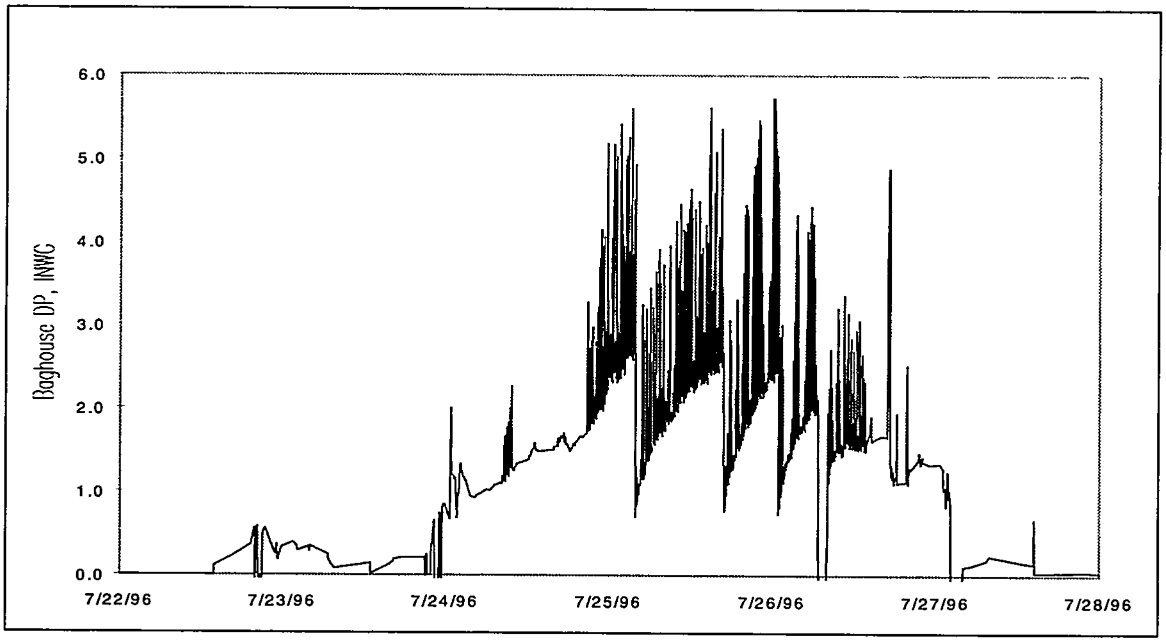

Figure 6.1.6-5 CCT1A Baghouse Differential Pressure

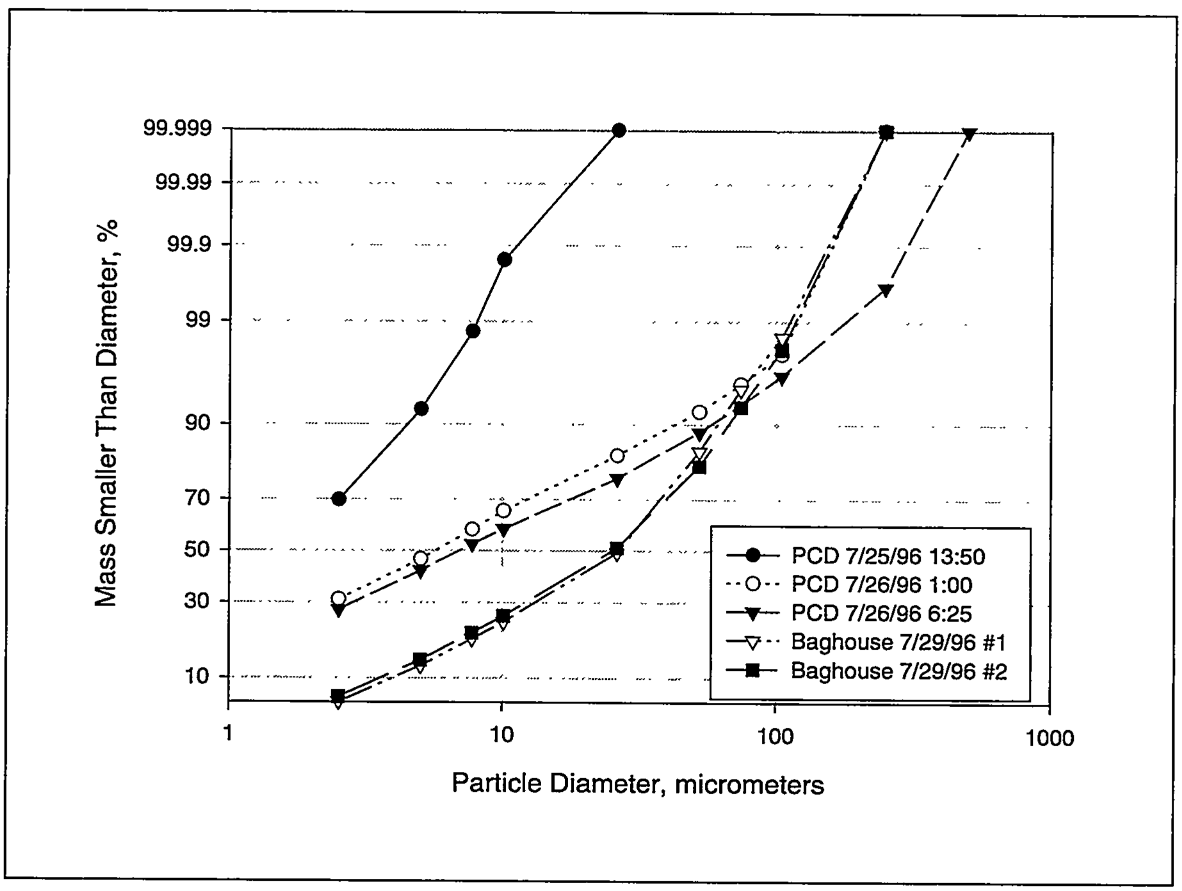

Figure 6.1.6-6 CCT1A PCD Hopper Vs Baghouse Hopper PSD

PSDF\1996\6.1.6

6.1.7 CCT1B Run

6.1.7.1 Summary

CCT1B was the second test run in which the Westinghouse PCD (FL0301) received particulate-laden gas from the transport reactor (TR). The test was short, ending when the pressure letdown valve failed due to erosion of the valve body. Preparations were just being completed to begin feeding coke breeze when the valve failed.

The PCD inadvertently reached a maximum temperature of 665°F when the primary gas cooler swap-over from a gas heater to a gas cooler did not occur at the proper time in the start-up. Once the swap-over was made, the temperature of the filter was about 525°F. The pressure of the PCD varied from 60 to 80 psig, and the face velocity was typically 3.5 to 4.5 ft/min.

The baseline pressure drop was approximately 35 inWG throughout the run. For the first time, solids were recycled from the PCD back to the TR. This had a negative effect on the filter ΔP as the fine material appeared to be quickly carried over from the TR to the PCD. Given time, the PCD would recover from each upset and return to the baseline pressure drop.

Test conditions for this run are listed in tables 6.1.7- and –2. Data from this run are shown in figures 6.1.7-1 and -2.

6.1.7.2 Test Objectives

The primary test objective was to support the TR/PCD start-up activities and gain additional operating experience with the PCD.

6.1.7.3 Observations/Events

A. Start-up Burner Pilot Lit - August 3 at 13:55. After completing the normal start-up activities: pressure testing, balancing pressure transmitters, etc., the TR start-up burner pilot was lit at 13:55.

B. Start-up Burner Main Lit - August 3 at 20:25.

C. TR Solids Circulation Started - August 3 at 22:25.

D. PCD ΔP Transmitters Started - August 3 at 23:00. The PCD ΔP transmitters had been reading zero up to this point in the run. The ΔP transmitters' impulse lines were purged to prevent plugging. The flow rate of the purge gas into each line was controlled with a pair of rotameters. (If the flow of one rotameter is greater than the other, an erroneous ΔP will result.) Upon inspection of the system, it was found that the needle valve on one of the rotameters supplying the purge gas had failed. This was corrected, and once the flows were balanced the transmitters began indicating the correct filter ΔP.

E. Feed of Recycled Solids From PCD to TR Started - August 4 at 08:15. Several times during CCT1A, coke breeze was added to the system in an attempt to run the TR on solid fuel. However, the thermal input from the start-up burner was not sufficient to ignite the coke breeze. Over time, the coke breeze accumulated in the TR as indicated by the solids samples removed from the PCD in CCT1A.

   As part of CCT1B, it was decided to recycle the solids from the PCD ash removal system back to the TR through the sorbent feed system. Apparently, upon recycling, this fine material was carried over to the PCD almost as quickly as it was added. This carryover increased the pressure drop across the PCD.

F. HX0203 Circulation Started - August 4 at 12:30. During start-up, the primary gas cooler is initially used as a gas heater for the PCD. This is accomplished by condensing saturated steam from the steam drum on the shell side of the primary gas cooler. As the gas temperature exiting the TR cyclone approaches the steam drum temperature, the valves are lined up so that the shell side is flooded with hot boiler feed water and the primary gas cooler becomes a steam generator as it cools the process gas from the TR.

   During the CCT1B start-up, this transition was forgotten until the cyclone outlet temperature was about 200 degrees above the saturated steam temperature. It was decided to cool the process gas by both reducing the firing rate of the start-up burner and increasing the solids circulation through HX0203. This increase in solids circulation caused a rise in the PCD differential pressure.

G. Primary Gas Cooler Started - August 4 at 14:20.

H. Recycled Solids From PCD Fed to TR - August 4 From 16:40 to 19:00. From 16:40 to 19:00 several thousand pounds of solids recycled from the PCD were fed into the TR. This had an adverse impact on the filter ΔP as the fines were carried over from the TR to the PCD.

I. Main Air Compressor Tripped - August 4 at 21:25. A cooling water pump tripped causing a trip in the main air compressor. The main air compressor trip caused the start-up burner to trip. Both were restarted by 21:45.

J. TR Solids Circulation Reduction Begun - August 4 at 13:00. From 22:00 until the pressure letdown valve failed at 15:00 on the next day, preparations were made to begin feeding coke breeze. The circulation rate in the TR was reduced so that the temperature in the TR could be maximized. This decrease in circulation allowed the PCD and its ash removal system to recover from the addition of the fine recycled solids.

K. Pressure Letdown Valve Failed - August 5 at 13:00. Preparations were almost complete to begin feeding coke breeze when the pressure letdown valve failed. A hole had eroded in the body of the valve that caused a depressurization of the system. The TR was shutdown and the test ended.

6.1.7.4 Analysis of Solid Samples

No solid samples were taken during the run.

6.1.7.5 Run Outcome

There was a slight rise in the baghouse ΔP during the run as had been seen in CCT1A, but the baghouse did not reach the "trigger" ΔP before the pressure letdown valve failed. Initially, the PCD was thought to be the source of the solids that caused the erosion of the valve body.

Once the valve failed, air was blown through the system for several hours to attempt to remove any remaining alumina in the lines. Also, it was noticed that there was a "puff" of solids out of the valve body every time the coal/sorbent feeder systems fluidized. The vent systems for the feeders enter the main process line upstream of the pressure letdown valve. The vents were inspected and found to be the source of the solids. They were modified and the pressure letdown valve replaced prior to the next run, CCT1C. The PCD was not inspected after this run.

Table 6.1.7-1

CCT1B Run Statistics

Start time	8/3/96 at 13:50
End time	8/5/96 at 15:00
Coal type	No fuel feed to TR
Hours on coal	
Sorbent type	No sorbent feed to TR
TR bed material	Alumina
Number of candles	91
Candle layout no.	1
Filtration area	~265 ft^2
Pulse valve open time	0.2 seconds
Pulse time trigger	30 minutes
Pulse pressure	450 ± 50 psi
Pulse DP trigger	120 inWG

Table 6.1.7-2

CCT1B Major Events (Refer to Figures 6.1.7-1 and -2)

Event	Description	Time
1	Start-up burner pilot lit	8/3/96 at 13:55
2	Start-up burner main lit	8/3/96 at 20:25
3	Solids circulation started	8/3/96 at 22:25
4	PCD ΔP transmitters started	8/3/96 at 23:00
5	Feed of recycled solids from PCD to TR started	8/4/96 at 08:15
6	HX0203 circulation started	8/4/96 at 12:30
7	Primary gas cooler started	8/4/96 at 14:20
8	Recycled solids from PCD fed to TR	8/4/96 at 16:40 to 19:00
9	Main air compressor tripped	8/4/96 at 21:25
10	TR solids circulation reduction begun	8/4/96 at 22:00
11	Pressure letdown valve failed	8/5/96 at 15:00

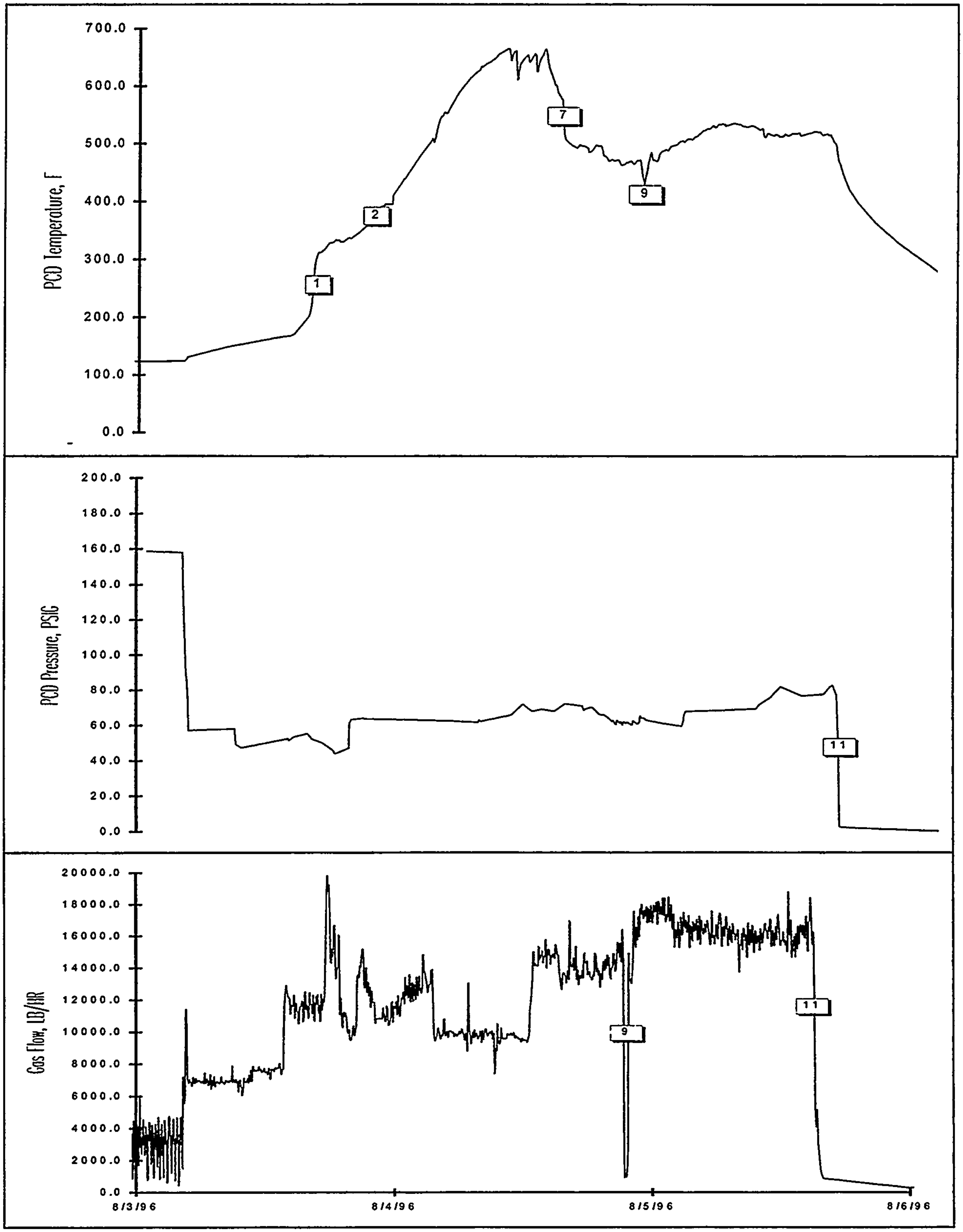

Figure 6.1.7-1 CCT1B Summary Information

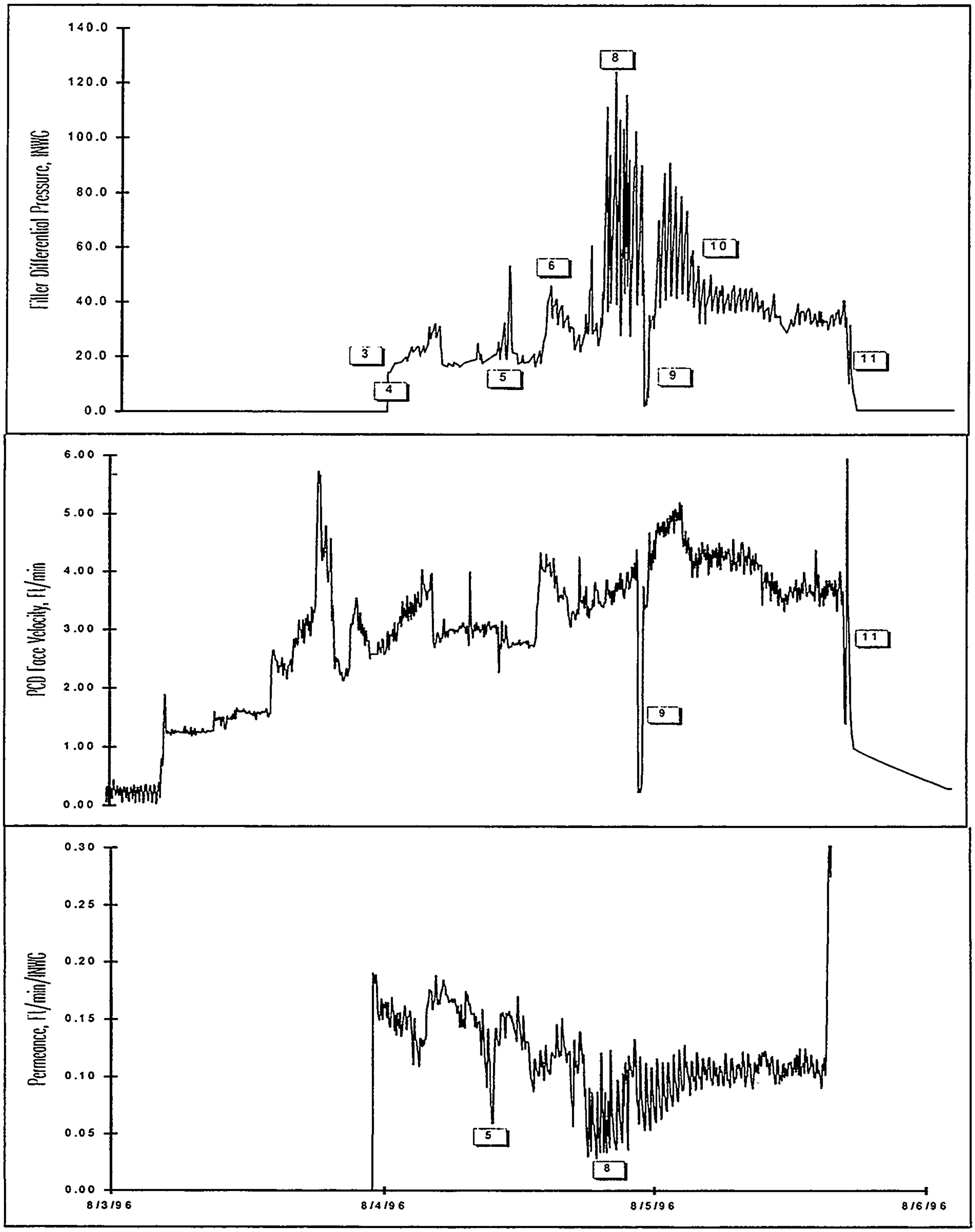

Figure 6.1.7-2 CCT1B Summary Information

6.1.8 CCT1C Run

6.1.8.1 Run Summary

The goal of running the transport reactor (TR) on coal was finally achieved during CCT1C. During the run, the TR operated for approximately 80 hours burning bituminous coal. Dolomite was also successfully fed into the reactor to control the level of SO_2 emissions.

The test run was divided into two parts due to a temporary shutdown to fix start-up burner problems. The initial start-up began at 22:00 on August 14, 1996, and was terminated 3 days later at 18:00 when the start-up burner tripped and could not be relit. Maintenance repaired the burner on August 17 and the second start-up occurred around noon. Since the refractory was already hot, the TR was quickly brought up to temperature and feeding of coke breeze started around midnight. Around 09:00 on August 18 the solids feed was transitioned to coal and the unit operated on coal until the shutdown on August 21.

Prior to coal feeding, there were several incidents where the fines from the PCD were recycled back to the TR. This recycle was first implemented in CCT1B and was continued in CCT1C. The primary reason for the recycle was to attempt to maintain TR bed level. Also, the recycled solids contained a significant amount of coke breeze from run CCT1A. It was believed that recycling these solids and maintaining an inventory of carbon in the TR would aid in the transition from propane firing to operating on solid fuel. However, this recycle of solids had a negative effect on the PCD. Apparently, when recycled material was fed into the reactor the fines were quickly separated from the feed and "carried over" to the PCD. This increased the filter ΔP dramatically, and at times the recycle of fines in this run caused the filter system to be automatically pulse cleaned due to high ΔP every 15 to 20 minutes.

Initially the PCD operated extremely well. While on coal, the filter operating temperature was around 680 to 700°F. The operating pressure (initially around 100 psig) was ultimately raised to 160 psig on August 20. With the increased pressure, the face velocity typically ranged from 2 to 2.5 ft/min. After the transition to coal was complete (and before the PCD began filling with solids) the filter baseline ΔP was around 20 inWG.

During start-up, one of the major areas of concern for the PCD team had been the use of thermocouples to monitor solids level in the PCD cone. The group monitoring the PCD had no experience from previous projects to draw on, and the experience gained during CCT1A and CCT1B was limited. This lack of experience became apparent as the PCD filled with solids (unnoticed) during this test run.

Shortly after the transition to coal, solids began accumulating in the PCD cone at a rate much higher than anticipated. Within 2 1/2 hours after coal feed started, the PCD cone was essentially full. However, if the magnitude of the problem had been realized, there would have been adequate time to recover because the filter elements were not covered with ash until about 40 hours after initial coal feed.

Once the run was terminated on August 21 the ash removal system continued to run through August 23. At that point, the screw cooler motor tripped because a ceramic filter element was broken by the metal screw. The screw cooler was restarted and continued to run until the ash removal system conveying line plugged with pieces of ceramic filter. In total, 77 of the 91 filter elements were broken (probably due to the mechanical load of the ash on the filter elements).

In spite of the magnitude of the breakage, there were many positive outcomes and lessons learned.

- This experience forced an intense review of the ash level thermocouple data from runs CCT1A through C and a review of operating procedures for the PCD and ash handling system. A commitment was made that CCT2A would not begin until the ash level could be reliably determined. During runs CCT2A through C the particulate loading was high, but the engineers and the operators had learned how to accurately determine the presence of ash in the filter cone. Additional thermocouples were added to the PCD after CCT3 to better define the level of the ash in the cone.

- In spite of the fact that 85 percent of the filter elements were broken, there was no significant accumulation of ash in the atmospheric baghouse or on the clean side of the PCD tubesheet. The pressure letdown valve (which had eroded due to the presence of solids in previous runs) was inspected and found to be undamaged. This absence of ash downstream of the PCD was due to the successful plugging of the Westinghouse failsafe devices. The failsafes from the broken elements were found to be completely plugged with ash, as designed.

- The filter elements used in CCT1A through C were used filter elements from Tidd. Because these elements were used, there was little impact to the project in capital cost. There were insufficient used elements to recandle the PCD system, so it was recandled with new filter elements.

Test conditions for this run are listed in tables 6.1.8-1 and -2. Data from this run are shown in figures 6.1.8-1 through -4.

6.1.8.2 Test Objectives

The primary test objective was to support the TR/PCD start-up activities and gain additional operating experience with the PCD.

6.1.8.3 Observations/Events

A. Main Air Compressor Flow to Reactor Started - August 14 at 22:00.

B. Start-up Burner Pilot Lit - August 15 at 09:20.

C. Start-up Burner Main Lit - August 15 at 10:30.

D. TR Solids Circulation Started - August 15 at 10:50. As seen in test runs CCT1A and CCT1B, there is typically a rise in the PCD ΔP whenever circulation is started in the TR.

E. Recycled PCD Solids Feed to TR Started - August 15 at 13:11. Approximately 2,700 lb of "recycled" alumina from the previous runs were fed into the TR through the coal and sorbent feed system over 6 hours. The fine material in the alumina was rapidly carried over to the PCD causing a rapid increase in the filter ΔP. The filter ΔP would rise from its baseline of about 40 inWG to the pulse trigger ΔP of 120 inWG in approximately 15 to 20 minutes.

   Recycled solids were also fed into the TR several times on August 16. The feed rate of solids into the reactor was small compared to the feed rate on August 15, however, there were sufficient fines present to cause an increase in the filter ΔP.

F. Solids Feed Stopped - August 15 at 19:00. Once the solids feed stopped, the PCD began to recover and the interval between pulses returned to 30 minutes. This pattern was also repeated on August 16. Given enough time, the filter ΔP returned to its baseline and the interval between pulse cleanings returned to 30 minutes.

G. TR Solids Circulation Reduced - August 15 at 20:40. The TR circulation rate was decreased in order to increase the reactor temperatures in preparation for burning coke breeze.

H. Coke Breeze Feed Started - August 16 at 13:50. After resolving problems with the coal feed system, coke breeze was batch fed into the TR. Coke breeze was batch fed at various intervals until the start-up burner tripped and the unit was shutdown.

I. Start-up Burner Tripped - Temporary Shutdown - August 16 at 18:00. The mechanics were called out and the burner was replaced. The TR was down until 12:00 on August 17.

J. Main Air Compressor Restarted - August 17 at 12:00.

K. TR Leak Test - August 17 at 12:00. The TR was leak tested to 200 psig before beginning the test to insure that the burner flange did not leak.

L. Start-Up Burner Pilot Lit - August 17 at 15:30.

M. Start-Up Burner Main Lit - August 17 at 16:00.

N. Recycled PCD Solids Feed to TR Started - August 17 at 17:00. Approximately 1,000 lb of recycled solids were fed into the TR through the sorbent system. Solids were continuously being recycled from the ash removal system back to the sorbent feed system. This recycle continued until the sorbent feed system began feeding dolomite at 12:40 on August 18.

O. Coke Breeze Feed Started - August 18 at Midnight. Since the refractory was already hot, the TR temperature was increased fairly quickly. Therefore, the TR was ready for coke breeze feed about 12 hours after the second start-up. By 05:00 the temperature in the TR riser was almost 1,500°F. At 08:40 coal was loaded into the coal feeder.

P. Coal Feed Started - August 18 at ~09:00. Around 09:00 the coke breeze inventory in the coal feeder had emptied and the TR was operating for the first time on coal feed.

Q. PCD Cone Began Filling With Ash - August 18 at 09:00. About the same time as coal feed began in the TR, ash began accumulating in the lower portion of the PCD cone (figure 6.1.8-5). The thermocouples in the bottom of the PCD cone appear to show that the cone was empty prior to this time.

(Figures 6.1.8-5 through -10 provide a representation of the ash level at various times based on analysis of the PCD instrumentation. These figures are not meant to imply that the ash level is uniform, they are only to convey the approximate levels indicated by the instruments.)

R. HX0203 Circulation Increased - August 18 at 10:45. The temperature in the TR began increasing, so the circulation rate through the combustion heat exchanger was increased to provide cooling. It is speculated that this increase in circulation rate caused an increase in the carryover of particulate to the PCD.

S. PCD Cone Filled With Ash - August 18 at 11:30. The ash level in the PCD cone reached the upper thermocouple that is located at the same elevation as the lower manway (figure 6.1.8-6). The difference in volume between the two thermocouples is 33 ft^3. The bulk density of the ash samples taken throughout this run was around 65 lb/ft^3, so the approximate accumulation of ash in the PCD cone was 800 lb/hr. The ash removal system was operational throughout this time. However, the speed of the removal screw was set at 3 rpm instead of the maximum speed of 8 rpm. This was not changed until the last day of the run. The gas flow at the time was around 14,000 lb/hr. At a design maximum loading of 16,000 ppm, the maximum solids carryover to the PCD would have been 225 lb/hr.

There is evidence that the PCD cone "rat holes" when rapidly filled with solids, but there is no evidence that the PCD cone bridged during this run. The thermocouples used for level indication only extended into the cone about 2 to 3 inches. These thermocouples were covered from 11:30 on August 18 until the remainder of the run. The temperature decreased, indicating that there was little flow of hot solids past the thermocouple and cooling was occurring. Another thermocouple in the transition piece between the outlet flange of the PCD and the inlet to the screw cooler increased until a "steady state" temperature of about 450°F was reached, some 150 to 200°F above the temperature reading of the cone thermocouples.

There is no evidence that the PCD cone "bridged" with ash during the run. The PCD ash removal lockhopper does not cycle until the level probe is covered (i.e., there is no cycle timer). The screw cooler continued to operate at 3 rpm until 17:00 on August 21. The lockhopper was cycling at a regular interval throughout this time period. If the cone had bridged, the lockhopper would have stopped cycling. Ultimately the screw cooler speed was increased to 8 rpm on August 21 and 22. There was a corresponding increase in lockhopper cycle frequency with the increase in screw cooler speed.

T. Dolomite Feed Begun - August 18 at 12:40. Dolomite was transferred to the sorbent feed system at 12:40 on August 18. Initially the dolomite was added for SO_2 control. The solids level in the TR had substantially lowered, so dolomite was added continuously from August 18 until the end of the run in an attempt to raise the level in the TR standpipe.

U. Reactor Pressure Raised - August 18 at 19:00. The TR pressure was raised to reduce the riser velocity. Raising the pressure decreased the face velocity, and as a result the filter ΔP was reduced.

V. PCD Lower Shroud Filled With Ash - August 19 at 03:45. Around 03:45 on August 19 the solids reached the level of a thermocouple which measures the gas temperature in the shroud. This thermocouple is located roughly halfway between the top and bottom of the filter elements on the lower level (figure 6.1.8-7).

Apparently there was a solids "seal" between the bottom of the shroud and the ash accumulating in the PCD cone. This may be caused by the geometry of the tangential gas inlet. Some solids are "knocked out" by the cyclonic action of the gas inlet and settle to the bottom cone without reaching the filter elements. Additional data to support this conclusion was gathered during runs CCT2A through C. In figure 6.1.8-7, the ash level is drawn uniformly in the shroud, but there is no evidence to support this. In actuality, it is probably much higher on one side than the other due to the flow patterns in the shroud.

At the time that this thermocouple began indicating the presence of solids, there was no indication that ash was beginning to cover the filter elements. In fact, the elements did not begin to cover with ash until 24 hours later. One can only assume that there was a "pocket" below the filter elements that filled with ash over the next 24 hours.

W. Lower Level of Filters Began to Cover - August 20 at ~04:00. Starting at about 04:00 on August 20 the lower level of filter elements began to be covered with ash (figure 6.1.8-8). This is apparent on the graph "Filter Differential Pressure" in figure 6.1.8-4. The rise in filter ΔP shown between events 23 to 24 is due to the covering of the filter elements with ash. The "face velocity" graph (also in figure 6.1.8-4) indicates that the face velocity was essentially constant during this period, so the rise in ΔP was due to a loss of active filter surface area.

Analysis of other Westinghouse proprietary instrumentation following the run clearly indicated that this rise in filter ΔP was due to burying of the lower level of filter elements.

X. Lower Level of Filters Covered - August 20 at ~16:00. The filter ΔP reached a "steady state" at a baseline of about 65 inWG. It is assumed that this indicates that the lower tier of filter elements was covered (figure 6.1.8-9).

Y. Pressure Letdown Valve Positioner Arm Broken - August 20 at 22:40. At 22:40 the positioner arm on the pressure letdown valve broke. This caused the pressure and temperature in the PCD to swing wildly. The valve was placed in manual, and manually "jacked" open. Once the valve was repaired by E&I, operation was continued.

Z. Upper Level of Filters Began to Cover - August 21 at 12:00. Starting around 12:00 on August 21 the upper level of filter elements began to be covered with ash (figure 6.1.8-10). The thermocouple located in the nozzle opposite the gas inlet that measures the gas temperature near the filter elements began to increase as the thermocouple began covering with ash. This created significant deviations between its reading and the gas inlet temperature. Additionally, the filter ΔP began rising again as the remaining surface area was covered with ash.

AA. System Shutdown Due to High Filter ΔP - August 21 at 19:00. The filter ΔP began rising uncontrollably until the interval between pulses reached 2 minutes. At that point, the decision was made to shutdown. Air was left blowing through the system on August 22 with the ash removal system continuing to remove particulate. On August 23 the screw cooler tripped when the remnants of a filter element entered the flights of the screw. The screw was restarted, but ultimately the ash conveying system discharge line plugged with broken filter element pieces. To avoid possible damage to the screw cooler, the ash removal system was shutdown.

6.1.8.4 Analysis of Solid Samples

Because of the accumulation of ash in the PCD, it is important to realize that the sample times do not reflect the time the ash was generated. Therefore, it is not possible to draw accurate conclusions to specific events that occurred in the TR with data generated from the ash samples taken from the PCD cone. However, some general remarks can be made.

Typically, the mass median particle diameter for the ash samples varied between 6 and 10 micrometers as measured by the Microtrak. One exception was the ash sample taken on the afternoon of August 20 that had a mass mean particle diameter of 15 micrometers (figure 6.1.8-11). The particle size distributions shown in figure 6.1.8-12 indicate that for the most part, the distribution of the particles was almost the same. Again, the distributions taken on August 20 are the exceptions to this trend.

The ash samples taken after combustion were sustained and were gray in color. Typical LOI values taken for these samples ranged from 8 to 11 percent. The chemical analysis of the major constituents of the ash (alumina, calcium, magnesium, silicon, and iron) is presented in figure 6.1.8-13. Again, it is not possible to correlate the samples to exact changes in the TR because of accumulation of ash in the PCD. However, the general trend shows that the concentration of calcium and magnesium in the ash was increasing with time while the concentration of alumina in the ash was decreasing. This probably reflects the addition of dolomite to the TR to make up for the loss of bed level (refer to event 20). The analysis of the coal ash and sorbent are added to the figure for comparison.

6.1.8.5 Run Outcome

On August 23 the PCD ash removal system plugged with ceramic filter parts. Due to inclement weather, the filter system was not disassembled until August 30. The area above the tubesheet was inspected early in the week and an insignificant quantity of dust was found. The entire surface was covered with a "dusting" of ash, but the layer was so thin it could not be measured. There were no "piles" of ash present on the tubesheet.

When the tubesheet/plenum was removed, it was discovered that 77 of the 91 filter elements were broken in the locations dipicted in figure 6.1.8-14. All but one of the filter elements in the lower level was broken and 23 of the 36 elements in the top level were broken. The broken filter elements and a significant quantity of ash were still in the PCD cone. These were removed with a vacuum truck once the tubesheet/plenum was moved to the maintenance bay. These remaining elements (and element pieces) were removed and replaced with new filters during the week of September 2.

Due to the large number (85 percent) of filter elements broken and the thin layer of ash on the tubesheet, the Westinghouse failsafes operated better than expected. When the filter elements were removed, the failsafes of the broken elements were found to be completely plugged with ash.

