Task 3.13 - Hot-Gas Filter Testing

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By:
Michael L. Swanson

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For
U.S. Department of Energy
Office of Fossil Energy
Federal Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

By
Energy & Environmental Research Center
University of North Dakota
P. O. Box 9018
Grand Forks, North Dakota 58202-9018

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ACKNOWLEDGMENT

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1.0 OBJECTIVES

The objectives of the hot-gas cleanup (HGC) work on the transport reactor demonstration unit (TRDU) located at the Energy & Environmental Research Center (EERC) is to demonstrate acceptable performance of hot-gas filter elements in a pilot-scale system prior to long-term demonstration tests. The primary focus of the experimental effort in the 3-year project is the testing of hot-gas filter element performance (particulate collection efficiency, filter pressure differential, filter cleanability, and durability) as a function of temperature and filter face velocity during short-term operation (100–200 hours). The filter vessel is used in combination with the TRDU to evaluate the performance of selected hot-gas filter elements under gasification operating conditions. This work directly supports the power systems development facility (PSDF) utilizing the M.W. Kellogg transport reactor located at Wilsonville, Alabama (1) and, indirectly, the Foster Wheeler advanced pressurized fluid-bed combustor, also located at Wilsonville (2).

2.0 BACKGROUND INFORMATION

The U.S. Department of Energy (DOE) Federal Energy Technology Center (FETC) has a HGC program intended to develop and demonstrate gas stream cleanup options for use in combustion- or gasification-based advanced power systems. One objective of the FETC HGC program is to support the development and demonstration of barrier filters to control particulate matter. The goal is not only to meet current New Source Performance Standards (NSPS) with respect to particulate emissions, but also to protect high-efficiency gas turbines and control particulate emissions to low enough levels to meet more stringent regulatory requirements anticipated in the future. DOE FETC is investing significant resources in the PSDF under a Cooperative Agreement with Southern Company Services, Inc. (SCS). The Wilsonville facility will include five modules, including an advanced gasifier module and a HGC module. The gasifier module incorporates the M.W. Kellogg transport reactor technology for both gasification and combustion (3). Several other demonstration-scale advanced power systems also utilizing hot-gas particulate cleanup technology will benefit indirectly from this research. These systems include the Clean Coal IV Piñon Pine IGCC Power Project located at the Sierra Pacific Power Company's Tracy Station near Reno, Nevada.

The TRDU was built and operated at the EERC under Contract No. C-92-000276 with SCS. The M.W. Kellogg Company designed and procured the reactor and provided valuable on-site personnel for start-up and during operation. The Electric Power Research Institute (EPRI) was involved in establishing the program and operating objectives with the EERC project team.

The purpose of the previous program was to build a reactor system larger than the transport reactor test unit (TRTU) located in Houston, Texas, in support of the Wilsonville PSDF transport reactor train. The program was to address design and operation issues for the Wilsonville unit and also help develop information on the operation of the unit to decrease start-up costs.

The TRDU (240-lb/hr coal–limestone feed rate) now provides an intermediate scale to the TRTU (up to 10-lb/hr coal–limestone feed rate) and the Wilsonville transport reactor (3400-lb/hr feed rate). Some of the design, construction, start-up, and operational issues for the Wilsonville transport train are being addressed during this project.

The four major design criteria that were established by EPRI were met. These included coal feed rate, operating pressure, carbon conversion, and high heating value of the product gas. Major accomplishments included showing that the TRDU performed well hydrodynamically, that it had the ability to switch from combustion mode to gasification mode easily and safely, that solids could be fed to and removed from the system, and that the J-leg/standpipe and cyclone performed according to their design specifications. The staged char combustion mixing zone design was not verified because of the lack of nonvolatile char and a reduced operational schedule. This resulted in oxygen breakthrough from the mixing section into the riser as a result of insufficient carbon inventory in the circulating solids.

3.0 PROJECT DESCRIPTION

This program has a phased approach involving modification and upgrades to the TRDU and the fabrication, assembly, and operation of a hot-gas filter vessel (HGFV) capable of operating at the outlet design conditions of the TRDU, a 200–300-lb/hr pressurized circulating fluid-bed gasifier similar to the gasifier being tested at the Wilsonville facility. The TRDU has an exit gas temperature of up to 980°C (1800°F), a gas flow rate of 325 scfm, and an operating pressure of 120–150 psig. Phase I included upgrading the TRDU based upon past operating experiences. Additions included a nitrogen supply system upgrade, upgraded LASH (lime ash) auger and coal feed lines, a second pressurized coal feed hopper, the addition of a dipleg ash hopper, and modifications to spoil the performance of the primary cyclone.

The TRDU system can be divided into three sections: the coal feed section, the TRDU, and the product recovery section. The TRDU proper, as shown in Figure 1 (figures are at end of document), consists of a riser reactor with an expanded mixing zone at the bottom, a disengager, and a primary cyclone and standpipe. The standpipe is connected to the mixing section of the riser by a J-leg transfer line. All of the components in the system are refractory-lined and designed mechanically for 150 psig and an internal temperature of 1090°C (2000°F). Table 1 summarizes the operational performance for the TRDU under the previous test program (4).

The premixed coal and limestone feed to the transport reactor can be admitted through three nozzles, which are at varying elevations. Two of these nozzles are located near the top of the mixing zone (gasification), and the remaining one is near the bottom of the mixing zone (combustion). During operation of the TRDU, feed is admitted through only one nozzle at a time.

TABLE 1

TRDU Design and Operational Parameters from Previous Program

Parameter	Design	Actual Operating Conditions[1]
Coal	Illinois No. 6	Wyodak
Moisture Content, %	5	20
Pressure, psig	120	117–122
Steam:Coal Ratio	0.34	0.38
Air:Coal Ratio	4.0	3.5–4.7
Ca:S Ratio, mole	1.5	1.5
Air Inlet Temperature, °C	427	425
Steam Preheat, °C	537	390
Coal Feed Rate, lb/hr	198	173
Gasifier Temperature, maximum °C	1010	850
ΔT, maximum °C	17	121
Conversion, %	>80	96
HHV of Fuel Gas, Btu/scf	100	104
Heat Loss as Coal Feed, %	19.5	14–27
Riser Velocity, ft/sec	31.3	28–30
Heat Loss, Btu/hr	252,000	420,000
Standpipe Superficial Velocity, ft/sec	0.1	0.4–0.54

[1] Steady-state conditions were not achieved.

The coal feed is measured by an rpm-controlled metering auger. Oxidant is fed to the reactor through two pairs of nozzles at varying elevations within the mixing zone. For the combustion mode of operation, additional nozzles are provided in the riser for feeding secondary air. Hot solids from the standpipe are circulated into the mixing zone, where they come into contact with the nitrogen and the steam being injected into the J-leg. This feature enables spent char to contact steam prior to the fresh coal feed. This staged gasification process is expected to enhance the process efficiency. Gasification or combustion and desulfurization reactions are carried out in the riser as coal, sorbent, and oxidant (with steam for gasification) flow up the tube. The solids circulation into the mixing zone is controlled by the solids level in the standpipe.

The riser, disengager, standpipe, and cyclones are equipped with several internal and skin thermocouples. Nitrogen-purged pressure taps are also provided to record differential pressure across the riser, disengager, and the cyclones. The data acquisition and control system scans the data points every ½ second, but saves the process data only every 30 seconds. The bulk of entrained solids leaving the riser is separated from the gas stream in the disengager and circulated back to the riser via the standpipe. A solids stream is withdrawn from the standpipe via an auger to maintain the system's solids inventory. Gas exiting the disengager enters a primary cyclone that has been modified to provide variable particulate collection performance. Solids from the primary cyclone are collected in a lock hopper. Gas exiting this cyclone enters a jacketed-pipe heat exchanger before entering the HGC filter vessel. The cleaned gases leaving the HGC filter vessel enter a quench system before being depressurized and vented to a flare.

The quench system uses a sieve tower and two direct-contact water scrubbers to act as heat sinks and remove impurities. All water and organic vapors are condensed in the first scrubber, with the second scrubber capturing entrained material and serving as a backup. The condensed liquid is separated from the gas stream in a cyclone that also serves as a reservoir. Liquid is pumped either to a shell-and-tube heat exchanger for reinjection into the scrubber or down to the product receiver barrels.

3.1 Hot-Gas Filter Vessel

Subtask 3.13 – Hot-Gas Filter Testing was a hot-gas filter program started in January 1995 as an addition to the Federal Energy Technology Center, Morgantown, Cooperative Agreement. First-year funding made available in March 1995 supported upgrades to the TRDU, installation of a filter vessel and the associated inlet–outlet piping, and the performance of three 200-hour filter tests. The filter design criteria are summarized in Table 2, and a schematic is given in Figure 2.

This vessel is designed to handle all of the gas flow from the TRDU at its expected operating conditions. The vessel is approximately 48 in. ID and 185 in. long and is designed to handle gas flows of approximately 325 scfm at temperatures up to 980°C (1800°F) and 130 psig. The refractory has a 28-in. ID with a shroud diameter of approximately 22 in. The vessel is sized such that it could handle candle filters up to 1.5 m long; however, 1-m candles are currently being utilized in the initial 540°C (1000°F) gasification tests. Candle filters are 2.375-in. OD with a 4-in. center line-to-center line spacing.

TABLE 2

Design Criteria for the Pilot-Scale Hot-Gas Filter Vessel

Operating Conditions	Design
Inlet Gas Temperature	540°–980°C
Operating Pressure	150 psig
Volumetric Gas Flow	325 scfm
Number of Candles	19 (1 or 1.5 meter)
Candle Spacing	4 in. ℄ to ℄
Filter Face Velocity	2.5–10 ft/min
Particulate Loading	<10,000 ppm
Temperature Drop Across HGFV	<30°C
Nitrogen Backpulse System Pressure	up to 800 psig
Backpulse Valve Open Duration	up to 1-s duration

The total number of candles that can be mounted in the current geometry of the HGFV tube sheet is 19. This enables filter face velocities as low as 2.5 ft/min to be tested using 1-m candles. Phases III through V consisted of 200-hr hot-gas filter tests under gasification conditions using the TRDU with the HGC operating at temperatures of 540°–650°C (1000°–1200°F), 120 psig, and increasing face velocities for each test. Higher face velocities would be achieved by using fewer candles. The current test matrix performed the first filter test at 540°–650°C (1000°–1200°F), 120 psig, 2.75 ft/min face velocity. The second test was performed after removing six candles to increase the face velocity to approximately 4.5 ft/min, at the same operating temperature and pressure. The openings for the six removed candles were blanked off. Because of the rapid buildup of pressure drop across the filter during Test P050, the third test investigate other parameters such as primary cyclone spoiling to improve the candle-cleaning efficiency and rate of pressure drop increase. This program has been testing an Industrial Filter & Pump (IF&P) ceramic tube sheet, silicon carbon-coated ceramic fiber candles from the 3M Company, and sintered metal (iron aluminide) and Vitropore silicon carbon ceramic candles from Pall Advanced Separation Systems Corporation.

The ash letdown system consists of two sets of alternating high-temperature valves with a conical pressure vessel to act as a lock hopper. Additionally, a preheat natural gas burner attached to a separate gasifier is used to preheat the filter vessel separately from the TRDU while the gasifier is heating up. The hot gas from the burner enters the vessel via a nozzle inlet separate from the dirty gas.

The high-pressure nitrogen backpulse system is capable of backpulsing up to four sets of four or five candle filters with ambient-temperature nitrogen in a time-controlled sequence. The pulse length and volume of nitrogen displaced into the filter vessel is controlled by regulating the pressure (up to 800 psig) of the nitrogen reservoir and the solenoid valves used to control the timing of the gas pulse. Figure 1 also shows the filter vessel location and process piping in the EERC gasifier tower. Since the first three filter tests are to be completed in the 540°–650°C (1000°–1200°F) range, a length of heat exchanger is used to drop the gas temperature to the desired range. Inserting an existing set of high-temperature valves in the fuel gas heat exchanger has allowed bypassing the filter vessel during start-up of the TRDU and switching to the preheated filter vessel when steady-state conditions are achieved. In addition, sample ports both upstream and downstream of the filter vessel have been utilized for obtaining particulate and hazardous air pollutant (HAP) samples.

