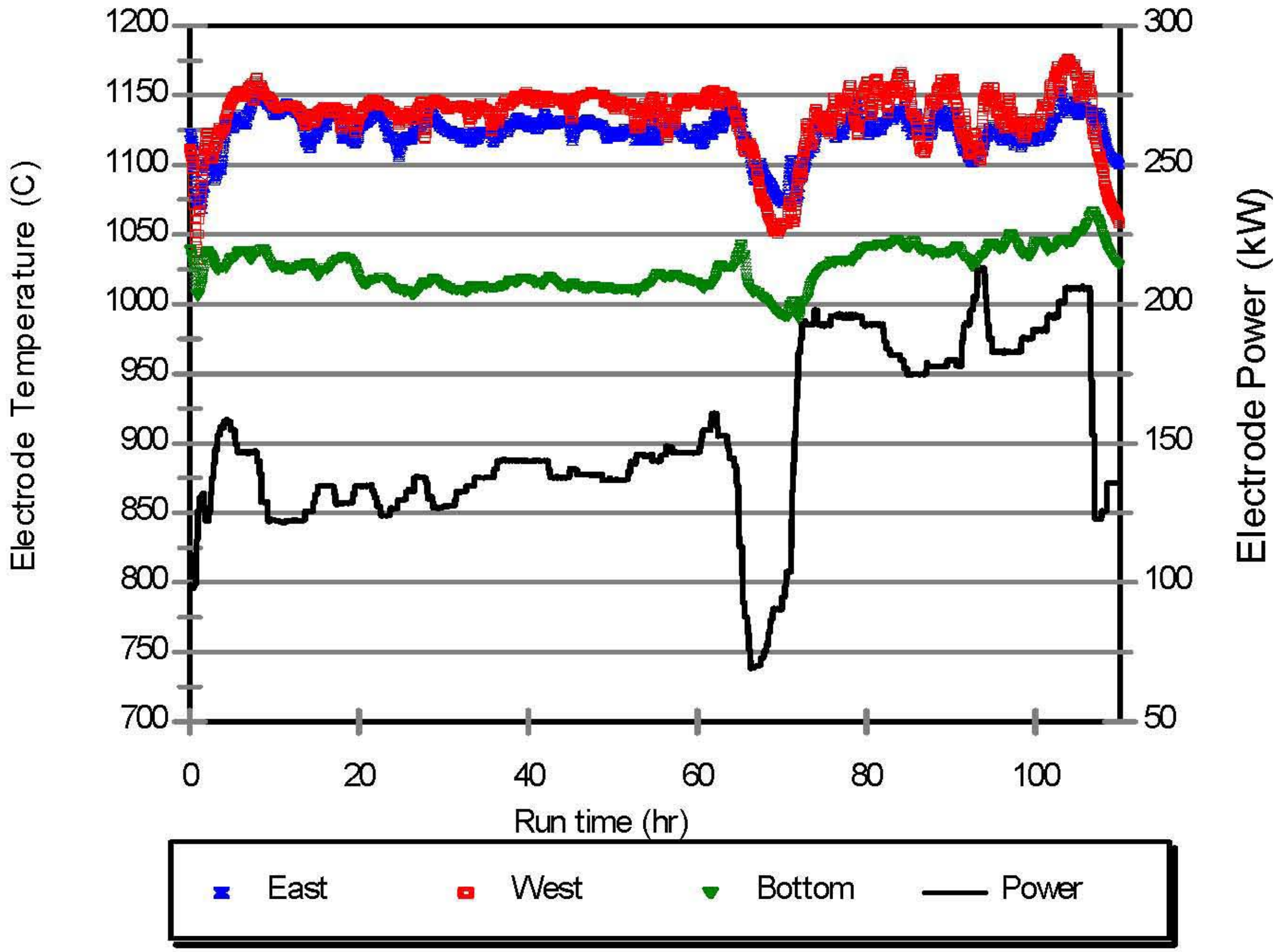

Figure 3.6.a. Electrode temperatures and power while processing the AZ-101 composition.

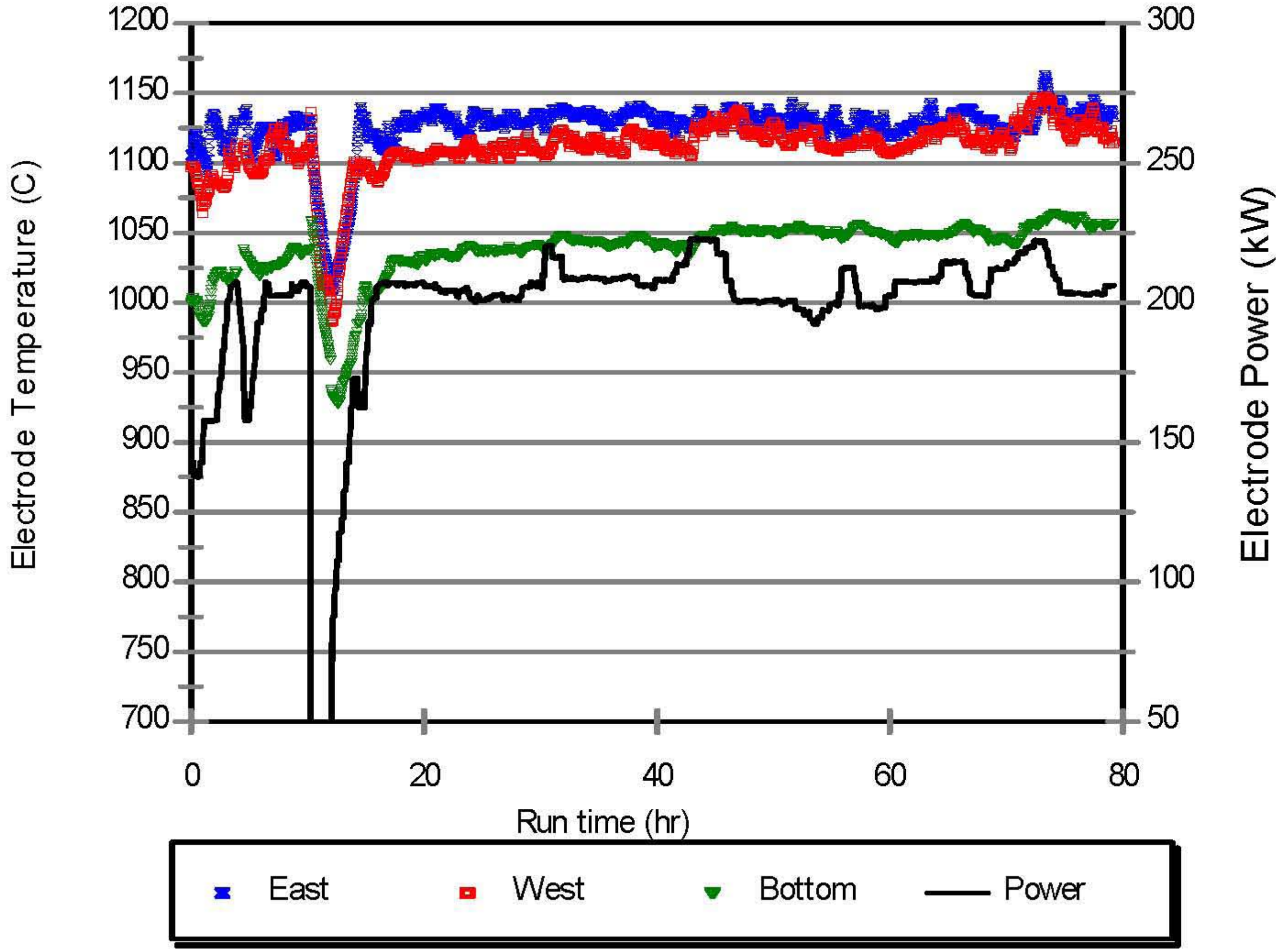

Figure 3.6.b. Electrode temperatures and power while processing the high aluminum composition.

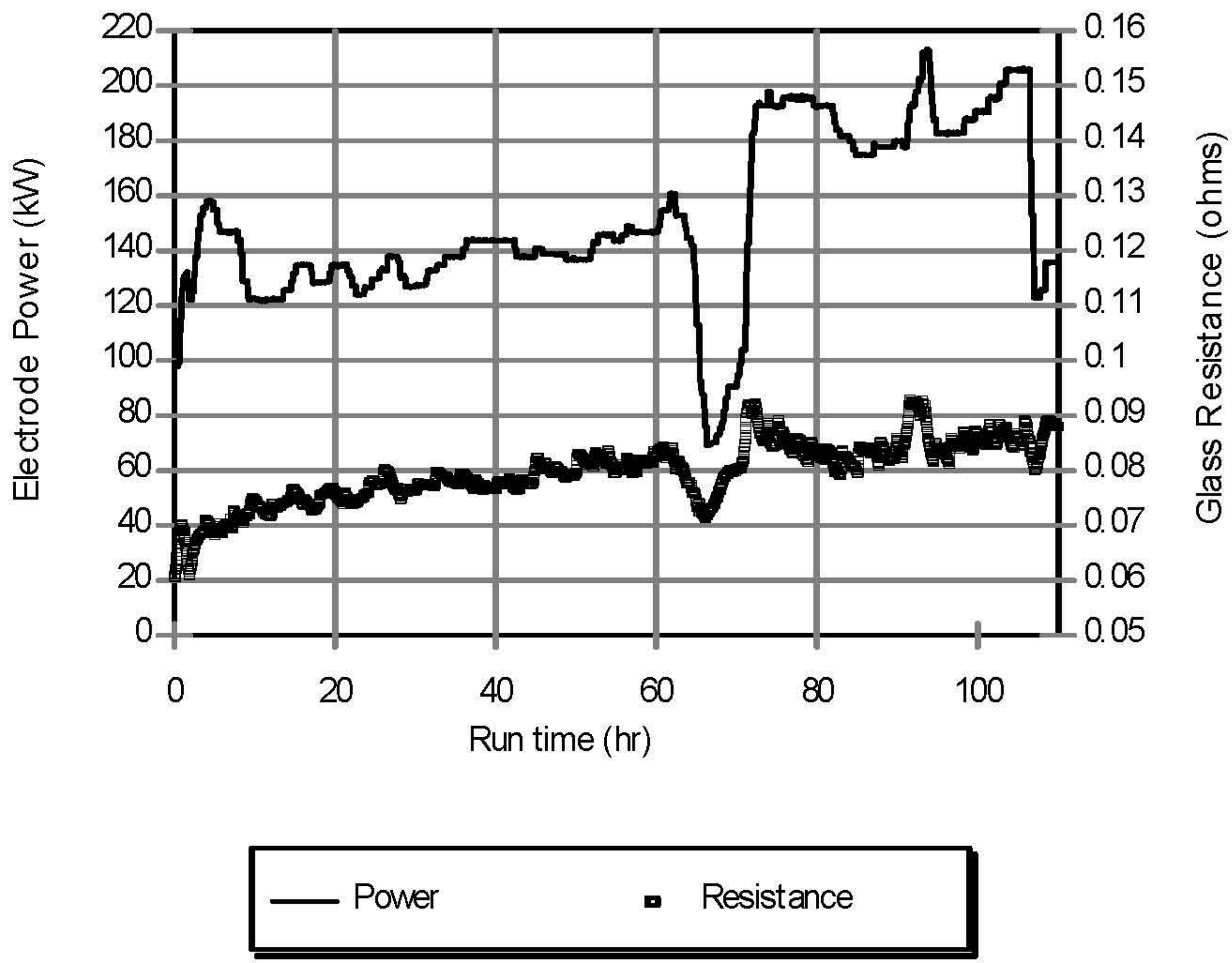

Figure 3.7.a. Electrode power and glass resistance while processing the AZ-101 composition.

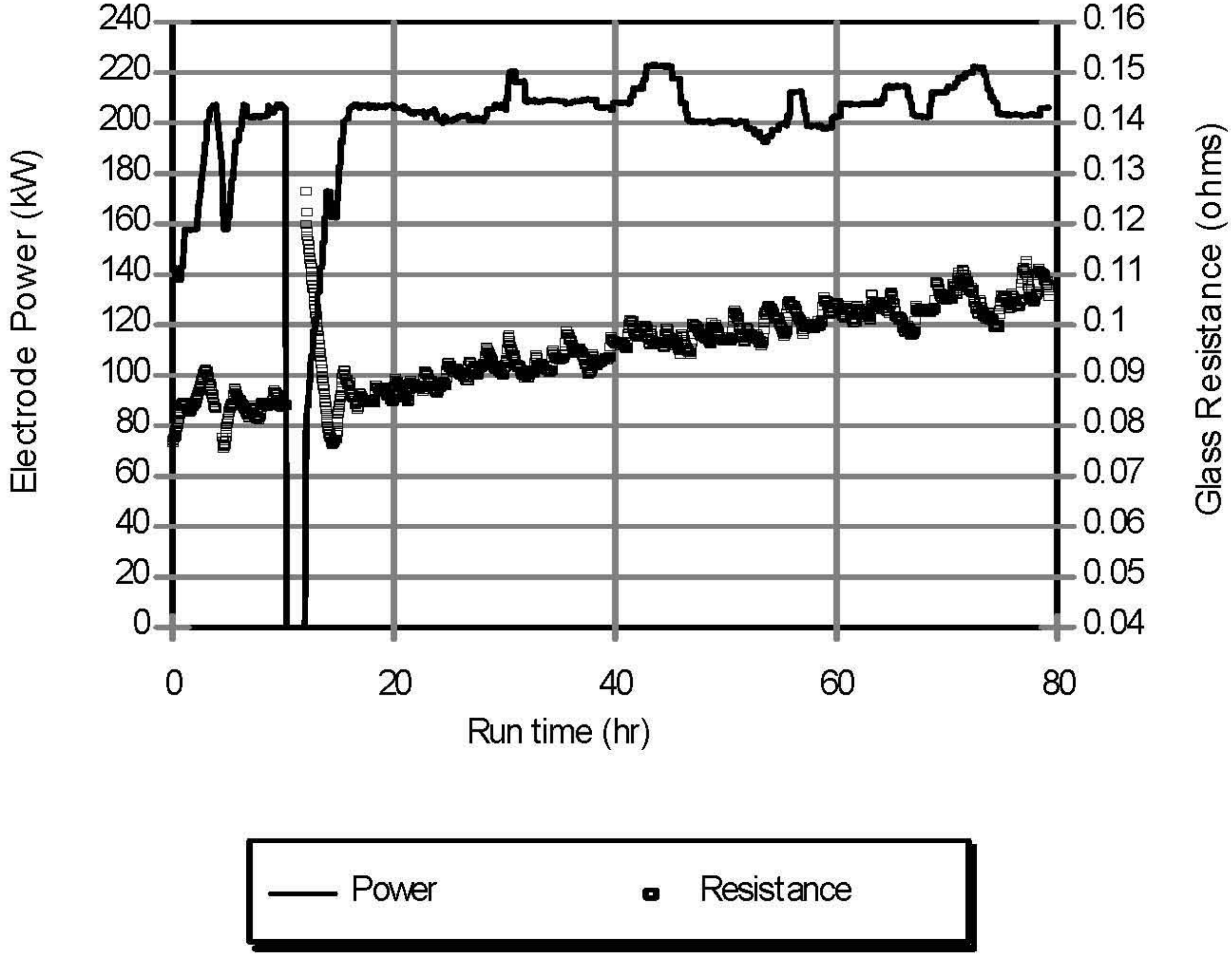

Figure 3.7.b. Electrode power and glass resistance while processing the high aluminum composition.

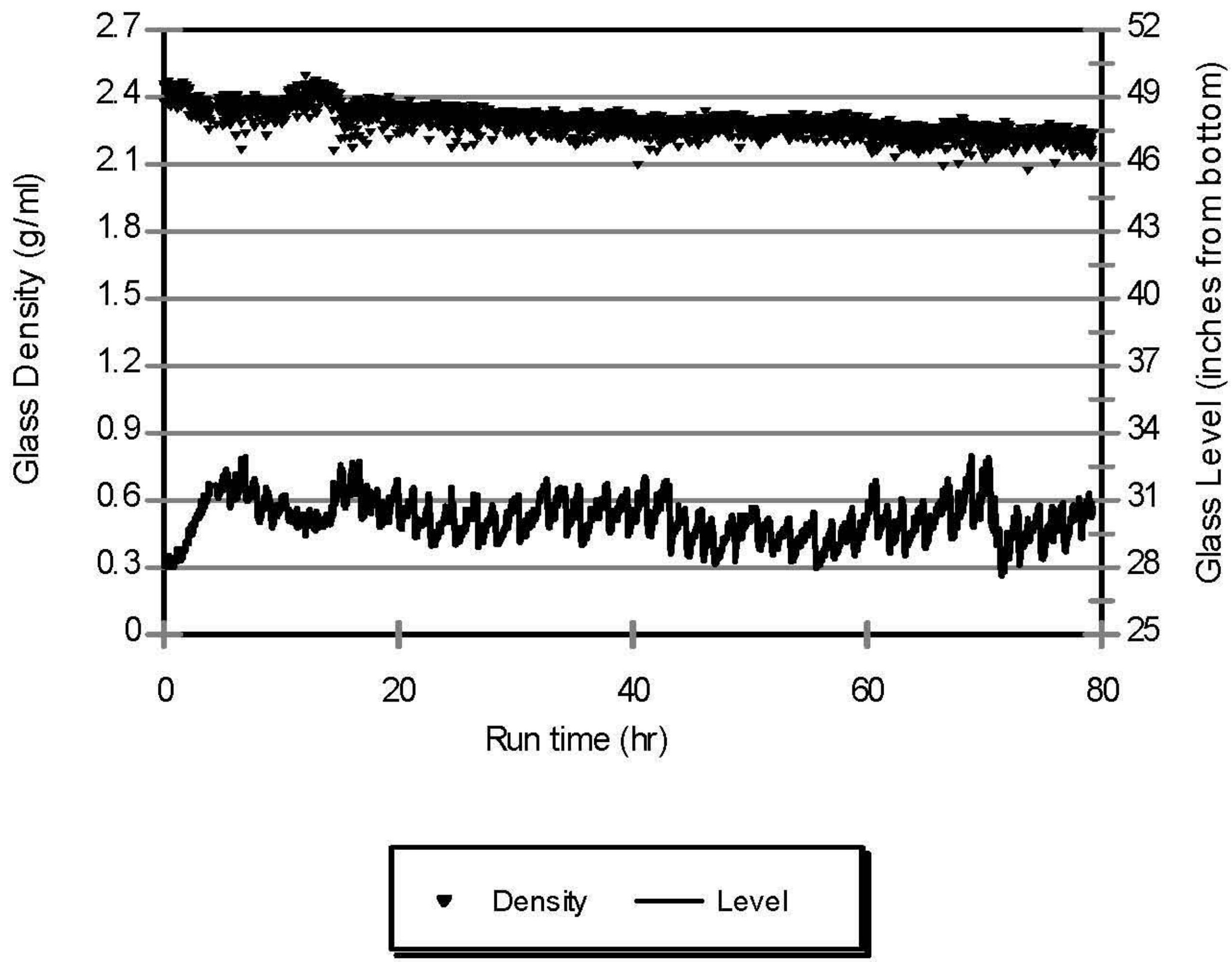

Figure 3.8. Glass density and level while processing the high aluminum composition.

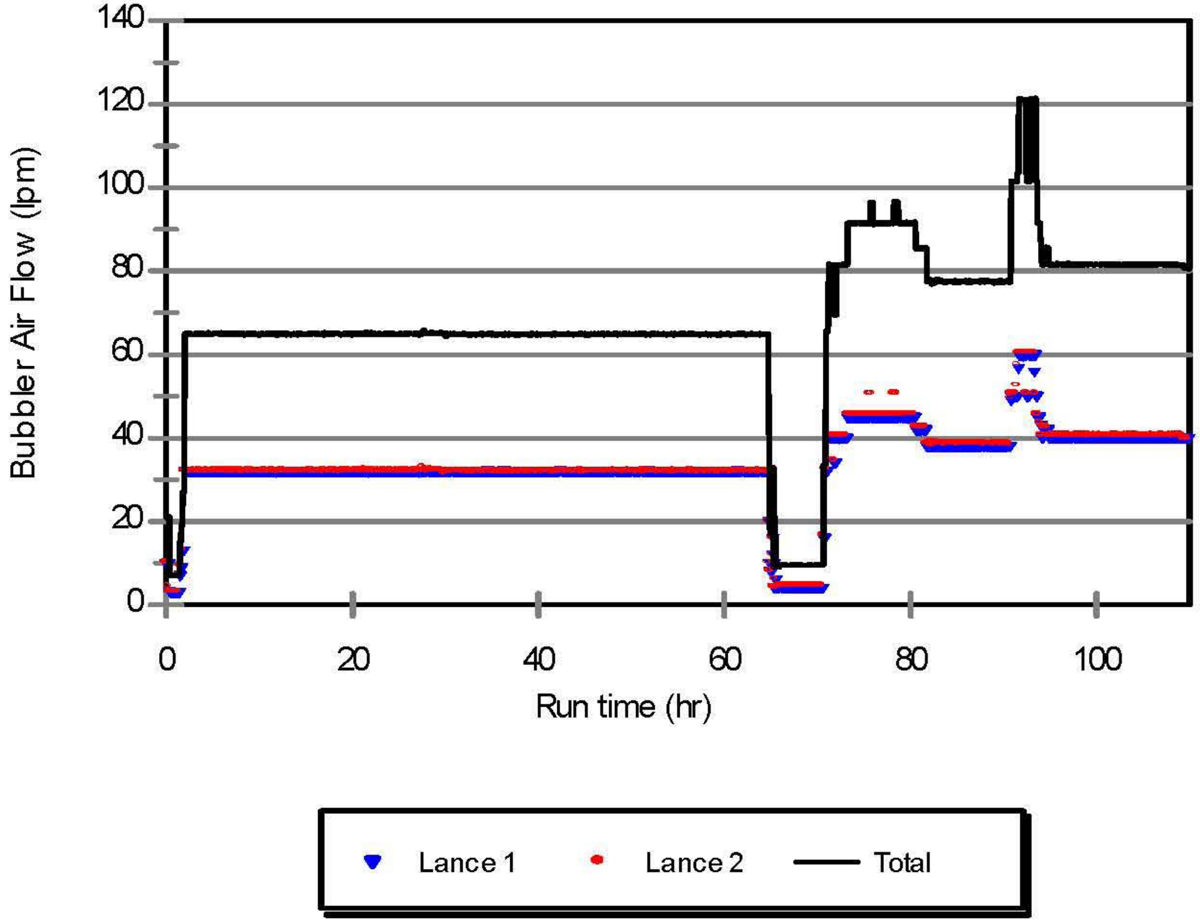

Figure 3.9.a. Glass pool bubbling while processing the AZ-101 composition.

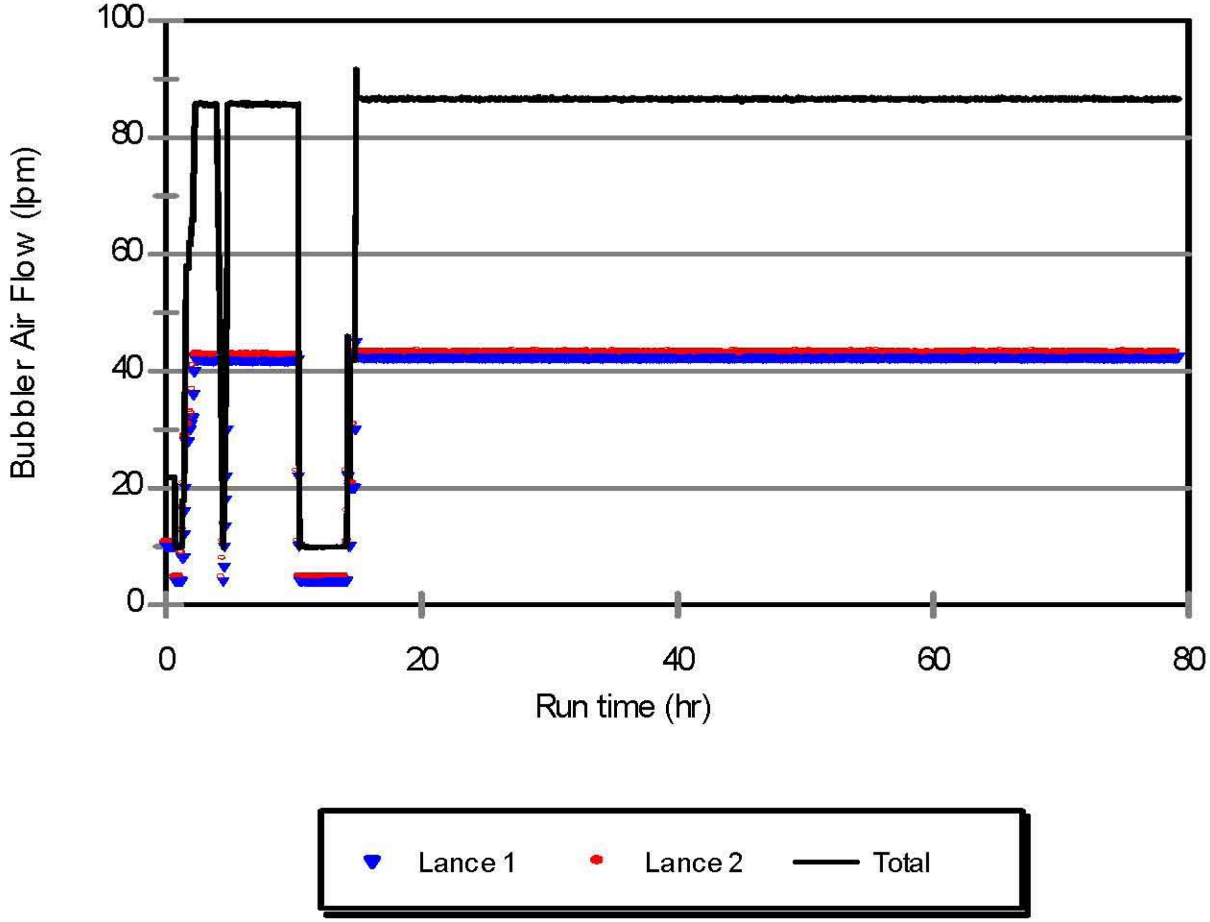

Figure 3.9.b. Glass pool bubbling while processing the high aluminum composition.

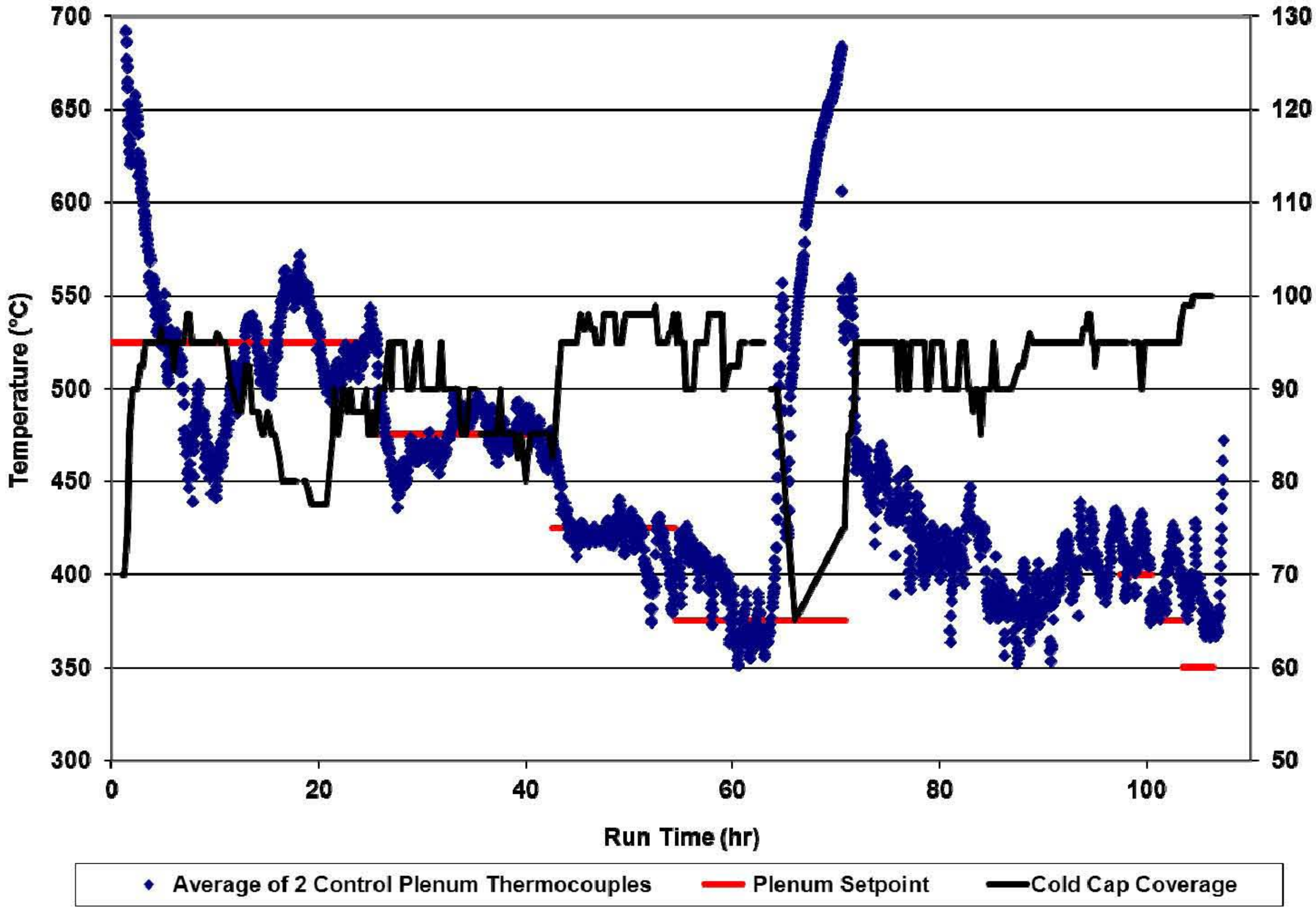

Figure 3.10.a. Control plenum temperatures, plenum temperature targets and observed cold cap coverage during Tests 1 and 2.

Figure 3.10.b. Control plenum temperatures, plenum temperature targets and observed cold cap coverage during Test 1.

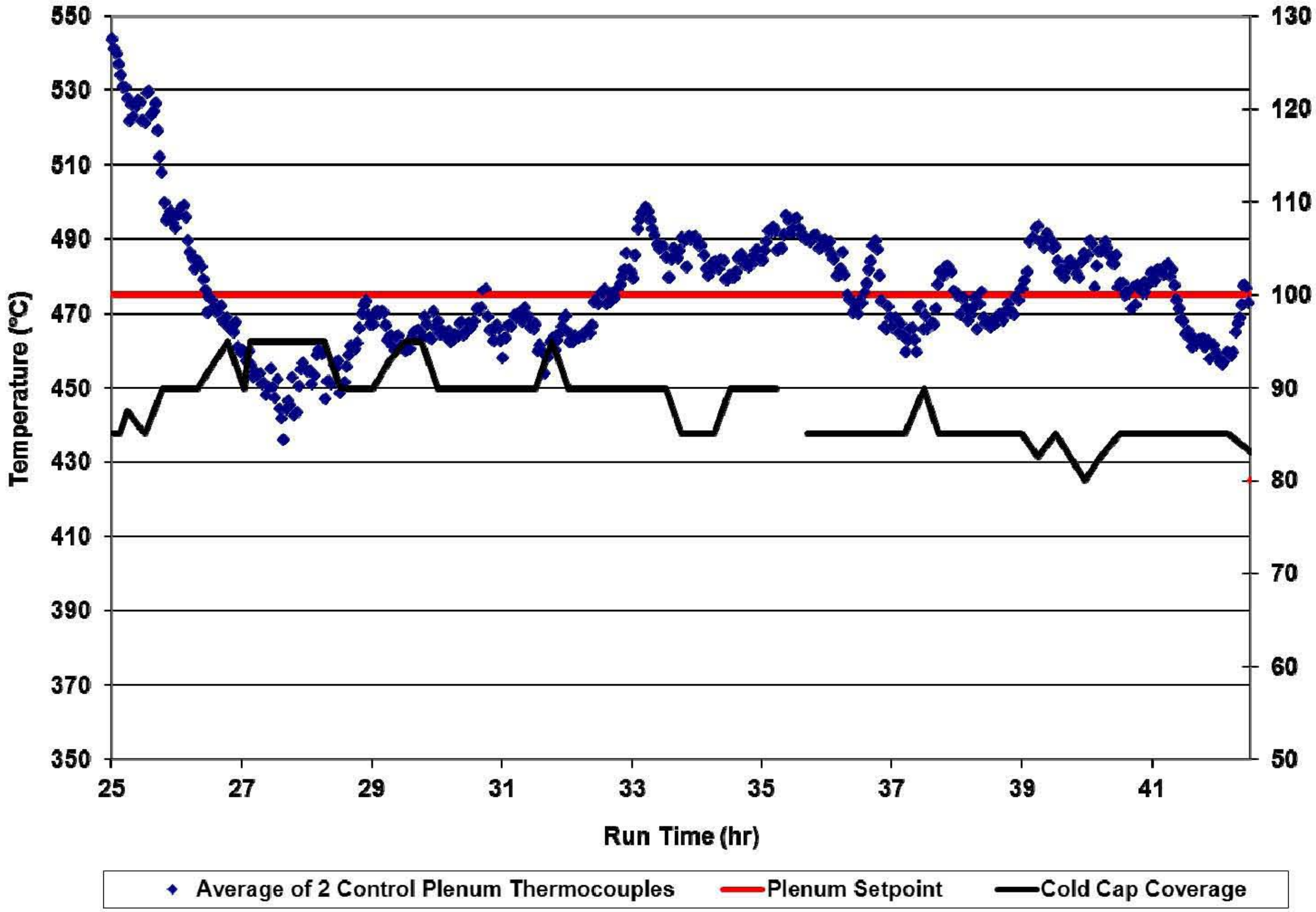

Figure 3.10.c. Control plenum temperatures, plenum temperature targets and observed cold cap coverage during Test 2a.