An intense review of the operating data from CCT1A through C took place over the next several weeks. Westinghouse personnel visited the job site to aid in this review. From this analysis, the following conclusions and changes to operating procedures were determined:

- Determining the ash level at various times by reviewing the various PCD instrumentation became fairly obvious with the knowledge that the PCD had been filled with ash during the run. A strategy was developed for determining the ash level based on PCD instrumentation as well as using the instrumentation for the PCD ash removal system. This strategy has worked very well, and there have been no incidents of ash filling the PCD cone during runs CCT2A through CCT3.

- As mentioned in section 4.0 (event 19) of this report the ash removal screw cooler was operating at only 37 percent of its design speed. The only explanation for this event is that throughout start-up, the screw cooler was arbitrarily set to operate at 3 rpm. This carried over into the test runs and was the initial condition for CCT1C. Short of consciously trying to maintain a level in the PCD cone, there is no reason for running the screw cooler at less than maximum speed. Therefore, this has become the "standard" operating procedure for this system. A design change was also made to the screw cooler prior to CCT2A that allows it to operate at almost 12 rpm.

- In runs CCT1B and CCT1C it became apparent that recycling the fine material from the PCD back to the TR had a negative impact on filter operation. Therefore, it was decided that under normal operating conditions this material would not be recycled.

- It was also decided that if the thermocouple at the top of the PCD cone appeared to be covered with ash, solids feed to the TR would be reduced. If the ash level could not be reduced within 1 to 2 hours, shutdown would begin. This should help prevent the possibility of breaking filter elements since, at least in this run, the time between filling the cone and covering the elements with ash was about 36 hours.

- Finally, it was decided that any major transition in operation would not occur before the PCD cone was empty. For example, operations would not feed coke breeze or coal for the first time to the TR if the PCD cone contained solids.

Even though the outcome of this test run was "painful" for all involved, it has become a very valuable learning experience. During runs CCT2A through C, additional experience and confidence was gained in determining the ash level using the existing PCD instrumentation. This experience in monitoring the level has been useful to the MWK Team as they have worked to resolve the issues leading to the appreciable carryover of particulate to the PCD.

Table 6.1.8-1

CCT1C Run Statistics

Start time	8/14/96 at 22:00
End time	8/21/96 at 19:00
Coal type	Calumet mine Alabama bituminous
Hours on coal	~80
Sorbent type	Plum run dolomite
TR bed material	Alumina
Number of candles	91
Candle layout no.	1
Filtration area	~265 ft^2
Pulse valve open time	0.2 seconds
Pulse time trigger	30 minutes
Pulse pressure	Variable
Pulse DP trigger	120 inWG

Table 6.1.8-2

CCT1C Major Events (Refer to Figures 6.1.8-1 and -2)

Event	Description	Time
1	Main air compressor flow to reactor started	8/14/96 at 22:00
2	Start-up burner pilot lit	8/15/96 at 09:20
3	Start-up burner main lit	8/15/96 at 10:30
4	TR solids circulation started	8/15/96 at 10:50
5	Recycled PCD solids feed to TR started	8/15/96 at 13:11
6	Solids feed stopped	8/15/96 at 19:00
7	TR solids circulation reduced	8/15/96 at 20:40
8	Coke breeze feed started	8/16/96 at 13:50
9	Start-up burner tripped - temporary shutdown	8/16/96 at 18:00
10	Main air compressor restarted	8/17/96 at 12:00
11	TR leak test	8/17/96 at 12:00
12	Start-up burner pilot lit	8/17/96 at 15:30
13	Start-up burner main lit	8/17/96 at 16:00
14	Recycled PCD solids feed to TR started	8/17/96 at 17:00
15	Coke breeze feed started	8/18/96 at 00:00
16	Coal feed started	8/18/96 at ~09:00
17	PCD cone began filling with ash	8/18/96 at 09:00
18	HX0203 circulation increased	8/18/96 at 10:45
19	PCD cone filled with ash	8/18/96 at 11:30
20	Dolomite feed begun	8/18/96 at 12:40
21	Reactor pressure raised	8/18/96 at 19:00
22	PCD lower shroud filled with ash	8/19/96 at 03:45
23	Lower level of filters began to cover	8/20/96 at ~04:00
24	Lower level of filters covered	8/20/96 at ~16:00
25	Pressure letdown valve positioner arm broken	8/20/96 at 22:40
26	Upper level of filters began to cover	8/21/96 at 12:00
27	System shut down due to high filter ΔP	8/21/96 at 19:00