TRDU operation and filter element testing have benefitted other ongoing projects at the EERC. The same sampling and analysis activities have been conducted to generate HAP data concerning trace metal transformations, speciation of mercury, and metal concentrations at selected points within the TRDU and HGC in support of a project entitled "Trace Element Emissions" funded by FETC. In addition, materials and ash data concerning the high-temperature filter media and ash interactions have been collected in support of a project entitled "Hot-Gas Filter Ash Characterization" jointly funded by FETC and EPRI. While the cost of this specific data collection will be covered by the individual projects, the synergy that results from the integration of these projects will minimize the cost of collecting this information for all involved projects.

3.2 High-Pressure and High-Temperature Sampling System

The high-pressure and high-temperature sampling system (HPHTSS) was designed and constructed to extract dust-laden flue gas isokinetically from either an oxidizing or reducing environment. The maximum gas temperature at which the sample probe can be operated is specified as 980°C (1800°F) for the HPHTSS. The maximum working pressure of the gas stream for the HPHTSS is specified as 150 psig.

The probe for the HPHTSS is a 3/8-in.-OD and 1/8-in.-ID 304 stainless steel tube. The probe can be used for only one sampling test. The key to the sampling system is the use of a vessel designed to withstand high-pressure and high-temperature conditions to enclose the low-pressure sampling devices.

The vessel was constructed of 5-in. schedule 80 pipe and fitted with raised-face 300-lb flanges. The material used for the HPHTSS pressure vessel was 316L stainless steel. The HPHTSS was designed to house both multicyclone assemblies with backup filter and a backup filter alone.

The principle of operation is to pressurize the outside of the sampling device (i.e., multicyclone assembly or backup filter) with nitrogen at a slightly higher gas pressure than the system pressure of the flue gas. The pressure differential between the nitrogen gas within the pressure vessel and the flue gas within the sampling device is maintained at less than 5 psig.

If the HPHTSS is operating in a reducing environment where the presence of organic vapors is a possibility, the pressure vessel is capable of operating at temperatures as high as 540°C (1000°F) and maintaining nitrogen gas pressures up to 150 psig. This will prevent the heavier organic vapors from condensing while passing through the particulate sampling assembly. Electric resistance heaters will be used to heat the pressure vessel to specified temperatures. This operating temperature also allows vapor-phase trace species to be maintained in the vapor phase through the backup filter.

Once the process gas exits the sampling assembly, the gas pressure is reduced through a throttling valve to approximately atmospheric pressure. The throttling valve will also act as the flow control valve for the sampling system. A second throttling valve was installed in series in the event that the primary throttling valve fails to close.

After the throttling valve, the process gas is cooled through a set of impingers to remove moisture and organic vapors if present. A set of up to six impingers may be used in this sampling system. These impingers are rated for 200 psig at 120°C (250°F) maximum operating conditions. The impingers are made of 304 stainless steel, with the interior surfaces coated with Teflon. The Teflon-coated surfaces allow the HPHTSS to be used for collecting the vapor-phase trace metal species.

The dry gas is metered through a rotameter and dry-gas meter to measure total flow before it is vented out of the stack.

4.0 ACCOMPLISHMENTS

A test campaign was conducted during the weeks of July 8–10, 1997, and October 5–7, 1997. During these weeks, approximately 98 hours of coal feed and 84 hours of gasification (with over 50 hours of continuous operation) were achieved, with the system gases and fly ash passing through the filter vessel during the whole test campaign. Operational problems with the data acquisition system for the TRDU gasification system and also with refractory erosion in the disengager cyclone caused a significant drop in cyclone efficiency, resulting in a shutdown before the desired 200 hours were achieved.

4.1 TRDU Operation

The TRDU was operated at an average temperature of 850°C. Table 3 summarizes the operational performance for the TRDU during these test periods. Coal feed rates ranged from 240 up to 320 lb/hr, and the gasifier pressure averaged 120 psig. The dry product gas produced ranged from 3.2% to 3.9% CO, 6.0% to 7.8% H_2, 11.5% to 12.7% CO_2, 0.81% to 1.5 % CH_4, with the balance being N_2 and other trace constituents. The moisture in the fuel gas averaged 15%. The H_2S concentration averaged approximately 1000 ppm. Calculated recirculation rates started at approximately 2000 lb/hr and slowly increased to approximately 4500 lb/hr until the end of the test. Relative bed density dropped from 98% for a 100% silica sand bed to approximately 75% with the high-carbon and coal ash bed. Figures 3 and 4 show the particle-size distributions of the bed material and primary cyclone ash as compared to different tests. The bed material particle size remained constant during these tests at approximately 200 μm. In general, the primary cyclone ash was becoming progressively coarser during the tests as a result of the continuing erosion of the disengeger cyclone and the resulting loss of cyclone efficiency.

4.2 Hot-Gas Filter Vessel Operation

Table 4 shows the nominal steady-state operating conditions achieved for Tests P052 and P055. Figures 5 through 7 show the 24-hour temperature history of the HGFV during its 3 days of operation in Test Period P052. The HGFV was held steady at an average temperature of 542°C, except during periods when a substantial coal feeder plug or data acquisition problem resulted in the HGFV being taken off-line or the TRDU being shut down for extended periods. Also shown in Figure 9 is a trace of the filter temperatures after a coal feed plug resulted in oxygen breakthrough back to the filter vessel. The filter outlet temperature spiked at approximately 730°C, while the carbon burned out on the surface of the candle filters.

Figures 8 through 10 show the pressure history of the filter vessel outlet static and differential pressures, and backpulse reservoir pressure for Test P052. The candles were backpulsed over 173 times during Test P052, with no major candle failures. As can be seen in the backpulse signature, the filter vessel was backpulsed at 20 to 30 in. H_2O above the just-cleaned baseline. As the baseline climbed initially from 20 to 35 in. H_2O, the filter vessel differential pressure trigger was increased from 40 to 50 in. H_2O. The baseline filter differential pressure dropped considerably whenever there was a coal feed plug and oxygen breakthrough to the

TABLE 3

TRDU Actual Operating Conditions

Parameter	P052–P055
Conditions	Gasification
Coal	Wyodak
Moisture Content, %	23.3
Pressure, bar	9.3
Steam:Coal Ratio	0.23
Air:Coal Ratio	2.7
Ca:S Ratio, mole	3.8
Coal Feed Rate, lb/hr	< 320
Mixing Zone, °C , avg. Riser, °C , avg. Standpipe, °C , avg.	840 825 740
Conversion, % (excluding dipleg)	96.5–98%
Carbon in Bed, %, Standpipe (dipleg)	3 to 12 (5 to 9)
Riser Velocity, ft/s	30
Standpipe Velocity, ft/s	0.35
Circulation Rate, lb/hr	2600 to 4400
Duration, hr	98

HGFV filter vessel. During this test, the backpulsing cycle time decreased to as little as every 5 minutes.

During Test P052, a fine silica sand flour was fed with some difficulty to the inlet of the HGFV to act as a filter aid to improve the hot-gas filter performance of the TRDU filter ash either by reducing the backpulse frequency or by reducing or eliminating the increase in the baseline filter differential pressure that had been observed in previous tests. The silica sand additive apparently did not improve backpulse frequency at all; however, it did appear to be slowing the increase in the baseline filter differential pressure from that observed under previous tests with the same coal.

Figures 11 through 13 show the 24-hour temperature history of the HGFV during its 3 days of operation in Test Period P055. The HGFV was held steady at an average temperature of 542°C, except during periods of substantial coal feeder plugging. Also shown in Figure 13 is a trace of the filter temperatures after a coal feed plug resulted in oxygen breakthrough back to the filter vessel. The filter outlet temperature spiked at approximately 720°C, while the carbon burned out on the surface of the candle filters. These data show the type of thermal transient that

TABLE 4

Operating Conditions for the Pilot-Scale Hot-Gas Filter Vessel

Operating Conditions	Actual
Inlet Gas Temperature, °C	520°–580°C
Operating Pressure, psig	120
Volumetric Gas Flow, scfm	350
Number of Candles	13 (1-meter)
Candle Spacing, in. ℄ to ℄	4
Filter Face Velocity, ft/min	4.5
Particulate Loading, ppm	< 7000
Temperature Drop Across HGFV, °C	25
Nitrogen Backpulse System Pressure, psig	250 to 300
Backpulse Valve Open Duration, s	½ and ¾

the candle filters might have to survive during a system upset or shutdown on a commercial-scale gasifier.

Figures 14 through 16 show the pressure history of the filter vessel outlet static and differential pressures, and backpulse reservoir pressure for Test P055. The candles were backpulsed over 286 times during test P055 with no major candle failures. As the backpulse signature indicates, the filter vessel was backpulsed at 20 to 30 in. H_2O above the just-cleaned baseline. As the baseline climbed initially from 20 to 35 in. H_2O, the filter vessel differential pressure trigger was increased from 40 to 60 in. H_2O until the Illinois No. 6 coal was fed at the end of the test. Once the Illinois No. 6 coal feed was started, the baseline differential pressure increased rapidly, requiring the trigger pressure to increase to 90 in. H_2O. This rapid increase was probably the result of way the gasifier was transitioned from the subbituminous to the bituminous coal. Again, the baseline filter differential pressure would drop considerably whenever there was a coal feed plug and oxygen breakthrough to the HGFV occurred. During this test, the backpulsing cycle time decreased to as little as every 7 minutes, but was approximately 9 minutes at the higher backpulsing pressures. Changes in the backpulse operating conditions show up in the pressure traces as either a step change in the reservoir peak pressure (i.e., an increase in reservoir pressure) or a drop in the minimum reservoir pressure (i.e., an increase in the pulse duration). Backpulse operating parameters were a 245-psig reservoir pressure with a ½-second pulse duration, which was not changed during the course of the test. The mechanical operation of the N_2 backpulse system and the filter vessel ash letdown system presented no operational problems.

During Test P055, a fine fluid-bed catalytic cracking (FCC) catalyst support was fed to the inlet of the HGFV to act as a filter aid to improve the hot-gas filter performance of the TRDU filter ash either by reducing the backpulse frequency or by eliminating the increase in the baseline filter differential pressure observed in previous tests. It appears that the FCC catalyst support only slightly improved backpulse frequency; however, it did appear to eliminate the increase in the baseline filter differential pressure from that observed under previous tests with the same coal, since the previous increases in the "cleaned" filter baseline (from ~20 to 90 in. H_2O) were not observed over the course of either test.

The average particulate loading going into the HGFV was approximately 5400 ppm and increased to over 6700 ppm as the disengager cyclone became more spoiled. The outlet loading started at 70 ppm and increased to over 245 ppm over the course of the test. Figure 17 compares the particle-size distribution of the particulate sample fly ash to the bulk filter ash that has been backpulsed from the candles. As can be seen, the filter ash is approximately the same size (7 to 8 μm) as the ash from the particulate samples even after feeding the FCC catalyst support into the filter. Figure 18 compares the bulk filter ash size distribution from the previous test to those from Tests P052 and P055. This figure shows that there was some increase in the particle-size distribution when the filter aid additives were fed (especially the FCC catalyst support); however, some of the increase in particle size is also due to the lower efficiency of the disengager cyclone. It appears that the Illinois No. 6 bituminous coal is also providing a larger size distribution than the Wyodak subbituminous coal. Carbon in the filter ash ranged from 40% to 50%, depending on the conditions.

Figure 19 is a photograph of the candle filters after Test P055. A small amount of bridging is evident around the tops of the 3M candles because of the penetration of the Nextel™ fiber gasket through the bottom of the tube sheet. The residual filter cake was approximately ¼ in. thick and could be easily removed from the filter with a spatula.

5.0 CONCLUSIONS AND FUTURE PLANS

In conclusion, the TRDU and hot-gas filters operated for 98 hours with coal feed and over 84 hours in gasification mode with no major filter problems. The TRDU average gasifier temperature was 850°C. A small amount of deposition was observed in the mixing zone. A small iron-based agglomerate was also found in the postrun bed material and was probably an artifact of the high-iron Illinois No. 6 bituminous coal fed at the end of the test. The candles were backpulsed over 450 times with no candle failures. The baseline "cleaned" filter differential pressure increased from 20 to 35 in. of H_2O over the course of the test while feeding either a fine silica sand or FCC catalyst support material as filter aids. Short backpulse intervals of approximately 5 to 9 minutes were still observed during the operation of HGFV on the TRDU, but the addition of the filter aid materials did improve the hot-gas filter performance of the TRDU filter ash by reducing or eliminating the increase in the baseline filter differential pressure that had been observed in previous tests. The inlet particulate loading ranged from approximately 5400 to 6700 ppm as the disengager cyclone was spoiled because of refractory erosion. The filter ash carbon ranged from 40 to 50 wt% carbon. The filter ash particle size was approximately 7–8 μm.

