POWER SYSTEMS DEVELOPMENT FACILITY

COMMISSIONING REPORT OF M.W. KELLOGG TRANSPORT REACTOR TRAIN, WESTINGHOUSE PARTICULATE CONTROL DEVICE, AND ASSOCIATED BALANCE-OF-PLANT EQUIPMENT: SEPTEMBER 1995 – DECEMBER 1996

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VOLUME II

Prepared by:
Southern Company Services, Inc.
Power Systems Development Facility
P.O. Box 1069
Wilsonville, AL 35186

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POWER SYSTEMS DEVELOPMENT FACILITY

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CONTENTS

Section — Page

Title Page — Inside Cover
Disclaimer

Acknowledgements

VOLUME 1

Listing of Tables and Figures — vii

1.0 EXECUTIVE SUMMARY 1.0-1

2.0 INTRODUCTION 2.1-1

2.1 The Power Systems Development Facility 2.1-1
2.2 Transport Reactor System Description 2.2-1
2.3 Westinghouse Particulate Control Device 2.3-1
2.4 Balance-of-Plant 2.4-1

3.0 SCHEDULE OF PSDF START-UP/COMMISSIONING ACTIVITIES 3.0-1

4.0 DESIGN, PROCUREMENT, AND INSTALLATION 4.1.1-1

4.1 Conceptual Design 4.1.1-1

4.1.1 Transport Reactor Train 4.1.1-1
4.1.2 Balance-of-Plant 4.1.2-1

4.2 Procurement 4.2.1-1

4.2.1 Transport Reactor Train 4.2.1-1
4.2.2 Balance-of-Plant 4.2.2-1

4.3 Installation 4.3-1

5.0 COMMISSIONING OF M. W. KELLOGG TRANSPORT REACTOR TRAIN 5.1.1-1

5.1 Transport Reactor Loop 5.1.1-1

5.1.1 Commissioning Test Run CR01 ..... 5.1.1-1
5.1.2 Commissioning Test Run CR02 ..... 5.1.2-1

5.1.3 Commissioning Test Run CR03 ..... 5.1.3-1
5.1.4 Commissioning Test Run CR04 ..... 5.1.4-1
5.1.5 Characterization Test Run CCT1A 5.1.5-1
5.1.6 Characterization Test Run CCT1B 5.1.6-1
5.1.7 Characterization Test Run CCT1C 5.1.7-1
5.1.8 Characterization Test Run CCT2A 5.1.8-1
5.1.9 Characterization Test Run CCT2B 5.1.9-1
5.1.10 Characterization Test Run CCT2C 5.1.10-1

TERMS ..... PSDF Terms-1

VOLUME 2

5.1.11 Disengager Performance Tests 5.1.11-1
5.1.12 Solids Conveying System 5.1.12-1
5.1.13 Pressure Letdown Valve 5.1.13-1

5.2 Operability Analysis of Commissioning Tests 5.2.1-1

5.2.1 Analysis of the Reactor Coal Feed Rate and Comparison With Other Processes 5.2.1-1
5.2.2 The Relationship Between the Coal Feed Rate and Solid Circulation Rate 5.2.2-1
5.2.3 The Relationship Between the Reactor Temperature and the Coal Feed Rate 5.2.3-1
5.2.4 Solid Carryover and Cyclone Separation Efficiency 5.2.4-1
5.2.5 Riser Pressure Drop and Solid Circulation Rate 5.2.5-1

6.0 COMMISSIONING OF WESTINGHOUSE PARTICLE FILTER SYSTEM 6.1.1-1

6.1 Westinghouse Filter System 6.1.1-1

6.1.1 1996 PCD Overview 6.1.1-1
6.1.2 Westinghouse PCD FL0301 System Description 6.1.2-1
6.1.3 Westinghouse PCD Installation 6.1.3-1
6.1.4 Candle Layout #1 ..... 6.1.4-1
6.1.5 Westinghouse PCD Gasket 6.1.5-1
6.1.6 Test Run CCT1A 6.1.6-1
6.1.7 Test Run CCT1B 6.1.7-1
6.1.8 Test Run CCT1C 6.1.8-1
6.1.9 Candle Layout #2 ..... 6.1.9-1
6.1.10 Test Run CCT2A 6.1.10-1

6.1.11 Test Run CCT2B 6.1.11-1
6.1.12 Test Run CCT2C 6.1.12-1
6.1.13 Coal Combustion Characterization Test CCT3 ..... 6.1.13-1
6.1.14 Filter System Permeance 6.1.14-1
6.1.15 Monitoring Ash Level in the Westinghouse PCD FL0301 ..... 6.1.15-1

6.2 High-Pressure Air and High-Pressure Nitrogen System 6.2.1-1

6.2.1 High-Pressure Air System 6.2.1-1
6.2.2 High-Pressure Nitrogen System 6.2.2-1

6.3 PCD Fines Removal System Commissioning 6.3.1-1

6.3.1 PCD Fines Screw Cooler 6.3.1-1
6.3.2 PCD Fines Transporter 6.3.2-1

7.0 SOUTHERN RESEARCH INSTITUTE (SRI) PARTICULATE SAMPLING SYSTEM 7.1-1

7.1 Description of Particulate Sampling System 7.1-1
7.2 Cold Shakedown 7.2-1
7.3 Hot Shakedown 7.3-1
7.4 System Modifications 7.4-1
7.5 Initial Sampling Runs 7.5-1
7.6 Port Inspection 7.6-1
7.7 Summary 7.7-1
7.8 Major Events (Chronology) 7.8-1

8.0 BALANCE-OF-PLANT 8.1.1-1

8.1 Feedstock Preparation 8.1.1-1

8.1.1 Coal and Sorbent (Feedstock) Reclaim System Description 8.1.1-1
8.1.2 MWK Coal Mill Process Description 8.1.2-1
8.1.3 MWK Sorbent Mill Process Description 8.1.3-1

8.2 Main Air Compressor 8.2.1-1

8.2.1 Description 8.2.1-1
8.2.2 Commissioning Tests/Runs 8.2.2-1
8.2.3 Highlights of Problems and Solutions 8.2.3-1
8.2.4 Performance During Normal Operation 8.2.4-1

8.3 Transport Air System 8.3.1-1

8.3.1 Description 8.3.1-1
8.3.2 Commissioning Tests/Runs 8.3.2-1
8.3.3 Highlights of Problems and Solutions 8.3.3-1

8.4 Recycle Gas Booster Compressor 8.4.1-1

8.4.1 Description 8.4.1-1
8.4.2 Commissioning Tests/Runs 8.4.2-1
8.4.3 Performance During Normal Operation 8.4.3-1

8.5 Process Gas Sampling System 8.5.1-1

8.5.1 System Description 8.5.1-1
8.5.2 Alternative Conceptual Designs Considered for Sample Extraction and Transport 8.5.2-1
8.5.3 Sample Conditions at Extraction 8.5.3-1
8.5.4 Checkout and Commissioning Experience 8.5.4-1
8.5.5 Operational Experience 8.5.5-1

8.6 Thermal Oxidizer 8.6.1-1

8.6.1 Description 8.6.1-1
8.6.2 Commissioning Tests/Runs 8.6.2-1
8.6.3 Highlights of Problems and Solutions 8.6.3-1
8.6.4 Performance During Normal Operation 8.6.4-1

8.7 Steam System 8.7.1-1

8.7.1 Description 8.7.1-1
8.7.2 Commissioning Tests/Runs 8.7.2-1
8.7.3 Highlights of Problems and Solutions 8.7.3-1

8.8 Sulfator System 8.8.1-1

8.8.1 System Description 8.8.1-1
8.8.2 Commissioning Status 8.8.2-1
8.8.3 Commissioning Experience 8.8.3-1
8.8.4 Sulfator Start-Up Heater Performance Test 8.8.4-1
8.8.5 Other General Problems 8.8.5-1

8.9 Baghouse, Baghouse Ash Removal, and MWK Ash Storage System 8.9.1-1

8.9.1 Baghouse Commissioning Report 8.9.1-1
8.9.2 Baghouse Ash Removal System 8.9.2-1
8.9.3 MWK Ash Storage 8.9.3-1

8.10 Heat Transfer Fluid System 8.10.1-1

8.10.1 Description 8.10.1-1
8.10.2 Commissioning/Operations 8.10.2-1

8.11 Medium- and Low-Pressure Nitrogen System 8.11.1-1

8.11.1 Description 8.11.1-1
8.11.2 Commissioning/Operating Experience 8.11.2-1

8.12 Propane System 8.12.1-1

8.12.1 Description 8.12.1-1
8.12.2 Commissioning/Operations 8.12.2-1
8.12.3 Performance During Normal Operations 8.12.3-1

8.13 Service and Instrument Air System 8.13.1-1

8.13.1 Description 8.13.1-1
8.13.2 Commissioning/Operations 8.13.2-1

8.14 Closed-Loop Cooling, Circulating, and Service Water Systems 8.14.1-1

8.14.1 MWK Closed-Loop Cooling Water System 8.14.1-1
8.14.2 SCS Closed-Loop Cooling Water System 8.14.2-1
8.14.3 Circulating Water System 8.14.3-1
8.14.4 Service Water System 8.14.4-1

8.15 Waste Water Treatment/Chemical Injection 8.15.1-1

8.15.1 Description 8.15.1-1
8.15.2 Commissioning/Operations 8.15.2-1

8.16 Station Service and Diesel Generator 8.16.1-1

8.16.1 Station Service 8.16.1-1
8.16.2 Diesel Generator 8.16.2-1

8.17 Flare System 8.17.1-1

8.17.1 Description 8.17.1-1
8.17.2 Commissioning Tests/Runs 8.17.2-1

9.0 SUPPORT SERVICES 9.1.1-1

9.1 Data Management Systems 9.1.1-1

9.1.1 LIMS 9.1.1-1
9.1.2 PI 9.1.2-1

9.2 Operations and Maintenance 9.2.1-1

9.2.1 Ultrasonic Thickness Measurements 9.2.1-1
9.2.2 Vibration Monitoring 9.2.2-1
9.2.3 Thermal Scan 9.2.3-1

9.3 DCS and PLC Configuration and Support 9.3-1

9.4 Environmental and Safety 9.4.1-1

9.4.1 Environmental 9.4.1-1
9.4.2 Safety 9.4.2-1

TERMS ..... PSDF Terms-1

Listing of Tables
(Page 1 of 2)

Table Page

VOLUME 1

2.2-1 Major Equipment in the Transport Reactor Train....2.3-3
2.2-2 Major Equipment in the Balance-of-Plant.... 2.2-4

3-1 Operational Dates for Various Systems in the Transport Reactor Train Along With Systems Associated With the Westinghouse PCD and Balance-of-Plant....3.0-2
3-2 Chronology of Major Events During Installation, Checkout, Shakedown, and Commissioning of Westinghouse PCD and Associated Systems....3.0-4
3-3 Chronology of Initial Commissioning and Characterization Test Runs....3.0-5

5.1.7-1 Results From Reactor Loop Skin Temperature Surveys.... 5.1.7-12

5.1.9-1 Results From Reactor Loop Skin Temperature Surveys.... 5.1.9-8

VOLUME 2

5.1.11A-1 Average Test Conditions 5.1.11-6
5.1.11A-2 Sand Makeup Into Reactor.... 5.1.11-6
5.1.11A-3 Summary of Results.... 5.1.11-6
5.1.11B-1 Disengager Test Results (GEESI).... 5.1.11-7

5.2.1-1 Comparison of Heat Release Rates From Different Combustion Processes 5.2.1-4

6.1.6-1 CCT1A Run Statistics.... 6.1.6-6
6.1.6-2 CCT1A Major Events (Refer to Figures 6.1.6-1 and -2).... 6.1.6-6

6.1.7-1 CCT1B Run Statistics.... 6.1.7-4
6.1.7-2 CCT1B Major events (Refer to Figures 6.1.8-1 and -2) 6.1.7-4

6.1.8-1 CCT1C Run Statistics.... 6.1.8-10
6.1.8-2 CCT1C Major Events (Refer to Figures 6.1.8-1 and -2).... 6.1.8-11

Listing of Tables
(Page 2 of 2)

Table | Page

6.1.9-1 Element Information for FL0301 Top Plenum 6.1.9-2
6.1.9-2 Element Information for FL0301 Bottom Plenum Tubesheet ID Numbers 1 through 30 ..... 6.1.9-3
6.1.9-3 Element Information for FL0301 Bottom Plenum Tubesheet ID Numbers 31through 55 ..... 6.1.9-4

6.1.10-1 CCT2A, Phase 1 Run Statistics 6.1.10-6
6.1.10-2 CCT2A, Phase 1 Major Events (Refer to Figures 6.1.10-1 and -2) 6.1.10-7
6.1.10-3 CCT2A, Phase 2 Run Statistics 6.1.10-8
6.1.10-4 CCT2A, Phase 2 Major Events (Refer to Figures 6.1.10-3 and -4) 6.1.10-8

6.1.11-1 CCT2B Run Statistics 6.1.11-5
6.1.11-2 CCT2B Major Events (Refer to Figures 6.1.11-1 and -2) 6.1.11-5

6.1.12-1 CCT2C Run Statistics 6.1.12-8
6.1.12-2 CCT2C Major Events (Refer to Figures 6.1.12-1 and -2) 6.1.12-8
6.1.12-3 Sampling Parameters and Process Conditions 6.1.12-9
6.1.12-4 Measured Particulate Loadings 6.1.12-9

6.1.13-1 CCT3 Run Statistics 6.1.13-4
6.1.13-2 CCT3 Major Events (Refer to Figures 6.1.15-1 and -2) 6.1.13-4

8.5.1-1 Process Gas Sampling System Instruments 8.5.1-2
8.5.1-2 Calibration Ranges for the GC 8.5.1-2

Listing of Figures

Figure Page

VOLUME 1

1-1 Schematic Process Flow Diagram of the Transport Reactor Train.....1.0-9
1-2 Combustion Test Runs With Hours of Solids Circulation and Coal Feed 1.0-10
1-3 Cluster Being Lifted From the Specially Designed Levels of the Maintenance Bay 1.0-11

2.2-1 Flow Diagram of the Transport Reactor Train 2.2-7

5.1.2-1 Start-Up Burner Flow/Temperature for June 11 Through 15, 1996 ..... 5.1.2-3
5.1.2-2 Reactor Mixing Zone and Riser Temperatures for June 11 Through 15, 1996..... 5.1.2-4
5.1.2-3 Standpipe/Dipleg Temperatures for June 11 Through 15, 1996..... 5.1.2-5
5.1.2-4 PCD Temperatures for June 11 Through 15, 1996 ..... 5.1.2-6
5.1.2-5 Reactor Pressure/Standpipe DP for June 11 Through 15, 1996..... 5.1.2-7
5.1.2-6 Reactor Flows for June 11 Through 15, 1996 ..... 5.1.2-8
5.1.2-7 CO0201 System Profile for June 10 Through June 12, 1996 ..... 5.1.2-9

5.1.3-1 CO0201 System Profile for June 17 Through 20, 1996 ..... 5.1.3-4
5.1.3-2 CO0201 Fourth-Stage Vane Position for June 17 Through 20, 1996..... 5.1.3-5
5.1.3-3 Transport Air System for June 17 Through 20, 1996..... 5.1.3-6
5.1.3-4 Coal Feed for June 17 Through 20, 1996..... 5.1.3-7
5.1.3-5 FD0210 Conveying Line Pres/Flow for June 17 Through 20, 1996 ..... 5.1.3-8
5.1.3-6 Start-Up Burner Flow/Temperature for June 17 Through 20, 1996 ..... 5.1.3-9
5.1.3-7 System Pressures Downstream of PCD June 17 Through 20, 1996..... 5.1.3-10
5.1.3-8 Total Gas In/Out Flow Rates for June 17 Through 20, 1996 ..... 5.1.3-11
5.1.3-9 Reactor Mixing Zone and Riser Temperatures for 17 Through June 20, 1996..... 5.1.3-12
5.1.3-10 Standpipe Temperatures for June 17 Through 20, 1996..... 5.1.3-13
5.1.3-11 Cyclone Dipleg Temperatures for June 17 Through 20, 1996..... 5.1.3-14
5.1.3-12 Temperature Profiles Downstream of Reactor for June 17 Through 20, 1996..... 5.1.3-15
5.1.3-13 System Temperatures Downstream of PCD for June 17 Through 20, 1996..... 5.1.3-16
5.1.3-14 Mixing Zone DP Profile for June 17 Through 20, 1996..... 5.1.3-17
5.1.3-15 Reactor Pressure/Riser DP Profiles for June 17 Through 20, 1996 ..... 5.1.3-18
5.1.3-16 Standpipe DP Profiles for June 17 Through 20, 1996 ..... 5.1.3-19
5.1.3-17 FD0510 Temperature Profiles for June 17 Through 20, 1996..... 5.1.3-20

5.1.3-18 Steam Drum Pressure and BFW Temperature for 17 Through June 20, 1996 ..... 5.1.3-21
5.1.3-19 Baghouse Temperatures and Differential Pressure for June 17 Through June 20, 1996 ..... 5.1.3-22

5.1.4-1 CO0201 System Profile for June 27 Through July 1, 1996 ..... 5.1.4-6
5.1.4-2 Recycle Gas System Temperatures for June 27 Through July 1, 1996 ..... 5.1.4-7
5.1.4-3 Recycle Gas System Pressure for June 27 Through July 1, 1996 ..... 5.1.4-8
5.1.4-4 Transport Air System for June 27 Through July 1, 1996 ..... 5.1.4-9
5.1.4-5 Coal Feed for June 27 Through July 1, 1996 ..... 5.1.4-10
5.1.4-6 Sorbent Feed for June 27 Through July 1, 1996 ..... 5.1.4-11
5.1.4-7 Start-Up Burner Flow/Temperature for June 27 Through July 1, 1996 ..... 5.1.4-12
5.1.4-8 System Pressures Downstream of PCD for June 27 Through July 1, 1996 ..... 5.1.4-13
5.1.4-9 Total Gas In/Out Flow Rates for June 27 Through July 1, 1996 ..... 5.1.4-14
5.1.4-10 Reactor Mixing Zone and Riser Temperatures for June 27 Through July 1, 1996 ..... 5.1.4-15
5.1.4-11 Standpipe Temperatures for June 27 Through July 1, 1996 ..... 5.1.4-16
5.1.4-12 Cyclone Dipleg Temperatures for June 27 Through July 1, 1996 ..... 5.1.4-17
5.1.4-13 Temperature Profiles Downstream of Reactor for June 27 Through July 1, 1996 ..... 5.1.4-18
5.1.4-14 System Temperatures Downstream of PCD for June 27 Through July 1, 1996 ..... 5.1.4-19
5.1.4-15 Mixing Zone DP Profile for June 27 Through July 1, 1996 ..... 5.1.4-20
5.1.4-16 Reactor Pressure/Riser DP Profiles for June 27 Through July 1, 1996 ..... 5.1.4-21
5.1.4-17 Standpipe DP Profiles for June 27 Through July 1, 1996 ..... 5.1.4-22
5.1.4-18 CY0201 Dipleg DP Profiles for June 27 Through July 1, 1996 ..... 5.1.4-23

5.1.5-1 CO0201 System Profile for July 22 Through 24, 1996 ..... 5.1.5-7
5.1.5-2 Transport Air System for July 22 Through 24, 1996 ..... 5.1.5-8
5.1.5-3 Coal Feed for July 22 Through 24, 1996 ..... 5.1.5-9
5.1.5-4 Sorbent Feed for July 22 Through 24, 1996 ..... 5.1.5-10
5.1.5-5 Start-Up Burner Flow/Temperature for July 22 Through 24, 1996 ..... 5.1.5-11
5.1.5-6 System Pressures Downstream of PCD for July 22 Through 24, 1996 ..... 5.1.5-12
5.1.5-7 Total Gas In/Out Flow Rates for July 22 Through 24, 1996 ..... 5.1.5-13
5.1.5-8 Reactor Mixing Zone and Riser Temperatures for July 22 Through 24, 1996 ..... 5.1.5-14
5.1.5-9 Standpipe Temperatures for July 22 Through 24, 1996 ..... 5.1.5-15
5.1.5-10 Cyclone Dipleg Temperatures for July 22 Through 24, 1996 ..... 5.1.5-16

5.1.5-11 Temperature Profiles Downstream of Reactor for July 22 Through 24, 1996 ..... 5.1.5-17
5.1.5-12 PCD Ash Temperatures for July 22 Through 24, 1996 ..... 5.1.5-18
5.1.5-13 System Temperatures Downstream of PCD for July 22 Through 24, 1996 ..... 5.1.5-19
5.1.5-14 Reactor Pressure/Riser DP Profiles for July 22 Through 24, 1996 ..... 5.1.5-20
5.1.5-15 Standpipe DP Profiles for July 22 Through 24, 1996 ..... 5.1.5-21
5.1.5-16 CY0201 Dipleg DP Profiles for July 22 Through 24, 1996 ..... 5.1.5-22
5.1.5-17 FD0520 Pressures for July 22 Through 24, 1996 ..... 5.1.5-23
5.1.5-18 FD0530 Feeder for July 22 Through 24, 1996 ..... 5.1.5-24
5.1.5-19 CO0201 System Profile for July 25 Through 27, 1996 ..... 5.1.5-25
5.1.5-20 Transport Air System for July 25 Through 27, 1996 ..... 5.1.5-26
5.1.5-21 Coal Feed for July 25 Through 27, 1996 ..... 5.1.5-27
5.1.5-22 Sorbent Feed for July 25 Through 27, 1996 ..... 5.1.5-28
5.1.5-23 Start-Up Burner Flow/Temperature for July 25 Through 27, 1996 ..... 5.1.5-29
5.1.5-24 System Pressures Downstream of PCD for July 25 Through 27, 1996 ..... 5.1.5-30
5.1.5-25 Total Gas In/Out Flow Rates for July 25 Through 27, 1996 ..... 5.1.5-31
5.1.5-26 Reactor Mixing Zone and Riser Temperatures for July 25 Through 27, 1996 ..... 5.1.5-32
5.1.5-27 Standpipe Temperatures for July 25 Through 27, 1996 ..... 5.1.5-33
5.1.5-28 Cyclone Dipleg Temperatures for July 25 Through 27, 1996 ..... 5.1.5-34
5.1.5-29 Temperature Profiles Downstream of Reactor for July 25 Through 27, 1996 ..... 5.1.5-35
5.1.5-30 PCD Ash Temperatures for July 25 Through 27, 1996 ..... 5.1.5-36
5.1.5-31 System Temperatures Downstream of PCD for July 25 Through 27, 1996 ..... 5.1.5-37
5.1.5-32 Reactor Pressure/Riser DP Profiles for July 25 Through 27, 1996 ..... 5.1.5-38
5.1.5-33 Standpipe DP Profiles for July 25 Through 27, 1996 ..... 5.1.5-39
5.1.5-34 CY0201 Dipleg DP Profiles for July 25 Through 27, 1996 ..... 5.1.5-40
5.1.5-35 FD0520 Pressures for July 25 Through 27, 1996 ..... 5.1.5-41
5.1.5-36 FD0530 Feeder for July 25 Through 27, 1996 ..... 5.1.5-42

5.1.6-1 Reactor Flows for July 31 Through August 2, 1996 ..... 5.1.6-7
5.1.6-2 Start-Up Burner Flow/Temperatures for July 31 Through August 2, 1996 ..... 5.1.6-8
5.1.6-3 Reactor Mixing Zone and Riser Temperatures for July 31 Through August 2, 1996 ..... 5.1.6-9
5.1.6-4 Standpipe/Dipleg Temperatures for July 31 Through August 2, 1996 ..... 5.1.6-10
5.1.6-5 PCD Temperatures for July 31 Through August 2, 1996 ..... 5.1.6-11

5.1.6-6 Reactor Pressure/Standpipe DP for July 31 Through August 2, 1996 ..... 5.1.6-12
5.1.6-7 Outlet Gas Compositions for July 31 Through August 2, 1996 ..... 5.1.6-13
5.1.6-8 PCD Pulse System Pressures for July 31 Through August 2, 1996 ..... 5.1.6-14
5.1.6-9 PCD Differential Pressures for July 31 Through August 2, 1996 ..... 5.1.6-15
5.1.6-10 Reactor Flows for August 3 Through August 5, 1996 ..... 5.1.6-16
5.1.6-11 Start-Up Burner Flow/Temperature for August 3 Through August 5, 1996 ..... 5.1.6-17
5.1.6-12 Reactor Mixing Zone and Riser Temperatures for August 3 Through August 5, 1996 ..... 5.1.6-18
5.1.6-13 Standpipe/Dipleg Temperatures for August 3 Through August 5, 1996 ..... 5.1.6-19
5.1.6-14 PCD Temperatures for August 3 Through August 5, 1996 ..... 5.1.6-20
5.1.6-15 Reactor Pressure/Standpipe DP for August 3 Through August 5, 1996 ..... 5.1.6-21
5.1.6-16 Outlet Gas Compositions for August 3 Through August 5, 1996 ..... 5.1.6-22
5.1.6-17 PCD Differential Pressures for August 3 Through August 5, 1996 ..... 5.1.6-23
5.1.6-18 PCD Pulse System Pressures for August 3 Through August 5, 1996 ..... 5.1.6-24
5.1.6-19 Sorbent Feed for August 3 Through August 5, 1996 ..... 5.1.6-25
5.1.6-20 PV287 Erosion (View 1 of 4) 5.1.6-26
5.1.6-21 PV287 Erosion (View 2 of 4) 5.1.6-26
5.1.6-22 PV287 Erosion (View 3 of 4) 5.1.6-26
5.1.6-23 PV287 Erosion (View 4 of 4) 5.1.6-26
5.1.6-24 FD0220 Vent Valve 5.1.6-26
5.1.6-25 FD0210 Vent Valve 5.1.6-26

5.1.7-1 CO0201 System Profile for August 14 Through 16, 1996 ..... 5.1.7-13
5.1.7-2 Transport Air System for August 14 Through 16, 1996 ..... 5.1.7-14
5.1.7-3 Coal and Sorbent Silo Levels for August 14 Through 16, 1996 ..... 5.1.7-15
5.1.7-4 Coal Feed for August 14 Through 16, 1996 ..... 5.1.7-16
5.1.7-5 Sorbent Feed for August 14 Through 16, 1996 ..... 5.1.7-17
5.1.7-6 Start-Up Burner Flow/Temperature for August 14 Through 16, 1996 ..... 5.1.7-18
5.1.7.7 System Pressures Downstream of PCD for August 14 Through 16, 1996 ..... 5.1.7-19
5.1.7.8 Total Gas In/Out Flow Rates for August 14 Through 16, 1996 ..... 5.1.7-20
5.1.7-9 Reactor Mixing Zone and Riser Temperatures for August 14 Through 16, 1996 ..... 5.1.7-21
5.1.7-10 Standpipe Temperatures for August 14 Through 16, 1996 ..... 5.1.7-22
5.1.7-11 Cyclone Dipleg Temperatures for August 14 Through 16, 1996 ..... 5.1.7-23
5.1.7-12 Temperature Profiles Downstream of Reactor for August 14 Through 16, 1996 ..... 5.1.7-24
5.1.7-13 PCD Ash Temperatures for August 14 Through 16, 1996 ..... 5.1.7-25

5.1.7-14 System Temperatures Downstream of PCD for August 14 Through 16, 1996 ..... 5.1.7-26
5.1.7-15 Reactor Pressure/Riser DP Profiles for August 14 Through 16, 1996 ..... 5.1.7-27
5.1.7-16 Standpipe DP Profiles for August 14 Through 16, 1996 ..... 5.1.7-28
5.1.7-17 CY0201 Dipleg DP Profiles for August 14 Through 16, 1996 ..... 5.1.7-29
5.1.7-18 O_2, SO_2, and NO_X Analyzers for August 14 Through 16, 1996 ..... 5.1.7-30
5.1.7-19 CO and H_2O Analyzer for August 14 Through 16, 1996 ..... 5.1.7-31
5.1.7-20 FD0510 Temperature Profiles for August 14 Through 16, 1996 ..... 5.1.7-32
5.1.7-21 FD0206 Pressure Profiles for August 14 Through 16, 1996 ..... 5.1.7-33
5.1.7-22 FD0520 Pressures for August 14 Through 16, 1996 ..... 5.1.7-34
5.1.7-23 FD0530 Feeder for August 14 Through 16, 1996 ..... 5.1.7-35
5.1.7-24 FD0530 Feeder for August 14 Through 16, 1996 ..... 5.1.7-36
5.1.7-25 PCD Temperatures for August 14 Through 16, 1996 ..... 5.1.7-37
5.1.7-26 PCD Differential Pressures for August 14 Through 16, 1996 ..... 5.1.7-38
5.1.7-27 PCD Pressure and Pulse Pressure for August 14 Through 16, 1996 ..... 5.1.7-39
5.1.7-28 CO0201 System Profile for August 17 Through 19, 1996 ..... 5.1.7-40
5.1.7-29 Transport Air System for August 17 Through 19, 1996 ..... 5.1.7-41
5.1.7-30 Coal and Sorbent Silo Levels for August 17 Through 19, 1996 ..... 5.1.7-42
5.1.7-31 Coal Feed for August 17 Through 19, 1996 ..... 5.1.7-43
5.1.7-32 Sorbent Feed for August 17 Through 19, 1996 ..... 5.1.7-44
5.1.7-33 Start-Up Burner Flow/Temperature for August 17 Through 19, 1996 ..... 5.1.7-45
5.1.7-34 System Pressures Downstream of PCD for August 17 Through 19, 1996 ..... 5.1.7-46
5.1.7-35 Total Gas In/Out Flow Rates for August 17 Through 19, 1996 ..... 5.1.7-47
5.1.7-36 Reactor Mixing Zone and Riser Temperatures for August 17 Through 19, 1996 ..... 5.1.7-48
5.1.7-37 Standpipe Temperatures for August 17 Through 19, 1996 ..... 5.1.7-49
5.1.7-38 Cyclone Dipleg Temperatures for August 17 Through 19, 1996 ..... 5.1.7-50
5.1.7-39 Temperature Profiles Downstream of Reactor for August 17 Through 19, 1996 ..... 5.1.7-51
5.1.7-40 PCD Ash Temperatures for August 17 Through 19, 1996 ..... 5.1.7-52
5.1.7-41 System Temperatures Downstream of PCD for August 17 Through 19, 1996 ..... 5.1.7-53
5.1.7-42 Reactor Pressure/Riser DP Profiles for August 17 Through 19, 1996 ..... 5.1.7-54
5.1.7-43 Standpipe DP Profiles for August 17 Through 19, 1996 ..... 5.1.7-55
5.1.7-44 CY0201 Dipleg DP Profiles for August 17 Through 19, 1996 ..... 5.1.7-56
5.1.7-45 O_2, SO_2, and NO_X Analyzers for August 17 Through 19, 1996 ..... 5.1.7-57
5.1.7-46 CO and H_2O Analyzer for August 17 Through 19, 1996 ..... 5.1.7-58
5.1.7-47 FD0510 Temperature Profiles for August 17 Through 19, 1996 ..... 5.1.7-59

5.1.7-48 FD0206 Pressure Profiles for August 17 Through 19, 1996 ..... 5.1.7-60
5.1.7-49 FD0520 Pressures for August 17 Through 19, 1996 ..... 5.1.7-61
5.1.7-50 FD0530 Feeder for August 17 Through 19, 1996 ..... 5.1.7-62
5.1.7-51 FD0530 Feeder for August 17 Through 19, 1996 ..... 5.1.7-63
5.1.7-52 PCD Temperatures for August 17 Through 19, 1996 ..... 5.1.7-64
5.1.7-53 PCD Differential Pressures for August 17 Through 19, 1996 ..... 5.1.7-65
5.1.7-54 PCD Pressure and Pulse Pressure for August 17 Through 19, 1996 ..... 5.1.7-66
5.1.7-55 CO0201 System Profile for August 20 Through 23, 1996 ..... 5.1.7-67
5.1.7-56 Transport Air System for August 20 Through 23, 1996 ..... 5.1.7-68
5.1.7-57 Coal and Sorbent Silo Levels for August 20 Through 23, 1996 ..... 5.1.7-69
5.1.7-58 Coal Feed for August 20 Through 23, 1996 ..... 5.1.7-70
5.1.7-59 Sorbent Feed for August 20 Through 23, 1996 ..... 5.1.7-71
5.1.7-60 Start-Up Burner Flow/Temperature August 20 Through 23, 1996 ..... 5.1.7-72
5.1.7-61 System Pressures Downstream of PCD for August 20 Through 23, 1996 ..... 5.1.7-73
5.1.7-62 Total Gas In/Out Flow Rates for August 20 Through 23, 1996 ..... 5.1.7-74
5.1.7-63 Reactor Mixing Zone and Riser Temperatures for August 20 Through 23, 1996 ..... 5.1.7-75
5.1.7-64 Standpipe Temperatures for August 20 Through 23, 1996 ..... 5.1.7-76
5.1.7-65 Cyclone Dipleg Temperatures for August 20 Through 23, 1996 ..... 5.1.7-77
5.1.7-66 Temperature Profiles Downstream of Reactor for August 20 Through 23, 1996 ..... 5.1.7-78
5.1.7-67 PCD Ash Temperatures for August 20 Through 23, 1996 ..... 5.1.7-79
5.1.7-68 System Temperatures Downstream of PCD for August 20 Through 23, 1996 ..... 5.1.7-80
5.1.7-69 Reactor Pressure/Riser DP Profiles for August 20 Through 23, 1996 ..... 5.1.7-81
5.1.7-70 Standpipe DP Profiles for August 20 Through 23, 1996 ..... 5.1.7-82
5.1.7-71 CY0201 Dipleg DP Profiles for August 20 Through 23, 1996 ..... 5.1.7-83
5.1.7-72 O_2, SO_2, and NO_X Analyzers for August 20 Through 23, 1996 ..... 5.1.7-84
5.1.7-73 CO and H_2O Analyzer for August 20 Through 23, 1996 ..... 5.1.7-85
5.1.7-74 FD0510 Temperature Profiles for August 20 Through 23, 1996 ..... 5.1.7-86
5.1.7-75 FD0206 Pressure Profiles for August 20 Through 23, 1996 ..... 5.1.7-87
5.1.7-76 FD0520 Pressures for August 20 Through 23, 1996 ..... 5.1.7-88
5.1.7-77 FD0530 Feeder for August 20 Through 23, 1996 ..... 5.1.7-89
5.1.7-78 FD0530 Feeder for August 20 Through 23, 1996 ..... 5.1.7-90
5.1.7-79 PCD Temperatures for August 20 Through 23, 1996 ..... 5.1.7-91
5.1.7-80 PCD Differential Pressures for August 20 Through 23, 1996 ..... 5.1.7-92
5.1.7-81 PCD Pressure and Pulse Pressure for August 20 Through 23, 1996 ..... 5.1.7-93
5.1.7-82 Coal and Dolomite Solids Size Distribution Run CCT1C 5.1.7-94
5.1.7-83 Solids Size Distribution Run CCT1C August 16 to 19, 1996 ..... 5.1.7-95
5.1.7-84 Solids Size Distribution Run CCT1C August 20 to 21, 1996 ..... 5.1.7-96

5.1.8-1 CO0201 System Profile for September 27 Through 30, 1996 ..... 5.1.8-6
5.1.8-2 Total Gas In/Out Flow Rates for September 27 Through 30, 1996 ..... 5.1.8-7
5.1.8-3 Reactor Mixing Zone and Riser Temperatures for September 27 Through 30, 1996 ..... 5.1.8-8
5.1.8-4 Standpipe Temperatures for September 27 Through 30, 1996 ..... 5.1.8-9
5.1.8-5 Cyclone Dipleg Temperatures for September 27 Through 30, 1996 ..... 5.1.8-10
5.1.8-6 Temperature Profiles Downstream of Reactor for September 27 Through 30, 1996 ..... 5.1.8-11
5.1.8-7 System Temperatures Downstream of PCD for September 27 Through 30, 1996 ..... 5.1.8-12
5.1.8-8 Reactor Pressure/Riser DP Profiles for September 27 Through September 30, 1996 ..... 5.1.8-13
5.1.8-9 CO0201 System Profile for October 2 Through October 6, 1996 ..... 5.1.8-14
5.1.8-10 Transport Air System for October 2 Through October 6, 1996 ..... 5.1.8-15
5.1.8-11 Start-Up Burner Flow Temperature for October 2 Through October 6, 1996 5.1.8-16
5.1.8-12 System Pressures Downstream of PCD for October 2 Through October 6, 1996 ..... 5.1.8-17
5.1.8-13 Total Gas In/Out Flow Rates for October 2 Through 6, 1996 ..... 5.1.8-18
5.1.8-14 Reactor Mixing Zone and Riser Temperatures for October 2 Through October 6, 1996 ..... 5.1.8-19
5.1.8-15 Standpipe Temperatures for October 2 Through October 6, 1996 ..... 5.1.8-20
5.1.8-16 Cyclone Dipleg Temperatures for October 2 Through October 6, 1996 ..... 5.1.8-21
5.1.8-17 Temperature Profiles Downstream of Reactor for October 2 Through October 6, 1996 ..... 5.1.8-22
5.1.8-18 PCD Ash Temperatures for October 2 Through October 6, 1996 ..... 5.1.8-23
5.1.8-19 System Temperatures Downstream of PCD for October 2 Through October 6, 1996 ..... 5.1.8-24
5.1.8-20 Mixing Zone DP Profile for October 2 Through October 6, 1996 ..... 5.1.8-25
5.1.8-21 Reactor Pressure/Riser DP Profiles for October 2 Through October 6, 1996 ..... 5.1.8-26
5.1.8-22 Standpipe DP Profiles for October 2 Through October 6, 1996 ..... 5.1.8-27
5.1.8-23 CY0201 Dipleg DP Profiles for October 2 Through October 6, 1996 ..... 5.1.8-28
5.1.8-24 CO0201 System Profile for October 14 Through October 17, 1996 ..... 5.1.8-29
5.1.8-25 Transport Air System for October 14 Through October 17, 1996 ..... 5.1.8-30
5.1.8-26 Start-Up Burner Flow/Temperature for October 14 Through October 17, 1996 ..... 5.1.8-31
5.1.8-27 System Pressures Downstream of PCD for October 14 Through October 17, 1996 ..... 5.1.8-32
5.1.8-28 Total Gas In/Out Flow Rates for October 14 Through 17, 1996 ..... 5.1.8-33
5.1.8-29 Reactor Mixing Zone and Riser Temperatures for October 14 Through October 17, 1996 ..... 5.1.8-34

5.1.8-30 Standpipe Temperature for October 14 Through October 17, 1996 .....5.1.8-35
5.1.8-31 Cyclone Dipleg Temperatures for October 14 Through 17, 1996.....5.1.8-36
5.1.8-32 Temperature Profiles Downstream of Reactor for October 14 Through October 17, 1996.....5.1.8-37
5.1.8-33 PCD Ash Temperatures for October 14 Through October 17, 1996 .....5.1.8-38
5.1.8-34 System Temperatures Downstream of PCD for October 14 Through October 17, 1996.....5.1.8-39
5.1.8-35 Mixing Zone DP Profile for October 14 Through October 17, 1996.....5.1.8-40
5.1.8-36 Reactor Pressure/Riser DP Profiles for October 14 Through October 17, 1996 .....5.1.8-41
5.1.8-37 Standpipe DP Profiles for October 14 Through 17, 1996 .....5.1.8-42
5.1.8-38 CY0201 Dipleg DP Profiles for October 14 Through 17, 1996 .....5.1.8-43
5.1.8-39 FD0510 Temperature Profiles for October 14 Through 17, 1996.....5.1.8-44
5.1.8-40 FD0206 Pressure Profiles for October 14 Through 17, 1996 .....5.1.8-45
5.1.8-41 FD0520 Pressures for October 14 Through 17, 1996 .....5.1.8-46
5.1.8-42 FD0530 Feeder for October 14 Through 17, 1996.....5.1.8-47
5.1.8-43 FD0530 Feeder for October 14 Through 17, 1996.....5.1.8-48
5.1.8-44 Disengager Cone Covered With Deposits.....5.1.8-49
5.1.8-45 Disengager Cone After Removal of Deposits 5.1.8-49
5.1.8-46 Primary Cyclone Showing Deposit Behind the Gas Outlet Tube 5.1.8-50
5.1.8-47 Primary Cyclone After Removal of Deposits.....5.1.8-50

5.1.9-1 CO0201 System Profile for November 3 Through 7, 1996 .....5.1.9-9
5.1.9-2 Transport Air System for November 3 Through 7, 1996.....5.1.9-10
5.1.9-3 Coal Feed for November 3 Through 7, 1996.....5.1.9-11
5.1.9-4 Sorbent Feed for November 3 Through 7, 1996.....5.1.9-12
5.1.9-5 Start-Up Burner Flow/Temperature for November 3 Through 7, 1996.....5.1.9-13
5.1.9-6 System Pressures Downstream of PCD for November 3 Through 7, 1996.....5.1.9-14
5.1.9-7 Total Gas In/Out Flow Rates for November 3 Through 7, 1996.....5.1.9-15
5.1.9-8 Reactor Mixing Zone and Riser Temperatures for November 3 Through 7, 1996.....5.1.9-16
5.1.9-9 Standpipe Temperatures for November 3 Through 7, 1996.....5.1.9-17
5.1.9-10 Cyclone Dipleg Temperatures for November 3 Through 7, 1996.....5.1.9-18
5.1.9-11 Temperature Profiles Downstream of Reactor for November 3 Through 7, 1996.....5.1.9-19
5.1.9-12 PCD Ash Temperatures for November 3 Through 7, 1996 .....5.1.9-20
5.1.9-13 System Temperatures Downstream of PCD for November 3 Through 7, 1996.....5.1.9-21
5.1.9-14 Mixing Zone DP Profile for November 3 Through 7, 1996.....5.1.9-22
5.1.9-15 Reactor Pressure/Riser DP Profiles for November 3 Through 7, 1996 .....5.1.9-23

5.1.9-16 Standpipe DP Profiles for November 3 Through 7, 1996 ..... 5.1.9-24
5.1.9-17 CY0201 Dipleg DP Profiles for November 3 Through 7, 1996 ..... 5.1.9-25
5.1.9-18 O_2, SO_2, and NO_X Analyzers for November 3 Through 7, 1996 ..... 5.1.9-26
5.1.9-19 FD0520 Pressures for November 3 Through 7, 1996 ..... 5.1.9-27
5.1.9-20 FD0530 Feeder for November 3 Through 7, 1996 ..... 5.1.9-28
5.1.9-21 FD0530 Feeder for November 3 Through 7, 1996 ..... 5.1.9-29
5.1.9-22 Feed Sand and PCD Solids Particle Size Distribution on November 4, 1996 ..... 5.1.9-30
5.1.9-23 Feed Sand and PCD Solids Particle Size Distribution on November 4, 1996 ..... 5.1.9-31
5.1.9-24 Standpipe and PCD Solids Particle Size Distribution on November 5, 1996 ..... 5.1.9-32
5.1.9-25 PCD Solids Particle Size Distribution on November 6 and 7, 1996 ..... 5.1.9-33

5.1.10-1 CO0201 System Profile for November 14 Through 17, 1996 ..... 5.1.10-11
5.1.10-2 Transport Air System for November 14 Through 17, 1996 ..... 5.1.10-12
5.1.10-3 Coal Feed for November 14 Through 17, 1996 ..... 5.1.10-13
5.1.10-4 Sorbent Feed for November 14 Through 17, 1996 ..... 5.1.10-14
5.1.10-5 Start-Up Burner Flow/Temperature for November 14 Through 17, 1996 ..... 5.1.10-15
5.1.10-6 System Pressures Downstream of PCD for November 14 Through 17, 1996 ..... 5.1.10-16
5.1.10-7 Total Gas In/Out Flow Rates for November 14 Through 17, 1996 ..... 5.1.10-17
5.1.10-8 Reactor Mixing Zone and Riser Temperatures for November 14 Through 17, 1996 ..... 5.1.10-18
5.1.10-9 Standpipe Temperatures for November 14 Through 17, 1996 ..... 5.1.10-19
5.1.10-10 Cyclone Dipleg Temperatures for November 14 Through 17, 1996 ..... 5.1.10-20
5.1.10-11 Temperature Profiles Downstream of Reactor for November 14 Through 17, 1996 ..... 5.1.10-21
5.1.10-12 PCD Ash Temperatures for November 14 Through 17, 1996 ..... 5.1.10-22
5.1.10-13 System Temperatures Downstream of PCD for November 14 Through 17, 1996 ..... 5.1.10-23
5.1.10-14 Mixing Zone DP Profile for November 14 Through 17, 1996 ..... 5.1.10-24
5.1.10-15 Reactor Pressure/Riser DP Profiles for November 14 Through 17, 1996 ..... 5.1.10-25
5.1.10-16 Standpipe DP Profiles for November 14 Through 17, 1996 ..... 5.1.10-26
5.1.10-17 CY0201 Dipleg DP Profiles for November 14 Through 17, 1996 ..... 5.1.10-27
5.1.10-18 Coal Feed Rate for November 14 Through 17, 1996 ..... 5.1.10-28
5.1.10-19 O_2, SO_2, and NO_X Analyzers for November 14 Through 17, 1996 ..... 5.1.10-29

5.1.10-20 Solids Withdrawal for November 14 Through 17, 1996 ..... 5.1.10-30
5.1.10-21 FD0510 Temperature Profiles for November 14 Through 17, 1996 ..... 5.1.10-31
5.1.10-22 FD0206 Pressure Profiles for November 14 Through 17, 1996 ..... 5.1.10-32
5.1.10-23 FD0520 Pressures for November 14 Through 17, 1996 ..... 5.1.10-33
5.1.10-24 FD0530 Feeder for November 14 Through 17, 1996..... 5.1.10-34
5.1.10-25 FD0530 Feeder for November 14 Through 17, 1996..... 5.1.10-35
5.1.10-26 CO0201 System Profile for November 18 Through 22, 1996..... 5.1.10-36
5.1.10-27 Transport Air System for November 18 Through 22, 1996 ..... 5.1.10-37
5.1.10-28 Coal Feed for November 18 Through 22, 1996 ..... 5.1.10-38
5.1.10-29 Sorbent Feed for November 18 Through 22, 1996..... 5.1.10-39
5.1.10-30 Start-Up Burner Flow/Temperature for November 18 Through 22, 1996..... 5.1.10-40
5.1.10-31 System Pressures Downstream of PCD for November 18 Through 22, 1996..... 5.1.10-41
5.1.10-32 Total Gas In/Out Flow Rates for November 18 Through 22, 1996 ..... 5.1.10-42
5.1.10-33 Reactor Mixing Zone and Riser Temperatures for November 18 Through 22, 1996..... 5.1.10-43
5.1.10-34 Standpipe Temperatures for November 18 Through 22, 1996 ..... 5.1.10-44
5.1.10-35 Cyclone Dipleg Temperatures for November 18 Through 22, 1996 ..... 5.1.10-45
5.1.10-36 Temperature Profiles Downstream of Reactor for November 18 Through 22, 1996..... 5.1.10-46
5.1.10-37 PCD Ash Temperatures for November 18 Through 22, 1996..... 5.1.10-47
5.1.10-38 System Temperatures Downstream of PCD for November 18 Through 22, 1996..... 5.1.10-48
5.1.10-39 Mixing Zone DP Profile for November 18 Through 22, 1996 ..... 5.1.10-49
5.1.10-40 Reactor Pressure/Riser DP Profiles for November 18 Through 22, 1996..... 5.1.10-50
5.1.10-41 Standpipe DP Profiles for November 18 Through 22, 1996..... 5.1.10-51
5.1.10-42 CY0201 Dipleg DP Profiles for November 18 Through 22, 1996 ..... 5.1.10-52
5.1.10-43 Coal Feed Rate for November 18 Through 22, 1996 ..... 5.1.10-53
5.1.10-44 O_2, SO_2, and NO_X Analyzers for November 18 Through 22, 1996 ..... 5.1.10-54
5.1.10-45 Solids Withdrawal for November 18 Through 22, 1996 ..... 5.1.10-55
5.1.10-46 FD0510 Temperature Profiles for November 18 Through 22, 1996 ..... 5.1.10-56
5.1.10-47 FD0206 Pressure Profiles for November 18 Through 22, 1996 ..... 5.1.10-57
5.1.10-48 FD0520 Pressures for November 18 Through 22, 1996 ..... 5.1.10-58
5.1.10-49 FD0530 Feeder for November 18 Through 22, 1996..... 5.1.10-59
5.1.10-50 FD0530 Feeder for November 18 Through 22, 1996..... 5.1.10-60

VOLUME 2

Figure Page

5.1.11A-1 Disengager Grade Efficiency Curve 5.1.11-8
5.1.11A-2 Disengager Grade Efficiency Curve 5.1.11-9
5.1.11B-1 Schematic Diagram of Experimental Setup at GEESI 5.1.11-10
5.1.11B-2 GEESI Disengager Cold Flow Test Results 5.1.11-10
5.1.11B-3 Comparison of Disengager Performance (PSDF vs GEESI) 5.1.11-11

5.1.13-1 Comparison of Flow Characteristics of Original Cage vs Modified Cage During Startup (PV-287 Whisper III Trim) 5.1.13-3
5.1.13-2 Flow Capacity vs Percent Valve (PV-287) Open for Inlet Pressure at 500°F (View 1) 5.1.13-3
5.1.13-3 Flow Capacity vs Percent Valve (PV-287) Open for Inlet Pressure at 500°F (View 2) 5.1.13-3
5.1.13-4 Flow Capacity vs Percent Valve (PV-287) Open for Inlet Pressure at 500°F (View 3) 5.1.13-3
5.1.13-5 Flow Capacity vs Percent Valve (PV-287) Open for Inlet Pressure at 500°F (View 4) 5.1.13-4
5.1.13-6 Flow Capacity vs Percent Valve (PV-287) Open for Inlet Pressure at 500°F (View 5) 5.1.13-4
5.1.13-7 Flow Capacity vs Percent Valve (PV-287) Open for Inlet Pressure at 500°F (View 6) 5.1.13-4

5.2-1 Comparison of Coal Feed Rates Calculated From Oxygen Balance and From Weight Cell Measurements for November 19 to 20, 1996, Test Period ..... 5.2 Exhibit - 1
5.2-2 Comparison of Coal Feed Rates Calculated From Oxygen Balance and From Weight Cell Measurements for November 20 to 21, 1996, Test Period ..... 5.2 Exhibit - 1
5.2-3 Comparison of Coal Feed Rates Calculated From Oxygen Balance and From Weight Cell Measurements for August 19 to 20, 1996, Test Period ..... 5.2 Exhibit - 2
5.2-4 Comparison of Coal Feed Rates Calculated From Oxygen Balance and From Weight Cell Measurements for August 20 to 21, 1996, Test Period ..... 5.2 Exhibit - 2
5.2-5 Variation of the Required Solid Circulation Rate With the Coal Feed Rate at Different Mass Fraction of Solid Circulating Through the Reactor Standpipe ..... 5.2 Exhibit - 3
5.2-6 Heat-Up Rate of a Single Particle vs the Dimensionless Radius ..... 5.2 Exhibit - 3
5.2-7 Variation of the Solid Circulation Rate With Time for the Test Period November 19 to 20, 1996 ..... 5.2 Exhibit - 4

5.2-8 Variation of the Measured Standpipe Pressure Difference With Time ..... 5.2 Exhibit - 4
5.2-9 Variation of Solid Circulation Rate With the Standpipe Pressure Difference ..... 5.2 Exhibit - 5
5.2-10 The Relationship Between the Coal Feed Rate and Solid Circulation Rate for the Test Period of November 19 to 20, 1996 ..... 5.2 Exhibit - 5
5.2-11 The Variation of Coal Feed Rate With Solid Circulation Rate for the First 12 Hours of Operation November 19 to 20, 1996 ..... 5.2 Exhibit - 6
5.2-12 The Variation of Coal Feed Rate With Solid Circulation Rate for the Test Period of August 20 to 21, 1996 ..... 5.2 Exhibit - 6
5.2-13 Variation of Solids Level in the Standpipe With Time for the Test Period of August 20 to 21, 1996 ..... 5.2 Exhibit - 7
5.2-14 Variation of Coal Feed Rate with Solid Circulation Rate for the Test Period of November 20 to 21, 1996 ..... 5.2 Exhibit - 7
5.2-15 Coal Feed Rate Vs Riser Temperature for Test Period November 19-20, 1996 ..... 5.2 Exhibit - 8
5.2-16 Coal Feed Rate Vs Riser Temperature for Test Period November 20-21, 1996 ..... 5.2 Exhibit - 8
5.2-17 Solid Circulation Rate Vs Riser Temperature for the Operation Period of November 19 to 20, 1996 ..... 5.2 Exhibit - 9
5.2-18 Estimated Solid Carryover Rate With Time for the Operation Period of November 19 to 20, 1996 ..... 5.2 Exhibit - 9
5.2-19 Estimated Solid Circulation Rate With Time for the Test Period of November 20 to 21, 1996 ..... 5.2 Exhibit - 10
5.2-20 Estimated Cyclone System Collection Efficiency Vs Solid/Gas Loading Ratio for the Test Period of November 19 and 20, 1996 ..... 5.2 Exhibit - 10
5.2-21 Estimated Cyclone System Collection Efficiency Vs Loading Ratio for the Test Period of November 20 and 21, 1996 ..... 5.2 Exhibit - 11
5.2-22 Solid/Gas Estimated Cyclone Efficiency Vs Solid/ Gas Loading Ratio for Given Disengager Efficiency ..... 5.2 Exhibit - 11
5.2-23 the Required Total Collection Efficiency of the Cyclone System Vs Solid/Gas Loading Ratio to Balance the Ash Production Rate and Solid Carryover Rate ..... 5.2 Exhibit - 12
5.2-24 Estimated Collection Efficiencies for the Individual Cyclone to Balance Ash Production Rate and Solid Carryover Rate ..... 5.2 Exhibit - 12
5.2-25 The Pressure Drop Across the Primary Cyclone for the Test Period November 20 to 21, 1996 ..... 5.2 Exhibit - 13

5.2-26 The Relationship Between the Cyclone Inlet Gas Velocity and the Cyclone Pressure Drop for the Test Period of November 20 to 21, 1996 ..... 5.2 Exhibit - 13
5.2-27 Estimated Solid Carryover Rate Vs the Solid Circulation Rate for the Test Period of November 20 to 21, 1996 ..... 5.2 Exhibit - 14
5.2-28 Estimated Solid Carryover Rate Vs the Solid Circulation Rate for the Test Period of November 19 to 20, 1996 ..... 5.2 Exhibit - 14
5.2-29 Comparison Between the Measured Pressure Drop Across the Riser and Calculated Pressure Drops Based on the Gas-Phase Flow, Only, Riser and Gas Phase With Only Solid Feed, to Show That the Measured Pressure Drop is Low ..... 5.2 Exhibit - 15
5.2-30 Comparison of the Measured Pressure Drop at the Top of the Riser With Calculated Pressure Drop for Test Period of November 19 to 20, 1996 ..... 5.2 Exhibit - 15
5.2-31 Comparison of Solid Circulation Rates Calculated From Energy Balance and Pressure Difference for the Test Period of November 19 to 20, 1996 ..... 5.2 Exhibit - 16
5.2-32 Comparison of Solid Circulation Rates Calculated From Energy Balance and Pressure Difference for the Test Period of November 20 to 21, 1996 ..... 5.2 Exhibit - 16
5.2-33 Comparison of Solid Circulation Rates Calculated From Energy Balance and Pressure Difference for the Test Period of August 20 to 21, 1996 ..... 5.2 Exhibit - 17
5.2-34 Comparison of Solid Circulation Rates Calculated From Energy Balance and Pressure Difference for the Test Period of August 19 to 20, 1996 ..... 5.2 Exhibit - 17

6.1.1-1 Operation Record for the PCD Over 994 Hours in 1996 ..... 6.1.1-3

6.1.2-1 PCD Flow Diagram 6.1.2-6
6.1.2-2 Westinghouse PCD FL0301 Filter Vessel 6.1.2-7
6.1.2-3 Westinghouse PCD Pulse Skid 6.1.2-8

6.1.3-1 PCD Maintenance Bay 6.1.3-3

6.1.4-1 FL0301 Tubesheet Map 6.1.4-2

6.1.5-1 Westinghouse PCD FL0301 ..... 6.1.5-5
6.1.5-2 Westinghouse PCD FL0301 Gasket Details 6.1.5-6
6.1.5-3 Westinghouse PCD FL0301 Orientation 6.1.5-6

6.1.6-1 CCT1A Summary Information 6.1.6-7
6.1.6-2 CCT1A Summary Information 6.1.6-8
6.1.6-3 CCT1A PCD Hopper Samples 6.1.6-9

6.1.6-4 CCT1A PCD Hopper Particle Size Distribution 6.1.6-9
6.1.6-5 CCT1A Baghouse Differential Pressure 6.1.6-10
6.1.6-6 CCT1A PCD Hopper vs Baghouse Hopper PSD 6.1.6-10

6.1.7-1 CCT1B Summary Information 6.1.7-5
6.1.7-2 CCT1B Summary Information 6.1.7-6

6.1.8-1 CCT1C Summary Information 6.1.8-12
6.1.8-2 CCT1C Summary Information 6.1.8-13
6.1.8-3 CCT1C Summary Information 6.1.8-14
6.1.8-4 CCT1C Summary Information 6.1.8-15
6.1.8-5 Approximate Ash Level on August 18 15 09:00 ..... 6.1.8-16
6.1.8-6 Approximate Ash Level on August 18 at 11:30 ..... 6.1.8-17
6.1.8-7 Approximate Ash Level on August 19 at 03:45 ..... 6.1.8-18
6.1.8-8 Approximate Ash Level on August 20 at ~04:00 ..... 6.1.8-19
6.1.8-9 Approximate Ash Level on August 20 at ~16:00 ..... 6.1.8-20
6.1.8-10 Approximate Ash Level on August 21 at ~12:00 ..... 6.1.8-21
6.1.8-11 CCT1C Hopper Samples 6.1.8-22
6.1.8-12 CCT1C PCD Hopper Particle Size Distributions 6.1.8-22
6.1.8-13 CCT1C PCD Hopper Ash Chemistry (Primary Constituents) 6.1.8-23
6.1.8-14 Broken Elements After CCT1C (Top of Page Is North) 6.1.8-24

6.1.9-1 FL0301 Tubesheet Map 6.1.9-5

6.1.10-1 CCT2A, Phase 1 Summary Information 6.1.10-9
6.1.10-2 CCT2A, Phase 1 Summary Information 6.1.10-10
6.1.10-3 CCT2A, Phase 2 Summary Information 6.1.10-11
6.1.10-4 CCT2A, Phase 2 Summary Information 6.1.10-12
6.1.10-5 CCT2A, Phase 1 PCD Hopper Samples 6.1.10-13
6.1.10-6 CCT2A, Phase 2 PCD Hopper Samples 6.1.10-13
6.1.10-7 CCT2A PCD Hopper Particle Size Distribution 6.1.10-14

6.1.11-1 CCT2B Summary Information 6.1.11-6
6.1.11-2 CCT2B Summary Information 6.1.11-7
6.1.11-3 CCT2B PCD Hopper Samples 6.1.11-8
6.1.11-4 CCT2B Hopper Particle Size Distribution 6.1.11-8

6.1.12-1 Run CCT2C Summary Information 6.1.12-10
6.1.12-2 Run CCT2C Summary Information 6.1.12-11
6.1.12-3 PCD Inlet Particle Size Distribution From Combined Sieve and Microtrac X-100 Measurements on In Situ Sample MWKIMT-3 ..... 6.1.12-12
6.1.12-4 Comparison of Size Distributions Measured by Microtrac Alone and Combined Sieve and Microtrac Measurements 6.1.12-12

6.1.12-5 Comparison of Microtrac Measured Size Distributions for Complete Sample and Particles Smaller Than 120 Mesh 6.1.12-13
6.1.12-6 Comparison of Cumulative Percent Particle Size Distributions for All Isokinetically Collected Samples 6.1.12-13
6.1.12-7 Comparison of Cumulative Mass Size Distribution for All Isokinetically Collected Samples 6.1.12-14
6.1.12-8 Comparison of Size Distributions From PCD Inlet In Situ Sample and PCD Cone Samples 6.1.12-14
6.1.12-9 PCD Cone Ash Analysis (Major Constituents) 6.1.12-15

6.1.13-1 CCT3 Summary Information 6.1.13-5
6.1.13-2 CCT3 Summary Information 6.1.13-6
6.1.13-3 CCT3 Hopper Particle Size Distribution - December 1996 (Reactor Solid Separation Efficiency Tests 1, 2, and 3) 6.1.13-7
6.1.13-4 CCT3 Hopper Particle Size Distribution - December 1996 (Reactor Solid Separation Efficiency Tests 4 and 5) 6.1.13-7
6.1.13-5 CCT3 PCD Hopper Samples 6.1.13-8

6.1.14-1 Resistances to Gas Glow 6.1.14-4
6.1.14-2 Buildup of Residual Cake ΔP 6.1.14-4
6.1.14-3 FL0301 1996 Permeance 6.1.14-5
6.1.14-4 CCT2C Filter ΔP and Particulate Loading 6.1.14-5

6.1.15-1 PCD/Ash Removal Instrumentation 6.1.15-7
6.1.15-2 Normal PCD Operation 6.1.15-8
6.1.15-3 Excessive Carryover to PCD 6.1.15-8
6.1.15-4 "Rat-Holing" of PCD Cone 6.1.15-9
6.1.15-5 "Normal" Operation of PCD Prior to Filling 6.1.15-9
6.1.15-6 Bottom of PCD Cone Filled With Ash 6.1.15-10
6.1.15-7 Top of PCD Cone Filled With Ash 6.1.15-11
6.1.15-8 Lower Shroud Filled With Ash 6.1.15-12
6.1.15-9 Beginning to Cover Lower Level With Ash 6.1.15-13
6.1.15-10 Lower Level Elements Covered With Ash 6.1.15-14
6.1.15-11 Beginning to Cover Upper Level With Ash 6.1.15-15

6.2.1-1 High-Pressure Air Accumulator Tank Pressure 6.2.1-3

6.3.1-1 Fines Removal Screw Cooler Operation November 20, 1996 ..... 6.3.1-2
6.3.1-2 Fines Transporter System Cycles November 20, 1996 ..... 6.3.1-2

7.1-1 Particulate Sampling System 7.1-1

8.1.2-1 Coal Particle Size Distribution 8.1.2-3

8.1.3-1 Dolomite Particle Size Distribution 8.1.3-2

8.2.4-1 Main Air Compressor Operations August 20 to 21, 1996 ....8.2.4-2
8.2.4-2 Main Air Compressor Operations November 15 to 16, 1996....8.2.4-2

8.4.2-1 Recycle Gas Booster Compressor Commissioning June 29, 1996....8.4.2-2

8.5.1-1 Porous Metal Cross-Flow Filter 8.5.1-3

8.6.2-1 Thermal Oxidizer Refractory Cureout 8.6.2-2

8.6.4-1 Two Views of Top Areas of Thermal Oxidizer December19, 1996 ....8.6.4-2

8.7.3-1 Steam System Operations August 5, 1996....8.7.3-2
8.7.3-2 Steam System Operations November 21, 1996 ....8.7.3-2

8.8.3-1 Sulfator Start-Up Heater Refractory Dry Out May 23 to 25, 1996....8.8.3-3

8.8.4-1 Sulfator Performance Test September 9 to October 7, 1996 ....8.8.4-4
8.8.4-2 Sulfator Performance Test October 14 to 18, 1996....8.8.4-4
8.8.4-3 Sulfator Performance Test November 3 to 6, 1996....8.8.4-5
8.8.4-4 Sulfator Performance Test November 8 to 14, 1996....8.8.4-5

8.9.1-1 Baghouse ΔP CCT1A 8.9.1-4
8.9.1-2 Baghouse ΔP CCT1B 8.9.1-4
8.9.1-3 Baghouse ΔP CCT1C 8.9.1-5
8.9.1-4 Baghouse ΔP CCT2A 8.9.1-6
8.9.1-5 Baghouse ΔP CCT2B 8.9.1-7
8.9.1-6 Baghouse ΔP CCT2C 8.9.1-7

8.14.3-1 Change in Behavior of Float Valve After Adding Larger Float and Installing Baffles 8.14.3-3

9.1.2-1 Typical PI Display 9.1.2-3

9.2.1-1 Typical Piping Schematic Showing How Each Component for a Particular System is Identified 9.2.1-3
9.2.1-2 Typical Trend Plot for Pipe Kinks in the FD0210 Line....9.2.1-3

9.2.2-1 Typical Spectrum Recorded at up to 30,000 rpm Where Vibration Was Measured in Velocity Units 9.2.2-3
9.2.2-2 Typical Summary Plot Showing Vibration Maximum Amplitude Reading for Each Measurement Location on Fluid Pump A....9.2.2-3
9.2.2-3 Typical Plot Including Current Spectrum, a Comparison of the Current Spectrum With the Past Spectrum, and a Magnitude Trend Plot 9.2.2-3

9.2.3-1 Various Shades of Gray (From Black to White) Showing a Typical Thermal Image (Test Run CR02) 9.2.3-5
9.2.3-2 A Scanned Image of the Top of the Combustor Heat Exchanger Taken During Coal Combustion of Test Run CCT1C 9.2.3-6
9.2.3-3 A Second Example of Scanned Image of the Top of the Combustor Heat Exchanger Taken During Test Run CCT1A 9.2.3-7
9.2.3-4 An Image Taken at Elevation 132 at the Start of Test Run CCT1C 9.2.3-8
9.2.3-5 A Second View of Scanned Image Shown in Figure 9.2.3-4 Taken After Coal Combustion in Test Run CCT1C 9.2.3-9
9.2.3-6 An Example of Temperature Differences Identified During Test Run CCT1C Where Elbows in the Pipe Slightly Hotter than the Pipe Itself 9.2.3-10
9.2.3-7 A Second Example of Temperature Differences Identified During Test Run CR02 Where Elbows in the Piping Were Slightly Hotter Than the Pipe Itself (Showing Primary Cyclone Gas Outlet During Coal Combustion of Test Run CCT1C) 9.2.3-11
9.2.3.-8 Results of Test Run CCT1C Indicating Temperature Differences Where Nozzle Temperature Was typically Hotter than Piping Showing Riser Crossover to the Disengager) 9.2.3-12
9.2.3-9 A Second Image of Test Run CCT1C Indicating Temperature Differences Where Nozzle Temperature Was Typically Hotter Than the Piping (Showing line PM04 From the Primary Gas Cooler to the PCD) 9.2.3-13
9.2.3-10 Results of Test Run CR02 Showing Temperature Differences Where Weld Joints Were Consistently at a Higher Temperature Than the Piping (Showing the Thermal Gradient at the at the Weld Joint in the Riser, Standpipe, and Dipleg) 9.2.3-14
9.2.3-11 Results of Test Run CCT1C Showing Temperature Differences Where Weld Joints Were Consistently at a Higher Temperature Than the Piping 9.2.3-15
9.2.3-12 Results of Test Run CCT1C Showing Various Temperature Gradients 9.2.3-16
9.2.3-13 A Typical Image of the Thermal Oxidizer Taken During the Start of Test Run CCT1C Showing Fairly Uniform Temperatures 9.2.3-17
9.2.3-14 An Image of the Standpipe Outlet Connection to the Screw Cooler Taken at Elevation 120 Feet at the Start of Test Run CCT1C 9.2.3-18
9.2.3-15 Second View of the Standpipe Outlet Connection to the Screw Cooler Taken from Ground Level During Test Run CCT1C 9.2.3-19

Sections 5.1.1 through 5.1.10

are contained in Volume I

of this report

5.1.11 Disengager Performance Tests

5.1.11.1 Background

During the October 1996 test run CCT2A, a high level of solids carryover from the reactor loop was observed when the system began operating with silica sand as start-up bed material. The geometric mean size of the sand was approximately 290 μm, with the top and bottom sizes of 500 and 45 μm, respectively. The solids separation system installed on the M. W. Kellogg Company (MWK) transport train was designed to separate ash and char with geometric mean sizes of less than 60 and 100 microns, respectively, with overall collection efficiencies of 99.96 percent with ash and 99.95 percent with char. Analysis of the test data collected indicated that the overall collection efficiency achieved ranged from 87 to 99.4 percent. The low collection efficiency resulted in greater than desired dust loading to the particulate control device (PCD). The excessive loss of solids from the reactor loop required frequent makeup of bed material to maintain a reasonable level of solids circulation in the reactor to permit the reactor to be operated at a lower than desired coal throughput.

A technical meeting held at Wilsonville on November 15, 1996, which was attended by representatives from GEESI (the cyclone system designer), MWK, SCS, and DOE who reviewed the performance of the solids separation system. It also provided an opportunity for GEESI to witness first hand the solids carryover from the reactor loop. At the meeting, the performance of the disengager was suspected to be the cause of the excessive solids carryover. It was speculated that difficulties of separated solids draining out of the disengager cone (cone angle of 8° to vertical) resulted in solids reentrainment out of the disengager. The design of the disengager was also discussed.

From operations to date, it was clear that solids carryover from the reactor loop increased whenever the solids circulation rate increased beyond a certain threshold, and it did not seem to be influenced very much by gas velocity. Also solids carryover at high-solids loading to the disengager did not seem to be affected by the particle size distribution. The material escaping the cyclone had geometric mean size comparable with the feed. The high solids loss as the standpipe solids level builds up does not permit filling the standpipe to the desired operating level. The excessive solids carryover makes it difficult to maintain the bed level in standpipe and more importantly it overwhelms the solids discharge system under the PCD, causing solids to accumulate in the PCD cone.

It was agreed at the meeting that GEESI would perform solids flowability test on the start-up bed material and that a test would be conducted at Wilsonville to characterize the performance of the disengager at high solids circulation rates approaching the design solids circulation rate of 250,000 lb/hr (combustion mode), at approximately 25 to 35 ft/s riser

superficial gas velocity, ambient temperature (~200 to 300°F), and at 60 psig reactor pressure. To accomplish this, the dipleg of the primary cyclone was isolated from the solids traffic by inserting a plug inside the dipleg. This temporary modification essentially eliminated the primary cyclone from the circuit to test the performance of the disengager without interaction with the cyclone dipleg perturbations. The test was identified as CCT3A.

5.1.11.2 Disengager Performance Tests CCT3A

The disengager efficiency tests were performed on December, 12, 1996, using silica sand with a geometric mean diameter of approximately 400 μm. The riser velocity and solids loading to the disengager were varied to investigate their effect on disengager operation. The reactor was operated at approximately 60 psig and nominal 200°F. Sand was continuously fed into the reactor during the test except during the last period of testing when sand was not fed. Solid samples were taken from the reactor and the discharge of the PCD to represent the size distribution exiting the disengager. The PCD solids at the end of each test run period were transferred to the ash silo and a solid sample was taken for analysis. The amount of material lost to the PCD was estimated from the transfer bin weigh cell differentials. The particle size distribution at the inlet to the disengager was calculated from the standpipe and PCD solid flow rates and their size distributions. The average test operating conditions are presented in table 5.1.11A-1. The average solids circulation rate was calculated by assuming a gas-solid slip factor of 2. The particle size distribution was relatively finer at the beginning of the test.

Except for test period 3, the HX0203 vent valve (PDV384) was 100-percent open. During period 3, HX0203 vent valve was closed to prevent gas entrained from the disengager with the particles from bypassing through the HX0203 vent into the primary cyclone. The results from test period 3 will indicate whether this type of gas bypassing affects the disengager efficiency.

Experimental Findings

During the test, makeup sand was added intermittently into the reactor. The amount of sand fed and the average feed rate during the periods analyzed are presented in table 5.1.11A-2. Using the solids circulation rate and the solids collected by the PCD, the average disengager efficiency was estimated. The results are presented in table 5.1.11A-3.

From the particle size distribution of the circulating solids and the solids captured by the PCD (using ash silo solids size distribution), the grade efficiencies were calculated for each period.

The grade efficiencies for all test periods (except for period 4) were plotted as a function of particle size distribution as shown in figure 5.1.11A-1. The disengager cut diameters were read from figure 5.1.11A-1 and the results are presented in table 5.1.11A-3. The disengager grade efficiency curve was replotted using the normalized particle size as shown in figure 5.1.11A-2.

The following general conclusions can be drawn from the test results:

A. The disengager efficiency is lower than expected for the coarser particle size distribution used for this test.

B. Within the operational range of aeration/fluidization flow through HX0203, closing off PDV384 does not appear to affect the disengager performance.

C. The disengager appears to be more efficient at low riser superficial velocity at lower circulation rates.

D. Comparing results from test periods 1 and 5, it appears that the disengager efficiency is not very sensitive to solids loading. However, comparison of test period 2 and test period 5 data indicates some dependency of disengager efficiency on inlet solids loading.

E. The performance of the disengager during this test does not appear to be significantly different from its performance during previous test runs.

5.1.11.3 Cold Flow Testing of Disengager at GEESI (CCT3B)

From February 6 to 7, 1997, a full-scale cold-flow model of the disengager constructed from sheet metal with a Plexiglas top was tested at the GEESI facilities located in Lebanon, Penn. Representatives from GEESI, SCS, and MWK conducted the testing. The objective of the test was to characterize the efficiency of the disengager with sand, and to understand and identify the cause of the low solids separation efficiencies at the PSDF. Prior to the test, performance of the disengager was suspected as the cause of the dust carryover.

A schematic drawing of the experimental setup is shown in figure 5.1.11B-1. The test solid was silica sand from the PSDF with size distribution as shown in figure 5.1.11B-2. A screw feeder with maximum feed rate of ~350 lb/min was used to feed the solids into the disengager. An induction fan was used to convey the solids through the disengager and the secondary cyclone. The solids separated in the disengager and cyclone were collected in 55-gallon drums. The capacity of the drum under the disengager limited the duration of

the test. If the disengager collected all the solids, it would hold approximately 700 to 800 lb of solids corresponding to a maximum test duration of 2.3 minutes.

Prior to February 2, 1997, GEESI completed a trial test (test 1). Samples from this test were sent to SCS for particle size distribution determination. The results are shown in figure 5.1.11B-2.

Discussions were held with GEESI regarding the possibility of increasing the feed rate into the disengager by either modifying the feeder motor-gear arrangement (which was later found to be impossible) or renting another feeder with a higher feed rate. The blower had enough capacity to allow the velocity through the disengager to be increased from 26 ft/s to 45 ft/s. In addition to sand, fly ash was also run through the disengager. Being of a lower density than sand, the maximum fly ash feed rate obtained was approximately a third of that of sand. Between February 6 and 7, 1997, nine test runs were completed. The results of the tests, including test 1, are summarized in table 5.1.11B-1. In test 2, two buckets of sand (each bucket containing ~50 lb of sand) were manually dumped directly into the disengager through the funnel while the screw was running at maximum speed. In test 4, the screw feeder was shut off and buckets of sand were manually dumped into the disengager in an attempt to increase the feed rate and also simulate slugs of solids entering the disengager. In test 5, the screw was not run. The solids were fed directly from the spout dumped from the bottom of the supersack. This run simulated a very high feed rate into the disengager. This test lasted for only 6.5 seconds. In tests 7 and 8, fly ash was used instead of sand.

The collection efficiencies are plotted in figure 5.1.11B-3 as a function of solid/gas weight ratio. Also included on the graph are data from the December 1996 test of the PSDF disengager with the cyclone dipleg blocked and test data from November 1996 operation of the PSDF transport reactor with the primary cyclone functional (dipleg not blocked off).

It appears from figure 5.1.11B-3 that the performance of the disengager during the cold flow tests at GEESI is similar to what had been observed during the PSDF disengager tests in December 1996. The data from the November 1996 test suggests strongly that the primary cyclone was not capturing solids since the disengager efficiency seemed to follow the same trend as the cold flow results. During all test campaigns at PSDF the cyclone dipleg was not sealed with solids in the standpipe. However, it is possible that gas was bypassing up through the dipleg into the cyclone causing the cyclone's efficiency to be penalized. It is also plausible that a hole (or gap) might have developed in the roof of the cyclone allowing gas and solids to bypass the gas outlet tube. Either of these scenarios would be consistent with the low-cyclone-pressure drop observed during the PSDF test runs.

The collection efficiency of the disengager with fly ash is significantly lower than with sand. Based on the fly ash and sand data, it could be speculated that the actual disengager efficiency with char and transport reactor ash may be significantly lower than the design values of 97.6 and 96.4 percent for combustion and gasification operations, respectively.

From the results of the disengager tests, the following recommendations and implementations were made:

A. Review the cyclone trend data from previous tests and compare the cyclone differential pressures with those of the December 1996 tests when the cyclone dipleg was blocked off. Trending should include cyclone dipleg temperature profile displayed with differential pressure.

   This was done and there was no evidence of significant gas bypass up the cyclone dipleg.

B. Provide GEESI with an alternate test material with properties close to the ash and char to be generated from the PSDF transport reactor for testing.

   Plans were drawn to test coke breeze at a later date.

C. Inspect the roof of the cyclone for cracks or holes that could provide a bypass path, especially around the gas outlet tube. It is possible that a dye test would be required to detect cracks that could seal when the unit is cold and open when the cyclone is heated up.

   Borescope inspection of the gas outlet pipe did not reveal any gross defects.

D. Conduct test at PSDF, with the cyclone dipleg sealed with solids, to investigate possible cyclone inefficiency caused by standpipe disengager gas venting up the cyclone dipleg. This test may require manually filling the dipleg.

E. Review data with GEESI and determine options available and action to take.

Modifications to cyclone gas inlet and outlet were suggested by GEESI. Cyclone inlet modifications (restriction of cross sectional area and change from a circular to a rectangular cross section) were carried out. Plans were made to move the disengager cold-flow model from GEESI to Wilsonville. This decision was made because more tests could be needed and since the disengager performance is expected to be very different in gasification than in combustion.

Table 5.1.11A-1

Average Test Conditions

Test No.	Average Riser Velo., ft/s	Average Solids Circ. Rate, lb/hr	Average Disengager DP, inH_2O	Average Cyclone DP, in H_2O	Average Riser Exit Temp. (TI355), °F	Average Reactor Pressure, psig
1	36	4,148	2.2	4.0	208	59
2	37	4,027	2.5	4.2	218	62
3	38	9,539	2.8	6.7	216	61
4	28	42,888	3.1	2.5	191	61
5	37	72,325	8.4	6.4	202	62

Table 5.1.11A-2

Sand Makeup Into Reactor

Test No.	Duration of External Feeding	Total Sand Fed, lb	Average Feed Rate, lb/hr
1	10:53 to 11:40	1,171	1,731
2	12:47 to 14:35	1,175	1,438
3	14:40 to 15:39	2,059	2,094
4	15:50 to 16:40	3,214	3,857
5	No External Feeding	0	0

Table 5.1.11A-3

Summary of Results

Test No.	Period Analyzed	Average Riser Velocity, ft/s	Average Solids Circ. Rate, lb/hr	Average Solids Loss Rate From Disengager lb/hr	Estimated Disengager Cut Diameter, μm	Disengager Efficiency Percent
1	10:37 to 11:40	36	4,148	213	72	94.5
2	12:39 to 14:35	37	4,027	556	82	86.2
3*	14:40 to 15:39	38	9,539	1,478	144	84.5
4	15:50 to 16:40	28	42,888	112	N/A	99.74*
5**	17:20 to 18:05	37	72,325	5,032	146	93

* Only one PCD dump cycle was observed in approximately 1 hour.
** With HX0203 solids circulation.
\# PDV384 was closed.
N/A Not estimated.

Table 5.1.11B-1

Disengager Test Results - GEESI

Test No.	Test Duration, Min	Disengager Inlet Velocity, ft/s	Solids Feed Rate, lb/hr	Solids Loss Rate, lb/hr	Solids/ Gas Ratio	Collection Efficiency, Percent
1	2.0	26.0	19,440	345	6.4	98.2
2	1.5	26.0	21,000	100	6.9	99.5
3	1.78	45.2	16,183	707	3.05	95.6
4	0.62	45.2	46,878	632	8.85	98.7
5	0.108	45.2	387,969	1,385	73.2	95.6
6	2.24	45.2	18,543	750	3.5	95.96
7	1.85	26.0	6,858	2,562	2.3	48.0
8	3.17	26.0	2,170	1,184	0.71	45.4
9	2.15	35.5	10,788	363	2.6	96.6
10	1.37	35.5	16,002	154	3.9	99.0

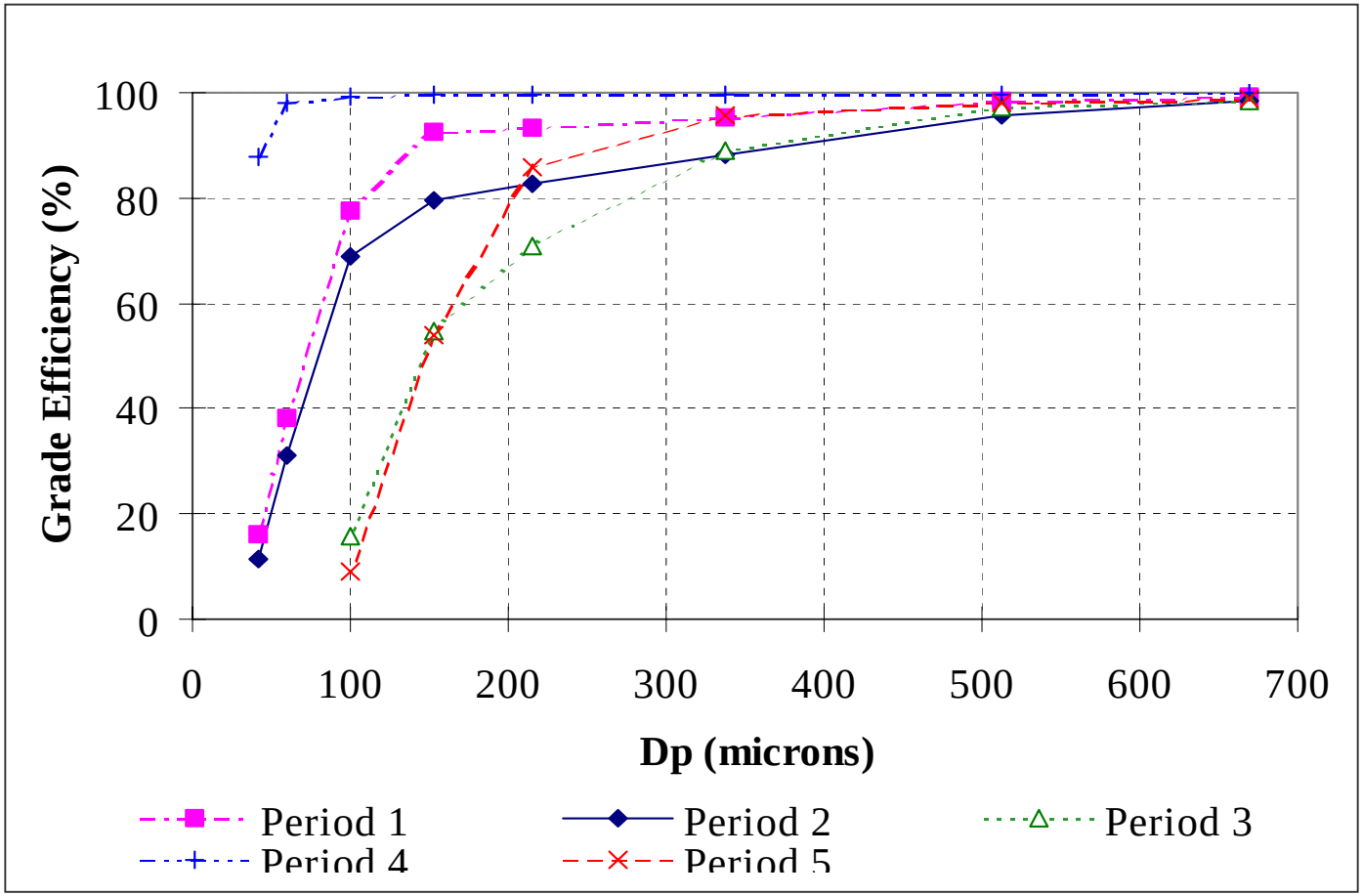


Figure 5.1.11A-1 Disengager Grade Efficiency Curve

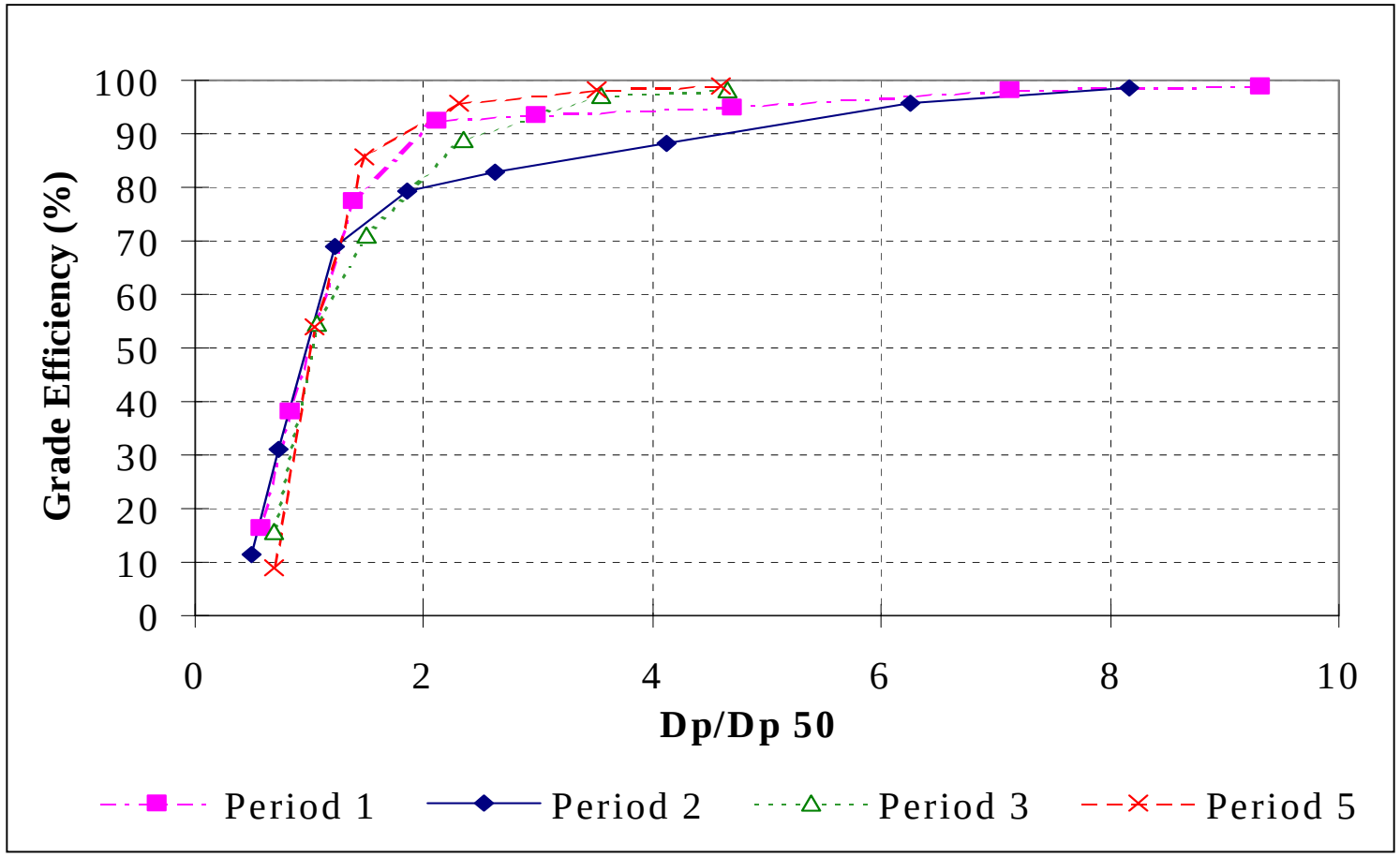


Figure 5.1.11A-2 Disengager Grade Efficiency Curve

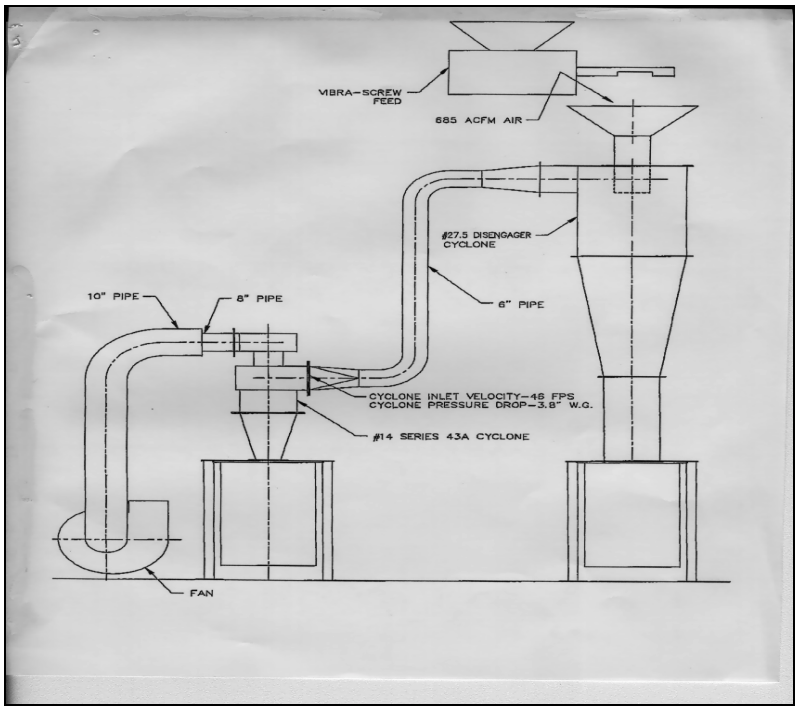


Figure 5.1.11B-1 Schematic Diagram of Experimental Setup at GEESI

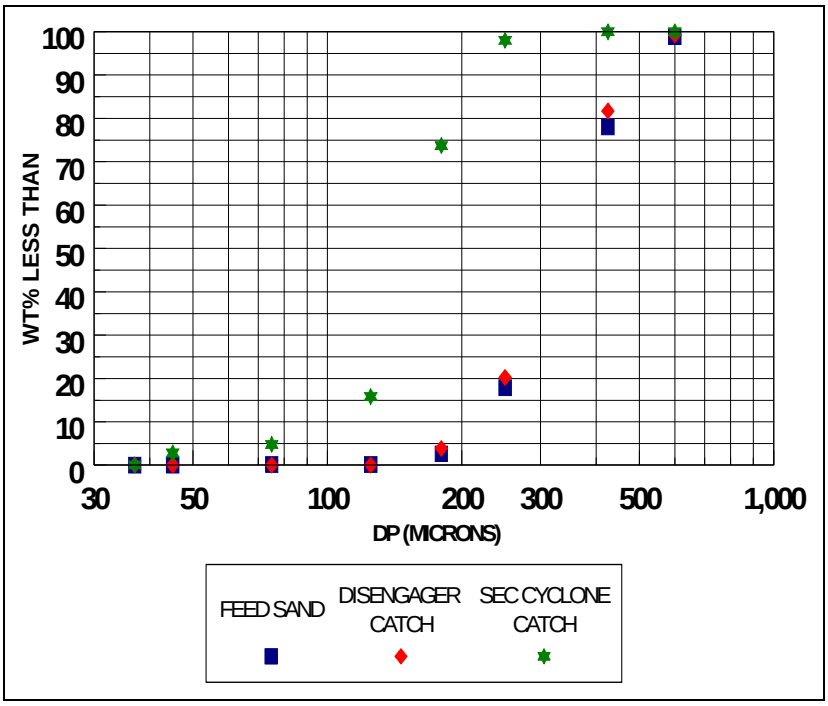


Figure 5.1.11B-2 GEESI Disengager Cold Flow Test Results

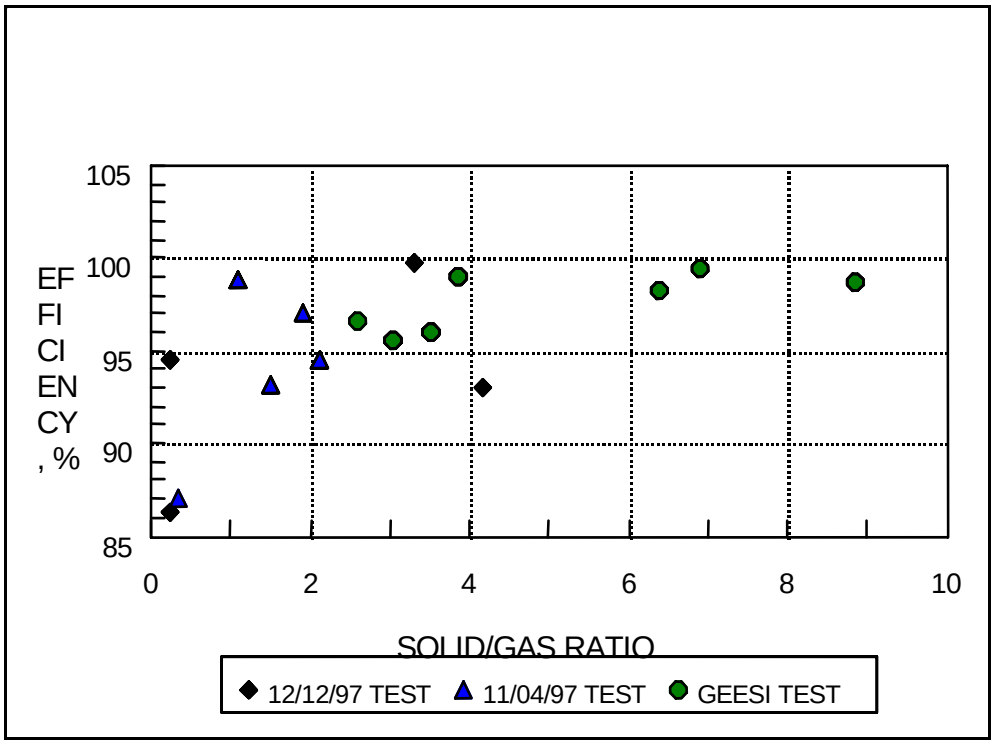


Figure 5.1.11B-3 Comparison of Disengager Performances (PSDF Vs GEESI)

5.1.12 Solids Conveying System

5.1.12.1 Introduction

This section provides operational background and history of various solids conveying systems in the process. All solid conveying systems were provided by Clyde Pneumatics. During the initial testing (when alumina was used), several problems developed with the Clyde Pneumatics conveying equipment. The rotofeeders on FD0210 (coal), FD0220 (sorbent), and FD0530 (spent solids) tended to bind and the motors had to be manually turned. For FD0210 and FD0530, spacers were installed to allow more clearance between the rotor and the internal plates. When FD0530 was taken apart for this operation, the plate on top of the rotor was extensively scored. There was an area near the center part of the driving shaft where the scoring was more severe. The metal rolled up causing the rotor to bind. The other problem was associated with the Spheri valves. The valves tended to bind between the valve hemisphere and the pressure seal. Additional spacing was added to the FD0520 (PCD fines) and the FD0510 (standpipe ash) bottom Spheri valves, the FD0210 (coal feeder) bottom and middle Spheri valves, and the FD0220 (sorbent feeder) middle Spheri valve so that the hemisphere part would not bind but the inflated seal would still provide sealing. The FD0140 (used for initial reactor filling) and FD0820 (baghouse ash) dense-phase pumps worked well, although the FD0820 had not transported as many solids as the FD0140 system. As of this time FD0810 (sulfator ash) and FD0610 (sulfator sorbent addition) had not been put in service.

5.1.12.2 Coal Feeder (FD0210)

Based on the binding problem experience with FD0530, a spacer was placed in the FD0210 rotofeeder. The bottom of the rotofeeder would not operate properly due to the presence of moisture. The rotofeeder was taken apart and cleaned out. Water had been introduced into the system through a vent line on the coal feeder that did not have a rain hat. A rain hat was installed to prevent this from occurring again. When alumina was added the rotofeeder bound frequently. Sometimes the rotofeeder could be freed by rotating the motor by hand. Pieces of grating were found plugging the 1-inch discharge line from FD0140. A screen was placed in the FD0140 silo to prevent the transfer of oversized material.

Solids carryover from the FD0210 and FD0220 vent lines to the process line upstream of the reactor pressure letdown valve (PV287) was found to be the cause of the PV287 erosion. These vents valves were intended to allow a flow through the dispense vessel while maintaining the dispense vessel at a pressure a few psig above the conveying line pressure. Valves were installed in these lines and were closed to prevent the erosion from occurring. A design was completed to route the vents to the silos above the feeders; however, it was found in CCT1C that the rotofeeders would operate without the vents. Differential pressure (between the dispense vessel and the nitrogen supply to the purge valves) controllers were added to reduce the flow rate through the dispense vessels when

operating at low pressures. This was done so that when operating at 50 psig there will not be too much air flow forced through the flow orifices that are supplied air at 315 psig. By controlling the upstream pressure, the amount of flow was reduced.

Other problems developed with the FD0210 feeder when it would not transfer solids. When the bottom was removed, epoxy paint chips were found. The inside of the vessels had been previously coated with epoxy (some of which had lost adhesion). Most of the loose epoxy was removed from the inside of the vessels. Also during CCT1C, the FD0210 tripped due to the top lock vessel Spheri valve failing to fully close. By enabling and disabling the fill cycle, the Spheri valve closed and the feeder was started. After coal was added to FD0210, the operation became smoother. Due to the plugging that occurred between the rotofeeder outlet and where the solids entered a smaller pipe, the bottom line was modified by adding a valve at the elbow to allow the rodding out of plugs or blowing out the line.

During CCT2C the coal flow into the feeder became erratic. The cycles became very short with the coal blowing back into the silo. Coal could be drained out of the drain chute very easily which indicated that the bottom of the coal bin was not plugged. The erratic feeding continued which resulted in the plant operation shutting down. Four drums of coal were drained from the feeder, and the feeder was inspected with a boroscope. The lock vessel was clean and the dispense vessel was clean except for missing patches of epoxy and a small amount of coal on the feeder plate. By using a boroscope for inspection, an area was found that appeared to be raised on the dispense vessel Spheri valve seal; however, when the vessel was taken apart, the raised area was determined to be corrosion on the outer plate. A Clyde representative indicated that when the level probe in the lock hopper was not working, it caused the vessel to overfill thereby causing the coal to pack in the lock vessel and on the walls during pressurization which can cause it to hang-up.