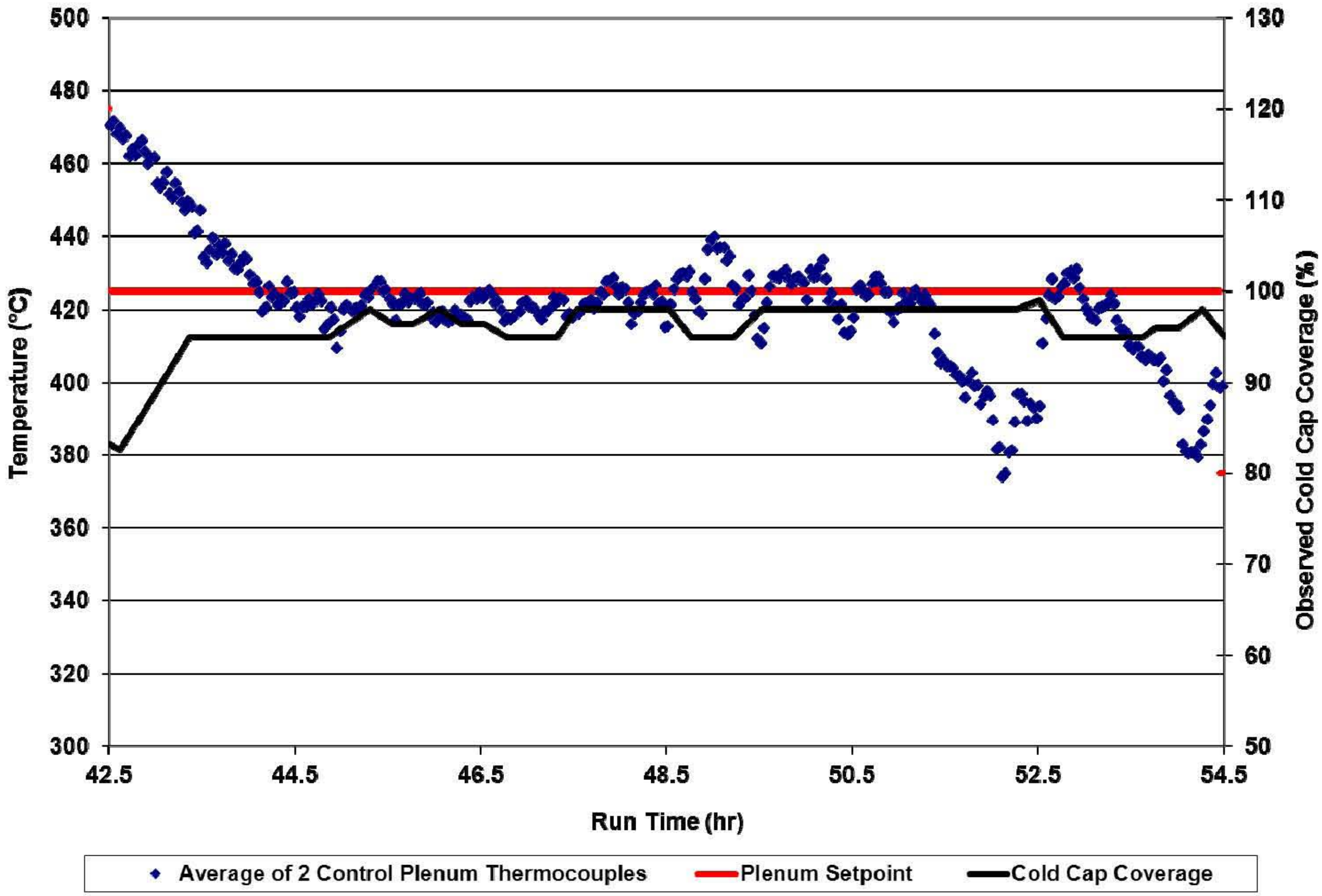

Figure 3.10.d. Control plenum temperatures, plenum temperature targets and observed cold cap coverage during Test 2b.

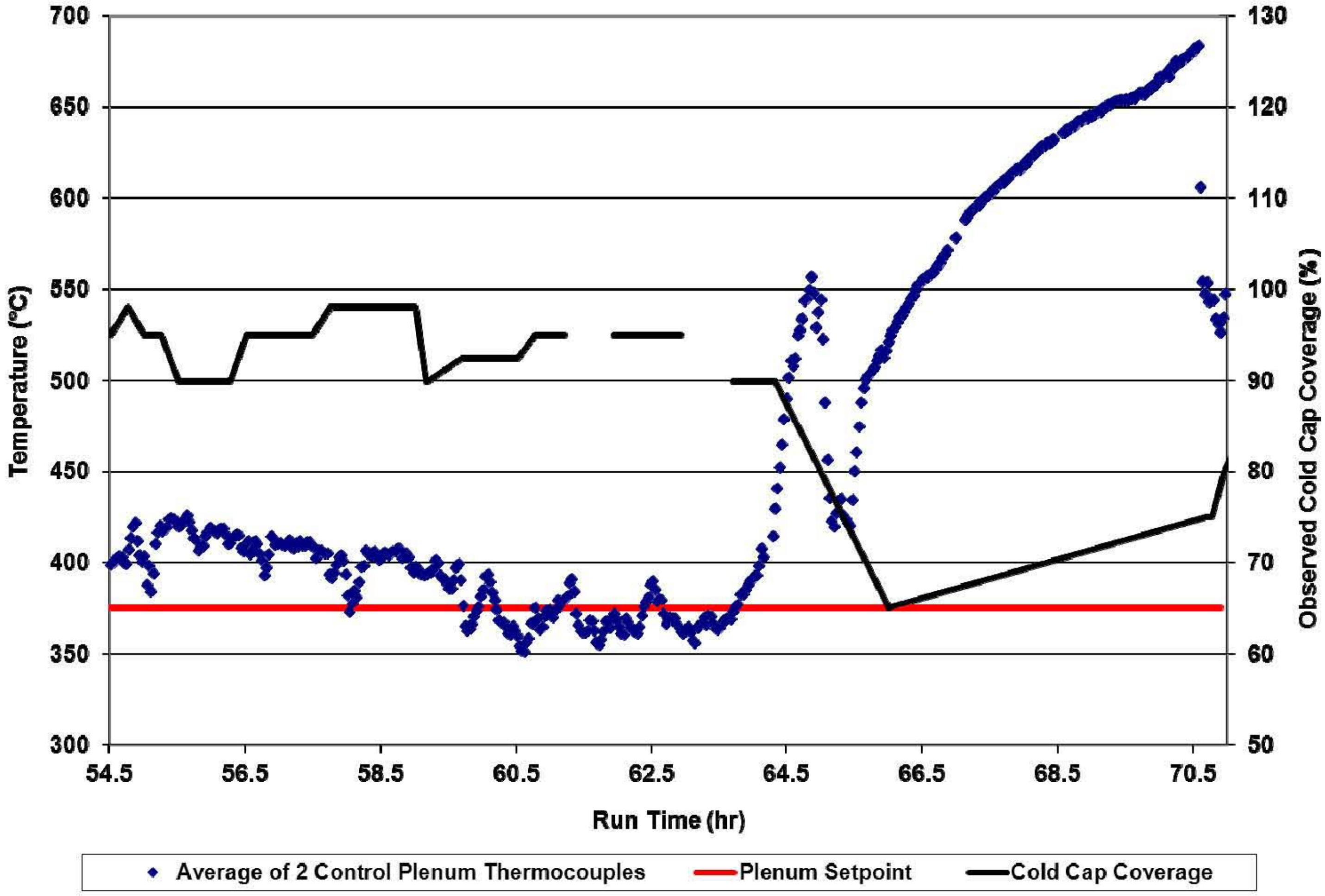

Figure 3.10.e. Control plenum temperatures, plenum temperature targets and observed cold cap coverage during Test 2c.

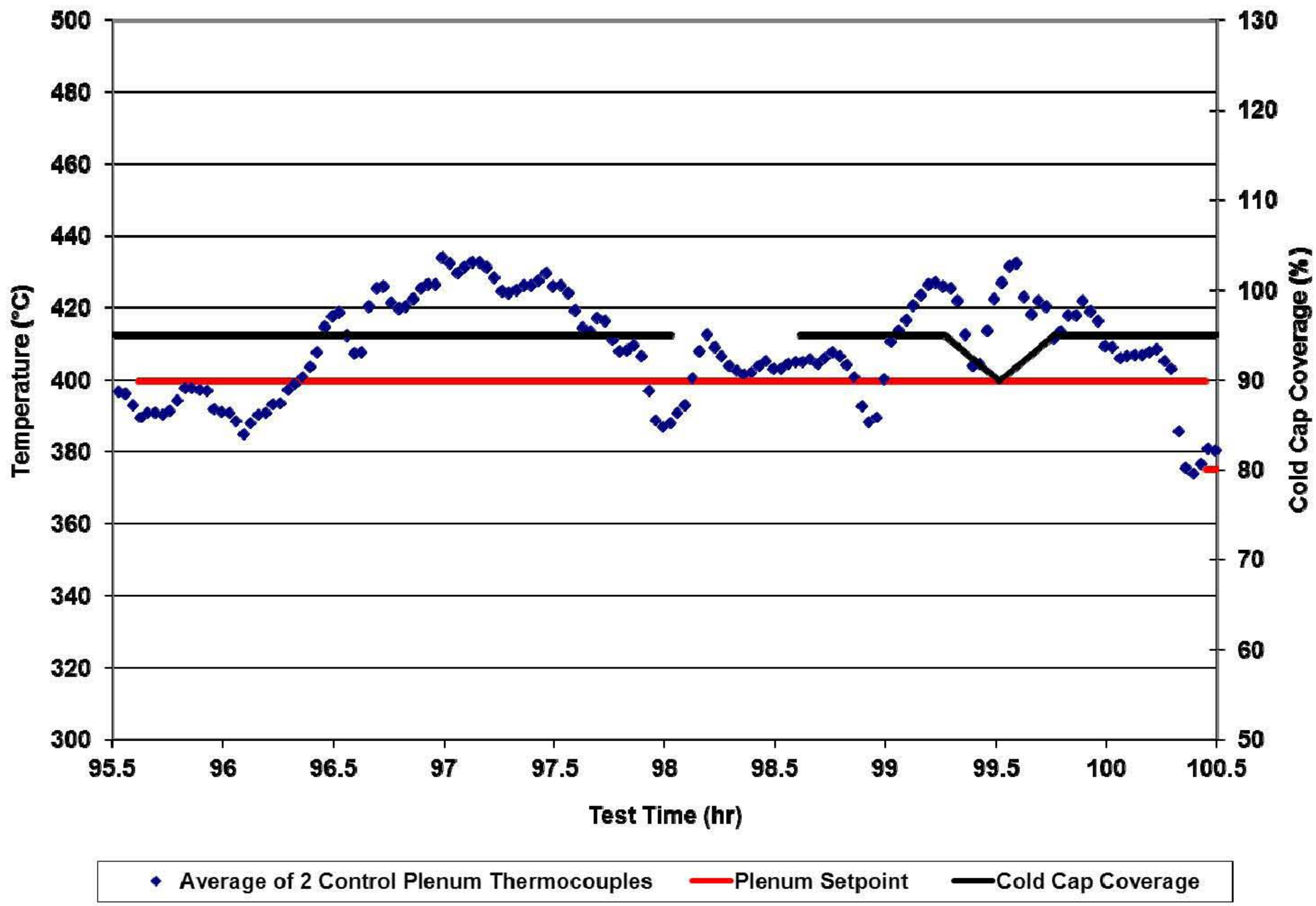

Figure 3.10.f. Control plenum temperatures, plenum temperature targets and observed cold cap coverage during Test 2e.

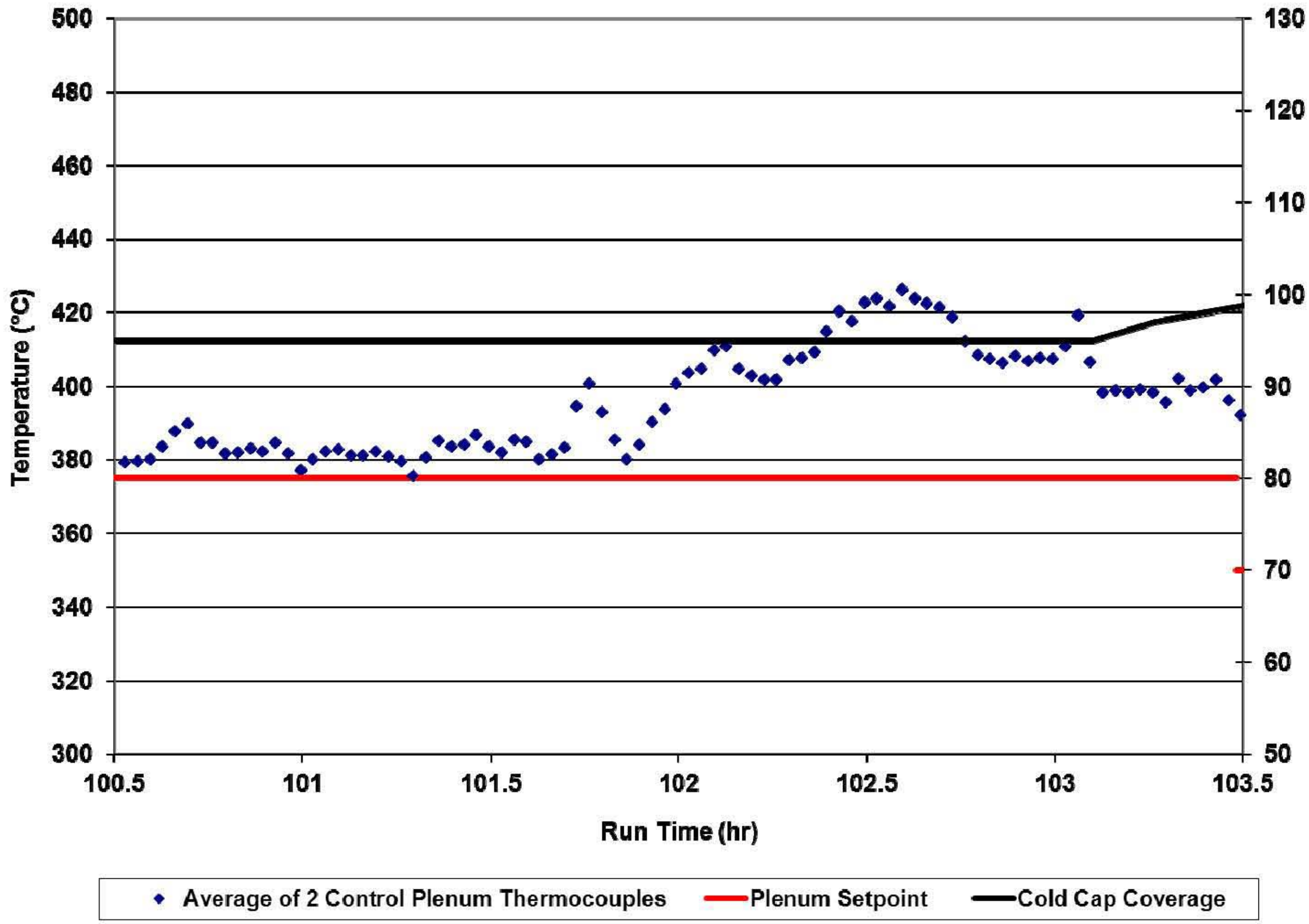

Figure 3.10.g. Control plenum temperatures, plenum temperature targets and observed cold cap coverage during Test 2f.

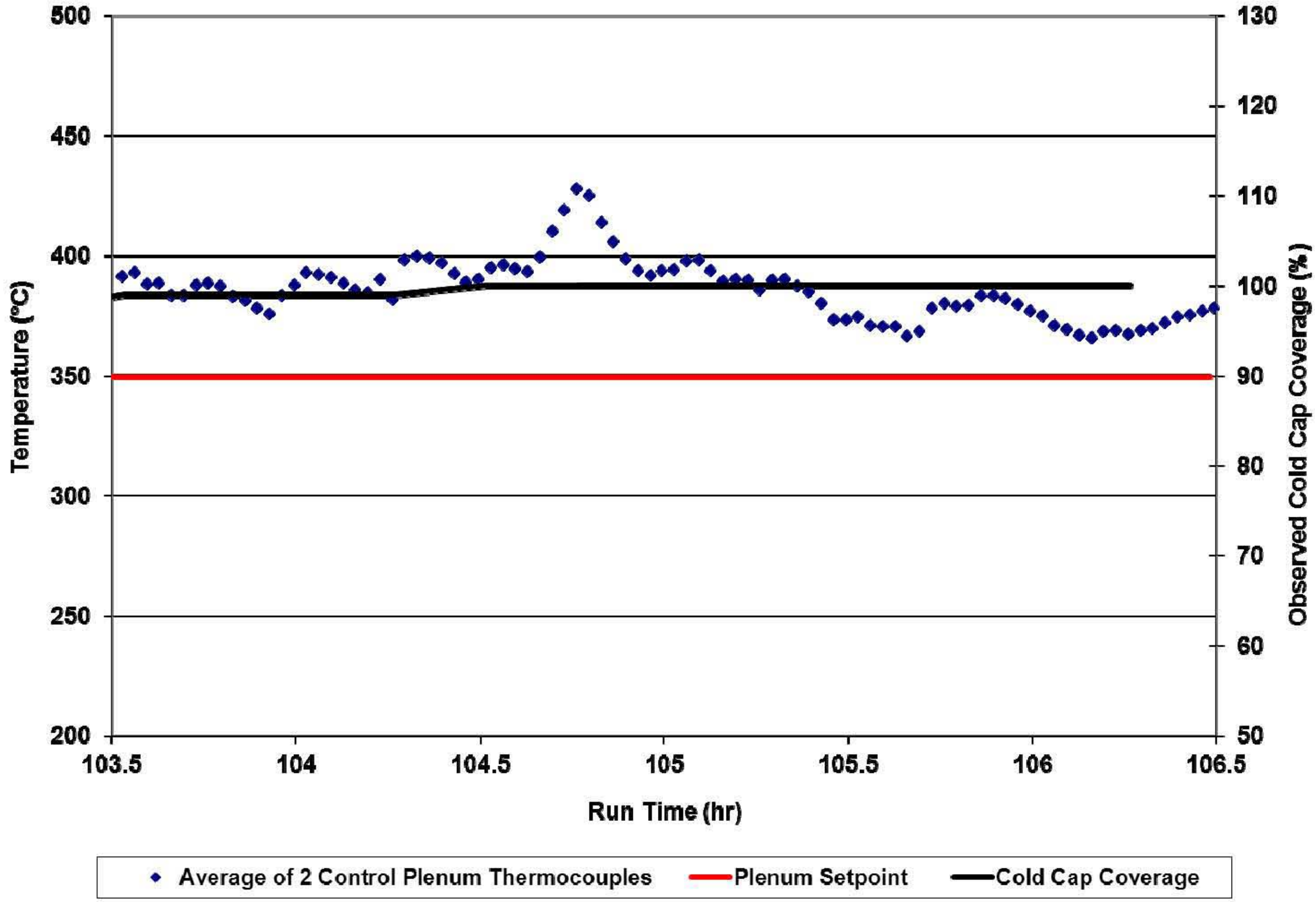

Figure 3.10.h. Control plenum temperatures, plenum temperature targets and observed cold cap coverage during Test 2g.

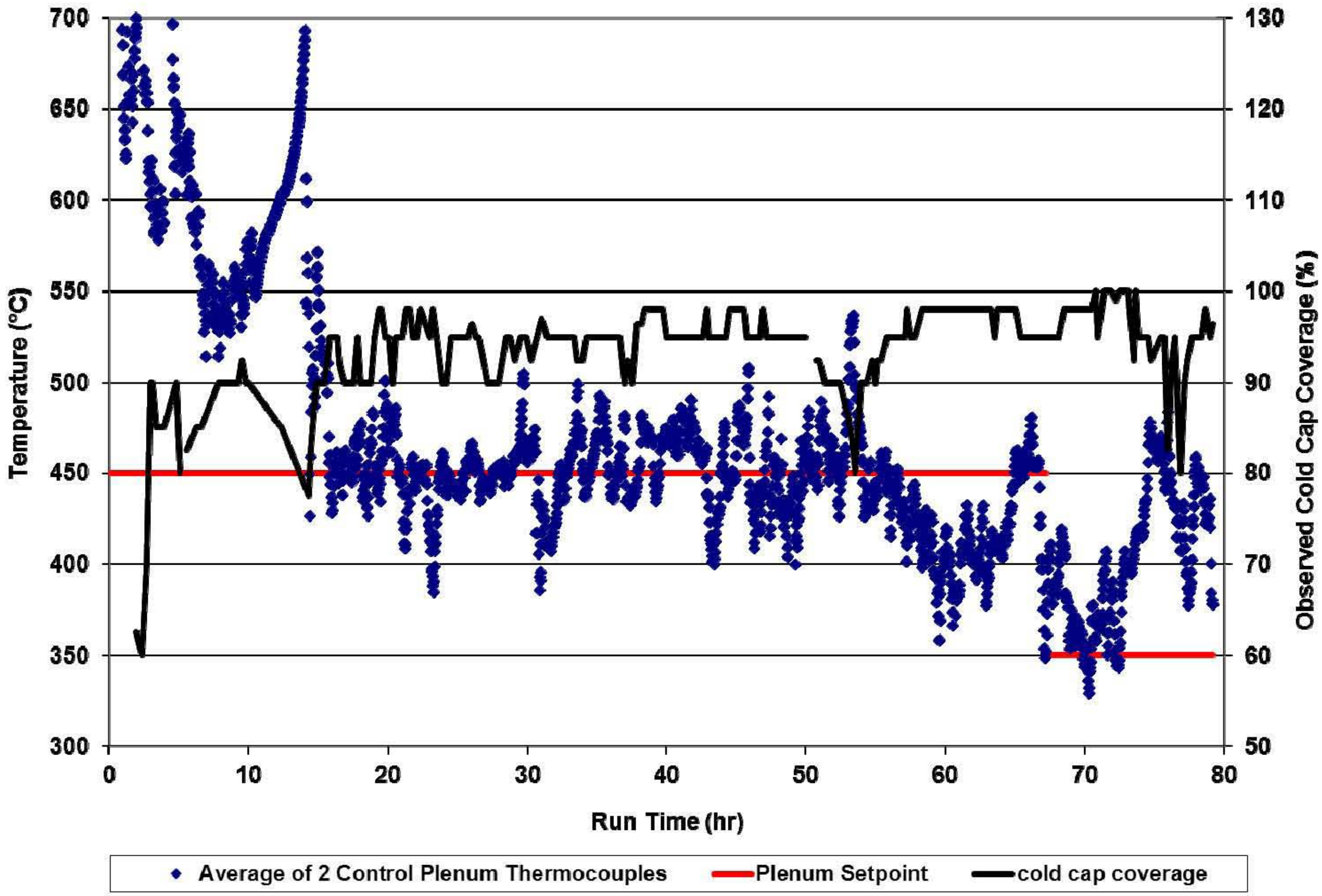

Figure 3.10.i. Control plenum temperatures, plenum temperature targets and observed cold cap coverage during Tests 3 and 4.

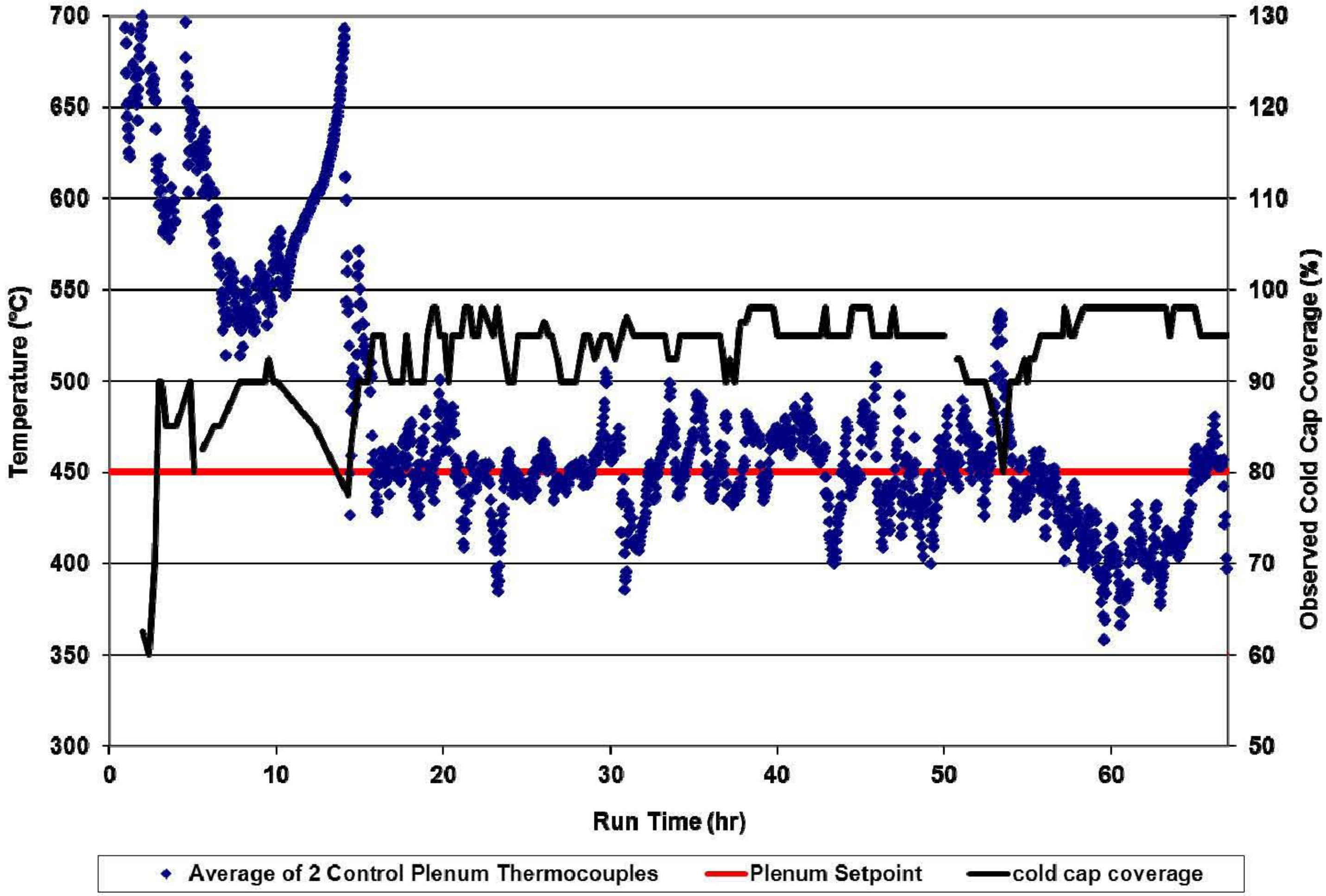

Figure 3.10.j. Control plenum temperatures, plenum temperature targets and observed cold cap coverage during Test 3.

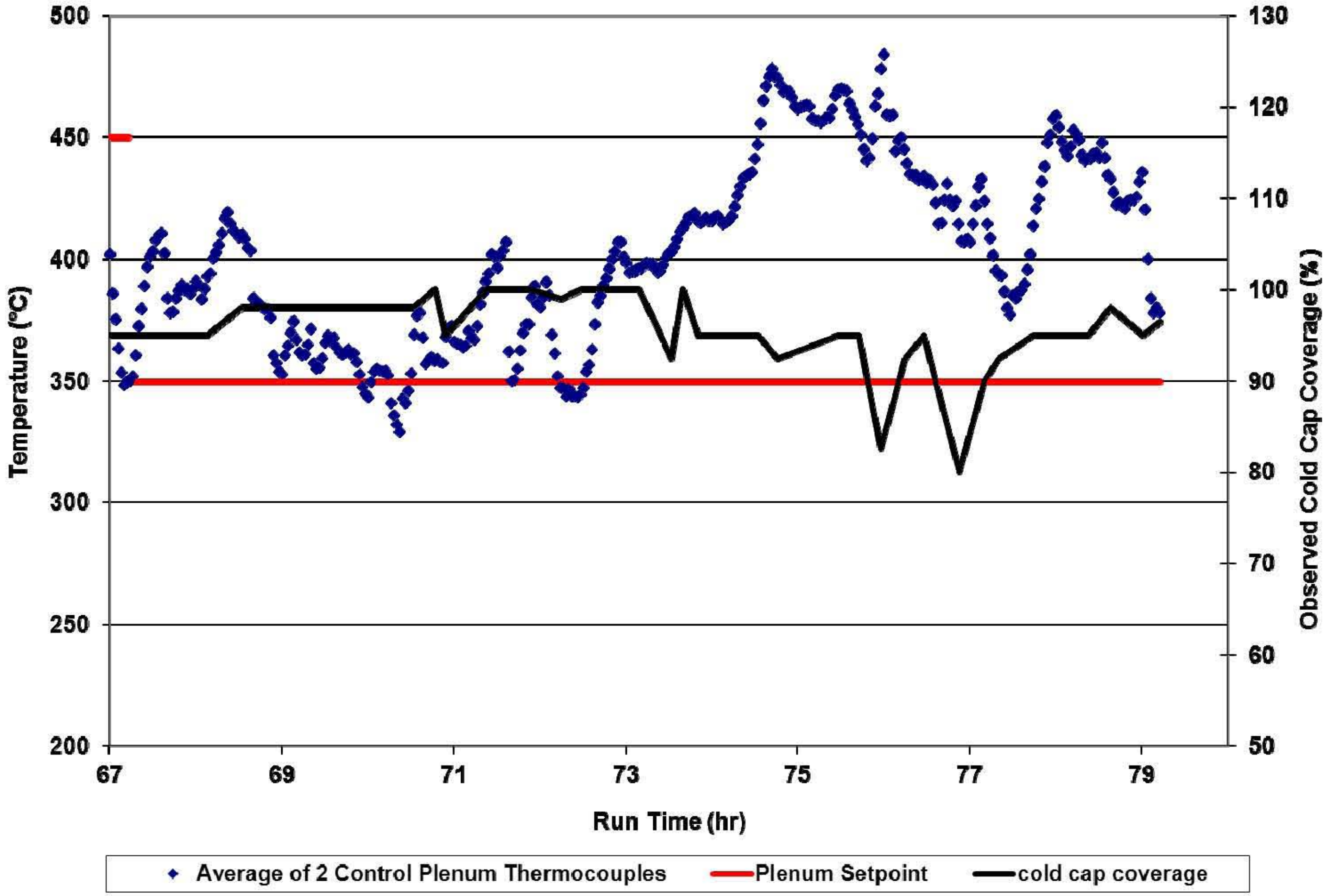

Figure 3.10.k. Control plenum temperatures, plenum temperature targets and observed cold cap coverage during Test 4.