The large increase in filter baseline differential pressure also suggests that a thin but low-porosity (permeability) filter cake is remaining on the surface of the candle and is not being removed during backpulsing. The low bulk density and high flowability of the filter ash possibly suggests that the inlet ash is able to move or shift on the surface of the candle to reach some optimum (minimum) porosity leading to a low gas permeability across the candle. The forces holding these filter cakes in place are not understood at this time, but warrant further investigation.

Future tests should probably not try to increase face velocity (which would compound the ash reentrainment problem) but should maintain the same face velocity and further investigate the addition of various additives to enhance cake release and possibly increase the interval between backpulses. In addition, a test should also investigate the role of candle surface roughness in hindering filter cake release. Other tests can also look at operating at higher filtration temperatures and different face velocities along with other tube sheet and candle fail-safe designs.

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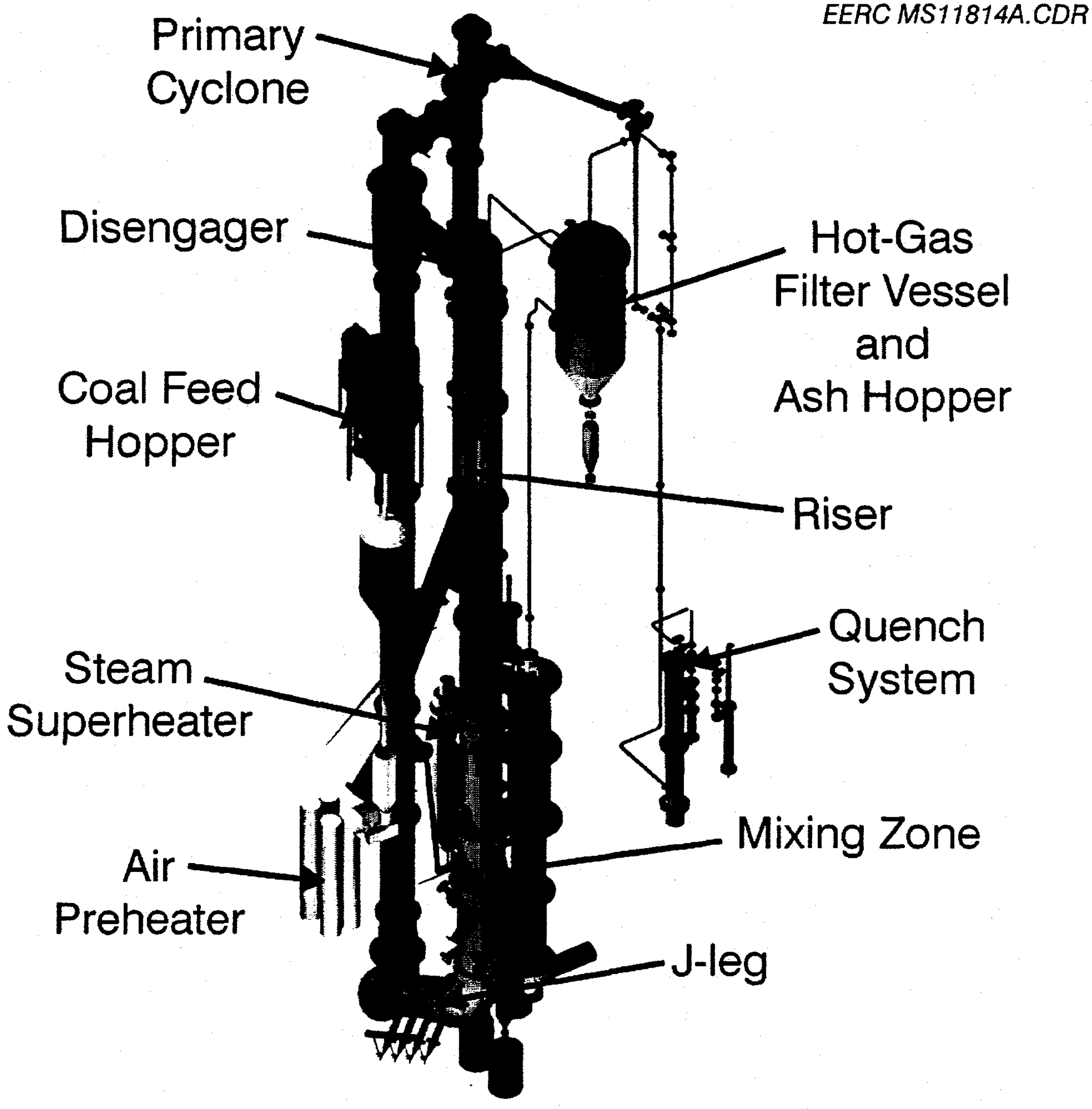

Figure 1. TRDU and hot-gas vessel in the EERC gasification tower.

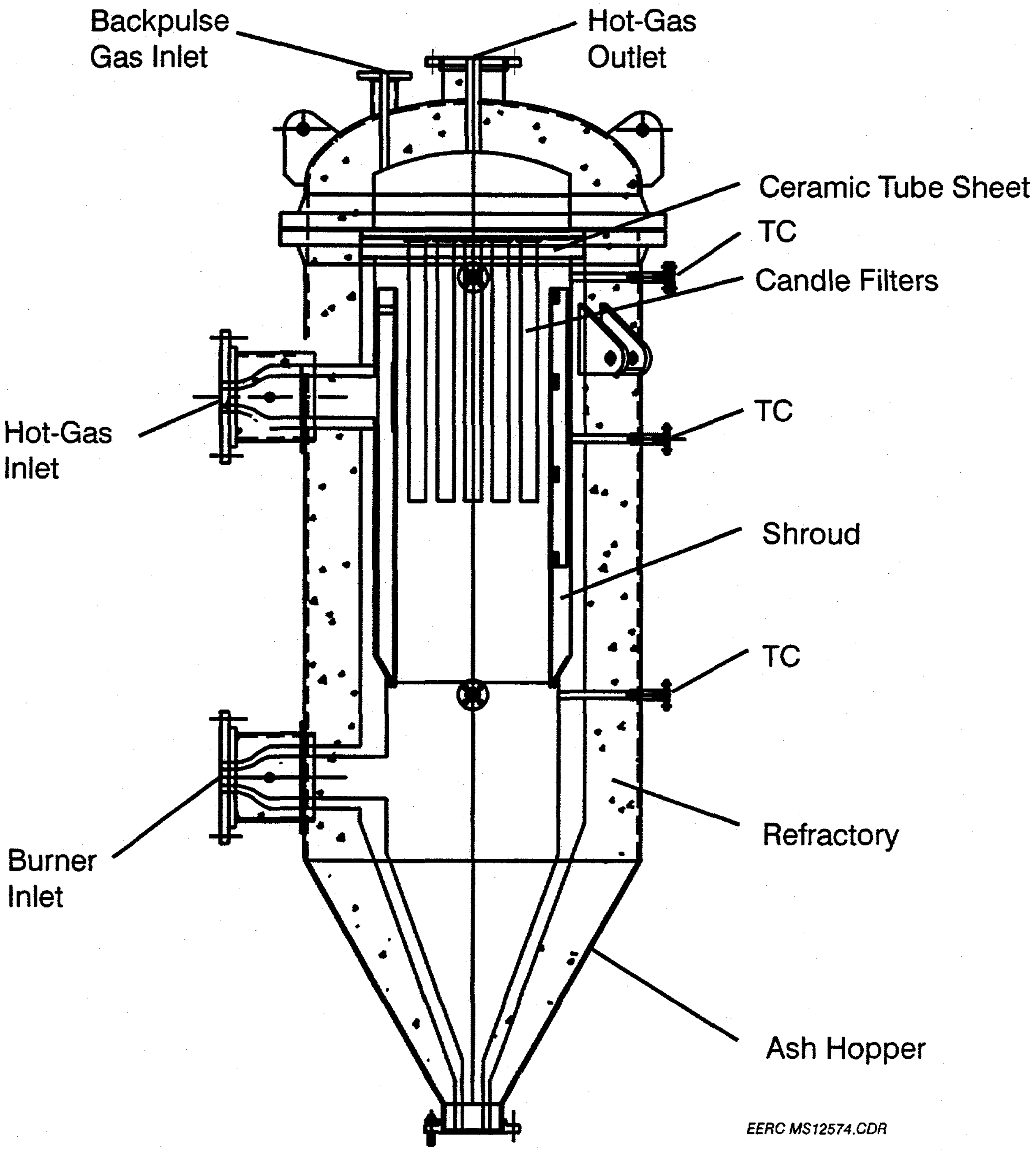

Figure 2. Schematic of the filter vessel design with internal refractory, tube sheet, and shroud.

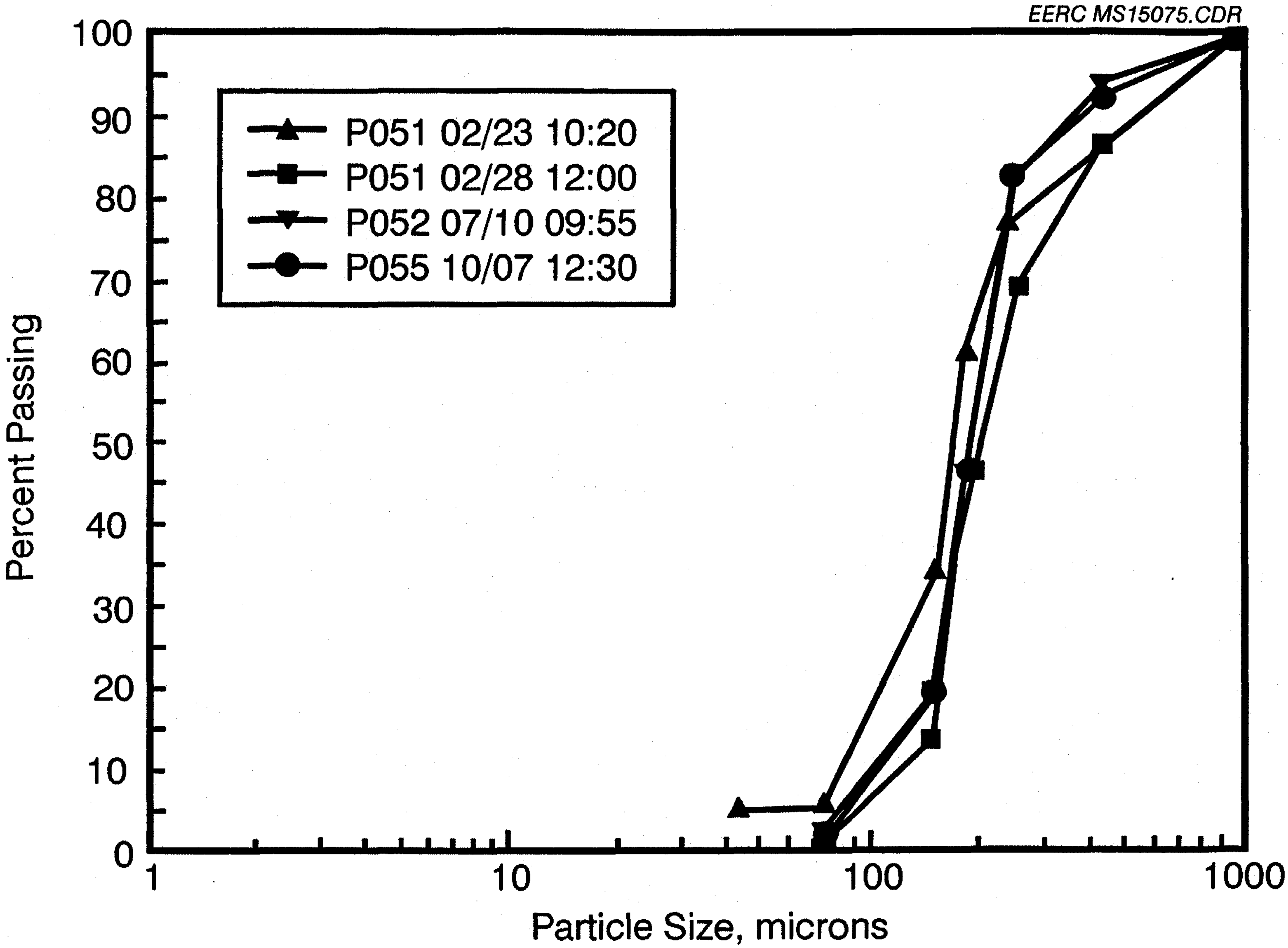

Figure 3. Particle-size distribution of bed material during Tests P052 and P055.