The feeder was taken apart to check the Spheri valves and the connection valve (XV8457). The connection valve was partially blocked by an off-center piece of gasket. The dispense vessel Spheri valve seal was found to be okay. Gaskets were installed to increase the spacing (to 0.020-inch clearance). The valve was very hard to turn so it was further inspected. It was found that the grease seals were too tight and the valve could not be turned by hand like other valves. The lock vessel Spheri valve was found to have a roughed surface on the Spheri valve seal. The seal was replaced and gaskets were added to space the seal further apart. A bridge of wet coal was found above the upper Spheri valve. The wet coal was removed. The upper valve of the three Spheri valves was not modified.

5.1.12.3 Sorbent Feeder (FD0220)

The FD0220 rotofeeder has a history similar to the FD0210 rotofeeder. The line from the rotofeeder is smaller and plugs easily. When the fines were recycled in August, the

pressure drop in the transfer line was erratic. As with the FD0210 feeder, a valve was added at the elbow to allow the rodding out of plugs or blowing out the line.

On several occasions the level probe in the dispense vessel would not function. The probe was adjusted and later readjusted with alumina in a bucket. On August 16 the pressure tubing within the purge control cabinet ruptured. Fortunately the cabinet relief valves were adequate for the flow. Most of the tube fittings were changed to Swagelock.

In October the lock vessel Spheri valve seal was found to be leaking because the O-ring was pinched. The O-ring and the seal were both replaced. After this repair, the nitrogen flow rate used for the Spheri valve seals became small as indicated by the FV490 valve position. At one point in November, the middle Spheri valve would not close. The shaft was oiled and has worked properly since that time.

5.1.12.4 Sorbent Material Transporter (FD0510)

When alumina was transferred from the reactor standpipe, both Spheri valves would not rotate. The gap for the bottom Spheri valve was increased to add clearance, and the pressure seal was replaced. The upper Spheri valve was loosened by increasing the pressure on the actuator piston. On another occasion, the top Spheri valve would not rotate. The air lines to one side of the actuator were removed and the valve rotated freely.

In August the top Spheri valve on FD0510 would not close. After adjusting the pressure to the cylinder that rotates the valve, the valve would close. The FD0206 and FD0510 were run for a few minutes each hour to avoid condensation. In October the dispense vessel level probe would not function. Water and a loose connector in the wiring was found and repaired. The dispense vessel Spheri valve seal was found to be leaking and was replaced.

5.1.12.5 PCD Fine Ash Transporter (FD0520)

In July the bottom Spheri valve would not completely close and had to be removed. Some chunks of refractory were found on top of the hemisphere and the top of the hemisphere was scored. The pressure seal was replaced, the spacing was increased, and the top of the hemisphere was polished with sand paper. Later the discharge clogged several times with refractory pieces. It was cleared by rodding into the discharge line. Due to the reduction in cross section between the vessel and 2-inch discharge line, there is little tolerance for larger particles.

In November the vent valve was found to be leaking a large amount of gas. (There is a 4.7-mm orifice downstream of the valve. The FD0530 baghouse was running 5 to 10 inches of water.) When inspected this valve was found to be severely scored. FD0520 also had to be tapped to get the solids to flow due to a leaking vent valve. Also, the Spheri valve was not closing within the delay timer's range due to a stuck shuttle valve. The piston and shuttle

valves on FD0210, FD0220, FD0510, and FD0520 (two per feeder) were greased with O-ring grease.

5.1.12.6 Standpipe to FD0510 Screw Conveyor (FD0206)

During initial pressure testing of the reactor, the screw cooler leaked and the packing glands were tightened to prevent additional leakage. During initial operation and testing the glands were loosened to prevent stalling the motor. After operating the motor, the packing was tightened again but the packing continued to leak as indicated by the purge flow. The original packing was replaced with rope packing and tightened. This has proved to be a satisfactory solution to the problem.

5.1.12.7 Sulfator Sorbent Feeder (FD0610)

Functional checks were written for FD0610 (limestone/sorbent to the sulfator) and completed.

5.1.12.8 Sulfator Overflow to Ash Silo Screw Conveyor (FD0602)

Functional checks were written for FD0602 (screw cooler on sulfator ash to FD0810) and completed October 31.

5.1.12.9 Standpipe and PCD Ash Transport to Ash Silo (FD0530)

FD0530 Logic: During the preliminary run through, the whole program remained locked in the first cycle. The PLC programs are geared to completion of every condition in order to continue to the next. If any condition is not satisfied the program does not continue.

The first step did not complete because the differential pressure switch (PDS8562) between the lock hopper and the storage bin would not indicate that the pressure had dropped when the lock vessel vent valve was opened. It was determined that the problem was that the high leg of the switch had water on the process side. The PDS8562 switch setting was increased from 0 to 15 millibar, i.e., at less then 15 millibar the lock vessel will be considered to be depressured. Should solids accumulate in the lock vessel vent the switch may not work in the future since 15 millibar is only about 6 inches of water (the maximum setting on the switch is 60 millibar). Thus, the vent line will need a purge to prevent water from entering the unit. During later operation, it was found that this pressure switch was wired to the normally open contacts whereas it should have been wired to the normally closed contacts.

The DCS showed that out-of-range was a condition as part of the interlock; however, there were no steps in the program that used the out-of-range condition. An out-of-range condition was put into the program so that when any instrument becomes out of range the program will stop on the next cycle.

One reading that was not present on the system was the storage bin temperature (TE8562 and TT8562). A resistor was installed on the PLC to take the place of the temperature switch until the temperature instruments can be installed.

After the above repairs, FD0530 would cycle completely through the rotofeed fill cycle. At the start of the rotofeed fill (which is started by a low level reading in the rotofeed vessel), the vent valve on the lock vessel is vented. When the pressure switch (PDS8562) is satisfied, the isolation Spheri valve is opened followed by the lock vessel Spheri valve. These valves remain open for 30 seconds or until the level switch in the lock vessel indicates level. Then the lock vessel vent valve is closed followed by the isolation Spheri valve and the lock vessel Spheri valve. The lock vessel pressure is then equalized with the rotofeed vessel. When the pressure has equalized the rotofeed vessel Spheri valve opens for 25 seconds. The rotofeed vessel Spheri valve then closes. At this point the cycle restarts if the level in the rotofeed vessel is still low. During this test the rotofeeder motor was running.

A DCS representation is needed for the level switches in the storage bin. Currently there is no method to know where the levels are.

FD0530 Operation: When first tested on alumina in March, the rotofeeder bound tight and the motor could not be rotated by hand. The rotofeeder was inspected and the plate on top of the rotor was found to be scored. The area near the shaft indicated metal-to-metal galling which could cause the binding. As a solution to the problem shims were used to increase the gap between the rotor and the top plate.

When alumina was transferred from the FD0530 bin to the ash silo, the motor would stop continuously. The motor could be turned by hand with some difficulty and could eventually be freed by rotating the motor forward and backward by hand. The rotofeeder would not operate continuously until the feeder was almost empty. The level probe in the dispense vessel indicated the vessel was full when it was not. In November the rotofeeder plugged. The rotorfeeder was cleaned and the shaft was greased. It worked for only a short time. Moisture contained in the blow through from the FD0520 vent valve leak was suspected as the cause of the problems.

5.1.12.10 Feedstock and Start-up Bed Material Transporters

The BOP dense phase was completed in April 1996. Functional check lists were prepared and used for the FD0140, FD0154, and FD0104 systems. For the FD0140 system, the three-way valves were not set up the same as the logic. The valves were therefore taken apart and reassembled so that the switch and the panel matched the valves actual function. Also, one of the proximity switches on the three-way valve was found to be broken. For the FD0154 and FD0104 systems, the high high-level switches on the FD0210 and FD0220 wiring was changed to make it function properly. Also the logic for the level switch on FD0104 had to be reversed. The FD0140 (used for initial reactor filling), the FD0154

(sorbent transport from pulverized silo to MWK silo), and the FD0104 (coal transport from the pulverized silo to the MWK silo) have worked well.

5.1.12.11 Summary

All of the balance of plant dense phase transports have performed well (FD0104, FD0105, FD0140, and FD0820). The instrumentation on FD0810 and FD0610 have been checked, but have not been operated with solids.

The five feeders in the structure had a number of problems (FD0210, FD0220, FD0510, FD0520, and FD0530). The current status of these feeders is unsatisfactory. With hind sight these feeders might have worked fine if they had not been operated with alumina which flows well and has created scoured parts since it is a hard substance.

Since the rotofeeders will not tolerate any large particles, any foreign material that falls into them of a slightly larger size will plug them. The rotofeeders were coated on the inside with epoxy paint which specifically should not have been done per the MWK purchase order. The slow peeling of the epoxy requires that the epoxy be completely removed from the FD0210 and FD0220 vessels to prevent future outages.

Due to the undersized line on FD0220 (3/4-inch diameter, XX strong), the plan is to replace the line with a larger line.

The FD0510 and FD0520 vessels have a major problem with the reduction at the exit from 4 to 2 inches which creates a natural choke point. Since larger lines would consume much more nitrogen, a number of ports have been added to blow backward and forward and to rod out the lumps.

5.1.13 Pressure Letdown Valve

5.1.13.1 Chronology and Modifications

This section is a discussion of the modifications made to the trim of the MWK reactor pressure letdown valve PV-287 and the results these modifications have on the flow characteristics of the valve.

Per MWK specifications, PV-287 was originally supplied with a modified Whisper III trim. However, it was soon discovered that the valve did not have the flow capacity required for start-up (50 psi inlet). Instead the valve was sized for normal operating conditions only (320 psi inlet). To remedy this, the valve trim was replaced with an equal percentage trim that provided the required flow capacity for start-up.

Upon replacing the Whisper III trim with the equal percentage trim, it was necessary to rotate the valve 180° horizontally in the pipe line so that flow was from top to bottom (as opposed to from bottom to top as with the Whisper III cage). The equal percentage cage performed well in allowing the desired flow capacity; however, due to solids in the line three sets of trim were soon eroded to the point of failure/inoperability (as well as three valve bodies). As the air/solids passed through the trim, this flow was divided into eight streams, each near sonic velocity and traveling directly downward toward the bottom of the body. This resulted in extreme wear problems. Therefore the third time that the valve/body deteriorated, it was decided to modify the original Whisper III cage to provide more flow capacity and place this modified trim back in the valve body. The theory was that cage flow in the Whisper III would enter the valve at the bottom of the trim, flow up through the cage where it would be dispersed into many small flow streams (816 with the valve 100-percent open), then flow out of the top of the trim. This upward flow path coupled with the multiple (816) small streams would be less erosive than the downward flow path with the eight large streams.

To determine the required modifications to the Whisper III cage, the holes in the cage were counted and the hole pattern mapped. An estimation was then made of how many holes would be exposed versus valve plug position. Each hole was one-sixteenth-inch diameter on the inlet side with a step to one-eighth-inch diameter on the outlet side. A simple orifice calculation was performed for a one-sixteenth-inch diameter orifice to determine the amount of flow each hole could pass. This calculation uncovered a discrepancy between the calculated valve flow coefficients (Cgs) and the ones on the MWK valve data sheet. The valve data sheet indicates that the flow characteristic is basically linear, while the orifice calculation indicated that the flow was similar to an equal percentage characteristic for the first 50 percent of travel, then linear for the remaining 50 percent of travel. To resolve this, Fisher Valves sent the actual Cg vs percent open data for the original valve trim that was provided. This data confirmed that the data sheets did not match what was actually provided. The maximum Cg was correct, but the flow characteristic was not.

To modify the Whisper III cage, all of the holes in the cage were drilled to seven-sixty-fourths of an inch (0.109) diameter on the inlet side. The outlet side remained at one-eighth-inch (0.125) diameter. Figure 5.1.13-1 compares the flow characteristic of the original cage vs the modified cage. As is shown, the original cage was extremely inadequate to provide the required flow during start-up, while the modified cage was sufficient.

During operation, when the valve is opened less than 50 percent, one method to detect wear in the valve trim is to compare the actual position of the valve with the predicted position based on calculations. If the valve is open considerably more than calculations predict, then wear may be a problem. Figures 5.1.13-2 through -7 show the flow capacity vs percent valve open for various inlet pressures. The outlet pressures have also been varied slightly to account for different operating parameters, but this has a minimal effect on the calculations. The main component is inlet pressure. For all calculations, 500°F was used as the operating temperature. This is conservative in that the higher the temperature, the higher the specific volume of the fluid and therefore the less flow capacity of the valve at a given position. Therefore, if the operating temperature is less, the flows shown will be greater. These curves will be helpful in monitoring the operability of valve PV-287 and determining the condition of the valve trim.

5.1.13.2 Summary

An anomalous venting operation from the feed system caused the high erosion of the back pressure control valve. The high erosion resulted in a valve failure which affected the control of the back pressure.

The original valve size was in error and has been corrected. The original Whisper III trim was changed to equal percentage trim, which allowed desired flow control at low air pressures during start-up. The Whisper III cage was modified to provide better control during start-up. It will be tested at a later date.

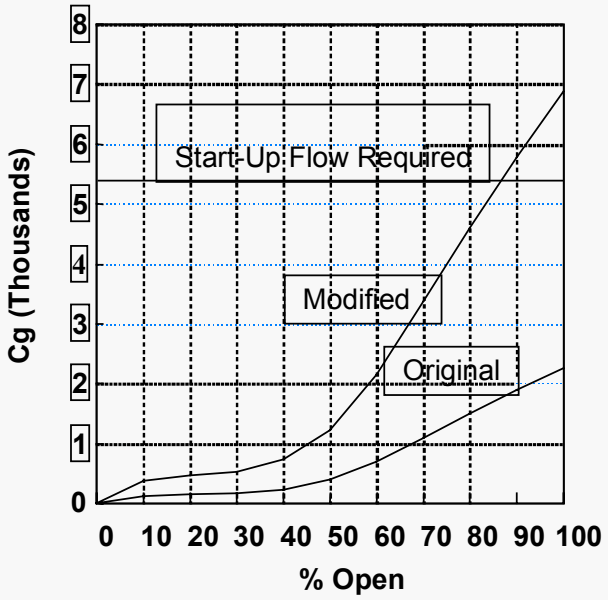


Figure 5.1.13- 1
PV-287 Whisper III Trim

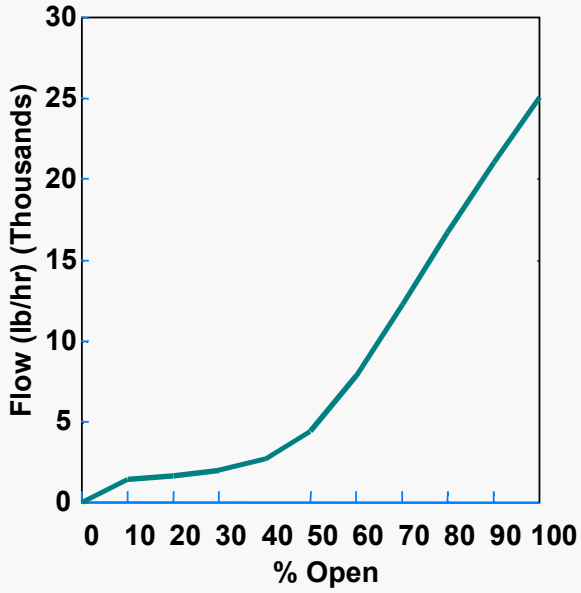


Figure 5.1.13-2
PV-287 P1= 50 psi, P2= 2 psi, T= 500 ° F

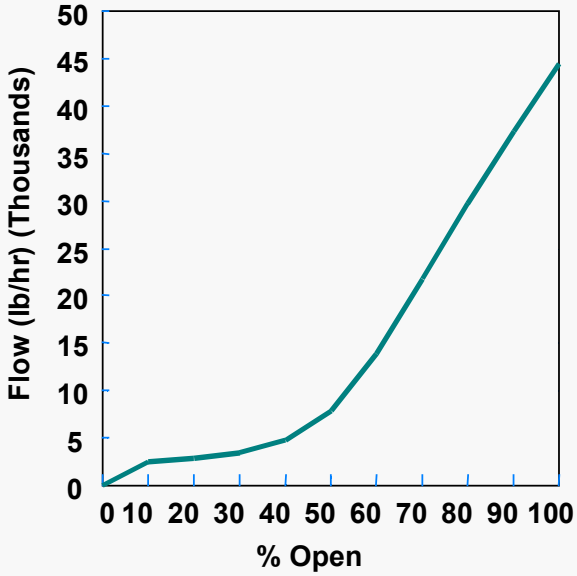


Figure 5.1.13-3
PV-287 P1= 100 psi, P2= 10 psi, T= 500° F

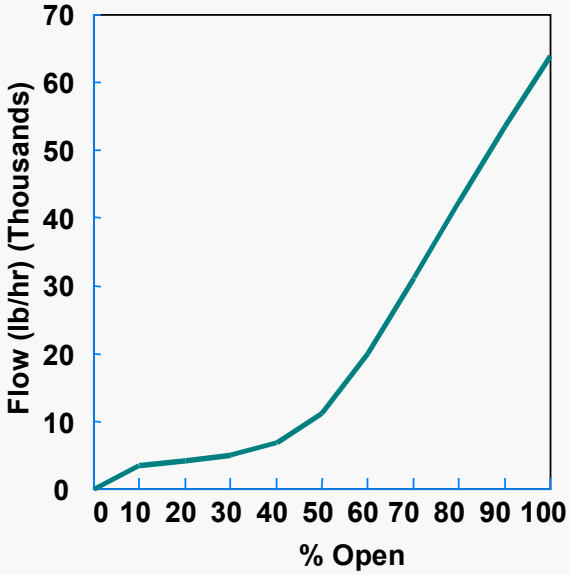


Figure 5.1.13-4
PV-287 P1= 150 psi, P2= 20 psi, T= 500° F

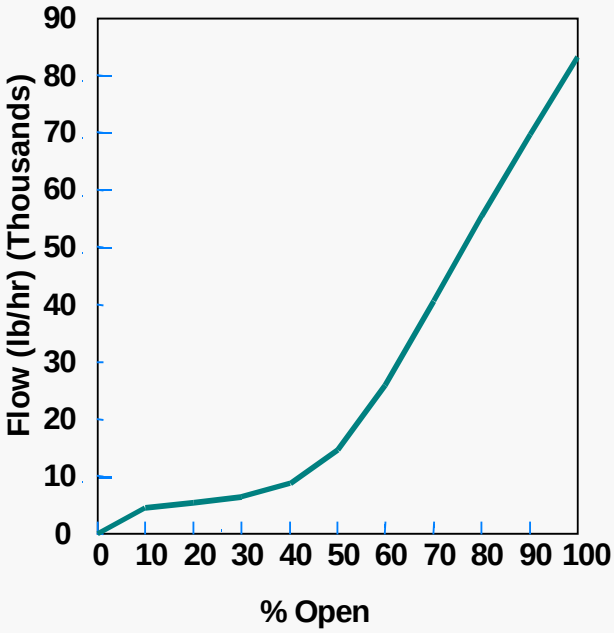


Figure 5.1.13-5
PV-287 P1=200 psi, P2=30 psi, T=500°F

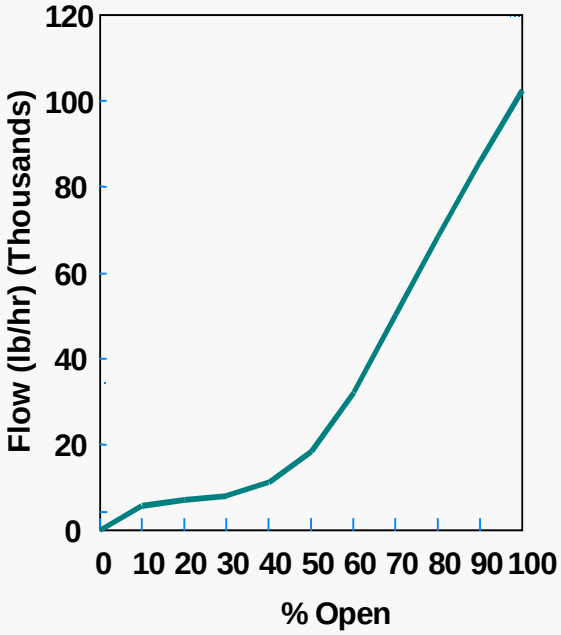


Figure 5.1.13-6
PV-287 P1=250 psi, P2=40 psi, T=500°F

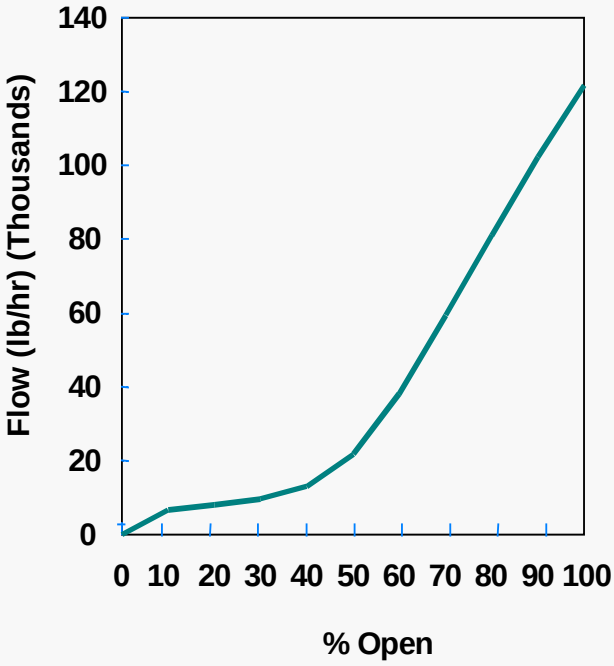


Figure 5.1.13-7
PV-287 P1=300 psi, P2=50 psi, T=500°F

5.2 OPERABILITY ANALYSIS OF COMMISSIONING TESTS

The purpose of this section is to analyze some of the operational data in order to achieve a better understanding of the reactor system and to provide a guideline for future operation and design. In the past two combustion tests during August (CCT1C test run) and November (CCT2C test run) of 1996 a large amount of data was collected. It is very difficult to cover all aspects of test data analysis. This section of analysis covers some of the operation data that will illustrate some important observations and give some insights for future operations and design.

5.2.1 Analysis of the Reactor Coal Feed Rate and Comparison With Other Processes

The coal feed rate for a given reactor size is an important index in assessing the pilot plant reactor's commercial potential because a higher coal feed rate means a smaller reactor for a given thermal output. This lowers not only the capital cost of the reactor system associated with procurement but also lower costs due to smaller footprint, less structural requirements, and faster installation. In the following, the coal feed rates that have been achieved during the reactor test runs are first presented and then these throughputs are compared with that in other combustion processes.

Ideally, the coal feed rate can be directly measured through weight cell in the coal feed system. In reality the coal feed rate is not very easy to measure due to the fluctuation of the weight cell readings. In order to achieve a better estimation, the coal feed rate is also calculated from the oxygen balance.

Figures 5.2-1 through 5.2-4 give comparisons of coal feed rate calculated from the oxygen balance and weigh cell. (All figures for section 5.2 are found as an exhibit following section 5.2.5.) The agreement between the coal feed rate calculated from the oxygen balance and that from weigh cell is acceptable considering the scatter in data. The coal feed rate comparison for the August 19 through 21 test period is better than that for November 19 through 21. The fluctuations in the weight cell readings during the August tests are less severe than that in November tests. Due to the FD0210 coal feeder problems in the November tests, FD0220 was used as a backup feeder and coal feed was switched between these two feeders quite often. Overall, it seems that the results of the coal feed rate calculated from oxygen balance are quite reasonable. For future tests, carbon balance will also be used as another method to calculate the coal feed rate.

These comparisons bring out an important issue for large pilot plant coal combustion processes. In general, the perception is that the direct measurement is always more reliable than indirect measurement. Taking the coal feed as an example, common preference is to measure the coal flow rate directly by many researchers. Unfortunately, the direct and instantaneous measurement of coal flow rate is difficult although one does not see it in formal publications. The weigh cell weight fluctuations and accuracy problems over a wide range are well known. Oxygen or carbon balance generally gives reliable results

because the gas flow rate and composition can be measured accurately. Figures 5.2-1 through 5.2-4 seem to indicate that the coal feed rate from the oxygen balance is, at least, if not more reliable than weight cell measurements.

It should be pointed out that the coal feed rates given in figures 5.2-1 through 5.2-4 are slightly lower than the coal feed rates expected at operating pressures. The coal feed rates can be increased further by operating the combustor heat exchanger with higher level of solids, which will increase the circulation of cold solids through the riser. However, the coal feed rates achieved during the reactor test runs are still quite high compared to other existing combustion processes. Table 5.2.1-1 gives a comparison of heat release rates among different combustion processes.

From table 5.2.1-1, one can see that even if the coal feed rate is 500 lb/hr the heat release rate for this reactor is still comparable with the pressurized circulating fluidized combustor. At the feed rate 700 lb/hr, which is roughly the feed rate that the reactor was operated for the November test run, the heat release rate is already about 30 percent higher than the pressurized circulating combustion processes. For the coal feed rate of 1,000 lb/hr, which corresponds to the feed rate of August 20 to 21 (CCT1C) test run, the reactor heat release rate is already double that of pressurized CFB.

The transport reactor operates with much smaller particle sizes. Therefore, the combustion process should be kinetically controlled and should not be diffusion limited. The main reasons for the higher heat release rate in transport reactor are the smaller coal particle size and the higher gas-phase velocity necessary for the reactor operation. Both factors are in favor of increasing the coal combustion reaction rate. The smaller particle means a higher reaction area is available. The higher gas flow rate means faster mass transfer rate between the gas and the solid phase. Under most circumstances the combustion process is diffusion controlled. Both factors (smaller particles and higher gas velocity) will increase the diffusion rate. The effect of the gas flow rate on the reactor heat release rate can be further illustrated from examples suggested by some researchers (e.g., Waters, 1975) that the reactor (or grate) heat release rate can be estimated for the circulating fluidized bed combustors using:

$$R_E \propto \frac{U_o}{E_x}, \qquad (5.2.1)$$

where R_E, U_O, and E_X are the grate heat release rate, the superficial gas velocity, and air flow factor relative to the stoichiometric air flow rate, respectively. The superficial gas velocity should be calculated based on 300°K temperature. Equation 5.2.1 indicates that the heat release rate will increase linearly with the superficial gas velocity. Since the transport reactor operates at a much higher gas velocity, the heat release rate will be higher. For the normal operating conditions, the CFB generally has a superficial gas velocity of 5 to 7 m/s while the transport reactor operates at 10 to 14 m/s. For the same

coal particle size, the heat release rate in transport reactor compared to CFB should be double based on equation 5.2.1. This extrapolation of equation 5.2.1 from CFB to the transport reactor probably goes too far since equation 5.2.1 is a pure empirical correlation which should be carefully applied to conditions that are beyond the experimental data from which the correlation is obtained. However, all the mass transfer studies in the fluidized bed reactors seem to indicate that the mass transfer rate should be proportional to the superficial velocity to a power of 0.5 to 1.0. Taking the lowest limit, the heat release rate should be roughly 1.5 times higher when the gas velocity increases by a factor of 2.

The smaller particle size gives a much higher diffusion rate which in-turn increases the combustion rate. For a spherical particle under steady state, the diffusion rate of oxygen to a single particle can be estimated:

$$R_d = D \left. \frac{dC}{dr} \right|_{r=R} \propto \frac{1}{R}, \qquad (5.2.2)$$

where R_d, D, R, and r, are the oxygen diffusion rate to the particle, diffusivity, particle diameter, and coordinate, respectively. The particle size used in the transport reactor is generally about half the size of a pressurized CFB. This means that the combustion rate in the transport reactor should be twice as much in lieu of equation 5.2.2, if the combustion process is diffusion controlled. The combination of the smaller particle and higher gas velocity makes it possible that the heat release rate in the transport reactor can be three times as high as the CFB. The above arguments show that the observed heat release rates as shown in table 5.2.1-1 are potentially achievable.

Table 5.2.1-1

Comparison of Heat Release Rates From Different Combustion Processes*

	Heat Release Rate (MW/m^2)	Heat Release Rate ($MBtu/hr\ ft^2$)	Operating Pressure (psig)
PC boiler	2.0	0.63	0
Atmosphere CFB	6.8	2.2	0
Pressurized bubbling bed	15.0	4.8	160
Pressurized CFB	50.0	15.8	160
MWK PSDF transport reactor at 500 lb/hr** coal feed rate	47.0	14.8	160
MWK PSDF transport reactor at 700 lb/hr** coal feed rate	65.0	20.7	160
MWK PSDF transport reactor at 1,000 lb/hr** coal feed rate	93.0	29.6	160
MWK PSDF transport reactor at 1,600 lb/hr** designed coal feed rate	149.0	47.0	280

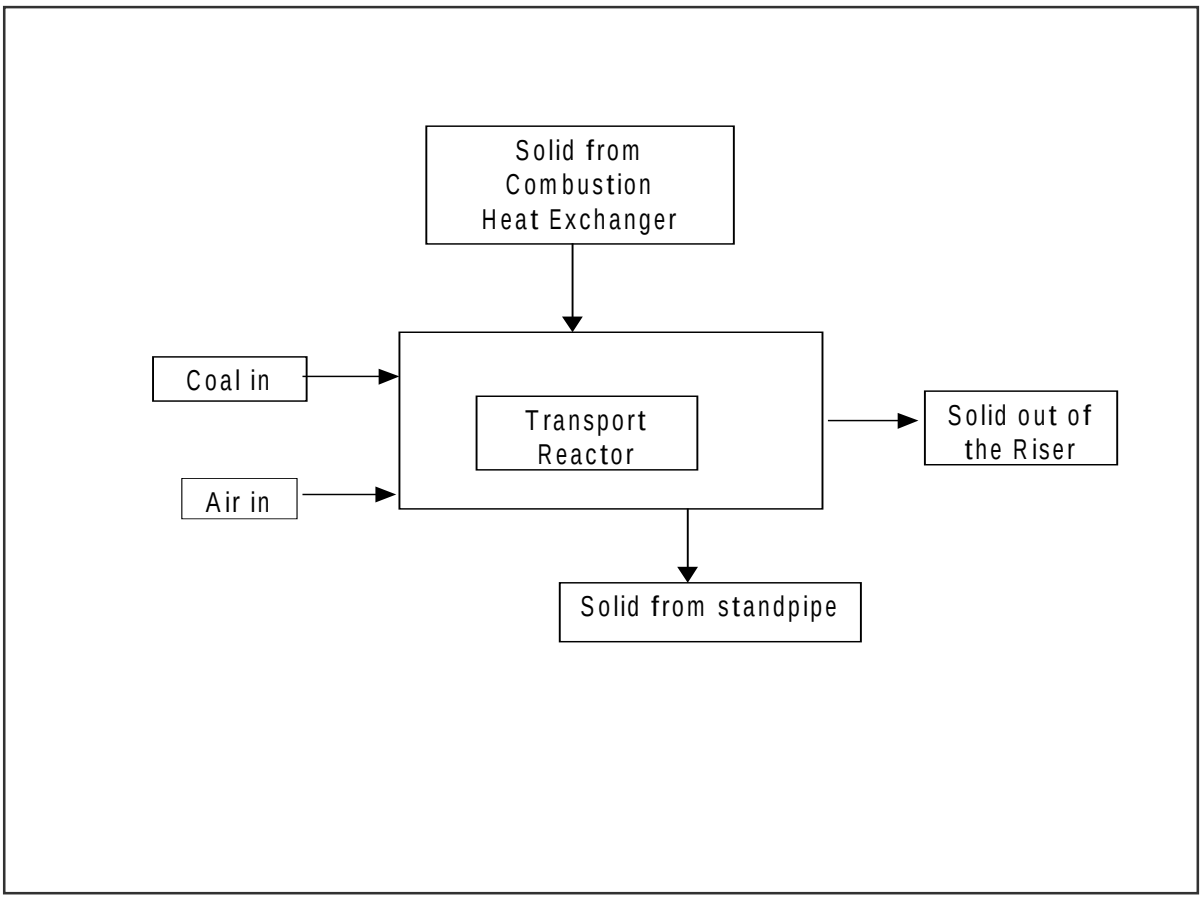
* Data for other processes from: Basu, P. and Fraser, S. A., *Circulating Fluidized Bed Boiler, Design and Operations*, Butterworth-Heinemann, Boston, 1991.

** Assuming 13,000 Btu/lb for the heating value of coal.

5.2.2 The Relationship Between the Coal Feed Rate and Solid Circulation Rate

It has been mentioned that circulation of the solid from the combustion heat exchanger can control the temperature in the reactor. In the last section, the upper limitation on the solid circulation rate is explored from reactor riser choking and standpipe free settling velocity considerations. In this section, the relationship between the solid circulation rate and the coal feed rate will be addressed.

The energy balance around the reactor can provide information about the amount of solid circulating through the combustion heat exchanger. A heat balance control volume can be drawn as follows:



The energy balance around the control volume can be written as:

$$W_c(\Delta H_c + T_c C_c) + W_a T_a C_a + (1-x) W_s T_{Hs} C_s + xWsT_{Js} C_s = W_T C_T T_T \qquad (5.2.3)$$

where,

C_a = heat capacity of air, Btu/(lb °F);
C_c = heat capacity of coal, Btu/(lb °F);
C_s = heat capacity of circulating solids, Btu/(lb °F);
C_T = mean heat capacity of fluid and solids at the exit conditions, Btu/(lb °F);
T = exit temperature of gas and solids;
T_a = inlet temperature of air;
T_c = inlet temperature of coal;
T_{Hs} = inlet temperature of solids from combustion heat exchanger;
T_{Js} = inlet temperature of solids from the reactor standpipe;
W_c = mass flow rate of coal, lb/hr;
W_a = mass flow rate of air, lb/hr;
W_s = mass flow rate of circulating solids, lb/hr; and
x = mass fraction of solids from the reactor standpipe.

The solid circulation rate can be simplified by the fact that the heat capacity of the materials flowing in the reactor is roughly the same. Then equation 5.2.3 can be rewritten as:

$$W_s = \frac{W_c \Delta H_c / C - W_c (T - T_c) - W_a (T - T_a)}{T - (1 - x) T_{Hs} - x T_{Js}} \qquad (5.2.4)$$

For a given feed rate and feed stream temperatures, equation 5.2.4 can be used to calculate the solid circulation rate. Figure 5.2-5 gives the results of the calculated solid circulation rate versus the coal feed rate at different mass fraction of solids circulating through the reactor standpipe with the mixture heat capacity of 0.25 Btu/(lb °F). To calculate the solid circulation rate using equation 5.2.4, the mass fraction of circulating solids from the reactor standpipe (which is unknown) is required. Another equation is needed to solve for the mass fraction from the reactor standpipe. However, the calculation becomes quite difficult because the temperature difference between the standpipe solids and those solids in the mixing zone is too small. This small temperature difference may cause larger calculation errors.

This problem can be avoided if the total solid circulation rate is calculated by selecting the top portion of the mixing zone and riser as the control volume. From such a control volume, the total solid circulation rate can be expressed as:

$$W_s = \frac{W_c \Delta H / C - W_a (T_o - T_i) - W_c (T_o - T_i)}{T_o - T_i} \qquad (5.2.5)$$

where T_i and T_o are the temperatures at the top of the riser and bottom of the control volume, respectively.

Equation 5.2.5 is remarkably simple. However, there is another pitfall in the application of equation 5.2.5 to calculate the circulation rate, the selection of the inlet temperature to control volume. Because it is possible that coal combustion may occur in the mixing zone, the inlet temperature estimated would be higher, which in turn will give an overestimated solid circulation rate. The reason for this situation is that in writing equation 5.2.5 it was assumed that all combustion reactions will be completed inside the control volume. It is almost unavoidable that some of the combustion reactions will occur outside the control volume selected. Our hope is that the amount of coal combustion in the selected region of the mixing zone can be minimized. Further, since the core temperature of a solid particle is lower than the surface temperature, it will partially compensate for the overestimated inlet temperature. The calculated solid circulation rate will be closer to the actual circulation rate.

The following will attempt to further explain why circulating solids may not be completely heated up to the fluid temperature in a short time and need some elaboration. Figure 5.2-6 gives the results of the heat up rate of a spherical particle. This figure shows the dimensionless temperature profile inside a spherical particle varying with dimensionless time. The dimensionless variables are defined as:

$$\tau = \frac{\alpha t}{R^2}, \quad \text{dimensionless time} \qquad (5.2.6)$$

$$\Theta = \frac{T - T_0}{T_f - T_0}, \quad \text{dimensionless temperature} \qquad (5.2.7)$$

where α is the thermal diffusivity of the solid particle and T, T_f, and T_o are temperatures inside of a particle, fluid, and solid inlet, respectively.

If a 400µ particle has a thermal conductivity of 0.025 Btu/hr ft °F, heat capacity of 0.25 and density of 160 lb/ft^3, the volume weighted average temperature of the particle is about 80 percent of the fluid temperature for a 1-second residence time. This is roughly the time period needed for a particle traveling from the bottom of the mixing zone to the bottom of the riser. Therefore, the solid may not completely heat up to the fluid temperature.

From the above reasoning, we may hope that equation 5.2.5 gives reasonable results for the solid circulation rate. Using equation 5.2.5, figure 5.2-7 gives the calculated solid circulation rate for a 24-hour operation period August 19 to 20, 1996. The corresponding coal feed rate is given in figure 5.2-1 for this operation period. Comparing figures 5.2-1 and 5.2-7, one can clearly see that there is a certain degree of correlation between coal feed rate and solid circulation rate in the first 12-hour period. The trend is that an increase in solid circulation rate corresponds to an increase in coal feed rate. This is not the case for the last 12-hour period in which the solid circulation rate is higher and the coal feed rate is

lower than the previous 12 hours. Equation 5.2.4 or figure 5.2-5 can better explain the phenomena. As shown in figure 5.2-5, if 40 percent of circulating solids comes from the combustion heat exchanger, the required total solid circulation rate is only 100,000 lb/hr to have a coal feed rate of 1,000 lb/hr. The solid circulation rate has to be 225,000 lb/hr for 10-percent circulating solids from combustion heat exchanger to obtain the same coal feed rate. That is why in the last 12-hour operation period the solid circulation rate is higher as shown in figure 5.2-7, and the coal feed rate is lower as shown in figure 5.2-1. In order to illustrate this point further, figure 5.2-8 gives the measured standpipe pressure difference, which is an indication of the solid column height in the standpipe. Comparing figure 5.2-7 with figure 5.2-8, one can see that an increase in the standpipe level results in an increase in the overall solid circulation rate as expected. Figure 5.2-9 gives the relationship between the solid circulation rate and the standpipe pressure difference. The solid line is a best-fit line using a polynomial of second degree. Notwithstanding the scatter of the data, a certain degree of correlation can be observed.

All data in figures 5.2-7 through 5.2-9 indicate that the majority of the solids circulating in the reactor are coming from the standpipe instead of from the combustion heat exchanger. That is why the solid circulation rate corresponds to the solid column height in the standpipe quite well. This also means that solids circulating in the reactor do not have the best cooling effect in the riser. Therefore, an increase in the solid circulation rate through reactor J-leg may not result in an increase in coal feed rate at constant reactor temperature.

Figure 5.2-10 shows a plot of coal feed rate vs. the solid circulation rate for the same operation period as in figure 5.2-1. On the surface, the coal feed rate does not appear to correlate with the solid circulation rate. However, if one examines the data carefully, one would find that the data in figure 5.2-10 have two branches. The upper branch covers the coal feed rate in the first 12-hour operation period. The lower branch covers the data from last 12-hour period. In this last 12-hour period the standpipe level is high and most of solids are circulating through the standpipe. As has been mentioned, solids from the standpipe do not have a good cooling effect. Therefore, the coal feed rate can not be increased with an increase in the solid circulation rate from standpipe while keeping the reactor temperature constant. Figure 5.2-11 shows the plot of coal feed rate vs. solid circulation rate in the first 12-hour period. It shows that with the increase in the solid circulation rate the coal feed rate increased. Even for this 12-hour period, the data on the plot is still quite scattered. The reason is that the mass fraction of circulating solids from the combustion heat exchanger was not constant due to problems in its operation. It was observed in the November test that solid circulation from combustion heat exchanger was quite unsteady. Solids in the combustion heat exchanger kept bridging and arching in the bottom of the combustion heat exchanger, and as a result, the pressure difference in the bottom of the combustion heat exchanger varied widely.

Figure 5.2-12 is another example of the coal feed rate varying with the solid circulation rate for the operation period of August 20 to 21. Comparing figure 5.2-12 with figures 5.2-10 and 5.2-11, one may notice that for the data in figure 5.2-12, the coal feed rate increases more rapidly with an increase in solid circulation rate. Furthermore, the overall circulation rate is lower in figure 5.2-12 than in figure 5.2-11 and coal feed rate is higher in figure 5.2-12 than in figure 5.2-11. One of the reasons is that the standpipe level was lower in the August 20 to 21 operation period compared with that in the November operation period. Figure 5.2-13 gives the standpipe pressure difference for the August 20 to 21 operation period. Comparing figure 5.2-13 with figure 5.2-8, it can be noted that the standpipe pressure difference was not only lower but also more stable during the August test. A lower standpipe solid column height means a relatively lower solid circulation rate from the standpipe. A low solid circulation rate and high coal feed rate means that the solid circulation rate from the combustion heat exchanger was relatively high. Other reasons the August 20 to 21operation coal feed rate correlate with the solid circulation rate better are (1) the smaller particle size and (2) different start-up bed material.

Still another example of the coal feed rate varying with the solid circulation rate is given in figure 5.2-14, in which the test data of November 20 to 21 are plotted. Again the coal feed rate does not correlate well with the solid circulation rate.

From figures 5.2-10 through 5.2-12 and 5.2-14, one can clearly see that an increase in the standpipe level will result in an increase in the solid circulation rate. However, from the viewpoint of combustion operations, the solids circulating from the standpipe is quite ineffective in controlling reactor temperature. That is why an increase in the solid circulation rate does not always increase the coal feed rate as shown in figures 5.2-10 and 5.2-14. Only those solids circulating through the combustion heat exchanger can effectively control the reactor temperature.

5.2.3 The Relationship Between the Reactor Temperature and the Coal Feed Rate

At constant coal feed to the reactor with solids circulation and heat removal from the system through the external heat exchanger not changing with time and the external heat loss is constant, the reactor temperature will be constant also. During the current runs being analyzed, some difficulties were experienced in establishing smooth solids circulation through the combustor heat exchanger. This resulted in the heat removal from the system to vary, decreasing as solids circulation through the heat exchanger drops and vice versa. An increase in coal feed rate when the combustor heat exchanger was circulating poorly resulted in an increase in reactor temperature.

Figures 5.2-15 and 5.2-16 give the relationship between the reactor temperature and the coal feed rate for a total of 48 hours of operations during November 19 through 21, 1996. The trend is quite clear that an increase in coal feed rate will increase the reactor temperature. This means that the amount of solids circulating through the combustion heat exchanger was quite limited and almost constant during this time period. This also means that the overall solid circulation rate will not correlate with the reactor temperature very well because the solids circulating through the reactor standpipe cannot be used as a cooling medium as has been mentioned in the previous section. This point can be borne out by figure 5.2-17, in which the solid circulation rate is plotted against the riser temperature. The increased solid circulation rate may not control the reactor temperature properly if those solids come from the reactor standpipe.

In order to control and maintain a constant reactor temperature, while increasing the coal feed rate, one can increase the solid circulation rate through the combustion heat exchanger and reduce the solid circulation rate from the reactor standpipe. The easiest way to realize a minimum solid circulation rate through the standpipe and a maximum solid circulation rate through the combustion heat exchanger is to lower the aeration rate in the standpipe and in the reactor J-leg.

5.2.4 Solid Carryover and Cyclone Separation Efficiency

One of the anomalous problems that has been troublesome during operations is the high solid carryover rate. The high solid carryover rate results in losing solids to the PCD faster than that generated through ash from coal combustion. In order to keep roughly a constant solid inventory, inert materials have to be added. Various causes for the high solid carryover rate have been speculated. In this section, the possible causes for the high solid carryover rate will be explored.

The estimated solid carryover rates for two 24-hour operations are given in figures 5.2-18 and 5.2-19. The average solid carryover rate in this 48-hour period is 600 lb/hr. The ash generation rate is about 100 lb/hr. This means that roughly 500 lb/hr of inert materials were fed to the reactor in order to keep a constant reactor inventory.

In order to diagnose the high solid carryover rate problem, the overall combined separation efficiency of the disengager and the primary cyclone is estimated as shown in figures 5.2-20 and 5.2-21. In preparing figures 5.2-20 and 5.2-21, the average solid carryover rate was used to calculate the separation efficiencies. Because of the operational instabilities experienced, the method used to calculate the separation efficiency is not accurate because the solid carryover rate in a 48-hour operation period is not a constant. In addition without a direct measurement, the solid carryover rate is very difficult to estimate. However, the average carryover rate still gives a reasonable estimation of the total separation efficiency. It is surprising that the correlation between the total collection efficiency and the solids-to-gas loading ratio is generally good considering the wide range of the solids-to-gas loading ratio that was used during the total 48-hour operation period. As a comparison, the collection efficiency of the disengager alone from the cold flow tests at GEESI is also given in figure 5.2-20. Considering the short test duration (a few minutes) of each test performed at GEESI, the data in figure 5.2-20 can be deemed as comparable with the tests at PSDF. It is very difficult to distinguish the exact amount of contribution from the disengager or from the cyclone to the total collection efficiency. Comparing the cold flow test data with PSDF operation data in December, it seems certain that the major gas-solid separation is from the disengager not the cyclone. One obvious reason is that the disengager is collecting larger particles. If it is assumed that the disengager efficiency is 1.0 to 2.0 percent lower than the total collection efficiency, the collection efficiency of the cyclone can be estimated. For a given total efficiency and disengager efficiency, the cyclone efficiency can be calculated as follows:

$$\eta_2 = 1 - \frac{1-\eta}{1-\eta_1}, \qquad (5.2.8)$$

where η, η_1, and η_2 are the total collection efficiency, disengager efficiency, and cyclone efficiency, respectively.

Figure 5.2-22 gives the estimated cyclone collection efficiency from the assumed disengager collection efficiency. It may be quite surprising that in order to increase the total collection efficiency by 1.0 percent, the cyclone collection must vary from 60 to 75 percent and for a 2.0 percent contribution to the total collection efficiency it must vary from 73 to 85 percent. For the particle size used in the test this efficiency may deemed to be low.

Figure 5.2-18 indicates the required efficiency to balance the solid carryover rate with the ash generation rate. The solid/gas loading ratio is taken from the same operation period as in figure 5.2-20. The required total collection efficiency must be greater than 99.8 percent to balance the ash production rate and ash generation rate. If we still assume that the disengager efficiency is 2.0 percent lower than the total efficiency, the cyclone efficiency will vary from about 91 to 96 percent as shown in figure 5.2-24. It is a difficult task to achieve such high total collection efficiencies. First, a certain amount of fines generally exists due to attrition, break up by high heat-up rate, and fines in the feed materials. These smaller particles will pass through both the disengager and cyclone uncollected.

Second, the overall collection efficiency is lower for a circulation system. Suppose that a cyclone has a constant cut size dp_{50}. The particle with a size corresponding to dp_{50} will have a 50-percent probability to be collected in one pass. For the same size particles, the second passing through the cyclones will have the same probability to be collected. From this reasoning, all the particles with a size of dp_{50} will be lost to the down stream. Furthermore, if the particle size is not extremely coarse, there are always some particles passing through the cyclone due to fluid entrainment. For each pass through, the amount of the particle carryover may not be very large. The collected amount of solid passing through the cyclone may be substantial after many cycles. It should be mentioned that the designed cyclone efficiency is much higher than the efficiency given in figure 5.2-24 required to balance the data.

It should be emphasized that the above argument does not mean that the current cyclone efficiency is already high enough. Certainly the cyclone has room for improvement. One indication that the cyclone efficiency can be improved is that the pressure drop across the cyclone is quite low. Figure 5.2-25 gives the pressure drop across the cyclone in terms of the inlet head, which is calculated from the following formula:

$$H_i = 0.003\overline{\rho}U_i^2$$

where,

H_i = the inlet pressure head, in H_2O
$\overline{\rho}$ = inlet mean density, lb/ft^3
U_i = Inlet gas velocity, ft/s

From figure 5.2-25, one can see that the pressure drop across the cyclone in terms of the number of the inlet velocity head is about 2. This is in the lower range of the pressure

drop through a cyclone. The low-pressure drop generally indicates the low efficiency within certain operation range.

The question is why the pressure drop across the cyclone is low. The main reason for the low-pressure drop is the lower inlet velocity. Figure 5.2-26 gives the plot of the cyclone inlet gas velocity vs. the pressure drop. Notwithstanding the scatter in the data, the increase in the cyclone inlet gas velocity will increase the overall pressure drop. The operation range of the inlet velocity should be deemed low for the particle size used in the operation.

Although both the cyclone pressure drop and inlet velocity are low, this does not explain why the cyclone cannot collect the particle size as large as 400μ This anomaly has not been resolved. The fact that large particle sizes can pass through the cyclone system is the phenomenon that was observed throughout operations thus far. It was also repeatedly observed that the solid carryover rate would increase whenever solids were fed to the reactor through the feeder systems. This provides further evidence that the cyclone can only collect larger size particles because the feed materials always contain some particles smaller than the average size of the circulating materials.

There are two interacting factors that prevent us from pinpointing the exact reason that the cyclone cannot collect the particle size as large as 400 μ. Both are related to the solid circulating through the combustion heat exchanger. The first factor is the gas short-circuit resulting in a reverse upward flow in the dipleg of the cyclone. It is not necessary that the reverse flowing gas velocity should be greater than the particle terminal velocity to interfere with the cyclone collection efficiency, but the reverse flowing gas provides some energy to help entrain the particle to the vortex tube.

Another important interaction that should be discussed is the relationship between the solid circulation rate and the rate of the solid carryover. Obviously, at a given cyclone efficiency (note that we have pointed out that an increase in the solid/gas loading ratio will increase the efficiency) the higher the solid circulation rate, the higher the solid carryover rate. Figures 5.2-27 and 5.2-28 give the relationship between the solid carryover rate and the solid circulation rate for a 48-hour operation period. Although data are quite scattered, the overall trend is that an increase in the solid circulation rate will result in an increase in the solid carryover rate. The point is that the overall efficiency of the whole cyclone system may not be as low as it appears. Comparing figures 5.2-20 and 5.2-28 for the same operation period, one can see that although the cyclone system has an efficiency above 99 percent, the solid carryover rate may still be quite high compared with the ash generation rate from coal combustion.

In summary, the high solid carryover rate may be caused by several reasons. The higher solid circulation rate will give a high carryover rate. Since the cyclone efficiency will improve with an increase in the solid gas load ratio, the carryover rate should reduce by a

decrease in the reactor gas velocity. However, the lower limit of the gas velocity is the choking velocity.

5.2.5 Riser Pressure Drop and Solid Circulation Rate

There are two pressure drop measurements in the riser. One measures the pressure drop for the entire riser. The other measures the pressure drop in the top section of the riser. The pressure drop in the top of the riser also gives the riser density from which the solid circulation rate can be estimated.

One problem that was noticed was that the measured pressure drop across the entire riser may be low. Figure 5.2-.29 gives the measured pressure drop vs. the gas velocity in the riser for a 24-hour operation period. For the purposes of comparison, the pressure drops calculated from gas flow only and gas flow with solids that were fed (no solid circulation) are also given figure 5.2-29. The measured average pressure drop for the riser in this 24-hour operation is about 6.5 inH_2O. If the measured pressure drop is representative to the actual pressure drop across the riser, it means that the solid circulation rate is extremely low.

The true reasons for this low measured pressure drop are not known. The speculation is that the leg that measures high static pressure in the pressure difference measurement is located in the fluid acceleration zone. In the acceleration zone, the higher the fluid acceleration rate, the lower the static pressure. If the higher pressure measurement leg measures the higher static pressure, the overall measured pressure drop will be lower.

There is another pressure drop measurement in the top of the riser. This pressure drop measurement seems reasonable (although still lower for the reasons given later). Figure 5.2-30 gives a comparison between the measured pressure drop and calculated pressure drop by the correlation of Konno and Saito. The calculated pressure drop is higher than the measured one for this period of the operation. Two obvious reasons are either the calculated pressure drop is too high or the measured pressure drop too low or both. It is possible that the calculated pressure drop is higher than the actual value because the solid circulation rate (calculated based on the energy balance) may be higher than the actual circulation rate. As mentioned previously, some of the coal may be combusted outside the control volume and will result in a higher inlet temperature of fluid entering the control volume, which affects the solid circulation rate calculations. It is possible that the measured pressure drop is lower than the actual one due to the location of the low leg of the static pressure measurement. The low-pressure measurement leg is located at the top of the riser very close to the crossover. At the very top of the riser, there is an extended dead leg to minimize the erosion of the bend. When the gas phase carrying the solids is flowing upwards, both phases are subject to reverse flow at the dead end. Some of the solids may flow downwards. According to the Bernoulli equation, this is a deceleration zone wherein the static pressure is higher. The low leg of the differential pressure measurement reads a higher static pressure. This will result in a differential pressure between the high leg and low leg, which is lower than the actual value. If one examines figure 5.2-30, one can see that the data between the measured pressure drop and calculated one are systematically biased. The higher the measured pressure drop, the bigger the

difference between the measured and calculated pressure drop. This result is consistent with the above reasoning. When the solid circulation rate is increasing, the probability of solid downward flow becomes larger. The static pressure in this deceleration zone will get higher.

Figures 5.2-31 and 5.2-32 give comparisons between the solid circulation rate calculated from the energy balance and from the measured pressure drop in the top of the riser. The solid circulation rate calculated from the riser pressure drop is based on no-slip between gas and solid phase. The data presented in figure 5.2-31 show that the solid circulation rates calculated from both methods agree reasonably well when the solid circulation rate is below 120,000 lb/hr. When the solid circulation rate is above 120,000 lb/hr, the solid circulation rate calculated from the measured pressure drop is much lower than that calculated from the energy balance. One of the reasons is due to the solids downward flow from the dead zone as mentioned above. The data presented in figure 5.2-32 are somehow different from those in figure 5.2-31. In figure 5.2-32, the solid circulation rate calculated from energy balance is much higher than that calculated from the pressure drop measurement. It is noted that the solid circulation rates calculated from the riser pressure drop are the maximum values because of the assumption of no-slip between the phases.

From figures 5.2-31 and 5.2-32, one is inclined to conclude that the calculated solid circulation rate from energy balance is always higher than that from the measured pressure drop. It also means that the calculated pressure drop based on the solid circulation rate is higher than measured pressure drop because the major factor that influences the pressure drop calculation is the solid circulation rate. In other words, the estimated solid circulation rate from energy balance is too high. In fact, further evidence shows that it is not the case. Figure 5.2-33 gives the solid circulation rate calculated from the riser pressure drop measurement and from the energy balance for the test period of August 20 to 21. One can see that the former is much higher than the latter. The same is true for figure 5.2-34, which represents data from the operation period of August 19 to 20. Figures 5.2-31 through 5.2-34 seem to indicate that the calculated solid circulation rate based on energy balance may be more reasonable than that based on the riser pressure difference. The data in figures 5.2-33 and 5.2-34 also indicate that a slip between the gas and solid phases exist. Figures 5.2-33 and 5.2-34 also seem to confirm the speculation that the solid downward flow at the top of the riser causes the measured pressure drop to be lower than the actual value during the test run in November. One major difference between August and November operations is the particle size. For the August operation, the particle size is about one-third to one-quarter the size used in the November operation. The smaller particle is easier to be entrained by the gas phase, and as a result, has less opportunity to flow downward near the top of the riser. Therefore, the lower leg of the pressure drop measurement may give results, which closely reflects the actual pressure.

Exhibit

Figures for

Section 5.2

Operability Analysis of Commissioning Tests

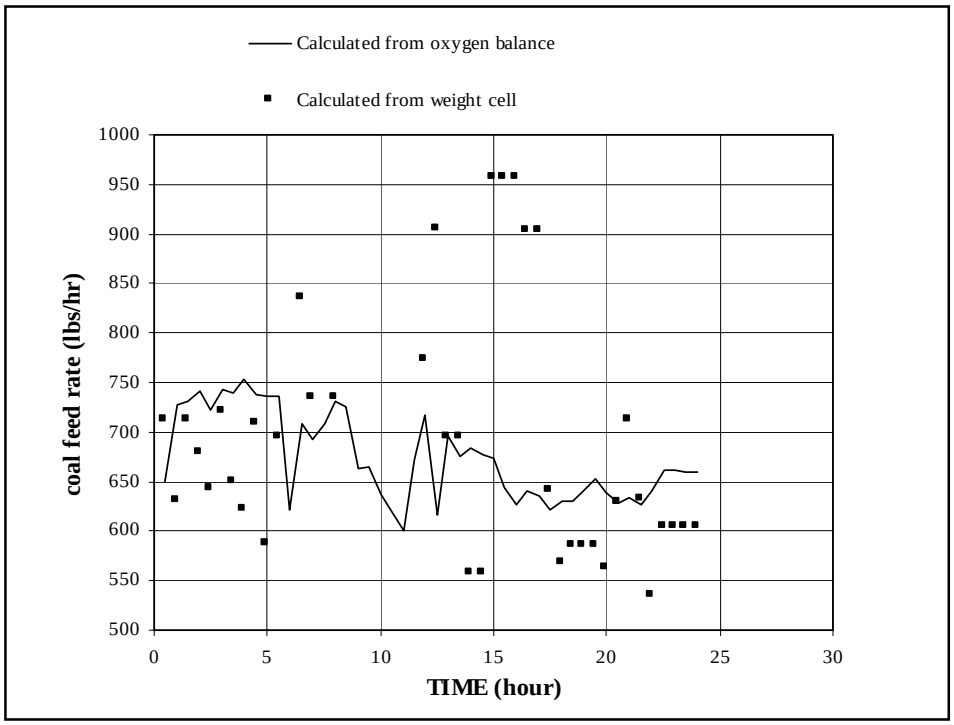


Figure 5.2-1 Comparison of Coal Feed Rates Calculated From Oxygen Balance and From Weight Cell Measurements for Test Period November 19 to 20, 1996

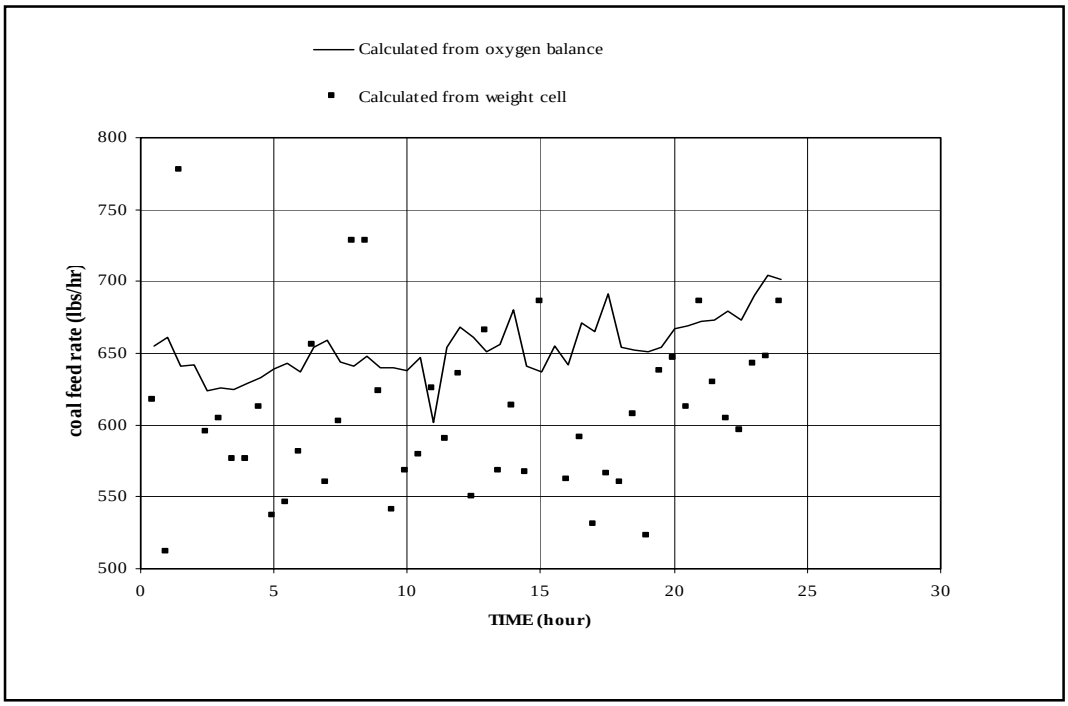


Figure 5.2-2 Comparison of Coal Feed Rates Calculated From Oxygen Balance and From Weight Cell Measurements for Test Period November 19 to 20, 1996

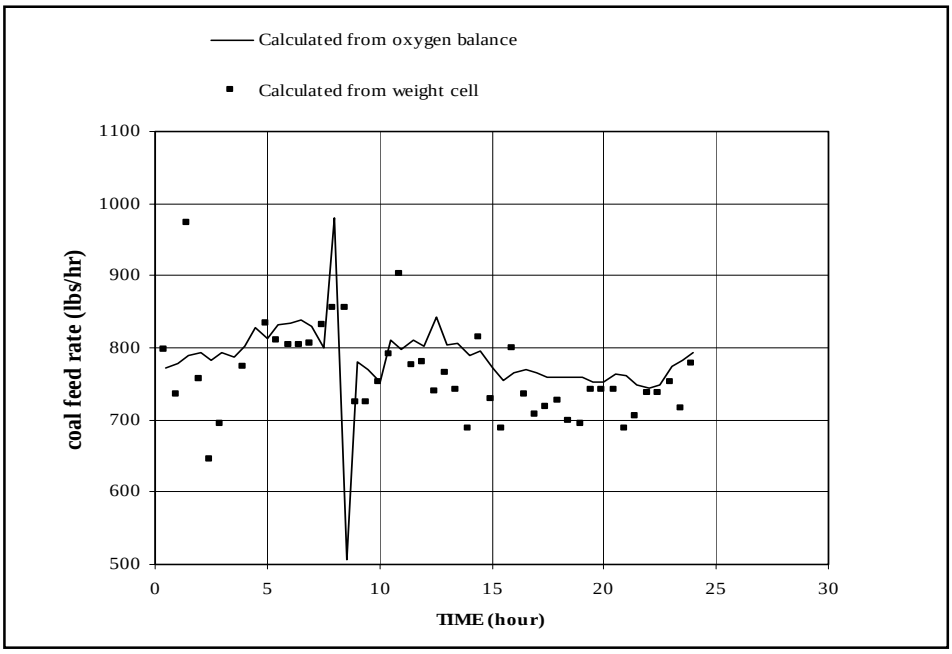


Figure 5.2-3 Comparison of Coal Feed Rates Calculated From Oxygen Balance and From Weight Cell Measurements for Test Period August 19 to 20, 1996

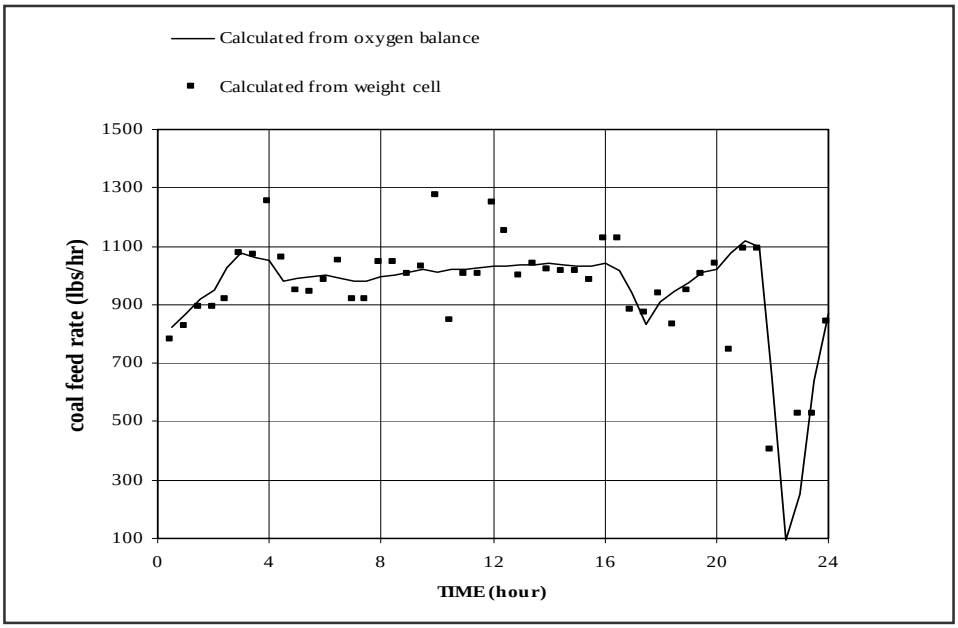


Figure 5.2-4 Comparison of Coal Feed Rates Calculated From Oxygen Balance and From Weight Cell Measurements for Test Period August 20 to 21, 1996

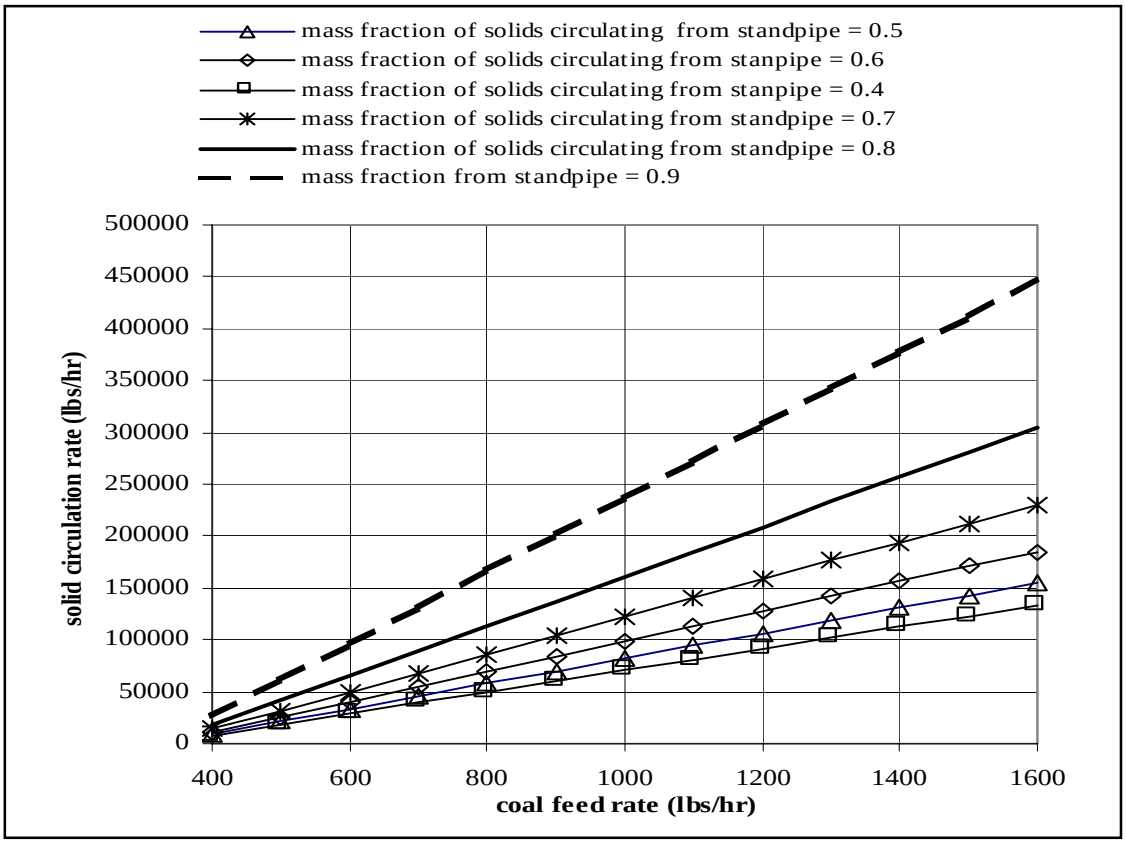


Figure 5.2-5 Variation of Required Solid Circulation Rate With Coal Feed Rate at Different Mass Fraction of Solid Circulating Through Reactor Standpipe (Assumes That the Solids Exit Combustion Heat Exchanger at 600°F)

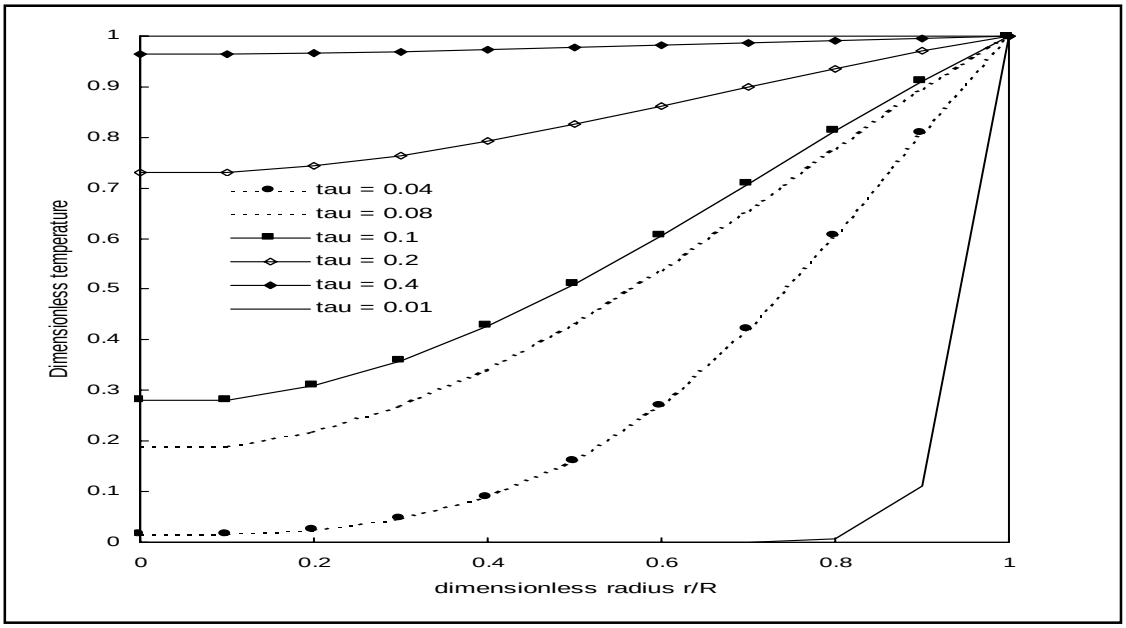


Figure 5.2-6 Heat-up Rate of a Single Particle vs Dimensionless Radius

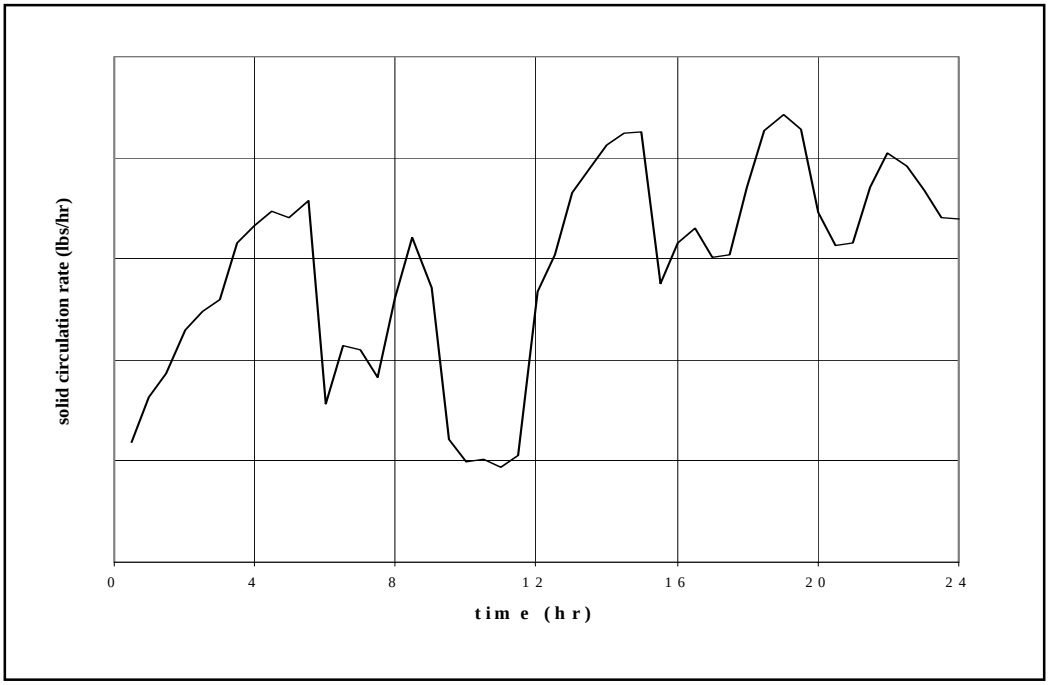


Figure 5.2-7 Variation of Required Solid Circulation Rate With Time for Test Period November 19 to 20, 1996 (Same Test Period as shown in Figure 5.2-1. Average coal Feed Rate for This Test Period was About 670 lb/hr)

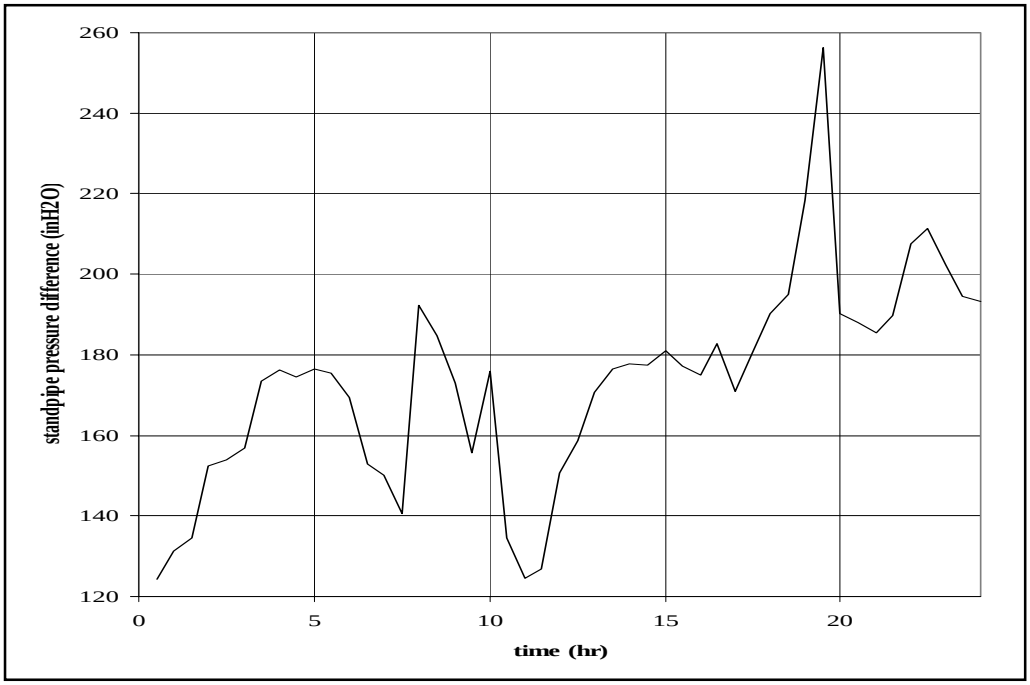


Figure 5.2-8 Variation of Measured Standpipe Pressure Difference (Which is an Indication of the Standpipe Level) With Time. Same Time Period as Shown in Figure 5.2-7)

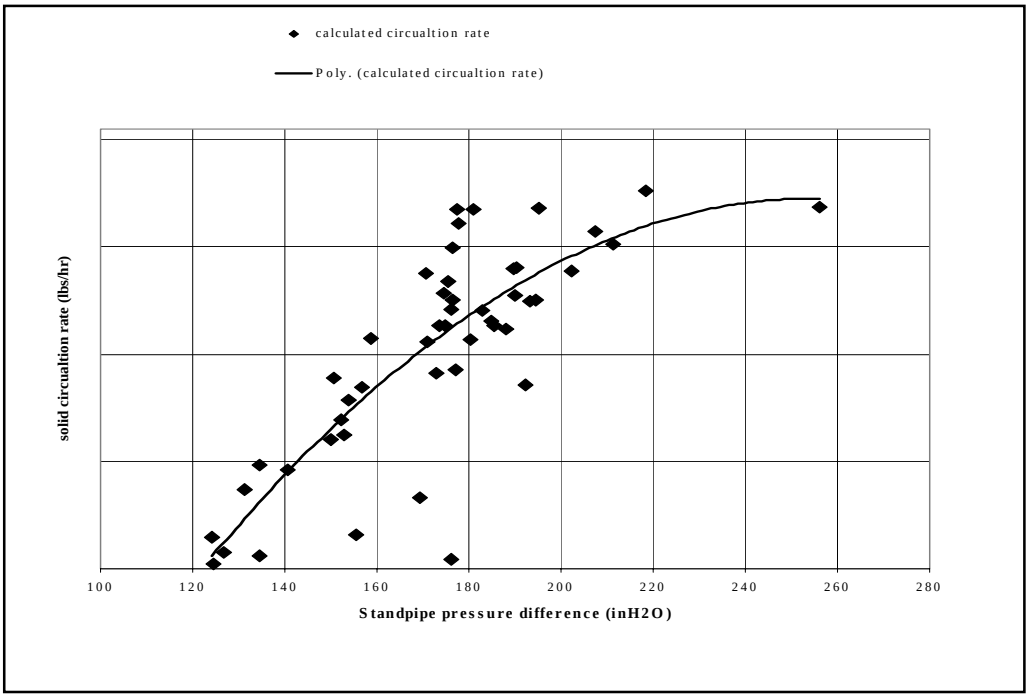


Figure 5.2-9 Variation of Solid Circulation Rate With Standpipe Pressure Difference (Solid Line is a Second-Degree Polynomial Fit of the Data)

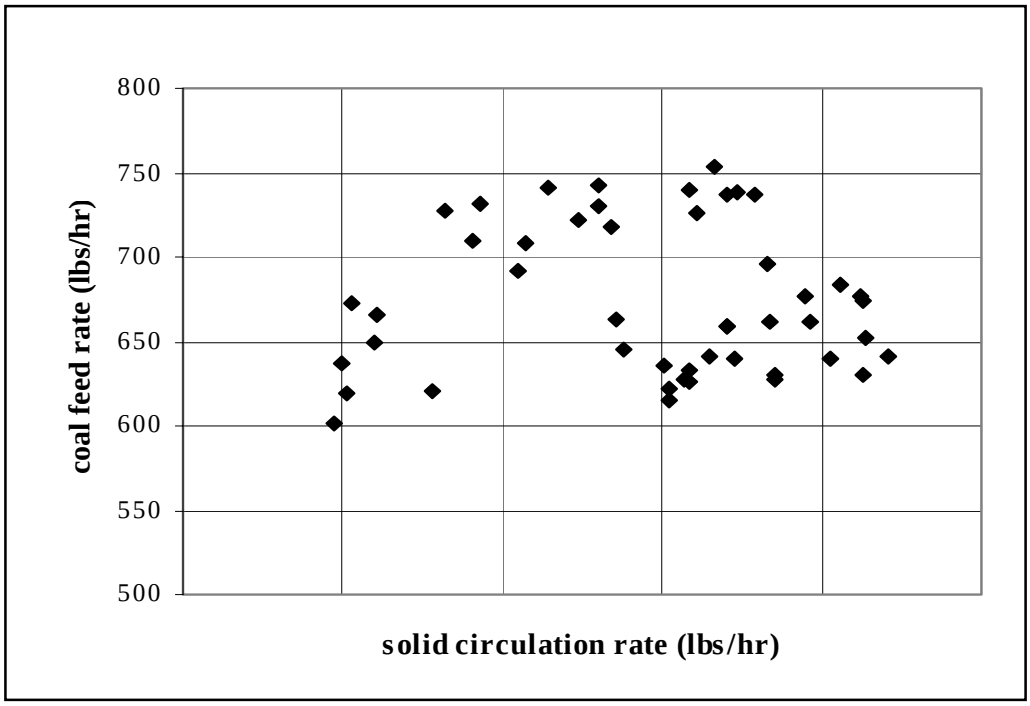


Figure 5.2-10 The Relationship Between the Coal Feed Rate and Solid Circulation Rate for Test Period November 19 to 20, 1996.

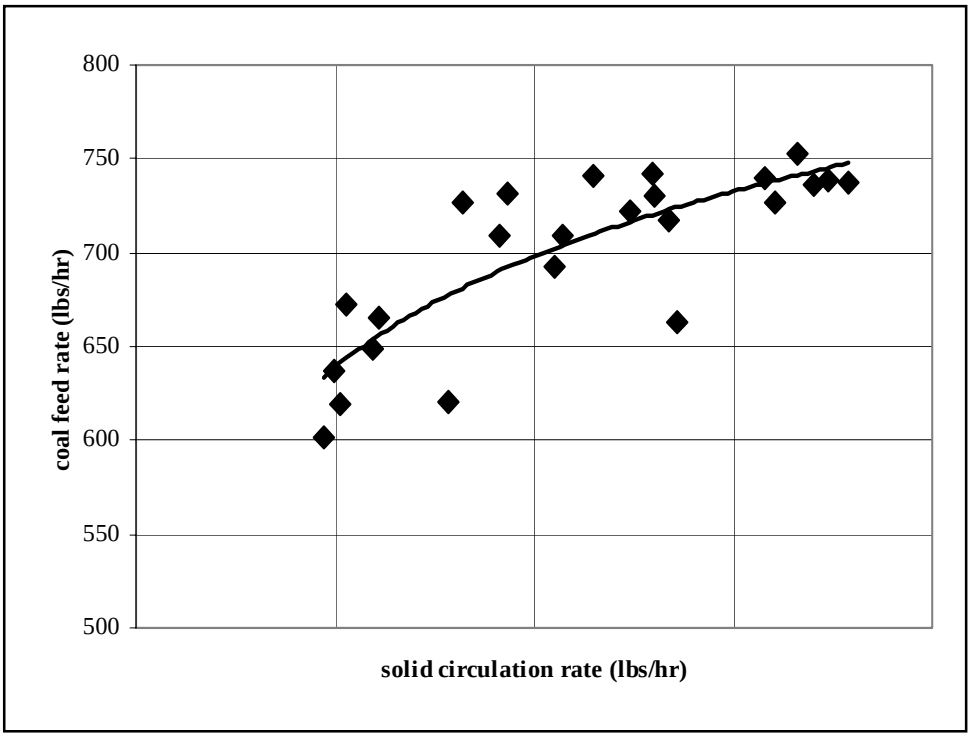


Figure 5.2-11 The Variation of Coal Feed Rate With Solid Circulation Rate for First 12 Hours of Operation on November 19 to 20, 1996

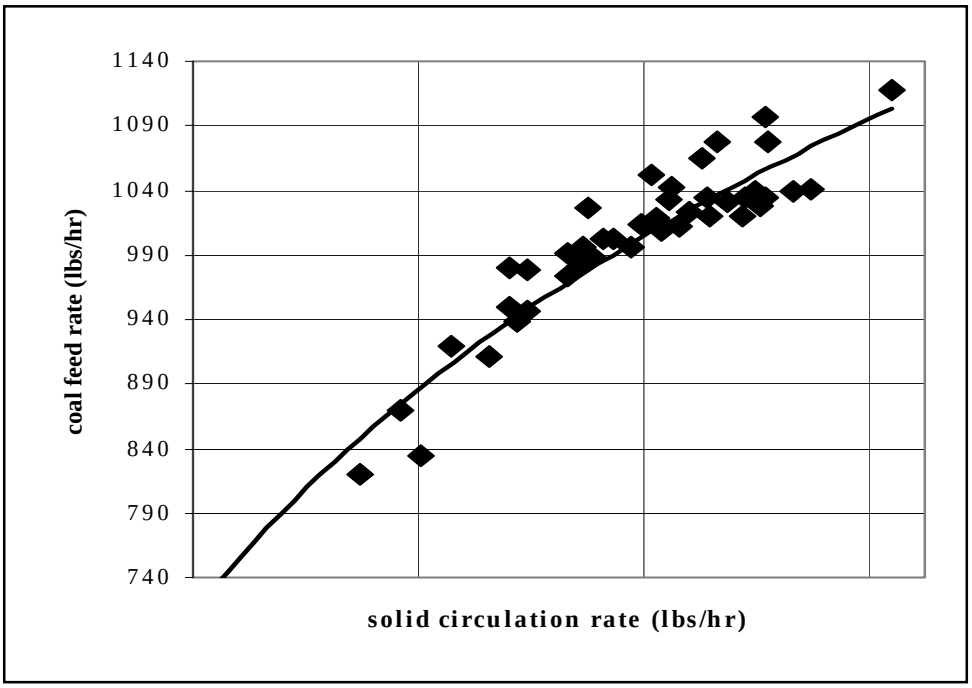


Figure 5.2-12 The Variation of Coal Feed Rate With Solid Circulation Rate for Test Period of August 20 to 21, 1996

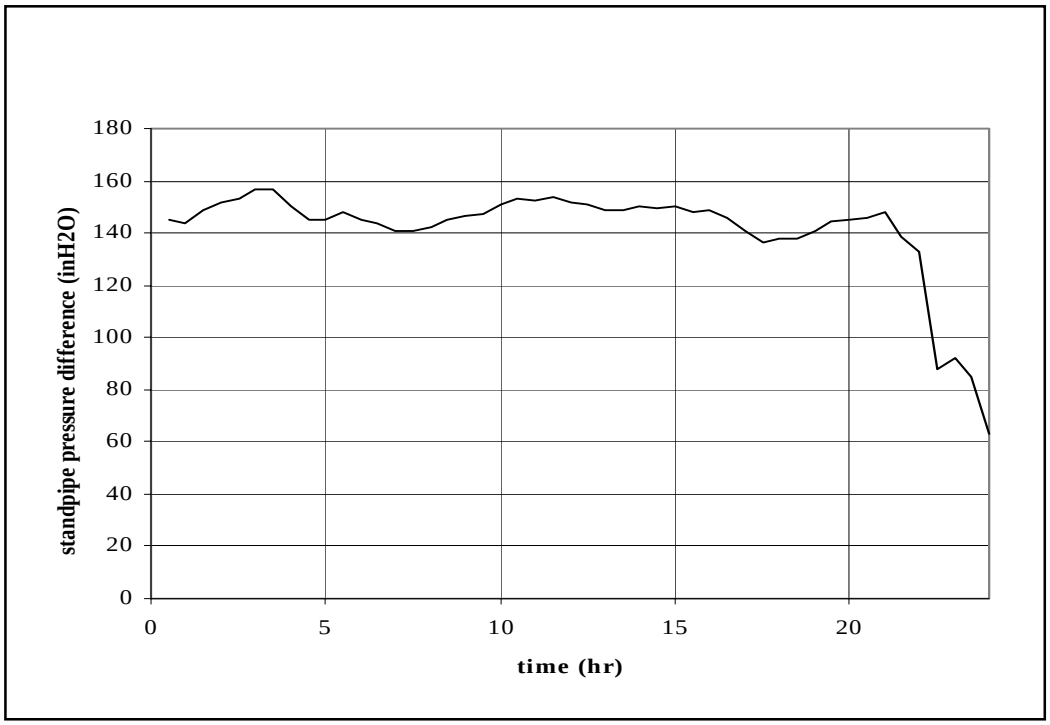


Figure 5.2-13 Variation of Solids Level in the Standpipe With Time for Test Period of August 20 to 21, 1996.

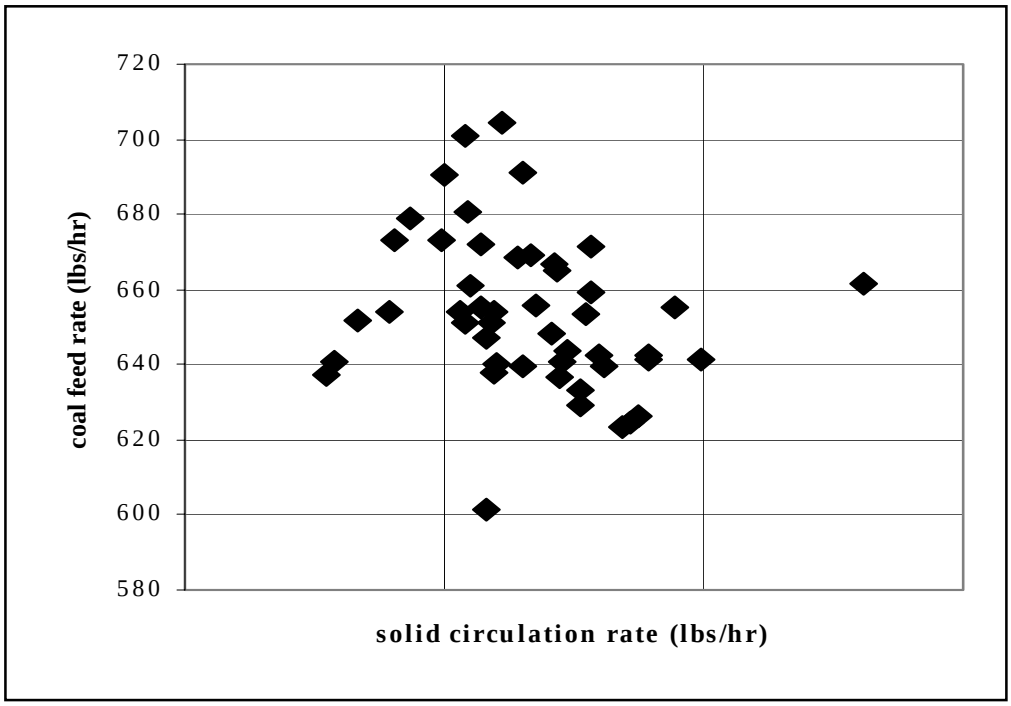


Figure 5.2-14 Variation of Coal Feed Rate With Solid Circulation Rate for Test Period of November 20 to 21, 1996.

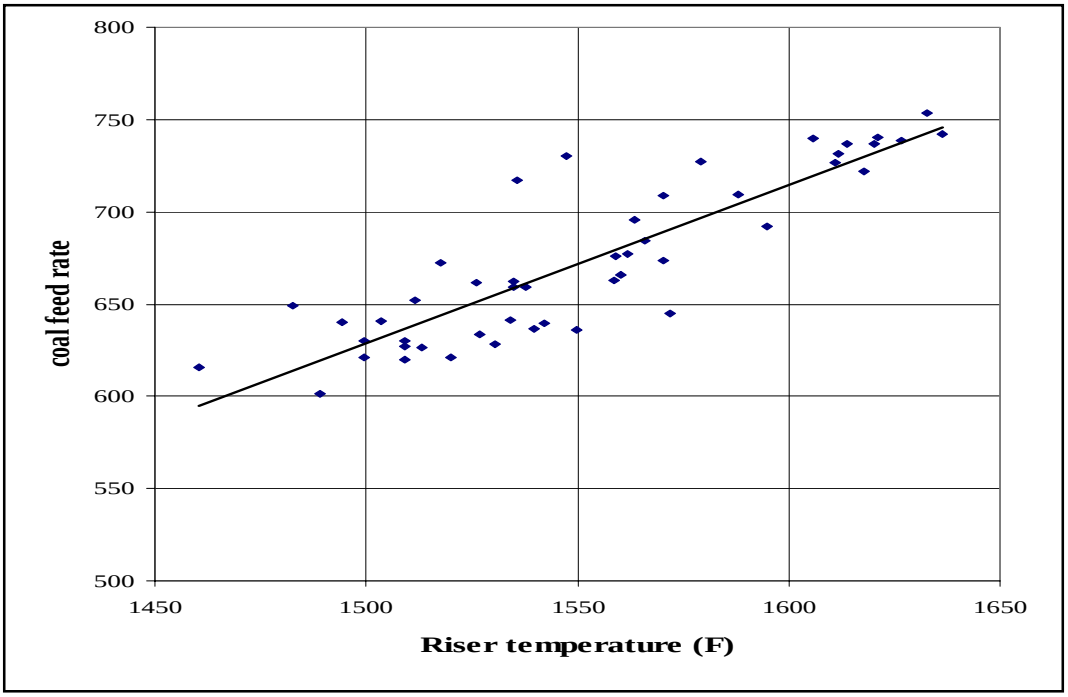


Figure 5.2-15 Coal Feed Rate vs Riser Temperature for Test Period of November 19 to 20, 1996

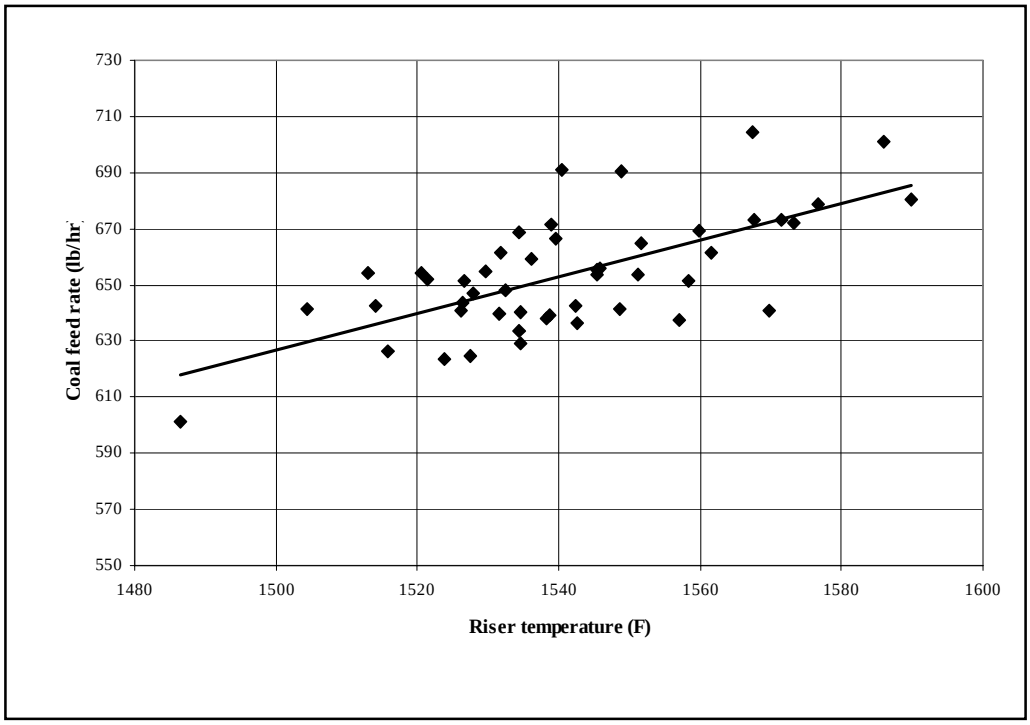


Figure 5.2-16 Coal Feed Rate vs Riser Temperature for Test Period November 20 to 21, 1996

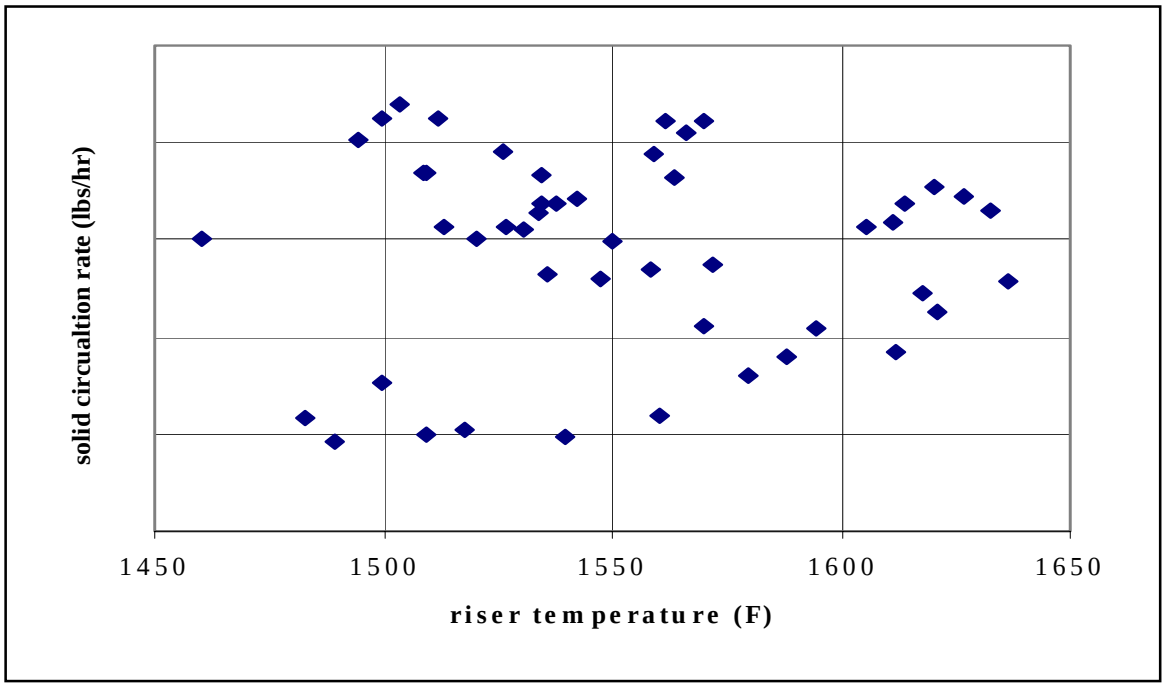


Figure 5.2-17 Solid Circulation Rate vs Riser Temperature for Operation Period of November 19 to 20,1996.