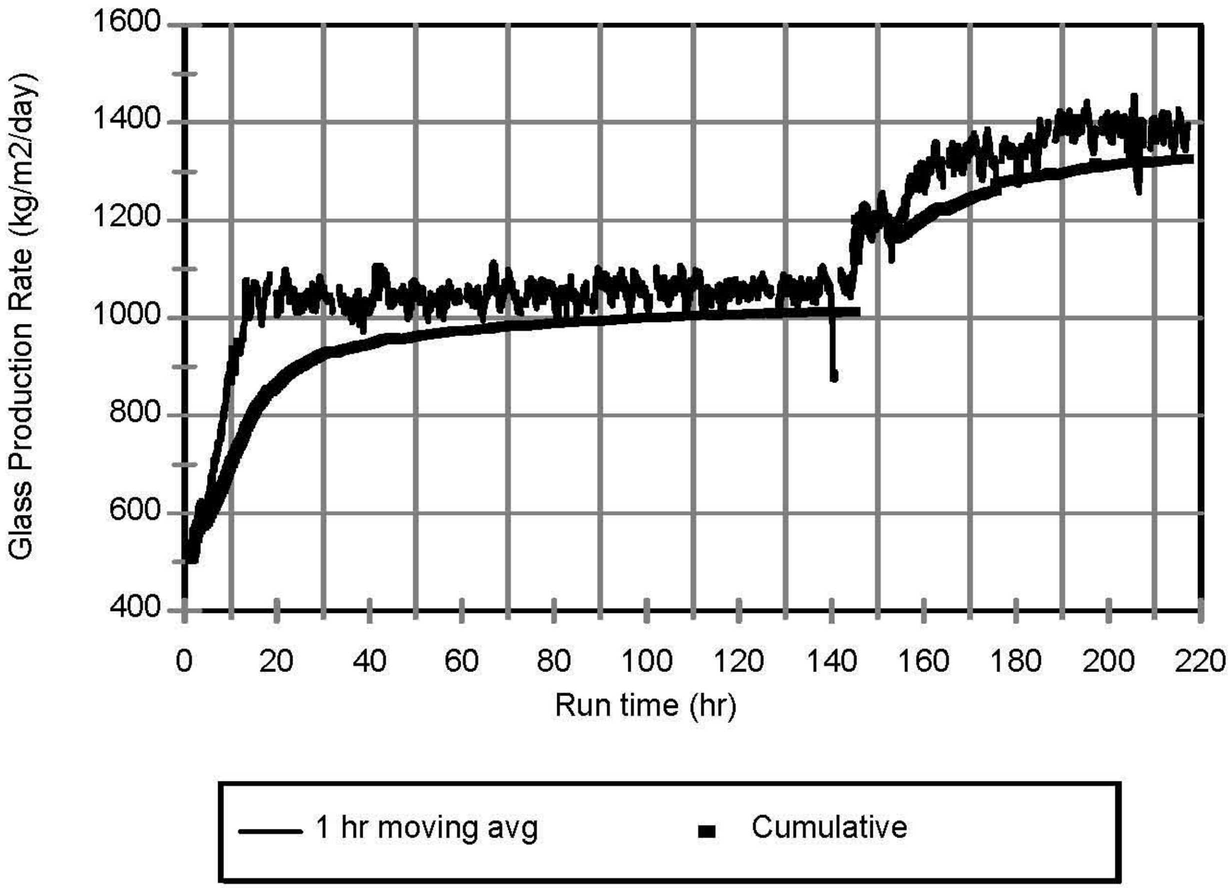

Figure 3.11.a. Production rates for AZ-101 composition (400 g glass/l, 2 double outlet bubblers) [15].

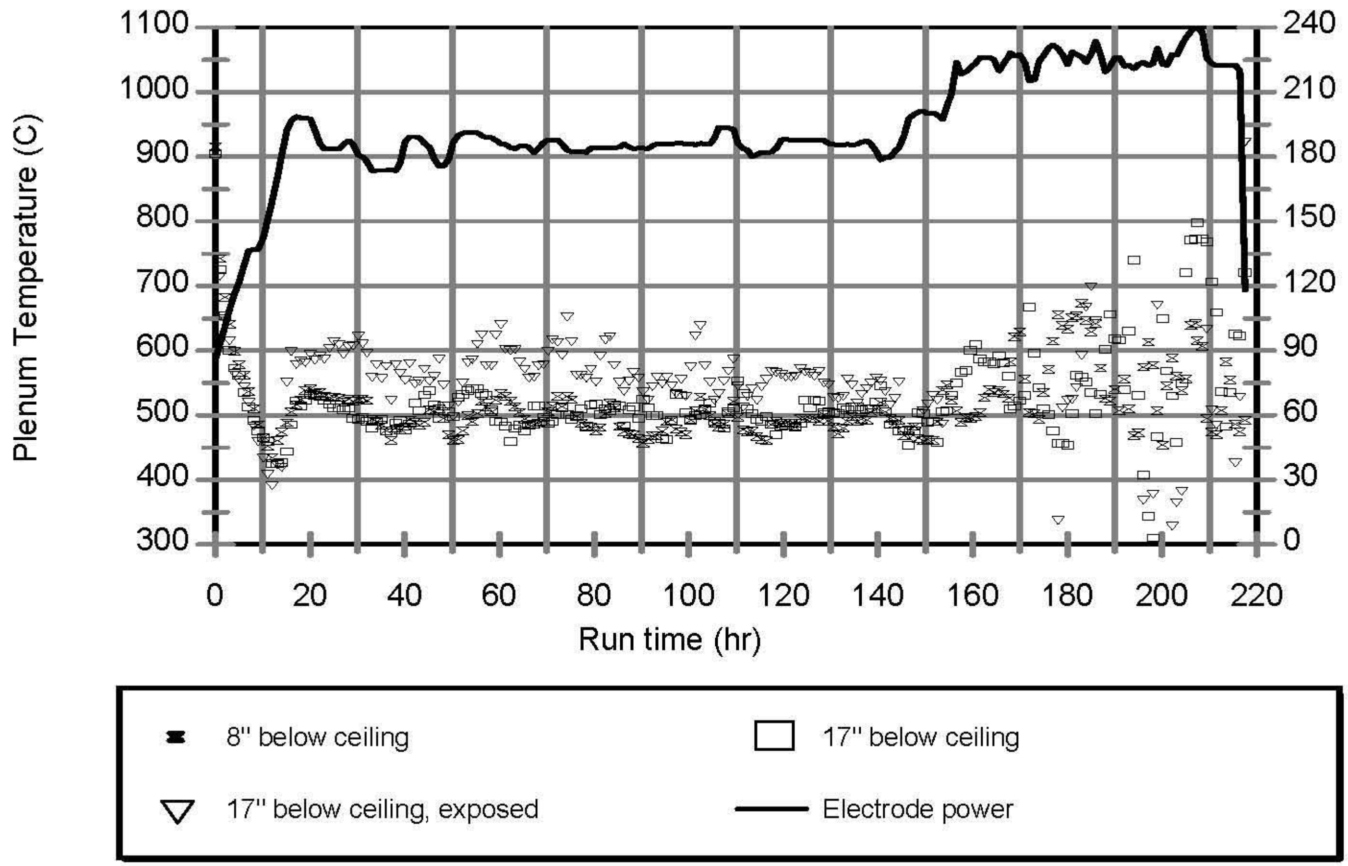

Figure 3.11.b. Plenum temperatures and electrode power (hourly averages) for AZ-101 composition (400 g glass/l, 2 double outlet bubblers) [15].

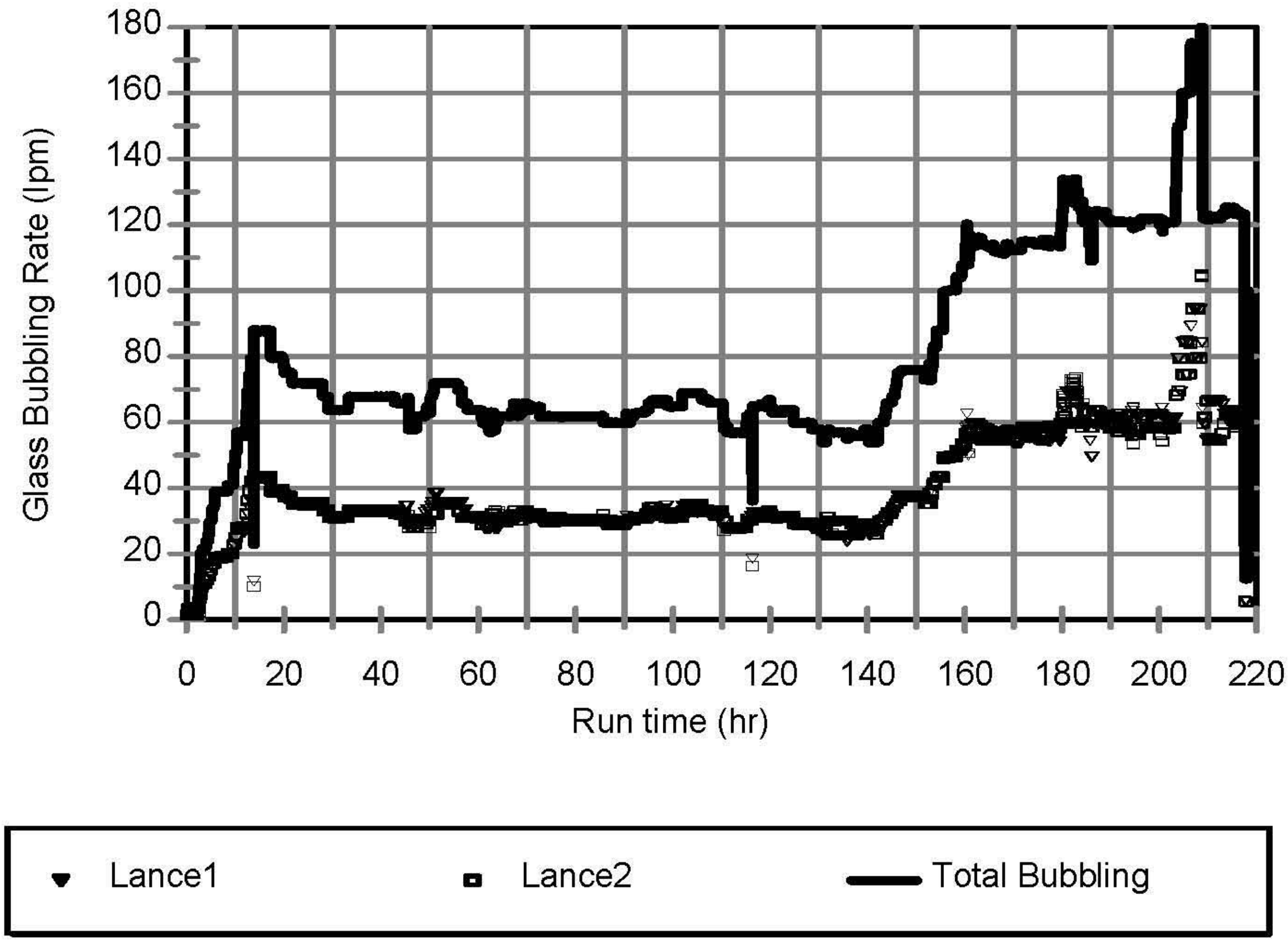

Figure 3.11.c. Glass pool bubbling for AZ-101 composition (400 g glass/l, 2 double outlet bubblers) [15].

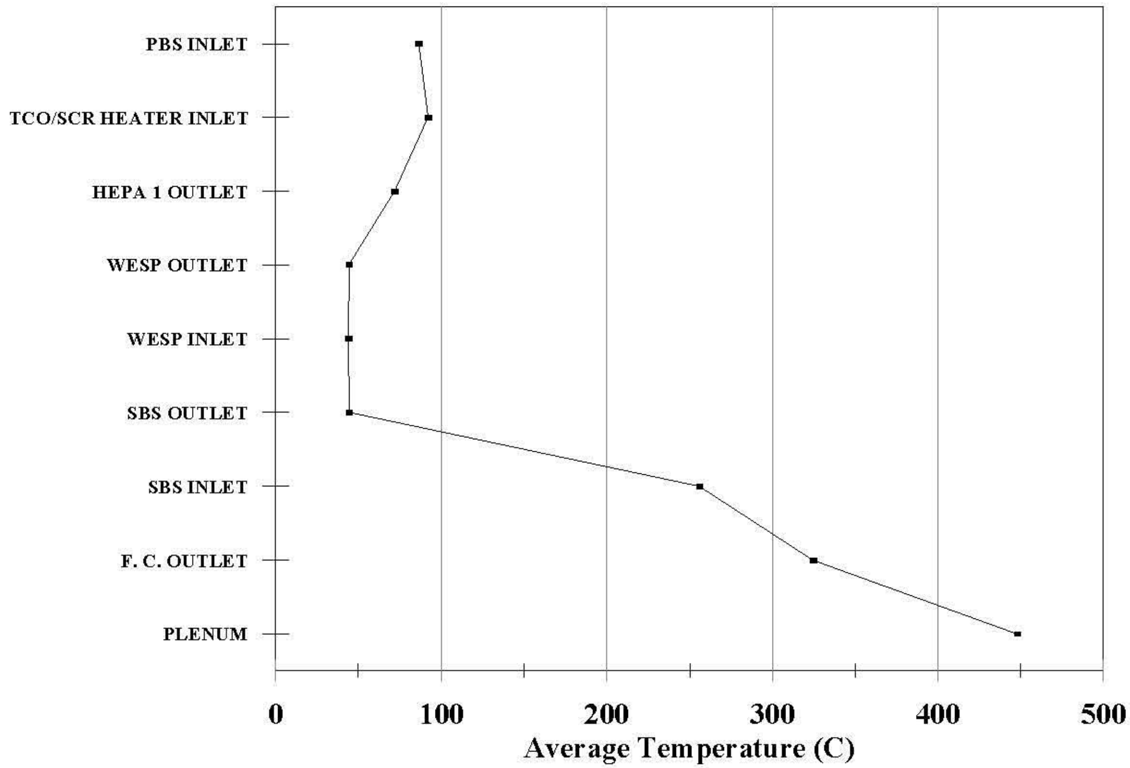

Figure 4.1. Average gas temperatures along the DM1200 off-gas train during Tests 1&2.

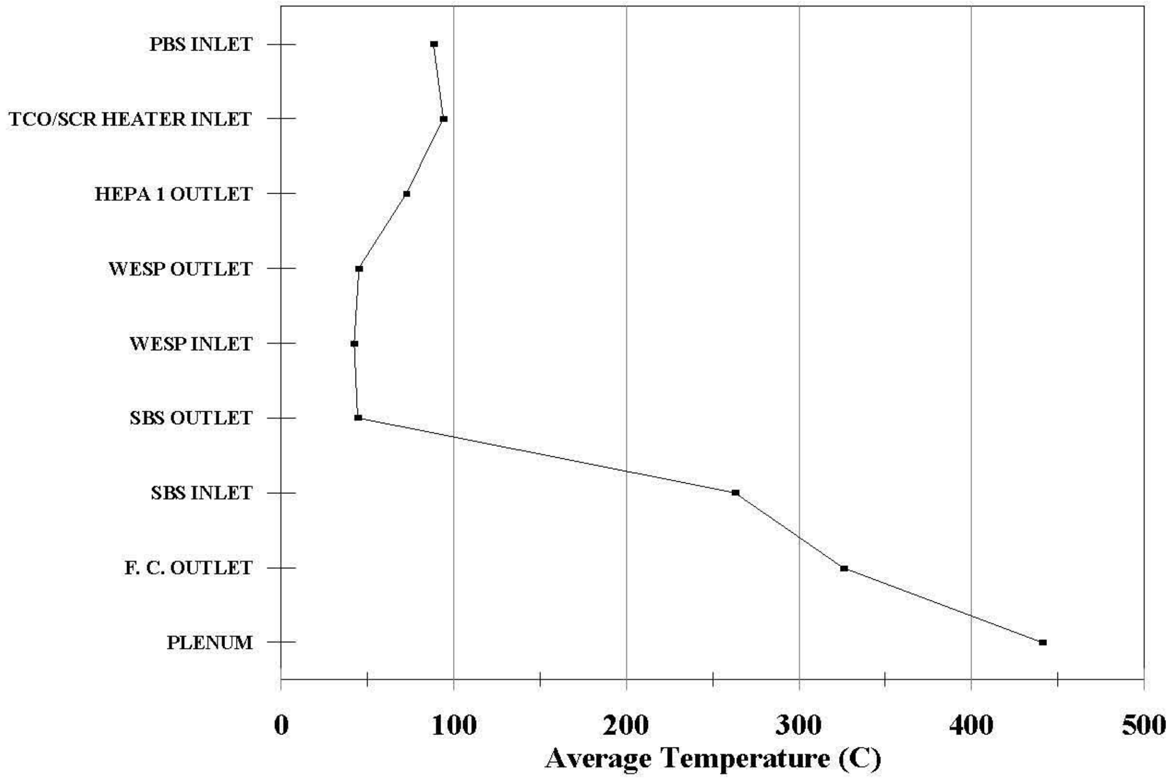

Figure 4.2. Average gas temperatures along the DM1200 off-gas train during Tests 3&4.

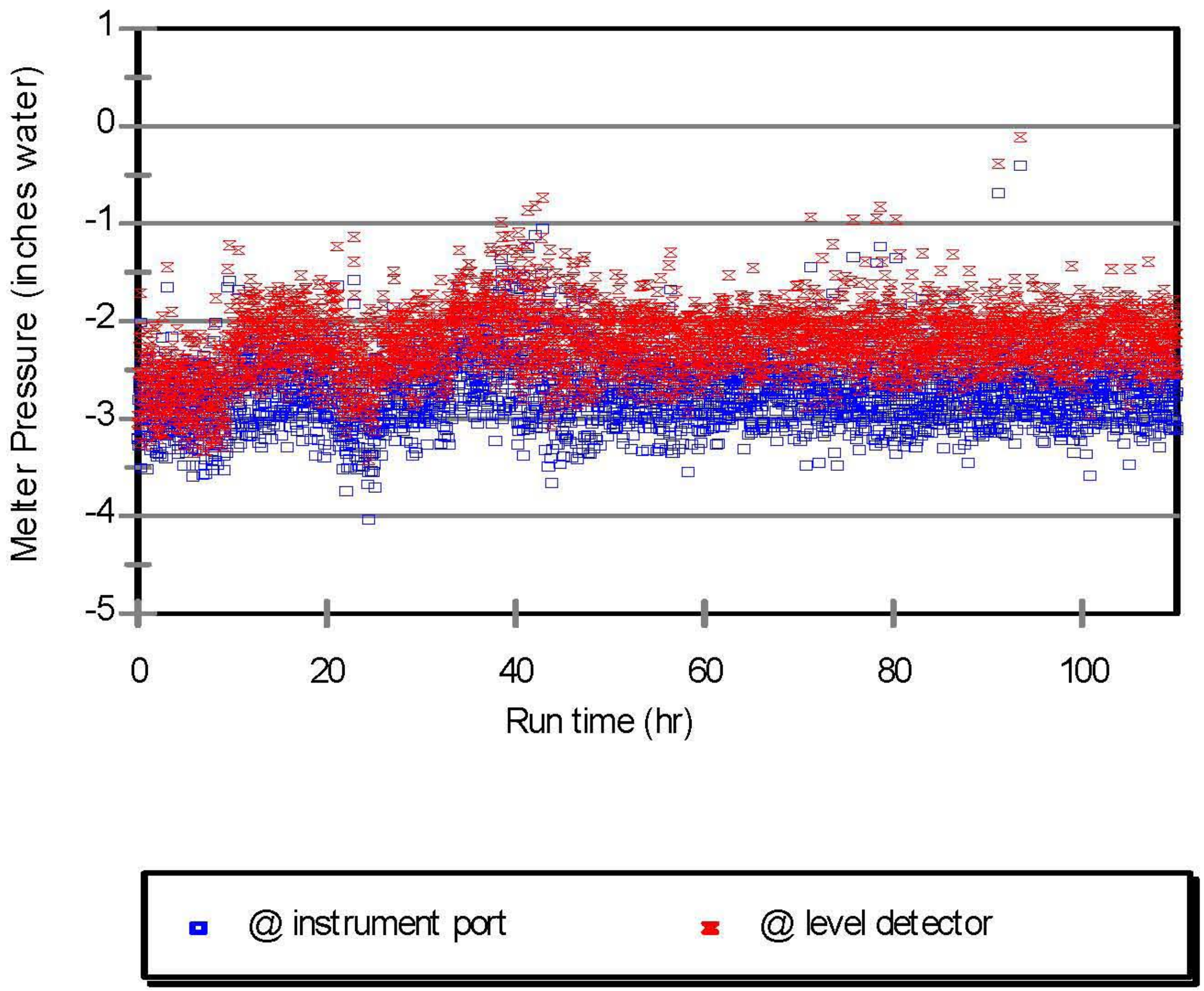

Figure 4.3. Melter pressure while processing the AZ-101 composition.

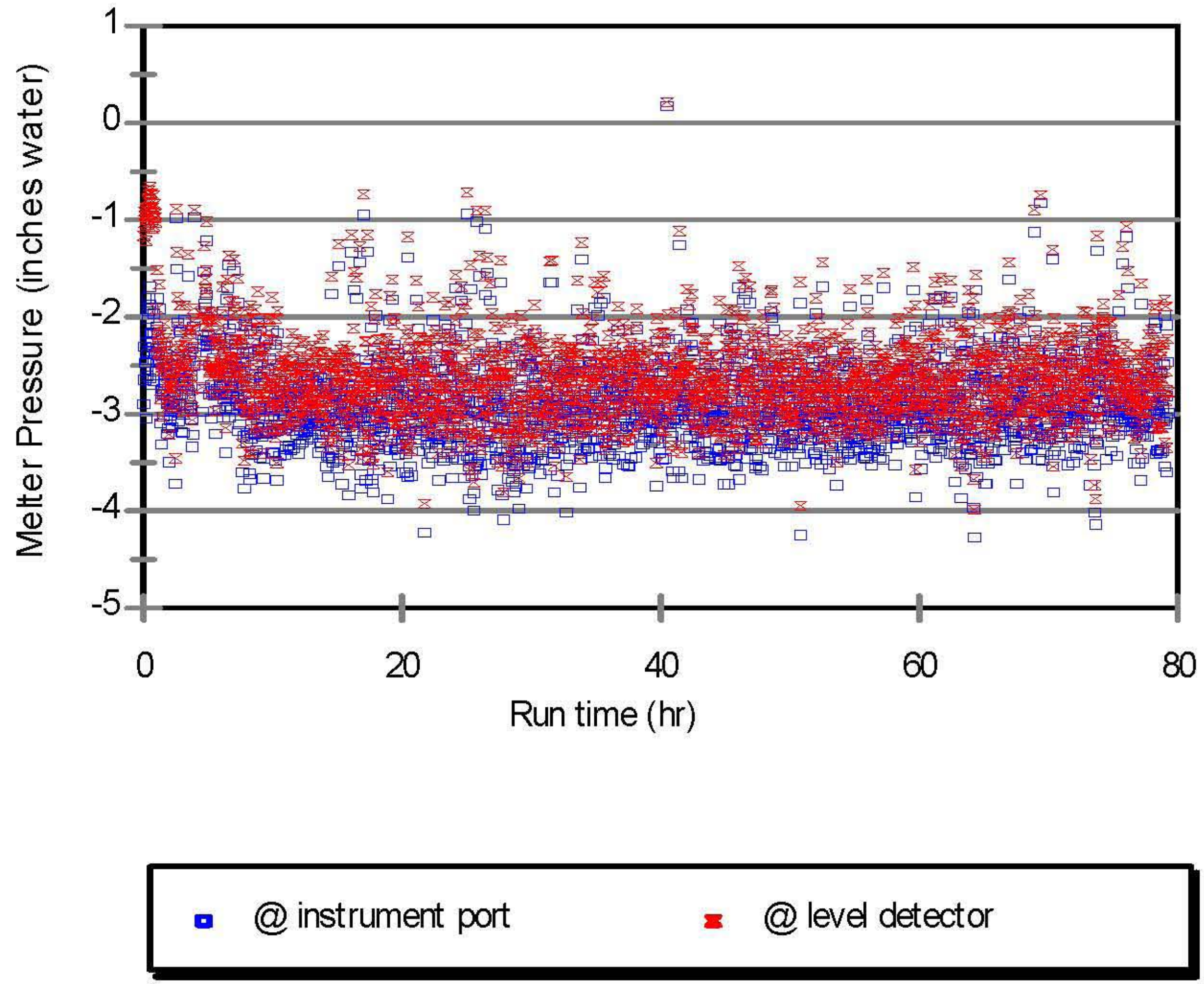

Figure 4.4. Melter pressure while processing the high aluminum composition.

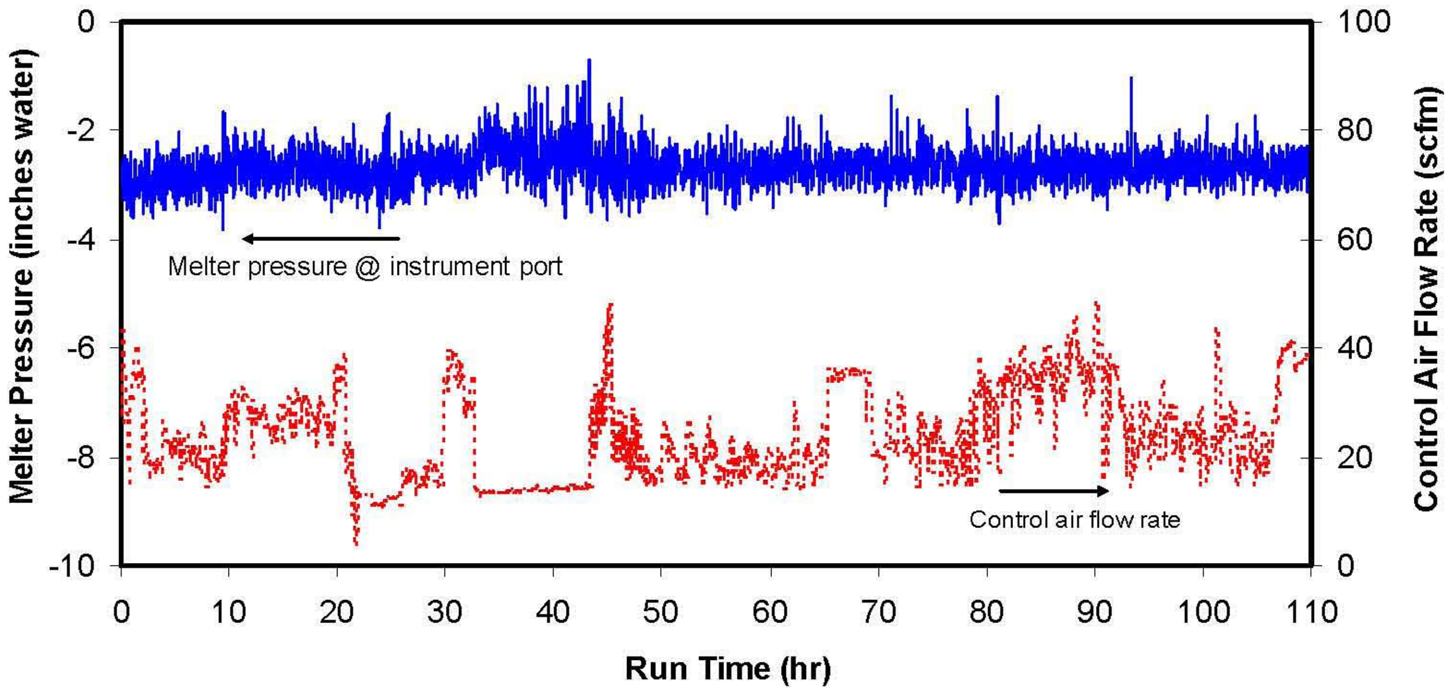

Figure 4.5. Melter pressure at instrument port and control air flow rate during Tests 1&2.

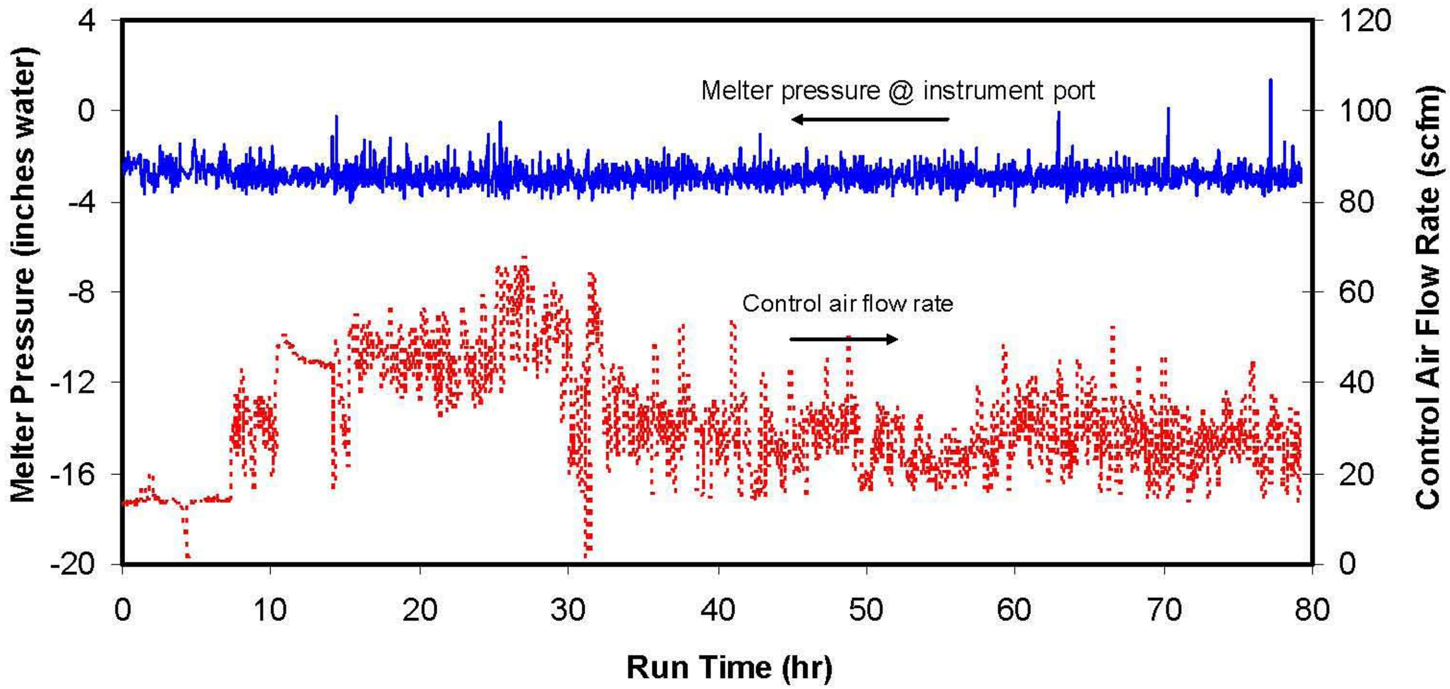

Figure 4.6. Melter pressure at instrument port and control air flow rate during Tests 3&4.

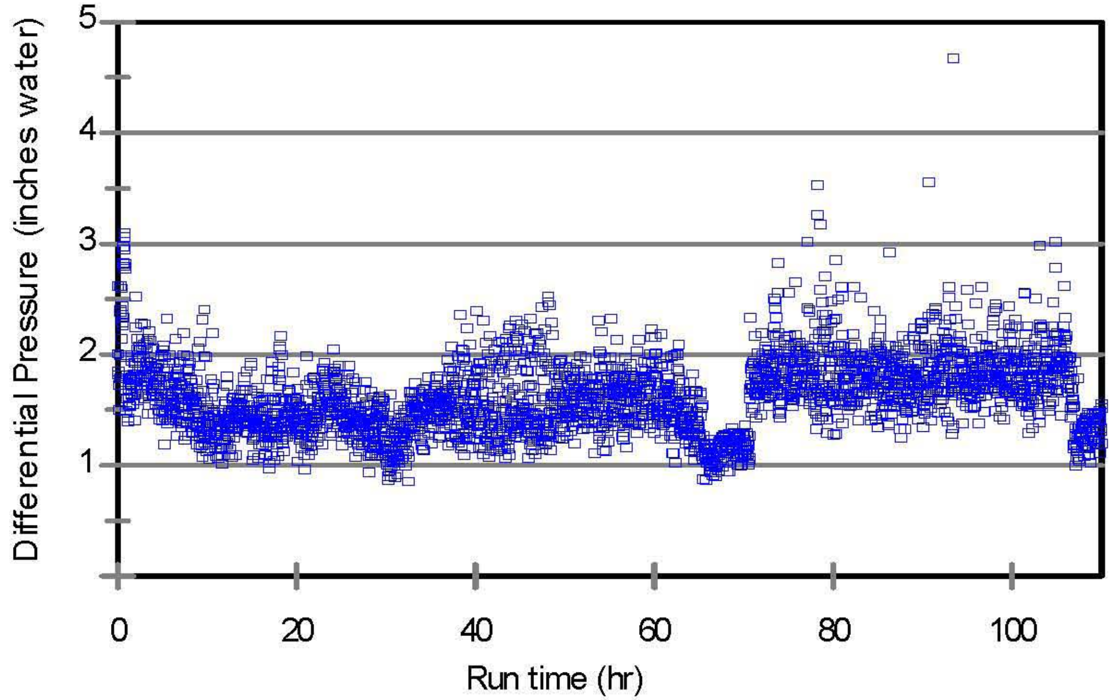

Figure 4.7. Differential pressure across the film cooler during Tests 1&2.