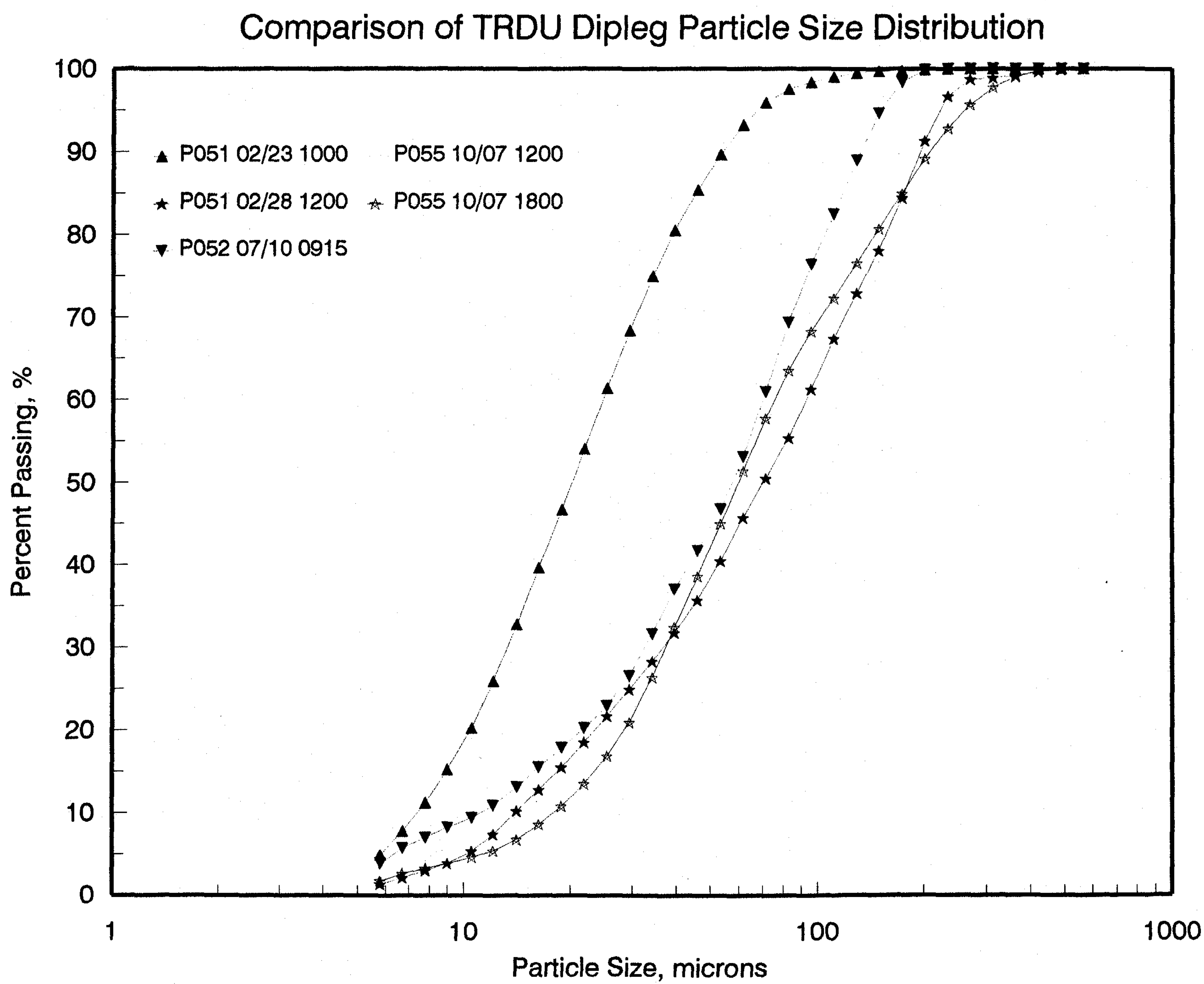

Figure 4. Particle-size distribution of primary cyclone ash during Tests P052 and P055.

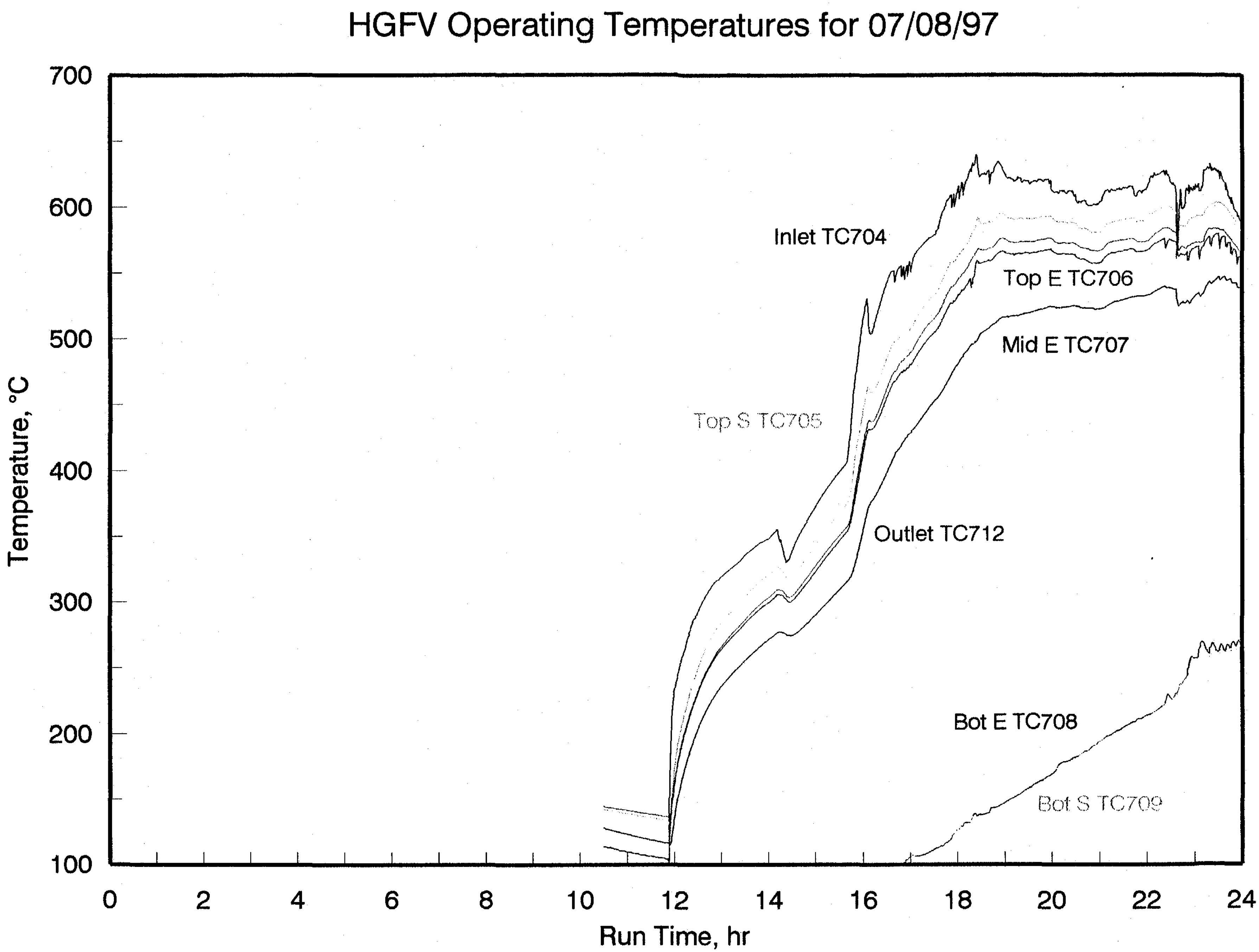

Figure 5. Hot-gas filter vessel temperature profile for 07/08/97.

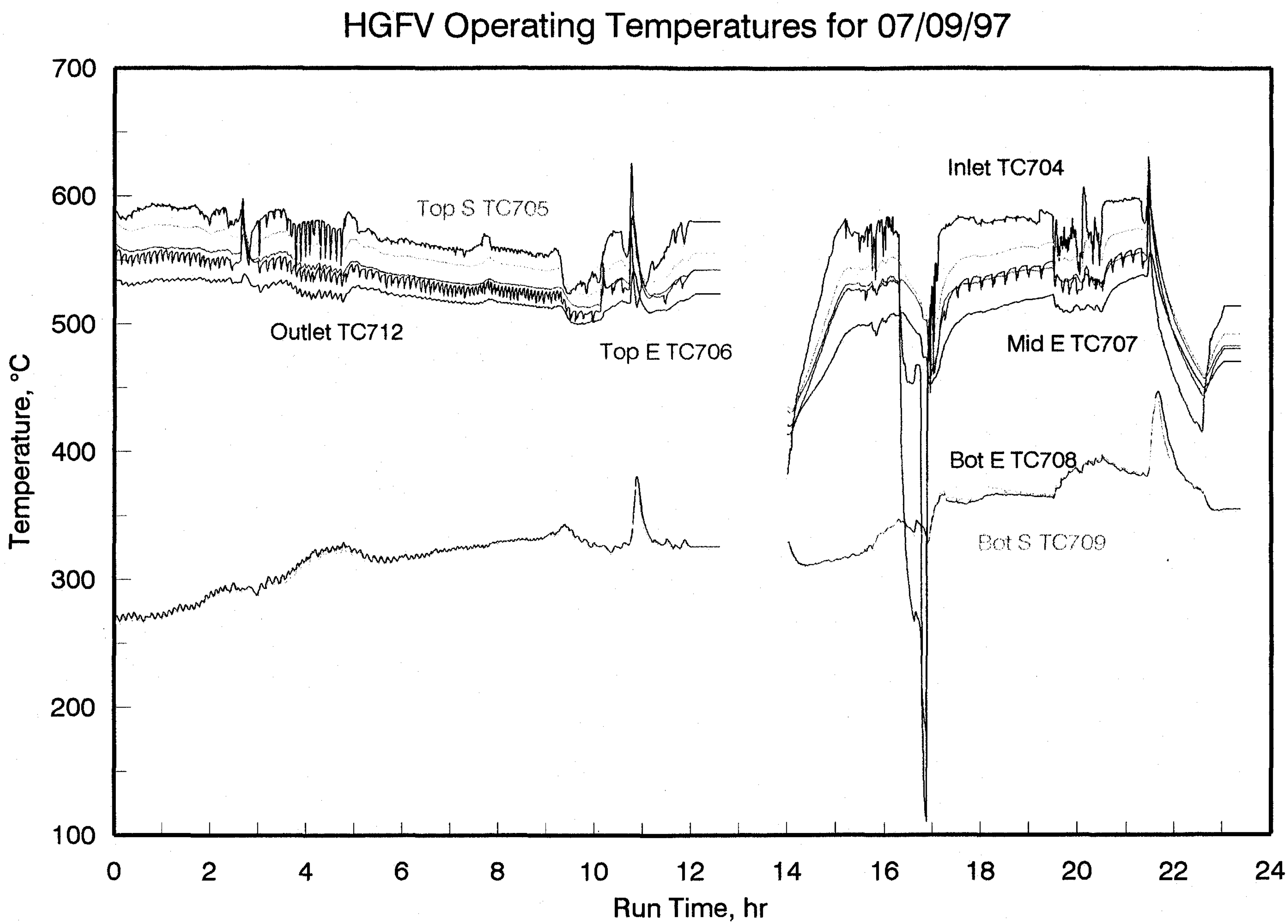

Figure 6. Hot-gas filter vessel temperature profile for 07/09/97.