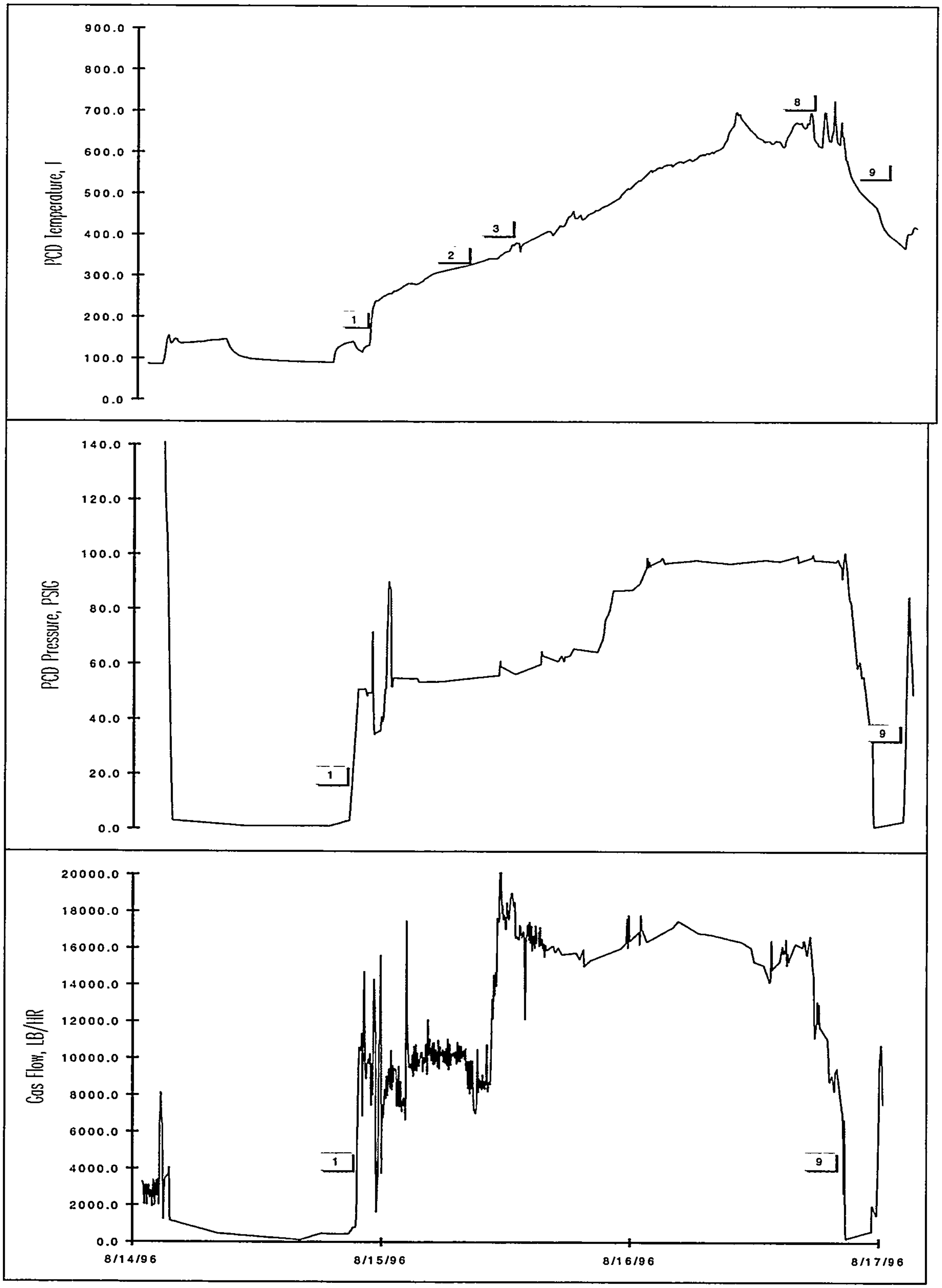

Figure 6.1.8-1 CCT1C Summary Information

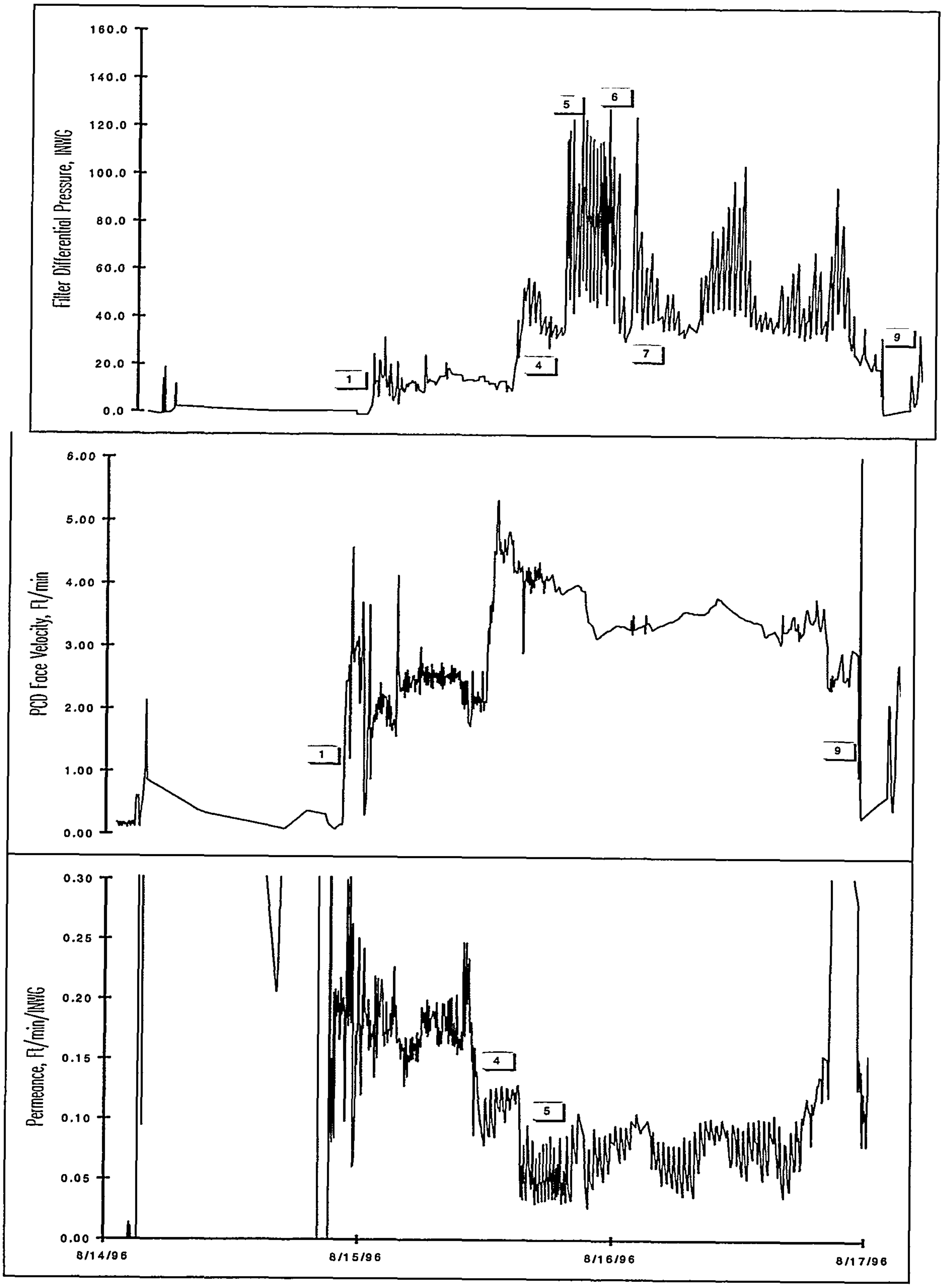

Figure 6.1.8-2 CCT1C Summary Information

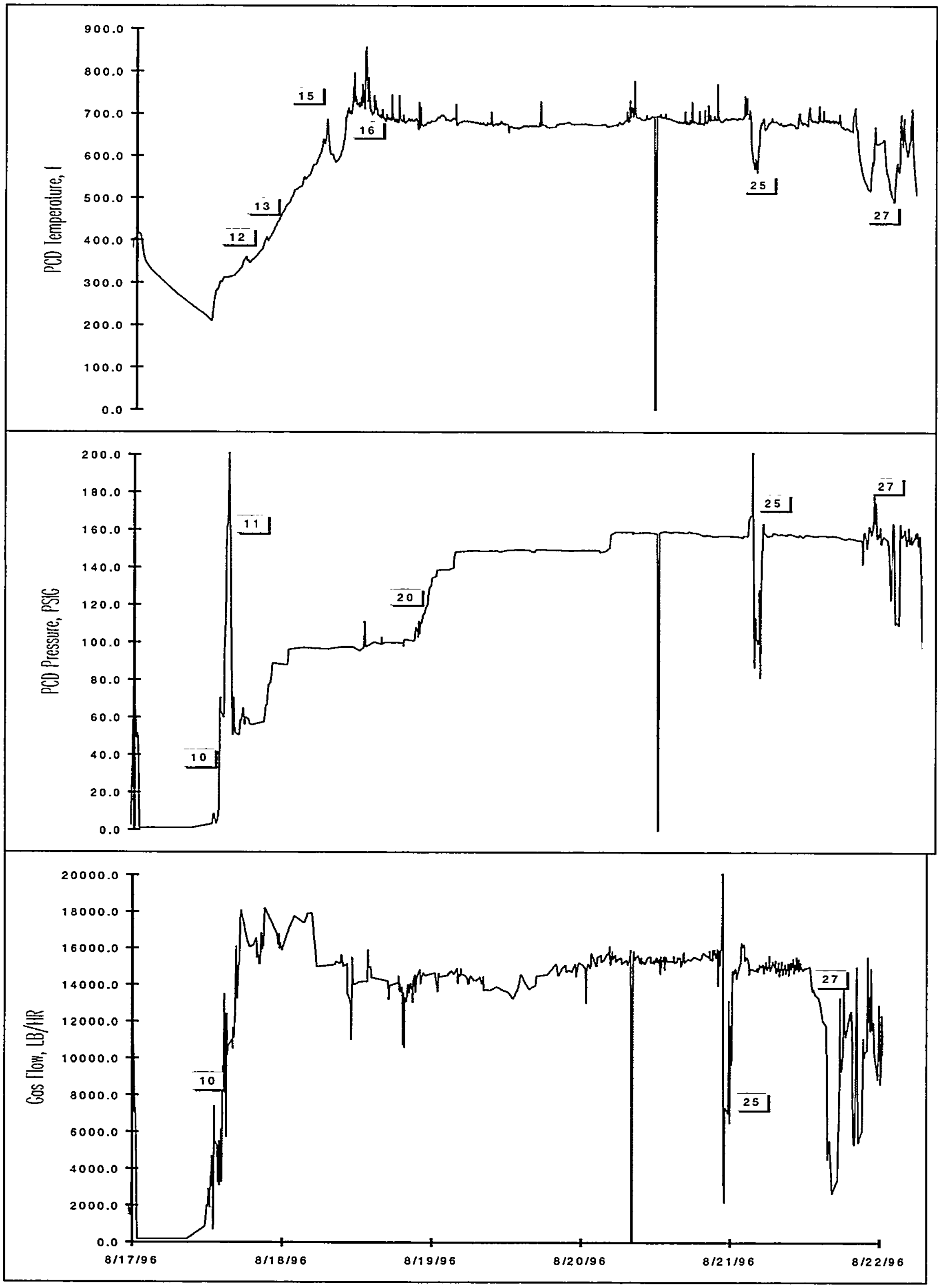

Figure 6.1.8-3 CCT1C Summary Information

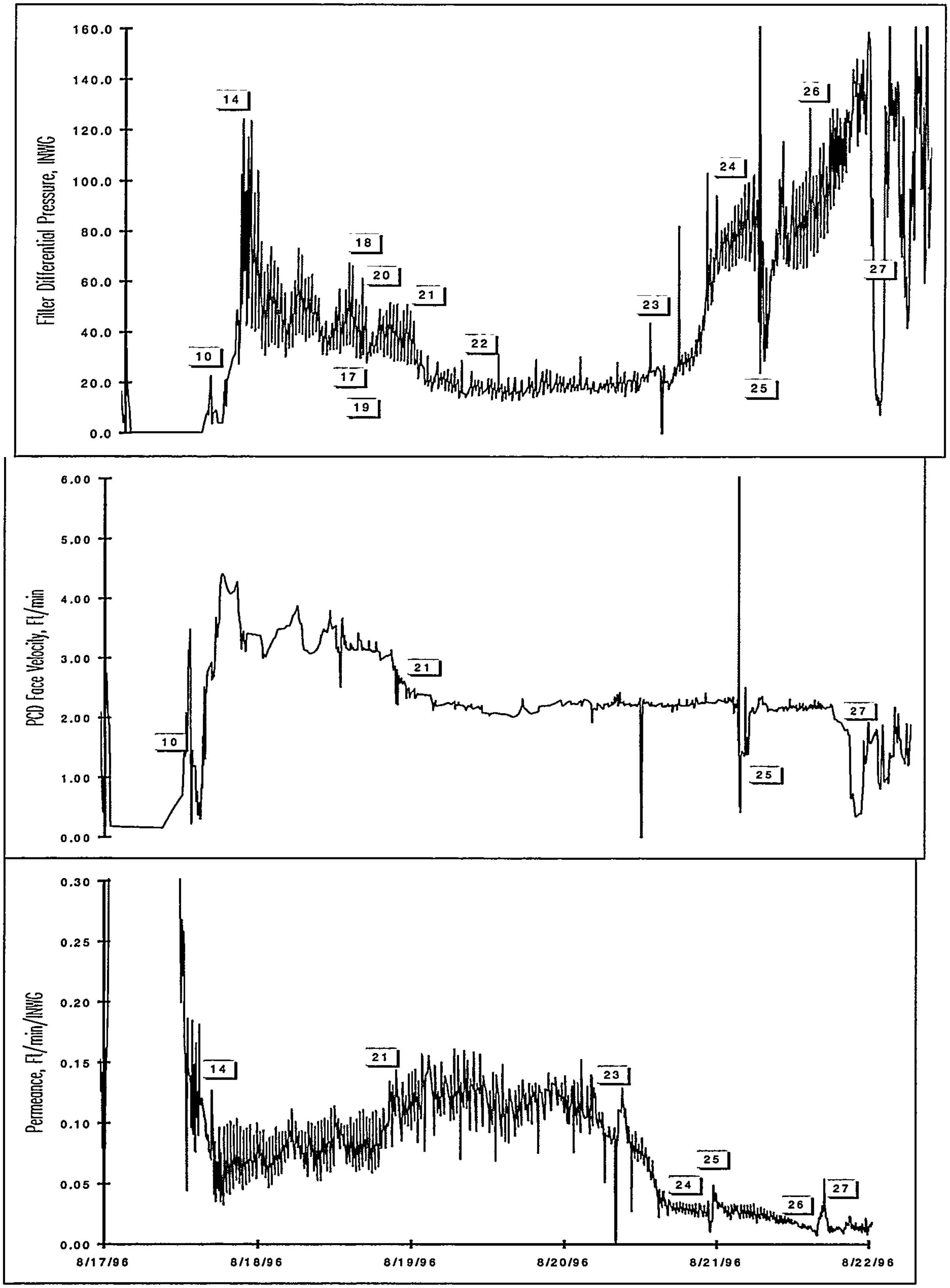

Figure 6.1.8-4 CCT1C Summary Information

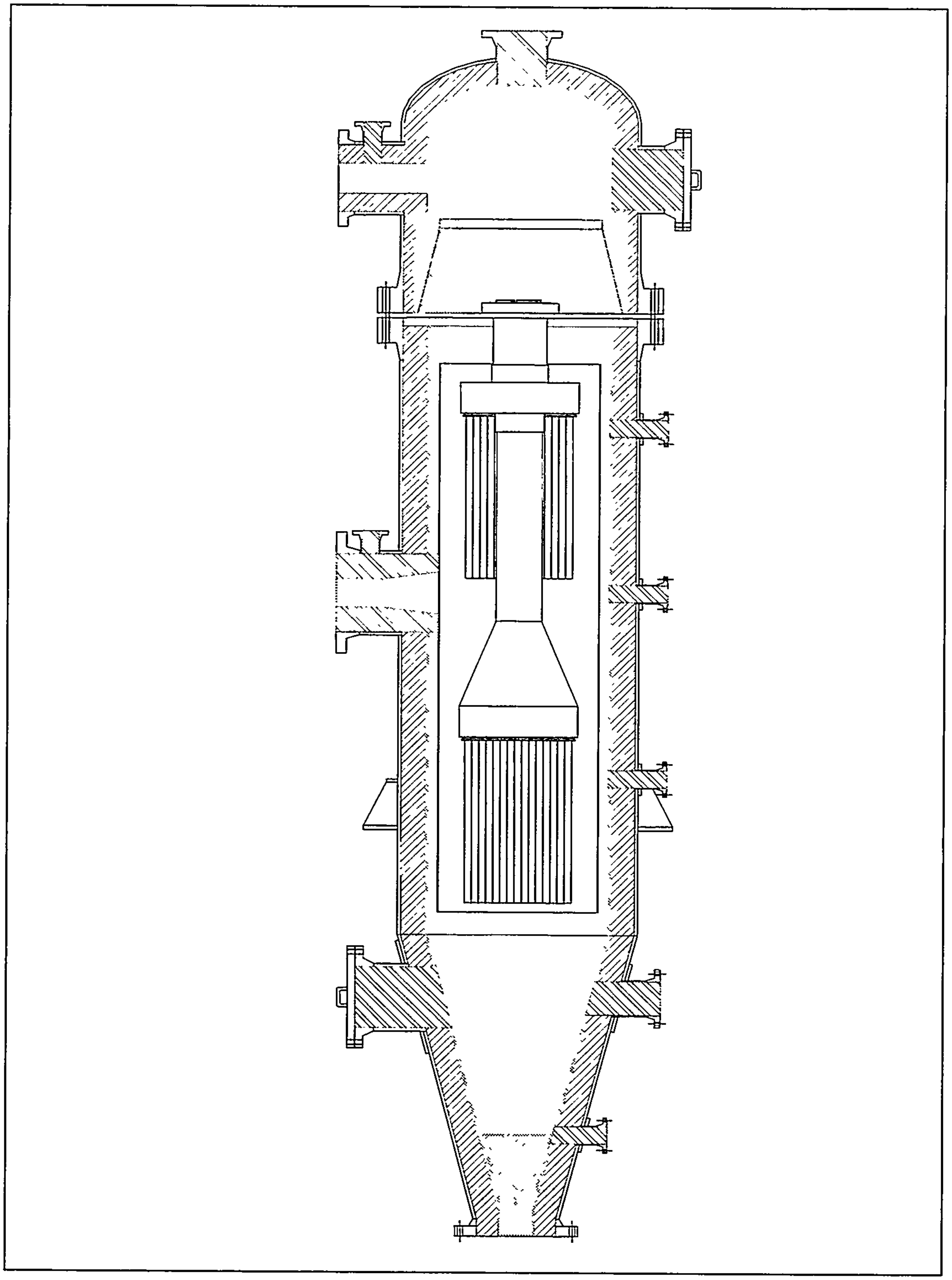

Figure 6.1.8-5 Approximate Ash Level on August 18 at 09:00

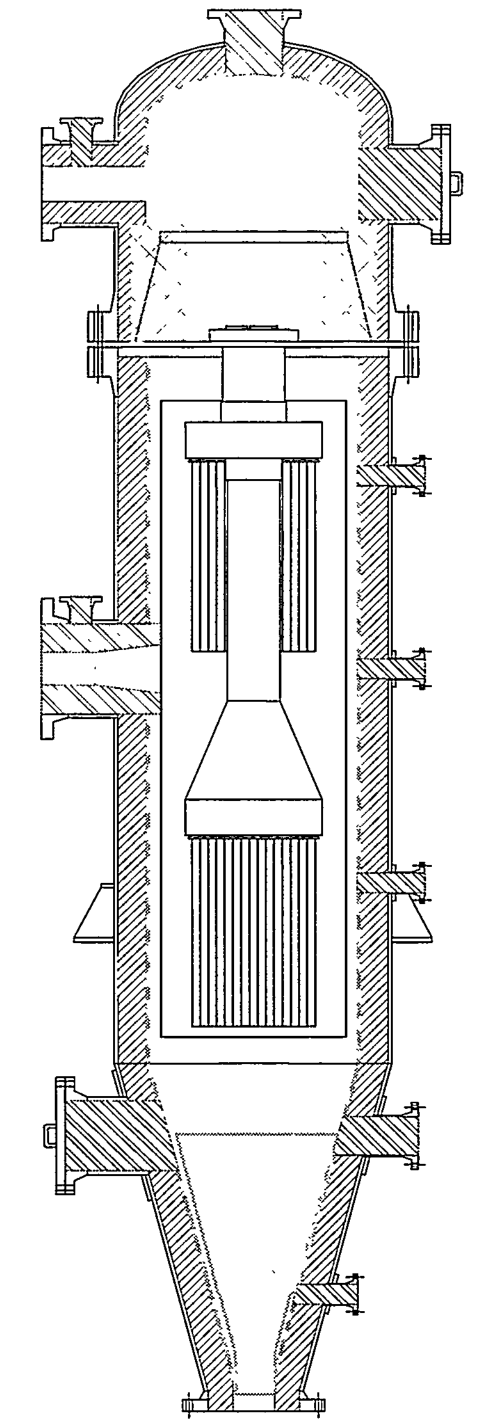

Figure 6.1.8-6 Approximate Ash Level on August 18 at 11:30

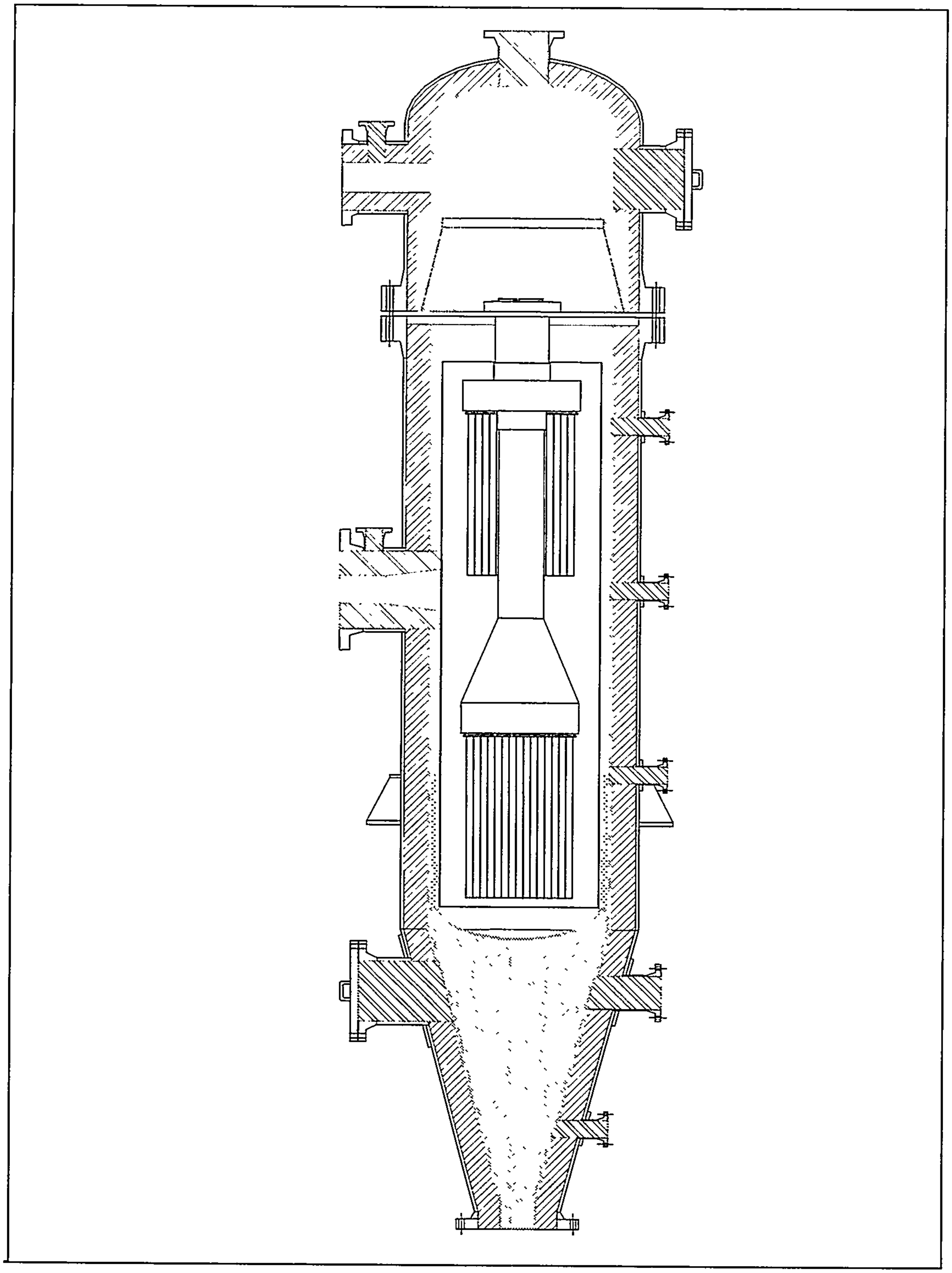

Figure 6.1.8-7 Approximate Ash Level on August 19 at 03:45

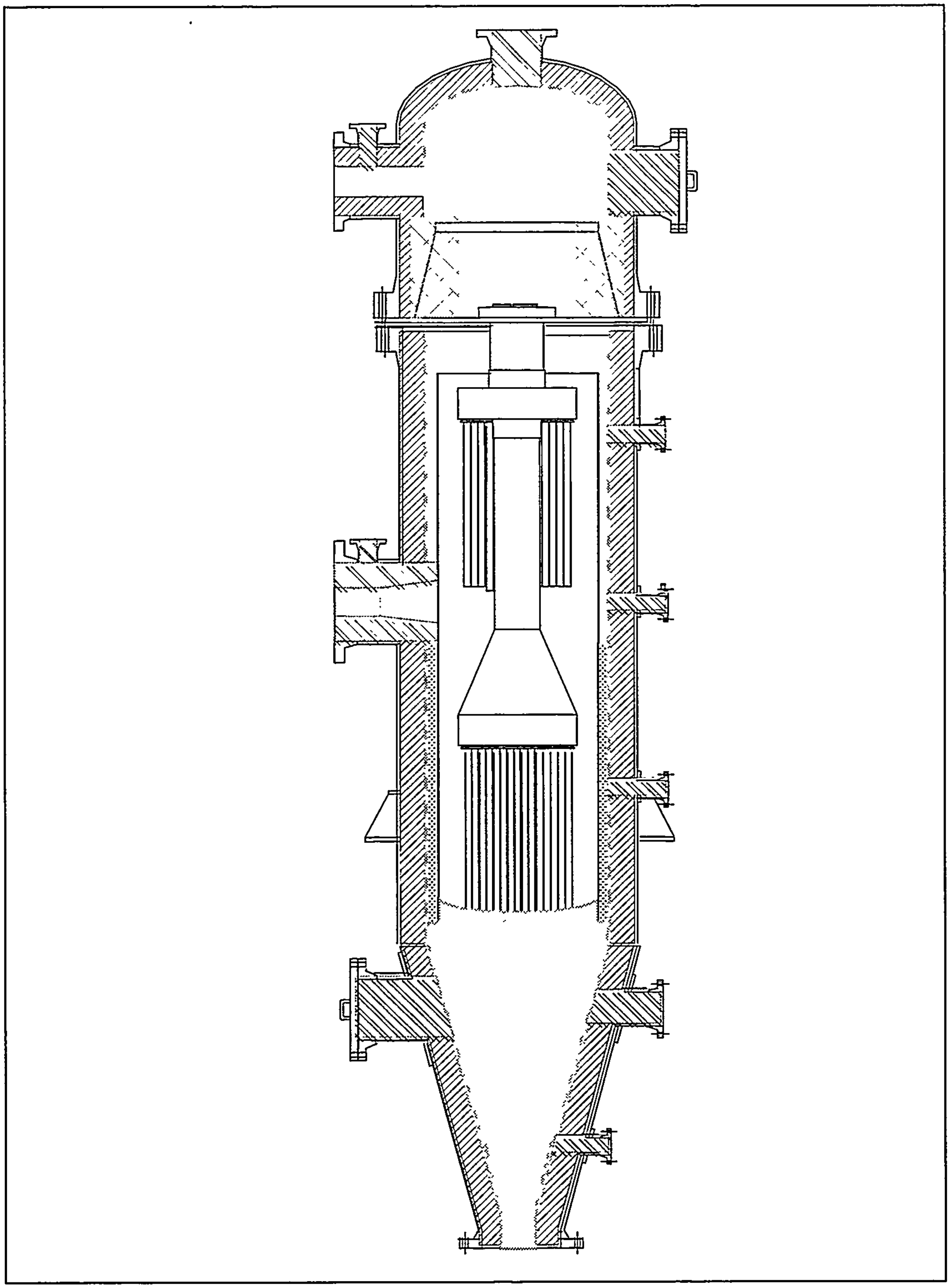

Figure 6.1.8-8 Approximate Ash Level on August 20 at ~04:00

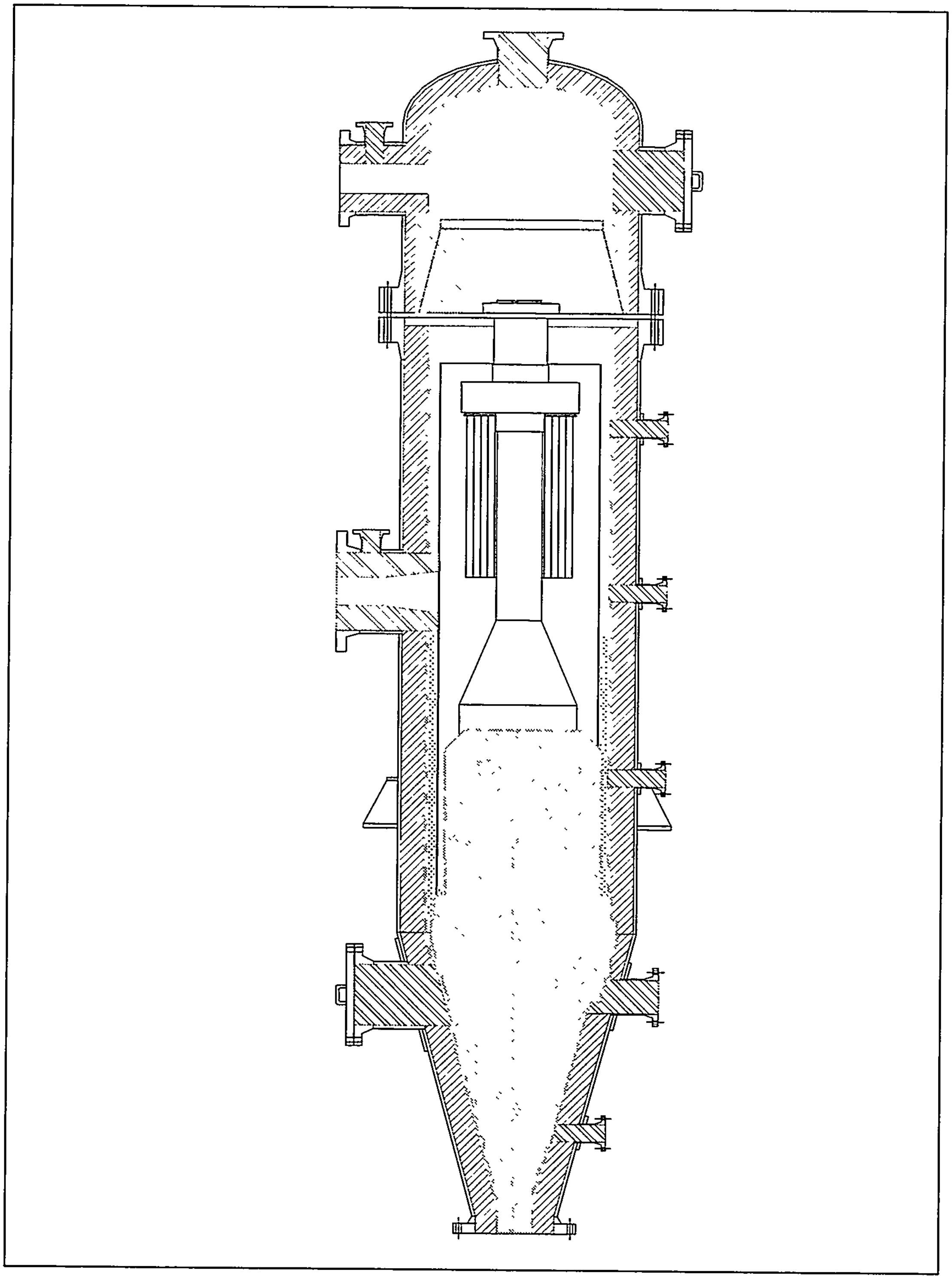

Figure 6.1.8-9 Approximate Ash Level on August 20 at ~16:00

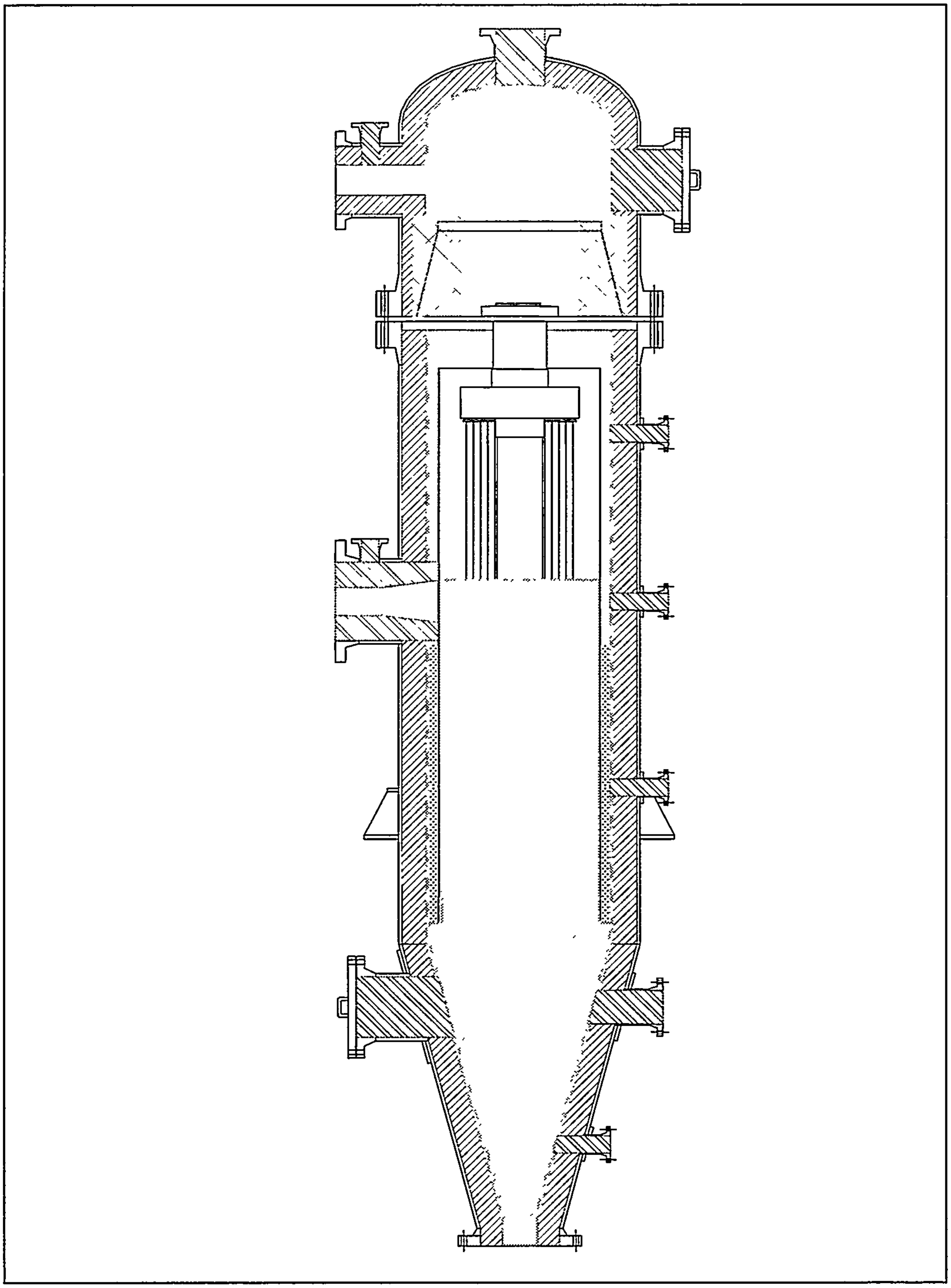

Figure 6.1.8-10 Approximate Ash Level on August 21 at ~12:00

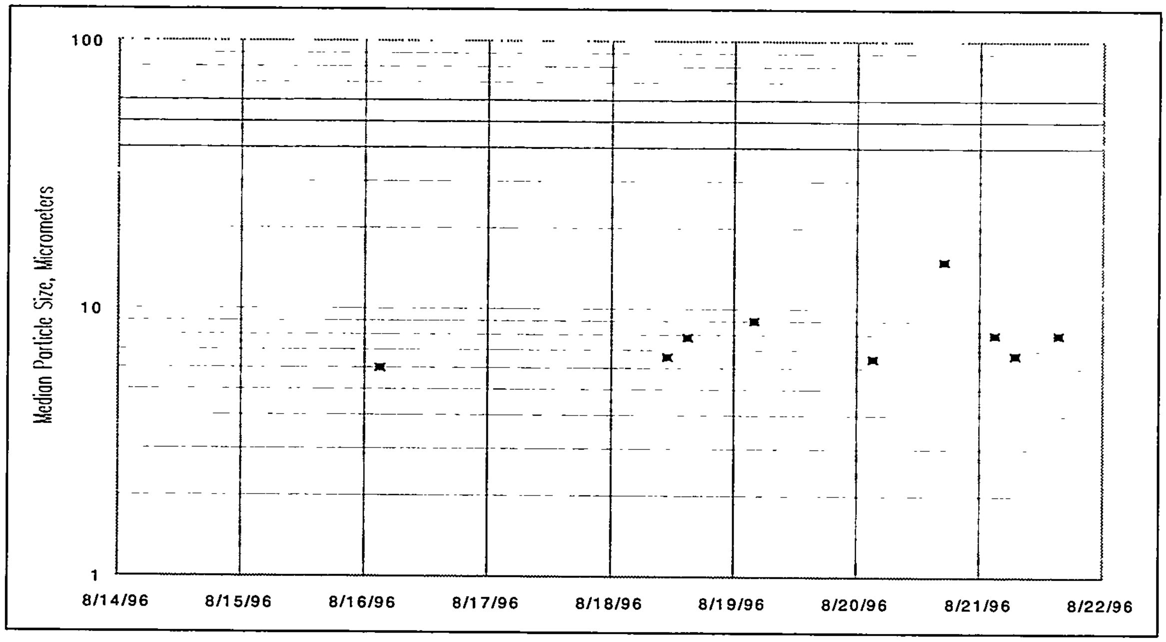

Figure 6.1.8-11 CCT1C Hopper Samples

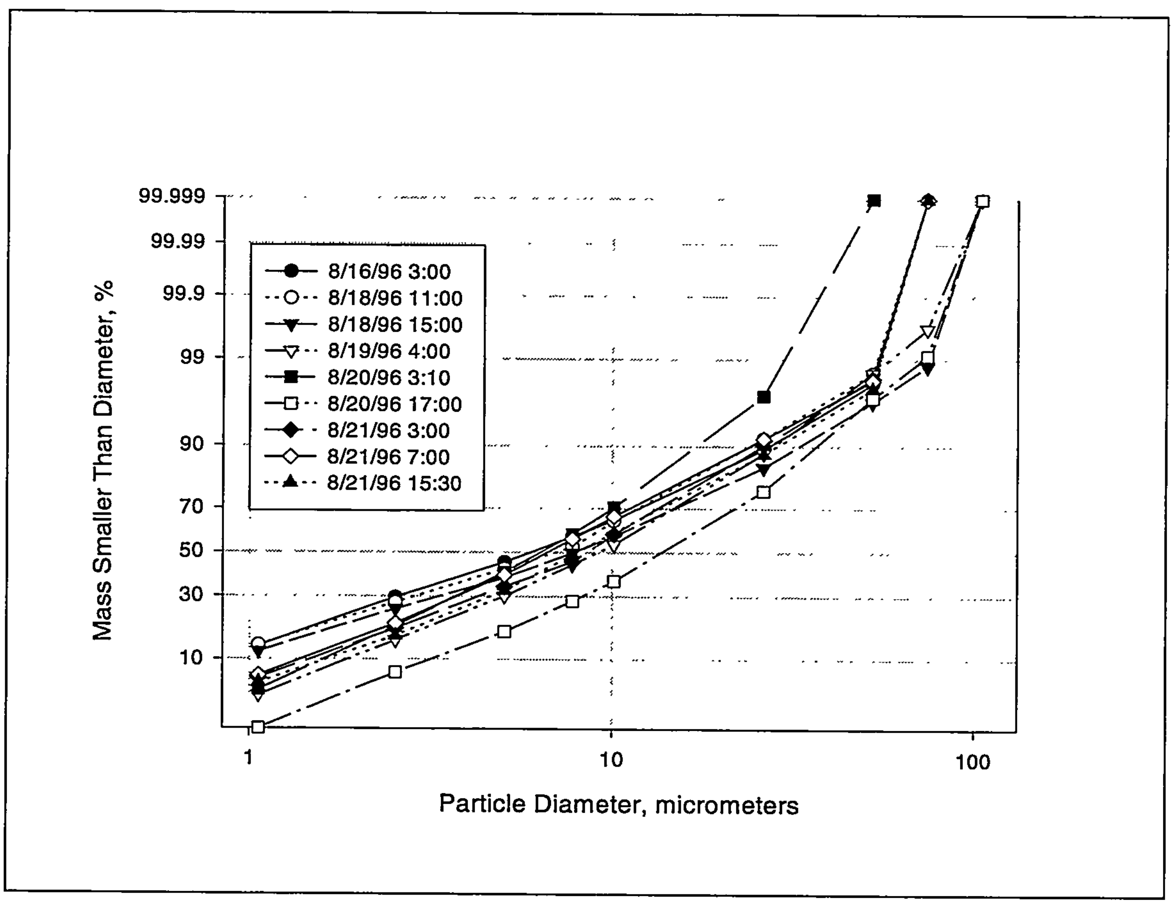

Figure 6.1.8-12 CCT1C PCD Hopper Particle Size Distributions

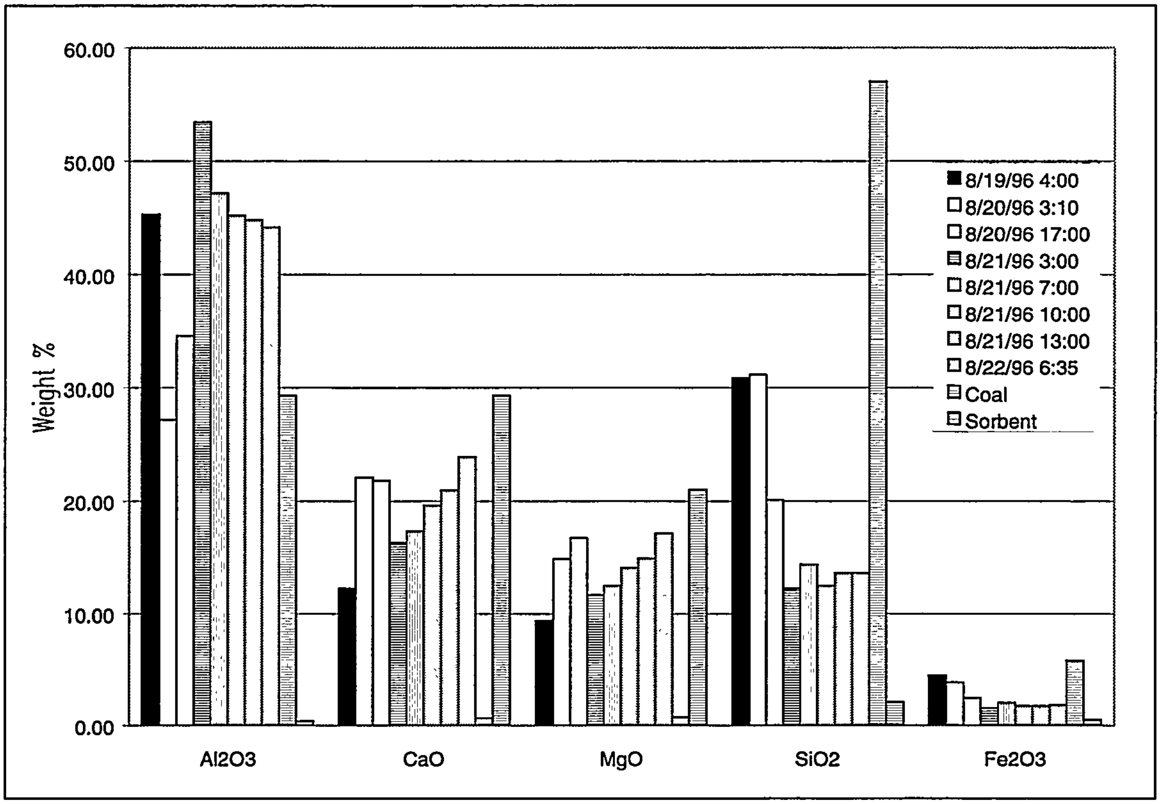

Figure 6.1.8-13 CCT1C PCD Hopper Ash Chemistry (Primary Constituents)

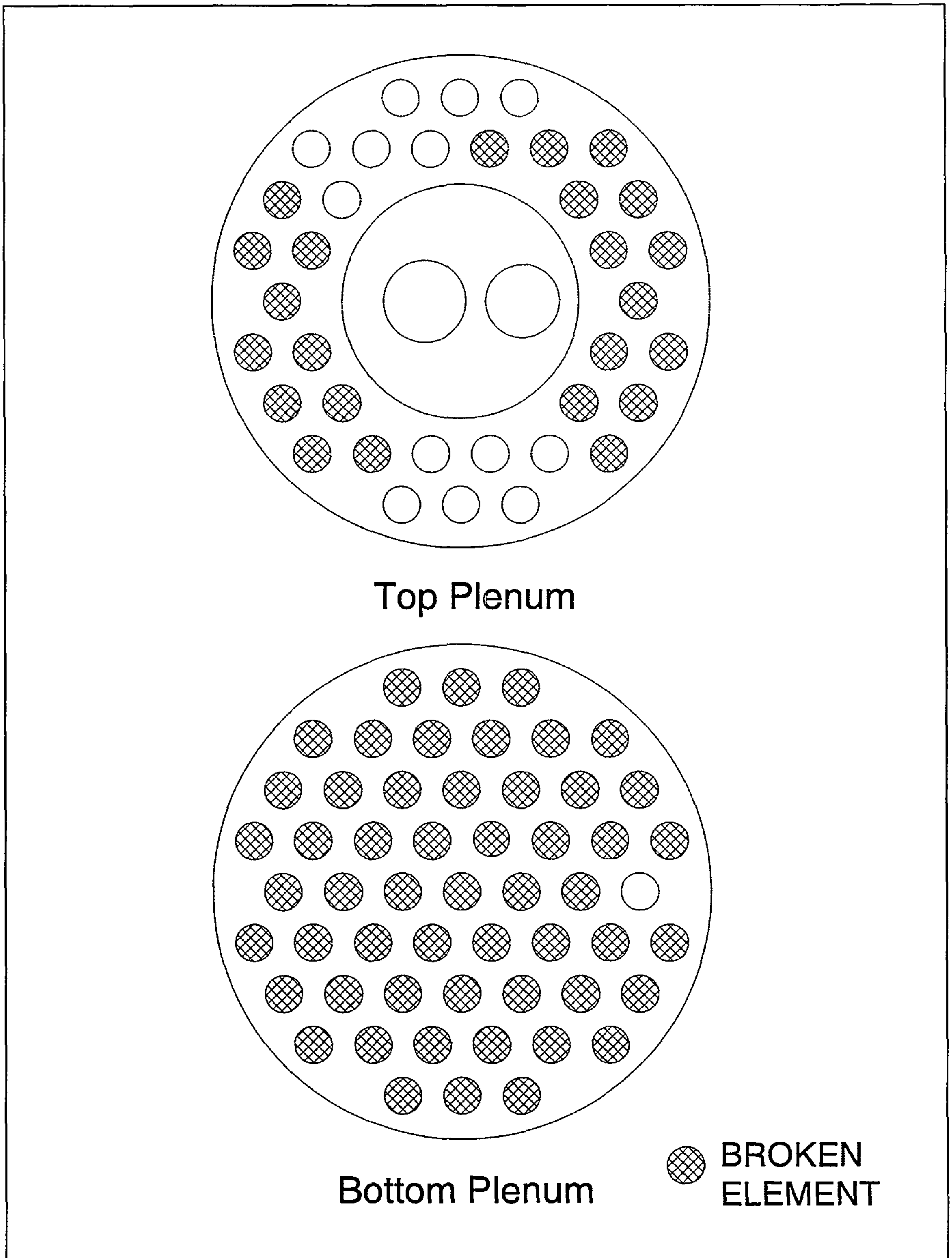

Figure 6.1.8-14 Broken Elements After CCT1C (Top of Page Is North)

6.1.9 Candle Layout #2

After test run CCT1C the PCD was disassembled and it was discovered that 77 of the 91 filter elements had been broken. Based on the extent of the damage to the filter elements, it was determined that all of the filter elements should be replaced. They were all replaced during the week of September 2, 1996.

The initial filter elements installed were used filters from the Tidd project. There was an insufficient number of used elements available to replace all filter elements, so it was decided that all new elements would be installed. The only new elements in storage at the PSDF were Pall 442T and Pall 326 elements. Several of the Pall 442T filter elements were unused elements from the Tidd project.

On the bottom plenum, 54 Pall 442T elements purchased by SCS were installed. Twelve Pall 326 elements and 23 of the Pall 442T elements from Tidd were installed on the top plenum. The tubesheet "map" for FL0301 is shown in figure 6.1.9-1 with each element holder numbered. This is the orientation of the elements as they sit in the filter vessel (viewed from the top of the vessel).

DOE/METC had shipped four used Schumacher filter elements from the Tidd project which support a contract with Dr. Roger Chen at West Virginia University. Because of the risk of breaking all four filter elements, only two of the four elements were installed. One element was installed on each level (element number 20).

Tables 6.1.9-1 through -3 detail which element was installed at each location on both the upper and lower tubesheet. The PSDF element number refers to a record number in the filter element database.

Table 6.1.9-1

Element Information for FL0301 Top Plenum

Tubesheet ID	Manufacturer	Type	PSDF No.	Comments
1	Pall	326	14	
2	Pall	326	15	
3	Pall	442T	122	From Tidd
4	Pall	442T	123	From Tidd
5	Pall	442T	124	From Tidd
6	Pall	442T	125	From Tidd
7	Pall	442T	126	From Tidd
8	Pall	442T	127	From Tidd
9	Pall	442T	128	From Tidd
10	Pall	442T	129	From Tidd
11	Pall	442T	130	From Tidd
12	Pall	442T	131	From Tidd
13	Pall	442T	132	From Tidd
14	Pall	442T	133	From Tidd
15	Pall	326	108	
16	Pall	326	117	
17	Pall	326	110	
18	Pall	326	103	
19	Pall	326	107	
20	Schumacher	F40	121	From Roger Chen - WVU
21	Pall	442T	134	From Tidd
22	Pall	442T	135	From Tidd
23	Pall	442T	136	From Tidd
24	Pall	442T	137	From Tidd
25	Pall	442T	138	From Tidd
26	Pall	442T	139	From Tidd
27	Pall	442T	140	From Tidd
28	Pall	442T	141	From Tidd
29	Pall	442T	142	From Tidd
30	Pall	442T	143	From Tidd
31	Pall	442T	144	From Tidd
32	Pall	326	109	
33	Pall	326	111	
34	Pall	326	119	
35	Pall	326	113	
36	Pall	326	118	

Table 6.1.9-2

Element Information for FL0301 Bottom Plenum Tubesheet ID Numbers 1-30

Tubesheet ID	Manufacturer	Type	PSDF No.	Comments
1	Pall	442T	21	
2	Pall	442T	49	
3	Pall	442T	75	
4	Pall	442T	52	
5	Pall	442T	39	
6	Pall	442T	55	
7	Pall	442T	44	
8	Pall	442T	50	
9	Pall	442T	23	
10	Pall	442T	42	
11	Pall	442T	24	
12	Pall	442T	40	
13	Pall	442T	27	
14	Pall	442T	28	
15	Pall	442T	73	
16	Pall	442T	89	
17	Pall	442T	25	
18	Pall	442T	34	
19	Pall	442T	95	
20	Schumacher	F40	120	From Roger Chen - WVU
21	Pall	442T	62	
22	Pall	442T	53	
23	Pall	442T	46	
24	Pall	442T	67	
25	Pall	442T	76	
26	Pall	442T	48	
27	Pall	442T	71	
28	Pall	442T	32	
29	Pall	442T	97	
30	Pall	442T	81	

Table 6.1.9-3

Element Information for FL0301 Bottom Plenum Tubesheet ID Numbers 31-55

Tubesheet ID	Manufacturer	Type	PSDF No.	Comments
31	Pall	442T	63	
32	Pall	442T	26	
33	Pall	442T	36	
34	Pall	442T	83	
35	Pall	442T	94	
36	Pall	442T	66	
37	Pall	442T	69	
38	Pall	442T	35	
39	Pall	442T	70	
40	Pall	442T	33	
41	Pall	442T	45	
42	Pall	442T	64	
43	Pall	442T	61	
44	Pall	442T	31	
45	Pall	442T	41	
46	Pall	442T	80	
47	Pall	442T	20	
48	Pall	442T	29	
49	Pall	442T	99	
50	Pall	442T	74	
51	Pall	442T	72	
52	Pall	442T	54	
53	Pall	442T	18	
54	Pall	442T	17	
55	Pall	442T	79	

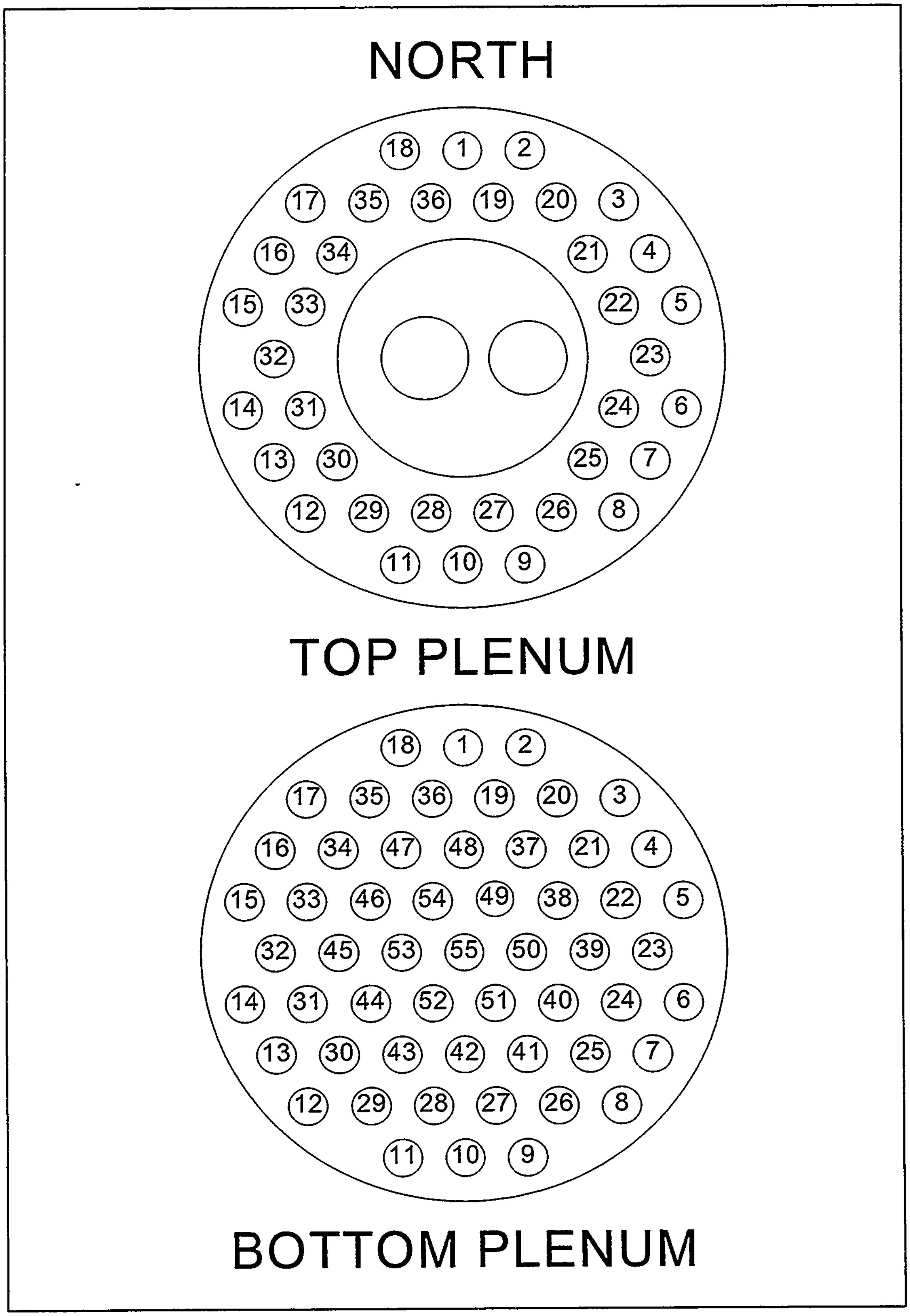

Figure 6.1.9-1 FL0301 Tubesheet Map

6.1.10 CCT2A Run

6.1.10.1 Run Summary

Coal combustion characterization test CCT2A was the first attempt at coal combustion since the August combustion run. Several changes were implemented since that run that significantly impacted the PCD. All new candle filters were installed in September, a different type of gasket was installed on the vessel flanges than was used in previous runs, and the bed material being used in the transport reactor (TR) was changed from alumina to sand. Test run CCT2A began on October 2, 1996, at 19:01 and ended on October 17, 1996, at 19:10. It was divided into two phases by an outage from October 6 to October 14. The outage after the first phase occurred due to problems with the start-up burner pilot that prevented lighting of the burner. The outage after the second phase occurred due to an inability to control carryover of transport reactor bed material (sand) to the PCD.

PCD performance was stable throughout. The high particulate loading coming over from the TR had no noticeable impact on PCD process conditions except that the solids outlet was continually being filled and the PCD fines transporter (FD0520) was removing solids regularly. Due to the large particle size of the solids carryover to the PCD, there appeared to be no significant build-up of particulate on the candle filter surfaces and, therefore, no significant changes in filter (PCD) differential pressure (ΔP) that were caused by particulate carryover. The maximum operating temperature of the PCD during phase 1 was approximately 490°F, and the pressure varied with TR pressure from 50 to 90 psig. The filter face velocity remained under 5 ft/min and the ΔP never reached 20 inWG. In phase 2, the maximum operating temperature was approximately 560°F, and the pressure varied from 50 to 100 psig. The face velocity again remained under 5 ft/min and the ΔP stayed under 20 inWG for almost the entire run. For both phases, the pulse cleaning pressure was set at 400 psig and the ΔP pulse trigger (although never used) was set at 50 inWG. Throughout the run, the filter was pulsed based on a 30-minute timer.

Test conditions for this run are listed in tables 6.1.10-1 through -4 and other data from the run are shown in figures 6.1.10-1 through -4.

6.1.10.2 Test Objectives

The primary test objective for PCD operation was to support the continued TR start-up activities and coal combustion characterization attempts and gain further experience operating the PCD. Since this was the first attempt at coal combustion since the August combustion run when the PCD was almost entirely filled with solids, emphasis was placed on monitoring the solids level in the PCD solids outlet. One TR test objective that had significant impact on the PCD was the evaluation of sand as the reactor bed material. Evaluation of the new PCD flange gaskets was also a priority.

6.1.10.3 Observations/Events

Phase 1

A. Test Started - Main Air Compressor (MAC) Started - October 2 at 19:01. The system was first pressure tested on September 27 and a few minor leaks were found, only one of which was on the PCD. This small leak was eliminated after additional compression was applied to the gasket. Garlock gaskets were used on the PCD flanges instead of the Flexitallic gaskets that had been used on previous runs, and this change evidently improved sealing of the flanges. Instrumentation problems with the thermal oxidizer and a blown Spheri valve seal on the reactor spent solids transporter system (FD0510) delayed the start of the test run until October 2 at 19:01.

B. MAC Stopped - Could Not Light Start-Up Burner Pilot - October 3 at 03:30. Several unsuccessful attempts were made late on October 2 and early on October 3 to light the transport reactor start-up burner pilot. The flame rod, the instrument used by the start-up burner for pilot flame detection, was found to be damaged and was replaced.

C. MAC Restarted - October 3 at 09:10.

D. Start-Up Burner Pilot Lit - October 3 at 11:44.

E. Transport Reactor (TR) Pressure Increased From 50 to 60 psig - October 3 at 18:15. The pressure in the TR was increased prior to lighting the start-up burner. This showed a corresponding increase in pressure and ΔP in the PCD.

F. Start-Up Burner Lit - October 3 at 18:55.

G. TR Flows Increased to Heat Reactor - October 4 at 06:30. Air flows through the various sections of the TR and the combustion heat exchanger (CHE) were increased to induce heat from the start-up burner into the TR and facilitate heat-up of the reactor just prior to feeding bed material (sand). These flow increases in the reactor resulted in corresponding increases in gas flow and ΔP in the PCD.

H. Start-Up Burner Tripped and Immediately Relit - October 4 at 16:38 to 17:23.

I. TR pressure Increased to 90 psig - October 5 at 02:55. The pressure in the TR was increased to decrease the velocity in the reactor and reduce carryover to the PCD as well as to maintain the burner firing rate. The pressure and ΔP in the PCD increased accordingly.

J. Start-Up Burner Tripped - October 5 at 05:51.

K. MAC Stopped to Inspect Start-Up Burner Flame Rod - October 5 at 09:00. The flame rod was removed from the burner assembly, and the tip was found to be burned off. The tip was replaced and the new assembly was installed.

L. MAC Restarted - October 5 at 13:15.

M. MAC Stopped - Could Not Light Start-Up Burner Pilot - October 5 at 17:25. The burner pilot assembly was removed, and the burner pilot nozzle was found to be plugged with rust from the propane fuel line. The assembly was cleaned and reinstalled.

N. MAC Restarted - October 5 at 23:25.

O. Start-Up Burner Lit - October 6 at 01:28.

P. TR Pressure Increased From 50 to 90 psig - October 6 at 02:30. TR pressure was increased to begin solids circulation and to keep reactor velocity low to reduce carryover to the PCD.

Q. Start-Up Burner Tripped - October 6 at 03:50.

R. Test Stopped - MAC Stopped - October 6 at 05:00. After the start-up burner tripped, several attempts to relight the burner were unsuccessful. The pilot was successfully lit each time, but the flame rod was not detecting the lit pilot and would not allow the start-up burner to be lit. On inspection, the flame rod tip was again found to be burned off.

Outage - October 6 to October 14

The outage in between phases 1 and 2 of CCT2A was taken predominantly to institute changes to the transport reactor start-up burner pilot assembly design. Changes were also necessary on the steam and condensate and propane systems prior to starting back up. The outage was extended due to failure of the circulating water supply line to the steam condenser. No changes were necessary or instituted to the PCD system during the outage.

Phase 2

A. Test Started - MAC Started and TR Start-Up Burner Pilot Lit - October 14 at 21:30.

B. TR Pressure Decreased and Start-Up Burner Pilot Shutdown to Blow Out Plugged Aeration Nozzles - October 15 at 01:00 to 02:50. Aeration nozzles for the CHE had become plugged with solids from the TR. Pressure in the TR had to be reduced down to about 10 psig before the solids could be cleared from the nozzles.

C. TR Pressure Increased, Start-Up Burner Pilot and Start-Up Burner Lit, and TR Solids Circulation Started - October 15 at 03:00 to 04:30. The TR was started back up and circulation of sand in the reactor was started. The PCD saw corresponding increases in pressure and ΔP due to the increase in pressure in the TR.

D. Start-Up Burner Tripped and Relit - October 15 at 08:02 to 08:30.

E. TR Solids Circulation Restarted - October 15 at 09:00. Sand circulation was previously stopped to bring the start-up burner back on line. There was no fluctuation in filter ΔP due to the large size of the sand being carried over from the TR.

F. PI System Shutdown - October 15 at 14:50 to 15:00. All data values collected during this period showed zero.

G. Start-Up Burner Tripped and Relit - October 15 at 21:44 to 21:54.

H. TR Pressure Increased and Solids Circulation Restarted - October 15 at 22:45. The PCD again saw corresponding increases in pressure and ΔP due to the increase in pressure in the TR.

I. TR Solids Circulation Increased Resulting in Large Carryover of Solids to PCD - October 16 at 10:00. During circulation of solids from the CHE to the TR, circulation was increased within the TR loop as well. This caused a large increase of solids carryover to the PCD. Again there was no significant change in ΔP due to the large particle size of the sand being carried over.

J. Start-Up Burner Shutdown Due to Inability to Control Solids Carryover to PCD - October 17 at 15:15. Sand feed and circulation during October 16 and 17 resulted in excessive carryover of large sized sand to the PCD. This carryover was not able to be controlled, so the start-up burner was shutdown in preparation for ending the test and analyzing the carryover problem.

K. Test Stopped - MAC Stopped - October 17 at 19:10.

6.1.10.4 Analysis of Solid Samples

A total of 8 samples were taken from the PCD fines transport system (FD0520), one sample during phase 1, and seven samples during phase 2. Sieve analyses were performed on all samples and results are shown in figures 6.1.10-5 through -7. Figures 6.1.10-5 and -6 show the median particle size of the solids collected from the FD0520 hopper to be around 200 µm, implying that the solids carryover to the PCD had a similar median particle size. There were two types of sand used as bed material for the TR during CCT2A with manufacturer's designations of F5574 and F6314. The median particle size of the F5574 sand was approximately 250 µm and that of the F6314 sand was approximately 200 µm. This appears to indicate that the particulate collected from FD0520 during CCT2A, and hence the particulate being carried over to the PCD, was the same material that was being fed into the TR. This conclusion is reinforced by figure 6.1.10-7, which shows that the particle size distributions of the PCD samples and TR bed material were very similar.

6.1.10.5 Run Outcome

Although carryover to the PCD was extensive during test run CCT2A, the PCD and its ash removal system performed as designed in removing particulate from the gas stream. An inspection of the PCD solids outlet and the candle filters immediately above the solids outlet was conducted on October 24, 1996. No solids were present in the outlet and only a thin layer of particulate appeared to be on the candle filters. There was no evidence of any damage to the candle filters.