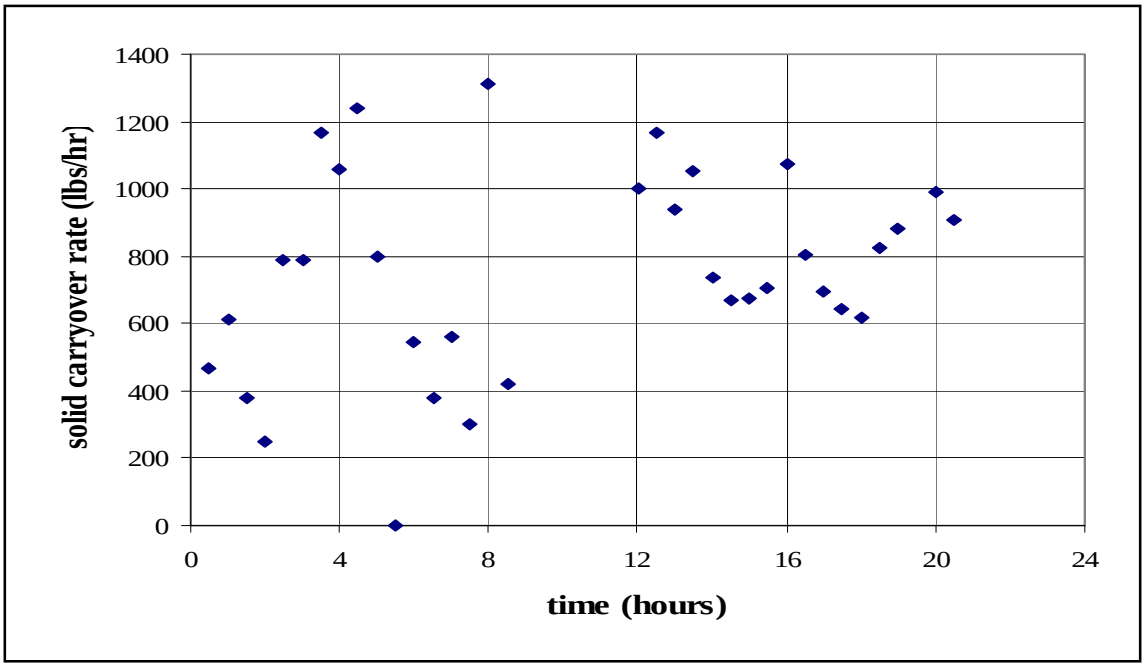


Figure 5.2-18 Estimated Solid Carryover Rate With Time for Operation Period of November 19 to 20, 1996

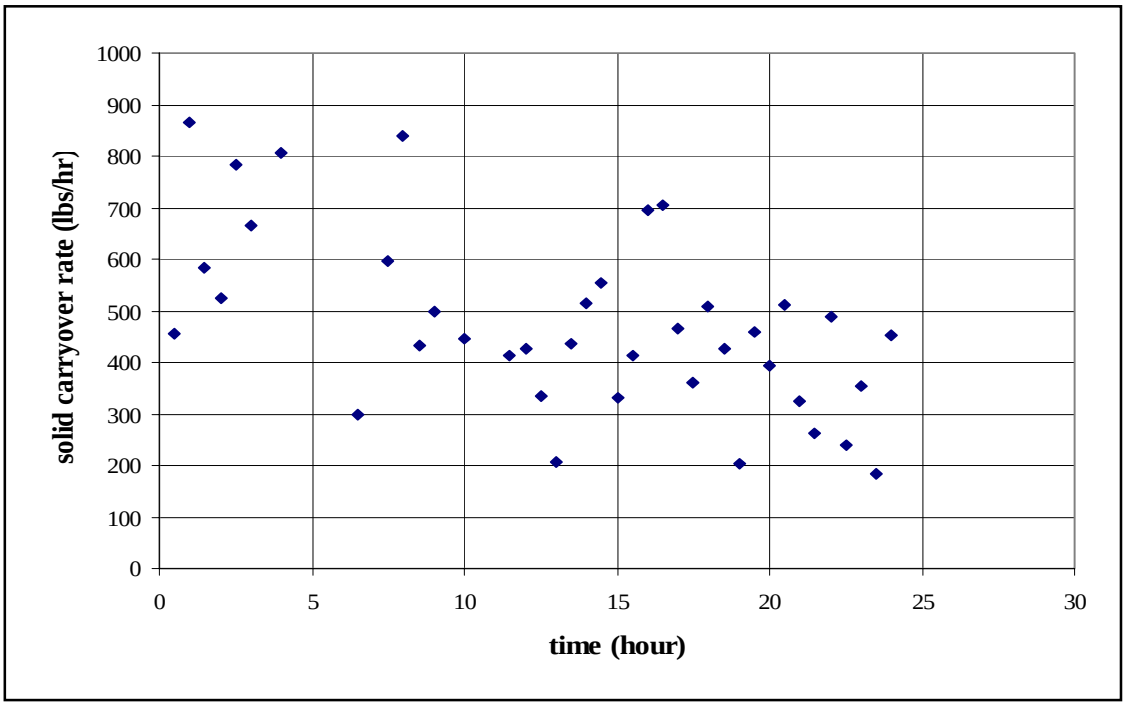


Figure 5.2-19 Estimated Solid Circulation Rate With Time for Test Period November 20 to 21, 1996

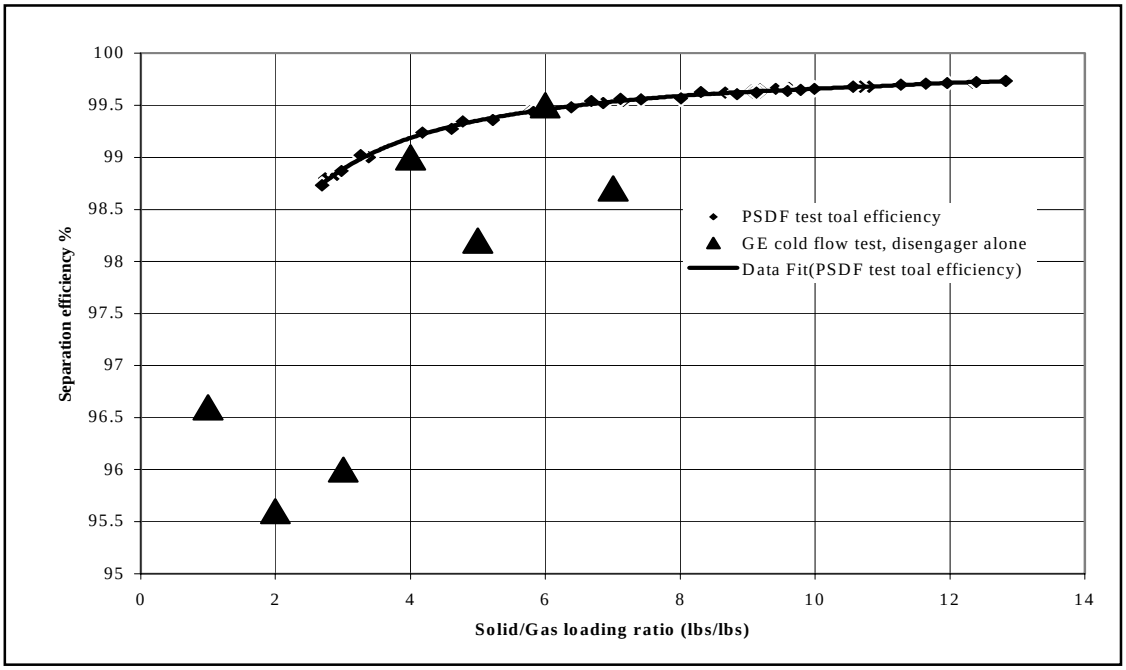


Figure 5.2-20 Estimated Cyclone System Collection Efficiency vs Solid/Gas Loading Ratio for Test Period November 19 and 20, 1996 (Cold Flow Test Data From GEESI is Also Provided in This Figure)

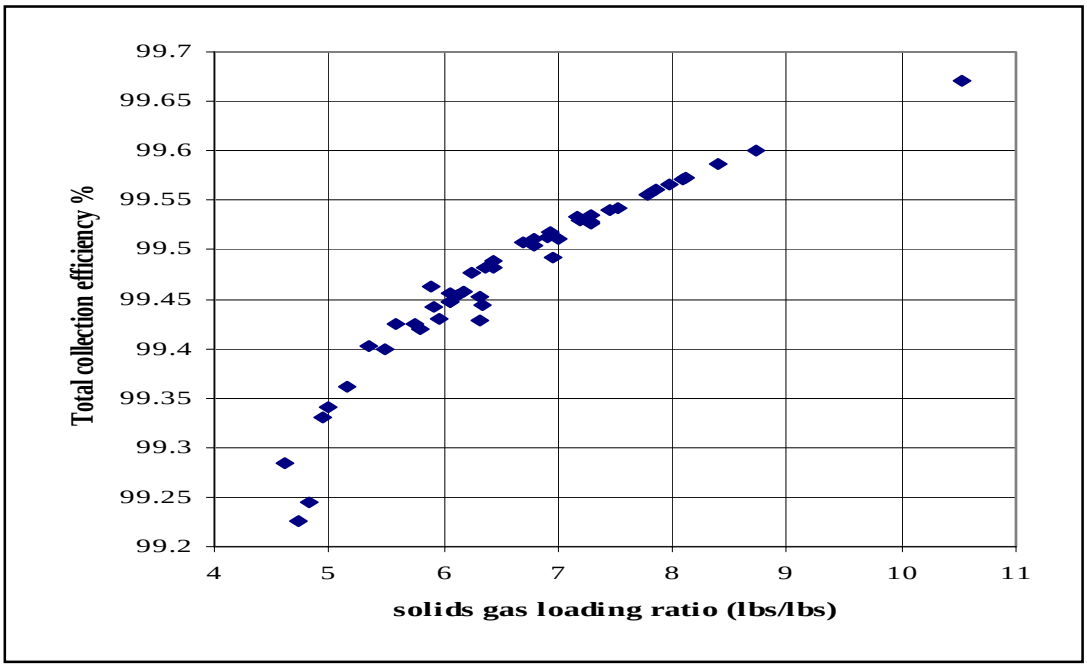


Figure 5.2-21 Estimated Cyclone System Collection Efficiency vs Solid/Gas Loading Ratio for Test Period November 20 and 21, 1996

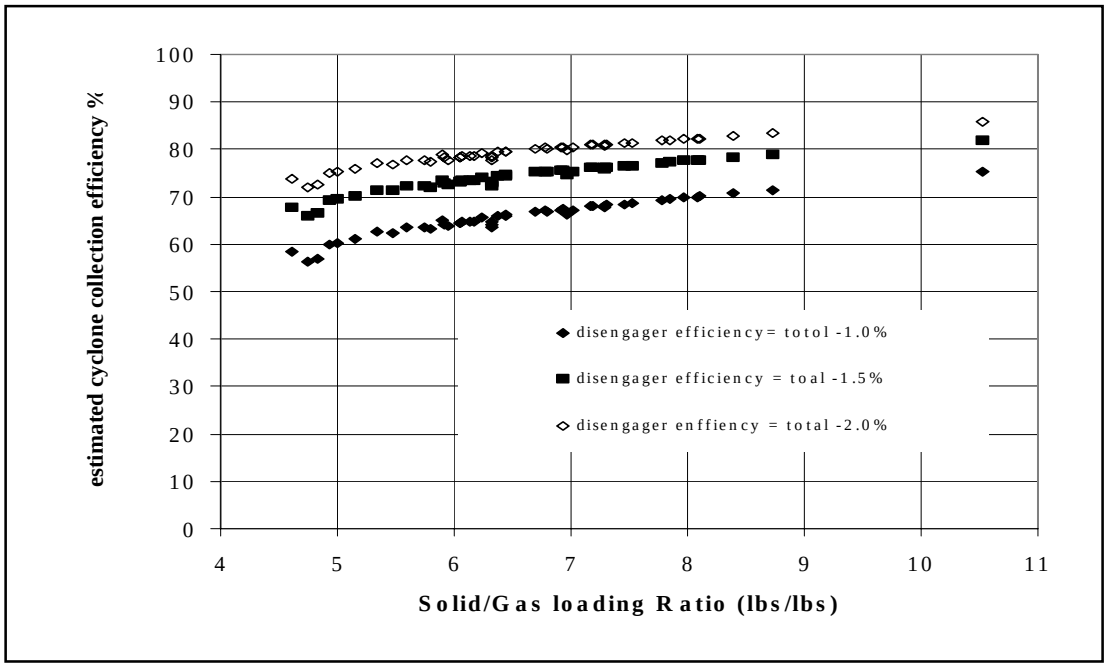


Figure 5.2-22 Estimated Cyclone Efficiency vs Solid/Gas Loading Ratio for Given Disengager Efficiency

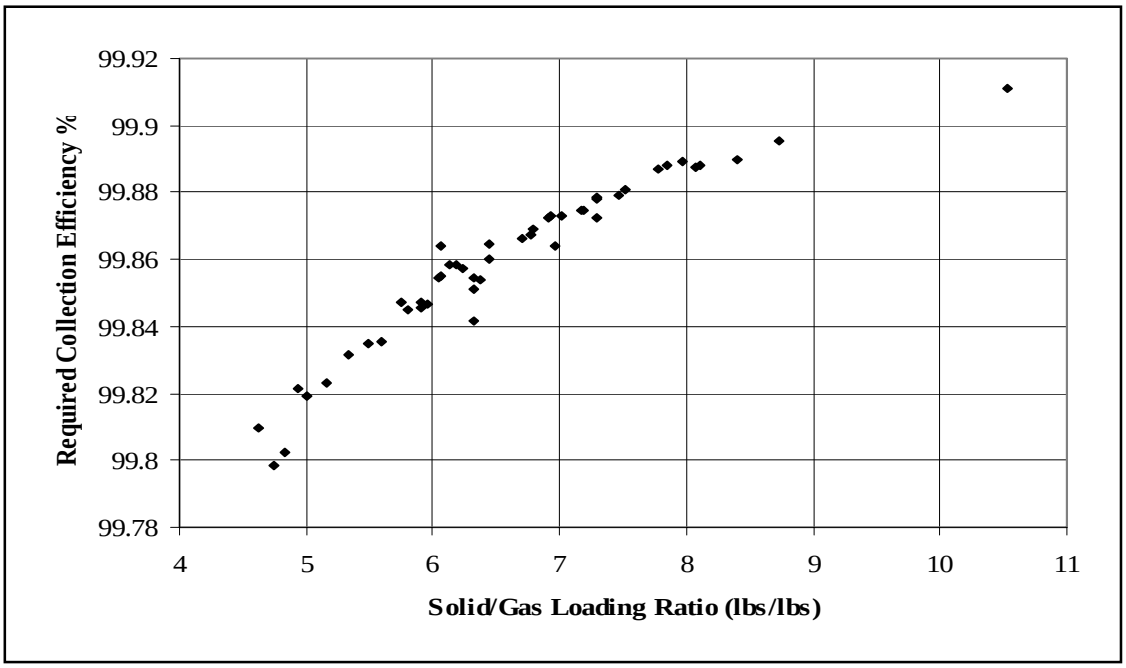


Figure 5.2-23 Required Total Collection Efficiency of Cyclone System vs Solid/Gas Loading Ratio to Balance Ash Production Rate and Solid Carryover Rate

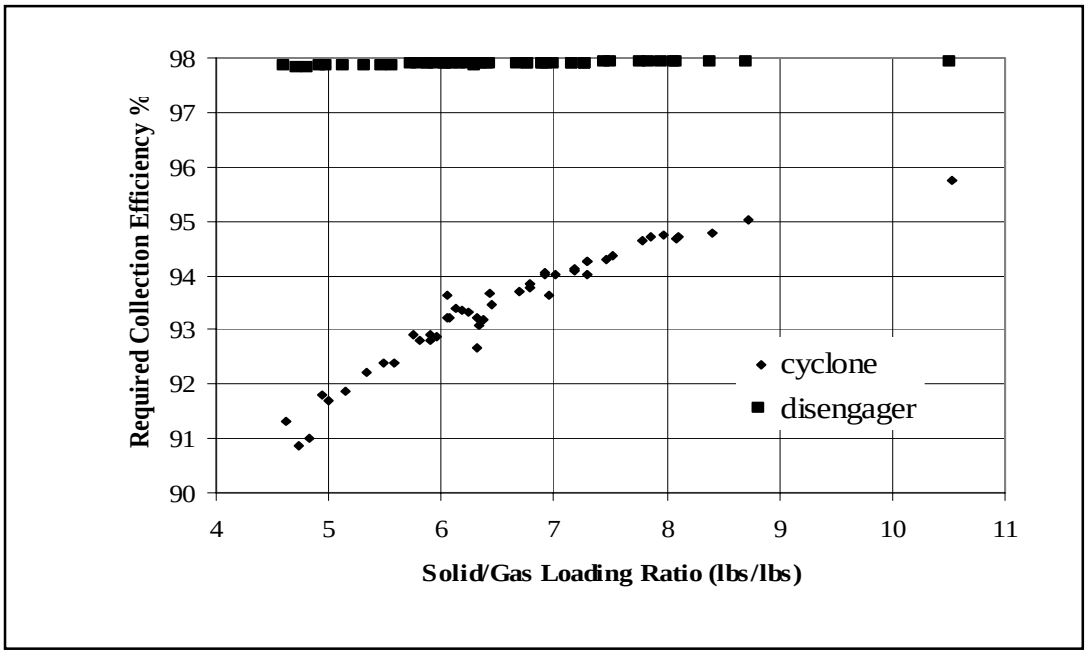


Figure 5.2-24 Estimated Collection Efficiencies for Individual Cyclone to Balance Ash Production Rate and Solid Carryover Rate

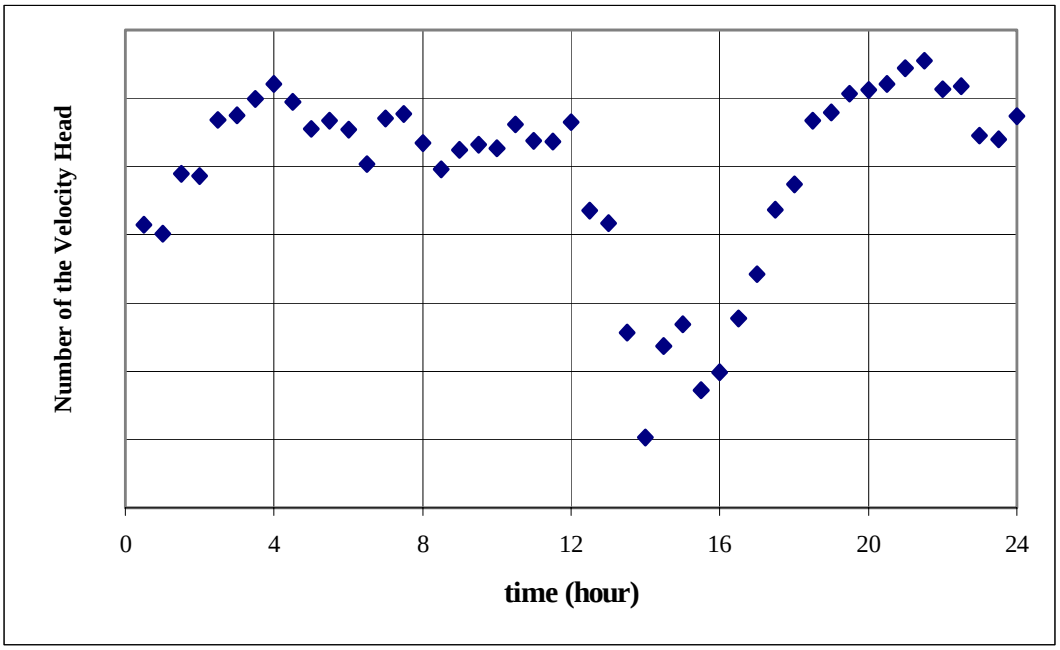


Figure 5.2-25 Pressure Drop Across Primary Cyclone for Test Period November 20 to 21, 1996.

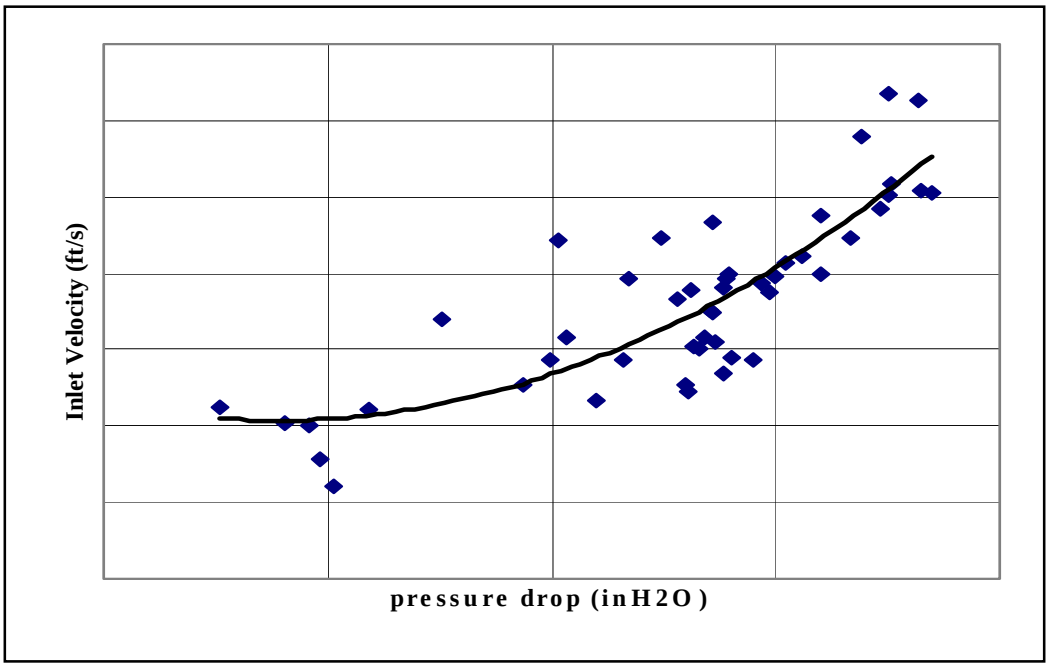


Figure 5.2-26 The Relationship Between Cyclone Inlet Gas Velocity and Cyclone Pressure Drop for Test Period November 20 to 21, 1996

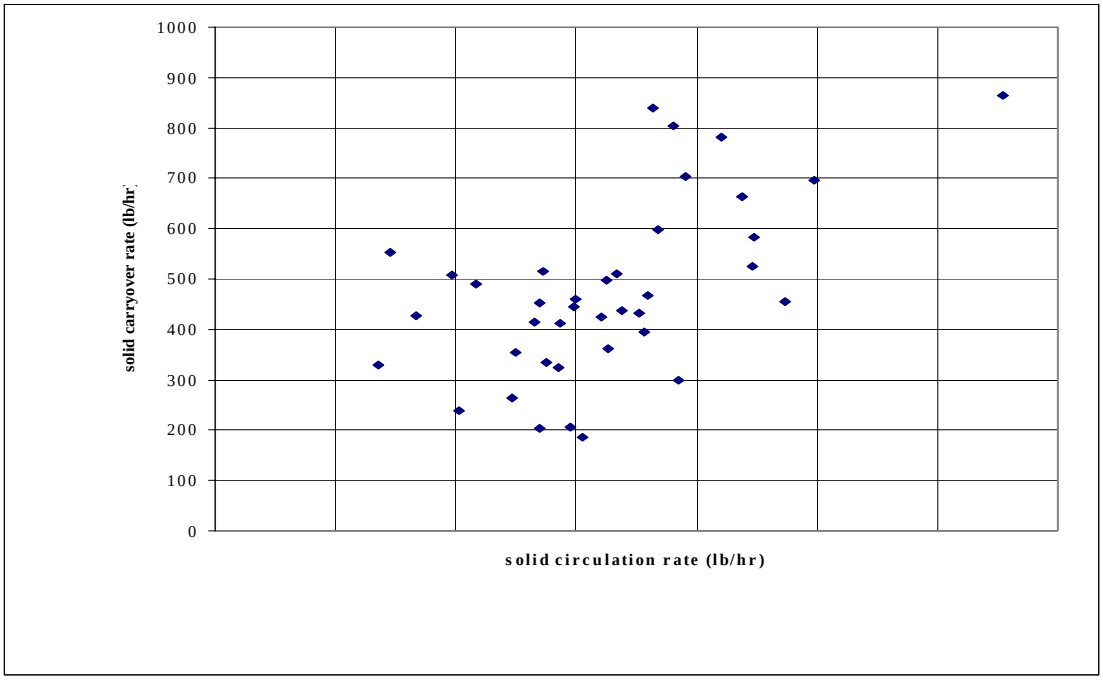


Figure 5.2-27 Estimated Solid Carryover Rate vs Solid Circulation Rate for Test Period November 20 to 21, 1996

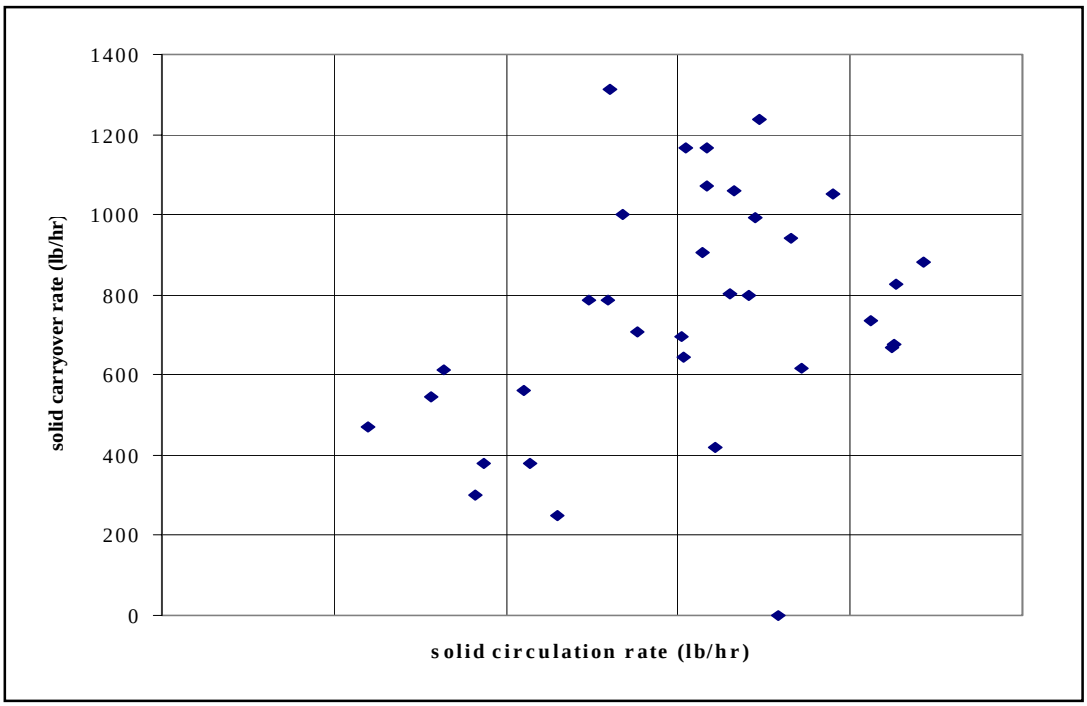


Figure 5.2-28 Estimated Solid Carryover Rate vs Solid Circulation Rate for Test Period November 19 to 20, 1996

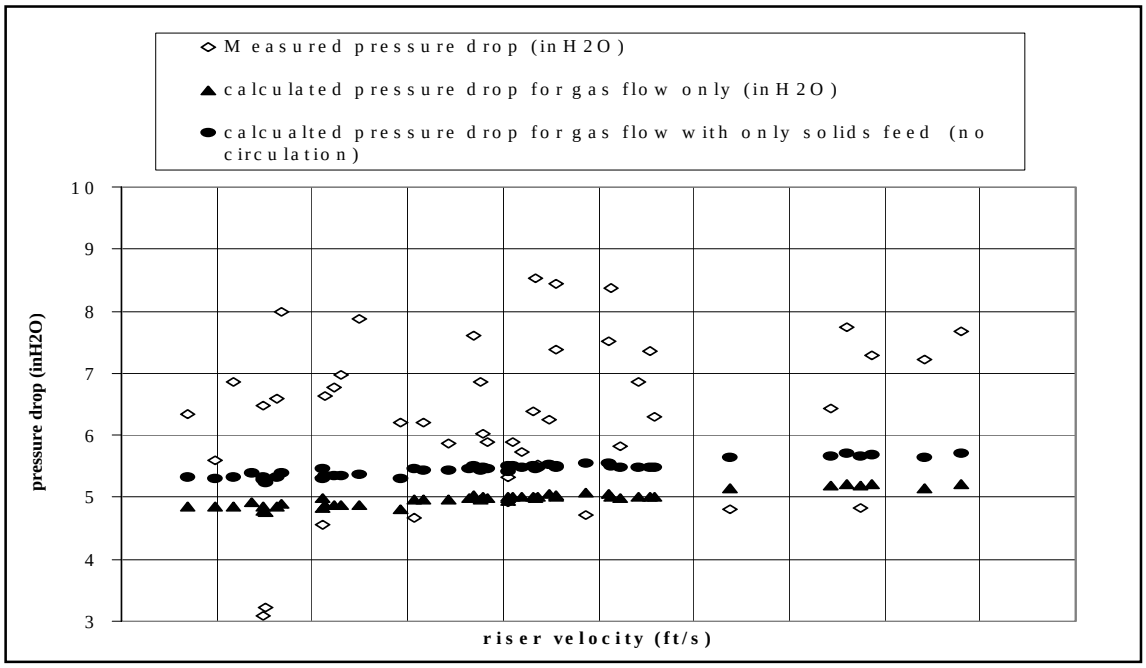


Figure 5.2-29 Comparison Between the Measured Pressure Drop Across Riser and Calculated Pressure Drop Based on Gas Phase Flow, Only, and Gas Phase With Only Solid Feed, to Show That the Measured Riser Pressure Drop is Low

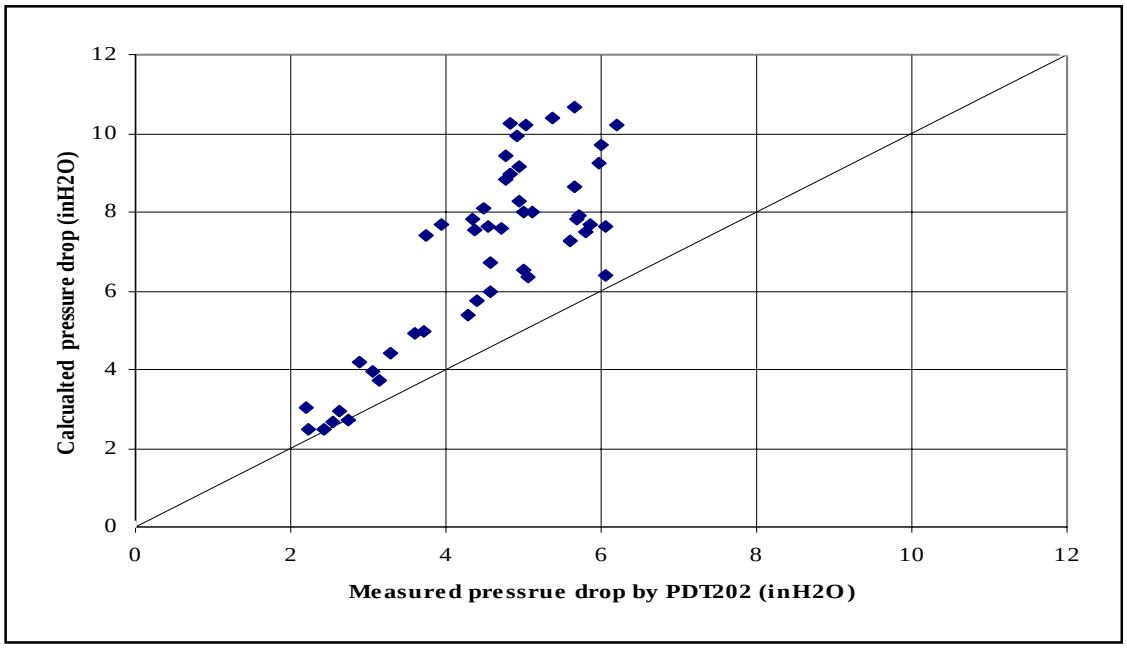


Figure 5.2-30 Comparison of the Measured Pressure Drop at Top of the Riser With Calculated Pressure Drop for Test Period November 19 to 20, 1996

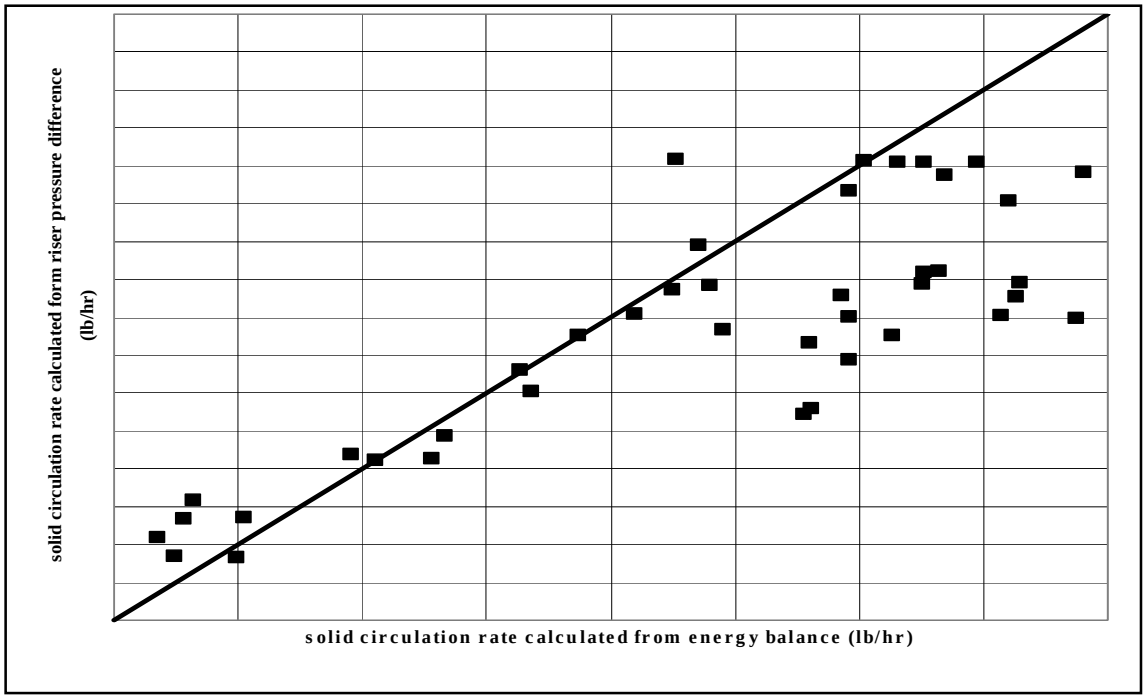


Figure 5.2-31 Comparison of Solid Circulation Rates Calculated From Energy Balance and Pressure Difference for Test Period November 19 to 20, 1996

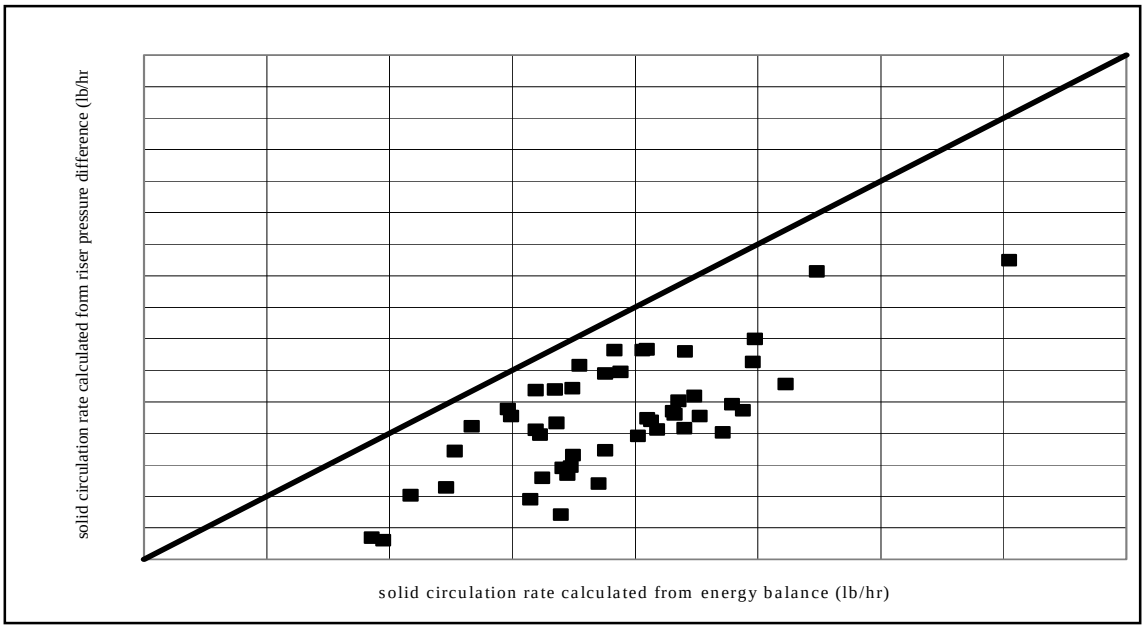


Figure 5.2-32 Comparison of Solid Circulation Rates Calculated From Energy Balance and Pressure Difference for Test Period November 20 to 21, 1996

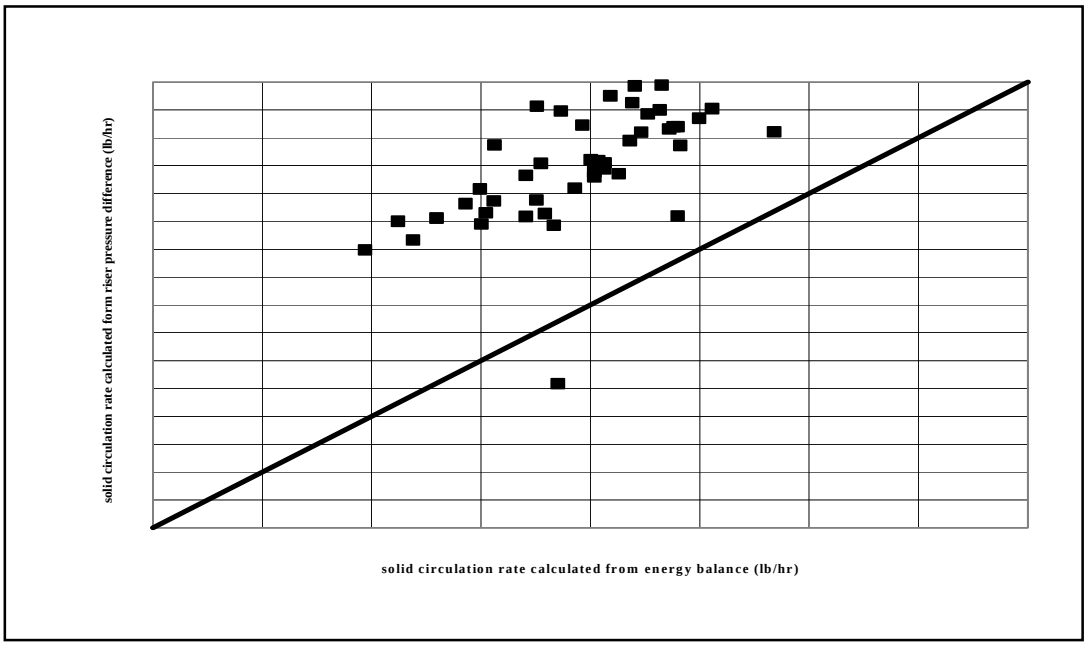


Figure 5.2-33 Comparison of Solid Circulation Rates Calculated From Energy Balance and Pressure Difference for Test Period August 20 to 21, 1996

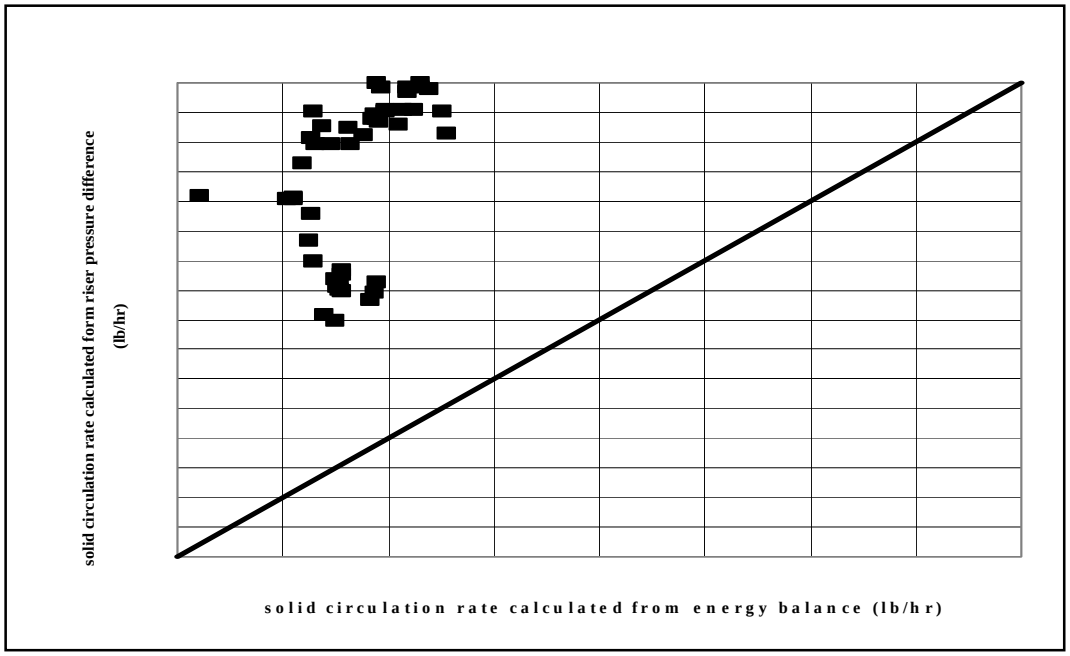


Figure 5.2-34 Comparison of Solid Circulation Rates Calculated From Energy Balance and Pressure Difference for Test Period August 19 to 20, 1996

6.0 COMMISSIONING OF WESTINGHOUSE PARTICLE FILTER SYSTEM

6.1 WESTINGHOUSE FILTER SYSTEM

6.1.1 1996 PCD Overview

Since this was the start-up and commissioning of the MWK transport reactor and the Westinghouse PCD it was a very challenging year. As with most plant start-ups there were some successes as well as some fairly dramatic setbacks. However, for all involved, 1996 was a year of learning and gaining experience with the equipment at the PSDF.

Overall, the PCD operated for a total of 994 hours in 1996 (figure 6.1.1-1). For approximately 226 of those hours the PCD was filtering coal derived flue gas. The operating temperature of the PCD during 1996 was relatively cool for a combustion system. The primary reason for the low PCD temperature was the start-up of the filter in a "safe" operating regime while commissioning the transport reactor. Typically, while burning coal the PCD temperature ranged between 550 and 650°F. The maximum temperature for the PCD this year was 853°F, which occurred during a transient in the first coal fire on August 18.

By far, the biggest challenge for the PCD operating staff has been learning how to reliably estimate the level of ash in the PCD cone. During the August coal firing the PCD accumulated ash to a degree where the entire lower level of filter elements was buried in ash and the upper level was partially buried. This resulted in the breakage of 77 of the 91 filter elements. Even though these elements were "used" filters from Tidd and installed for shakedown purposes it was a painful learning experience for the PSDF staff. From this experience an operating methodology has been developed which allowed for the successful monitoring of ash level during the remaining four runs of 1996.

The performance of the PCD was substantially different during the last fours runs than for the initial test runs. This was primarily due to the use of silica sand as the start-up bed material in the transport reactor instead of alumina. Particulate samples taken from the PCD hopper when using alumina typically had a mass median diameter of 10 micrometers. Once the start-up material was changed to silica sand the mass median diameter of samples taken from the hopper rose to around 200 micrometers. In addition to the large particle size the particulate loading from the transport reactor was well above design and was measured as high as 70,000 ppm. In spite of this there have been very few operational problems with the PCD. The baseline pressure drop has remained low and relatively constant throughout the four runs.

Southern Research Institute commissioned their batch sampling system on the PCD gas inlet line during the November coal run (CCT2C). Four samples were taken that produced particulate loading data consistent with estimates derived from ash removal

system data. However, the particle size distributions from the sampling system were substantially different than samples taken from the PCD hopper. This probably is due to the geometry of the PCD, and it is theorized that there is a mechanical separation within the filter vessel which biases samples taken from the hopper. Additional information gathered in 1997 should provide insight into this phenomenon.

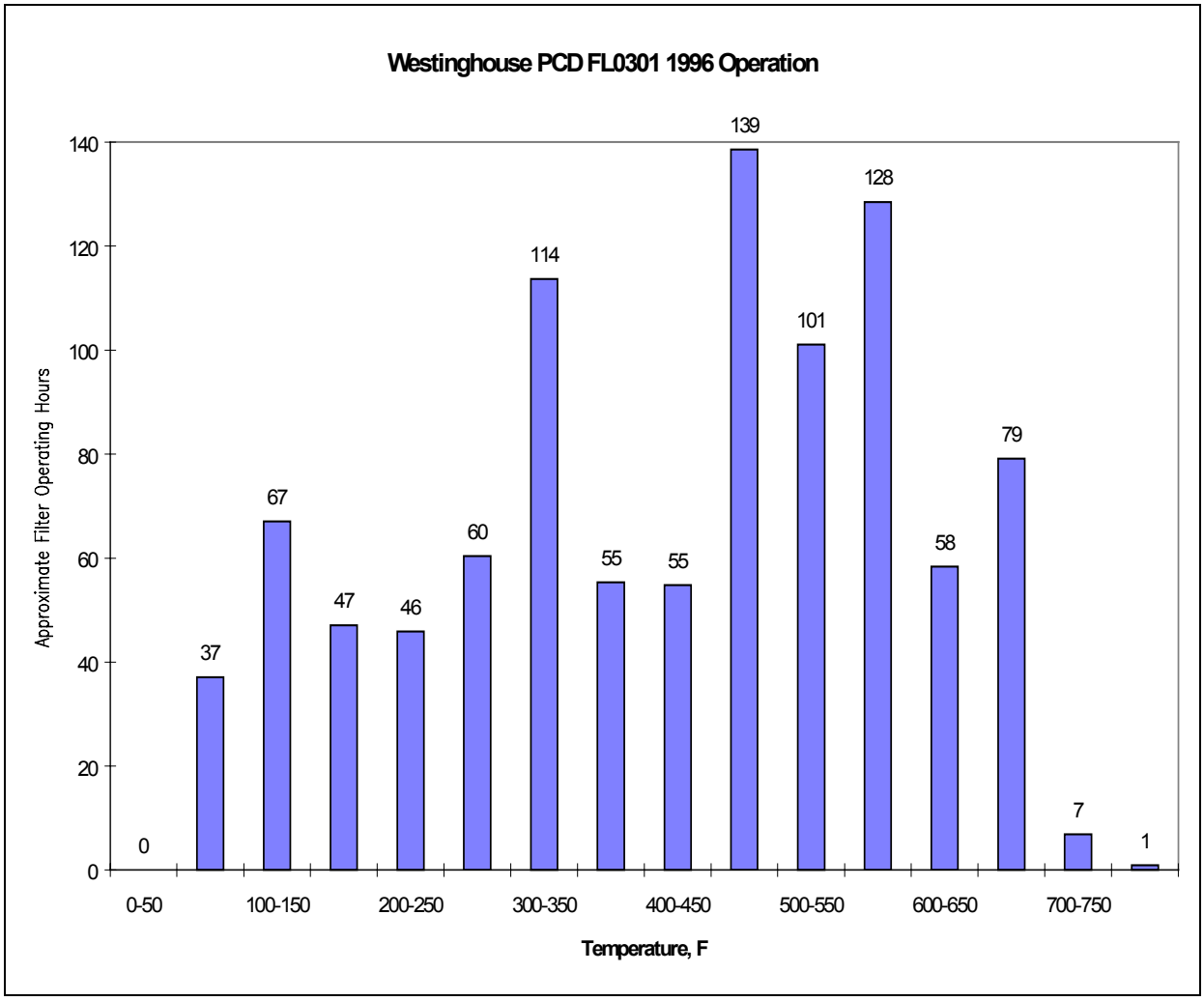


Figure 6.1.1-1 Operation Record for the PCD Over 994 Hours in 1996

6.1.2 Westinghouse PCD FL0301 System Description

6.1.2.1 General Description

The Westinghouse PCD (FL0301) is a high-temperature, high-pressure (HTHP) gas filtration system designed to remove fine particulate at gas temperatures up to 1,800°F. The filter system can operate in either a reducing or an oxidizing environment at pressures up to 300 psig.

A process flow diagram for the filter is shown in figure 6.1.2-1. The dirty gas enters the PCD below the tubesheet via stream 1. The dirty gas flows through the elements, and the ash collects on the outside of the elements. The clean gas passes from the filter elements through the plenum pipe to the outlet pipe (stream 3).

As the ash collects on the outside surface of the filter elements, there is typically a gradual increase in the pressure drop across the filter system. The filter cake is periodically dislodged by injecting a high-pressure gas pulse (stream 2) to the clean side of the filters. The cake then falls to the discharge hopper (stream 4).

The PCD system consists of two major components:

1. Filter vessel.

   The filter vessel is a code-stamped pressure vessel which contains the filter elements as well as the support mechanism for the filter elements.

   The filter vessel is designed to operate at pressures up to 300 psig at a gas temperature of up to 1,800°F. The particulate loading design basis is from 4,000 to 20,000 ppm.

2. Back pulse system.

   The pulse system consists of the pulse tanks, pulse valves, and associated piping to deliver the high-pressure pulse required to remove the ash from the surface of the filter elements.

   The back pulse system can operate at a pressure between 400 and 1,500 psig. The pulse valves are quick acting valves capable of opening and closing in as little as 0.2 seconds.

6.1.2.2 Filter Vessel

Figure 6.1.2-2 shows the general arrangement of the PCD pressure vessel and internals. Dirty gas from the transport reactor is fed to the PCD vessel through a 30-inch diameter internally insulated pipe. Gas enters the vessel through a tangential inlet nozzle, then flows in an annulus between the vessel wall and the shroud. The gas flows both upward and downward in the annular region outside the shroud and finally flows over the top and bottom of the shroud into the central filtration zone of the vessel. Dirty gas flows through the filter elements, depositing the particulate on the filter surface.

The filter elements are attached to one of two plenums (or levels) that support filter elements, collect the clean gas, and distribute the pulse flow. There are 55 candle-type filter elements attached to the lower plenum and 36 filter elements attached to the upper plenum. Each filter element has a series of gaskets to provide a dust-tight seal and there is a Westinghouse "fail-safe" device located above each filter element. The fail-safe is designed to plug with ash in the event of a filter element failure.

The clean gas flows from the plenum to the top of the filter vessel through the support tube. This tube is also used to convey the pulse gas from the pulse pipes to the filter elements. The pulse gas is used to remove the particulate (or filter cake) from the filter surface.

From the support tube the cleaned process gas flows into the top of the PCD where it leaves the vessel through the 26-inch diameter refractory-lined outlet pipe. The support tube is attached to the vessel tubesheet. The tubesheet provides a physical barrier separating the "dirty" and "clean" sides of the PCD. The Westinghouse tubesheet is designed with a double-cone expansion joint that provides a positive seal at a variety of operating temperatures.

As the particulate accumulates on the outside of the filter surface, the differential pressure will continually rise. Periodically, the cake of particulate is removed by a pulse of high-pressure gas generated by the pulse skid. This gas flows into the filter vessel through the pulse piping and is channeled to the individual plenums via the support tube. When the filter cake is removed from the filter, the cake falls to the bottom of the vessel where it is cooled and removed by an ash removal screw cooler and a lockhopper system.

The instrumentation for the filter vessel is relatively simple and consists primarily of:

- Differential pressure, measured in two places: across the tubesheet and from the gas inlet nozzle to the gas outlet nozzle. The differential pressure is used as part of the
- pulse logic to determine when the filter elements need cleaning and to monitor filter system performance.

- Thermocouples (several located within the filter system) that monitor gas temperature, the temperature of the expansion joint on the tubesheet, and the temperatures inside the plenum.

- Ash Level Thermocouples used to determine the level of ash in the PCD. These thermocouples are located at several locations in the bottom cone. By monitoring changes in these thermocouples, the ash level in the cone can be approximated.

In general the filter elements are cylindrical, having an outside diameter of approximately 2.5 inches and an overall length of about 60 inches. The filter element has an internal bore of approximately 1.5 inches. This bore is used to channel the cleaned gas from the filter surface to the plenum. The bottom of the filter element is plugged and the top is flanged for attachment to the plenum.

Filter elements are constructed from a ceramic or a metal alloy. The ceramic elements may be manufactured from a variety of materials including alumina/mullite, cordierite or silicon carbide. Metal alloys typically used include stainless steel, inconel alloys, hastelloy, and iron aluminide. Metal elements have superior strength but are limited by corrosion from sulfur and/or chloride compounds in the coal ash at high temperatures. Ceramic filter elements can operate at higher temperatures and more aggressive gas chemistries but are substantially weaker mechanically than metal elements.

6.1.2.3 Pulse Skid

The pulse skid is diagrammed in figure 6.1.2-3. This diagram illustrates the pulse system that supplies pulse gas to the lower plenum. There is an identical system for the upper plenum not shown in this drawing but which is parallel to and behind the system shown.

High-pressure air or nitrogen enters the pulse skid at pressures up to 1,500 psig. The pressure is reduced to the desired pulse pressure by a regulator located between the gas inlet and the pulse tank. The pulse gas is then stored in a tank of approximately 15 ft^3. Each plenum has a completely redundant system of isolation and pulse valving. The upper line is the primary supply and the lower line is the backup.

From the pulse tank, the pulse gas flows through two isolation valves (one automatic) and then through a high-speed pulse valve. The pulse valve is a Müller coaxial valve (VSV-F80) manufactured in Germany. This valve is designed to operate from fully open to fully closed in a fraction of a second. The high-pressure pulse then flows through the pulse piping to the filter vessel.

In the event of pulse valve failure, the lower backup system is used. The pulse system is supplied with a double block-and-bleed system to allow for the pulse valves to be safely removed and replaced during operation.

The pulse sequence is started by one of three methods:

- Manual Pulse: The plant operators have the ability to pulse the filter system at any time through a "push button" located on the DCS screen.

- High Filter ΔP Trigger: When the filter ΔP exceeds the "trigger" ΔP set in the pulse logic the pulse sequence is started.

- Time Trigger: A time "trigger" in the pulse logic is typically set at 30 minutes. Once the pulse system is activated the pulse sequence is initiated every 30 minutes. If the pulse sequence is activated before 30 minutes by the manual push button or the ΔP trigger the timer is reset.

Once the pulse sequence is initiated, the following events occur:

A. The pulse logic checks to make sure that the pulse pressure is greater than the system pressure. If not, the pulse will not occur and an alarm will sound on the DCS.

B. If the pulse pressure is okay, the automatic isolation valve for the upper plenum is opened. This valve contains limit switches which are used by the pulse logic to determine if the valve is opened. If not, an alarm is sent to the DCS.

C. Once the isolation valve is opened, the pulse valve fires for the preset duration. During 1996 this setpoint was 0.2 seconds.

D. The pulse logic checks the pressure in the pulse tank.

E. If the pressure did not fall below a certain level the logic assumes the valve did not open and sends an alarm to the DCS.

F. If the pressure does not rise above a certain level within a specified time the pulse logic assumes that the valve has failed open and sends an alarm to the DCS.

G. After the pulse event the isolation valve is closed.

H. The sequence is repeated for the lower plenum.

Currently, the backup pulse system is activated manually by changing a parameter in the pulse logic. There is a plan to make this swap-over an automatic part of the pulse control logic in 1997.

The pulse system has been operated with a high reliability in 1996. The only significant problem has been with the pressure control valves upstream of the pulse tank.

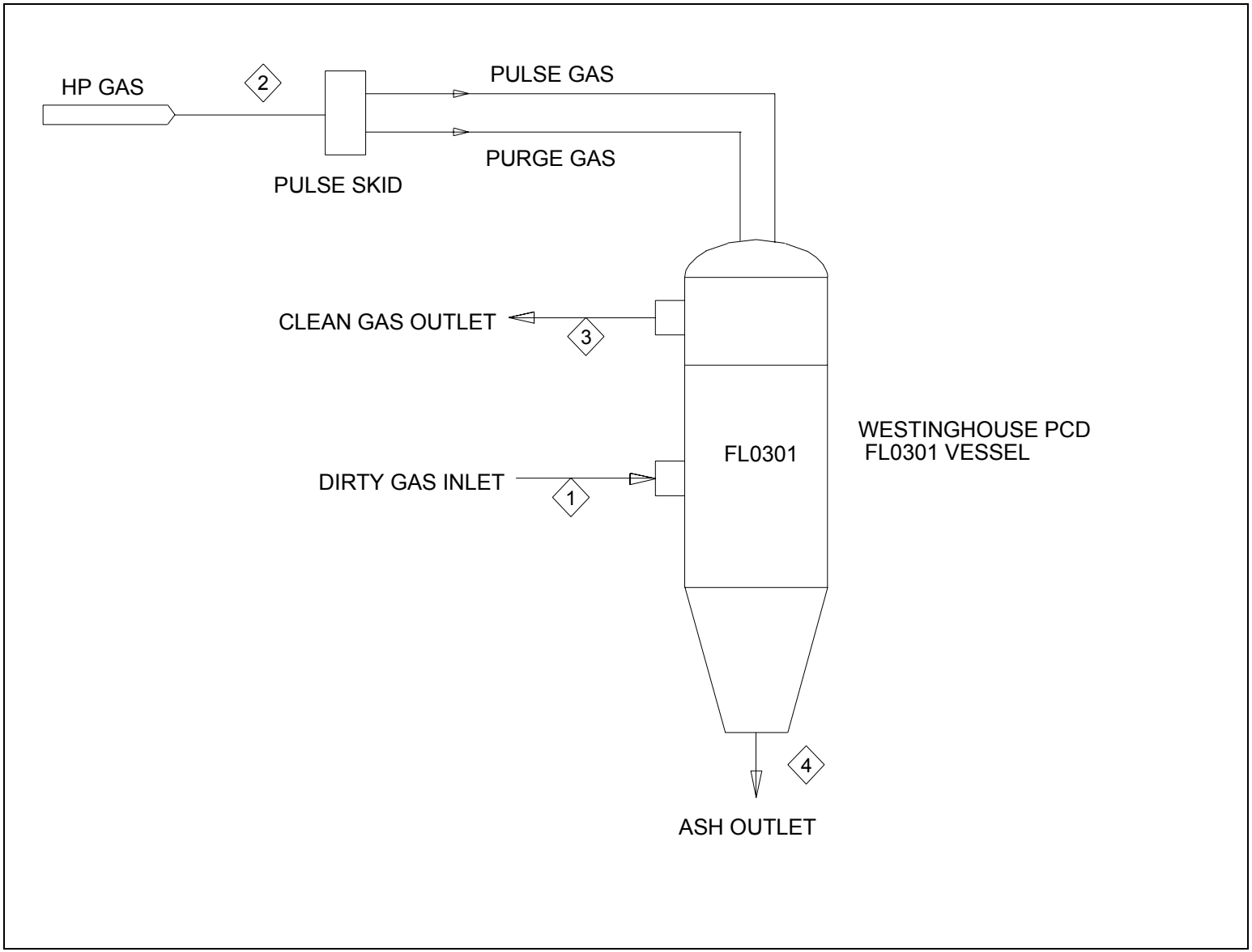


Figure 6.1.2-1 PCD Flow Diagram

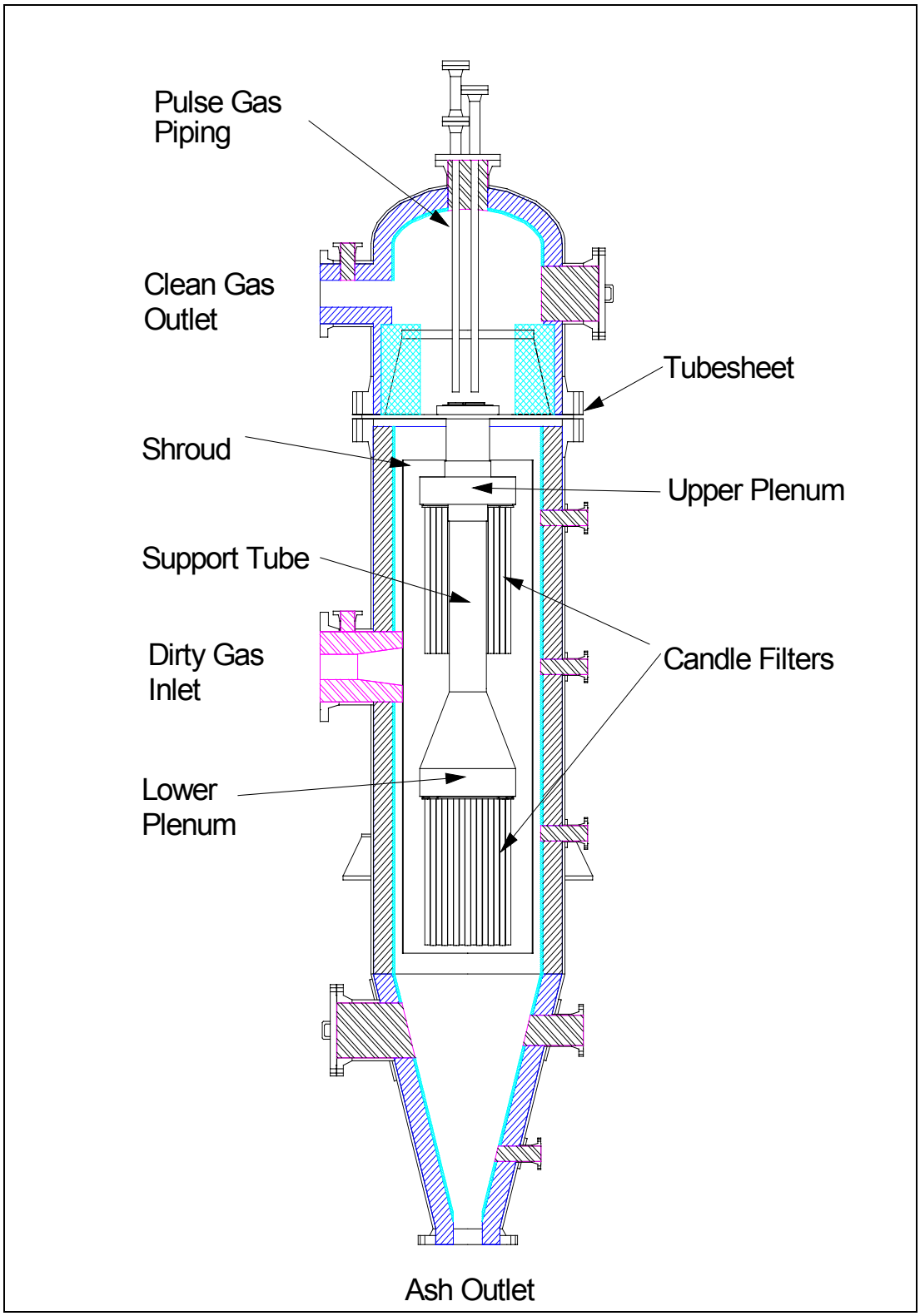


Figure 6.1.2-2 Westinghouse PCD FL0301 Filter Vessel

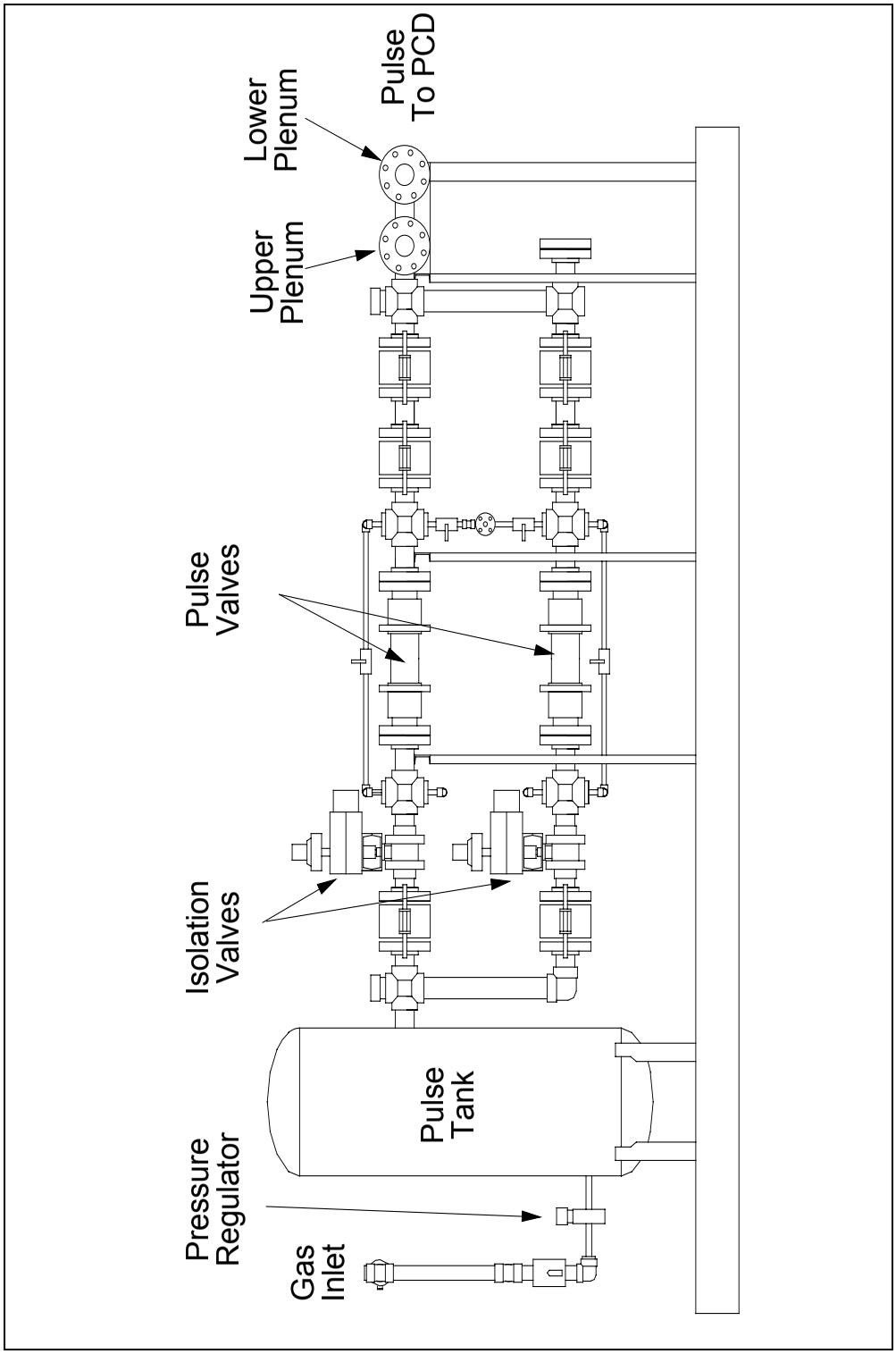


Figure 6.1.2-3 Westinghouse PCD Pulse Skid

6.1.3 Westinghouse PCD Installation

6.1.3.1 General

The filter vessel was installed into the structure in May 1995. Over the following 10 months the refractory lined inlet/outlet piping was installed as well as the pulse skid and its associated piping. However, the majority of installation activities occurred between March and June 1996. During that time the filter internals, filter elements, and the vessel instrumentation were installed.

Programming the pulse logic and commissioning of the pulse system occurred during the latter part of May and early June 1996. The biggest challenge was to convert the logic supplied by Westinghouse into "ladder logic" so that the Foxboro DCS could activate the pulse valves at the high speeds required.

6.1.3.2 Internals Installation

Installation of the filter internals and elements occurred the week of March 25, 1996. Westinghouse employees Zal Sanjana and John Meyers were present to assist and three employees from the Pinon Pines project were on site to watch since there are many similarities between the Westinghouse filter vessel at the PSDF and the vessel supplied by Westinghouse for Pinon Pines.

The filter cluster was attached to the tubesheet by the construction staff. Overall, the installation was straightforward and uneventful. However, due to a misinterpretation of the drawings supplied by Westinghouse, the filter cluster was installed 90° from its correct orientation. This required minor modifications to the piping connecting the pulse skid with the filter vessel. Additionally, the pulse logic had to be modified because the piping modifications required reversing the pulse sequence.

6.1.3.3 Filter Element Installation

Once the internals installation was completed, the filter elements were installed by the PSDF maintenance staff. Installation of the 91 filter elements took about a day and a half for five maintenance workers.

All maintenance work on the filter internals is performed on three temporary platforms installed in the maintenance bay (see figure 6.1.3-1). The platforms are attached to the structure with four pins. When they are not in use, two pins are removed and the other two act as a hinge so that the platforms can be "folded" out of the way to the side of the maintenance bay. This greatly reduces the amount of time required to install the platforms.

The "normal" sequence of events for installing the filter elements is as follows:

A. Lower the maintenance platforms into position and install the handrails.

B. Remove the instrumentation attached (both inside and outside of the filter head).

C. Unbolt the 26-inch refractory lined elbow at the gas outlet and lift it to the platform at elevation 218.

D. Remove the pulse piping between the pulse skid and the filter vessel. Also, remove the platform above the filter vessel at elevation 218 and store it at elevation 218.

E. Remove the 80 flange bolts holding the PCD head.

F. Once everything is disconnected, remove the PCD head and store it at elevation 218.

G. Lift the tubesheet and filter cluster from the PCD vessel and set it down on the maintenance platforms.

H. Once work required is completed, the process is reversed for installation.

The entire process, from the initial lifting of the maintenance platforms to lowering them at the end of the job, requires all five maintenance workers for about five 8-hour days.

6.1.3.4 Pulse Logic Checkout

For the Foxboro DCS to operate the pulse valves at the high speeds required, the logic supplied by Westinghouse had to be converted to "ladder logic." The logic required to pulse the primary valves was relatively straightforward. However, as mentioned in the system description report, there is a backup valve for each primary pulse valve. The intention of the logic was to automatically swap over from the primary pulse valve to the secondary pulse valve if a failure of the primary valve is detected.

Implementing this detection scheme using "ladder logic" proved to be a challenge and was deferred until 1997. Currently, if the pulse logic detects a pulse valve failure it registers an alarm on the DCS. In order to swap over to the backup valve one parameter in the pulse logic must be manually changed.

Confirmation of this logic occurred during the month of June. Overall, the pulse skid worked reliably for the first year of testing. No problems were experienced with the pulse valves in 1996.

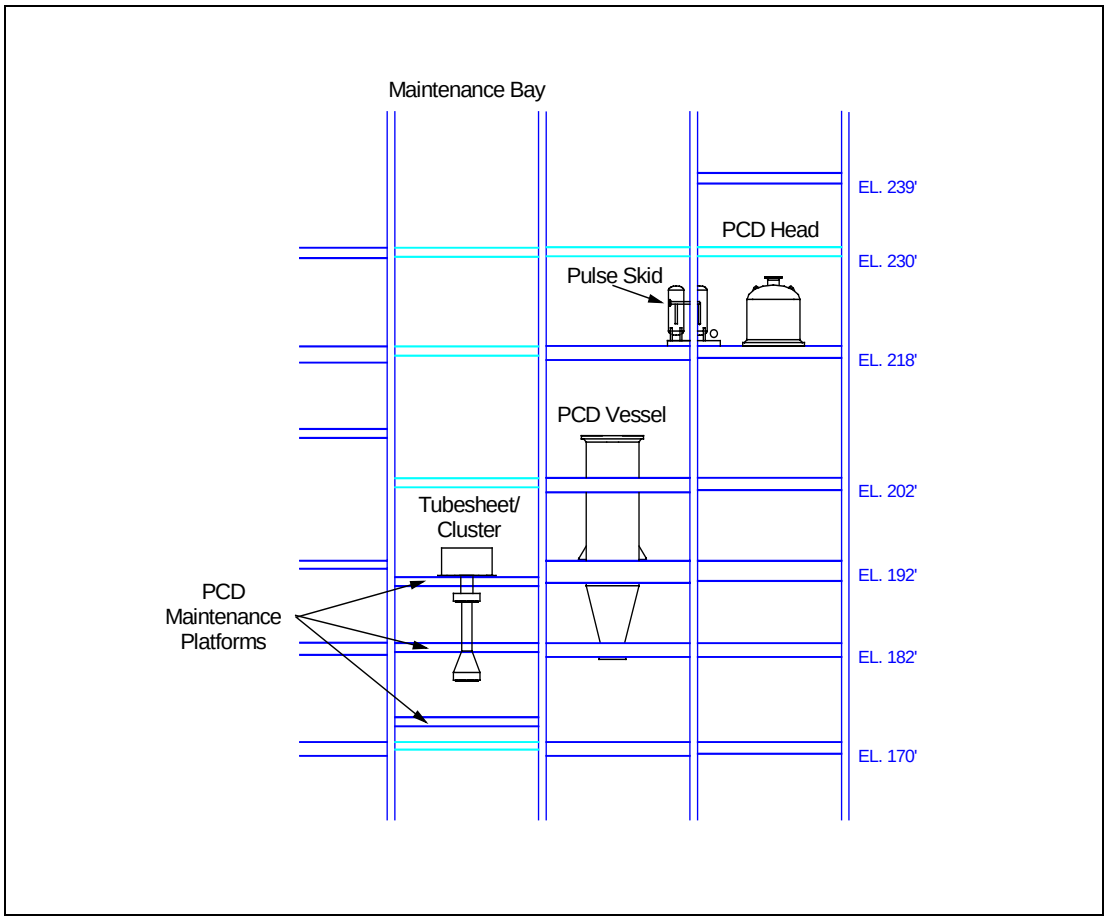


Figure 6.1.3-1 PCD Maintenance Bay

6.1.4 Candle Layout #1

All of the filter elements for the initial operations of the Westinghouse PCD were used candle filters from the Tidd Project. These elements had been cleaned by Westinghouse and some qualification of the elements had occurred prior to their shipment to the PSDF. The initial installation of the filter elements occurred the week of March 25, 1996.

Of the 91 filter elements installed, 90 were Pall 442T elements and one was a Schumacher F40. It was installed on the bottom level of elements, at tubesheet ID #32 (figure 6.1.4-1, bottom plenum). Four elements were shipped to the PSDF by DOE to support an ongoing project with Dr. Roger Chen at West Virginia University. Due to poor packaging, two of these elements arrived broken. The decision was made to not install the other two elements since they were possibly also damaged during shipping.

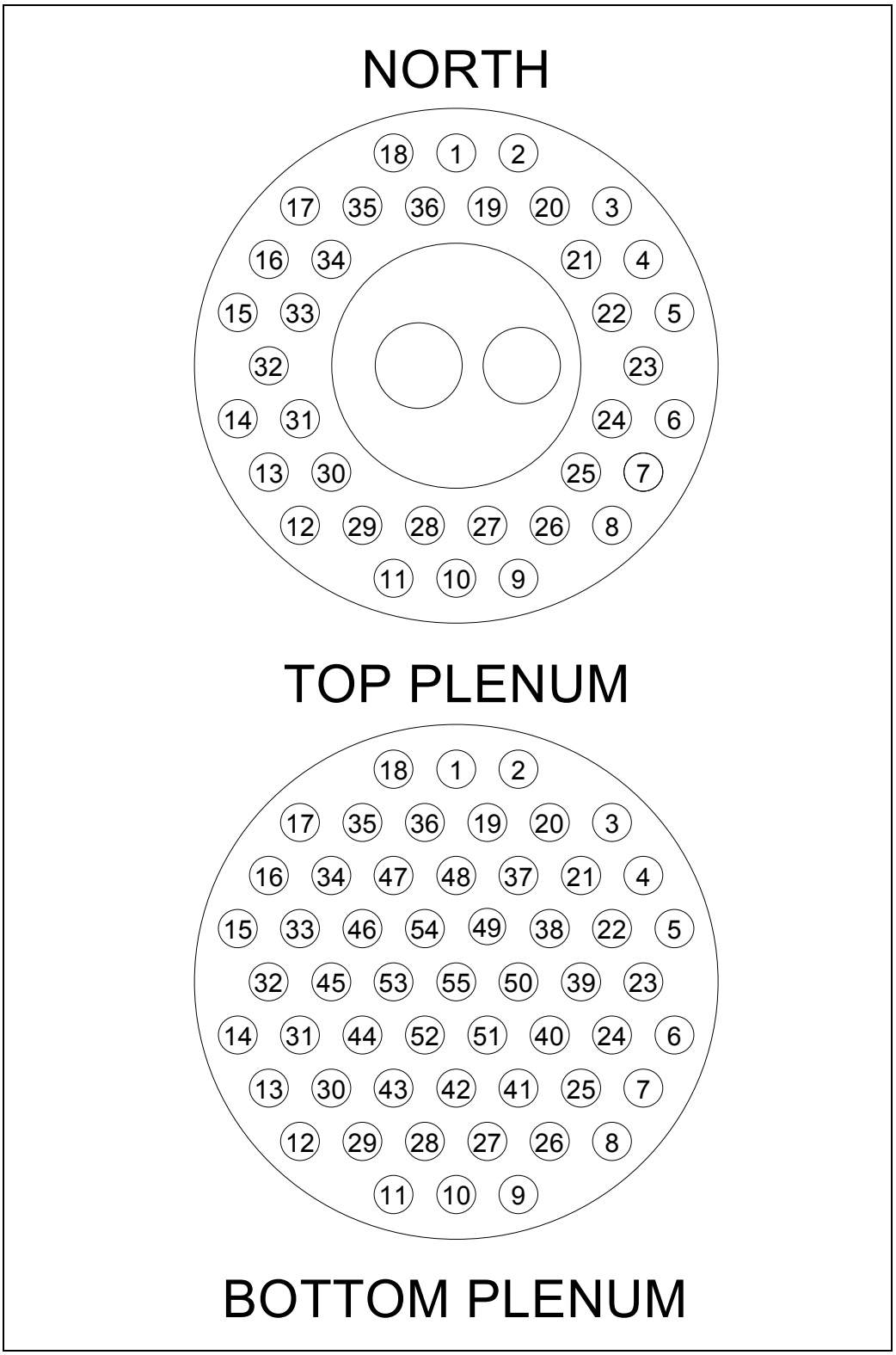


Figure 6.1.4-1 FL0301 Tubesheet Map

6.1.5 Westinghouse PCD Gasket

Most filter systems (whether gas or liquid) contain some type of tubesheet which supports the filter elements and separates the "dirty" side from the "clean" side. The Westinghouse PCD is no exception. The filter elements are arranged in two levels as shown in figure 6.1.5-1. The elements are attached to a tubesheet at each level, with a plenum above each tubesheet to collect the cleaned gas from the individual filter elements. The tubesheets are supported by a central pipe which provides mechanical support and is a conduit for the cleaned gas to ultimately flow out of the filter vessel. This central pipe is in turn supported by a tubesheet which is "clamped" between two 84-inch flanges welded to the cylindrical body of the filter vessel.

The mating surfaces between the tubesheet and the 84-inch flanges are part of the filter system pressure boundary and have proven to be challenging to seal. The pressure boundary consists of five components; the two 84-inch vessel flanges, the tubesheet, and two gaskets as shown in figure 6.1.5-2.

The original gaskets installed during the assembly of the vessel in March 1996 were Flexitallic spiral wound gaskets. Flexitallic gaskets are fabricated of two major components, the spiral wound gasketing material, and an integral metal gauge ring. The gauge ring is primarily for support of the gasketing material. Since it is thinner than the gasket, it also serves as a maximum compression limit. Based on the size of the flange and the operating pressure and temperature, the gasket had an inside diameter (ID) of $88^{3}/_{8}$ inches and an outside diameter (OD) of $90^{1}/_{8}$ inches. The metal gauge ring OD was 91½ inches. Due to its large size, the gasket was stored upright.

The 84-inch flange is sealed with 80 studs which each have a diameter of $1^{5}/_{8}$ inches. Maintenance personnel initially torqued the bolts to 1,100 ft-lb, as specified by the manufacturer. The bolts were torqued with a single Hytorq hydraulic wrench. A pattern for torquing the bolts was used so that the load could be applied uniformly. The load was applied in multiple passes so that on the last pass the full load was applied.

The initial pressure test for the filter vessel was on July 14, 1996. The pressure inside the filter was 50 psig when the flange was tested for leaks. When checked, it leaked profusely, especially on the northwest side. (See figure 6.1.5-3 for vessel orientation.) Maintenance increased the torque on the bolts to 1,600 ft/lb, and ultimately to 2,200 ft/lb, but still the vessel would not seal. At 2,200 ft/lb torque, the gasket had collapsed against the metal gauge ring, so it was not possible to apply a higher load to the gasket. Also, the final load was near the maximum tensile strength for the bolts, so it was decided to shutdown to inspect the vessel.

Westinghouse employees Zal Sanjana and John Meyers visited the job site for inspection. Several discussions were held and the following was learned:

- When the vessel was fabricated and hydrotested as part of its ASME Section VIII certification, the tubesheet was not in place. This was the first time the entire pressure boundary had been tested. This was a normal Westinghouse procedure and had not presented problems on other jobs.

- Unlike the pressure vessel supplied for the Tidd project (and the large Westinghouse vessel supplied for the PSDF Foster Wheeler unit) no provisions had been made for seal welding this filter vessel to provide a pressure boundary.

- Laser-based measurements of the flanges to determine flatness was suggested. However, this was impractical because it would be impossible to check the tubesheet due to its construction. Also, the vessel head would have to be lowered to the ground and flipped over so that the flange was at the top. Since the vessel head weighs over 11 tons, it was decided to inspect the vessel first for obvious problems.

- Flexitallic was consulted to provide information about flange flatness requirements, surfacing, etc. Arrangements were made to bring a Flexitallic engineer from Houston to look at the vessel but schedule conflicts prevented his visit. Flexitallic recommended using 40-bolt tensioners instead of the Hytorq to apply the sealing load. It was decided to consider this only as a last resort due to the very high cost of purchasing the equipment or having a company provide the service.

The bolts were removed on July 16; a gap was visible at the top of the tubesheet on the northwest side. This gap was near one-eighth of an inch in places. Also, the metal gauge ring on the gasket was found "notched" in several places where it had been sheared by the bolts as the load was being applied. The OD of the backing ring was essentially the same as the ID of the bolt circle, meaning that if the gasket was perfectly round, it would just touch the bolts. This "notching" was not uniform around the circumference of the gasket and was more pronounced on the northwest side of the gasket. In addition, it was apparent that the gasket was elliptical and not perfectly round. As mentioned previously, this gasket had been stored upright in the warehouse due to space restrictions and became elliptical over time.

It was discovered that the gaskets were of two different thicknesses. When the gaskets were ordered, only the inside and outside diameters of the gasket and the OD of the backing ring were specified. The OD of the gasket is $90^{1}/_{8}$ inch, and according to Flexitallic's sales literature, a gasket smaller than 90 inches would have a thickness of 0.175 inches, and a gasket larger than 90 inches would have a thickness of 0.25 inches. When the history of the gaskets was checked, it was determined that they were ordered at two different times. Apparently, when the factory received the orders different gasket thicknesses were supplied.

The vessel head and tubesheet were removed and then reassembled without the gaskets. Upon close investigation it was noticed that the refractory lining inside the vessel head protruded slightly (less than one-eighth of an inch) beyond the flange and prevented the head from sitting flat on the tubesheet. The head was removed and the refractory ground flush.

The local Flexitallic representative visited the job site and recommended trying a Garlok 3125SS gasket. This was considered for a while, but it could not be supplied in a one-quarter inch thickness within 2 weeks. Because there was another set of Flexitallic gaskets in the warehouse, it was decided to use them again. Several of the mechanics had successfully used a high temperature silicone caulk in the past on large flanges in steam turbines, so it was decided to place a bead of the caulk on all four gasket surfaces. The vessel was put back together and a load of 1,600 ft lb torque was applied in five passes (20 percent of the load on each pass) with a single head Hytorq wrench. The vessel was pressure tested on July 21 and the flange slightly leaked at 180 psig. It was decided to proceed with test run CCT1A and limit the operating pressure to 160 psig.

During the CCT1 test series, a set of gaskets (Garlok 3125SS) was ordered for the next installation. The gaskets had an OD which matched the OD of the tubesheet (so it would not engage the vessel bolts) and was 2 inches wide. Garlok 3125SS is a very soft graphite material and it was believed that it would "flow" into any imperfections in the flange surface and seal better than the Flexitallic. Because of the size of the gasket and the nature of the material it was supplied in five segments with the individual segments joined by a dovetail.

Maintenance lead the effort in determining the advantages/disadvantages of Hytorq vs. multitensioners. Apparently, Phillips Petroleum had performed a study which found no apparent advantage of one system over another. Therefore, it was decided to modify the Hytorq system currently owned by the PSDF so that four torque heads could be used simultaneously.

During CCT1C the filter vessel was filled with ash and 77 of the 91 filter elements were broken. When the head was removed from the vessel, there was significant corrosion on the tubesheet surfaces and on the upper manway door. The corrosion was removed with wire brushes, treated, and the Garlok gasket installed. The manufacturer recommended strongly against using a silicone caulk so none was used. The Garlok gasket was much simpler to install than the Flexitallic gasket. Because of the large diameter and thinness of the Flexitallic gasket it took eight people to place it without bending. Since the Garlok gasket is installed in five segments and joined by dovetails, it could be installed by two employees.

The manufacturer recommended a torque of 900 ft/lb (which was used) even though based on the Flexitallic experience there was skepticism that it would seal. There was also some

concern about whether or not the dovetailed joints would leak. The bolts were torqued with the four-head Hytorq in multiple passes to the manufacturer's recommendations. The vessel was pressure tested; there was a small leak at one of the dovetailed joints at 300 psi. The torque was increased to 1,100 ft/lb and the vessel joint held to 330 psi.

To minimize the corrosion on the manway doors, the maintenance crew installed a solid disc of Garlok 3125SS. This has worked extremely well, and during an inspection in December 1996 there was no corrosion found on the doors. For the tubesheet, the next set of Garlok gaskets ordered were $4^1/_2$ inches wide. This is much wider than required for the pressure rating, but it will entirely cover the exposed metal surfaces and help prevent corrosion.

It is unknown why the Flexitallic gasket was unable to seal the filter vessel. Both maintenance and the PCD team have considered attempting once more to use the Flexitallic gaskets with the four-head Hytorq wrench to see if it will successfully seal. However, this is difficult to justify because the Garlok gasket has the following advantages over the Flexitallic:

- At least in this application, the Garlok gasket sealed successfully and the Flexitallic did not.

- As mentioned, the Garlok gasket is much easier to handle and install.

- Because it is segmented, the Garlok gasket can be stored in a fraction of the space. (A separate storage facility for the gaskets for this vessel and the FL0352 vessel (120-inch flange) had been designed and was about to be constructed, which would have allowed for horizontal storage of the gaskets to prevent them from becoming elliptical. Construction of this facility has been canceled, which saved the project several thousand dollars.)

- A 4 1/2-inch wide Garlok gasket 1/4-inch thick costs less.

At least for the near term, there are no plans to use Flexitallic gaskets on any of the large (>60-inch) flanges for the PCDs. The largest flange on the Foster-Wheeler combustor PCD (FL0352) is 120 inches in diameter. This vessel is designed to be seal welded to provide a pressure boundary, but at this time it is believed that this vessel can be adequately sealed using only the Garlok gaskets.

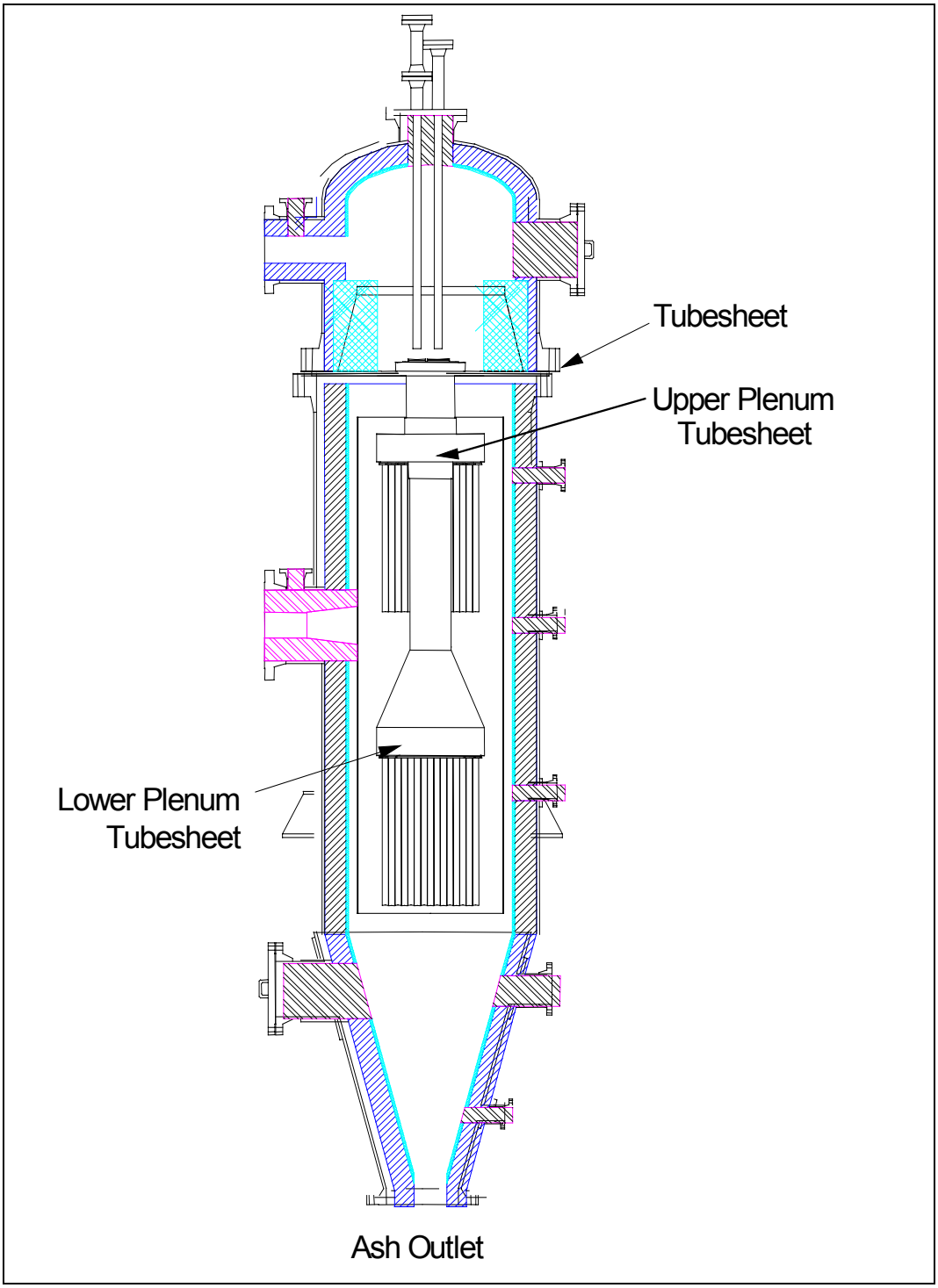


Figure 6.1.5-1 Westinghouse PCD FL0301

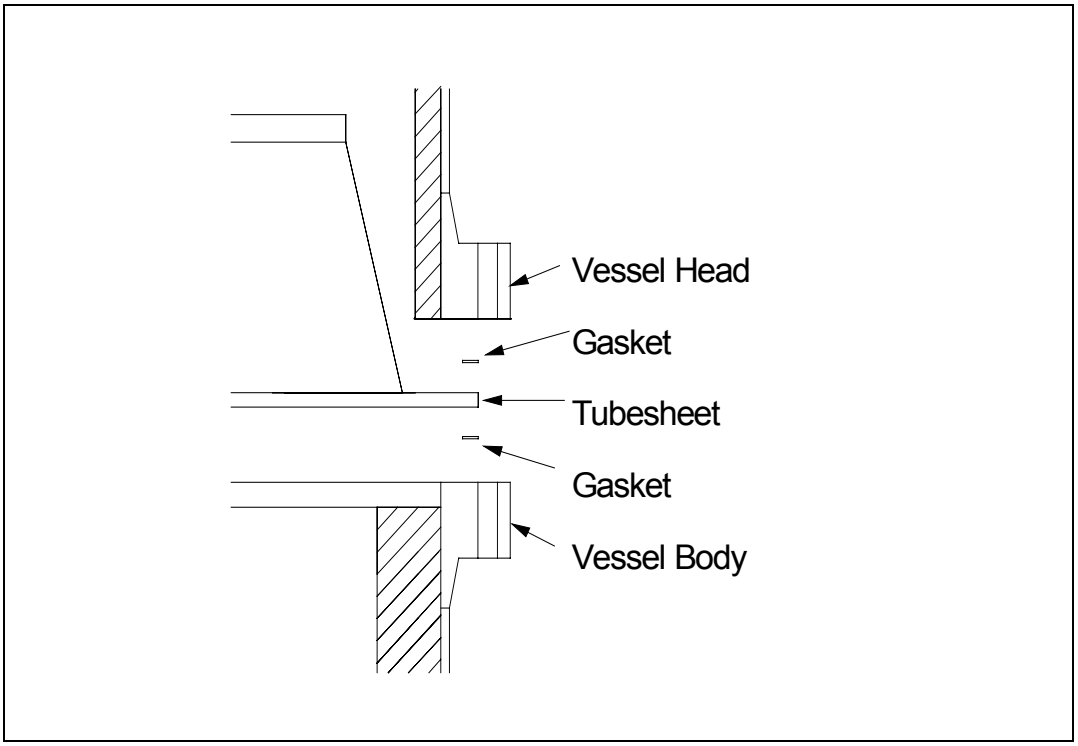


Figure 6.1.5-2 Westinghouse PCD FL0301 Gasket Details

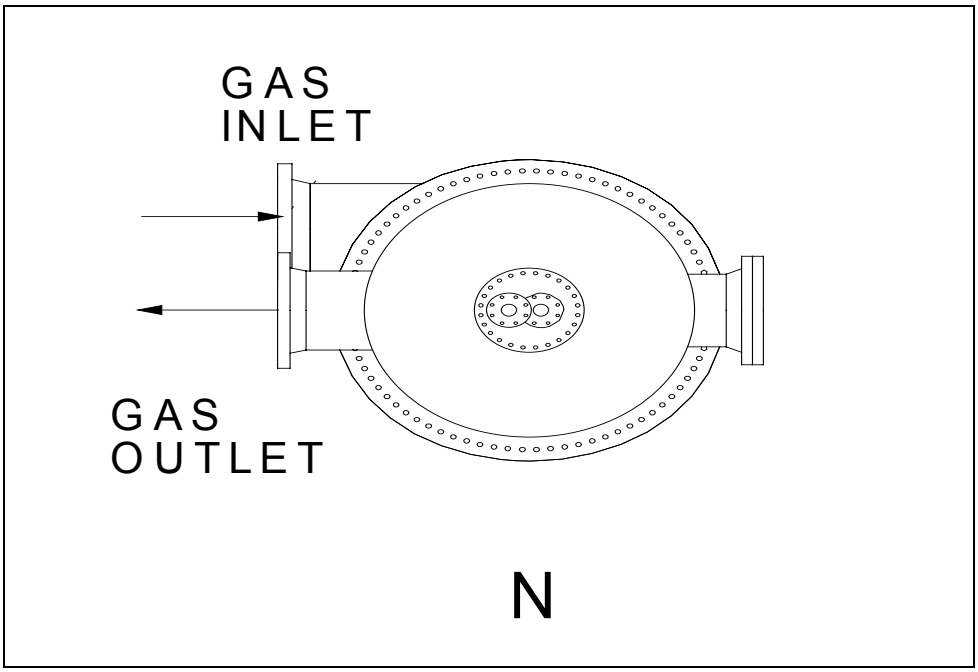


Figure 6.1.5-3 Westinghouse PCD FL0301 Orientation

6.1.6 Test Run CCT1A

6.1.6.1 Summary

CCT1A was the initial run for the Westinghouse PCD (FL0301.) The test lasted from July 22 to July 26, 1996. Because this was the initial test run with both the PCD and the transport reactor (TR) connected, the first part of the test concentrated on circulation of alumina within the TR to evaluate the interactions of the two systems. On July 24 coke breeze was added to the TR in an attempt to begin combusting solid fuel. However, due to low thermal input from the start-up burner the temperature in the TR was too low to burn the coke breeze. Ultimately, the test ended for two reasons: the ash removal screw conveyor for the TR jammed and the start-up burner plugged (due to the formation of deposits).

Overall, the performance of the PCD was fairly stable. The maximum temperature reached was 550°F and the operating pressure throughout the run was approximately 60 psig. The filter face velocity during the run was about 6 ft/min, and the filter baseline pressure drop was typically 40 inWG. The pulse pressure for the run was set at 450 psig and the pulse ΔP trigger varied from 50 to 100 inWG. In addition to the ΔP trigger, the pulse system automatically pulsed every 30 minutes. The rate of increase in the filter ΔP was typically a function of circulation rate in the TR. If the circulation rate was low (or stopped) the ΔP rise between pulses was small. However, at high circulation rates, the filter ΔP would rise from the baseline pressure drop to the trigger pressure drop within the 30-minute interval between pulses.

On July 25 and 26 the atmospheric baghouse ΔP increased to the point where it pulsed three times. Ash samples removed from the baghouse appeared to be fine and gray in color and became progressively darker with time. At that point there was concern about a leak/breakage within the PCD. The PCD was inspected on July 30 and no problems were discovered. Ultimately, it was discovered that the majority of particulate was probably alumina remaining in the piping from previous circulation tests before the PCD was installed. The dark color was due to coke breeze from the feeder system vent.

Test conditions for this run are listed in tables 6.1.6-1 and -2. Data from this run are shown in figures 6.1.6-1 and -2.

6.1.6.2 Test Objectives

The primary test objective was to support the TR/PCD start-up activities and gain experience operating the PCD. The only PCD-related objectives were to complete typical "shakedown" activities (varying the pulse ΔP trigger, checking out the pulse logic and instrumentation, etc.); there were no PCD-specific test objectives.

6.1.6.3 Observations/Events

The following sections refer to numbers in the graphs found in figures 6.1.6-1 and –2. Refer to table 6.1.6-2 for related information on the following observations and events.

A. Start-up/PI System Restarted - July 22 at 14:00. The system was pressure tested up to 330 psig from July 19 through 21. There were two small leaks in the 84-inch PCD flange at 185 psig, so the decision was made to limit the operating pressure for the test to 150 psig.

   At 07:40 the balancing of all the pressure transmitters was completed and steam flow started to the primary gas cooler to begin warming the PCD. The PCD backpulse system was started at 16:40 with a pulse ΔP trigger of 50 inWG.

   The PI system had been "down" most of this time period. The system began recording data at 14:00 on July 22.