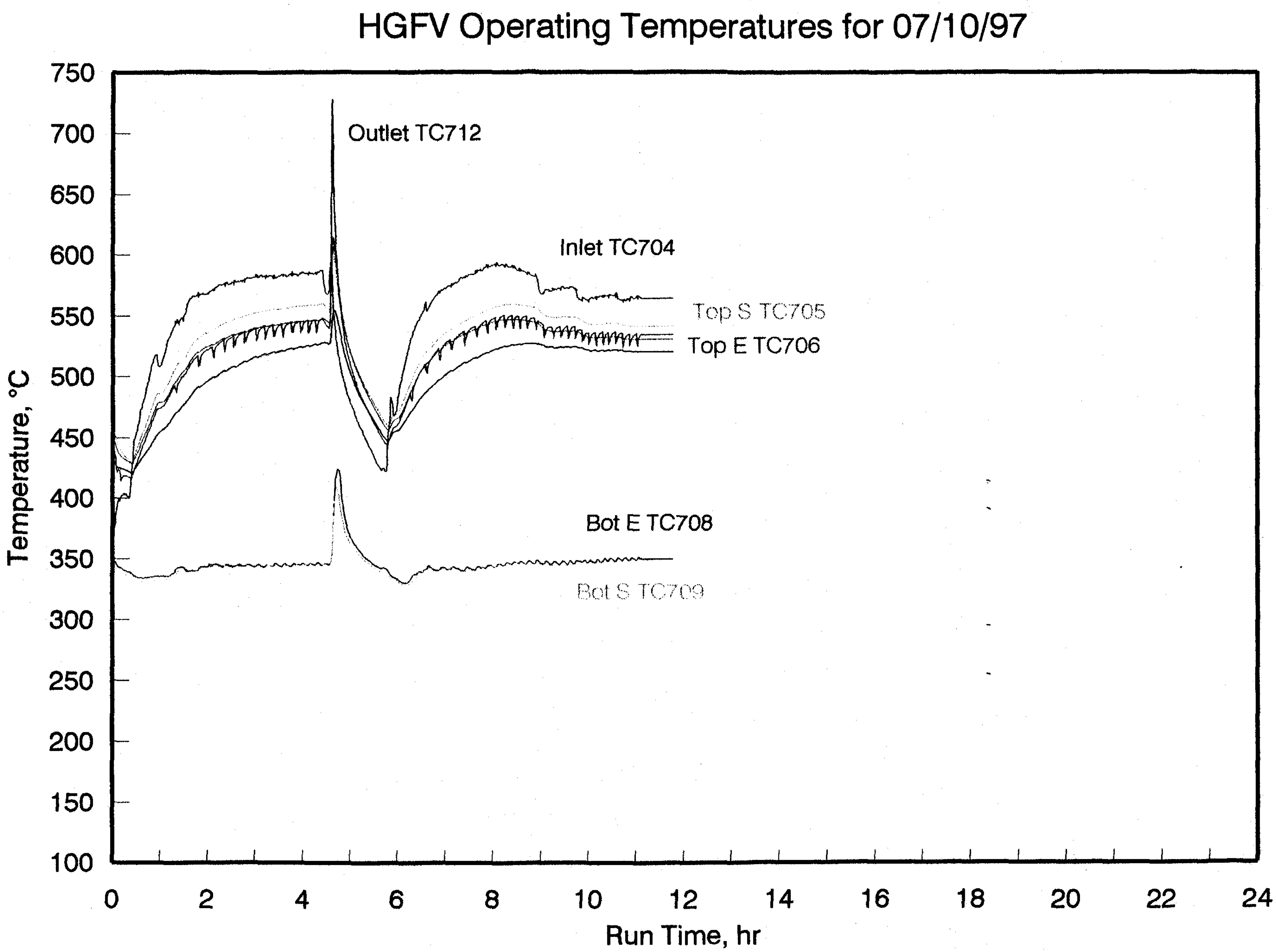

Figure 7. Hot-gas filter vessel temperature profile for 07/10/97.

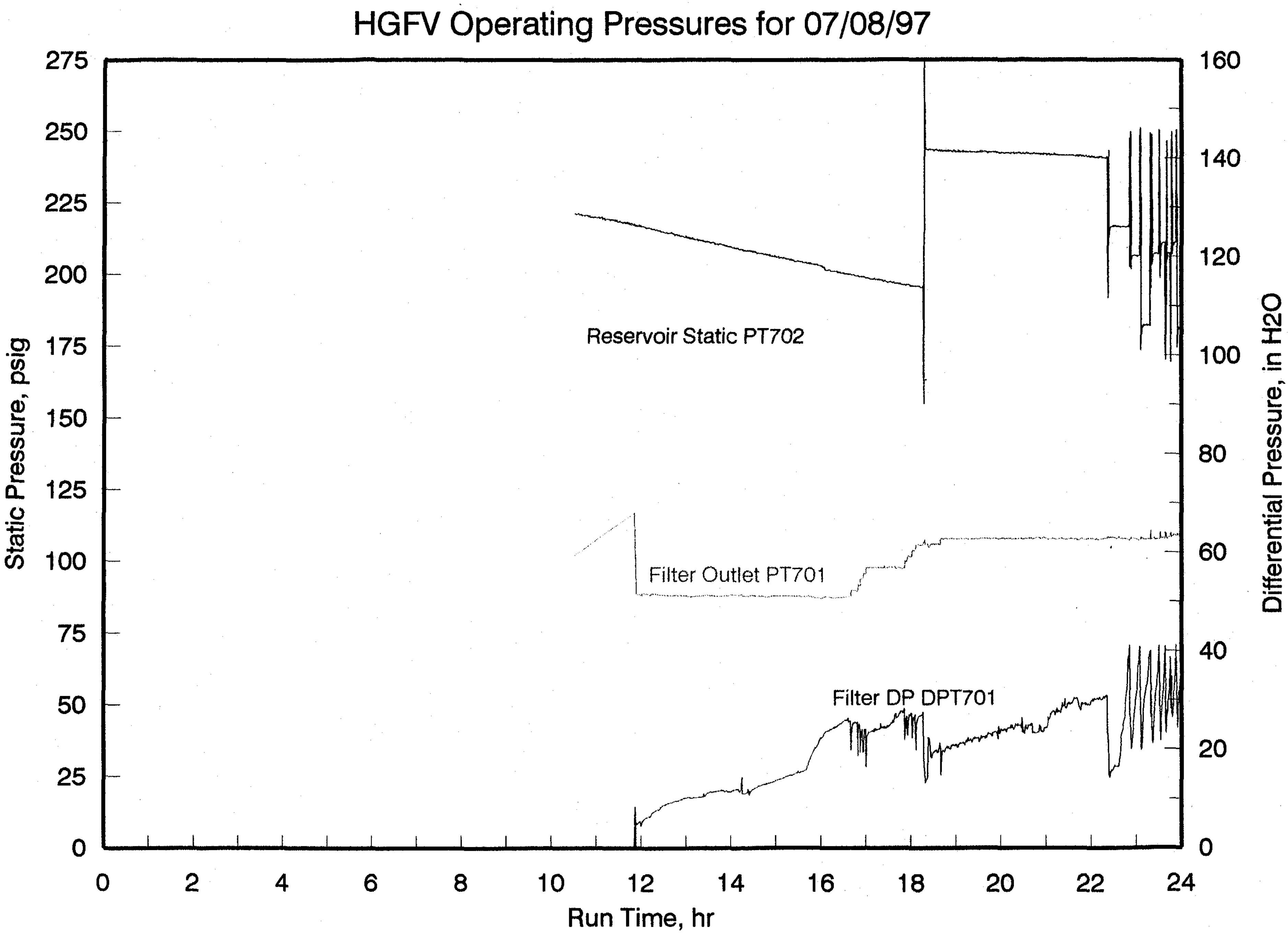

Figure. 8 Hot-gas filter vessel pressure profile for 07/08/97.

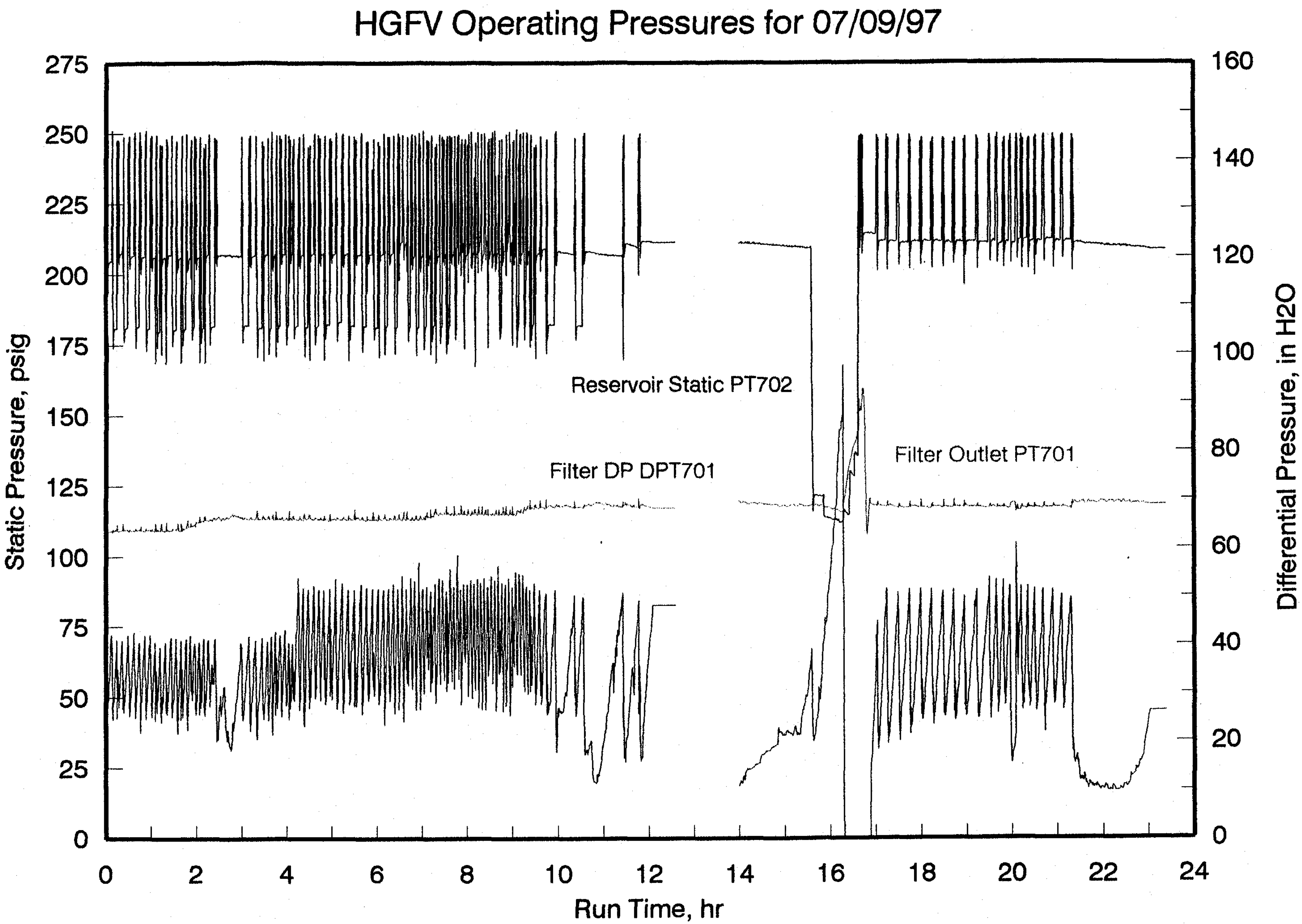

Figure 9. Hot-gas filter vessel pressure profile for 07/09/97.