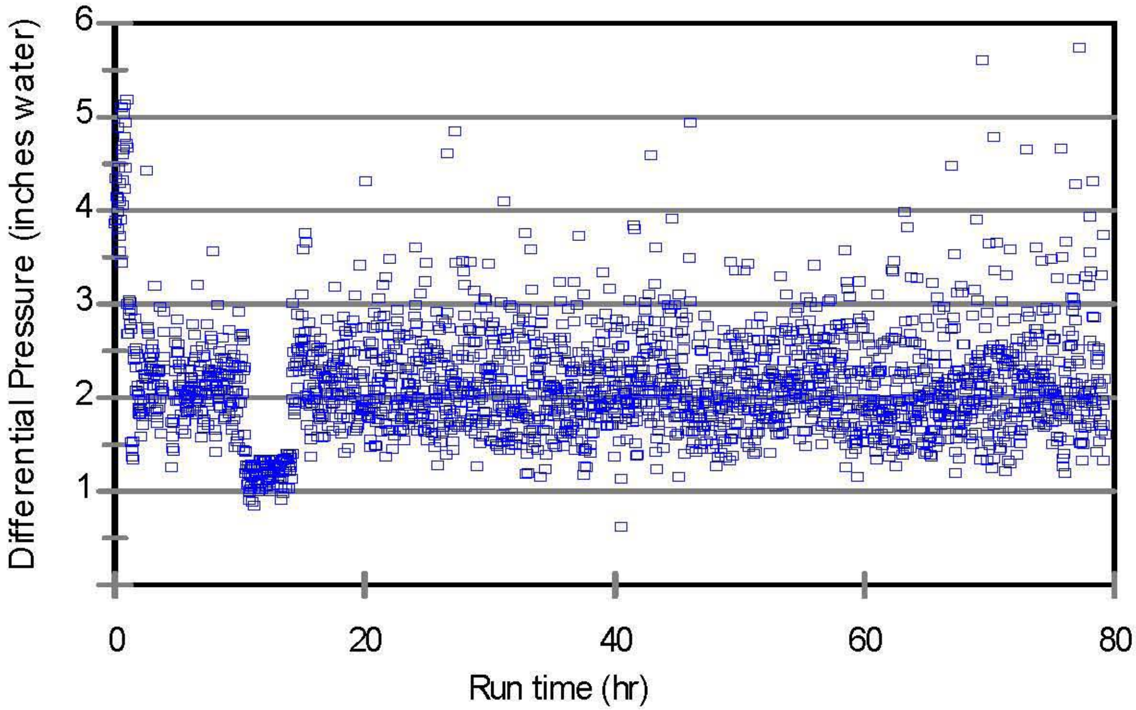

Figure 4.8. Differential pressure across the film cooler during Tests 3&4.

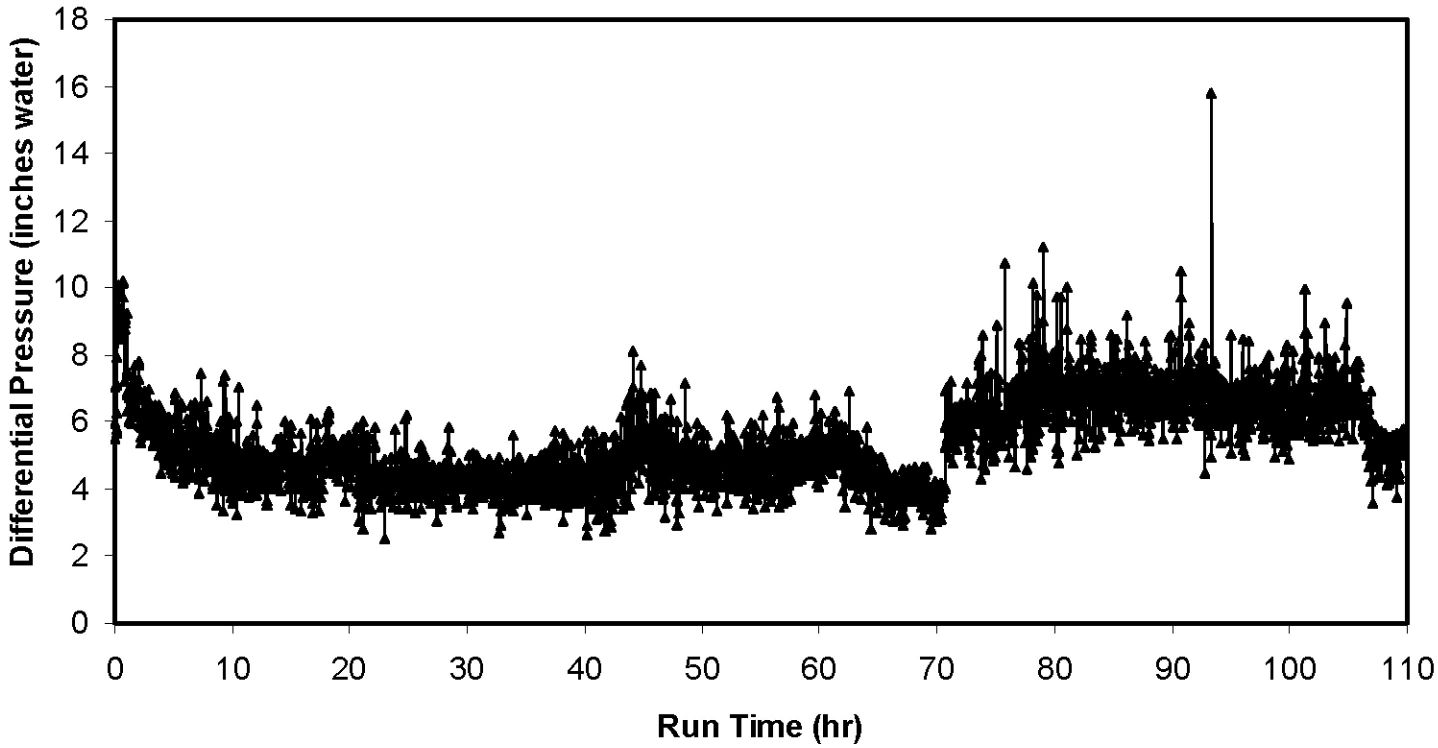

Figure 4.9. Differential pressure across the transition line during Tests 1&2.

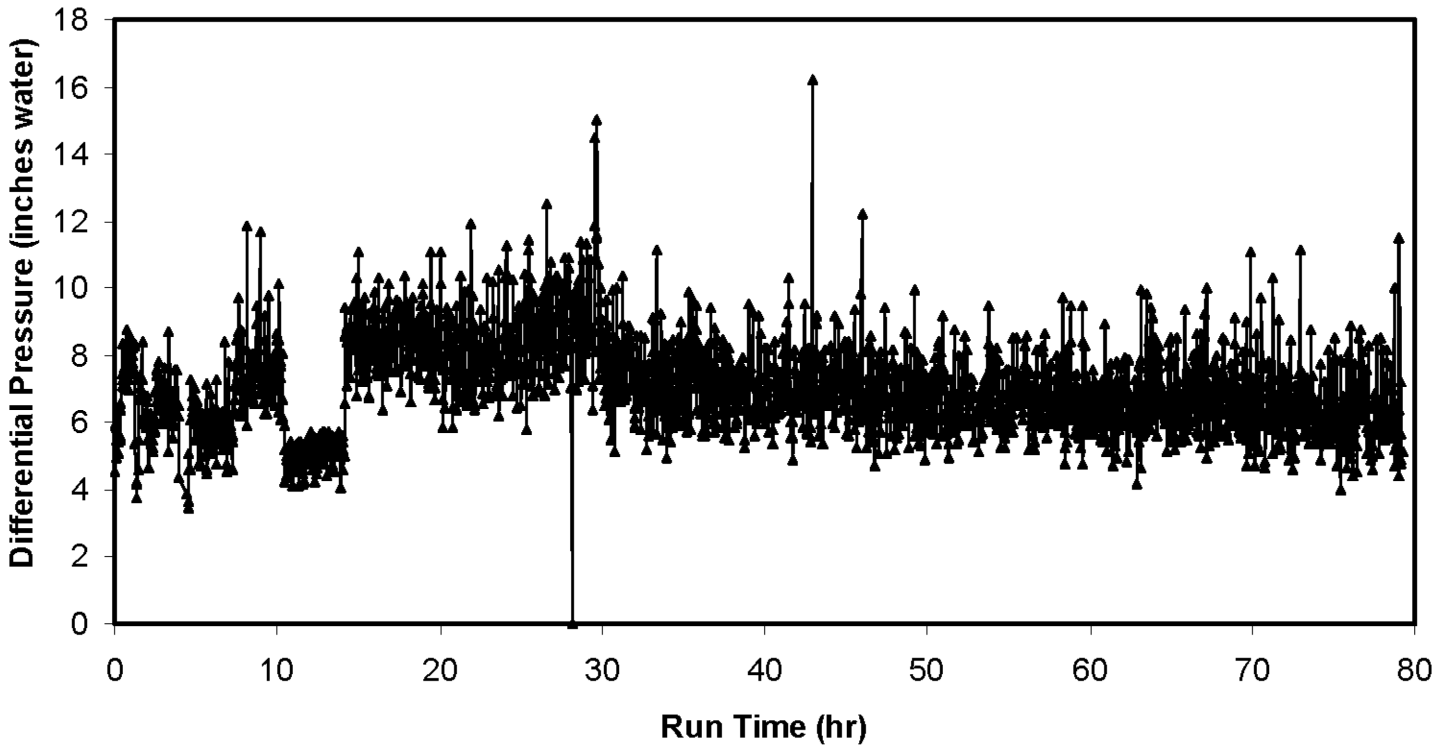

Figure 4.10. Differential pressure across the transition line during Tests 3&4.

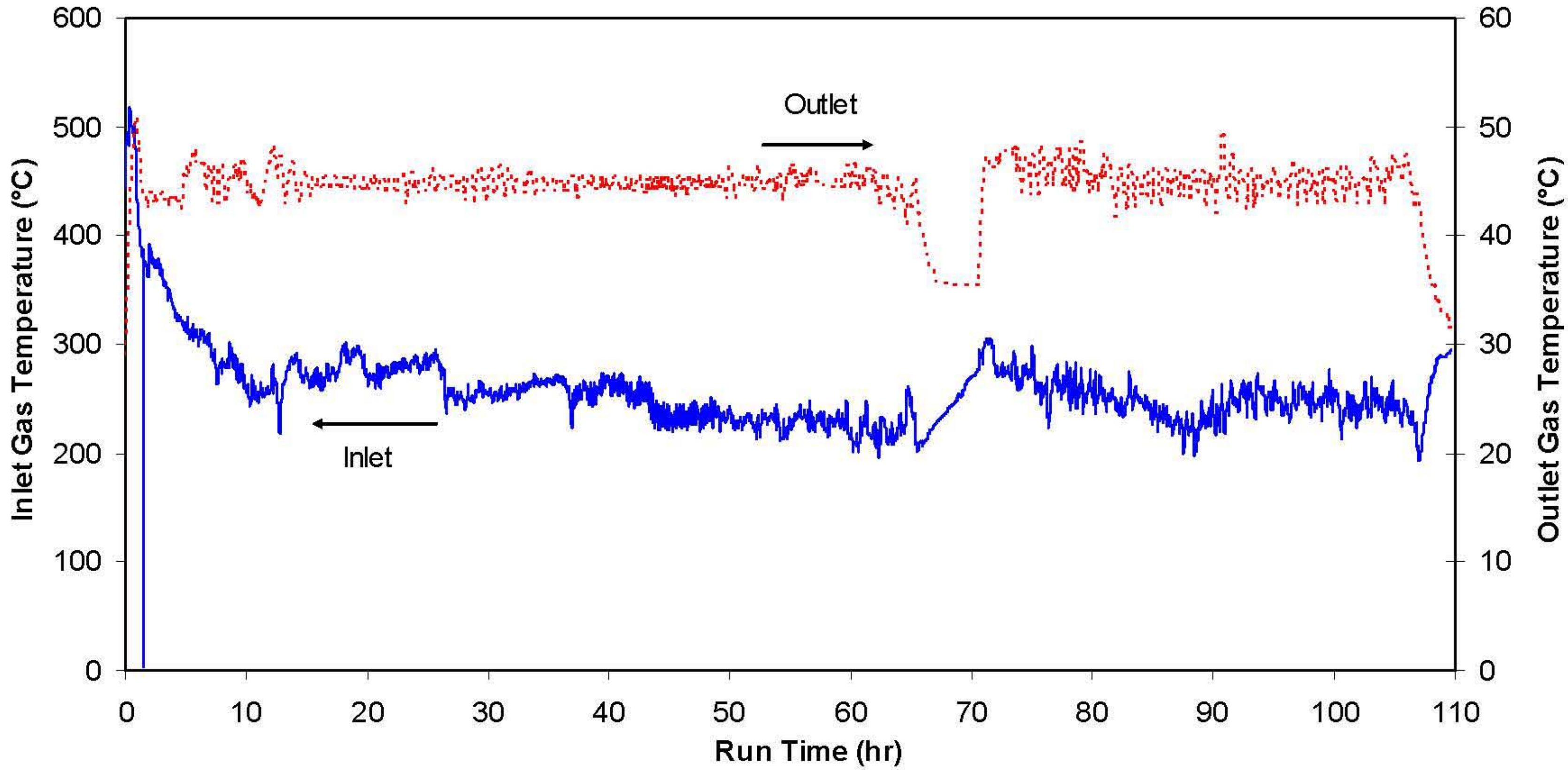

Figure 4.11. SBS inlet and outlet gas temperatures during Tests 1&2.

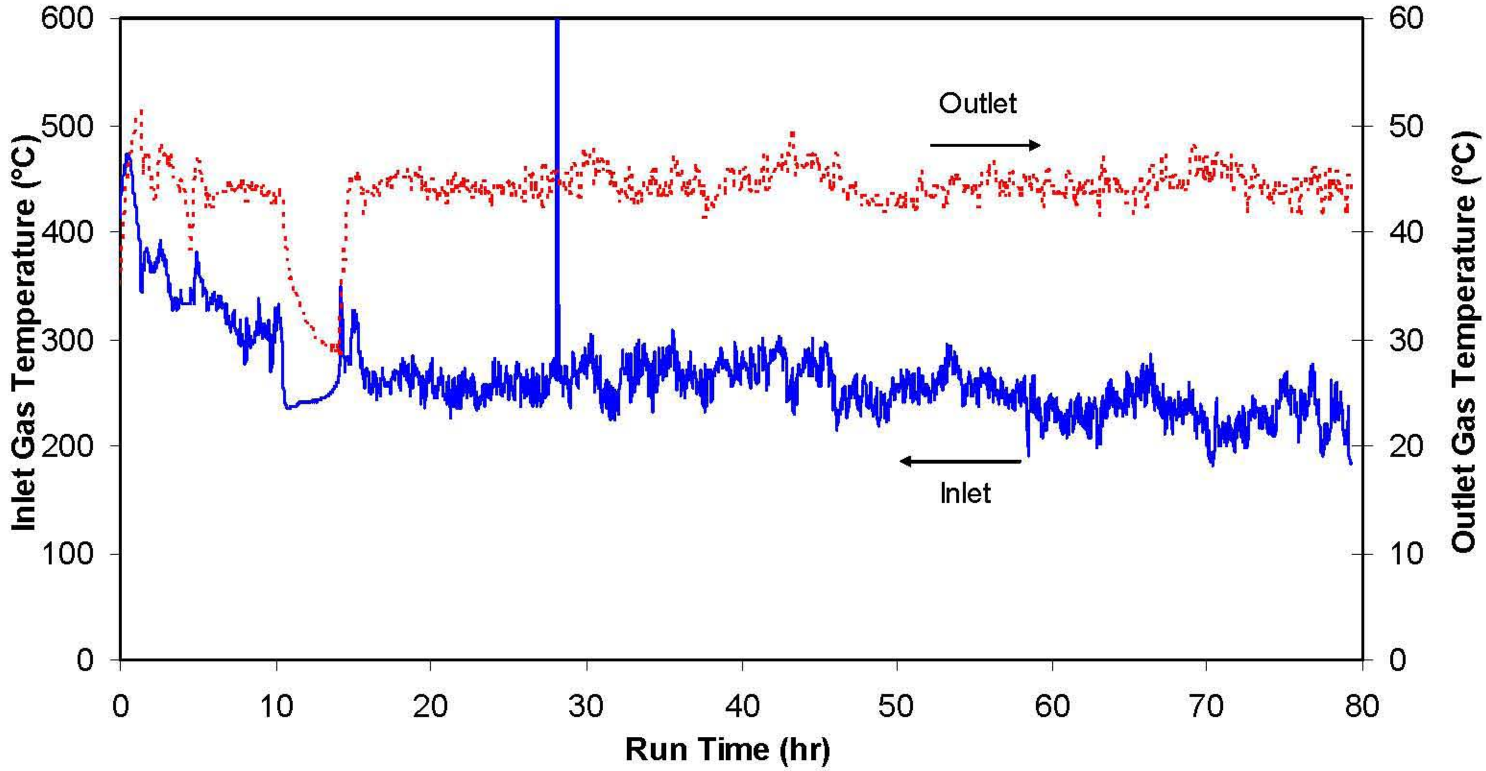

Figure 4.12. SBS inlet and outlet gas temperatures during Tests 3&4.

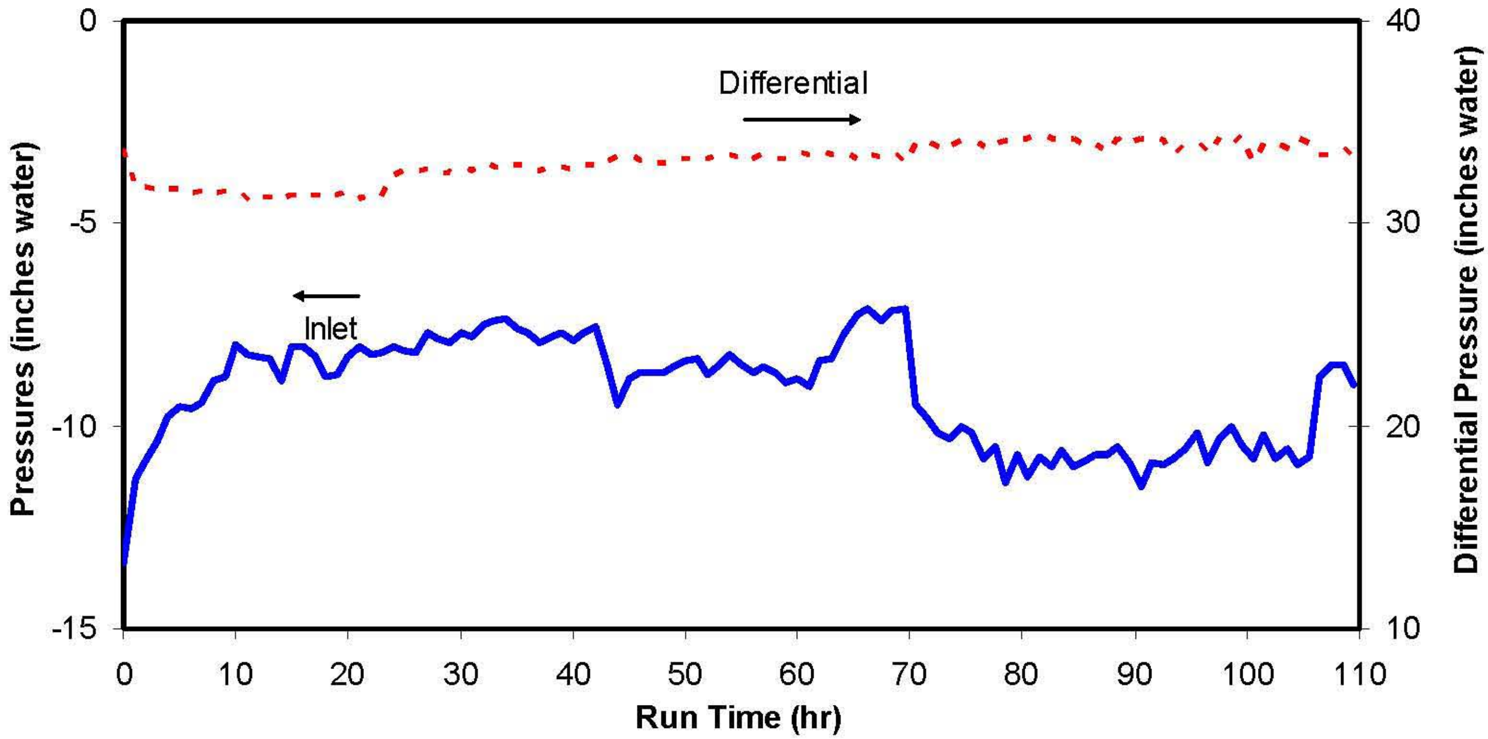

Figure 4.13. SBS inlet and differential pressures (hourly average values) during Tests 1&2.

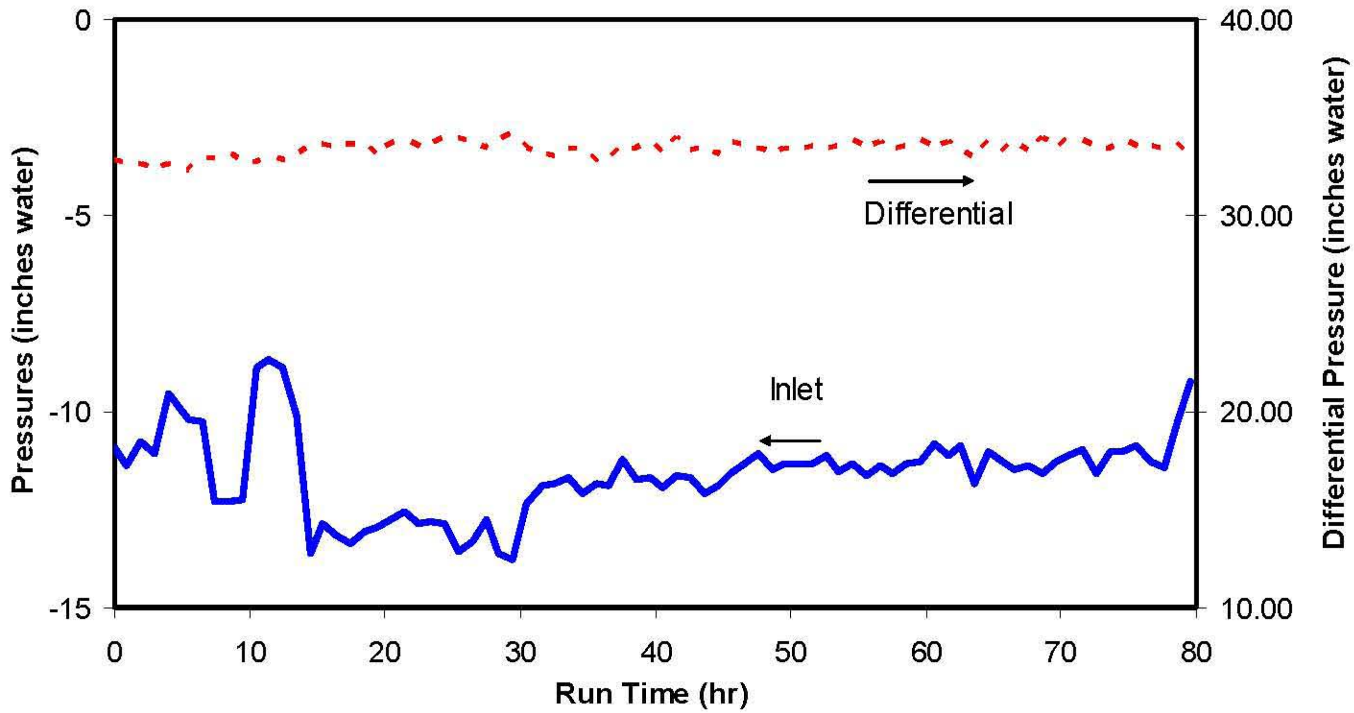

Figure 4.14. SBS inlet and differential pressures (hourly average values) during Tests 3&4.

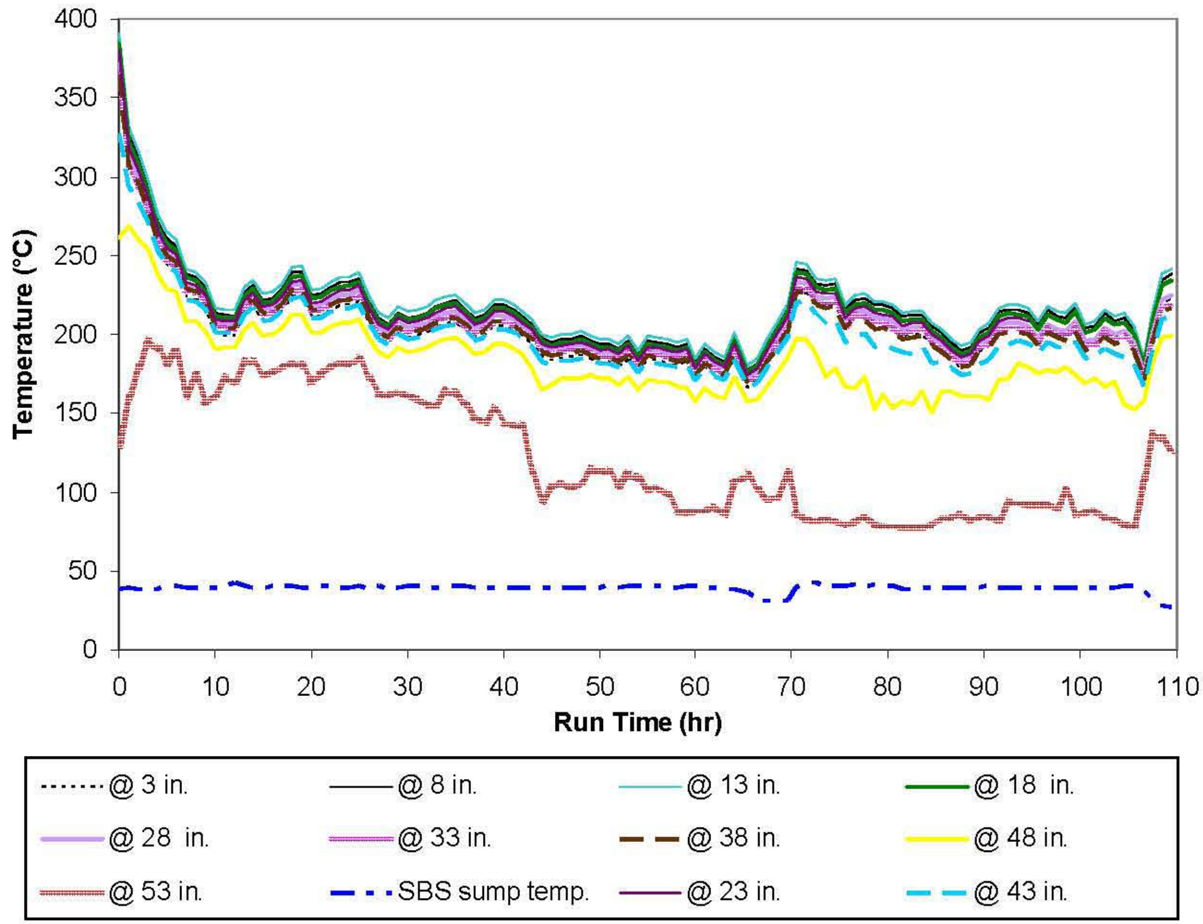

Figure 4.15. Off-gas temperatures in the SBS downcomer and sump water temperatures (hourly average values) during Tests 1&2.

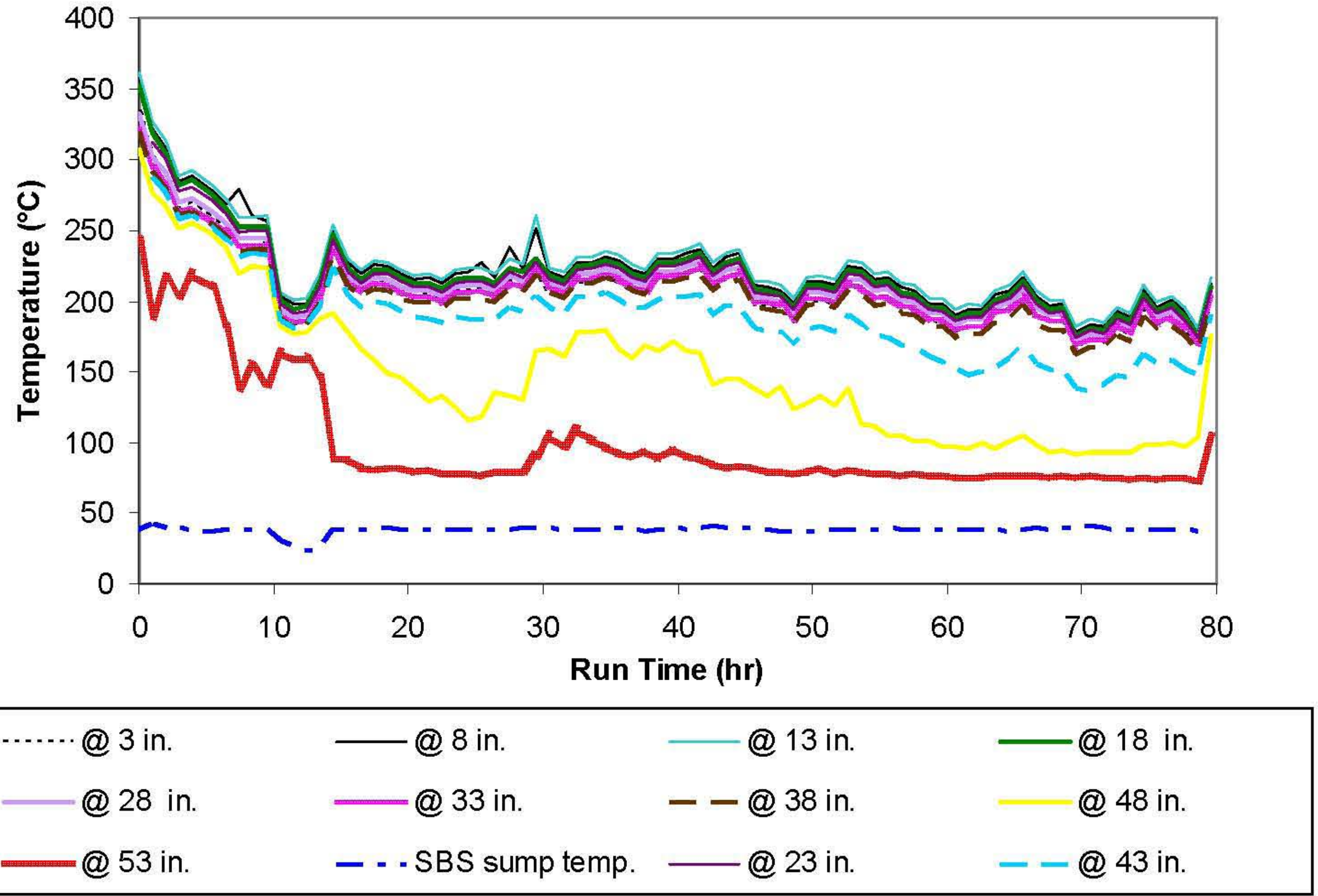

Figure 4.16. Off-gas temperatures in the SBS downcomer and sump water temperatures (hourly average values) during Tests 3&4.