B. PCD Ash Removal System Plugged - July 23 at 05:30. At 05:30 on July 23 the PCD ash removal dense-phase system (FD0520) tripped due to a piece of refractory plugging the outlet conveying line. The reactor was depressurized so that maintenance could safely remove the pluggage. The ash removal system was operational by 15:30.

   Even though the TR was depressurized, there was a slight flow of air into the system to keep the nozzles and instrumentation from plugging. This air flow was sufficient to carryover enough particulate to the PCD to cause a rise in the filter ΔP. Because of plant safety procedures, the pulse system was also depressurized while maintenance was working on the FD0520 system. By 13:00 the ΔP had reached about 70 inWG, so the air flow to the TR was reduced.

C. Pulse System Restarted - July 23 at 15:50. Once maintenance had completed their work, the pulse system was repressurized and put back into operation.

D. Transport Reactor Main Burner Lit - July 23 at 21:00. The TR pilot was lit at 17:40 and the main burner lit at 21:00.

E. TR Circulation Started - July 24 at 00:30. Circulation was initiated in the TR at 00:30 on July 24. There was a rise in the filter ΔP as fine alumina was carried over to the PCD.

F. TR Circulation Stopped - July 24 at 05:20. Several times throughout the run the TR circulation rate was stopped (or reduced) and then restarted. This happened for a variety of reasons, but the response of the PCD to the change was consistent. Whenever the TR was circulating solids, the filter ΔP would typically rise from the baseline ΔP of about 40 inWG to the pulse ΔP trigger before the pulse system was activated by the 30-minute timer. If the TR was not circulating solids, the rise in filter ΔP would be very small over the 30-minute pulse interval.

G. PCD Pulse ΔP Trigger Raised to 75 inWG - July 24 at 12:30. At two occasions in the run, July 24 at 12:30 and July 25 at 18:30, the pulse ΔP trigger was changed. The primary reason for this change was to verify that the pulse logic was working correctly.

H. TR Circulation Started - July 24 at 15:20.

I. Coke Breeze Batch Fed to Transport Reactor - July 25 at 01:10 until July 26 at 04:30. From 01:10 on July 25 until 04:30 on July 26 several attempts were made to burn coke breeze in the TR. At that time, the thermal input from the start-up burner was not sufficient to heat the TR to a temperature where the coke breeze would ignite. Typically, the circulation was minimized to maximize the temperature in the TR in hopes that the coke breeze would ignite. After a period of time, the circulation was restarted to minimize temperature differentials throughout the system. Throughout this period there were several events when the circulation was minimized, stopped, or restarted for this reason.

J. TR Circulation Stopped - July 25 at 01:50.

K. TR Circulation Started - July 25 at 03:20.

L. TR Main Burner Tripped - July 25 at 05:55.

M. TR Circulation Decreased - July 25 at 09:40.

N. PCD Pulse DP Trigger Raised to 100 inWG - July 25 at 18:30.

O. TR Ash Removal Screw Jammed, Began Shutdown - July 26 at 15:30. The TR ash removal screw (FD0206) jammed and the decision was made to shut down by reducing the burner firing rate.

P. TR Main Burner Tripped, End of Test - July 26 at 18:05. While the temperature was being reduced, the burner tripped. The burner was difficult to restart, so the run was ended.

6.1.6.4 Analysis of Solid Samples

Only three samples were taken during the run. The first sample, taken on July 25 at 01:50, was very fine and almost pure white. When analyzed by the Microtrak, the sample had a mass mean particle diameter of about one micron. No chemical analysis was performed on the sample as it was assumed that the sample was fine alumina.

Two samples were taken on July 26, one at 01:00, and one at 06:25. The color of the samples became progressively darker due the accumulation of unburned coke breeze within the system. The 06:25 sample was essentially black. A loss of ignition (LOI) was performed on the two samples. The sample at 01:00 had a LOI of 5.2 percent and the sample at 06:25 had a LOI of 12.7 percent.

Both of the samples had a broad distribution of particle sizes ranging from 0.2 to 270 micrometers (probably due to the addition of the unburned coke breeze). The mass mean particle size of both of these samples ranged from 8 to 10 micrometers. Figure 6.1.6-3 indicates the mass mean particle size and the time the samples were taken. Figure 6.1.6-4 shows the particle size distributions (PSDs) for the three samples.

A chemical analysis was performed on the sample taken at 01:00 on July 26. The analysis of the ashed sample indicated that it was 95-percent alumina oxide with traces of calcium, iron, phosphorous, potassium, and silicon.

6.1.6.5 Run Outcome

Starting on July 25 the differential pressure in the process baghouse began rising, indicating the presence of solids. From July 25 to 26 the baghouse back-pulsed three times as shown in figure 6.1.6-5. (The "spikes" above the ΔP curve are due to an improperly tuned temperature control loop for the dilution air blower upstream of the baghouse. The controller would cause the fan inlet vanes to oscillate, causing an increase in flow to the baghouse and therefore an increase in ΔP.) There was a significant quantity of ash removed from the baghouse. The ash was dark gray in appearance and the LOI for the ash was about 1.0 percent. However, the PSD of the ash was significantly different that than of the ash removed from the PCD. As shown in figure 6.1.6-6, the mass mean particle diameter of the ash from the baghouse was approximately 25 micrometers, while the mass mean diameter of the PCD ash was 8 to 10 micrometers.

Initially it was assumed that there was a breech in the PCD. The upper manway door was opened on July 30 to inspect the clean (upper) side of the tubesheet. There was no dust present on any part of the tubesheet.

Due to the large PSD of the material in the baghouse, it is speculated that the "ash" was actually alumina which was left in the system from circulation tests conducted prior to the Westinghouse PCD commissioning. The gray color and the LOI of the material probably came from coke breeze that was carried over from the vent system on the coal feeder. This vent line discharged upstream of the system pressure letdown valve and the carryover of material through this line caused the failure of the pressure letdown valve during the next run (CCT1B).

Table 6.1.6-1

CCT1A Run Statistics

Start time	7/22/96 at 07:40
End time	7/26/96 at 18:05
Coal type	Coke breeze
Hours on coal	No sustained combustion
Sorbent type	No sorbent feed
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 $\pm$ 50 psi
Pulse DP trigger	Variable (50 inWG initially)

Table 6.1.6-2

CCT1A Major Events (Refer to Figures 6.1.6-1 and –2)

Event	Description	Date at Time
1	Start-up/PI system restarted	7/22 at 14:00
2	PCD ash removal system plugged	7/23 at 05:30
3	Pulse system restarted	7/23 at 15:50
4	Transport reactor (TR) main burner lit	7/23 at 21:00
5	TR circulation started	7/24 at 00:30
6	TR circulation stopped	7/24 at 05:20
7	PCD pulse DP trigger raised to 75 inWG	7/24 at 12:30
8	TR circulation started	7/24 at 15:30
9	Coke breeze batch fed to transport reactor	7/25 at 01:10 to 7/26 at 04:30
10	TR circulation stopped	7/25 at 01:50
11	TR circulation started	7/25 at 03:20
12	TR main burner tripped	7/25 at 05:55
13	TR circulation decreased	7/25 at 09:40
14	PCD pulse DP trigger raised to 100 inWG	7/25 at 18:30
15	TR ash screw jammed, began shutdown	7/26 at 15:30
16	TR main burner tripped, end of test	7/26 at 18:05

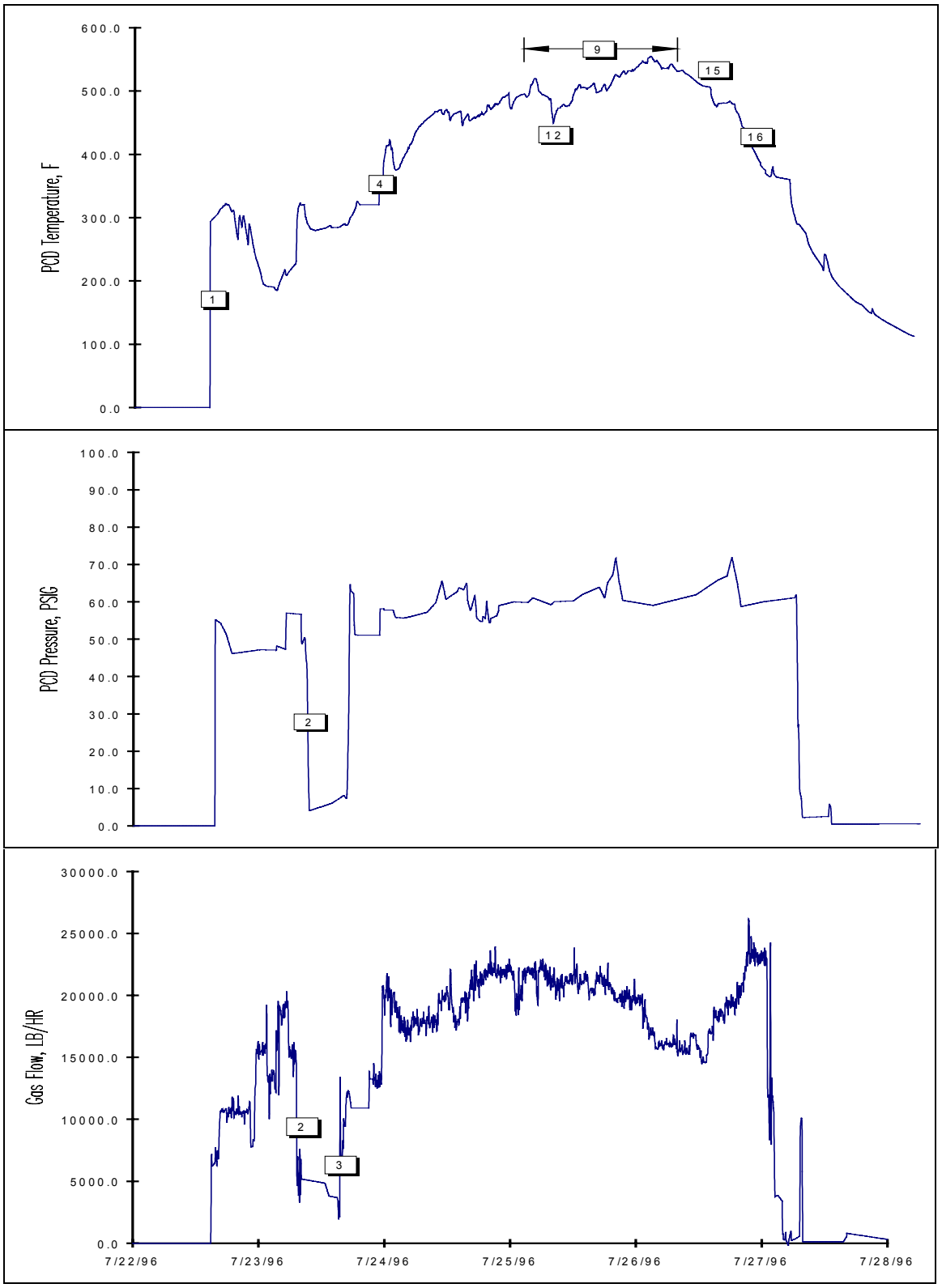


Figure 6.1.6-1 CCT1A Summary Information

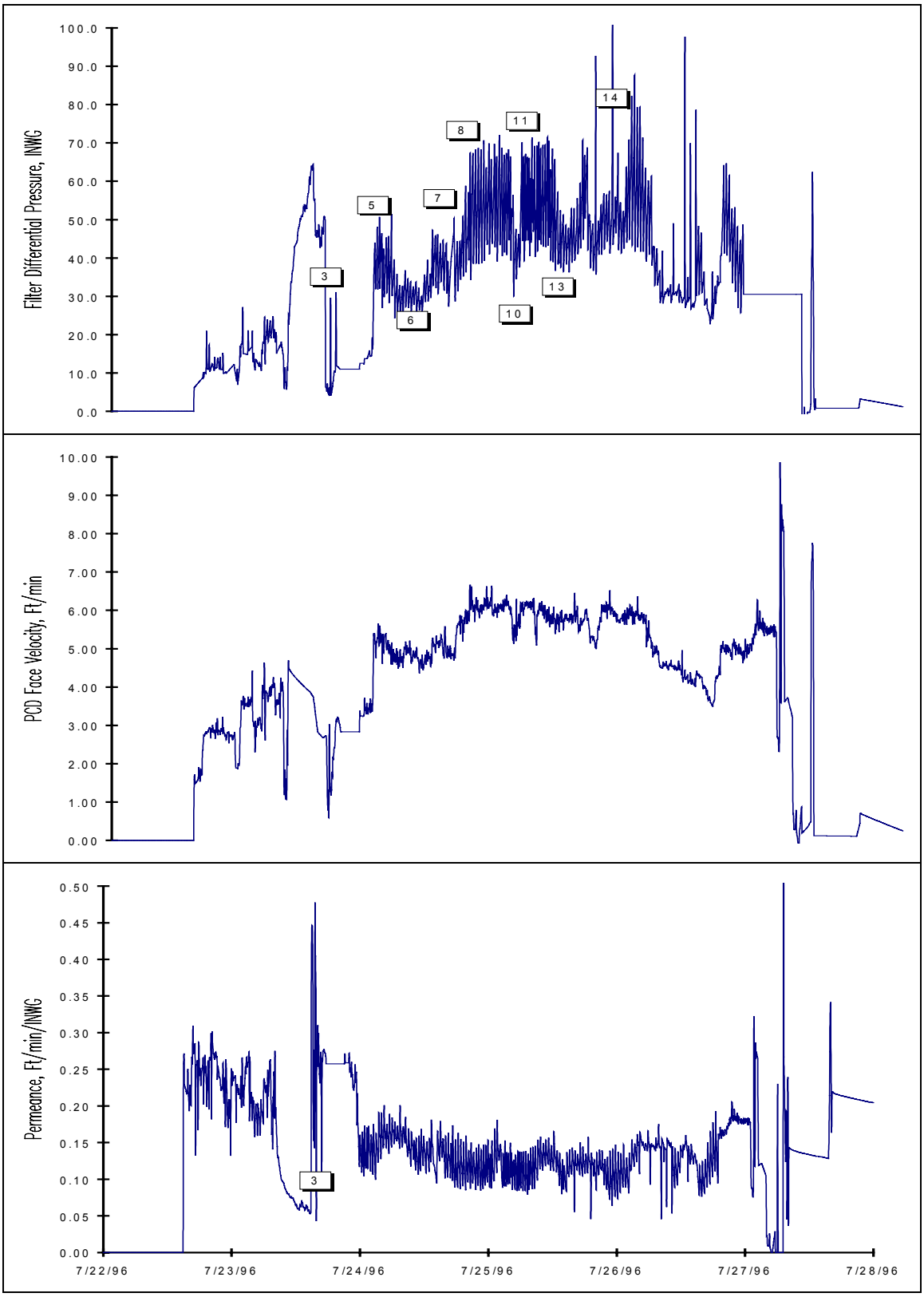


Figure 6.1.6-2 CCT1A Summary Information

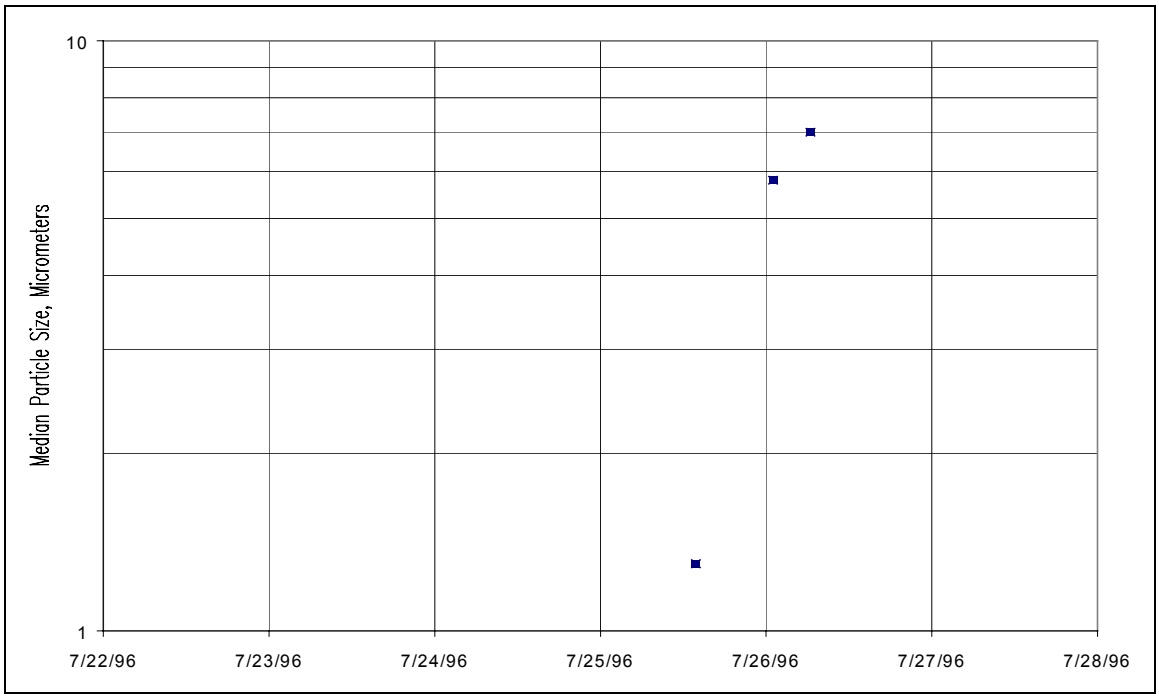


Figure 6.1.6-3 CCT1A PCD Hopper Samples

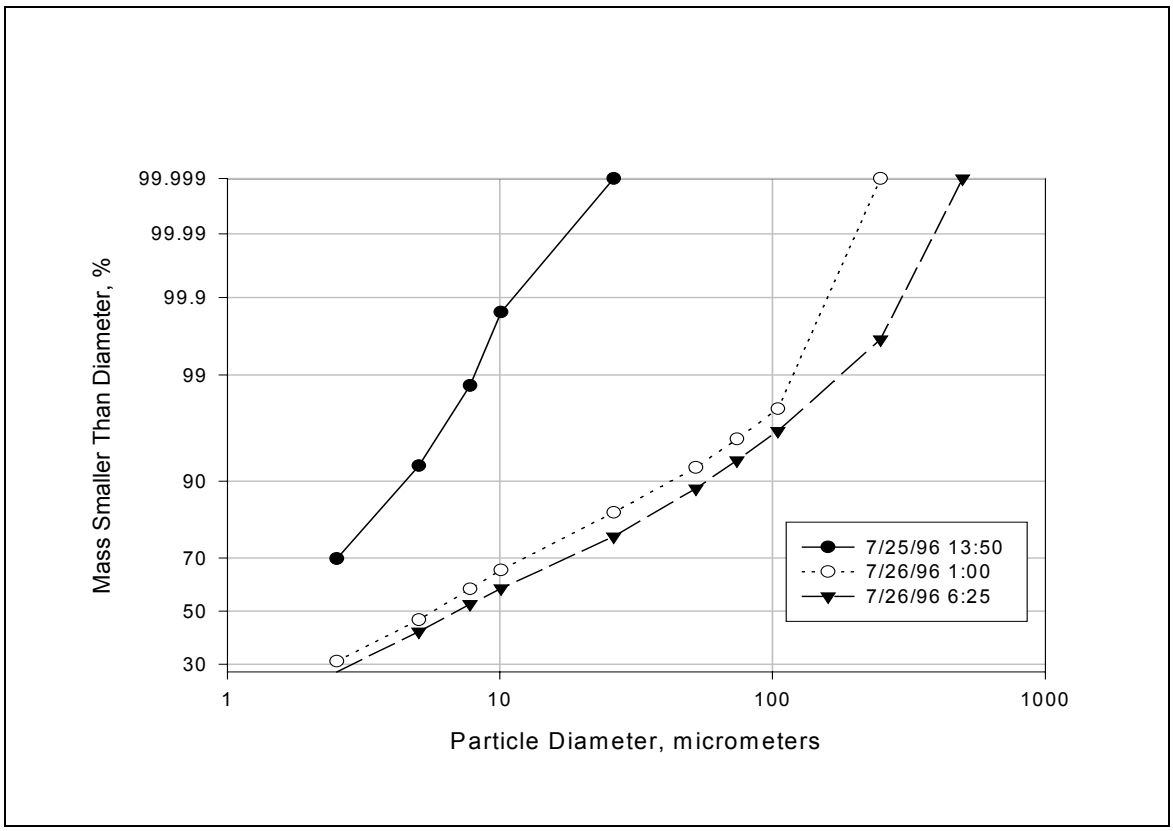


Figure 6.1.6-4 CCT1A PCD Hopper Particle Size Distribution

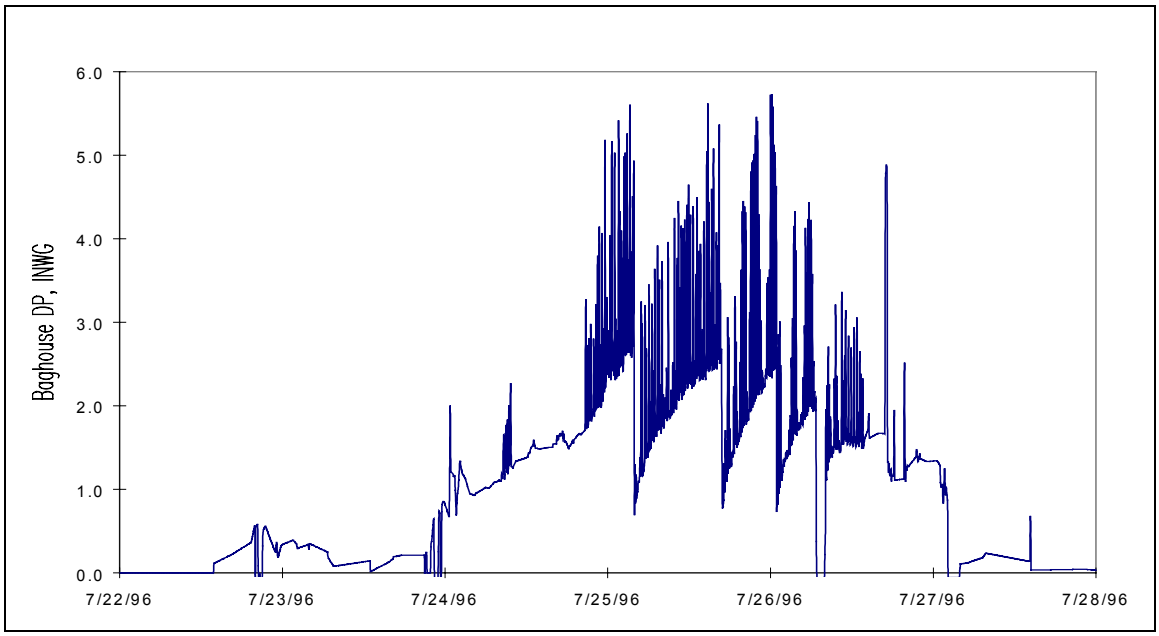


Figure 6.1.6-5 CCT1A Baghouse Differential Pressure

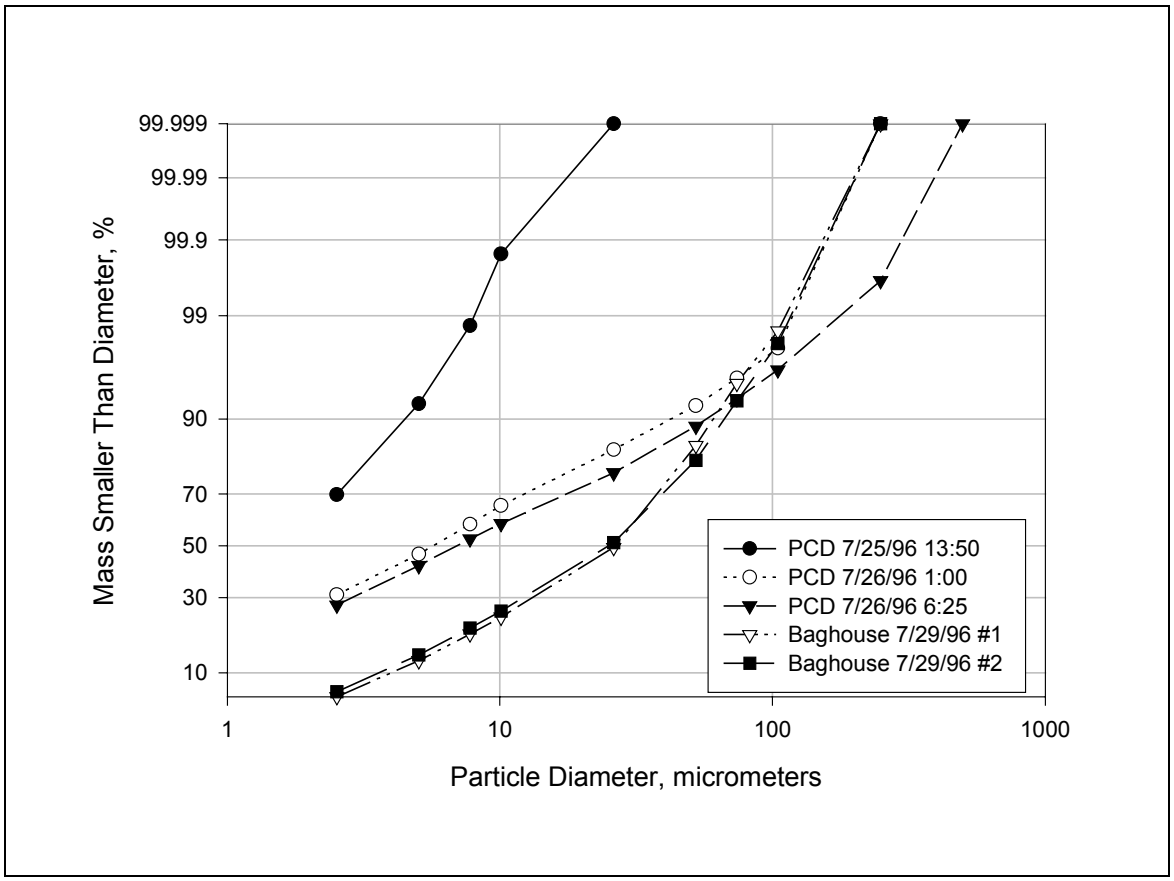


Figure 6.1.6-6 CCT1A PCD Hopper Vs Baghouse Hopper PSD

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 6.1.7-1 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 $\pm$ 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

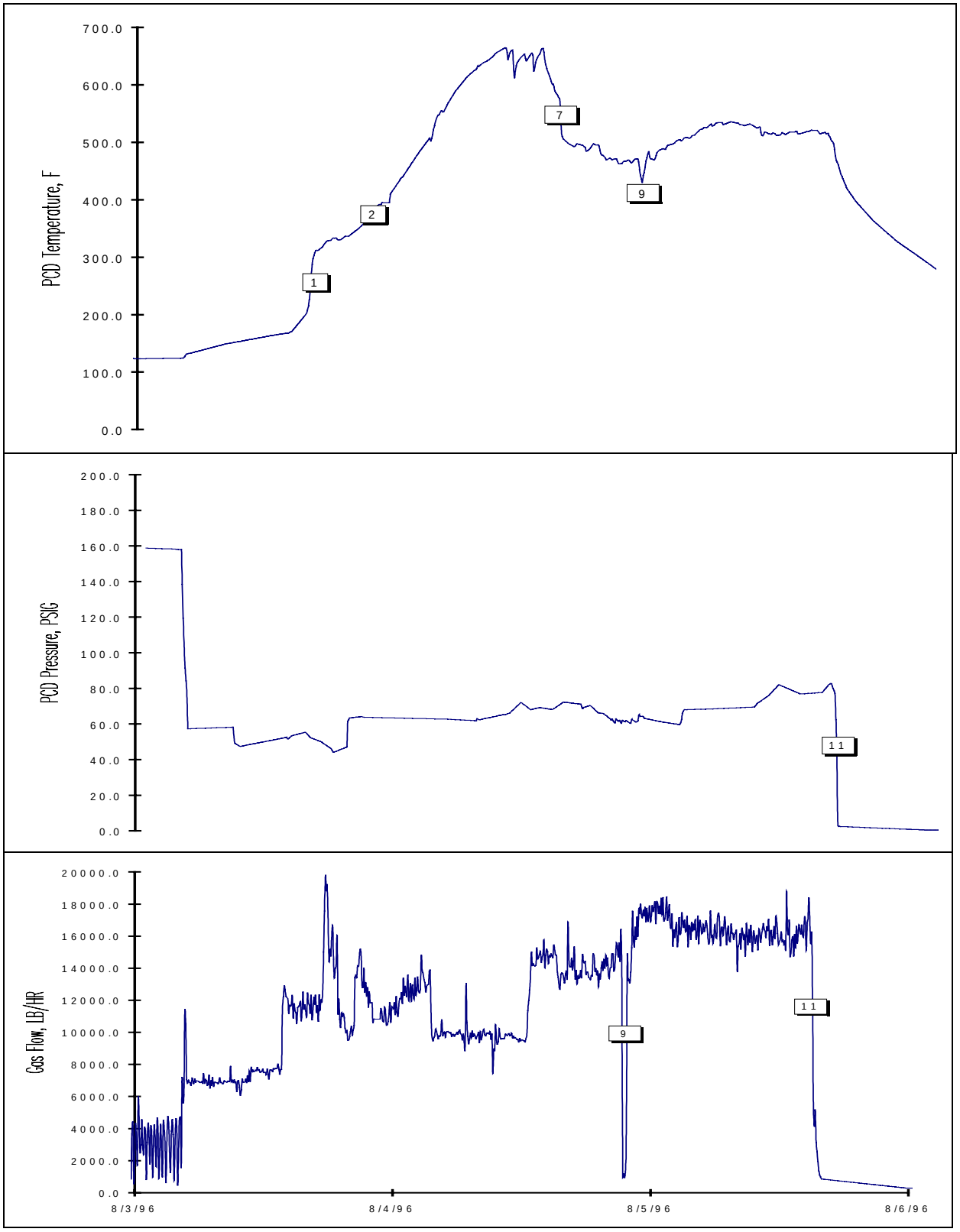


Figure 6.1.7-1 CCT1B Summary Information

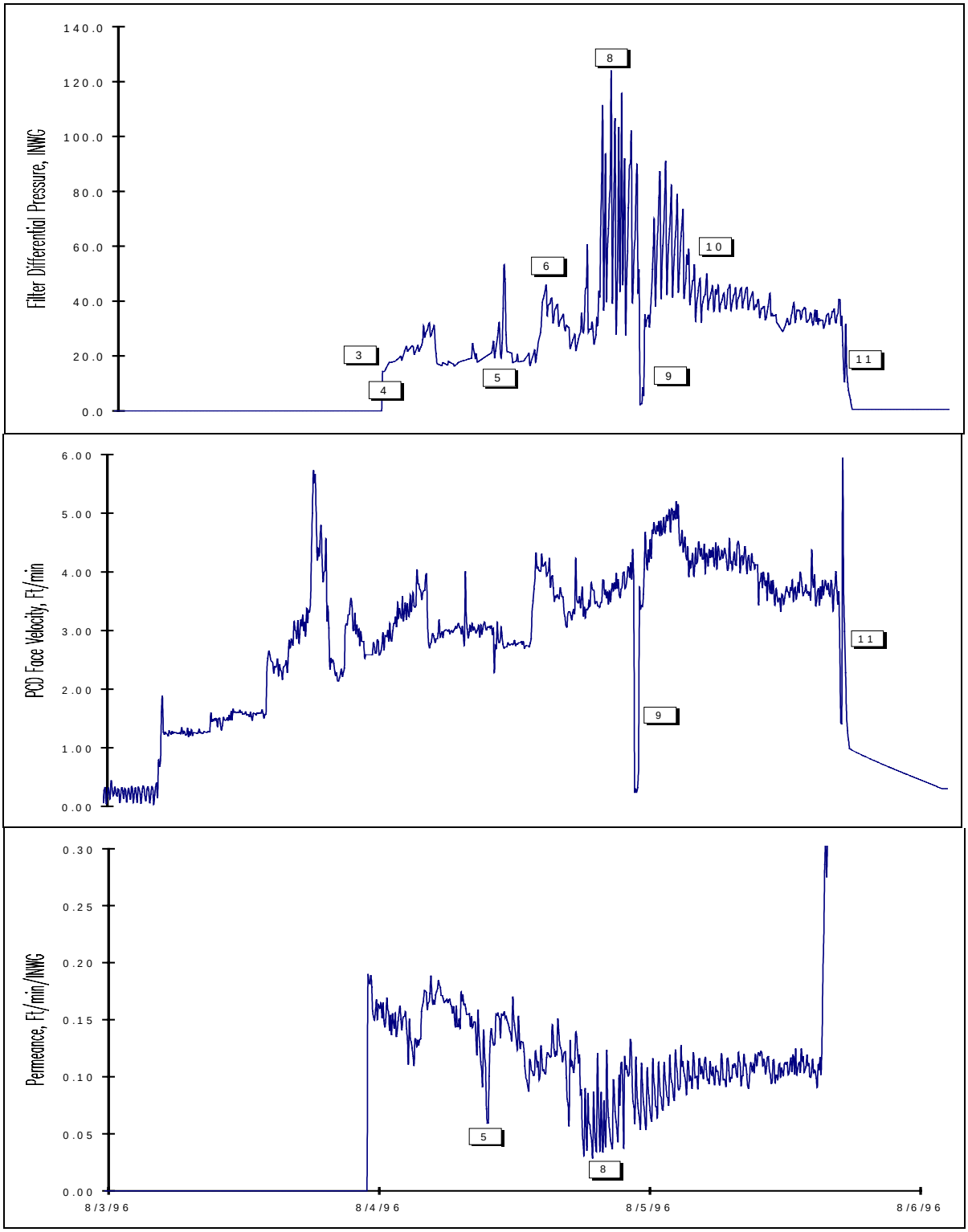


Figure 6.1.7-2 CCT1B Summary Information

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

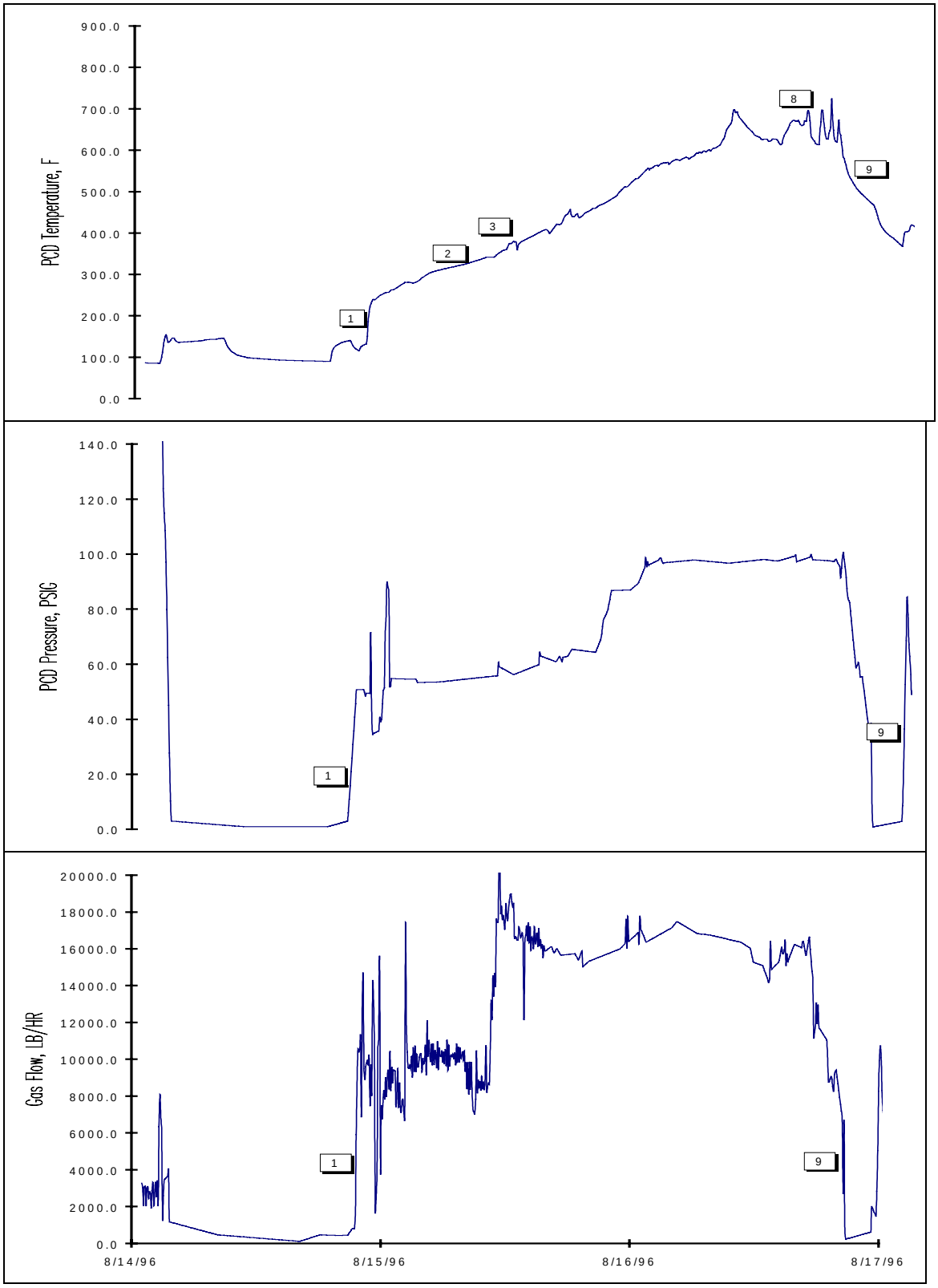


Figure 6.1.8-1 CCT1C Summary Information

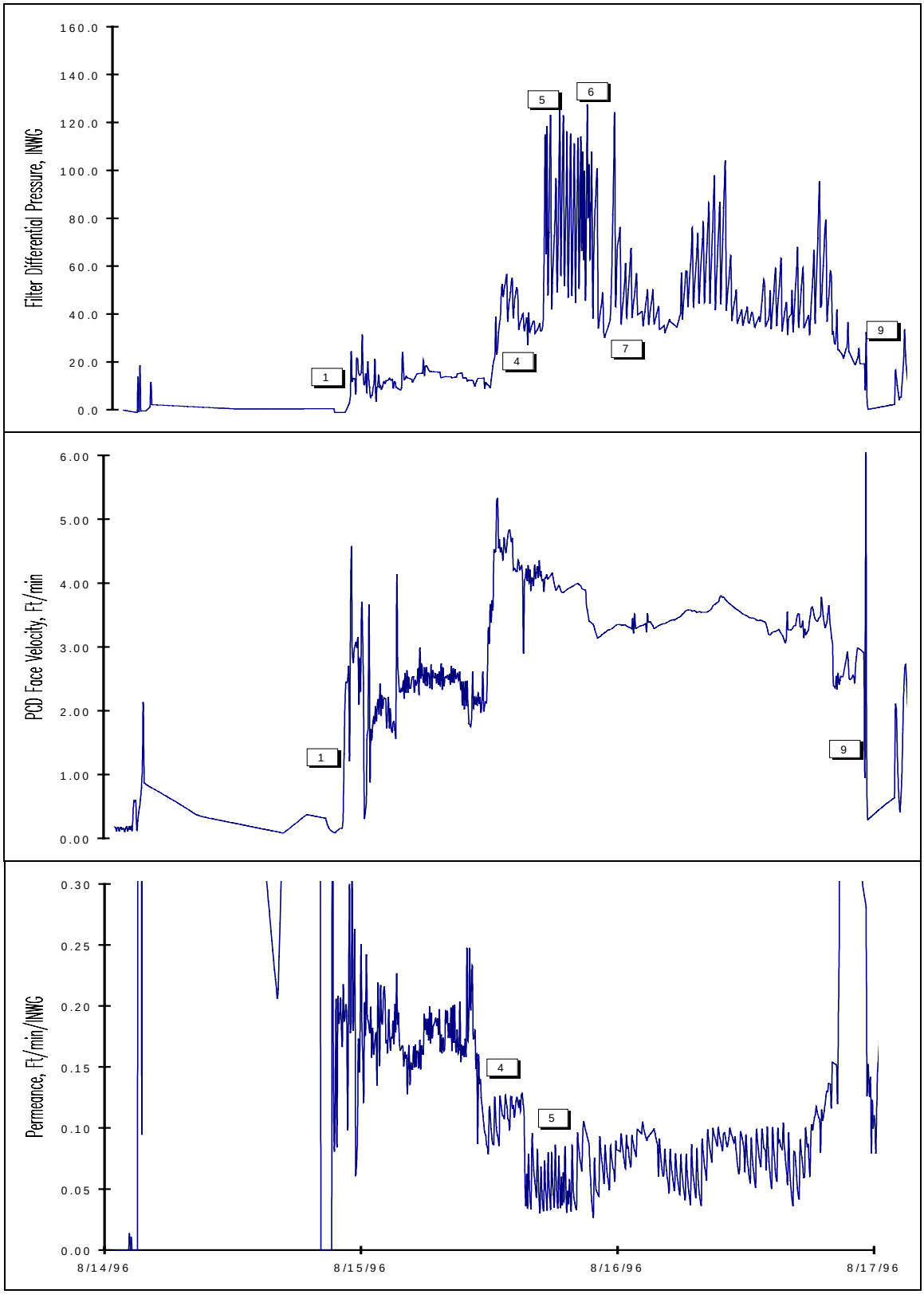


Figure 6.1.8-2 CCT1C Summary Information

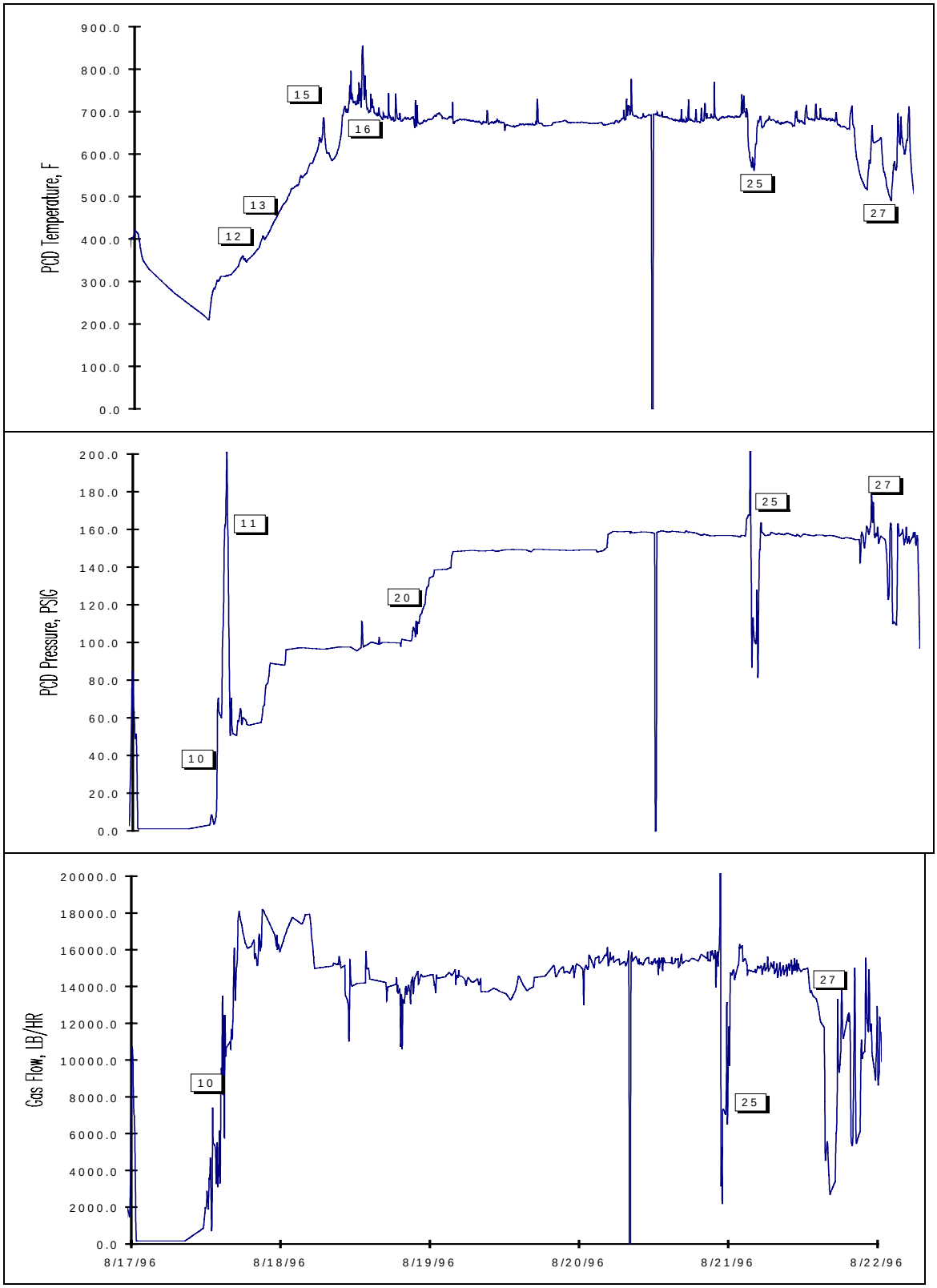


Figure 6.1.8-3 CCT1C Summary Information

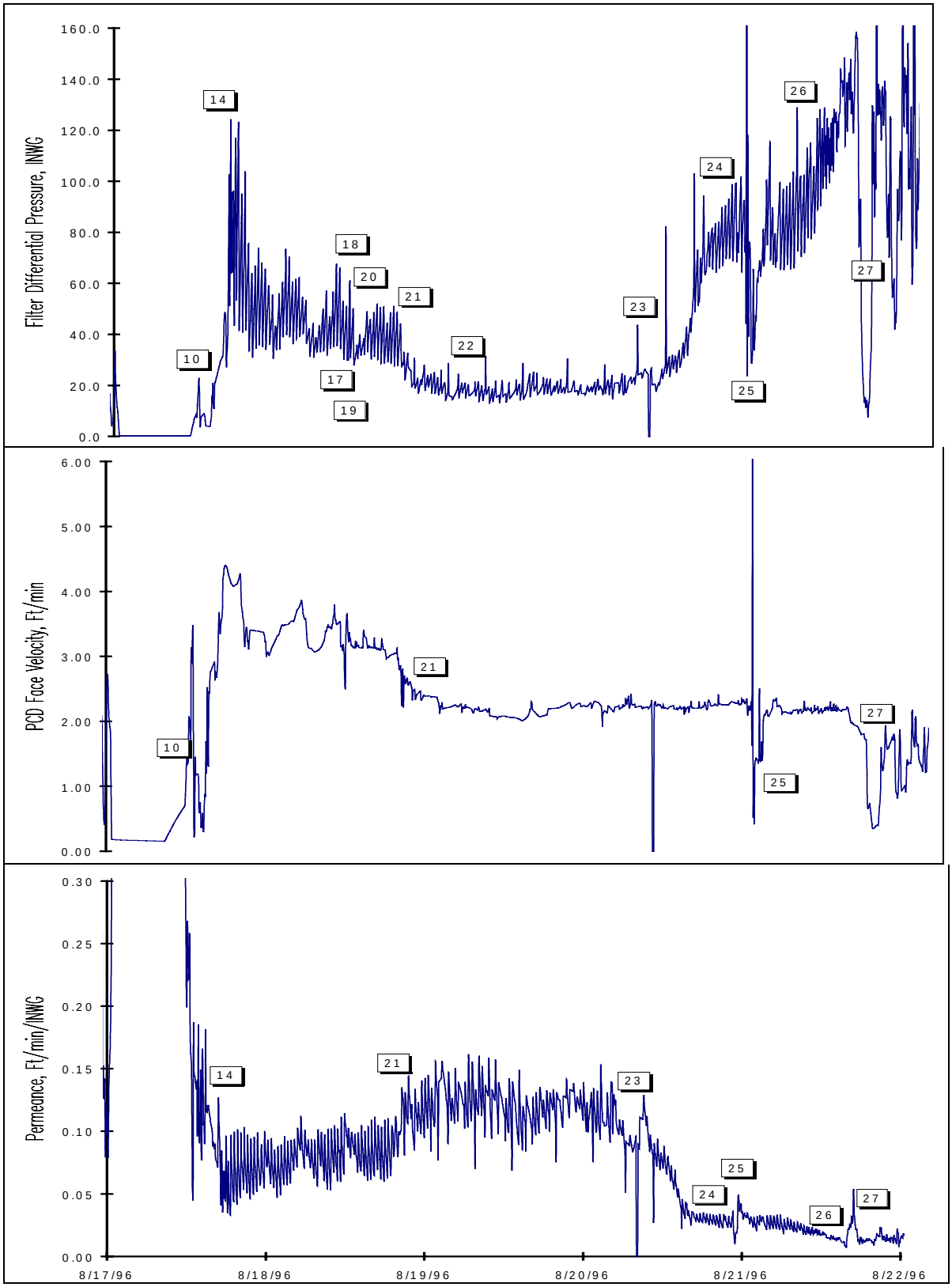


Figure 6.1.8-4 CCT1C Summary Information

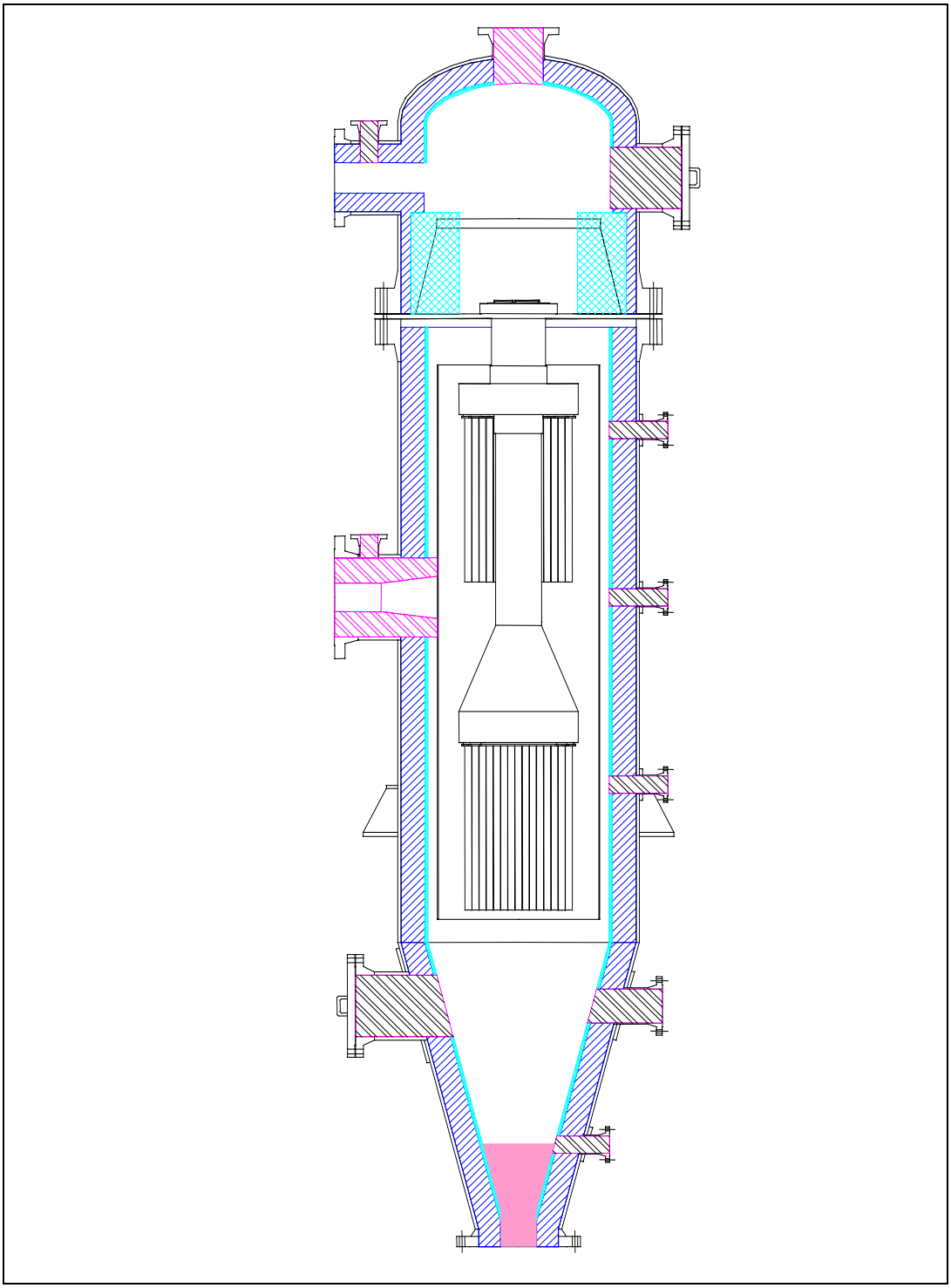


Figure 6.1.8-5 Approximate Ash Level on August 18 at 09:00

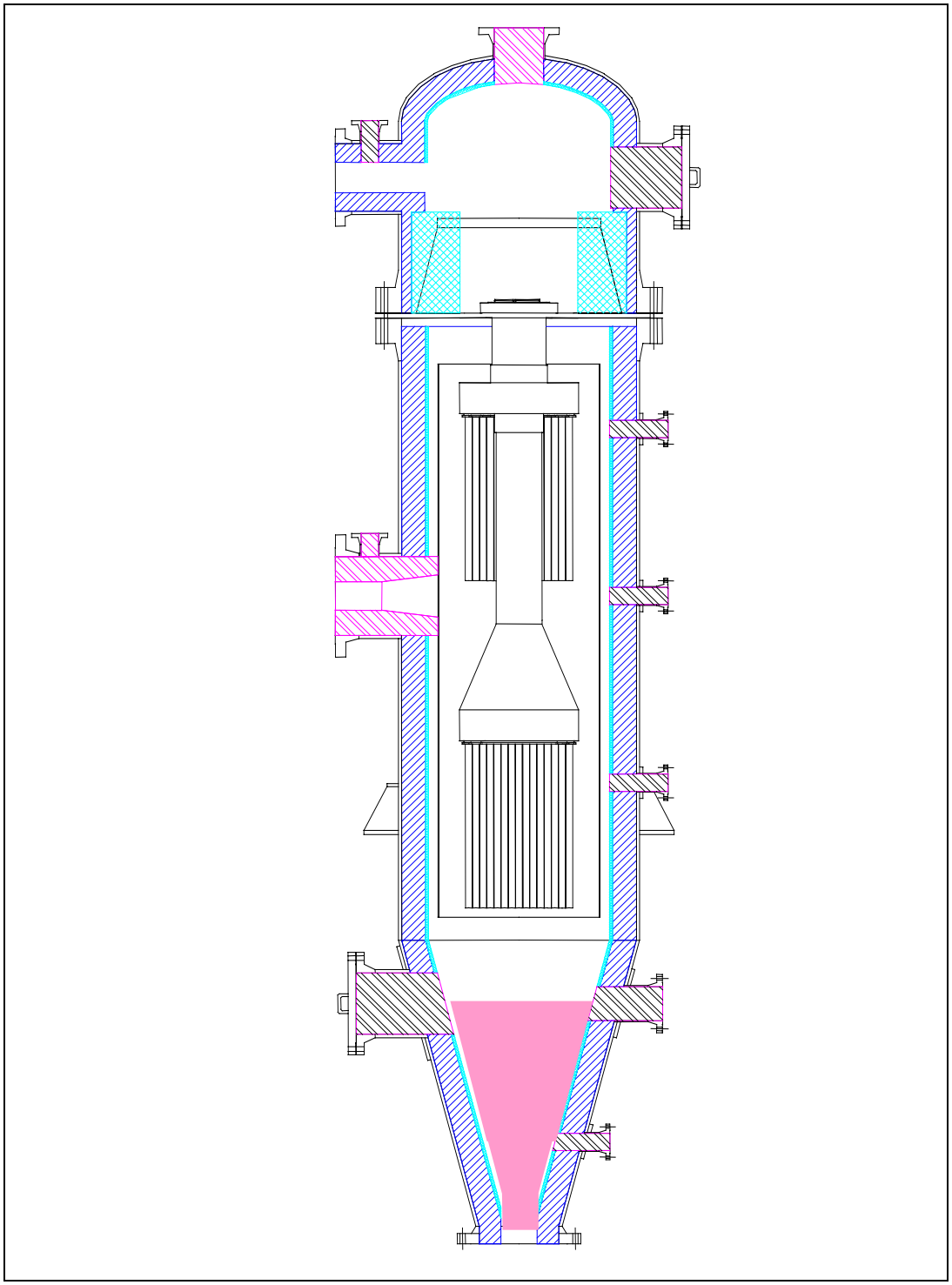


Figure 6.1.8-6 Approximate Ash Level on August 18 at 11:30

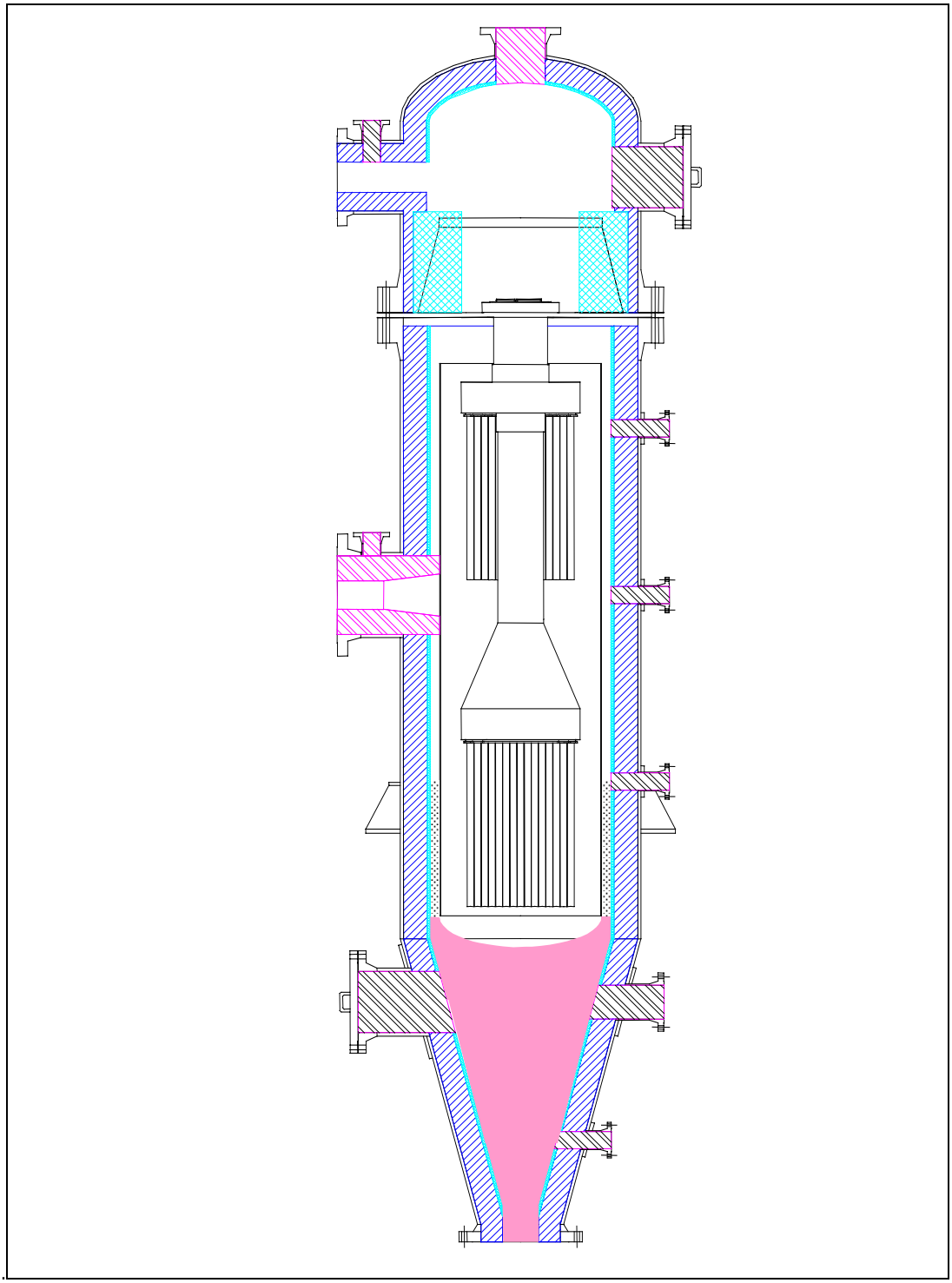


Figure 6.1.8-7 Approximate Ash Level on August 19 at 03:45

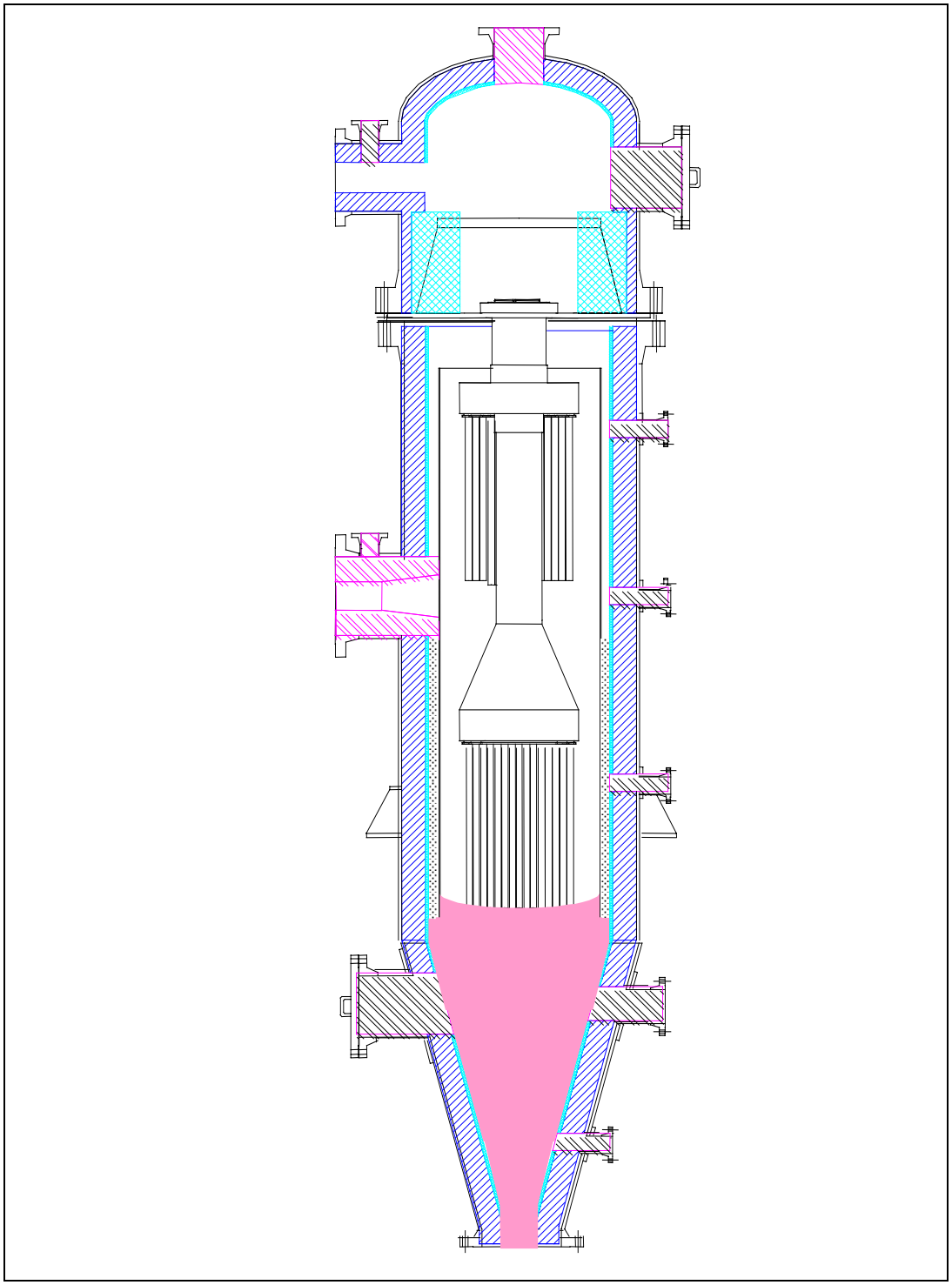


Figure 6.1.8-8 Approximate Ash Level on August 20 at ~04:00

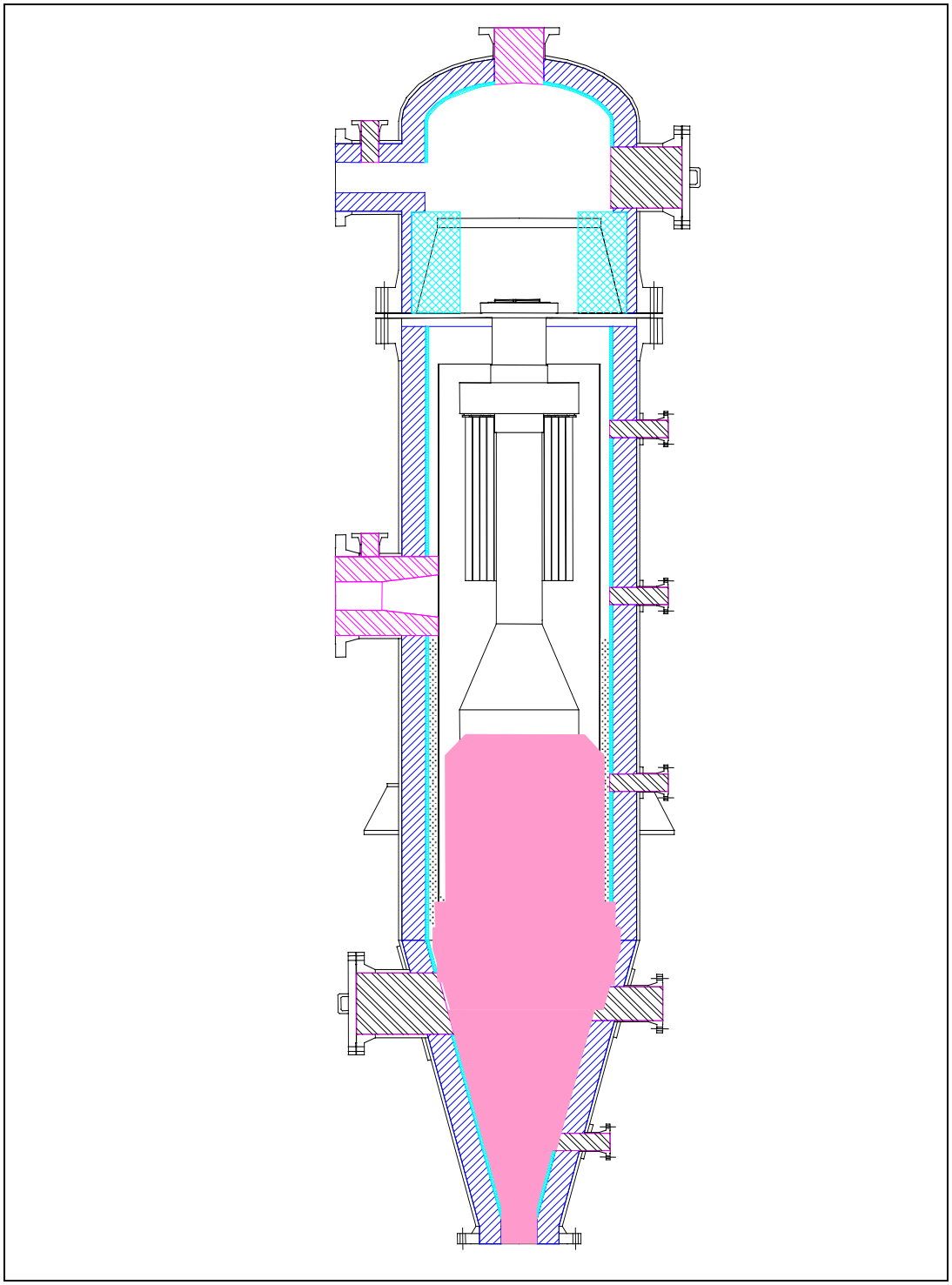


Figure 6.1.8-9 Approximate Ash Level on August 20 at ~16:00

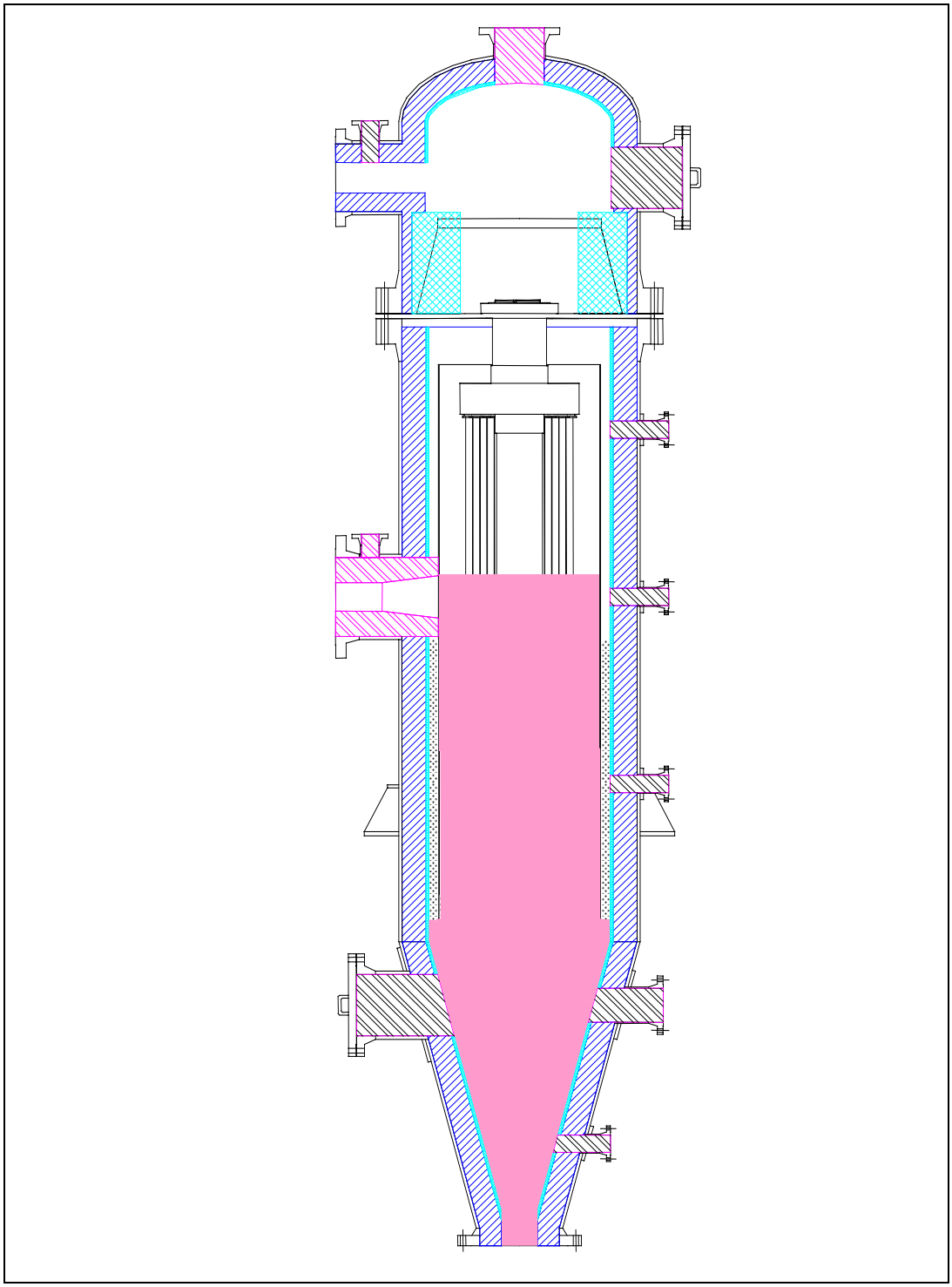


Figure 6.1.8-10 Approximate Ash Level on August 21 at ~12:00

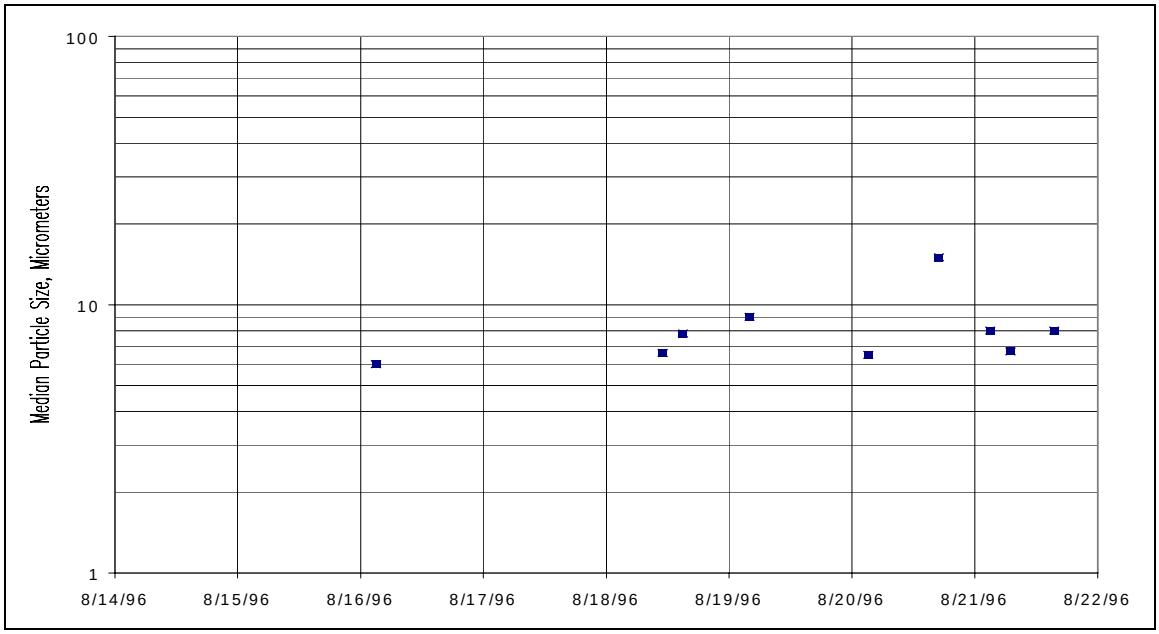


Figure 6.1.8-11 CCT1C Hopper Samples

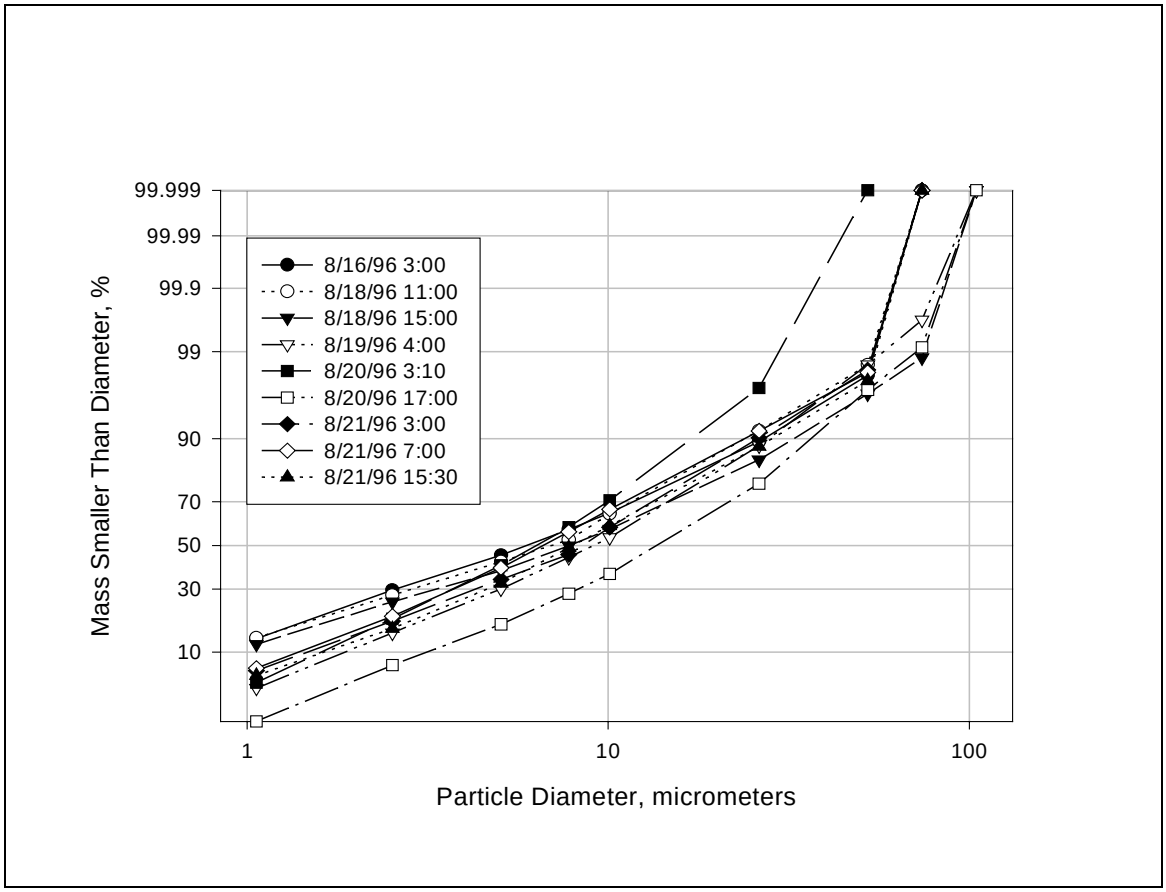


Figure 6.1.8-12 CCT1C PCD Hopper Particle Size Distributions

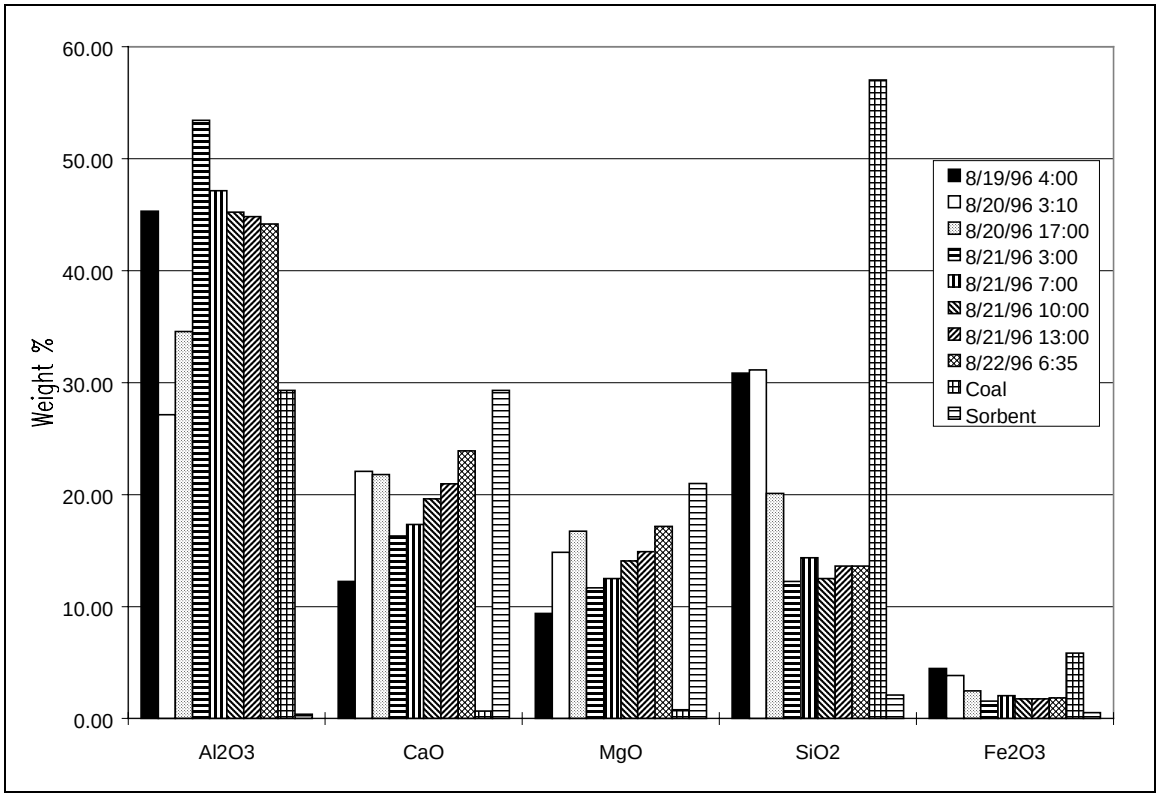


Figure 6.1.8-13 CCT1C PCD Hopper Ash Chemistry (Primary Constituents)

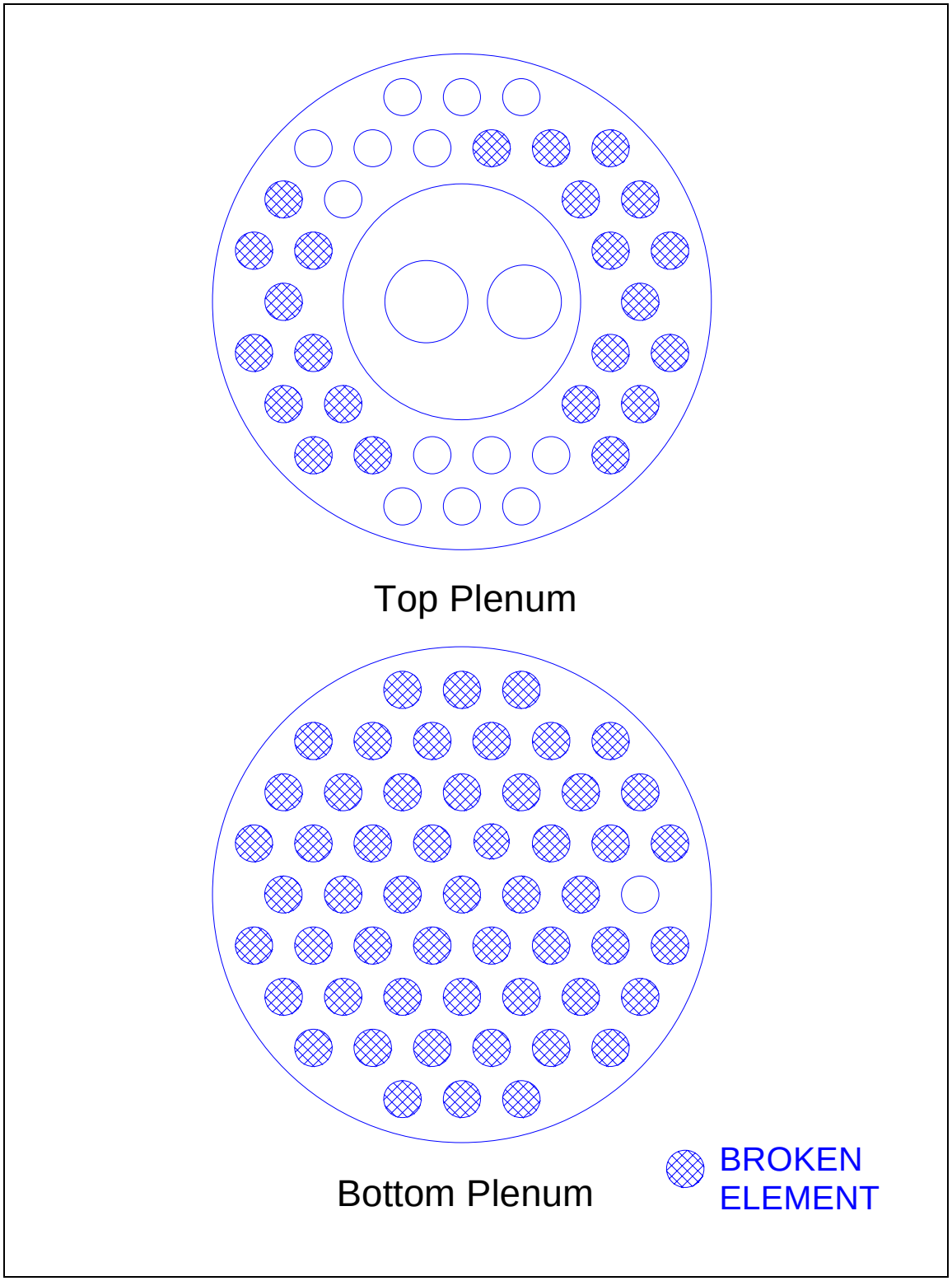


Figure 6.1.8-14 Broken Elements After CCT1C (Top of Page Is North)

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	
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54	Pall	442T	17	
55	Pall	442T	79	

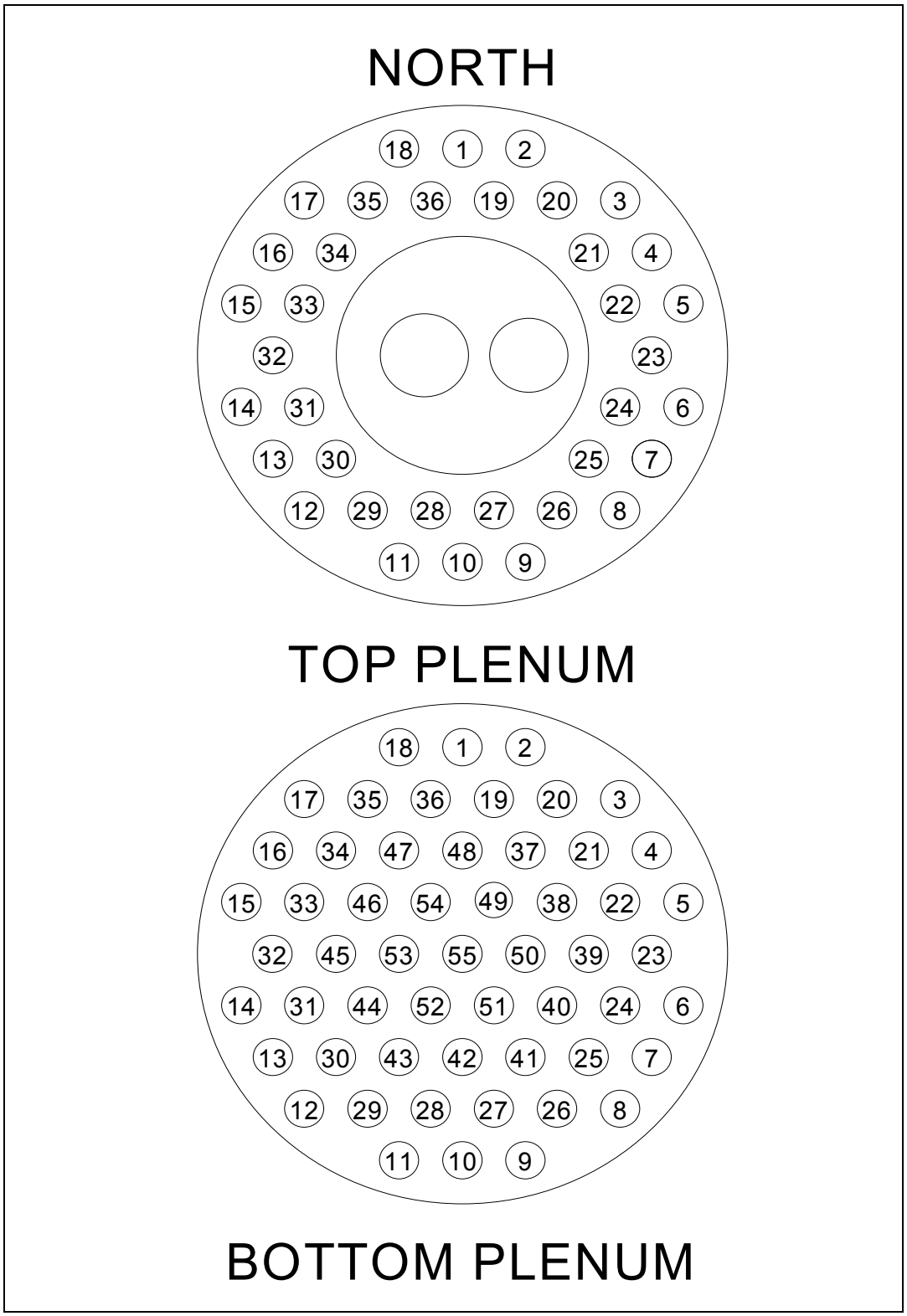


Figure 6.1.9-1 FL0301 Tubesheet Map

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 $\pm$ 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