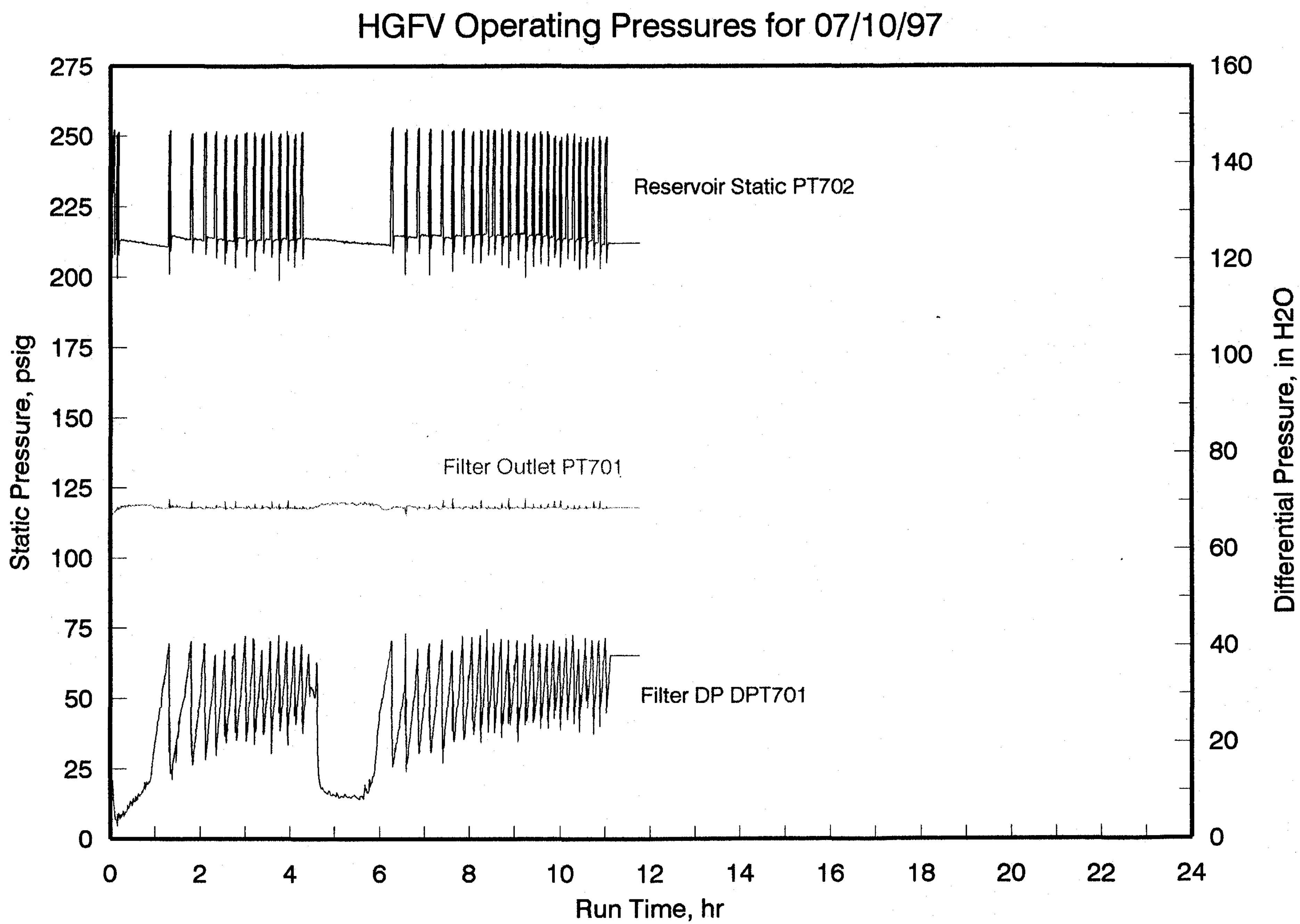

Figure 10. Hot-gas filter vessel pressure profile for 07/10/97.

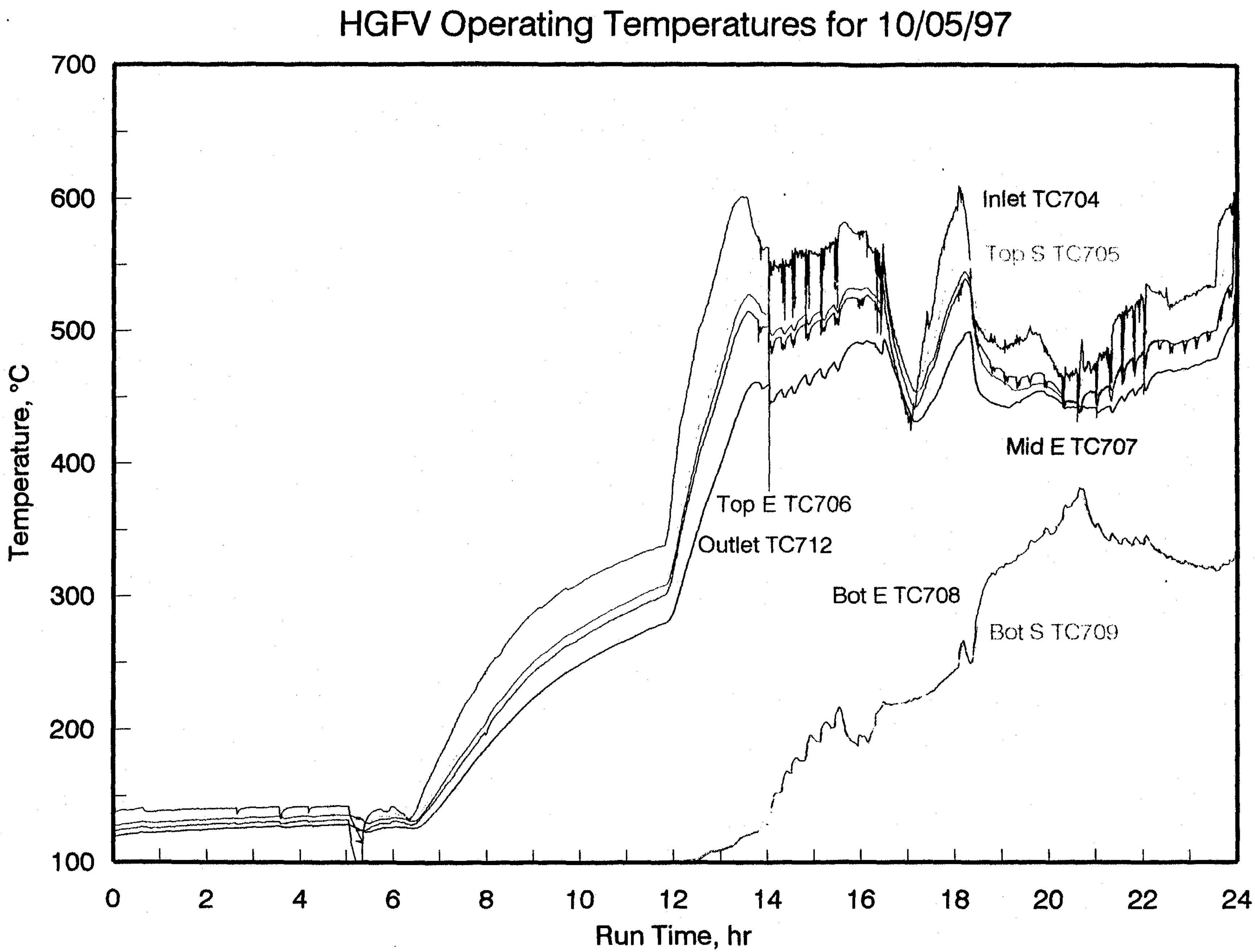

Figure 11. Hot-gas filter vessel temperature profile for 10/05/97.

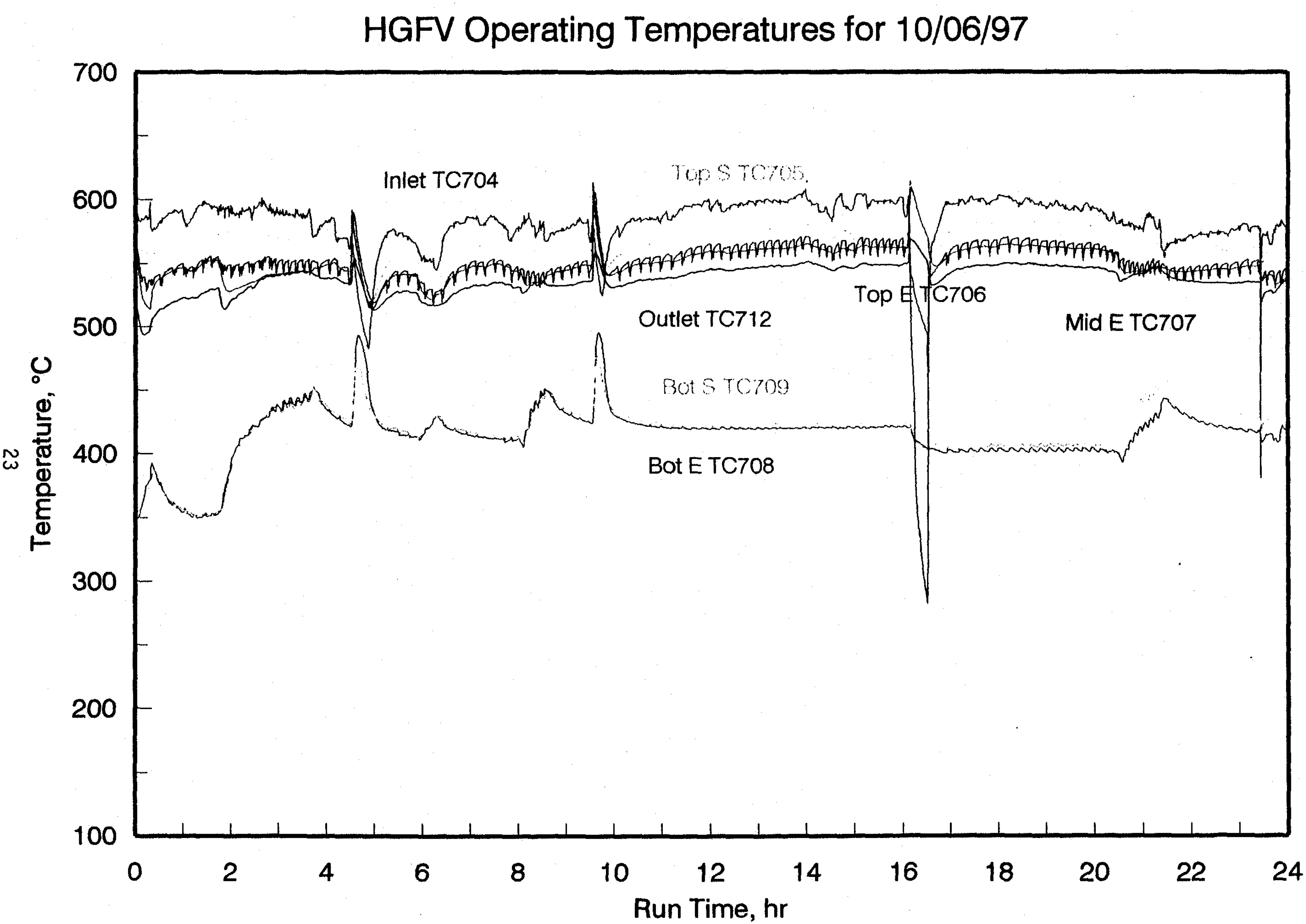

Figure 12. Hot-gas filter vessel temperature profile for 10/06/97.