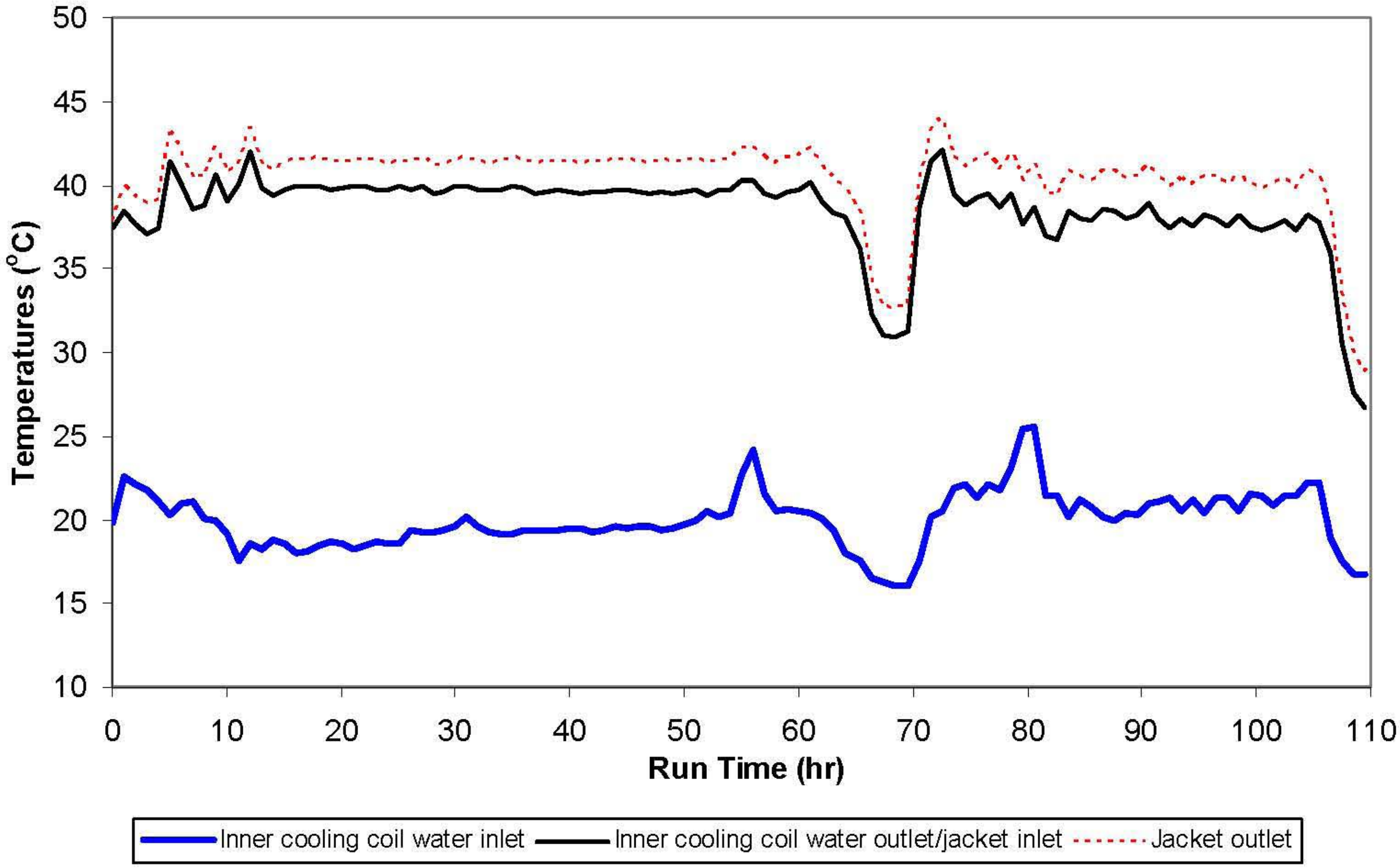

Figure 4.17. SBS cooling coil inlet, cooling coil outlet/jacket inlet and jacket outlet water temperatures (hourly average values) during Tests 1&2.

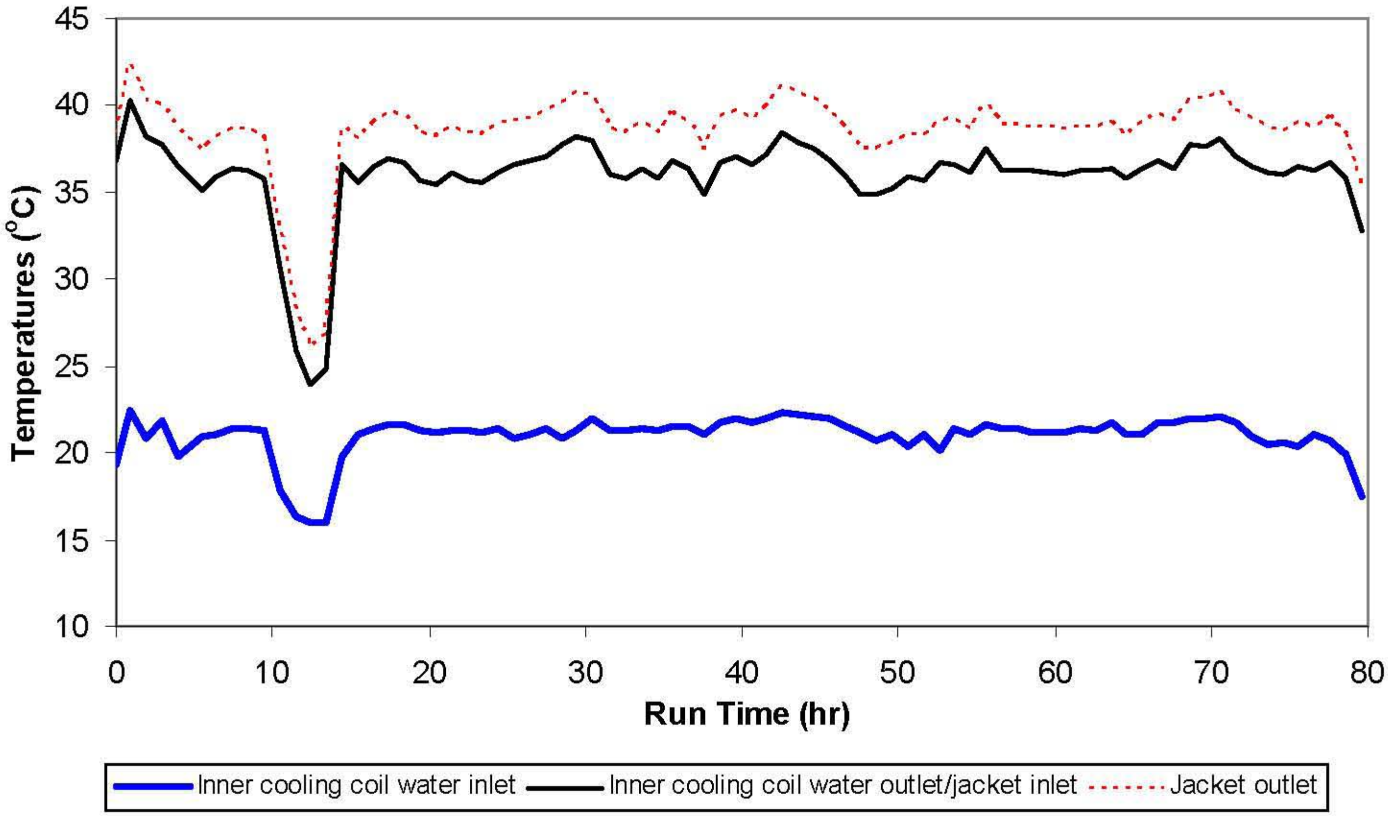

Figure 4.18. SBS cooling coil inlet, cooling coil outlet/jacket inlet and jacket outlet water temperatures (hourly average values) during Tests 3&4.

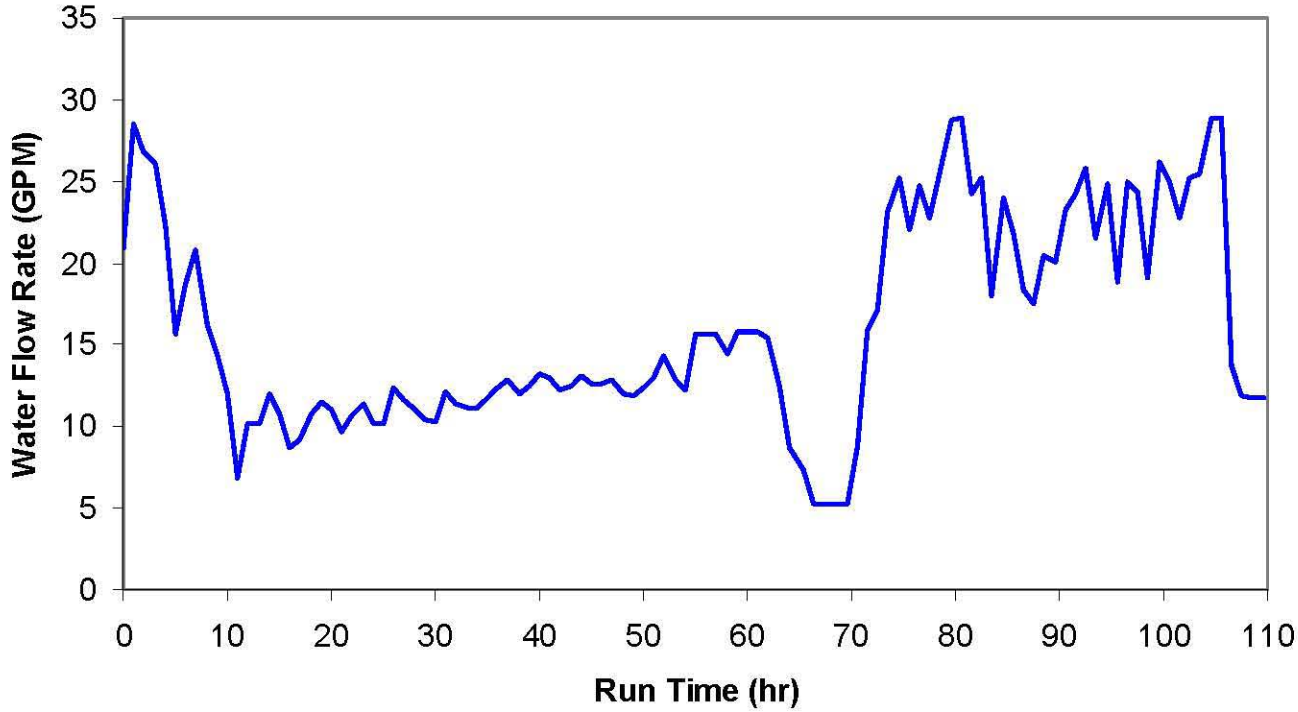

Figure 4.19. SBS cooling coil/jacket water flow rate (hourly average values) during Tests 1&2.

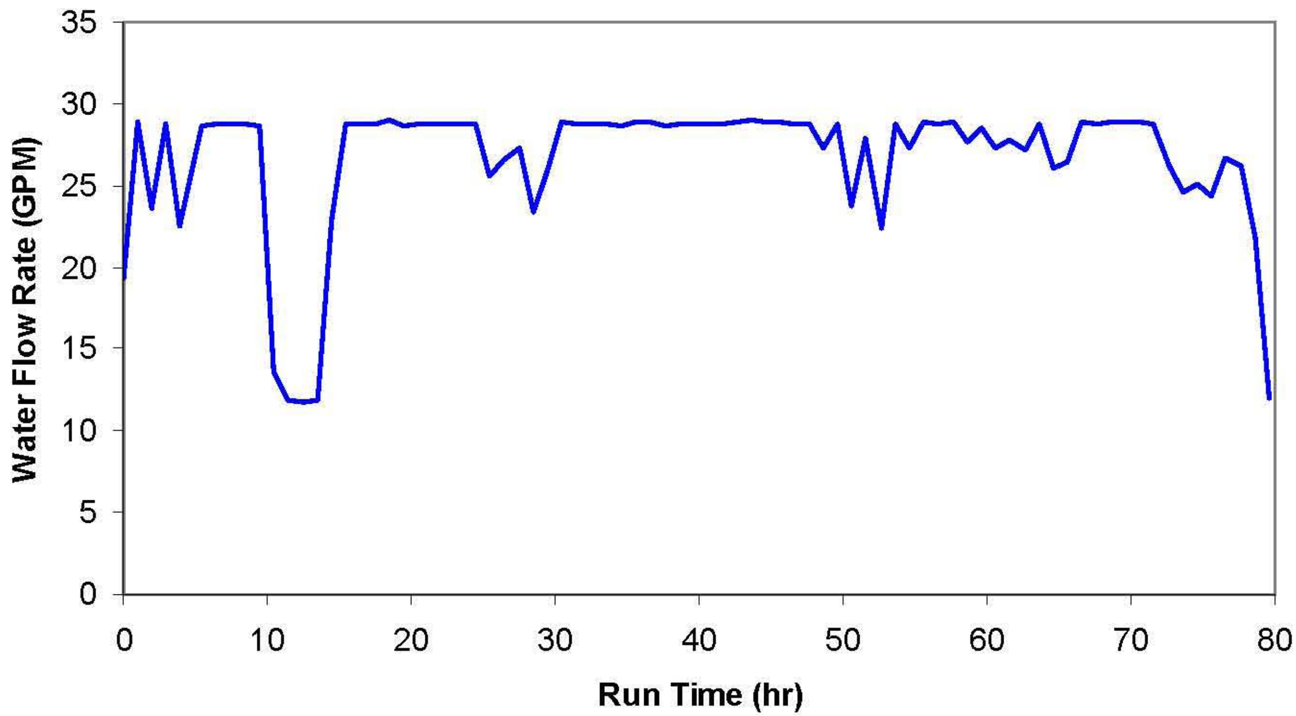

Figure 4.20. SBS cooling coil/jacket water flow rate (hourly average values) during Tests 3&4.

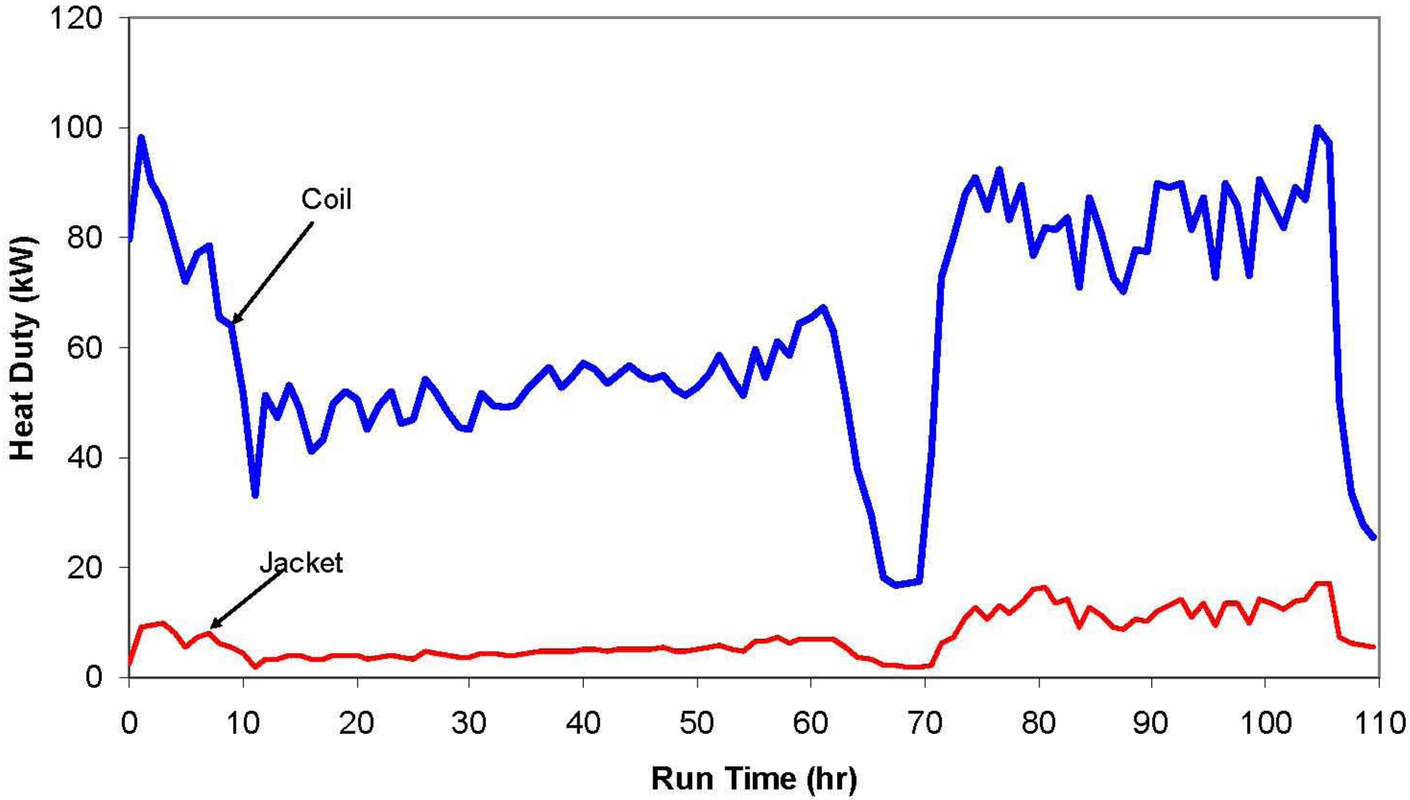

Figure 4.21. Calculated heat loads on the inner coil and jacket (hourly average values) during Test 1&2.

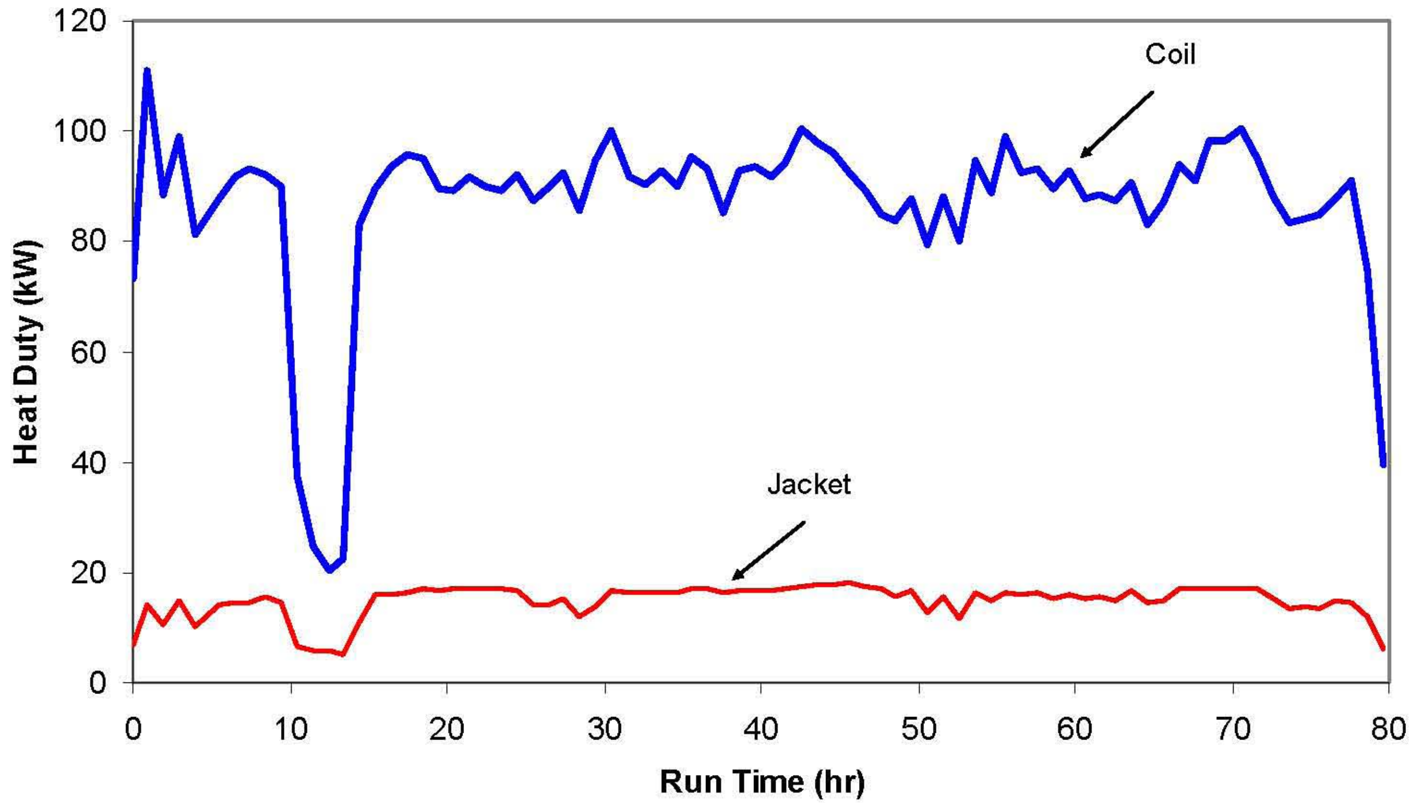

Figure 4.22. Calculated heat loads on the inner coil and jacket (hourly average values) during Test 3&4.

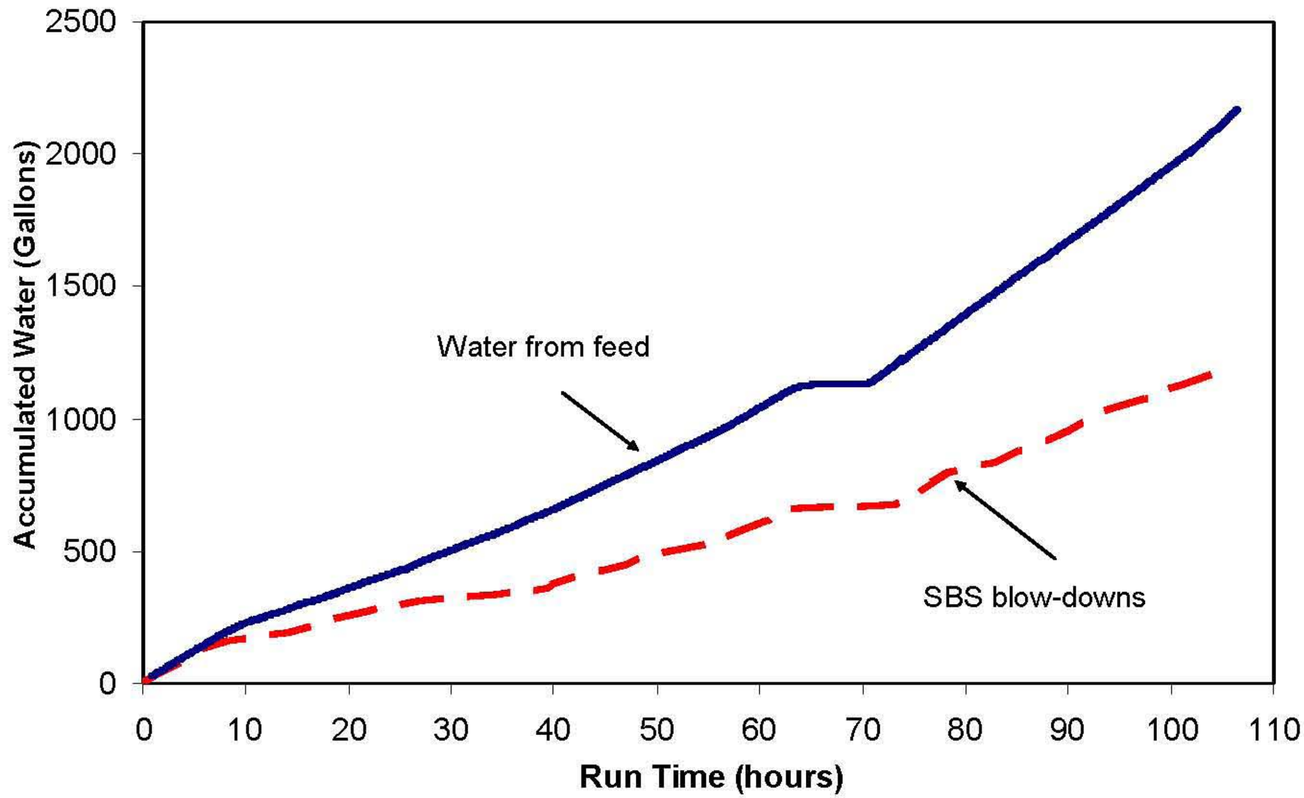

Figure 4.23. Accumulated SBS blow-down volume and accumulated feed water during Tests 1&2.

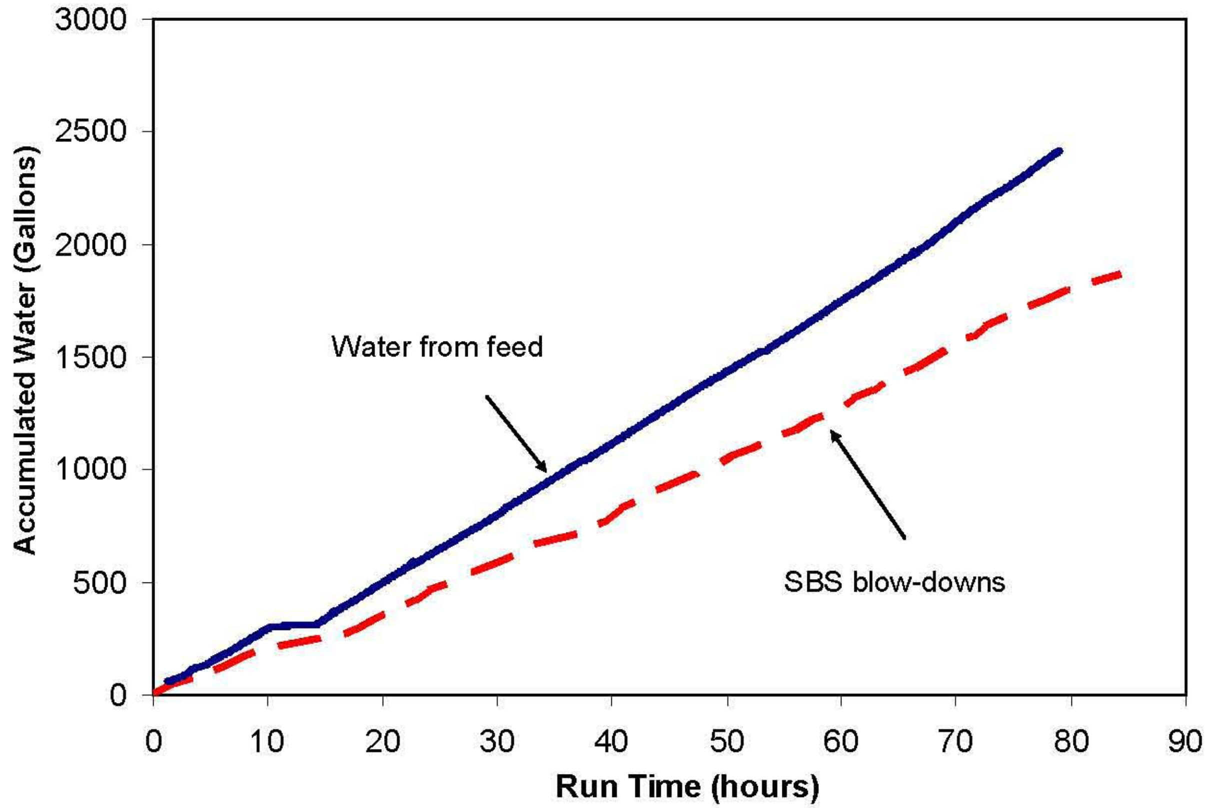

Figure 4.24. Accumulated SBS blow-down volume and accumulated feed water during Tests 3&4.

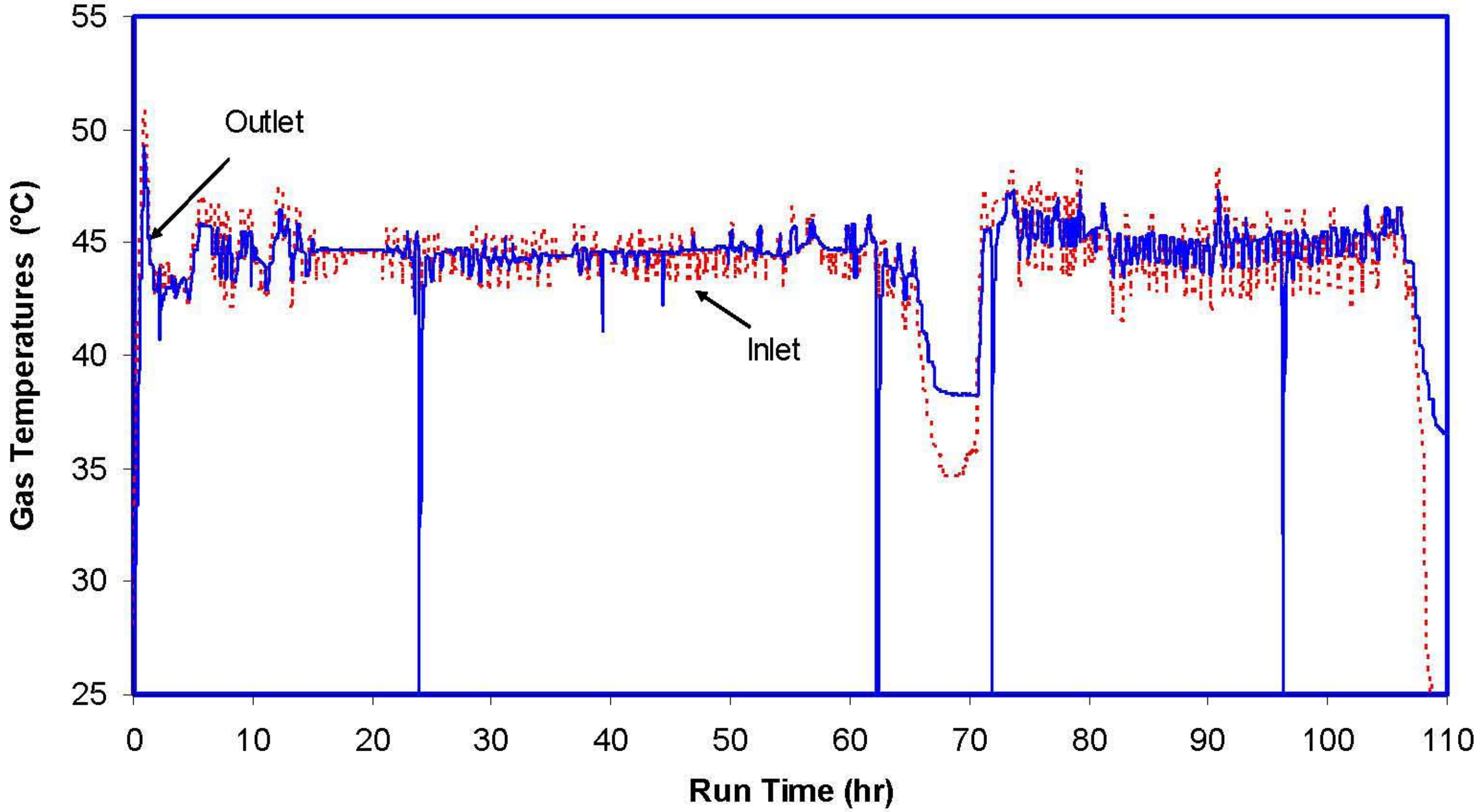

Figure 4.25. WESP inlet and outlet gas temperatures during Tests 1&2.
(Note: downward outlet temperature spikes are the result of WESP deluges.)