Table 6.1.10-1

CCT2A, Phase 1 Run Statistics

Start Time	10/2/96 19:01
End Time	10/6/96 05:00
Coal Type	No Coal Feed
Hours on Coal	No Coal Feed
Sorbent Type	No Sorbent Feed
TR Bed Material	Sand
Number of Candles	91
Candle Layout No.	2
Filtration Area	~265 ft^2
Pulse Pressure	400 ± 50 psig
Pulse DP Trigger	50 inWG
Pulse Time Trigger	30 minutes
Pulse Valve Open Time	0.2 seconds

Table 6.1.10-2

CCT2A, Phase 1 Major Events (Refer to Figures 6.1.10-1 and -2)

Event	Description	Time
1	Test started - main air compressor (MAC) Started	10/2/96 at 19:01
2	MAC stopped - could not light transport reactor (TR) start-up burner pilot	10/3/96 at 03:30
3	MAC restarted	10/3/96 at 09:10
4	Start-up burner pilot lit	10/3/96 at 11:44
5	TR pressure increased from 50 to 60 psig	10/3/96 at 18:15
6	Start-up burner lit	10/3/96 at 18:55
7	TR flows increased to heat reactor	10/4/96 at 06:30
8	Start-up burner tripped and immediately re-lit	10/4/96 at 16:38 to 17:23
9	TR pressure increased to 90 psig	10/5/96 at 02:55
10	Start-up burner tripped	10/5/96 at 05:51
11	MAC stopped to inspect start-up burner flame rod	10/5/96 at 09:00
12	MAC re-started	10/5/96 at 13:15
13	MAC stopped - could not light start-up burner pilot	10/5/96 at 17:25
14	MAC re-started	10/5/96 at 23:25
15	Start-up burner lit	10/6/96 at 01:28
16	TR pressure increased from 50 to 90 psig	10/6/96 at 02:30
17	Start-up burner tripped	10/6/96 at 03:50
18	Test stopped - MAC stopped	10/6/96 at 05:00
*	Plant Information (PI) system shutdown	10/2/96 at 11:15 to 11:25 10/3/96 at 12:50 to 13:00 10/4/96 at 14:55 to 15:05

Table 6.1.10-3

CCT2A, Phase 2 Run Statistics

Start Time	10/14/96 21:30
End Time	10/17/96 19:10
Coal Type	No Coal Feed
Hours on Coal	No Coal Feed
Sorbent Type	No Sorbent Feed
TR Bed Material	Sand
Number of Candles	91
Candle Layout No.	2
Filtration Area	~265 ft^2
Pulse Pressure	400 $\pm$ 50 psig
Pulse DP Trigger	50 inWG
Pulse Time Trigger	30 minutes
Pulse Valve Open Time	0.2 seconds

Table 6.1.10-4

CCT2A, Phase 2 Major Events (Refer to Figures 6.1.10-3 and -4)

Event	Description	Time
1	Test started - MAC started and TR start-up burner pilot lit	10/14/96 at 21:30
2	TR pressure decreased and start-up burner pilot shutdown to blow out plugged aeration nozzles	10/15/96 at 01:00 to 02:50
3	TR pressure increased, start-up burner pilot and start-up burner lit, and TR solids circulation started	10/15/96 at 03:00 to 04:30
4	Start-up burner tripped and re-lit	10/15/96 at 08:02 to 08:30
5	TR solids circulation restarted	10/15/96 at 09:00
6	Plant Information system (PI) shutdown	10/15/96 at 14:50 to 15:00
7	Start-up burner tripped and relit	10/15/96 at 21:44 to 21:54
8	TR pressure increased and solids circulation re-started	10/15/96 at 22:45
9	TR solids circulation increased resulting in large carryover of solids to PCD	10/16/96 at 10:00
10	Start-up burner shutdown due to inability to control solids carryover to PCD	10/17/96 at 15:15
11	Test stopped - MAC stopped	10/17/96 at 19:10

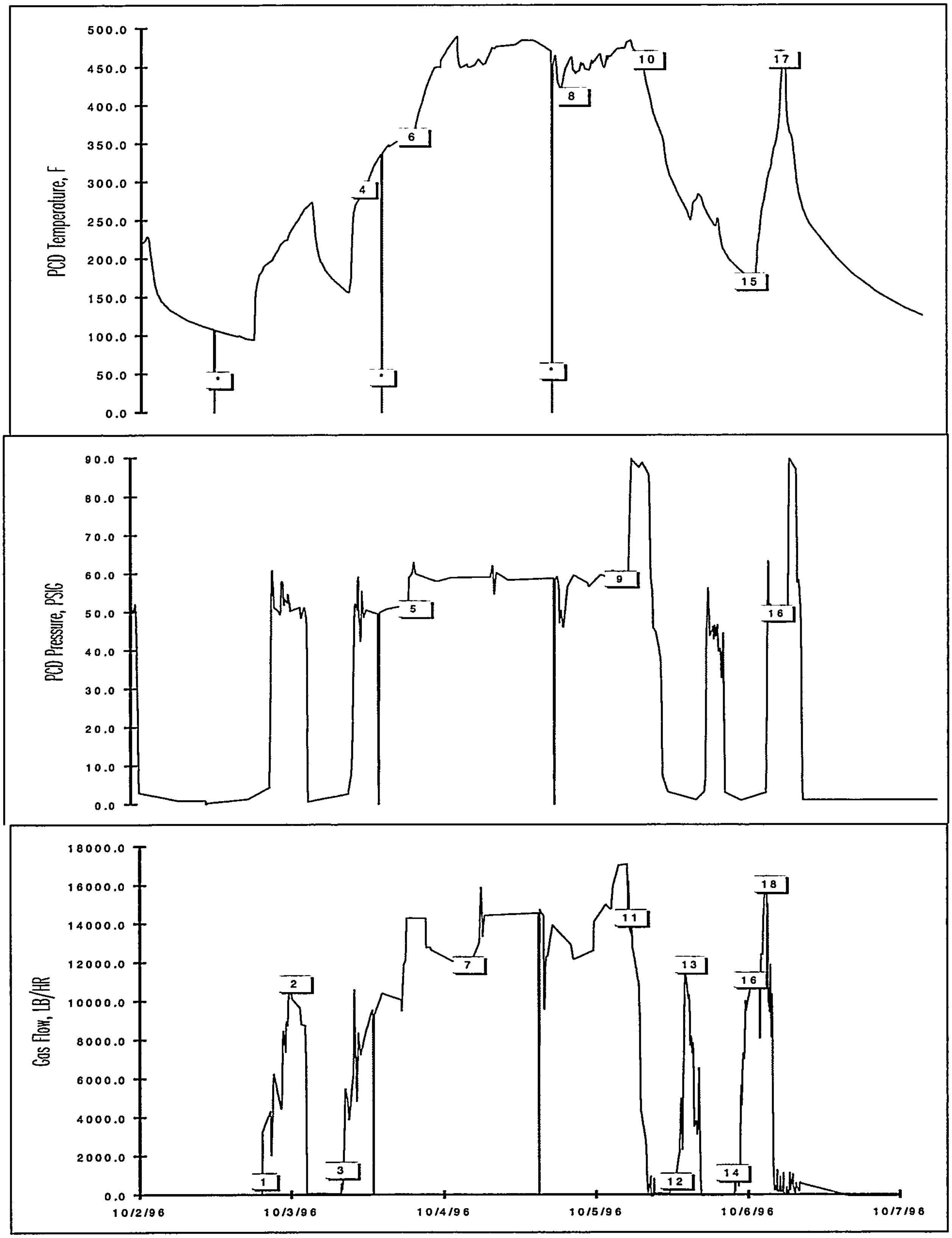

Figure 6.1.10-1 CCT2A, Phase 1 Summary Information

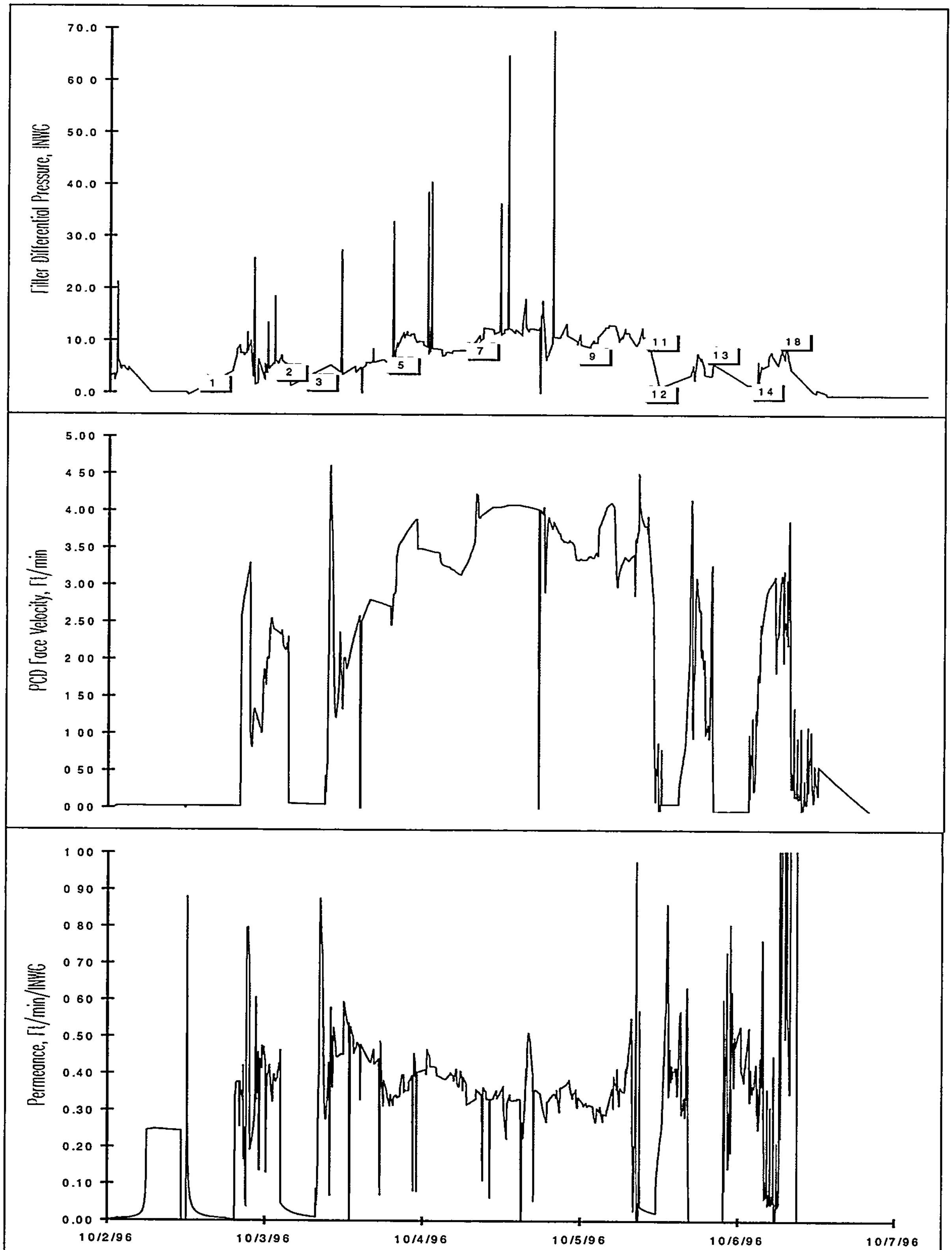

Figure 6.1.10-2 CCT2A, Phase 1 Summary Information

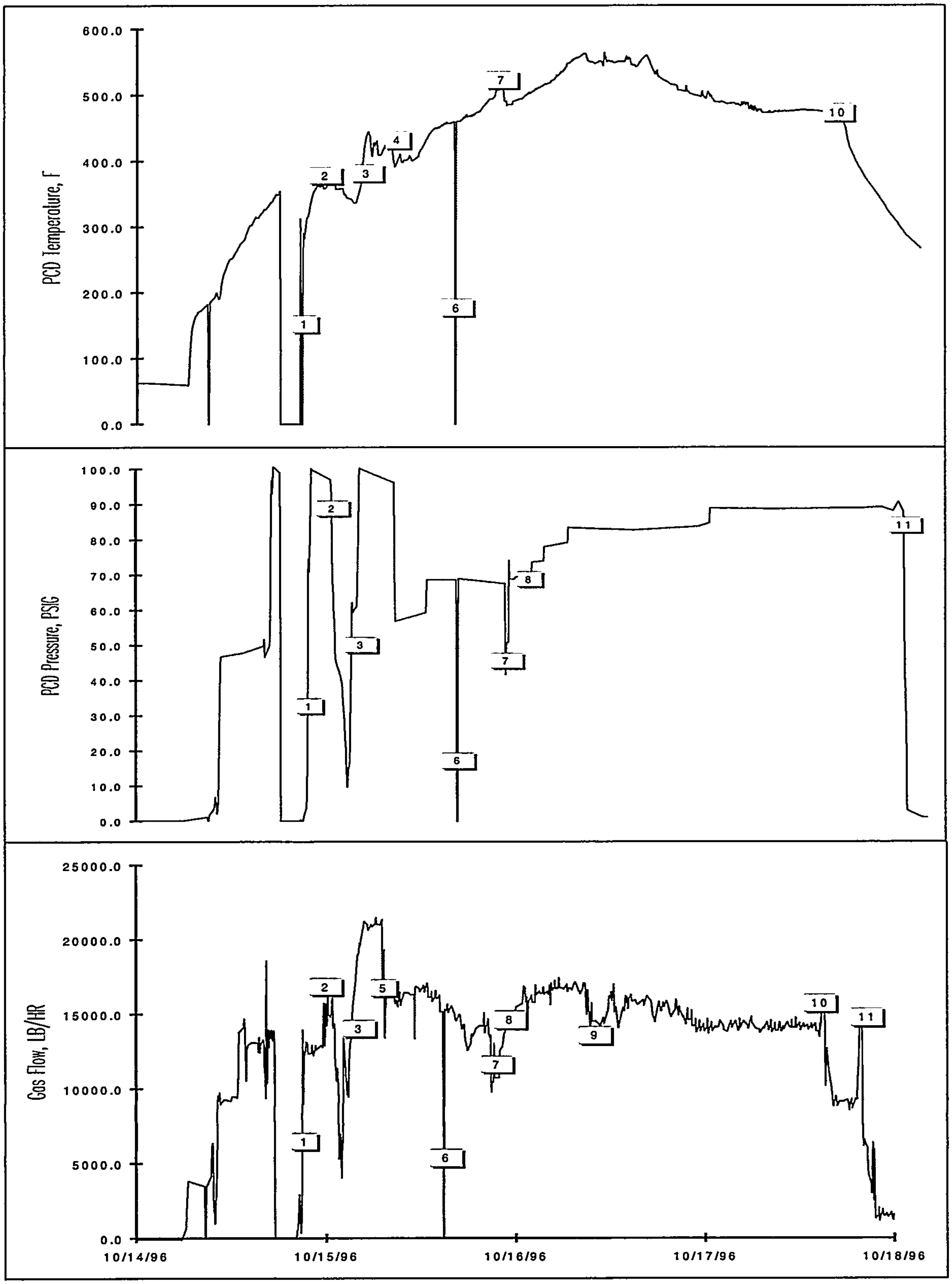

Figure 6.1.10-3 CCT2A, Phase 2 Summary Information

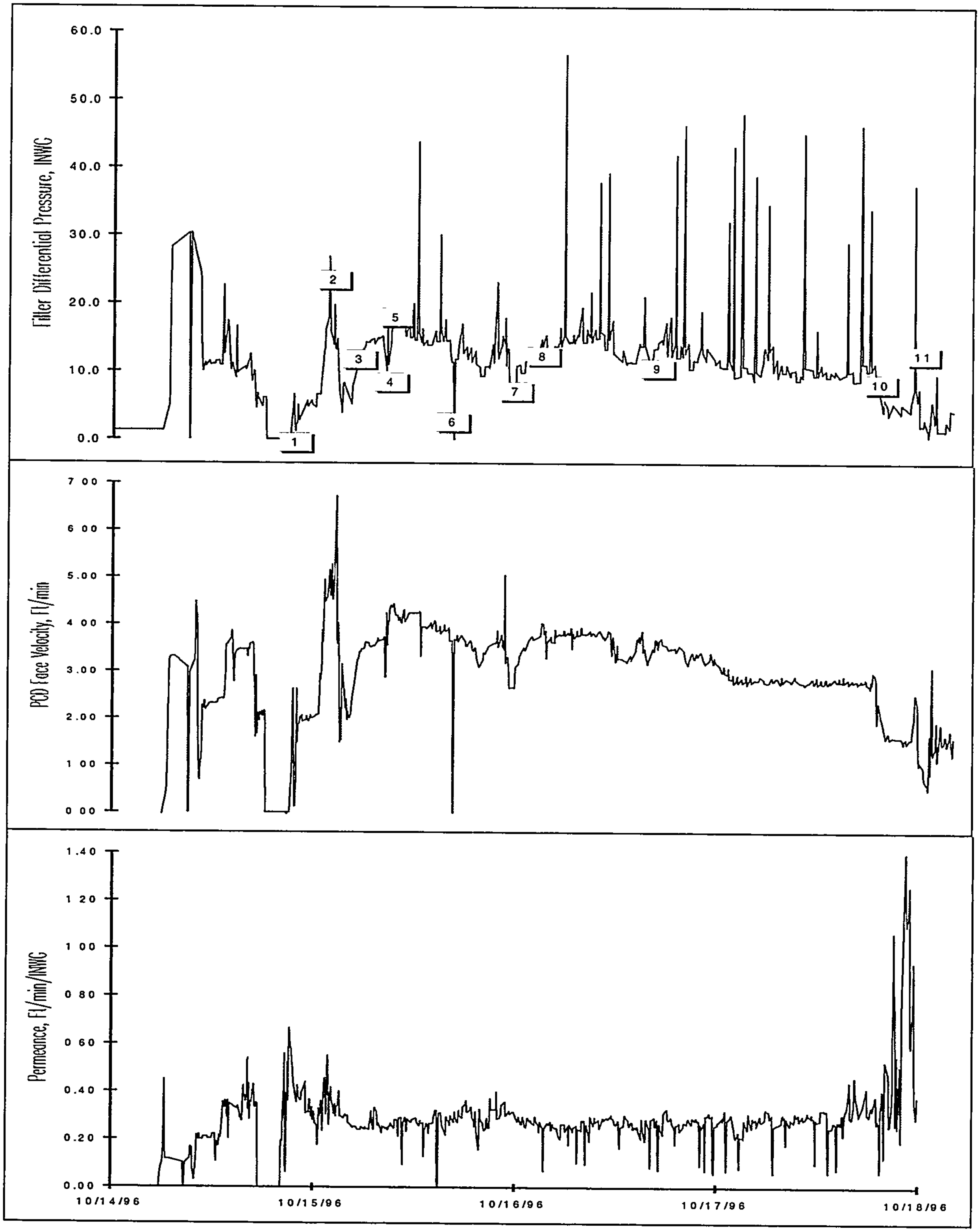

Figure 6.1.10-4 CCT2A, Phase 2 Summary Information

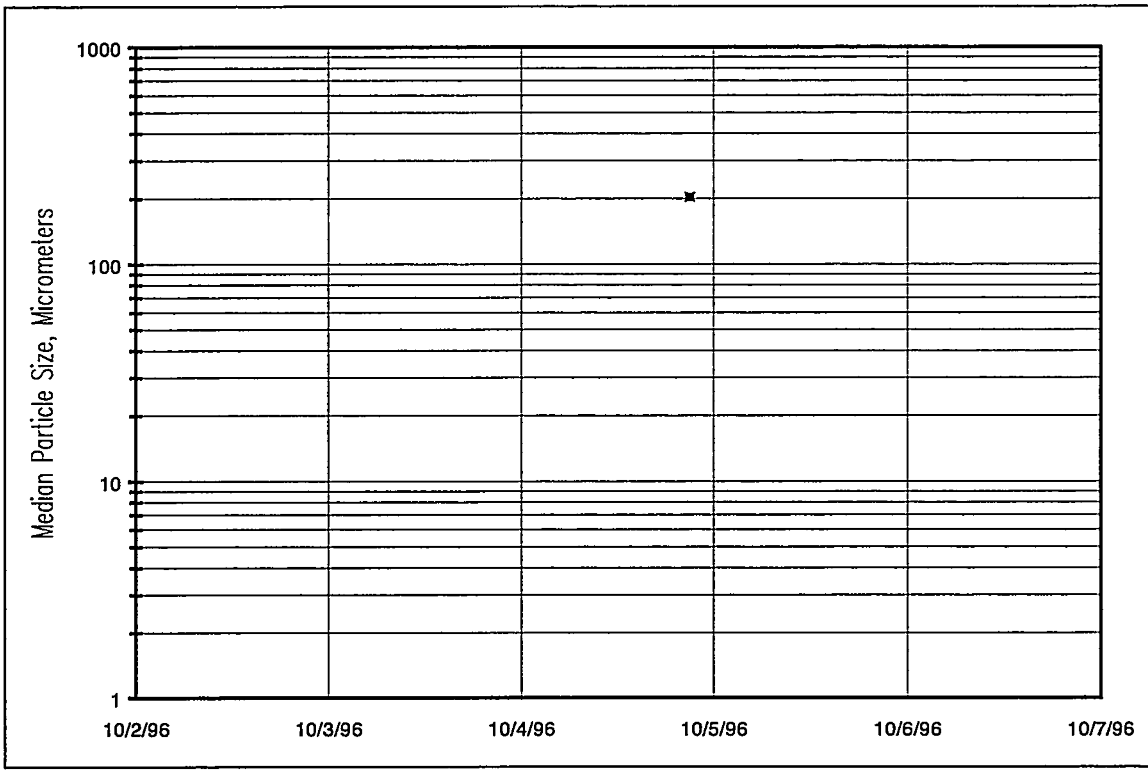

Figure 6.1.10-5 CCT2A, Phase 1 PCD Hopper Samples

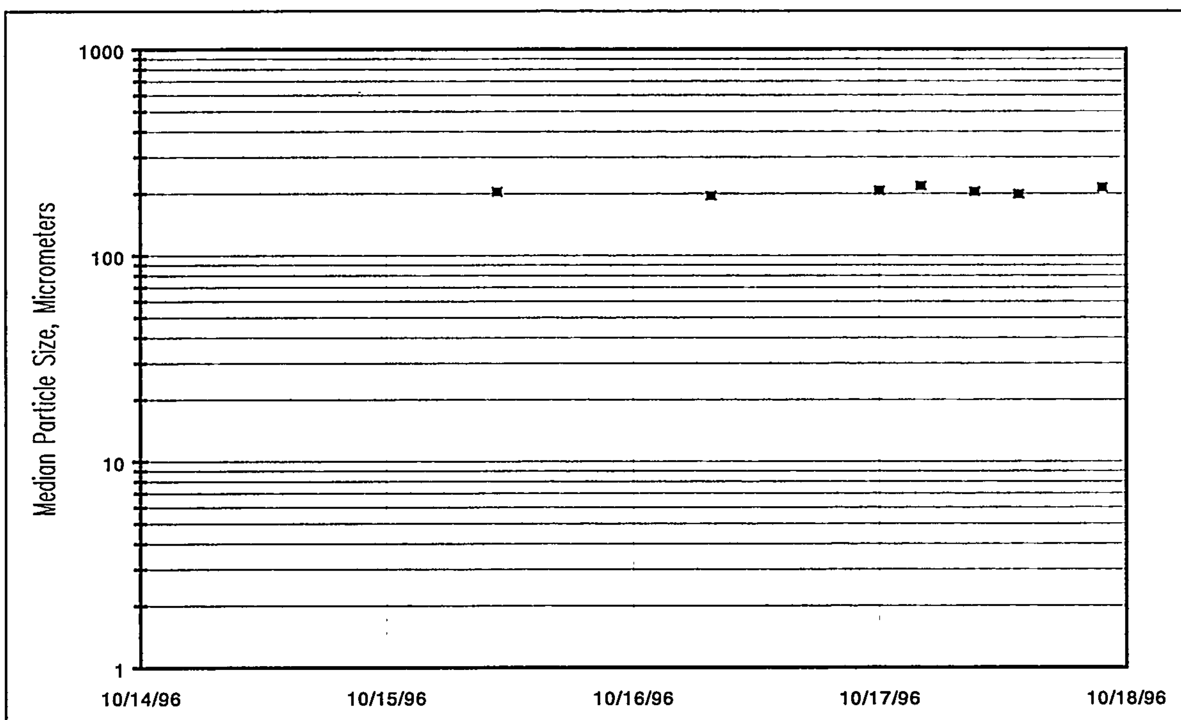

Figure 6.1.10-6 CCT2A, Phase 2 PCD Hopper Samples

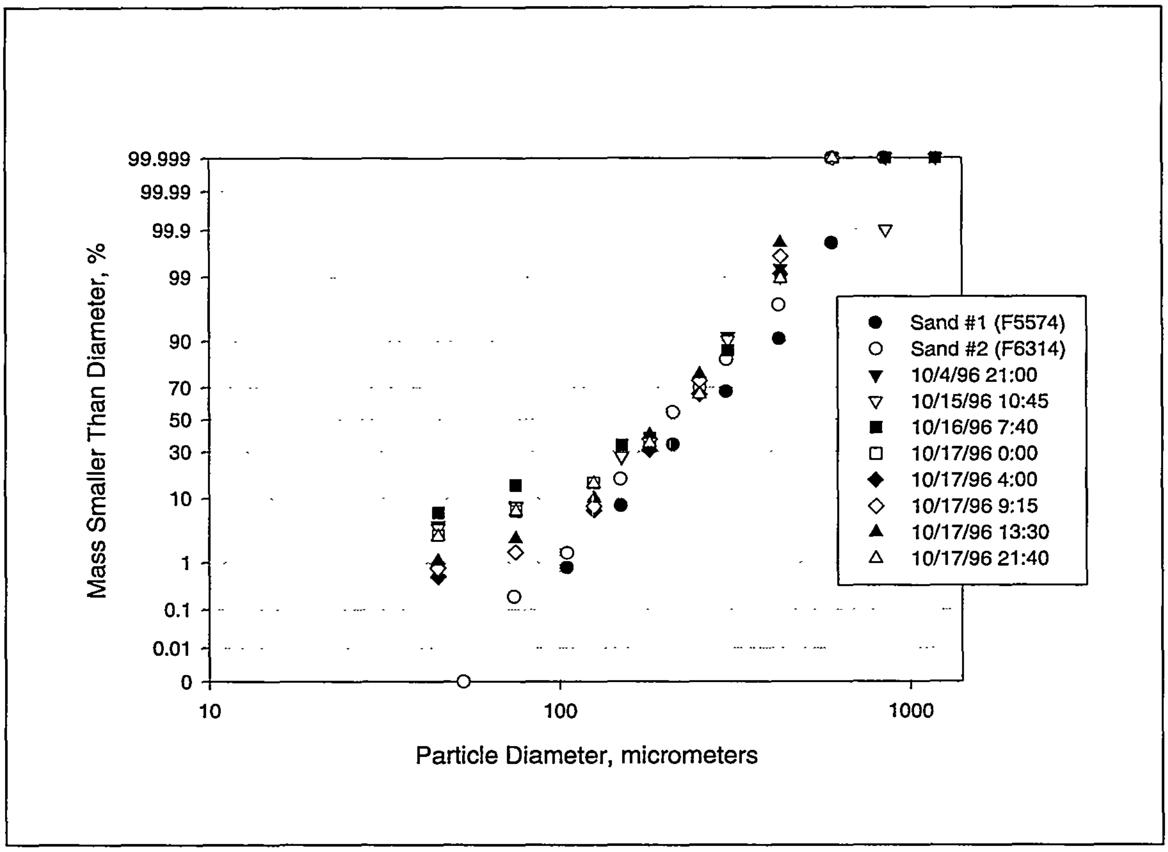

Figure 6.1.10-7 CCT2A PCD Hopper Particle Size Distribution

6.1.11 CCT2B Run

6.1.11.1 Run Summary

Coal combustion characterization test (CCT2B) was the second attempt at coal combustion since the August coal combustion test CCT1C. The previous attempt (CCT2A) ended due to problems with the transport reactor (TR) start-up burner pilot assembly and excessive carryover of TR bed material to the PCD. During the outage between CCT2A and CCT2B, the burner pilot assembly design was modified and a TR operations philosophy was established that was believed would decrease reactor bed material carryover.

Test run CCT2B began on November 4, 1996, at 03:10 and ended on November 7, 1996, at 20:05. PCD performance was again stable, although the carryover of sand from the TR still could not be adequately controlled without operating the TR solids circulation significantly below design specification. It was decided to operate TR solids circulation at acceptable carryover levels until after sustained coal combustion was achieved. The long-term carryover problem was to be addressed at a later date.

The maximum operating temperature of the PCD in CCT2B was 620°F, and the pressure varied with TR pressure between 40 and 100 psig. As in CCT2A, due to the large size of the particulate carryover, there was no significant increase in filter differential pressure (ΔP). The ΔP remained under 20 inWG, and the face velocity stayed below 4 ft/min. The same pulse cleaning parameters were used in CCT2B as in CCT2A: pulse pressure of approximately 400 psig and ΔP trigger of 50 inWG. As in CCT2A, the ΔP trigger was not used since the ΔP never exceeded 50 inWG before the 30-minute time interval for automatic cleaning ended.

Test conditions for this run are listed in tables 6.6.6-1 and -2. Data from this run are shown in figures 6.6.1-1 and -2.

6.1.11.2 Test Objectives

The primary test objective for PCD operation was the same as that for CCT2A: support TR start-up and coal combustion characterization objectives and gain further experience in PCD operation. By this run, the ability to monitor solids level in the PCD solids outlet had significantly improved but continued to be emphasized. Further evaluation of sand as TR bed material was to be conducted. CCT2A had revealed that problems with the TR design may have been contributing to what was perceived in earlier tests to be a problem associated with bed material.

6.1.11.3 Observations/Events

A. Test Started – November 4 at 03:10. The system was pressure tested on October 31 with only a few minor leaks discovered, none of which were on the PCD. After depressurizing and eliminating the leaks, the next few days were spent in preparing auxiliary systems for start-up and preheating the PCD. The main air compressor (MAC) was started on November 4 at 03:10 signifying the start of combustion characterization test run CCT2B.

B. TR Start-Up Burner Pilot Lit – November 4 at 10:40. After further preheating the PCD with air from the MAC, the start-up burner pilot was lit.

C. Sand Feed to TR Started – November 4 at 12:45. Sand feed to the TR was started in order to build the reactor bed material level in preparation for coal/coke feed. The feeding of sand caused a pressure balancing effect in the TR and, therefore, caused an increase in the reactor solids circulation rate and an increase in carryover to the PCD. The PCD saw a corresponding increase in flow and ΔP.

D. TR Pressure Temporarily Decreased From 60 to 40 psig – November 5 at 02:10 to 03:10. Aeration nozzles for the combustion heat exchanger (CHE) solids outlet had become plugged with solids. At 60 psig, the TR pressure was too high to allow the nozzles to be blown clear, so the pressure was lowered to allow the nozzles to clear. The result in the PCD was an increase in flow as the nozzles cleared.

E. TR Start-Up Burner Lit and Pressure Increased to 80 psig – November 5 at 15:00.

F. TR Pressure Increased to 100 psig – November 5 at 17:16. The pressure was again raised to approach the desired initial conditions for feeding coal.

G. Plant Information (PI) System Shutdown – November 6 at 13:00 to 23:05. At about 13:00 on November 6 the application workstation (AW) crashed. Among other functions, this computer controls the interface between the plant's distributed control system (DCS) and the PI system. Therefore, the PI system was unable to access the DCS to obtain operating data until the AW was restored, after which PI could be set up again and restarted.

H. Batch Coal Feed to TR – November 7 at 05:00 to 06:00. Batch feed of the coal/coke mixture was begun after the TR had been sufficiently preheated by the start-up burner to allow ignition of the mixture. The PCD experienced slight increases in temperature and ΔP during this time period.

I. Continuous Coal Feed to TR – November 7 at 07:30 to 10:30. After successful ignition was achieved with batch feed, continuous feed was started. During this time, the start-up burner was shutdown after ignition was deemed sustainable through the feed of combustible material. Again the PCD experienced increases in temperature and ΔP that were even sharper than those during batch feed.

J. Batch Coal Feed to TR Resumed – November 7 at 10:30 to 14:30. In order to maintain temperature control in the TR during continuous coal/coke feed, solids from the CHE had to be circulated into and out of the TR. This caused an unacceptable increase of solids carryover to the PCD. Therefore, it was necessary to resume batch feed to the TR in order to maintain temperature and solids carryover control.

K. Coal Feed Stopped, TR Pressure Decreased, and Burner Lit – November 7 at 14:30 to 15:05. At 14:30 on November 7 it was discovered the PCD fines removal screw cooler (FD0502) had tripped 2 hours earlier and had not operated since that time. Therefore (from 12:30 to 14:30), there were no solids removed from the PCD. It was decided to shutdown the coal feed until it could be determined that the solids level in the PCD solids outlet was acceptable. In order to maintain temperature in the TR, the TR pressure was decreased and the start-up burner lit.

L. TR Start-Up Burner Tripped – November 7 at 17:00.

M. Test Ended – November 7 at 20:05. After several unsuccessful attempts to relight the start-up burner, it was decided to shutdown and again assess the continued problems with the start-up burner pilot assembly. The MAC was therefore stopped at 20:05 signifying the end of CCT2B.

6.1.11.4 Analysis of Solid Samples

Sieve analyses of the samples taken from the FD0520 fines removal system showed similar results to those of CCT2A. The median particle sizes of the PCD hopper samples (as displayed in figure 6.1.11-3) indicate that there was little size separation of particulate in the TR. The sand used as bed material in CCT2B was the same as that used in CCT2A and had a median particle size around 200 μm. Figure 6.1.11-4 seems to indicate that the particle size distribution (PSD) of the hopper solids was decreasing slightly during the test, however, the decrease was not significant enough to indicate an increase in TR particulate size separation efficiency. This decrease is most clearly displayed by the samples taken on November 7 and indicates that the carryover particle size would decrease as combustible material was fed into the TR. After combustion, the resulting ash would have replaced some of the sand in the reactor and decreased the PSD of the particulate being carried over to the PCD, resulting in a decrease in the PSD of the hopper samples.

6.1.11.5 Run Outcome

Once again carryover to the PCD was extensive during test run CCT2B, but the PCD again performed as designed in removing particulate from the gas stream. The trip of the fines removal screw (FD0502) was ultimately traced to the trip of the PCD fines ash removal system (FD0520) downstream of the screw. The FD0520 system is linked through control logic to FD0502 to trip the screw in the event of an FD0520 system trip. In December of 1996 mechanical inspection of the FD0520 system revealed that lubrication problems with the pilot valves used for pressurizing seals on the FD0520 system were causing periodic trips of the system. This was deemed to be the cause of the trip during CCT2B. These problems were corrected and should not hinder future operation.

The PCD was not internally inspected following CCT2B for several reasons: there were no suspected internal problems, the PCD was internally inspected following CCT2A, and there was a strong desire to minimize the turnaround time between CCT2B and CCT2C.