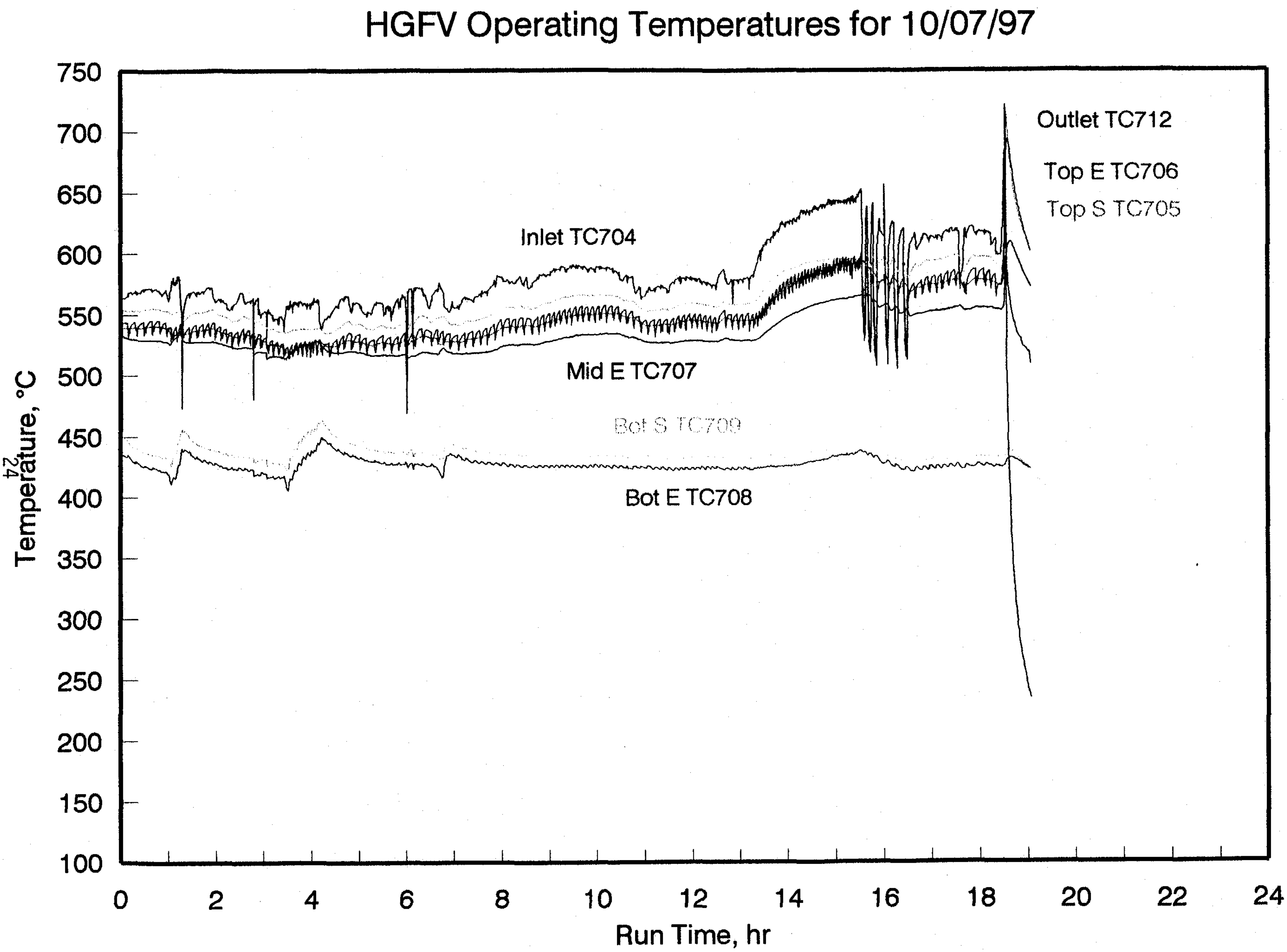

Figure 13. Hot-gas filter vessel temperature profile for 10/07/97.

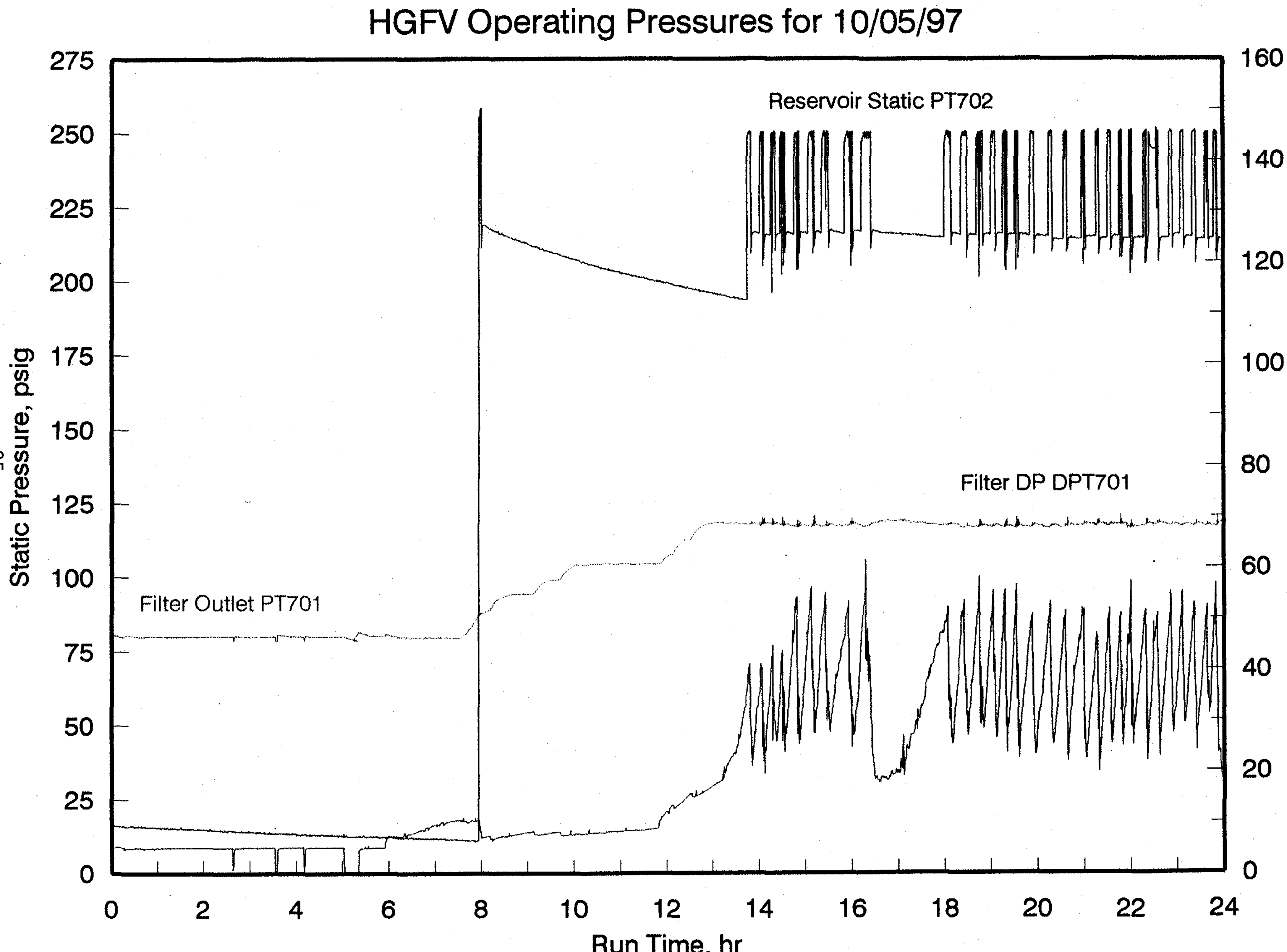

Figure 14. Hot-gas filter vessel pressure profile for 10/05/97.

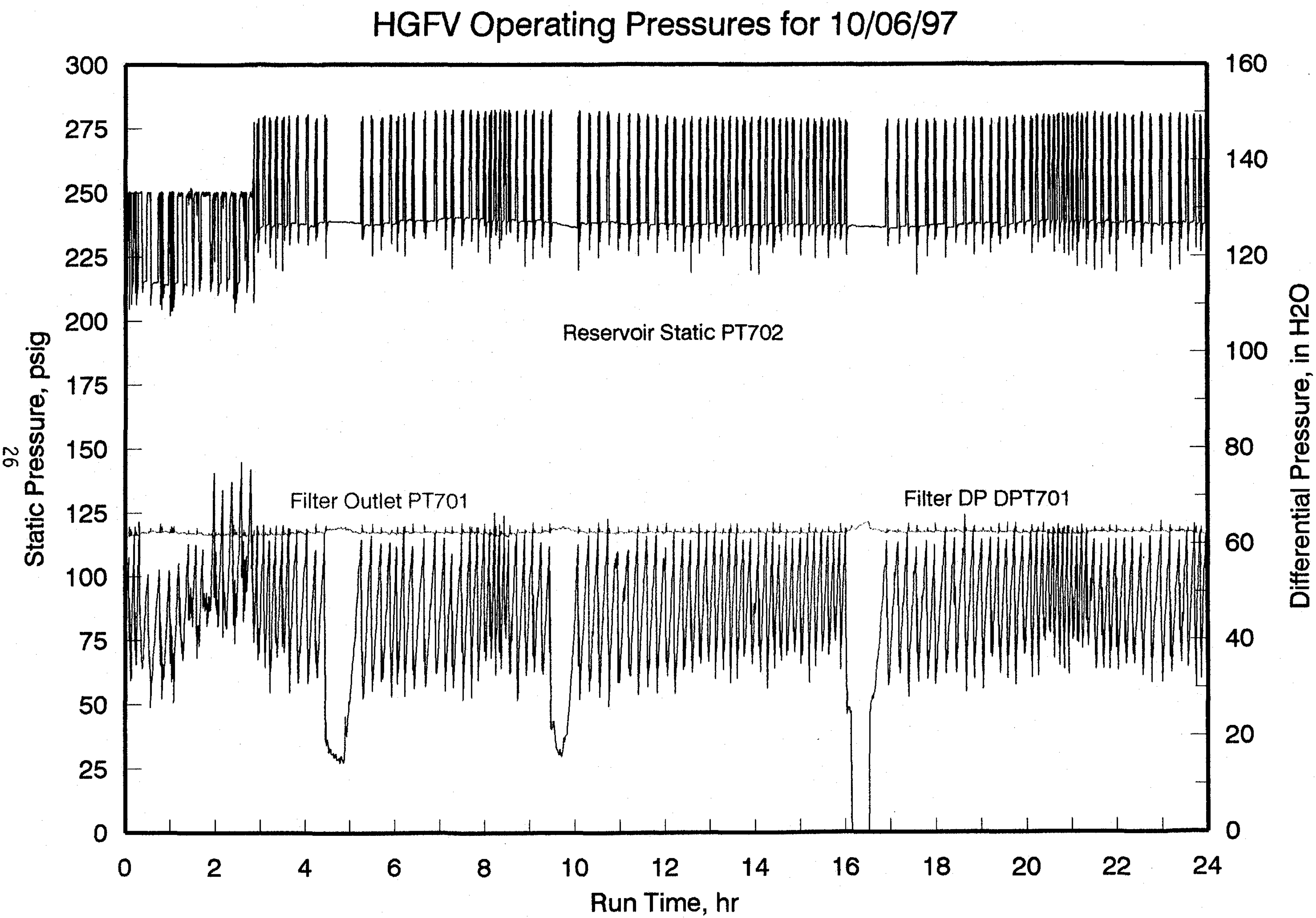

Figure 15. Hot-gas filter vessel pressure profile for 10/06/97.