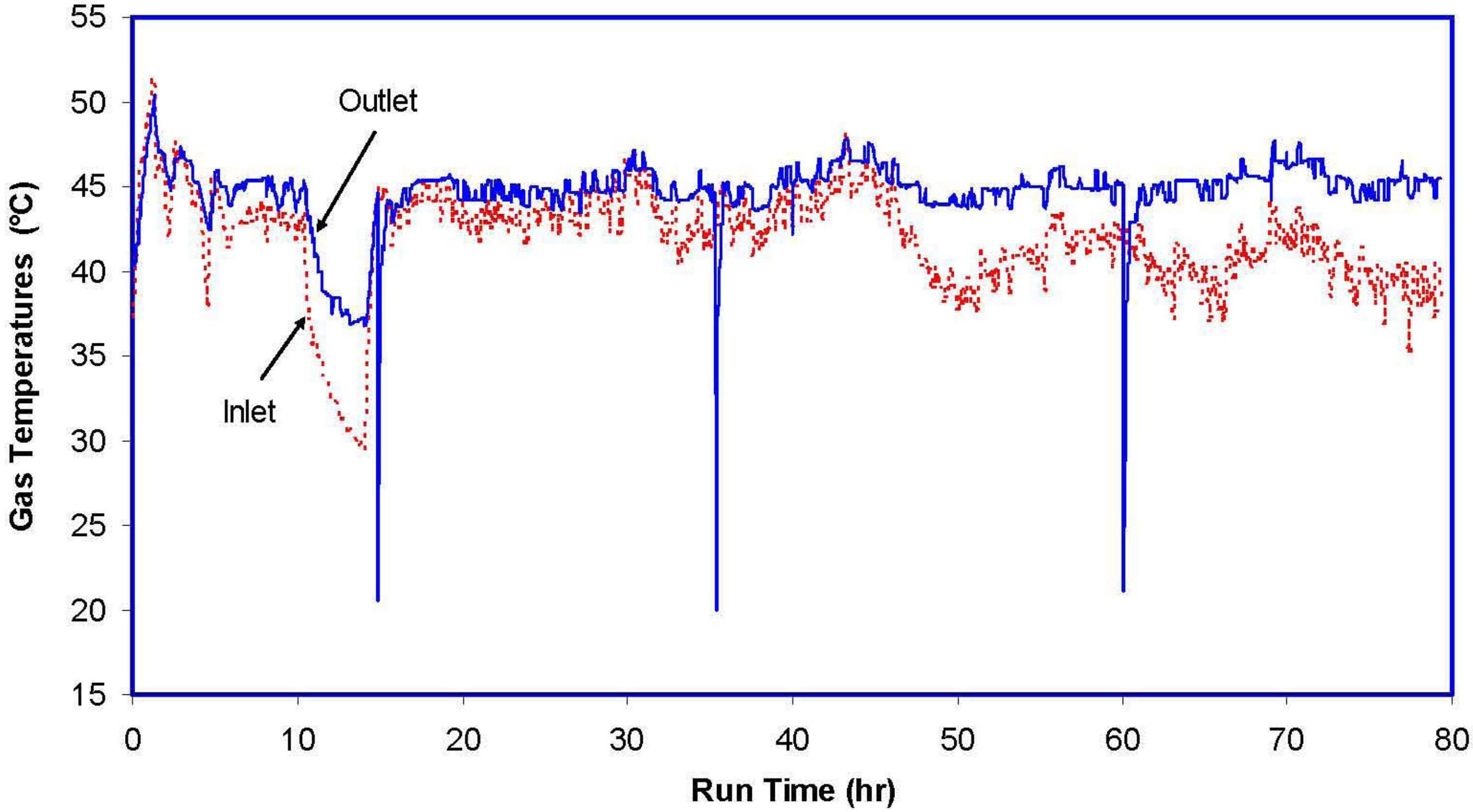

**Figure 4.26. WESP inlet and outlet gas temperatures during Tests 3&4.
(Note: downward outlet temperature spikes are the result of WESP deluges.)**

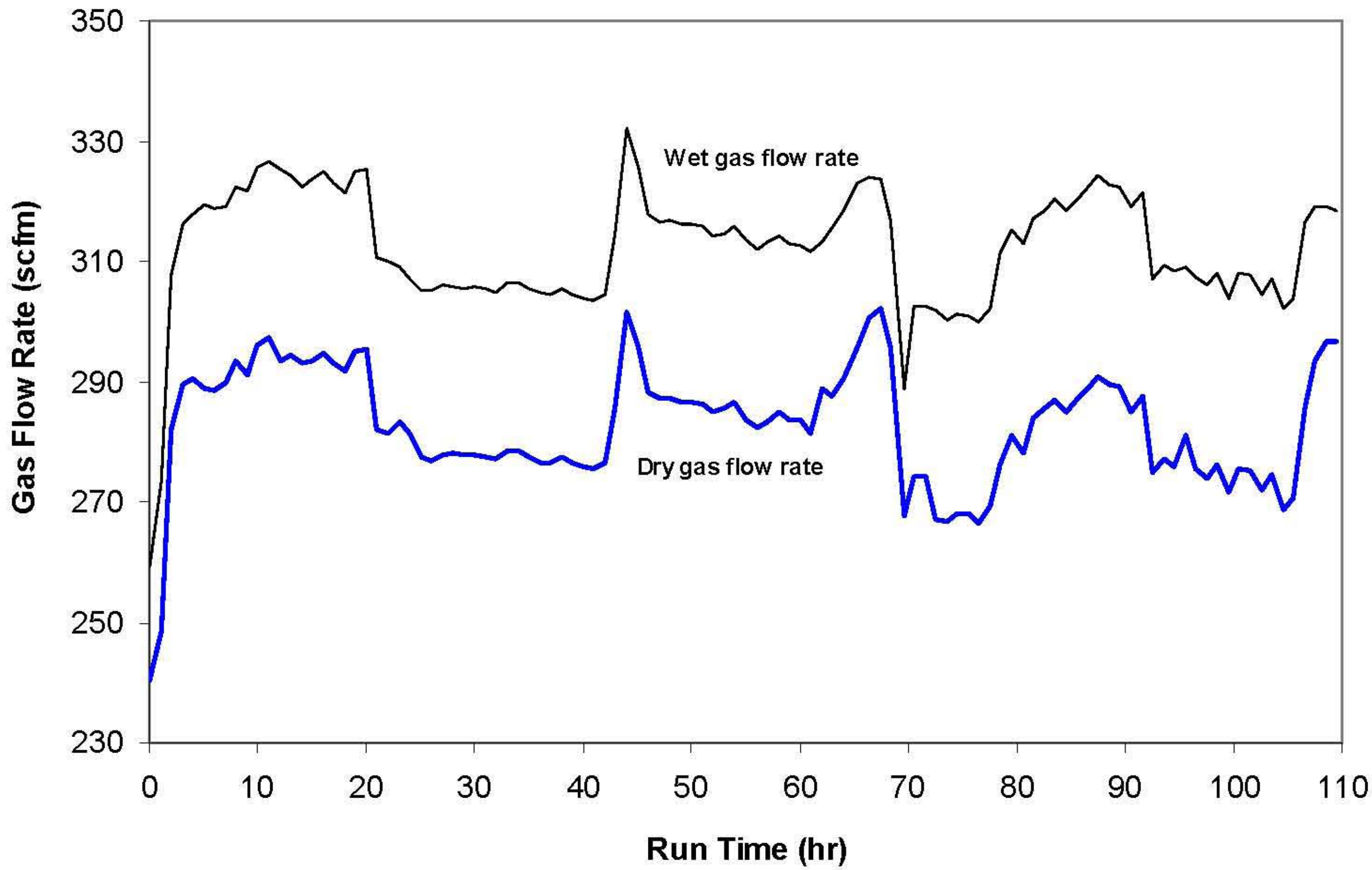

Figure 4.27. WESP outlet gas flow rate (hourly average values) during Tests 1&2.

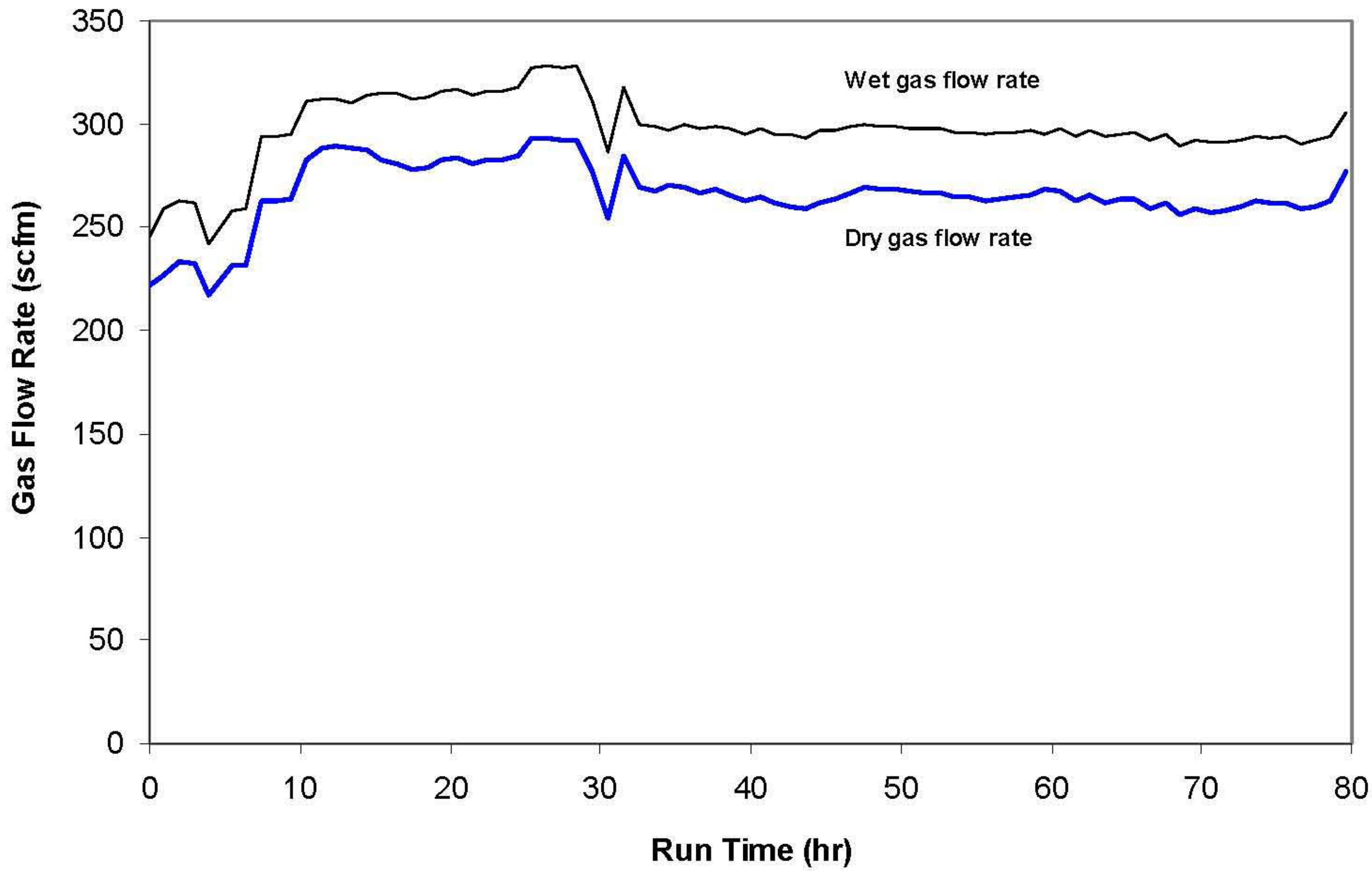

Figure 4.28. WESP outlet gas flow rate (hourly average values) during Tests 3&4.

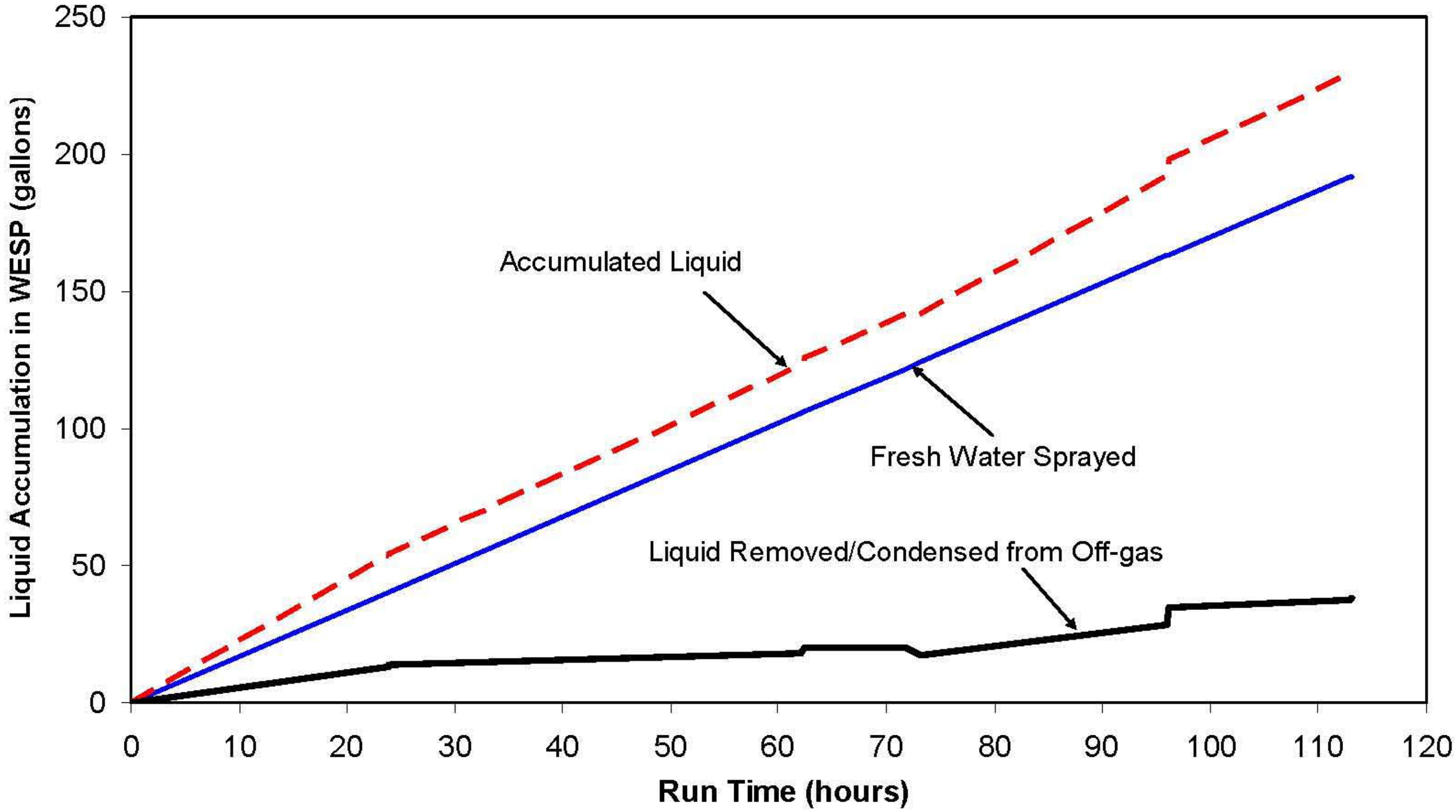

Figure 4.29. Accumulated WESP blowdown volume, accumulated fresh spray water, and water removed from off-gas during Tests 1&2.

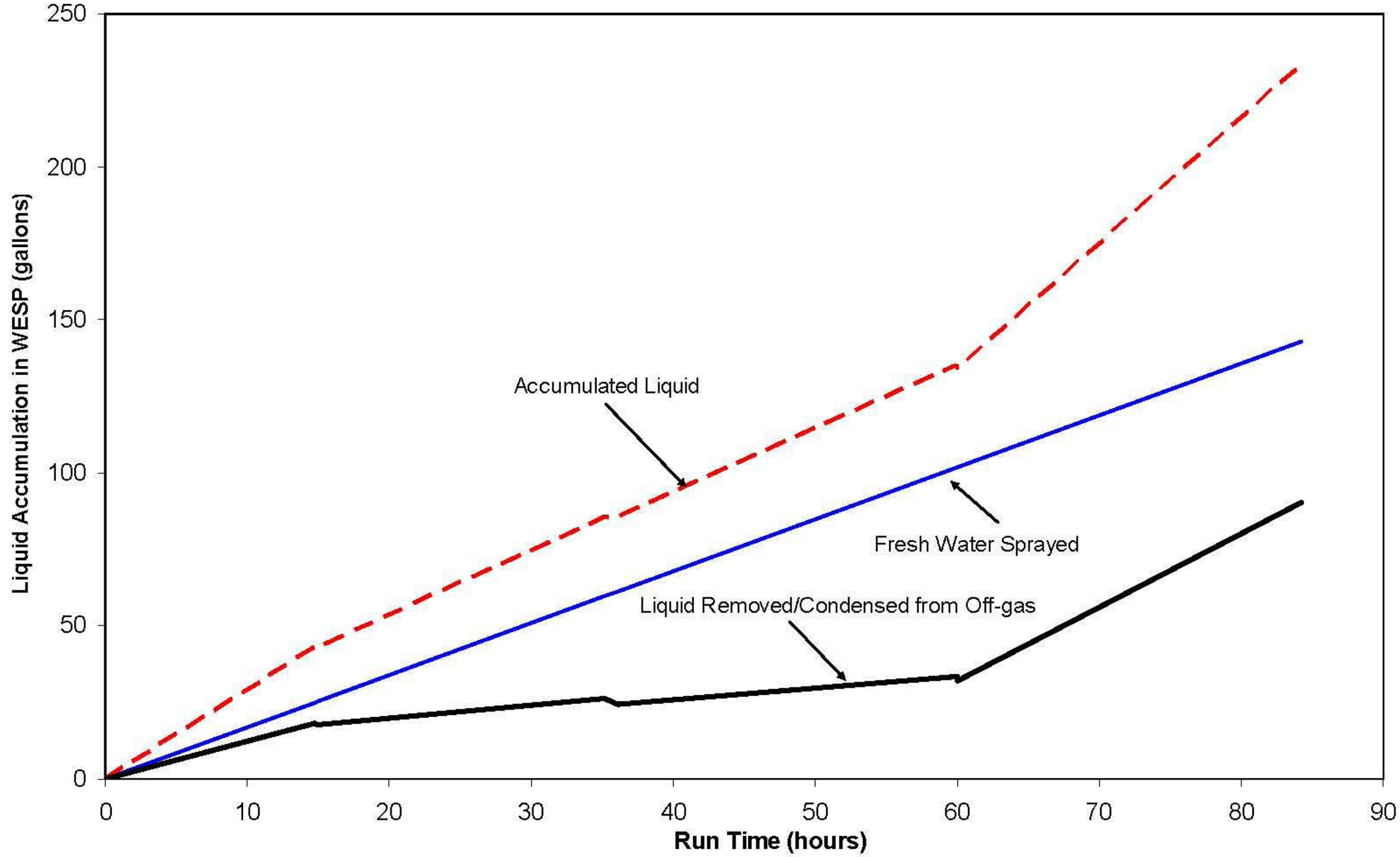

Figure 4.30. Accumulated WESP blowdown volume, accumulated fresh spray water, and water removed from off-gas during Tests 3&4.

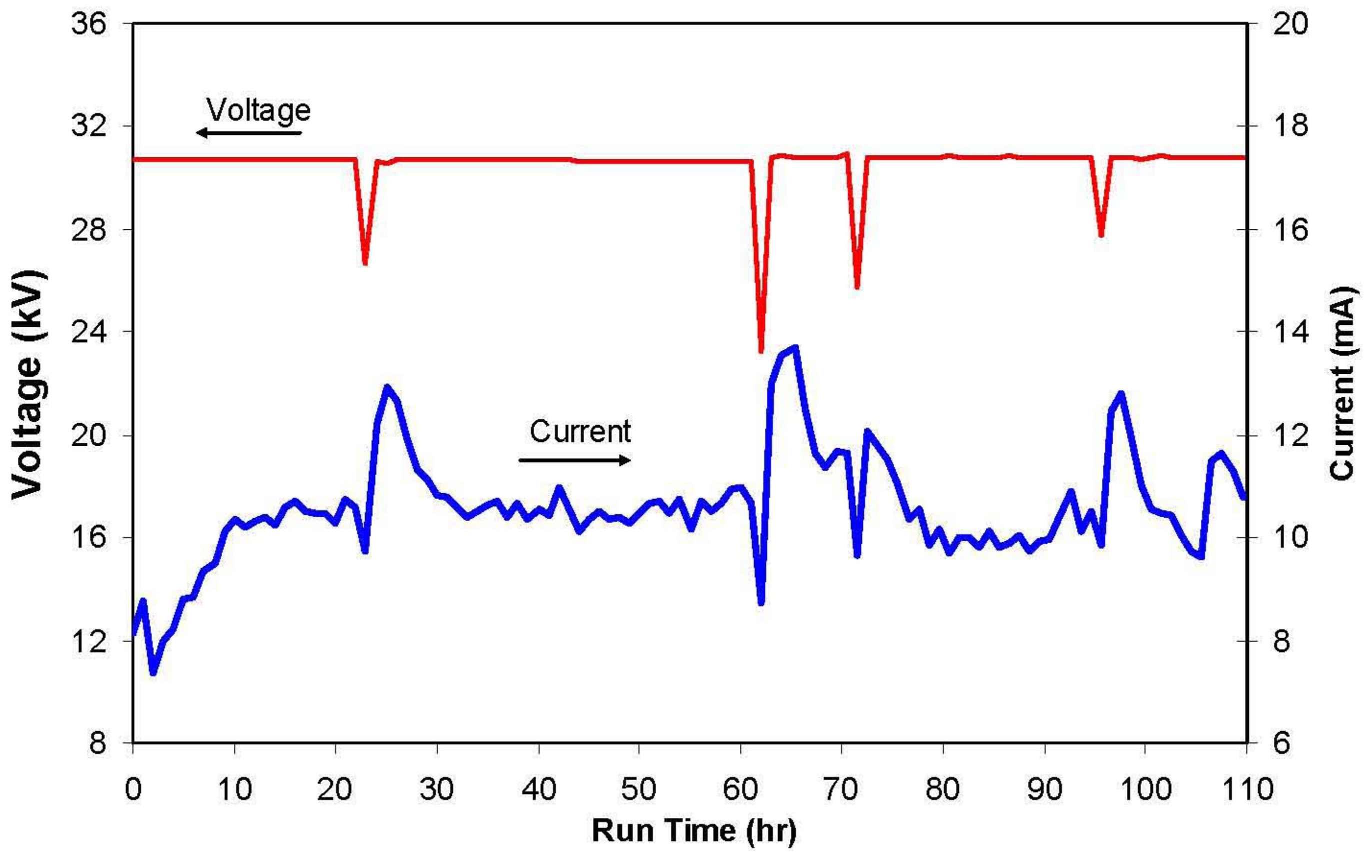

Figure 4.31. Voltage and current across the WESP (average hourly values) during Tests 1&2.

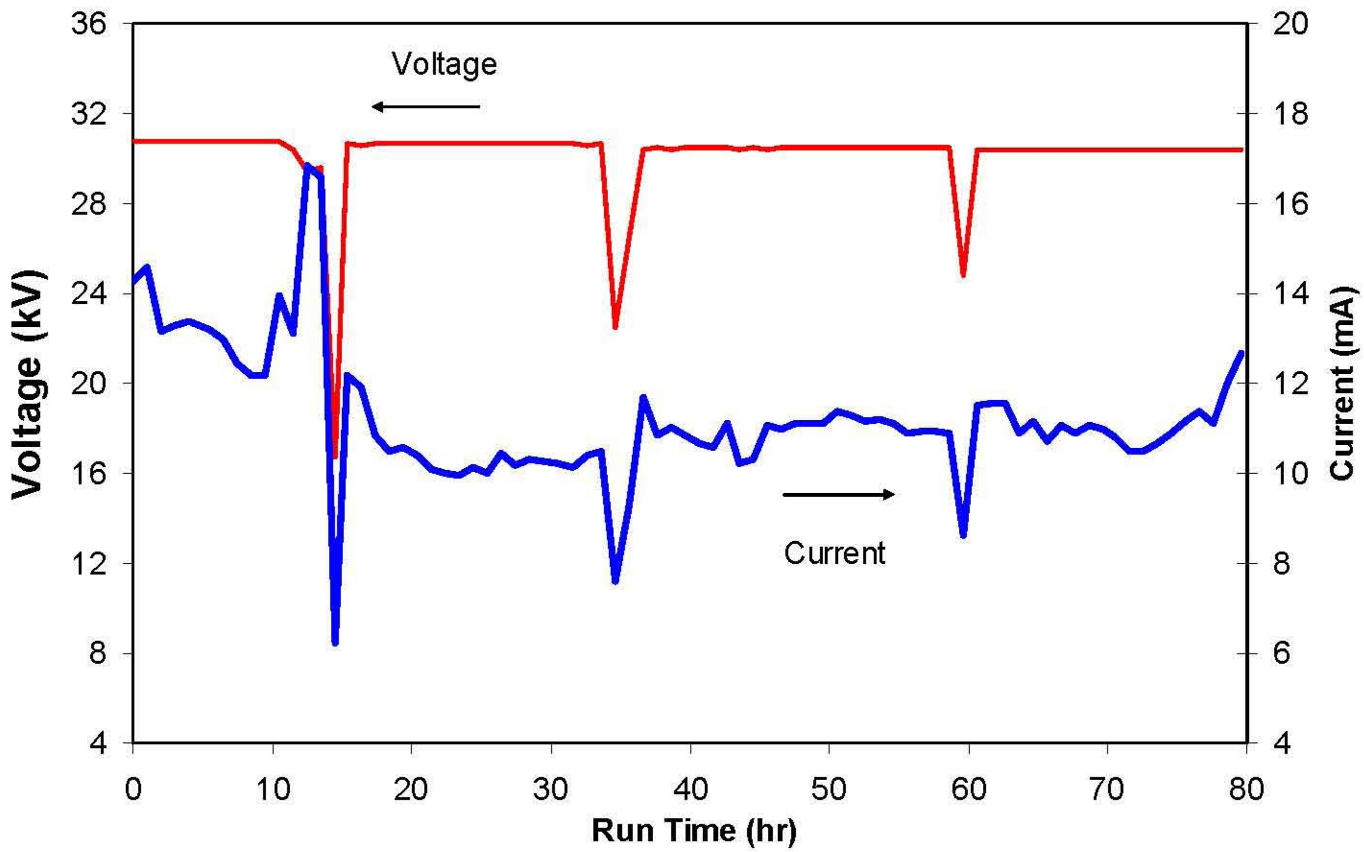

Figure 4.32. Voltage and current across the WESP (average hourly values) during Tests 3&4.

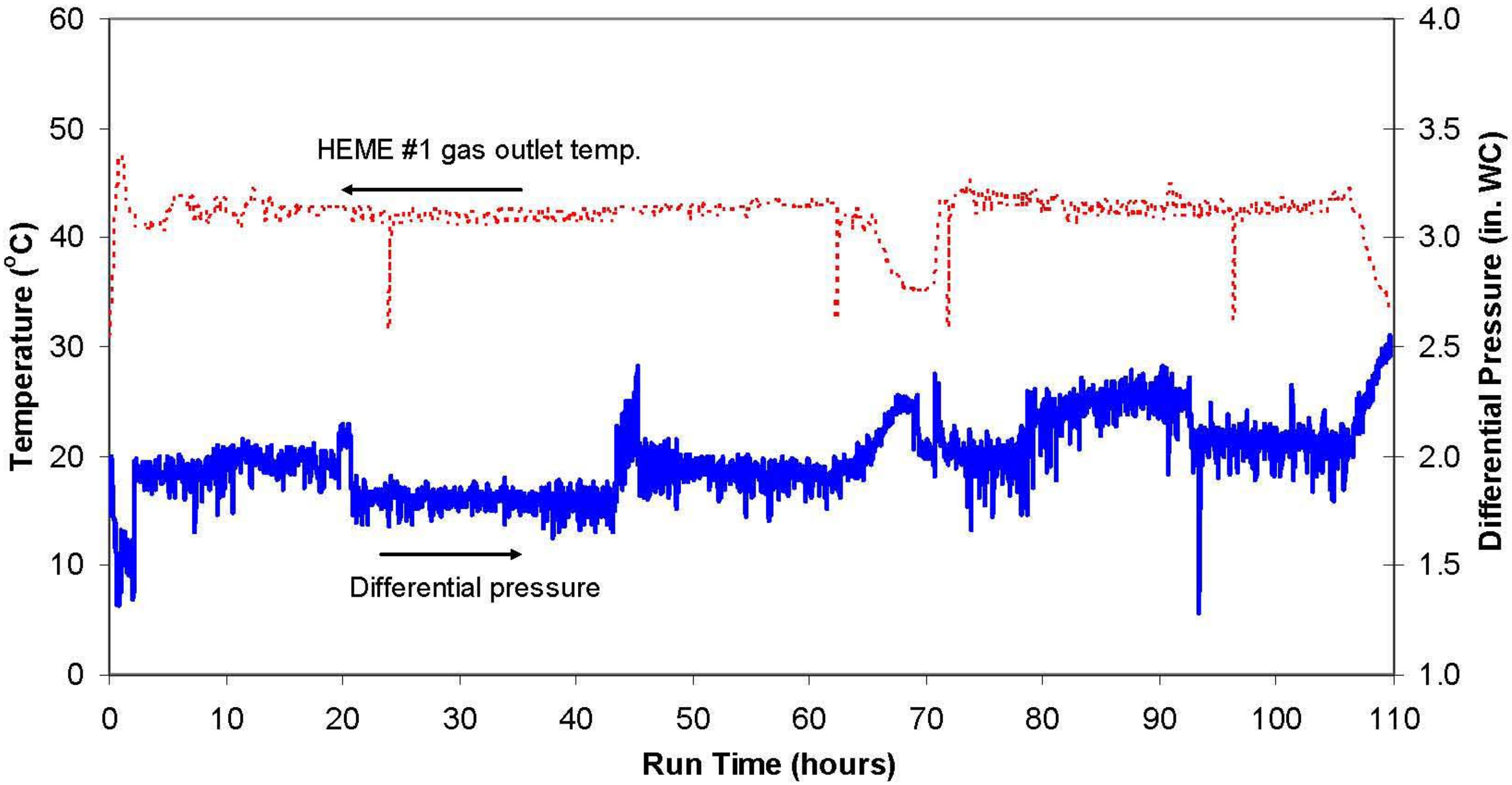

Figure 4.33. Outlet temperature and differential pressure for HEME #1 during Tests 1&2.

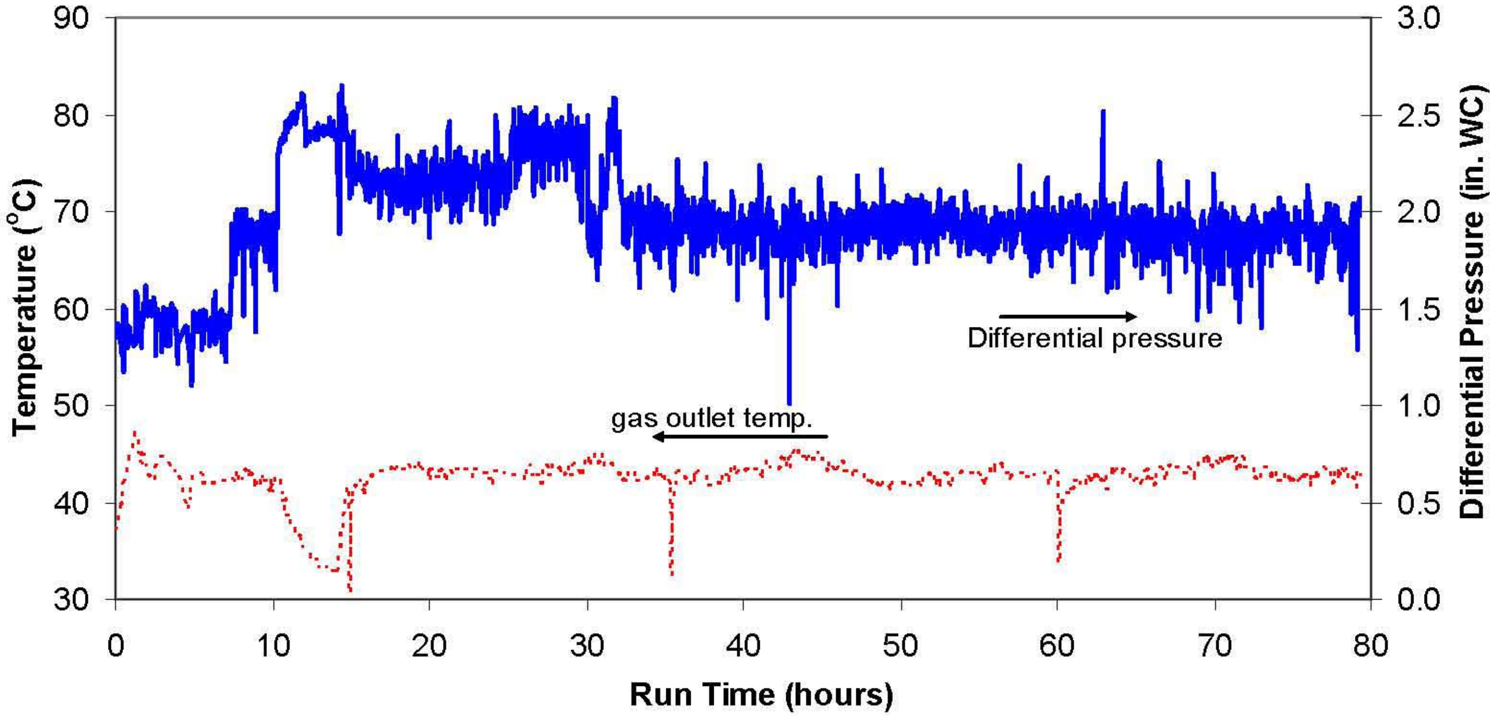

Figure 4.34. Outlet temperature and differential pressure for HEME #1 during Tests 3&4.