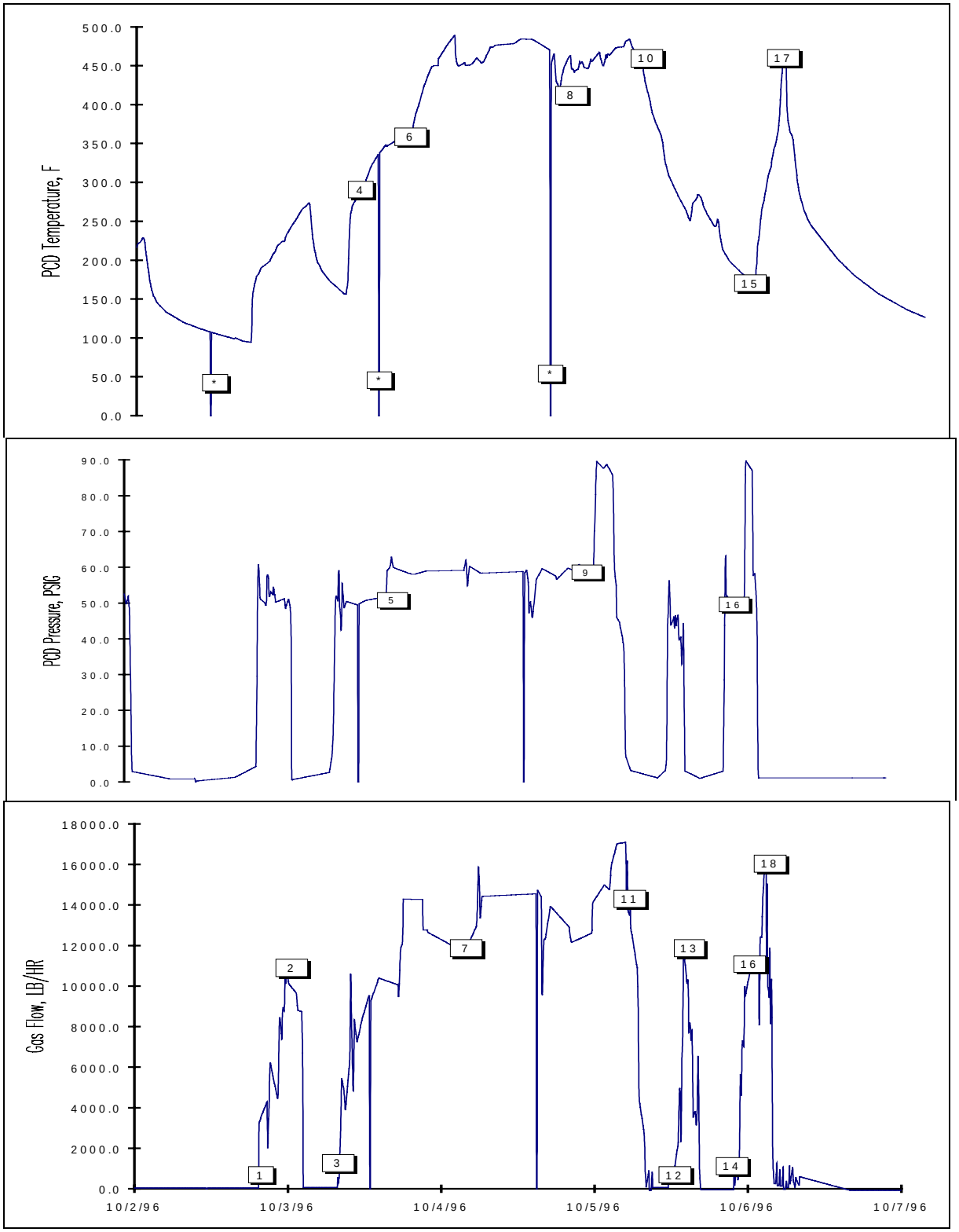


Figure 6.1.10-1 CCT2A, Phase 1 Summary Information

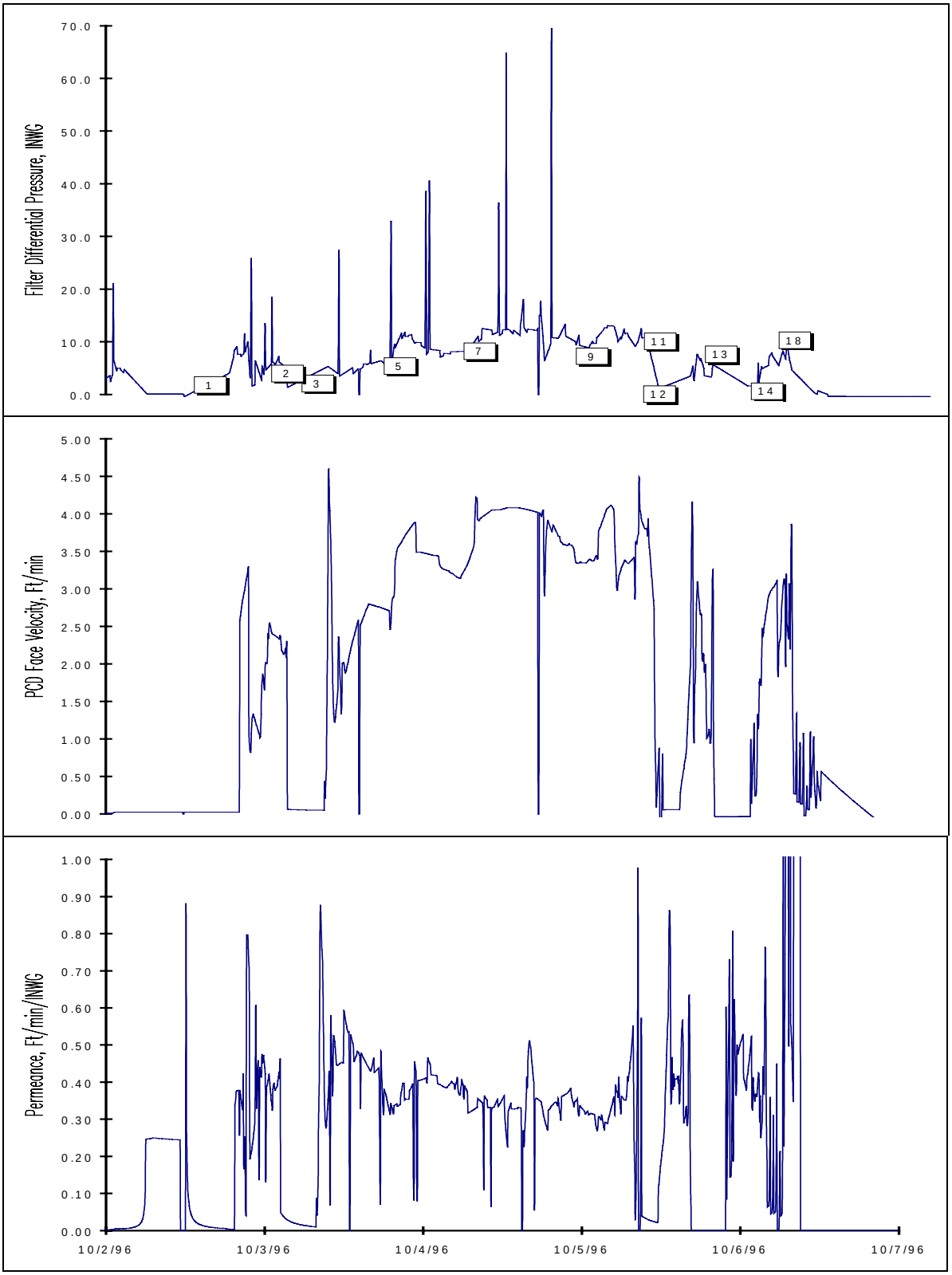


Figure 6.1.10-2 CCT2A, Phase 1 Summary Information

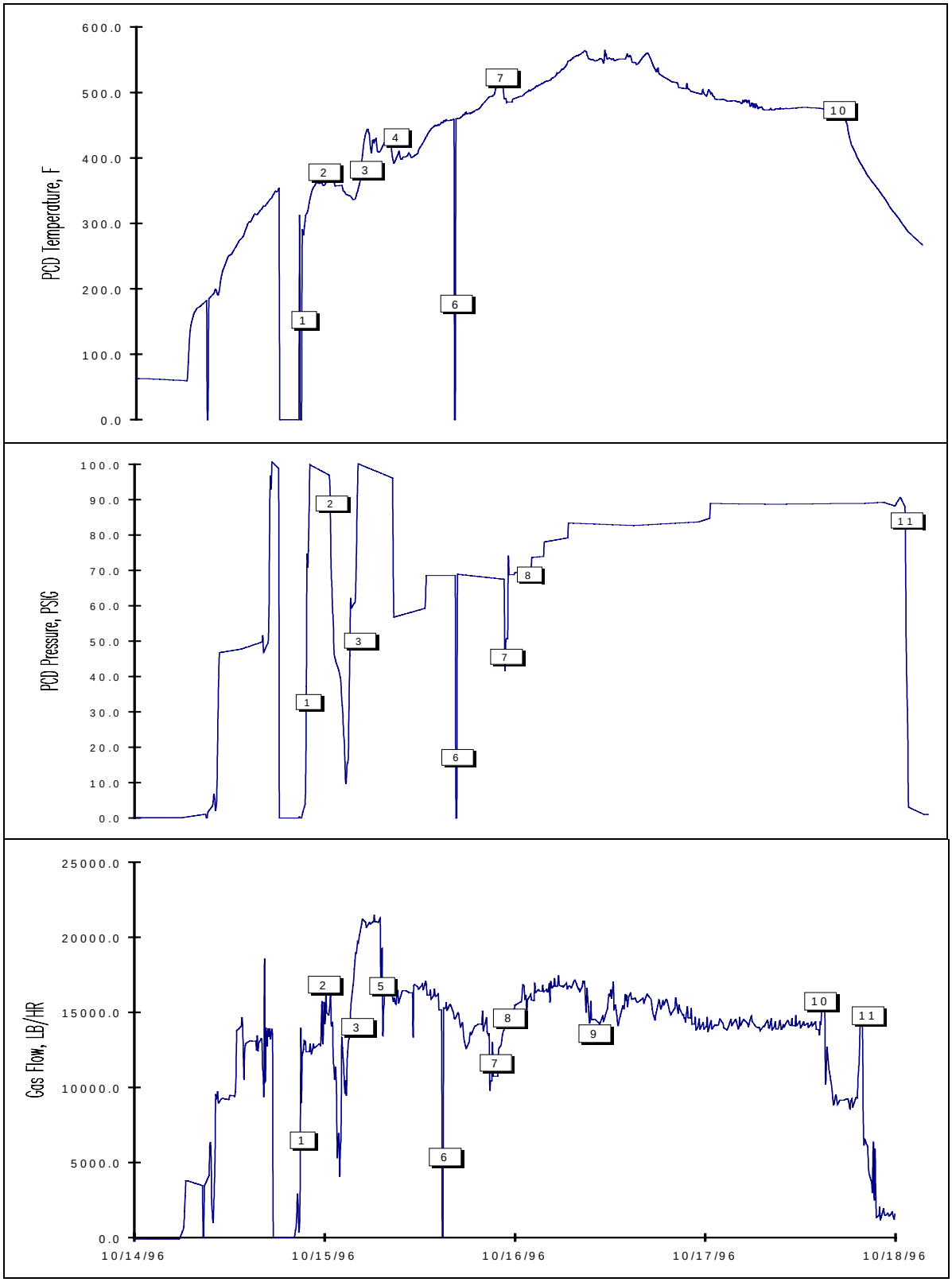


Figure 6.1.10-3 CCT2A, Phase 2 Summary Information

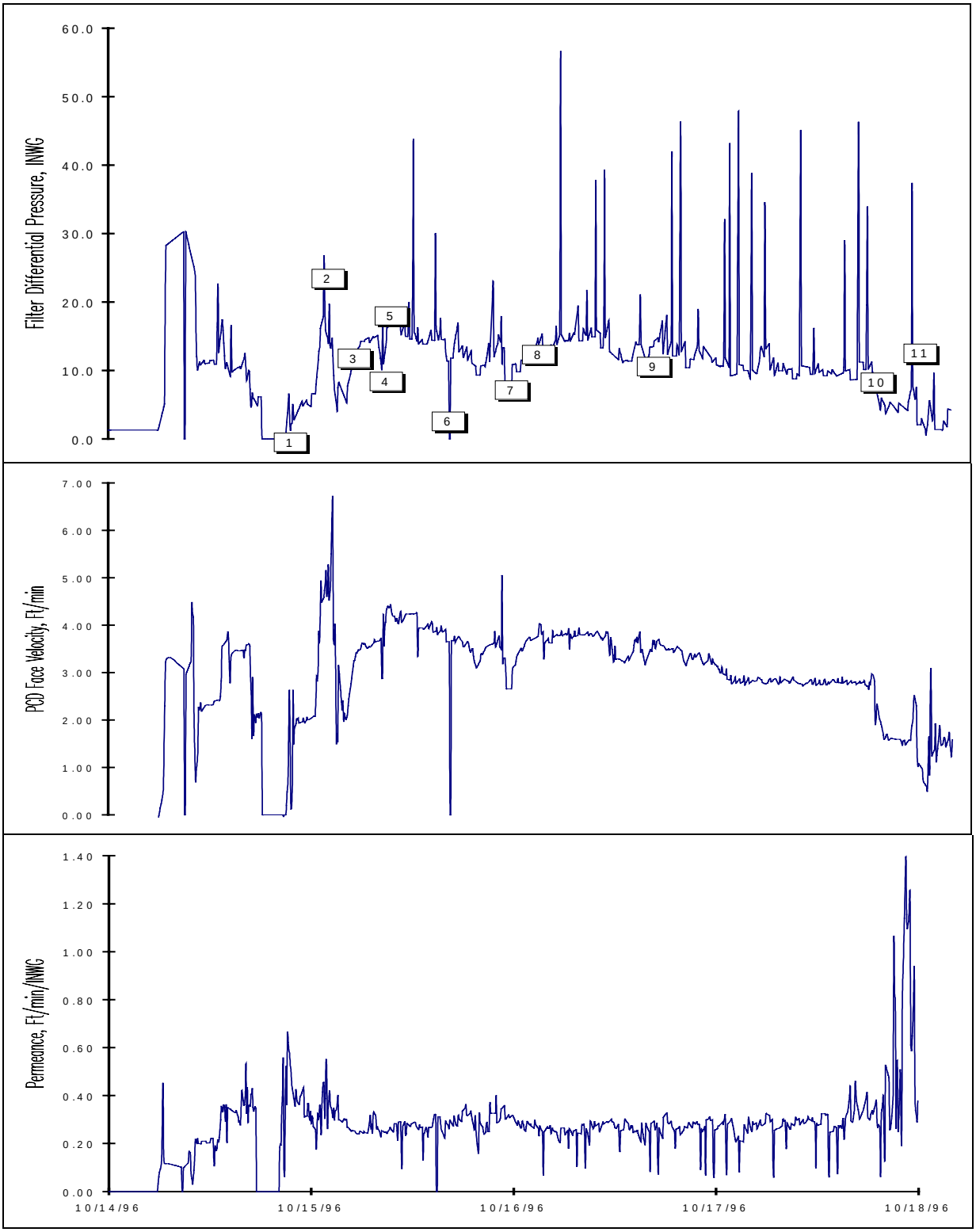


Figure 6.1.10-4 CCT2A, Phase 2 Summary Information

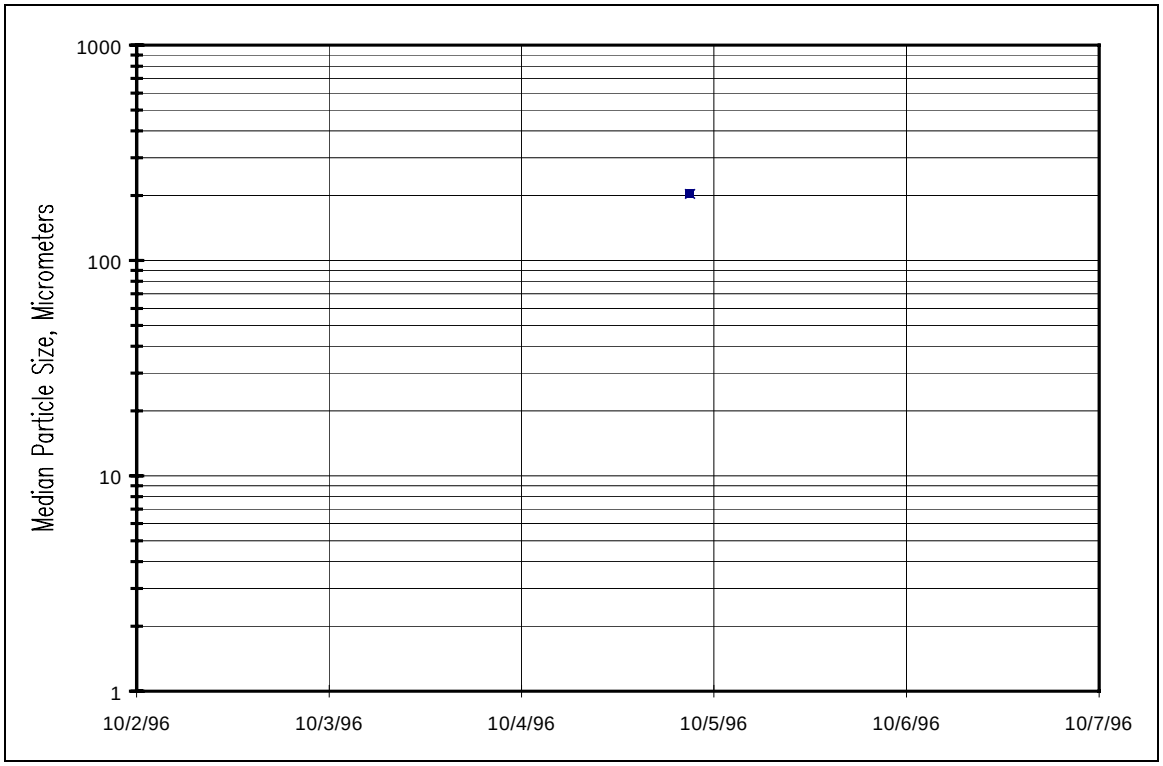


Figure 6.1.10-5 CCT2A, Phase 1 PCD Hopper Samples

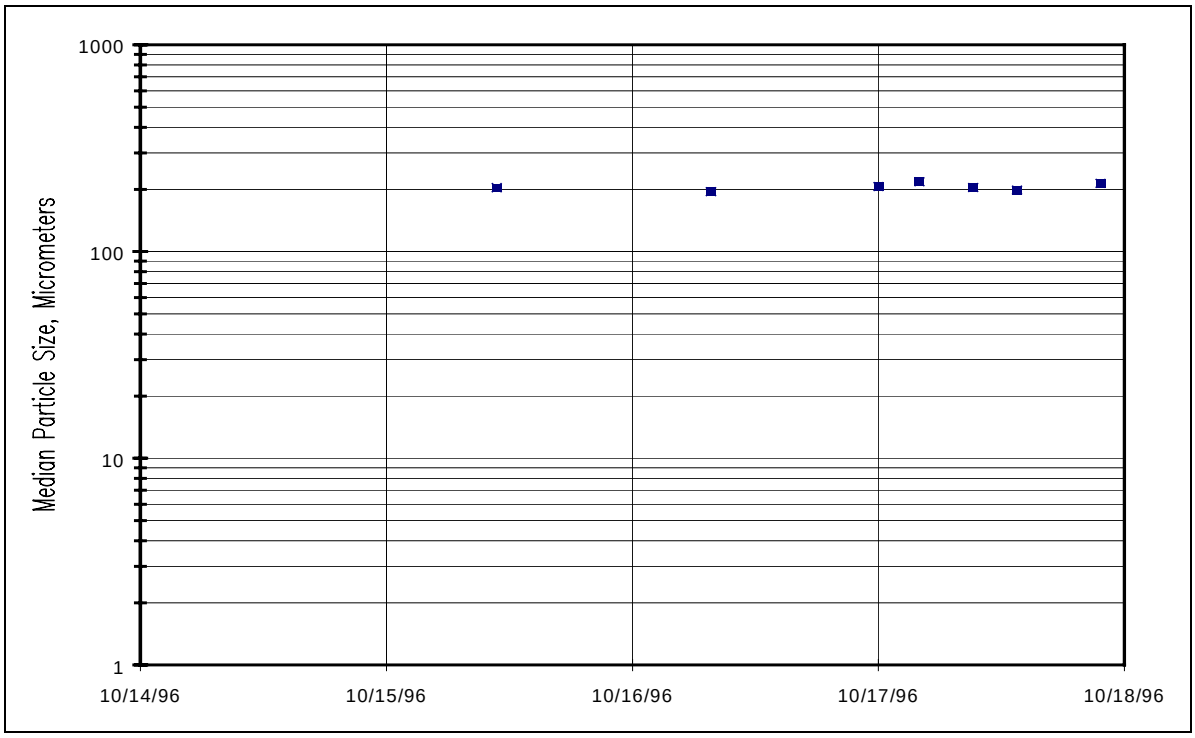


Figure 6.1.10-6 CCT2A, Phase 2 PCD Hopper Samples

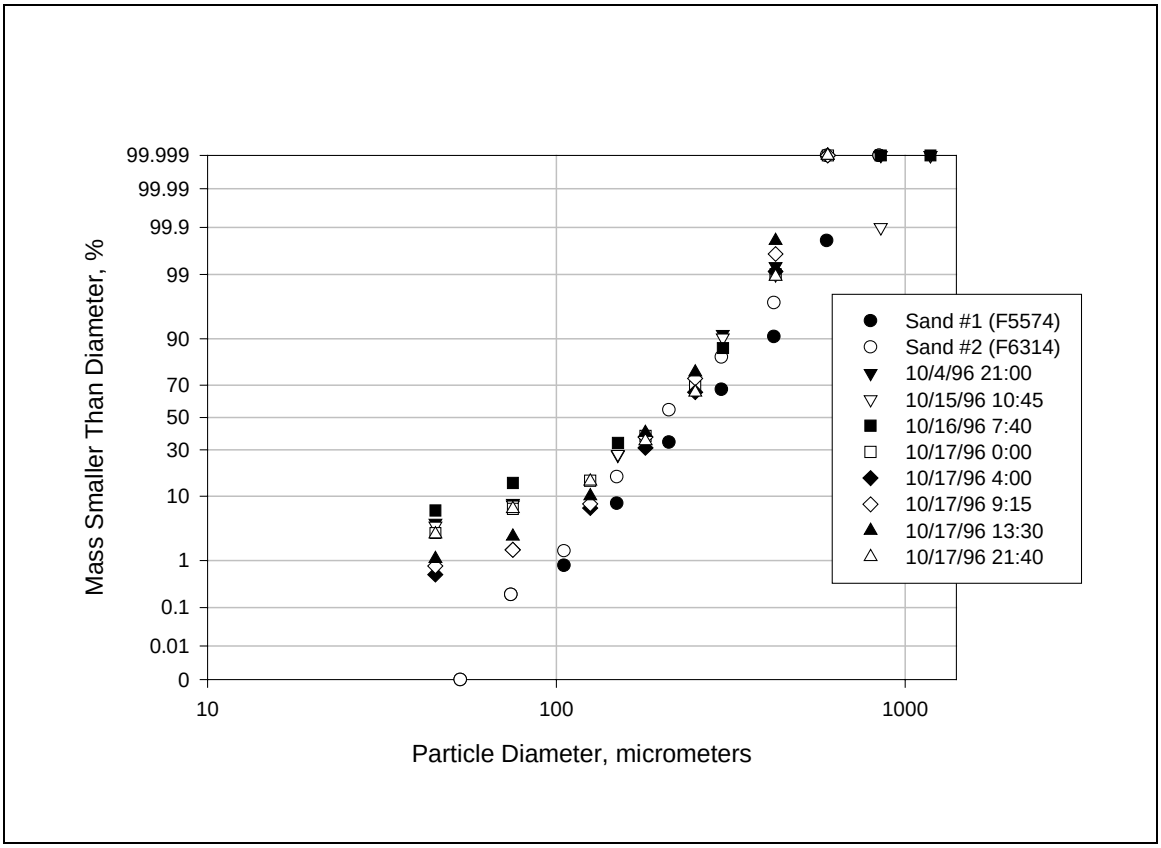


Figure 6.1.10-7 CCT2A PCD Hopper Particle Size Distribution

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 6.1.11-1 and -2. Data from this run are shown in figures 6.1.11-1 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

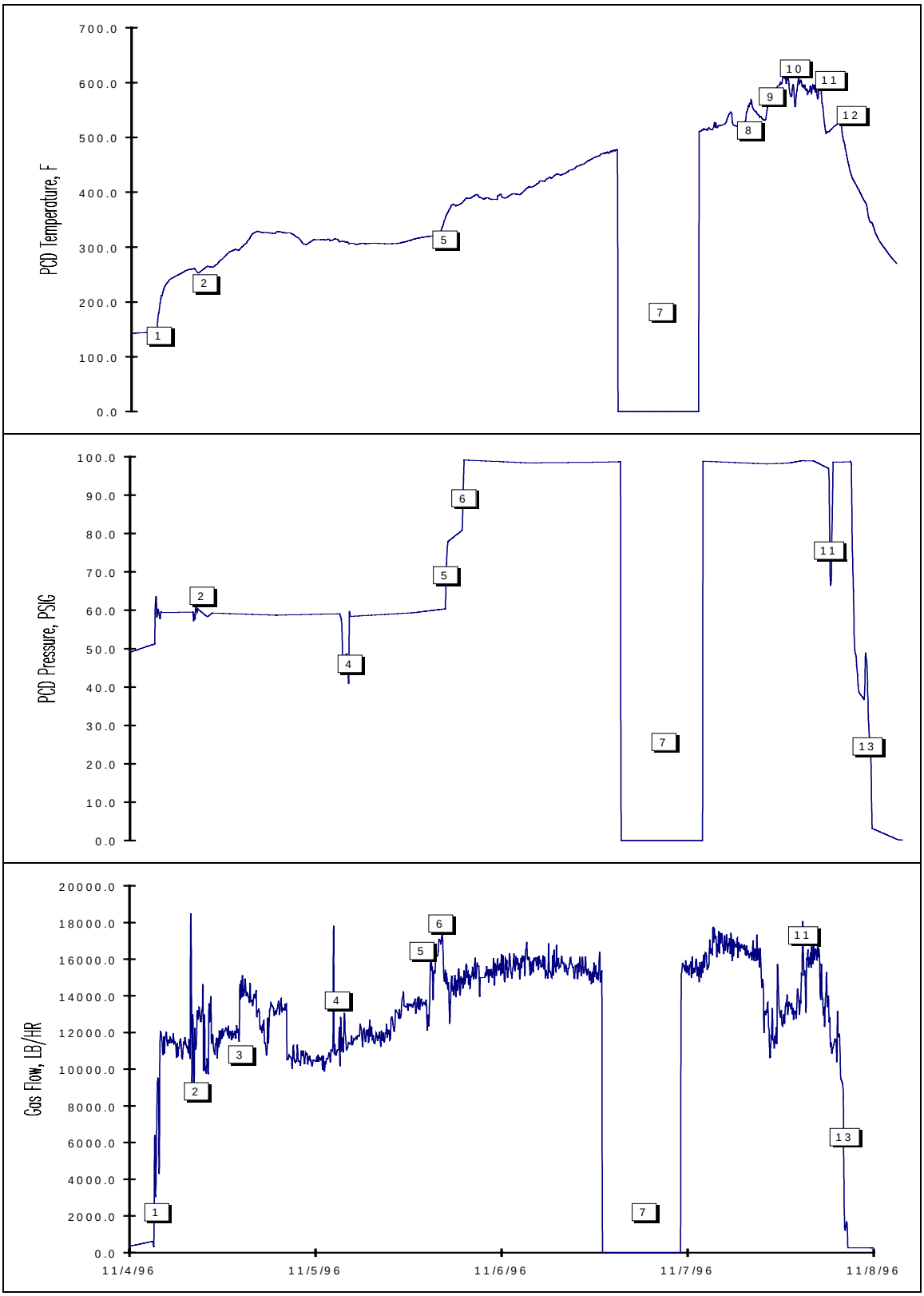


Figure 6.1.11-1 CCT2B Summary Information

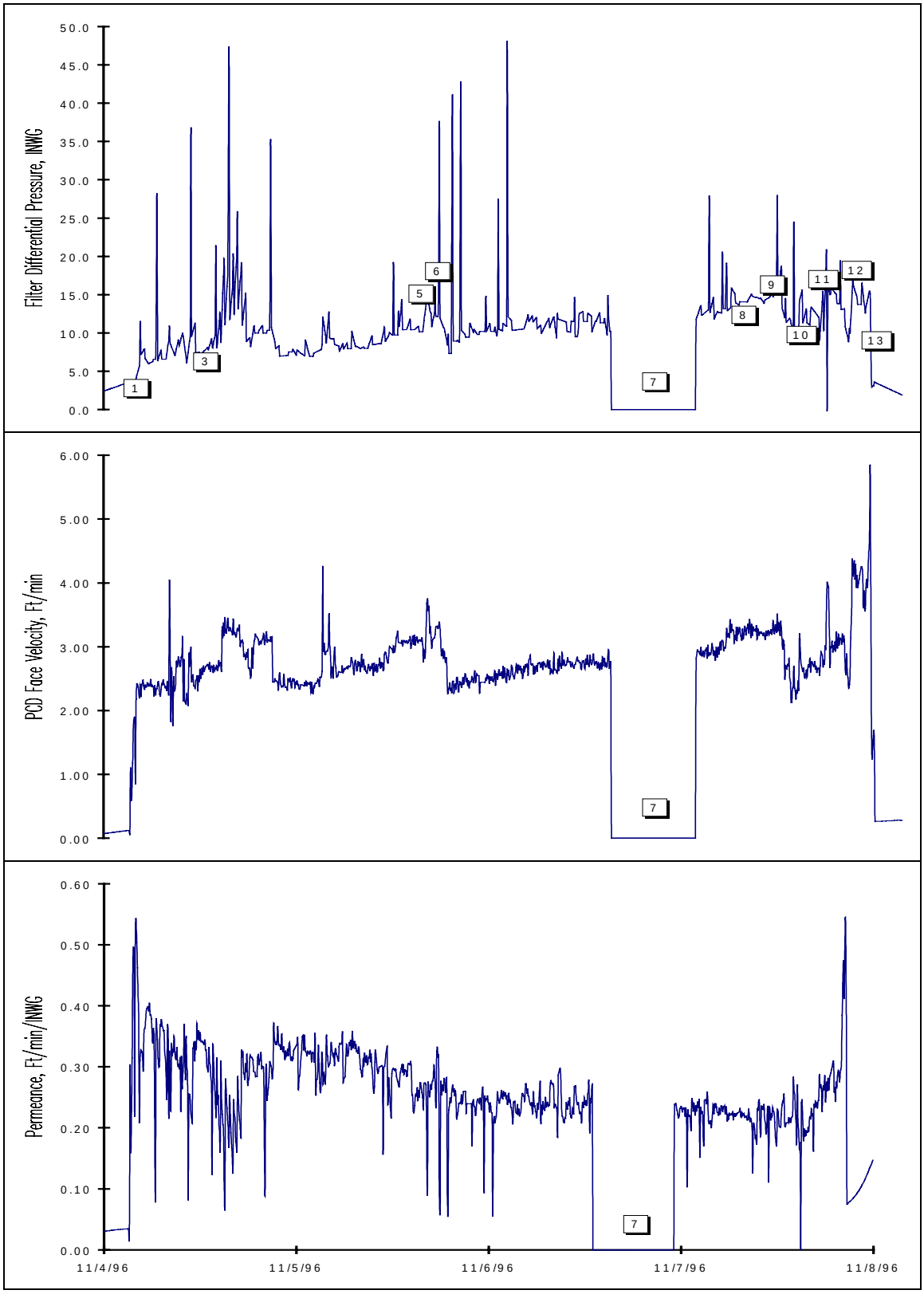


Figure 6.1.11-2 CCT2B Summary Information

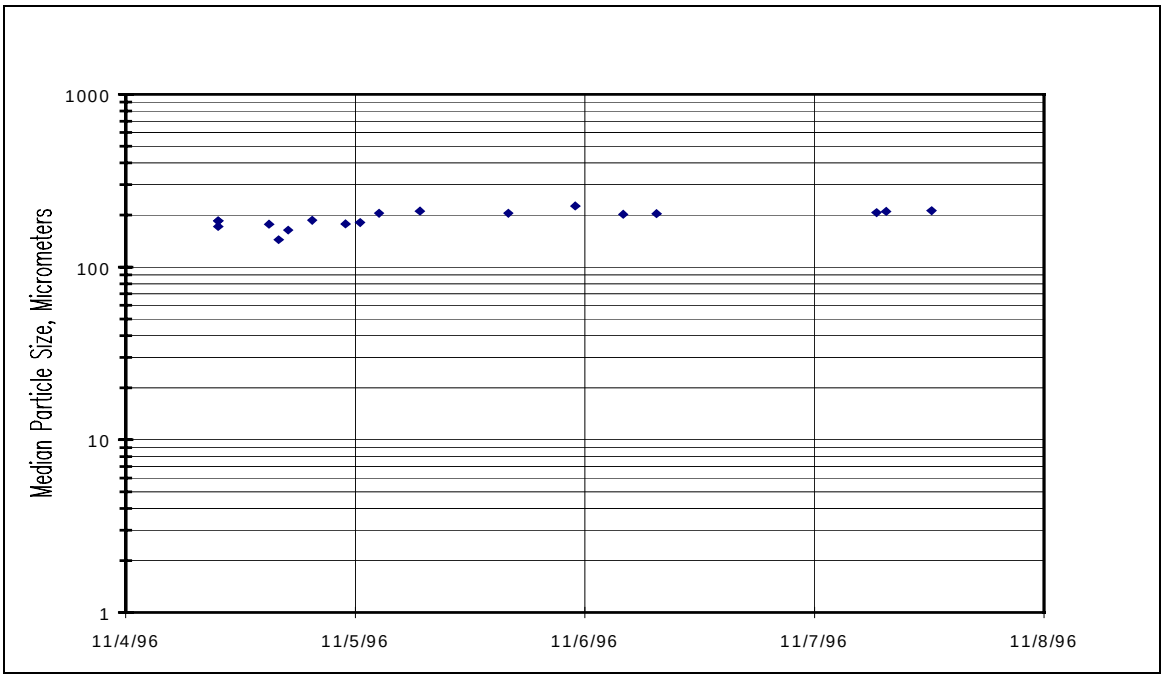


Figure 6.1.11-3 CCT2B PCD Hopper Samples

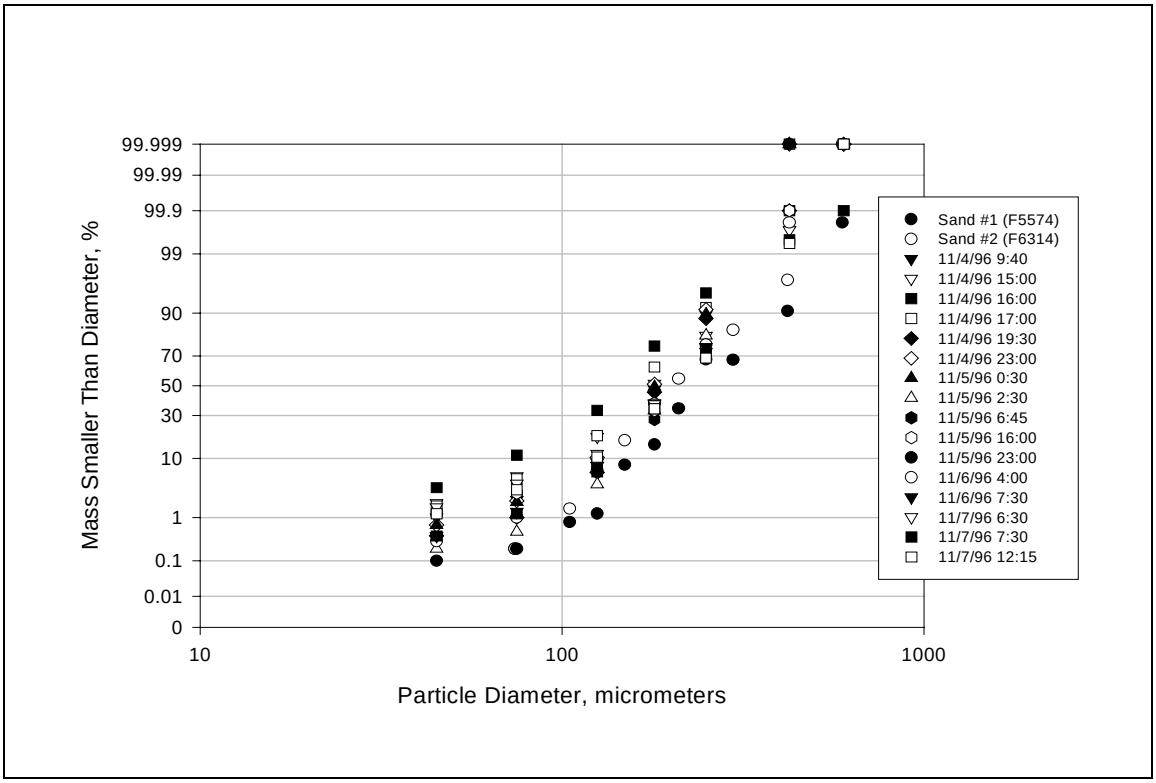


Figure 6.1.11-4 CCT2B Hopper Particle Size Distribution

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 figures 6.1.12-1 and -2.

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 Started	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

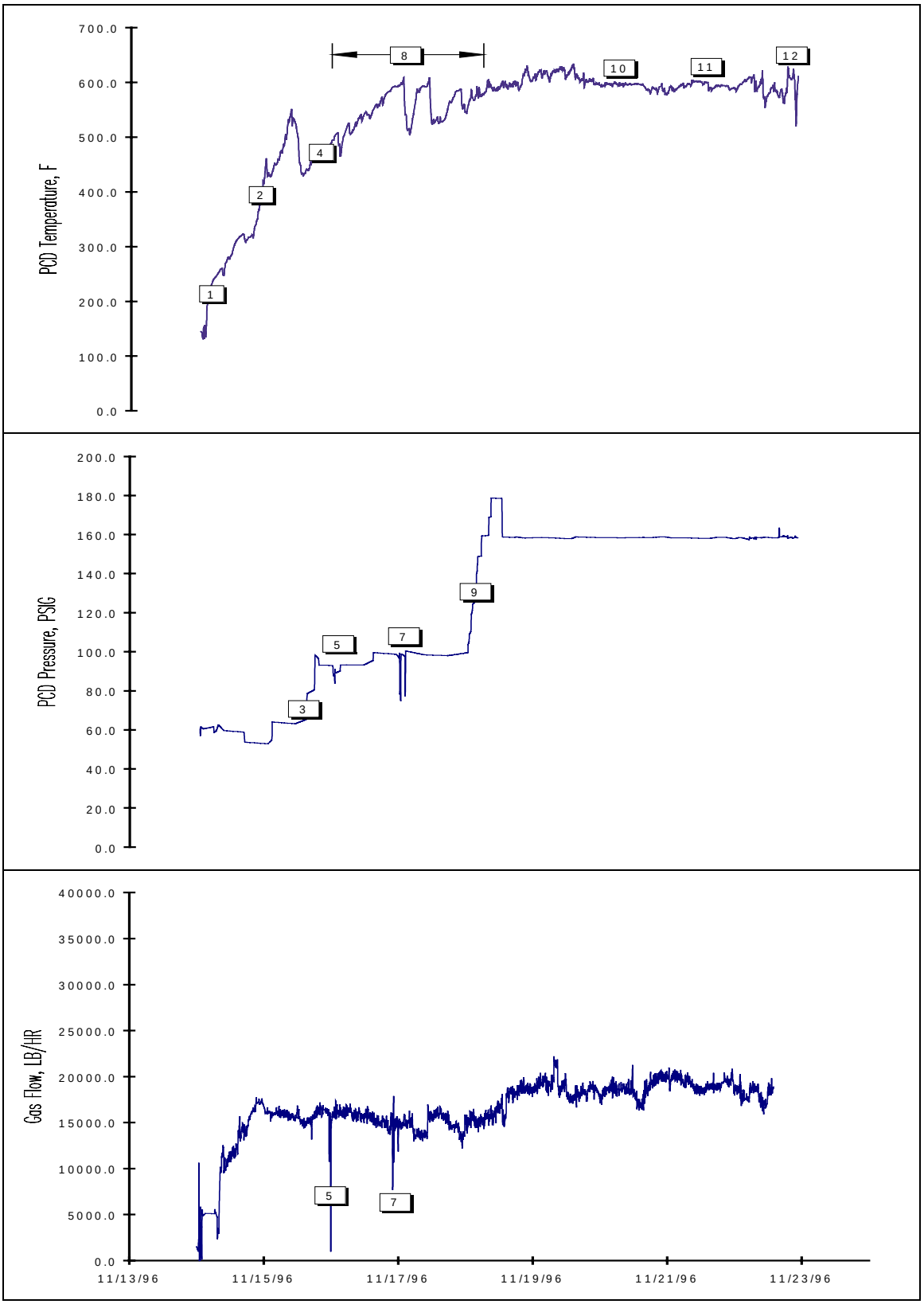


Figure 6.1.12-1 Run CCT2C Summary Information

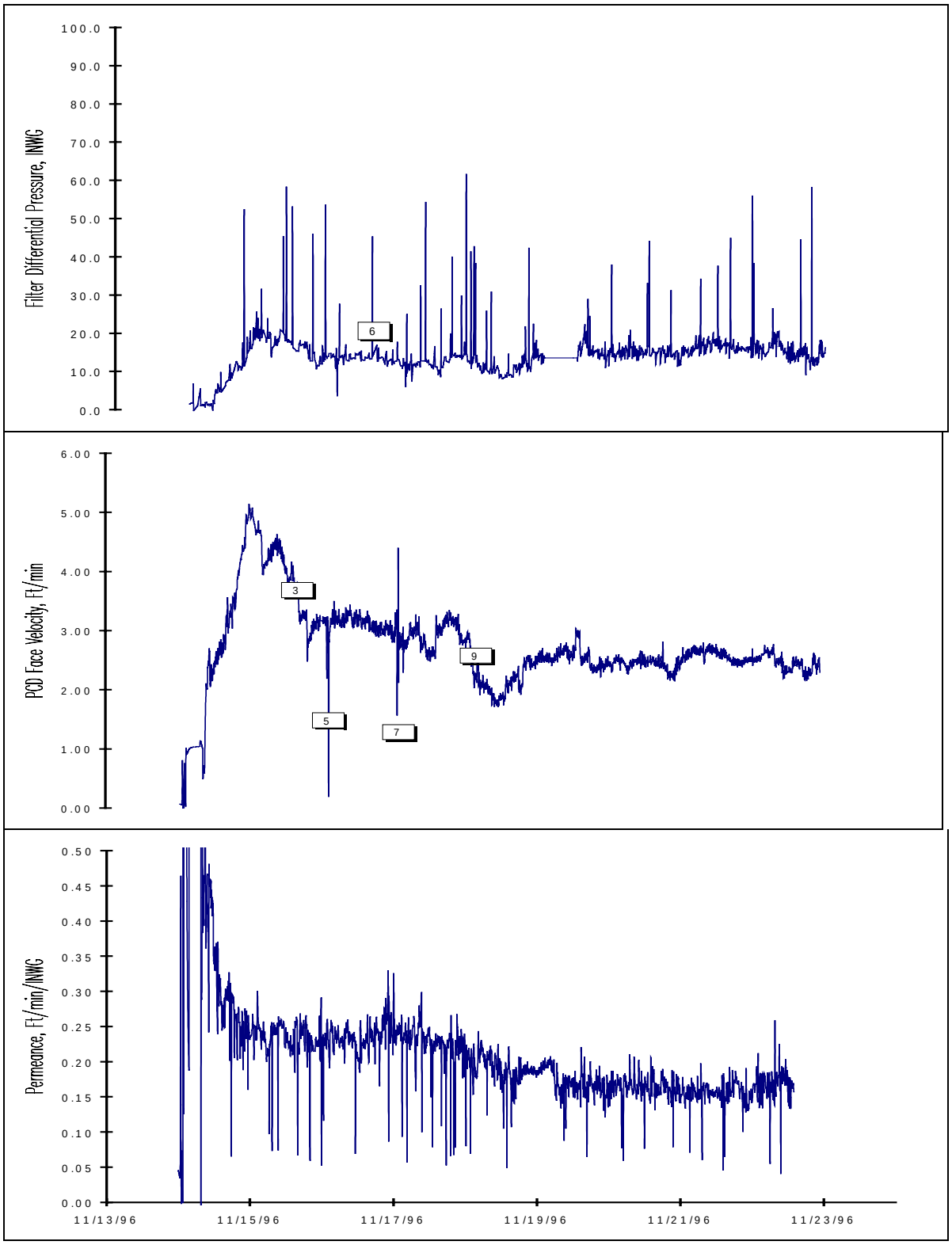


Figure 6.1.12-2 Run CCT2C Summary Information

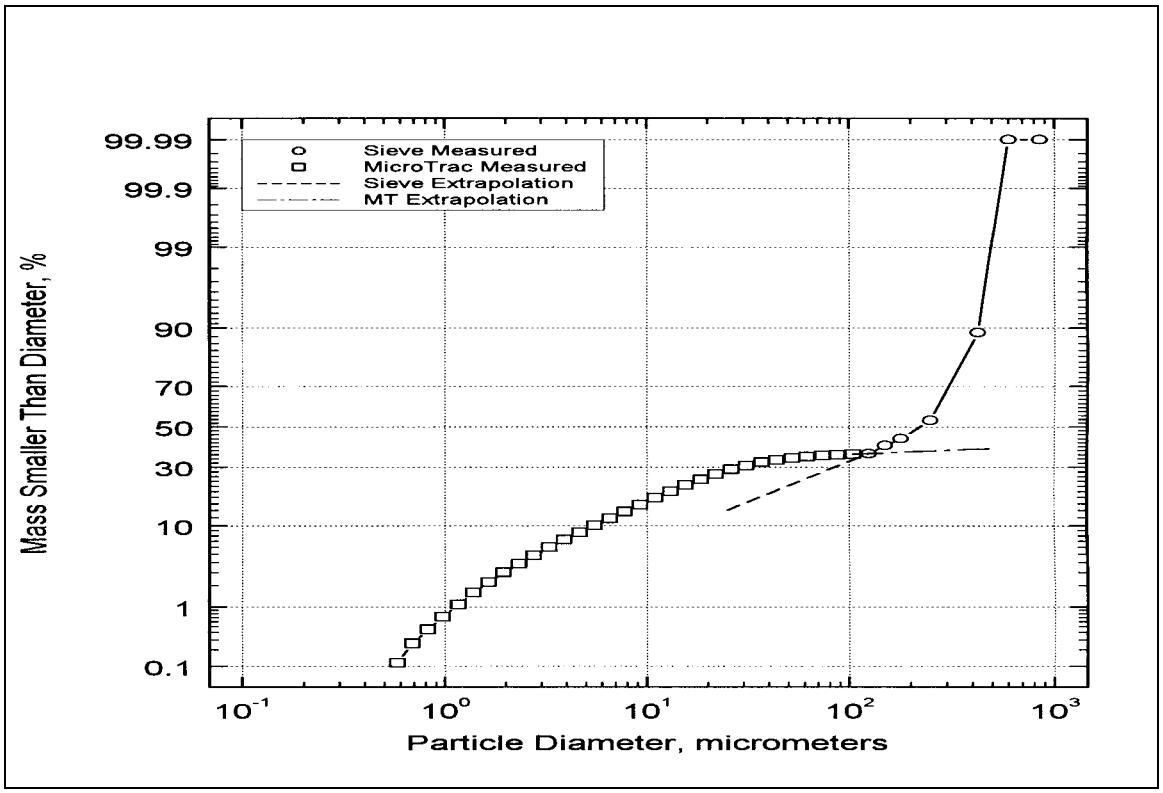


Figure 6.1.12-3 PCD Inlet Particle Size Distribution From Combined Sieve and Microtrac X-100 Measurements on In Situ Sample MWKIMT-3

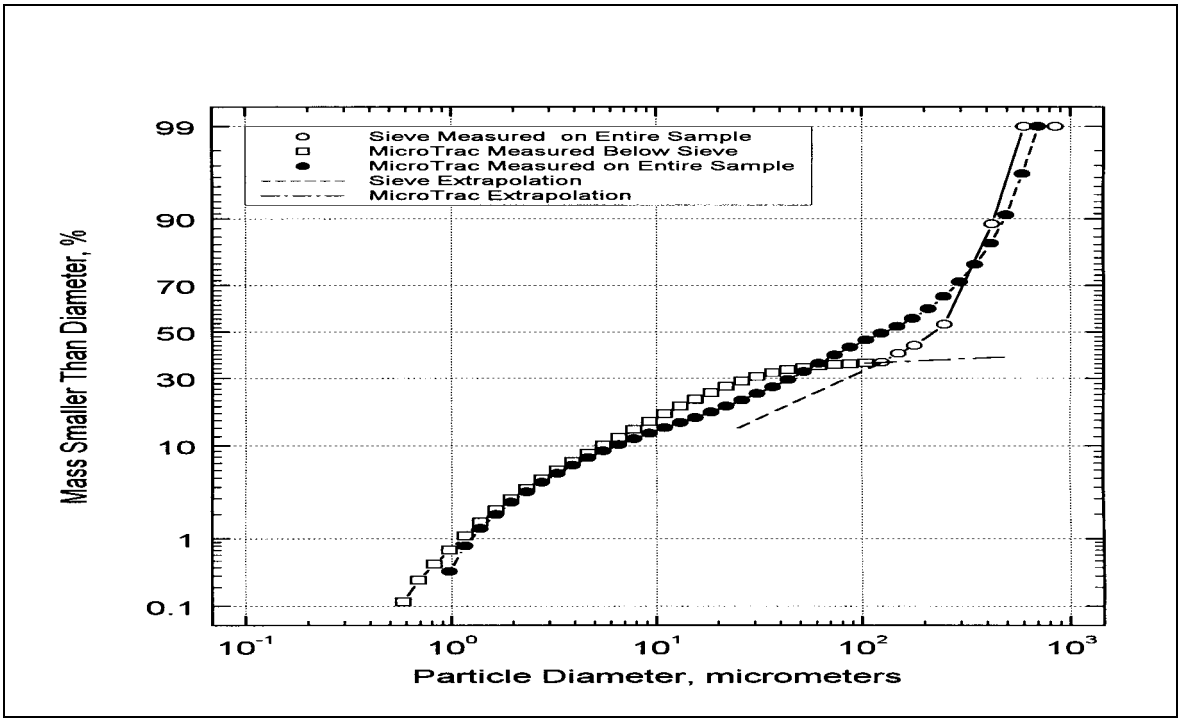


Figure 6.1.12-4 Microtrac Alone and Combined Sieve and Microtrac Measurements

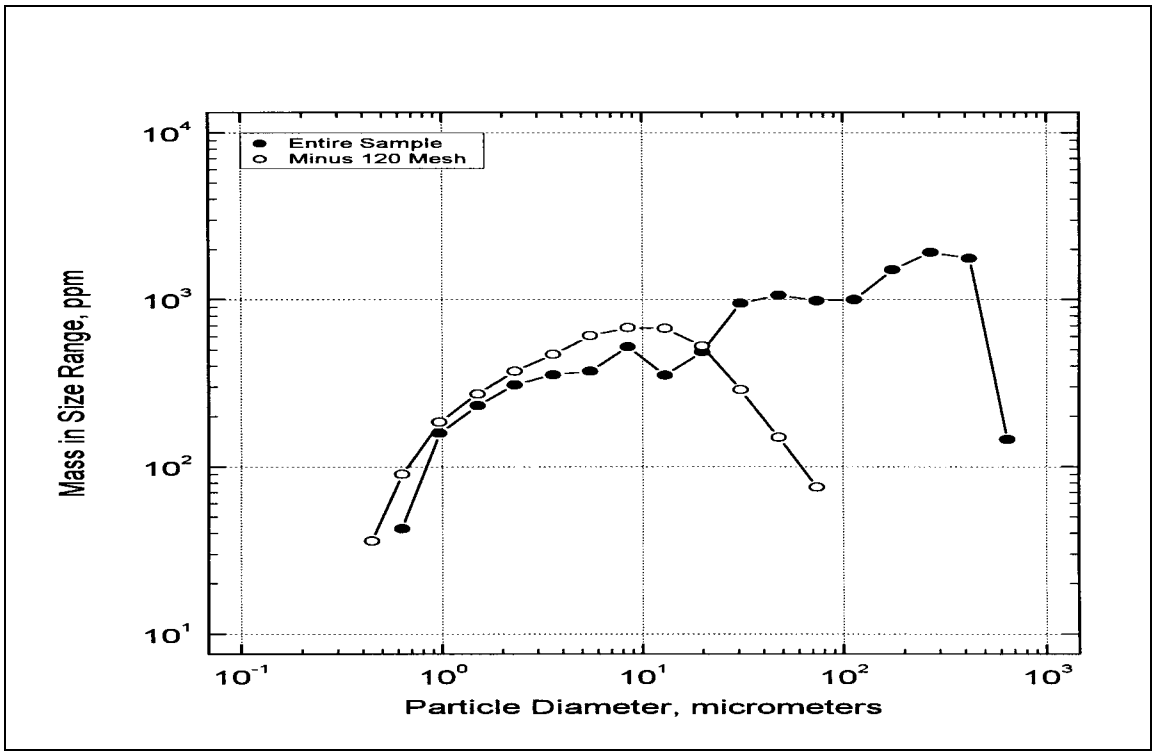


Figure 6.1.12-5 Comparison of Microtrac Measured Size Distributions for Complete Sample and Particles Smaller Than 120 Mesh

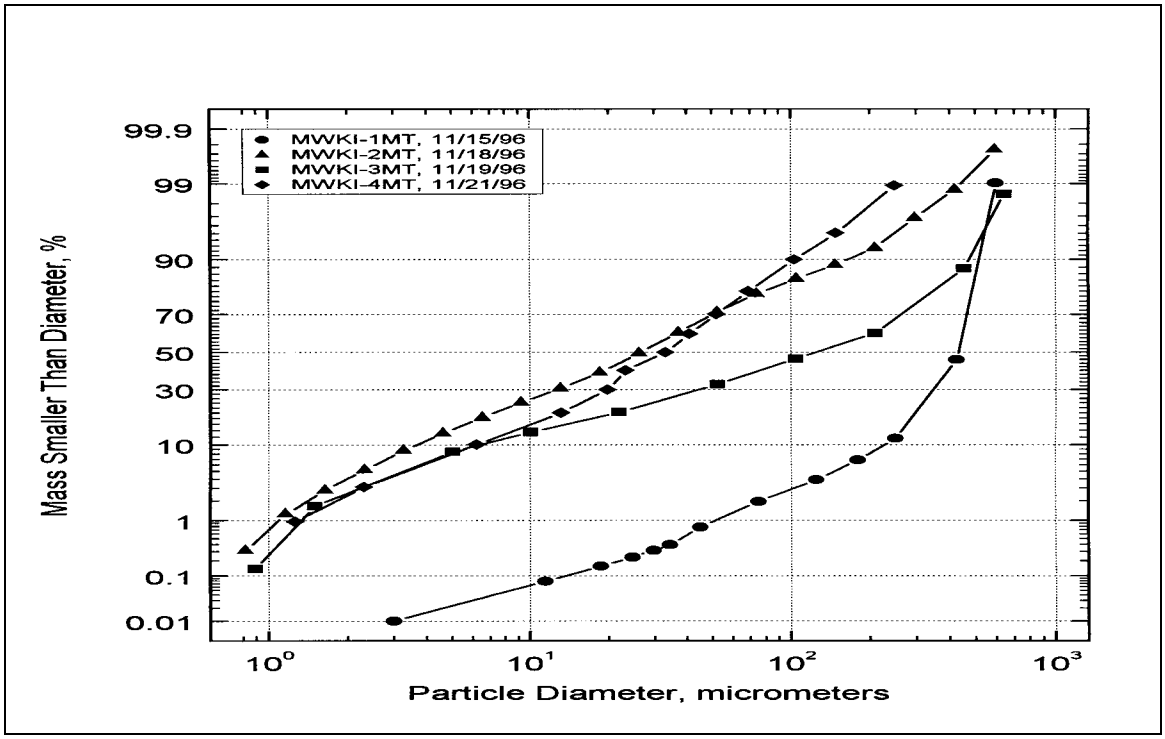


Figure 6.1.12-6 Comparison of Cumulative Percent Particle Size Distributions for All Isokinetically Collected Samples

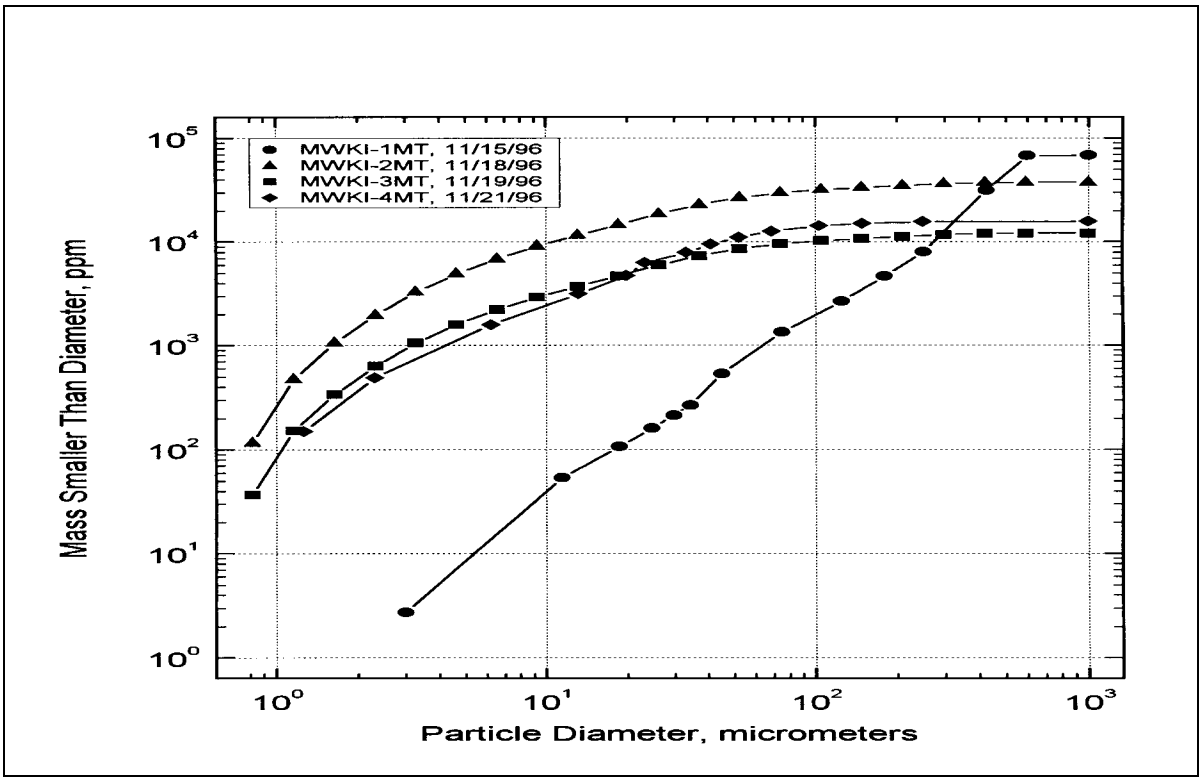


Figure 6.1.12-7 Comparison of Cumulative Mass Size Distribution For All Isokinetically Collected Samples

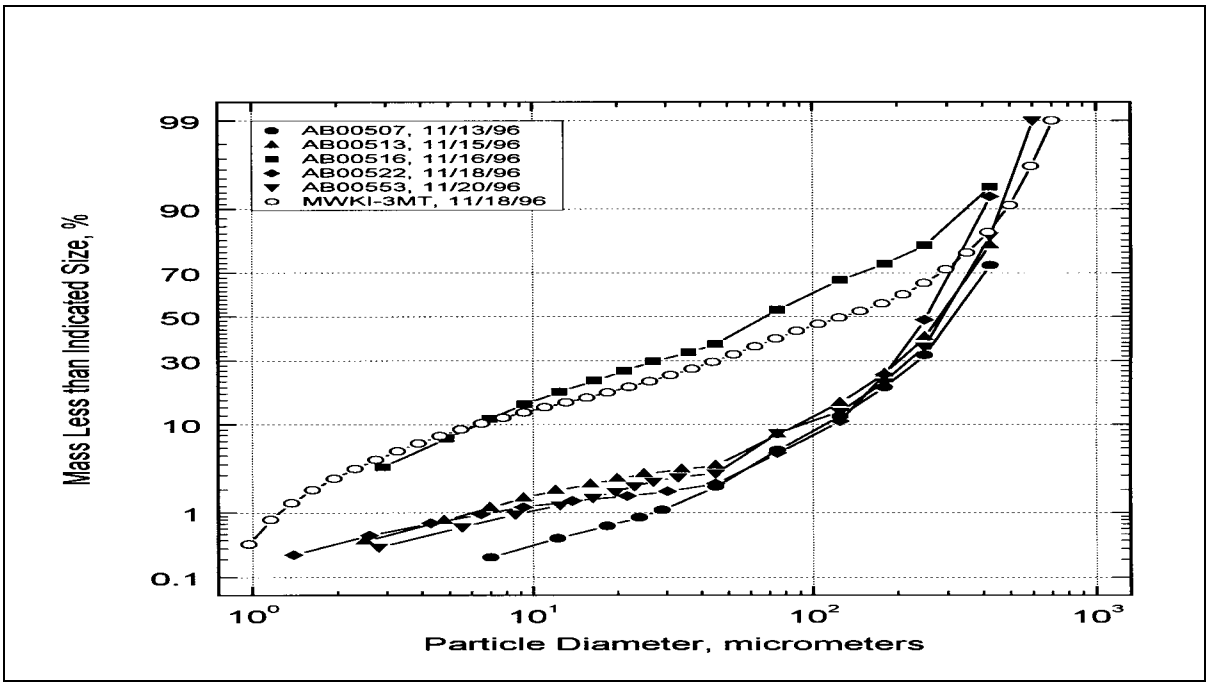


Figure 6.1.12-8 Comparison of Size Distributions From PCD Inlet In Situ Sample and PCD Cone Samples

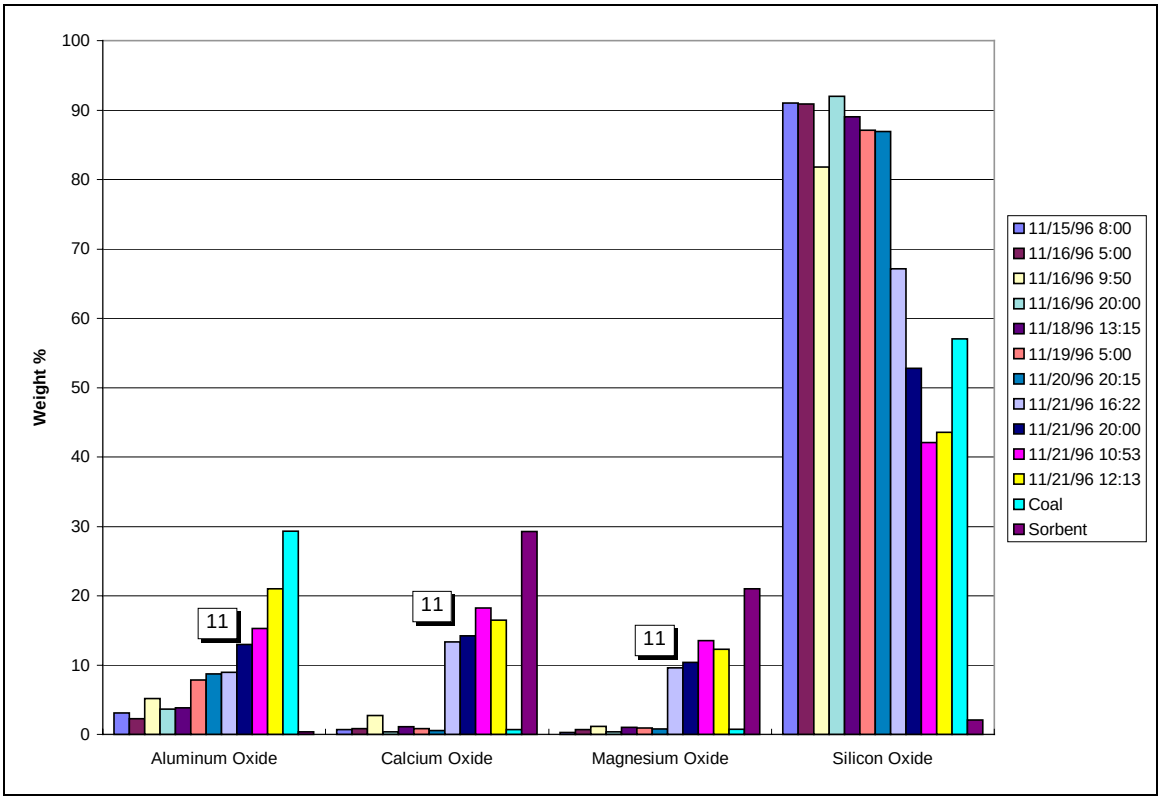


Figure 6.1.12-9 PCD Cone Ash Analysis (Major Constituents)

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

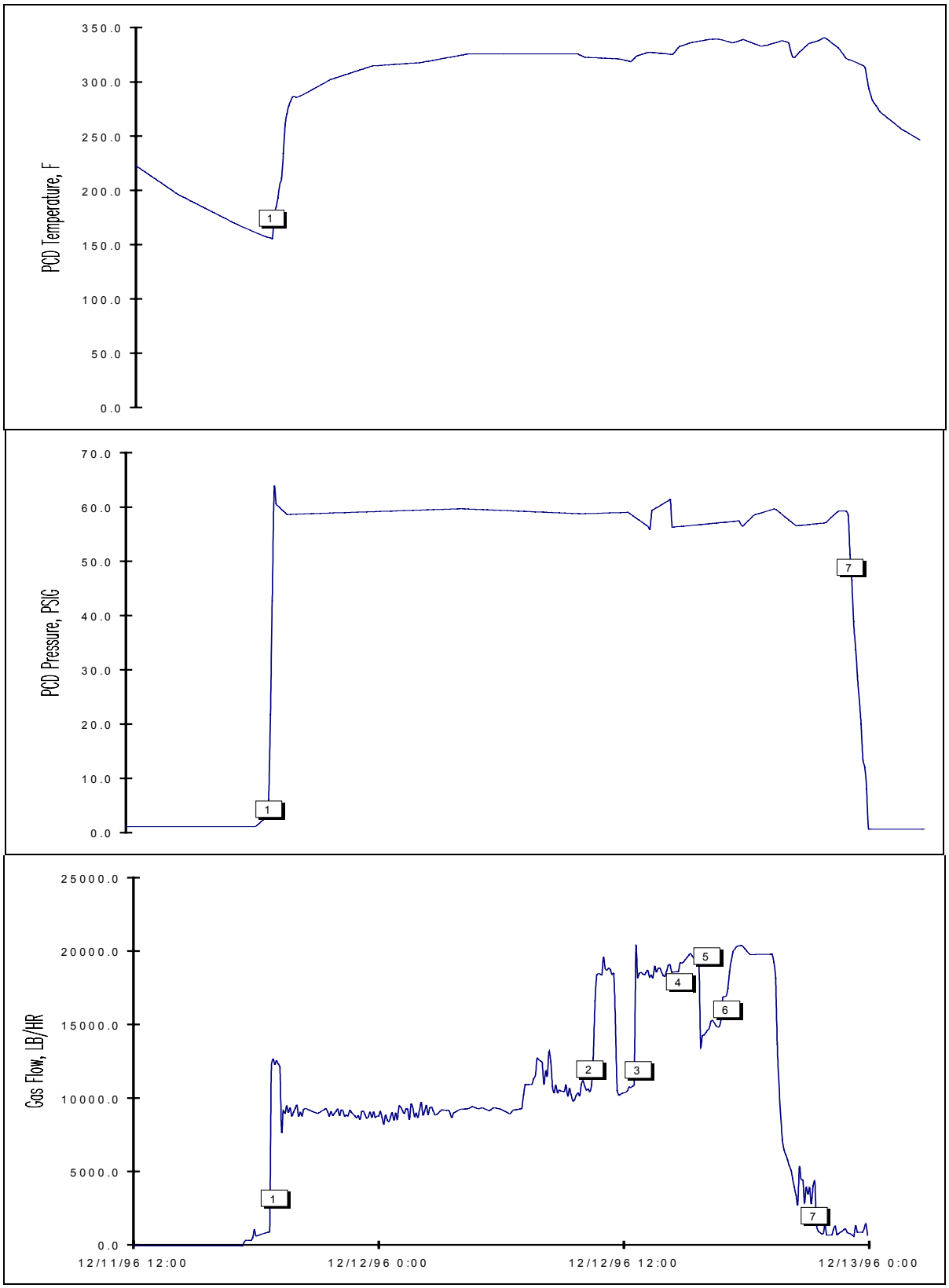


Figure 6.1.13-1 CCT3 Summary Information

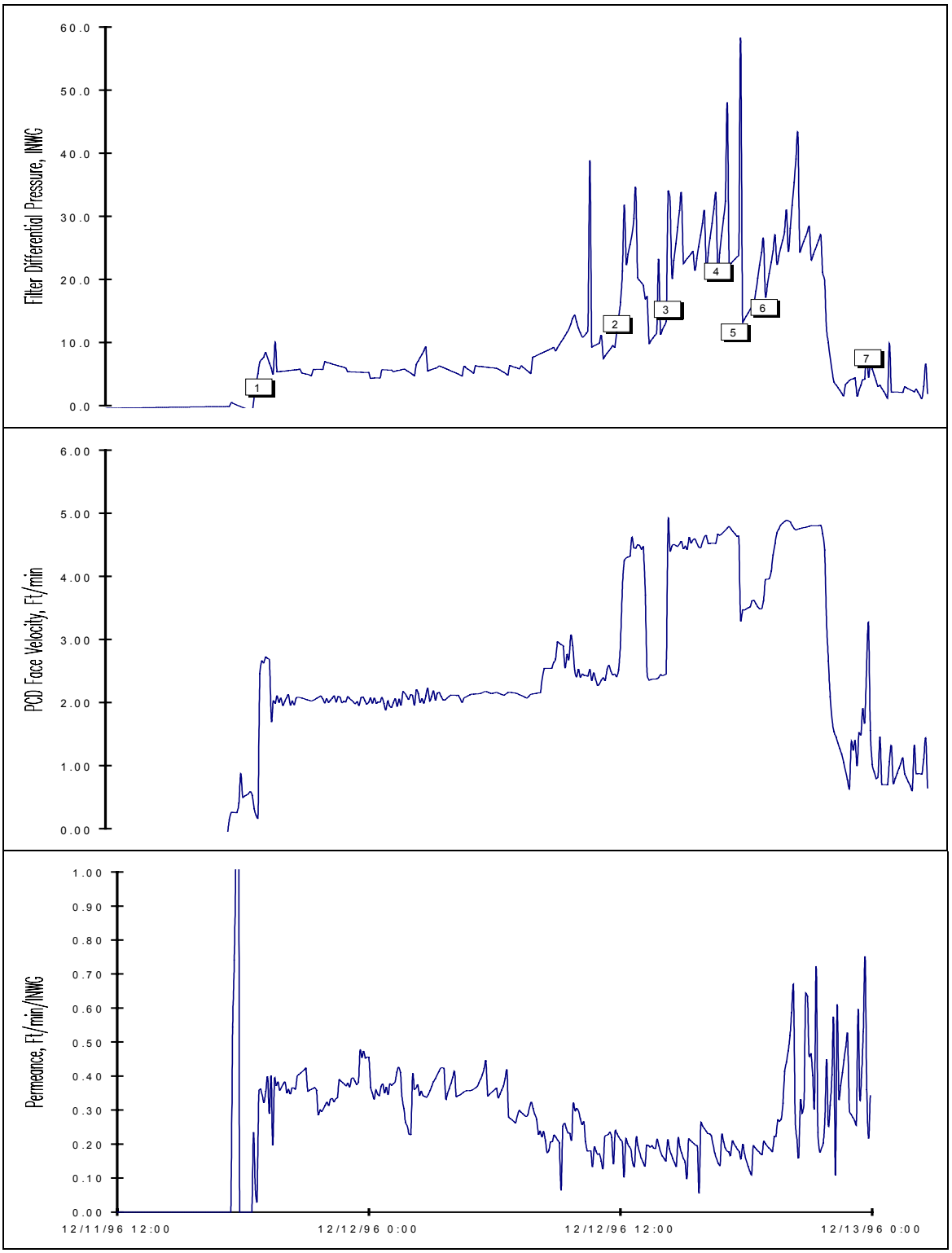


Figure 6.1.13-2 CCT3 Summary Information

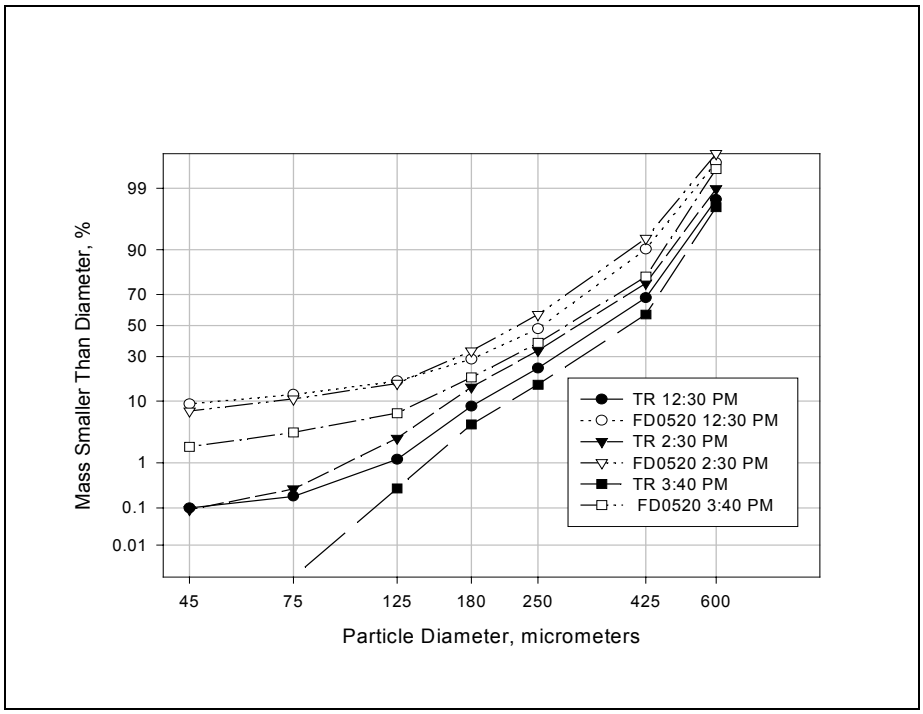


Figure 6.1.13-3 CCT3 Hopper Particle Size Distribution - December 1996 (Reactor Solid Separation Efficiency Tests 1, 2, and 3)

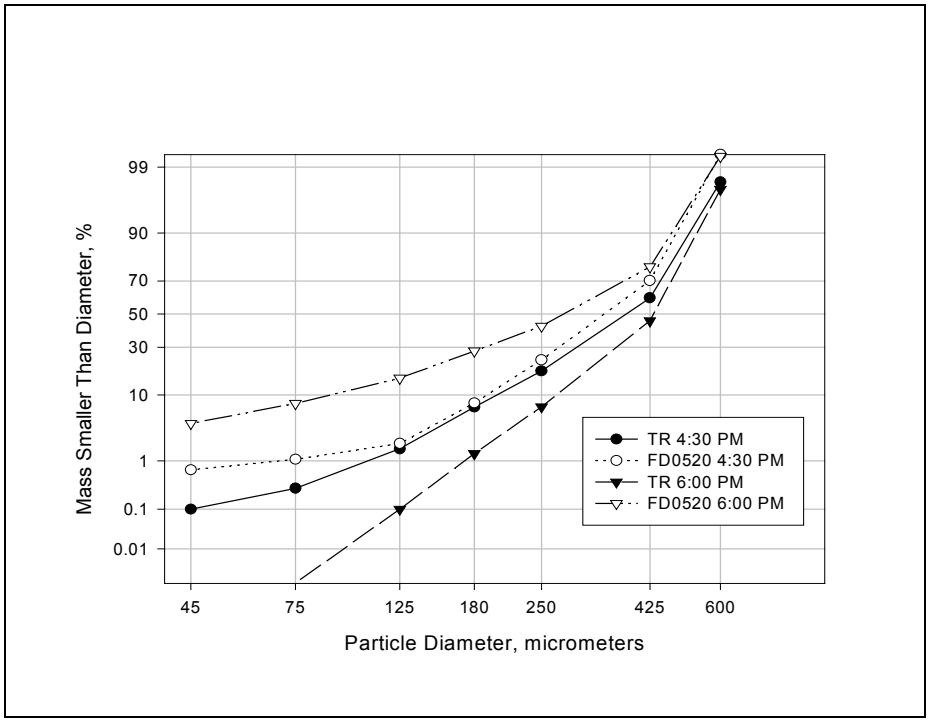


Figure 6.1.13-4 CCT3 Hopper Particle Size Distribution - December 1996 (Reactor Solid Separation Efficiency Tests 4 and 5)

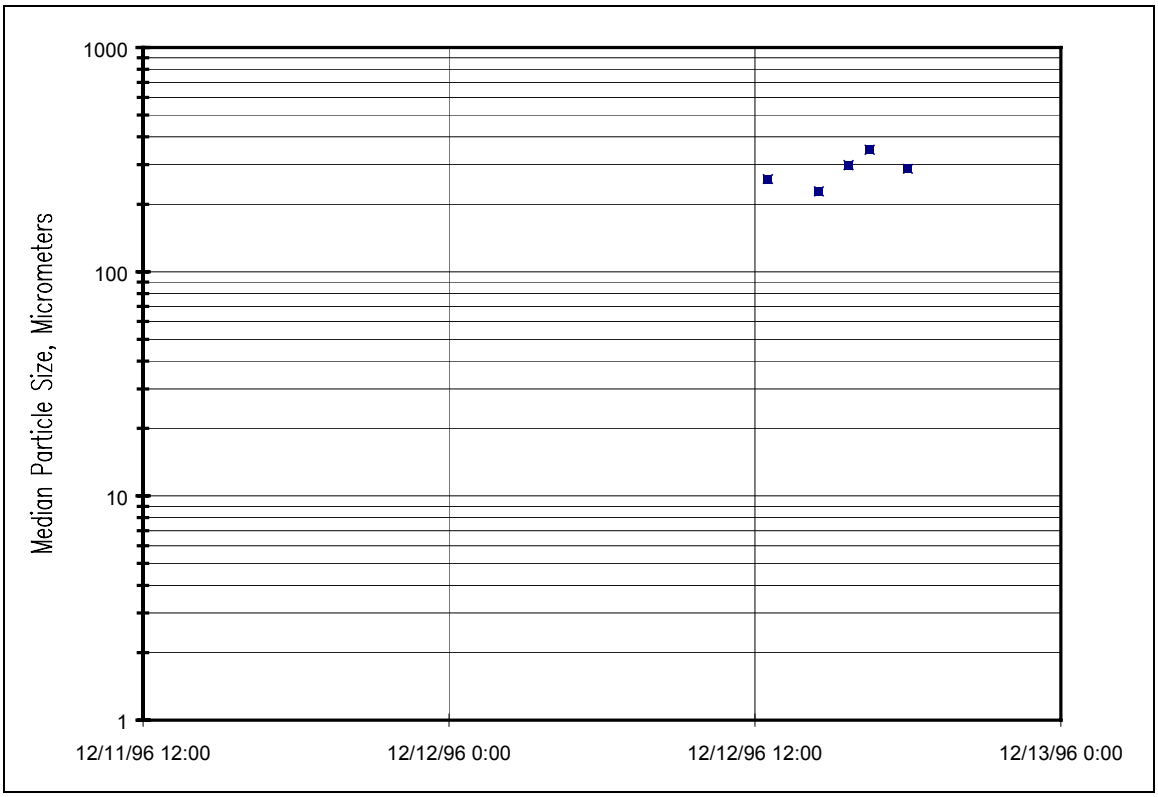


Figure 6.1.13-5 CCT3 PCD Hopper Samples

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.

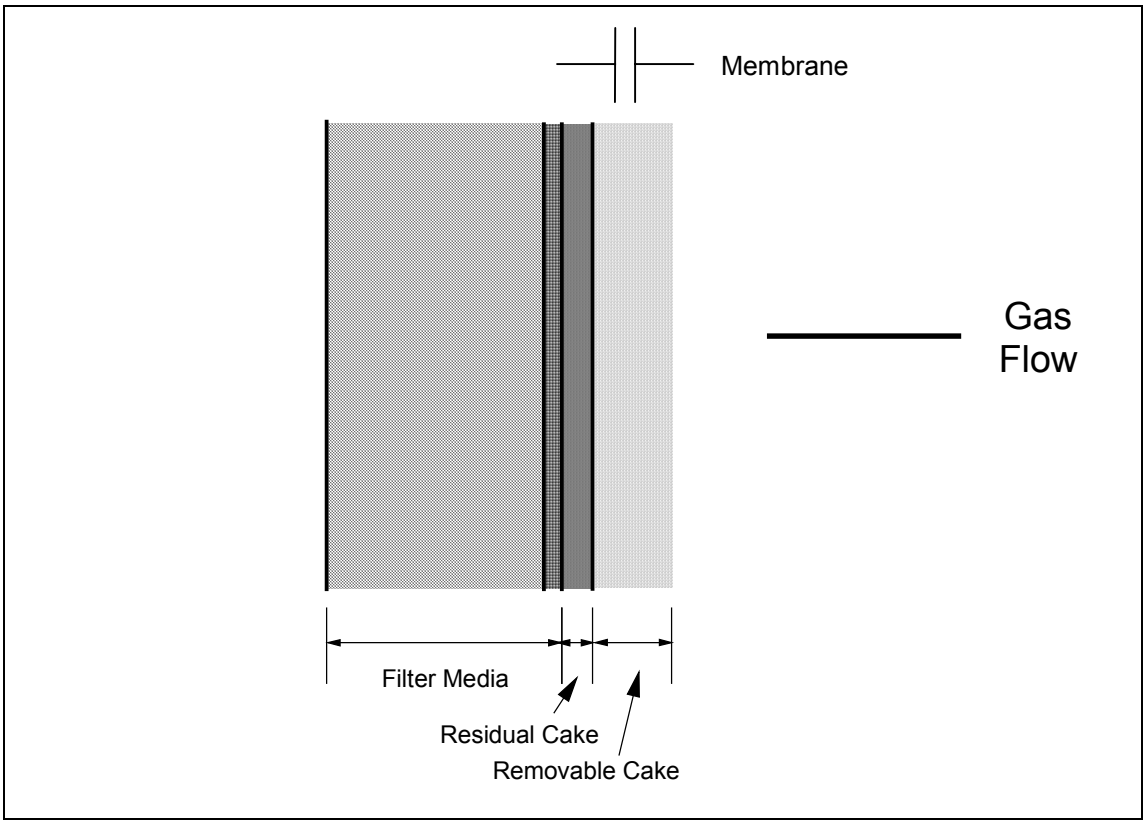


Figure 6.1.14-1 Resistances to Gas Flow

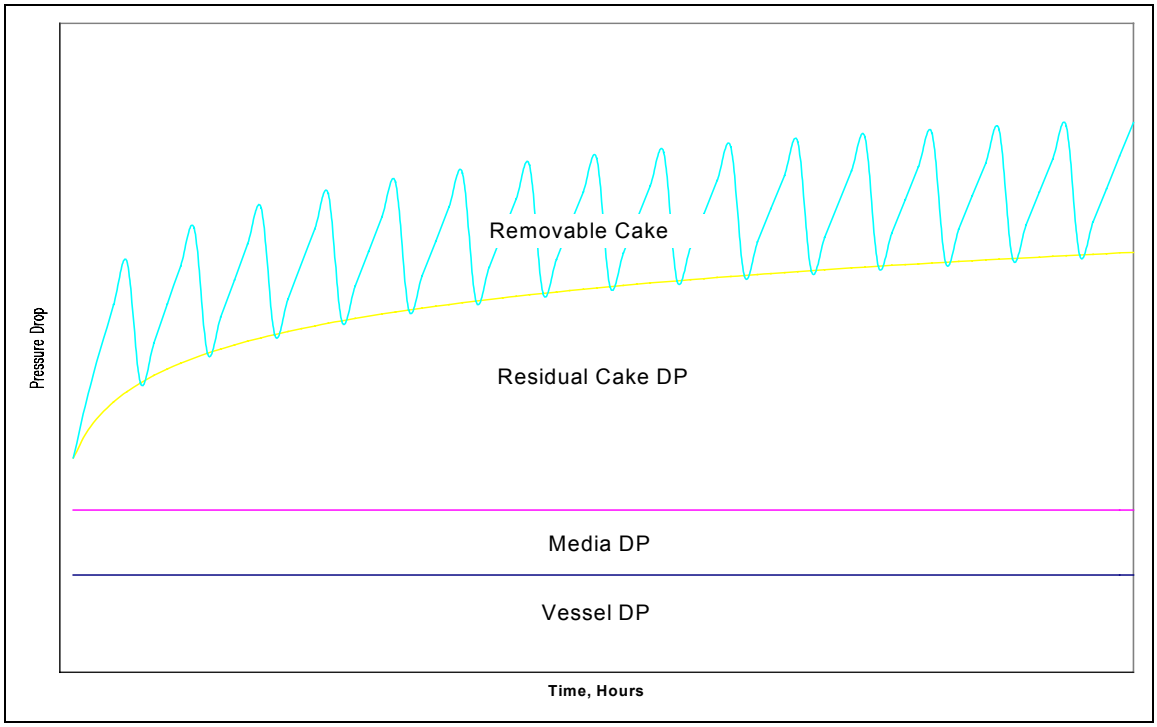


Figure 6.1.14-2 Buildup of Residual Cake ΔP

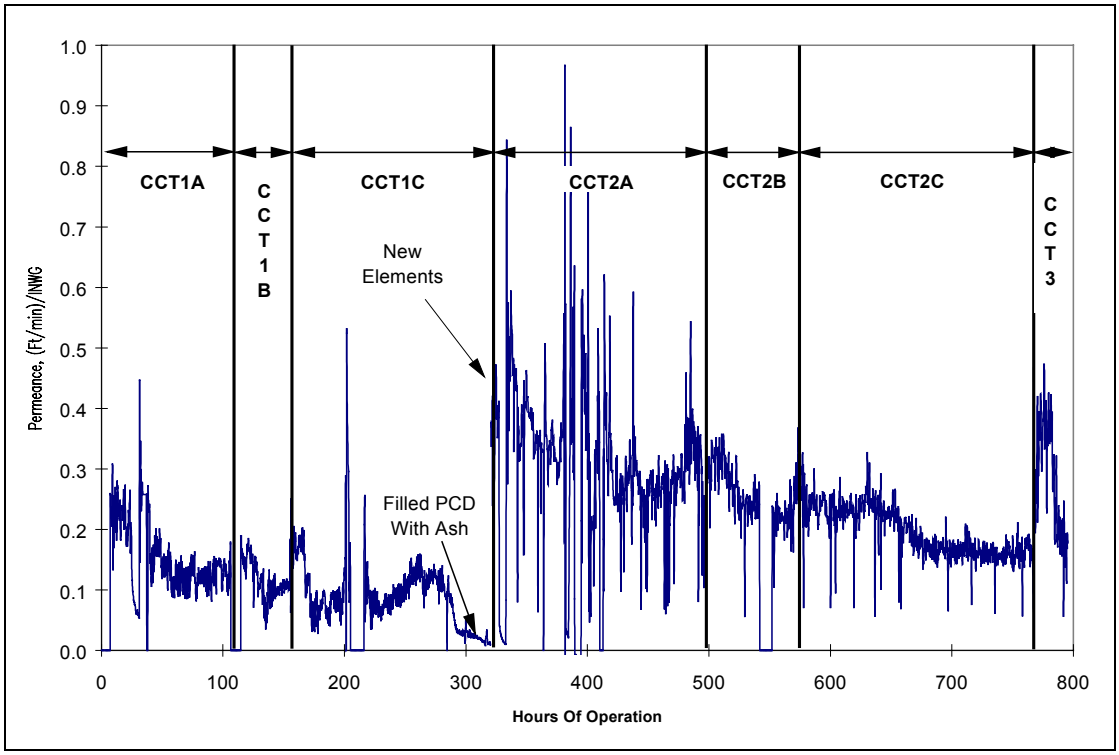


Figure 6.1.14-3 FL0301 1996 Permeance

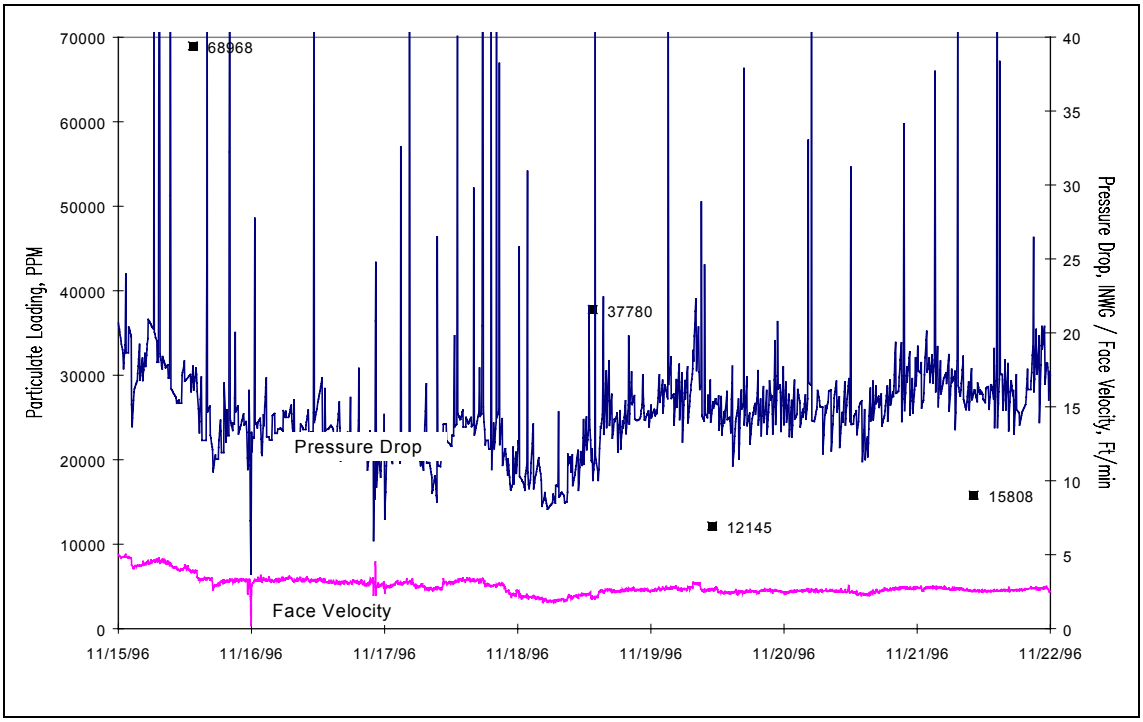


Figure 6.1.14-4 CCT2C Filter ΔP and Particulate Loading

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.

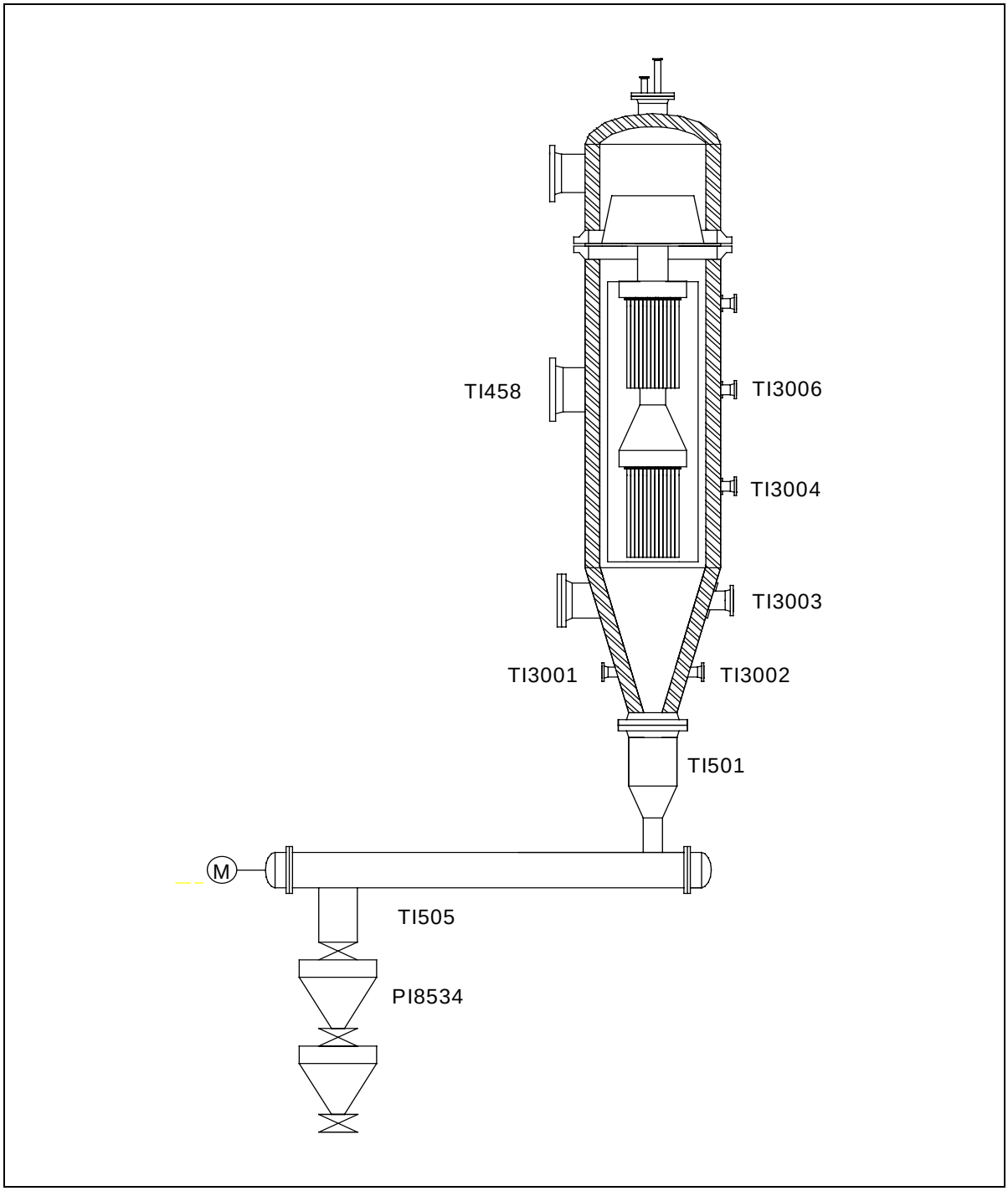


Figure 6.1.15-1 PCD/Ash Removal Instrumentation

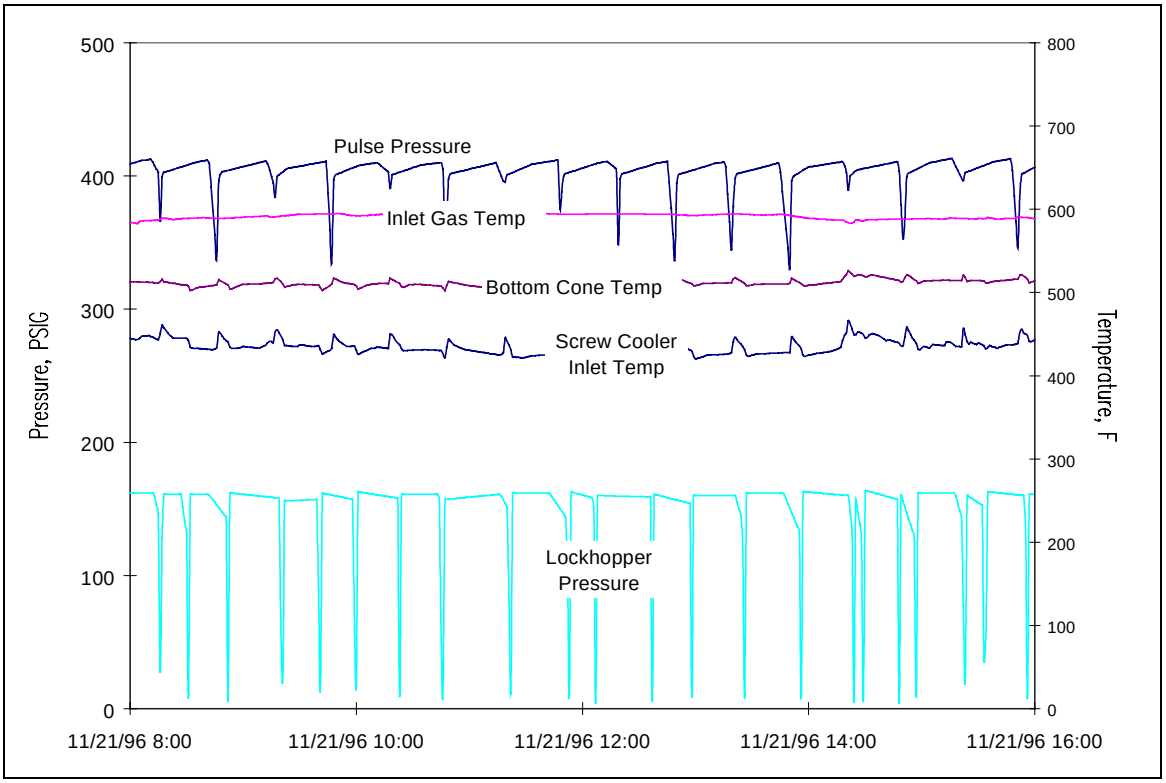


Figure 6.1.15-2 Normal PCD Operation

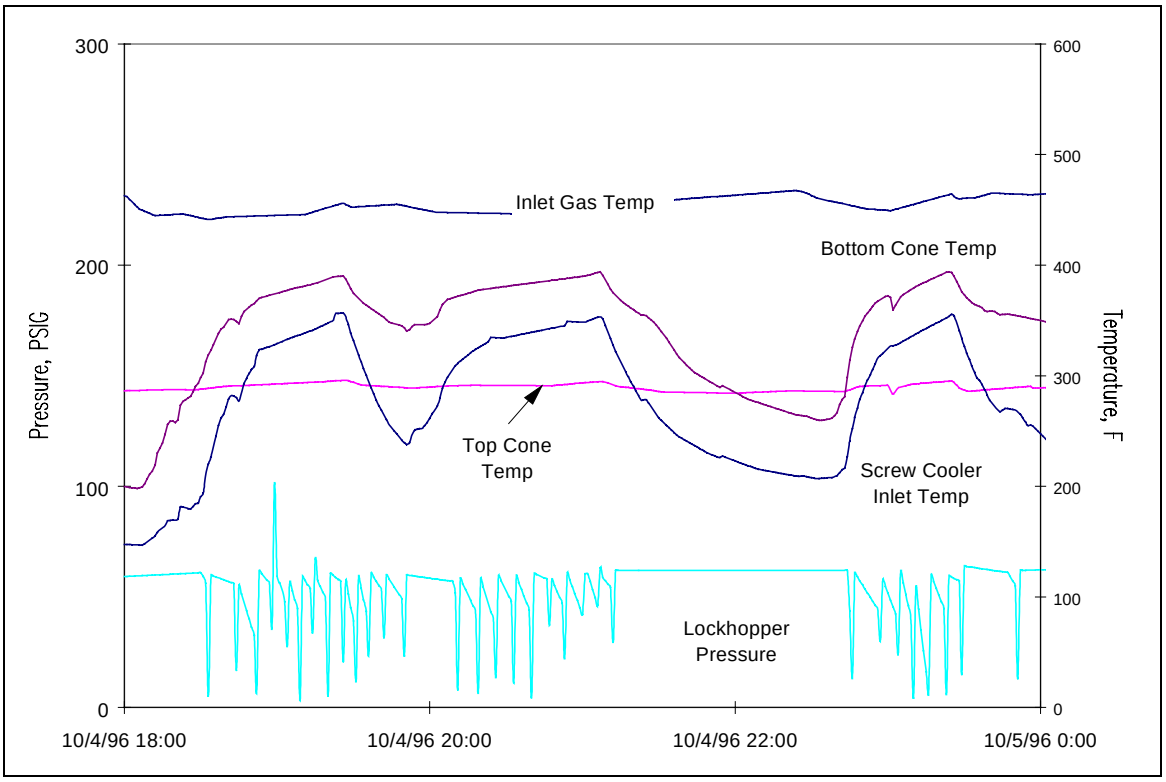


Figure 6.1.15-3 Excessive Carryover to PCD

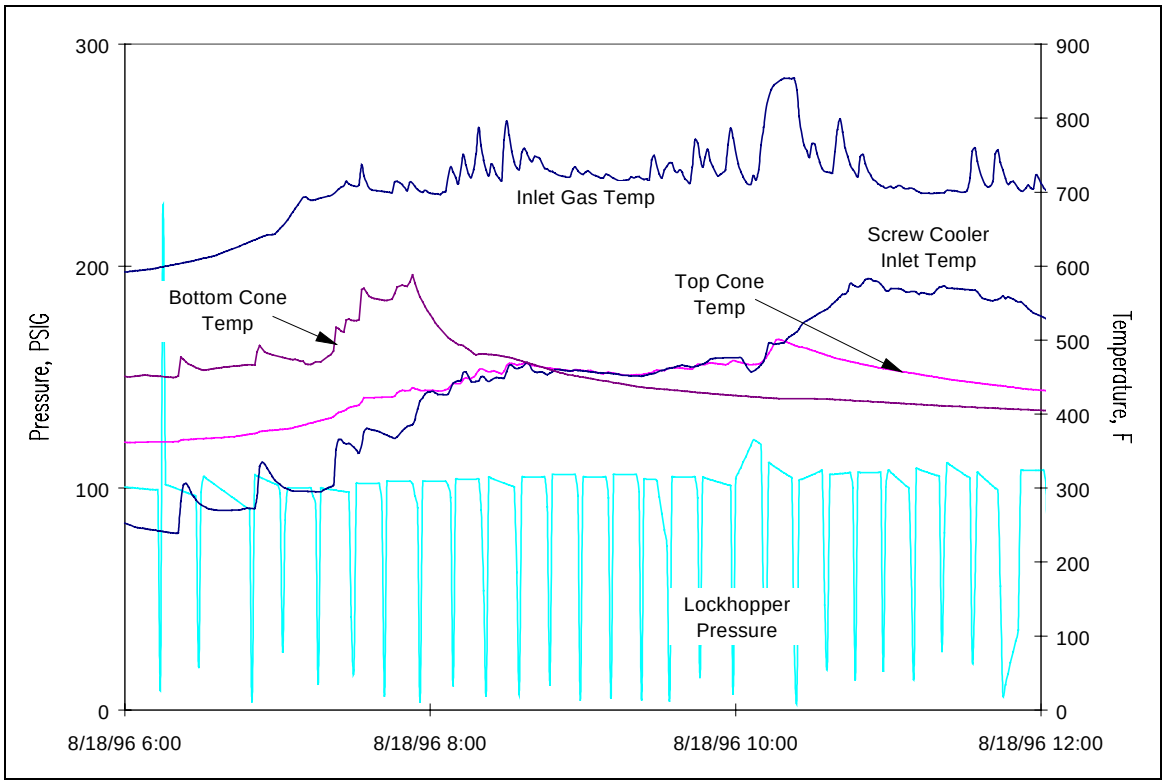


Figure 6.1.15-4 "Rat-Holing" of PCD Cone

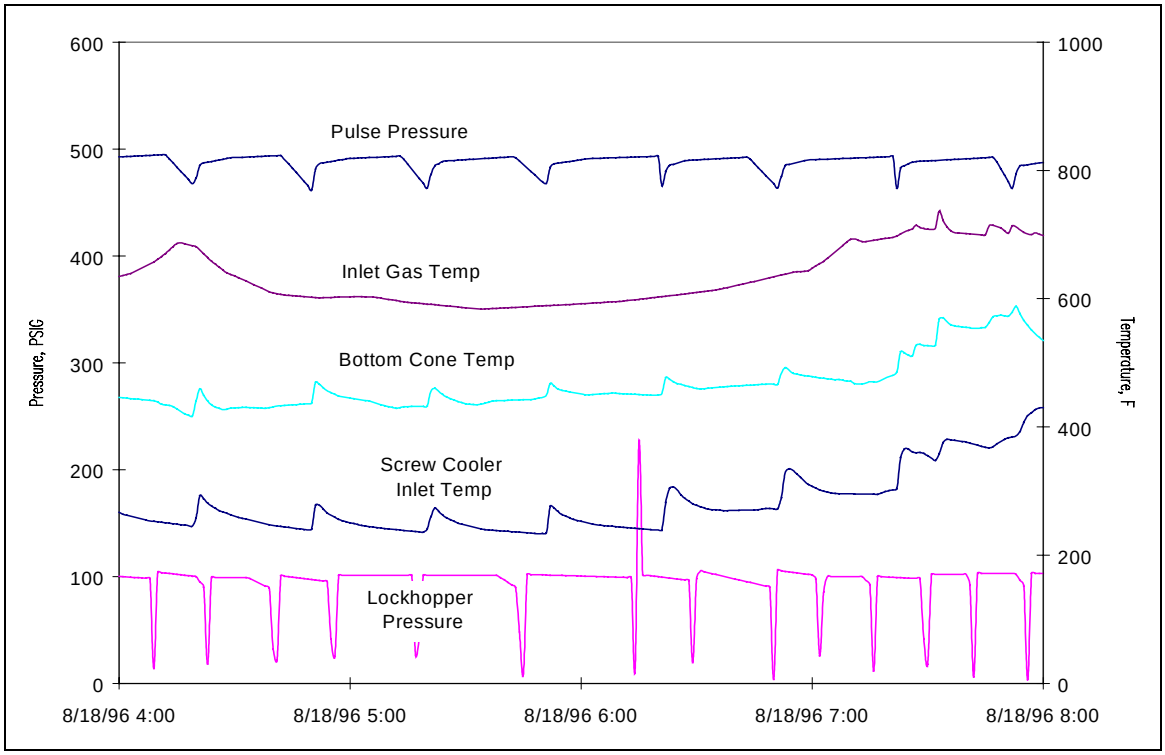
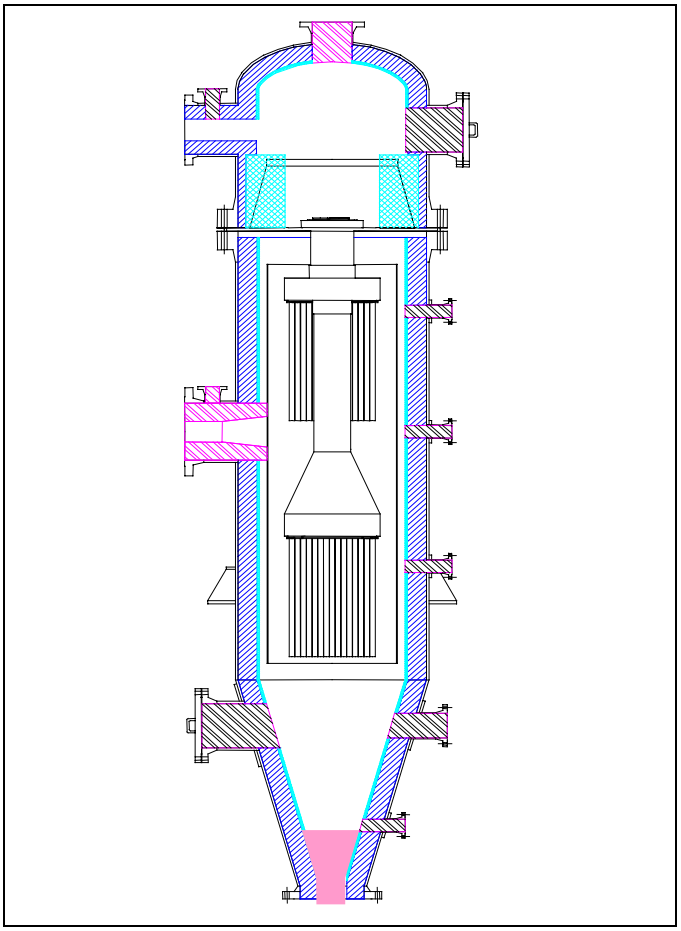