Table 6.1.11-1

CCT2B Run Statistics

Start Time	11/4/96 03:10
End Time	11/7/96 20:05
Coal Type	Coke Breeze/Subbituminous Coal Mixture
Hours on Coal	5 hrs batch feed; 3 hrs continuous feed
Sorbent Type	No Sorbent Feed
TR Bed Material	Sand
Number of Candles	91
Candle Layout No.	2
Filtration Area	~265 ft^2
Pulse Pressure	400 $\pm$ 50 psig
Pulse DP Trigger	50 inWG
Pulse Time Trigger	30 minutes
Pulse Valve Open Time	0.2 seconds

Table 6.1.11-2

CCT2B Major Events (Refer to Figures 6.1.11-1 and -2)

Event	Description	Time
1	Test Started	11/4/96 at 03:10
2	Transport Reactor (TR) Start-up Burner Pilot Lit	11/4/96 at 10:40
3	Sand Feed to TR Started	11/4/96 at 12:45
4	TR Pressure Temporarily Decreased From 60 to 40 psig to Clear Plugged Aeration Nozzles	11/5/96 at 02:10 to 03:10
5	TR Start-up Burner Lit and Pressure Increased to 80 psig	11/5/96 at 15:00
6	TR Pressure Increased to 100 psig	11/5/96 at 17:16
7	Plant Information (PI) System Shutdown	11/6/96 at 13:00 to 23:05
8	Batch Coal Feed to TR	11/7/96 at 05:00 to 06:00
9	Continuous Coal Feed to TR - Start-up Burner Shutdown During This Period	11/7/96 at 07:30 to 10:30
10	Batch Coal Feed to TR Resumed	11/7/96 at 10:30 to 14:30
11	Coal Feed Stopped, TR Pressure Temporarily Decreased to 70 psig to Light Start-up Burner, and Start-up Burner Lit	11/7/96 at 14:30 to 15:05
12	TR Start-up Burner Tripped	11/7/96 at 17:00
13	Test Ended	11/7/96 at 20:05

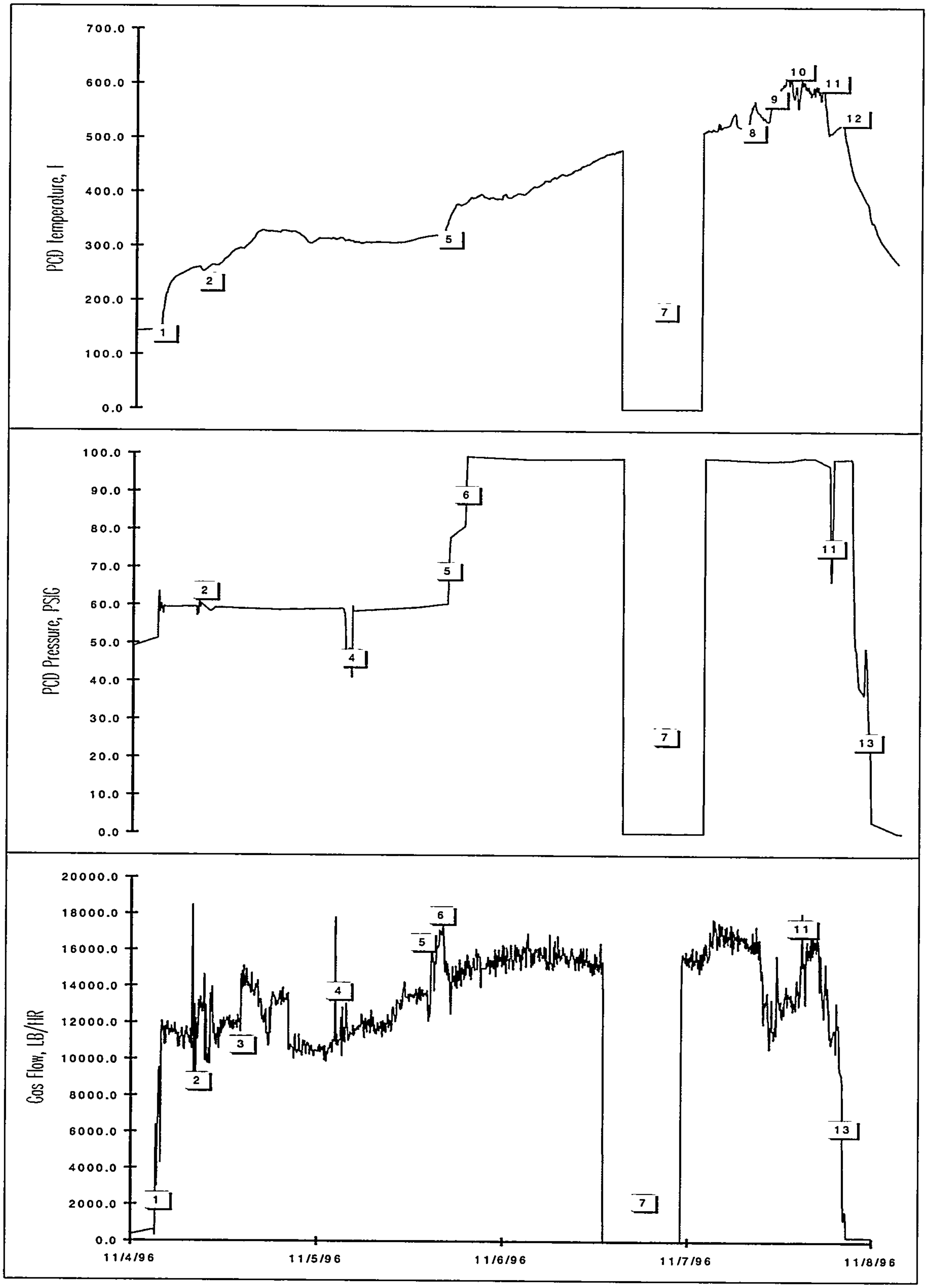

Figure 6.1.11-1 CCT2B Summary Information

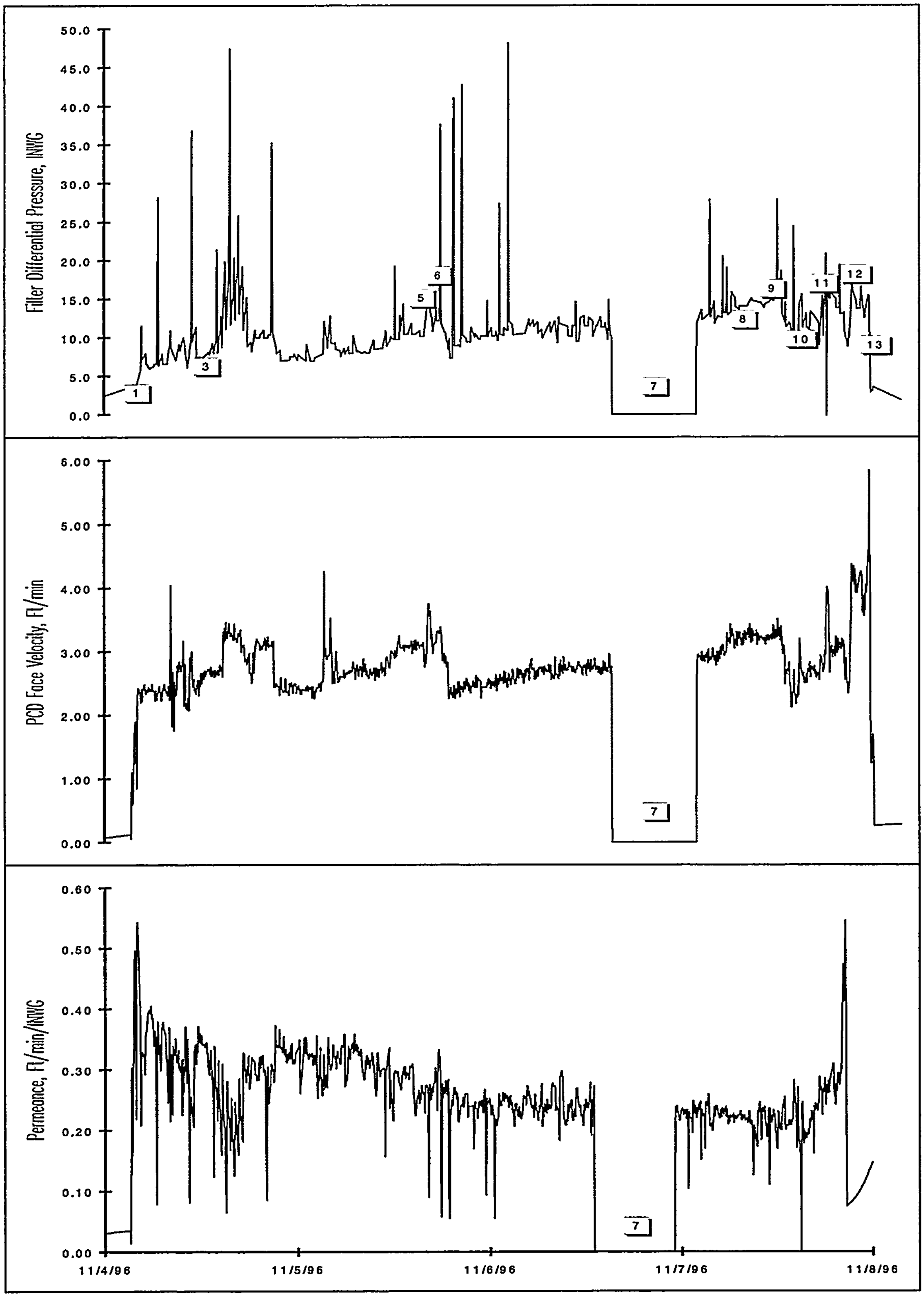

Figure 6.1.11-2 CCT2B Summary Information

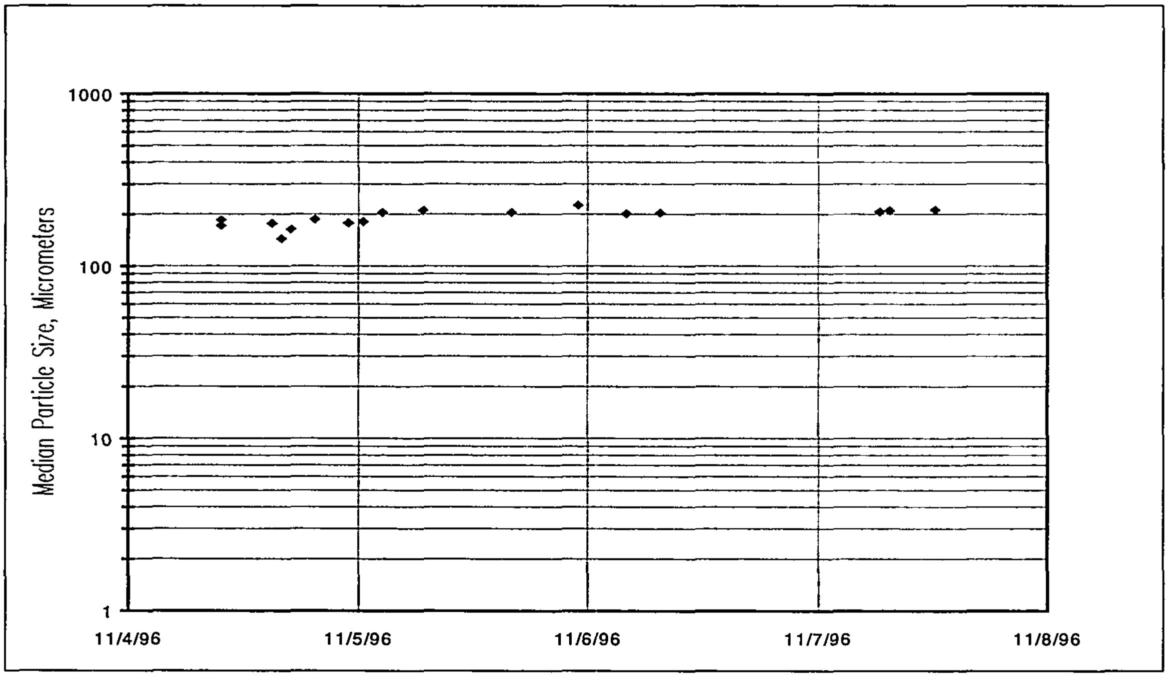

Figure 6.1.11-3 CCT2B PCD Hopper Samples

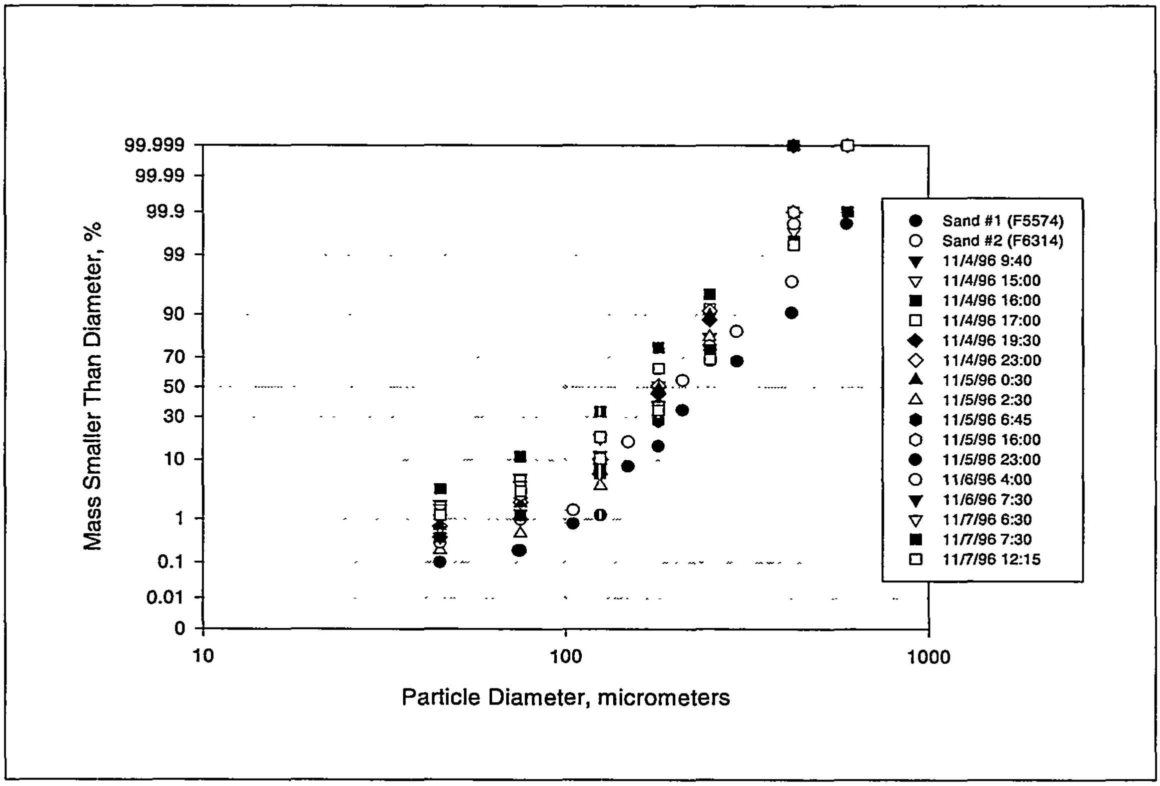

Figure 6.1.11-4 CCT2B Hopper Particle Size Distribution

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6.1.12 Test Run CCT2C

6.1.12.1 Summary

Test run CCT2C began on November 14, 1996, and ended on November 22, 1996. A coke breeze and Powder River Basin coal mixture was batch fed to the transport reactor (TR) for 9 hours between November 15 at 20:30 and November 16 at 07:20, and Alabama bituminous coal was fed for 146 hours between November 16 at 07:20 and November 22 at 14:00. Dolomite was fed periodically during the last 2 days of operation.

The operation of the PCD was stable with a few exceptions. The PCD ΔP remained very low (averaging below 15 inWG), which was probably due to the large particle size of the solids entering the filter for the majority of the run. The maximum operating temperature was approximately 630°F and the operating pressure ranged from 60 to 160 psig. The filter face velocity averaged 2.5 ft/min. The pulse pressure was 400 psig and the pulse ΔP trigger was 50 inWG. The filter ΔP setting did not trigger a pulse so the system was automatically pulsed every 30 minutes.

The TR was able to achieve long periods of stable operation. The periods of high carryover of particulate to the PCD were the result of start-up burner trips, coal feeder plugging, and inconsistent circulation due to bridging at the combustion heat exchanger outlet. Even during these periods of TR upset, there did not appear to be a solids level established in the PCD cone and the solids appeared to be removed by the ash removal system as fast as they entered the PCD.

SRI performed four sampling runs to test the operation of the inlet particulate sampling system and to collect particulate samples. All samples were collected in a bulk particulate sampler that isokinetically collects the particulate on a filter mounted within a cascade impactor shell. The measured particulate loadings and particle-size distributions are presented below along with a comparison with particle-size distributions measured on samples taken from the PCD cone.

Test conditions for this run are listed in tables 6.1.12-1 and -2. Data from this run are shown in figure 6.1.12-1.

6.1.12.2 Test Objectives

The primary objectives of test run CCT2C were:

- To support the TR/PCD start-up activities and gain experience operating the PCD.

- To establish the operability of the particulate sampling system installed at the PCD inlet.

- To determine the total particulate loading in the flue gas entering the PCD under various operating conditions and to compare the measured loadings with loadings estimated from the rate of ash removal from the PCD cone.

- To collect in situ particulate samples for subsequent particle-size analysis in the laboratory and to compare the particle-size distributions of the in situ samples with those of the PCD cone samples.

6.1.12.3 Observations/Events

A. Start-Up — November 14 at 13:00. The reactor system was checked for leaks up to 300 psig reactor pressure. Instrument purges were set and the start-up burner pilot was lit at 10:00. Sand was used as makeup for the reactor bed level.

B. The PCD backpulse system was started at 11:00.

C. First Sample by SRI — November 15 at 13:30. The primary purpose for the first sample was to check out the sampling procedures. During the sample run, the TR was not under steady-state conditions and the solids carryover to the PCD was continually increasing.

D. TR Pressure Increased to 100 psig — November 15 at 17:00. While increasing reactor pressure, the TR team experimented with increasing the riser velocity in an attempt to increase the disengager/cyclone efficiency and reduce carryover of solids to the PCD. There was an improvement in solids carryover for several hours.

E. Began Feeding Coke Breeze and PRB Coal Mixture — November 15 at 20:40. The coke breeze and PRB coal mixture feeding, using the limestone feeder was started.

F. Main Compressor Tripped — November 15 at 23:00. The main air compressor tripped which resulted in several start-up burner trips. The main air compressor was placed on manual control.

G. Began Feeding Alabama Bituminous Coal — November 16 at 14:30. Solids feed to the TR transitioned from the coke breeze/PRB mixture to coal. Various upsets in the TR increased carryover of particulate to the PCD, but the ash removal system was able to prevent accumulation of solids in the PCD cone. The PCD performance remained smooth as evidenced by the filter differential pressure (figure 6.1.12-2).

H. Main Compressor Tripped — November 16 at 22:00. The fluidizing air flow in the cyclone dipleg was optimized and the amount of carryover was greatly reduced. However at 22:00, the main air compressor surged. This caused the start-up burner and coal feeder to trip and all fluidization air to the TR was temporarily lost.

I. Intermittent Coal Feed — November 16 through November 18. Coal feed to the TR was resumed but feed was intermittent due to three primary causes:

- The start-up burner tripped several times either due to low propane flow or low air flow.

- Coal was being fed into the TR via the limestone feeder and it plugged several times.

- Coal was fed batchwise via the coal feeder in order to maintain reactor temperatures between 1,550 and 1,600°F.

Once the process stabilized and the reactor pressure was increased to 160 psig, coal feed was generally consistent for the remainder of the run.

The operation of the PCD was stable with a few exceptions. Carryover of solids from the TR was high throughout most of the period due to increased reactor feed rates and circulation of the combustion heat exchanger. There was no indication that a solids level was established in the PCD cone as they were being carried over from the TR. The PCD ΔP remained very low at about 10 inWG primarily because of the relatively large particle size.

J. TR Pressure Increased to 160 psig — November 17 at 23:00. The TR engineers changed the flow rate of the fluidization air directly under the cyclone. This decreased the carryover to the PCD but other system upsets negated the possible benefits.

K. Cyclone Spoiling Test — November 20 at 15:50. The primary cyclone was spoiled to determine the effect on solids carryover to the PCD. At the time of spoiling, the solids carryover to the PCD was lower than it had been for a few days and no increase in the solids carryover to the PCD was noticed. The cyclone spoiling tests were completed in about 1 hour.

L. Dolomite Feed Started — November 21 at 08:00. Seventeen-hundred pounds of dolomite were fed to the TR from 0800 until 2300; carryover to the PCD was higher than desirable (greater than 10,000 ppm) but the ash removal system was able to remove the solids without incident. There was a sharp decrease in the particle size distribution of the samples removed from the PCD cone during dolomite feed. Without the dolomite, the mass median particle diameter (measured by sieve analysis) ranged from 200 to 300 micrometers. With the dolomite feed the median particle diameter was 40 to 60 micrometers. However, this change in particle size did not impact the PCD differential pressure.

M. Test Ended — November 22 at 14:00. An orderly shutdown of the TR train was initiated at 14:00 after stopping coal feed to the reactor. The shutdown was required due to the frequent cycling of the coal feeder required to maintain the feed rate.

6.1.12.4 Analysis of Solid Samples

During CCT2C, four sampling runs were performed to test the operation of the inlet particulate sampling system and to collect particulate samples. All samples were collected in a bulk particulate sampler described in previous SRI reports. This sampler isokinetically collects all particle sizes on a filter mounted within the cascade impactor shell. The particulate samples were desiccated and weighed to determine the total particulate loadings, then subjected to laboratory particle-size analysis. The measured particulate loadings and particle-size distributions are presented below, along with a comparison with particle-size distributions measured on samples taken from the PCD cone.

Sampling Parameters And Process Conditions

In general, the TR operation was unstable during the sampling runs and the carryover of sand from the reactor loop was greater than expected. These conditions produced very high particulate loadings which tended to overload the precollector, resulting in the presence of large particles in the filter catch. This carryover of large particles made it impossible to draw conclusions about the particle sizes collected in situ, but it had no effect on the measurement of the total particulate loading. Table 6.1.12-3 summarizes the sampling rates, sampling times, and process conditions during all of the sampling runs.

Measured Particulate Loadings

The measured particulate loadings are summarized in table 6.1.12-4. The loadings generally exceeded the PCD design loadings, but the decrease in loading throughout the test reflected the success of various efforts to reduce the loss of bed material from the transport reactor. It should be noted that the transport reactor was being fired with propane during the first run, so the particulate matter collected reflects the bed material that was carried out of the transport reactor.

The measured particulate loadings could not be rigorously compared to the loadings determined from the rate of ash discharge from the PCD cone. However, estimates made from the ash removal system performance suggested the measured particulate loadings were reasonable.

Particle-Size Analysis

The in situ particulate samples were subjected to laboratory particle-size analysis along with samples collected from the PCD cone during roughly the same time intervals. The size measurements were made using a combination of sieves and a Leeds and Northrup Microtrac X-100 particle-size analyzer, although a few samples were measured with only the Microtrac. The sieves were used to remove and size-segregate (the largest) particle fractions, while the Microtrac measured the distribution of finer particles that fell through the last sieve. The Microtrac could not be used alone when large quantities of sand were present in the samples because of settling problems with the larger particles.

Figure 6.1.12-3 shows the composite size distribution resulting from the combination of the sieve and Microtrac measurements on one of the in situ samples. In this case, the sieve measurement (open circles) included 7 size cuts from 30 to 120 mesh corresponding to particle sizes from 600 to 125 μm. The Microtrac data for the particles that passed through the last sieve (nominally smaller than 125 μm) is represented by the open squares. The dashed lines on the figure are extrapolations of the slopes of the last two data points of each measurement system's range. The difference in slope where the two data sets coincide indicates there are some problems with this method of producing a composite distribution. This will be evaluated further below.

Since the sample shown in figure 6.1.12-3 did not contain an excessively high concentration of sand or other large particles, a portion of it was run through the Microtrac without sieving. These results are compared to the composite size distribution in figure 6.1.12-4 and indicate fairly good agreement between the general shape of the Microtrac and composite distributions. However, the median particle sizes obtained from the two distributions are different by a factor of 2 (125 μm for Microtrac versus 250 μm for the composite). The Microtrac-only distribution also suggests the dip in the composite distribution at the intersection of the two measurement systems may be artificially induced.

Figure 6.1.12-5 compares the two Microtrac measurements (entire distribution and minus 120 mesh) on a differential mass basis rather than cumulative percentage basis. Viewed in this way, the problem with the composite distribution becomes obvious. Based on the Microtrac analysis, the sieve is undercutting its rated size of 125 μm and removing particles all the way down to 20 μm. The reduced concentration of particles in the 20- to 125-μm range leaving the sieve is responsible for the dip in the composite distribution. However, this does not necessarily indicate a problem with the sieve measurement, but could be related to differences in the characteristics of the two measurements.

The size data measured on all four of the in situ samples are shown in figures 6.1.12-6 and -7 as cumulative percentage and cumulative mass distributions, respectively. These data illustrate the change in size distribution during the period of the combustor run. On November 15, 1996, the combustor was operating on propane with only sand circulating in the reactor loop. The in situ sample collected at the PCD inlet on that date (MWKIMT-1) shows a coarse size distribution. The other three samples were obtained during coal combustion and indicate concentrations of fine fly ash particles two orders of magnitude higher than with sand alone. The sample on November 18, 1996, indicated carryover of bed material was still higher than desired, while by November 19, 1996, conditions had stabilized with lower carryover.

Dust samples were collected from the PCD cone several times each day of the coal combustion run. Size distributions measured on selected PCD cone samples spread over the test period are compared with one of the in situ samples in figure 6.1.12-8. One would expect the cone samples collected before coal combustion began would be very coarse. However, with one exception, all of the cone samples are dominated by large particles and have a much coarser size distribution than indicated by the in situ samples. This may be caused by the immediate and continuous gravitational settling of large particles into the PCD cone, while the small particles that are initially collected on the filters fall into the cone only after a cleaning pulse. This segregation of particle sizes by the PCD would make obtaining a representative cone sample of the inlet dust very difficult.

Ash Chemical Analysis

The chemical analysis of ash samples removed from the PCD cone is shown in figure 6.1.12-9. The most interesting change in the analysis occurred on November 21, 1996, when the dolomite feed started (event 11). There was a significant increase in both the calcium and magnesium concentration of the ash, indicating that dolomite was being carried over from the TR to the PCD.

6.1.12.5 Run Outcome

This test run demonstrated stable PCD operation and the ash removal system's ability to remove large quantities of particulate while burning coal. The particulate loading to the PCD exceeded 10,000 ppm for most of the run with excursions up to 70,000 ppm. However, due to the large particle size, the filter ΔP remained constant (regardless of the loading). Visual inspection of the candles after the test run confirmed no elements had been damaged nor were there any visible signs of ash bridging.

The test objectives for CCT2C were met with the successful commissioning of the SRI particulate sampling probe. The operability of the sampling system was established and particulate loading was measured under four different operating conditions. The results of the samples taken indicate the current method of sampling from the PCD cone may not yield representative samples. The cone samples appear to have a much coarser size distribution than samples collected in situ, indicating a possible size segregation within the PCD. Future testing will further investigate the possibility of size segregation.

Table 6.1.12-1

CCT2C Run Statistics

Start Time	11/14/96 at 13:00
End Time	11/22/96 at 18:25
Coal Type	Alabama bituminous
Hours On Coal	146
Sorbent Type	Dolomite
TR Bed Material	Sand
Number of Candles	91
Candle Layout No.	2
Filtration Area	˜265 ft^2
Pulse Pressure	400 ± 50 psi
Pulse DP Trigger	50 inWG
Pulse Time Trigger	30 minutes
Pulse Valve Open Time	0.2 seconds

Table 6.1.12-2

CCT2C Major Events (Refer to Figures 6.1.12-1 and 6.1.12-2)

Event	Description	Time
1	Test Started	11/14/96 at 13:00
2	First Sample by SRI	11/15//96 at 13:30
3	TR Pressure Increased to 100 psig	11/15//96 at 17:00
4	Began Feeding Coke Breeze and PRB Coal Mixture	11/15//96 at 20:40
5	Main Compressor Tripped	11/15//96 at 23:00
6	Began Feeding Alabama Bituminous Coal	11/16//96 at 14:30
7	Main Compressor Tripped	11/16/96 at 22:00
8	Intermittent Coal Feed	11/16 through 11/17
9	TR Pressure Increased to 160 psig	11/17/96 at 23:00
10	Cyclone Spoiling Test	11/20/96 at 15:50
11	Dolomite Feed Dtarted	11/21/96 at 08:00
12	Test Ended	11/22/96 at 18:25

Table 6.1.12-3

Sampling Parameters and Process Conditions

Run No.	MWKIMT-1	MWKIMT-2	MWKIMT-3	MWKIMT-4
Date of run	11/15/96	11/18/96	11/19/96	11/21/96
PI time at start of run	13:22	13:30	10:42	10:01
Duration of run, min	15	1	30	20
Sampling rate, acfm	0.48	0.21	0.31	0.30
Transport reactor fuel	Propane	Coal	Coal	Coal
Process pressure, psig	64	160	159	159
Process temperature, °F	447	586	602	591
Flue gas oxygen, %	16.5	12.5	13.9	13.9
Flue gas carbon dioxide, %	2.1	5.0	5.8	5.6
Flue gas water vapor, %	2.9	6.0	2.0	1.4

Table 6.1.12-4

Measured Particulate Loadings

	Particulate Loading,
Run No.	Ppm(w)
MWKIMT-1	68,968
MWKIMT-2	37,780
MWKIMT-3	12,145
MWKIMT-4	15,808

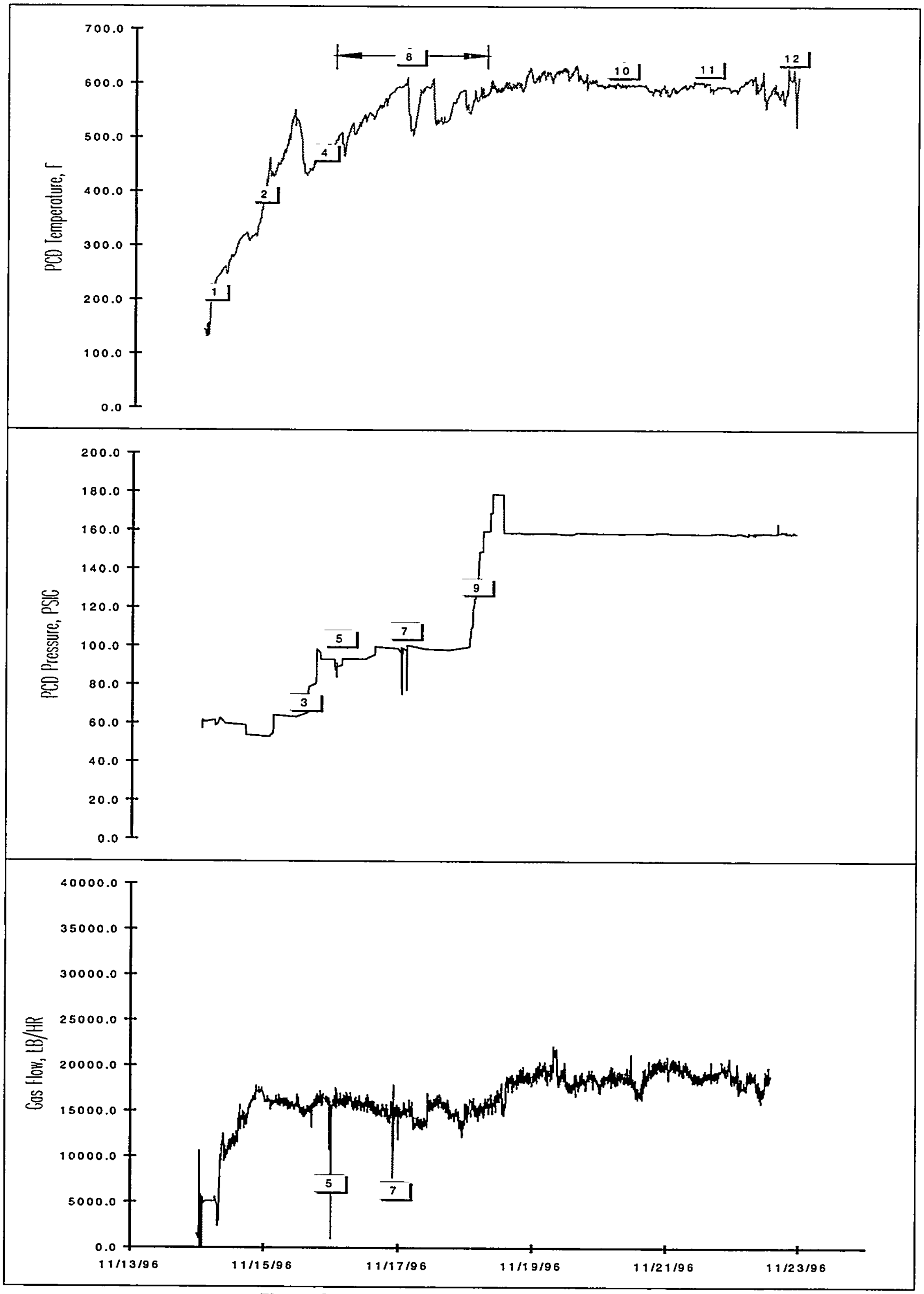

Figure 6.1.12-1 Run CCT2C Summary Information

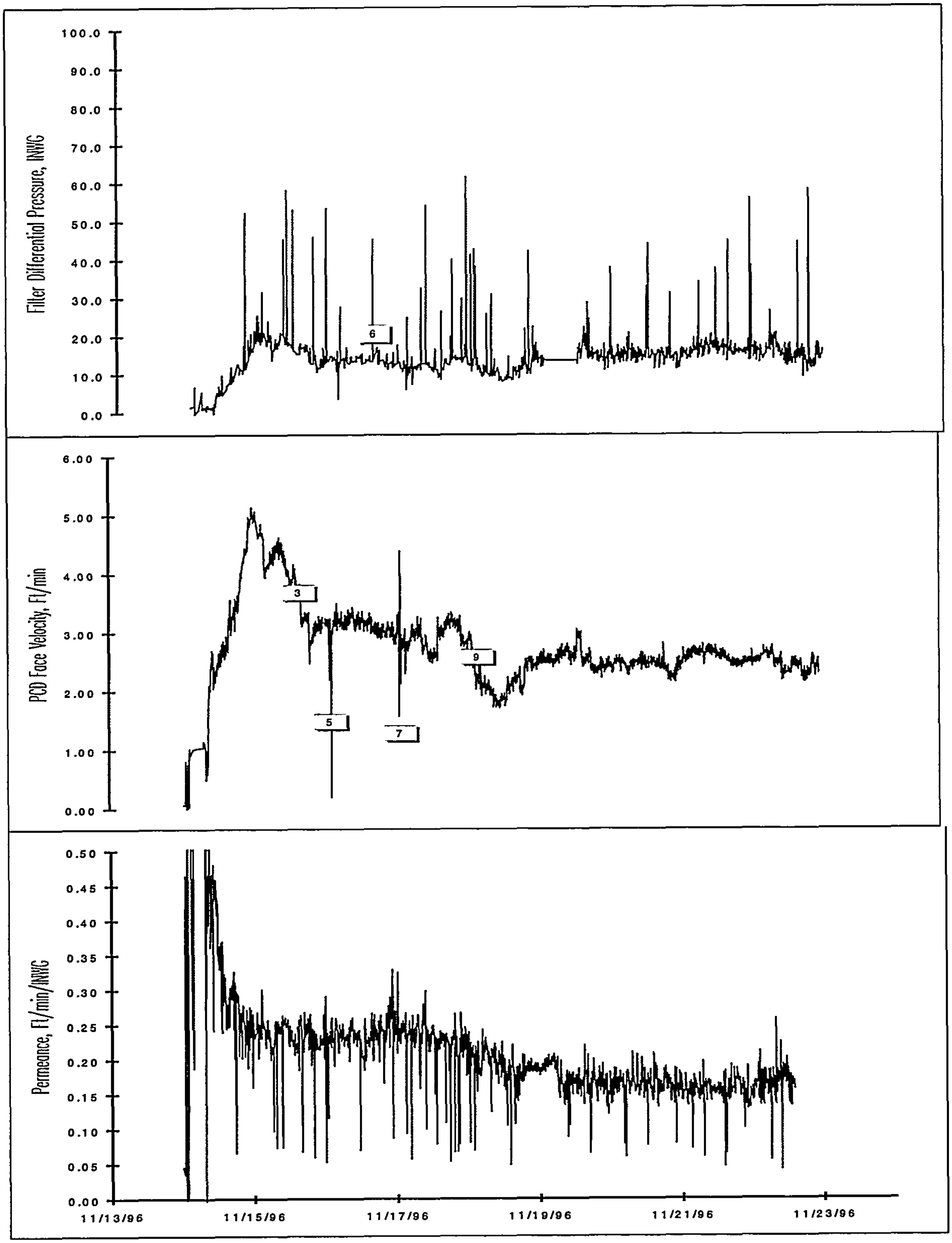

Figure 6.1.12-2 Run CCT2C Summary Information

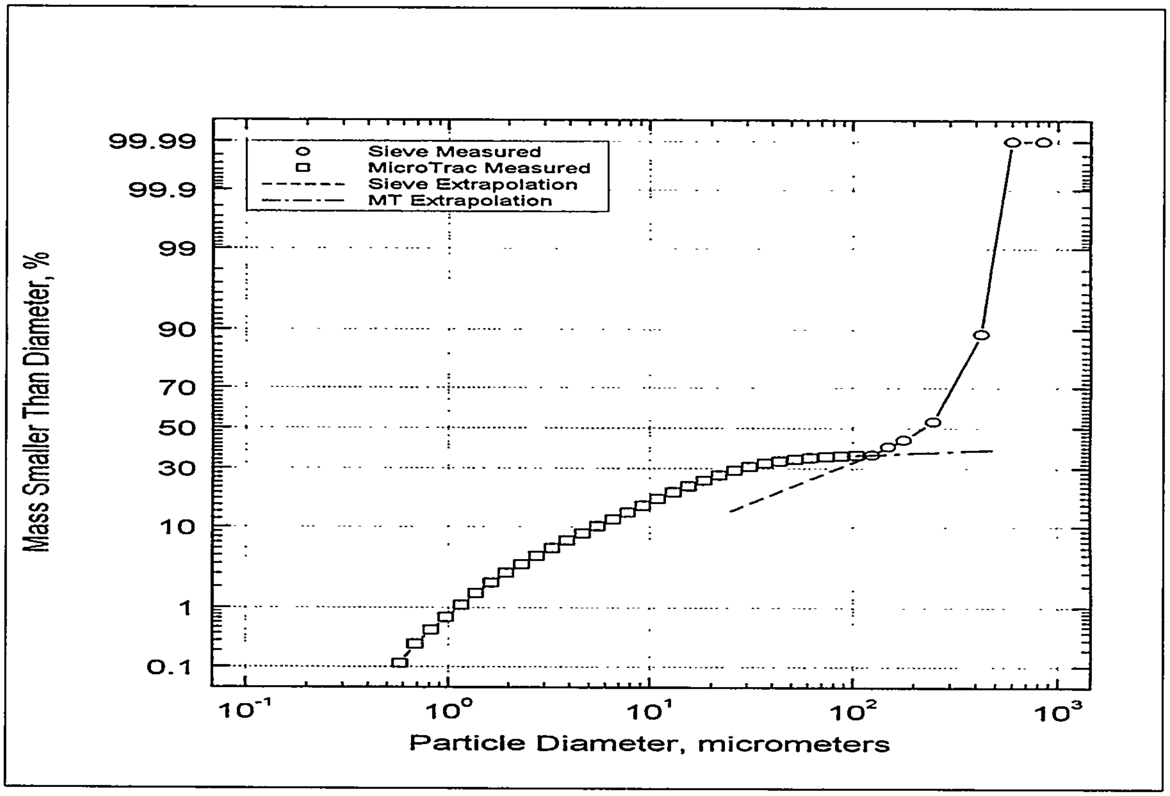

Figure 6.1.12-3 PCD Inlet Particle Size Distribution From Combined Sieve and Microtrac X-100 Measurements on In Situ Sample MWKIMT-3