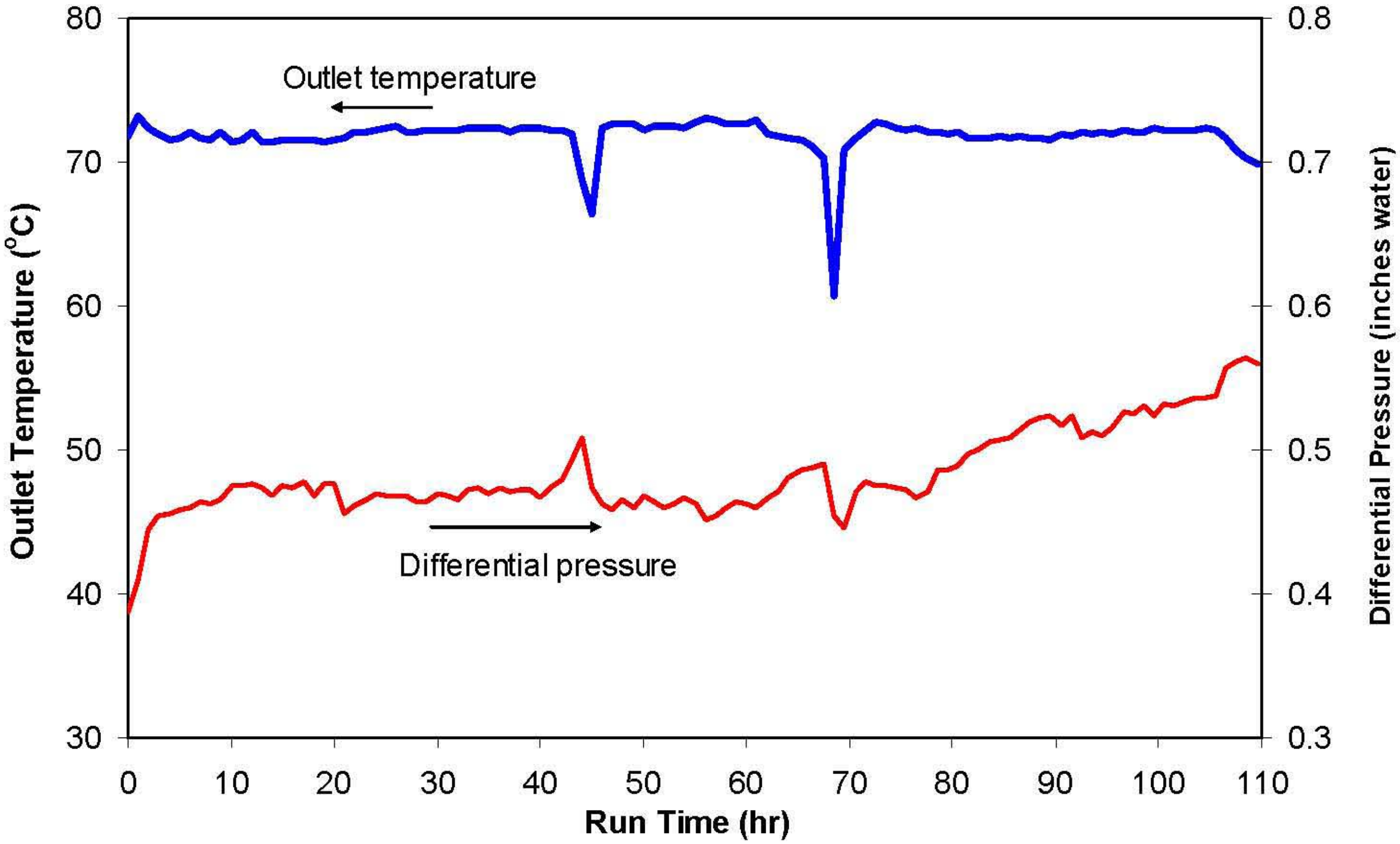

Figure 4.35. Outlet temperature and differential pressure for HEPA #1 (hourly average values) during Tests 1&2.

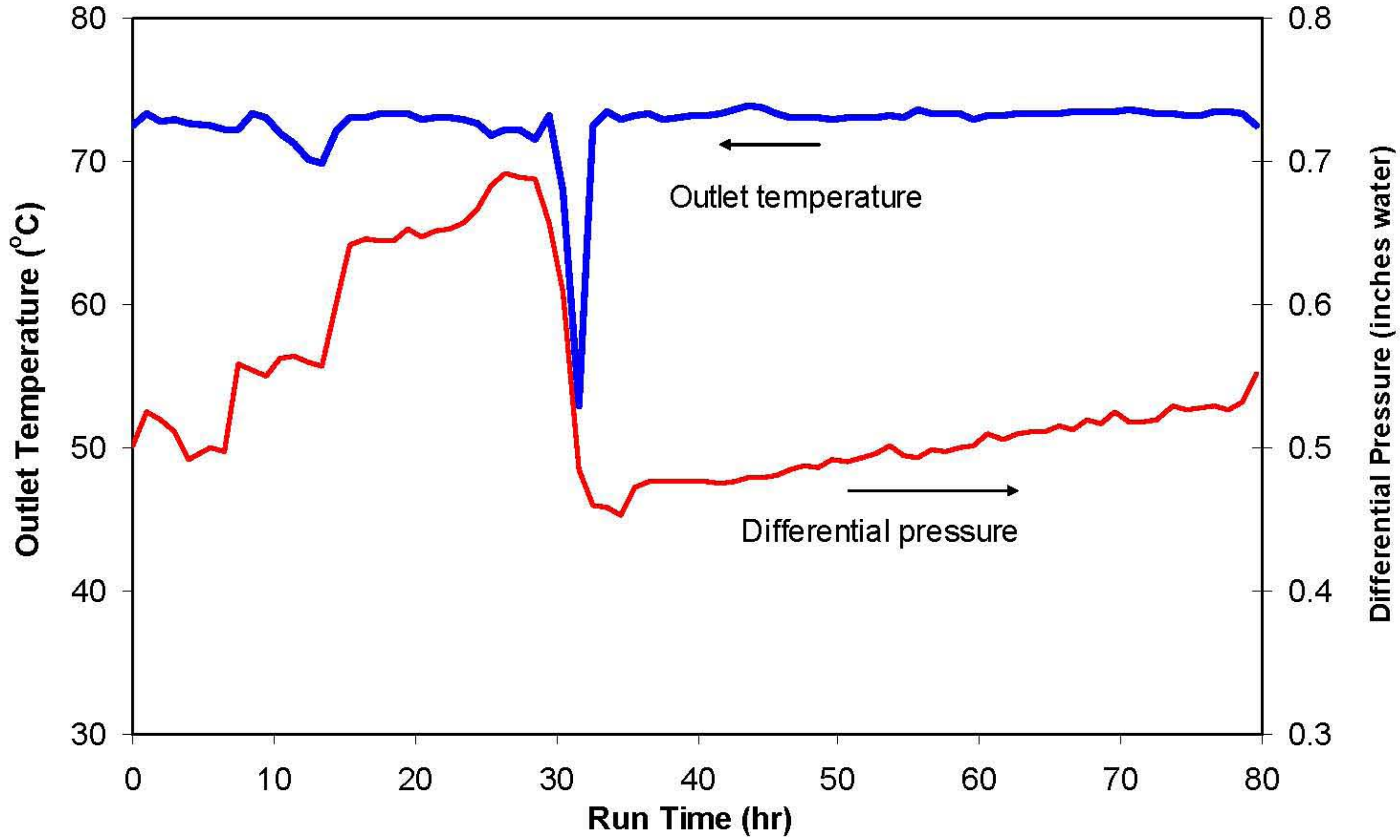

Figure 4.36. Outlet temperature and differential pressure for HEPA #1 (hourly average values) during Tests 3&4.

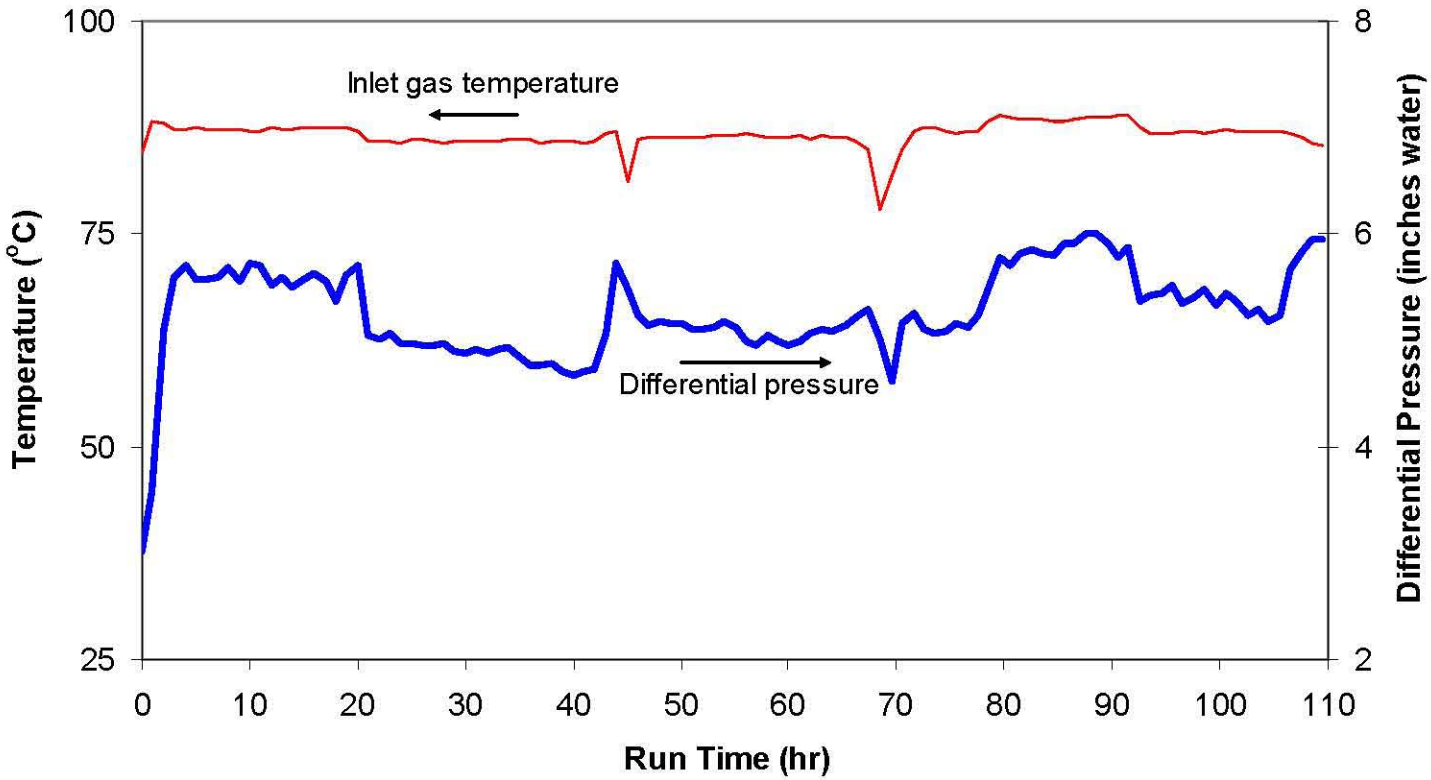

Figure 4.37. Inlet gas temperature and differential pressure for PBS (hourly average values) during Tests 1&2.

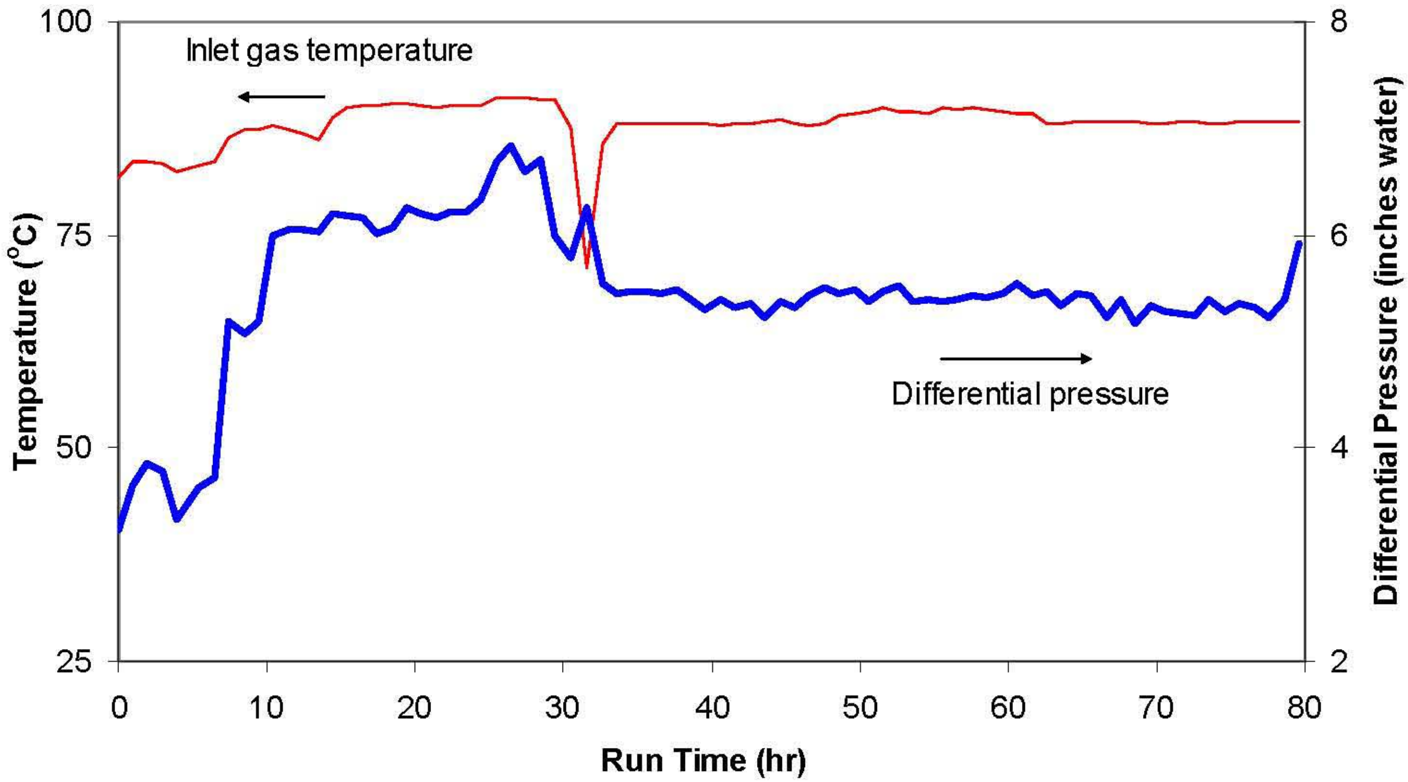

Figure 4.38. Inlet gas temperature and differential pressure for PBS (hourly average values) during Tests 3&4.

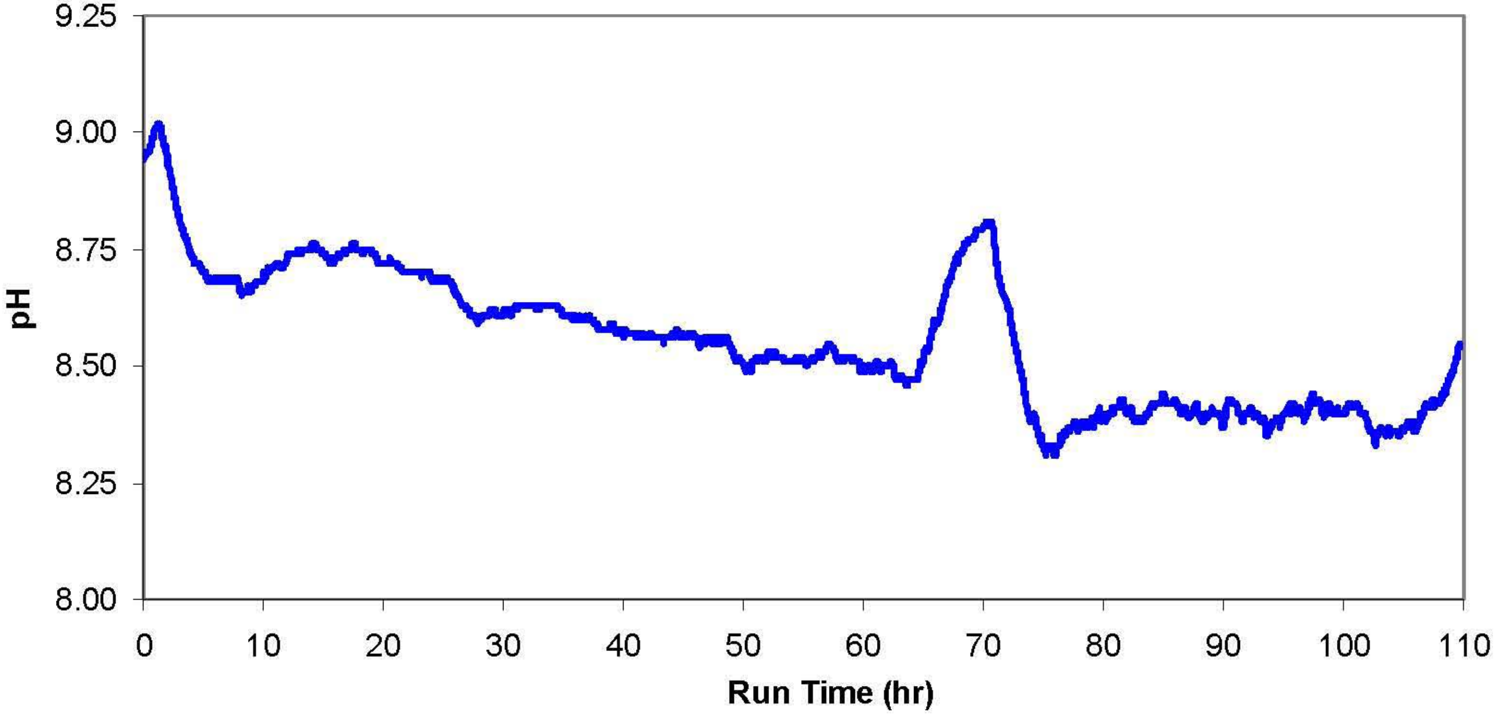

Figure 4.39. pH for PBS during Tests 1&2.

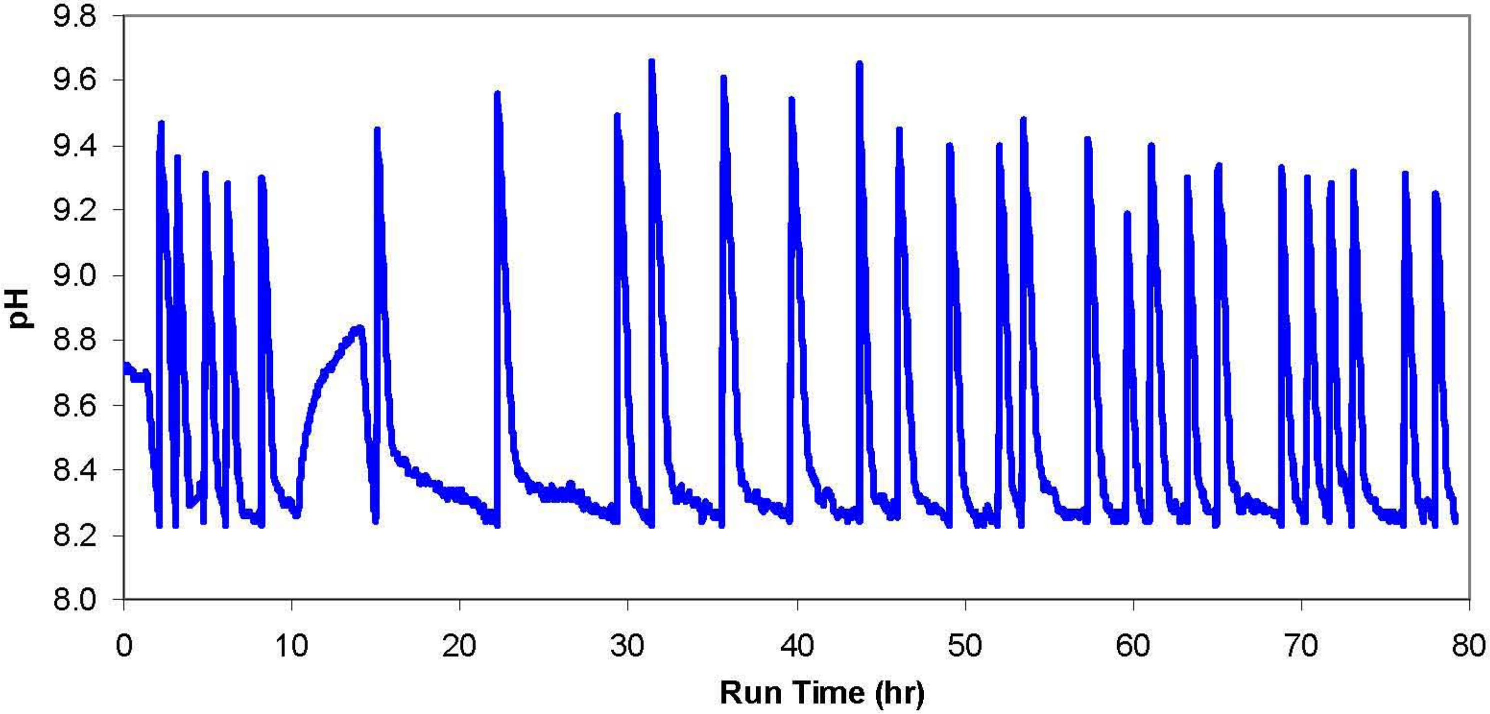

Figure 4.40. pH for PBS during Tests 3&4.

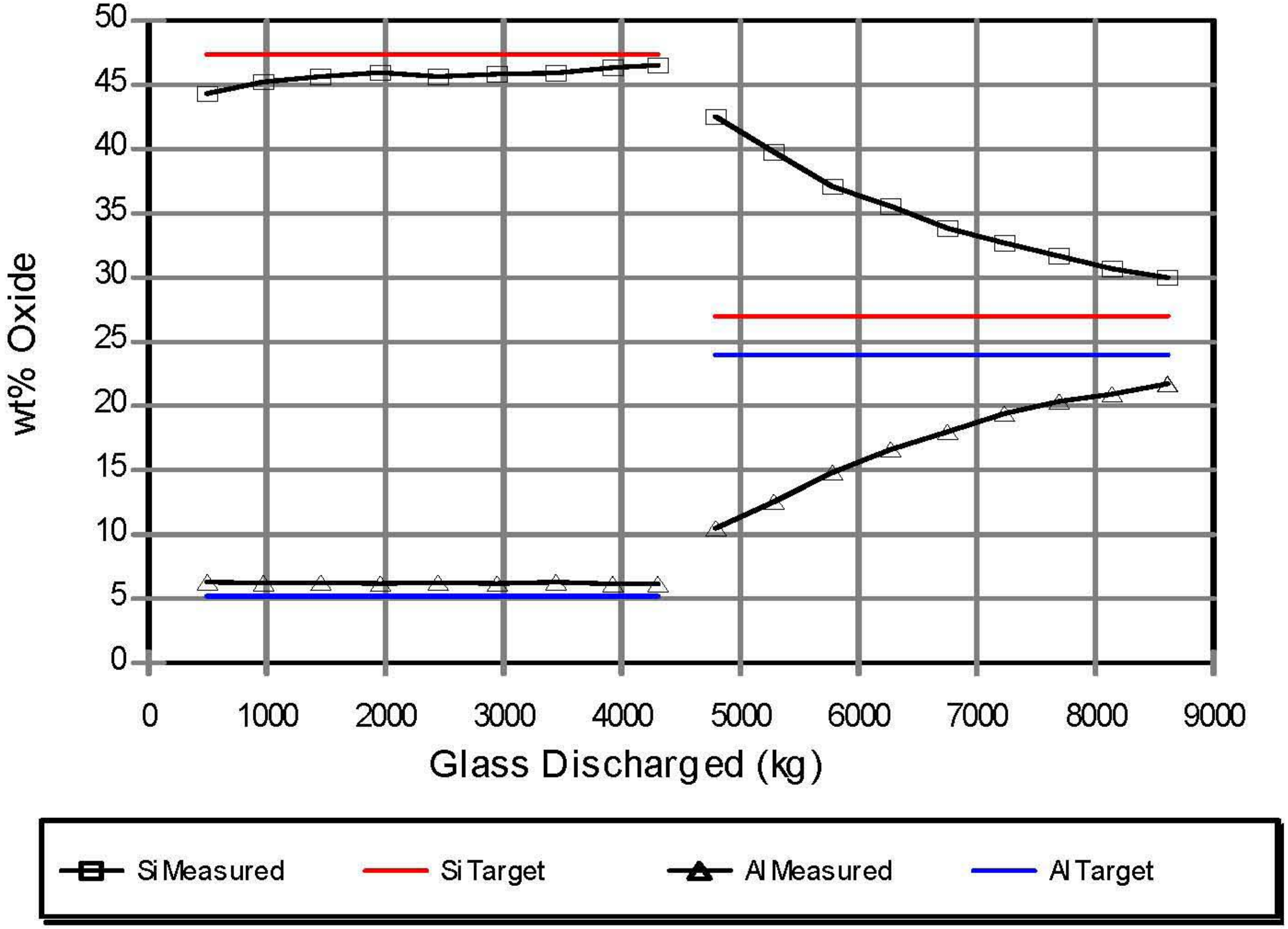

Figure 5.1.a. DM1200 product and target glass compositions determined by XRF.

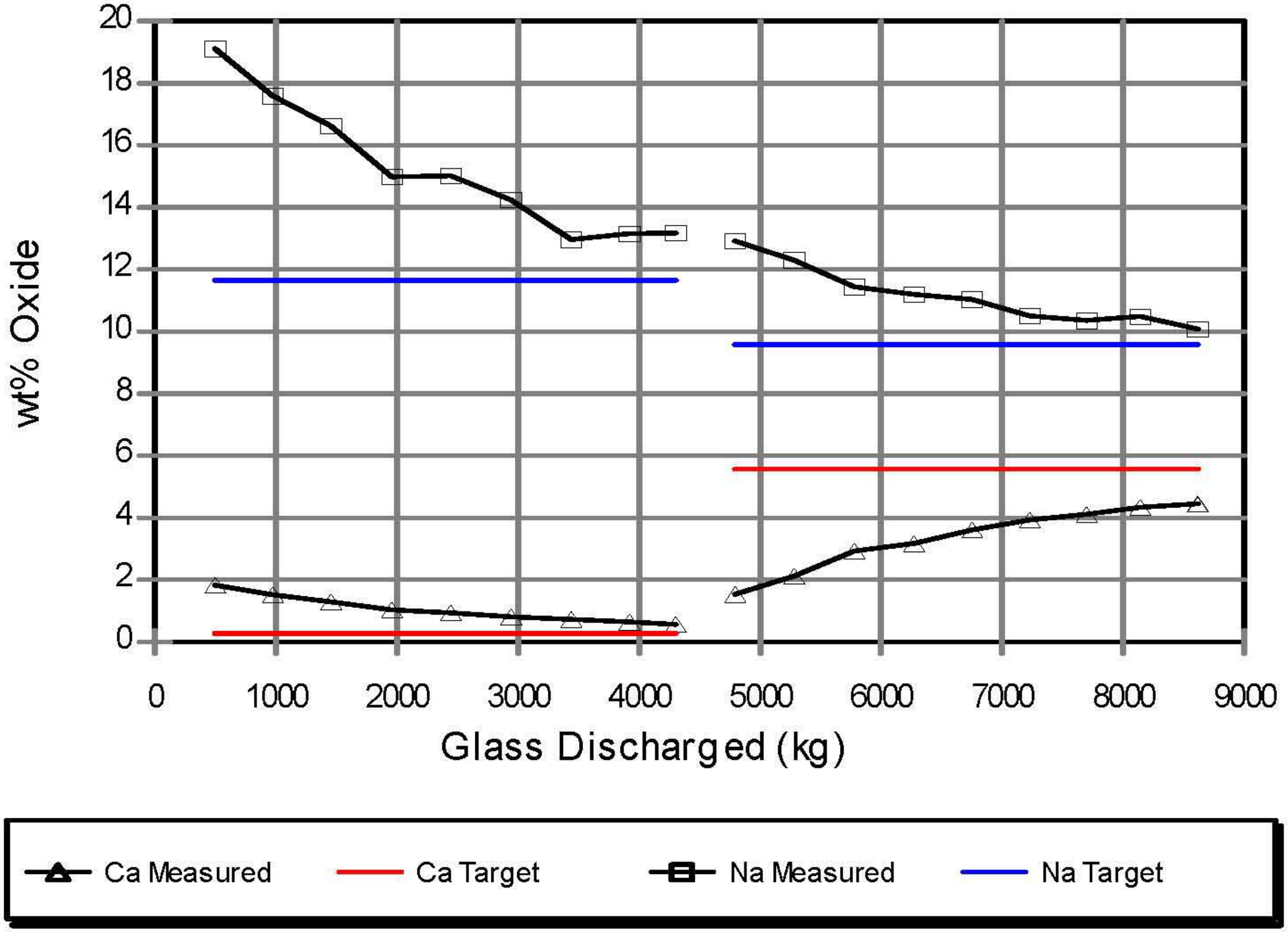

Figure 5.1.b. DM1200 product and target glass compositions determined by XRF.

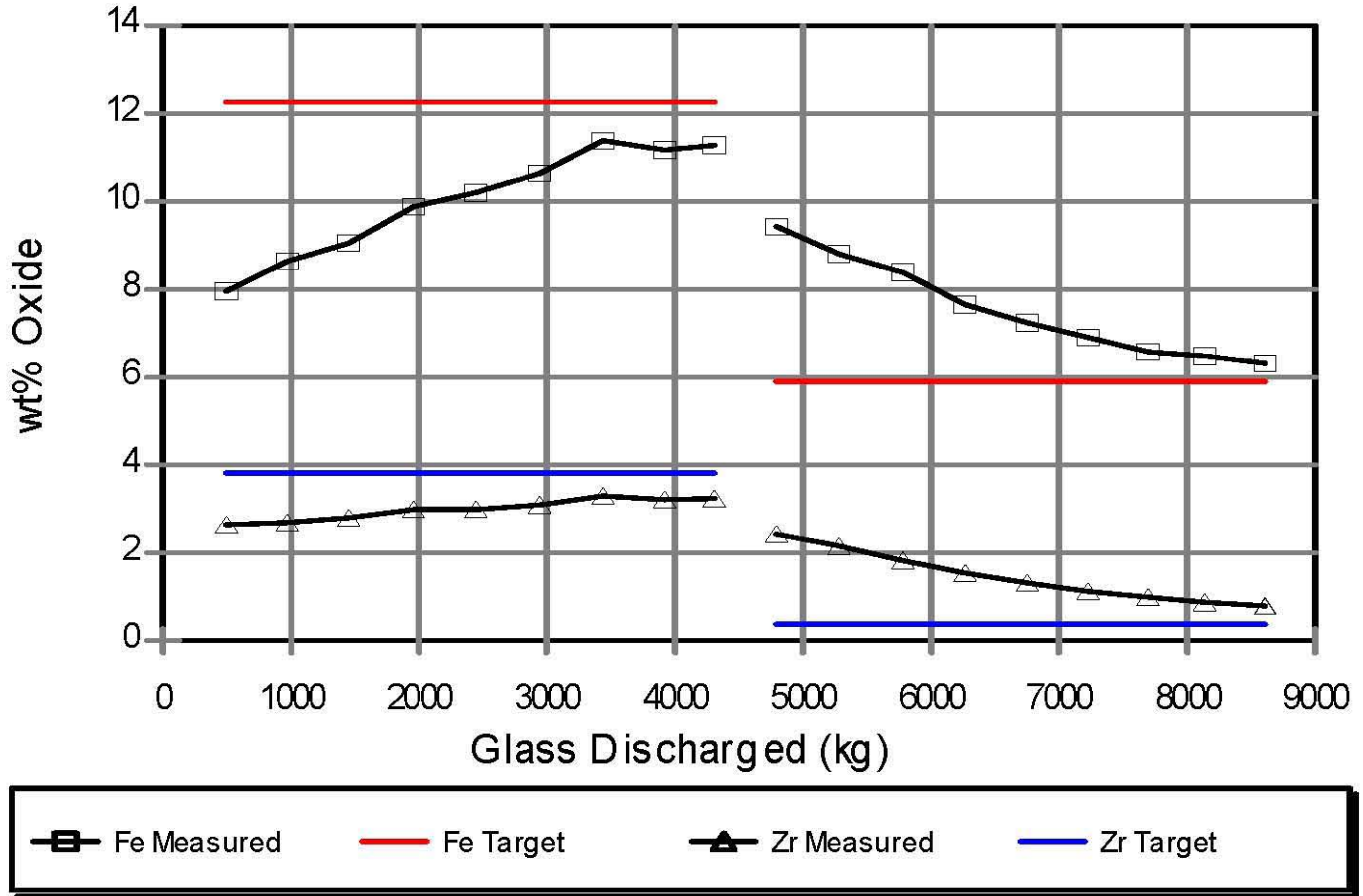

Figure 5.1.c. DM1200 product and target glass compositions determined by XRF.