Figure 6.1.15-5 "Normal" Operation of PCD Prior to Filling



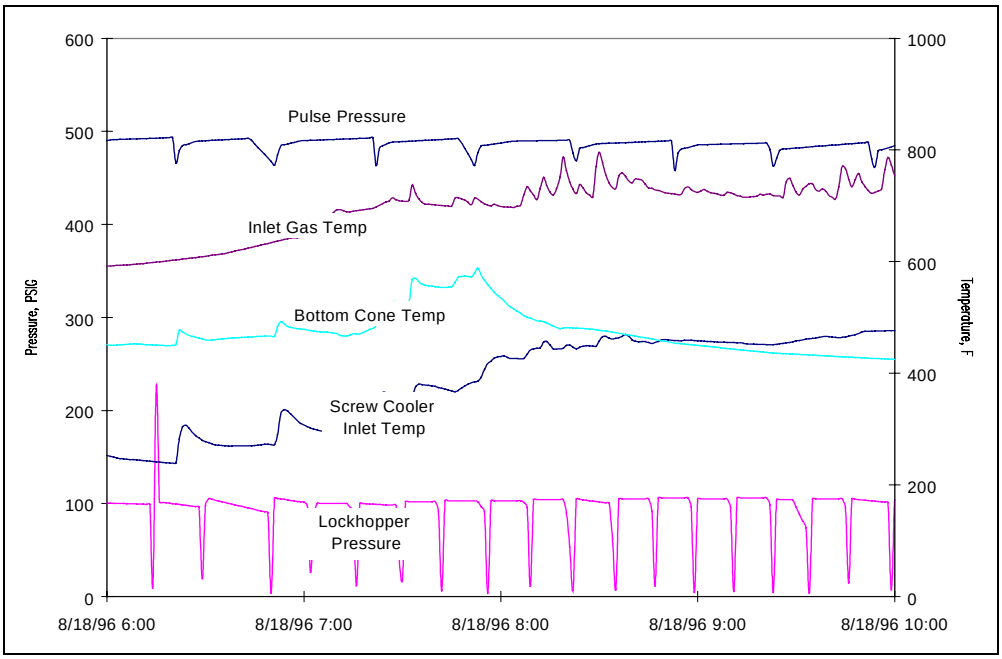
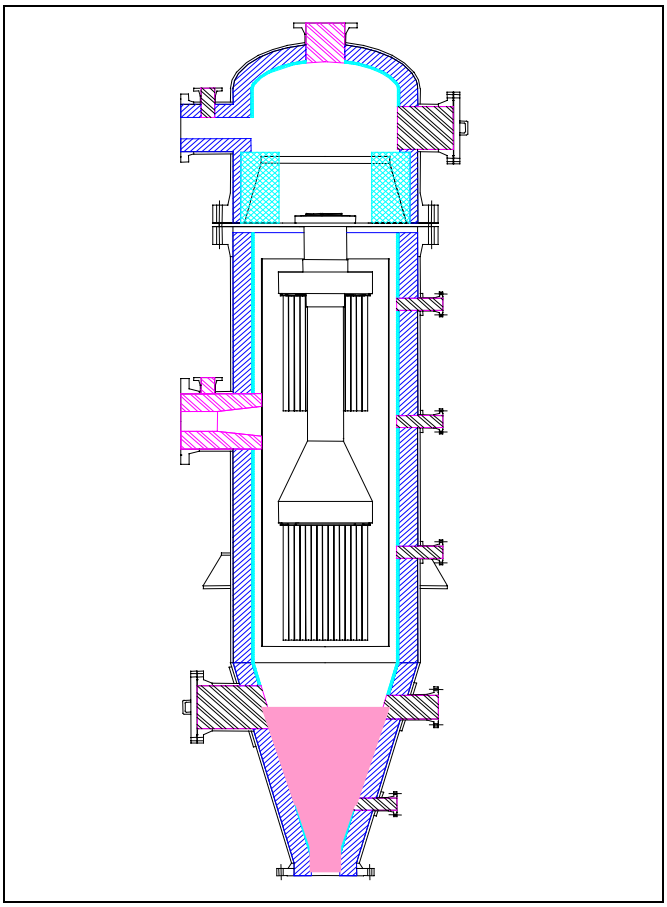


Figure 6.1.15-6 Bottom of PCD Cone Filled With Ash



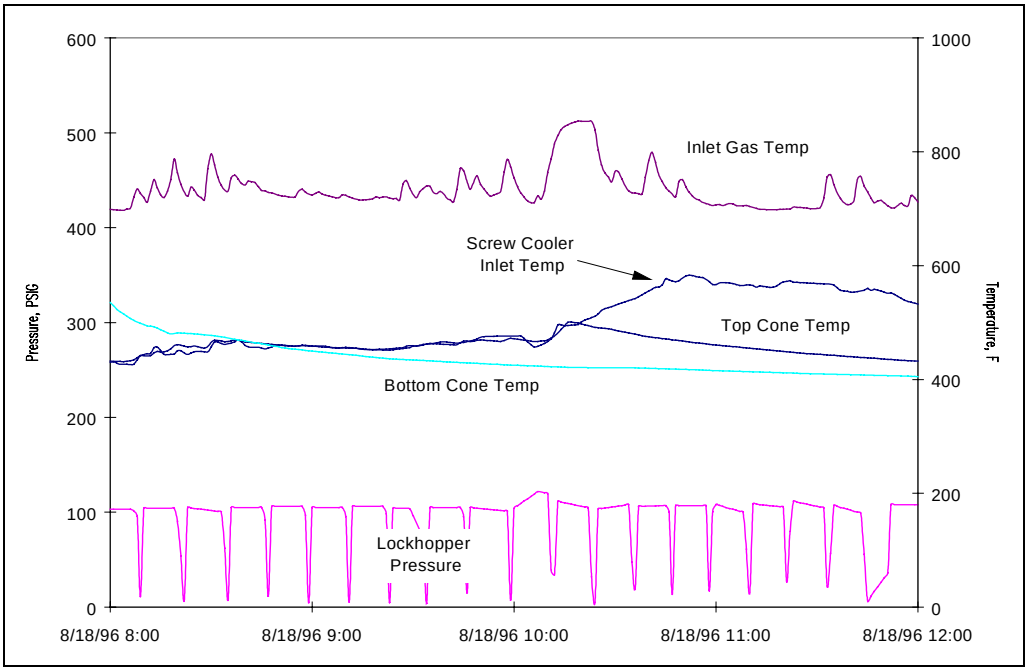
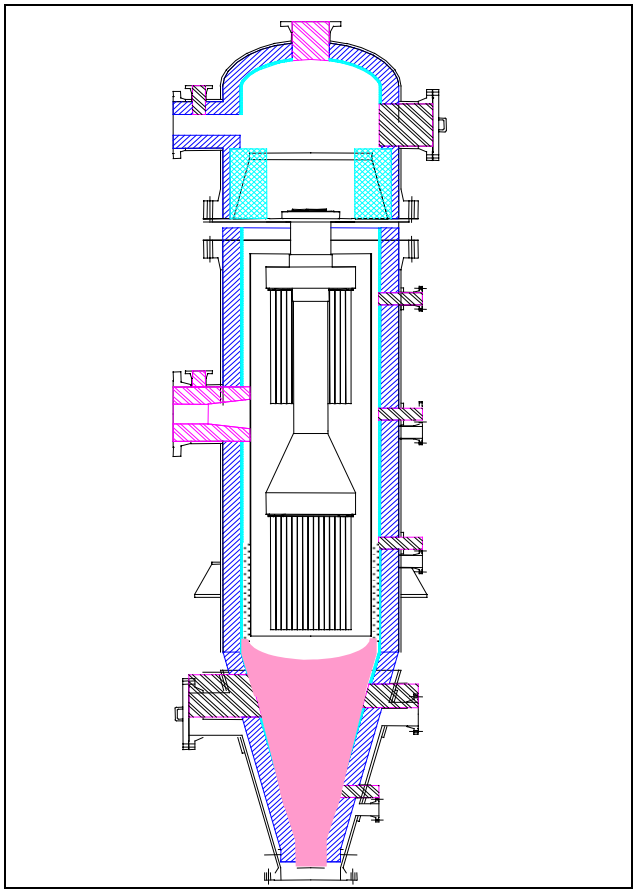


Figure 6.1.15-7 Top of PCD Cone Filled With Ash



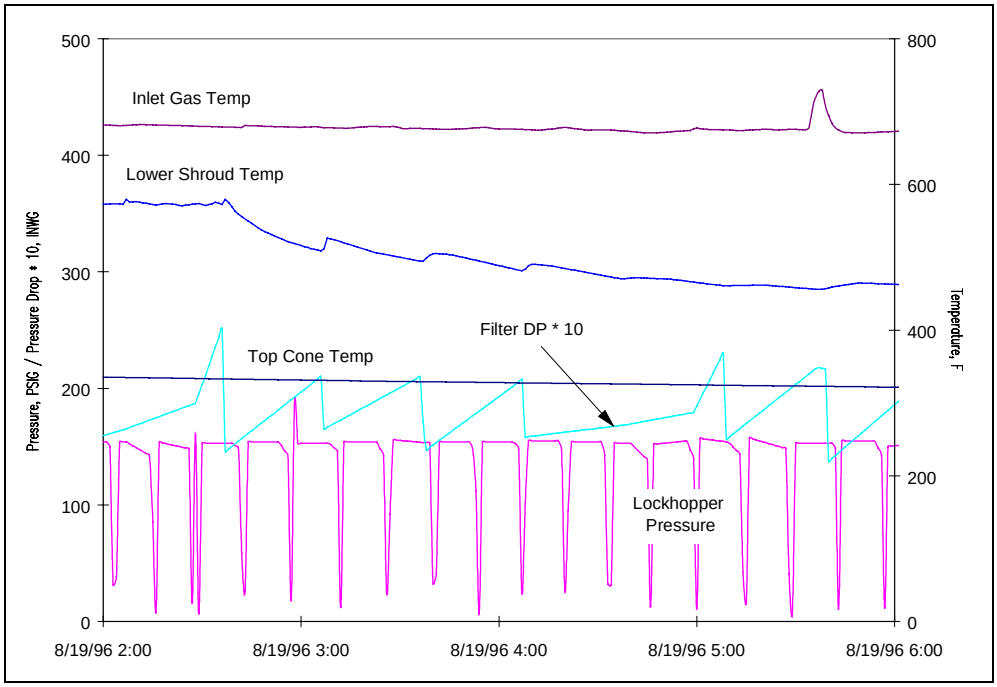
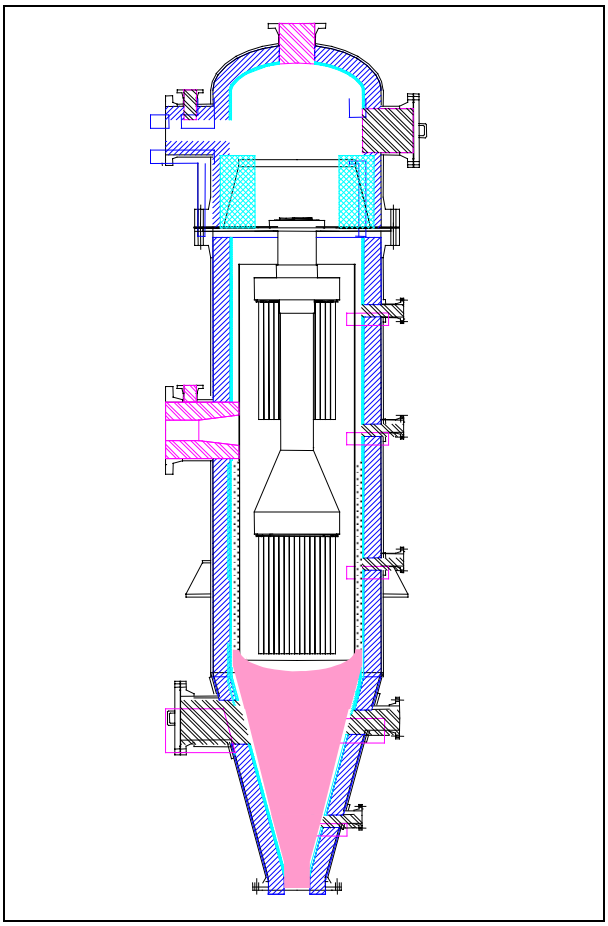


Figure 6.1.15-8 Lower Shroud Filled With Ash



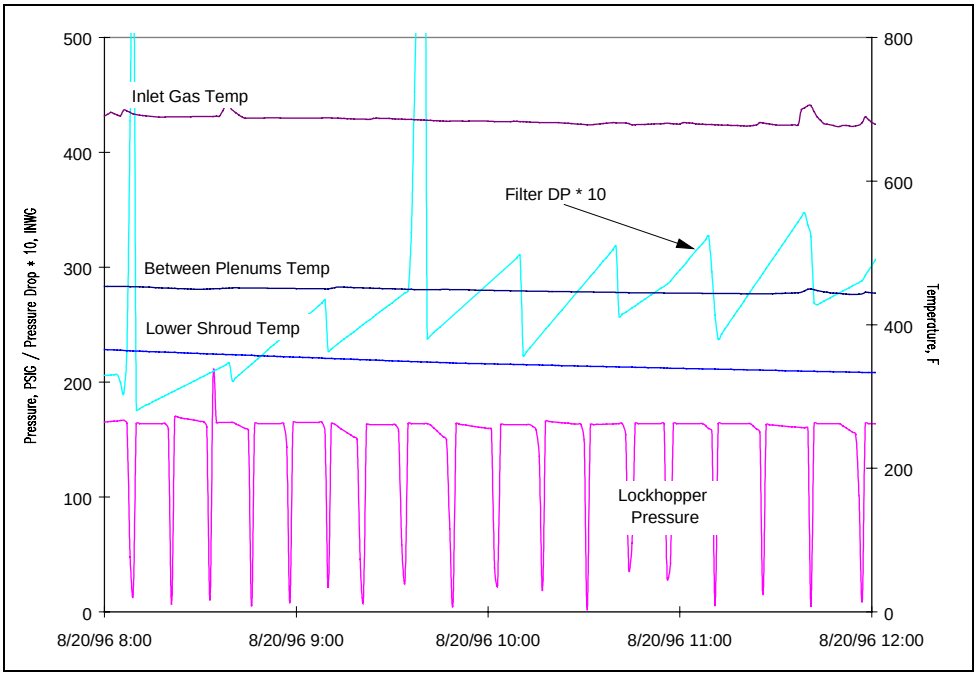
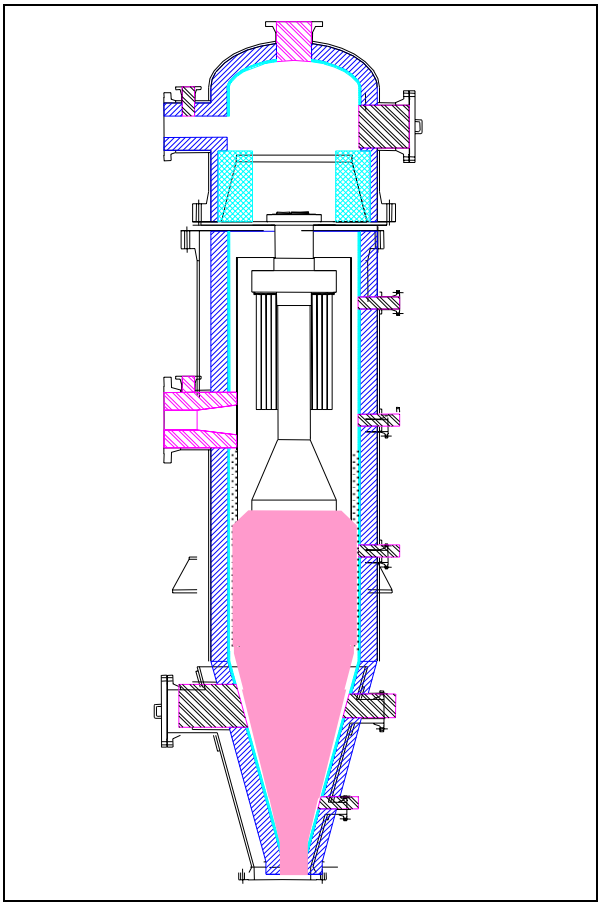


Figure 6.1.15-9 Beginning to Cover Lower Level With Ash



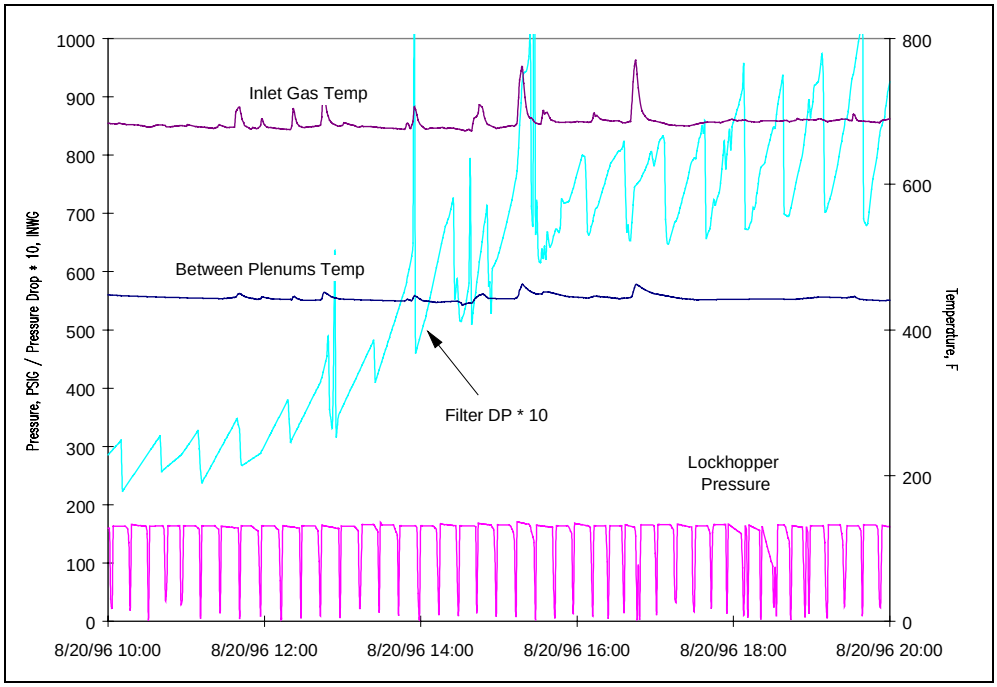
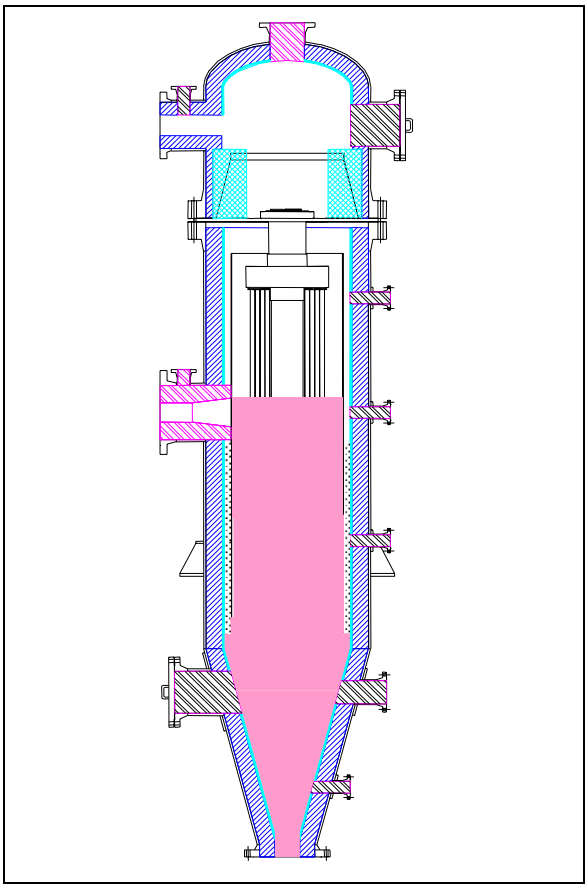


Figure 6.1.15-10 Lower Level Elements Covered With Ash



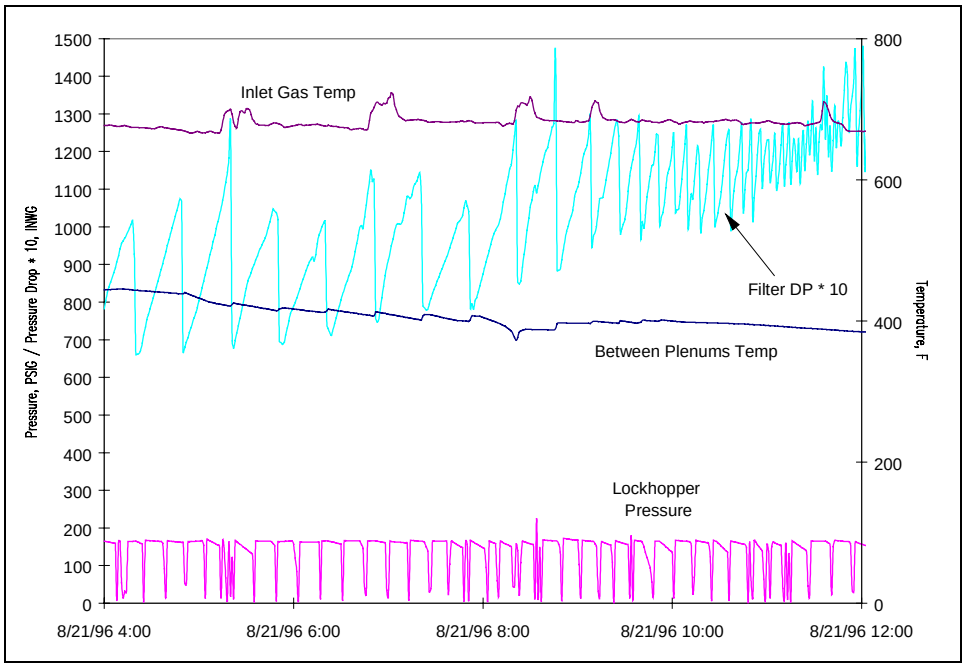


Figure 6.1.15-11 Beginning to Cover Upper Level With Ash

6.2 HIGH-PRESSURE AIR AND HIGH-PRESSURE NITROGEN SYSTEM

6.2.1 High-Pressure Air System

The high pressure air compressor (CO2203) is used for on-line back-pulse cleaning of the Westinghouse PCD(s) on the MWK transport reactor and the FW combustor. The unit is a dual-cylinder, double-throw reciprocating compressor manufactured by the Norwalk Co. designed to produce ca. 1,450 lb/h of air at a maximum pressure of 1,500 psig. The compressor receives air from the service/instrument air system during combustion operation or nitrogen from the low pressure nitrogen system in the event that the high pressure nitrogen (RIX) compressors are not functional during MWK gasification operation. The gas is stored in a primary accumulator near the compressor and is then delivered to secondary accumulator tanks located on the Westinghouse back-pulse skid before entering the PCD.

6.2.1.1 Commissioning

The compressor was commissioned during May and June of 1996 by Norwalk, Hydromatics, and PSDF personnel. Two vendor visits were required due to miscellaneous problems described below.

6.2.1.2 Problems and Solutions

The following briefly summarizes the problems that were encountered, reason(s) for the problems, and the corresponding resolution(s):

PROBLEMS	SOLUTIONS
• Low discharge pressure (combination of three leaking valves and poor sealing surface of number 1 cylinder).	• Rebuilt the valves and remachined sealing surface.
• Overheating of number 1 cylinder and lifting of intercooler PRV.	• Solutions above also corrected this problem.
• Rain water in oil reservoir.	• Removed and cleaned reservoir and redesigned cover of oil reservoir.

6.2.1.3 Performance

The compressor was successfully functionally checked and commissioned. The unit performed as expected for back-pulsing the Westinghouse PCD during the MWK runs with

no major complications. The compressor has been run a total of 72 hours from commissioning through

MWK test run operation. The low-run time is due to the noncontinuous mode of operation of the system. Operation of the compressor consisted of running it only long enough to build maximum pressure in the primary accumulator tank and then shutting it down. As the pressure in the accumulator tank approached the PCD pulse pressure setting, the compressor was restarted to build the accumulator tank supply. There are plans to modify the system for automatic unloading operation prior to the need for higher pressures and larger volumes of pulse gas needed for future tests. Figure 6.2.1-1 shows a plot of accumulator pressure variation during MWK test run CCT1 in July 1996. This plot is typical of system operation during all MWK commissioning activities and test runs.

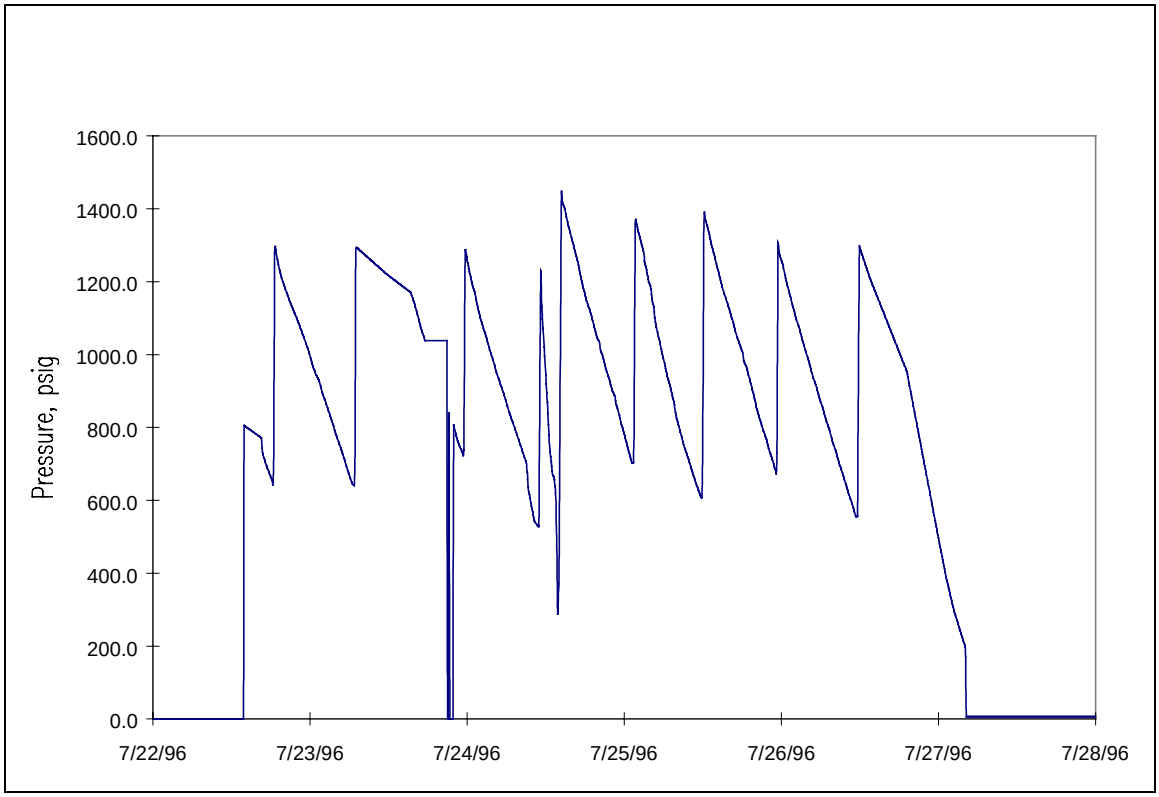


Figure 6.2.1-1 High-Pressure Air Accumulator Tank Pressure

6.2.2 High-Pressure Nitrogen System

The high pressure nitrogen system consists of 3, 3-stage reciprocating compressors, each capable of producing 115 SCFM of oil-free nitrogen at 2,030 psig and ca. 280°F. The units are manufactured by the RIX Co., but assembled and programmed by Compressed Air Products (CAP). These units are used for gasification mode back-pulsing of the PCD(s) on the MWK train and/or the carbonizer PCD on the FW train. Nitrogen is supplied at 30 psig by the on-site BOC Nitrogen plant, either from the plant's generation or the liquid lack-up system, to the compressors and then delivered to an accumulator assembly (6 tanks in parallel) with a capacity of 62.9 ft^3. The gas is then delivered to the PCD skid-mounted accumulators on an as-needed basis.

6.2.2.1 Commissioning

Commissioning of these compressors occurred in two phases due to PLC programming changes and personnel availability. CAP, Hydromatics, and RIX initially came to the site during September 1996. Due to a host of problems discussed below, CAP came back in mid-October to complete the installation and finalize commissioning.

6.2.2.2 Problems and Solutions

PROBLEMS	SOLUTIONS
• On skid water leaks.	• Tightened fittings.
• Poor welds on accumulators.	• Cut heads off and rewelded.
• Melted discharge valves.	• Wrong valve material: replaced valve.
• Motor shaft rubbed housing.	• Adjusted housing.
• Exposure to hot (>300°F) lines.	• Insulated lines.
• Inoperable.	• Miscellaneous PLC changes.

6.2.2.3 Performance

During commissioning in late October 1996, the compressors ran according to the design specifications after several days of effort and numerous PLC changes. The compressors have not been run since this time since they are required for gasification operation and only combustion operation has been attempted through the end of 1996.

6.3 PCD FINES REMOVAL SYSTEM COMMISSIONING

6.3.1 PCD Fines Screw Cooler

The purpose of PCD fines screw cooler FD0502 is to convey material from the MWK PCD solids outlet to the fines transport system (FD0520) and to simultaneously cool the material to an acceptable temperature prior to depressurization. It consists of a motor-operated screw conveyor with heat transfer fluid both within the screw shaft and in the jacket of the metal casing which encloses the screw shaft.

For the most part, the FD0502 screw cooler was commissioned and operated in conjunction with the PCD fines transporter system that is described below. There were, however, some operational issues associated only with the screw cooler. The screw cooler mechanical operation was essentially flawless. The only mechanical problems associated with the screw cooler involved heat transfer fluid leaks, which were repaired. Functional checks in March and April of 1996 revealed some control logic problems that were easily solved.

Operation of the screw cooler was crucial to MWK operation since solids had to be removed from the PCD to avoid failure of the filter elements and subsequent shutdown of the transport reactor from solids build-up in the PCD. For this reason, the screw cooler was run constantly throughout all MWK reactor commissioning activities and operation. Its total run time in 1996 is comparable to that of the FD0520 system, which ran for close to 900 hours, because the two systems were almost always run simultaneously for PCD solids removal. Prior to the coal combustion run CCT1C in August the screw cooler was operated at 3 rpm because it was not known that a higher removal rate was necessary. This rate was increased by increasing the screw speed to the maximum value of 8 rpm for subsequent runs. The maximum value was increased to 12 rpm for test run CCT2C, and the rate is to be maintained at this maximum value for all subsequent operation. Figure 6.3.1-1 shows the screw cooler speed during CCT2C on November 20. Also shown in figure 6.3.1-1 are the inlet and outlet temperature of the screw cooler, which show the amount of solids cooling provided by the screw to be approximately 275°F ΔT. The spikes in inlet temperature occur approximately every 30 minutes and are due to the influx of hot solids from the PCD immediately following pulse cleaning of the candle filters which is on a 30-minute cycle.

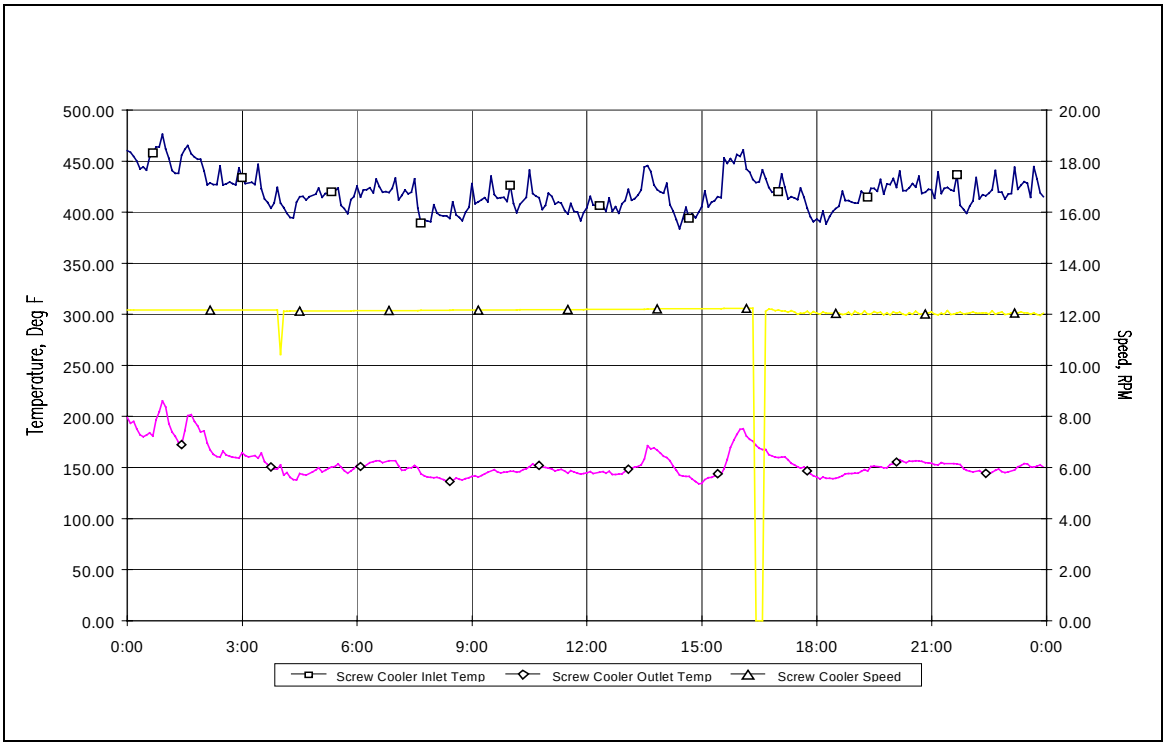


Figure 6.3.1-1 Fines Removal Screw Cooler Operation November 20, 1996

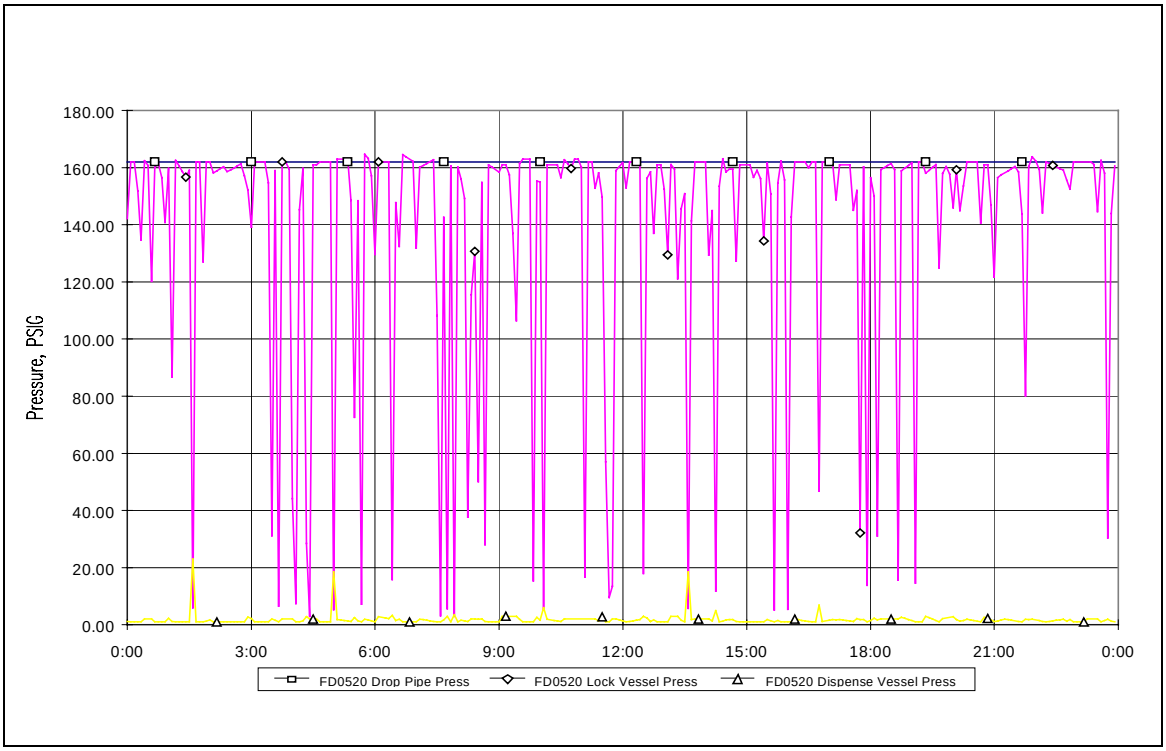


Figure 6.3.1-2 Fines Transporter System Cycles November 20, 1996

6.3.2 PCD Fines Transporter

The PCD fines transporter (FD0520) functions to depressurize solids from the fines screw cooler (FD0502) and pneumatically convey the solids to a common collection bin for both PCD and transport reactor spent solids (part of the FD0530 system). The system consists of two vessels, the lock vessel and the dispense vessel, in series separated by Spheri valves. Solids from FD0502 enter a drop pipe above the lock vessel, at which time the lock vessel Spheri valve is open to accept the solids at system pressure. A level probe in the lock vessel determines when the vessel is full (approximately 1.4 ft^3 capacity) and then closes the Spheri valve. The lock vessel is then vented to atmospheric pressure and the dispense vessel Spheri valve opens to accept the depressurized solids. After a set time to allow the solids to fall by gravity from one vessel to the other, the dispense vessel Spheri valve closes and the solids are blown, using air in combustion mode operation and nitrogen in gasification mode operation, into the common collection bin. The lock vessel is then repressurized with nitrogen and the lock vessel Spheri valve is opened to receive more solids. This completes one cycle of the system.

In March 1996 Clyde Pneumatic Conveying (CPC, formerly Simons Air Systems) personnel were on site to functionally check the systems supplied by them, one of which was the PCD fines removal transporter (FD0520). They completed checks and necessary modifications to the system in early April and reported no existing problems. When MWK transport reactor commissioning activities were to begin in late April, it was assumed that the FD0520 system would be ready for operation. Attempts to perform checks of the system by conveying material that had been placed in the bottom of the PCD to the FD0530 system revealed that, in actuality, the system had some remaining control logic and mechanical problems that needed to be addressed prior to integration into the MWK process. After these problems were addressed by PSDF personnel the FD0520 system was placed into operation for the MWK transport reactor commissioning activities. The FD0520 system was the most active of the CPC systems, which include all MWK reactor feed and ash removal systems, running for a total of 891 hours during commissioning and operation. The system was crucial in maintaining operation of the transport reactor since the reactor had to be shutdown if solids could not be removed from the PCD. The FD0520 system was also crucial in monitoring solids loading to the PCD since the SRI on-line PCD inlet sampling system had only started commissioning activities at the end of 1996 and could not provide accurate loading measurements. This solids loading monitoring will be further discussed below.

There were various mechanical problems experienced with the FD0520 system during commissioning as it adjusted to steady state operation. The main problem was with the Spheri valves, the valves that control the transfer of material through the system as the material is being depressurized from transport reactor pressure to atmospheric pressure. The valves tended to bind, and the spherical metal surfaces had to be polished to allow the valve bodies to rotate. Also, to aid in rotation and to prevent damage to the seals, the clearances between the valve bodies and their respective rubber seals had to be increased.

Problems were also experienced with false level indications from the level probe that controls the conveying cycle of the system. However, these problems cleared up after further conditioning of the system. Additionally, the vent valve became eroded from solids venting through it. The valve was replaced but this problem has not been solved for the long term. Also, it was discovered the pilot valves used for pressurizing the Spheri valve seals were not adequately greased, causing slow seal pressurization resulting in periodic system trips. Another problem which still awaits solution is that of ash agglomeration on the sides of the lock vessel. This was most acutely experienced during the November coal run (CCT2C) as more ash accumulated in the MWK system than had accumulated in any previous run. The ash agglomeration provided a false level indication and caused insufficiently sized solids transfer volumes.

There were also various problems associated with the PLC control logic for the system. There was no flexibility in the logic for operating the system below maximum reactor operating pressure, and this flexibility had to be written into the logic. The pressurization and depressurization of the vessels was not accurate enough resulting in over pressurization of the lock vessel. This also was corrected with PLC logic changes. Additionally, various timers had to be adjusted for different materials that took varying amounts of time to convey. Nuisance alarms were also a problem causing unnecessary system trips at crucial times and had to be removed from permissive control.

Figure 6.3.1-2 shows typical operation of the FD0520 system. The downward spikes in lock vessel pressure are the clearest indicators of the individual cycles of the system as the lock vessel depressurizes and then repressurizes during each cycle. The drop pipe pressure essentially tracks system pressure. The spikes of the dispense vessel pressure show the initial rise in pressure as conveying gas enters the dispense vessel containing the solids to be conveyed and then the decrease in pressure back to atmospheric pressure as the solids are removed from the vessel. Figure 6.3.1-2 is an example of a plot that is constantly watched during operation to monitor solids carryover to the PCD from the transport reactor. Each conveying cycle transfers approximately 1.4 ft^3 of material, so an estimation can be made of solids loading to the PCD by counting the number of conveying cycles during a given time period.

7.0 SOUTHERN RESEARCH INSTITUTE (SRI) PARTICULATE SAMPLING SYSTEM

This report describes the commissioning of the particulate sampling system installed at the inlet of the PCD on the transport reactor train. Commissioning of this system included cold shakedown tests performed in October 1996 and hot shakedown tests performed in November 1996. No major problems were encountered during the shakedown tests, but the need for several modifications to address operational problems and make the system easier to operate was identified. The problems encountered and the modifications made to address these problems are discussed below.

7.1 DESCRIPTION OF PARTICULATE SAMPLING SYSTEM

Sampling systems are provided at the PCD inlet and at the PCD outlet to collect representative particulate samples from the process gas streams entering and leaving the PCD. (See figure 7.1-1 on the following page.) The sampling systems make it possible to isokinetically collect bulk samples as well as size-segregated samples using a filter sampler (mass train), a five-stage cyclone assembly, and a cascade impactor. Throughout each sampling run, the sample gas flow is monitored and controlled to maintain isokinetic sampling conditions and to allow accurate determination of the total quantity of gas sampled. In combination with the sample weights, this information is used to determine the mass loadings and size distributions of particles entering and leaving the PCD and the overall and size-dependent collection efficiencies of the PCD. Particulate samples may also be used in laboratory studies of ash permeability, cohesivity, chemistry, and morphology.

To ensure the collected samples are representative, the sampling systems are designed to allow in situ sampling in the process gas stream at process conditions. This approach minimizes any alteration of particle properties caused by particle deposition and reentrainment in sampling lines and by condensation of alkali vapor or other condensibles on the particles. On-line access to the process gas stream is provided by a set of double block-and-bleed valves. The outer block-and-bleed valve is connected to a flanged spool piece with a packing gland assembly through which the sampling probe is inserted. Accurate positioning of the sampler is ensured through the use of a screw insertion mechanism operated by a stepper motor with a built-in encoder. Insertion and retraction sequences are controlled remotely with a specially designed computer program, and software and hardware interlocks are provided to ensure that the system operates safely.

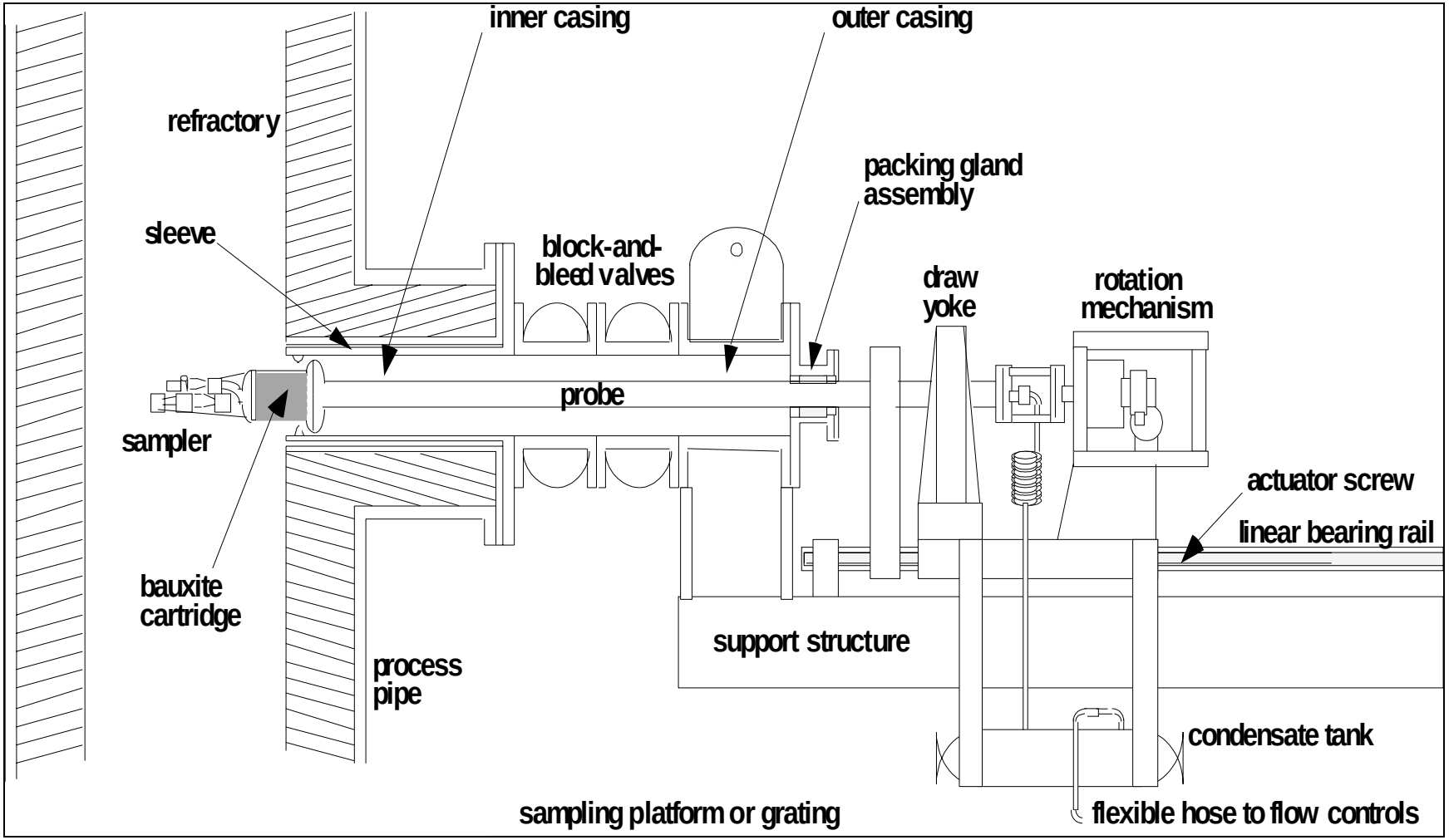


Figure 7.1-1 Particulate Sampling System

7.2 COLD SHAKEDOWN

The cold shakedown testing was comprised the following major elements:

A. Debug the computer control system and instrumentation.

B. Check for leaks and set flows in the cooling water, nitrogen purge, and instrument air systems.

C. Conduct operational checks on all solenoid-operated purge and vent valves and all local push-button controls and indicator lights.

D. Test the cycling of the block-and-bleed valves and gas sampling valve.

E. Conduct leak checks on the outer casing and packing gland.

F. Calibrate the probe positioning system and sample flow orifice.

The debugging of the computer control system included checking the control software, aligning position sensors, checking the operation of the Compumotor AT6400 controllers, stepper motors, analog and digital I/O, and interface between the control system and the DCS. The instrument loop checks revealed a number of wiring problems that were corrected prior to continuing through the cold shakedown tests. Noise in the signals from the temperature transmitters (which was affecting the accuracy of the analog inputs to the computer control system) was eliminated by digitally filtering the signal. Several of the stepper motors were returned to the manufacturer to correct a wiring problem that caused the position encoders to malfunction.

The leak checks revealed some minor leaks that were corrected. Several of the solenoid valves (which were pilot-assisted valves) failed to operate because of inadequate pressure differential across the valve. These valves were later replaced with zero-differential valves.

The sampling flow orifice was calibrated using a laminar flow element installed immediately downstream from the orifice. Four calibration runs were performed over a range of flows from 0.430 to 1.612 scfm, as determined from the flow curve for the laminar flow element. The corresponding orifice flows were calculated using rigorous equations supplied by Rosemount and used to determine the calibration constant for the orifice (i.e., the ratio of the measured flow to the actual flow). Calibration constants determined in this manner varied from 0.937 to 1.016. For the four initial sampling runs discussed later, the calibration factor amounted to a correction of 1.4 to 2.0 percent.

7.3 HOT SHAKEDOWN

Hot shakedown testing was begun in November and comprised the following major elements:

A. Conduct operation check of the block-and-bleed system with hot process gas.

B. Insert the sampling probe into the hot process gas stream and the retraction back into the outer casing.

C. Conduct leak checks on the outer casing and packing gland.

D. Monitor gas temperature at inboard block-and-bleed valve and adjustment of nitrogen purge flow.

E. Perform initial sample runs to test performance of sampler.

F. Inspect filter material and gaskets after sample runs.

The hot shakedown testing was done with process gas at temperatures of 500 to 600°F and at pressures of 60 to 160 psig. Under these conditions, any change in the alignment of the casing or the probe as a result of the increased temperature was not able to be detected. There did not appear to be any warpage of components exposed to the hot gas. The probe moved smoothly through the packing gland and casing and no leaks were detected in either one. Gas temperatures at the inboard valve remained below 200°F throughout the hot shakedown testing, suggesting the nitrogen purge was more than adequate to protect the block-and-bleed valves. This will also need to hold true with higher process temperatures.

During the hot shakedown testing, one of the solenoid valves in the vent lines failed. Examination of the valve revealed ash had entered the valve through the vent line. To address this problem, filters were added to the vent lines upstream of the solenoid valves, and the vent line connections were moved from the bottom of the casing to the top.

In addition to the problem with the solenoid valves in the vent lines, several other problems were identified and addressed to make the system easier to operate. The absence of a remote pressure indication made it difficult to match the outer casing pressure to the process pressure before opening the block-and-bleed valves. The location of the sample flow-control valve allowed flow surges through the sampler during pressurization and depressurization. Accurate measurement of the nitrogen purge rate was difficult because the flow indicator on the main nitrogen purge line was scaled too high for the required flow rate.

7.4 SYSTEM MODIFICATIONS

The following system modifications were made to address the problems mentioned above and to make the sampling system easier to operate.

A. Added filters ahead of the solenoid valves in the vent lines and changed the vent connections from the bottom to the top of the casing.

B. Replaced pilot-assisted solenoid valves with zero-differential valves.

C. Added manual ball valves for isolation of the vent system and on-line servicing of the solenoid valves.

D. Installed pressure equalization lines to balance the outer-casing pressure with the process pressure before opening the block-and-bleed valves.

E. Added a metering valve at the back end of the probe to act as a surge limiter during pressurization and depressurization.

F. Added a pressure transmitter to allow remote monitoring of the outer casing pressure and pressure gauges to check the pressures in other portions of the casing.

G. Replaced the flow indicator on the main nitrogen purge line with one scaled for lower flow rates.

The above changes were implemented in the outlet sampling system as well as the inlet system.

7.5 INITIAL SAMPLING RUNS

Four sampling runs were performed at the PCD inlet in support of characterization test CCT2C. In general, the measured particulate loadings tracked the changes in solids carryover as expected. Particle-size analyses performed on the in situ samples and samples taken from the PCD hopper suggested the hopper samples were not appropriate for use in determination of particle size entering the PCD. The results of the initial sampling runs and particle-size analyses are discussed in detail in the CCT2C run report.

7.6 PORT INSPECTION

Following the four initial sampling runs, the port cover opposite the sampling probe was removed to inspect the area for deposits. There was concern the cold nitrogen purge gas introduced through the port could cause localized condensation and deposit buildup in this area. The inspection revealed no evidence of deposits or buildups.

7.7 SUMMARY

The particulate sampling system functioned as intended and successfully collected particulate samples from the process gas stream. Samples were collected in situ at process temperature and pressure to ensure they were representative of the ash entering the PCD. Isokinetic sampling conditions were maintained using the calibrated sample flow orifice. Operational problems identified during the shakedown tests were addressed with appropriate system modifications completed.

7.8 MAJOR EVENTS (CHRONOLOGY)

On November 15, 1996, the inlet particulate sampling system was commissioned. Shakedown testing was completed and sample collection with the particulate sampling system installed at the PCD inlet was started.

8.0 BALANCE-OF-PLANT

8.1 Feedstock Preparation

8.1.1 Coal and Sorbent (Feedstock) Reclaim System Description

Feedstock is loaded into the reclaim hopper (HO0100) from the feedstock storage shed via rolling stock (front end loader). From the reclaim hopper the feedstock travels via conveyor (CV0100) through a magnetic separator (MG0102) to the crusher (CR0104). The magnetic separator removes any metal debris from the feedstock before it enters the crusher. The crusher reduces the size of the feedstock to three-fourths of an inch or smaller. From the crusher, the feedstock travels up the trifold conveyor (CV0101) and through the crushed material surge bin (CU0106). If the feedstock is coal it is diverted past the sorbent flop gate (ME0100) through the coal flop gate (ME0101) and on to the drag-chain conveyor (CV0103). If the feedstock is sorbent it is diverted past the coal flop gate (ME0101) through the sorbent flop gate (ME0100) and on to the drag-chain conveyor (CV0102). The drag-chain conveyor deposits crushed coal into the MWK crushed coal silo (SI0101) or the crushed sorbent in the crushed sorbent silo (SI0103). Both crushed material silos are equipped with a baghouse to remove any dust displaced from the storage silo.

8.1.1.1 Coal and Sorbent Reclaim System Commissioning

Commissioning of the reclaim system went as expected. No major problems were encountered.

8.1.1.2 Reclaim System Control

The reclaim system is controlled by an Imperial Technologies PLC. The system runs at two speeds—one for coal and a (slower) speed for the heavier sorbent.

8.1.1.3 Normal Operation

The reclaim system has operated as expected.

8.1.2 MWK Coal Mill Process Description

Crushed coal (zero to three-fourths of an inch) from silo SI0101 moves through an isolation slide gate and is fed by a rotary valve (FD0111) to a William's Patent Crusher (WPC) 30-inch diameter roller mill (ML0111) where the coal is pulverized. A spinner separator (SP0111) returns a certain amount of oversize coal particles to the mill. Air heated by a 3-MBtu/hr air heater (HR0111) transports the pulverized coal to a cyclone collector (CY0111). The main fan (FN0111) and a combustion blower (BL0111) are used to move the transport air. The pulverized coal from the mill travels to the cyclone collector where it is separated from the transport gas. Part of the gas is reused and part is vented to the atmosphere through a baghouse (FL0111). Any additional gas that passes through the baghouse is recycled to the air heater. The baghouse collects the coal dust and deposits it into the pulverized coal silo (SI0111) through a discharge rotary valve (VL0121). An exhaust fan (FN0114) moves the transport gas through the baghouse. The pulverized coal collected by the cyclone is fed by a discharge rotary valve (VL0114) to a vibrating screen (SC0111). The screen separates the oversize coal particles (presently any over 1,000 microns) and returns them to the crushed coal silo by the use of a 12-inch pipe. The correct size coal passes through the vibrating screen to the MWK pulverized coal silo (SI0111). A level transmitter (LT4891A) indicates the coal level in the silo. A low-level alarm will notify the control room when the silo needs to be refilled. A high-level setting stops the rotary feed valve (FD0111) and allows the feed handling equipment to empty. The lubrication requirement of the mill is controlled by the automatic lubrication system. The mill is sealed with nitrogen.

8.1.2.1 MKW Coal Mill System Commissioning

Three basic goals guided commissioning of the coal mill system. First, the mill must operate smoothly and steadily with minimal vibration of the mill and without drastic oscillations of controlling parameters while in the automatic mode. Secondly, the mill must operate below the NFPA O_2 concentration limit of 13.8 percent. Finally, the mill must produce the desired particle size distribution.

8.1.2.2 Mill Control

The mill speed and other parameters are controlled by the WPC PLC to obtain a desired coal particle size distribution and steady mill operation. Along with mill speed, the other controlling parameters are spinner separator speed (SP0111), transport air flow rate, and feeder speed (FD0111). The parameters' setpoints and ranges are adjusted based on experience to vary particle size output. To obtain steady mill operation, the WPC PLC attempts to reach a pressure drop setpoint across the mill by varying the control parameters.

WPC performed the initial system tuning on-site. During a subsequent production run WPC tuned the system via a modem link to the PLC. Because mill tuning relies heavily on experience, WPC will be called periodically for tuning help. Also, if major changes (i.e., coal type change) are made WPC will be needed for tuning help.

8.1.2.3 Limiting Oxygen Concentration Requirements

Section 2.7.2.1 of NFPA 69 states for a continuously monitored process the oxygen concentration must be kept at least 2.0 percent below a limiting oxygen concentration (LOC). For bituminous coal the standard lists the LOC as 15.8 percent, making the maximum allowable O_2 concentration 13.8 percent (for subbituminous coal 11.8 percent). Mill combustion products are recycled to reduce O_2 levels. Hence the need as mentioned in the introduction for recycling the transport gas after the baghouse back to the air heater. (Instead of drawing in excess cooling air from the atmosphere for the heater recycle transport gases are used.) An Ametek Series 2000/WDG in situ measuring system is used to monitor O_2 concentration.

The major problem encountered during commissioning was achieving the NFPA O_2 concentration requirement. Because the system was designed for coals with higher moisture content than the coal used for commissioning more conveying gas must be exhausted to cool the air heater. As more conveying gas is exhausted, more fresh air is introduced, driving up the O_2 concentration. Even with the air heater at its minimum setting, too much conveying gas must be exhausted for cooling the air heater to keep the O_2 concentrations below required levels. Therefore, a method for reducing the O_2 had to be found.

Consultations between PSDF and WPC engineers resulted in an eventual solution of water injection into the mill windbox because the air heaters were sized to remove more water than was present. The water is carried from the windbox into the mill by hot conveying gas. With the coal currently in use about 0.75 g/m of water is added to drive down the O_2 concentration. Once the mill is operating steadily, an O_2 concentration of approximately 12.8 percent is achieved and maintained.

8.1.2.4 Particle Size Distribution

The WPC roller mill system is capable of producing a range of particle size distributions. During commissioning, the mill system was tuned over a range of distributions until the required particle size distribution was acquired (figure 8.1.2-1). The nature of the commissioning process is to gain a certain amount of experience with this particular setup for future changes and troubleshooting by both the PSDF staff and WPC. For this reason one of the results of the commissioning process is a table of particle size distributions along with corresponding setpoints for the various control parameters. This table allows for easier change over to different particle size distributions for future test runs.

8.1.2.5 Normal Operation

The MWK coal mill system operated very well during normal operation. Getting coal flow started from the crushed coal silo was the only real problem encountered. This problem resulted from a water leak in the silo which caused a coal-mud buildup at the silo exit. The leak was repaired and the problem seems to have been corrected.

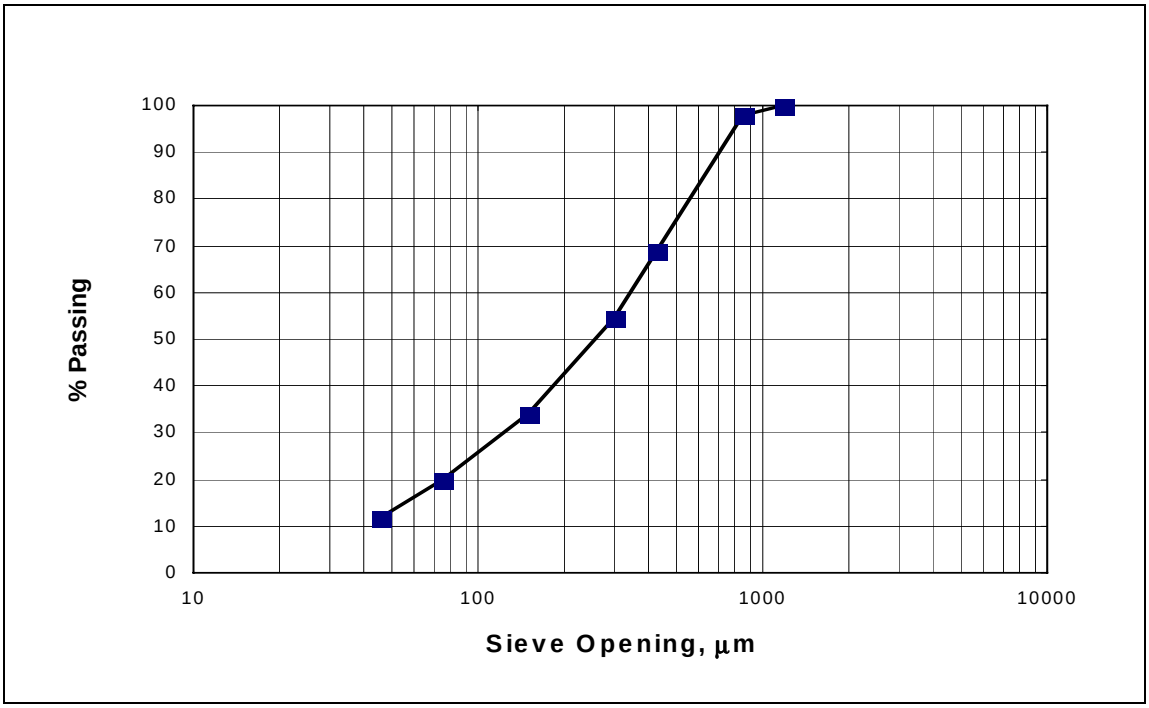


Figure 8.1.2-1 Coal Particle Size Distribution

8.1.3 MKW Sorbent Mill Process Description

Crushed sorbent (zero to three-fourths of 1.0 inch) from silo SI0103 moves through an isolation slide gate and is fed by rotary valve (FD0113) to the William's Patent Crusher (WPC) 30-inch diameter roller mill (ML0113) where the sorbent is pulverized. The spinner separator (SP0113) returns a certain amount of oversize sorbent particles to the mill. Air heated by a 1-MBtu air heater (HR0113) transports the pulverized sorbent to the cyclone collector (CY0113). The main fan (FN0113) and combustion blower (BL0113) are used to move the transport air. The pulverized sorbent from the mill travels through the cyclone diverter slide gate (VL0136) to the cyclone collector where it is separated from the transport air. Part of the air is reused and the rest is vented to the atmosphere through a baghouse (FL0113). The baghouse collects the sorbent dust and deposits it into the MWK pulverized sorbent silo (SI0113) through a discharge rotary valve (VL0123). An exhaust fan (FN0116) moves the air through the baghouse. The pulverized sorbent collected by the cyclone is fed by the discharge rotary valve (VL0116) to the vibrating screen (SC0113). The screen separates the oversize particles (currently any over 500 microns) and returns them to the crushed sorbent silo by the use of a screw feeder (FD0118). The correct size limestone passes through the vibrating screen to the MWK pulverized sorbent silo (SI0113). The level transmitter (LT4892A) indicates the sorbent level in the silo. A low-level alarm notifies the control room when the silo needs to be refilled. A high-level setting will stop the rotary feed valve (FD0113) and allows the feed handling equipment to empty. The lubrication requirement of the mill is controlled by the automatic lubrication system. The mill is sealed with air.

8.1.3.1 MKW Sorbent Mill System Commissioning

The sorbent mill system commissioning was guided by the requirement for the system to operate smoothly and steadily and by the particle size requirement. Dolomite was used during commissioning and for the following two combustion test runs.

With the exception of the NFPA O_2 concentration requirement the sorbent mill system operates identically to the coal mill system. Mill control is achieved in the same fashion. Particle size distribution is likewise achieved in the same fashion as with the coal mill system. A graph of the resulting particle size distribution is shown in figure 8.1.3-1. The commissioning procedure moved along in the same manner as the coal mill commissioning.

8.1.3.2 Normal Operation

The sorbent mill operated very well during normal operation. The mill-feed rotary valve caused the only recurring problem. Because the dolomite is so hard, it caused the rotary vanes to bind against the housing of the valve. The valve housing was changed to relieve this binding.

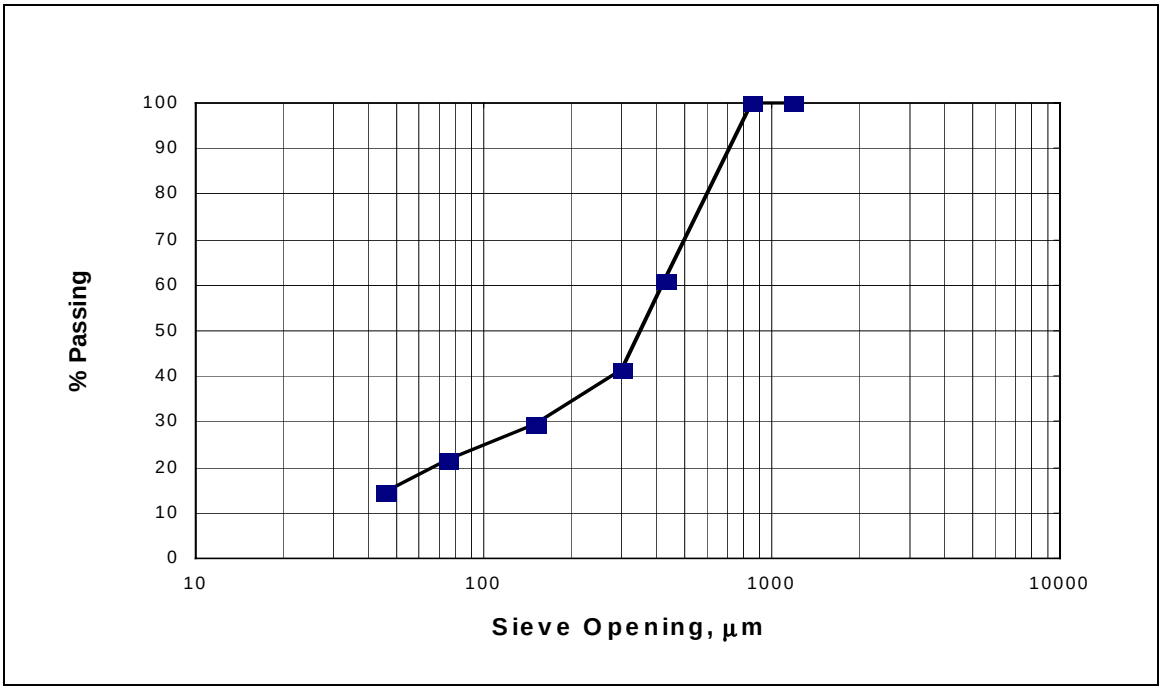


Figure 8.1.3-1 Dolomite Particle Size Distribution

8.2 MAIN AIR COMPRESSOR

8.2.1 Description

The main air compressor (CO0210) was designed to supply 18,000 lb/hr of air at 365 psia and 400°F for gasification, combustion, solids conveying, standpipe aeration, and start-up burner operation. It is a four-stage, integrally geared centrifugal constant speed compressor, with interstage cooling driven by a 1,750-hp Siemens induction motor. The main air compressor takes suction from the atmosphere through an inlet filter. Depending on the process requirements, an Allen Bradley PLC controls the compressor via adjustment to the inlet guide vanes and the blowoff valve.

8.2.2 Commissioning Tests/Runs

Commissioning activities started with a vendor visit at the end of 1995. Since the reactor system was not ready for air flow, all checks were done with the air going through the blowoff valve. Once the system was ready for air in the spring of 1996, the vendor again came to the site to tune the control. It was determined during this 2-day check out that the tuning parameters were incorrect, causing the compressor to frequently, and erroneously, unload since the PLC "thought" a surge condition was imminent. During commissioning by on-site personnel, it was identified that there was a potential for water carryover into stages 2 and 3 without any preventive alarms. Level switches were installed in intercoolers 1 and 2 to activate alarms at the DCS in the event of a high water level in either, or both, intercoolers. DCS-related functional checks were satisfactorily completed April 30.

8.2.3 Highlights of Problems and Solutions

As discussed, there were some initial tuning problems which the vendor was able to address in the spring of 1996. An additional control problem encountered during late 1996 was apparently due to the variation in atmospheric conditions. An inlet temperature compensation will be installed during February of 1997 to address this problem.

8.2.4 Performance During Normal Operation

After some initial tuning problems, the compressor ran well in automatic and responded quickly to changes in downstream conditions. For example, when the positioner arm on the pressure letdown valve broke and the reactor pressure increased from 150 to 260 psig in 30 seconds, the compressor was able to make the necessary adjustments without surging or unloading, figure 8.2.4-1 shows the compressor discharge pressure and the reactor pressure during this event.

However, late in the year during test run CCT2C and CCT3A the compressor experienced some additional control problems. On two consecutive nights during CCT2C, the compressor began to surge and then automatically unload and tripped several other systems. At this time, problems were also experienced with the transport air dryer which was causing some pressure swings (~60 psig) in the compressor downstream pressure. However, the compressor continued to have control problems during CCT3A after the dryer had been repaired. The problems (according to Atlas Copco) are believed to have been caused by the variations in atmospheric conditions operating with "winter air" while the compressor tuning parameters were set in the summer position for "summer air" (humidity ~90 percent and temperature ~90°F). To address this problem, an inlet temperature compensation will be installed during February 1997. Figure 8.2.4-2 is a graph of discharge pressure, inlet guide vane position, and blowoff valve position showing a compressor unload during CCT2C. The compressor ran for a total of 1,570 hours during 1996.

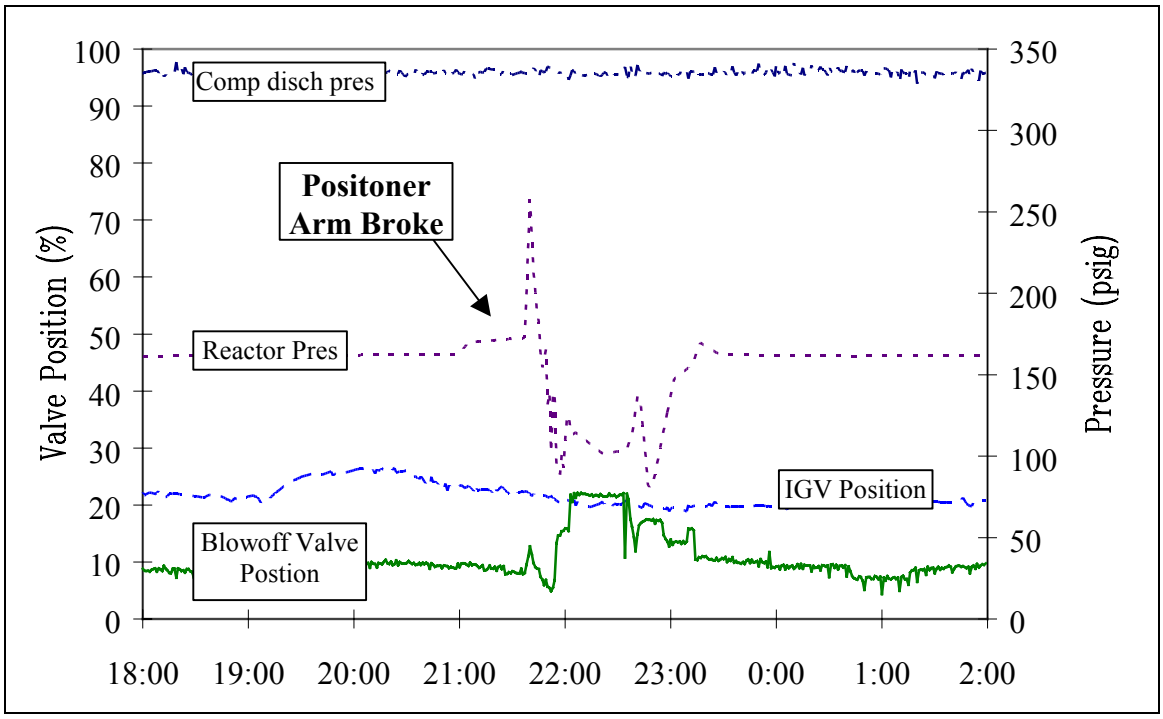


Figure 8.2.4-1 Main Air Compressor Operations August 20 to 21, 1996

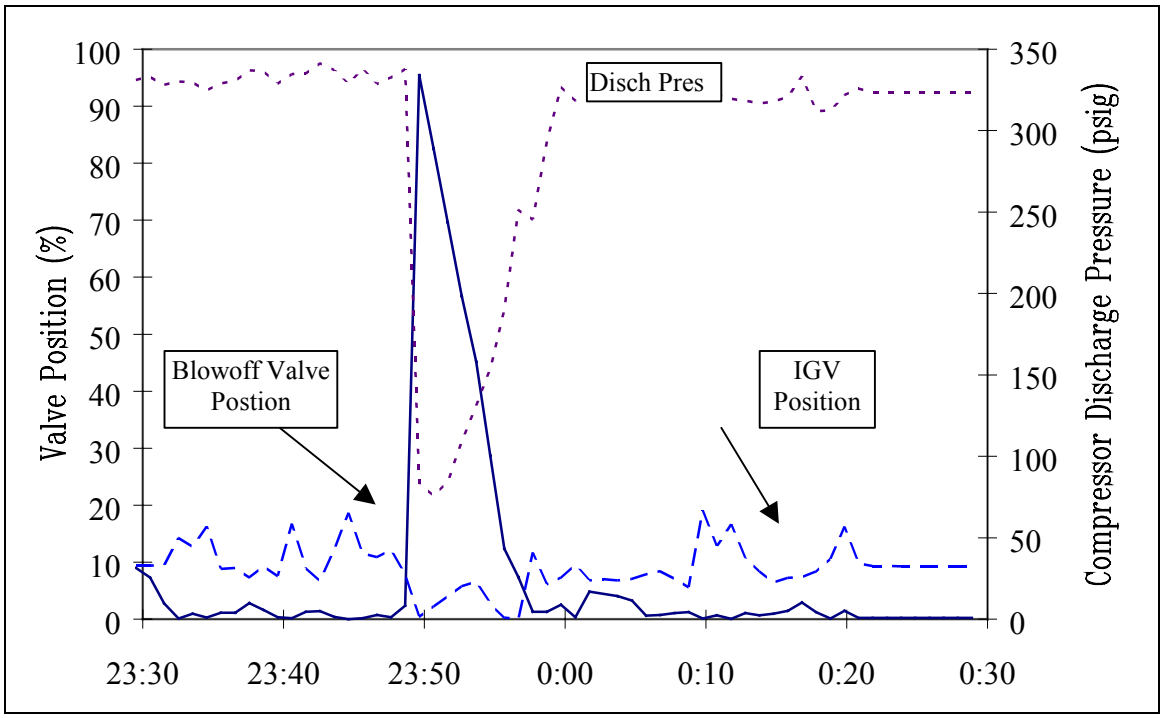


Figure 8.2.4-2 Main Air Compressor Operations November 15 to 16, 1996

8.3 Transport Air System

8.3.1 Description

The transport air system is designed to supply transport air for the coal and limestone feed streams. Air from the main air compressor is cooled to approximately 95°F in the transport air cooler (HX0204) and then dried to a dewpoint of -10°F by the transport air dryer (DY0210). The transport air dryer consists of two unheated drying towers, only one of which is in service at a time. The transport air flows through one desiccant tower where water vapor is adsorbed from the process air stream. At the same time, the other desiccant bed is being regenerated by a flow of dry gas. A coalescing prefilter and trap upstream of the dryer inlet protects the desiccant from liquid condensate and oil carryover from the compressor and a particulate afterfilter is installed downstream of the dryer to remove any desiccant fines from the outlet stream.

8.3.2 Commissioning Tests/Runs

The dryer functional checks were successfully completed during April and the dryer was commissioned in June with essentially no problems.

8.3.3 Highlights of Problems and Solutions

Performance During Normal Operations

On November 16, 1996 (during CCT2C), tower 1 of the transport air dryer was repressurizing rapidly because the regeneration blowoff valve (XV8116) was not closing and the purge flow meter was not maintaining its set point. The dryer was taken out of service and all the valves (XV8116, XV8117, XV8118, and XV8119) were taken apart and cleaned. Since the tower had been repressurizing so rapidly there was a chance some of the desiccant could have been blown out. The afterfilter was inspected and the filter cartridge was found relatively clean. The afterfilter cartridge and the orifice purge flow meter were blown clean. When the dryer was placed back in service, tower 1 repressurized slowly and the purge rate flow maintained its set point, i.e., the dryer was successfully repaired.

Also during this run, the prefilter was draining much more water than in the previous runs indicating that there could be a problem with the upstream separator.

During the following outage, the separator, the drain trap, and the prefilter were inspected. The separator inspection revealed no problems. The drain trap was inspected and the outlet orifice was cleaned. The prefilter coalescing cartridge was damaged due to the excessive water carryover and had to be replaced.

8.4 RECYCLE GAS BOOSTER COMPRESSOR

8.4.1 Description

The recycle gas system supplies an oxygen deficient gas stream at 350 psig for aeration of the combustor heat exchanger, for aeration of the transport reactor mixing zone, standpipe, and J-leg, for spent solids transport, and for spoiling gas to the primary cyclone. The system consists of the compressor feed cooler (HX0405), a separator (SP414), the recycle gas booster compressor intake filter (FL0401), and the recycle gas booster compressor (CO0401). A slipstream of gas leaving the secondary gas cooler (HX0402) feeds the recycle gas system. A portion of this gas flows through the compressor feed cooler to control the compressor discharge temperature at 300°F. Any liquid condensed in the cooler is knocked out by the separator and is injected into the flue gas feed stream that is flowing to the thermal oxidizer. Particulate matter that may be in the gas is filtered out by the intake filter before the gas enters the compressor. The compressor is a 200-hp, 2-cycle, reciprocating compressor driven by a Siemens motor and controlled by an Allen Bradley PLC.

8.4.2 Commissioning Tests/Runs

The functional checks were completed May 17, 1996, with only minor problems encountered and addressed. On May 20 and 21, a vendor representative verified the compressor piston striking distance, crosshead distances, proper installation of the compressor valves, motor and compressor-side thrust, and coupling alignment. After these checks, the compressor was successfully started and run using instrument air with an intake pressure of 50 psig and discharge around 100 psig. During operations the motor amps were checked and found acceptable. On June 29 the compressor was run again so that it could be tested under normal operating conditions. The compressor was started with a suction pressure of 130 psig, and the suction pressure was gradually increased to 250 psig while the discharge pressure was controlled at 325 psig via pressure controller, PIC478. Only minor problems were encountered which were solved by changing a switch point setting and a few PLC rungs. During the operating period various controllers were tuned and it was demonstrated that a smooth transition could be made from air to recycle gas for fluidization of the combustor heat exchanger. Also, vibration readings were taken and found acceptable. The compressor tripped (as programmed) once during this period due to a high suction pressure. Figure 8.4.2-1 shows a graph of this operating period.

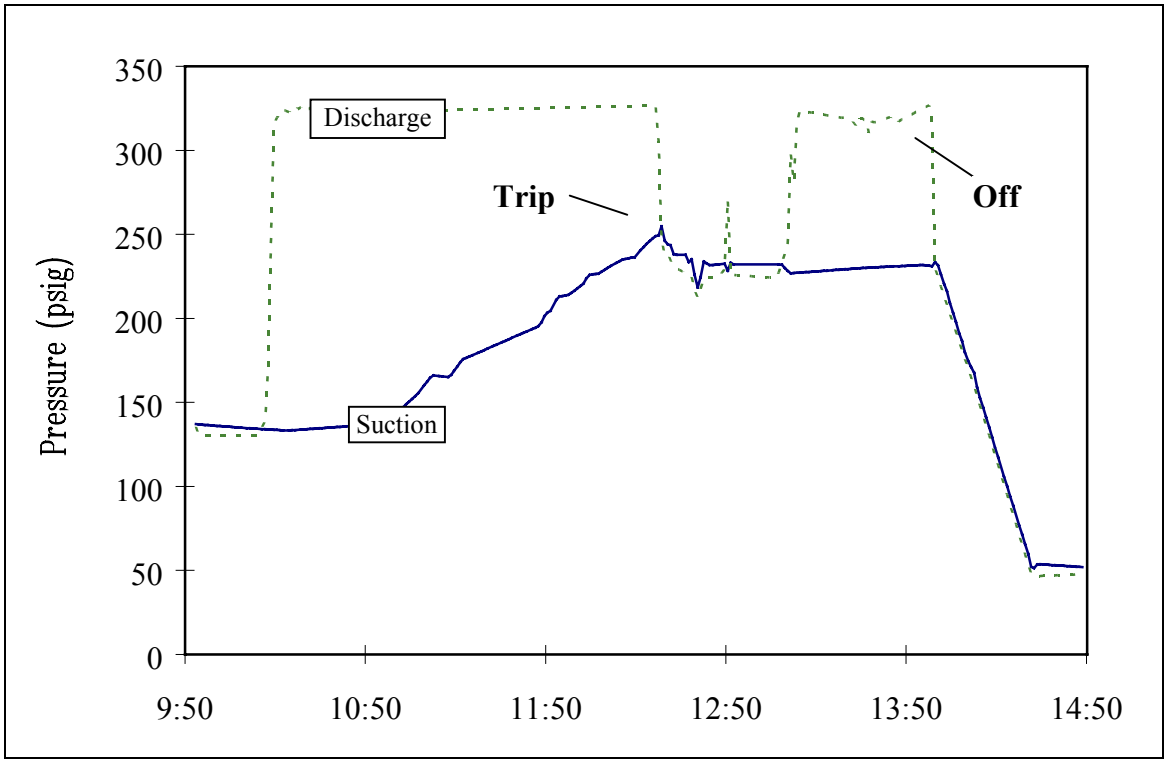


Figure 8.4.2-1 Recycle Gas Booster Compressor Commissioning June 29,1996

8.4.3 Performance During Normal Operation

Since an air line was installed to fluidize the combustor heat exchanger, the compressor was not operated during any of the 1996 reactor test runs.

8.5 PROCESS GAS SAMPLING SYSTEM

8.5.1 System Description

The process gas sampling system extracts gas from two points in the M. W. Kellogg process. One sample stream (designated AE464) is extracted from the transport reactor port S4, located just downstream of the secondary gas cooler (HX0402), and is transported to all gas analyzers in the process gas sampling system. The other sample stream (designated AE610) is extracted from the sulfator system just downstream of the sulfator heat recovery exchanger (HX0601), and is transported solely to the Rosemount Model 890 SO_2 analyzer. The Rosemount SO_2 analyzer is the only analyzer that is switchable between the sample stream AE464 and sample stream AE610.

The process gas sampling system is composed of the instruments shown in table 8.5.1-1. The table also shows the components that are measured by the process gas sampling system along with the detection methodology used.

The Rosemount NGA 2000 analyzer system consists of a common platform controller and three analysis modules: the modules measure CO, NO_x, and O_2. The detection methodology is NDIR for CO, Chemiluminescence for NO_x, and Paramagnetism for O_2. Software loaded into the NGA platform controller allows the O_2 analyzer range to be changed from 0 to 25 percent for combustion mode operations and to the 0 to 5000 ppm for gasification mode operations. Each module is a continuous analyzer with local or remote zero and autospan calibration. The calibration can be programmed to occur daily at a user-specified time.

The Rosemount 890 SO_2 analyzer utilizes an ultraviolet (UV) detection methodology and provides continuous sampling, and local or remote zero and auto-span calibration. The calibration can be programmed to occur daily at a user-specified time.

The ABB model 3501 moisture analyzer utilizes an IR detection methodology. Both manual and automatic zero and calibration are available by menu selection.

The gas chromatograph (GC) is an applied automation GC. The GC is set up for dual sample injections during each cycle with the components routed to two thermal conductivity detectors. The GC is not a continuous analyzer; it operates on a 330 second sample cycle. Table 8.5.1-2 depicts the components measured by the GC and the corresponding calibration ranges.

Owing to possible reaction among some of the components of interest, two calibration streams are required. One of the calibration streams has H_2, CO, CO_2, CH4, and C_2+ with a balance of helium. The other stream is comprised of O_2 and N_2 with a balance of argon.

All of the analyzers transmit a 4- to 20-mA DC signal to the DCS. Also, common trouble alarms from each analyzer are transmitted to the DCS.

The analyzer house (located on the eighth floor of the structure) in the location of all of the process gas sampling system analyzers. The analyzer house is a totally enclosed walk-in shelter which is air-conditioned, heated and ventilated to provide a safe environment for the analytical equipment and personnel. For the protection of the personnel inside the analyzer house, an ambient monitoring system with associated alarms and flashing beacons, is provided to detect unsafe concentrations of CO, H_2S, combustibles, and O_2 deficiency.

Table 8.5.1-1

Process Gas Sampling System Instruments

Instrument	Calibration Range	Sample Stream	Component	Detection Methodology
Rosemount NGA 2000	0-25%	AE464	CO	NDIR
Rosemount NGA 2000	0-1000 ppm	AE464	NO_x	Chemiluminescence
Rosemount NGA 2000	0-25% (comb.)	AE464	O_2	Paramagnetic
Rosemount NGA 2000	0-5000 ppm (gas.)	AE464	O_2	Paramagnetic
ABB Model 3501	0-20%	AE464	Moisture	IR
Rosemount Model 890	0-5000 ppm	AE464/AE610	SO_2	UV

Table 8.5.1-2

Calibration Ranges for the Gas Chromatograph

Component	Calibration Range Percent
CO	0-25
N_2	0-100
O_2	0-25
CO_2	0-25
H_2	0-25
C_2+	0-10
CH4	0-10

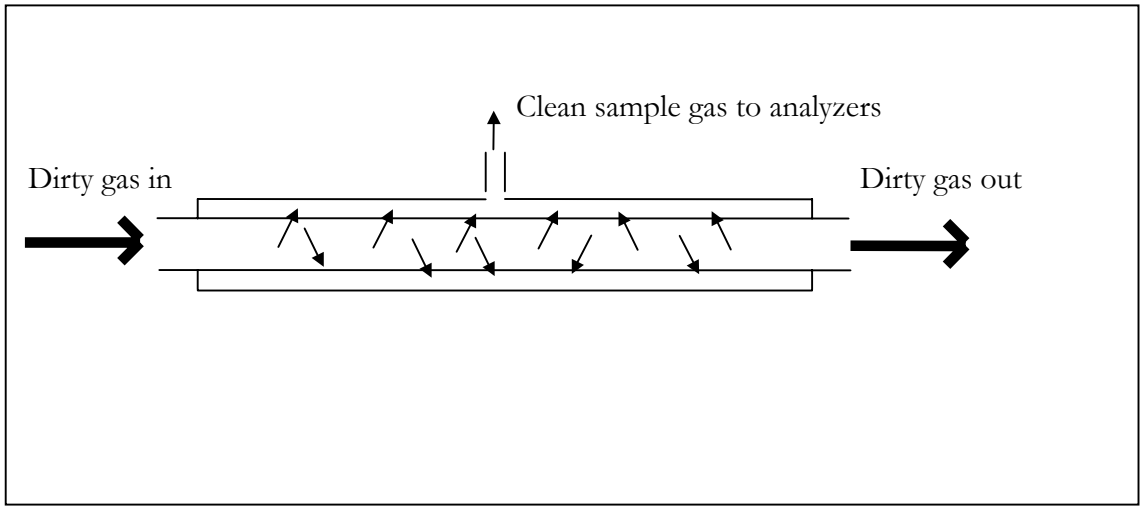


Figure 8.5.1-1 Porous Metal Cross-Flow Filter

8.5.2 Alternative Conceptual Designs Considered for Sample Extraction and Transport

The original design of the AE464 sample stream called for extracting the sample from a point just above the primary heat exchanger (HX0202). However, this sample point would be located in a dead leg if HX0202 were to be bypassed. Therefore, another sample extraction point was considered necessary. An acoustic detector port, located between HX0202 and the particulate control device (PCD), was investigated as a first alternate sample extraction point. However, the process gas at this point had a high-solids loading at an elevated temperature (1,000 to 1,600°F) and was considered too severe for sample extraction. A second alternate sample extraction point located downstream of the secondary gas cooler (HX0402), was considered and selected because of the less severe process conditions (600°F).

The original and the first alternate designs included the use of a porous metal cross-flow filter manufactured by the Mott Metallurgical Corporation. This filter consists of a porous metal filter housed in a solid metal tube with connections for a flow inlet, a flow outlet and a clean sample port. (See figure 8.5.1-1.) A relatively large quantity of flow would have been drawn off the main process and passed through the inside diameter of the porous metal filter. The gas velocity along the inside filter wall had to be between 75 and 100 feet per second in order to clean the dust cake buildup. The bulk of the process gas would have passed through the inside diameter of the filter, then been dropped in pressure by an orifice or pressure control valve, and returned to the process just downstream of the back pressure regulator valve, PV287. The small stream of filtered gas would have been transported to the analyzer house.

The designs utilizing the porous metal cross-flow filter would have required about 180 lb/hr of gas to be drawn from the process. With the high concentration of solids in the process gas, erosion would likely have been severe. Thus, the designs that utilized the porous metal cross-flow filter were rejected and the sample point downstream of HX0402 was considered and selected. Considering the operation of the process sampling system was an absolute necessity for transport reactor operation, the decision to move the sample extraction point was appropriate.

With the original sample extraction designs, the process sample would have been transported 30 feet before reaching the analyzer house. With the current design, the sample must be transported 200 feet. The longer sample transport distance certainly adds time lag in the sampling process; however, during operations a process change was detected within a few seconds by the analyzers. The first 110 feet of the installed sample transport line is a fast loop design which decreases the analyzers detection time of a process change. With a fast loop design, a majority of the sample extracted is bypassed to the flare and a smaller quantity filtered and transported to the analyzers.

The sample transport tubing for sample stream AE610 was installed as designed but was not commissioned. Commissioning of sample stream AE610 will occur in 1997.

8.5.3 Sample Conditions at Extraction

At the extraction point, the temperature of stream AE464 is 600°F and the pressure is at the transport reactor operating pressure (121 to 283 psig). The tube-in-tube cooler located in the AX464 preconditioner box was bypassed since the process temperature is much lower at the selected sample extraction point. The sample stream AE610 is extracted at 490°F and atmospheric pressure.

8.5.4 Checkout and Commissioning Experience

The overall quality of the analyzer house assembly was excellent. However,some aspects such as component selection providing documentation to complete the checkout and commissioning of the process gas sampling system, were less than optimum.

A representative from Cegelee, the analyzer house vendor, and an M. W. Kellogg Company engineer visited the PSDF site in early May to oversee the repair of the heat damaged components, calibrate the analyzers, complete the functional checkout of the analyzer systems, and provide a general overview on the operation of the process gas sampling system. At that time the analyzer house vendor announced they would no longer be building analyzer systems for the petrochemical process industry.

Most of the wiring and other plastic components in the moisture analyzer box were damaged by heat and had to be replaced by the vendor. The heat damage was a result of the installation of an incorrect temperature switch. The temperature switch was replaced and the damaged wires were replaced with high temperature wire.

A service representative from Applied Automation visited the site in early September to check out and calibrate the Gas Chromatograph (GC). Several unsuccessful attempts were made to calibrate the GC. During the troubleshooting, the Applied Automation representative found that an incorrect application program was loaded into the GC and that one of the seven GC columns was bad. The correct program and a replacement column were ordered and installed. Also, the auto-calibration setup was tested and a few wiring problems were corrected.

All of the analyzers except for the NO_x and the GC were brought on-line in August. During the checkout of the analyzers, the communication card in the NGA2000 control platform assigned to the NO_x analyzer failed to function and had to be sent out for repair. The pressure regulator located in AX464 preconditioner box had to be cleaned and reinstalled. The GC was brought on-line in October after the CEM technician attended specialized training required to operate and maintain the GC.

8.5.5 Operational Experience

The process gas sampling system O_2, NO_x, CO, and SO_2 analyzers were on-line for all but 4 hours of the 84-hour August run on coal. The only significant problem was that a pressure regulator located in the AX464 preconditioner box became plugged after being on-line for 72 hours. Most of the material that plugged the regulator appeared to be rust from the secondary heat exchanger (HX0402). To avoid additional pluggage problems, the regulator was moved downstream of the filters located in box AX464.

The Cegelec Automation Artic VI refrigeration sample gas dryer leaked refrigerant and had to be sent back to Cegelec Automation for repair. The refrigeration gas dryer was insufficiently cooling the sample gas and moisture was being carried downstream. A coalescer filter (located downstream) collected most of the carryover.

In early October the range of the Rosemount NGA 2000 CO analyzer module was changed from 0 to 25 percent to 0 to 50,000 ppm. However, when instrument air was fed through the CO analyzer, a lot of noise was present in the output. Thus, the CO analyzer data should only be used when the CO concentration is greater than 10,000 ppm (1 percent). Even though the CO analyzer can be ranged from 0 to 50,000 ppm, the analyzer module cell is too short for accurate readings at low ranges. The range of this analyzer module will be changed back to 0 to 25 percent for 1997 operations.

8.6 THERMAL OXIDIZER

8.6.1 Description

The thermal oxidizer (BR0401) is a downfired, vertical combustion chambered vessel. Other major components are the combustion air blower (BL0401) and a horizontal waste heat recovery section. The thermal oxidizer was designed to function as an incinerator for the syngas and as a steam producer for the steam needed for the gasification reactions. However, during 1996 it was used as a heat source to generate steam to start-up the steam system, to provide steam to indirectly preheat the PCDs, and to supply steam to the propane vaporizer since the auxiliary boiler was not in service. A 125-hp combustion air blower takes suction from the atmosphere and supplies air required for combustion and quench. The blower can deliver a maximum of 10,000 scfm of air and is capable of being turned down to 2,200 scfm. Burner ignition is attained with an Allen Bradley PLC that is dedicated to sequencing the burner management system, and firing of the burner is controlled by a DCS temperature set point.

8.6.2 Commissioning Tests/Runs

Functional checks were performed on the thermal oxidizer burner management system (BMS) on April 25 and 26. The initial checks were performed in a sequence that followed the ladder logic start-up procedure. Trip scenarios were also simulated. The thermal oxidizer blower functional checks including blower discharge pressure, thermal oxidizer temperature, and excess oxygen controls were completed on May 6. All checks were satisfactory with only a few minor problems being detected.

On May 6 and 7 the initial attempts to light the thermal oxidizer pilot were unsuccessful. The combustion air valve at its minimum position allowed too much air flow into the thermal oxidizer causing the pilot to be blown out. The air flow was reduced by using the instrument air purges for the sightglass and flame scanners as the only sources of air. The pilot was successfully lit but when the combustion air valve was opened slightly, the additional air blew out the pilot flame. In addition, the positioner on the combustion air valve was of poor quality and was unable to hold the air flow constant at low flow rates. Since the waste air enters at about the same elevation as the main burner tip, it could be increased without blowing the pilot out. So, the pilot was relit and the waste air flow was increased to provide combustion air in preparation to light the main burner. As soon as the main burner start was pressed, the primary combustion air was increased. The main burner ignited and maintained a stable flame.

The thermal oxidizer refractory was cured to 1,600˚F from May 12 to 17. During the cureout, the thermal oxidizer generated steam at approximately 100 psig drum pressure, commissioning the steam and condensate system, providing steam to commission the high pressure propane system and demonstrating that the thermal oxidizer was an efficient way to heat up the steam drum. Figure 8.6.2-1 shows a plot of the thermal oxidizer outlet temperature and steam drum pressure for this operating period. While in operation, the thermal oxidizer was checked for "hot spots" indicating gaps/failure of the refractory but none were found.

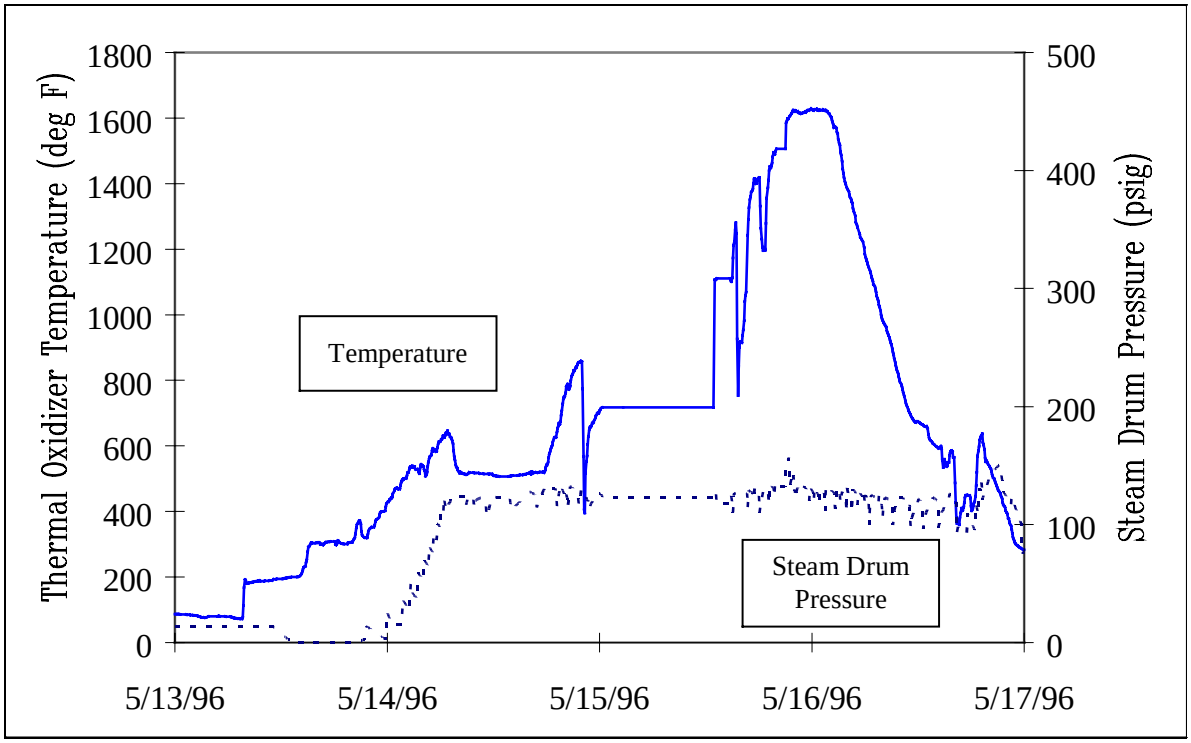


Figure 8.6.2-1 Thermal Oxidizer Refractory Cureout

8.6.3 Highlights of Problems and Solutions

Control problems with the combustion air valve continued, so a 3-inch bypass line with a manual valve was installed around the combustion air valve. The positioner on the combustion air valve was also replaced. During subsequent runs, the bypass around the combustion air valve was used for starting the pilot. The other problem during commissioning dealt with questionable oxygen analyzer readings. At higher firing rates the oxygen analyzer reading was much lower than calculated based on the propane/air flow rates. The oxygen concentration of the gas downstream of the waste heat recovery section was checked, and the reading at that location reflected the calculated oxygen concentration. The above differences could be explained if the oxygen analyzer was reading an unmixed portion of the flame zone, giving unreliable results. The analyzer was moved downstream of the waste heat recovery section to provide more accurate readings.