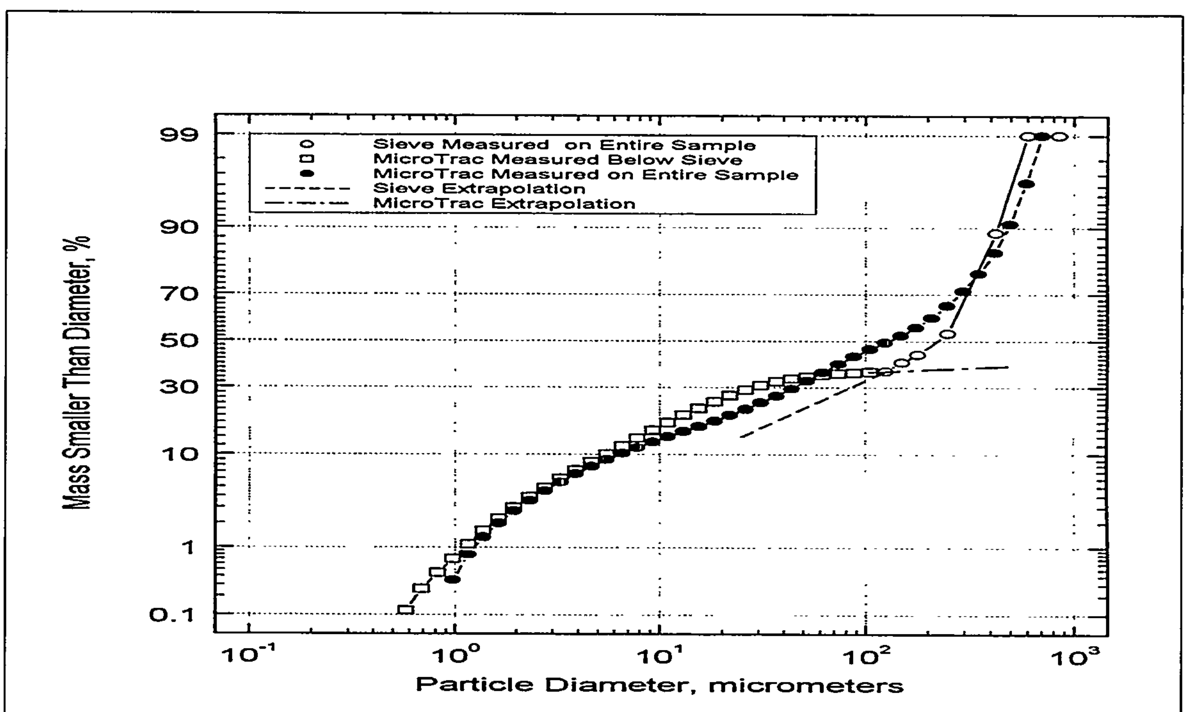

Figure 6.1.12-4 Microtrac Alone and Combined Sieve and Microtrac Measurements

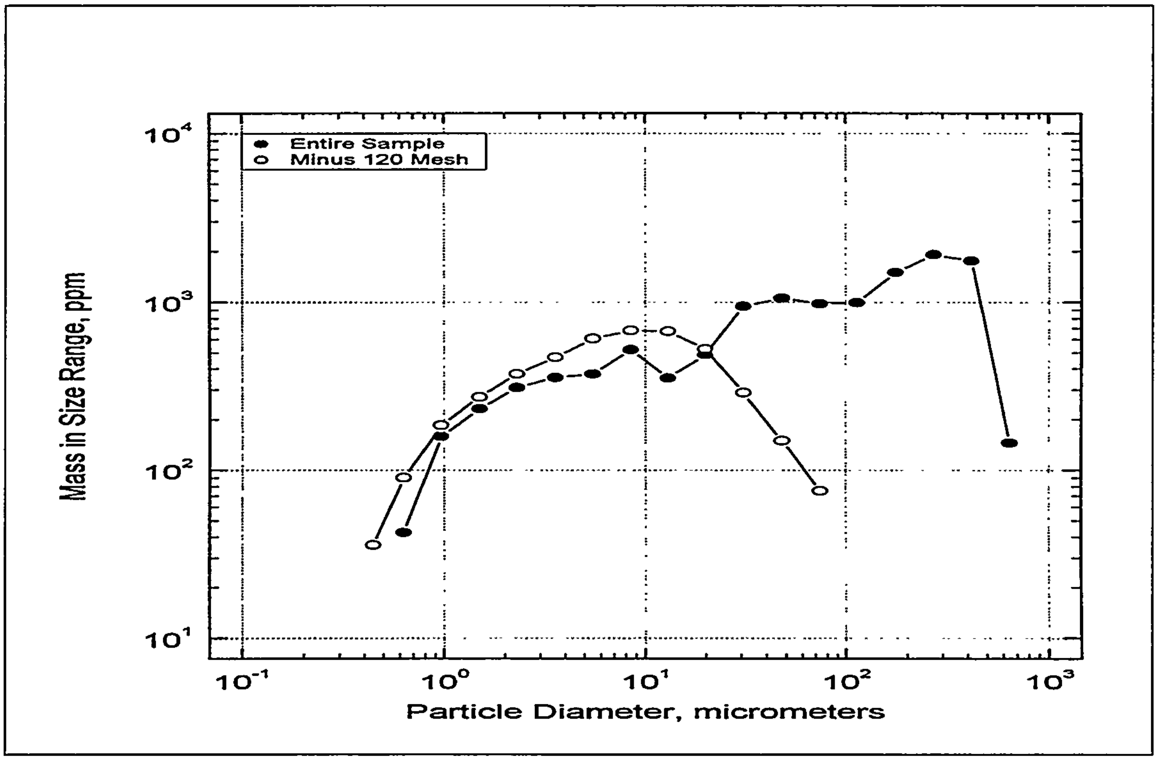

Figure 6.1.12-5 Comparison of Microtrac Measured Size Distributions for Complete Sample and Particles Smaller Than 120 Mesh

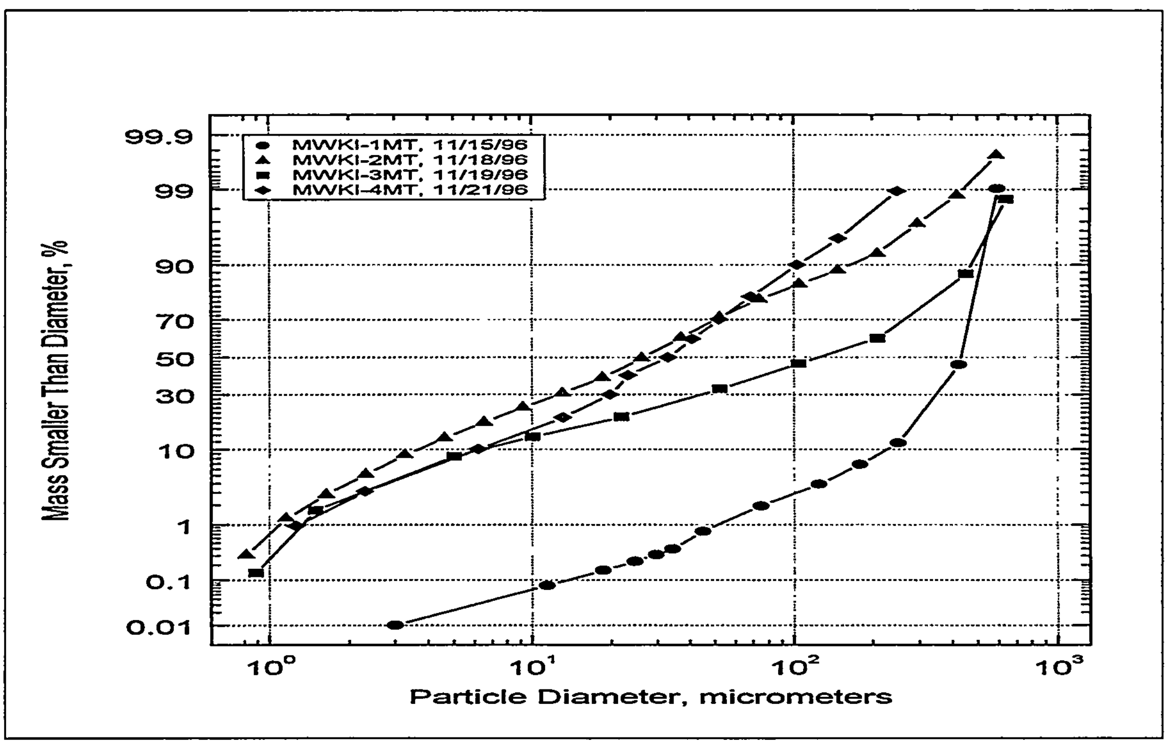

Figure 6.1.12-6 Comparison of Cumulative Percent Particle Size Distributions for All Isokinetically Collected Samples

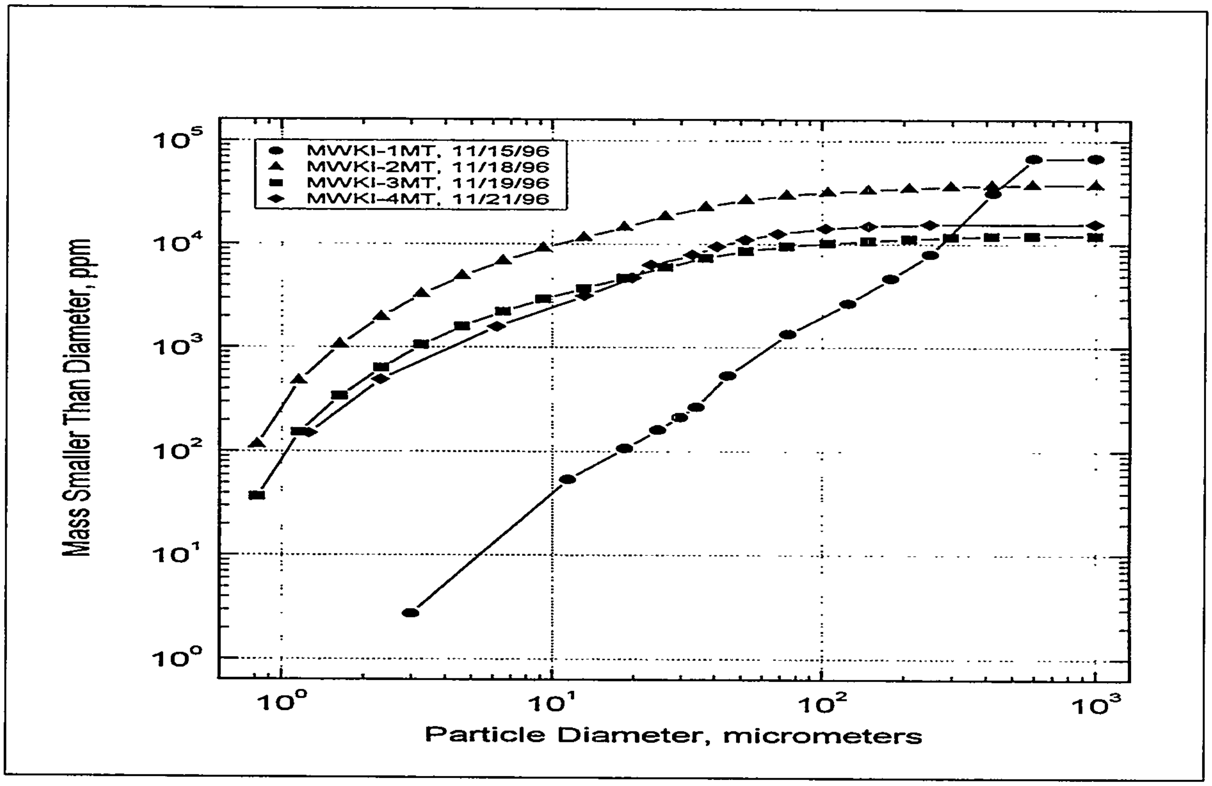

Figure 6.1.12-7 Comparison of Cumulative Mass Size Distribution For All Isokinetically Collected Samples

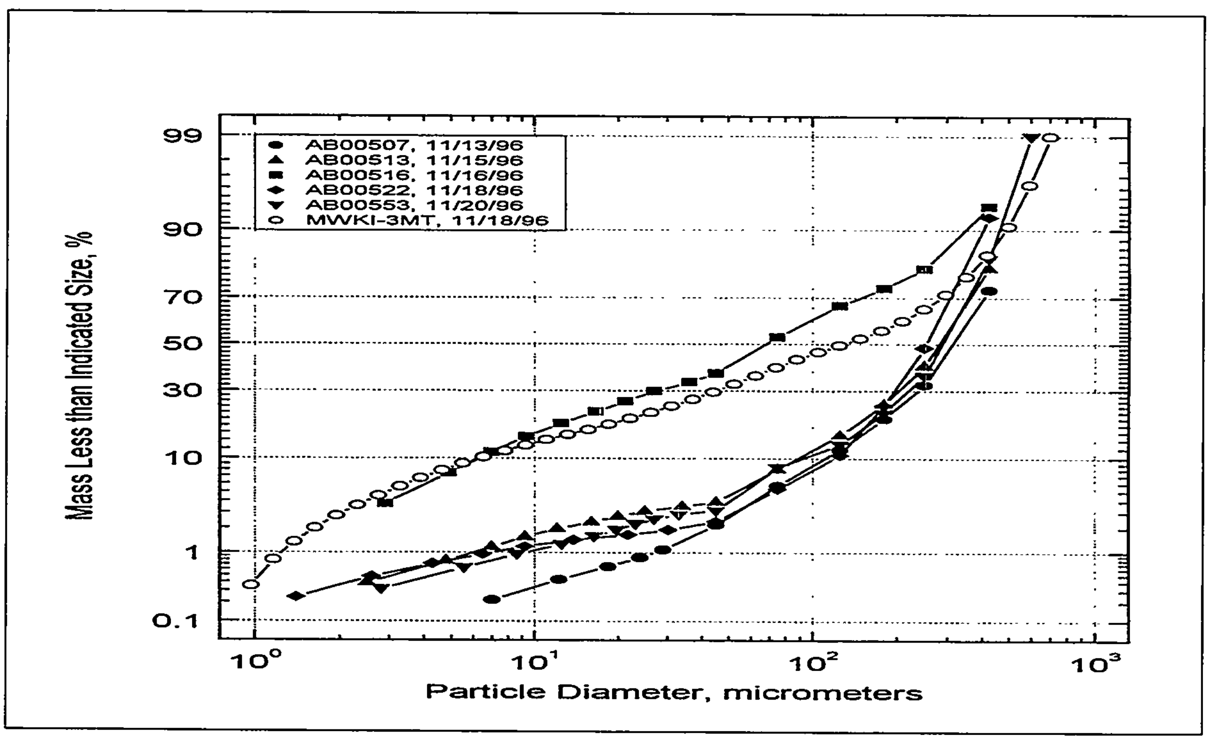

Figure 6.1.12-8 Comparison of Size Distributions From PCD Inlet In Situ Sample and PCD Cone Samples

PSDF\1996\6.1.12figs

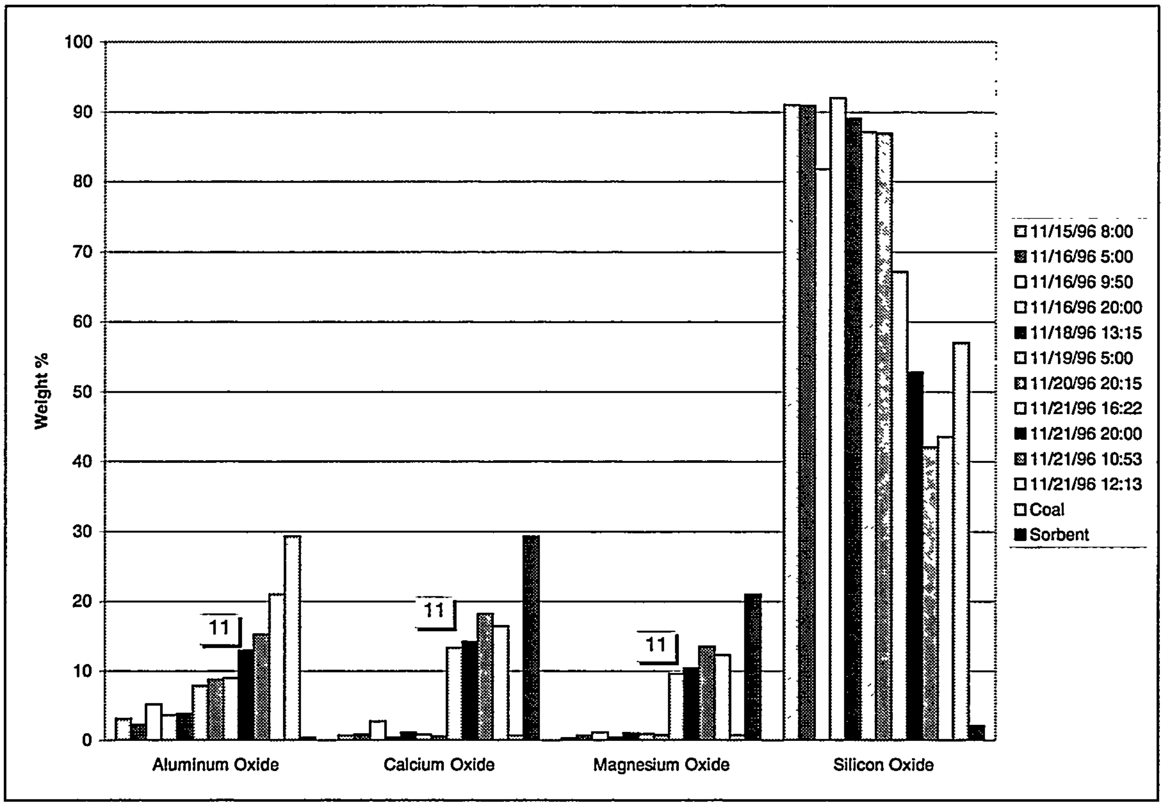

Figure 6.1.12-9 PCD Cone Ash Analysis (Major Constituents)

6.1.13 Coal Combustion Characterization Test CCT3

6.1.13.1 Run Summary

Coal combustion characterization test CCT3 was conducted on December 12, 1996, for the purpose of analyzing the solid separation efficiency of the transport reactor (TR). The need for this test was recognized during the CCT2 tests when it appeared that the particle size of the solid carryover to the PCD from the TR was the same as that of the reactor bed material. This indicated that the reactor separation mechanism, which functions to remove solids for recirculation from the reactor outlet gas stream, was not functioning properly. CCT3 was conducted in a series of five separate tests, hereafter referred to as reactor solid separation efficiency (RSSE) tests. During these tests, various TR operating parameters (e.g., solids circulation rate, solids feed rate to the reactor, solids residence time in the reactor, and combustion heat exchanger (CHE) operation) were varied to determine the effect of the variations on TR solid separation efficiency.

The effects of CCT3 on PCD performance were similar to those of the CCT2 tests. There was definite carryover of solids to the PCD but due to the relatively large size of the particles, no appreciable increase in filter differential pressure (ΔP) was observed. The maximum operating temperature in the PCD for CCT3 was around 340°F and the pressure remained at about 60 psig throughout the test. The baseline ΔP never exceeded 30 inWG and the face velocity was 5 ft/min or below. Filter pulse cleaning parameters were not changed from the CCT2 settings for this test.

Test conditions for this run are listed in tables 6.1.13-1 and -2. Data from this run are shown in figures 6.1.13-1 and -2.

6.1.13.2 Test Objective

The primary test objective for PCD operation was to support TR operation in determining the solid separation efficiency of the reactor.

6.1.13.3 Observations/Events

A. Test Started — December 11 at 18:45. The main air compressor (MAC) was started on December 11 at 18:45 for the purpose of conducting CCT3. This, coupled with the effects of the primary gas heat exchanger, caused the PCD to reach its maximum operating temperature range of 300 to 350°F since no combustible material was added to the system during CCT3.

B. TR Solids Circulation Rate Increased to Start RSSE Test 1 — December 12 at 10:30. There was a considerable delay between starting the MAC and initiating the first RSSE test for several reasons. First, there were several leaks found in the reactor system that needed to be repaired. Also, it was desired to conduct the test during the day when most plant personnel would be available. Additionally, there were difficulties in operating the TR feed systems and these systems were needed to feed sand into the reactor. Finally, it was necessary to stabilize TR solids circulation at an acceptable carryover rate before increasing the circulation rate for the RSSE tests.

RSSE test 1 was initiated at 10:30 on December 12 by a decrease in reactor solids residence time that caused an increase in TR solids circulation. Sand feed to the reactor was started prior to this test and maintained during the test. An increase in solids carryover rate to the PCD was observed.

C. TR Solids Circulation Rate Increased to Start RSSE Test 2 — December 12 at 12:30. RSSE test 2 consisted of maintaining the same parameters as test 1. Solids carryover rate to the PCD approximately doubled from that of test 1 due to the increase of solids inventory in the TR.

D. TR Solids Circulation Rate Increased and CHE Vent Valve Closed to Start RSSE Test 3 — December 12 at 14:30. The feed rate of sand to the reactor was increased in RSSE test 3, which caused an increase in TR solids circulation rate. The same parameters were used as in test 2 except that the sand feed rate was increased and the process gas vent from the CHE was closed. Solids carryover rate to the PCD approximately tripled from that of test 2.

E. TR Solids Circulation Rate and Residence Time Increased to Start RSSE Test 4 — December 12 at 15:40. For RSSE test 4, the sand feed rate was increased further causing the circulation rate to increase by a factor of 5. However, the reactor solids residence time was increased, and the process gas vent from the CHE was reopened and remained open for Test 5. The effect of these changes was a substantial decrease in solids carryover rate to the PCD from the TR (back to about half of the rate of test 1).

F. TR Solids Circulation Rate Increased to Start RSSE Test #5 — December 12 at 16:40. Sand feed to the reactor was stopped for RSSE test 5. However, the reactor solids residence time was decreased back to that of the first three tests. The decreased residence time combined with the accumulation of solids from the previous four tests caused the TR solids circulation rate to approximately double from that of test 4. The result was that the carryover rate to the PCD increased substantially to about three times that of test 3 (which had previously been the maximum carryover rate).

G. Test Ended — December at 12 at 19:15. All tests were completed, so the TR was depressurized and the MAC was shutdown to end CCT3.

6.1.13.4 Analysis of Solid Samples

Sieve analyses were performed on solid samples from the TR and the PCD solids removal hopper and the results are presented in figures 6.1.13-3 through -5. Figure 6.1.13-3 shows the results of samples taken during RSSE tests 1, 2, and 3, with sample times of 12:30, 14:30, and 15:40, respectively, on December 12. Figure 6.1.13-4 shows the samples taken during tests 4 and 5, with sample times of 16:30 and 18:00, respectively. Both plots imply there was some particle size separation occurring in the reactor. However, as shown in figure 6.1.13-4, there appeared to be little size separation of particulate between the TR and the PCD during RSSE test 4, the test during which there was the least carryover to the PCD from the TR. Figure 6.1.13-5 shows the median particle size of the PCD hopper samples were between 200 and 400 µm, implying that the particle size of the carryover to the PCD was still quite large throughout CCT3.

6.1.13.5 Run Outcome

Several conclusions could be hypothesized based on CCT3. TR solids residence time appeared to substantially impact solids carryover rate to the PCD (i.e., solids retention rate in the TR). Another slightly less influential factor that influenced carryover rate was TR solids circulation rate, which was affected by solids feed rate and residence time. The solids size separation efficiency in the TR was shown to be better than previously experienced but still not up to design specification, as seen by the large size of the particulate collected by the PCD. The PCD performed as required and no damage was discovered upon subsequent internal inspection.

Table 6.1.13-1

CCT3 Run Statistics

Start Time	12/11/96 18:45
End Time	12/12/96 19:15
Coal Type	No Coal Feed
Hours On Coal	No Coal Feed
Sorbent Type	No Sorbent Feed
TR Bed Material	Sand
Number of Candles	91
Candle Layout No.	2
Filtration Area	~265 ft^2
Pulse Pressure	400 ±50 psig
Pulse DP Trigger	50 inWG
Pulse Time Trigger	30 minutes
Pulse Valve Open Time	0.2 seconds

Table 6.1.13-2

CCT3 Major Events (Refer to Figures 6.1.15-1 and -2)

Event	Description	Time
1	Test Started	12/11/96 at 18:45
2	TR solids circulation rate increased to start RSSE. Test 1	12/12/96 at 10:30
3	TR solids circulation rate increased to start RSSE. Test 2	12/12/96 at 12:30
4	TR solids circulation rate increased and CHE vent valve closed to start RSSE. Test 3	12/12/96 at 14:30
5	TR solids circulation rate and residence time increased to start RSSE. Test 4	12/12/96 at 15:40
6	TR solids circulation rate increased to start RSSE. Test 5	12/12/96 at 16:40
7	Test Ended	12/12/96 at 19:15

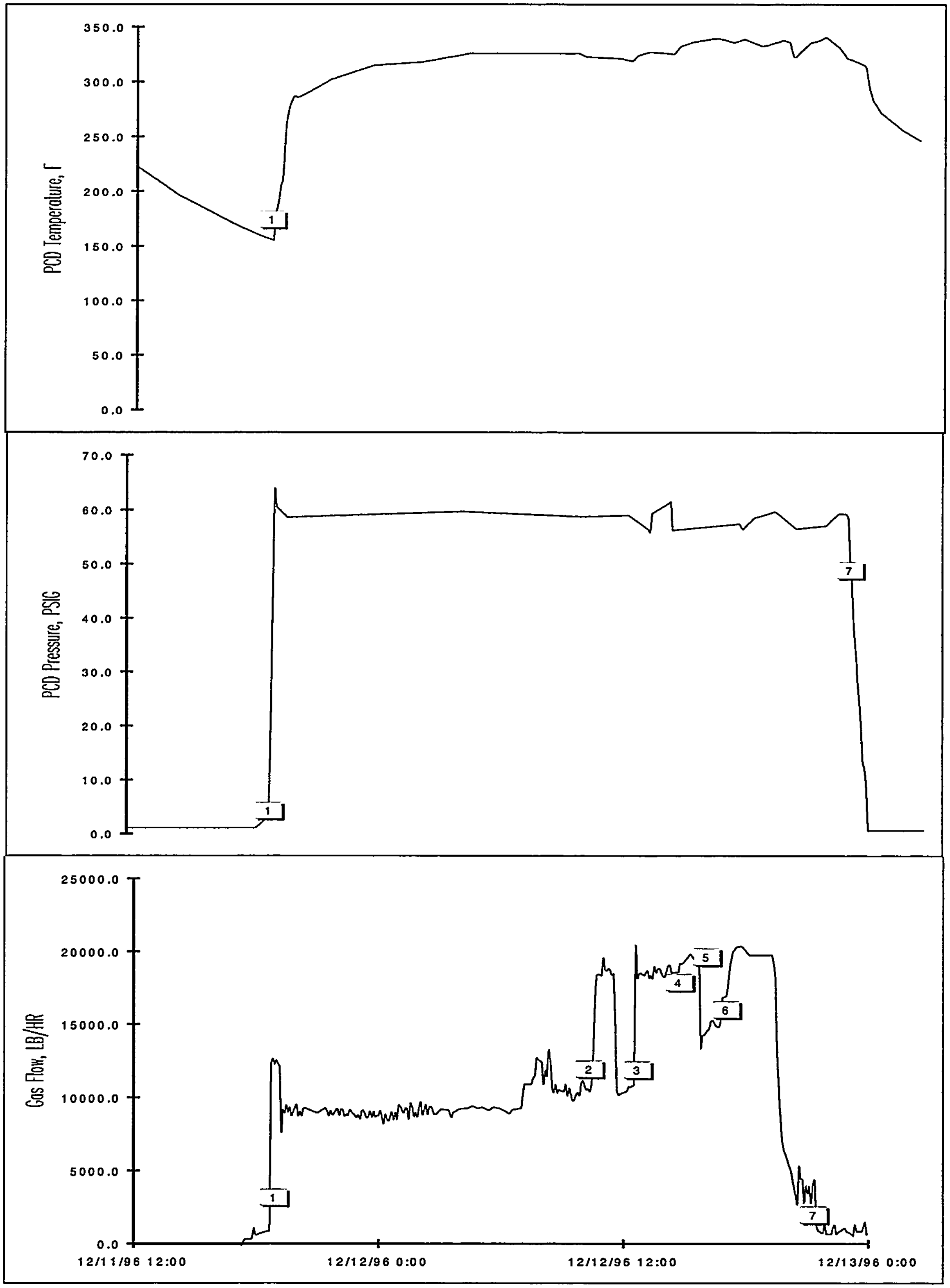

Figure 6.1.13-1 CCT3 Summary Information

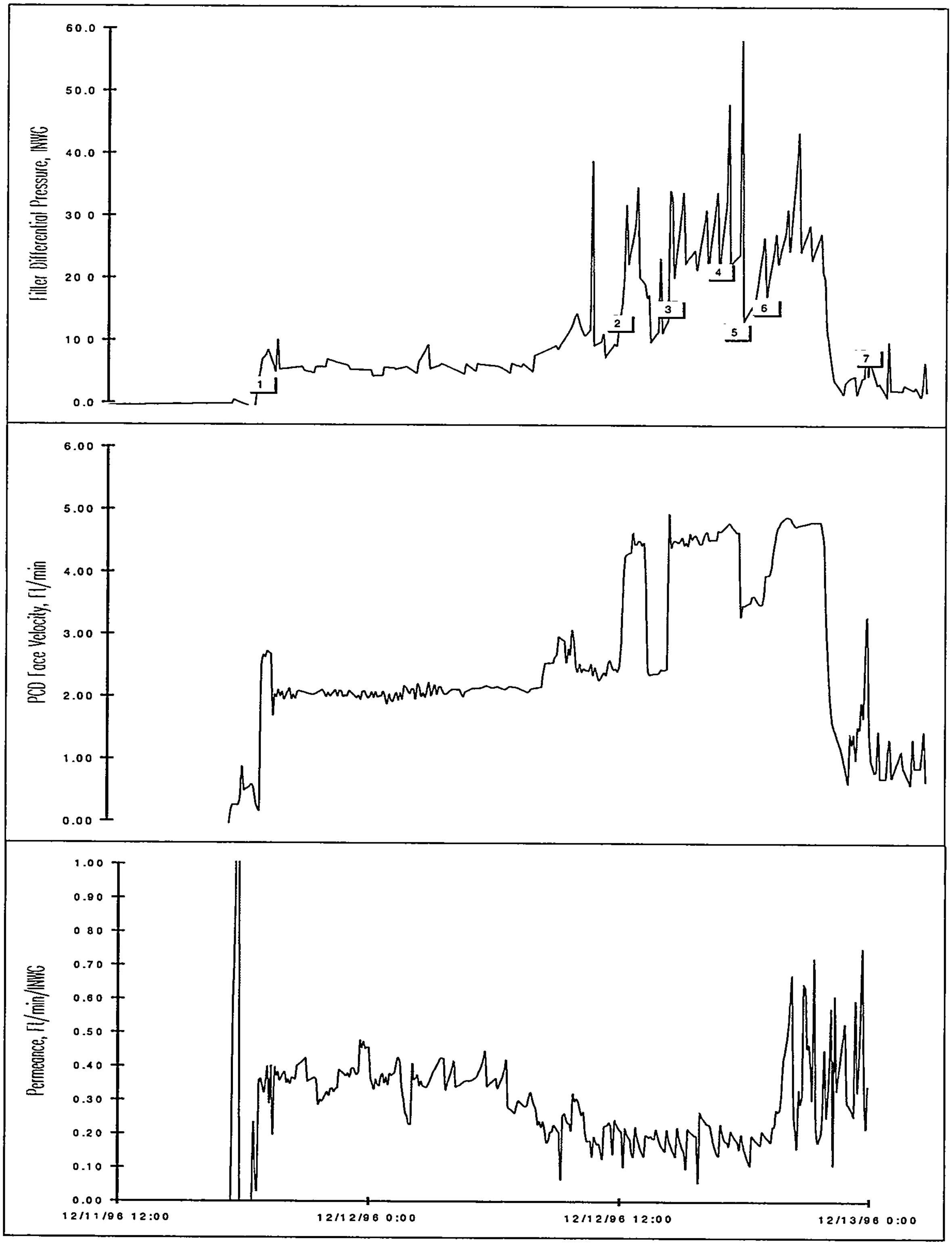

Figure 6.1.13-2 CCT3 Summary Information

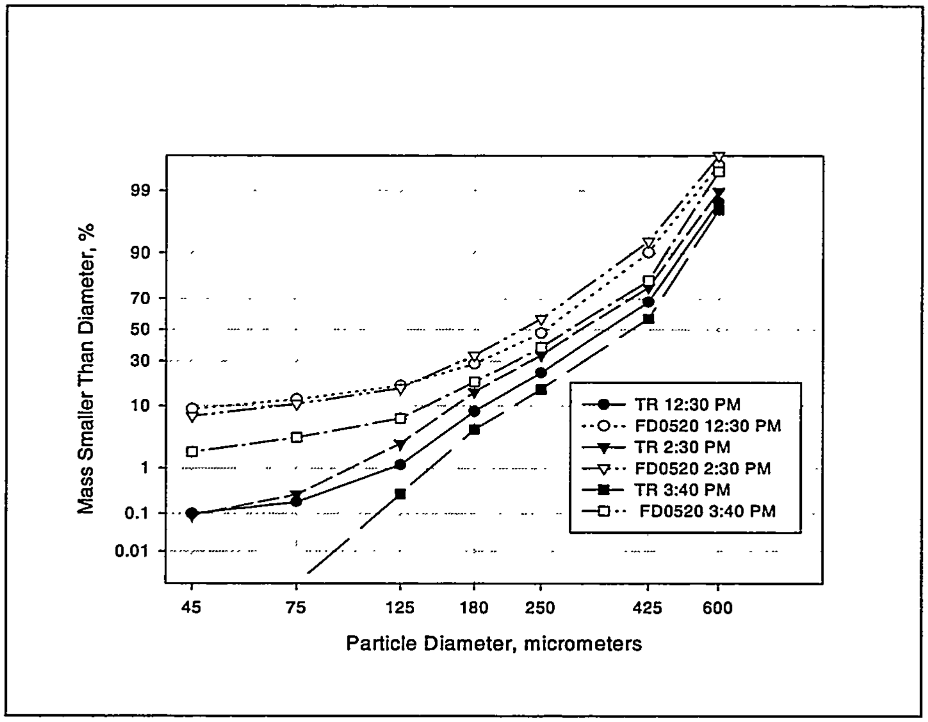

Figure 6.1.13-3 CCT3 Hopper Particle Size Distribution - December 1996 (Reactor Solid Separation Efficiency Tests 1, 2, and 3)