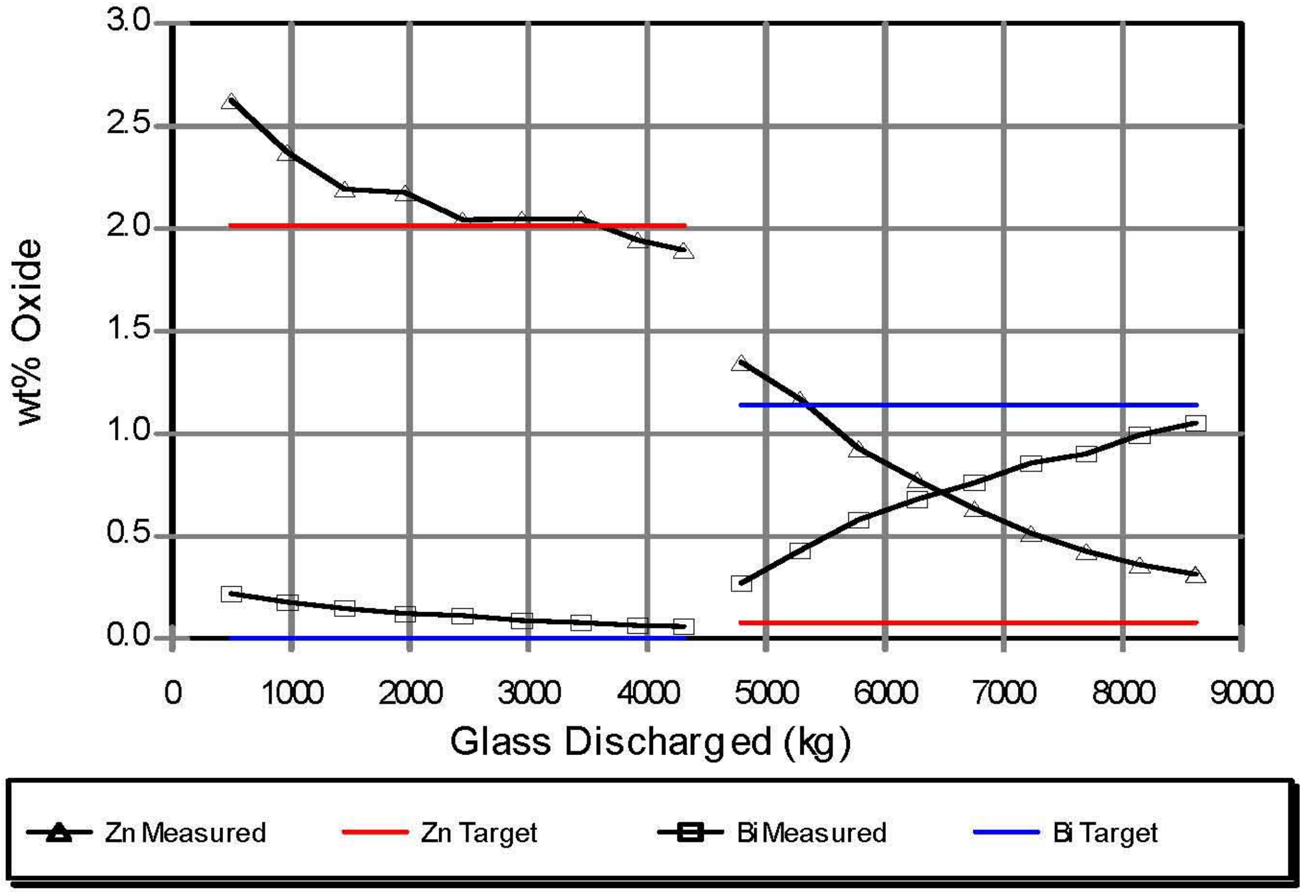

Figure 5.1.d. DM1200 product and target glass compositions determined by XRF.

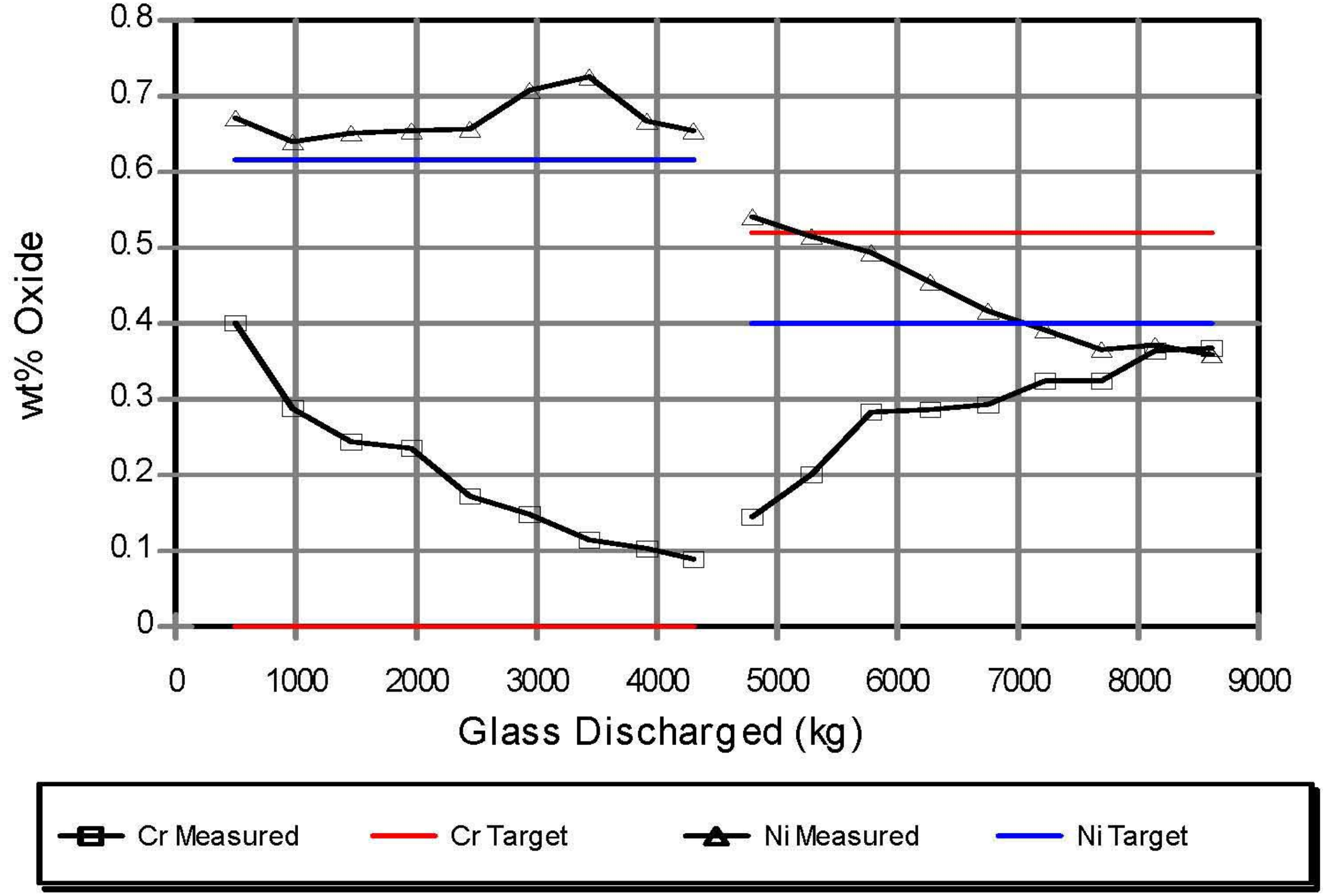

Figure 5.1.e. DM1200 product and target glass compositions determined by XRF.

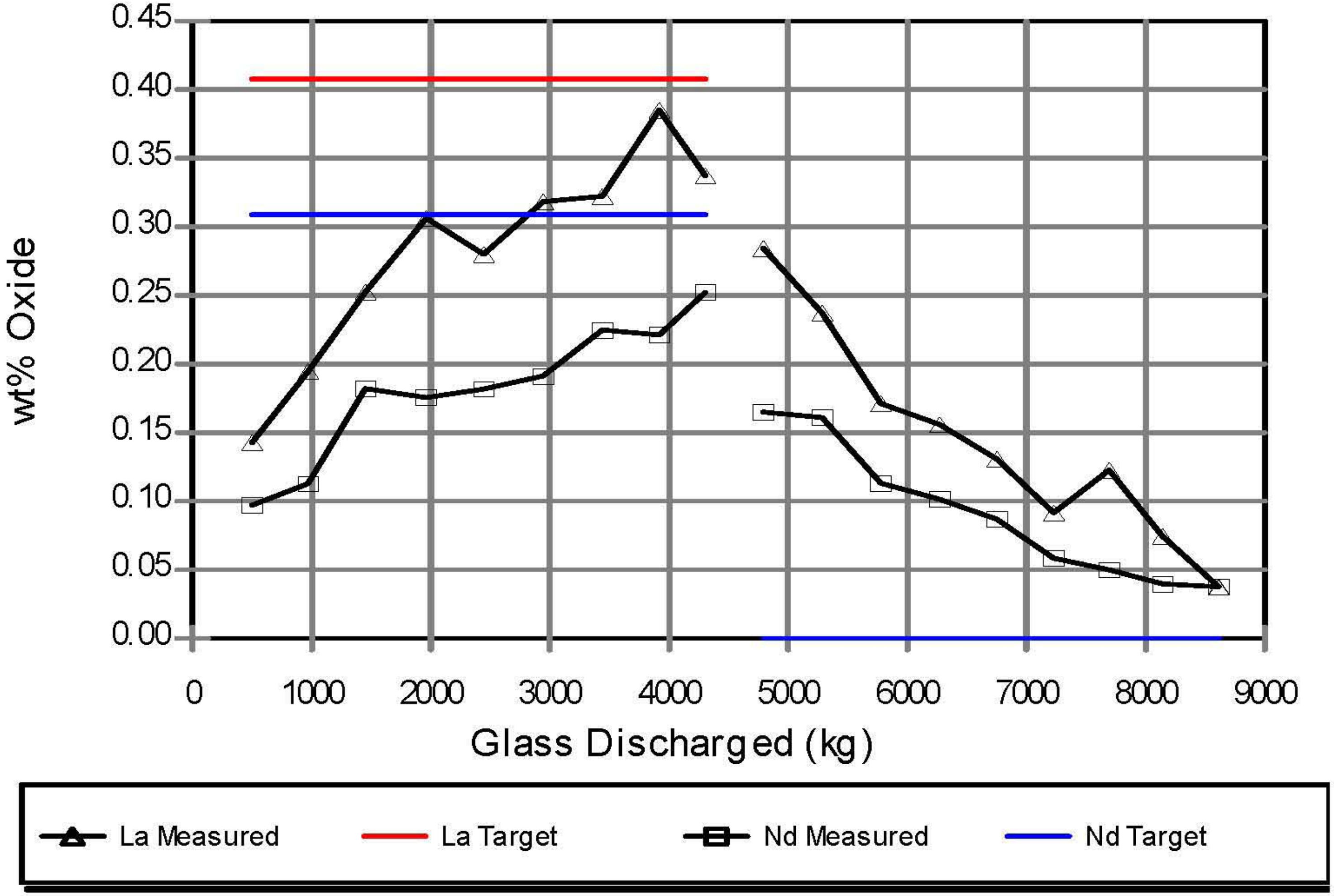

Figure 5.1.f. DM1200 product and target glass compositions determined by XRF.

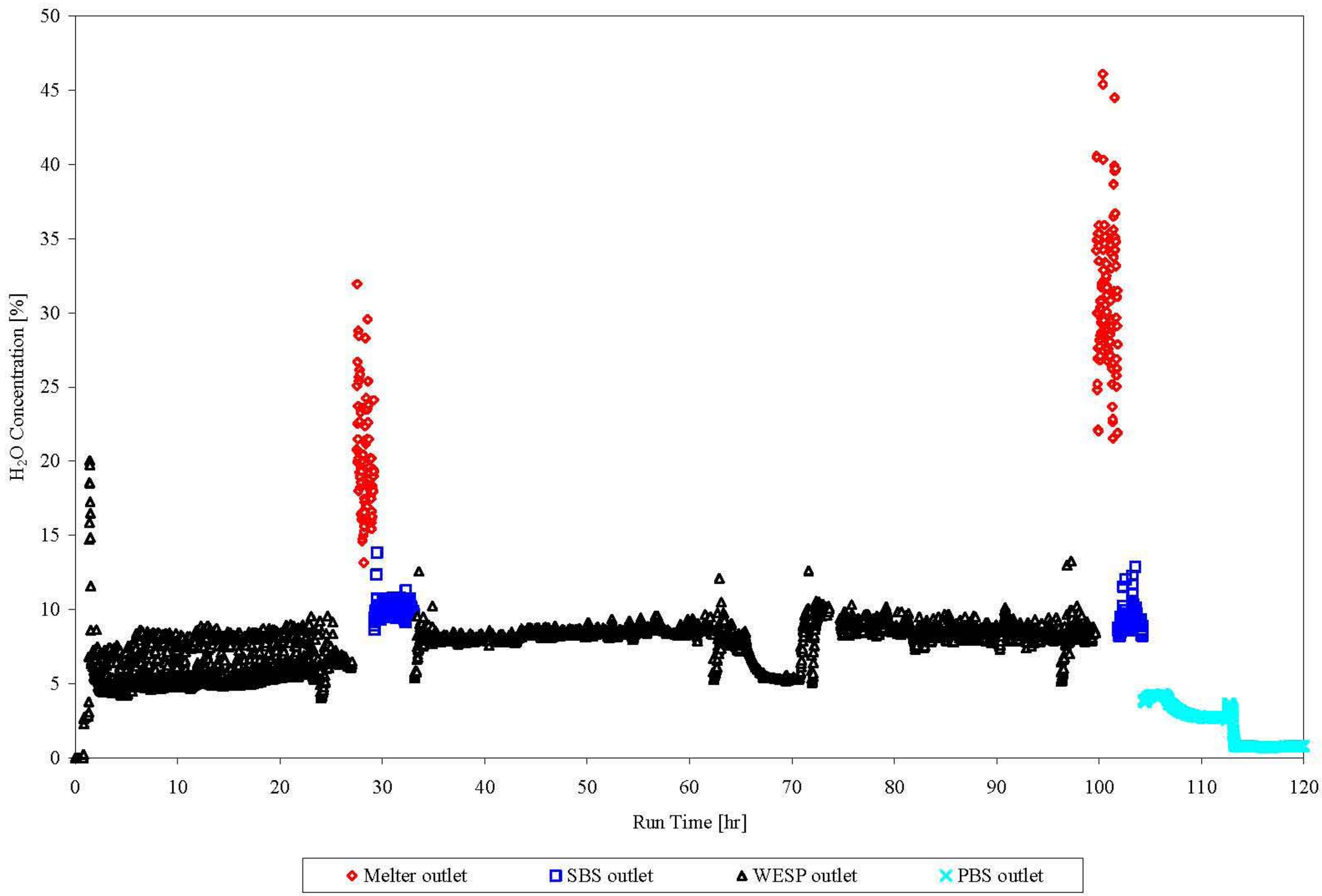

Figure 6.1. FTIR Monitored water emissions during Tests 1 and 2.

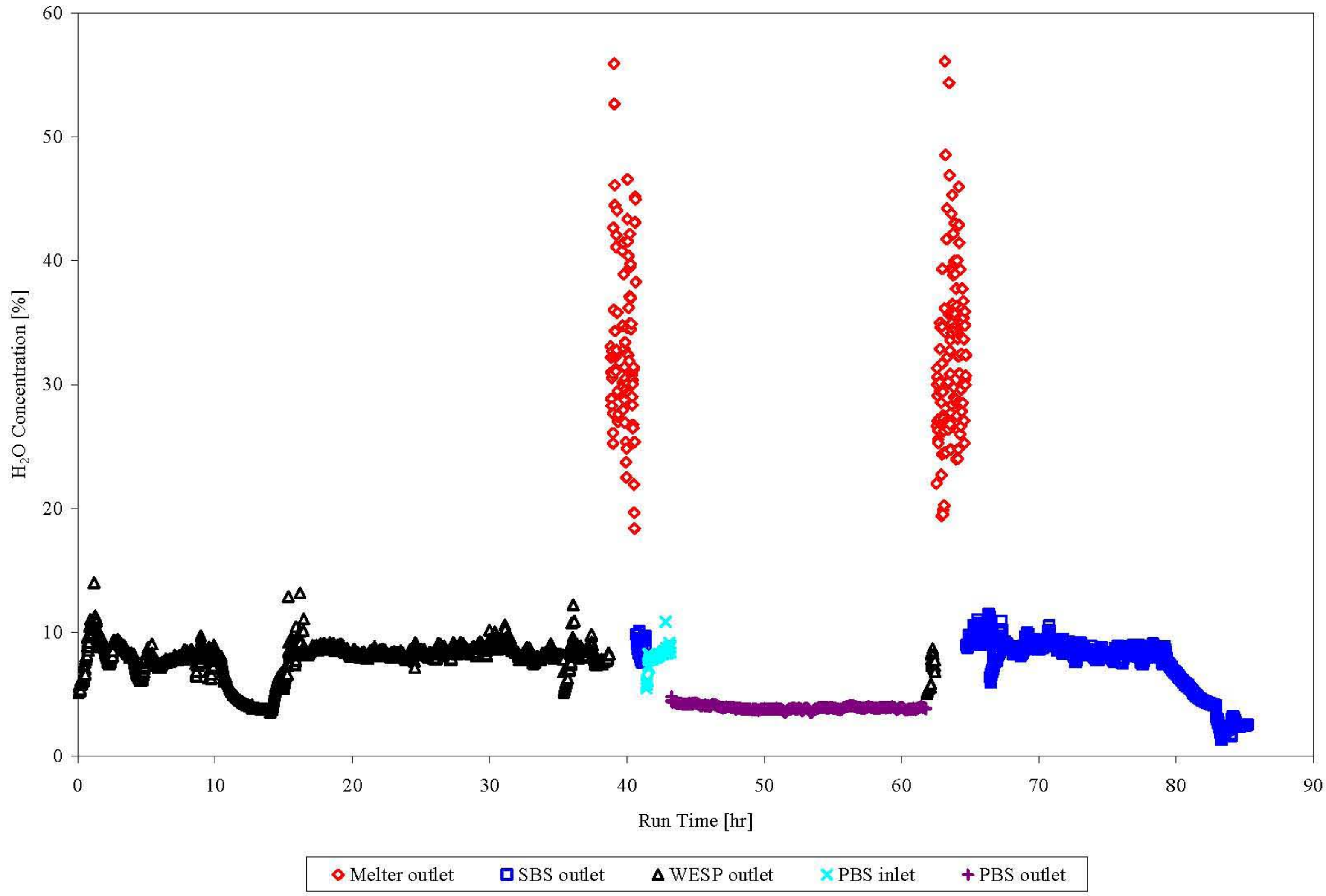

Figure 6.2. FTIR Monitored water emissions during Tests 3 and 4.

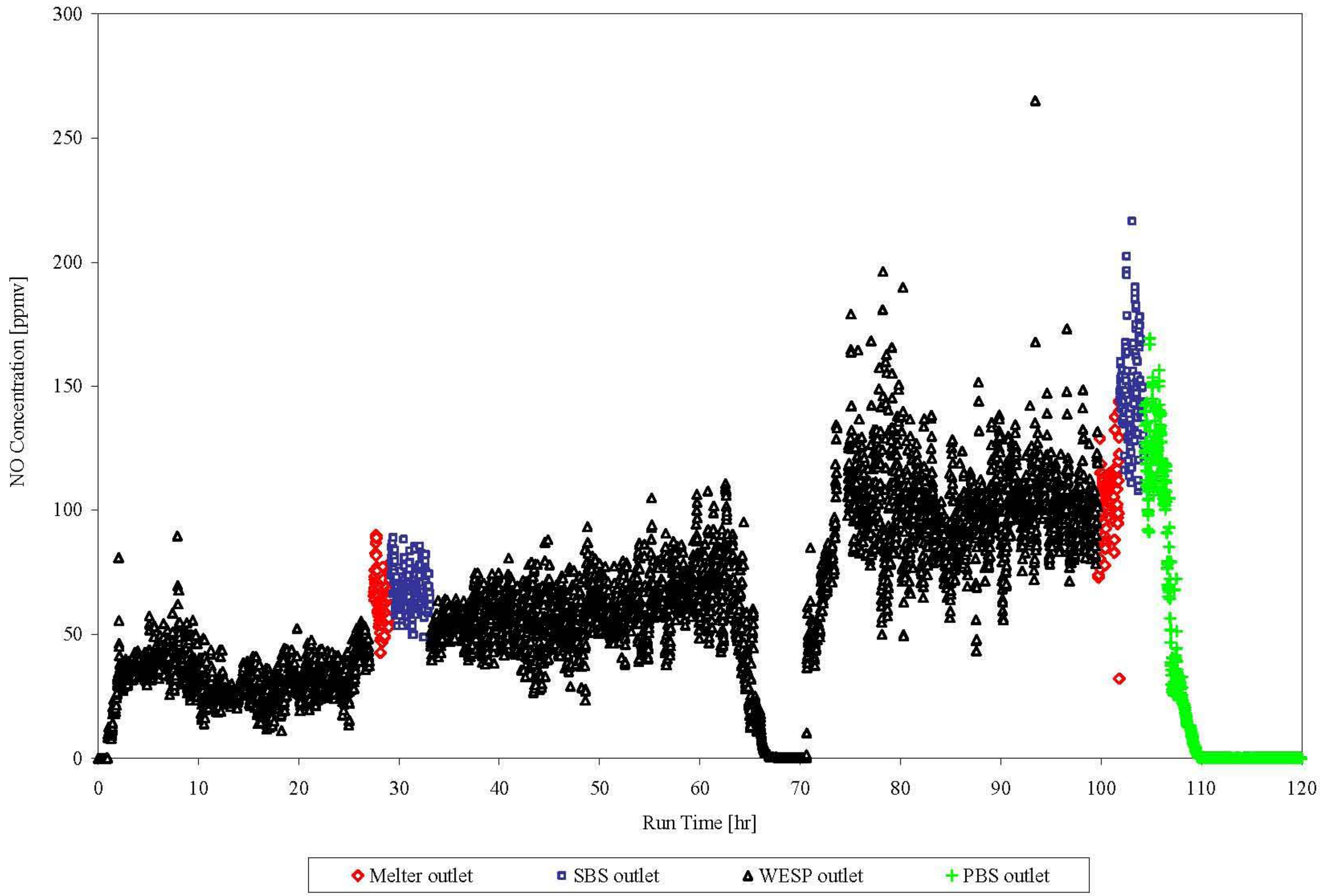

Figure 6.3. FTIR Monitored NO emissions during Tests 1 and 2.

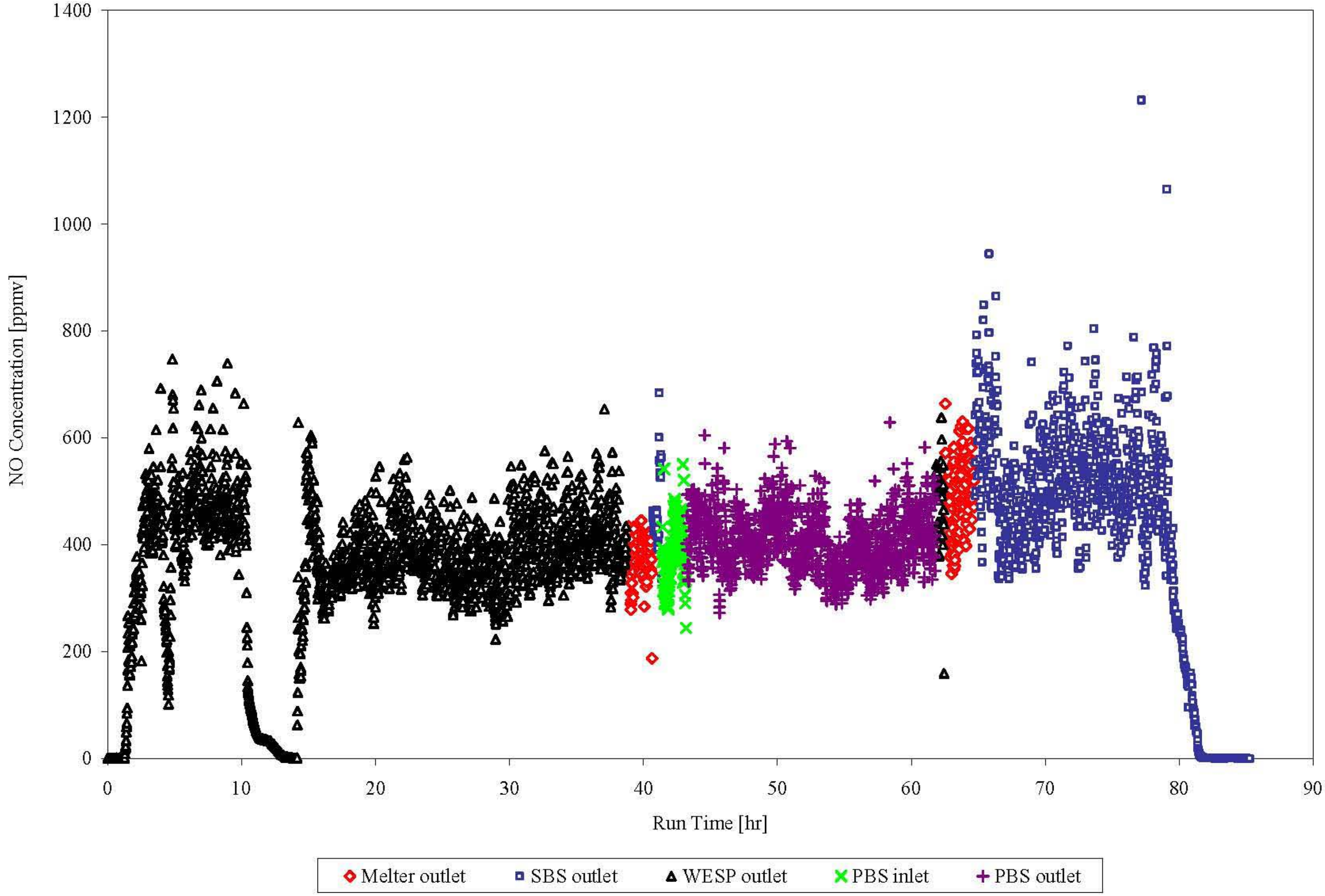

Figure 6.4. FTIR Monitored NO emissions during DM1200 Tests 3 and 4.

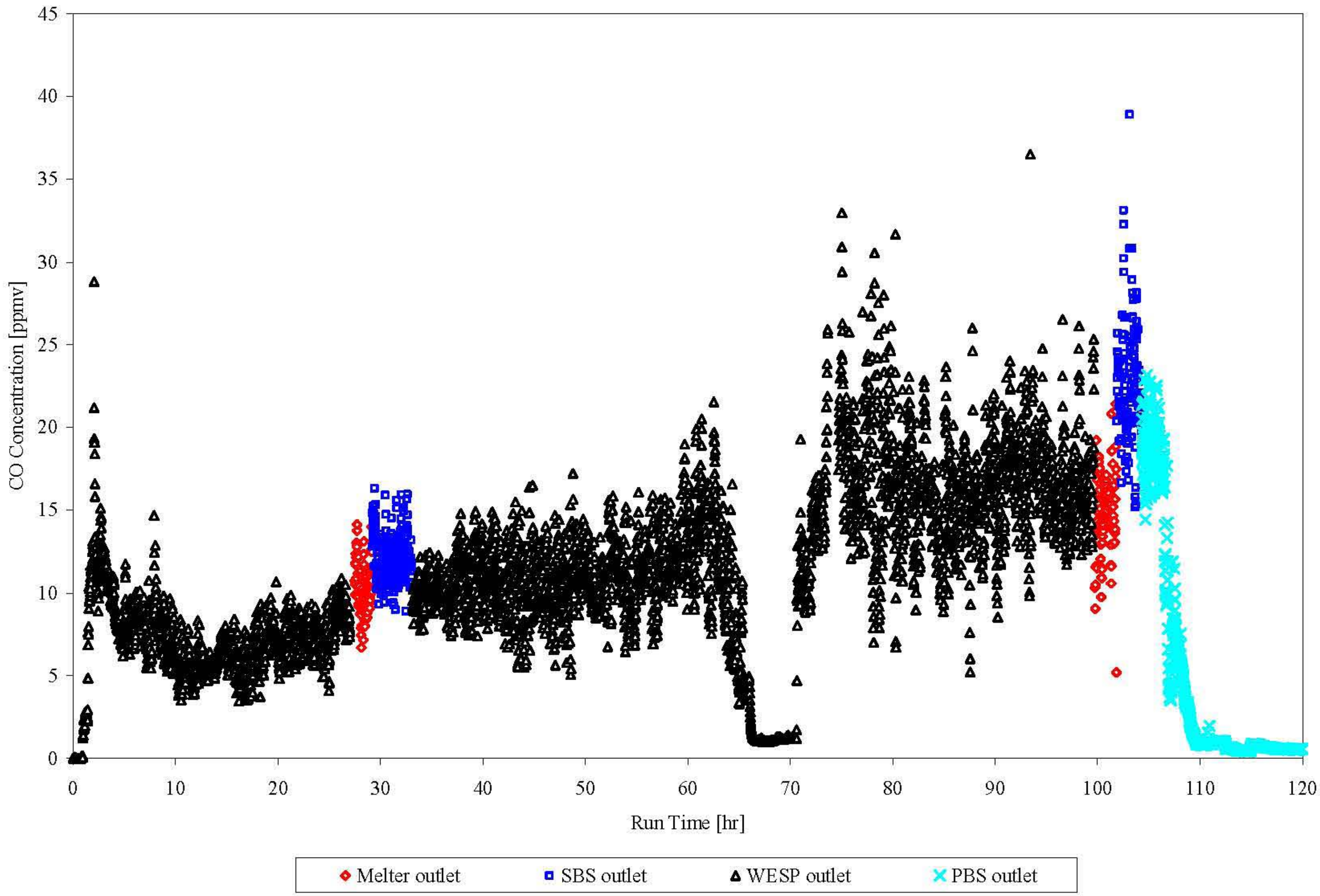

Figure 6.5. FTIR Monitored CO emissions during Tests 1 and 2.

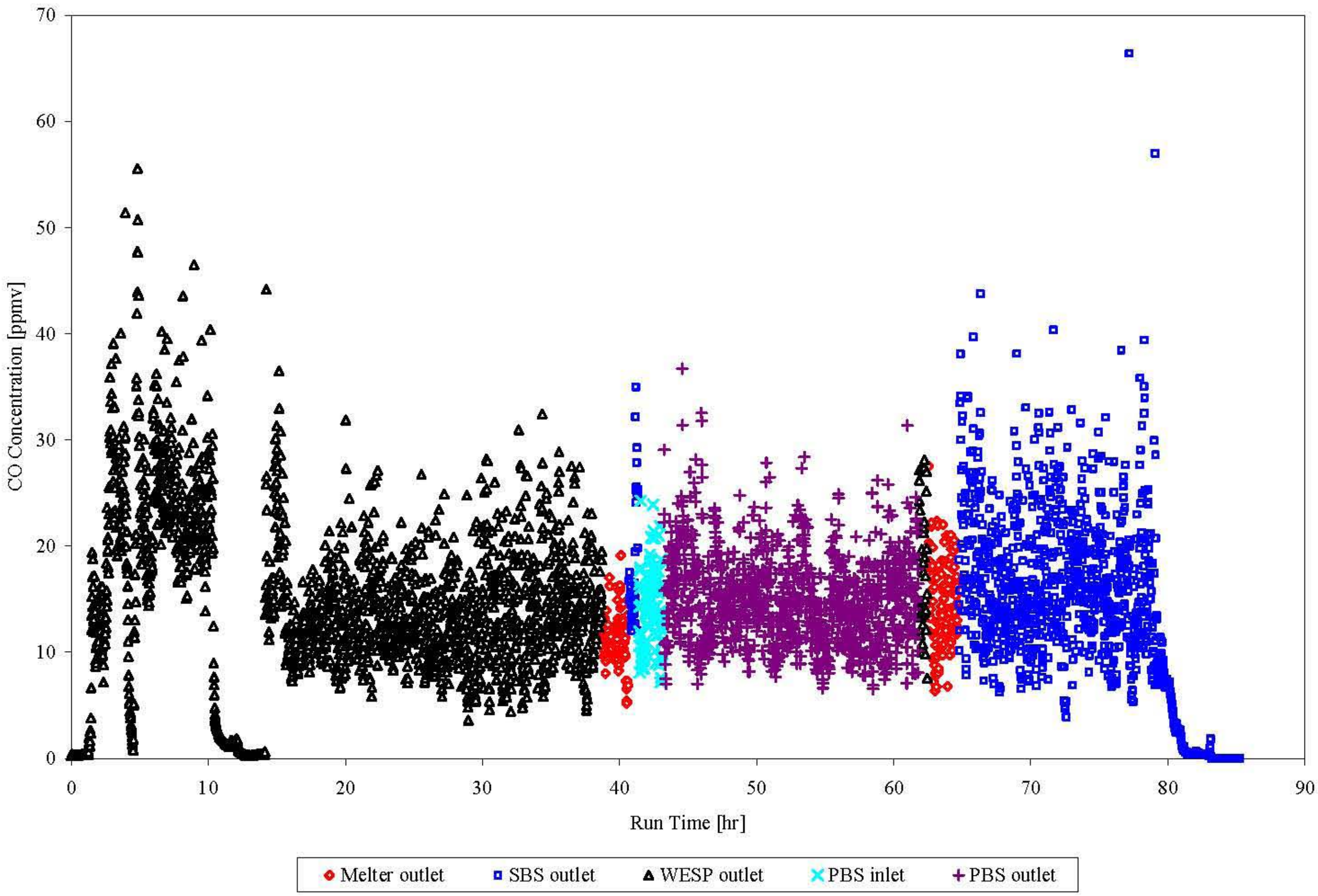

Figure 6.6. FTIR Monitored CO emissions during DM1200 Test 3 and 4.