8.6.4 Performance During Normal Operation

The thermal oxidizer has run for a total of 2,700 hours and has been fired as high as 14 MBtu/hr. The thermal oxidizer has operated well during all test runs of 1996 with only a few instrumentation problems. It has met the steam demands for both the PCD preheat and the propane vaporizer.

During July 1996 the refractory was inspected. There were several small cracks which were all less than one-eighth of an inch in width, probably caused by differential expansion of the metal shell and the refractory. On December 4, following test run CCT2C, another inspection of the thermal oxidizer refractory was completed. The cracks in the refractory were not noticeably larger than they were during the previous inspection. However, there were a few small areas of spalling about 1-inch long and 0.25 inches deep. Some larger refractory pieces were found in the bottom of the vessel which possibly came from the upper part of the vessel, located some 25 feet above grade. Therefore, an inspection of the top section of the thermal oxidizer was conducted on December 19 (after CCT3A) when the appropriate equipment had been gathered for the inspection. This inspection revealed that there was some flaking and minor cracks less than one-eighth of an inch deep in the upper section, but overall the refractory was in good condition. Figure 8.6.4-1 shows two photographs taken during the inspection of the top area of the thermal oxidizer.

Figure 8.6.4-1 Two Views of Top Areas of Thermal Oxidizer December 19, 1996

8.7 STEAM SYSTEM

8.7.1 Description

Boiler feed water (BFW) flows by natural circulation from the steam drum to the primary gas cooler, the secondary gas cooler, the combustor heat exchanger, the thermal oxidizer, and the sulfator heat recovery exchanger for cooling purposes. The steam produced flows back to the steam drum where the pressure is regulated by pressure controller, PIC405. Excess steam flows from the steam drum to the MWK steam condenser, then to either the MWK feed water heater or the condensate subcooler based on the BFW inlet temperature controller. Depending on the mode of operation, saturated steam may also flow to the thermal oxidizer and the CPC PCD. The steam drum is equipped with continuous and intermittent blowdowns and a chemical injection system to maintain boiler feed water chemistry in a condition to prevent scale, sludge, and alkalinity from becoming a serious problem. Blowdown water is sent to a blowdown tank and then disposed. Each exchanger and/or coil that is generating steam is also equipped with an intermittent blowdown to control solids buildup.

8.7.2 Commissioning Tests/Runs

The demin pump logic (I4700) was checked on April 5, 1996, when the pumps were run to fill the steam and condensate tank. On April 12 the boiler feed pumps were checked while filling the MWK closed-loop cooling water system to ensure that the pumps could be run from the DCS and to set the recirculation valve (CV4003) position. The remaining functional checks, including all alarm points and control loops, were satisfactorily checked by the end of April. On April 19 the steam drum was filled and blanketed with nitrogen.

8.7.3 Highlights of Problems and Solutions

Performance During Normal Operation

Due to low coal feed rates during all commissioning runs, the steam and condensate system has operated below design conditions causing some control problems and a persistent water hammer in the BFW line. The water hammer problem may have resulted from the low BFW temperature and the low BFW flow combined with the fact that the BFW is introduced into the vapor space of the drum. To address this problem and the drum level control problems, a line is being installed which will introduce the BFW into the drum via a chemical injection line below the water level. Low steam production has also caused problems with supplying sufficient steam to the propane vaporizer. A different operating philosophy concerning the drum pressure was implemented to address this issue. The drum operating pressure was reduced and the thermal oxidizer was fired higher so the drum pressure could be maintained with the steam pressure control valve operating around 40-percent open. Figures 8.7.3-1 and -2 show two graphs which illustrate the operations.

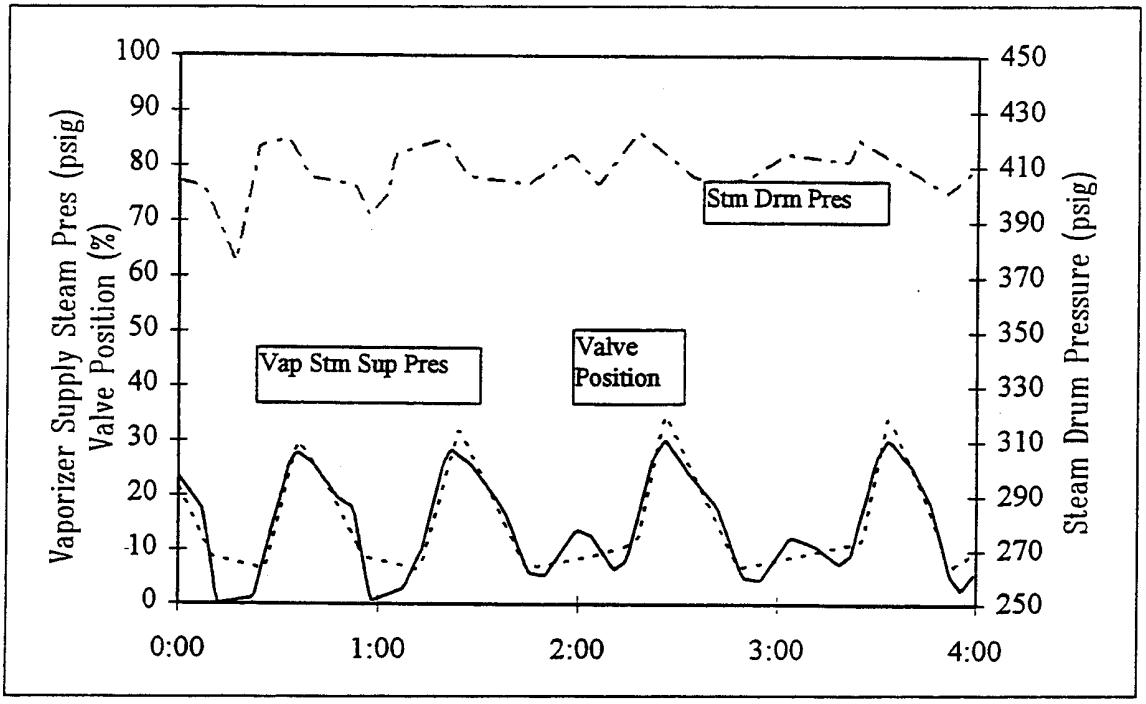


Figure 8.7.3-1 Steam System Operations August 5, 1996

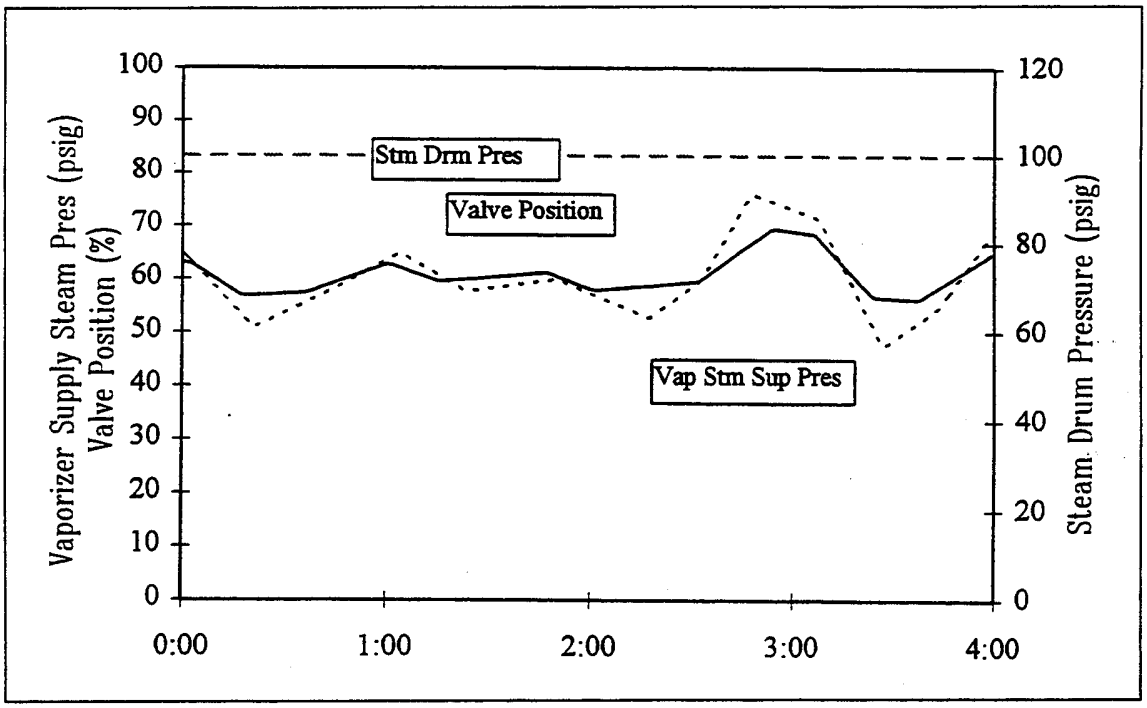


Figure 8.7.3-2 Steam System Operations November 21, 1996

8.8 SULFATOR SYSTEM

8.8.1 System Description

When the transport reactor operates in the gasification mode, the solids removed will be a mixture of carbon, CaS, CaO, and coal ash that must be rendered environmentally safe before disposal. Solids from the transport reactor will be pneumatically transported to the atmospheric fluidized bed sulfator (SU0601) where carbon will be oxidized to CO_2 and CaS will be converted to $CaSO_4$. To control SO_2 emissions, limestone will be introduced by the limestone feeder system (FD0610).

The reaction temperature in the sulfator vessel will be controlled to 1,650°F by superheating saturated steam. The sulfator air compressor (CO0601) will supply the process air required for combustion in SU0601. To preheat SU0601, the process air will be heated by the sulfator start-up heater (BR0602). Flue gases leaving the sulfator will flow through the sulfator cyclone (CY0601) and travel to the sulfator heat recovery exchanger (HX0601). The solids removed by CY0601 will be returned to SU0601. The flue gas exiting CY0601 will be cooled in HX0601 by generating steam. The SU0601 spent solids will be removed and cooled by the sulfator solids screw cooler (FD0602), transported to the spent solids silo (SI0602), and then transferred to the SCS sulfator spent solids removal system (FD0810) for transport to the SCS ash silo.

8.8.2 Commissioning Status

Since the transport reactor has not operated in the gasification mode, the sulfator system has not been fully commissioned. BR0602 and CO0601 were the only parts of the sulfator system fully commissioned. The loop and functional checks were completed on FD0610, FD0602, and FD0810. Only the loop checks were completed on the SI0602 and the spent solids silo vent filter (SI0602-FL01).

8.8.3 Commissioning Experience

8.8.3.1 Commissioning of the Sulfator Start-Up Heater

During the checkout of BR0602, numerous small problems were found and corrected. The internals of the pressure switches on the BR0602 burner management skid were corroded beyond repair. Apparently, this occurred while the skid sat outdoors for over a year. Also, the solenoid valve vents for the air operated valves were plugged with mud deposited by wasps.

Instructions from the BR0602 manufacturer, Tulsa Heater, Inc., stated no flow should pass through the process coils during BR0602 refractory dry out. In order to commission BR0602, the low process flow switch had to be jumped. Also the permissive to operate (HS619) had to be manually forced from the DCS. This DCS manual forcing was not used for subsequent BR0602 operations because it removed the operator's ability to remotely shutdown BR0602 from the DCS. Instead a few temporary changes were made to the DCS logic to permit the BR0602 to operate without steam flowing through the sulfator vessel.

After completing the BR0602 checkout, the burner was lit for the first time on May 14, 1996, and the refractory dry out soon followed.

8.8.3.2 Sulfator Start-Up Heater Dry Out

In late May the dry out of BR0602 was started. A trend of the stack temperature during the dry out is shown in figure 8.8.3-1. Controlling the rise in the BR0602 stack temperature (TI8840) was a major problem. The burner operating manual from John Zinc, Inc., stated the burner should not be operated below a firing rate of 1 MBtu/hr. This firing rate required the propane flow valve (FV688) to be 48-percent open which resulted in a rapid increase in the stack temperature (TI8840) when the burner was lit. The main burner was shut off and propane gas pressure to the pilot was increased from 10 to 15 psig in an attempt to raise the stack temperature to 300°F. After an hour and a half, the stack temperature only increased to 160°F, therefore the burner had to be used to reach the desired temperature.

After consulting with the manufacture, the BR0602 burner was fired at a lower rate. (The only risk was potential carbon buildup on the burner tip - which did happen.) BR0602 was lit and the propane flow valve (FV688) was set to 10-percent open. This allowed better control of the heat-up rate.

With the pilot and the main burner burning, TI8840 indicated 370°F. The pilot valve was closed and the stack temperature dropped to 340°F. The stack temperature was then raised per the dry out schedule. The dry out of BR0602 was successful and BR0602 was

not operated again until the end of September. A trend of the stack temperature (TI8840) for the refractory dry out is shown in figure 8.8.3-1.

8.8.3.3 Sulfator Air Compressor Commissioning and Operation

As part of the system checkout, the sulfator air compressor motor was bump started in early September 1996 and was found to have bad bearings. The bearing problem was likely a result of long-term storage. The sulfator air compressor (CO0601) was started for the first time on September 27 and test run for 4 hours. Two cross members were added to stiffen the compressor frame. After a few days of operation, a strap holding the inlet silencer broke and had to be repaired.

A positioner was added to the process air flow control valve (FV620) in order to improve air flow control to the sulfator. Also a flow element (FE620) had to be reinstalled because the guidevanes were not lined up with the flow path.

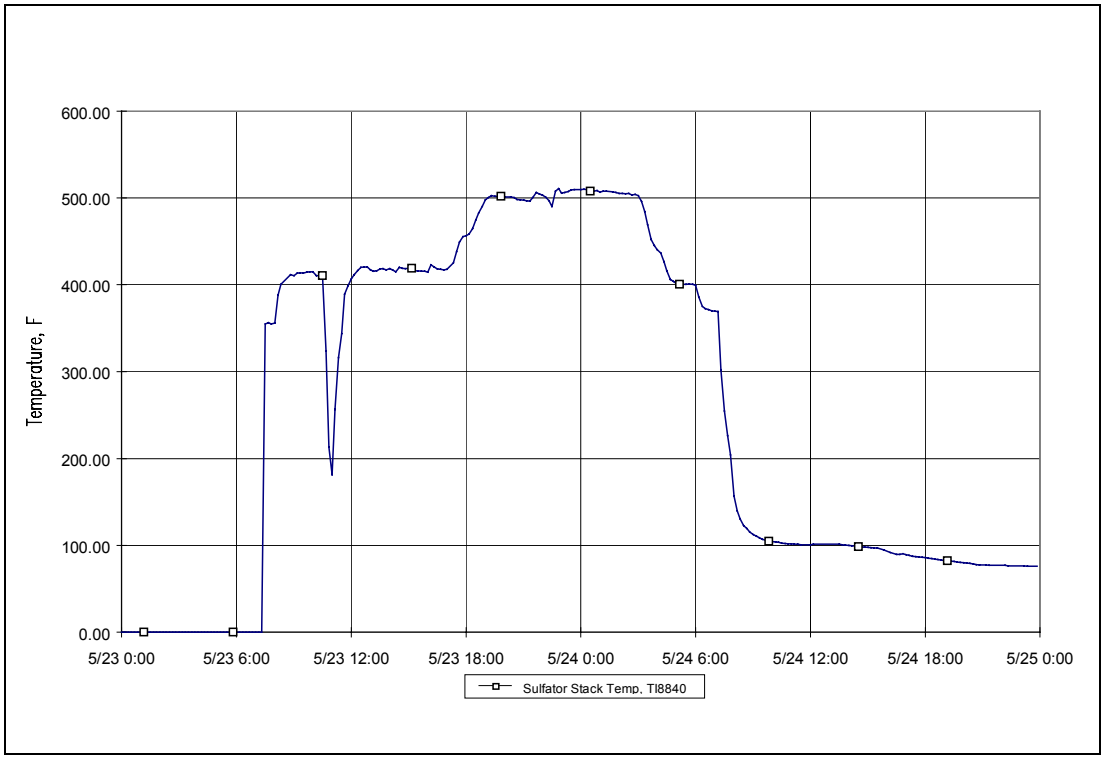


Figure 8.8.3-1 Sulfator Start-Up Heater Refractory Dry Out May 23 to 25, 1996

8.8.4 Sulfator Start-Up Heater Performance Test

The initial plan was to cure the joint refractory in the sulfator system. However, experience from the transport reactor proved that solids would first have to be introduced into the sulfator vessel. Therefore, only a performance test of the sulfator start-up heater was run. The purpose was to evaluate how well BR0602 could preheat SU0601.

The first performance test began on September 27. CO0601 was operated for 48 hours to air dry the sulfator system and then, the BR0602 pilot was lit and burned for 24 hours as part of the initial heatup.

On September 30 the BR0602 burner was lit and the pilot was shut off. The propane flow valve (FV688) was set at 10-percent open. For the next couple of days BR0602 had to be restarted for various reasons. On one occasion, when the sulfator heat recovery exchanger (HX0601) was opened to the steam system, the steam system pressure dropped and steam flow to the propane vaporizer was lost and the propane vaporizer shut down. Similarly, BR0602 tripped once again when the thermal oxidizer was taken off line to fix control problems.

On October 2 when FV688 (propane to BR0602) was opened from 20-to 28-percent open, the flow to BR0602 started to decrease. The propane vaporizer was found to be full of condensate. The condensate was drained and the steam bypass valve was opened.

On October 3 the propane flow valve (FV688) to BR0602 was opened from 10-to 18-percent open and the flow stayed at 1 lb/hr. Then suddenly the flow jumped to 28 lb/hr and the flame was blown out. The restart of BR0602 was attempted to four times but it would not stay lit. The propane pressure regulator (PCV8810) located on the BR0602 burner management skid was fouled. The regulator was cleaned and BR0602 was relit.

On October 5 when FV688 was opened from 69 to 70 percent, BR0602 tripped on high pressure (PSH8816). The drop across the burner (PI8817) was 22 psig when FV688 was 69-percent open and 23 psig when the FV688 was increased to 70-percent open. The design propane flow rate for BR0602 is 120 lb/hr. At the time of the high pressure trip, the flow rate was 140 lb/hr, the stack temperature was 1,360°F, and yet the process outlet temperature (TI617) was only 830°F, well below the design of 1,200°F. The problem was too much excess air was being drawn into the naturally drafted BR0602, cooling the flame and thereby reducing the radiant heat transfer to the process air. A hand-held O_2 sensor was used to measure the stack O_2 levels while the stack damper and bottom register were adjusted to obtain 3 percent oxygen in the stack (~15 percent excess air). With the reduced excess air level, the flame temperature increased and the quantity of propane required was reduced. Shutdowns due to high pressure drop across the burner did not occur again.

Because of the problems with the transport reactor start-up burner (BR0201) and the propane vaporizer, the performance test was suspended on October 6. The trend for TI8840 and TI617 during this period is shown in figure 8.8.4-1.

The performance test was restarted on October 14. The goal was to achieve a process outlet temperature of 1,200°F while keeping the stack temperature below the design of 1,360°F with an excess air level of 15 percent. On October 16 the BR0602 process outlet temperature (TI617) had only reached 850°F, even after the top damper and bottom register were set to get 3-percent O_2 in the flue gas and while maintaining 1,360°F in the stack.

After checking on the temperature limitations of the stack, the propane flow was increased until the stack temperature was 1,450°F. After increasing the propane flow, BR0602 tripped four times with each trip about 4 hours apart. It was discovered the trips occurred because of an accidental removal of a manually set steam flow (FI602) in the DCS. Since these tests were being performed with the SU0601 steam piping dry, FI602 output was manually set to 19,000 lb/hr on September 27. However, on October 15 this manually inserted valve was accidentally removed. With the manually inserted flow rate removed, the permissive to run was lost when a temperature indication in the sulfator (TI568) exceeded 550°F. In the DCS interlock logic during normal operations, BR0602 can only be operated when less than 18,500 lb/hr steam is flowing through the sulfator and TI568 is below 550°F. The inserted steam flow rate was restored.

The trend for this performance period is shown in figure 8.8.4-2. The process outlet temperature (TI617) reached 945°F. BR0602 was shutdown on October 18 to evaluate the performance problem, and the draft in BR0602 was observed to be too high. A Magnehelic gauge was installed, and it was determined that SU0601 temperature (TI567) had reached only 590°F.

The performance test was restarted on November 3. Two days into the test, flame was seen below the burner gas tip. The test was suspended and the burner was removed for inspection. The burner gas tip was covered with carbon which was a result of extended firing of the burner at low propane flows. Flame was seen below the burner gas tip because the threaded connection was leaking. The trend for this period is shown in figure 8.8.4-3.

On November 8 the performance test was restarted. The trend for this period is shown in figure 8.8.4-4. The design process outlet temperature (TI617) of 1,200°F was reached. The process air flow indication (FI620) was 6,283 lb/hr, however, that flow reading is believed to be in error. The process air flow was calculated to be 5,450 lb/hr which is 14 percent below the design flow rate of 6,200 lb/hr. Flow element FE620 is scheduled to be sent off for calibration in early 1997.

One factor that affected the performance of BR0602 was the process air temperature (TI624) entering BR0602 at 50°F below design. The inlet air temperature to BR0602 was 150°F because of the relatively low ambient temperature. The design temperature is 200°F. The temperature of the process air entering BR0602 was affected by the ambient conditions. During previous runs, TI624 had normally reached 215°F. If the process air inlet was at the design temperature, calculations indicated 5,700 lb/hr could have been heated to 1,200°F.

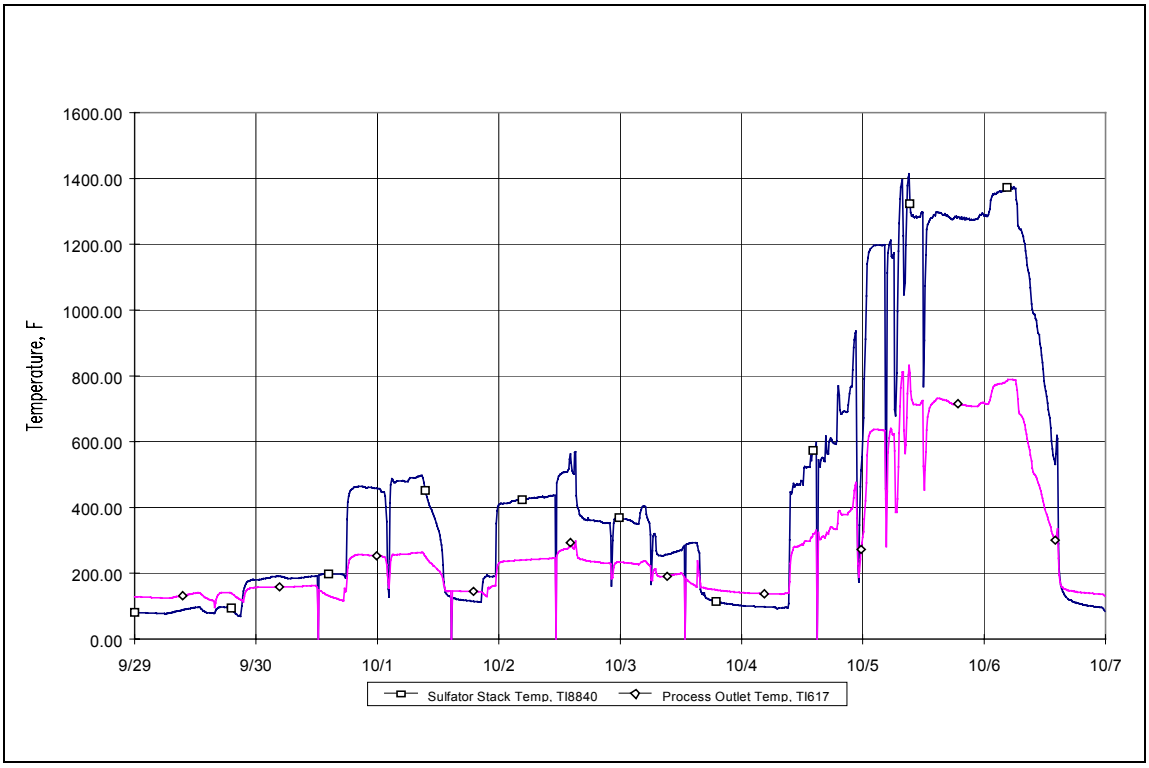


Figure 8.8.4-1 Sulfator Performance Test September 9 to October 7, 1996

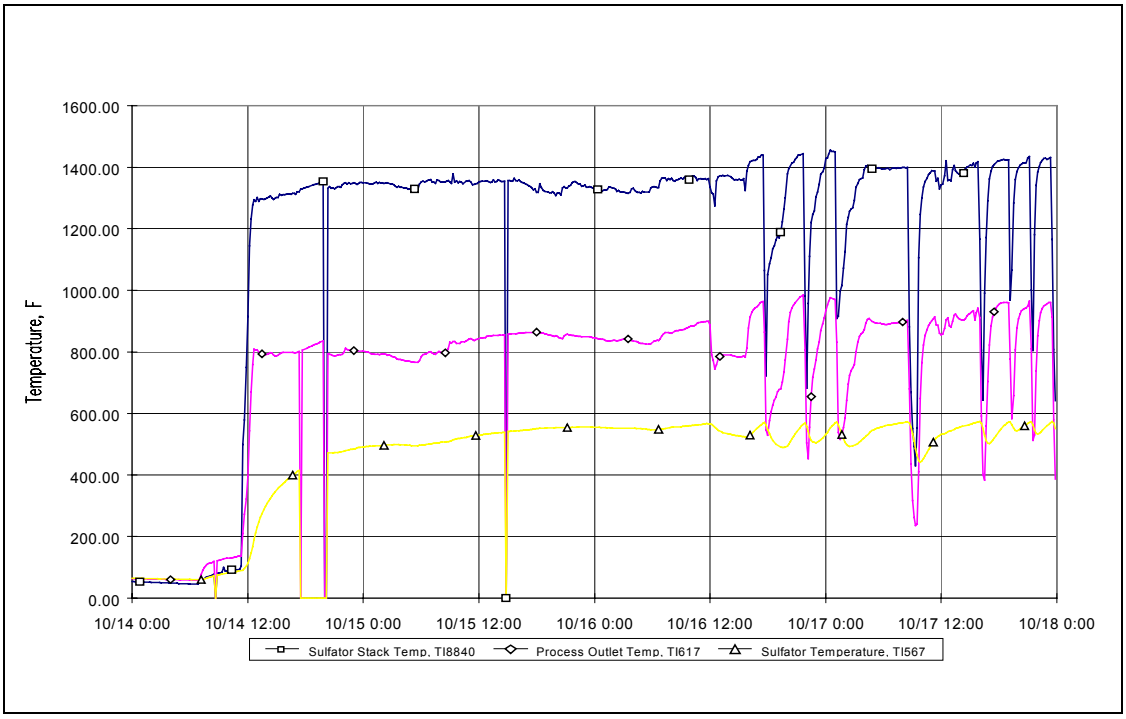


Figure 8.8.4-2 Sulfator Performance Test October 14 to 18, 1996

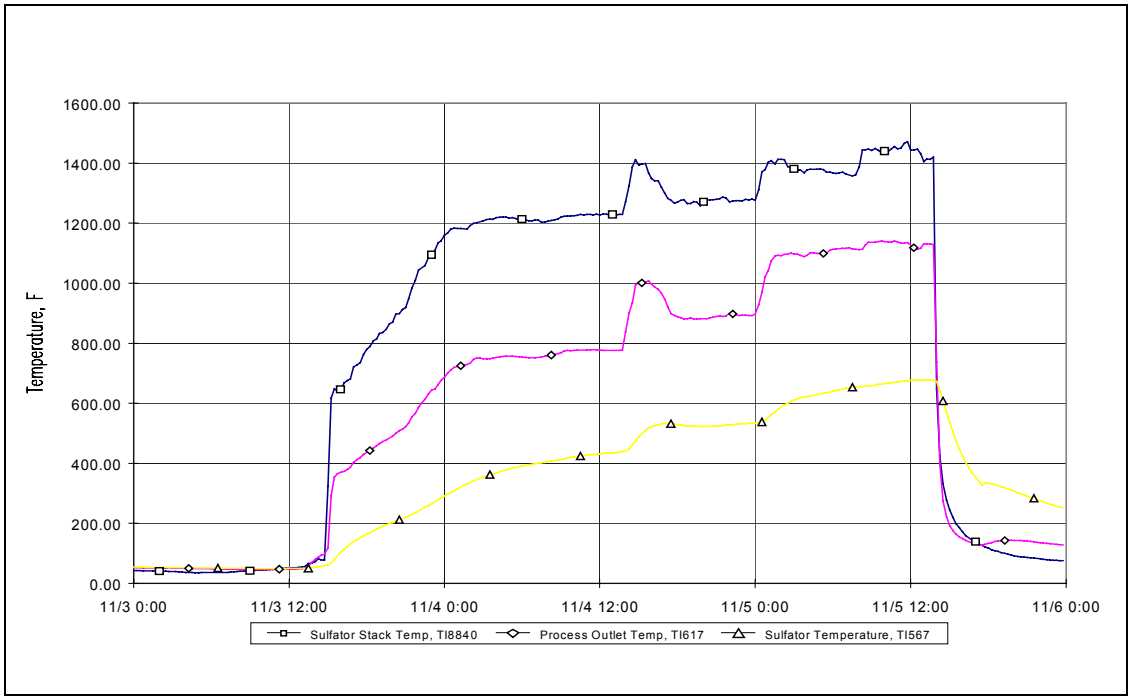


Figure 8.8.4-3 Sulfator Performance Test November 3 to 6, 1996

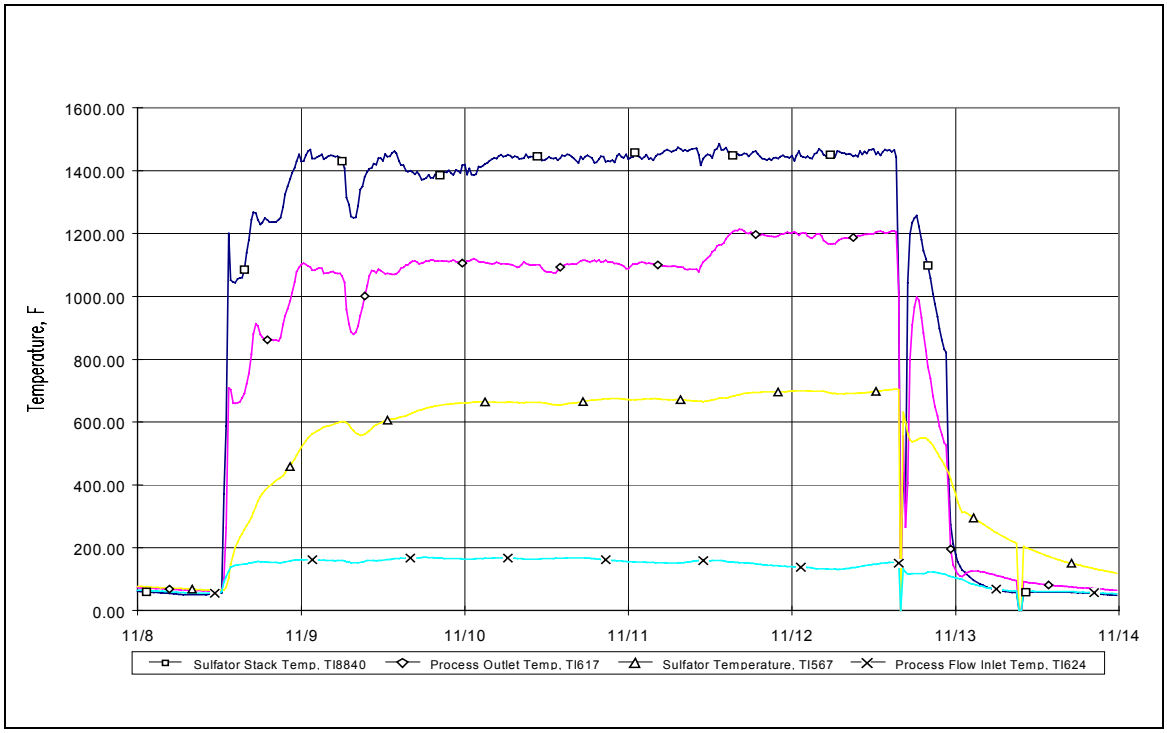


Figure 8.8.4-4 Sulfator Performance Test November 8 to 14, 1996

8.8.5 Other General Problems

When the propane pressure in the structure piping going to the transport reactor start-up burner (BR0201) was increased from the design of 110 to 175 psig, the propane supply pressure to BR0602 increased. Therefore, a new pressure regulator was installed in the piping branch going to BR0602 and set to the design of 85 psig. However, this created a problem with the DCS flow calculation. The flow calculation block was using the pressure indication from PI622 which is located on the Kellogg structure propane header and before the newly installed regulator. As a result, when the propane header pressure was above 85 psig the calculation was in error. The DCS calculation block was changed to use the PI622 input when the Kellogg structure header pressure is less than 85 psig. When the header pressure is above 85 psig, the flow calculation block uses a set 85 psig input.

The flame scanner was tested and worked without any problems during the first few months of operation. However, later in the year the scanner had to be removed and cleaned. The eye of the scanner points up toward the flame which allows debris from the heater to settle on the eye.

8.9 BAGHOUSE, BAGHOUSE ASH REMOVAL, AND MWK ASH STORAGE SYSTEM

8.9.1 Baghouse Commissioning Report

8.9.1.1 Description

The purpose of the final hot gas clean-up system is to filter process gas at the back end of the MWK process. The system primarily serves as a back-up filter system for the PCD systems in case of a failure. The system also provides some additional cooling of the gas before it enters the stack and discharges to the atmosphere. The system consists of three main pieces of equipment: dilution air fan, atmospheric baghouse, and screw conveyor. Process gas from the thermal oxidizer is cooled by the dilution air fan to a temperature which is acceptable for the bags in the baghouse. If, for some reason, the gas is still too hot prior to entering the baghouse, there are two opposite action dampers in parallel just upstream of the baghouse which cause the gas to bypass the baghouse and flow directly to the stack. The bypass dampers are also activated by excessive ΔP across the baghouse. The baghouse (which houses 704 cloth filter bags supported by metal cages) filters the process gas stream. The bags are cleaned using pulse jet valves which deliver compressed cleaning air to a series of plenums. Each plenum traverses the width of the baghouse above a row of bags and cleans the bags in the row simultaneously as the pulse sequence reaches its row. Any resulting solids removed from the gas are conveyed by the screw conveyor (which is attached to the baghouse collection trough along the entire underside length of the baghouse) to a pneumatic pump at one end of the baghouse. From here the solids are pneumatically conveyed to the MWK ash silo.

8.9.1.2 Commissioning Activities

The final hot gas clean-up system (baghouse) was completed by construction and turned over to operations in the early part of the second quarter 1996. Until June 1996 the system operated periodically in bypass mode to provide a flow path for the thermal oxidizer commissioning activities. In early June a technical representative from Fuller-Kovako, the supplier of the majority of the components for the system, was on-site to provide guidance and advice for start-up. The plant, however, was not yet ready for start-up activities, so the dust collecting bags had not been installed in the baghouse.

A Fuller-Kovako representative performed a preoperation inspection of the system. This inspection included blowing down the compressed air supply piping, energizing the pulse cleaning timer board, sequencing the pulse cleaning valves, bumping the screw conveyor for rotation, and performing a general inspection of the installation of the equipment. No significant problems were discovered during the vendor visit. Some of the compression fittings between the pulse tubes and the compressed air header were found to be leaking, so the insulation around the fittings was removed and they were tightened further. While pressurizing the compressed air header during the vendor visit, a sizable leak was discovered which was later eliminated by rewelding the area. However, after eliminating

this large leak, it was discovered that almost every vertical connecting pipe emerging from the compressed air header was leaking from the threads. Correction of this problem was more involved than the previous ones because it required removal of the compression fittings and pulse tubes in order to tighten these threaded pipes by no less than one revolution each for alignment purposes.

During the time before commissioning activities were to begin, the PSDF technical lead examined the system control schemes in order to prepare a functional checklist for a precommissioning check. It was discovered that the existing control logic was inadequate for automation and equipment protection purposes. All equipment was independently and manually controlled and no allowances were made for equipment interactions or system interdependence. Control logic was written and incorporated into the plant DCS to address these issues. After these control issues and the aforementioned mechanical issues were resolved, the system was ready for final commissioning activities.

The functional checks of the system were also performed in June 1996 during a thermal oxidizer outage period. The system responded to logic simulations of process conditions, and timer values for pulse cleaning and screw conveyor operation were monitored and adjusted. All alarm responses were checked and responded appropriately. The system performed as designed and was ready for preconditioning and on-line service. The preconditioning involved introducing a coating material (fine alumina) through the dilution air fan and into the inlet gas stream to provide a preliminary solids coating for better filtration effectiveness. The screw conveyor was run to remove the coating alumina that had fallen from the bags. On July 10, 1996, a baghouse leak check was performed using a fluorescent powder which was blown into the baghouse through the dilution air fan. Only 1 of the 704 bags leaked and it was quickly reinstalled to prevent further leaks. Four welds on the top of the tubesheet showed slight leaks and a few slight leaks were also identified in the blow tubes. None of these leaks required repair, but a reinspection to determine whether or not the leaks have grown is recommended. After this leak test was performed and satisfactory results were produced, the system was considered commissioned and ready for MWK operation.

8.9.1.3 MWK Operation

The baghouse was fully operational for the MWK coal characterization test runs which began in July 1996. The most important operating parameter for monitoring baghouse performance is the differential pressure (ΔP) across the bags. A steady rise in ΔP indicates collection of solids in the baghouse and, more importantly, indicates a problem upstream of the baghouse since under normal operating conditions there should not be any significant accumulation of solids in the baghouse. The control logic for the system initiates a pulse cleaning sequence at a certain ΔP value, which is set in the DCS. This ΔP trigger was maintained at 6 inWG throughout the test runs.

The ΔP plots for CCT1A and CCT1B (figures 8.9.1-1 and -2) show definite and steady rises in ΔP and are good indications of MWK operating conditions. During these runs, the MWK transport reactor feed systems were venting to a point in the process gas stream that was downstream of the PCD. This was causing solids to be entrained in the "clean" gas stream and ultimate accumulate in the baghouse. Another cause of the rises in ΔP was the accumulation of alumina which had remained in the MWK system downstream of the PCD from commissioning activities prior to CCT1A. As can be seen from figures 8.9.1- 3 through -6, the ΔP remained within consistent ranges for the remainder of the tests due to the correction of the feeder vent problem and the removal over time of alumina which had remained in the MWK system downstream of the PCD.

Another operating condition of note was the large degree of oscillation of the ΔP up until CCT3. Although the three pulse cleaning cycles displayed in figure 8.9.1-1 indicate the ΔP reached the trigger value of 6 inWG three times, the baseline was actually around 3 inWG and oscillation caused the pulse cleaning to commence. This gave the appearance that there were more solids in the baghouse than actually were. The oscillation was discovered to be caused by the dilution air fan. The fan inlet vanes are adjusted automatically by a temperature controller which measures the inlet temperature of the baghouse and controls the cooling function of the dilution air fan. This temperature controller was not accurately tuned and was causing the inlet vanes to oscillate within a certain temperature range. This oscillation was, in turn, causing the actual ΔP of the baghouse to oscillate as the fan was delivering pulses of air to the inlet gas stream. The temperature controller was tuned and the oscillation of the ΔP subsided which can be clearly seen by comparing figures 8.9.1-1 through -5 to figure 8.9.1-6.

Other problems experienced during the first test runs included the screw conveyor reversing action, leaking water into the baghouse at the access doors, and level probes malfunctioning in the baghouse trough. The screw conveyor was discovered to be wired backwards; which was easily corrected. The access doors were adjusted to prevent leaking, and the level probes were replaced during the outage at the end of 1996.

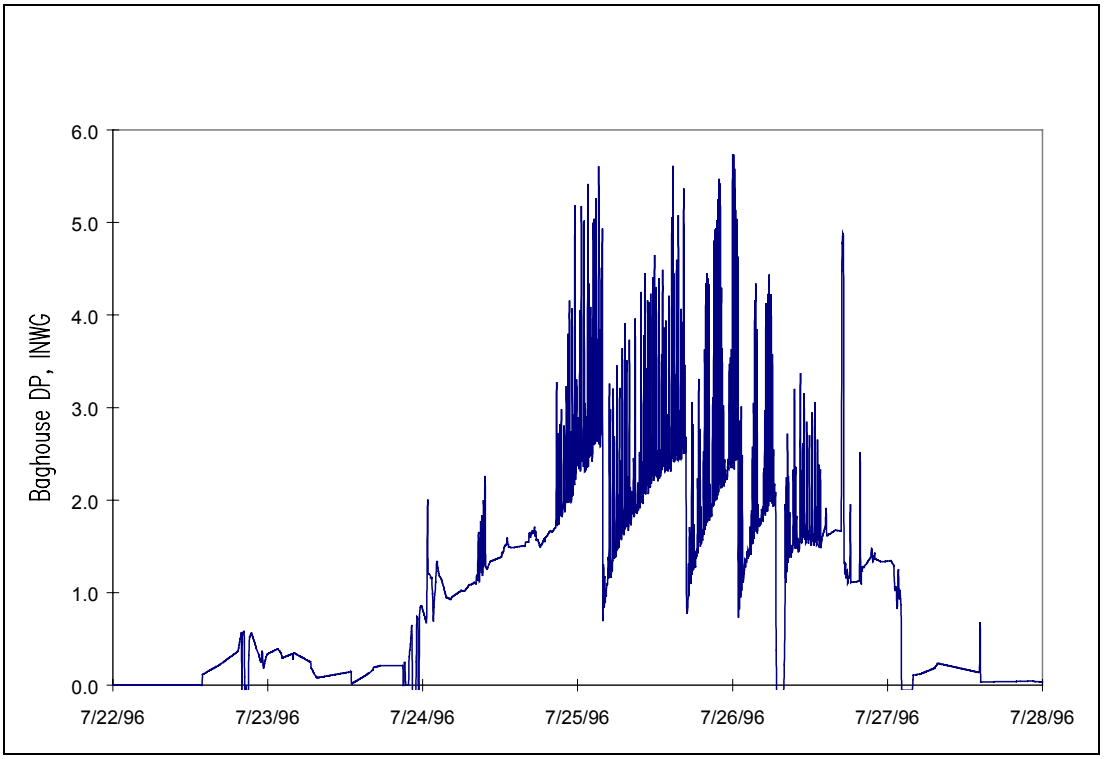


Figure 8.9.1-1 Baghouse ΔP CCT1A

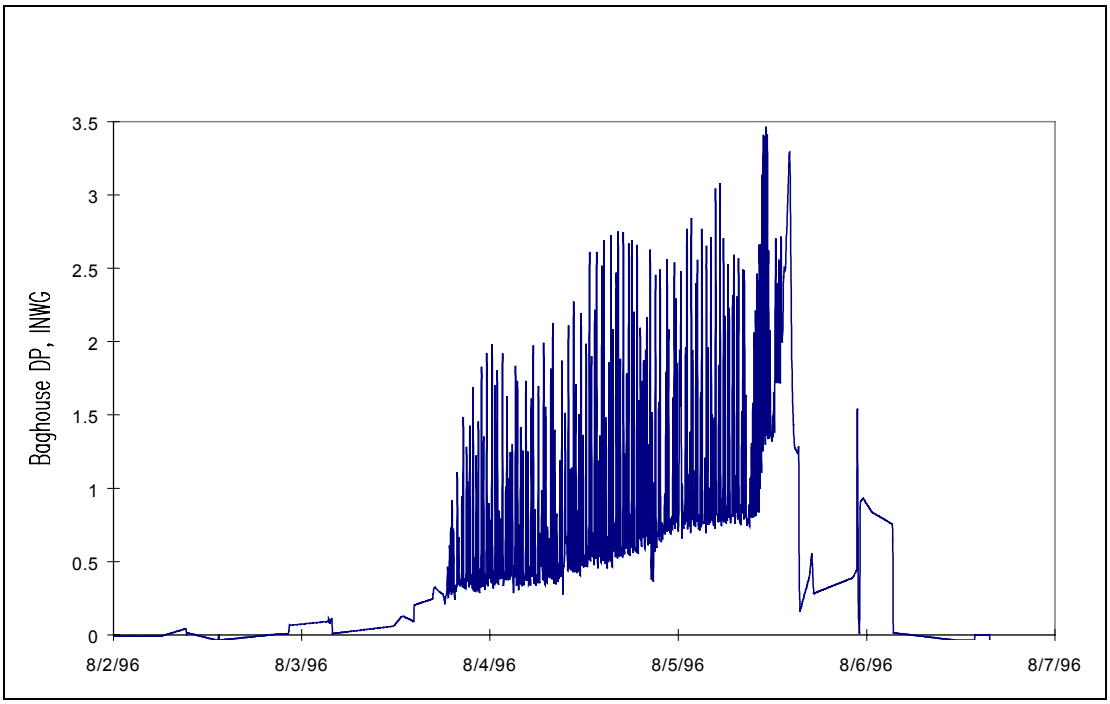


Figure 8.9.1-2 Baghouse ΔP CCT1B

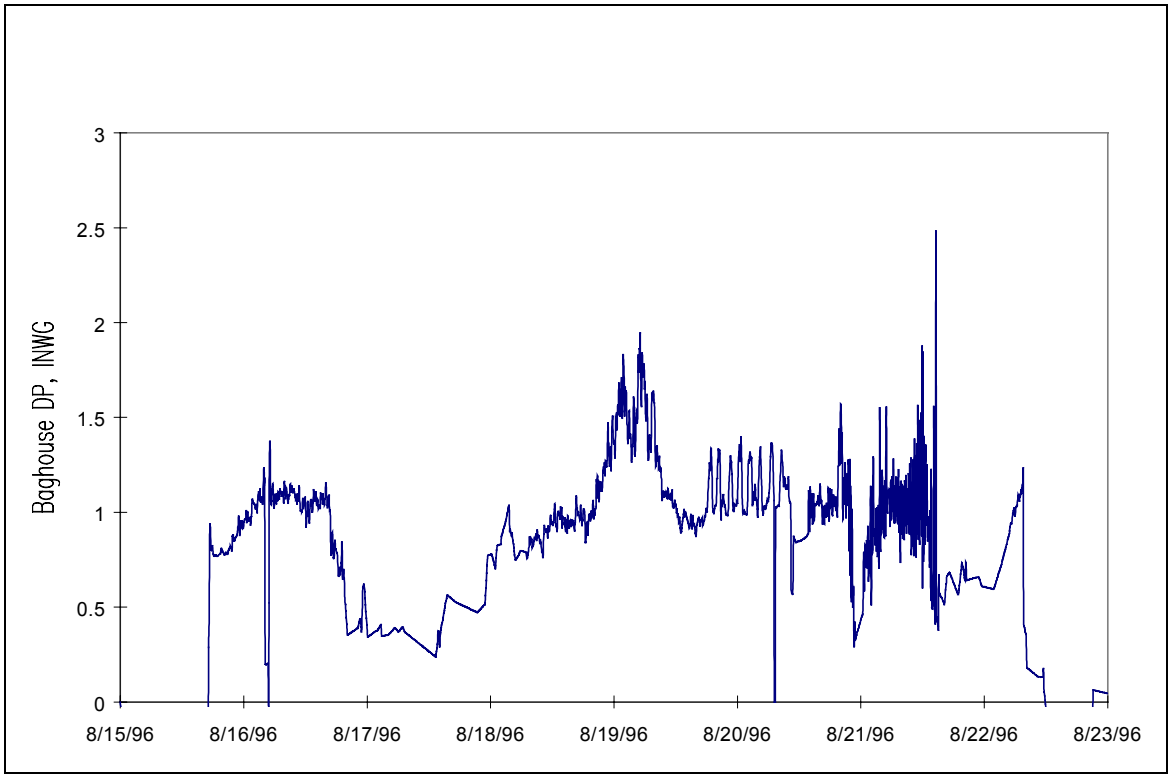
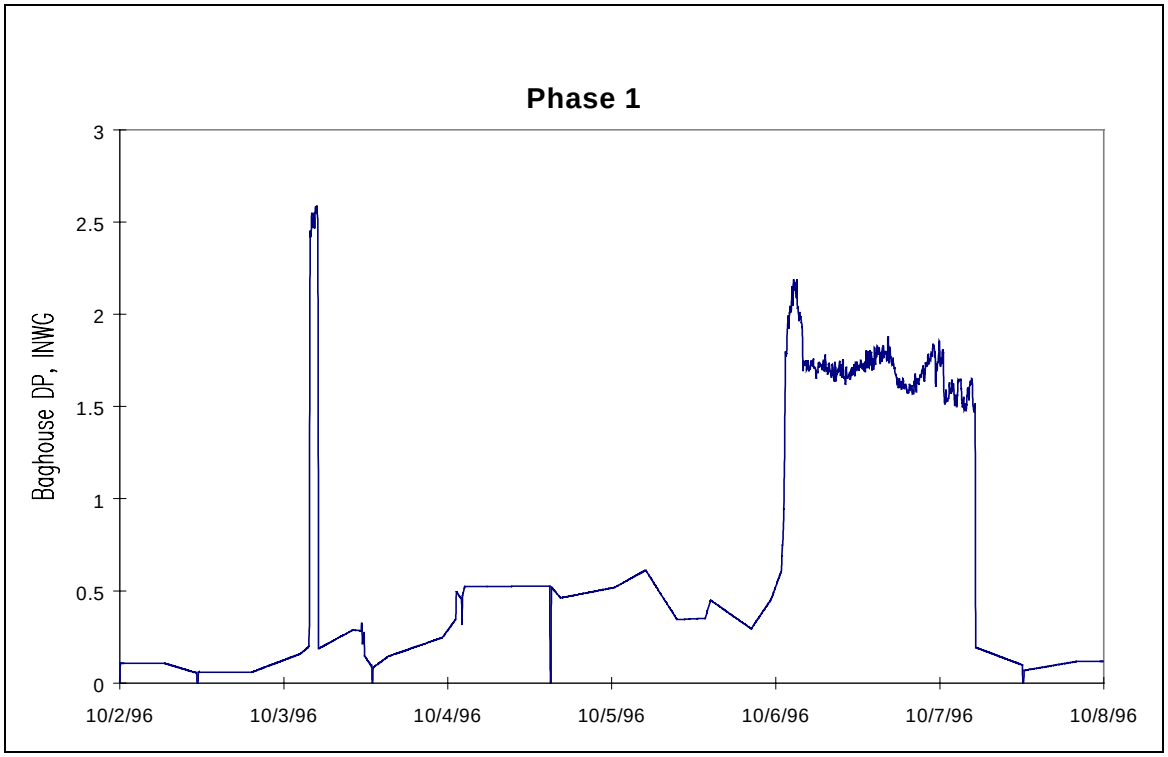


Figure 8.9.1-3 Baghouse ΔP CCT1C



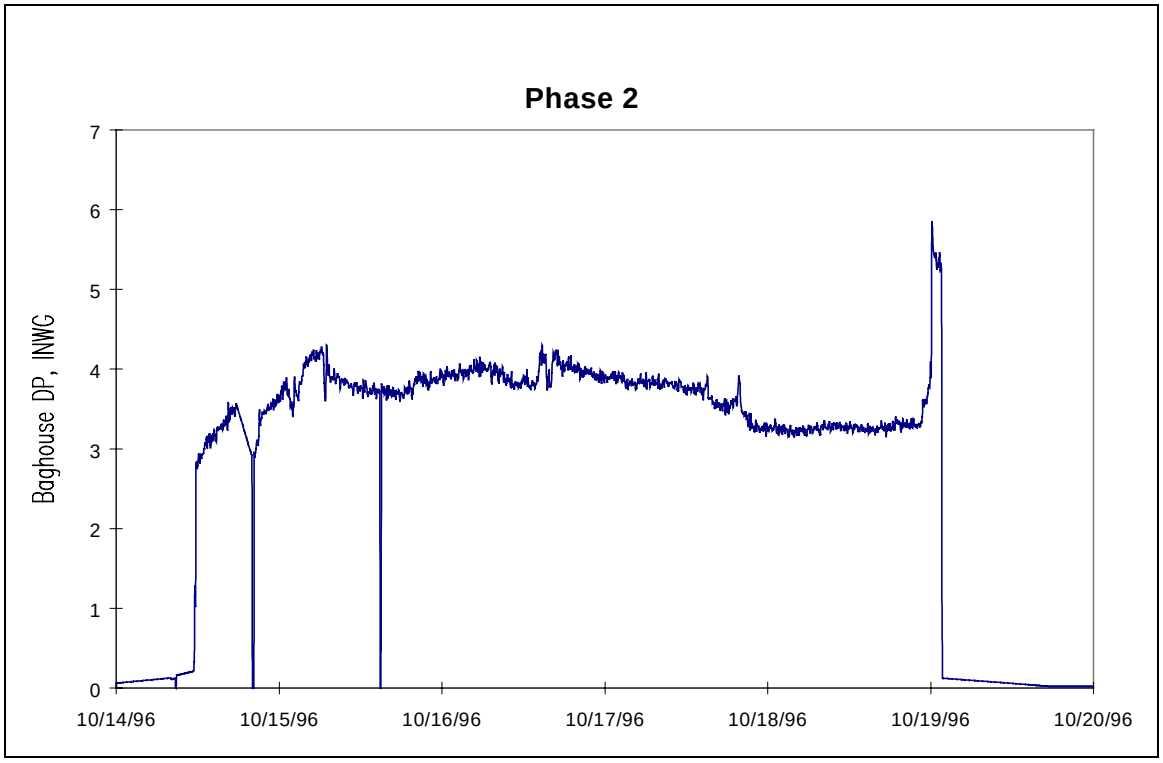


Figure 8.9.1-4 Baghouse ΔP CCT2A

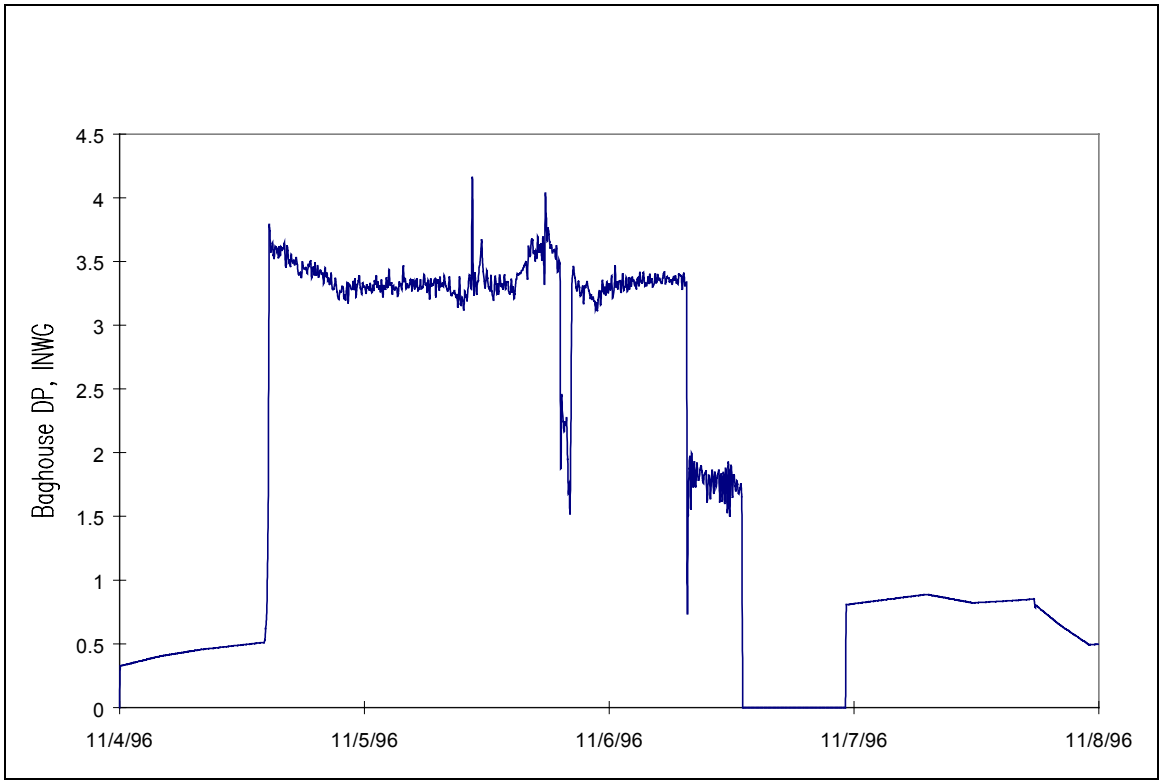


Figure 8.9.1-5 Baghouse ΔP CCT2B

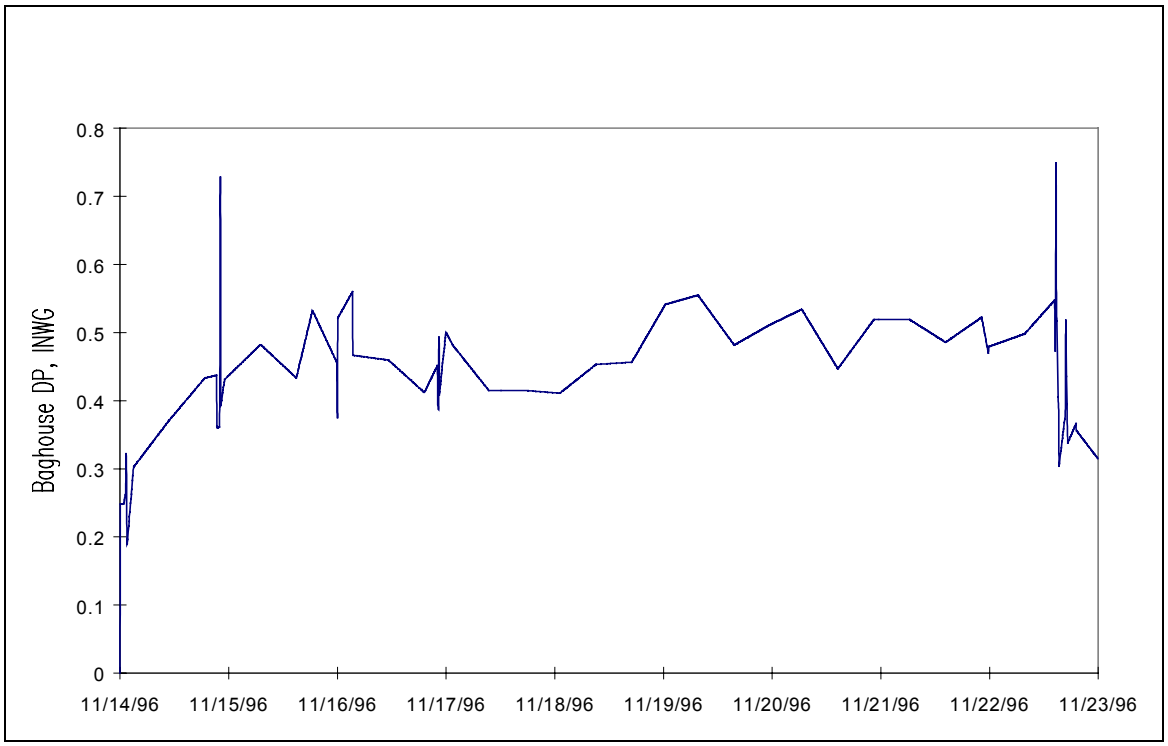


Figure 8.9.1-6 Baghouse ΔP CCT2C

8.9.2 Baghouse Ash Removal System

8.9.2.1 Description

The baghouse ash removal system (FD0820) is a Clyde Pneumatic Conveying system which conveys solids from the MWK baghouse to the MWK ash storage system during combustion and gasification modes of operation. The system consists of a 2-ft^3 surge hopper and a 4-inch inlet by 2-inch outlet dense-phase pump which pneumatically conveys the material through 2-inch NB pipework to the ash silo. The surge hopper receives material from the baghouse screw conveyor and the material falls by gravity into the pump. Conveying air then flows into the pump and blows the material to the silo. When the pressure in the pump decreases back to atmospheric pressure, the cycle ends and immediately repeats as long as there is still material in the surge hopper up to the level of the probe. If there is no material in the surge hopper up to the probe, the cycle waits for an extended amount of time before repeating.

8.9.2.2 Commissioning/Operations

Functional checks of this system were conducted in June 1996 and revealed problems with the interaction of the surge hopper level probe with the PLC control logic. After modification of the logic and the action of the probe, the system functioned as specified. However, there was additional control logic deemed necessary to prevent the baghouse screw conveyor from overfilling the surge hopper in the event the dense-phase pump could not keep up with the screw conveyor feed rate. The DCS control logic that controls the final hot gas clean-up system (baghouse, screw conveyor, etc.) was modified to incorporate the FD0820 surge hopper level probe. The modification consisted of shutting down the screw conveyor in the event that the level probe remained covered for two consecutive cycles of the dense-phase pump. The first solids conveyed by the system were alumina solids that had been used to precondition the baghouse bags in June 1996. The only problem experienced with the FD0820 system through commissioning and operation has been the occasional plugging of the surge hopper due to moisture in the baghouse solids. To date the system has completed 21,307 cycles of virtually trouble-free operation.

8.9.3 MWK Ash Storage

8.9.3.1 Description

The MWK ash storage system (SI0814) is also a Clyde Pneumatic Conveying system designed to receive ash from three different sources within the MWK process. The system consists of an approximately 3,000-ft^3 capacity storage silo which can discharge either through a 12-inch Spheri valve and retractable loading spout into a truck or bin or through an 8-inch rotary valve into a 55-gallon drum. The 12-inch Spheri valve and the retractable loading spout are controlled by a hand-held pendant located on a landing above the spout. The spout is also equipped with a capacitance probe which hangs below the end of the spout and controls a light panel also located on the landing with the pendant. When the truck or bin is full, the material touches the probe which sends a signal to the light panel telling the operator to close the Spheri valve with the pendant and stops the loading. The 8-inch rotary valve controls the flow of material to a 55-gallon sampling drum. The sampling pipe is equipped at the end with a permanent drum lid equipped with a level probe. Any 55-gallon drum can be attached to the lid and is attached or removed via an adjustable stand. When the drum becomes full during operation of the rotary valve, the level probe automatically shuts the valve down and prevents overfilling of the drum. The main silo is equipped with high and low level probes, the high level probe being used by the systems feeding the silo as a permissive to feed and the low level probe being used for indication purposes only. The silo is also equipped with temperature probes located in the top, the discharge cone, and the discharge chute sections of the silo, which have only been used for indication purposes during previous operation. These temperature probes are being considered for implementation as personnel protection during future operation by linking them through PLC control logic to the loading spout operation.

There are three separate inlet pipes connected to the silo, only two of which feed the silo at any time during operation. During combustion mode operation, ash from the FD0530 system (combined ash from the PCD and transport reactor) and ash from the FD0820 system (discussed above) feed the silo. During gasification mode operation, char from the FD0530 system must first pass through the sulfator before being fed to the silo. After the char leaves the sulfator, it is conveyed to the silo by the FD0810 system. The FD0820 system also feeds the silo in gasification mode.

8.9.3.2 Commissioning/Operations

The MWK ash storage system has been in frequent operation since June 1996 when functional checks were completed and solids were first conveyed to it from the baghouse. Its functions have been numerous and have ranged from a storage system to a sampling point. Prior to first operation, functional checks of the system were virtually problem-free

with only some minor PLC control logic changes necessary for the system to function as specified. The first material conveyed to the system in June was alumina that had been used to precondition the bags in the MWK baghouse. The material was successfully collected and removed from the silo via the unloading spout. No significant operational problems have been experienced with the system through the end of 1996.

8.10 HEAT TRANSFER FLUID SYSTEM

8.10.1 Description

The heat transfer fluid system (HTF) system is used to cool the solids that are removed from the transport reactor standpipe, the sulfator, and the fines from the particulate collection devices (PCDs). The fluid is circulated through both the outer shell and the flights of the screw cooler in all three applications. The fluid used is UCON-500 which is a mixture of polyalkylene glycols from Union Carbide. The fluid is pumped from a storage tank to a surge drum at the 183-foot elevation. The storage drum operates under a nitrogen blanket at a pressure of about 50 psig. The surge drum provides about 5 minutes of fluid capacity if fluid flow to the drum is lost. From the surge drum, the fluid flows by gravity to the three screw coolers and into a return header. The fluid flows through an air-cooled heat exchanger before being returned to the storage tank. The temperature of the fluid is maintained at 210°F by diverting a portion of the flow around the exchanger. If the fluid temperature drops below 210°F, electric heaters in the tank activate to maintain set point. A total flow of about 120 gpm is provided to the screw coolers.

8.10.2 Commissioning/Operations

The HTF system was successfully commissioned during the first quarter of 1996. After loop checks and functional checks of the instrumentation and control loops, the system was filled with water. Strainers were installed in several locations and the water was circulated to flush out the piping. The electric heaters in the storage tank were also tested with water in the tank. After flushing, the water was drained and the system was refilled with HTF, leaving the strainers in place. Following the manufactures procedure, the HTF fluid was heated to about 250°F to remove water from the fluid. The fluid was circulated for several days with the strainers in place to remove any particulates left from the water flush.

During the commissioning tests, it was discovered that the three-way control valve that diverts fluid flow around the air-cooled heat exchanger was installed incorrectly and had to be repaired. Other modifications to the HTF system were made during commissioning and start-up. A line was added to the pump discharge to recirculate fluid to the storage drum in case the control valve to the surge drum was closed. An orifice, sized to allow the minimum flow to pass at the pump's discharge pressure, was installed to prevent the pump from deadheading. A drain line to the storage tank was installed at the low point in the HTF supply header. Vents were added to allow air to be vented from parts of the system. A sight glass was added to the storage tank. Lastly, a valve was added to the nitrogen line to the surge drum to allow the drum to maintain a nitrogen blanket during an outage.

With the above modifications, the HTF system has performed well during normal operation.

8.11 MEDIUM- AND LOW-PRESSURE NITROGEN SYSTEM

8.11.1 Description

The medium- and low-pressure nitrogen system comprises the nitrogen generation, liquid nitrogen storage facilities (BOC Group, Inc., owned and operated), and the SCS balance-of-plant distribution piping.

The nitrogen generation plant is a cryogenic air separation plant that generates 8,095 lb/hr of gaseous nitrogen. The liquid nitrogen storage facility holds 60,000 lb of nitrogen at 150 psig and 120,000 lb of liquid nitrogen at 450 psig.

The liquid storage facility serves as a backup to the nitrogen generation plant, provides additional nitrogen during peak demand periods, and supplies nitrogen when the nitrogen generation plant is shut down. Additionally, the liquid storage facility supplies the nitrogen required for the emergency shutdown of the M. W. Kellogg and the Foster Wheeler processes.

BOC provides gaseous nitrogen at 30, 150, and 450 psig to the various PSDF consumption points.

8.11.2 Commissioning/Operating Experience

The nitrogen generation plant and liquid nitrogen storage facility were commissioned by BOC. Numerous problems plagued the liquid nitrogen storage facility throughout the year; however, the facility was always online when required. The nitrogen generation plant operated with very few problems.

The medium pressure liquid nitrogen is stored in the insulated tanks at 300°F. Heat transferred into the storage tanks raises the temperature and boils off some nitrogen, thereby increasing the pressure. This pressure build must be bled by venting gaseous nitrogen and is termed heat release. BOC experienced many problems with their instrumentation and valve setup for this. The pressure switches and vent solenoid valves failed numerous times and the vaporizer pressure relief valves started to lift repeatedly. BOC plans to replace the vent solenoid valves in early 1997.

On one occasion when one of the vent solenoids valves failed, the pressure climbed in the tanks and one of the vaporizer pressure relief valves began to chatter. The pipe nipple holding the relief valve broke and nitrogen was lost to the atmosphere. The pressure relief valves on the medium pressure vaporizers were braced to prevent a reoccurrence.

Normally, the heat release consumes 0.5 to 1.0 percent of the tank volume per day when medium pressure nitrogen is not being consumed by any of the PSDF processes.

8.12 PROPANE SYSTEM

8.12.1 Description

The propane system consists of a truck unloading station, three liquid propane tanks (30,000 gallons each), a liquid propane pump, a propane vaporizer, condensate cooler, condensate return system, and the assorted instrumentation, piping and valves required to operate the system.

The propane system supplies low and high pressure propane. The low pressure propane is drawn from the vapor space in the storage tanks and regulated to 40 psig. The high pressure propane is pumped up to pressure as a liquid and fed to a vaporizer before distribution to the various consumption points. The high pressure propane system pressure can be regulated from tank pressure up to 235 psig. The tank pressure is nominally between 85 and 130 psig.

The original design specified low pressure propane be delivered to the auxiliary boiler to generate the steam required for vaporizing the high pressure propane liquid. However, the auxiliary boiler installation was postponed until late 1996. Since the auxiliary boiler was not available, low pressure propane piping was plumbed to the thermal oxidizer, and the thermal oxidizer was used to generate the steam for the vaporizer.

Piping was installed to provide low pressure propane to the feedstock preparation structure to allow the processing of coal when the thermal oxidizer was not operating.

8.12.2 Commissioning/Operations

The propane system vendor (Energistics, Inc.) commissioned the propane pump, pressure regulator, and vaporizer. When the propane pump was stopped, it was noted the pump spun backwards and the pump seals leaked. The propane system vendor replaced the pump seals and installed a check valve to prevent propane back-flow through the pump. No other problems were observed during the commissioning phase. Commissioning was completed by May 14, 1996.

8.12.3 Performance During Normal Operations

During operations in 1996, the propane vaporizer throughput was always less than two percent of design. The vaporizer manufacturer was surprised the vaporizer worked at all at such low throughput. Many difficulties with the propane flow to the start-up burner and the sulfator start-up heater were experienced. Some of these problems were a result of trash in the piping, condensation problems, and possibly the low propane vaporizer throughput. The thermally actuated steam flow control valve on the vaporizer was not believed to be operating correctly which may have partly been a result of the vaporizer size compared to propane throughput. A hand-actuated globe valve was installed to bypass the steam flow control valve and provide constant steam flow.

The pressure relief valve on the propane vaporizer had to be replaced because it was leaking through at 178 psig.

8.13 SERVICE AND INSTRUMENT AIR SYSTEM

8.13.1 Description

The service and instrument air system is designed to supply clean, oil-free, low-moisture (-40°F dewpoint) compressed air at approximately 100 psig to the consumption points throughout the PSDF. Due to the low amount of service air requirements, the service and the instrument air are supplied from the same system. The system consists of four Atlas Copco water-cooled air compressors rated at 600 scfm and one Sullair air-cooled compressor rated at 300 scfm. Each air compressor train consists of an aftercooler, a prefilter, a desiccant air dryer, an after filter, and a receiver tank. The five receiver tanks are tied to a common 3-inch header where the air is distributed to the plant. Two of the five compressors are tied to the emergency backup power supply.

The four Atlas Copco air compressors are controlled by a compressor controller sequencer. The compressor sequencer controller is a pressure band controller which regulates the system pressure within programmable limits by starting, loading, unloading, and stopping the compressors in accordance with a fixed sequence. The programmable limits set at the PSDF are 98 and 105 psig.

The air dryers are designed to work even when the power is turned off. The dryers fail to a fail-safe feature that allows the desiccant to continue to absorb moisture even with the power off. This feature allows the dryer to continue to operate as problems are being resolved. However, when the desiccant is saturated, the moisture will be carried over.

8.13.2 Commissioning/Operations

The four Atlas Copco compressors and the five Pneumatic Product air dryers were fully commissioned by the sellers service technicians. The Sullair air compressor was commissioned by PSDF operations in 1995. The service and instrument air system was fully operational by May 1996 and has operated without any significant problems.

One of the drain valves for the instrument air dryers failed because water from the inlet side of the instrument air dryer damaged a seal in the drain valve pilot. To remedy the problem, the air source for the pilot line was changed from the inlet side of the dryer to the outlet side on all five instrument air dryers. Filters were also installed to keep the dryer desiccant from plugging the pilot air line, valve, or orifice.

One of the solenoid valves in dryer DY2201B failed resulting in a valve malfunction warning indication and the shutdown of the dryer. The solenoid possibly got water in it sometime before the dryer was set or before the roof was placed over the instrument air pad. The service technician was able to get the solenoid operating again by manually forcing the actuation of the solenoid.

The Hydromatics service technician recommended a guard be installed over the air compressor intakes. Without the guard, the air compressor's housing could collapse if the air inlets were accidentally covered.

Preventive maintenance was performed on the air compressors in December 1996. Only a few minor problems (small oil leaks) were found and fixed.

8.14 CLOSED-LOOP COOLING, CIRCULATING, AND SERVICE WATER SYSTEMS

8.14.1 MWK Closed-Loop Cooling Water System

8.14.1.1 Description

In the MWK closed-loop cooling water system, two centrifugal pumps (one available as a spare) are designed to deliver 580 gpm of demineralized water at 115 feet of head-to-process equipment in the MWK train. The cooling water is supplied at a maximum temperature of 92°F and at a pressure of 85 psig. After returning from the MWK system, the water is cooled by exchanging heat with the circulating water system in a plate-and-frame heat exchanger. The demineralized water pumps provide initial fill for the system. Make-up during operation is provided by the MWK steam and condensate system. A head tank located at the 202-foot level of the structure provides a constant head on the pump suction. A corrosion inhibitor is fed into the system via a pot feeder.

8.14.1.2 Commissioning/Operations

The MWK cooling water pumps were installed and tested in March 1996 and the MWK closed-loop piping was flushed in April. Strainers were installed at several points and the system was flushed with demineralized water and drained several times. The only major problem was an inadequate supply of cooling water for the steam drum sample cooler. There was not enough head available at the cooler to supply water at the needed flow rate and then into the return header as designed. After the cleaning of all applicable lines failed to fix the problem, the water exiting the cooler was diverted to the drain. Both of the pumps were initially on the same MCC. This has been changed and several vents were also modified to allow them to be operated from the ground.

8.14.2 SCS Closed-Loop Cooling Water System

8.14.2.1 Description

In the SCS closed-loop cooling water system, two centrifugal pumps (one available as a spare) are designed to deliver 1,100 gpm of demineralized water at 170 feet of head to process equipment in the balance-of-plant area. The cooling water is supplied at a maximum temperature of 92°F and at a pressure of 90 psig. After returning from the BOP equipment, the water is cooled by exchanging heat with the circulating water system in a plate-and-frame heat exchanger. Initial fill for the system is provided by the demineralized water pumps and makeup during operation is provided by a booster pump connected to the MWK steam and condensate tank. A head tank located at the 173-foot level of the ash structure provides a constant head on the pump suction. A corrosion inhibitor is fed into the system via a pot feeder.

8.14.2.2 Commissioning/Operations

The SCS closed-loop system was commissioned in March 1996. Strainers were placed in the piping at several points and the system was flushed and drained with demineralized water multiple times. At first, excessive flow through the heat exchanger caused a larger pressure drop than design. This caused the pump suction to lose pressure. The problem was fixed by restricting the flow of water from the supply header to the return header in the feedstock preparation structure. Some of the air vents on the system piping were modified to allow them to be opened and closed from the ground. The original flowmeter location was changed and a second flowmeter was added to allow the water flows to the utility island and to the feedstock preparation structure to be measured separately.

8.14.3 Circulating Water System

8.14.3.1 Description

The circulating water system provides cooling water at a maximum temperature of 90°F and at a pressure of 55 to 60 psig to the MWK, SCS, and FW closed-loop cooling systems and to the MWK steam and condensate system and the FW condenser. There are four centrifugal pumps delivering 3,400 gpm each at 120 feet of head. The number of pumps in operation at any one time depends on the number of systems demanding cooling water. If both the FW and MWK trains are in operation, three pumps operate with one pump remaining as a spare. The cooling tower is a modular fiberglass design with six cells and a common basin. Each cell has two fans, each with a single-speed motor. Makeup is to the common basin. If the basin level drops below the operating level of 22 inches, a float valve opens allowing service water to gravity flow into the system from the raw water tank. If the level continues to fall, a makeup pump activates at 14 inches and a second pump activates at a level of 10 inches. Cooling tower blowdown is to an unnamed tributary of Yellow Leaf Creek.

8.14.3.2 Commissioning/Operations

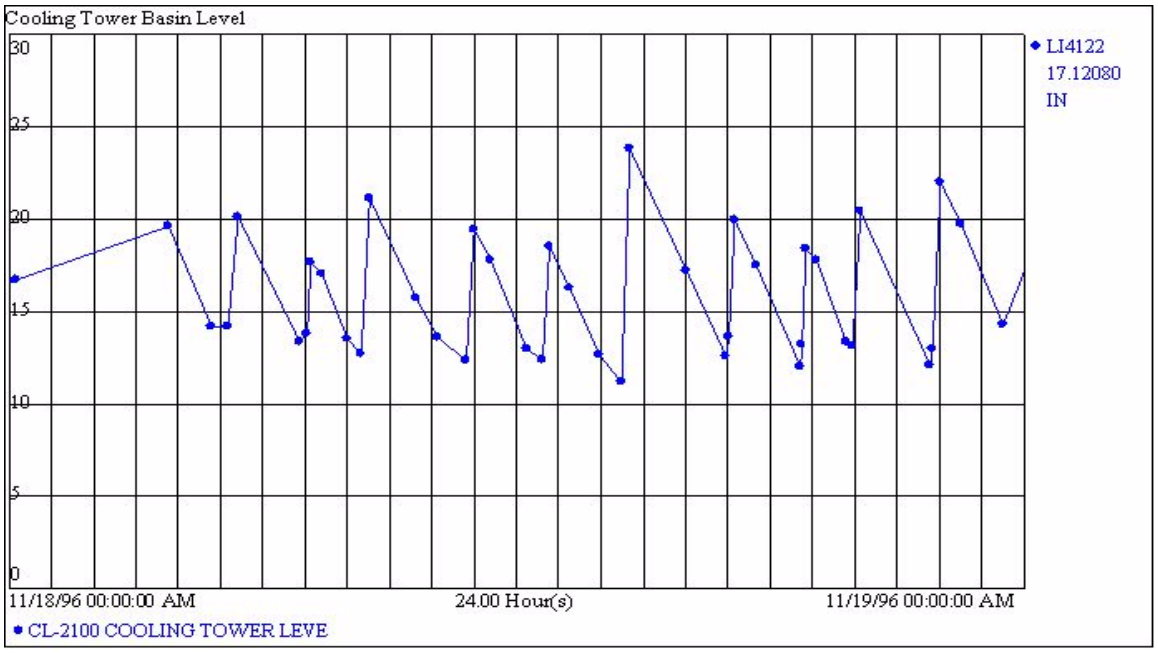
The circulating water system was tested, the pumps operated, and the three loops flushed in March 1996. Strainers were installed in several locations and the system was flushed with filtered river water. Initial vibration monitoring of the cooling tower fans indicated the fans had high vibrations. It was later determined that excessive vibration of the cooling tower fans was due to insufficient lateral supports. This problem was fixed by replacing the fiberglass fan supports with steel supports. The cooling towers have been operated as needed for support of commissioning and start-up activities under partial load conditions with no more than 8 (of 12 total) fans operated at any time except for vibration testing.

Continuous problems were experienced from the float valve on the makeup line. The turbulence in the basin loosens the float resulting in the water flow continuing to the tower when the proper operating level has already been reached. A larger float was attached and baffles were installed around the float to isolate it from much of the turbulence. Performance has improved since these modifications. (See figure 8.14.3-1.)

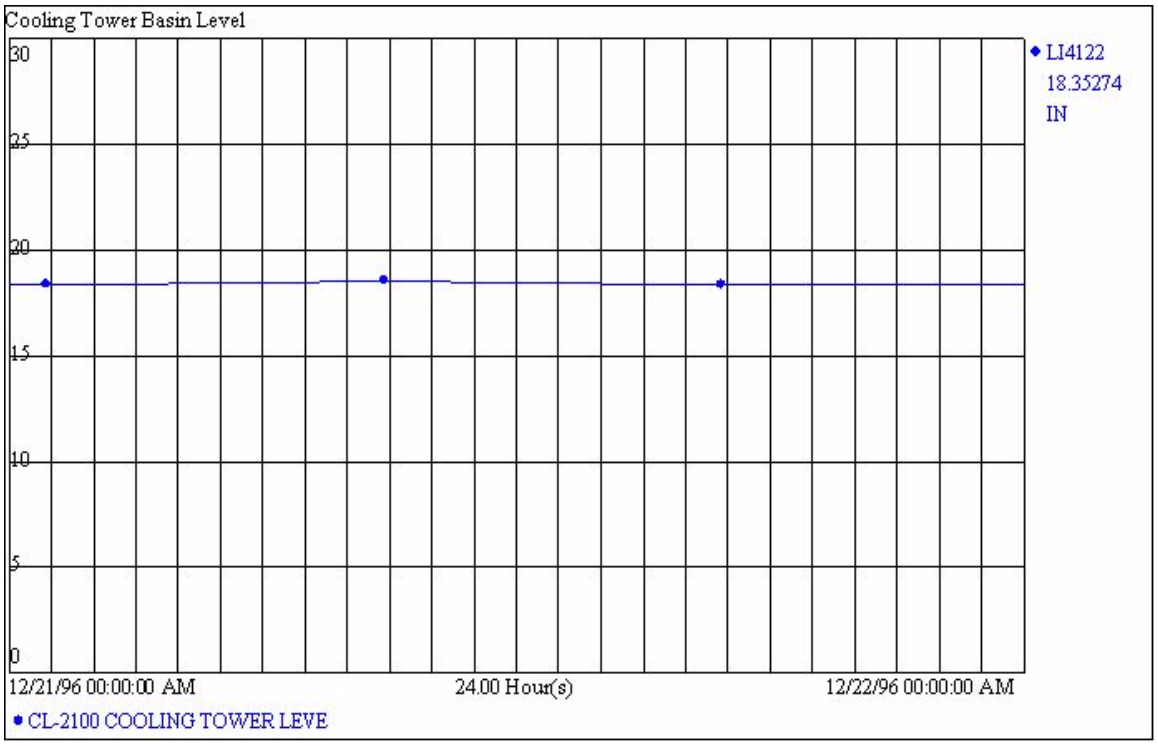
A few modifications were made to the system during construction. For winter operation, thermometers were installed in the drainage sump from each cell to check for ice formation within the cell. An 8-inch bypass line was also installed so the towers could be completely bypassed when operating under low load during freezing conditions. Vents were added to the pump suction header. Pressure gauges were added to the return lines to the tower to check the pressure drop across the loops. The blowdown flow meter and

manual control valve were moved to a location adjacent to the wastewater treatment basin. The original location was too close to two elbows. The valve was also changed from a gate valve to a globe valve.

There have been three instances of the underground circulating water lines rupturing. In each case the break occurred at a slip joint where the lines reemerge from underground. In the first instance, a butterfly valve that controls the flow of water to one of the cooling water loops opened too quickly causing a water hammer. In the second case, a pump was started with one of the butterfly valves already open causing a water hammer. (Normal procedures call for starting pumps with only the recirculation line open.) In the third case, the pressure control valve for the steam drum was rapidly opened when trying to make a change in operating conditions. This allowed a surge in steam flow to the MWK steam and condensate system. The circulating water flow to the heat exchanger was also being greatly restricted by closing a 12-inch gate valve in the discharge line from the condenser and only letting water flow through a 2-inch bypass line. The steam flashed the circulating water causing damage to the piping before the relief valve lifted. As a result of each of these ruptures, the affected lines have had a cement thrust plate installed around the lower section of piping and the connection bolted together.



24-Hour Period Before Repairs



24-Hour Period After Repairs

Figure 8.14.3-1 Change in Behavior of Float Valve After Adding Larger Float and Installing Baffles. Graphs Show the Water Level in the Common Basin.

8.14.4 Service Water System

8.14.4.1 Description

The service water system provides water to the utility stations, the flare seal drum and makeup to the cooling tower. There are two service water pumps (one as a spare) that pump 350 gpm at 300 feet of head. The service water header is maintained at a pressure of 145 psig which is different from the design pressure of 100 psig. The cooling tower makeup pumps are sized for 350 gpm at 30 feet of head. The service water tank is maintained at a level of 30 to 35 feet, with feed coming from two raw water pumps located at the river intake structure of neighboring Plant Gaston on Yellow Leaf Creek. Each vertical raw water pump can deliver 350 gpm at 225 feet of head. The water is filtered before being sent to the storage tank. One pump is started when the tank level drops below 30 feet. A second pump is started if the level drops below 25 feet. The raw water pumps also supply the fire protection tank which take precedence over the service water when both require makeup water.

8.14.4.2 Commissioning/Operations

Raw water system pumps were first tested in early November 1995 in preparation for the MWK steam/condensate system chemical cleaning. It was necessary to extend the suction side piping of the vertical raw water pumps to ensure that the foot valve would be submerged when the river level was at its lowest normal conditions. The raw water pumps and strainers were tested again in December. At that time, the timer for the raw water filter back-flush was set and the pressure control valve in the raw water recirculation line was set. The discharge of the back-flush piping was also moved from the intake to the Gaston intake screen trough. The raw water system flush was completed in late January 1996. In March the automatic operation of the pumps and valves was demonstrated; at which point the raw water system was declared operational. During the checkout of the service water system, the level switches for the flare seal drum were also checked and the level control valve for the flare seal drum was adjusted to provide a minimum flow of water through the drum.

In testing the cooling tower makeup pumps, one of the pumps was found to have abnormally high vibration and temperature readings. Upon inspection, it was found the inboard bearing seal had leaked and allowed rainwater through the seal. The manufacturer replaced the motor. The cooling tower pumps were designed to shut off based on high pressure when the float valve closed off the makeup line. However, the flat pump curve of the makeup pumps produced a situation where a suitable setpoint for the pressure switch could not be found because of the level variation in the raw water tank. The high pressure switch was replaced with a low pressure switch.

8.15 WASTE WATER TREATMENT/CHEMICAL INJECTION

8.15.1 Description

The chemical injection system uses a combination of pumps and pot feeders for chemical injection to maintain the quality of the water in the plant. In the circulating water system, sulfuric acid (for pH control) and a corrosion inhibitor are added to the common basin, and an algaecide and sodium hypochlorite (as a biocide) are added using a pot feeder. The cooling tower blowdown is dechlorinated by adding sodium bisulfite. The closed-loop cooling water systems have molybdates added (via a pot feeder) as a corrosion inhibitor. The steam and condensate system is treated with a pH controller, oxygen scavenger, and phosphate. The wastewater treatment basin uses aluminum sulfate to flocculate suspended solids and sulfuric acid and sodium hydroxide to control pH.

The wastewater from the diesel fuel storage sump, process area sump, and the coal and limestone storage area sump are collected and pumped to the wastewater treatment system. High level switches in the sumps activate the sump pumps. The wastewater treatment area consists of an oil/water separator, a rapid mix chamber, a flocculation chamber, two settling chambers, and a hold basin that discharges to an unnamed tributary of Yellow Leaf Creek. The rapid mix chamber has a 15-hp constant speed mixer and the flocculation chamber has two 3-hp variable speed mixers. The wastewater treatment area also has a storage building and pumps for the addition of chemicals into the water. The water from the various sumps is initially sent either to the oil/water separator or to the rapid mixing chamber. The water flows into each of the chambers in succession through overflow weirs or through valves.

8.15.2 Commissioning/Operations

The chemical injection systems for the steam and condensate system, the SCS closed-looped cooling water system, the MWK closed-loop cooling water system, and the circulating water system were successfully tested in April 1996. These systems were operated without any difficulty during the second and third quarters of 1996. Two minor pump problems occurred during the fourth quarter. The pump which injects trisodium phosphate at the steam drum and the pump which feeds sulfuric acid to the cooling tower failed. Both situations were resolved and spare pumps were ordered and delivered to reduce potential downtime in the future due to the possibility of a complete pump failure.

Construction of the wastewater treatment system was completed and the wastewater basin began normal operation during the third quarter of 1996. Other than a few minor pH excursions, the wastewater basin has not required chemical treatment. The basin normally maintains a pH between 6.0 and 8.5 without any caustic or acid addition. Testing has shown the suspended solid levels have been within acceptable limits without the addition of alum. The flow meter for the basin was struck by lightening on July 7 and was repaired. The pH probe in the flocculation chamber was broken and had to be replaced.

8.16 STATION SERVICE AND DIESEL GENERATOR

8.16.1 Station Service

8.16.1.1 Description

The PSDF station service supplies electric power to all the plant equipment including outlying buildings and components. The power is supplied directly from an Alabama Power 230-kV transmission line and is stepped down through a series of transformers to supply power at 4,160 V, 480 V, 208 V, and 110 V. The power is distributed through various kinds of switchgear, breakers, starters, contactors, and breaker panels.

8.16.1.2 Commissioning/Operations

This system was the first to finish commissioning and reach operational service in September and October of 1995. Testing of the components began in April 1995 with preinstallation testing of the 4,160-V and the 480-V switchgear. This testing identified several control relays that were incorrectly installed or failed. The distributed control system was energized in early May using a temporary power supply and started system testing and configuration updating at that time. Additional testing and calibration of the protective relaying and cabling continued during the installation of the switchgear that summer. The final preparations for the testing and energizing of the 4,160-V switchgear included the following: cable being pulled between switchgear and transformers, the protective relaying and cabling being tested for integrity and function, DCS configuration and operator interface screens being designed and installed, and the completion of substation installation. The 4,160-V switchgear was energized on September 17, 1995; as well as one 480-V buss, the other 480-V busses were energized by the end of the month. This progressed smoothly, with only minor problems with transmitters and relaying found that were not previously identified. Energization of various electrical systems, such as the dc battery charger, the UPS, and more of the 480-V Motor Control Centers continued in October. There was an outage in November on the permanent power substation to correct problems with the transformer oil tank and with the lightning arrestors, and missing switcher position circuit was pulled to the DCS. Since the initial testing and energization of the switchgear was completed, there was one instance were the protective relaying setpoints were set too close to the conditions of lightly loaded busses and a heavily loaded power grid; these were adjusted and the system has since continued highly reliable operation.

8.16.2 Diesel Generator

8.16.2.1 Description

Because both the MW Kellogg and the Foster Wheeler processes cannot be safely shutdown without forced circulation of solids, purging of combustible gases, and withdrawal of partially reacted char and calcium, there is a minimum requirement for operating equipment and electrical power at all times. To meet this minimum requirement and to make equipment operation more intuitive for the operators, the station service switchgear was designed to allow operation of the minimum required equipment using a minimum of energized busses. These busses can be supplied by an on-site diesel generator sized to carry the minimum load requirements. This generator was equipped with the necessary relaying to allow synchronization with an energized buss allowing testing of the auxiliary generator and also an orderly transfer if the transmission line outage has some early warning. This ability to synchronize with the power grid is useful for load sharing and to provide an extra margin if the grid is unstable due to outside load demands or failures.

8.16.2.2 Commissioning/Operations

This diesel generator was run in the last week of May 1996. This generator required much more testing than a typical auxiliary generator because of its size (almost 2,000 hp or 1.6 megawatts), and because of the extra ability to tie the generator into the power grid while the normal power feed is operating. The diesel completed all testing with capabilities at or above design. The diesel was used during a planned 2-day outage of the supply transmission line and experienced no trouble.

8.17 FLARE SYSTEM

8.17.1 Description

The flare system consists of the collection header (RV1031), the flare seal drum (DR0402), the flare tip (BR0402), and the flame front generator (BR0402-IG01). The function of the flare system is to gather and ignite any spontaneous releases of combustible gases resulting from process upsets or controlled depressurizing and purging of equipment. Propane is the fuel gas for the pilots and the enrichment gas. The flare is required only for gasification mode of operation. At the far extremity of the collection header, a small continuous flow of nitrogen is injected as a sweep gas to provide a positive pressure against air ingress into the flare stack. The flare header is connected to the flare seal drum which knocks out any particulates in the gas stream and serves as the base for the flare stack and flare tip assembly. The water in the seal drum acts as a water seal and cools the gas. The flame front generator (FFG) is the pilot ignitor system and is controlled by hardwired logic. When the FFG is in the automatic position, it will ignite pilot #1 and then automatically switch to initiate firing of pilot #2 once pilot #1 has lit. The gases that may be discharged into the flare system from the process have a very low heat value; therefore, the flare contains an enrichment system to add propane to increase the heat value of the total outlet gas flow to a minimum of 200 Btu/scf, ensuring complete combustion (40 CFR 60.18 compliance).

8.17.2 Commissioning Tests/Runs

The flare system functional checks were completed in two parts. First, the flare seal drum level control was checked in February of 1996 and second, the burner skid hardwire logic was checked in August. All checks were satisfactorily completed with the exception of one bad switch and two bad relays. Other prechecks and punchlist items were identified and are scheduled for completion in January 1997 with the final commissioning scheduled for February 1997.

9.0 SUPPORT SERVICES

9.1 DATA MANAGEMENT SYSTEMS

Two software packages have been acquired to assist with maintaining reliable records of process and laboratory data at the PSDF. Labworks, a lab information management system (LIMS) from Automated Analytical Solutions (AAS) in Baton Rouge, Louisiana, has been purchased to serve as a database for all laboratory data. OSI Software in San Leandro, California, has provided their plant information (PI) system for recording process data under an evaluation agreement for a trial period. A purchase decision will be made at the end of the trial period.

9.1.1 LIMS

9.1.1.1 Description

Labworks serves as the permanent electronic record of laboratory analysis performed both by the on-site laboratory and by the off-site laboratory that renders the balance of the analyses. Because the off-site lab also uses the product, transferring results obtained from their lab to the on-site lab and entering the data into Labworks is much simplified. When lab personnel register a new sample the software assigns that sample an ID number and provides a list of the tests to be performed on that specimen. The software helps the lab workers track the sample all the way through until the results are validated. These results are available to the engineers who also have the software installed on their workstations. Most engineers receive needed information by having the lab personnel export the data from the software to other formats that can be sent to the process engineers.

9.1.1.2 Commissioning/Operations

The software was delivered in January 1996. Initial training occurred in February 1996. Initial use of the software was hampered for several months by the lack of a version specifically written for Windows NT. Since the problems have been resolved the software has worked well.

9.1.2 PI

9.1.2.1 Description

The plant information system at the PSDF consists of four separate programs, all supplied by OSI Software. Data Archive is a Windows NT-based program residing on a server dedicated to data acquisition. An interface between the Foxboro DCS and Data Archive runs on the same Sun Solaris box as the Foxboro application workstation. Process Book and Datalink are two client applications that plant personnel use to extract data from Data Archive.

The essential part of the PI system is the Data Archive program. It receives all plant data from the DCS, compresses the data, archives the data, and serves the data to the client applications on demand. The compression routine uses an algorithm known as "swinging door compressor" to achieve a significant reduction in the space necessary to store data. On average, the system uses 2 to 4 MB of disk space per day to store all of a day's data. Once the data has been compressed and archived, it becomes available to the client applications that are used by plant engineers. With the current resources available on the PI server, about 5 years of data should be able to be kept online at any give time.

9.1.2.2 Commissioning/Operations

The server software was installed in March 1996. The Windows NT version had only been released 4 months earlier (November 1995) as PI 3.0. There were several early version updates during 1996 and numerous bugs were found in each. The software reliability gradually increased as problems were found and resolved by OSI. With the release of PI 3.1 later in 1996, the reliability issues were finally settled. Since the installation of this version, no serious problems have been encountered. The release of version 3.1 also brought about the capability to secure the PI data on a point-by-point basis.

Process Book and Datalink both use the PI application programming interface API to access the PI database from the workstations on the LAN. Process Book uses a graphical interface to show both historical and real-time data. Displays can be built which combine graphics with current process values and trends of data. Datalink is an add-in to MS Excel that allows engineers to pull PI data directly into spreadsheets for manipulation.

The spring and summer of 1996 was spent configuring data archive for MWK operations and training plant personnel in the use of Process Book and Datalink. The bulk of the MWK configuration was done from databases provided by the DCS team. The remaining points were generally configured either from data provided by process engineers who identified a needed point and by pulling the needed information for missing points directly from the DCS. A general training session was held for the process engineers in late spring to teach them how to use the client applications. Later, operations personnel were trained

in small groups on the use of Process Book. Process Book has become a very valuable supplement to the DCS for operations. Process Book's powerful, easy trending functions have become crucial to plant operations.

An example of a typical, real-time PI process and data display is given in figure 9.1.2-1.