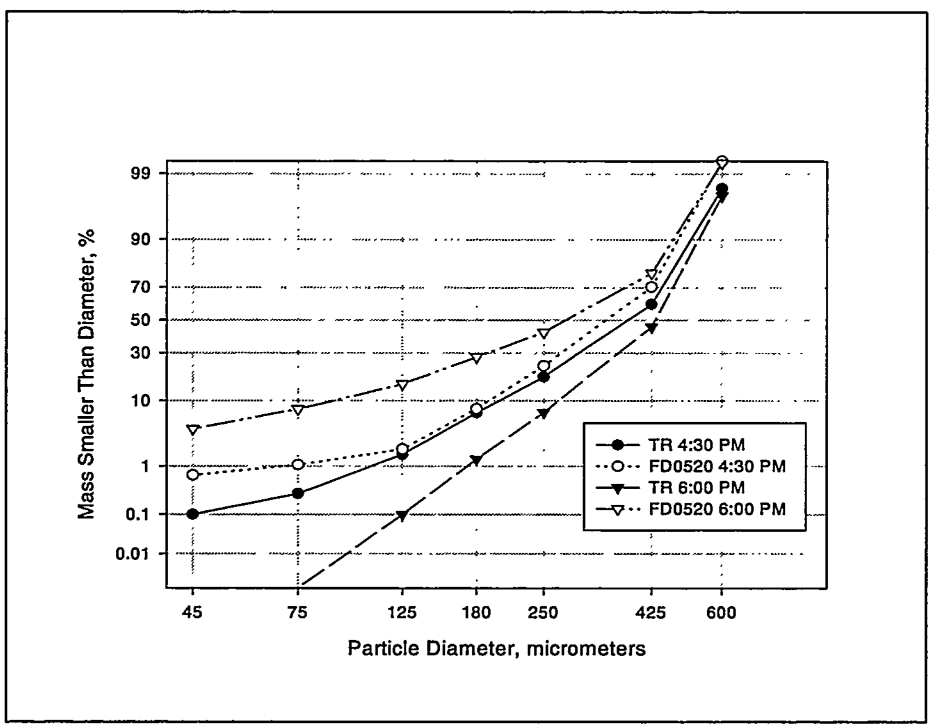

Figure 6.1.13-4 CCT3 Hopper Particle Size Distribution - December 1996 (Reactor Solid Separation Efficiency Tests 4 and 5)

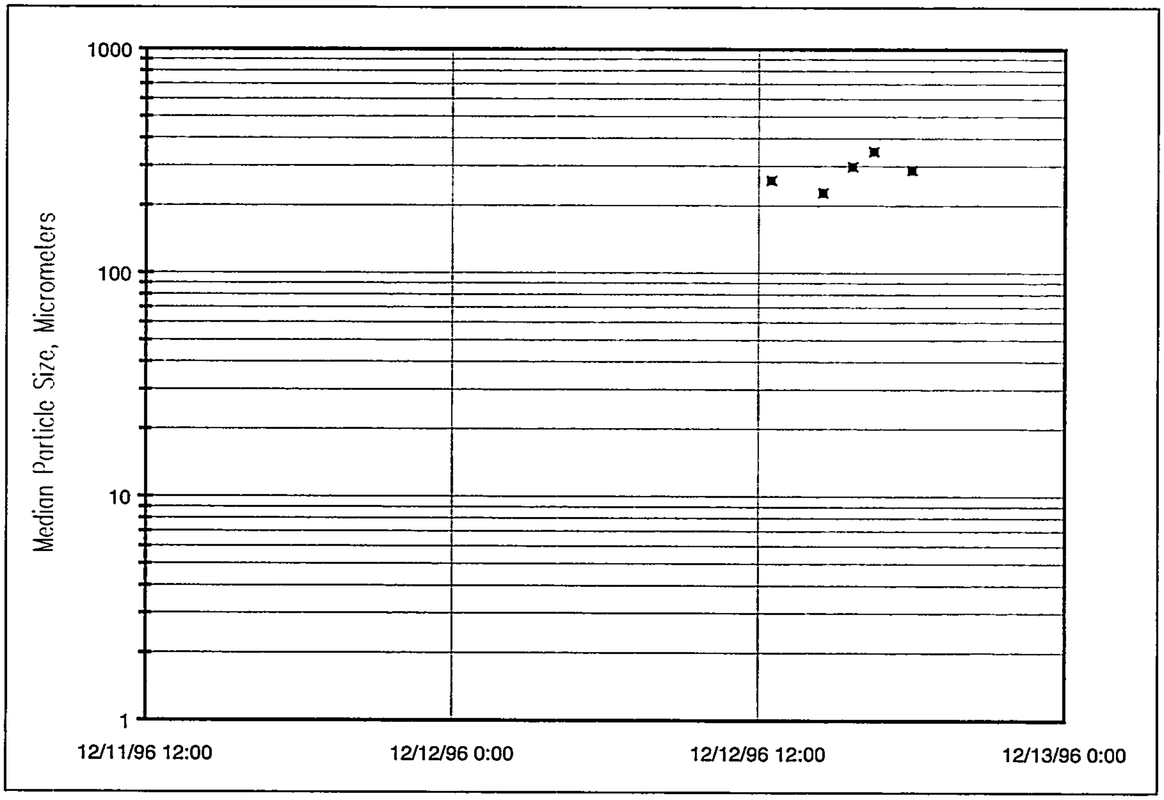

Figure 6.1.13-5 CCT3 PCD Hopper Samples

6.1.14 Filter System Permeance

During 1996 almost all of the filter elements tested were either type 442T or 326 elements manufactured by Pall. Both of these filter types are commonly referred to as "membrane" or "surface" filters due to their construction. The filter elements are cylindrical and fabricated with coarse silicon carbide grains held together with a binder. This coarse inner structure provides support and strength for the filter element. On the outer surface of the element is a very thin membrane that consists of a combination of ceramic fibers and/or grains. The pore size of the outer membrane is much smaller than that of the support structure and provides the filtration characteristics of the element.

When measuring filter performance one of the most common terms used is the face velocity. It is defined as the actual volumetric gas flow divided by the total active filtering surface area. The Westinghouse PCD (FL0301) used throughout 1996 contains approximately 265 ft^2 of surface area. The face velocity through this filter media has varied over the seven tests from 2 to 6 ft/min depending on the total gas flow rate, pressure, and temperature of the system for any given test.

The pressure drop across the filter system can be thought of as the sum of several individual pressure drops that are all dependent on the face velocity:

$$\Delta P_{total} = \Delta P_{vessel} + \Delta P_{media} + \Delta P_{residual\ cake} + \Delta P_{removable\ cake}$$

The ΔP_{vessel} is the pressure drop of the dirty and clean gas through the gas inlet, the gas distribution system, the inner bore of the filter element, and the gas outlet ductwork. The remaining resistances to flow are illustrated in figure 6.1.14-1.

Clean filter media, due to its high porosity, produces very little resistance to flow. The typical value of pressure drop for a new, clean filter element under ambient conditions is about 1 inWG at a 5 ft/min face velocity.

6.1.14.1 Residual Cake

Under steady state conditions (constant face velocity, particulate size, and loading) the baseline pressure drop of a new filter system will rise with time as shown in figure 6.1.14-2. For a membrane element this rise in the baseline ΔP will typically decrease over time until a stable pressure drop is reached.

The rise in the baseline ΔP is due to the formation of a residual cake on the filter element surface. The mechanics of the formation of this residual cake are not fully understood, but it is generally accepted that fine particulate infiltrates the filter membrane during operation causing partial "blinding" of the membrane. To some degree, the thickness of the residual cake is a function of the back-pulse pressure. Literature suggests that a high back-pulse pressure will usually produce a thinner residual cake than a low back-pulse pressure. In fact, if the pulse system is inadequate, particulate will continuously accumulate within the residual cake and the baseline ΔP will never reach a steady state condition. Ultimately this constant rise in ΔP will cause the entire process to be shutdown as the mechanical limitations of the system are reached.

During operation, the permeance is used as a measure to indicate changes in the filter operation. Increases in the particulate loading, decreases in the particle size distribution, and consolidation of the filter cake due to high ΔP, temperature, or ash chemistry all have a negative impact on the permeance. Permeance is calculated as:

$$Permeance = \frac{FaceVelocity \times GasVisc}{\Delta P}$$

However, "on-line" estimations of gas viscosity are rather complex and difficult to calculate using a distributed control system (DCS). Under steady state conditions the filter operating temperature is relatively constant and, therefore, the gas viscosity is constant. Calculating the permeance as:

$$Permeance = \frac{Face\ Velocity}{\Delta P}$$

is a relatively simple task for a DCS and can be used on-line to evaluate changes in filter performance. Figure 6.1.14-3 shows the permeance calculated in this manner for the PSDF 1996 operations.

After CCT1C the PCD was recandled with new filter elements. The permeance for these new elements was relatively high, and over several hundred hours of operation the permenace has decreased as the filter elements have become "conditioned" with ash. It appears that the permeance reached a steady state level during CCT2C.

6.1.14.2 Removable Cake

The ΔP caused by the removable cake is due to the formation of a relatively thick filter cake that forms on the surface of the residual cake between pulse cycles. The magnitude of the rise in the ΔP due to the removable cake is a function of the particulate size, the particulate loading, reentrainment potential, cake porosity, and resistance, etc.

The ΔP of the filter system between pulse cycles during the CCT1 series of tests was much more sensitive to loading than in CCT2 series. During CCT1 the particulate loading was primarily increased by changes in the transport reactor circulation rates and by recycling fines from the PCD ash removal system to the transport reactor. The particulate collected from the PCD cone during the test series typically had a median particle diameter less than 15 micrometers. Usually any change in the particulate loading during the CCT1 series was evidenced in the PCD by a rapidly rising ΔP and increased frequency of pulse cleaning.

During the CCT2 test series the filter system was almost insensitive to particulate loadings primarily due to the carryover of large particulate to the PCD. The batch sampling system operated by SRI collected four samples during CCT2C and measured particulate loadings ranging between 12,000 and 69,000 ppm. However, there was no appreciable change in the filter ΔP due to loading as seen in figure 6.1.14-4.

6.1.14.3 Future Plans

During 1997 process changes will be varied to study changes in the residual and removable filter cakes. After the combustion tests and before the first gasification run FL0301 will be completely recandled with new filter elements.

6.1.14.4 Reference

Durst, M., A. Reinhardt, and H. Vollmer. High Efficiency Particulate Collection With The Aid Of Ceramic Filter Media. First European Symposium, Separation Of Particulate From Gases. Nuremberg, Germany, April 1989.

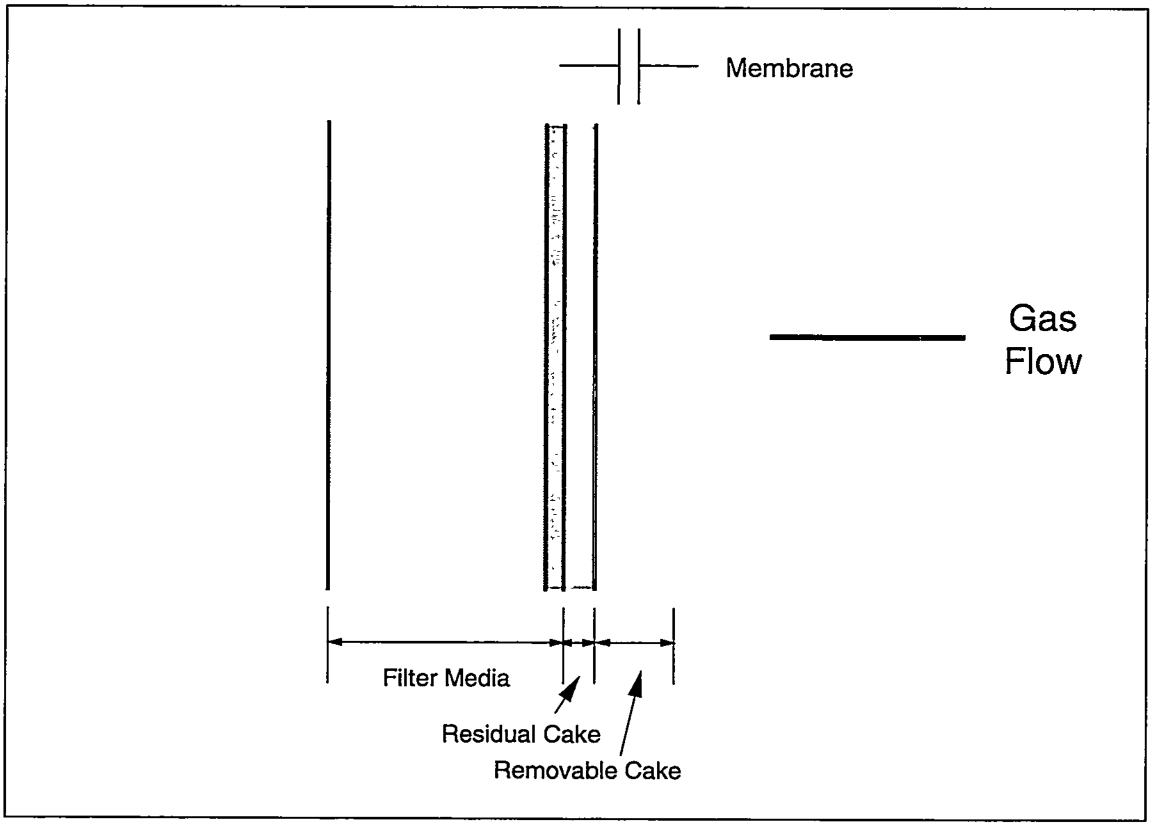

Figure 6.1.14-1 Resistances to Gas Flow

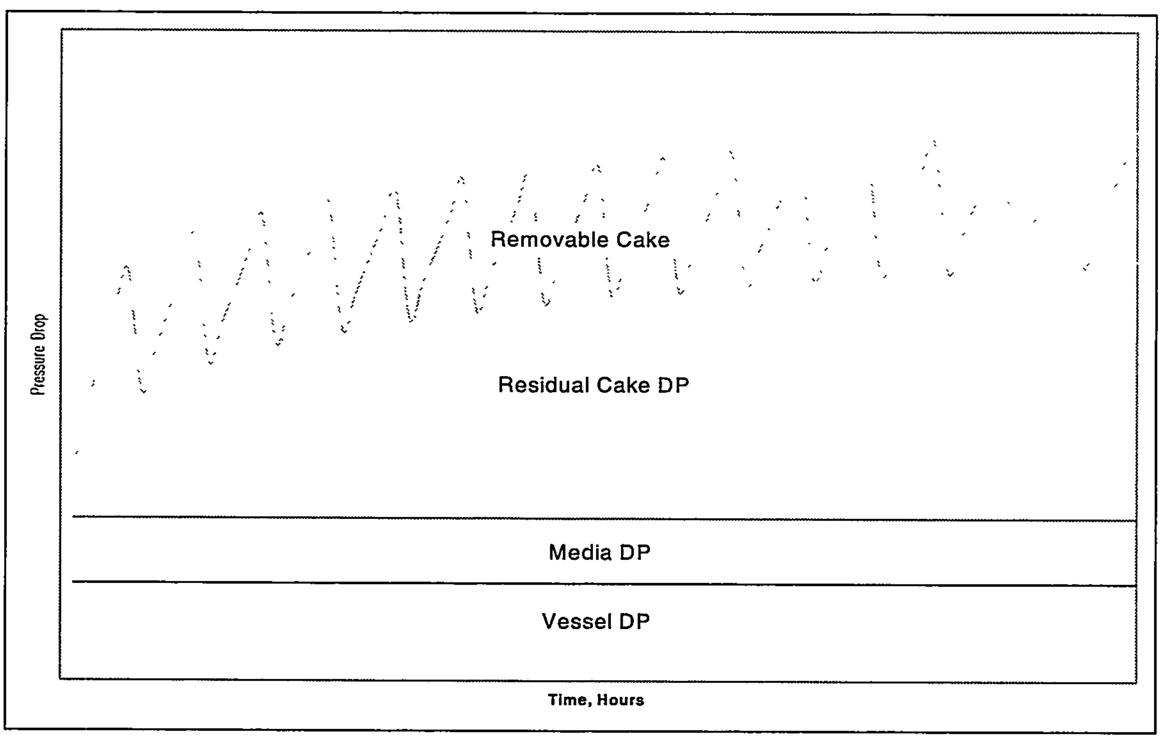

Figure 6.1.14-2 Buildup of Residual Cake ΔP

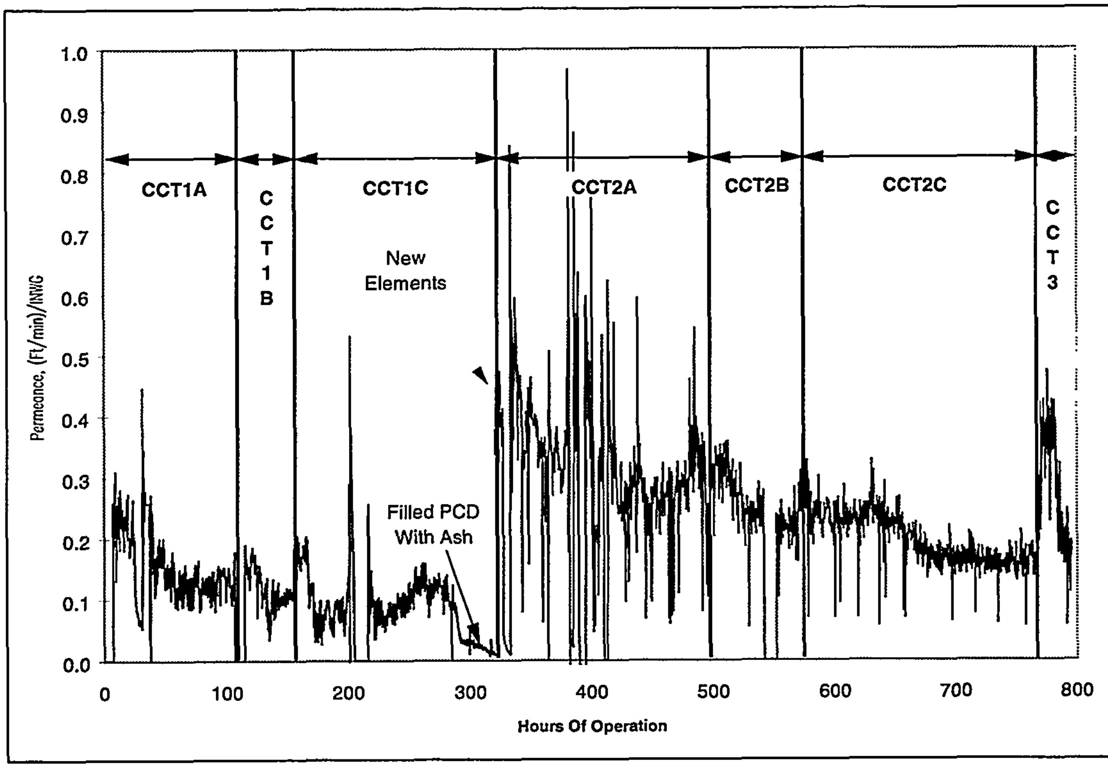

Figure 6.1.14-3 FL0301 1996 Permeance

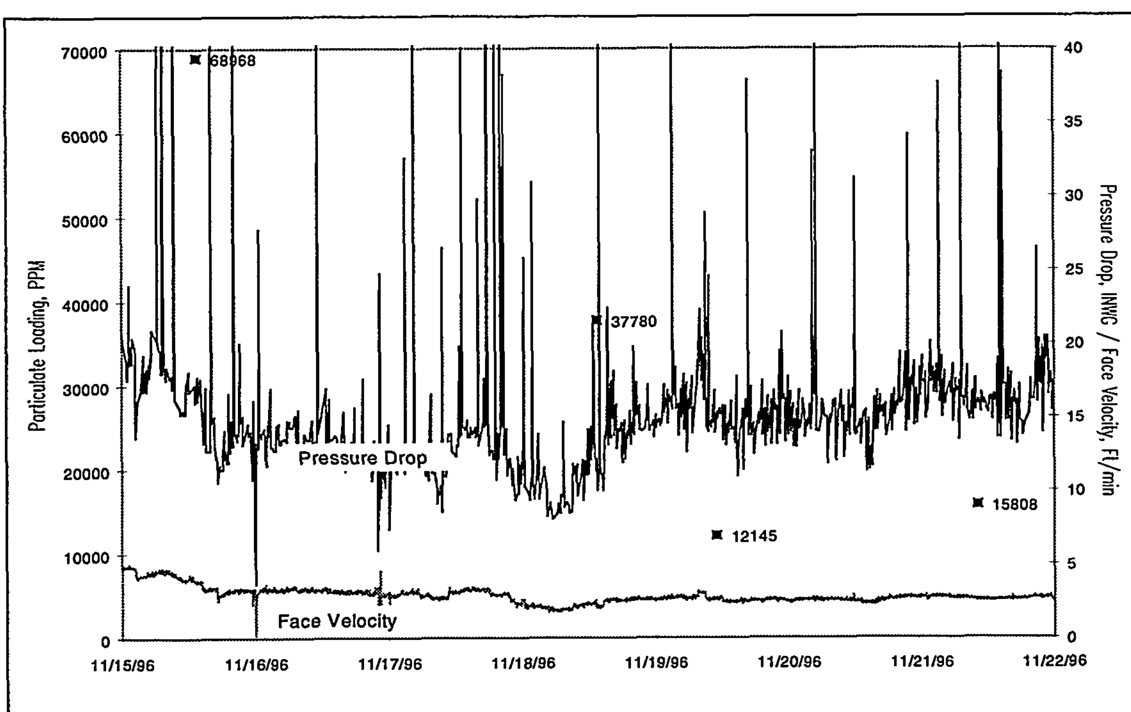

Figure 6.1.14-4 CCT2C Filter ΔP And Particulate Loading

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6.1.15 Monitoring Ash Level in the Westinghouse PCD FL0301

6.1.15.1 General

The instrumentation most watched on a PCD is the pressure drop across the filter system. The pressure drop is a good indication of particulate loading as well as an indication of changes within the filter cake. However, to reliably operate the filter, monitoring the ash level in the PCD is critical. Ceramic filter elements can be easily broken if the ash level in the filter cone reaches the filter elements.

This was demonstrated at the PSDF during the August 1996 coal run (CCT1C). The ash level in the PCD rose unnoticed to a point where the lower level of filter elements was completely covered and the upper level of filter elements was partially covered.

After carefully reviewing the operating data from CCT1C and previous runs the PSDF staff developed an operating methodology which has allowed for the successful operation of the PCD in subsequent runs. The particulate loading to the PCD during the fourth quarter of 1996 was much higher than design, but careful monitoring of the PCD ash level prevented further incidents.

The purpose of this report is to illustrate how ash level is monitored in the PCD. Also, operating data from the August 1996 run will be discussed to illustrate how (in hindsight) the level of ash within the PCD was determined.

6.1.15.2 Instrumentation

Figure 6.1.15-1 shows the instrumentation installed on both the PCD and the ash removal system during 1996:

- TI458 - Inlet Gas Temperature. This thermocouple is located upstream of the PCD in the refractory lined piping.

- TI3006 - Between Plenum Temperature. This thermocouple extends through the shroud into the region between the upper and lower level of filter elements.

- TI3004 - Lower Shroud Temperature. This thermocouple does not extend through the shroud, but extends into the annular region between the PCD wall and the shroud.

- TI3003 - Upper Cone Temperature. TI3003 is at the upper part of the cone opposite the lower manway. The volume of the cone from this thermocouple to the outlet flange is approximately 38 ft^3. This thermocouple protrudes only a few inches into the PCD.

- TI3001/TI3002 - Lower Cone Temperatures. These thermocouples are located about 3 feet above the outlet flange. The volume of the cone below the thermocouples is about 5 ft^3. Like TI3003, these thermocouples protrude only a couple of inches into the PCD cone.

- TI501 - Screw Cooler Inlet. TI501 is located in the transition piece between the PCD and the screw cooler.
- TI505 - Screw Cooler Outlet. The screw cooler is designed to cool the PCD fines from 1,800 to 350°F. TI505 measures the temperature of the ash as it falls from the screw cooler into the lockhopper system.
- PI8534 - Lockhopper Pressure. The lockhopper pressure changes as the system cycles from the PCD pressure to nearly atmospheric pressure. The lockhopper only cycles when the ash level reaches a level probe, not on a timer. Therefore, the frequency of this cycle is an indication of the loading into the PCD.
- Screw Cooler Speed - The rotational speed of the screw cooler is also monitored by the DCS.

6.1.15.3 Normal PCD Operation

Under normal operating conditions, ash entering the PCD will collect on the surface of the filter elements. The ash is then removed with a high-pressure pulse of gas which produces a reverse flow across the filters. The ash then falls to the bottom of the PCD cone where it is cooled and conveyed to the lockhopper system by the screw cooler. When the ash level in the lockhopper reaches the level probe the lockhopper is depressurized and the ash is conveyed to the ash silo.

This normal operation can be seen in figure 6.1.15-2, which is from the second coal combustion run, CCT2C. In this graph the pulse pressure has been added so that the interaction of the pulse cycle and the ash removal cycle can be seen.

There is no gas flow through the bottom of the PCD, so it is normal for the inlet gas temperature and the bottom cone temperature to differ. The ash being removed by the filter elements is essentially the same temperature as the gas inlet, so as it passes by the bottom cone and screw cooler inlet thermocouples it creates a "spike" in the temperature. The ash is then conveyed by the screw cooler to the lockhopper where it is removed.

There was not an exact 1-to-1 relationship between the pulse cycle and the lockhopper cycle due to the carryover of large (>100 μm) particulate during the test. It was speculated that due to the PCD geometry, large particulate would be mechanically separated and fall to the PCD cone instead of reaching the filter elements. This material was continuously conveyed to the lockhopper.

6.1.15.4 Excessive Carryover to PCD

During the CCT2 and CCT3 series of tests, silica sand was used as the start-up bed material for the transport reactor instead of the alumina used in the CCT1 test series. This had a dramatic impact on both transport reactor and PCD operations. Large quantities of ash/sand were carried over to the PCD during these test runs and particulate loadings as high as 70,000 ppm were measured.

Whereas this high loading could have had an adverse impact on PCD operations, the size of the particle being carried over to the PCD was quite large. Typical median particle sizes (as measured by sieve analysis) taken from the PCD cone have ranged from 200 to 300 µm. As mentioned previously, it is speculated that material of this size does not reach the filter elements but falls directly to the PCD cone.

Figure 6.1.15-3 is an example from test run CCT2A where a large quantity of solids were carried over to the PCD from the transport reactor. During this transient event, both the PCD bottom cone temperature and the screw cooler inlet temperature rapidly increased as the hot solids flowed into the cone. The lockhopper began cycling rapidly to remove the solids. About 1.5 hours after the event began, the temperatures started to drop once the solids were removed. The lockhopper cycle frequency also decreased as the solids were removed. This same type of transient occurs two additional times during this 6-hour period.

It is important to note that even though there was a surge in the bottom cone temperature with the influx of solids there was no change in the top cone temperature. Throughout these transients the top cone temperature followed the trend of the inlet gas temperature. This is an indication that the hot solids never covered this thermocouple (i.e., never completely filled the PCD cone).

6.1.15.5 PCD Cone "Rat-Holing"

Based on the analysis of the data from CCT1C, it appears that the PCD cone has a tendency to "rat-hole," meaning that the flow of solids out of the cone is not uniform. Prior to 08:00 on August 18 it appeared that the PCD cone was empty, due to the "spikes" in screw cooler inlet temperature as the filters were pulse cleaned (figure 6.1.15-4).

Beginning at about 08:00 there was an influx of solids into the PCD as indicated by the sudden rise in the bottom cone temperature. Apparently the solids near the wall of the PCD cone remained stationary while hot solids flowed through the center of the cone. In figure 6.1.15-4 the bottom cone temperature is shown as slowly decreasing while the screw cooler inlet temperature continued to increase.

Until 10:00 the top cone temperature trended the inlet gas temperature. (The fluctuations in the inlet gas temperature resulted from efforts to control temperature in the transport reactor.) However, after 10:00 the top cone temperature began decreasing even though the screw cooler inlet temperature continued increasing. This indicated that "rat-holing" of the cone was taking place.

6.1.15.6 Filling the PCD With Ash - August 18 through 21, 1996

During the initial coal run (CCT1C) the ash level in the PCD rose essentially unnoticed until the lower level of filter elements were completely covered with ash and the upper level partially covered. The primary reason that the ash level rose unnoticed was the lack of experience of the staff in using thermocouples to monitor ash level in the PCD. Given the hindsight of knowing what physically happened inside the PCD it is obvious from the instrumentation what occurred at various times.

A. August 18 – Prior to 07:00. As shown in figure 6.1.15-5 there was a "spike" in the bottom cone and screw inlet temperature which coincided with each pulse cycle. This pattern is typical of normal PCD operation and evidence that the bottom cone was empty.

B. August 18 at 08:00. Starting just before 08:00 there was an influx of particulate into the PCD cone as can be seen in figure 6.1.15-6. There was a sudden increase in the bottom cone temperature and for the rest of the run the temperature decreased. The screw cooler inlet temperature also began increasing and ultimately exceeded the temperature reading in the lower PCD cone. This was indicative of "rat-holing" in the PCD cone.

C. Two other pieces of data point to the cone being filled with solids. The screw cooler inlet temperature and the bottom cone temperature no longer registered the temperature "spikes" associated with back-pulsing. Also, the cycle frequency of the ash removal system became regular, suggesting that there was a "constant" flow of particulate out of the PCD cone. Prior to this event the lockhopper cycle frequency was irregular.

D. August 18 at 10:00. Shortly after 10:00 the upper cone thermocouple indicated that it was also covered with ash (figure 6.1.15-7). Again, there was evidence of "rat-holing" in that the screw cooler outlet temperature exceeded the temperature measured by either of the cone thermocouples.

E. August 19 at 02:00. The Westinghouse PCD has a tangential inlet similar to a cyclone. The combination of the tangential inlet and the shroud provides some size segregation of particulate. Since the larger solids flow to the PCD cone via the annular gap between the shroud and the vessel wall the level of solids near the wall of the PCD cone is probably higher than the level in the center. Over time, the level in the PCD cone appeared to reach a point where the gap at the lower portion of the shroud became "sealed" and solids could no longer flow out of the shroud. This lead to an accumulation of solids within the shroud as indicated by the thermocouple TI3004 (figure 6.1.15-8).

F. Thermocouple TI3004 does not penetrate the shroud but measures the temperature in the annular region between the shroud and the vessel wall. Around 02:30 this temperature began to fall, indicating that it was also covered with ash. However, there was no indication that the filter elements were covered with ash. The baseline pressure drop at this time was about 15 inWG. As the filter elements began covering with ash on August 20 there was a sharp rise in the filter differential pressure due to the loss of filtration area. From 02:00 on August 19 until about 08:00 on August 20 the baseline pressure drop for the PCD was essentially constant.

G. August 20 at 08:00 to 18:00. The transport reactor had lost a substantial amount of bed material during the run and it was decided to attempt to rebuild level with dolomite. The dolomite feed rate was increased to a maximum prior to the rise in filter ΔP. Throughout the day there was not a significant rise in bed level as essentially all of the fine dolomite was carried over to the PCD. The rise in filter ΔP was thought to be due to this increased particulate loading. When the filter baseline ΔP began reaching a new "steady state" at 18:00 there was less concern about the rise.

As learned later, the increase in ΔP was not due to increased particulate loading but through loss of filtration surface area as the lower filter elements became buried in ash. This loss of area caused an increase in the face velocity of the remaining filter elements and a corresponding increase in filter ΔP. The rise in ΔP started occurring about 08:00 (figure 6.1.15-9) and the rise in ΔP stopped when the filter elements were fully covered at around 18:00 (figure 6.1.15-10). The "steady state" ΔP between 18:00 on August 20 and 08:00 on August 21 occurred as ash accumulated in the region between the lower and upper plenums. This area has no active filtration so the accumulation had no affect on filter ΔP.

H. August 21 at 06:00. Starting at around 06:00 on August 21 the level of ash reached the upper level of filter elements. This was evidenced first by a decrease in the temperature indication of TI3006 (figure 6.1.15-11). This thermocouple penetrates through the shroud into the main filtration area at the same elevation as the gas inlet. Around 08:00 the filter ΔP again starting rising as the upper filter elements were covered with ash. The face velocity for the remaining active filter surface was dramatically rising, which lead to an uncontrollable rise in filter ΔP and caused the plant shutdown.

I. Aftermath. When the PCD was disassembled for inspection, 77 of the 91 filter elements were found to be broken. On the lower level 54 of the 55 elements were broken with 23 out of 36 broken on the top. This experience lead to essentially a "minute-by-minute" review of all the operational data for the first three runs. From this review an operating procedure was developed for monitoring the ash level with thermocouples. All of the operators and engineers responsible for operation of both the transport reactor and the PCD have been trained on this procedure.