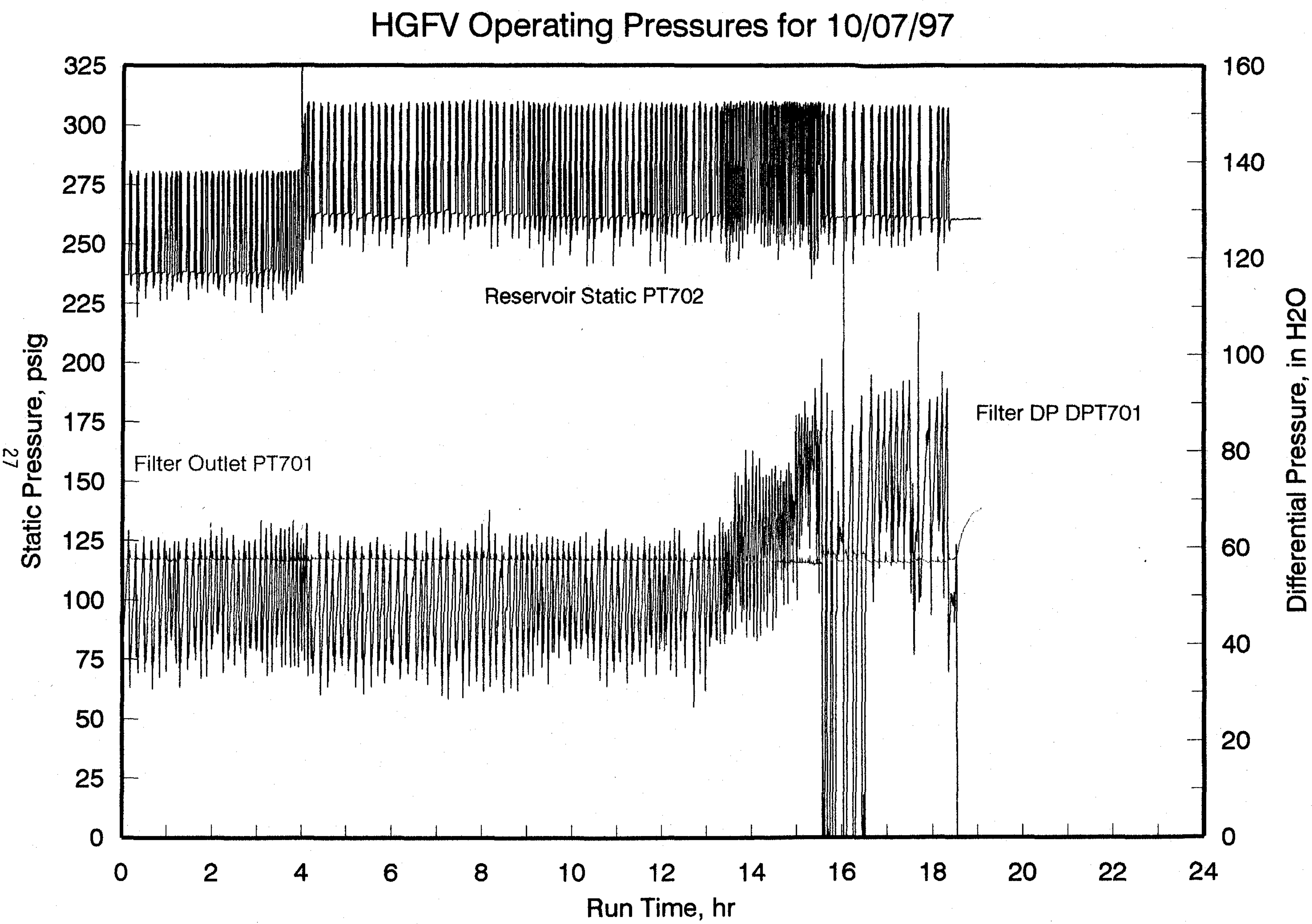

Figure 16. Hot-gas filter vessel pressure profile for 10/07/97.

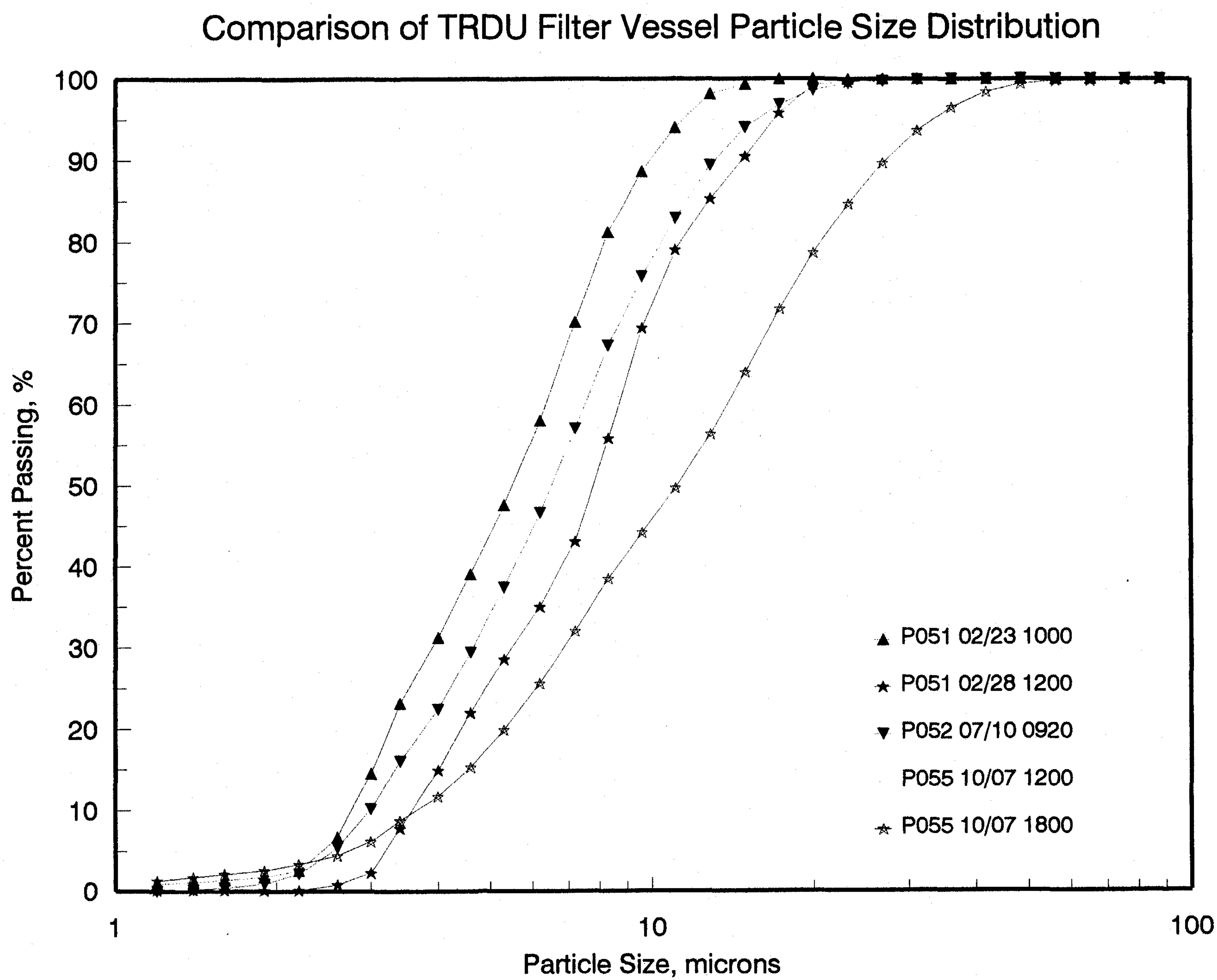

Figure 17. Particle-size distribution of filter ash for Tests P052 and P055.

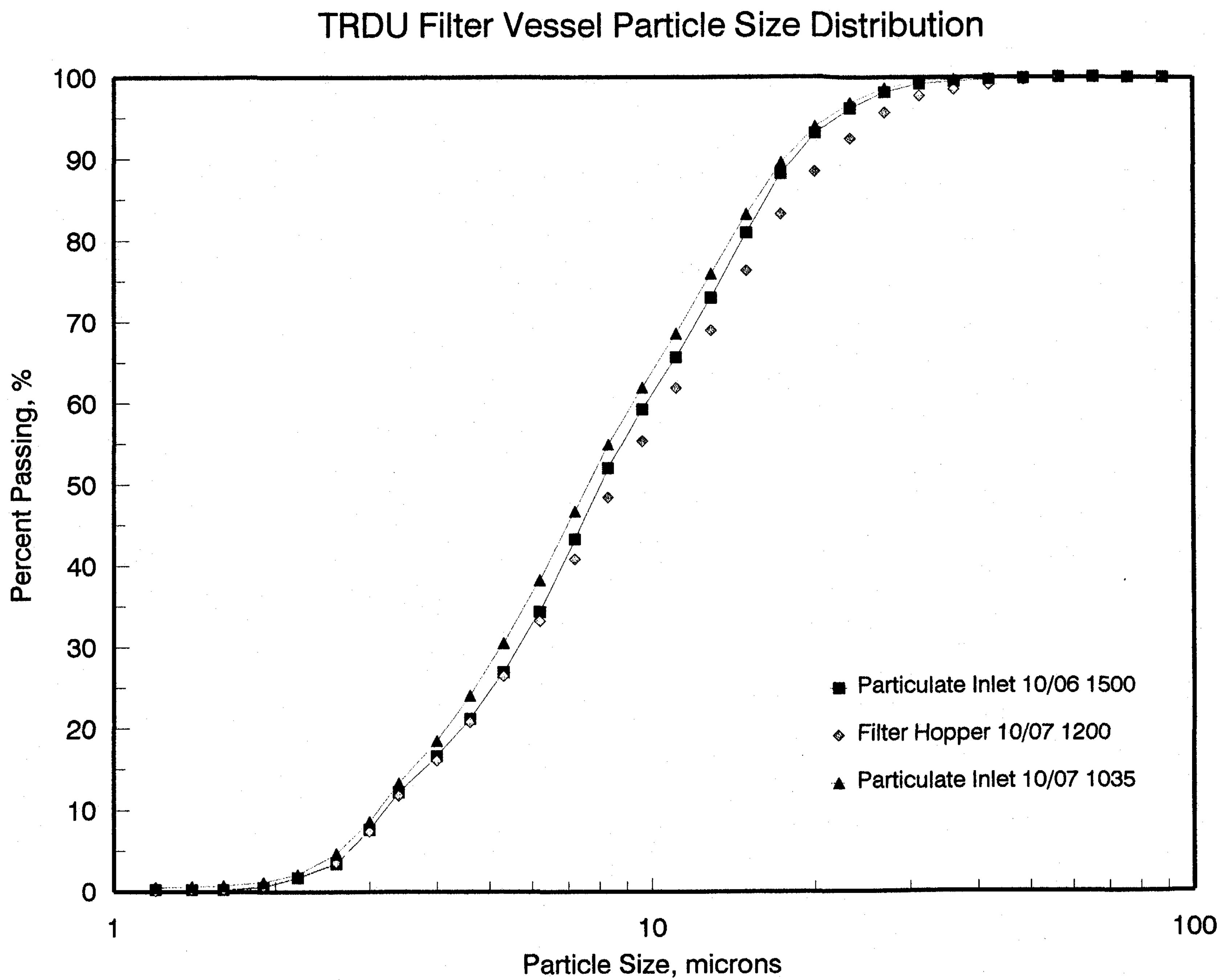

Figure 18. Comparison of filter ash particle-size distribution from Tests P051, P052, and P055.

HGFV Candle Filters P055

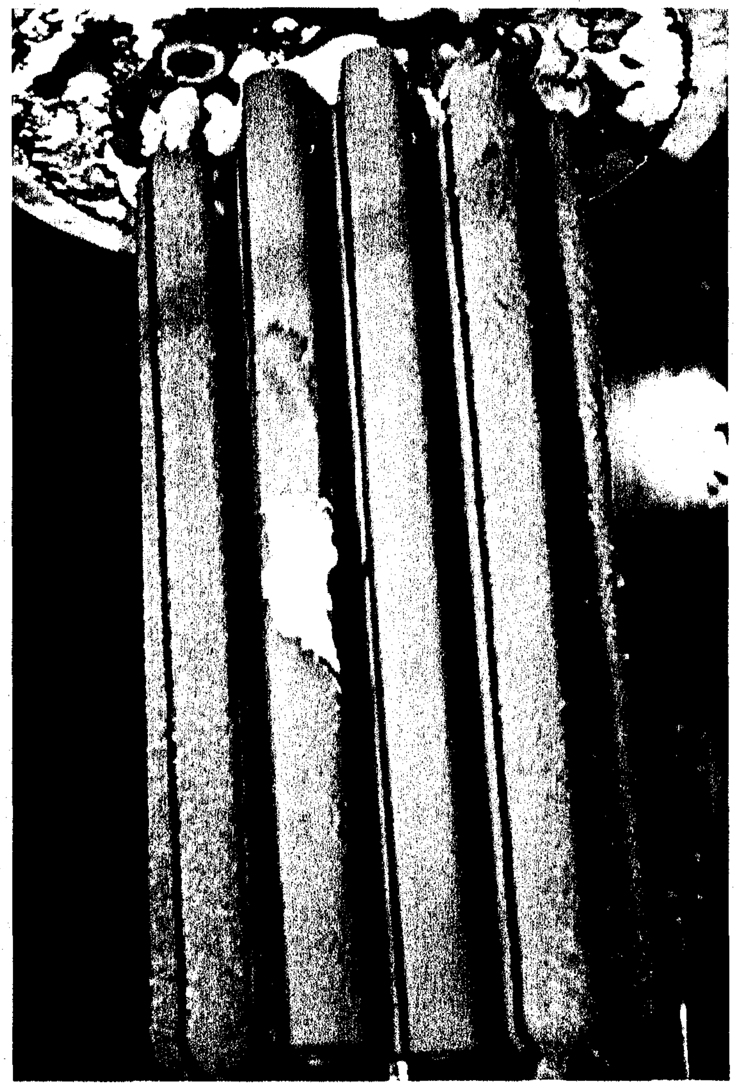

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Figure 19. Photograph of HGFV candles after Test P055.