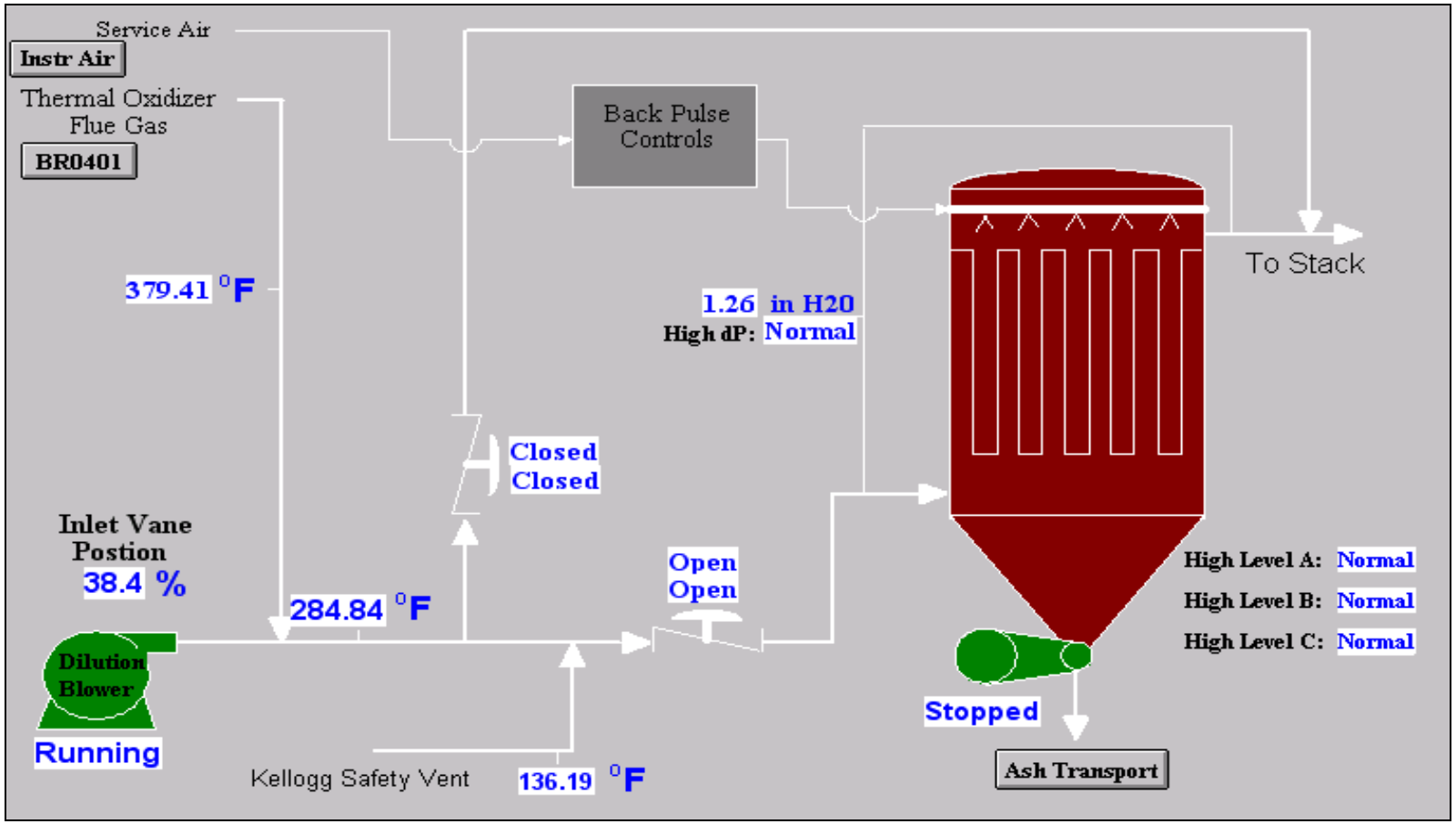


Figure 9.1.2-1 Typical PI Display

9.2 OPERATIONS AND MAINTENANCE

9.2.1 Ultrasonic Thickness Measurements

Solids are conveyed from one location to another through piping via a pneumatic transport system. As the solids are conveyed through the pipelines, erosion is a concern at the elbows or wherever a change of direction occurs. To monitor this erosion and thus prevent unnecessary shutdown due to piping component failure, thickness readings are taken (with an ultrasonic thickness gage) and trended on all change-of-direction components in each pneumatic transport system. Thickness readings cannot be taken on basalt lined elbows due to the multilayer construction, however they can be taken on all other types of components including Ni-Hard elbows and carbon steel elbows and tees. Listed below are the systems that are monitored along with the number of piping components monitored in each:

FD0104	MWK Coal Transport System	7 components
FD0140	Coke Breeze Transport System	16 components
FD0154	MWK Limestone Transport System	6 components
FD0210	Coal Feed to Reactor	4 components
FD0220	Sorbent Feed to Reactor	2 components
FD0510	Spent Solids Transport System	0 components (4 basalt lined)
FD0520	Spent Fines Transport System	1 component (4 basalt lined)
FD0530	Spent Solids Feeder System	17 components
FD0810	MWK Ash Transport System	8 components
FD0820	SCS Baghouse Ash Transport System	8 components

The actual locations on each component where thickness readings are trended are strategically selected based on the type of component (or the flow path through the component). A long radius elbow has three wear points, a short radius elbow has one wear point, a tee bend has three wear points, and some of the fabricated elbows have two wear points.

Figure 9.2.1-1 is a typical piping schematic showing how each component for a particular system is identified. Each component is assigned a unique number and then for each number the orientation of the various reading points is identified. This schematic is for system FD0210. Note in this system that readings are also taken in the piping at a location where the pipe exhibited a slight bend or kink that occurred during pipe installation. Since this is also a change of direction, the potential for wear is higher than it would be in a straight pipe section.

Thickness readings for all locations are recorded periodically. A trend plot is then created for each component. On this plot all measurements taken for that particular component

are shown. Figure 9.2.1-2 shows a typical trend plot. This plot is for the pipe kinks in the FD0210 line. Readings were taken in August 1996 and then again in November 1996 after a series of coal combustion runs. As can be seen, the overall thickness reduction of this piping was very minimal and thus no maintenance was required on this section during the outage.

Monitoring these trend plots for each piping component provides a system to detect extreme erosion and thus allow replacement of the component during an outage rather than having to shutdown the entire MWK system due to component failure.

Ultrasonic thickness measurements are also periodically taken on the reactor pressure letdown valve PV287. Twice the MWK system has been shutdown due to erosion problems in this valve, and a third time the valve was replaced during a planned outage due to erosion. To prevent this from reoccurring, the valve design was changed and the anticipated high erosion regions on the valve body were identified. The erosion in these regions is monitored by taking thickness readings at 24 unique points. Any significant reduction in wall thickness will provide an early warning system for valve erosion.

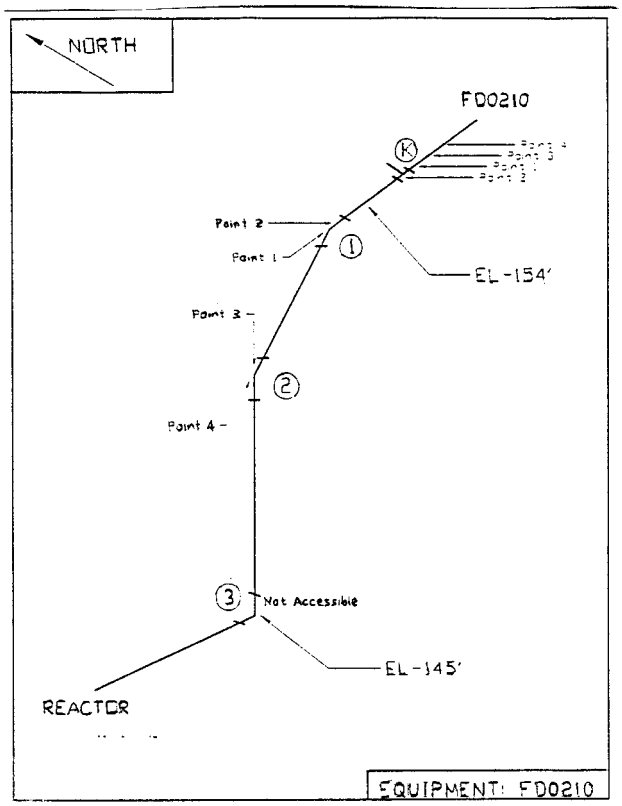


Figure 9.2.1-1 Typical Piping Schematic Showing Identified Components

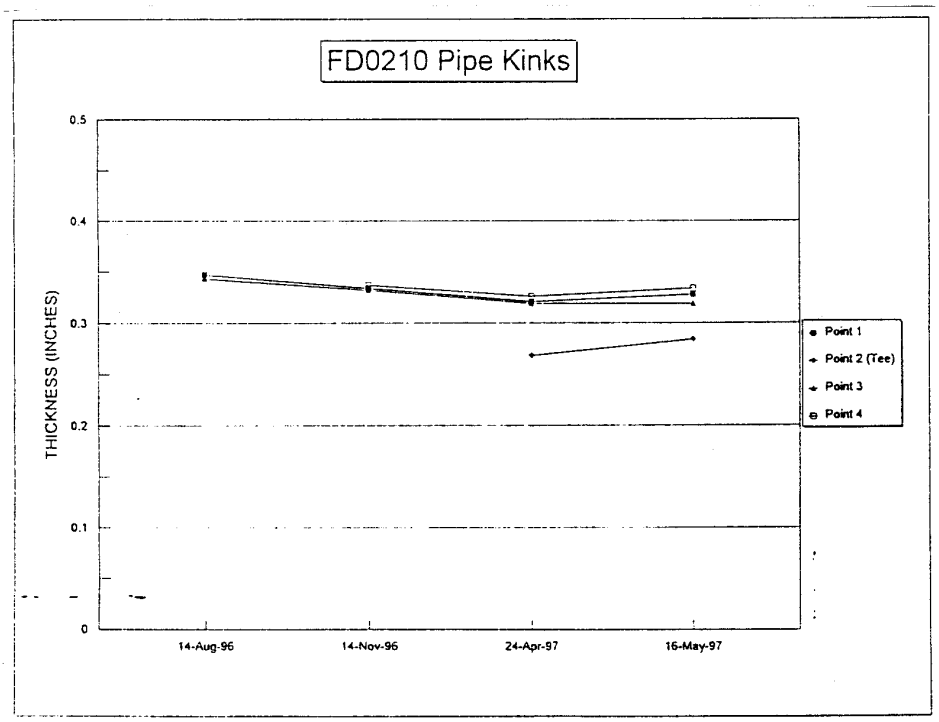


Figure 9.2.1-2 Typical Trend Plot for Pipe Kinks in the FD0210 Line

9.2.2 Vibration Monitoring

Vibration readings are periodically recorded and trended on all major pieces of rotating equipment. By monitoring the vibration and analyzing the results, such defects as misalignment, unbalance, foot/frame resonance, oil whirl, eccentric armature, loose base, bent shaft, defective bearings, etc., can be discovered and corrected before catastrophic failure occurs. Catastrophic failure would not only result in a more costly repair of the equipment, but could also necessitate shutdown of the entire MWK transport reactor system if an adequate alternate source was not available.

The list of rotating equipment that is vibration monitored includes 27 pumps, 16 fans/blowers, 8 compressors, and 2 mills. For each machine, vibration readings are recorded in the horizontal and vertical planes of each bearing housing and in the axial plane on each component (i.e., one axial for the pump and one axial for the motor). Thus for a standard pump/motor combination, 10 vibration readings are recorded. For a compressor unit with a gearbox, as many as 20 readings are recorded.

Each vibration measurement consists of a spectrum and a magnitude reading in either displacement, velocity, or acceleration units depending on the rotating speed. All of this information is recorded in a portable data collector and then down loaded to a computer software database. This database provides a historical record of the data and allows trending of the data as well as a detailed analysis of the spectrum. Pertinent information about each piece of equipment such as operating speed, number of blades, bearing types, gear sizes, etc., is also stored in the software to aid in spectrum analysis.

Figure 9.2.2-1 shows a typical spectrum. For this figure, the vibration was measured in velocity units (inches/sec) and the spectrum was recorded up to 30,000 rpm. All of the pertinent frequencies are labeled to indicate the various vibration sources. Note that the bearing frequencies include the ball pass inner and outer race frequencies (BPIR and BPOR), the ball spin frequency (BSF), and the fundamental train frequency (FTF). Thus not only can a defective bearing be discovered, but also it can be determined which component of the bearing contains the defect.

Figure 9.2.2-2 is a typical summary plot created for each piece of equipment every time a new set of data is recorded. This plot shows the vibration maximum amplitude readings for each measurement location on the equipment. If a value should significantly change from one period to the next, a detailed vibration analysis of this equipment would be performed. Figure 9.2.2-3 shows a typical plot used for the analysis. This figure includes the current spectrum, a comparison of the current spectrum with the past spectrum, and a magnitude trend plot. If a conclusion cannot be reached from this information, then further data, such as phase angle, will be measured to aid in the analysis.

Vibration readings were taken on all of the major rotating equipment during initial start-up to verify that the equipment was installed and running smoothly and also to record a

baseline set of readings that will be used for future comparison. Using vibration monitoring techniques, the following problems were discovered and corrective actions taken:

- Misalignment of one of the service water pumps due to foundation settling.
- Misalignment of the main compressor motor at operating temperature.
- Inadequate support of all cooling tower fans.
- Inboard bearing defect on one of the HTF pumps.
- Misapplication of the fire protection jockey pump.
- Insufficient recirculation flow for the circulating water pumps.
- Inadequate support of the mill motors.

Discovering and correcting these problems at an early stage not only saved the cost of extensive repairs but also prevented unexpected failure of these pieces of equipment and possibly prevented a forced shutdown of the MWK transport reactor system.

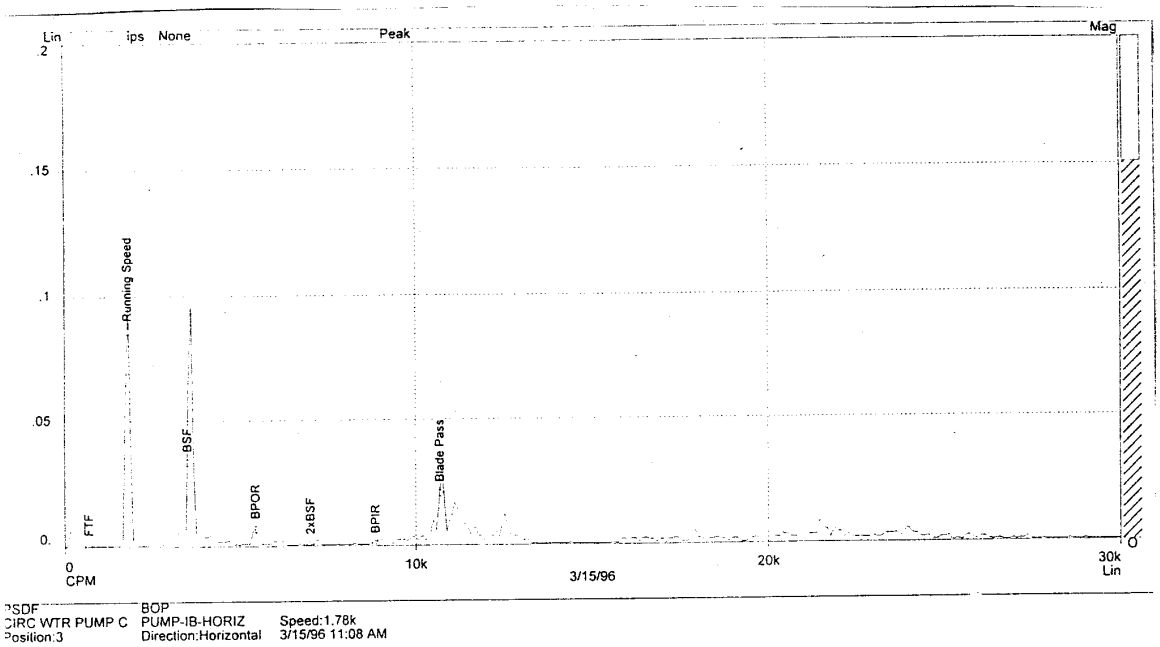


Figure 9.2.2-1 Typical Spectrum Recorded at Up to 30,000 rpm Where Vibration Was Measured In Velocity Units

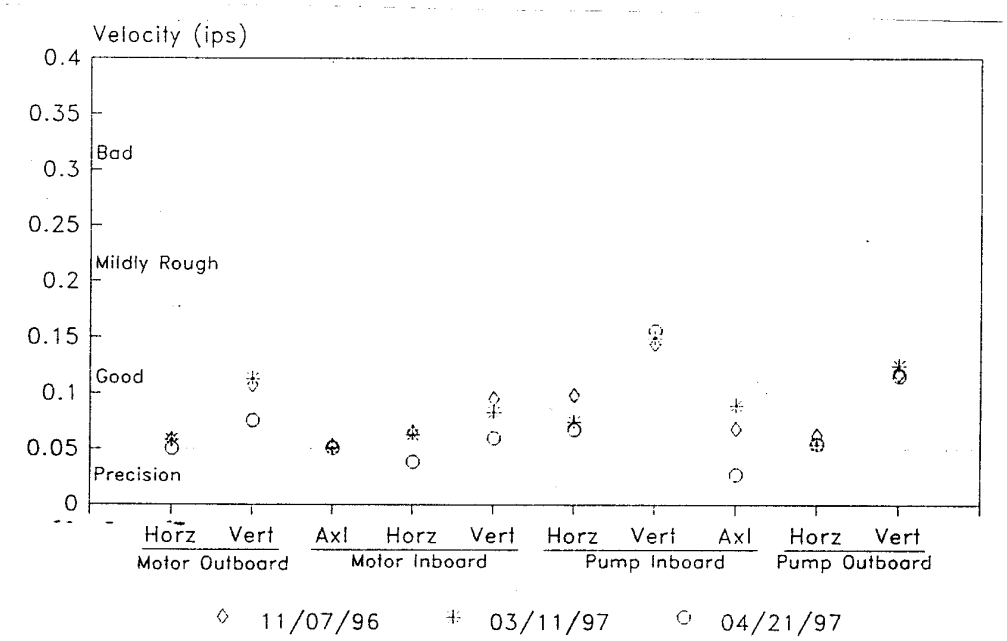


Figure 9.2.2-2 Typical Summary Plot Showing Vibration Maximum Amplitude Reading for Each Measurement Location on Fluid Pump A

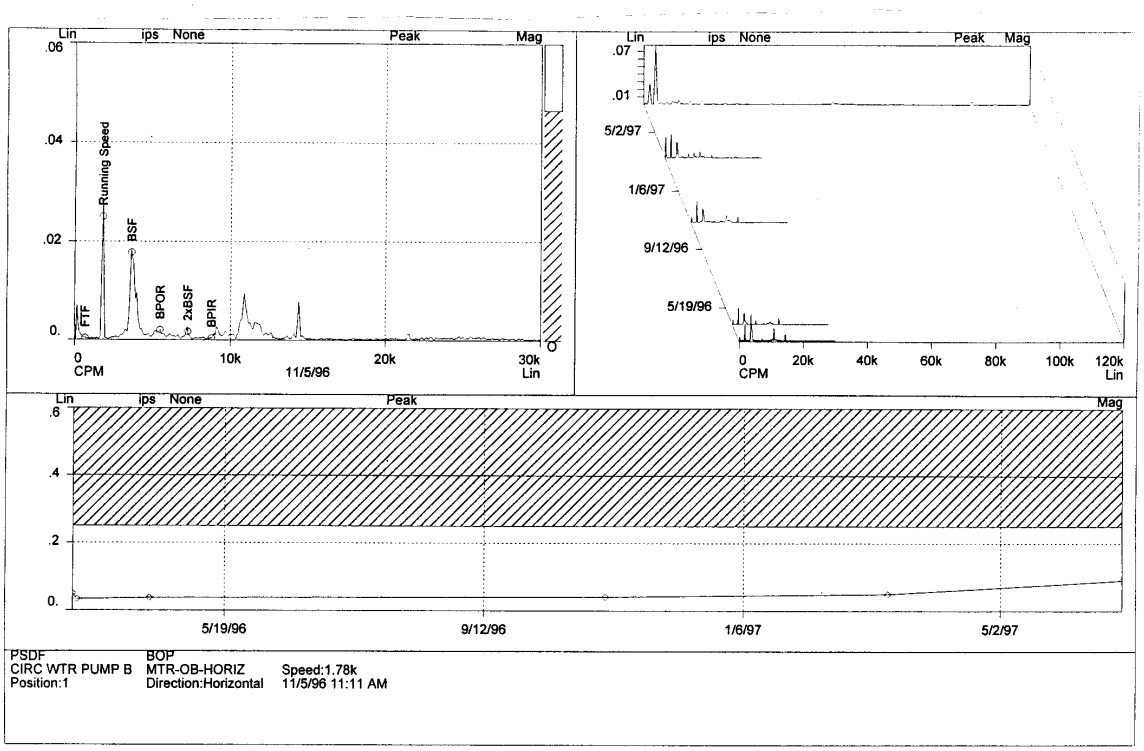


Figure 9.2.2-3 Typical Plot Including Current Spectrum, a Comparison of the Current Spectrum With the Past Spectrum, and a Magnitude Trend Plot

9.2.3 Thermal Scan

During start-up of the MWK transport reactor system and during several of the test runs, a thermal scan was performed on all piping and equipment within the system. There were three main objectives for the thermal scan. The first was to detect thermal anomalies such as "hot spots" in the piping and vessels that would indicate a breakdown in the performance of the refractory lining. A second objective was to periodically document and trend the temperature signatures of the various piping and vessels throughout the system. The third objective was to monitor these trends to assure that the integrity of the refractory is maintained and to provide a preliminary indication of degradation of the refractory lining.

All thermal scans were performed with an Agema 782 black and white short-wave infrared camera. The features of this camera include continuous real-time imaging, -5 to 1,500°F range, 0.2°F sensitivity at 86°F, 280 lines per frame, 100 elements per line, automatic and manual range and level adjustment, 9 calibrated ranges, 10-turn graduated thermal level readout, 8 aperture settings, 5 picture modes, and 2 isotherm functions. The selected thermal image is recorded on an electronically synchronized Polaroid photograph and then scanned into the computer for a stored digital image.

To date, thermal scans have been performed at the following times: (All scans except the May 13 scan were performed on the entire transport reactor system including the PCD and associated piping.)

- May 13, 1996, (thermal oxidizer only) – Internal air temperature = 1,600°F at initiation of scan.

- June 13, 1996, during test run CR02 – Start-up Burner gas outlet = 1,500°F, Primary Cyclone gas inlet = 874°F at initiation of scan.

- July 24, 1996, during test run CCT1A – Start-up Burner gas outlet = 1,590°F, Primary Cyclone gas inlet = 600°F at initiation of scan.

- August 18, 1996, start of test run CCT1C – Start-up Burner gas outlet = 2,000°F, Primary Cyclone gas inlet = 1,200°F at initiation of scan.

- August 21, 1996, after coal combustion of test run CCT1C – Primary Cyclone gas inlet = 1,644°F at initiation of scan.

- November 18, 1996, during test run CCT2C – Primary Cyclone gas inlet = 1,503°F at initiation of scan.

A thermal scan was also performed on the Foster Wheeler refractory lined piping and vessels on August 22, 1996, during cureout of the refractory.

The results of each thermal scan were documented in a report and the report included all thermal images recorded during the scan. All temperatures listed in the report (as well as all temperatures reported in the following paragraphs) were recorded with a surface probe digital thermometer. The infrared camera was used to detect the various temperature gradients, and the digital thermometer was used to record the exact temperatures.

A typical thermal image will exhibit various shades of gray from black to white. In the picture mode in which all images were taken for this project, the darker the shade the cooler the object (for a given emissivity), as shown in figure 9.2.3-1. This figure was taken during test run CR02. This is a thermal image of the top of the disengager on the left and the cyclone on the right. Note the varying shades of gray in the photograph. In this image, the large horizontal flange set at the top of the disengager (lower left hand corner of photograph) is 113°F, the smaller flange set above this is 140°F, and the primary cyclone is 182°F.

As was mentioned earlier, one of the main objectives in performing the thermal scan is to detect any "hot spots" in the piping or vessels. If a "hot spot" occurs somewhere in the system, the infrared camera would easily detect it as illustrated in figure 9.2.3-2. This is an image of the top of the combustor heat exchanger (CBHE) taken during coal combustion of test run CCT1C. In this photograph the dipleg at the left is 228°F and the large horizontal flange set at the top of the CBHE in the middle of the photograph is 220°F. Note the very bright object to the right of the CBHE. This is a spool section in the steam line that connects to the CBHE. The insulation was removed from this spool to repair a leak and had not yet been replaced at the time of the run. The temperature of this spool is 383°F, which is very easily detected. Another example of this is shown in figure 9.2.3-3. This is an image of the riser at the left and the primary gas cooler to the right taken during test run CCT1A. In this image the riser is 174°F. Note the hot section on the primary gas cooler. This is the location of the boiler feedwater (bfw)/steam piping connection on the cooler which is not insulated. The temperature of this section is 314°F. Once again note the ease of detection. During coal combustion runs these bfw/steam piping connections on the primary and secondary gas coolers are the hottest skin temperatures in the system.

During all of the thermal scans (including start-up and coal combustion), the hottest skin temperature of any object in the system was the reactor start-up burner. Figure 9.2.3-4 is an image taken at elevation 132'- 0" at the start of test run CCT1C. In this photograph the start-up burner is shown to the left. The skin temperature of the burner vessel is 448°F, as compared to the reactor at 203°F, the standpipe at 205°F, and the CBHE at 133°F. Figure 9.2.3-5 provides this same view taken after coal combustion of this same test run. Note now that the start-up burner has cooled down (since it is no longer in use) and thus does not show in the photograph. In this photograph the start-up burner is 122°F, the reactor

is 242°F, the standpipe is 249°F, and the CBHE is 223°F. During coal fire the average pipe/vessel skin temperature was 230 to 270°F.

Often during the thermal scans the elbows in the piping were slightly hotter than the pipe itself. This temperature difference was not enough to cause concern but is nevertheless a point worth noting. One example of this is shown in figure 9.2.3-6. This is an image of the CBHE gas outlet taken during test CR02. In this photograph the pipe temperature is 132°F but the elbow temperature is 152°F. Figure 9.2.3-7 is another example of this occurrence. This is an image of the primary cyclone gas outlet taken during coal combustion of test run CCT1C. In this photograph the pipe temperature is 218°F but the elbow temperature is 256°F.

Another observation was made for nozzles located at a change of direction in the piping, i.e., the nozzle temperature was typically hotter than the piping. Figure 9.2.3-8 is an illustration of this. This is an image of the riser crossover to the disengager taken during the start of test run CCT1C. In this photograph the riser temperature is 201°F but the nozzle on top of the riser (H1) is 258°F. The crossover also shown in this photograph is 183°F. Another example of this is shown in figure 9.2.3-9. This is an image of a line (PM04) from the primary gas cooler to the PCD at elevation 170'-0" taken during the start of test run CCT1C. In this photograph the elbow temperature is 151°F but the nozzle temperature is 168°F.

Typically weld joints were also consistently at a higher temperature than the piping. This is expected because at a pipe weld joint there is also a refractory joint that is caulked in before welding. Figure 9.2.3-10 is an image at elevation 182'-0" taken during test run CR02. This image shows the thermal gradient at the weld joint in the riser, standpipe, and dipleg. In this photograph the bottom-to-top temperature gradient in the riser is 167°F in the region below the weld joint, 203°F in the region around the weld joint, and 193°F in the region above the weld joint. For the standpipe, the bottom-to-top gradient is 163°F, 202°F, and 181°F. For the dipleg, the bottom-to-top gradient is 183°F, 203°F, and 176°F. Figure 9.2.3-11 shows the same view taken during coal combustion of test run CCT1C. In this photograph, the riser temperature of the pipe region below the weld joint is 248°F and at the weld joint is 276°F. For the standpipe, these regions are at 248°F and 292°F, and for the dipleg these regions are 237°F and 257°F. One interesting observation in viewing these last two figures is that regardless of the absolute temperature of the piping, the temperature differential between the piping and weld joint is about the same and range from 20 to 40°F depending on the joint.

As was noted earlier, each time a thermal scan was performed the Westinghouse PCD (FL0301) was also viewed. Figure 9.2.3-12 is an image of the head of the PCD and shows the gas outlet pipe connection. This was taken during coal combustion of test run CCT1C. As can be seen, there are various temperature gradients in this component. The

highest temperature point is at the top of the nozzle on the left of the head (Nozzle 11) where the temperature is 234°F. In contrast to this, the bottom of this nozzle is at 149°F. This gradient could either be due to the flow path of the gas or the construction of the refractory. The head temperature is 158°F near the gas outlet connection, and 124°F near the head to vessel flange. The gas outlet pipe skin temperature is 150°F.

The thermal oxidizer was also viewed each time a thermal scan was performed. Figure 9.2.3-13 is a typical image of the thermal oxidizer. This was taken during the start of test run CCT1C. As can be seen, the skin temperature is fairly uniform. In this photograph the skin temperature taken near the manway is 232°F.

One final observation made was at the connection of the standpipe outlet to the screw cooler (FD0206). Figure 9.2.3-14 is an image of this section taken at elevation 120'- 0" looking down. This was taken during the start of test run CCT1C. Note how much cooler the standpipe to screw cooler connecting spool is as compared to the neck of the screw cooler. In this photograph the connecting spool is 172°F while the neck of the screw cooler is 307°F. The reason for this may be due to a minimal flow of cooling fluid through the neck of the screw cooler. The connecting spool has independent inlet and outlet piping for the cooling fluid, while the neck of the screw cooler is fed from the same supply piping that feeds the screw cooler jacket and screw. Thus, the pressure drop through the neck of the cooler may limit the amount of flow that passes through the neck. However, this has not been proven and the neck is designed for 350°F. Figure 9.2.3-15 is another view of the screw cooler taken from the ground level during the same test run. This shows that the neck is at a higher temperature than the screw cooler jacket, which is about 170°F.

Thermal scans will continue to be performed on the MWK system after all major outages and at any other time necessary. Also, once the Foster Wheeler system is constructed similar thermal scans will be performed on this system. All images will continue to be stored in a database for future reference and trending. Thus significant changes in the thermal signatures may be detected and actions may be taken to correct any problems.

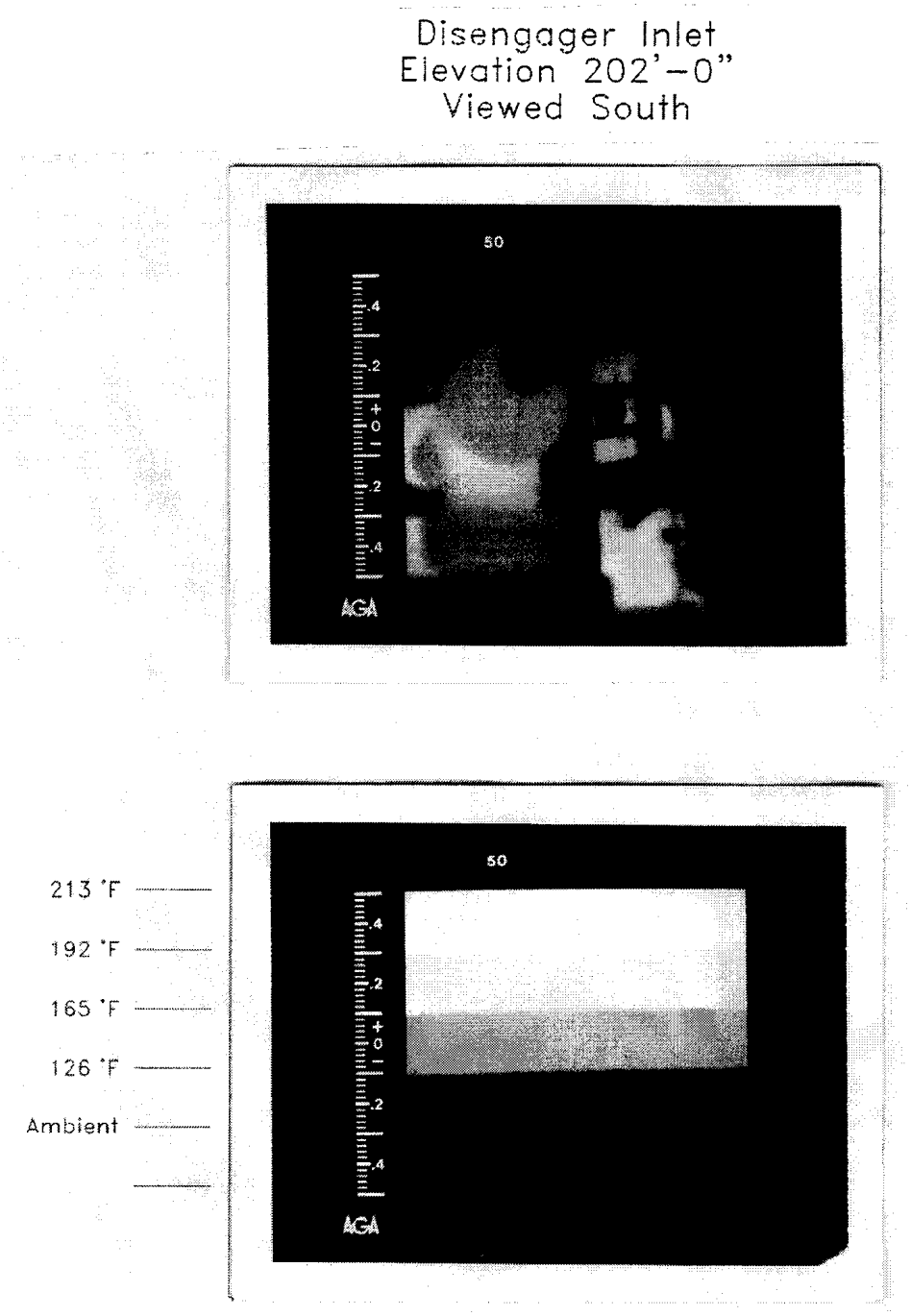


Figure 9.2.3-1 Various Shades of Gray (From Black to White) Showing a Typical Thermal Image (Test Run CR02)

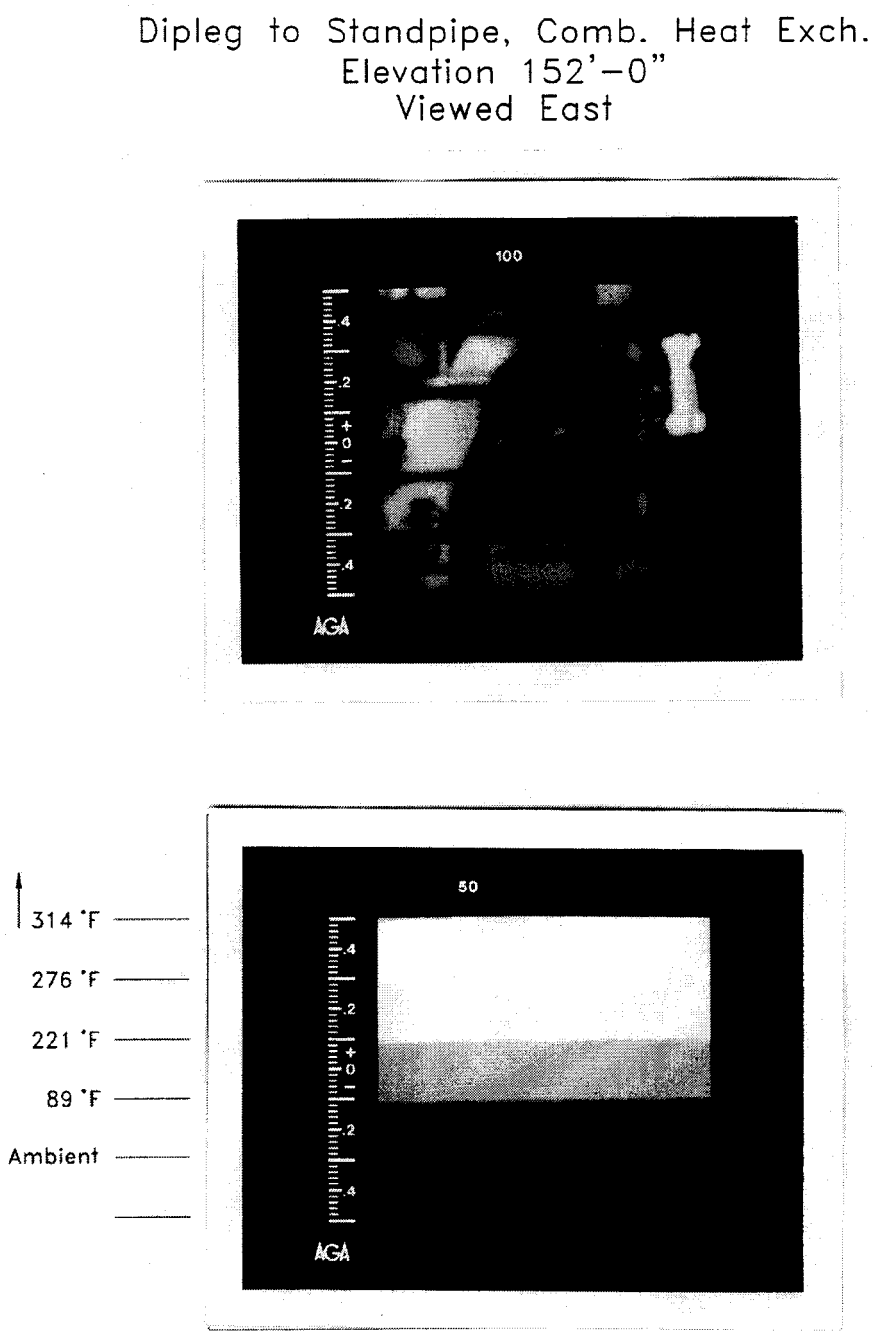


Figure 9.2.3-2 A Scanned Image of the Top of the Combustor Heat Exchanger Taken During Coal Combustion of Test Run CCT1C Showing Hot Spots in the Piping or in the Vessels

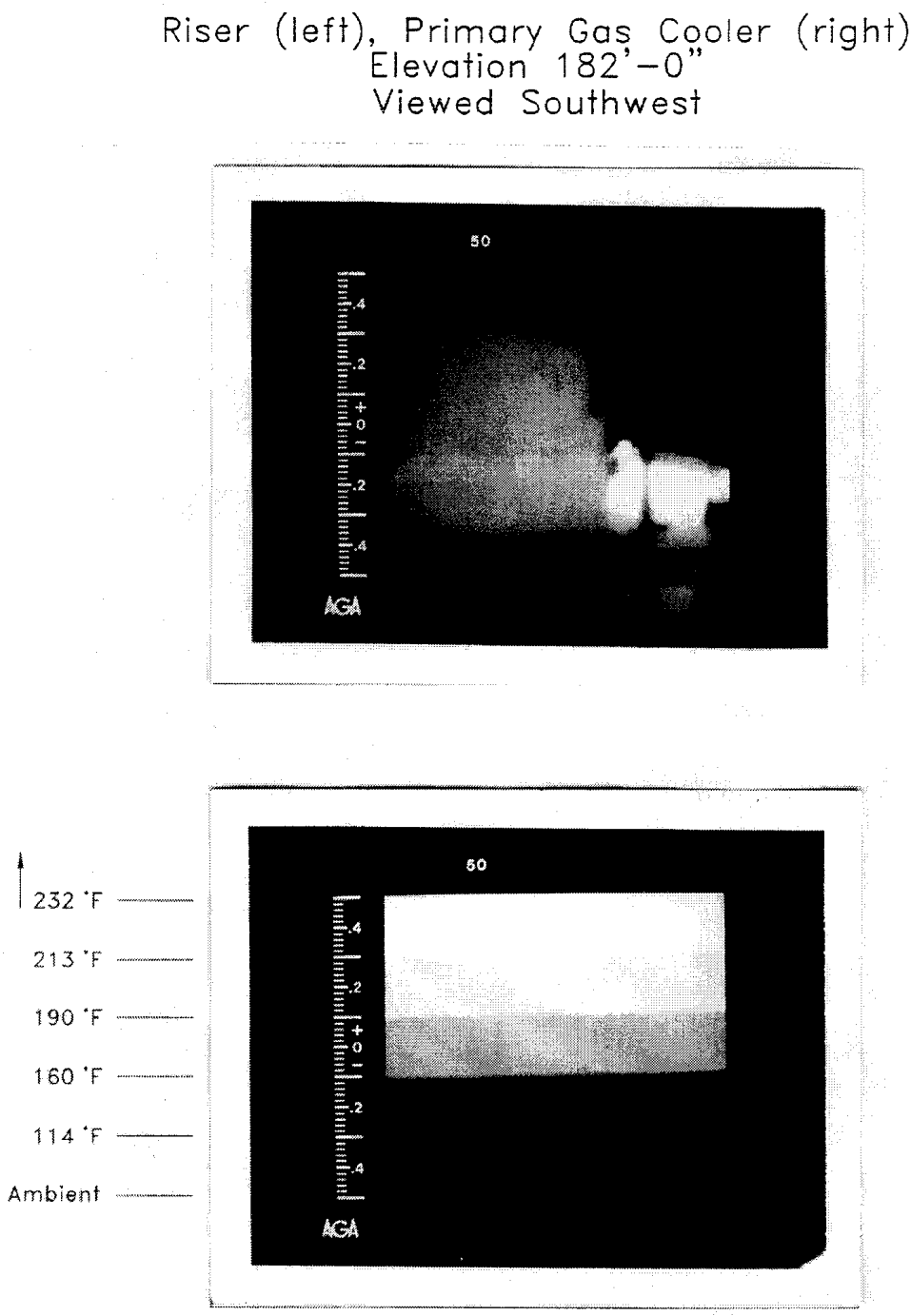


Figure 9.2.3-3 A Second Example of Scanned Image of the Top of the Combustor Heat Exchanger Taken During Coal Combustion of Test Run CCT1C Showing Hot Spots in the Piping or in the Vessels

SU Burner, Reactor, Stdpipe, Comb Heat Exch.
Elevation 132'–0"
Viewed South

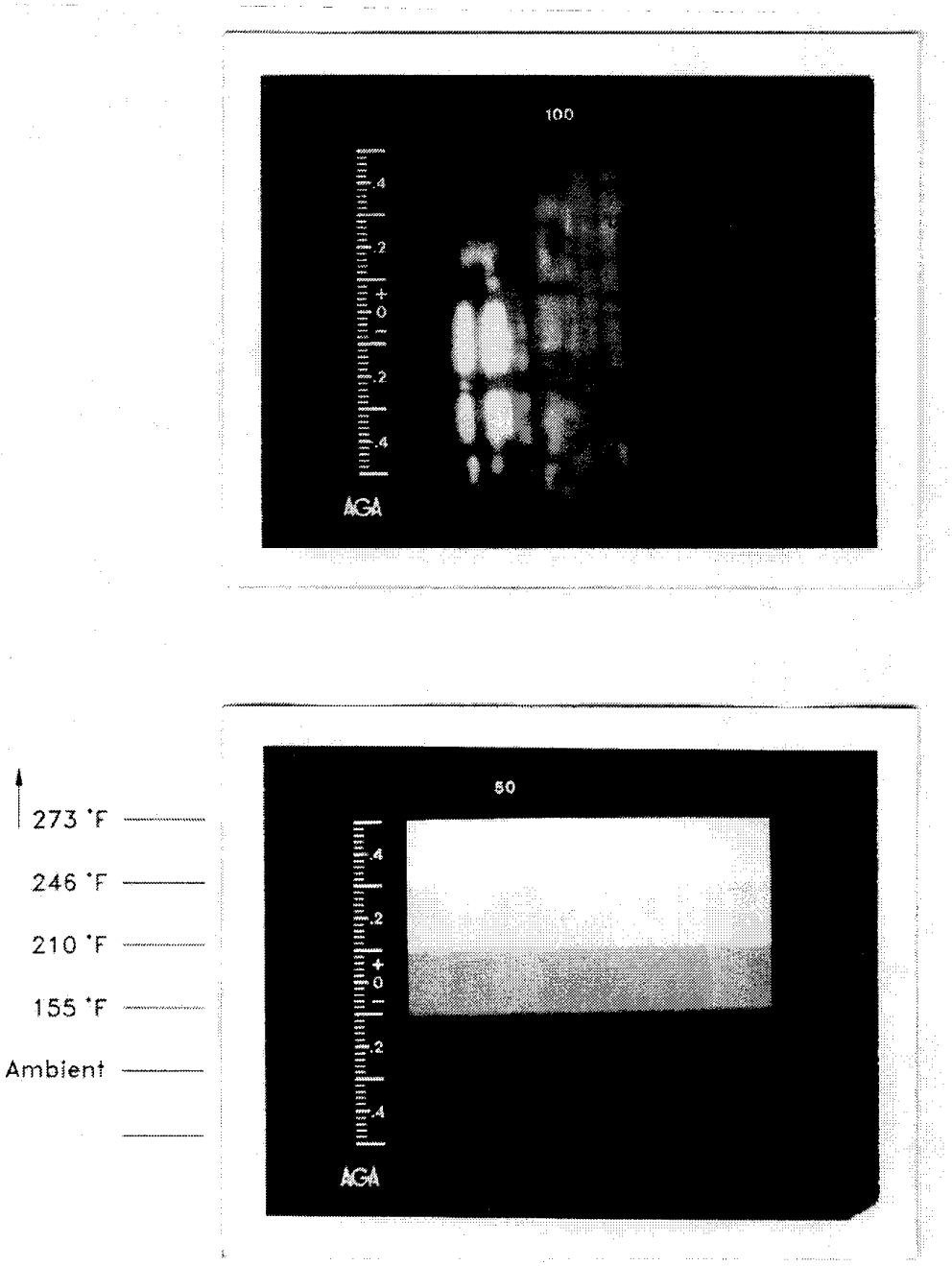
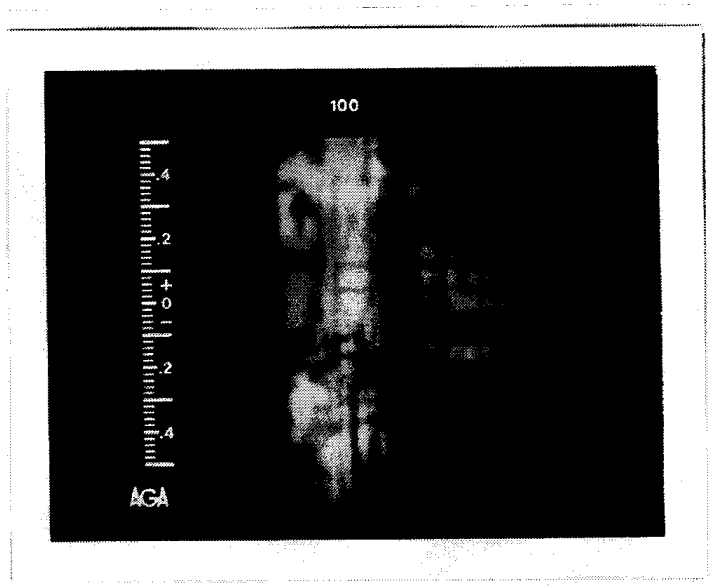


Figure 9.2.3-4 An Image Taken at Elevation 132 Feet at the Start of Test Run CCT1C Showing the Start-Up Burner on the Left

Reactor (left), Standpipe (center), CHE (right)
Elevation 132'–0"
Viewed South



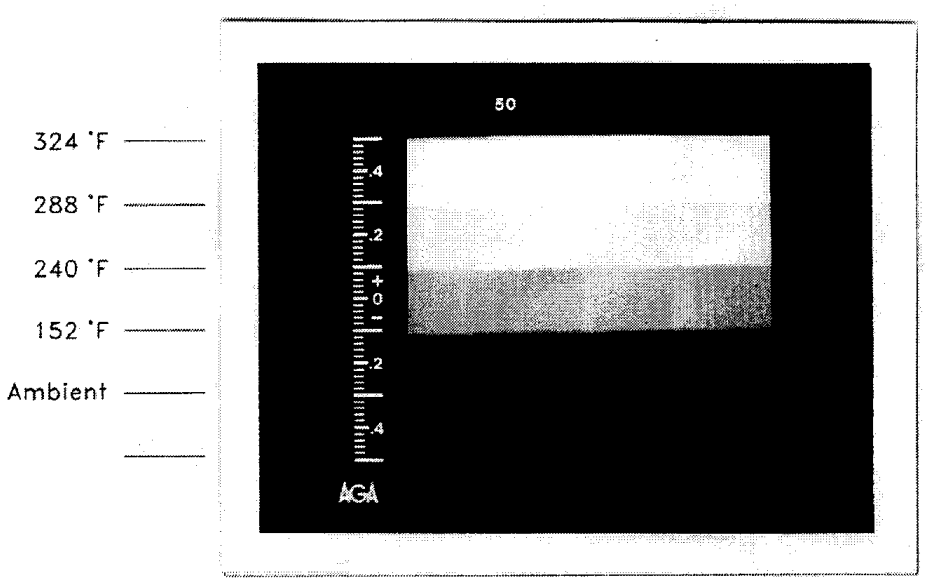
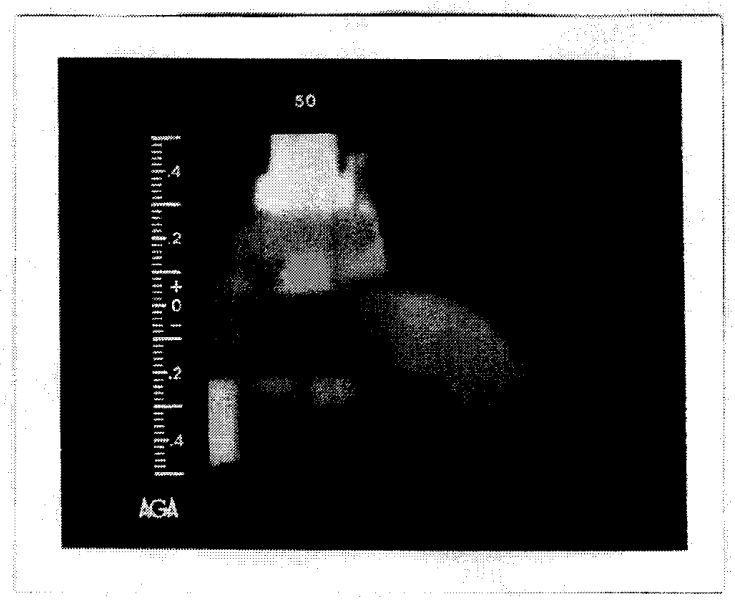


Figure 9.2.3-5 A Second View of Scanned Image Shown in Figure 9.2.3-4 Taken After Coal Combustion of Test Run CCT1C

Combustor Heat Exchanger Gas Outlet
Elevation 202'–0"
Viewed South



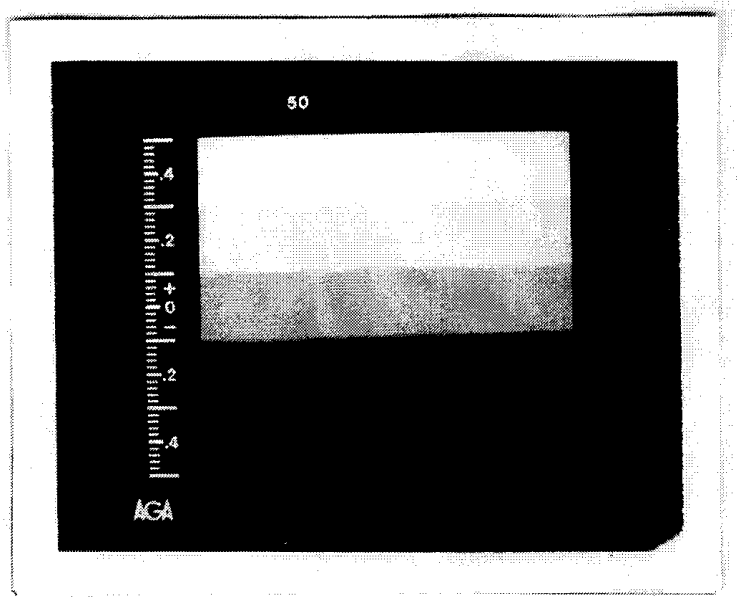


Figure 9.2.3-6 An Example of Temperature Differences Identified During Test Run CR02 Where Elbows in the Piping Were Slightly Hotter Than the Pipe Itself

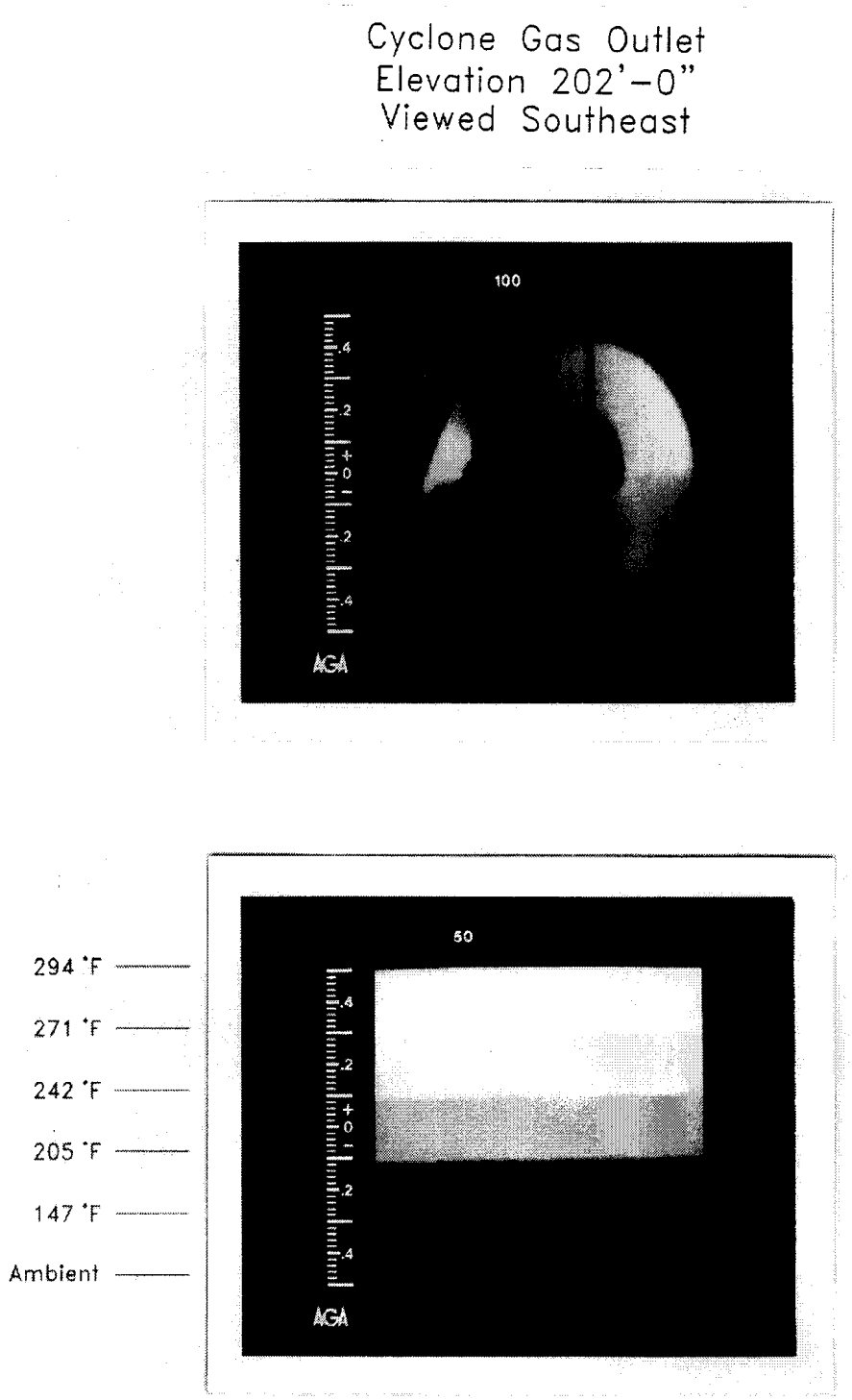
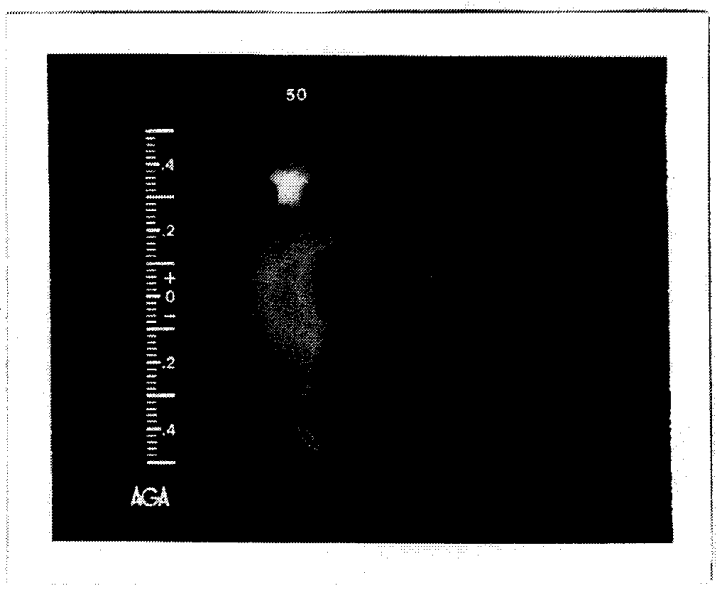


Figure 9.2.3-7 A Second Example of Temperature Differences Identified During Test Run CR02 Where Elbows in the Piping Were Slightly Hotter Than the Pipe Itself (Showing Primary Cyclone Gas Outlet During Coal Combustion of Test Run CCT1C)

Riser Crossover to Disengager
Elevation 202'–0"
Viewed Southwest



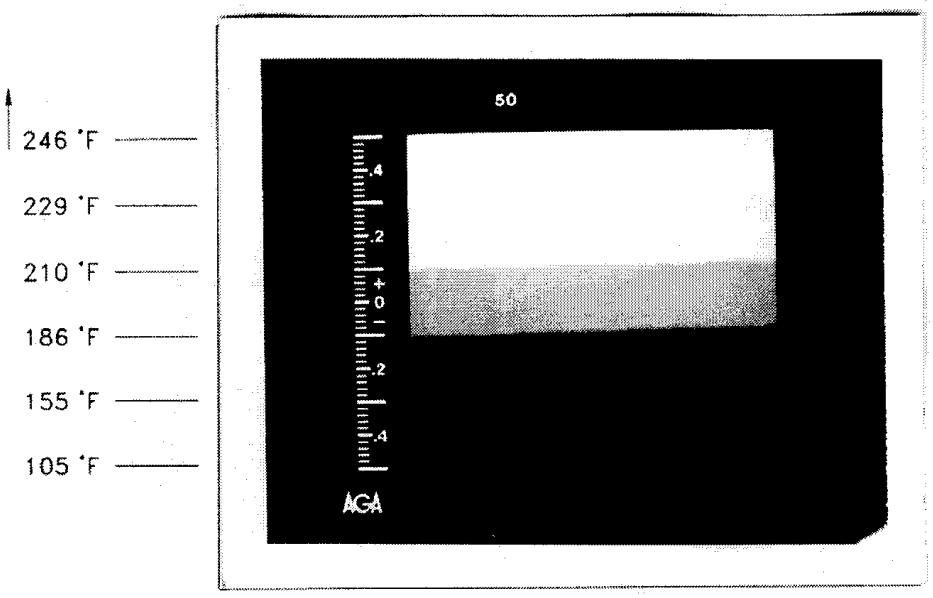


Figure 9.2.3-8 Results of Test Run CCT1C Indicating Temperature Differences Where Nozzle Temperature was Typically Hotter Than the Piping (Showing Riser Crossover to the Disengager)

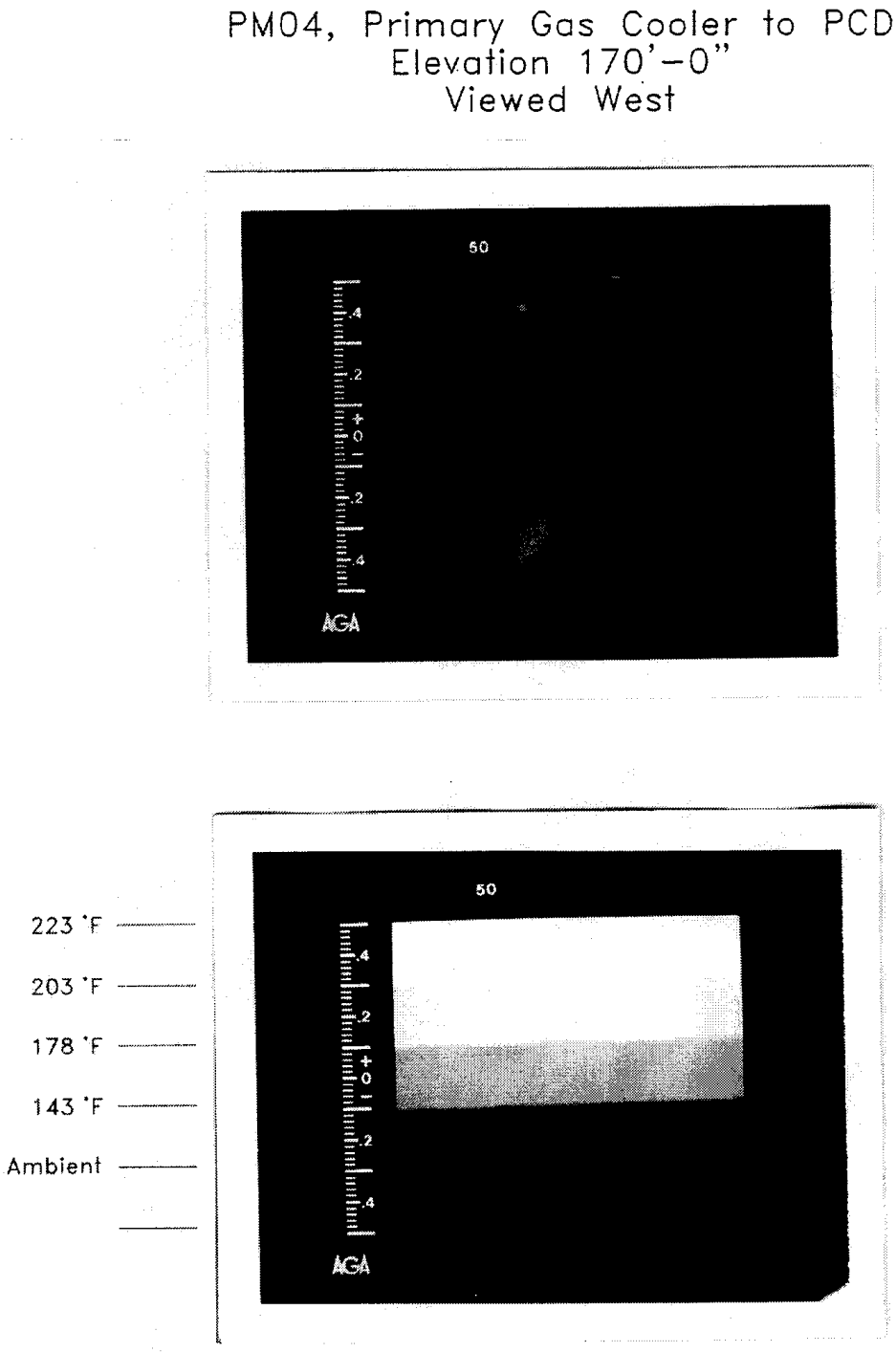
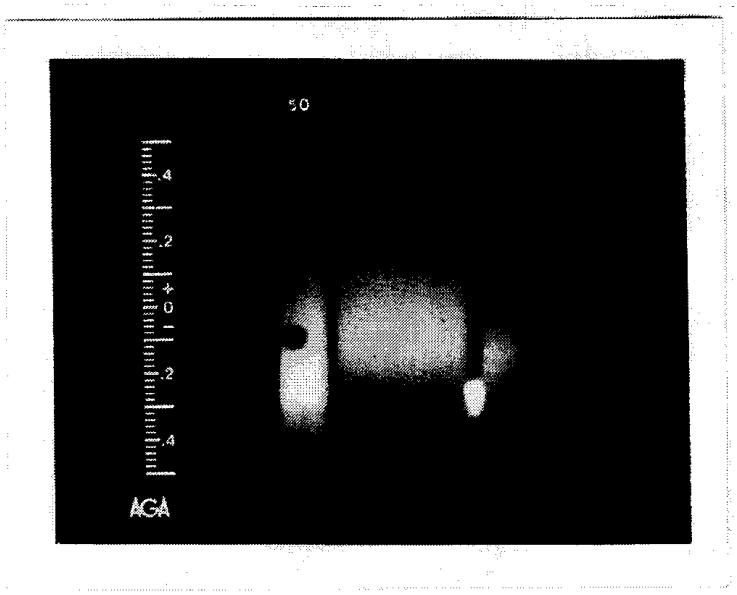


Figure 9.2.3-9 A Second Image of Results of Test Run CCT1C Indicating Temperature Differences Where Nozzle Temperature was Typically Hotter Than the Piping (Showing Line PM04 from the Primary Gas Cooler to the PCD)

Riser, Standpipe, Dipleg
Elevation 182'-0"
Viewed South



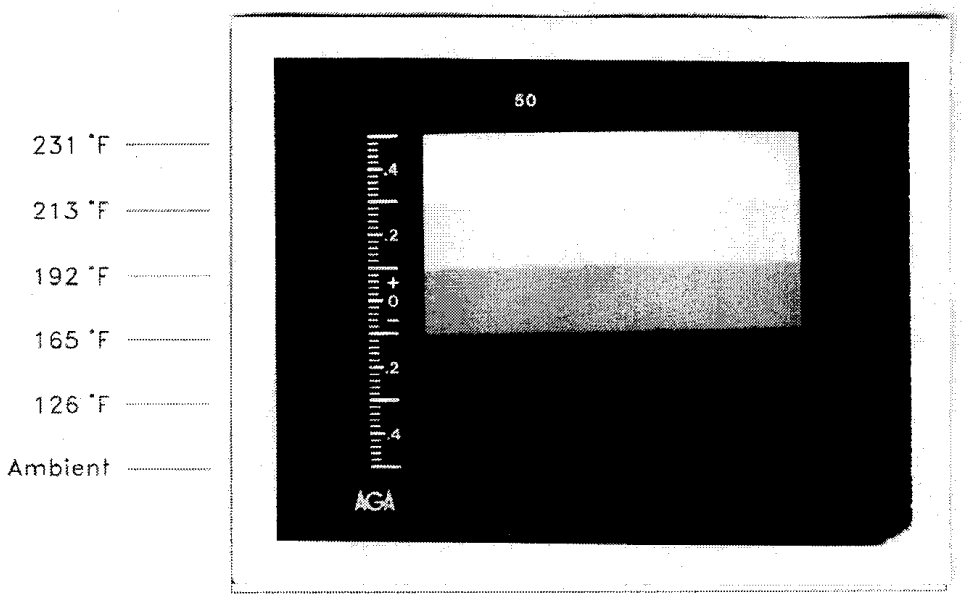
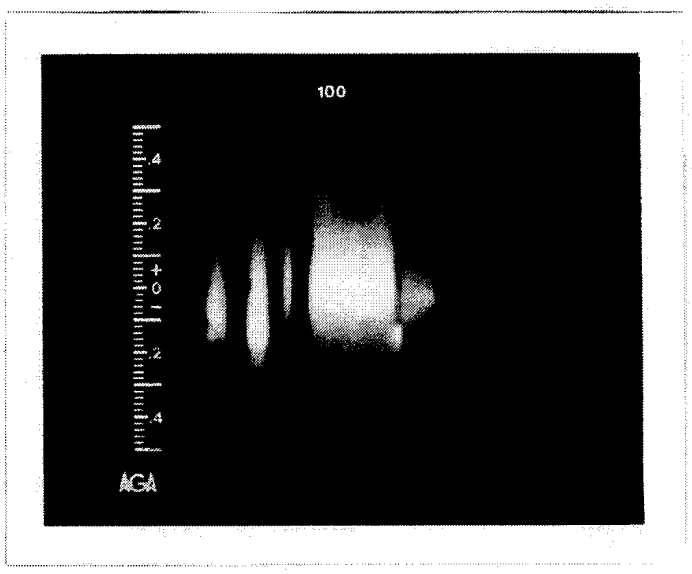


Figure 9.2.3-10 Results of Test Run CR02 Showing Temperature Differences Where Weld Joints Were Consistently at a Higher Temperature Than the Piping (Showing the Thermal Gradient at the Weld Joint in the Riser, Standpipe, and Dipleg)

Riser (left), Standpipe (center), Dipleg (right)
Elevation 182'–0"
Viewed South



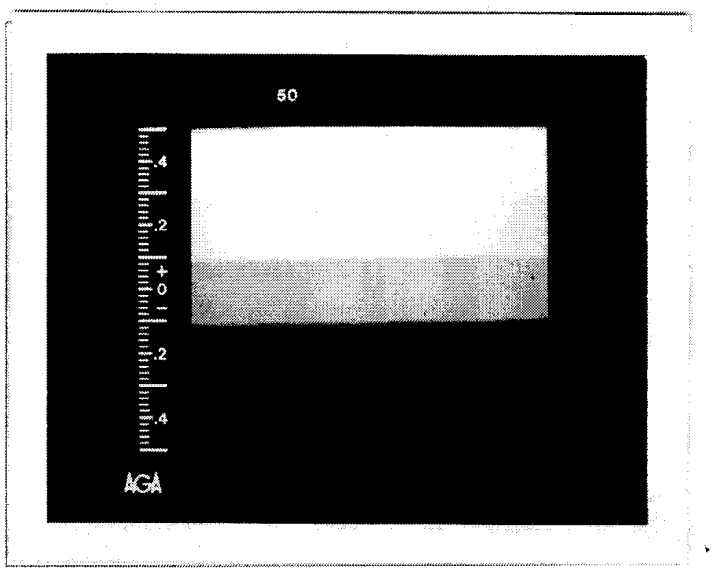


Figure 9.2.3-11 Results of Test Run CCT1C Showing Temperature Differences Where Weld Joints Were Consistently at a Higher Temperature Than the Piping (Showing the Thermal Gradient at the Weld Joint in the Riser, Standpipe, and Dipleg)

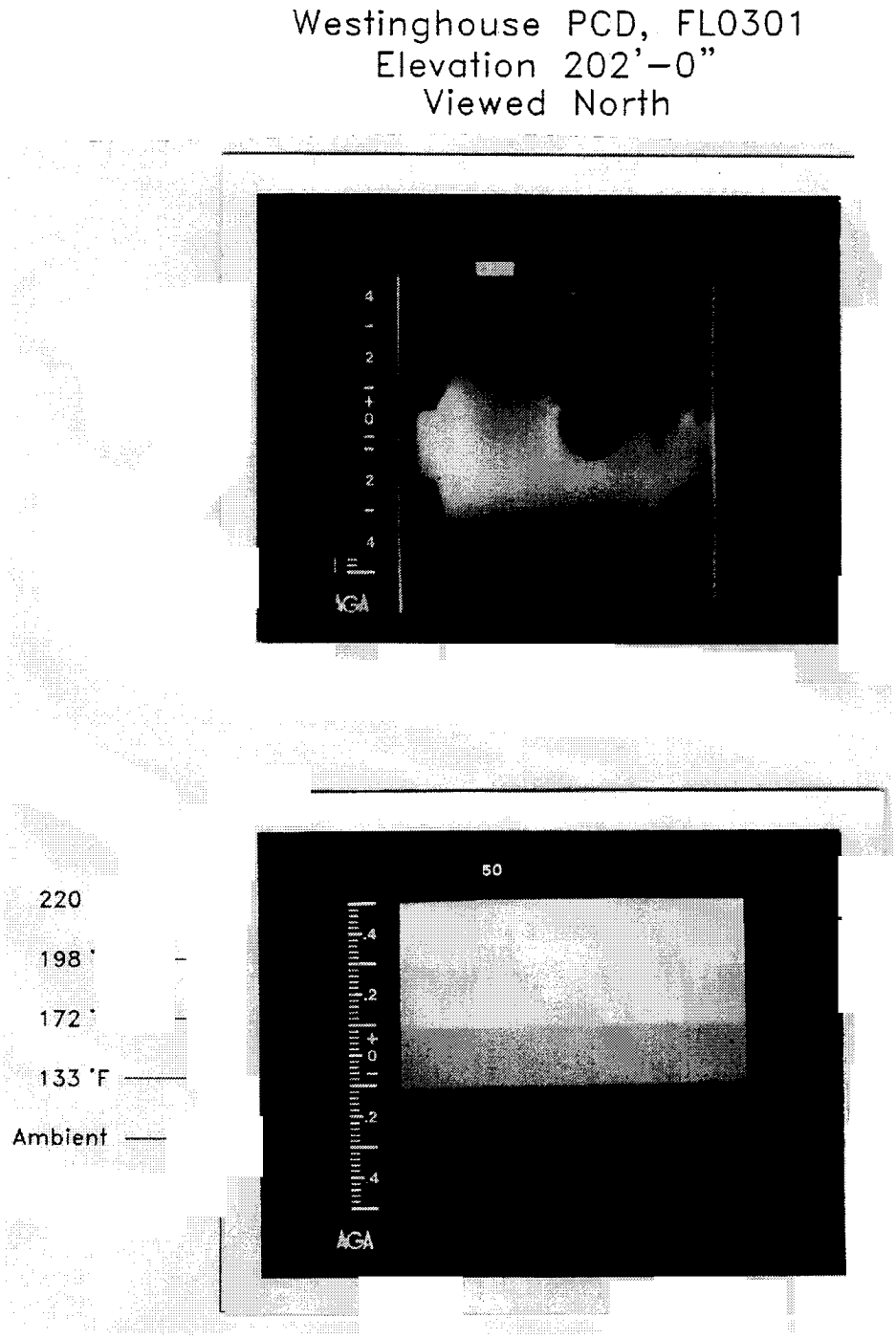


Figure 9.2.3-12 Results of Test Run CCT1C Showing Various Temperature Gradients (Showing an Image of the Head of the PCD and the Gas Outlet Pipe Connection)

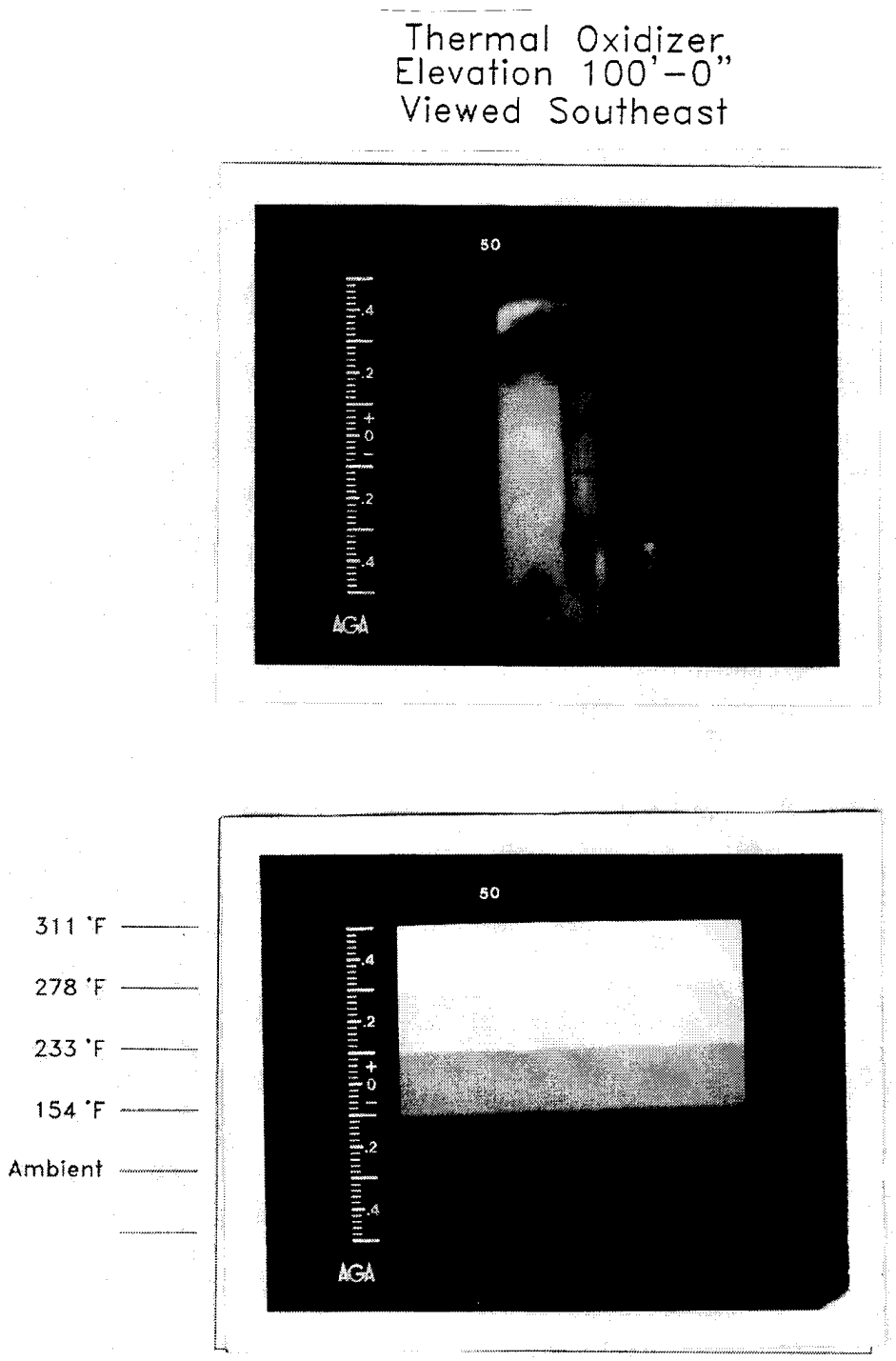
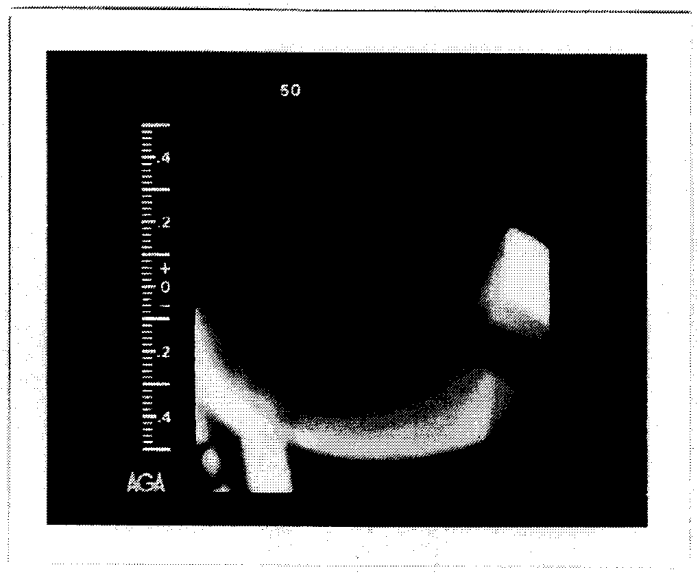


Figure 9.2.3-13 A Typical Image of the Thermal Oxidizer Taken During the Start of Test Run CCT1C Showing Fairly Uniform Temperature

Standpipe Outlet to Screw Cooler (FD0206)
Elevation 120'–0"
Viewed Northwest and Down



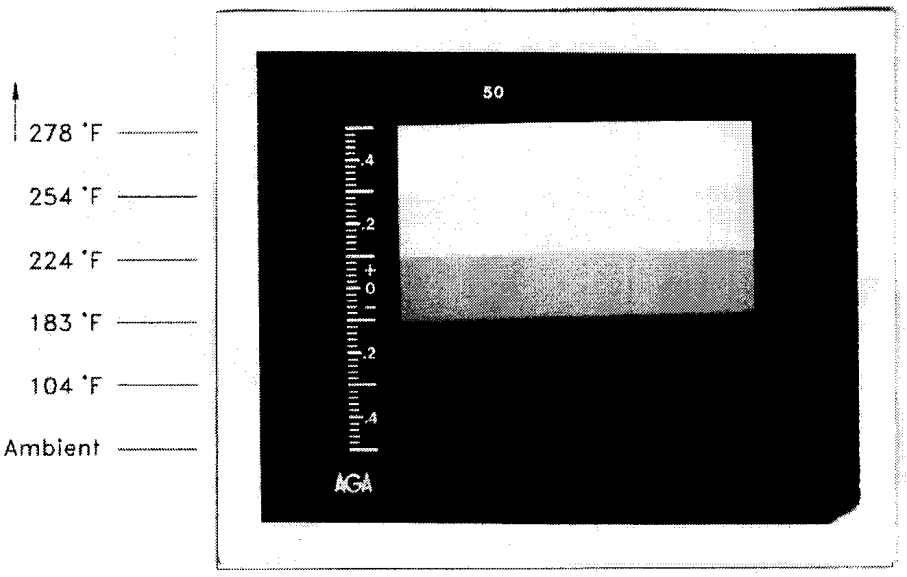


Figure 9.2.3-14 An Image of the Standpipe Outlet Connection to the Screw Cooler Taken at Elevation 120 Feet Taken at the Start of Test Run CCT1C

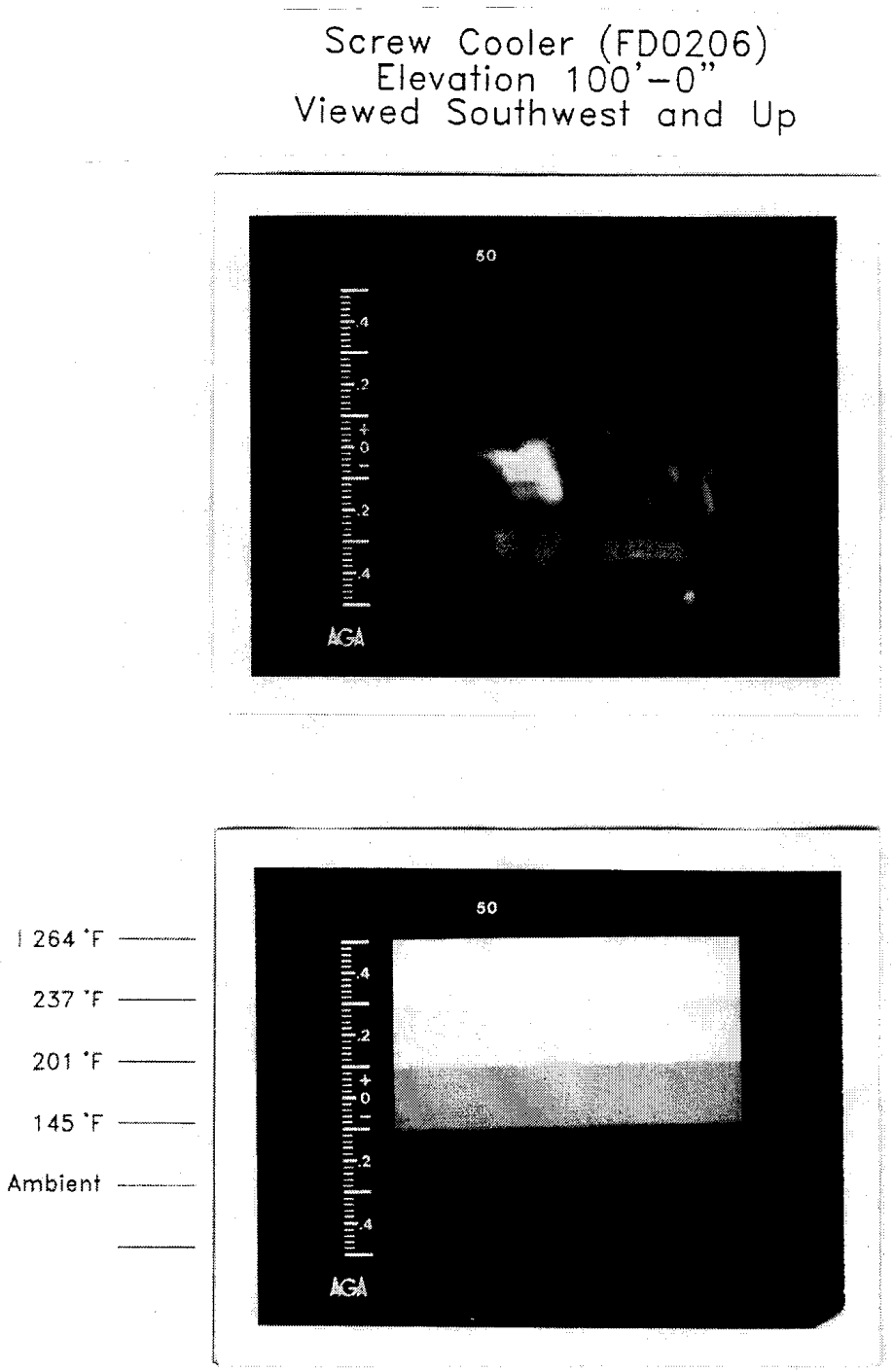


Figure 9.2.3-15 Second View of the Standpipe Outlet Connection to the Screw Cooler Taken From Ground Level During Test Run CCT1C

9.3 DCS AND PLC CONFIGURATION AND SUPPORT

The PSDF control system has the additional function of data collection for the project. At the present time the PSDF control system is managing more data points than control systems on 660-MW pulverized coal power plants designed for digital control systems and built only 10 years ago. The Foxboro IA Distributed Control System consists of the following: an application workstation that supervises and coordinates the several control processors that actually handle the calculations and logic for component and system control, operator workstations that provide the control inputs and feedback to the operators, the gateways that interface with several vendor supplied programmable logic controllers (PLCs) for data feedback, the historian that collects & stores process data, the interface with the plant information (data collection) system, and the X-vision display manager for engineer's workstation monitoring of the process. The Foxboro system is a Unix-based network controller using fiber optics communication with the remotely mounted control processors and I/O panels. Most of the PLCs used by the project are Allen-Bradley PLC-5s and SLC-504s. These were selected as the plant 'standard' because of the interface and data transfer capabilities.

Due to the fact that the DCS will control both the M.W. Kellogg (MWK) and Foster-Wheeler (FW) processes simultaneously, as well as SCS designed common BOP systems, it was agreed that the final controls design and configuration would be included in SCS' scope of work. SCS has significant experience in control system design for pulverized coal power plants, including the use of neural nets for burner optimization, which supported the decision. Logic and control design of the MWK process was completed by the Kellogg process engineers and turned over to SCS for configuration and uploading into the Foxboro system. Originally, the fundamental differences in design philosophies between petro/chemical plant controls design and power plant controls design caused confusion in the configuration. Some of these differences include design conventions such as energized as a normal state and deenergized as an alarm state, operating (energized) circuits shown as red or green, the extensive use of normally closed contacts for alarms, and extensive use of 'negative' logic as a result. Once these differences were recognized and understood the configuration effort progressed smoothly.

Due to the philosophical differences between the petro/chemical industry design and the power industry design (namely automatic local control versus automatic remote control) unanticipated enhancements have been required to the DCS. Among these are upgrades of one of the PLC gateways and one of the nine control processors. Future upgrades are anticipated to be possibly more control processors upgrades, an application processor upgrade, and additional operator workstations. In several instances PLCs were a better choice to control systems than the DCS control processors (especially very high speed control loops such as those on the PCD back-pulse controls). After significant time was spent by both the PCD process engineer and the configuration specialists, plans have been made to migrate the PCD back-pulse control to a dedicated PLC in the near future to solve this timing issue.

Because both processes have never been integrated at this scale before, the control algorithms have yet to be developed for 'unit' control; therefore, the controls design will evolve over time and operation will be based on the project's results.

Programmable logic controllers (PLCs) are used throughout the process to implement complex high-speed binary control logic in a cost-effective manner. Systems utilizing PLCs include the pneumatic coal, limestone, and ash transport, thermal oxidizer, main air compressor, coal crusher/conveyor, and both the recycle gas booster and nitrogen compressors. In the case of the pneumatic transport systems, one large PLC controls several transport systems such as FD0210, FD0220, FD0510 etc. Each of these systems could have been controlled by a smaller PLC, however, due to interlocks required between the systems, one large PLC reduced the overall cabling and raceway costs. This was accomplished by keeping data communications between systems within the large PLC rather than interconnecting smaller PLC with binary communication paths using cable and raceways.

Most of the PLCs used on this site are Allen-Bradley models PLC-5 and the smaller and lower cost SLC504. Both models have Ethernet communication ports and are connected into the DCS via gateways to allow display of analog and binary points for the operators. A side benefit of this communication is that a programming terminal can also be attached to the same network in the control room for trouble-shooting from a central location. This allows the integrity of the PLC to be established in conjunction with the DCS and DCS displays in a timely manner. The centralized approach has the benefit of support documents being available in the control room while the alternative requires significant set-up time.

As mentioned above, most of the PLCs are provided by one manufacturer and are networked into a LAN. There are General Electric and Moore Inc. PLCs utilized on site as well. There is one Allen-Bradley PLC, the crusher/conveyor system PLC, that does not have networking capability. Having different brands of PLCs introduces training and training retention problems for the control technicians. Technicians must be trained to maintain and modify the PLC software and hardware and must keep this knowledge up-to-date by hands-on experiences. Even when the technicians receive initial training, there are not enough failures per brand to provide the technicians with the sufficient maintenance opportunities to develop a strong knowledge base for a given brand. PLCs that are not networked for centralized maintenance tend to be serviced the least. This is due to the time required for programming terminal set-up and lack of centralized support documentation. Should such a system have an annoying glitch, the glitch is usually tolerated for a while rather than being resolved immediately.

One vendor-supplied system (the pulverizers) utilizes a custom-programmed microcomputer rather than a PLC. Although the system could have been programmed initially using a PLC, the vendor quoted a "price break" if their standard microcomputer was used. The down side to the microcomputer is that on-site personnel cannot maintain

and modify the system as needed. The vendor must be utilized for those services. A remote link to the vendor's technical support center via modem does reduce costs over an on-site visit.

Commissioning support from vendors of PLC-based systems varied from vendor to vendor and even within the vendor's organization. Ultimately the support and quality of the programming provided depended upon the qualities and capabilities of the individual programmer. Some systems were programmed in such a manner that plant personnel could start-up and check out the systems without vendor-supplied support. Others have required more vendor/programmer involvement.

9.4 ENVIRONMENTAL AND SAFETY

9.4.1 Environmental

For commissioning the M.W. Kellogg Transport Reactor Train, several environmental parameters had to be in place in advance of the actual commissioning period. Water discharges through the National Pollution Discharge Elimination System (NPDES) permit had been identified and the appropriate processes and procedures in place to manage these discharges. The two major discharges were cooling tower blowdown and wastewater treatment which were two different point sources. The cooling tower has established limits for total free residual chlorine, temperature, and pH. The wastewater unit collected from several sources including the runoff from the coal and limestone piles, stormwater from the immediate plant structure area, and runoff from the fuel oil storage. The wastewater treatment discharge has limits on total suspended solids (TSS), oil and grease, pH, naphthalene, and benzene. For the commissioning period, all effluent test results were within permit limits for both wastewater and cooling tower blowdown. The Alabama Department of Environmental Management (ADEM) requires a Quarterly NPDES Discharge Monitoring Report for the facility. During the 1996 fourth quarter commissioning period, the cooling tower blowdown flow averaged 2,100 gallons per day with a maximum flow of 20,500 achieved on 1 day. The wastewater treatment unit averaged 3,600 gallons of flow per day with a maximum flow achieved at 30,000 gallons for 1 day. General stormwater runoff from the plant area is diverted into underground culverts that carry the runoff to outfalls located north and south of the plant area. Stormwater is sampled twice per year for TSS. The facility has its own sewage treatment plant that is also included in the NPDES permit. The sewage treatment unit had been used in the previous coal liquefaction project and it was transferred over to the PSDF NPDES permit at the time of application submittal.

The PSDF air permit limits and reporting requirements are also established by ADEM. The ADEM requires an initial compliance test for the M.W. Kellogg reactor train operating in the combustion and gasification modes. The permit requires testing for sulfur dioxide, nitrogen oxides, carbon monoxide, particulate matter, and volatile organic compounds (VOCs). Each pollutant has established maximum daily emissions in pounds-per-hour, which are stated in the air permit. In order to be prepared for a compliance test, an outside vendor was selected to perform these tests. The vendor selected was Sanders Engineering and Environmental Testing from Mobile, Alabama. In conjunction with Southern Company Services, a compliance test protocol was prepared and submitted to ADEM before the commissioning period. The test protocol was accepted by ADEM and therefore was in place prior to the commissioning period. No compliance test was performed during the commissioning period due to operational instability. The ADEM was kept informed of plant status during this period.

Prior to the commissioning period, arrangements had been made to transport and dispose of waste generated from the process and in particular ash waste. Browning-Ferris

Industries (BFI) had been selected to transport and dispose of nonhazardous waste ash. Prior to any disposal a waste profile on the ash had to be submitted to BFI and ADEM for approval. The approval was in place prior to the commissioning period. Chemical Waste Management had been selected to dispose of hazardous waste ash generated from the facility. Ash was handled and transported in 20-cubic yard rolloff containers. After the ash was loaded into the container, a representative sample was taken and submitted to the laboratory for sulfide analysis and toxicity characteristic leaching procedure (TCLP) for metals. The ash remained on site until the analytical results were obtained and the proper disposal destination was determined based on the analytical results. During the commissioning period, all samples passed both the sulfide and TCLP for metals testing, and two loads of nonhazardous ash were shipped to the BFI facility.

9.4.2 Safety

Prior to the commissioning period, all employees at the PSDF were made aware of the potential dangers involved in commissioning a new plant. Safety awareness was made a part of commissioning individual components that made up the process and this level of awareness was transported into the commissioning period. Some of the essential safety programs that were in place prior to the commissioning period included personal protective equipment (PPE), respiratory protection program including the pulmonary function and respirator fit tests, hearing protection and audiograms, clearance procedure, confined space, hazard communications, and blood-borne pathogens. Plant operators, mechanics, and E and I personnel were trained on fire extinguishers and fire hoses in order to respond to fires at the incipient level. Each of these OSHA programs was discussed in safety meetings and special training periods well in advance of the commissioning period. Special emphasis was placed on how to handle burns, how to administer first aid, and CPR. During the commissioning period, one OSHA recordable accident occurred that involved a short period of restricted duty but there was no lost-time away from work due to the injury.

TERMS

List of Abbreviations

AAS	Automated Analytical Solutions
ADEM	Alabama Department of Environmental Management
APFBC	Advance Pressurized Fluidized-Bed Combustion
ASME	American Society of Mechanical Engineers
AW	Application Workstation
BFI	Browning-Ferris Industries
BFW	Boiler Feed Water
BMS	Burner Management System
BOC	BOC Gases
BOP	Balance-of-Plant
BPIR	Ball Pass Inner Race, Frequencies
BPOR	Ball Pass Outer Race, Frequencies
BSF	Ball Spin Frequency
CAD	Computer-Aided Design
CEM	Continuous Emissions Monitor
CFB	Circulating Fluidized Bed
CFR	Code of Federal Regulations
CHE	Combustor Heat Exchanger
CPC	Combustion Power Company
CPR	Cardiopulmonary Resuscitation
DC	Direct Current
DCS	Distributed Control System
DOE	U.S. Department of Energy
E & I	Electrical and Instrumentation
EERC	Energy and Environmental Research Center
EPRI	Electric Power Research Institute
FCC	Fluidized Catalytic Cracker
FETC	Federal Energy Technology Center
FFG	Flame Front Generator
FI	Flow Indicator
FIC	Flow Indicator Controller
FOAK	First-of-a-Kind
FTF	Fundamental Train Frequency
FW	Foster Wheeler
GBF	Granular Bed Filter
GC	Gas Chromatograph
GEESI	General Electric Environmental Services, Inc.
HTF	Heat Transfer Fluid
HTHP	High-Temperature, High-Pressure
I/O	Inputs/Outputs
ID	Inside Diameter
IF&P	Industrial Filter & Pump
IGV	Inlet Guide Vanes
IR	Infrared

LAN	Local Area Network
LIMS	Laboratory Information Management System
LOC	Limiting Oxygen Concentration
LOI	Loss on Ignition
LPG	Liquefied Propane Gas
LSLL	Level Switch, Low Level
MAC	Main Air Compressor
MCC	Motor Control Center
MS	Microsoft Corporation
MWK	The M. W. Kellogg Company
NDIR	Nondestructive Infrared
NFPA	National Fire Protection Association
NOx	Nitrogen Oxides
NPDES	National Pollutant Discharge Elimination System
NPS	Nominal Pipe Size
OD	Outside Diameter
OSHA	Occupational Safety Health Administration
OSI	OSI Software, Inc.
P&IDs	Piping and Instrumentation Diagrams
PC	Pulverized Coal
PCD	Particulate Control Device
PDI	Pressure Differential Indicator
PDT	Pressure Differential Transmitter
PFBC	Pressurized Fluidized-Bed Combustion
PI	Plant Information
PLC	Programmable Logic Controller
PPE	Personal Protection Equipment
PSD	Particle Size Distribution
PSDF	Power Systems Development Facility
PT	Pressure Transmitter
RFQ	Request for Quotation
RO	Restriction Orifice
RSSE	Reactor Solid Separation Efficiency
SCS	Southern Company Services, Inc
SRI	Southern Research Institute
TCLP	Toxicity Characteristic Leaching Procedure
TR	Transport Reactor
TRDU	Transport Reactor Demonstration Unit
TSS	Total Suspended Solids
UND	University of North Dakota
UPS	Uninterruptible Power Supply
UV	Ultraviolet
VOCs	Volatile Organic Compounds
WPC	William's Patent Crusher
XXS	Extra, Extra Strong

List of Units

acfm	Actual Cubic Feet Per Minute
Btu	British Thermal Units
°F	Degrees Fahrenheit
°C	Degrees Celsius or Centigrade
ft	Feet
gpm	Gallons Per Minute
hp	Horsepower
hr	Hour
inWG	Inches, Water Gauge
mA	milliamps
MB	Megabytes
MW	Megawatts
m/s	Meters per second
μ or μm	Microns or Micrometers
dp_{50}	Particle Size Distribution at 50 Percentile
ppm (W or V)	Parts Per Million (by weight (w) or volume(v))
lb	Pounds
pph	Pounds per hour
psia	Pounds Per Square Inch Gauge
psig	Pounds Per Square Inch Gauge
ΔP	Pressure Drop
rpm	Revolutions Per Minute
s or sec	Seconds
scf	Standard Cubic Feet
scfm	Standard Cubic Feet Per Minute
V	Volts
W/PPPM	weight/parts per million

POWER SYSTEMS DEVELOPMENT FACILITY

COMMISSIONING REPORT OF M.W. KELLOGG TRANSPORT REACTOR TRAIN, WESTINGHOUSE PARTICULATE CONTROL DEVICE, AND ASSOCIATED BALANCE-OF-PLANT EQUIPMENT: SEPTEMBER 1995 – DECEMBER 1996

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Prepared by:
Southern Company Services, Inc.
Power Systems Development Facility
P.O. Box 1069
Wilsonville, AL 35186

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