During the fourth quarter of 1996 the PCD operated for nearly 450 hours with 145 hours of coal firing. The particulate loading to the PCD varied greatly and at times was measured as high as 70,000 ppm. But the level in the PCD cone has been closely monitored and has not been allowed to reach a point where the top cone thermocouple (TI3003) has detected the presence of solids.

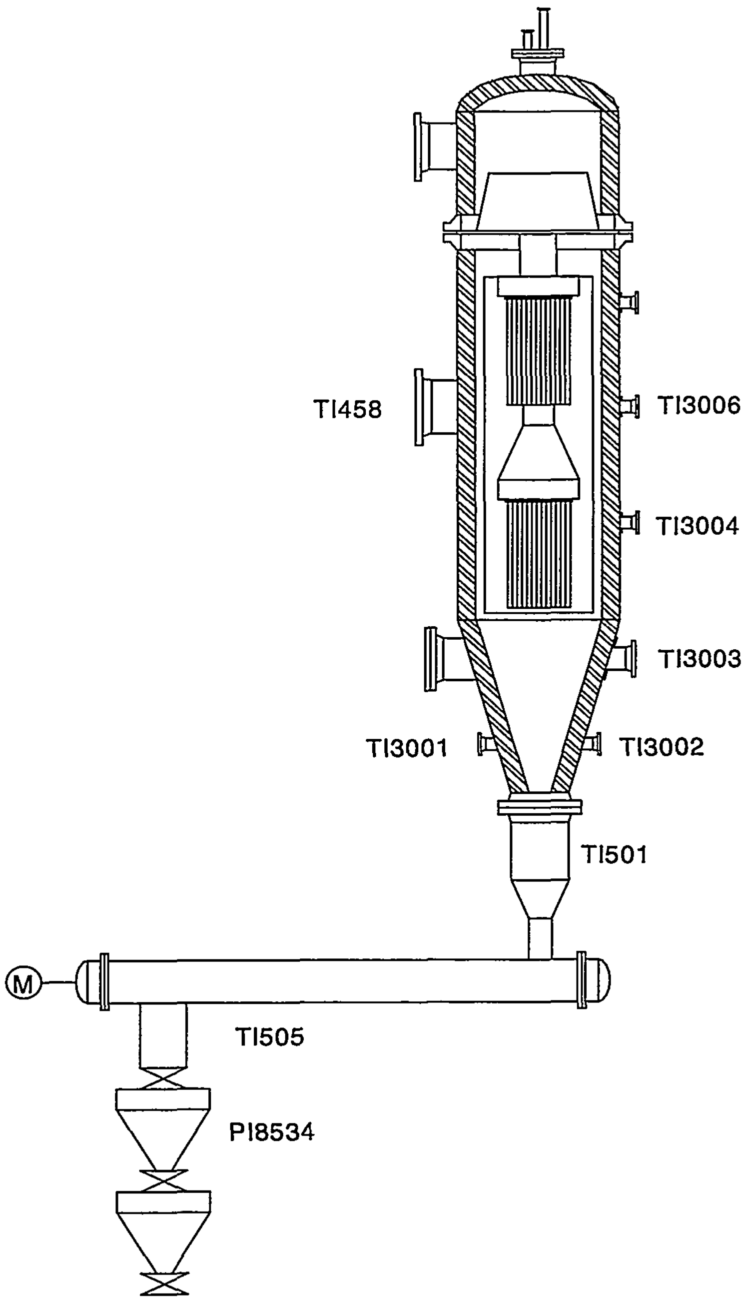


Figure 6.1.15-1 PCD/Ash Removal Instrumentation

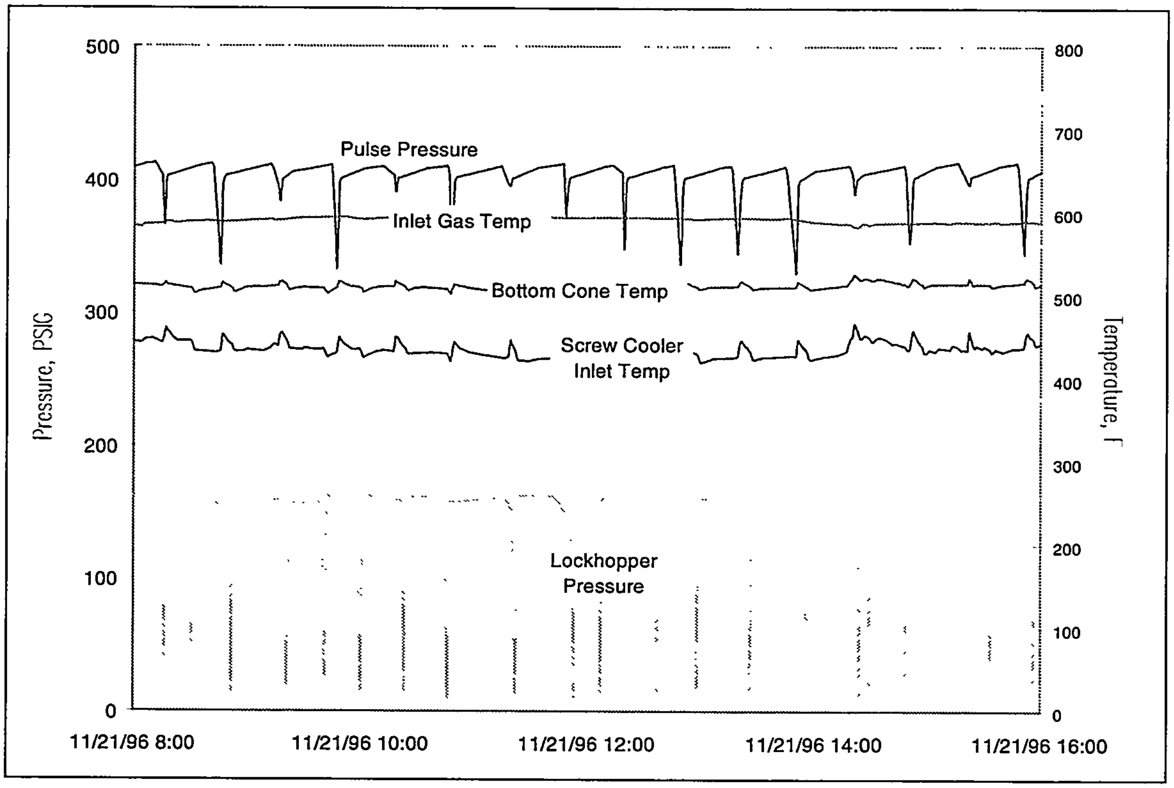


Figure 6.1.15-2 Normal PCD Operation

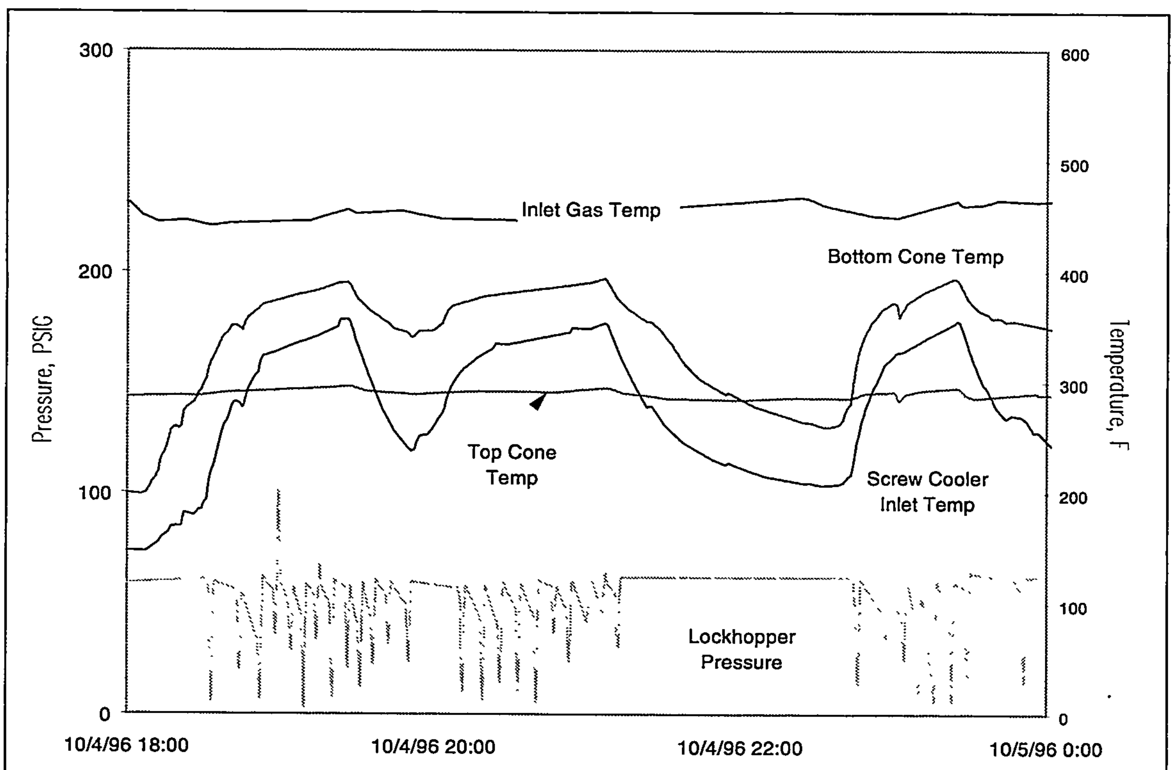


Figure 6.1.15-3 Excessive Carryover to PCD

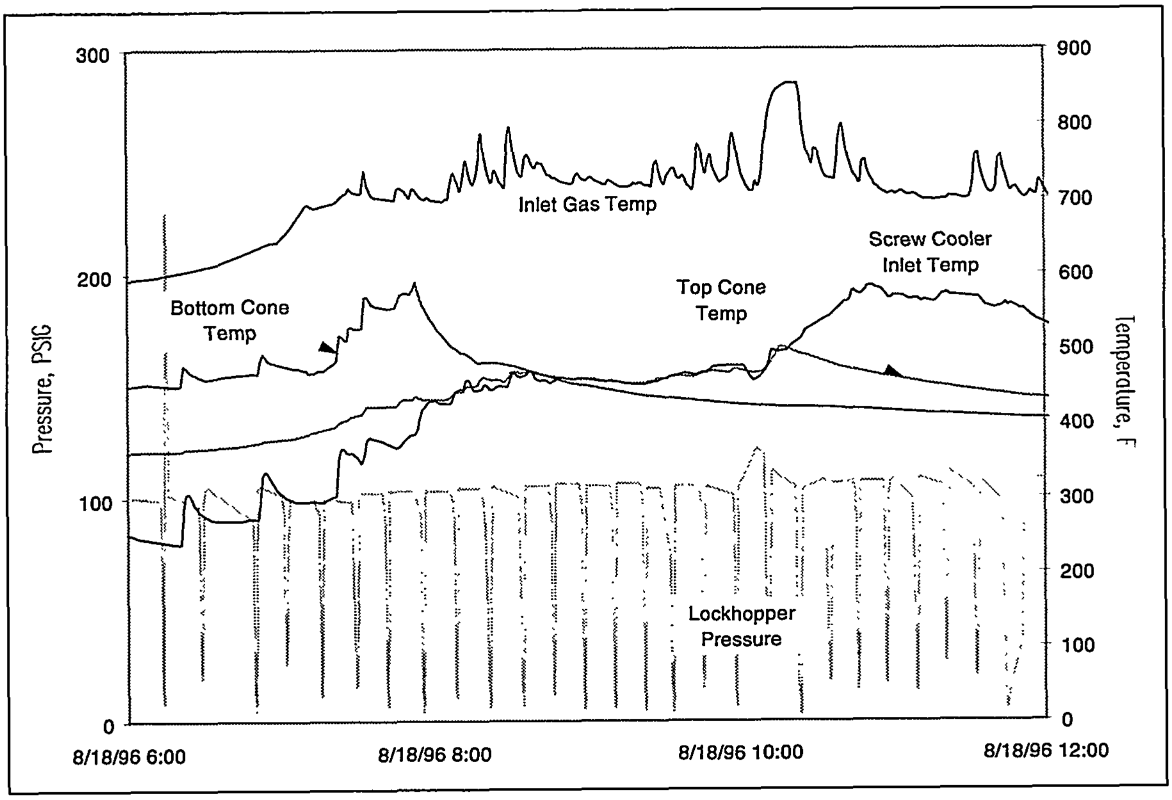


Figure 6.1.15-4 "Rat-Holing" of PCD Cone

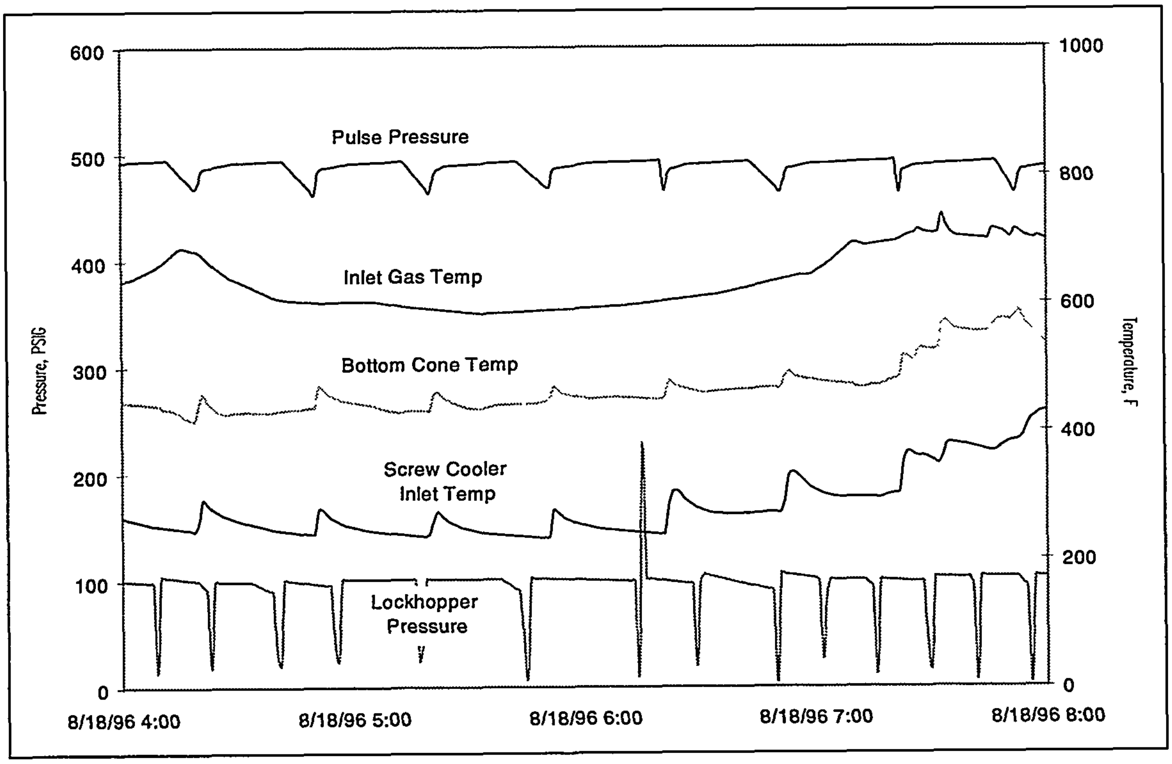
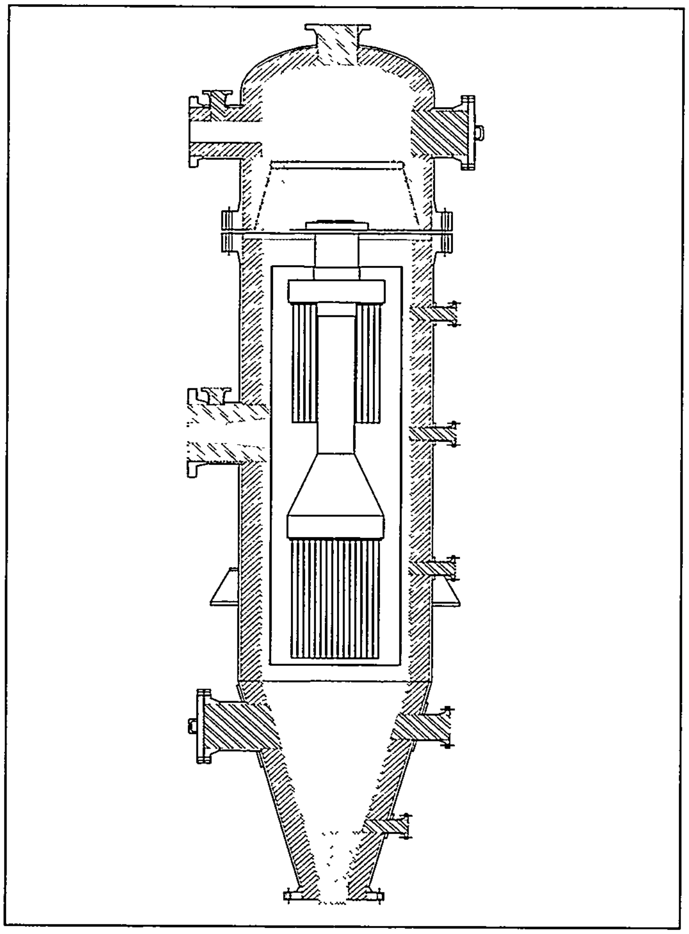


Figure 6.1.15-5 "Normal" Operation of PCD Prior to Filling



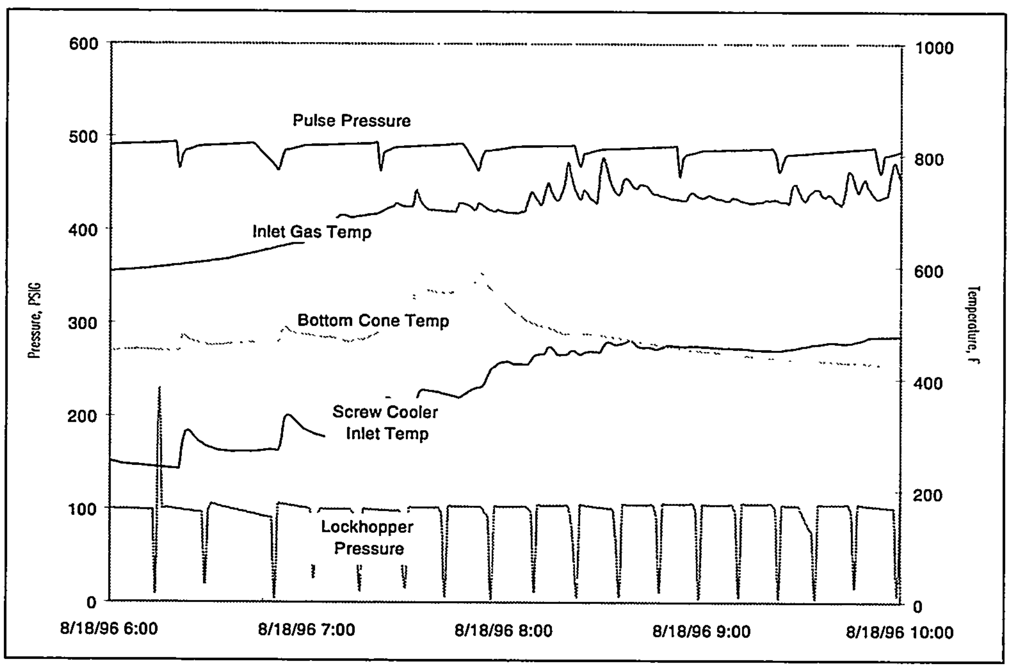


Figure 6.1.15-6 Bottom of PCD Cone Filled With Ash

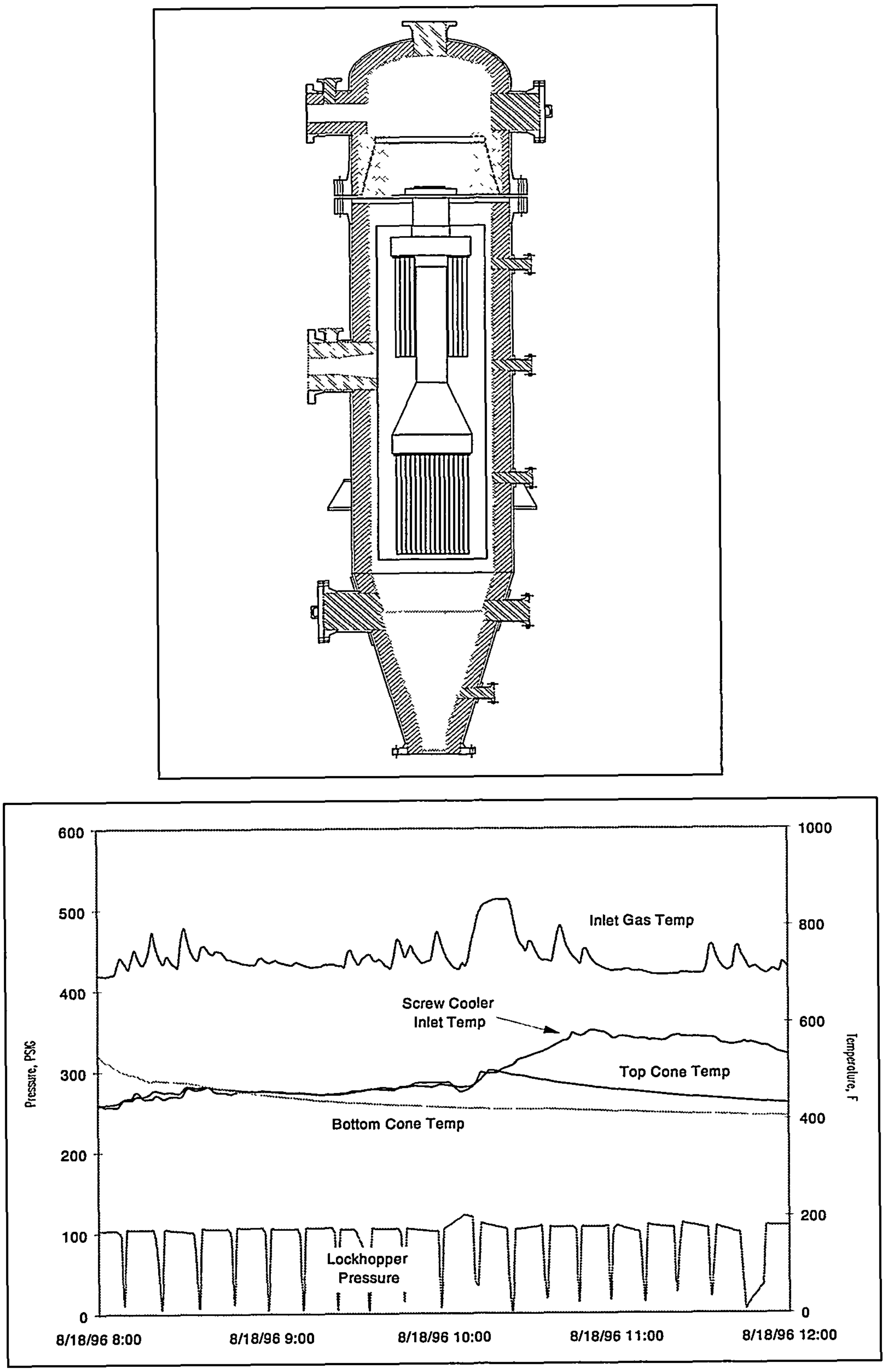
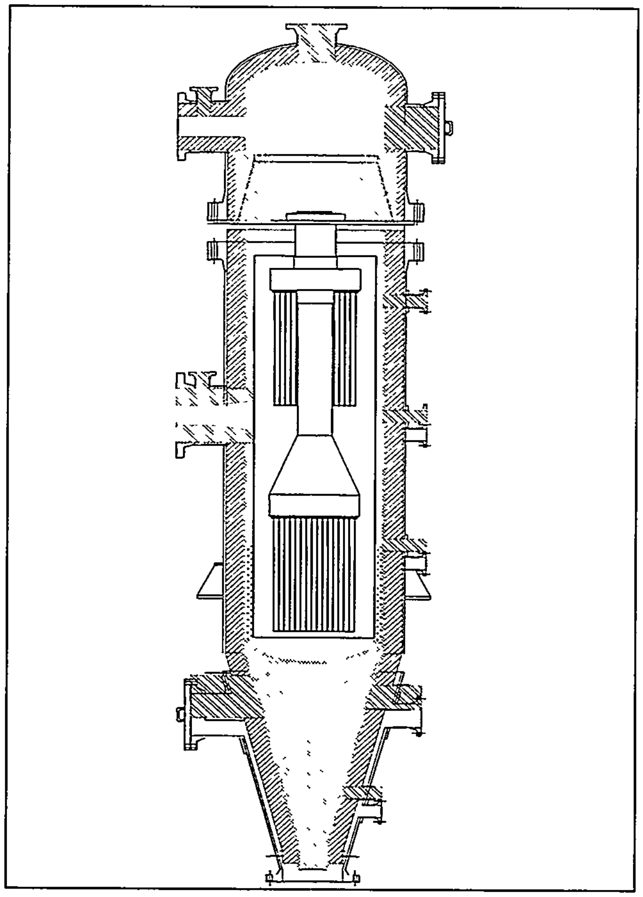


Figure 6.1.15-7 Top of PCD Cone Filled With Ash



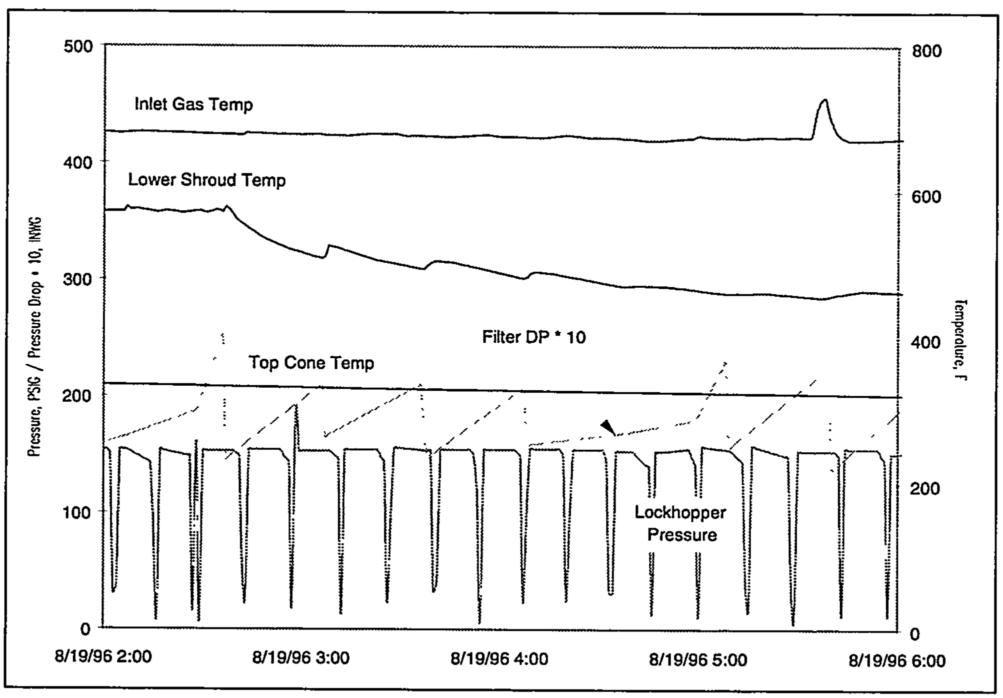
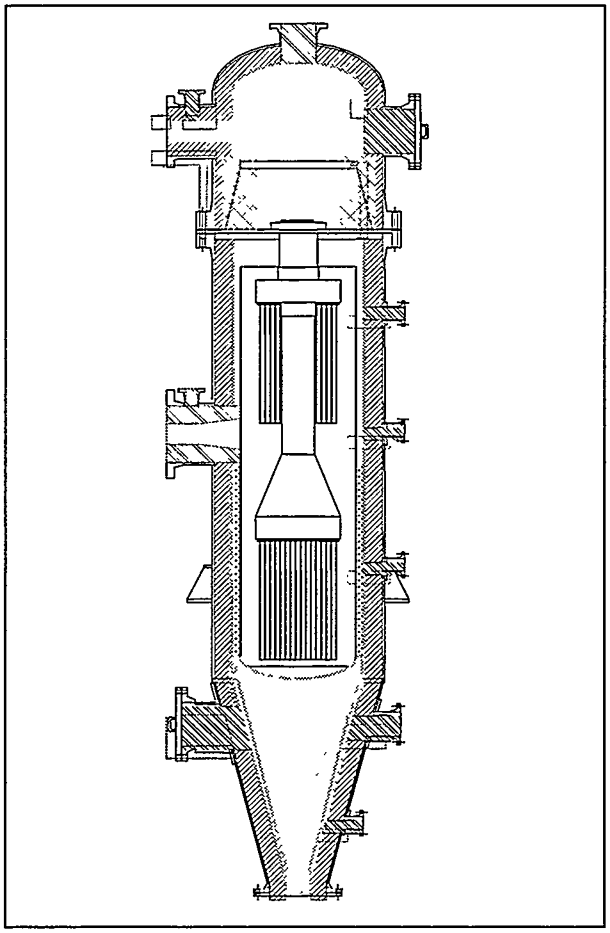


Figure 6.1.15-8 Lower Shroud Filled With Ash



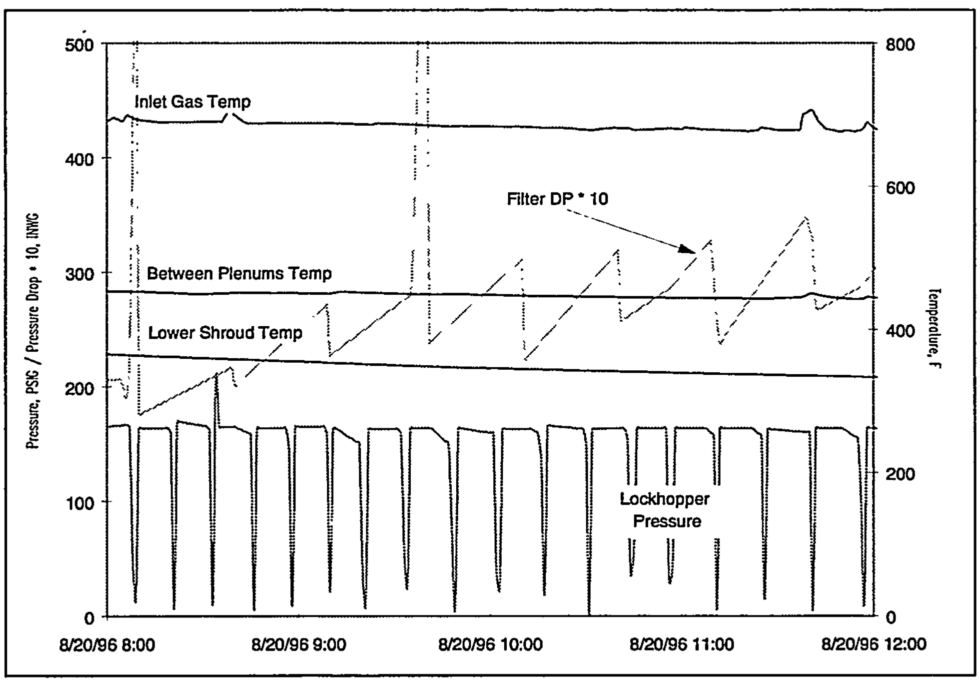
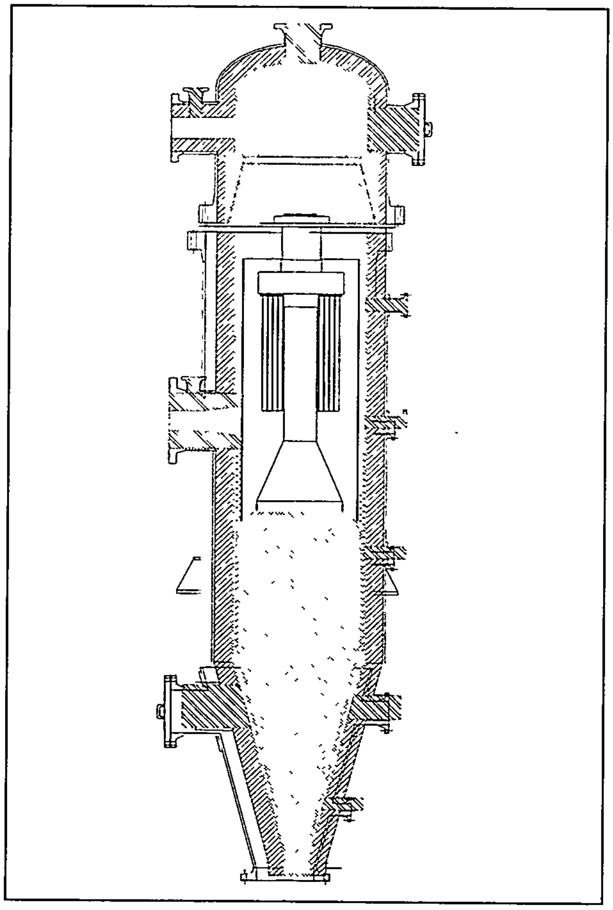


Figure 6.1.15-9 Beginning to Cover Lower Level With Ash



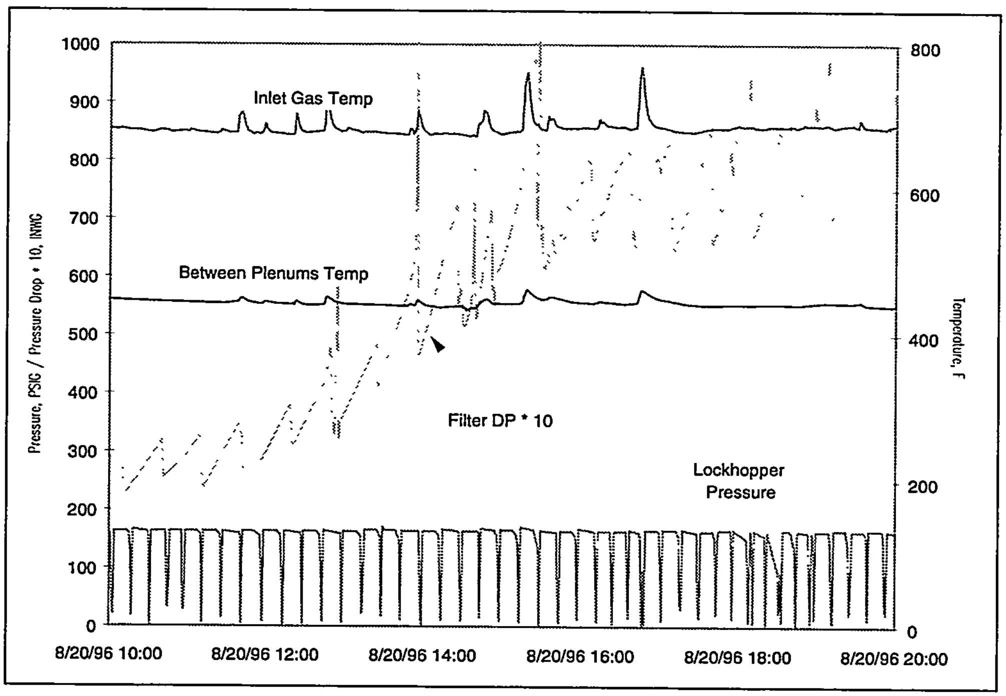


Figure 6.1.15-10 Lower Level Elements Covered With Ash